Ministry of Road Transport & Highways

Guidelines for Expressways

PART - I

Volume-I : Planning
Volume-II : Design

Published by:
Indian Roads Congress

**On behalf of the Government of India,
Ministry of Road Transport & Highways**

New Delhi

Ministry of Road Transport & Highways

Guidelines for Expressways

PART - I
Volume - I : Planning
Volume - II : Design

Published by :
Indian Roads Congress
on behalf of the Govt. of India
Ministry of Road Transport & Highways

Price Rs. 2000
For Part I & II
(packing & postage extra)

First Published : April, 2010

Copies can be had from :
The Secretary General, Indian Roads Congress,
Jamnagar House, Shahjahan Road,
New Delhi - 110 011

Printed at I G Printers Pvt. Ltd. New Delhi - 110020

FOREWORD

Government of India has taken a mission to develop a National Expressway Network dedicated to provide road infrastructure comparable to the world standards, recognizing the importance of providing high-speed facilities connecting ports, major cities, industrial/ agricultural centers and major markets to the significant economic growth. Construction of fully access controlled expressways for 1000 km under National Highways Development Program (NHDP) Phase VI are about to be launched.

Accountability for providing safe, reliable and user comfortable road network utimately rests with the Government. It is, therefore, essential that the Guidelines for Expressways laid down for development of expressways should cover sound engineering practices, safety features and amenities for the users.

Ministry took up the preparation of the Guidelines for Expressways through technical cooperation from Japan International Cooperation Agency (JICA) and constituted a Technical Committee comprising of the following officers for its finilization:

1	Sh. Nirmal Jit Singh, Director General (Road Development) and Special Secretary, MORTH	Chairman
2	Sh. A.V. Sinha, Additional Director General-I, MORTH	Member
3	Sh. S.K. Puri, Additionnal Director General-II, MORTH	Member
4	Sh. C. Kandasamy, Chief Engineer, MORTH	Member
5	Sh. A.N. Dhodapkar, Chief Engineer, MORTH	Member
6	Sh. A.K. Sharma, Chief Engineer, MORTH	Member
7	Sh. S.K. Marwah, Chief Engineer, MORTH	Member
8	Sh. V.L. Patankar, Member (Technical), National Highways Authority of India	Member
9	Sh. Chaman Lal, Director, National Institute for Training of Highway Engineers	Member
10	Sh. S.K. Verma, Superintending Engineer, MORTH	Member
11	Sh. Mamoru TANAKA, JICA Expert	Member

The Guidelines for Expressways, as prepared, highlights appropriate planning and design principles for promoting safety conscious planning and design and will go a long way in guiding the highway engineers and planners to make our expressways safer, comfortable and of international standards.

Guidelines have been structured in four (4) volumes :

Volume - I : Planning
Volume - II : Design
Volume - III : Operations and Management
Volume - IV : Maintenance

The intended users of this guideline will be the transportation professionals/engineers who participate in or are responsible for any phase in the project preparation of the Expressway Project. This includes all public or private "practitioners" (e.g. managers, supervisors, engineers, planners, or technicians) who are involved with any issue or decision (e.g. managers, supervisors, engineers, planners, or technicians) who are involved with any issue or decision (e.g. legislation, policy, program, funding, operation & management and maintenance scenario) that may directly or indirectly infuence the performance of an Expressway facility.

In planning design process, the Highway Engineer strives to develop, within the limits of given constraints, the dimensional layout or geometric configuration that will lead to high level of safety, efficiency and ease in driving. Therefore, the intent of this document is to provide guidance to the designer with the critical aspects of project preparation for an expressway. This guideline is dynamic in nature and the users, based on their experience, give appropriate feedback so as to enable the Guidelines to be revised/improved from time to time.

(Nirmal Jit Singh)
Director General (Road Development) and Special Secretary
Ministry of Road Transport and Highways

Dated February, 2010

ACKNOWLEDGEMENT

The Guidelines for Expressways was prepared under the Japan International Cooperation Agency (JICA) Technicial Cooperation Project for Capacity Development on Sustainable Development of Expressways for the Ministry of Raod Transport & Highways (MORTH). This document was produced with inputs and contribution from the following team of JICA experts from Japan with assistance from Consulting Engineering Services (India) Private Limited (CES).

Mr. Mamoru TANAKA (Team Leader)	:	JICA long-term Expert for Expressway Development
Mr. Kiyoshi DACHIKU	:	JICA long-term Expert for Training Expressway Engineers
Mr. Takehiko TSUJI	:	JICA short-term Expert for Road Safety
Mr. Takeshi MATSUSHITA	:	JICA short-term Expert for Traffic Control
Mr. Mitsuyoshi FUSE	:	JICA short-term Expert for Service Area Managememnt
Mr. Takahiro YANO	:	JICA short-term Expert for Toll Plaza Operation
Mr. Jun TAKEUCHI	:	JICA short-term Expert for Expressway Maintenance
Mr. Kiyoshi OGAWA	:	JICA short-term Expert for Tunnel
Mr. D.C.De (Consultant engaged by JICA)	:	Consulting Engineering Services (India) Pvt. Ltd. (CES)

MORTH express its gratiude to the JICA team, the Members of the Technical Committee and other Officers who took great pains and contributed immensely in the preparation of this Guideline.

The contributions of Mr D P Gupta, Director General (Retired), MORTH, in editing the Guidelines and Mr R P Indoria, Secretary General, IRC along with his entire IRC team for their efforts in bringing out this publication is thankfully appreciated and acknowledged.

(Nirmal Jit Singh)

Director General (Road Development) and Special Secretary

Ministry of Road Transport and Highways

Dated February, 2010

LIST OF ABBREVIATIONS

AADT	:	Annual Average Daily Traffic
AASHTO	:	American Association of State Highway and Transportation Official
AAV	:	Aggregate Abrasion Value
ADB	:	Asian Development Bank (ADB)
ADS	:	Automatic Debiting Systems
ADT	:	Average Daily Traffic
AMC	:	Annual Maintenance Contract
AP	:	Aerial Photography
APL	:	Longitudinal Profile Analyzer
ATCC	:	Automatic Traffic Counters cum Classifier System
ATIS	:	Advanced Traffic Information System
AVC	:	Automatic Vehicle Classification
AVI	:	Automatic Vehicle Identification
B/C	:	Benefit Cost Ratio
BFC	:	Braking Force Coefficient
BI	:	Bump Integrator
BIS	:	Bureau of Indian Standards
BOOT	:	Built Own Operate and Transfer
BOT	:	Built Operate and Transfer
CCR	:	Central Control Room
CCTV	:	Closed Circuit Television
C-D	:	Collector – Distributor
CDMA	:	Code Division Multiple Access
CFRP	:	Carbon Fiber Reinforced Plastics
CO	:	Carbon Monoxide
CPU	:	Central Processing Unit
CRRI	:	Central Road Research Institute
CVI	:	Coarse Visual Inspection

dB	:	Decibels
DBFO	:	Design Build Finance and Operate
DCF	:	Dynamic User Flow
DDHV	:	Directional Design Hourly Volume
DNPT	:	Diagonal Non-Pull through type
DSRC	:	Dedicated Short Range Communication System
DTM	:	Digital Terrain Model
DUE	:	Dynamic User Equilibrium
DVI	:	Detailed Visual Inspection
ECB	:	Emergency Call Boxes
ECP's	:	Emergency Crossing Points
EIA	:	Environmental Impact Assessment
EIRR	:	Economic Internal Rate of Return
EIS	:	Environmental Impact Statement
EMP	:	Environmental Management Plan
EOCC	:	Economic Opportunity Cost of Capital
ETC	:	Electronic Toll Collection
FAQ	:	Frequently Asked Questions
FFS	:	Free-flow Speed
FIRR	:	Financial Internal Rate of Return
FRL	:	Finished Road Levels
FS	:	Feasibility Study
GAD	:	General Arrangement Drawing
GDP	:	Gross Domestic Product
GIS	:	Geographic Information System
GNP	:	Gross National Product
GPS	:	Global Positioning System
GSDP	:	Gross State Domestic Product
GSM	:	Global System for Mobile Communications

GVW	:	Gross Vehicle Weight
HAR	:	Highway Advisory Radio
HCM	:	Highway Capacity Manual
HCV	:	Heavy Commercial Vehicle
HDC	:	High Density Corridors
HDT	:	High Density Traffic
HFL	:	High Flood Level
HTMS	:	Highway Traffic Management System
HTV	:	Heavy Truck Vehicle
HWL	:	High Water Level
IC	:	Interchange
IDRS	:	Integrated Digital Referencing Scheme
IEE	:	Initial Environmental Examination
IR	:	Infrared Ray
IRC	:	Indian Roads Congress
IRI	:	International Roughness Index
IRR	:	Internal Rate of Return
ITS	:	Intelligent Transport Systems
JICA	:	Japan International Cooperation Agency
JKR	:	Jabatan Kerja Raya
km	:	kilometer
kmph	:	km per hour
LCDs	:	Liquid Crystal Displays
LCV	:	Light Commercial Vehicle
LED	:	Light Emitting Diodes
Lm	:	Linear meter
LN	:	lane
LOS	:	Level of Service
LUP	:	Land Use Planning

LWL	:	Low Water Level
MAV	:	Multi Axle Vehicle
MCA	:	Model Concession Agreement
MDR	:	Major District Roads
MMS	:	Maintenance Management System
MOEF	:	Ministry of Environment and Forests
MORTH	:	Ministry of Road Transport & Highways
NATM	:	New Austrian Tunnelling Method
NBSS	:	National Bureau of Soil Surveys
NCMA	:	National Concrete Masonry Association
NEXCO	:	Nippon Expressways Company
NH	:	National Highway
NHAI	:	National Highway Authority of India
NHDP	:	National Highway Development Project
NMS	:	Network Management System
NO	:	Nitric Oxide
NO_2	:	Nitrogen Dioxide
NPV	:	Net Present Value
NRSA	:	National Remote Sensing Agency
NSDP	:	Net State Domestic Product
NSRC	:	National Remote Sensing Centre
NTPC	:	National Transport Policy Committee
O&M	:	Operation and Maintenance
OBU	:	On Board Unit
O-D	:	Origin-Destination
ODR	:	Other District Road
OECD	:	Organisation for Economic Cooperation and Development
pc/hr/ln	:	Passenger Car Per Hour Per Lane
PCPHPL	:	Passenger Car Per Hour Per Lane

PCU	:	Passenger Car Unit
PFS	:	Pre-Feasibility Study
PHF	:	Peak Hour Factor
PIJF	:	Polythene Insulated Jelly Filled
PPP	:	Public Private Partnership
PPPAC	:	Public Private Partnership Appraisal Committee
PPR	:	Preliminary Project Report
PSV	:	Polished Stone Value
PwD	:	Persons with Disabilities
RAP	:	Resettlement Action Plan
RIS	:	Road Information System
ROE	:	Return on Equity
ROW	:	Right-of-Way
RUCS	:	Road User Cost Study
SA	:	Service Areas
SAM	:	Strain Alleviating Membranes
SCF	:	Standard Conversion Factor
SCRIM	:	Sideway-force Coefficient Routine Investigation Machine
SCTP	:	Steering Committee of Transport Planning
SDP	:	State Domestic Product
SFAP	:	Small Format Aerial Photography
SH	:	State Highway
SO_2	:	Sulphur Dioxide
SOI	:	Survey of India
SPCB	:	State Pollution Control Board
SPV	:	Special Purpose Vehicle
SUE	:	Stochastic User Equilibrium
TL	:	Test Levels
TMC	:	Traffic Management Center

TOR	:	Terms of Reference
TRRL	:	Transport and Road Research Laboratory
UPS	:	Uninterrupted Power Supply
VES	:	Vehicle Enforcement System
VFM	:	Vehicle Fleet Modernization
VGF	:	Viability Gap Funding
VICS	:	Vehicle Information and Communication System
VMS	:	Variable Message Signs
VOC	:	Vehicle Operating Cost
vph	:	vehicles per hour
VR	:	Village Road
WIM	:	Weigh in Motion

GUIDELINES FOR EXPRESSWAYS

CONTENTS

PART - II

Volume – III: Operations and Management

Volume – IV: Maintenance

VOLUME - I : PLANNING

EXECUTIVE SUMMARY

VOLUME – I : PLANNING

EXECUTIVE SUMMARY

INTRODUCTION

The Document Volume-I: Planning, is complementary to other guideline volumes. The objective of this document is to assist the expressway professionals/engineers with the basic requirements in project preparation for the identified sections of "National Expressway Network".

IRC:SP:19-2001 "Manual for Survey, Investigations and Preparation of Road Project" may be treated as a base document along with its limitations for use under the present context. This Volume-I: Planning document intends to provide comprehensive information on project preparation under commercial format (PPP – BOT, BOOT, DBFO etc.)

The contents of this document are necessarily a compilation on illustrative requirements which are generally not covered comprehensively by the available documents/practices.

This document has been structured into 4 (four) chapters as follows:

Chapter – 1	:	Survey, Investigation and Preparation of the Project
Chapter – 2	:	Route Planning
Chapter – 3	:	Economic and Financial Viability Analysis
Chapter – 4	:	Expressway Capacity

Chapter – 1 : Survey, Investigations and Preparation of the Project

This chapter provides broad stages in project preparation involving basic data assembly, socio-economic profile, environmental impact study and resettlement & rehabilitation action plan and soil material investigations.

Stages in project preparation inter-alia include knowledge of legislative policies and various requirements, such as, PPPAC for implementation under Public Private Partnership (PPP). For details the user may refer to www.pppindia.com and www.infrastructure.gov.in. Demographics, current transportation scenario along with regional development have been broadly discussed in socio-economic section.

The requirements on basic data assembly inter-alia provide (a) information on use of satellite imageries for alignment identification; (b) Global Positioning System (GPS); and (c) Geographic Information System (GIS).

Environmental impact study and resettlement & rehabilitation action plan is based on current practices and are subject to modification conforming to future developments.

Soil material investigation section covers broadly the aspect on collection of data on material availability, geotechnical & sub-soil exploration and the hydraulic & hydrological studies.

Chapter – 2 : Route Planning

This chapter documents "expressway alignment selection process" considering engineering, economic, social, ecology and aesthetics aspects.

Evaluation of alternative alignments has been based on (i) social-economic and environmental criteria; and (ii) engineering (operational) aspects including costs. Individual ranking matrices has been developed for evaluation. A simultaneous use, appreciation and considerations of the ranking developed in the above matrices will help in deciding selection of final alignment. This may not be "least cost one".

Chapter – 3 : Economic and Financial Viability Analysis

For implementation under BOT – DBFO format, financial analysis is of prime consideration. Toll rates play a significant role. The toll rates and link wise estimation of traffic as available from "National Expressway Network" study will form the basis. However, for individual project segments, it would be prudent to consider toll elasticity analysis, diversion-ratio curve analysis and possible business development at road side facilities for possible "traffic - toll rate" estimation. The aspect of business development at road side has been included in Volume-III: Operations and Management.

The current practice on financial analysis has been explained along with considerations for sensitivity analysis. Apart from financial analysis, it is desirable to undertake economic analysis of the Expressway projects as these will contribute to overall growth of the influence area and the economy of the region as well as the country.

Chapter – 4 : Expressway Capacity

On this aspect "Highway Capacity Manual (HCM) – 2000" is the document considered to be authentic. However, highway capacity analysis is a complex procedure involving generation of diverse data requirements for individual project segments.

Realizing the necessity of capacity analysis for situation in India, the MORTH have taken up a research study to develop “HCM-India”. The capacity analysis is primarily required for (a) expressway segment between interchanges and; (b) at entry and exit ramps junctions. In absence of the conclusions from the above mentioned research study, as an interim measure, the following have been presented for planning purposes.

For capacity analysis of expressway segments between interchanges, a user friendly method has been illustrated considering the default values given in HCM-2000 and subjective adoption of the necessary parameters. With the foregoing preamble, a Table has been generated for use by the designer and deals with 2x2 lane and 2x3 lane configuration using the cross-sectional elements and geometric criterion presented in Volume-II: Design.

For capacity analysis at the junction of entry and exit ramps, the HCM procedure appears to be too complex and require a lot of subjective data adoption. The simplified procedure as developed and practiced in Japan has been adopted and included in this chapter.

CONTENTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER - 1

SURVEY, INVESTIGATIONS AND PREPARATION OF THE PROJECT

CHAPTER – 1

SURVEY, INVESTIGATIONS AND PREPARATION OF THE PROJECT

1.1 INTRODUCTION

The Government of India, Ministry of Road Transport and Highways have decided to construct fully access controlled expressways for 1000 km under National Highway Development Project (NHDP-VI) through PPP (Public Private Participation) route on BOT (Toll) mode following a DBFO (Design Build Finance and Operate) pattern with a maximum Viability Gap Funding (VGF) of 40 percent.

In November 2009, the Final Project Report on MORTH study on “Formulation of Master Plan for Indian National Expressway Network” has been submitted. The study is aimed at phased development by the year 2012, 2017 and 2022.

The above two actions reflect the Government’s commitment for building Expressway Network to strengthen the overall transportation system in the country.

These Expressway projects are conceived as green field projects and are planned to be implemented through Public Private Partnership (PPP) using Built Operate and Transfer (BOT) or Design Build Finance and Operate (DBFO) or any other mode with primarily private financing. Implementation of Expressway network is likely to be divided into several packages involving different concessionaires.

Preparation of expressway projects involves a chain of activities, such as, field surveys and Investigations, selection of alignment, carrying out various designs, preparation of drawings and estimates, etc.

The extent and quality of investigations have a strong influence on selection of the most cost-effective design, assessment of projects cost including building, maintenance and operations cost and execution of the job itself. As such, accuracy and completeness of surveys deserve special attention in project preparation.

Systematic presentation of project details is the primary requirement. The project document is the very basis of technical, administrative and financial assessment of a project. It is also crucial for accurate execution of work in the field. The project preparation document should, therefore, be comprehensive enough for appreciation as well as easy understanding of the details.

1.2 STAGES IN PROJECT PREPARATION

1.2.1 Context of IRC:SP:19-2001 for BOT/DBFOT Projects

The IRC:SP:19-2001, Manual for Survey, Investigations and Preparation of Road Projects, gives detail guidance on project preparation, generally for projects funded by the national government or international funding agencies. For PPP (Public Private Partnership) projects under DBFO format, the requirements for project preparation including bidding process are different which are not sufficiently covered in IRC:SP:19-2001. This Guideline Volume-I : Planning

i) highlights special features in project preparation
ii) provides additional aids to IRC:SP:19

For Greenfield Expressway

With the above preamble and to make this document self sufficient, IRC:SP:19-2001 is briefly explained below alongwith the additional requirements for DBFO/DBFOT project preparation. The conventional stages in project preparation are:

1) Pre-Feasibility Study (PFS)
2) Feasibility Study (FS)
3) Preliminary Project Report (PPR)
4) Detailed Project Report (DPR)

The **Pre-Feasibility Study (PFS)** will be based on the MORTH study which has identified expressway network for implementation considering traffic and axle load prediction, LA plan, R&R analysis, EIA, cost analysis and economic evaluation. Pre-feasibility Study for implementation under BOT, BOOT, PPP, etc., section specific data need to be compiled for further appreciation which shall be necessarily exhaustive. This may include information on the present status of the alignment, development potential, potential environmental impact, traffic data, and preliminary cost assessment. The analysis may also involve traffic studies, assessment of resource generation potential, funding pattern and probable risks. The location of toll plaza, interchanges and wayside amenities may also need to be examined.

The **Feasibility Study (FS)** is intended to establish whether the proposal is acceptable in terms of engineering soundness and expected benefits from the project for the investments involved. The prime objective of the Feasibility Study (FS) is to develop and evaluate alternative possible alignments. Alternative alignments are done by studying the satellite imageries and digital terrain model. The process is essentially a desk study supplemented by limited field visits and secondary data. On broad terms, the alternatives are ranked on commercial considerations.

The **Preliminary Project Report (PPR)** involves a closer look on the identified alignments in FS. Using Digital Terrain Model (DTM), the vertical profile for each alignment shall be developed. Using the process of iteration and assigning numerical weightages/values, an evaluation matrix shall be developed. From this matrix, the “Optimum solution” shall be derived. On the optimum solution, the location of interchanges, cross drainage facilities, underpasses and facility centres (wayside amenities, rest/service areas, traffic control centres, toll plaza etc.) shall be identified and referenced in terms of latitude and longitude of the probable places.

The **Detailed Project Report** covers detailed alignment surveys, soil and material investigations, geological studies, drainage studies, detailed designs, environment management plan based on environment impact assessment studies, rehabilitation and resettlement action plan base on socio impact analysis, detailed drawings, estimates and implementation schedules and other implementation related documents.

For projects under PPP, the requirements at various stages are different and may include specific informations involving various degrees of accuracy in survey and investigations.

Currently, it has become a trend to go for bidding after completion of the FS and PPR stage and DPR is left to the selected bidder.

The sequence of survey operations and project preparation may thus, have to be structured to meet the specific needs of the project, its funding option and the requirements of the authority responsible for implementation.

1.2.2 Legislative policies

While developing the alignment between two identified terminal locations, defined under network planning, a designer has to deal with Social, Economic and Environmental issues in parallel with Engineering and Technical studies.

The designer agency has to face project related approvals, agreements and permissions. The various Acts which need to be satisfied are as follows:

i) The Environmental Protection Act 1986 and the Environmental Impact Assessment notification 1994. Various steps and requirements have been prescribed for obtaining environmental clearances.

ii) The Water and Air (Prevention and Control of Pollution) Act, 1974, resulting in establishment of Central and State Pollution Control Boards

iii) The Forest Conservation Act, 1980 which pertains to diversion of forest area for non-forestry use. It describes various steps for examination of such cases.

iv) The Wild Life Protection Act,1972 to protect flora and fauna. A number of national parks and sanctuaries were established in the last 25 years.

v) The Motor Vehicles Act, 1988. It empowered the state government transport authorities to enforce standards of vehicular pollution, its prevention and control.

vi) The Ancient Monument and Archaeological Sites and Remains Act, 1938. According to this Act, the area within a radius of 100 m and 300 m from the protected property area is designated as protected area and controlled area respectively.

vii) State level legislations and other Acts. The Forest Conservation Act, 1980 has been amended in 1998 in respect of road side plantation as protected forest. Under this amendment, NHAI or any other competent authority shall have to get clearance from departments for cutting trees.

The Applicable Acts and Rules relevant to the Expressway project are summarized in **Table 1.01**.

Table 1.01 Summary of Relevant Legal Requirements considered for the Project and Institution Responsible for that

Act	Year	Objective	Responsible Institutions
Environmental (Protection) Act	1986	To protect and improve the overall environment	MOEF, DOF, CPCB, SPCB
Notification on Environment Impact Assessment of Development Project (and amendments) (referred as the Notification on Environmental Clearance	1994	To provide environmental clearance to new development activities following environmental impact assessment	MOEF, DOF, CPCB, SPCB
Water (Prevention and Control of Pollution) Act (and subsequent amendments)	1974	To control water pollution by controlling discharge of pollutants as per the prescribed standards	SPCB
Air (Prevention and Control of Pollution) Act (and subsequent amendments)	1981	To control air pollution by controlling emission of air pollutants as per the prescribed standards	SPCB and Transport Authority
Public Hearing notification of MOEF of 10th April, 1997	1997	To provide procedure of public hearing	SPCB
National Highways Act	1956	To acquire land	NHAI, State PWD, BRO
Wildlife (Protection) Act	1972	To protect wildlife in general and National Parks and Sanctuaries in particular.	Wildlife Division, Forests Department, Govt. of Maharashtra
Ancient Monuments and Archaeological Sites and Remains Act	1938	Conservation of Cultural and historical remains found in India	Archaeological Survey of India and State Department of Archaeology

Source: *Formulation of Master Plan for Indian National Expressway Network, Final Project Report, November 2009*

MOEF- Ministry of Environment and Forests; DOF - Department of Forest

CPCB - Central Pollution Control Board; SPCB - State Pollution Control Board

The Expressway network shall have to be developed within the ambits of the Acts as mentioned here. However, there may be situations where special considerations may have to be extended to this project particularly, in the realm of land acquisition.

1.2.3 Considerations for Public Private Partnership (PPP)

1.2.3.1 Viability Gap Funding (VGF) Scheme

Viability Gap Funding (VGF) is to provide finance in the form of grant-in-aid for public-private-partnership projects in infrastructure. VGF is meant to be available to PPP projects with estimated internal rate of return of at least 12 percent. Generally, PPP projects have a debt-equity ratio of 70**:**30.

Currently, the maximum VGF for project is pegged at 40 percent of total project cost, of which the Central Government pay 20 percent and another 20 percent comes from the states/local administration bodies. The idea is to encourage private investments in areas where the remunerative return is low in the absence of VGF element. In fact, VGF reduces the capital cost for the concessionaire to make the project commercially viable.

An Empowered Committee has been formed for the purpose and there is a Guideline for forwarding proposal for financial support to PPP in infrastructure project under VGF scheme. Project preparation requires to be submitted in the structured format devised by the empowered Committee. The designer may consult **www.pppinindia.com/p&f/guidelines** for the guidelines and format.

1.2.3.2 PPPAC - Requirements

The Central Government has notified a system for appraisal/approval of projects to be under taken through Public Private Partnership (PPP) and the Guidelines were notified by the Ministry of Finance, Department of Economic Affairs vide O.M. No. 1/5/2605-HP dated 12th January 2006.

Pursuant to the decision of the Cabinet Committee on Economic Affairs (CCEA), in its meeting of 27th October, 2005, a Public Private Partnership Appraisal Committee (PPPAC) has been set up comprising of the following:

a) Secretary, Department of Economic Affairs (Chairperson)
b) Secretary, Planning Commission
c) Secretary, Department of Expenditure
d) Secretary, Department of Legal Affairs and
e) Secretary of the Department sponsoring a project

The Committee may Co-opt experts as necessary. Therefore, for all the PPP projects (BOT, BOOT, BOLT, DBFO & DBFOT etc.) there is need to prepare the proposal as required by PPPAC and presented in their structured format for approval.

The designer may consult **www.infrastructure.gov.in** for the guidelines and the format.

1.3 SOCIO-ECONOMIC PROFILE

1.3.1 General

Given the terminal locations and the possible alignment options, it becomes necessary to study the socio-economic profile of the project influence area. The green field expressways will pass through mostly agricultural, barren or forest areas. Socio-economic studies, comprising demographic aspects, macro-economic indicators and main economic sectors provide an overview of the socio-economic setup of the project influence area as well as a broad assessment of the perspective economic growth.

For a DBFO concessionaire, the objective of this study could be to look for development in the adjoining lands for commercial gain, thus to offset the project cost and less reliance on toll revenue (rates). This may also serve as device to control the ribbon development.

1.3.2 Demographics

Compiling regional (State level) and local (project influence area) economic and demographic data is an important first step in assessing the possible alignment. Data on population by geographic area provide a key indicator of the market served by the expressway together with the existing/proposed transport network in the region and thus the potential demand. Additional demographic data, such as income, vehicle ownership, and children and elderly population can further help identify personal transport needs.

Source of obtaining demographic data is the “Census of India” which is generally not updated and consultation with local agencies may help in updating. It may be prudent to use the satellite imagery or aerial photogrammetry to estimate population and economic data. Photographic details can be analyzed to determine the location of housing units and thereby to estimate the population of an area. Photographic/mosaics can also be used for broad land use pattern, extent of urbanization, concentrations of businesses as well as major industries.

1.3.3 Current transport conditions

An inventory of the location, extent and quality of the present day transport network is a key step for assessment of the possible future development options by the concessionaries. Key characteristics of roads and highways include functional class (NH,SH,MDR,ODR,VR etc.) and other route designation (Panchayat, forest etc), truck and/or bus routes, limited access (seasonal), number of lanes, shoulder widths, design speed, capacity and pavement type and condition. The location of intermodal terminals including rail, airports, ports and places of importance alongwith the characteristics of roads accessing these terminals (especially suitability for truck traffic) are also the key data element. A combination of interviews with local professionals, site visits, field data collection and other appropriate means can be adopted alongwith use of satellite imagery and aerial photogrametry.

1.3.4 Other important considerations

Additional data such as Economic data on number of establishments and total employment in an area can indicate major destinations of goods movement and business travel. Economic data by type of industry is important for assessing needs of transport services. The major indicators of importance (not necessarily exhaustive) are as follows:

- **Urbanization**

  The share of urban population in terms of percentage of the state populations and Average Density (population/sq.m) and the pattern of urban development are good indicators.

- **State Income: Net State Domestic Product (NSDP)**

  The rate of change of NSDP at constant prices is the main economic indicator for measuring real growth in economy which can be related to growth in transport demand. Time series data on sectoral growth (primary, secondary and tertiary) and sectoral composition provides overall status of developmental economy. The time series data on NSDP may be collected from the State.

- **Economic Perspective – State Level**

  The likely traffic movements are indicated by the overall State economy and especially in the project hinterland and influence area.

This can be decided/assessed/appreciated by analyzing time series data on NSDP at constant prices and income originating from the main economic sectors.

- **Future – Five Year Plans and Perspective Growth Rate**

  The "Five Year Plans" sets targets for Gross State Domestic Product (GSDP) annual growth rate. These are assumed to be achieved by the accelerated economic development in the State through infrastructure development, with more private participation in all possible areas, ensuring higher order growth in industrial, agricultural and creating large-scale employment.

  On study of long term (preferably for last 10 years) growth rate, expected/ planned strengthening measures, the perspective growth rates for short term and long term (Stable) can be assessed.

- **Economic Perspective – Project Area Economies**

  In order to prepare the perspective for project area economies, the relative importance of project influence area in the respective State economy used to be studied. For this purpose, various socio-economic indicators broadly related to demography and state of economy are considered. The main indicators, subject to availability of data at district level, are as follows:

  - Population density (persons per sq.km)
  - Level of urbanisation (percentage of urban population)
  - Literacy rate in percentage
  - Work participation rate
  - Percentage area irrigated
  - Number of personal vehicles per 1000 of population
  - Road length in km per 1000 of population

As indicated above, the choice of indicators has been based on the data availability at district level. On the basis of the above indicators, the performance of the districts is compared with that of the State average.

Based on such analysis, the perspective growth rates for Project Area Economies for different periods shall be prepared.

1.4 BASIC DATA ASSEMBLY

1.4.1 Introduction

This covers primarily desk studies of various documents to collect information on strategic importance. The objective is to select the most feasible route, or routes, for more detailed investigation. The green field expressway network with broad identification of terminal locations in the “National Expressway Network Study”, would require geographically locating the cardinal points. Fixing the alignment would require the following steps:

a) Preparing the alignment options on Survey of India (SOI) Topographic Sheets (Topo Sheets) (generally 1:50,000) with the objective to identify the corridor on which satellite imagery data shall be obtained. Alternatively, NRSC can provide reference maps for the different satellite missions from which data is acquired. An Integrated Digital Referencing Scheme (IDRS) software package which can be run on any PC with Windows environment is also available. By utilising this package, the user’s area of interest (place, polygon, mapsheet, etc.) can be converted into path/row number of the required satellite mission. A print out of the plot showing the nominal coverage can also be obtained. IDRS package is available at NRSC web site as free download. It is available under utilities option in the website. (**http://www.nrsa.gov.in/products/area_coverage.html**)

b) Large scale satellite imagery with road and rail network overlaid there on, provides updated ground information on natural and manmade features. The preliminary selection of various alternatives can be made on the satellite imageries. These alignments (based on latitude-longitude values) shall be transferred on topographic sheets (Survey of India) for physical identification as well as ground contour and land use information.

c) For each of these alternatives, using Digital Terrain Model (DTM), the vertical profiles can be developed and optimum solutions can be evolved comparing/appreciating merits and demerits of each alignment.

d) On the selected alignment, the locations of interchanges and facilities (wayside amenities, automatic traffic control centres etc.) shall be marked and a preliminary land acquisition plan, demarcating the Right of Way, shall be prepared.

This selected alignment will form the basis of further studies relating to the planning, design, development, construction and operation of the Expressway.

With the above preamble, the following informations have been collated as designer's aid.

1.4.2 Methods for reconnaissance survey

The quality of the study is dependent on the available data, the thoroughness and care exercised in its collection and the professional utilization of this information to the fullest extent.

Base mapping is a prime necessity. This can be either topographic or photographic aerial mosaic or satellite imageries. Moreover, the requirement to some extent is also dependent on the nature of the terrain concerned.

In a flat or gently rolling terrain, the contour intervals may be of less importance, whereas the information on existing culture, land use, afforestation etc. may be dominant features for considerations.

In rolling and hilly terrain, the road location may mainly be governed by the topography due to limitations imposed by hills, valleys, steep slopes, rivers, swamps and lakes. Information regarding topography and physical features should, therefore, be obtained in the early stages of planning and design.

The possible sources of data, not necessarily exhaustive and updated to the extent available, are as follows:

1.4.3 Survey of India (SOI) maps

i) Topographical Maps on Scale 1:25,000; 1:50,000 and 1:250,000

Map coverage on 1:50,000 and 1:250,000 scale is available for whole of India. Certain restricted areas require permission/approval of appropriate authority for usage and study of the maps of those areas. Map coverage on 1:25,000 scale is for about 30 percent of the Indian Territory.

ii) State Maps on Scale 1:1,000,000

Most of the states are covered and preparation of maps for a few states is in progress. These state maps are useful as an index map or to get an overview on impact of the project.

iii) Plastic Relief Maps on Scale 1:15,000,000

These maps are uniquely applicable to expressway location planning because they provide a three dimensional map of the area delineating ridges, valleys, peaks etc with cultural, broad land uses and contour information. These are useful for presentation aids to demonstrate the general terrain of the location area.

Although the maps mentioned above may have been prepared long ago and are not updated, still these are very much useful and a reliable source of information on elevations and overall perceptions of the topography specially on major waterways natural or manmade and important water bodies.

iv) Forest Survey of India, Vegetation Maps on scale 1:25,000,000

The incidence of vegetation e.g. orchards, reserve forest, cluster of trees or social forestry are the 'hazards' in selection of alignment. Ministry of Environment and Forests have set guidelines on these aspects. A reference to these maps may prove beneficial in decision making.

v) National Bureau of Soil Surveys and Land Use Planning (NBSS & LUP), Nagpur

The NBSS & LUP, Nagpur publishes soil maps as well as information on land use. The information on soil includes classification in terms of geological formation. The land use includes information on built-up areas, agriculture, plantation, wasteland, rivers/streams/lakes, grassland, meadows and areas prone to land slides etc.

vi) Geological Survey of India and State Geology and Mining Departments

Information on geology, geomorphology, construction material, drainage and changes in river courses, ground water are quite vital for the feasibility of the alignment. Above mentioned Departments produce maps of geology and allied themes periodically. These maps are generally available on scale 1:250,000 or smaller.

1.4.4 Aerial photography

i) Status of Existing Aerial Photography (AP) in India

Aerial Photography on scale 1:50,000 is available for whole of India. The negatives of this photography can be enlarged reasonably around five times. The enlargement can be done even up to ten times depending on the quality of AP. Photo enlargements on scale 1:10,000 and/or 1:5,000 can also be obtained. These photo enlargements are quite adequate for the study of:

a) Geology, geomorphology and groundwater prospecting,
b) Environmental factors e.g. vegetation, soil conditions, land use etc.

Some information like power lines, telephone lines, hidden pipelines etc. have to be supplemented by field visits. Since procurement of photographs presents some difficulty due to the security reasons, adequate prior actions need to be taken.

Existing aerial photographs have a wealth of information which can also be of help in locating quarry-site, approach roads, etc and the expressway planner can derive immense use of these aerial photographs. The ground can be seen in three dimensions using a stereoscope.

ii) Aerial Photography is being used intensively in India for long. There are agencies who can provide the conventional (formats 23 cm x 23 cm) aerial photography on commercial basis and after due clearance from the Ministry of Defence. The clearance can take 3 to 4 months and even more and takes considerable perseverance and follow up. The coverage on various scales is given below:

1:10,000	23 cm x 23 cm format	cover 2.3 km x 2.3 km
1:5,000	23 cm x 23 cm format	cover 1.2 km x 1.2 km

1.4.5 Photogrammetry support

Photogrammetry as technology is useful in many ways. Large scale maps on scales of 1:2,000 to 1:25,000 can be very precisely produced through photogrammetric process. The contouring can also be produced; the contour interval depends on the height of camera. Since very minute and precise measurements are made on geometric optical model, accurate measurements amounting to sub-meter accuracy can be performed. In other words, profile (with height values) and sections across expressway centre line can be extracted from optical model.

1.4.6 Satellite remote sensing and allied activities

Photographic products of imagery are available from National Remote Sensing Centre (NRSC), Hyderabad on scales of 1:12,500; 1:25,000 and 1:50,000. Digital products are also available in floppy, cartridge and tapes. The launch of IRS-P6 (Resourcesat -1) in October 2003 and IRS-P5 (Cartosat-1) in May, 2005 provided an excellent opportunity to obtain high resolution multi spectral data for large scale mapping and terrain modelling application.

The cartridge tape can be digitally processed in the computer and the image on the monitor can be interpreted with the possibility of enhancement of the quality of image through manipulation of image processing software.

A major advantage of satellite imagery is its repeatability. On a regular basis Orbiting satellites even monitor a natural phenomenon. We also get the latest information on the physical features. Survey of India map even in a restricted area can, therefore, be updated in planimetry with the help of the imagery. The latest information about the extent of development and change in land use is very useful in the alignment study.

Interpretation of natural resources themes, namely geology, geomorphology, land use, soil status (water logging, erosion), ground water, drainage, vegetation and forests is quite easily done on the satellite imagery. Indeed, land information from satellite imagery is the most useful.

1.4.7 Small Format Aerial Photography (SFAP)

As mentioned earlier, conventional aerial photography (format 23 cm x 23 cm) has been practiced in India for the last fifty years or more. There are three agencies in India who carry out the aerial photography, namely, National Remote Sensing Agency (NRSA), Hyderabad, Air Survey Company, Kolkata and Indian Air Force. The traditional format is quite alright if the project area is large and mapping is the main objective.

In Small Format Aerial Photography (SFAP), the simple method of taking aerial photography has been designed. Instead of large format (format 23 cm x 23 cm), an ordinary/commercial camera of 35 mm or 70 mm format is used. The film is also ordinary film which is available in the market. This can be colour or black and white.

The camera is placed on a single engine small aircraft at low cruising speed. In some cases, a simple modification is done in the aircraft by putting a hole and camera is fitted with a suitable mount. Of course any aerial photography requires clearance from the Ministry of Defence. The major advantages of SFAP are:

i) Very large scale true colour photo enlargements can be done. Scale upto 1:1,000 to 1:2,000 scales are possible from 1:10,000 scale SFAP. Acquisition plans alongside of expressway can be prepared on 1:4,000 scale.
ii) Monitoring of urban areas, villages and environment along the corridor is possible at comparatively lower cost than ground surveys.

1.4.8 Geographic Information System (GIS)

GIS is the current methodology to handle vast amount of complex spatial data in an optimum manner. Naturally, use of computer hardware and software are the basic requirements. Preparation of data-base which is an input to GIS takes most of the efforts.

Gradual emphasis has started emerging, for use of GIS in highways discipline. GIS is being strongly recommended. Besides, physical (land information) GIS is capable of storing data about traffic, accidents, road inventory, environmental parameters, drainage structures and a host of other information and ‘attributes’ of the data needed by an expressway planner. This is done through different layers stored in the computer.

A properly organised GIS will eventually become the workhorse for the planner/designer of the expressway. Recently, NHAI has developed a GIS based Road Information System (RIS).

1.4.9 Global Positioning System (GPS)

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. These are orbiting around the earth at a distance of 20,000 kilometers. A minimum of four satellites are needed to give a 'reselected fix' (X,Y and Z) on the ground, at any time of the day or night. The observations are made on an instrument called geo-receiver.

GPS works in five logical steps:

i) The basis of GPS is, "triangulation" from satellites.

ii) To "triangulate," a GPS receiver measures distance using the travel time of radio signals.

iii) To measure travel time, GPS needs very accurate timing which it achieves with some tricks.

iv) Along with distance, you need to know exactly where the satellites are in space. High orbits and careful monitoring are crucial.

v) Finally it requires correction for any delays which the signal experiences as it travels through the atmosphere.

When GPS is used in a single instrument mode, (shown in **Fig. 1.01(a)**), the accuracy is nearly a few meters or so. This accuracy is not adequate for the expressway (fixing of centre line). For precise work with required accuracy (few centimeters), two instruments of geo-receivers are used as ground stations. One instrument is fixed on a point whose coordinates are known which means it monitors variations in the GPS signal and communicates those variations to the other receiver, while the other is taken to the site, this can then correct its calculations for better accuracy. This mode is known as Differential GPS (DGPS) (shown in **Fig. 1.01(b)**).

Another technique called **"Carrier-phase GPS",** takes advantage of the GPS signal's carrier signal to improve accuracy. The carrier frequency is much higher than the GPS signal which means it can be used for more precise timing measurements.

The GPS technology does not need the pre-requisite of the intervisibility of two ground points. This technology gives the highest productivity in field surveys and allied tasks. It is eminently suitable for fixing the centre line of the alignment. The determination of level/ elevation is still a weak point of this technology.

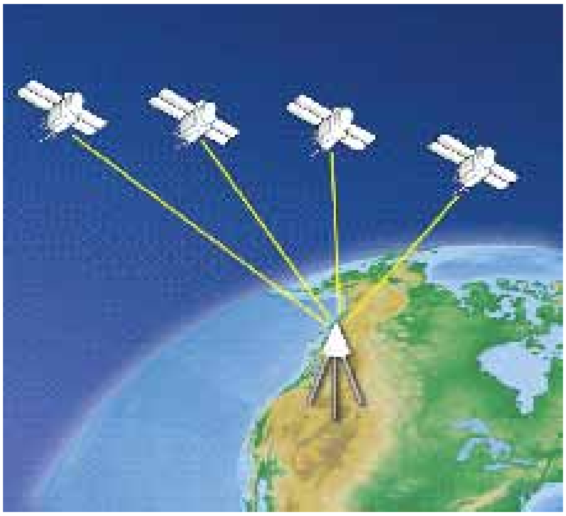


Fig.1.01 (a) Point Positioning (X, Y, Z)
Accuracy 1-2 m

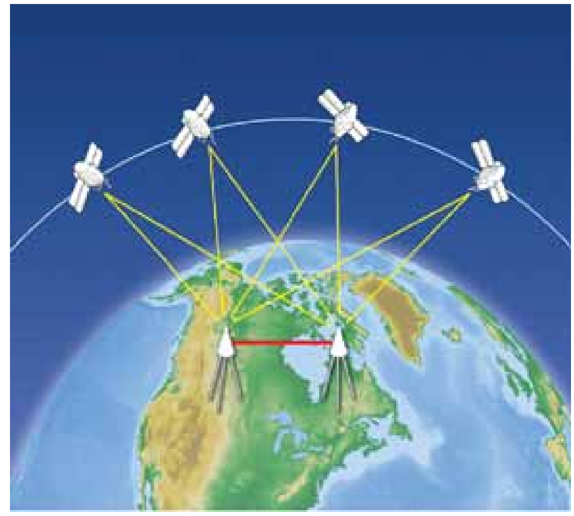


Fig.1.01 (b) Relative Positioning (ÄX, ÄY, ÄZ)
Accuracy 1-2 cm

1.5 ENVIRONMENTAL IMPACT STUDY AND RESETTLEMENT AND REHABILITATION ACTION PLAN

1.5.1 General

An expressway facility provides numerous socio-economic benefits including all weather reliability, reduced transportation costs, increased efficiency to emerging/existing markets, growth centres, access to employment centres, employment to local workers on the project itself, better access to health care and other social services and strengthening of regional economies in particular and national economies in general.

However, such large scale highway projects as i.e. expressways are likely to be associated with several adverse impacts during construction, maintenance and operation stages. The most significant construction related impacts are those related to clearing, grading or road bed construction; loss of vegetative cover; foreclosure of land uses; property severance at community and individual levels; changes in natural drainage patterns; changes in ground water elevation, land slides, erosion, stream, ponds and lake sedimentation, degradation of cultural sites, and interference with movements of wild life, live stock and local residents. Many of these impacts can arise not only at construction sites but also at quarries, borrowpits and material storage areas serving the project. In addition, these adverse environmental and socio-cultural impacts can occur during planning, construction and maintenance stages as a result of property/land severance; air and ground pollution from construction plants; and vehicle movements dust, noise from construction equipment and blasting; use of pesticides; fuel and oil spills; trash and garbage etc.

The probable expressway potential benefits and adverse impacts are as follows:

A) Potential Benefits (positive impacts)

i) Employment opportunities to local people

ii) Enhancement of agro-based industries and handicrafts

iii) Enhancement in exports

iv) Enhancement of rural development

v) Reduction in congestion levels, air pollution and noise pollution on existing corridor

vi) Improvement in road safety

vii) Faster development of urban centres, growth centres and regional development

viii) Improvement in tourism resulting in additional income from visitors and taxes

ix) Faster accessibility and growth in socio-economic activities

x) Improvement in quality of life through development of human and economic activities in the region

xi) Opening up of opportunities for new occupations

xii) Enhancement in transportation, processing and marketing of agricultural inputs and outputs

B) Potential Adverse Impacts (negative impacts)

i) Encroachment on precious culture and ecology

ii) Encroachment on historical/cultural areas

iii) Encroachment on agricultural land and property severance

iv) Loss of livelihood and roadside vegetation

v) Shifting of habitations and resettlement problems, severance on indigenous persons

vi) Disruption of communication network

vii) Impairment of fisheries, wild life, local forests and aquatic ecology due to habitat loss and encroachments

viii) Soil erosion, sedimentation of lakes and reservoirs during construction and operation

ix) Pollution of surface and/or ground water

x) Increase in concentration of run-off, traffic litter, noise vibration and air pollution in influence area during construction and operation

xi) Hazardous spills during construction and operation

xii) Migration tendency from rural to urban areas leading to unplanned growth

xiii) The poor expressway drainage may lead to flooding problems, degradation of water resources and formation of new gullies

xiv) Air quality in the influence zone of expressway will get deteriorated due to vehicular exhaust and smoke

xv) Impairment of scenic beauty, openness and aesthetics during construction and operation of facility

The direct impacts from expressway use may include creation of physical barriers to existing physical and social linkages, increased demand for motor fuels; increased air pollution, noise and road side litter, injury and death to animals and people during accidents, health risk and environmental damage from accidents involving hazardous materials in transit, and water pollution from spills or accumulated contaminants on road surfaces.

Many of these direct impacts on natural systems, historical and cultural resources and right-of-way land uses (i.e. property severance) can be avoided if their causes and effects are understood at planning stage and remedial measures/mitigating measures incorporated at design stage and their implementation monitored during construction and post-construction stages.

On the other hand, an aesthetically planned, designed, developed and maintained expressway is not only pleasing to the eye but it also adds to travelling comfort, enhances environmental quality and provides better safety in traffic operations. Therefore, while planning expressway facility, various activities such as choice of location for interchanges, toll plazas, access and exit points, wayside amenities, facilities etc; selection of pleasing alignment which merges with surrounding topography and natural environment; grassing and planting on road-side; provision of services and utilities, etc should be given due consideration and incorporated in design.

It is also important to examine the distribution of impacts. Equity among social classes may also be important. Besides Expressway funding (by concessionaires), additional funding for regional development shall also be looked into.

As a safeguard against the adverse impacts on the environment, it has been considered essential to carry out Initial Environmental Examination (IEE), Environmental Impact

Assessment (EIA) including Environmental Impact Statement (EIS), Possible Mitigation Measures and Environmental Management Plan (EMP), be prepared at different stages matching with significant impacts identified during IEE.

The basic aim of these guidelines is for study, examination, evaluation of environmental issues and preparation of Environmental Management Plan arising out of human activities on account of planning, design and implementation of an expressway project. An expressway project which generally provides numerous direct and indirect benefits should also be environmentally sound so as to ensure sustainable development of the region.

Therefore, for undertaking any development activity, whether new project including roads and highways or expansion or modernization, it has been made mandatory to seek environmental clearance from the Ministry of Environment and Forests (MOEF), Government of India as per their Notification dated 27.1.1994 and amended on 4.5.1994 for projects listed under Schedule I of the said notification. As per this notification, no highway project shall be undertaken in any part of India unless it has been accorded environmental clearance by the Central Government, MOEF, India.

The procedure for seeking environmental clearance from MOEF is covered under Schedule II of this notification accompanied by a Detailed Project Report which in turn shall interalia include an Environmental Impact Assessment (EIA) Report and Environmental Management Plan (EMP) prepared in accordance with Environmental Guidelines for Rail/ Road/Highway Projects by MOEF, Department of Environment, Forests and Wildlife, Government of India, New Delhi, 1989 and modified from time to time.

These guidelines on environmental system and aesthetics will go a long way in planning, design and implementation of expressway projects on sustainable basis under Indian conditions and have been provided under the following heads:

i) Objectives and Definitions;

ii) Scope (matching various project activities);

iii) Property Severance Effects;

iv) Procedure for Environmental Impact Assessment (EIA);

v) Preparation of Environmental Impact Statement (EIS);

vi) Environmental Management Plan (EMP);

vii) Approach to Data Collection, Investigations and Identification of Impacts;

viii) Measures for Mitigation of Adverse Impacts;

xi) Environmental Monitoring;

x) Expressway Aesthetics.

Latest (May 2009) Scenario

For grant of environmental clearance by the Expert Committee for Infrastructure and Miscellaneous Projects formed by the Ministry of Environment and Forests, the NHAI require the documents for submission to the committee as follows:

1) Filled – in Application Form – I
2 (a) Environmental Impact Assessment (EIA)
2 (b) Environment Management Plan (EMP)
2 (c) Resettlement Action Plan (RAP)

The above documents are to be submitted in structured format prescribed by the Ministry of Environment and Forests (MOEF).

3) No Objection Certificate from respective State Pollution Control Board (SPCB) as per Air Act, 1981 & Water Act, 1974 – in structured format.
4) Feasibility Study Report.
5) Detailed Project Report (DPR) – Main Report.
6) Typical Cross-sections of the embankment, cuts, river bridges, underpasses and flyovers.
7) General Arrangement Drawing (GAD) for all structures.
8) Present day Land Use Map superimposed on Survey of India Topographic sheet.

Alongwith the above documents, the NHAI or the concerned road agency and the designers have to make a Power Point presentation to the Expert Committee.

The process is complex and the ''Guideline-user'' may refer to the website of MOEF for details of documentations in structured format. In the following paragraphs, a brief outline is presented for Environment related documentations.

1.5.2 Environmental and social analysis

A Preliminary environmental/screening of the expressway may be carried out to determine the magnitude of actual and potential impact and ensure that environmental considerations are given adequate weightage in the selection and design of the expressway.

In **Table 1.02**, a chart for initial environmental examination (IEE) and suggested grading and protection measures have been indicated.

Table 1.02 Recommended Mitigating Measures and Suggested Gradings for Initial Environmental Examination (IEE)

(Source: IRC:SP:19-2001)

Action Affecting Environmental Resources and Values		Recommended Feasible Mitigating Measures	IEE Grading
a)	**Environmental Impacts Due to Project Location**		
	i) Disruption to hydrology	May be avoided through planning measures	D2
	ii) Resettlement	Suitable compensation and resettlement planning require consideration	D1
	iii) Environmental aesthetics degradation	Care shall be taken to avoid/ minimise effect	D2
	iv) Inequitable locations for rural roads	Cross roads suitability clubbed for access to the road. For the purpose, suitable connectors to be planned as part of project.	D3
	v) Loss of terrestrial ecology including forests and wildlife	May be avoided through planning exercise or minimize the effect with mitigation measures	D2
	vi) Loss of swamp ecology	May be avoided through planning exercise or minimize the effect with mitigation measures	D2
b)	**Impacts During Construction Phase**		
	i) Site runoff from cut and fill area	Suitable measures to be adopted during construction	D1
	ii) Safety creation hazards	All safety measures may be incorporated in tender document	D1
	iii) Slum creation hazards	Appropriate planning for housing of construction workers must be made and incorporated in tender document	D1

	iv) Cultural differences hazards	Should preferably be avoided and public learning be made and considered	-
	v) Escape of hazardous material	Strict monitoring the movement of hazardous materials	D2
	vi) Escape of air pollution (including dusts)	Suitable measures will be adopted to prevent/minimize	D1
	vii) Noise and vibrations	Effect shall be assessed and measures tak en based on significance	D1
	viii) Quarrying hazards (including use of explosives)	Appropriate planning operation of blasting and use of operating quarries	D3
	ix) Disruption of utilities along route	Shifting of utilities shall be planned in advance and provision kept in the project	D1
	x) Disruption of traffic along route	Judiciously planned to avoid / minimize disruption	D1
C)	**Impacts during Project Operation**		
	Action Affecting Environmental Resources and Values	**Recommended Feasible Mitigating Measures**	**IEE Grading**
	i) Noise disturbances	Shall not go up from present level consider provision of suitable noise abatement measures	D1
	ii) Vibration disturbances	Appropriate planning and post-construction monitoring may be made	D1
	iii) Air pollution	Appropriate planning and post-construction monitoring may be made	D1
	iv) Continuing erosion	Protective vegetation and other methods shall be adopted	D2
	v) Expressway runoff contamination	Appropriate planning and post-construction monitoring to take care	D2
	vi) Expressway spills of hazardous materials	Appropriate spills control program and post-construction monitoring to take care	D1
	vii) Escape of sanitary wastes	Appropriate planning/post - construction monitoring to be considered	D1
	viii) Congestion at access / exit points	Appropriate planning/post-construction monitoring be made to reduce/ eliminate the effect	D2
	ix) Inadequate Expressway maintenance	Post-construction monitoring is recommended	D3

Note: Suggestive IEE Grading Scale: *D1 – Not significant*
D2 – Small significant effect
D3 – Moderate significant effect
D4 – Major significant effect

Information should be collected on existing environmental conditions for IEE along the selected alignment to determine the need for further environmental assessments, design and management studies.

Positive and negative impacts of new expressway shall be identified. Cost-effective measures shall be proposed to enhance the positive impacts and to avoid or mitigate the effect of negative impacts.

Where felt necessary, public consultation on positive and negative impacts with the affected groups or involved NGO's may be carried out. Specially mitigation measures for negative impacts and assuring measures for positive impacts shall be explained.

1.5.3 Environmental design

From the environmental analysis, all elements with potential for adverse impacts should be identified, for which steps can then be taken to avoid/mitigate through judicious design changes, for example, shifting the road alignment to save trees on one side of the road. Adverse impacts, such as, soil erosion, flooding, loss of vegetation cover, etc. should be identified and appropriate mitigating measures, like, ground cover planting, installation of proper drainage system, etc. incorporated in design to reduce the impact. Cost effective proposals may also be included in the design proposal to suitably enhance the environmental quality along the expressway alignment in a sustainable manner.

1.5.4 Environmental management action plan

An implementation schedule and supervision programme may be prepared for timely execution of environmental mitigation and design works and all efforts may be made to follow the same. The programme for monitoring environmental impacts during construction and operation should be developed.

For such large projects, the requirement for institutional strengthening and training facility for personnel to be deployed on environmental works should be specified.

Any further studies of environmental issues, which are required to be undertaken during project implementation, should be recommended.

1.5.5 Resettlement and rehabilitation action plan (RAP)

Whenever the project will entail acquisition of land, structures and other assets and cause displacement or loss of assets within the public right-of-way, the project should undertake a socio-economic base-line study and prepare a resettlement and Rehabilitation Action Plan (RAP).

The RAP has three main objectives

i) To assess and bring out the impacts of land acquisition and assets for the project civil works on the people who own properties in the area to be acquired or live on the land to be acquired and/or derive their income from the land or own enterprises operating on the land to be acquired.

ii) To present the entitlement policy for compensation and assistance to persons affected by the project,

iii) To prepare an action plan for delivery of compensation and assistance outlined in the policy to the persons duly identified as entitled to such assistance.

The present policy of the Government is that the persons adversely affected by the project should receive benefits from it or at the least, they should not be worse off than before because of the project. Since acquisition of land and other assets may be unavoidable and an integral part of project design and implementation, undertaking a social impact assessment and preparing RAP shall also be included as a part of project design from the start and undertaken in close co-ordination with environmental analysis and environmental action plan. Also, as far as possible involuntary settlement may be avoided or at least minimized wherever possible, by exploring other alternative project designs.

In cases where displacement, loss of assets or other negative impacts on people are unavoidable, the project should assist the affected persons with means to improve their former living standards, income-earning capacities, production levels or at least maintain the previous standards of living.

Since no civil work can be undertaken on any stretch of road before land acquisition and payment of compensation as per RAP, it is essential that planning and implementation of civil works may be co-ordinated with RAP.

Preparation of RAP requires a thorough understanding of the local people, and the social, economic and cultural factors influencing their lives. It is essential that detailed base-line studies are conducted with a participatory approach through consultation with potentially affected persons and other stake holders in the area, the local NGOs, municipal authorities, etc. and a mutually satisfactory solution is achieved.

1.6 SOIL AND MATERIAL INVESTIGATIONS

1.6.1 Study of available information

The soil and materials location surveys should include study of all available information such as geological maps, data published by the various authorities regarding location of construction materials and the information available with ground water authorities regarding depth of water table. Soil maps prepared by the local agricultural department. A study of these data, if available, will be of great help in the planning and conduct of further surveys and investigations.

After studying the available information, detailed programme of survey can be drawn up. Points needing attention during detailed soil survey are highlighted further on.

1.6.2 Soil investigations for embankments

The first operation in the detailed soil survey is to demarcate the possible borrow areas. The extent of borrow areas should be commensurate with the volume of work involved in the embankment.

The general character of material excavated from test pits should be recorded alongwith on site visual identification and tests conducted on it in the laboratory. Where the type of material varies in a single pit, the tests should be conducted on each type of soil separately and the horizon of occurrence noted. Similar tests should be carried out on material from cuts for ascertaining the suitability of its use in the embankment.

1.6.3 Soil and material investigation

The activities shall include:

i) Identification of potential sources (including use of fly-ash/slag), quarry sites and borrow areas.

ii) Estimate quality and quantities of various construction materials available for collection of samples and conducting relevant laboratory tests.

iii) Evaluation of test results and asses the suitability thereof for incorporation in the various works and making recommendation on the use of the materials from different sources based on techno-economic considerations.

iv) Preparation of mass haul diagram and lead charts for quarry and borrow areas indicating the location of selected borrow areas, quarries and the respective estimated quantities.

v) Preparation and testing of bituminous and concrete mixes of different grades using prospected materials and testing for conformity with MORTH specifications.

a) Collection of Secondary Data

To start with, secondary data as follows will be collected from the concerned State PWD/other sources as appropriate.

- Location maps of operating quarries and material sources
- Technical report on survey and evaluation of locally available materials
- Land use/Land cover map
- Geological map of the area

Discussion will also be held with Consultants/Contractors working on nearby projects to ascertain the sources used by them, the cost of extraction, etc.

b) Sample Collection

Each quarry/material source will be visited by the Materials cum Geotechnical Engineer, and the available material examined in detail. The location of the source, the approachability, ownership, any environmental and social restrictions, volumes of material available for extraction, any special installation/equipment required for extraction, visual assessment about suitability, and other relevant information will be recorded.

Samples (30-40 kg) will be collected from each source adopting standard sampling procedures. These will be packed in suitable bags, labelled and sent to laboratory for testing.

c) Laboratory Testing of Borrow Soils and Granular Materials

The samples of materials for use in embankments, sub-grade and granular sub-base will be subjected to the following tests:

- Determination of water content	- As per IS: 2720 (Part 2)-1973
- Grain size analysis	- As per IS: 2720 (Part 4)- 1985
- Liquid and Plastic Limit	- As per IS: 2720 (Part 5)-1985
- Compaction Test (Heavy Compaction)	- As per IS: 2720 (Part 8)-1983

- Determination of CBR - As per IS: 2720 (Part 16)-1979

d) Laboratory Testing of Quarry Sample

- Gradation - As per IS Codes and Specifications
- Flakiness & Elongation Index - As per IS:2386 (Part I)-1963
- Aggregate Impact Value - As per IS:2386 (Part IV)-1963
- Specific Gravity and Water Absorption - As per IS:2386 (Part III)-1963
- Soundness - As per IS:2386 (Part V)-1963
- Bitumen Affinity Test - As per AASHTO T –182-84

e) Laboratory Testing of Natural Sand

- Gradation and Fineness modulus - As per relevant IS codes
- Deleterious Constituents - As per relevant IS codes

1.6.4 Geotechnical investigations and sub-soil exploration

Geotechnical Investigations and sub-surface explorations for the bridges/road over bridges/ tunnels/viaducts/interchanges and underpasses with the minimum scope laid down as under:

Sl. No.	Description	Location of Boring
1)	Overall length 6-30 m	Each abutment location.
2)	Overall length 30-60 m	One abutment location and at least one intermediate location between abutments for structures having more than one span.
3)	Overall length > 60 m	Each abutment and each pier locations.

This investigation work is to be carried out at major/minor bridge and high embankment (more than 6 m height) locations by exploratory boreholes.

Backfilling of Boreholes

Boreholes shall be backfilled with free flowing sand or silt as the borehole casing is withdrawn, in such a manner that collapse of the sides of the borehole is precluded. The cost of backfilling shall be deemed to be included in the rates for boring.

1.6.5 Hydraulic and hydrological investigations

Detailed field investigation study shall be carried out for hydraulic and hydrological studies for all existing drainage structures which include the following:

i) Hydraulic Condition (Adequate or inadequate and reasons for the same)
ii) Catchments Area Characteristics
iii) Stream Characteristics
iv) Overtopping Condition (if any)
v) Drainage assessment of the road.

The Consultants will undertake a desk study of available data on topography (topographic maps, stereoscopic aerial photography), storm duration, rainfall statistics, top soil characteristics, vegetation cover etc. so as to assess the catchment areas and hydraulic parameters for all existing and drainage provisions. The findings of the desk study would be further supplemented and augmented by a reconnaissance along the area. All important hydrological features will be noted during this field reconnaissance.

The information collected will consist of the details of High Flood Level (HFL), Low Water Level (LWL), bed level discharge and velocity from available past records, local enquiry and visible signs. It will also consist of details of scouring, siltation, river characteristics and stream characteristics.

The study shall identify the suitability of existing structures and requirement of additional waterway as per the hydraulic conditions and as computed from design discharge and design HFL.

CHAPTER - 2

ROUTE PLANNING

CHAPTER – 2

ROUTE PLANNING

2.1 ROUTING OF EXPRESSWAY

The selection for alignment or routing is a multi-stage process carried out interactively with traffic and environmental assessments moulded with the aesthetic considerations and social-development requirements.

On different facet, the selection of alignment is largely a compromise among the competing sets of considerations:

Physical engineering features, safety, aesthetics, environmental and ecological aspects, and the life cycle cost (i.e. construction, maintenance and operating costs). The objective is to select the alignment which provides an optimum balance between the overall costs and the identified needs of the population to be served by the expressway corridor.

The above requirements as well as guiding factors are mostly subjective, case specific involving topography, regional settings and social environment. Very few recommendations/ guidelines are defined in code of practices in different countries covering all aspects of selection of alignment. Hence attempt has been made to compile the various excerpts available from books, publications, journals, periodicals and various project reports.

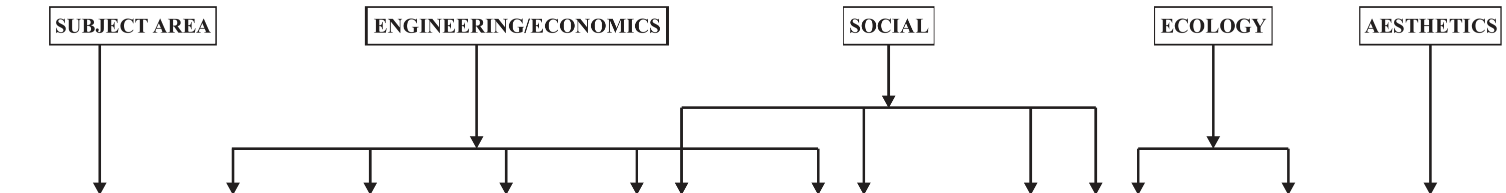
The various factors which influence alignment selection as identified in IRC:SP:19-2001 and TRRL Supplementary Report 279 are given in **Fig. 2.01.** This primarily demonstrates the interlinkages on the diverse aspects in the route planning process. These have been further illustrated in the subsequent sections.

The selection of alignment requires collection of available maps and information on the possible connecting routes. Hence the approach for this varies depending on the availability of the related maps, land records and related documents.

2.2 CONSIDERATIONS IN EXPRESSWAY ALIGNMENT SELECTION

The major identifiable study activities (and the usual sequence) leading to the selection of the most feasible alternatives can be grouped into two broad requirements.

A) Basic data assembly or collection of information
B) Review of data and evaluation of alternatives, which include



FEATURES	CONSTRUCTION COSTS	MAINTENANCE COSTS	USER COSTS	RIGHT - OF-WAY COSTS	DEVELOPMENT POTENTIAL	NEIGHBOURHOOD LOCATE	RECREATIONAL/ CONSERVATION	POLLUTION	SCENIC VALUE
FACTORS	Topography Geology Geomorphology Soils Materials Vegetation Drainage Design Standard Safety	Climate Traffic Soils Materials Topography Drainage Geomorphology Maintenance Standard	Traffic Topography Travel Time Safety	Land Value Land Use Replacement Costs Traffic Design Standard Utilities /Services Tax Base	Agriculture Forestry Mineral Extraction Trade/Industry Tourism Personal Mobility Political Strategy Economic Zones	Population Culture Land Use Tax Rate Land Value Institutions Transportation Historical Sites Utilities/Services Traffic Employment Dynamic Change Tax Base	Land Use Vegetation Fish Life Scenic Areas Wildlife Drainage Topography Erodibility Sedimentation Land Marks	Noise Air Water Spillage Thermal Chemical Waste	Scenic Areas View from Road View of Road Eye Sores Topography Vegetation Drainage

Fig 2.01 Factors Affecting Road Alignment Selection
(Source: IRC:SP:19-2001 and TRRL Supplementary Report 279)

i) Reviewing of data, understanding the problem and identifying controls,

ii) Developing alternative solutions, refinement of alignment to minimize potential adverse impacts:
   - Crux of the study
   - Testing alternatives
   - Refining alternatives

iii) Evaluation and selection of preferred alternatives;

iv) Warrants against common mistakes.

2.3 SELECTION OF ALTERNATIVE ALIGNMENTS

The most critical aspect is to develop alternative alignments. The two basic processes are:

i) **Identification of controls** - physical, economical, social, environmental, religious places, historical monuments, swamps, social forestry etc;

ii) **Engineering aspects** - that is technical solutions to overcome the hazards along the alignment with economic consideration in view.

It is essential to become familiar with the project area before beginning the selection of alignment and therefore collection and collation of sufficient information is prerequisite. This should be followed by review of the data and reconnaissance of project area.

i) *Identification of Controls*

The controls imposed on a route location may take many forms, important of which are physical, economic, social, political and environmental controls. Most of these become evident at the data assembly stages.

Physical controls are most influential because predominantly these affect basic corridor selection, particularly from technical and operational aspects of the road users. Economic controls generally take the form of development influence on a particular route vis-à-vis the alternative. The most important single control is disruption to people and housing.

Land use - Economic and Development Potential

The achievement of a proper balance between the creation of new opportunities for development and preservation of existing community values poses a unique challenge in selection of alignment. During this phase, possibilities of land use development for commercial gain should be given emphasis for prospective BOT schemes.

The prime objective will be focused towards promoting development. The alternative goal is sometimes prominent in selection of an alignment; that is, an area is either already sufficiently developed or there are plans for future development. Under such circumstances, the aspect of access control and the need for providing service road facilities become important considerations.

Development of Alternative Alignments

Selection of alternative alignment is started on updated base map after the control points have been identified and sufficient knowledge is developed on the region. Basic guidelines which merit considerations are stated below.

ii) ***Engineering Aspects***

The alignment selection should be done keeping in mind that the expressways are conceived to provide a high speed and high quality of service to the users of traffic. The followings should form the basis for development of alternative alignments.

i) Safety is a primary consideration. Accordingly, the design parameters like speed, curvature, gradient etc. shall be selected to match with the topography. The driver shall be ensured of safe and comfortable driving. Consideration is given to the high percentage of trucks in selection of geometric elements.

ii) The alignment should be free flowing in nature and based on the driver’s expectation which is normally guided by his immediate past experience on observations of roadway, terrain, environmental and traffic conditions. Any design which fails to meet these expectations such as abrupt changes in some geometric features might surprise the driver and precipitate to severe accidents.

iii) The alignment shall maintain a good balance and shall fit into the surrounding natural and social conditions such as topography, natural features and land utilization plans. A balance should be maintained on technical and economic suitability.

iv) Aesthetic considerations and environmental factors play an important role which should be clearly defined and the impacts are studied before finalization of the alignment. The factors to be examined are: presence of historic, heritage or religious places, environmentally sensitive streams, agricultural land, impacts and mitigating approaches, ground water impacts, wet lands, noise etc.

Broadly the alignment can be defined as a combination of horizontal and vertical geometric elements. The general rules for their use are stated below:

Horizontal Alignment

Horizontal Alignment is a combination of curves and straight lines. The followings are the general principles:

- The alignment shall be continuous out fitted to topography;
- The largest possible curve radius or straight lines are to be used on high embankment and on cut sections;
- Clothoid curves shall be inserted between the straight and curve elements
- Compounding of circular curves are to be avoided and a clothoid be inserted;
- Broken back alignment shall be avoided;
- Maintain a relationship with vertical alignment for satisfaction of aesthetics and avoiding visual distortion

Application of Straight Lines

Straight lines shall preferably be avoided from safety and aesthetic considerations. However, under the following circumstances, straight lines may be adopted

- Flat land and wide valley located between mountains;
- An area which has straight lines element of road network, in an urban area or suburbs;
- Long and large bridges or long viaduct sections;
- Tunnel sections.

Within the limitations, straight lines are adopted with length restrictions. The recommendations of various standards are:

- Road Element Guidance for rural areas in **Germany** recommends a maximum length of twenty (20) times (in metre) the design speed (in km/hour);
- **Japan** recommends the maximum straight lengths same as Germany and for minimum lengths as given below:

Design Speed (kmph)	120	100	80	60	50
Maximum length of straight line(m)	2400	2000	1600	1200	1000
Medium length of straight line between curves of reverse direction (m)	240	200	160	120	100
Minimum length of straight line between curves of same direction(m)	720	600	480	360	300

- **IRC** recommends a maximum length of three (3) km.

Japan practice may be useful since the same provides better considerations.

Combination of horizontal and vertical profile

This Guideline in Volume-II: Design has dealt with this aspect in more depth. However, the following narrations are expected to be handy in decision making process. The proper combination of horizontal alignment and profile is obtained by engineering study and consideration of the following general controls:

i) Curvature and grades should be in proper balance. Tangent alignment or flat curvature at the expense of steep or long grades and excessive curvature with flat grades are both poor design. A logical design that offers the most in safety, capacity, ease and uniformity of operation, and pleasing appearance within the practical limits of terrain and area traversed is a compromise between the two extremes.

ii) Vertical curvature superimposed on horizontal curvature, or vice versa generally results in a more pleasing facility, but it should be analyzed for effect on traffic. Successive changes in vertical profile not in combination with horizontal curvature may result in a series of humps visible to the driver for some distance, an undesirable condition as previously discussed. The use of horizontal and vertical alignments in combination, however, may also result in certain undesirable arrangements, as discussed later in this section.

iii) Sharp horizontal curvature should not be introduced at or near the top of a pronounced crest vertical curve. This condition is undesirable in that the driver cannot perceive the horizontal change in alignment, especially at night when the headlight beams go straight ahead into space. The difficulty of this arrangement is avoided if the horizontal curvature leads the vertical curvature, i.e, the horizontal curve is made longer than the vertical curve. Suitable design can also be made by using design values well above the minima for the design speed.

iv) On divided expressways with varying width of median, the use of separate profiles and horizontal alignments should be considered to drive design and operational advantage of one-way roadways.

v) In residential areas, the alignment should be designed to minimize nuisance factors to the neighbourhood. Minor horizontal adjustments can sometime be made to increase the buffer zone between the expressway and clusters of residences.

vi) The alignment should be designed to enhance attractive scenic views of the natural and manmade environment, such as rivers, rock formations, parks, outstanding buildings, and golf courses. The expressway should head into rather than away from those views that are outstanding, it should fall toward those features of interest at a low elevation, and it should rise toward those features best seen from below or in silhouette against the sky.

2.3.1 Evaluation of alternative alignments

The objective of this phase of the alignment study is to compile all the information on the alternative routes in a manner which can be documented with text and maps. This inter-alia includes the selection and recommendation of alternatives, the satisfaction of set goals, preliminary geometric/safety analysis, and documentation with reasons for elimination of less feasible alternatives. The evaluation of the alternatives may be based on:

i) Social, Economic and Environmental criteria;
ii) Engineering considerations.

The criteria of both the above two sets are interdependent and should be considered together.

Social, Economic and Environmental Criteria

Of the inputs affecting alignment evaluation, none are more subjective than the social, economic and environmental criteria. It is very difficult to quantify these factors in a generally acceptable manner. However, to make the evaluation more objective (ie. less subjective), the approach for evaluation may be based on:

1) Transportation related criteria;
2) Economic criteria;
3) Social criteria;
4) Regional planning criteria; and
5) Aesthetic design criteria.

The five classifications can be analysed by assigning relative percentage weights, totalling one hundred percent, with respect to stated project goals or objectives, if a consensus can be reached. Each of the five major classifications is then subdivided into several subordinate classifications for more thorough evaluation. The twenty-five factors for social, economic and environmental effects **Table 2.01** identified by the FHWA are subordinate classifications established for individual evaluation. Each of the twenty-five sub-classifications can be assigned a relative weight within the major criteria divisions. The example presents a hypothetical set of route alternatives applied to the rating system.

Each of the alternative alignments can be evaluated with respect to these criteria and the location receiving the highest "grade" would be most beneficial (under the assumed weightings), and hence the recommended alignment. Each of the twenty-five sub-classifications is rated on a percentage basis (with 100 per cent being the ideal condition) for each alternative, and this is multiplied by the weighting factor for the element to produce a score for each alternative in each classification. Thus further rankings within each criterion are possible. The influences on the criteria classifications are discussed in the following paragraphs.

1) **Transportation Related Criteria-** Annual road-user costs are the basis for comparing alternatives with respect to fast, safe and efficient transportation. Lower road user costs are indicative of more efficient traffic service. This is a function of alignment geometrics and length of the alignment.

   Ratings for engineering, right-of-way, and construction costs are inversely related to the respective amounts. The lower cost alternatives receive higher ratings.

   Maintenance and operating costs are primarily a function of length but potential erosion and stability problems must be considered. This includes factors such as the terrain and topography, deep cuts and high fills, waterway diversions and crossings, and the like. The highest ratings in this classification are achieved by the shorter alternatives with minimal disturbance to the existing terrain. The rating is influenced by the relation of its total to the prevailing conditions.

Table 2.01 Social, Economic and Environmental Ratings

(Example)

Sl. No.	Factors	Relative Weight
	Transportation Related Criteria	45
1)	Fast, Safe and Efficient Transportation	15
2)	Engineering. Right-of-Way and Construction Costs	10
3)	Maintenance and Operating Costs	10
4)	National Defence	2
5)	Fire Protection	2
6)	Public Utilities	2
7)	Operation and Use of Existing Expressway Facilities During and After Construction	4
	Economic Criteria	15
1)	Economic Activity	5
2)	Employment	5
3)	Property Values	5
	Social Criteria	15
1)	Displacement of Families and Business	4
2)	Residential and Neighbourhood Character	2
3)	Religious Institutions and Practices	1
4)	Rights and Freedoms of Individuals	2
5)	Natural and Historical Landmarks	1
6)	Replacement Housing	3
7)	Education	2
	Regional Planning Criteria	15
1)	Open Spaces	4
2)	Recreation and Parks	4
3)	Conduct and Financing of Government	5
4)	Multiple Use of Space	2
	Aesthetic Design Criteria	10
1)	Aesthetics	2
2)	Public Health and Safety	3
3)	Noise, Air and Water Pollution	3
4)	Conservation	2
	TOTAL EVALUATION CRITERIA RANK	

With respect to serving national security, the ratings are higher for alignments which generate highest design standards and those which provide superior service to the traffic movement.

Alternatives which better interconnect with the existing highway network, and disrupt it least, rate higher. Higher ratings are also given to alignments which provide better continuity and lesser interruption of existing public service and utility networks.

Alternatives that disrupt the operation and use of the existing facilities the least during and after construction, rate highest in this classification evaluation.

2) **Economic Criteria-** The sub-classification of the economic criteria are economic activity, employment, and property values. In the example shown each is *assigned an equal point value* because of the close interrelationships among the three. Alternative locations which open new areas for development enhance all three criteria and are rated high. Locations which provide superior connections to the existing system also encourage economic growth, and are rated accordingly. Alternatives that tend to isolate or conflict with economic activity receive the lowest ratings in this criteria class.

3) **Social Criteria-** The two most influential sub-classifications under social criteria are displacement of families and businesses, and replacement housing. The locations which, for the most part, do not impact upon existing development naturally displace fewer families and businesses, require less attention to replacement provisions, and should thus receive high ratings.

   Alternatives which best preserve local residential and neighborhood character rate highest in this category. These alternatives likely are less disruptive to existing educations districts and religious institutions also.

   Alternatives which preserve and incorporate natural and historic landmarks receive the highest rankings in this sub-classification.

4) **Regional Planning Criteria-** Regional planning criteria which include open spaces, parks and recreation, conduct and financing of government, and multiple use of space are best satisfied with the regional planning departments. Alternatives with known adjoining area support have built-in advantages over less preferred routes.

The inclusion of joint development projects which promote multiple use of space and enhance the economic gain definitely result in higher regional planning ratings. Conversely, locations which neglect or adversely impose upon local parks, recreation, open spaces, and local government financial tax bases fare poorly in the rating of regional criteria.

5) **Aesthetic Design Criteria-** The factors influencing ratings for aesthetics are the view of the road, the view from the road, geometric form, and the fit to the terrain. Locations which best satisfy these factors are rated the highest. The objective of superior aesthetic design is of major concern.

   The most important thing in aesthetic consideration is that the visual information that the driver receives while driving should not make the driver misunderstand and get confused. The following points should be given attention in expressway routing.

   - Preserve natural beauties and avoid crossing places which should be protected. Routing should be selected to be in harmony with the natural landscape and the regional culture.

   - In mountainous and hilly areas, routing should have an alignment to harmonize with the landform of the nature. The change of the view creates enjoyable driving. A vast panoramic view opens out after a mountain path or sudden appearance of a grand view of a mountain after a curve gives a great change of atmosphere.

   - In open country areas, making the expressway embankment as low as possible with gentle inclination of the slopes of the embankment produces harmonious blending of the expressway with the topography.

   - When there is a famous building or a historic relic, routing should incorporate them as landmarks. When they appear and disappear while driving along the vicinity, it gives enjoyable change of view to the driver.

Noise and air pollution associated with a highway location are directly related to traffic volume on the facility and the capacity of the facility to carry the traffic in a smooth and efficient manner. Wider rights-of-way, depressed sections, and roadside landscaping contribute to noise abatement. Construction of new expressway facilities improves the traffic flow conditions which reduce the amount of contaminants in the air.

Moreover, vehicle emission control standards had become more effective in the early 2000's. This would also help in reducing air pollution.

Water pollution associated with a new highway facility is usually the result of the application of various chemicals to control dust, weeds, ice, or snow. These applications usually do not constitute a pollution threat. The alignment locations which exhibit the fewest pollution generating characteristics receive the highest ratings in the sub-classification.

Ecology, wildlife, and sedimentation in water bodies due to soil erosion influence the evaluation of alternatives with respect to conservation. Locations requiring extensive clearing of natural flora, deep cuts, high fills and severe side hill construction are rated lower due to the increased probability of erosion and sedimentation. Valley locations parallel to water bodies are also likely to create this condition. The alternatives which preserve and protect the natural environment with minimal disruption are rated high.

Analysis by Weighting

It may be noted, the approach suggested is seen as a significant tool for policy analysis. The factors themselves and the weightages indicated for these factors are neither ''etched in concrete'' nor should they be. Thus: ''This list of effects is not meant to be exclusive, nor does it mean that each effect considered must be given equal weight in making a determination upon a particular highway location or design''. In other words, the rating values are by nature examples. They are also subjective in nature.

Any listing or weighting system will be subjective. Furthermore, extreme difficulties can be expected in developing a consensus, particularly within a multidisciplinary group. These difficulties can be lessened, or at-least a perspective on the points of differences can be obtained, by solving the problem by assigning a series of weights. This could be done (1) systematically, (2) by an iterative process, and/or (3) in response to specific requests. The net result would be to demonstrate how sensitive (or insensitive), the route location is to individual social, economic, and aesthetic criteria.

Source: FHWA Report in Hand Book on Highway Engineering – by R. Baker

Engineering Considerations

The various alternatives developed are to be evaluated from the operations considerations and the problems and cost of construction. The entire alignment may be subdivided into sections for evaluations which may thus be combined for assessment of the entire route.

Operations Consideration

As mentioned earlier, the straight lines would be the most preferred choice but it is likely to encounter obstacles that would intervene. It may not be economically attractive to pass through these obstacles. Moreover, long straight alignments are boring and may make the drivers less alert.

A curvilinear alignment would be the most suited one. The broad aspects of assessments are presented in **Table 2.02.**

Table 2.02 Operational Considerations

Subsection Length	Principal Alternatives		
	A	B	C
VERTICAL ALIGNMENT			
Max. Grade and Length			
– Length of Longest Max. Grade			
– Speed at Approach of Longest Max. Grade			
– Speed at End of Longest Max. Grade			
– % Length with Grades over 3%			
HORIZONTAL ALIGNMENT			
Max. Degree of Curve			
– No of Curves over 3.5 degree			
– % Length with Curves over 3.5 degree			
EARTHWORK			
– Max. Depth of Cut over 3 m			
– Total Length of Cut over 30 m length			
– Max. Height Fill over 3 m			
– Total Length of Fills Over 30 m length			
RUNNING TIMES (Minutes) *			
– Trucks up gradient			
down gradient			
average			
– Buses up gradient			
down gradient			
average			
– Cars average			
AVERAGE RUNNING SPEED *			
Trucks (kmph)			
Buses (kmph)			
Cars (kmph)			
RANK			

****These are subjective assessments based on length of gradients.***

Technical Considerations

These involve identification of various elements of the alignment such as waterway, grade separators, viaducts, tunnels, length of structures etc. These are first compared on length basis followed by cost implications.

Preliminary cost computations and the evaluation matrix followed for different Projects are presented in **Table 2.03** and **Table 2.04**

A simultaneous use, appreciation and considerations of the matrices developed will decide the final alignment. This may not be the least cost one.

Table 2.03 Route Comparisons, Length of Structures and Tunnels Section

	Unit	A	B	C
Route Length	km			
Intrusion in City	km			
Waterway	Lm			
Grade Separators	Lm			
Viaducts	Lm			
Tunnel	Lm			
Total Structures	Lm			
Weighting				
Preference				

Broad Costs of Section (Comparison only)

	Unit	A	B	C
Earthwork & Pavement	Rs Million			
Structures	Rs Million			
Tunnels	Rs Million			
Miscellaneous	Rs Million			
Construction	Rs Million			
Mobil., DSM, Contingent	Rs Million			
Land & Building	Rs Million			
Total Cost				
Weighting Overall Costs Preference				

Table 2.04 Indicative Costing Table (Example) for Comparison only

Broad Items	Unit	Rate Rs Million	Cost of Alternatives In Rs Million					
			A		B		C	
			Quantity	Amount	Quantity	Amount	Quantity	Amount
Roadway Plain	km							
Roadway Rolling	km							
Roadway Mountainous	km							
Frontage Roads	km							
Major Bridges Shallow Well	Lm							
Major Bridges Open Foundations	Lm							
Waterway & Canal Crossings	Each							
Flyovers	Lm							
Railway Crossings	Each							
National Highway Crossings	Each							
State Highways & MDR Crossings	Each							
ODR VR & Other Crossings	Each							
Underpasses	km							
Cross Drains Plain Terrain	km							
Cross Drains Rolling Terrain	km							
Cross Drains Mountainous Terrain	km							
Tunnels Less Than 350 m long	Lm							
Tunnels 350 m to 750 m long	Lm							
Tunnels Greater than 750 m long	Lm							
Shifting Utilities	km							
Appurtenances	km							
Erosion Control	km							
Traffic Safety	m							
Landscaping	Ha							
Interchanges	Each							
Toll Plaza	Each							
Service Area	Each							
Maintenance Areas	Each							
Sub Total Construction Cost								
Mobilization (2%)								
Contingencies (5%)								
Land Cost for Reserve & Protected Forest	Ha							
Barren/Low Productive Farm Land	Ha							
Medium Productive Farm Land	Ha							
High Productive Farm Land	Ha							
Rural Residential/Industrial	Ha							
Semi-Urban Res/Industrial	Ha							
Acquisition of Structures	Nos.							
Land Costs								
Total Costs								
Length of Section								

Source: Experience on Project Roads

CHAPTER - 3

ECONOMIC AND FINANCIAL VIABILITY ANALYSIS

CHAPTER – 3

ECONOMIC AND FINANCIAL VIABILITY ANALYSIS

A FINANCIAL ANALYSIS

3.1 INTRODUCTION

The approach methodology presented in this chapter is based on current practices followed by National Highways Authority of India (NHAI) for Economic and Financial Analysis of the projects undertaken in National Highway Development Projects (NHDP). At the beginning in late 70's and early 80's, the Asian Development Bank (ADB) and the World Bank framed guidelines for project appraisal on investment decisions. These guidelines provided mostly for carrying out Economic Analysis. Subsequently with the change in funding mechanism, during mid 90's, the project appraisal and economic analysis were modified. Finally when the Government of India (GoI) decided to levy fees for use of highways by the road users, the guidelines for Financial Analysis were framed to assess commercial viability with or without Government grant.

For implementation of Toll based Express Highway network, the Financial analysis shall be carried out for decision making on project packages. The level of financial viability will indicate the attractiveness of the package to the private sector. This will also help the Authority to frame strategy as to the most appropriate financing structure for the package (project).

In financial analysis, the toll rates play a significant role and shall be considered.

3.1.1 Contextual appraisal

Before any analysis can be conducted respecting either general financial viability of the project or prospects for private sector participation, a determination must be made as to the rationale behind seeking private partners. If it is for purposes of full cost recovery, the options and analyses cover a wider variety of choices; if it is solely for purposes of recovery of recurrent costs (operations and maintenance only), the choices would be again different.

For full cost recovery which is the case for implementation of expressway network, the analysis must be particularly rigorous, and the traffic forecasts detailed and set in the context of various scenarios, with sensitivity analyses conducted.

3.1.2 Link to overall economy

Separate financial and economic appraisals need to be performed for each project; the former provides a measure of the commercial (financial) viability of the toll road, while the latter measures the overall value of the project to the broader economies of the region and the country as a whole. Both have similar features and draw upon the same basic data. Both estimate the net benefits of an investment project.

Financial and Economic analyses are complementary.

While both types of analysis are conducted in monetary terms, the major difference lies in the definition of costs and benefits. In financial analysis, all expenditures incurred under the project, and all revenues resulting from use of the project are taken into account. This form of analysis is necessary to:

i) assess the degree to which a project will generate revenues sufficient to meet its financial obligations;
ii) assess the incentives for producers; and
iii) ensure that traffic and other forecasts on which the analysis is based are consistent with financial charges or otherwise available resources.

In the financial analysis, the unit of analysis is the *project* which may differ from the overall program of highway construction. The project is the segment or segments of Expressway network to be subject to tolling, combined with a program of construction for all or part of that segment or segments. The *de facto* presumption will be that the stretch of highway to be tolled is identical to the stretch to be constructed or upgraded.

3.1.3 Quality of work required

A financial evaluation is based on traffic forecasts, cost estimates and revenue assumptions. As such it is not infallible. The objective is to determine whether a private sector investor will find the project financially attractive, with subsequent responsibility for verification of data and assumptions is left to the private investor and the financing consortium to carry out due diligence. However, the evaluation does need to be as realistic is possible so as not to mislead the private sector. This will be the case where the authority has to maintain high standards of quality control and base all work, wherever possible, on the best available empirical data.

3.1.4 Importance of traffic forecasts

For purposes of private sector participation, traffic forecasts become a key element in the financial analysis as this is the cornerstone for revenues based on tolls. Traffic counts therefore need to be conducted over a timeframe which is consistent with reality and consideration of both peak hours of travel as well as seasonal variations. In this regard, if tolls are to be introduced, a further assessment on future traffic in terms of likelihood and extent of toll diversion also must be taken into account as this would significantly affect revenue projections.

Traffic forecasting for a green field expressway network with the presence of widened 4/6 lane National Highway Network is a complex process.

The traffic forecast on new expressway network (green field) need to be considered on the basis of the benefits provided by the expressway. The traditional approach is to focus on the benefits for the users, in terms of changes in travel time, safety, comfort, and operating costs. These aspects are prone to vary on various segments of the expressway network (10,000 km). A prudent approach would be (as followed in other countries also) to integrate with the development of regional economy. These aspects are broadly identified as

- User benefits (for trucks and non business vehicles only) in terms of travel time, safety and vehicle operating costs
- Business expansion impacts
- Business attraction impacts
- Tourism impacts

Based on Japan's experience, the following aspects may be considered by the user of this Guideline as cautionary measures.

- The considerations which are too risky for toll road business
- The concession period shall not be too long (i.e. more than 30 years)
- The most important is users acceptance of toll rate
- Adopting complex processes involving "difficult-to-find" database needing more time and cost.

To appreciate and apprise the users of this document, special attention is drawn (for avoidance of doubt, and by way of illustrations – based primarily of Japan's experience) to the followings.

Toll Elasticity Analysis: With a lower toll rate, the toll road may have larger number of users. However, this does not necessarily mean larger revenue. Toll elasticity means that when the toll is lowered by one percent, by how much percent the traffic volume increases. If the value is larger than one, then the toll revenue will be larger with the lower toll rate.

It is also important to understand the link between financial and economic viability in toll roads. Because a distinctive feature of toll roads is that the realization of the economic benefits for the toll road is irrelevant to the economic viability. The level of toll rates that meet debt service and financial returns may cause traffic diversion to an alternative route, which may be highly inefficient outcome in terms of traffic allocation in the corridor.

In the case of a toll road project, an accurate estimate of the amount that the potential users are ready to pay – the willingness to pay – is in theory a prerequisite of setting toll level. In developing countries, the quick changes occurring in income distribution and overall wealth make willingness to pay difficult to estimate over the periods of the economic appraisal.

Users' willingness to pay tolls is largely a function of their income, the value they assign to time savings and other toll road benefits, and the cost and quality of competitive alternatives. Assessing willingness to pay is in fact trying to figure out the elasticity of transport demand.

"Diversion-Ratio" Curve Analysis: The diversion ratio curve will be made by assessing how toll charging will affect traffic demand. The diversion ratio curve is derived from the relation between the toll amount charges, divided by the time saving resulting from using a toll road instead of an existing toll-free road and the percentage of vehicles that will divert from the free road to the toll road. These diversion ratio curves are calculated for each type of vehicle.

The time value for each type of vehicle can be obtained by calculation but should eventually be based on experience. Time values and diversion ration curves will have to be revised regularly in accordance with the actual traffic volume on toll roads as the years pass.

With the above considerations, the traffic forecast (including, generated, induced and diverted traffic) may be made. Prior to arriving at a conclusion, the sensitivity of the forecast traffic need to be tested for the assumptions built in the process.

3.2 APPRAISAL METHODOLOGY

3.2.1 Assumptions

The Expressway segments are part of the overall network of expressways and prima-facie financially viable projects and meet the current regulations set by the Central Government or the Authority established for the purpose. This preliminary viability, presumed to consider the appropriate traffic forecast for the project duration.

3.2.2 Overview of the financial analysis process

The financial analysis includes the following steps to establish and understand a reasonable likelihood of being financially viable:

Step 1 - Define the project scope;
Step 2 - Assess the veracity of the traffic forecasts;
Step 3 - Set up the financial model for use in analysis of the project or prepare;
Step 4 - Determine the annual toll revenues and all other relevant revenues;
Step 5 - Determine the project capital costs and other associated cost;
Step 6 - Determine the project operating and maintenance costs base assumptions for analysis
Step 7 - Calculate key financial ratios;
Step 8 - Perform risk and sensitivity analysis;
Step 9 - Conclude on financial viability of the project.

Each of these steps, except the project scope and traffic forecast aspects which have already been described in the preceding paragraphs are discussed hereunder.

Step 3: Set up the Financial Model

The new Model Concession Agreement (MCA) for Public Private Partnership (PPP) in National Highways has been published by the Planning Commission in September 2006. A similar MCA for Expressway network projects need to be developed and shall be considered in Financial Analysis. The aspects which are generally considered are (i) grant; (ii) concession fee; (iii) user fee; (iv) discounts (for frequent users and local non-commercial users); and (v) concession period.

Step 4: Annual Toll Revenues and all other Relevant Revenues

Estimating the likely toll revenue to be earned by the toll road over a period of twenty five years is an extremely important task. Sufficient data collection and analysis must be carried out to ensure that reliance can be placed on the forecasts. The revenue estimation process consists of the following steps:

Step 1 : Define the toll influence area;
Step 2 : Carry out traffic counts at a number of points within the toll influence area, on significant adjoining roads;
Step 3 : Conduct link specific Origin/Destination surveys of traffic in the toll influence area;
Step 4 : Estimate traffic growth over the concession period for each class of vehicle;
Step 5 : Estimate the time savings associated with the new facility;

Step 6 : Develop a driver route choice model within the toll influence area, for each class of vehicle;

Step 7 : Estimate the tolls to be charged on the road over the concession period including provision for reductions and exemptions for some classes of local traffic;

Step 8 : Using the driver route choice model calibrated with the toll rates and time savings, and the projected traffic in the toll influence area, calculate gross and net revenues from the road.

a) *Revenue Estimation Process*

i) *Definition of the Toll Influence Area*

The toll influence area consists of those roads where the level of traffic will be affected by the opening of the new expressway. Some traffic will be attracted onto the new alignment because of the time savings available, and some traffic will divert off the road to avoid tolls. A necessary first step in determining the likely level of traffic on the new alignment at different toll levels is to determine the existing level of traffic on all roads, which is likely to divert to the expressway. Designers/planner need to use their judgment as to what roads to consider, so that the analysis includes all significant roads but avoids unnecessary complexity. The roads included may change as the analysis progresses, based on what is learnt about traffic behaviour.

ii) *Estimate Traffic Growth and Assess Traffic Level*

This aspect will primarily be based upon the traffic data for the entire project life. Further processing or fine-tuning required during project preparation stage shall be developed. *The development of expressways not considered in the planned network will have significant change in methodology.*

iii) *Estimate Time Savings*

Where it may be possible for travelers to avoid the toll road by taking alternative routes, it is necessary to calculate average travel times for each class of vehicle on each alternative route with the differences in travel times representing time savings associated with using the expressway.

iv) *Develop Driver Route Choice Model*

Drivers make route choices based on the relative costs of alternative routes. Costs include direct and indirect vehicle operating costs, tolls, and the value of time. It is usually accepted that there is also an additional value attributable to traveling on a new expressway.

A well-developed model of route choice will utilize econometric techniques and data obtained from both revealed preference and stated preference studies i.e. willingness to pay. The output of the model is expressed as a probability that a vehicle of a particular class will use the toll road.

v) *Tolling Options and Strategy*

Maximum toll rates are set by legislation, and actual toll rates vary with local conditions. Set toll rates based on best estimate that are likely to be charged from the users of the road. Legislated toll rates (if mandatory) may have to be used for each vehicle class, escalated over time using a suitable escalation factor.

vi) *Compute Toll Revenue*

Based on tollable traffic and toll rates, the toll revenue can be assessed with due credit to discounts applicable to specific traffic types. This may involve a process of disaggregation/reduction in total tollable traffic.

vii) *Revenue Streams*

Net project revenues consist of, for each year of the project, gross revenue less the costs of toll collection, other operation, management and maintenance.

Step 5 : Project Capital Cost and Other Cost

For purposes of financial analysis all relevant project costs must be included in the equation. That includes construction cost, if applicable any land acquisition, resettlement and relocation costs, costs related to the shifting of utilities, as well as environmental mitigation costs and costs for processing environmental approvals, costs for supervision and administration. Financing charges, such as interest during construction, carrying charges for debt, etc, are automatically calculated by the financial model. It should be noted that in India, the aspects of land acquisition, relocation and resettlement of affected individuals as well as shifting of utilities is the responsibility of the government and hence excluded from overall project costs for the purpose of financial model for BOT projects. Nonetheless, this needs to be verified for each project. Finally operations and maintenance costs of the roadway itself must be included in the financial analysis, either as costs or as deductible from the toll revenues as cash inflow.

Step 6 : Project Operating and Maintenance Cost

Base Assumptions for Analysis

In practice, different approaches of estimating O&M cost are used. One approach is to estimate the O&M costs as a percentage of the capital cost of the road. Another approach is to use the knowledge and experience gained from constructed projects and development in other countries. Overall, as in Japan, the O&M costs of expressways are twice as expensive as those of the major National Highways – attributable to higher level of service provided.

The financial analysis should include as separate items routine maintenance, which would be performed regularly throughout the year, and periodic maintenance, which consists of larger works that would be performed perhaps every five years. It is important that the maintenance costs reflect the expected cost profile over the entire life of the project or the concession period as the case may be.

It may be noted that it is usual for a concessionaire to be required to transfer the road back to the Government at the end of the concession period in a specified condition. Provision should be made within maintenance cost for the cost of bringing the road to the specified condition at the end of the concession period.

Step 7 : Key Financial Ratios

The financial model (spread sheet) automatically calculates project equity and IRR, and the minimum and average debt service coverage ratio. These results, together with details of the loan repayment schedule, are used to generate a measure of project financial viability. Where the results appear unreasonable, the assumptions in the model should be checked to ensure nothing has been entered incorrectly in the model.

Step 8 : Sensitivity and Risk Analysis

The financial analysis is based on forecasts of traffic growth and construction cost and timing. These variables are included in the financial model at their most probable values. Actual values may differ significantly from forecast values, depending on future events.

A prudent investor will consider the effects of likely changes in key variables on the financial viability of the project through sensitivity and risk analysis.

Sensitivity analysis shows to what extent the viability of a project is influenced by variations in major parameters such as project cost, traffic forecasts and revenue assessments.

Risk analysis considers the probability that changes to major quantifiable variables will actually occur.

In practice it is very difficult to be precise about the probability of future events. It is better to present the results of the sensitivity and risk analysis separately. Where there is a clear risk to financial viability, it will be necessary to consider whether there is any strategy that can be used to ensure that the risk *to the project* does not eventuate. It may be possible to shelter the project from the risk even if it is not possible to prevent the future event from happening.

i) Sensitivity Analysis

The viability of projects is evaluated principally by reference to the project internal rate of return (IRR). The sensitivity analysis is conducted by changing key variables in the financial model one at a time, and noting the effect on IRR of the change in that variable. Important variables that may be tested include:

- *Changes to construction cost*. The amount of variation modeled should be based on experience of similar projects. It might be thought necessary to model variations of ± 20 percent. Higher percentage variations are more likely to occur where there are significant unknowns related to the construction, for example in bridge foundations.

- *Changes to construction timing*. Adverse changes may result from such factors as unfavourable weather conditions, delays in the land acquisition process or labour disputes. Again, experience should be the guide as to the likely range of variation in construction timing for similar projects.

- *Changes in base year traffic.* Most highway projects are sensitive to variation in traffic volumes, and there has been a history internationally of over-optimistic traffic forecasts for toll roads, particularly where the willingness to pay tolls has been over-estimated. It is preferable to consider the specific characteristics of the road when deciding on the amount of variation to model, rather than applying a standard percentage. For example, the traffic projections may indicate that significant truck traffic will feed into the road from a new port facility, but there is a risk that the new port will not be completed in originally stipulated time. In such a case, the sensitivity modeled would be that of *zero truck traffic* emanating from the port.

- *Changes in traffic growth rates*. Over time small variations in growth rates can have large impacts on financial viability. One scenario that should be modelled is what would happen if growth in traffic was equal to the historical and expected growth rates in GDP for the state and for India. It is also useful to check that the traffic volumes projected to occur say twenty years from construction of the project are still within the capacity of the road.

- *Changes in O&M costs*. Maintenance cost is partly a function of traffic volumes and the weight of traffic using the road. Overloaded trucks can cause accelerated wear on the road surface, necessitating sooner and more frequent major maintenance works.

Sensitivity analysis should not be restricted to the above list, but should also include other variables that the circumstances of the project and the professional experience indicate may have significant impact on financial viability. The financial model generally computes sensitivities for 20% variations in construction cost, O&M Cost, and Revenue. Other sensitivities can be calculated by re-running the model with varied assumptions.

ii) Defining Finance Related Risks

Risk analysis should be performed after the sensitivity analysis. Risk should be evaluated qualitatively unless there is a robust methodology available to meaningfully quantify certain identified risks. In the absence of this methodology, risks may be classified into three categories:

- Highly likely to occur;
- Probable, neither highly likely nor highly unlikely to occur;
- Highly unlikley to occur.

To be useful, sensitivity and risk analysis should not only identify the risk likely to occur on project financial viability, but it should also provide some guide as to how to mitigate that risk, and so ensure financial viability. For example, if the construction cost of a major bridge is highly uncertain, it might be possible to separate the bridge from the project, or to provide appropriate guarantees. Note that normally risk should be borne by the party best able to manage that risk; and in the case of construction risk, it would normally be the constructor who bears that risk. However, where the risk is so that it threatens financial viability of an otherwise attractive project, it may be appropriate to have some carefully defined strategy of risk transfer and mitigation measure.

The results of the analysis can be presented in table format, as given in **Table 3.01**, using illustrative data.

Table 3.01 Summary of Sensitivity Analysis (As example only)
Base Case 21.5 Percent

Risk	Variation	Highly likely	Probable	Highly unlikely
Construction cost	+20%		18.6%	
	-20%			23.2%
Construction timing	+1 year	19.3%		
	-6 months		22.0%	
Traffic in base year	+20%		23.7%	
	-20%		17.6%	
Traffic growth rates	+20%		22.9%	
	-20%		18.0%	
O&M costs	+20%		21.0%	
	-20%			21.9%

Note: ***This is a sample only and subject to change***

Step 9 : Financial Analysis Conclusions

The financial model generates an indication of the suitability of the project for different financial structures. Therefore, one should interpret the results of the model in the light of detailed knowledge of the characteristics of the project. Review the conclusions of the model and satisfy that these are reasonable. Where a project is not suitable for BOT without Government support, the exercise should vary the amount of support, up to the current maximum of 40 percent of total project cost, to determine the minimum level of support required to allow a BOT structure.

The analysis should provide detailed comments on the reasons for lack of financial viability, and the reasons for significant sensitivities/risks to financial viability. Where appropriate, remedies should be identified and suggested. For example, where a high cost bridge is detrimental to project financial viability, it would be useful to analyze the project without the bridge and with the bridge.

B ECONOMIC ANALYSIS

3.3 INTRODUCTION

Expressway network development under Public Private Partnership (PPP) as toll road project necessarily relies more on Financial Analysis (commercial format) than Economic Analysis. However, an economic analysis is carried out to appreciate the contribution of the expressway network in improvement of transport network from regional as well as national angle. Therefore, economic analysis needs to be considered for linkages with National and Sectoral policies, including connectivity, regional development and importance to the national economy.

3.3.1 Overall context appraisal

Any investment in transportation network brings about a variety of impacts, some of which can be quantified and then valued in monetary terms, and others which cannot. Most cost attributable to development/improvement of a transport network can be assessed to a high degree of accuracy. However, the same cannot be said regarding benefits. Although both quantifiable and non-quantifiable benefits need to be identified, it is with those that can be quantified and valued that the economic analysis in carried out. This approach is also referred to as cost benefit analysis. The costs and benefits are quantified in monetary values over a specified time period and the key indicators are computed in terms of Economic Internal Rate of Return (EIRR) and Net Present Value (NPV).

Economic analysis is undertaken at constant prices, that is, without allowing for the effects of general inflation on costs or benefits, but incorporating projected relative price changes for key items.

3.3.2 Traffic demand analysis and forecasting

Contrary to other NHDP projects, this Expressway network development process identifies and quantifies the traffic generation over a given period of time under separate study. For Economic analysis, traffic data is generally required in terms of Passenger Car Units (PCU) whereas for Financial analysis, number and types of vehicles are required.

3.4 METHODOLOGY FOR ECONOMIC ANALYSIS

Toll roads are essentially in commercial format and more on business approach including profit making fund arrangement etc.

3.4.1 Inputs for economic appraisal

An expressway project should, ideally, be taken on consideration of analysis – regional/ national development is the key. When there are wide discrepancies between prices (tariffs, tolls, fees) and costs. However, the financial and economic analyses may not lead to the same investment decision.

3.4.2 Identification, quantification and valuation of key economic costs and benefits

There are basic steps for analyzing the economic viability of road projects. These are:

- Calculate the financial cost of each input separately and determine which are valid as economic costs;
- Identify other economic costs which may be excluded from the financial costs;
- Convert financial costs to economic costs using standard procedures,
- Identify the economic benefits
- Identify those benefits which can be quantified;
- Assign values to the benefits wherever applicable; and
- Compare the benefits with the costs to determine a rate of return on investments

In highway economic analysis, the sum total of all costs associated with the construction, operation and maintenance of the project is included. Economic costs are based on financial costs but also include a number of costs which may not normally be included in the financial analysis. The following is a brief list of costs which would be considered part of the economic cost analysis:

- civil works and supervision
- land acquisition
- resettlement and productive compensation costs
- environmental costs including mitigation

- road safety costs (usually part of the overall cost of construction)
- road maintenance and traffic management costs
- other costs as identified within the project scope

3.4.3 Determining economic costs

Economic costs are derived by using a standard conversion factor (SCF), usually equivalent to the elimination of taxes, duties and subsidies from the financial costs. In most cases the value would be between 80% and 90% of the financial cost (generally fixed by the Planning Commission of India). The other method is of shadow pricing and it requires a good database as well excellent judgment neither of which may be always available. Therefore, determining the shadow price of an individual project is not practicable.

3.4.4 Determining economic benefits

Measuring the economic benefits of transport projects usually involves more complex conceptual and practical problems than does measuring their economic costs. It involves not only a comparison with the situation without the project, but also a comparison with the next best alternative to make certain that the project is the best alternative. In terms of roads there are a number of design options which may be taken into consideration – each of which may have a different cost.

The quantification and valuation of economic benefits attributed to highway projects are usually more difficult to Identify than its costs. This is due to a number of factors such as:

- benefits form highway projects are varied in nature, some are considered to be direct and can be relatively easily quantified while others, more indirect, are more difficult to quantify. The indirect benefits such as improved agricultural productivity, reduced transport costs, improved household income, improved access to places of employment, education and health care, are more difficult to quantify and value.

- even some direct benefits are difficult to quantify such as time savings. However, as is the case with VOC (Vehicle Operating Cost) calculations there is now a reasonably large body of work which deals with time savings and the related issues therein.

The most commonly used and widely accepted benefit deriving from road projects is Vehicle Operating Cost (VOC) savings. Others mostly subjective would include:

- time savings, for passengers who are traveling for business/economic purposes;
- savings due to reduced accidents, specifically fatalities;
- maintenance cost savings;
- increased agricultural productivity and value of goods sold;
- increased GDP resulting from increased industrial productivity;
- increased benefits resulting from tourist expenditures; and
- other benefits as identified within the project scope

Although most of the above-noted costs can be identified, quantified and valued, the same is not true of the benefits. Not all of these benefits exist for each project, and their relative importance can differ markedly from project to project. However there are now tools and techniques which have been developed to assist in the quantification and valuation of a number of key benefits. In NHDP projects for purposes of determining VOC savings, the use of HDM – 4 is a prerequisite. The next most important benefit is that of time saving, followed by accident cost savings. Both time savings and accident cost savings, however, are still considered to be in a preliminary stage of development although there is data available in both cases, for India. Time savings, in particular, are included as a standard, critical benefit in NHAI-sponsored projects. Finally, maintenance cost savings due to the new or rehabilitated road are also included in the analysis.

3.4.5 Economic viability: procedures for evaluation

The economic analysis of highway projects is based on comparing benefits and costs in the situation without the project with that which would occur with the project in place. The without-project and with-project situations both have to be projected. Certain effects of a project do not impose a cost or confer a benefit within the confines of the project itself and therefore are excluded in the analysis of financial benefits and costs. However external effects on consumers or other producers, such as environmental costs and benefits, are included in an economic analysis.

Project outputs need to be separated into two categories. Some project outputs will substitute for other outputs without the project. The rest of project outputs will add to total supply. Project outputs that substitute for without-project supplies are valued at the cost savings of not acquiring those alternative supplies. Project outputs that add to total supply are valued through the willingness to pay of the users. The willingness to pay should take into account any reduction in price brought about by the extra project supplies. Where a project output consists of an intermediate good, its value can also be assessed through the net economic value of extra productive activities generated as a result of the project.

The basic criteria for a projects analysis are: the expected economic net present value (ENPV); the expected economic internal rate of return (EIRR); and the benefit cost (B/C) ratio. For the project (or subproject) to be acceptable, the EIRR should equal to or exceed the Economic Opportunity Cost of Capital (EOCC). Government of India – Planning Commission fixes this rate around 12 percent in constant economic prices, depending on the extent of unquantified net benefits associated with the project.

3.4.6 Environmental impact in economic analysis

The methodology of integrating the costs and benefits of environmental impacts into economic analysis is still evolving. Therefore this type of evaluation should focus only on projects where environmental impacts, both costs and benefits, are large, can be easily identified and where these can be quantified and valued. There are basically three major impacts that can occur. The first relates to human health and includes costs related to death or illness; the second relates to human welfare and includes damage to property, traffic congestion, changes in soil productivity or land use. The last relates to environmental resources and includes impacts on coastal waters, freshwater eco-systems, biodiversity, etc.

There are two distinct approaches to valuation: objective valuation based on technical relationships between the environment and the damage quotient; and subjective valuation assessments of possible damage expressed or revealed in market behaviour. Willingness to pay is one of the valuation techniques for assessing benefits to environmental change.

3.4.7 Identification of non-quantifiable benefits or secondary benefits

Road projects may have a host of secondary benefits which are not fully reflected in the economic cost-benefit analysis. The first relates to the contribution of projects to objectives other than increases in national income and efficiency and are sometimes referred to as intangible benefits. Projects may, for example, contribute to more effective national integration, regional development, to greater self-sufficiency of the population, to a more equitable distribution of income. In an economic analysis, the non-quantifiable benefits need to be identified to allow for a broader overview of project benefits by the decision makes.

3.5 STEPWISE APPROACH FOR ECONOMIC APPRAISAL

The economic appraisal of projects requires certain activities to be carried out in sequence. The stepwise procedure indicating the key activities and their requirements is given herewith together with **Table 3.02** indicating the format for economic appraisal.

Step 1: Project Definition

- Identify the project and define the scope of work clearly

Step 2: Collection of Base Economic Data

- GDP and state specific growth rates
- Key economic sectors and their growth rates, such as agriculture, industry, services, etc.
- Population growth rates
- Motor vehicle registration growth rates
- Labour force characteristics and employment profile, Per capita income

Step 3: Traffic Assessment

- For road tolling, conduct tolling preference surveys (willingness to *pay* surveys) to determine level of acceptance at specified toll rates, and toll diversion surveys to determine the level of traffic which would not materialize if tolls were applied.

Step 4: Selection of Key Project Assumptions

- road life (usually 20-30 years)
- construction period and percent expenditure/year
- maintenance and operation costs, including savings derived
- discount rate (12 percent is commonly used in India)
- road salvage factor

Step 5: Developing Traffic Forecasts

- Determine historical growth rates for traffic; GDP. Population;
- Determine extent and potential for diverted traffic from: other roads

and other transport networks (if applicable) including rail and other roads;

- Estimate level of diverted traffic (as percent of normal traffic);
- Estimate level of generated traffic (as a percent of normal traffic);
- Conduct toll diversion analysis;
- Determine elasticity of demand;
- Determine applicable growth rate (simple deduction would be to use state GDP plus elasticity of demand) for five yearly intervals;
- Estimate average annual traffic in vehicles/annum, and convert if necessary to PCUs. Apply PCU standard conversion factor as indicated in Table 7 of IRC:SP:30
- Prepare forecast for the project life under two scenarios: “do minimum” and “with project”.

Step 6: Identification of Financial Costs

- physical works costs from engineering estimates
- land acquisition costs from engineering and revenue department estimates
- relocation and resettlement from social assessment
- environmental mitigation from environmental assessment
- operations and maintenance from engineering estimates

Step 7: Conversion of Financial Costs to Economic Costs

- deduct all taxes, duties and subsidies from above noted costs, OR
- use a standard conversion factor, generally 0.85

Step 8: Identification of Socio-Economic Benefits

- what is a socio-economic benefit
- key economic benefits
- key social benefits

Step 9: Methodology for Quantification and Valuation of Benefits

- vehicle operating cost savings
- time savings
- accident savings

- others such as overall regional development etc.

Step 10: Economic Distribution of Benefits

- fiscal: budgetary savings; increased tax
- social: increased land value
- social: HIV Costs
- poverty: employment

Step 11: Choosing Cost-Benefit Parameters

- project life
- construction period
- conversion factor (financial to economic)
- discount rate
- salvage value

Step 12: Modeling Cost-Benefit Analysis

- high volume roads — use of HDM 4

Step 13: Undertaking Sensitivity Analyses

- cost increase/benefit decrease
- construction delay/deferment of commencement
- traffic decrease
- advanced heavy maintenance
- switching values

Step 14: Conclusion – Appraisal Report

- Formal for Economic Appraisal (enclosed)

Table 3.02 Format for Economic Appraisal

Title	Description of Activity
Methodology	Assumptions and Parameters
	Models Used
Economic Costs	Identification of all costs
	Conversion of Financial Costs to Economic Costs
Economic Benefits	Identification of all Benefits
	Assumptions relating to quantification and valuation of key Benefits
Cost-Benefit Analysis	Results of Analysis in terms of: - EIRR NPV at specified rate of discount B/C Ratio at specified rate of discount
Sensitivity Analysis	Results of Analysis in terms of: - cost increase/benefit decrease - switching values - construction delays - traffic drop
Sustainability and Project Risks	Analysis of capability for sustaining asset Identification of critical project risks and mitigation measures
Performance Indicators	Identification of key performance indicators Identification of Targets and milestone dates

CHAPTER - 4

EXPRESSWAY CAPACITY

CHAPTER - 4

EXPRESSWAY CAPACITY

4.1 INTRODUCTION

How much traffic can a facility carry? This is one of the fundamental questions, designers and traffic engineers have been facing since highways have been constructed. The term ‘‘capacity’’ has been used to quantify the traffic-carrying ability of transportation facilities. The value of capacity is used when designing or rehabilitating highway facilities, to obtain design elements such as the required number of lanes. It is also used in evaluating whether an existing facility can handle the traffic demand expected in the future.

The definition and value for highway capacity have evolved over time. The *Highway Capacity Manual* (*HCM 2000*) is the publication most often used to estimate capacity. The current version of the *HCM* defines the capacity of a facility as ‘‘the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period, under prevailing roadway, traffic and control conditions’’ (*HCM 2000*). Specific values for capacity are given for various types of facilities. For example, for freeway facilities capacity values are given as 2,250 passenger cars per hour per lane (pc/hr/ln) for freeways with free-flow speeds of 88 km per hour (kmph), and 2,400 pc/hr/ln when the free-flow speed is 120 kmph (ideal geometric and traffic conditions).

The main objective of this chapter is to provide an understanding of highway capacity and the factors that affect it, and to provide guidance on obtaining and using field values of capacity. The next part of this chapter discusses the method of assessing Expressway capacity on free flow segment between interchanges. Next, it discusses capacity analysis for an interchange since this forms the major hindrance so far as the expressway capacity is concerned.

4.2 CAPACITY ANALYSIS

4.2.1 Indian scenario

Determination of Highway Capacity is a complex process including road and traffic characteristics, the most important of which are (i) traffic homogeneity (ii) traffic control devices and signals, iii) access control and side friction (traffic), (iv) Overloaded – leading to slow moving commercial vehicles. MORTH under Research Programme entrusted IIT Roorkee for development of "Technically Appropriate Values of Design Services Volumes and for Capacity Analysis of Multilane Highways for Traffic Flow in Indian Conditions".

Subsequently, IIT Roorkee in May 2008 presented a paper on "Estimation of Capacity and Design Service Volume for 4/6-Lane Highway" using Highway Capacity Manual 2000 (HCM-2000). While appreciating the paper, IIT Roorkee was requested to have on site validation of the assumptions and the process is ongoing.

4.2.2 Expressway capacity terminology

Expressway capacity: The maximum sustained 15-min flow rate, expressed in passenger cars per hour per lane, that can be accommodated by a uniform expressway segment under prevailing traffic and roadway conditions in one direction of flow.

Traffic characteristics: Any characteristics of the traffic stream that may affect capacity, free-flow speed, or operations, including the percentage composition of the traffic stream by vehicle type and the familiarity of drivers with the expressway.

Roadway characteristics: The geometric characteristics of the expressway segment under study, including the number and width of lanes, left shoulder lateral clearance, clearance from the median edge, interchange spacing, horizontal and vertical alignment, and lane configurations.

Free-flow speed (FFS): the mean speed of passenger cars that can be accommodated under low to moderate flow rates on a uniform expressway segment under prevailing roadway and traffic conditions.

Base conditions: An assumed set of roadway and traffic conditions used as a starting point for computations of capacity and level of service (LOS)

Capacity analysis is based on expressway segments with uniform traffic and roadway conditions. If any of the prevailing conditions change significantly, the capacity of the segment and its operating conditions change as well. Therefore, each uniform segment should be analyzed separately.

4.2.3 Flow characteristics

Traffic flow within basic expressway segments can vary highly depending on the conditions constricting flow at upstream and downstream bottleneck locations. Bottlenecks can be created by ramp merge and weaving segments, lane drops, maintenance and construction activities, accidents, and objects in the roadway.

Traffic flow within a basic expressway segment can be categorized into three flow types: under-saturated, queue discharge, and oversaturated. Each flow type is defined within general speed-flow density ranges, and each represents different conditions on the expressway.

Under-saturated

- Traffic flow that is unaffected by upstream or downstream conditions.

Queue discharge

- Traffic flow passed through a bottleneck and is accelerating back to the FFS of the expressway.

Over-saturated

- Traffic flow is influenced by the effects of downstream bottleneck.

4.2.4 Factors Affecting Free Flow Speed (FFS)

The FFS of an expressway depends on traffic and roadway conditions. These conditions are described below.

- Lane width
- Lateral clearance
- Number of lanes
- Interchange density
- Geometric design

Lane Width and Lateral Clearance

When lane widths are less than 3.6 m, drivers are forced to travel closer to one another laterally than they would normally desire. Drivers tend to compensate for this by reducing their travel speed.

The effect of restricted lateral clearance is similar. When objects are located too close to the edge of the median and roadside lanes, drivers in these lanes will shy away from them, positioning themselves further from the lane edge. This has the same effect as narrow lanes, which force drivers closer together laterally. Drivers compensate by reducing their speed. The closeness of objects has been found to have a greater effect on drivers in the leftmost travel lane than on those in the median lane. Drivers in the median lane appear to be unaffected by lateral clearance when minimum clearance is 0.6 m, whereas drivers in the left lane are affected when lateral clearance is less than 1.8 m

Number of Lanes

The number of lanes on an expressway segment influences FFS. As the number of lanes increases, so does the opportunity for drivers to position themselves to avoid slower moving traffic. In typical expressway driving, traffic tends to be distributed across lanes according to speed. Traffic in the median lane typically moves faster than in the lane adjacent to the left shoulder. Thus, a four-lane expressway (two lanes in each direction) provides less opportunity for drivers to move around slower traffic than does an expressway with 6, 8, or 10 lanes. Decreased manoeuvrability tends to reduce the average speed of vehicles.

Interchange Density

Expressway segments with closely spaced interchanges, such as those in heavily developed urban areas, operate at lower FFS than suburban or rural expressways where interchanges are less frequent. The merging and weaving associated with interchanges affect the speed of traffic. Speeds generally decrease with increasing frequency of interchanges. The ideal average interchange spacing over a reasonably long section of expressway is 3 (three) km or greater. The minimum average interchange spacing considered possible over a substantial length of expressway is 4 (four) km.

Geometric Design

The design speed of the primary physical elements of an expressway can affect travel speed. In particular, the horizontal and vertical alignments may contribute to the FFS of a given expressway segment. If an expressway has significant horizontal or vertical curves, the analyst is encouraged to determine FFS from field observations and field density.

4.2.5 Expressway capacity calculation

Step 1: *Calculation of Free Flow Speed (FFS)*

The first step is to estimate free flow speed (FFS) and is given by,

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} \quad \text{.. (4.01)}$$

where

$BFFS$ = base free flow speed

f_{LW} = adjustment factor for lane width

f_{LC} = adjustment factor for left shoulder lateral clearance

f_N = adjustment factor for number of lanes

f_{ID} = adjustment factor for interchange density

Base Free Flow Speed

BFFS is set at 100 kmph for urban facilities and 120 kmph for rural facilities.

Adjustment Factor for Lane Width (f_{LW}) is given is **Table 4.01**

Table 4.01 Adjustment Factor for Lane Width (f_{LW})

Lane Width (m)	Reduction in FFS (kmph)
3.6	0.0
3.5	1.0
3.4	2.1
3.3	3.1
3.2	5.6
3.1	8.1
3.0	10.6

Adjustment Factor for Left Shoulder Lateral Clearance (f_{LC}) is given in **Table 4.02**

Table 4.02 Influence of Left Shoulder widths on FFS

Left Shoulder width (m)	Reduction in FFS (kmph; f_{LC})			
	Number of Lanes in One Direction			
	2	3	4	≥ 5
≥ 1.8	0.0	0.0	0.0	0.0
1.5	1.0	0.6	0.3	0.2
1.2	2.0	1.3	0.6	0.3

Adjustment Factor for Number of Lanes (f_N) is given in **Table 4.03**

Table 4.03 Adjustment Factor for Number of Lanes (f_N)

Number of Lanes (One direction; Urban Only)	Reduction in FFS
≥ 5	0.0 kmph
4	2.4 kmph
3	4.8 kmph
2	7.2 kmph

Based on the number of lanes in one direction, for two way operation the number of lanes in one direction is divided by 2; for one-way facilities the value is used directly. The adjustment is made for urban expressways only; for rural facilities f_N is set to 0.

Adjustment Factor for Interchange Density (f_{ID}) is given in **Table 4.04**

Table 4.04 Influence of Interchange Density on FFS

Functional Class	Area Size	Interchange Density	Interchange Adj. Factor, (f_{ID}) *
Urban Interstates	Small urban	0.70	1.0 kmph
	Small urbanized	0.76	1.3 kmph
	Large urbanized	0.83	1.7 kmph
Other Urban Highways Qualifying as Expressways	Small urban	0.83	1.7 kmph
	Small urbanized	0.88	1.9 kmph
	Large urbanized	0.91	2.1 kmph

* *Reduction in Free Flow Speed (FFS)*

Step 2: Calculation of Base Capacity (Base Cap)

The Base Capacity (pcphpl) of an Expressway facility is given by

$Base\ Cap = 1.700 + 10 FFS$; for $FFS \leq 112$ .... **(4.02)**

$Base\ Cap = 2.400$; for $FFS > 112$

Step 3: Determination of Peak Capacity (Peak Cap)

The Peak Capacity is given by,

$Peak\ Cap = Base\ Cap * PHF * N * f_{HV} * f_P$ .... **(4.03)** where

Peak Cap	=	Peak Capacity, vehicles per hour (all lanes, one direction)
PHF	=	Peak Hour Factor
N	=	Number of lanes in one direction
	=	Number of Peak Lanes
f_{HV}	=	Adjustment factor for heavy vehicles
f_P	=	Adjustment factor for driver population

Peak Hour Factor (PHF)

The Peak Hour Factor is used to account for variations in flow within the peak hour. The *HCM 2000* recommends defaults of 0.92 for urban facilities and **0.88** for rural facilities. It also states that congested facilities have larger values (0.95 is "typical") than non-congested (unsaturated) ones. Clearly, these factors can have a large impact on capacity.

By setting PHF in Equation 4.03 equal to 1.0; peak capacity can be computed

Determination of initial volume-to-capacity ratio (V/C),

where

V = AADT * K-Factor * D-Factor

(where the K and D-factors are expressed as decimals)

C = Peak Capacity

Assign a final PHF as follows:

Area Type	V/C Ratio	PHF
Rural	< 0.7744	0.88
	0.7744 ≤ V/C ≤ 0.9025	Equation (4.04)
	> 0.9025	0.95
Urban	< 0.8100	0.90
	0.8100 ≤ V/C ≤ 0.9025	Equation (4.04)
	> 0.9025	0.95

Where, *PHF* = $(0.9025 * V/C)^{0.5}/0.95$ for special cases above ……………….…… **(4.04)**

Adjustment Factor for Heavy Vehicles (f_{HV})

The adjustment factor for heavy vehicles (recreational vehicles are ignored) is based on calculating passenger-car equivalents for trucks and buses.

$f_{HV} = 1/1 + P_T(E_T - 1)$ ………………..........…… **(4.05)**

where

P_T = Proportion of trucks and buses in the traffic stream, expressed as a decimal (e.g., 0.15 for 15 percent)

E_T = Passenger-car equivalents
= 1.5 for all urban expressways
= 1.5 for rural expressways in level terrain
= 2.5 for rural expressways in rolling terrain
= 4.5 for rural expressways in mountainous terrain

Adjustment Factor for Driver Population (f_P)

For Urban Expressways, the driver population factor is set to 1.0 to indicate that drivers are familiar with roadway and traffic conditions (by virtue of the fact that most of the traffic is composed of commuters).On Rural Expressways, the factor is set to **0.975**.

4.2.6 Level of service of the expressway

Once an appropriate design speed has been selected, the other basic defining elements of the highway (i.e., the number of lanes and the basic configuration of junctions with other highway facilities) can be determined through application of the concept of acceptable peakhour level of service. Level of service is a grading system for amount of congestion, using the letter A to represent the least amount of congestion and F to refer to the greatest amount (forced flow conditions). For a comprehensive treatment of this topic, refer to the Highway Capacity Manual'. **Table 4.05** presents a brief description of the operating characteristics associated with each level of service. For Expressways, **Level B** is desirable and **Level C** is acceptable.

Table 4.05 Level-of-Service Characteristics

Level of Service	Description
A	Free flow with low volumes and high speeds.
B	**Reasonably free flow, but speeds beginning to be restricted by traffic conditions.**
C	**In stable flow zone, but most drivers are restricted in the freedom to select their own speeds.**
D	Approaching unstable flow; drivers have little freedom to select their own speeds.
E	Unstable flow; may be short stoppages

Source: HCM – 2000

4.2.7 Example: assessment of service volume for basic expressway segment (Illustrative only)

The following section presents an approach for illustrative purposes only. The values are highly dependent on the assumptions used. It should not be used for operational analysis or final design. The tables presented below were derived using default values as given in Highway Capacity Manual – 2000 (HCM-2000) and subjective adoption where the specified range of values have been mentioned.

As mentioned earlier and in absence of Indian version of the Highway Capacity Manual (HCM-India), these tabulated values may be considered for preliminary assessment of number of lanes.

The basic cross sectional features have been considered from Geometric Design Chapter in Volume-II. In brief for a) 2 x 2 lane or 2 x 3 lane configuration, b) lane width of 3.75 m, c) verge side clearance (3.0+1.5) 4.5 m, d) median side clearance 0.75 m, e) plain terrain and gradient limited to 3 percent. With the above preamble

a) Peak capacity values are presented in **Table 4.06**
b) Service volumes for Basic Expressway Segment has been presented in **Table 4.07**

Table 4.06 Peak Capacity Values (Vehicles Per Hour)

For 2 x 2 Lane Expressway

P_T (Percent Trucks) (%)	70	60	50	40	30	25
E_T (PCU equivalent)	4.5	4.5	3.6	3.6	2.5	2.5
Peak Cap. for PHF=0.88	1224	1363	1837	2071	2913	3072
Peak Cap. for PHF=0.92	1280	1425	1920	2165	3046	3212
Peak Cap. for PHF=0.95	1322	1471	1983	2235	3145	3316

For 2 x 3 Lane Expressway

P_T (Percent Trucks) (%)	70	60	50	40	30	25
E_T (PCU equivalent)	4.5	4.5	3.6	3.6	2.5	2.5
Peak Cap. for PHF=0.88	1837	2044	2755	3106	4370	4608
Peak Cap. for PHF=0.92	1920	2137	2880	3247	4568	4817
Peak Cap. for PHF=0.95	1983	2206	2974	3353	4717	4975

Table 4.07 Service Volumes of Basic Expressway Segment (Vehicle Per Hour)

For 2 x 2 Lane Expressway

P_T (Percent of Trucks) (%)	70	60	50	40	30	25	Level of Service
Peak Cap. for PHF = 0.88	428	477	643	725	1020	1075	A
	673	750	1010	1139	1602	1690	B
	918	1022	1378	1553	2185	2304	C
Peak Cap. for PHF = 0.92	448	499	672	758	1066	1124	A
	704	784	1056	1191	1675	1767	B
	960	1069	1440	1624	2285	2409	C
Peak Cap. for PHF = 0.95	463	515	694	782	1101	1161	A
	727	809	1091	1229	1730	1824	B
	992	1103	1487	1676	2359	2487	C

For 2 x 3 Lane Expressway

PT (Percent of Truck1) (%)	70	60	50	40	30	25	Level of Service
Peak Cap. for PHF = 0.88	643	715	964	1087	1530	1613	A
	1010	1124	1515	1708	2404	2534	B
	1378	1533	2066	2330	3278	3456	C
Peak Cap. for PHF = 0.92	672	748	1008	1136	1599	1686	A
	1056	1175	1584	1786	2512	2649	B
	1440	1603	2160	2435	3426	3613	C
Peak Cap. for PHF = 0.95	694	772	1041	1174	1651	1741	A
	1091	1213	1636	1844	2594	2736	B
	1487	1655	2231	2515	3538	3731	C

Note:For Service volumes at Level of Service – A, B & C the peak capacity values have been multiplied by 0.35, 0.55 and 0.75 respectively.

4.3 INTERCHANGE CAPACITY ANALYSIS

HCM-2000 in Chapter 24 and 25 explains the methodologies applicable for analyzing capacity of an interchange. Broadly an interchange capacity analysis is controlled by the operations facilities/capacities at ramp terminals. HCM-2000 presents ideas and concepts relating to most of the interchange types. In absence of extensive database required for the analysis, designer has to depend on subjective default values – either adopting from the tabulated values in HCM-2000 or allocate from experience.

In Japan, the process has been simplified and based on their research and experience, regression equations as well as charts have been developed to evaluate adequacy of the ramp terminals. These ramp terminals may be on or off from the expressway.

4.3.1 Design capacity of rampway

Design traffic capacity of one-lane ramp shall be as under

1,200 pcu/h - design speed ≤ 50 km/h

1,500 pcu/h - design speed > 50 km/h

However, adjustment factor for heavy vehicles may be considered as per **Table 4.08**.

Basically, the traffic capacity of connecting point (merging & diverging) is less than that of ramp, so the traffic capacity of ramp is determined by the capacity of connecting point. Therefore, if the design traffic volume is more than one-lane ramp capacity, consideration to increase the traffic capacity of connecting point should be given first.

Table 4.08 Adjustment Factor for Heavy Vehicles

Proportion Trucks and Buses (%)	10	20	30	40	50	60
Reduction Ratio (%)	88	81	77	74	72	71

4.3.2 Ramp junction capacity

The traffic capacity of ramp junction is affected by design traffic volume on through lane, traffic capacity of through lane and number of lane. The method followed Highway Capacity Manual – methodology and validated for Japan Traffic Condition. In the process, the approach was simplified.

The capacity of ramp (V_r : traffic capacity of connecting point) can be calculated by following formula:

i) 1-lane on - ramp to 2-lane carriageway (2 x 2 configuration)

$V_r = 1.13\ V_d - 154 - 0.39 V_f$

$V_r = 2\ V_d - 0.39 V_f$

(Smaller value shall be adopted as V_r)

ii) 1-lane off - ramp from 2-lane carriageway (2 x 2 configuration)

$V_r = 1.92\ V_d - 317 - 0.66 V_f$

iii) 1-lane on - ramp to 3-lane carriageway (2 x 3 configuration) ....**(Fig. 4.01)**

$V_r = V_d + 120 - 0.244 V_f$

$V_r = 3\ V_d - V_f$

(Smaller value shall be adopted as V_r)

iv) 1-lane off - ramp from 3-lane carriageway (2 x 3 configuration) ……**(Fig. 4.02)**

$V_r = 2.11\ V_d - 203 - 0.488 V_f$

v) 2-lane on - ramp to 3-lane carriageway (2 x 3 configuration) ....**(Fig. 4.03)**

$V_r = 1.739\ V_d - 357 - 0.499 V_f$

$V_r = 3\ V_d - V_f$

(Smaller value shall be adopted as V_r)

vi) 2-lane off - ramp from 3-lane carriageway (2 x 3 configuration) .....**(Fig. 4.04)**

$V_r = 1.76\ V_d + 279 - 0.062 V_f$

where

V_d = Design traffic capacity of through lane (v/h/lane)
V_f = Traffic volume on through lane
V_r = Traffic capacity of connecting point

The ramp terminal capacity can be assessed based on the regression equations mentioned above or using **Fig. 4.01** through **Fig. 4.04**.

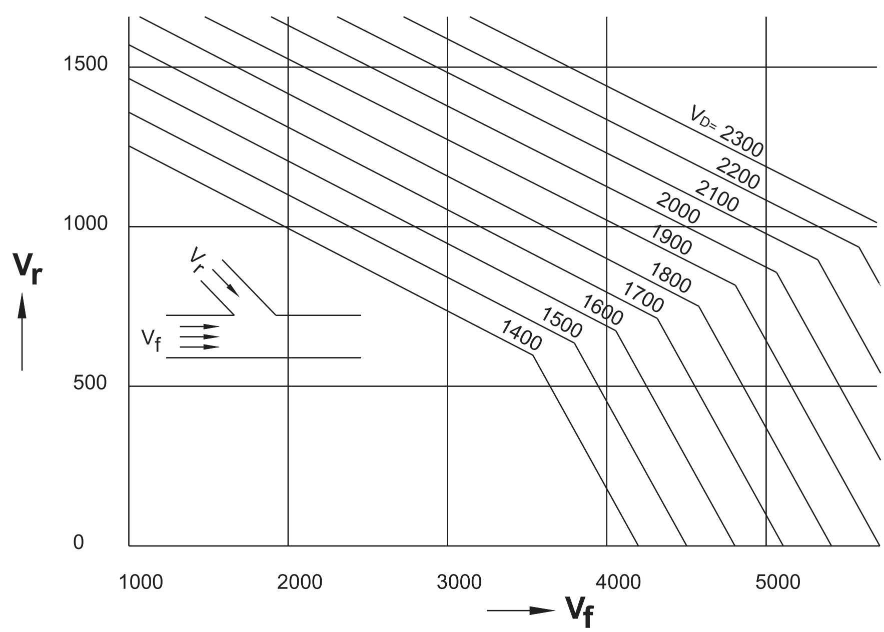


Fig. 4.01 1-Lane on-Ramp to 3-Lane Carriageway

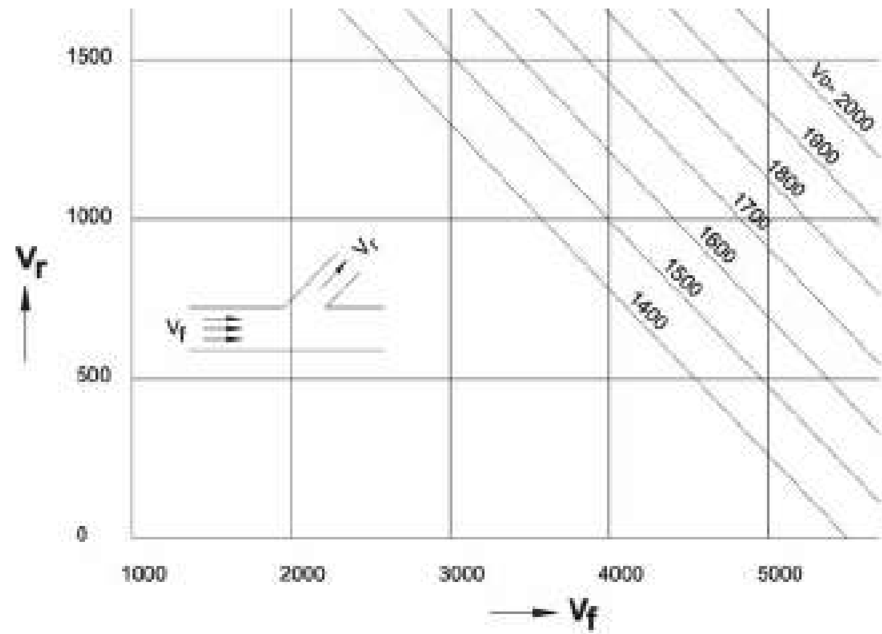


Fig. 4.02 1-Lane off-Ramp from 3-Lane Carriageway

Note: V_f = Traffic Volume on Through Lane Vehicles Per Hour (VPH)
V_r = Traffic Volume at Ramp Function Vehicles Per Hour (VPH)
V_D = Design Traffic Capacity of Through Lane (VPH)

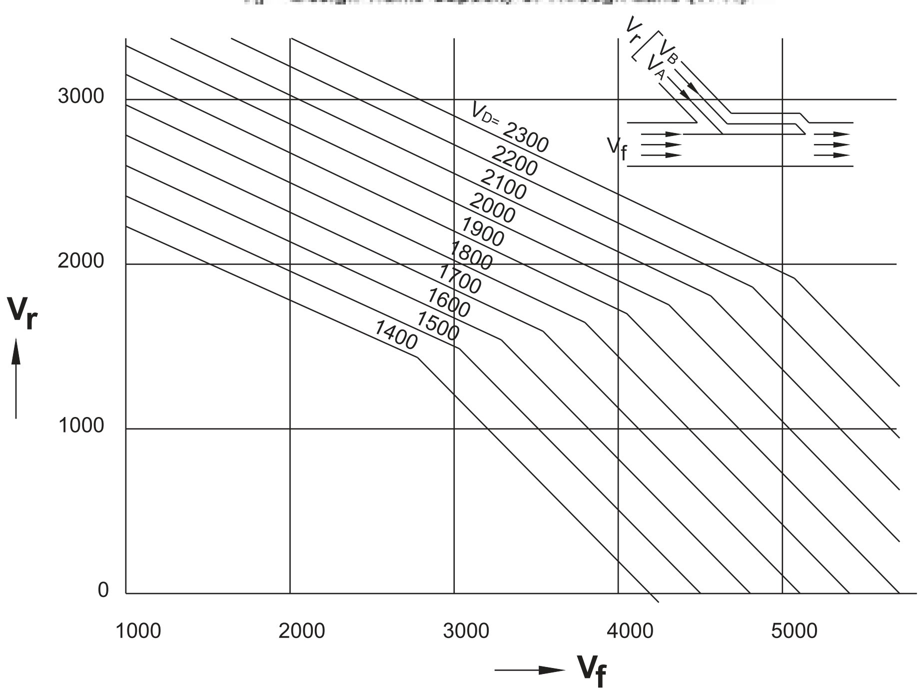


Fig. 4.03 2-Lane on-Ramp to 3-Lane Carriageway

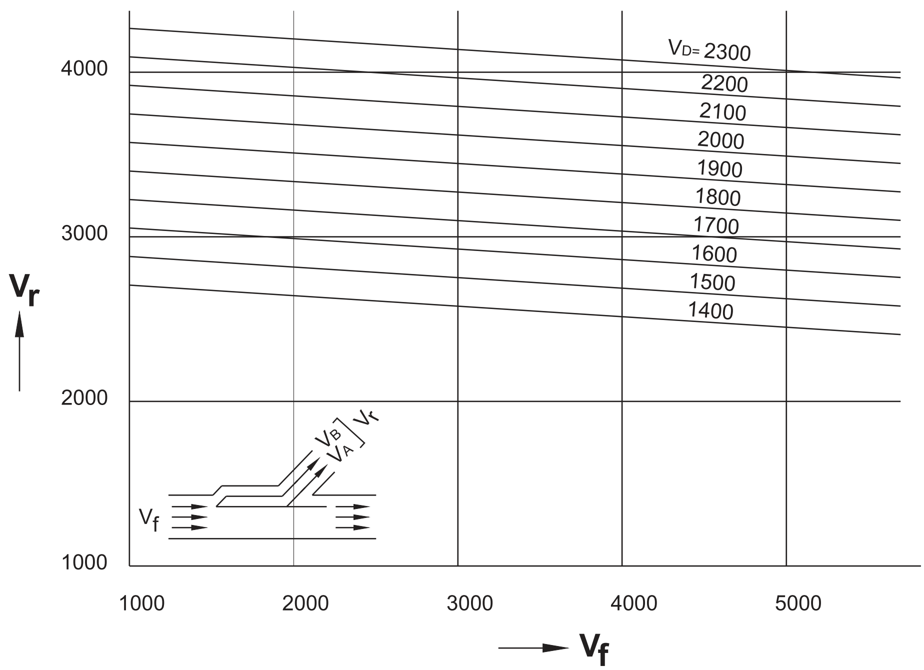


Fig. 4.04 2-Lane off-Ramp from 3-Lane Carriageway

Note: V_f = Traffic Volume on Through Lane Vehicles Per Hour (VPH)
V_r = Traffic Volume at Ramp Function Vehicles Per Hour (VPH)
V_D = Design Traffic Capacity of Through Lane (VPH)

VOLUME - II : DESIGN

EXECUTIVE SUMMARY

VOLUME – II: DESIGN

EXECUTIVE SUMMARY

The objective of the document Volume-II: Design is to assist the design engineer in project preparation for the identified sections of "Expressway Design". These design standards deal with geometric design of inter-city expressways located in open country outside the built-up area. The alignment may, however, pass through isolated small stretches of built-up area as long as the basic character of the expressway as a whole does not change. The standard is not directly applicable to the design of urban expressways.

IRC documents have limitations for use under the present context. This Volume is intended to assist expressway planners/designers with the basic information on project preparation. The contents of this document are necessarily illustrative. This document does not intend to replace text books or other published commercially available documents.

This document has been structured into 14 (fourteen) chapters as follows:

Chapter – 1 : Geometric Design

Chapter – 2 : Interchange Design

Chapter – 3 : Embankment and Cutting

Chapter – 4 : Pavement Design

Chapter – 5 : Design of Structures

Chapter – 6 : Tunnels

Chapter – 7 : Drainage and Erosion Protection

Chapter – 8 : Safety Barriers

Chapter – 9 : Traffic Signs and Pavement Markings

Chapter – 10 : Toll Plaza Design

Chapter – 11 : Service Areas

Chapter – 12 : Pick-up Bus Stops

Chapter – 13 : Lighting

Chapter – 14 : Noise Barriers

Chapter – 1: Geometric Design

This section describes primarily the salient aspects considered in alignment design with specific importance for the high density, high speed access controlled expressways. The considerations involve Terrain Classification, Design speeds, Cross Sectional elements, Safety barriers, Sight distance, Horizontal and Vertical alignment, Climbing lane, Coordination of Horizontal and Vertical alignment, Lateral and Vertical clearances at underpasses, safety barriers, signages and associated features.

- Decision sight distance for avoidance manoeuvres has been considered. The critical locations where it is desirable to provide Decision Sight Distance are (i) Interchange and intersection locations and (ii) Wherever changes in cross-sections occur such as toll plazas and lane drops areas demanding concentration due to competing sources of information.
- Radius beyond which no super elevation is required has been adopted based on normal crossfall and friction value of 0.035.
- Length of Horizontal Curve

  The horizontal curve length at the centerline of the carriageway should not be less than two times the transition curve where intersecting angle is not less than 7 degree.
- The Clothoid type transition curves have been considered for smooth manoeuvring of a vehicle at high speed.

Chapter – 2: Interchange Design

The considerations involve Location planning, Spacing, Types and forms, Capacity, Geometric design, Lane balance, Weaving sections, Exit and entrance terminals, Speed changes lanes and Traffic dispersal Schemes.

For closed tolling system, trumpet type interchanges integrated with toll plazas are desirable and have been deliberated.

As a general guide the following may be useful for preliminary design consideration of interchanges spacing.

- Between Cities – a spacing of 20 - 30 km would be desirable
- City outskirt areas – a spacing of 15 - 25 km would be desirable
- Urban areas – In areas of concentrated urban development where the habitation and development is considerable: a spacing of 5 - 10 km would be desirable

Chapter – 3: Embankment and Cutting

Structural design of embankement and cutting shall be as per relevant IRC documents. Expressways are to be built in embankment or cutting or on long elevated structures. Desirably, a minimum height of 3.5 m shall be considered to accommodate animals, pedestrians, agricultural vehicles etc requiring a minimum vertical clearance of 3.0 m. The Finished Road Levels (FRL) shall be finalized with this minimum value as datum.

Chapter – 4: Pavement Design

Structural design of pavements shall be as per relevant IRC documents. The three main characteristics expected of an expressway pavement surface from the user's point of view are i) Good riding quality (low roughness value); ii) Skid-resistance i.e. good "pavement – tyre" friction during wet weather situation; and iii) Absence or limitation of rutting on wheel tracks. These have been deliberated in the chapter.

Chapter – 5: Design of Structures

Structural design of structures shall be as per relevant IRC documents. An expressway alignment would meet various hazards in the form of cross roads, railways, the rivers/ waterways, canals, and topographical features such as dips, gorges, valleys, lakes and water bodies and other physical barriers.

Chapter – 6: Tunnels

The classifications of tunnels have been adopted from NEXCO practices in Japan and are based on traffic volume and length of tunnel. The standards for installation of the emergency facilities according to this classification have also been adopted from the same source. Tunnel emergency facilities are designed for mitigating damage in the event of fire or accident which may occur in the tunnel.

Tunnel Cross Sections are designed based on safety considerations and cost considerations. An efficient and effective water proofing and drainage system is required in all road tunnels for removal of water from rainfall, seepage, tunnel washing operations, vehicle drippings/spillage or fire-fighting operations. Ventilation in tunnels is to provide fresh air so as to reduce the effect of contaminants so that they are within permissible limits during operation of expressway facility

Chapter – 7: Drainage and Erosion Protection

Structural design of drainage and erosion protection shall be as per relevant IRC documents. The considerations involve Road side drains, Median drains, Culverts and cross drainage, Subsurface drainage, Subgrade drainage, Edge drain collector, Erosion control measures, Existing drain and Rainwater harvesting and conservation.

Chapter – 8: Safety Barriers

Barrier Acceptance Standards are generally in accordance with NCHRP Report 350.

For the expressway, the barriers shall be provided for the entire length. However, a crashworthy end treatment is considered essential near the Toll plaza and at Gore areas. In addition this may also be required to protect bridge piers, utility poles and foundation of overhead sign boards.

Chapter – 9: Traffic Signs and Pavement Markings

To provide adequate level of safety to high speed users of expressways long distance visibility; large lettering and symbols; and short legends for quick comprehension are the basic necessity.

Interchange exit numbering provides valuable information for the users of Expressway. Interchange exit shall be guided in a consistent manner by traffic signs such as advance Guide sign, Exit direction sign and Gore sign.

The other considerations involve Rest area and general service, Toll plaza, Route Markers, Distance marker, Regulatory signs, Cautionary Warning signs, Design, Pavement marking, and Colour and material.

Chapter – 10: Toll Plaza Design

This chapter deals with Toll System based on “Closed system with ticketing payment mode”. The considerations involve Toll plaza elements such as lane width at toll booth, toll plaza lane length and Utility Bridge/Tunnel, number of toll lanes, ETC systems, Management and Operation facilities and Audit systems.

Chapter – 11: Service Areas

For the expressway, the service areas shall be planned to be provided at intervals of 30 minutes to one hour drive, which corresponds to around 50 – 100 km spacing. The facility previsions have been adopted from "AASHTO – Guide for Development of Service Areas on Major Arterials and Freeways – third edition" and NEXCO practices in Japan.

From security considerations, it is of prime consideration that service areas will be provided near interchanges and at intermediate locations where the distance between successive interchanges is more than 100 km.

Consideration for Physically challenged persons is mandatory for the facilities provided on expressways.

Chapter – 12: Pick-up Bus Stops

The expressway bus stops shall be located in the service area adjacent to local bus routes. For a closed toll system of expressway, the basic philosophy of design is to provide layout convenient for both local and expressway bus services and do not involve passing through toll plaza.

Chapter – 13: Lighting

The primary purpose of warrants is to assist designers in evaluating locations or lighting needs and selecting locations for installing. AASHTO - Warrants for expressway lighting categories as (i) Continuous Expressway Lighting; (ii) Interchange Lighting – Complete and Partial; (iii) Bridge Structures and Underpasses; and (iv) Special situations.

Lighting Standards has been adopted from CIE 180:2007 Road Transport Lighting for Developing Countries. Tunnel Lighting has been adopted from CIE 88:2004 Guide for the Lighting of Road Tunnels and Underpasses.

Guidance facilities during night time comprise of interior/exterior illuminated signs, blinker lights and delineators.

Glare reduction devices are required for reducing the headlight glare of opposing traffic at night which may distract the drivers from driving tasks.

Chapter – 14: Noise Barriers

Noise Barrier shall be provided to protect sensitive land uses from expressway noise. The considerations involve Placement, reduction effect, Design and Types of barriers.

CONTENTS

CONTENTS

LIST OF TABLES

CHAPTER – 1: GEOMETRIC DESIGN

CHAPTER – 2 : INTERCHANGE DESIGN

CHAPTER – 8 : SAFETY BARRIERS

CHAPTER – 9 : TRAFFIC SIGNS AND PAVEMENT MARKINGS

CHAPTER – 10: TOLL PLAZA DESIGN

CHAPTER – 11 : SERVICE AREAS

CHAPTER – 13 : LIGHTING

CHAPTER – 14 : NOISE BARRIERS

LIST OF FIGURES

CHAPTER – 1: GEOMETRIC DESIGN

CHAPTER – 2 : INTERCHANGE DESIGN

CHAPTER – 4 : PAVEMENT DESIGN

CHAPTER – 6: TUNNELS

CHAPTER – 7: DRAINAGE AND EROSION PROTECTION

CHAPTER – 10: TOLL PLAZA DESIGN

CHAPTER - 1

GEOMETRIC DESIGN

CHAPTER – 1

GEOMETRIC DESIGN

1.1 DEFINITION AND SCOPE

This Guideline is mainly for Expressways planned as green field projects. For this purpose, the Expressway is defined as an arterial highway for motorized traffic, with divided carriageways for high speed travel, with full control of access and usually provided with grade separators at location of intersections. Generally, only fast vehicles are allowed access on expressways. Parking/standing, loading/unloading of goods and passengers and pedestrians/animals are not permitted on these expressways. They are inter-city highways located in open country outside the built up area. The alignment may, however, pass through isolated small stretches of built up area as long as the character of the expressway as a whole does not change. This Guideline is not directly applicable to the design of urban expressways.

1.2 TERRAIN CLASSIFICATION

Terrain is classified by the general slope of the country across the highway alignment for which the criteria given in **Table 1.01** shall be followed. While classifying the terrain, short isolated stretches of varying terrain shall not be taken into consideration.

Table 1.01 Terrain Classification

Sl. No.	Terrain classification	Percent cross slope of the country
1)	Plain	< 10
2)	Rolling	10-25
3)	Mountainous	25-60
4)	Steep	> 60

In this context for better appreciation during design process, a discussion on the definitions as provided by other international agencies would be of help.

AASHTO 2004 and the HCM-94, HCM-2000 (USA) have classified the terrain in more general terms but under the same nomenclature.

AASHTO and Malaysian Geometric Design Standards defines the classification as follows:

Level Terrain: It is that condition where expressway sight distances, as governed by both horizontal and vertical restrictions, are generally long or could be made so without major expense of construction difficulty.

Rolling Terrain: It is that condition where the natural slopes consistently rise above and fall below the road grade, and where occasional steep slopes offer some restriction to normal horizontal and vertical roadway alignment.

Mountainous Terrain: It is that condition where longitudinal and transverse changes in the elevation of the ground with respect to the road are abrupt and where benching and side hill excavation are frequently needed to obtain acceptable horizontal and vertical alignment.

The HCM definitions of the terrain related to vehicle operations and speeds, are as follows:

Level Terrain: It is any combination of grades and horizontal or vertical alignment that permits heavy vehicles to maintain the same speed as passenger cars; this generally includes short-grades of no more than 1 to 2 per cent.

Rolling Terrain: It is any combination of grades and horizontal or vertical alignment that causes heavy vehicles to reduce their speeds substantially below those of passenger cars, but does not cause vehicles to operate at crawl speeds for any significant length of time.

"Crawl speed" is the maximum sustained speed which trucks can maintain on an extended upgrade of a given per cent.

Mountainous Terrain: It is any combination of grades and horizontal or vertical alignment that causes heavy vehicles to operate at crawl speeds for significant distances or at frequent intervals.

In the Road User Cost Study in India carried out by the Central Road Research Institute (CRRI) for the purpose of speed studies, terrain was divided into the same three classes i.e. plain, rolling and mountainous and classified based on rise/fall per km and the alignment curvature as given in **Table 1.02**:

Table 1.02 Terrain – Rise/Fall and Curvature

Terrain	Rise/Fall m/km	Curvature	
		Low Degrees/km	High Degrees/km
Plain	0 – 15	0 – 50	Over 51
Rolling	16 – 30	0 – 100	Over 101
Mountainous	Over 31	0 – 200	Over 201

Source: CRRI, Road User Cost Study in India - 1982

1.3 DESIGN SPEEDS

Design Speed is defined as the speed which determines the inter-relationship of every element comprising the design of external and conditions of the road, which affects the driving of a vehicle. When the weather is good and the traffic density is low, the maximum speed can be maintained with safety and comfort, by an average driver. The assumed design speed should be a logical one with respect to the topography, the adjacent land use, and the operations for expressway. Every effort should be made to use as high a design speed as practicable to attain a desired degree of safe mobility and efficiency under the given constraints of environmental quality, economics and social impacts.

Once selected, all the pertinent features (both longitudinal and cross sectional) of the expressway should be related to the design speed for consistency and balanced design. Ruling design values mentioned above should be used where feasible, but in view of the numerous constraints encountered, minimum values should be recognised and adopted.

Some features, such as curvature, superelevation and sight distance are directly related and vary appreciably with design speeds.

Other features, such as widths of pavements and shoulders and clearances to walls and railings and barriers, are not directly related to design speed but they affect vehicle speed and higher standards should be according to these features for the higher design speeds. Thus, when a change is made in design speeds, many design elements of the expressway are subject to change.

Design speeds for Expressways for different terrains shall be as given in **Table 1.03**.

Table 1.03 Design Speeds in kmph for Different Terrain

Sl. No.	Nature of Terrain	Cross slope of the country (percent)	Design speed (km/hr)	
			Ruling	Minimum
1)	Plain	< 10	120	100
2)	Rolling	10 - 25	100	80
3)	Mountainous	25 - 60	80	60
4)	Steep	> 60	80	60

Short stretches (say less than 1 km) of varying terrain in the project stretch shall not be taken into consideration while deciding the terrain classification for a given section of Expressway.

In general, the ruling design speed shall be adopted for geometric design of the highway. Only in exceptional circumstances, minimum design speed may be adopted where site conditions are extremely restrictive and adequate land width is not available. Abrupt changes in design speed shall be avoided.

Ruling design speed shall be the guiding criteria for correlating the various geometric design features. Minimum design speed may be adopted in sections where site conditions including costs do not permit a design based on the Ruling design speed.

The design speed shall be uniform along the expressway. For those sections of expressway where variations in terrain may make changes in speed unavoidable, the design speed shall be changed in a gradual manner, by introducing sections of increasing/decreasing design speed as the case may be.

1.4 CROSS-SECTIONAL ELEMENTS

1.4.1 *Right of way, building lines and control lines*

Minimum Right of Way for different terrains for upto 8 lane expressways is indicated in **Table 1.04.**

Table 1.04 Minimum Right of Way

Sl. No.	Terrain		Right of Way (m)*
1)	Plain		90
2)	Rolling		90
3)	Mountainous	Same level	60
		Split level	30

* ***This ROW width will contain 2 m wide corridor for placement of utility inside boundary fencing.***

The need for a wider right of way at toll plazas, interchange locations, high embankments / deep cuts, wayside amenities, provision of service road for connecting cross roads at close intervals, future widening, etc., shall also be kept in view.

Building activity shall not be allowed wherein the prescribed distance from the expressway which is defined by a hypothetical line set back from the right-of-way boundary and called the 'Building Line' **(Fig 1.01).** In addition, it is desirable to exercise control on the nature of building activity for a further distance beyond the building line upto the Control Lines **(Fig 1.01)**.

Recommended standards for building and control lines are given in **Table 1.05.**

Table 1.05 Recommended Standards for Building Lines and Control Lines

Terrain	Open Areas		Built-up Areas
	Overall. width between Building Lines (m)	Overall Width between Control Lines (m)	Distance between Building line and right of way boundary (set – back) (m)
Plain	110	130	5
Rolling	110	130	5
Mountainous	70	80	5

Fencing shall be provided along the ROW to avoid accidents due to unauthorized access by local traffic and cattle.

As an aid to designer, a few cross-sectional features are presented in **Fig. 1.02A to Fig. 1.02D.**

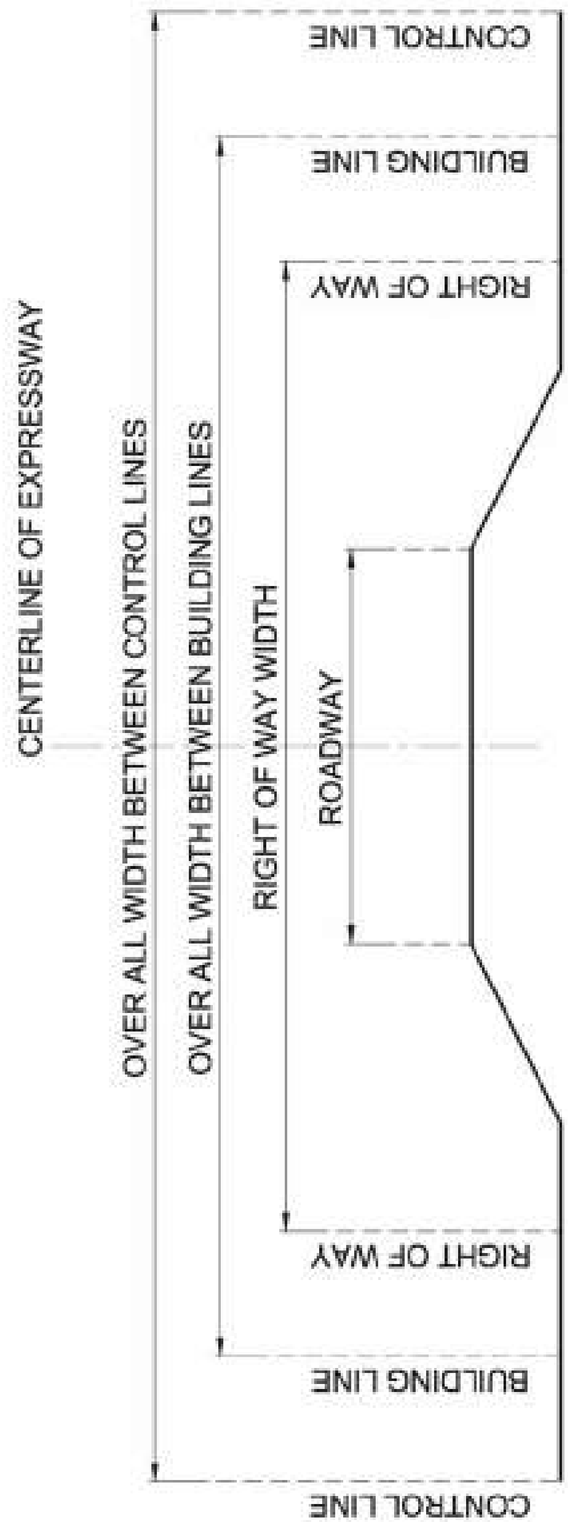
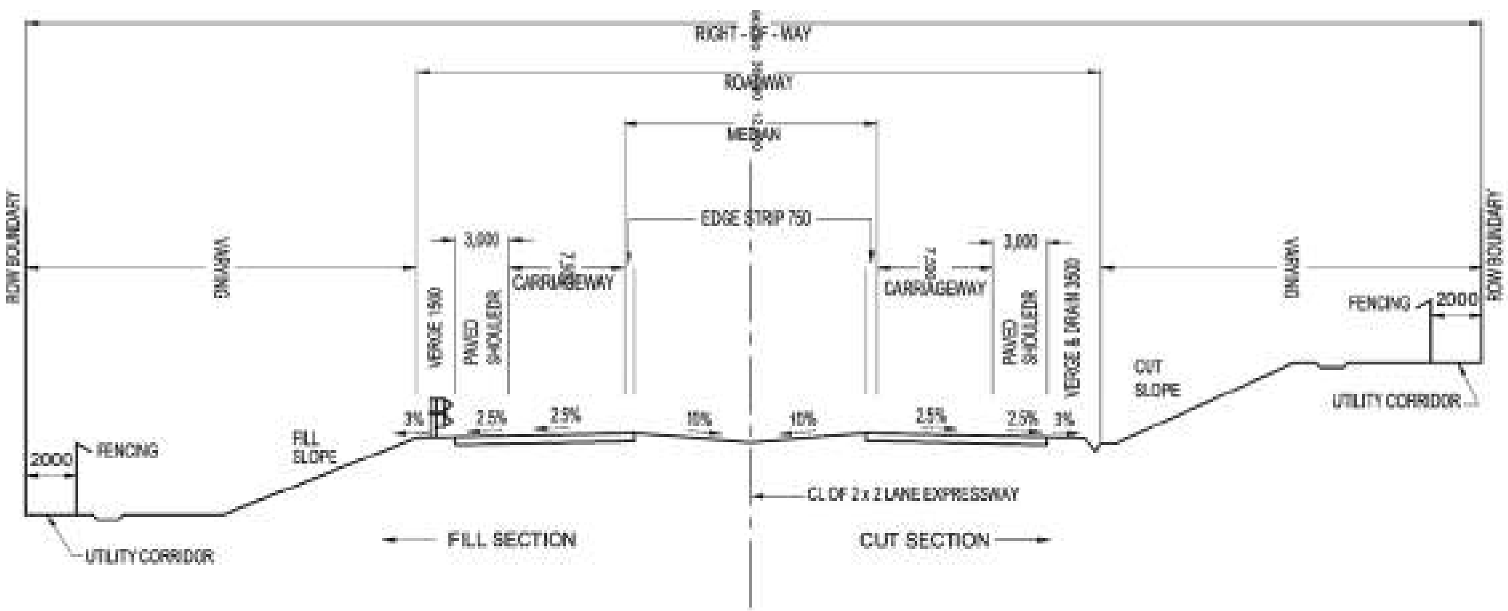


Fig 1.01 Right of way Building Line and Control Line



NOTES:-

1. ALL DIMENSIONS ARE IN MILLIMETRES.
2. THE ROW WIDTH IS ENVISAGED AS 60 METRES CORRESPONDING TO FILL HEIGHT/DEPTH OF CUTTING 5-6 METRES. FOR HIGH FILL/DEEP CUTTING SITUATIONS AND AT INTERCHANGES ROW MAY BE INCREASED AS REQUIRED.
3. THE CARRIAGEWAY WIDTH, PAVED SHOULDER & VERGE WIDTH MAY BE INCREASED CONSIDERING GEOMETRY AND SIGHT DISTANCE CONSIDERATION.

Fig 1.02A Cross-Sectional Layout for 2 x 2 Lane Expressway in Plain or Rolling Terrain

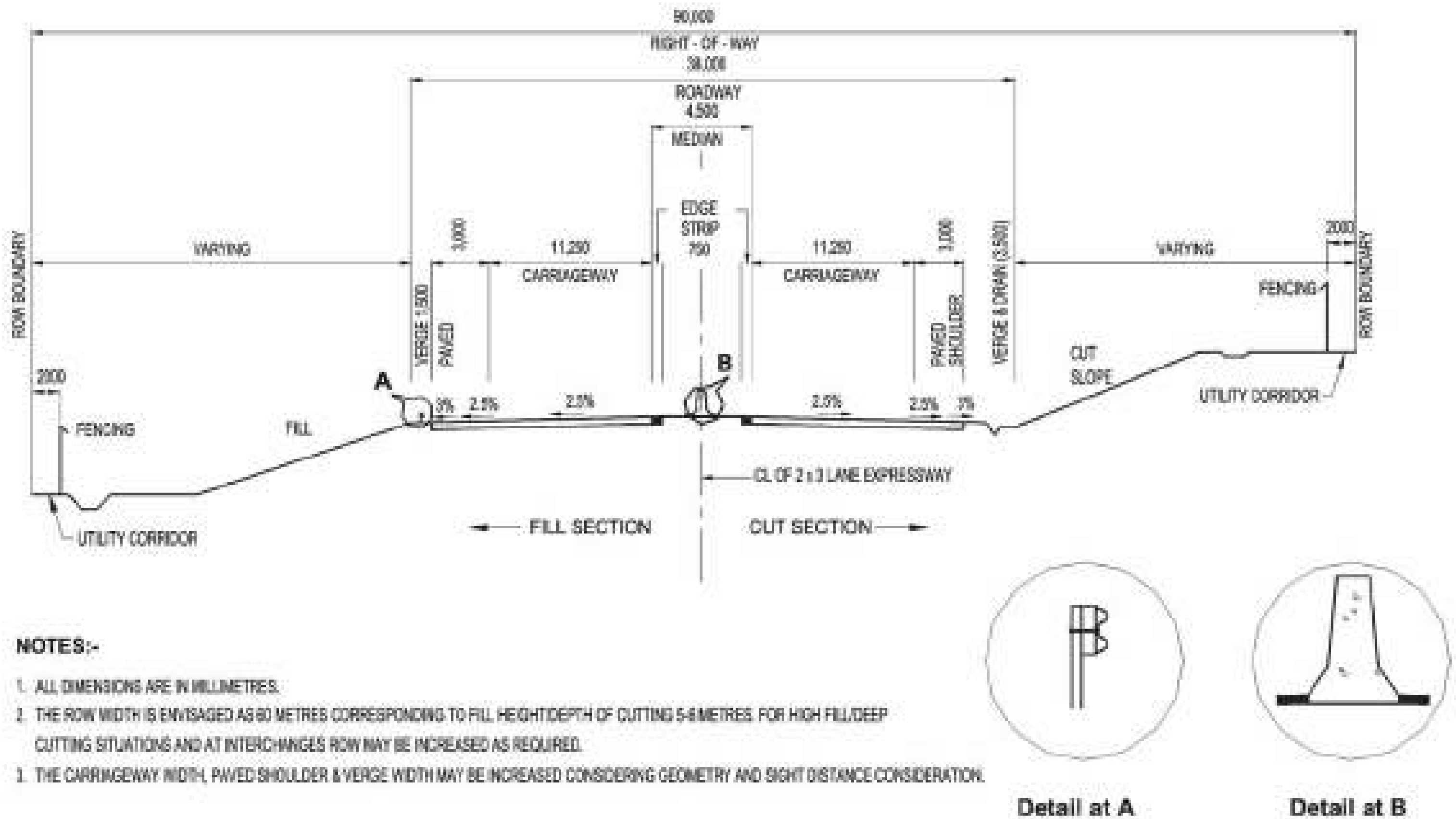
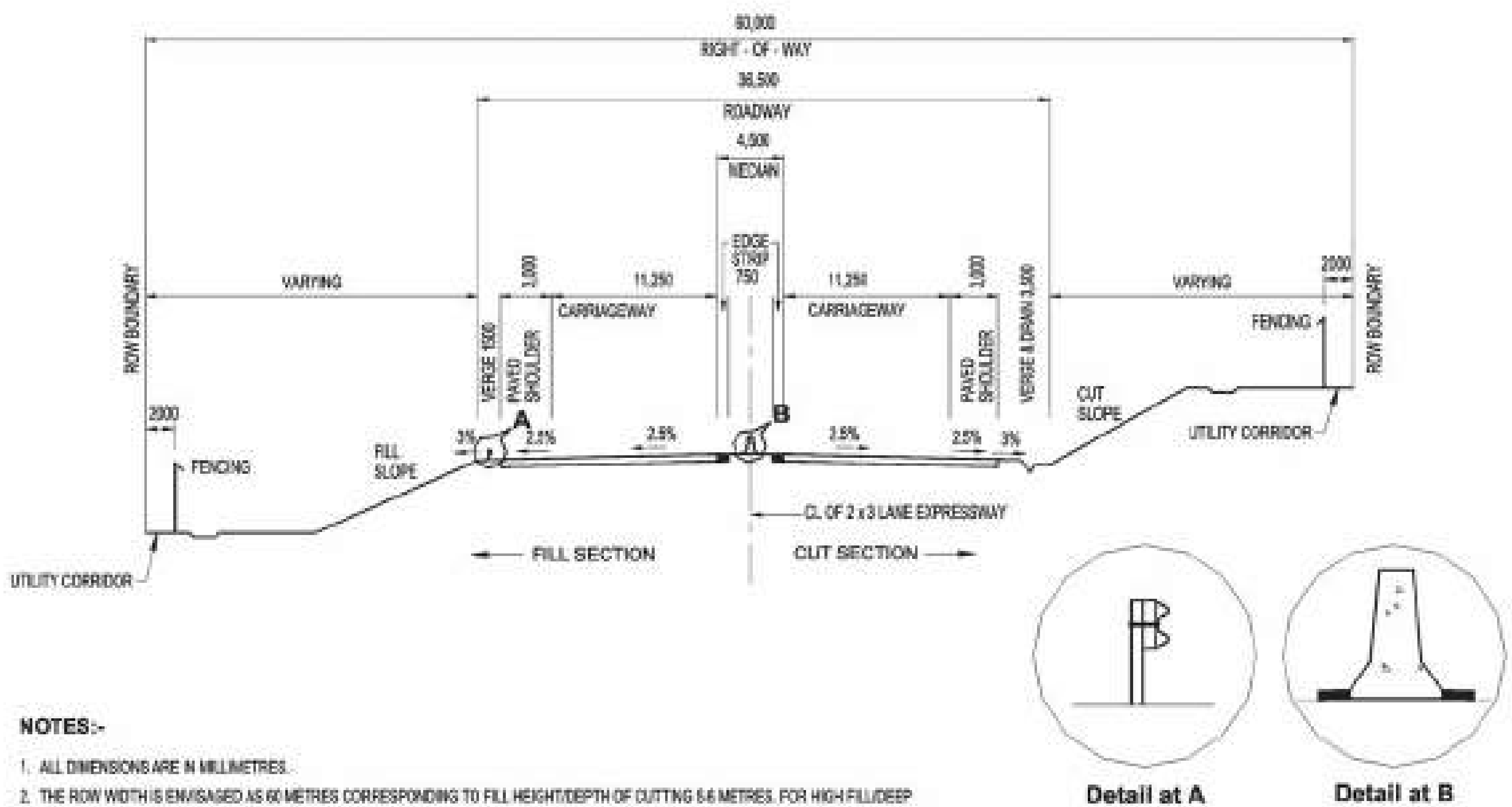


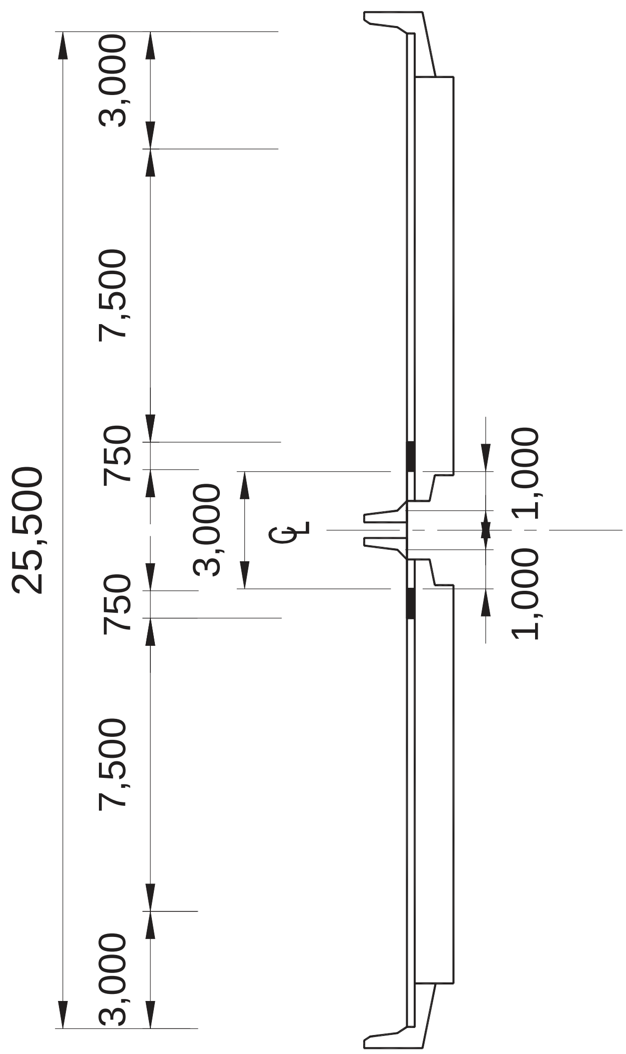
Fig 1.02B Cross-Sectional Layout for 2 x 3 Lane Expressway in Plain or Rolling Terrain



NOTES:-

1. ALL DIMENSIONS ARE IN MILLIMETRES.
2. THE ROW WIDTH IS ENVISAGED AS 60 METRES CORRESPONDING TO FILL HEIGHT/DEPTH OF CUTTING 5-6 METRES. FOR HIGH FILL/DEEP CUTTING SITUATIONS AND AT INTERCHANGES ROW MAY BE INCREASED AS REQUIRED.
3. THE CARRIAGEWAY WIDTH, PAVED SHOULDER & VERGE WIDTH MAY BE INCREASED CONSIDERING GEOMETRY AND SIGHT DISTANCE CONSIDERATION.

Fig 1.02C Cross-Sectional Layout for 2 x 3 Lane Expressway in Mountainous Terrain



NOTE: ALL DIMENSIONS ARE IN MILLIMETRES.

Fig 1.02D 2 x 2 Elevated Expressway (Bridge Section)

1.4.2 *Lane width*

The recommendation of lane width for cross-sectional elements is an extremely complex process. Several countries like USA, UK, France, Germany, Japan etc have carried out lot of research and has estimated the effects in terms of safety and comfort of drivers. There is no internationally consistent model of the simultaneous effects of lane width, shoulder width and type on elevating comfort of drivers as well as the safety level.

But it has been widely accepted that wide lanes and shoulders (paved and earthen) provide drivers increased opportunity for safe recovery when their vehicles run-off the road. Therefore, it has remained largely subjective.

Wide carriageway lane widths provide sufficient sense of safety and lateral space to maintain high speed driving for which the expressways are constructed.

The width of a lane for an expressway in plain and rolling terrains shall be 3.75 m, and in mountainous terrain 3.50 m.

Where the lane width changes e.g. from 3.50 m to 3.75 m or vice versa, the transition shall be effected through a taper of 1 in 60 or flatter.

1.4.3 *Edge strip width*

Technically edge strip is part of carriageway but functionally it may not be considered as part of carriageway. They are widely adopted in Europe and Japan, but not common in USA. Edge strips should provide lateral support to the carriageway proper and will also accommodate the edge markings.

The width of edge strip [**Fig. 1.03, 1.04 and 1.05A and 1.05B**] shall be as given in **Table 1.06**.

Table 1.06 Width of Edge Strip

Terrain	**Width of Edge strip (m)**	
	Left (outer side)*	Right (median side)
Plain	0.5	0.75
Rolling	0.5	0.75
Mountainous	0.5	0.75

* *This 0.5 m width of edge strip is included in 3.0 m wide paved shoulder.*

Edge strip shall be provided on both sides of each carriageway so as to enhance the delineation effect to drivers and to constitute a part of lateral clearance for the safety of vehicles. Edge strip shall also accommodate the edge markings.

Edge strip shall have the same pavement crust and camber as that of the carriageway.

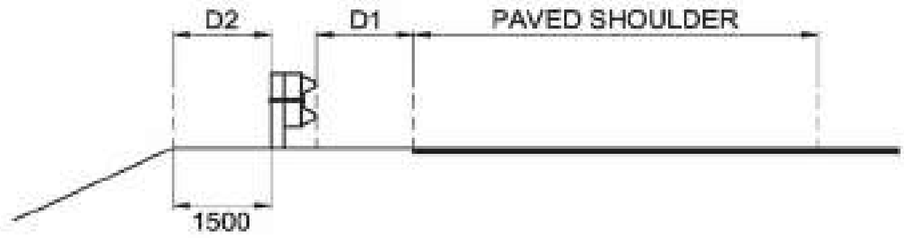
Location of safety barrier on outer side, is shown in **Fig. 1.03.**

1.4.4 *Shoulder width*

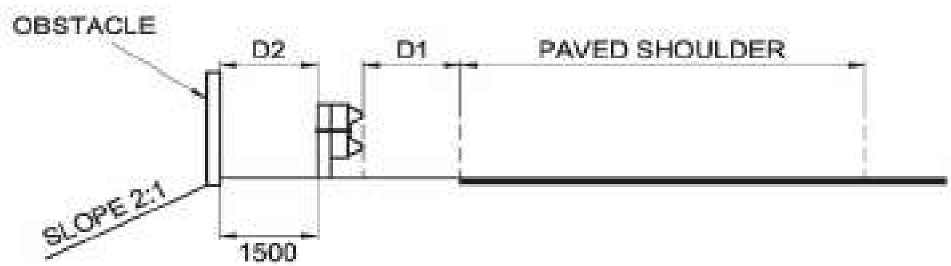
A shoulder is the portion of the roadway contiguous with the carriageway. Well-designed and properly maintained shoulders are necessary and the important advantages derived are:

i) Space is provided for stopping of vehicle and make the through traffic lane free from obstruction because of mechanical difficulty, a flat tyre, or other emergency;
ii) Space is provided for the occasional driver who is required to stop, to decide road ramps, service areas, or for other reasons;
iii) Space is provided to escape potential accidents or reduce their severity;
iv) The sense of openness created by shoulders of adequate width contributes much to driving ease and freedom from strain;
v) Sight distance is improved in cut sections, thereby improving safety;
vi) Expressway capacity level is maintained and uniform speed is encouraged;
vii) Lateral clearance is provided for signs and guardrails;
viii) Surface run-off can be discharged further from the carriageway, and seepage adjacent to the carriageway can be minimized. This reduces pavement edge fretting;
ix) Structural support is given to the pavement;
x) Space is provided for maintenance, operation and security.

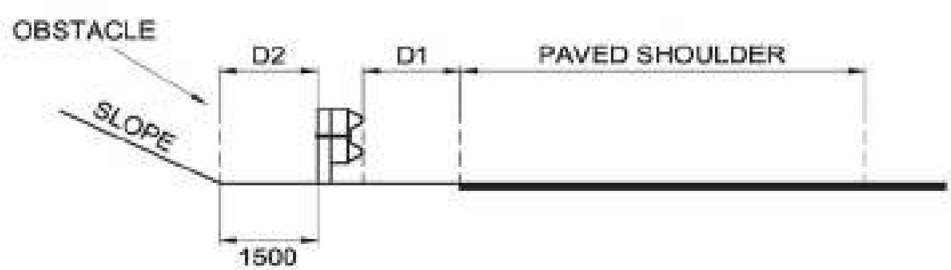
Desirably, a vehicle stopping on the shoulder should clear the pavement edge by at least 0.3 m, preferably by 0.6 m. This preference has led to the adoption of 3.0 m as the normal shoulder width that should be provided along the expressway for plain and rolling terrain. For mountainous terrain paved shoulder width may be reduced to 2.5 m as given in the **Table 1.07**.



D1 = 250
D2 = 600 (minimum)



D1 = 250
D2 = 600 (minimum)



D1 = 250
D2 = 600 (minimum)

NOTE: ALL DIMENSIONS ARE IN MILLIMETERS

Fig 1.03 Location of Safety Barrier

The earthen shoulder provides lateral support to the paved shoulder and provides space for foundation of safety barriers, road signs and other road appurtenances and utility poles. This also provides additional space for errant vehicle to manoeuvre and return back to driving lane. This earthen shoulder needs to be protected against erosion with adequate non-eroding cross slopes and turfing or other measures as applicable and decided by the designer.

The width of paved shoulders on left (outer) side for different terrains shall be as given in **Table 1.07**.

Table 1.07 Width of Paved Shoulder

Terrain	Paved shoulder (m)
Plain	3.0
Rolling	3.0
Mountainous	2.5

i) Paved shoulder is not necessary on the median side. However, in the case of split level carriageways (carriageways at different levels), median side paved shoulder shall be of 1.75 m width. (**Fig.1.04**)

ii) The width of verge on the outer side (i.e., towards the embankment slope) shall be minimum 1.5 m. This verge shall provide lateral support to the paved shoulder and provide space to accommodate safety barrier, signs, open drain, etc. (**Fig. 1.06**).

1.4.5 *Median width*

Median

Where traffic lanes in opposite directions are separated laterally, the road cross-section between opposing traffic lanes is referred to as the median.

The median width is expressed as the dimension between the through traffic lanes including the paved/hard shoulder. The principal functions of a median are:

- To separate the opposing traffic
- To provide a recovery area for out-of-control vehicles

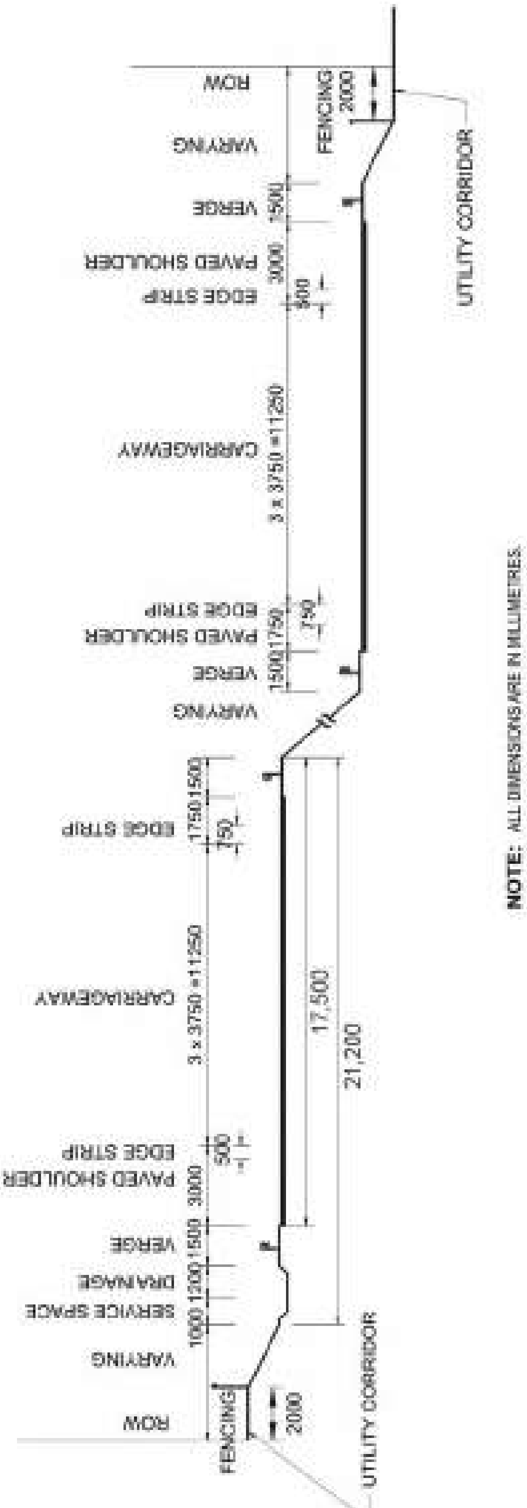


Fig 1.04 Cross-Section 2x3 Lane Expressway at Different Level (Shoulder on Median Side)

Fig 1.05A Part Cross Section of (4-Lane 2x2 Expressway)

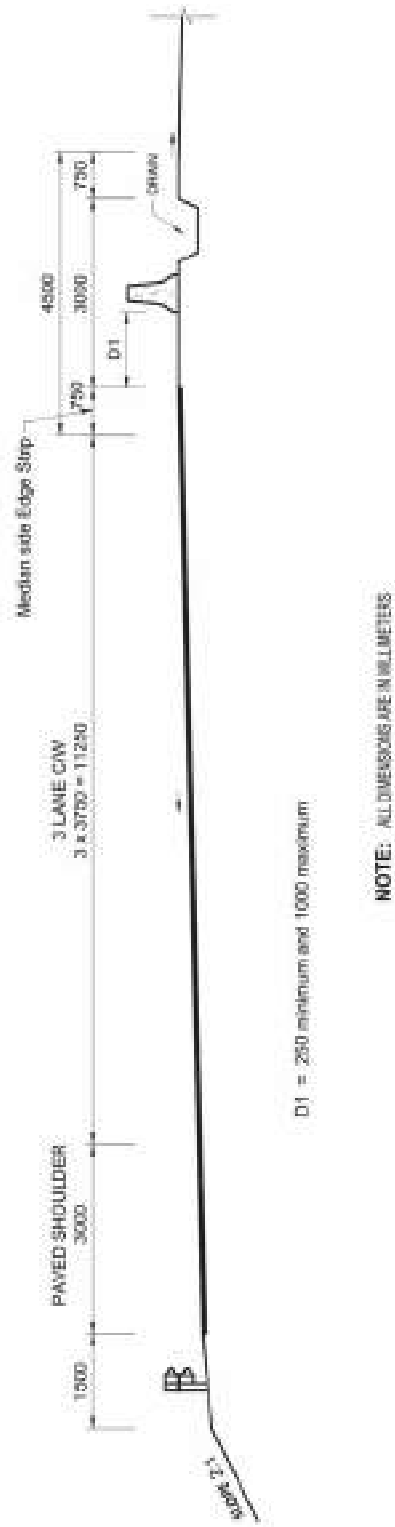
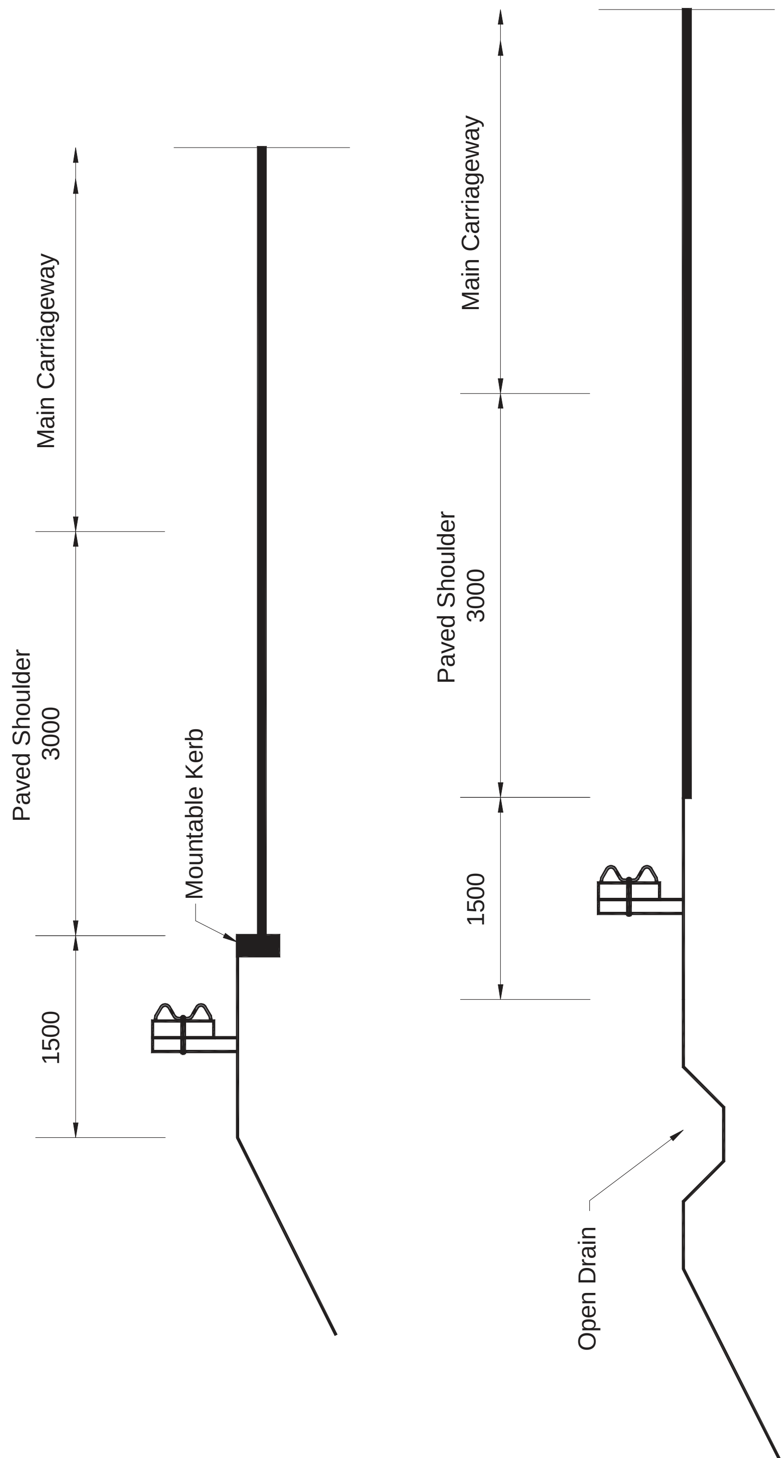


Fig 1.05B Part Cross Section of (6-Lane 3x2 Expressway)



NOTE : ALL DIMENSIONS ARE IN MILIMETERS

Fig. 1.06 Location of Outer Edge Strip Safety Barier Mountable Kerb and Open Drain

- To provide a stopping area in case of emergencies,
- To minimize head light glare, stoppage for right turn and U-turn vehicles

Median should be as wide as feasible. In any case, the median width should be in balance with the other cross sectional elements and the character of the area.

AASHTO Road side design guide 1996 and updated 2006 have the following recommendation in respect of median barriers on high-speed, fully access controlled roadways :

- For median width up to 10 m – Barrier is recommended
- For median width between 10 and 15 m – Barrier is optional
- For median width of more than 15 m – Barrier is not normally considered

For the situations requiring restricted median width, barrier need to be considered. The minimum width of median is dependent upon the maximum lateral deflection that a barrier system experiences during impact which can vary from 0-3 m. Minimum deflection is experienced by rigid concrete barriers and maximum by flexible cable type barriers.

Wide medians offer scope for future widening of the carriageway on the median side without disturbing paved shoulder or side slope protection.

Median Width

A physical hurdle may be ensured by providing shrubs to prevent vehicles from attempting to cross over.

As far as possible, the median shall be of uniform width in a particular section of the expressway. Wherever changes occur in median width, transition shall be effected through a taper of 1 in 60.

Median opening with detachable barrier shall be provided for traffic management for maintenance works and removal of vehicles involved in accidents. Such barriers shall be located before and after tunnels, interchanges, and rest areas. It is desirable to provide median opening with detachable barriers at every 2 to 5 km spacing.

Length of Median Opening shall be not less than 20 m (for emergency and for repair/ maintenance works). Detachable guard barrier shall be provided at every opening.

Median width based on the requirement of barrier or without barrier and future widening considerations are:

Considerations	Recommended Median Width
• Without median barrier	Minimum – 10 m Desirable – 15 m
• With median barrier (Depends on barrier type)	Desirable – 4.5 m
• With median barrier (to accommodate structure/pier on median)	Desirable – 8.0 m
• For future widening	Minimum – 12.0 m Desirable – 15.5 m (to also accommodate structure/pier)

Depressed medians are the recommended configuration on expressways, the recommended crossfall shall be 1 in 8 but can be 1 in 6 on narrow median and can be 1 in 4 to meet the highest amount of overlay (Pavement Thickness).

Raised medians with mountable kerbs may have to be provided in curves where super elevation is to be provided. Appropriate railings/crash barriers shall be provided.

Paving of narrow medians helps maintenance and may also be adopted in difficult climatic conditions which do not permit grassing/turfing. Wider medians should be turfed and lightly planted, using species which might not cause interference with water-balance in the pavement-subgrade system.

Flush medians when used on expressways, a median barrier may be required. The median should be slightly crowned or depressed for drainage. In warmer climates, the crowned type is frequently used because it eliminates the need for collecting drainage water in the median. However, the slightly depressed type is generally preferred with a cross slope of about 4 percent or with a minor steepening of the roadway cross slope.

Typical median treatment is shown in **Fig. 1.06A.**

Median Opening

Median openings on expressways are provided for emergency use. These openings, also known as Emergency Crossing Points (ECP's), are generally meant for repair/ maintenance works, traffic control and other emergency services such as fire, accidents etc. Normally these should be closed by a removable safety fence where normal traffic is not allowed to use these facilities.

Median openings shall be provided for emergency and for repair/maintenance works with detachable crash barriers at every 2.5 km spacing.

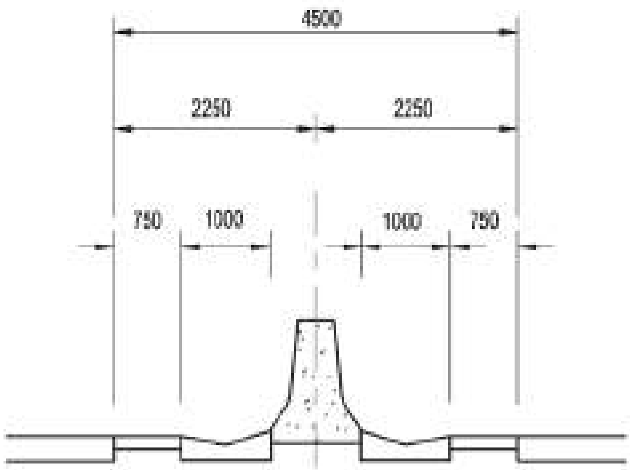
Fig. 1.06B & 1.06C presents typical layout and details of median opening.

1.4.6 *Crossfall/camber*

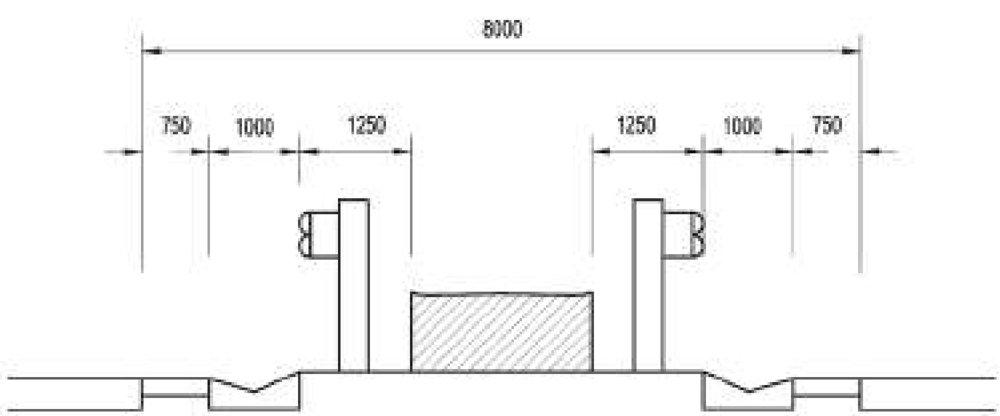
The crossfall on the expressway section shall be as given in **Table 1.08**. Each carriageway shall have unidirectional crossfall. The rate of cross slope on curves as well as on tangent alignment is an important aspect in cross-section design. A reasonably steep lateral slope is desirable to minimize water ponding on non-kerbed pavements with flat longitudinal profile grades as a result of pavement imperfections or unequal settlement.

Table 1.08 Crossfall on Different Surfaces

Cross-Sectional Element	Surface	Rainfall	
		100 cm or more	Less than 100 cm
Pavement, Edge Strip and Paved Shoulder	Bituminous Surface	2.5%	2%
	Concrete Surface	2.5%	2%



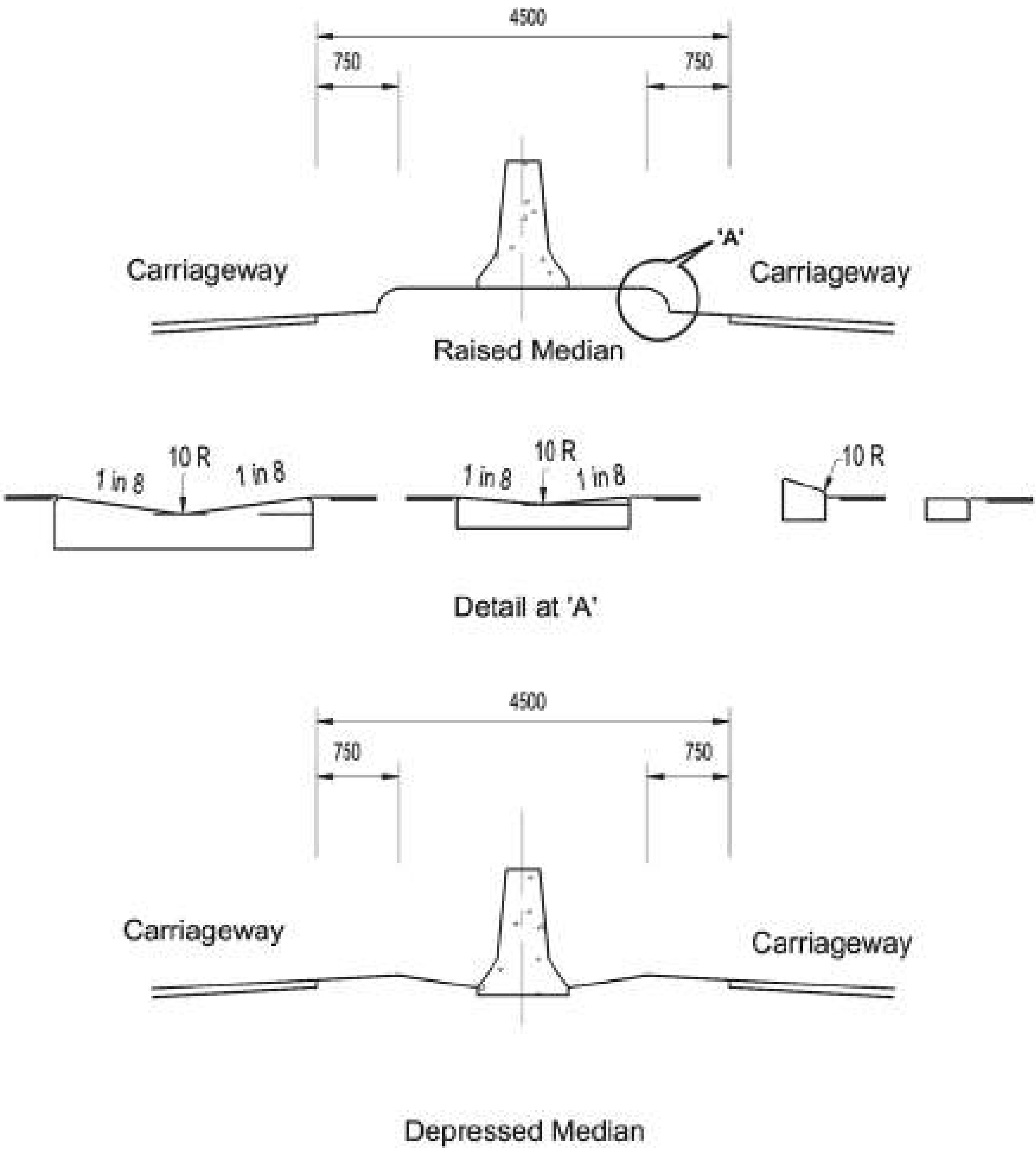
(1) Typical Median Treatment



(2) With Bridge Pier

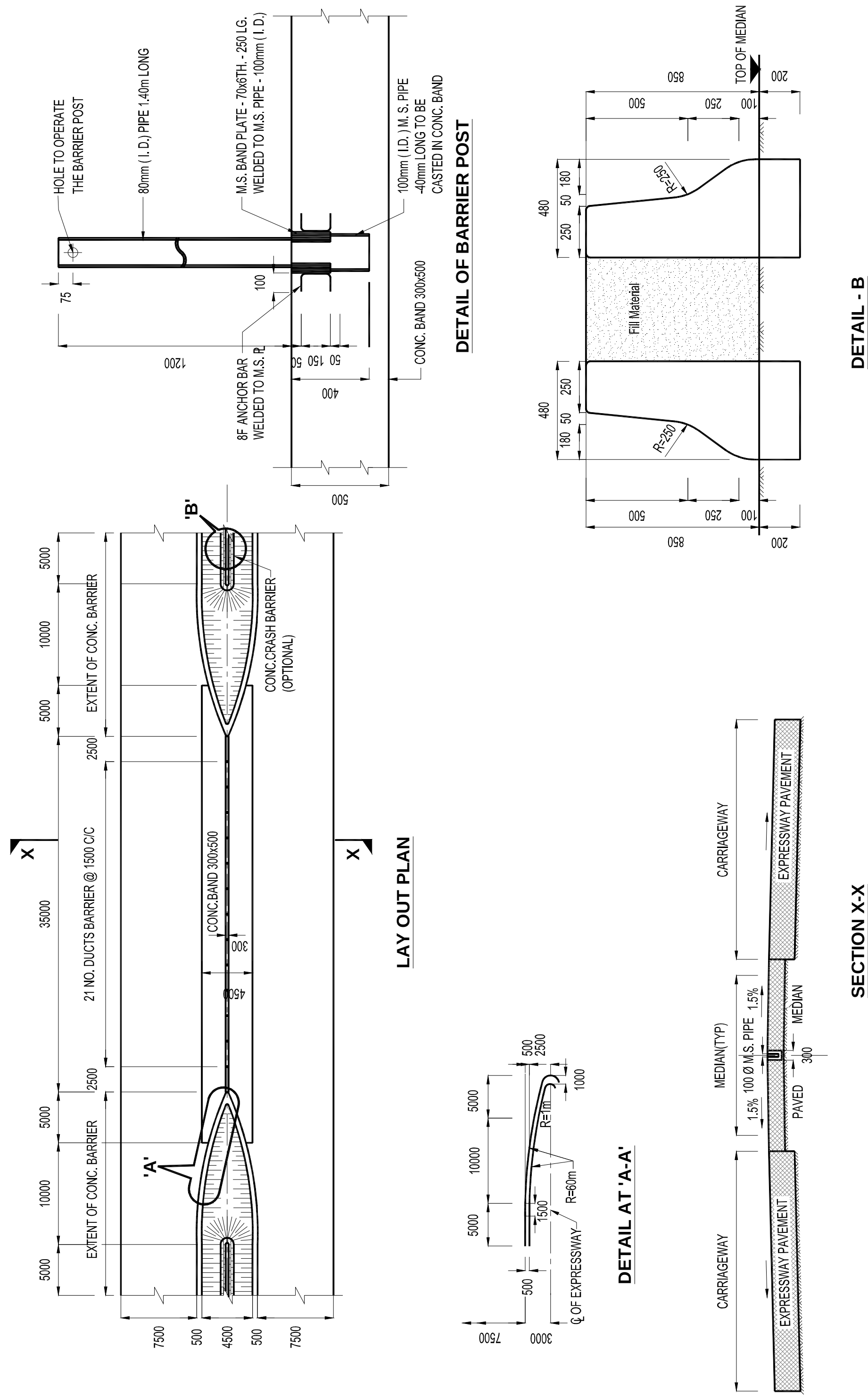
NOTE: All Dimensions are in Milimeters

Fig 1.06 A Expressway Median Treatment



NOTE: All Dimensions are in Millimeters

Fig 1.06B Expressway Median Treatment



NOTE:- All Dimensions are in Millimetres

Fig 1.06C Typical Details of Median Crossings

Camber/Unidirectional crossfall shall be provided for each carriageway including paved shoulders. The crossfall for earthen shoulder shall be 0.5 percent steeper than that of the carriageway subject to a minimum of 3 percent. On horizontal curves, the shoulder on the high side of the super elevated portion may be with reverse slope from the super elevated carriageway portion, but ensuring that the rate of change between pavement cross slope and outside shoulder is not exceeded by 5 percent.

1.4.7 *Embankment*

1.4.7.1 General

The height of the embankment shall be based on the final carriageway levels. The following principles shall be followed:

i) The vertical clearance requirement of the cross roads and in addition, considering that the top of the subgrade of the cross road pavements is at least 1.0 m above the high flood level/high water table/pond level.

ii) To fulfil the minimum free board requirement and provide smooth vertical profile for portions forming approaches to structures and over waterways.

1.4.7.2 Structural features and design of embankment

Embankment shall be designed to ensure the stability of the total formation width and the subsoil strata below the embankment formation at toe level.

1.4.7.3 Embankment slope

Flat, rounded side-slopes, fitting with the topography and consistent with available right-of-way, shall be provided on rural Expressways. Embankment slope shall not be steeper than 1V: 2H. Slopes of 1V:4H or flatter are desirable for embankments of moderate height **(Fig. 1.07)**. For high embankments, steeper slopes protected by safety barriers may be needed **(Fig. 1.03**). For embankment heights more than 6.0 m slope stability of the embankment will dictate the side slopes. The stability analysis shall follow IRC:75 - Guidelines for the Design of High Embankments.

1.4.7.4 Cut slope

Generally the slope is decided by the stability and erosion prevention consideration and the soil/rock formation through which the road passes.

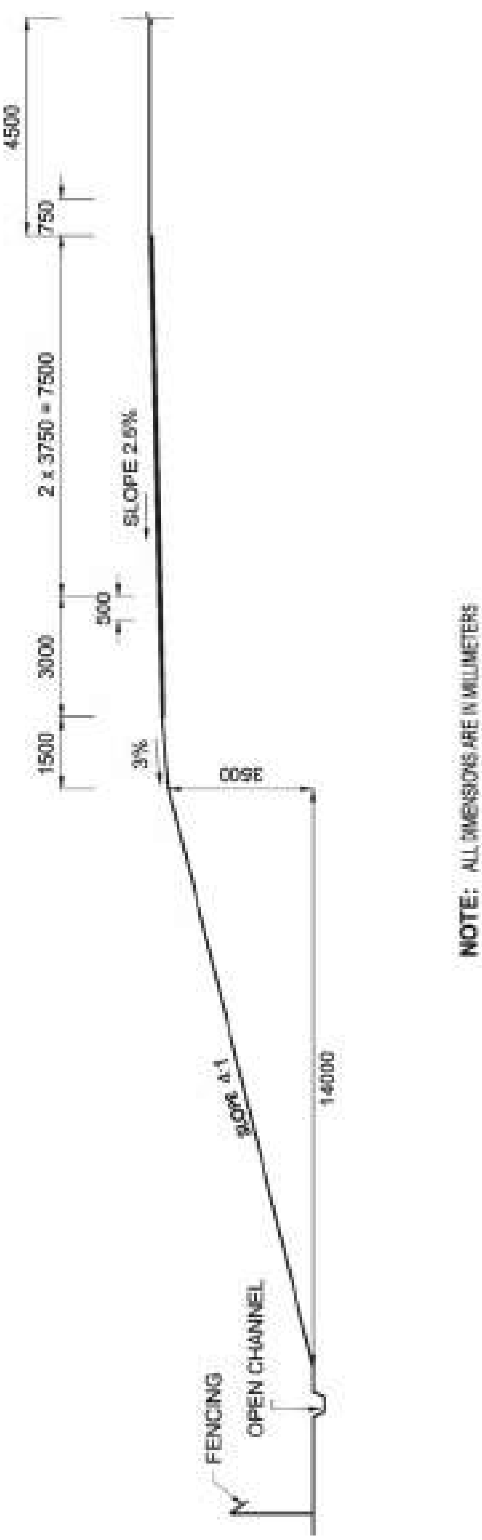


Fig 1.07 Typical Cros-Section of Expressway on Embankment

1.4.7.5 Retaining structures

The embankment shall be retained by a retaining structure in accordance with **Clause 4.6.**

Where the embankment is to be supported on a weak stratum, it shall be necessary to specially design the embankment and also adopt appropriate remedial/ground improvement measures.

High embankments (height 6 m or above) in all soils shall be designed from stability considerations. For design of high embankments IRC: 75 and MORTH – Guidelines for Design of High Embankments may be referred to.

The side slopes shall be protected against erosion by providing turfing/vegetative cover, stone/c.c. block pitching, geo-synthetics, gabion walls or any other measures depending on the height of the embankment, type of soil involved and susceptibility of soil to erosion as per IRC: 56. Pitching works on slopes shall be as per MORTH Specifications.

1.4.7.6 Use of fly ash for embankment construction

i) Fly ash shall be used for construction of embankment in accordance with guidelines of MORTH. The embankment shall be designed and constructed in accordance with IRC: SP-58. The thickness of soil cover shall not be less than 1 m for embankments up to 3 m height. For high embankments, the thickness of soil cover shall be increased as per design.

ii) The side slopes of the embankment, shall be protected against erosion as stated above.

iii) The stability analysis of the embankment shall be carried out as per IRC: 75.

1.5 SAFETY BARRIERS

1.5.1 *Outer side barrier*

1.5.1.1 Safety Barriers shall be provided all along the edge of the embankment. In case, the side slope is flatter than 1V to 4H, safety barriers are not warranted.

1.5.1.2 For safety of road users, safety barrier may be provided (irrespective of the height or slope of embankment), on approaches to bridges on all four sides (for a distance of 150 m each), on the outside of horizontal curves for each carriageway (in the transition and the curved portion), and close to any hazardous location/object.

1.5.1.3 Road side safety barriers shall be located at a clear distance of 0.25 from the outer edge of paved shoulder (**Fig. 1.03**).

1.5.2 *Median barrier*

1.5.2.1 At locations where the two adjacent carriageways are at the same level and the width of median is less than 12 m, the barrier shall be placed at a clear distance of 0.25 – 1.5 m from the outer edge of paved area as shown in **Fig.1.06A** and **Fig. 1.06B**, duly taking into consideration the drainage requirements.

1.5.2.2 In split level carriageways, where the slope of embankment on the median side is steeper than 1V : 10 H, median barrier shall be provided on the higher side carriageway to prevent vehicle from rolling down to the other carriageway. Median barrier on the lower side carriageway shall be provided if the median slope is steeper than 1V to 4H and it will be as in the case of outer side barrier. The requirement of **para 1.5.1.1** will also be applicable to median barriers

Fig. 1.08 presents barrier placement in split level medians. Illustrations are explained in **Section 8.4.1.**

1.6 SIGHT DISTANCE

1.6.1 *Stopping sight distance*

Stopping Sight Distance shall be as given in **Table 1.09**. These are based on perception and brake-reaction time of 2.5 seconds and co-efficient of longitudinal friction 0.35.

Table 1.09 Stopping Sight Distance

Design speed (km/h)	Stopping Sight Distance (metres)
120	250
100	180
80	120
60	80

Source: IRC-73

The criteria for measuring the Stopping Sight Distance are (i) the driver's eye height at 1.2 m above the road surface and (ii) the object's height of 0.15 m above the surface. The Stopping Sight Distance shall be checked at the centre of concerned lane.

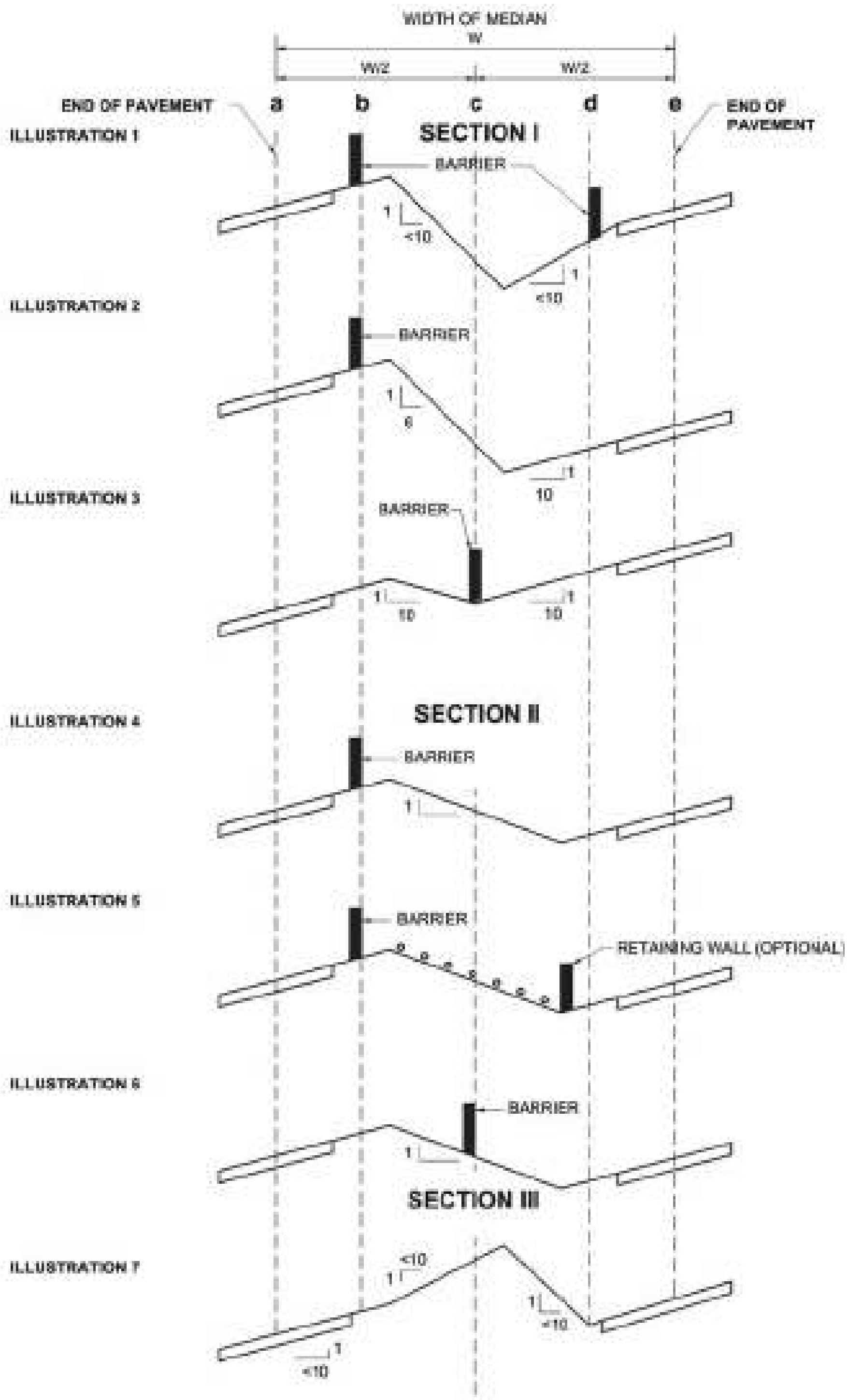


Fig 1.08 Barrier Placement in Split-Level Medians

Visibility shall be greater than the Safe Stopping Distance throughout the expressway.

As per IRC: 73 for all sight distance calculations, the height of the driver's eye is assumed to be 1.2 m above the road surface. For stopping sight distance calculations, the height of object is assumed to be 0.15 m above the road surface.

Calculation of Stopping Sight Distance

Sight distance is the length of roadway ahead visible to the driver. The minimum sight distance available on a roadway should be sufficiently long to enable a vehicle travelling at or near the design speed to stop before reaching a stationary object in its path.

Stopping sight distance is the sum of two distances; the distance traversed by the vehicle from the instant the driver sights an object necessitating a stop to the instant the brakes are applied and the distance required to stop the vehicle from the instant brake application begins. These are referred to as brake reaction distance and braking distance, respectively.

The stopping sight distance is computed by the use of the standard equation:

$$D = \frac{V}{3.6}t + \frac{V^2}{2gf(3.6)^2}$$

where

D = stopping sight distance, m;
V = initial speed, km/h;
f = coefficient of friction between tires and roadways (0.35)
t = reaction time, sec.

In this formula, the first term is the brake reaction distance, and the second term is the braking distance. Substituting t=2.5s, g=9.8 m/s^2, into the above equation, stopping sight distance, D is obtained as follows.

$$D = 0.694V + 0.00394\frac{V^2}{f}$$

When an expressway is on a grade, the standard formula for braking distance is the following:

$$d = 0.00394\frac{V^2}{(f+G)}$$

In which G is the grade expressed as a decimal and the other terms are as previously stated. The safe stopping distances on upgrades are shorter; those on downgrades are longer. However, G is usually very small compared to f and thus, the effect of G is negligible. Also, sufficient margin is included in reaction time. Consequently, it is not necessary to take the effect of grade into consideration in calculation of stopping sight distance.

1.6.2 *Decision sight distance*

Decision sight distance is defined as the distance required for a driver to detect an unexpected or otherwise difficult to perceive information source or hazard, recognize the hazard or its threat potential, select an appropriate speed and path, initiate and complete the required manoeuvre safely and efficiently. The values of decision sight distances are greater than the stopping sight distances. It gives the driver sufficient distance to complete his manoeuvre at the same or reduced speed without having to stop. The values of decision sight distance are given in **Table 1.10.** These can be used at critical locations indicated below:

Table 1.10 Decision Sight Distance

Design Speed (km/h)	Decision Sight distance for Avoidance manoeuvres (m)	
	Stopping	Speed/Path/Direction change
120	265	360
100	200	315
80	140	230
60	95	170

The critical locations where it is desirable to provide Decision Sight Distance are:

a) Interchange and intersection locations
b) Wherever changes in cross-sections occur such as toll plazas and lane drops
c) Areas demanding concentration due to competing sources of information, such as roadway elements, traffic and traffic control devices.

If it is not possible to provide these distances because of difficult horizontal or vertical alignment, consideration shall be given to relocating those points. If it is not possible to relocate, adequate advance warning/traffic control devices, shall be ensured.

The criteria for measuring the Decision Sight Distance as above are:

i) the driver's eye height at 1.2 m above the road surface; and
ii) the object's height of 0.15 m above the road surface.

The Decision Sight Distance shall be checked at the centre of concerned lane.

1.7 HORIZONTAL ALIGNMENT

1.7.1 *General*

The following general principles shall be kept in view while designing the horizontal alignment:

i) Alignment should be fluent and blend well with the surrounding topography.
ii) The curves should be designed to have largest practical radius but in no case less than ruling value corresponding to ruling design speed.
iii) Sudden change of alignment, for example, sharp curve at the end of long tangent section shall be avoided, since these can be extremely hazardous.
iv) Long tangent sections exceeding 3 km in length shall be avoided as far as possible. A curvilinear alignment with long curves is better from the point of safety and aesthetics.
v) The curves shall be sufficiently long, and have suitable transitions to provide pleasing appearance.
vi) Reverse curves may be needed in difficult terrain. Sufficient length between two curves shall be provided for introduction of requisite transition curves, and required superelevation.
vii) The curves in the same direction separated by short tangents known as broken back curves should be avoided as far as possible in the interest of aesthetics and safety. Wherever possible, such portion may be designed with longer single curve.
viii) Sharp curves shall not be provided in high embankment section. If this is not possible, proper delineation/safety barriers must be provided.
ix) To avoid distortion in appearance, the horizontal alignment should be coordinated carefully with the vertical alignment.

1.7.2 *Horizontal curves*

In general horizontal curves shall consist of a circular portion flanked by spiral transitions at both ends.

1.7.2.1 Radii of horizontal curves

The radius of horizontal curve shall be calculated from the equation:

$$R = \frac{V^2}{127(e+f)}$$

R=radius in metres

V= vehicle speed in km/h

e= super elevation ratio in metre per metre

f= coefficient of lateral friction between vehicle tyres and pavement as given in **Table 1.11**

Table 1.11 Coefficient of Friction

Design Speed (km/h)	120	100	80	60
f	0.10	0.11	0.125	0.14

Combining the coefficient of frication (f) and the maximum permissible values of superelevation the minimum radii for horizontal curves can be computed using the above equation. A typical value for e=7% is given in **Table 1.12**.

Table 1.12 Radius of Minimum Horizontal Curve (for e=7%)

Design Speed (kmph)	120	100	80	60
Absolute Minimum radius (m)	670	440	260	140
Desirable Minimum radius (m)	1000	700	400	200

The desirable radius of horizontal curve is calculated assuming the friction developed as 50 percent of the values given in **Table 1.11.** For other superelevation values (e) may be worked out.

Japanese experience testifies that there is not much difference in cost of construction using desirable radius and the absolute minimum radius curves. However, in most cases an alignment can be drawn with curves larger than the desirable radius as mentioned above.

1.7.2.2 Radii beyond which no superelevation is required

Table 1.13 shows the radii of the horizontal curves beyond which super elevation will not be required (assuming f=0.035). In such cases, the normal cambered section shall be continued on the curved portion without providing any superelevation.

Table 1.13 Radii Beyond which Superelevation is not Required

Design Speed (km/h)	Minimum Curve Radius (m)	
	e=2%	e=2.5%
120	7000	11400
100	5500	7900
80	3500	5100
60	2000	2900

1.7.2.3 Length of horizontal curve

The curve length at the centreline of carriageway should not be less than two times the transition curve length in case the intersecting angle is more than 7 degrees. When the intersecting angle is less than 7 degrees, the length of curve should not be less than the desirable value given in **Table 1.14.** However, in unavoidable cases, the value may be reduced to the minimum value regardless of the intersection angle.

Table 1.14 Minimum Length of Horizontal Curve (m)

Design Speed (km/h)	Desirable ϕ	Minimum ϕ
120	1400/Δ	200
100	1200/Δ	170
80	1000/Δ	140
60	700/Δ	100

where Δ is the total deviation angle between straight alignments.

When a vehicle runs on a short curve section of the road, the driver and passengers undergo a horizontal impact and are exposed to danger particularly while on an expressway because of need for frequent steering. Where the radius of curve is relatively large, theoretically a relatively short curve is enough for centrifugal acceleration. However, in such a case, if the intersection angle is small, a driver feels that the curve length is shorter and the radius of curve is smaller than actual values, causing the driver to reduce speed. If the driver tries to run his vehicle without decreasing speed, the vehicle will run along a larger radius and may enter other lanes and cause collision.

To be on safe side, the minimum curve length shall be the length that a vehicle runs for 6 seconds, because it requires at least 3 seconds for the driver to steer one direction, so the minimum length of curve shall be the length that a vehicle runs for two times of 3 seconds.

1.7.2.4 Setback distance at horizontal curves

Requisite stopping sight distance shall be available across the inside of horizontal curves. Lack of visibility in the lateral direction may arise due to obstructions like walls, cut slopes, buildings, wooded areas, tall farm crops etc. Distance from the road centre line within which the obstructions shall be cleared to ensure the needed visibility, i.e. the set back distance, can be calculated vide procedure described below. But in certain cases due to variations in alignment, road cross section, and the type and location of obstruction, it may become necessary to resort to field measurements to determine the limits of clearance.

The set-back distance is calculated from the following equation:

m=R-(R-n) Cos è **(Fig 1.09)**

è $= \frac{S}{2(R-n)} \textit{radians};$

m = the minimum set back distance to sight obstruction in metres (measured from the centre line of the road);

R = radius at centre line of the road in m

n = distance between the centre line of the road and the centre line of the inside lane in m; and S=sight distance in m

In the above equation, sight distance is measured along the middle of inner lane.

Where there are sight obstructions (such as walls, cut slopes, buildings, or a guardrail under certain conditions) on the inside of curves, a design to provide adequate sight distance may require adjustment in the normal expressway cross section or change in alignment if the obstruction cannot be removed. Using design speed and a selected sight distance as a control, the designer should check the actual condition and make the necessary adjustments in the manner most fitting to provide adequate sight distance.

For general use in design of a horizontal curve, the sight line is a chord of curve, and the applicable stopping sight distance is measured along the centre line of the inside lane around the curve.

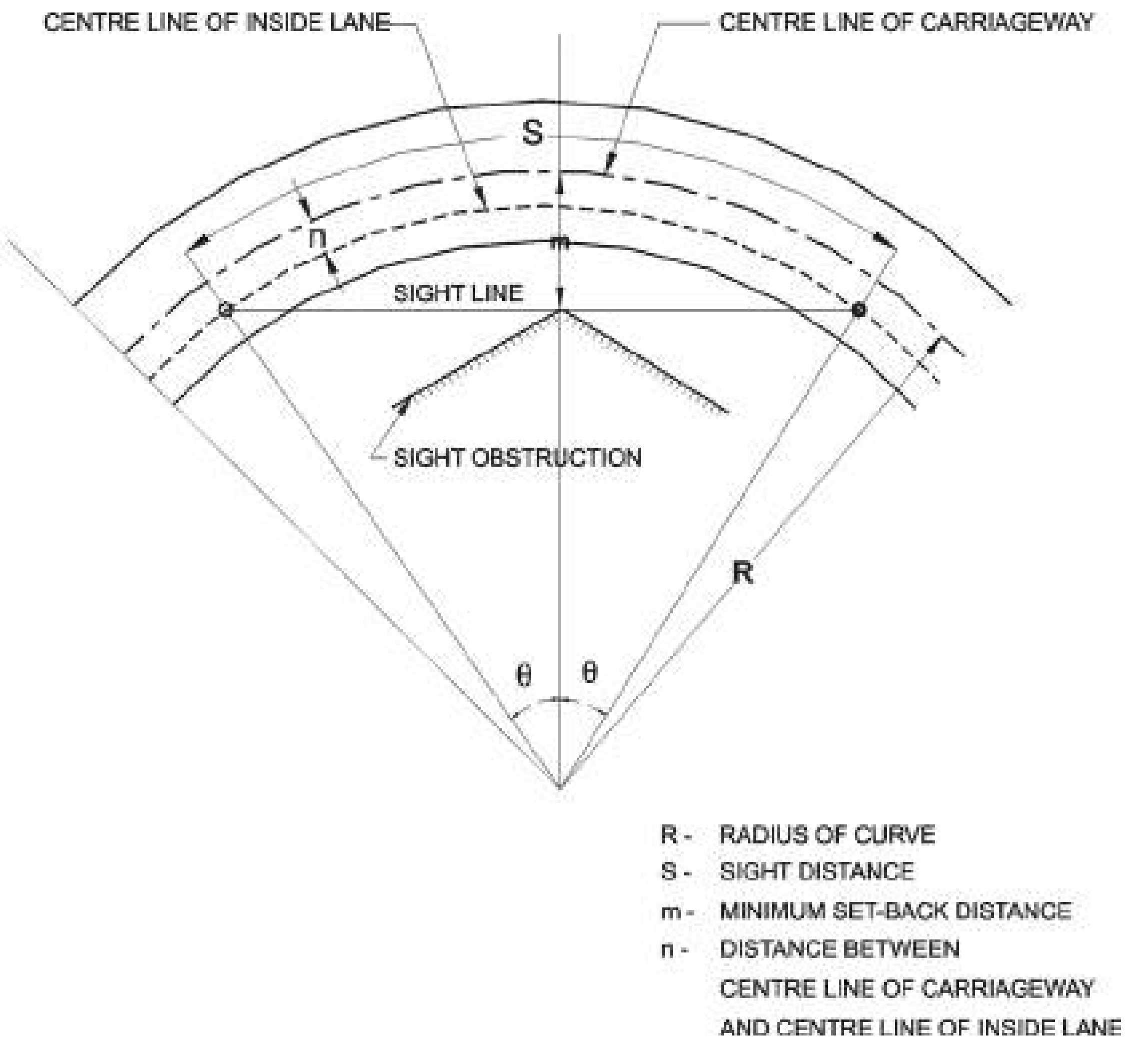
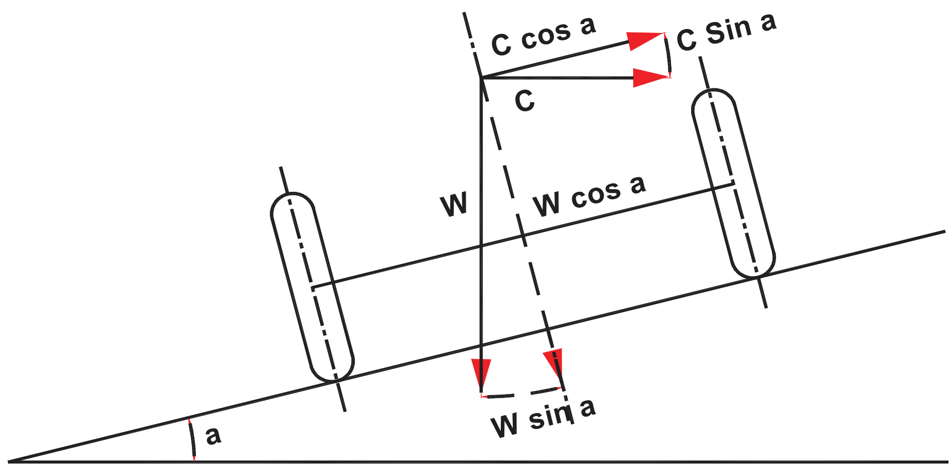


Fig 1.09 Visibility at Horizontal Curves

1.7.3 Super-elevation



Geometry for Running on the Curve

C : Centrifugal force generated due to movement of vehicles on curve alignment
W : Weight of vehicle
R : Resultant of C & W
e : Super Elevation

1.7.3.1 Design values

Superelevation required on horizontal curves shall be calculated from the following formula.

$$e + f = \frac{V^2}{127\,R}$$

where

e= super elevation in metre per metre

V= speed in km/h,

f = coefficient of friction **(Table 1.11)** and

R= radius in m

Super elevation obtained from the above expression shall however be limited to the following:

a)	In plain and rolling terrain	7%
b)	In snow bound areas in all terrain	6%
c)	Mountainous areas not bound by snow	8%

1.7.3.2 Attaining superelevation

The normal cambered section is changed into superelevated section in two stages. First stage is the removal of adverse camber in outer half of the pavement. In the second stage, superelevation is gradually built up over the full width of the carriageway so that required superelevation is available at the beginning of the circular curve. **Fig. 1.10** Illustrates the method diagrammatically. The small cross-sections at the bottom of each diagram indicate the pavement cross slope condition at different points.

The superelevation shall be attained gradually over the full length of the transition curve so that the design superelevation is available at the starting point of the circular portion. In developing the required super elevation, it shall be ensured that the super elevation run-off rate (i.e. the rate of change of super elevation) is not steeper than 1 in 200 for roads in plain and rolling terrains and 1 in 150 for roads in mountainous-terrain.

For expressways with divided carriageways the points of rotation are generally considered at the junction of carriageway edge and the median.

The median is held in a horizontal plane and the two carriageways are rotated separately around the median edges to superelevate the roadway. Expressways warrant a greater attention to appearance. Accordingly the values for length of runoff should be considered as minimum, and the adoption of yet longer values is desirable.

When cross-drainage structures fall on a horizontal curve, their deck should be superelevated in the same manner as described above.

1.7.4 *Transition curves*

Generally, the Euler spiral, which is also known as the clothoid, is used in the design of spriral transition curves. The radius varies from infinity at the tangent end of the spiral to the radius of the circular arc at the end that meets the circular arc. By definition, the radius of curvature at any point on an Euler spiral varies inversely with the distance measured along the spiral. When a driver keeps constant speed and turns the steering wheel with constant angular velocity, its tire track draws spiral, which is called clothoid. Clothoid curves give smooth manoeuvring of a vehicle which is especially important for a high speed driving.

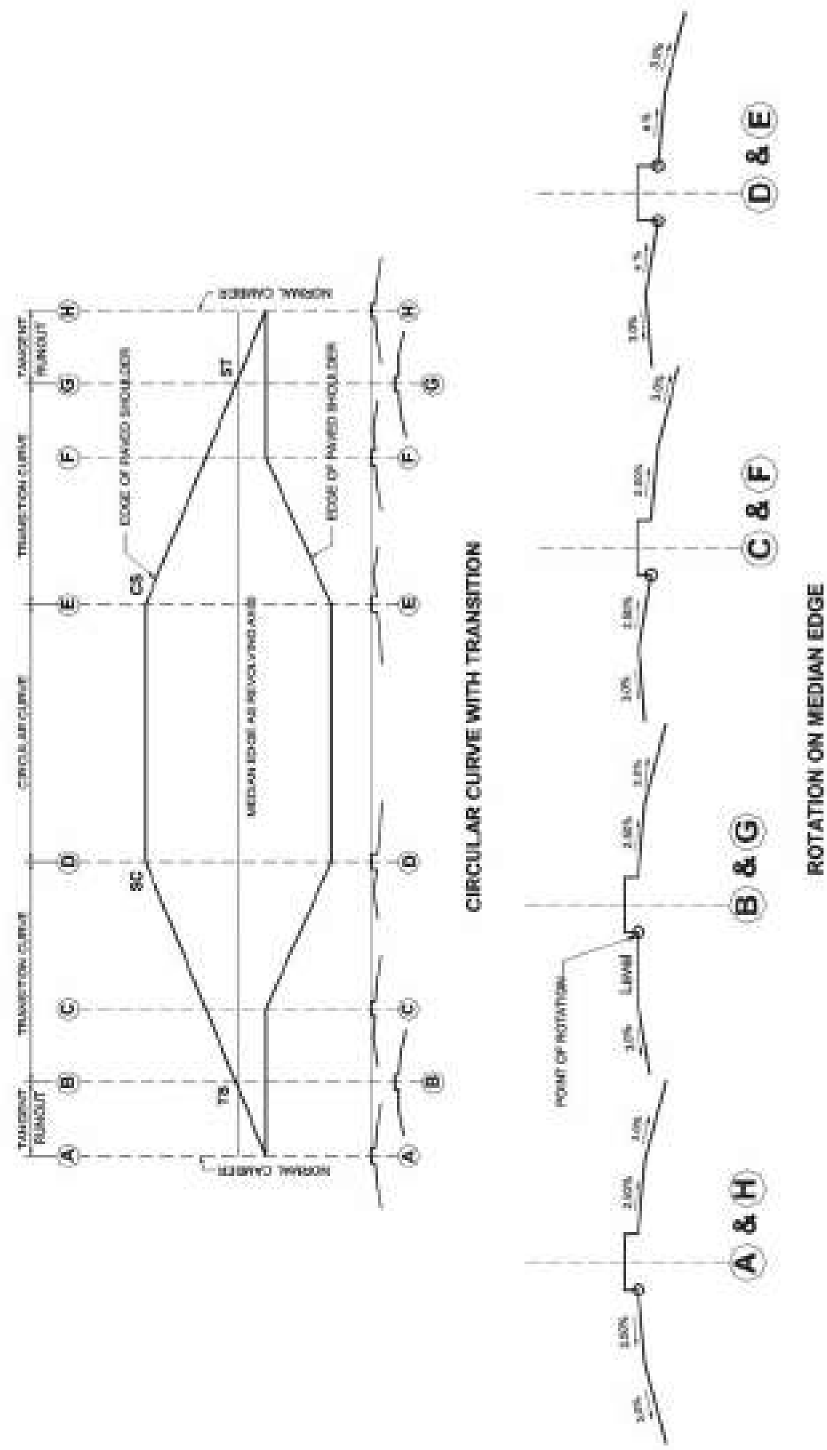


Fig 1.10 Method of Attaining Superelevation

Length of transition shall be the greater of the three values derived from the following criteria:

a) Rate of change of centrifugal acceleration

$$L_S = \frac{0.0215\,V^3}{CR}$$

L_s= Length of transition in metres
V= speed in km/h
R= radius of circular curve in metres

$C = \frac{80}{75+V}$ (subject to a maximum of 0.6 and minimum of 0.4)

b) Rate of change of super elevation or runoff.
The rate of change of super elevation or run off shall not be steeper than 1 in 200 (0.5 percent) for roads in plain and rolling terrain and 1 in 150 for roads in mountainous terrain.

c) Three seconds time for manipulating the steering. The minimum lengths of transition curves for this criteria is as in **Table 1.15**

Table 1.15 Minimum Length of Transition Curve

Design Speed (km/h)	Min. Length of transition curve (m)
120	100
100	85
80	70
60	50

The principal advantages of transition curves in horizontal alignment are as follows:

- A properly designed transition curve provides a natural, easy-to-follow path for drivers, such that the lateral force increases and decreases gradually as a vehicle enters and leaves a circular curve. Transition curves minimize encroachment on adjoining traffic lanes and tend to promote uniformity in speed. A spiral transition curve simulates the natural turning path of the vehicles.

- The transition curve length provides a suitable location for the superelevation runoff. The transition from the normal pavement cross slope on the tangent to the fully superelevated section on the curve can be accomplished along the length of the transition curve in a manner that closely fits the speed-radius relationship for vehicles traversing the transition. Where superelevation runoff is introduced without a transition curve, usually partly on the curve and partly on the tangent, the driver approaching the curve may have to steer opposite to the direction of the approaching curve when on the superelevated tangent portion in order to keep the vehicle within its lane.

- A spiral transition curve also facilitates the transition in width where the travelled way is widened on a circular curve. Use of spiral transitions provides flexibility in accomplishing the widening of sharp curves.

- The appearance of the expressway is enhanced by the application of spiral transition curves. The use of spiral transitions avoids noticeable breaks in the alignment as perceived by drivers at the beginning and end of circular curves.

1.7.4.1 Radii beyond which no transition is required

The transition curves may not be provided when the radius of curve is more than or equal to that specified in **Table 1.16**.

Table 1.16 Minimum Radius of Horizontal Curve Beyond which Transition Curves Not Required

Design Speed (km/h)	Minimum Curve Radius(m)
120	4000
100	3000
80	2000
60	1000

1.8 VERTICAL ALIGNMENT

1.8.1 *General*

The design should follow the vertical alignment as indicated below unless modification is required to meet the specific provisions or additional features/facilities to be provided as per this Guideline. The following general principles shall be kept in view while designing the vertical alignment:

The vertical alignment shall provide for a smooth longitudinal profile consistent with the terrain. Grade changes shall not be too frequent as to cause kinks and visual discontinuities in the profile. Desirably there shall be no change in grade within a distance of 150 m.

A short valley curve within an otherwise continuous profile is undesirable since this tends to distort the perspective view and can be hazardous.

Broken-back grade lines, i.e. two vertical curves in the same direction separated by a short tangent, shall be avoided due to poor appearance and shall be replaced by a single long curve.

Decks of small cross drainage structure (i.e. culverts or minor bridges) shall follow the same profile as the flanking road section, without any break in the grade line.

The vertical alignment shall be coordinated with the horizontal alignment as discussed in Section 1.10.

i) Gradients up to the value corresponding to ruling gradient shall be adopted as far as possible. Value corresponding to limiting gradient shall be adopted only in very difficult situations and for short lengths.
ii) Long sweeping vertical curves shall be provided at all grade changes. These shall be designed as square parabolas.
iii) The vertical profile of the two carriageways shall be designed in such a manner that difference in road level between the two carriageways at the locations of median openings would not be more than 0.25 m.
iv) The aspect of efficient drainage shall also be kept into consideration while designing vertical profile and cross-sections of the highway as stipulated in IRC: SP: 42 and IRC: SP: 50.

1.8.2 Gradients

i) The maximum gradients shall be as indicated in **Table 1.17**:

Table 1.17 Maximum grades

Terrain	Gradient %
Plain 120 - 100 km/h	3
Rolling 100 - 80 km/h	4
Mountainous 80 - 60 km/h	5

The absolute maximum gradient may be 1 percent steeper than the value shown above and may be provided in mountainous terrain or in urban area with crucial right of way control.

ii) Minimum gradient for drainage

On embankments, near level grades are not objectionable when the pavement has sufficient camber to drain the storm water laterally. However, in cut-sections, minimum gradient for drainage considerations is 0.5 percent (1 in 200) if the side drains are lined and 1.0 percent (1 in 100) if these are unlined.

1.8.3 *Vertical curves*

Summit curves and Valley curves shall be designed as square parabolas. The length of the vertical curve is controlled by sight distance requirements, but curves with greater length are aesthetically better and shall be provided where possible. The minimum grade change requiring vertical curve and the minimum length of vertical curve shall be as in **Table 1.18**.

Table 1.18 Minimum Length of Vertical Curve

Design Speed km/h	Minimum grade change requiring vertical curve	Minimum length of vertical curve(m)
120	0.5	100
100	0.5	85
80	0.6	70
60	0.8	50

Traffic on expressway is unidirectional. The length of vertical curve should, therefore, be computed on the following basis.

Summit Curves to be designed considering

Sight distance (S) = Stopping sight distance

Height of eye (H) = 1200 mm

Height of object (h) = 150 mm (Stopping)

The basic formulae for lengths of a parabolic vertical curve in terms of algebraic difference in grade and sight distance are:

$$L = \frac{NS^2}{2\left(\sqrt{H} + \sqrt{h}\right)^2} \text{ for } S < L \qquad \text{..... } \textit{Eq. a}$$

and

$$L = 2S - \frac{2\left(\sqrt{H} + \sqrt{h}\right)^2}{N} \text{ for } S > L \qquad \text{..... } \textit{Eq. b}$$

where

L	=	Length of the vertical curve in metres
S	=	sight distance in meters
N	=	Algebraic difference in grades
H	=	Height of eye above roadway surface (metres)
h	=	Height of object above roadway surface

The length of summit curve is governed by the stopping sight distance. The length is calculated as follows:

i) when the length of the curve exceeds the required sight distance i.e., L > S

$$L = \frac{NS^2}{4.4}$$

N = deviation angle, i.e. the algebraic difference between the two grades in percentage

L = length of parabolic vertical curve in metres.

S = stopping sight distance in metres

ii) when the length of the curve is less than the required sight distance i.e., L < S

$$L = 2S - \frac{4.4}{N}$$

Valley Curves to be designed considering head light sight distance, assuming height of headlight 0.6 m above the pavement with a one (1) degree upward divergence of the light beam from the longitudinal axis of the vehicle.

$$L = \frac{NS^2}{(120 + 3.5\,S)} \text{ for } L > S \qquad \text{..... } \textit{Eq. c}$$

$$L = 2S - \left(\frac{120 + 3.5\,S}{N}\right) \text{ for } L > S \qquad \text{..... } \textit{Eq. d}$$

where

L = Length of the curve in metres
S = Sight distance in metres
N = Algebraic difference in grade

The length of valley curve shall be such that for night travel, the headlight beam distance is equal to the stopping sight distance. The length of valley curve shall be calculated as under.

i) when the length of the curve exceeds the required stopping sight distance i.e., L > S

$$L = \frac{NS^2}{1.5 + 0.035\,S}$$

ii) when the length of curve is less than the required stopping sight distance i.e., L< S

$$L = 2S - \frac{1.50 + 0.35\,S}{N}$$

L = length of parabolic vertical curve in metre
N = deviation angle i.e. the algebraic difference between the two grades in percentage.
S = stopping sight distance in metres.

For convenience in design usage, the length of vertical curve is expressed as:

L = KN

where

L = Length of vertical curve
N = Algebraic difference in grades
K = Factor defined as length of vertical curve per percentage of N

Based on friction factors for wet pavements and on vehicular speeds equal to average running speed and the design speed of the expressway. Table 1.19 and 1.20 presents the Design Control for Summit and valley curves respectively.

Upper range values are for the sight distance corresponding to design speed and lower range values corresponds to running speed.

Table 1.19 Design Controls for Summit Curve

Design Speed (km/h)	Assumed Speed for Condition (km/h)	Coefficient of Friction f	Stopping Sight Distance for Design (m)	Rate of Vertical Curvature, K (length (m) per % of N)	
				Computed	Rounded for Design
30	30-30	0.40	29.6-29.6	2.17-2.17	3-3
40	40-40	0.38	44.4-44.4	4.88-4.88	5-5
50	47-50	0.35	57.4-62.8	8.16-9.76	9-10
60	55-60	0.33	74.3-84.6	13.66-17.72	14-18
70	63-70	0.31	94.1-110.8	21.92-30.39	22-31
80	70-80	0.30	112.8-139.4	31.49-48.10	32-49
90	77-90	0.30	131.2-168.7	42.61-70.44	43-71
100	85-100	0.29	157.0-205.0	61.01-104.02	62-105
110	91-110	0.28	179.5-246.4	79.75-150.28	80-151
120	98-120	0.28	202.9-285.6	101.90-201.90	102-202

Table 1.20 Design Controls for Valley Curve

Assumed Design Speed (km/h)	Speed for Condition (km/h)	Coefficient of Friction f	Stopping Sight Distance for Design (m)	Rate of Vertical Curvature, K (length (m) per % of N)	
				Computed	Rounded for Design
30	30-30	0.40	29.6-29.6	3.88-3.88	4-4
40	40-40	0.38	44.4-44.4	7.11-7.11	8-8
50	47-50	0.35	57.4-62.8	10.20-11.54	11-12
60	55-60	0.33	74.3-84.6	14.45-17.12	15-18
70	63-70	0.31	94.1-110.8	19.62-24.08	20-25
80	70-80	0.30	112.8-139.4	24.62-31.86	25-32
90	77-90	0.30	131.2-168.7	29.62-39.95	30-40
100	85-100	0.29	157.0-205.0	36.71-50.06	37-51
110	91-110	0.28	179.5-246.4	42.95-61.68	43-62
120	98-120	0.28	202.9-285.6	49.47-72.72	50-73

1.9 CLIMBING LANE

Climbing lanes are normally not required for Expressways having a divided carriageway with two or more lanes on each carriageway. However, considering the presence of large number of truck traffic as prevalent in India, for free and safe movement of traffic on sections having up-gradient, the desirability of providing climbing lanes may be examined depending on the volume of traffic including the percentage of truck traffic, designs surveys volume and cost of the project.

The requirement of climbing lane needs to be examined if

- the length of the section exceeds 2 km/1 km/500 m for upgradients of 3 percent, 4 percent, and 5 percent or more respectively
- the service volume in the section on gradient, exceeds that for the next poor level of service from that used for the design of the Expressway, and in any case, not exceeding level of service D

The width of the climbing lane shall be 3.5 m. The climbing lane is to be provided on the left side of the carriageway, i.e., on the shoulder side. The full width of the climbing lane shall be provided from the cross-section where the gradient becomes 3 percent or more and preceded by a tapered length 150 m. The full width of climbing lane shall be maintained upto a length of 400 m ahead of the cross-section where the gradient becomes 2 percent or less, followed by a tapered length of 150 m.

1.10 COORDINATION OF HORIZONTAL AND VERTICAL ALIGNMENT

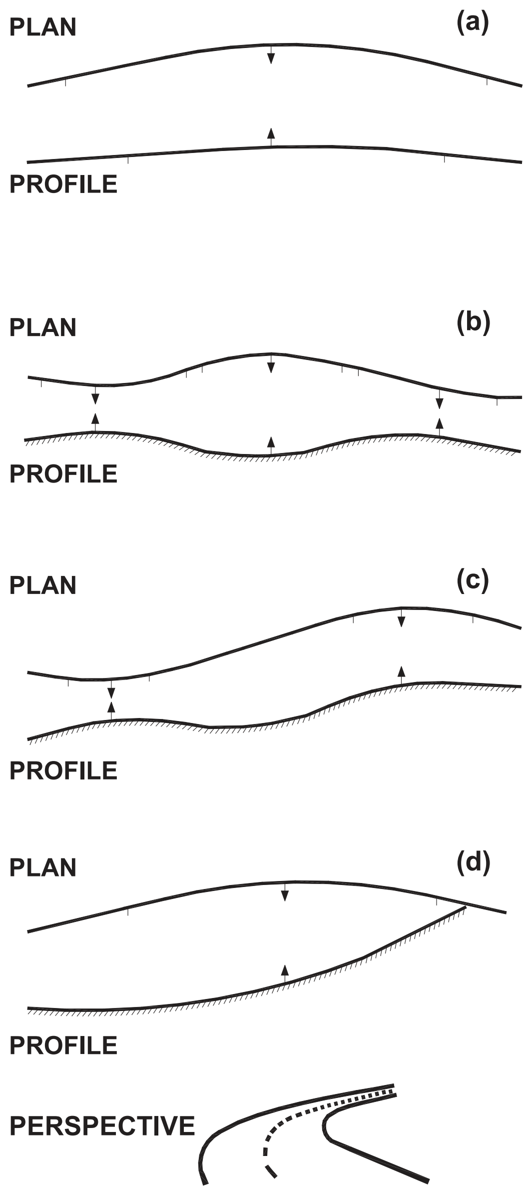
The overall appearance of an expressway can be enhanced considerably by judicious combination of the horizontal and vertical alignments. Plan and profile of the road shall not be designed independently but in unison, so as to produce an appropriate three-dimensional effect. Proper co-ordination in this respect will ensure safety, improve utility of the expressway and contribute to overall aesthetics.

The degree of curvature shall be in proper balance with the gradients. Straight alignment or flat horizontal curves at the expense of steep or long grades, or excessive curvature in a road with flat grades, do not constitute balanced design and shall be avoided.

Vertical curvature superimposed upon horizontal curvature gives a pleasing effect. As such the vertical and horizontal curves shall coincide as far as possible and their length shall be more or less equal. If this is difficult for any reason, the horizontal curve shall be somewhat longer than the vertical curve. Short vertical curve superimposed on long horizontal curve and vice versa gives distorted appearance and shall be avoided.

Sharp horizontal curves shall be avoided at or near the apex of pronounced summit / sag vertical curves from safety considerations.

IRC:73 presents examples of Good Design Form and Undesirable Design Forms in alignment coordination. **Fig. 1.10A** shown the Illustrating Good Alignment Coordination. **Fig. 1.10B** presents pictorially an “Undesirable Design Form”.



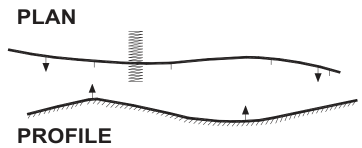
(a) VERTICES OF HORIZONTAL AND VERTICAL CURVES COINCIDE. VERTICAL CURVE KEPT WITHIN HORIZONTAL CURVE. BRINGS OUT A VERY PLEASING APPEARANCE.

(b) SAME AS (a) BUT INVOLVING A SERIES OF CURVES VERTICES OF HORIZONTAL AND VERTICAL CURVES COINCIDE. PRODUCING A VERY PLEASING APPEARANCE.

(c) SIMILAR TO (b) BUT ONE PHASE SKIPPED IN THE HORIZONTAL PLANE. VERTICES OF CURVES STILL COINCIDE. A SATISFACTORY APPEARANCE RESULTS.

(d) PROVISION OF LONG VERTICAL CURVE COMPATIBLE WITH THE HORIZONTAL CURVE PRODUCES A SMOOTH FLOWING ALIGNMENT AND A PLEASING THREE DIMENSIONAL VIEW.

Fig 1.10A Illustrating Good Aligment Coordination



HAZARDOUS LEVEL CROSSING (OR ROAD INTERSECTION) AND SHARP HORIZONTAL CURVE ARE OBSCURED FROM DRIVER'S VIEW BY SUMMIT CURVE. DANGEROUS SITUATION.

Undesirable Design Form

NOT TO SCALE

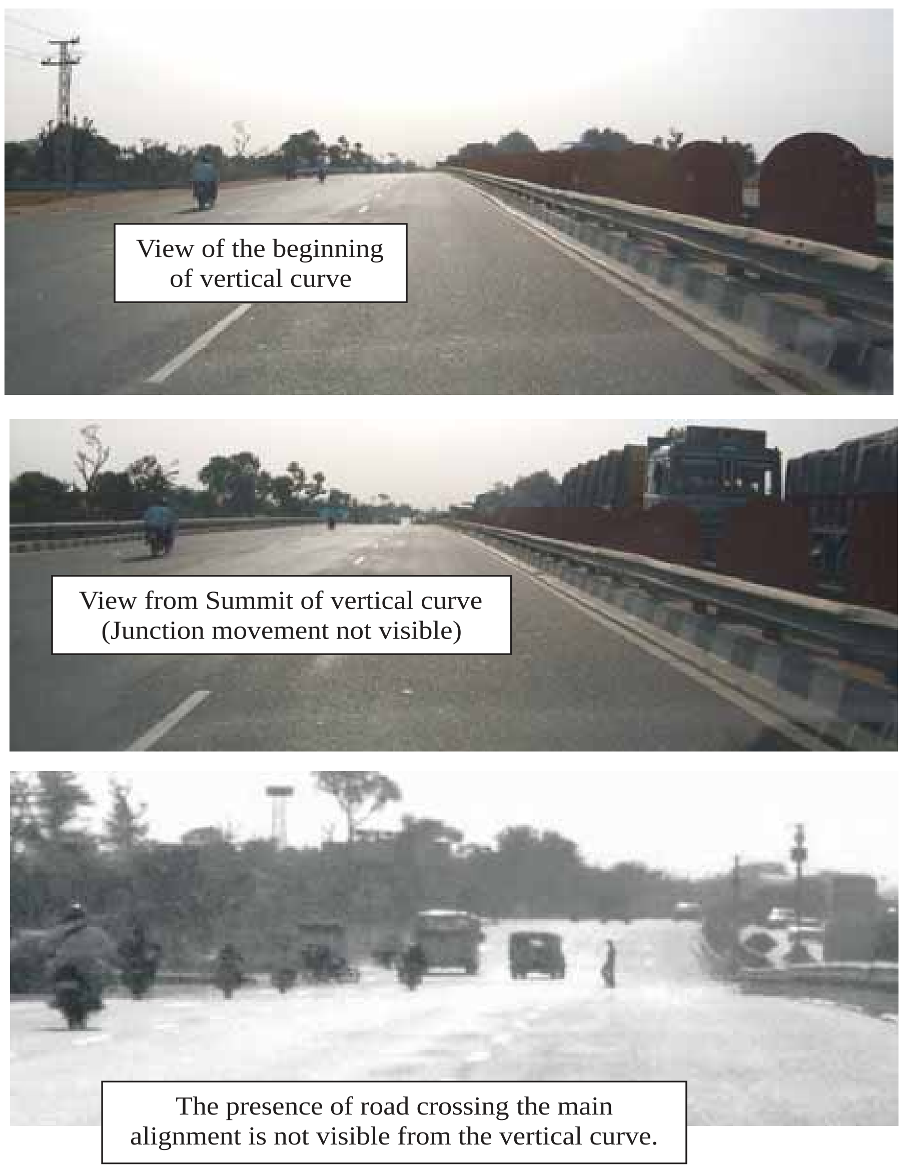


Fig 1.10B Example of Undesirable Design Form in Alignment Coordination

1.11 THREE-DIMENSIONAL ALIGNMENT

1.11.1 *Design approach*

The essential form of expressways expresses their function, which is to move people and goods safely and rapidly from one place to another. Expressways should have a pleasing appearance, and they should fit gracefully into their surroundings and become acceptable components of the landscape as viewed from outside the expressways. The coordination or proper fitting together of the horizontal and vertical alignments and the cross-section is an important technique for achieving an aesthetically pleasing expressways design.

The design of a road may consist of individual elements, the combination of the horizontal alignment (plan) and the vertical alignment (profile) that results in a spatial or three-dimensional creation. The resulting driving space can be described in its sequence with the concept of road characteristics. It includes all of the structural elements and determines the driving behaviour of the driver. Road characteristics should not be greatly changed much over short roadway sections. A consistent sequence of images of the driving space should be balanced in relation to the design parameters among themselves (relation design). Different roadway sections should be connected by gradual transitions.

The goal of the following recommendations is to produce the best alignment that provides optimum safety and the traffic quality. Well-balanced road sections, in which each single design element contributes to a good road characteristic, should be created. Well-balanced sections eliminate unsafe feelings and driver discomfort. With the use of these recommendations, the designer will be able to recognize and evaluate preliminary road designs that result from superimposing selected horizontal and vertical design elements. In this way, the designer can create three-dimensional design elements that achieve perceptible, sound road characteristics.

Thus, in the design of expressway alignments, horizontal and vertical design elements are necessarily superimposed. Combining the cross-section of the road, which includes shoulders, pavement width, and pavement lane and edge markings, with horizontal and vertical design elements results in a three-dimensional design element. The design of any road is made up of a series or a sequence of three-dimensional design elements. Typical three-dimensional design elements are shown in **Fig. 1.11**.

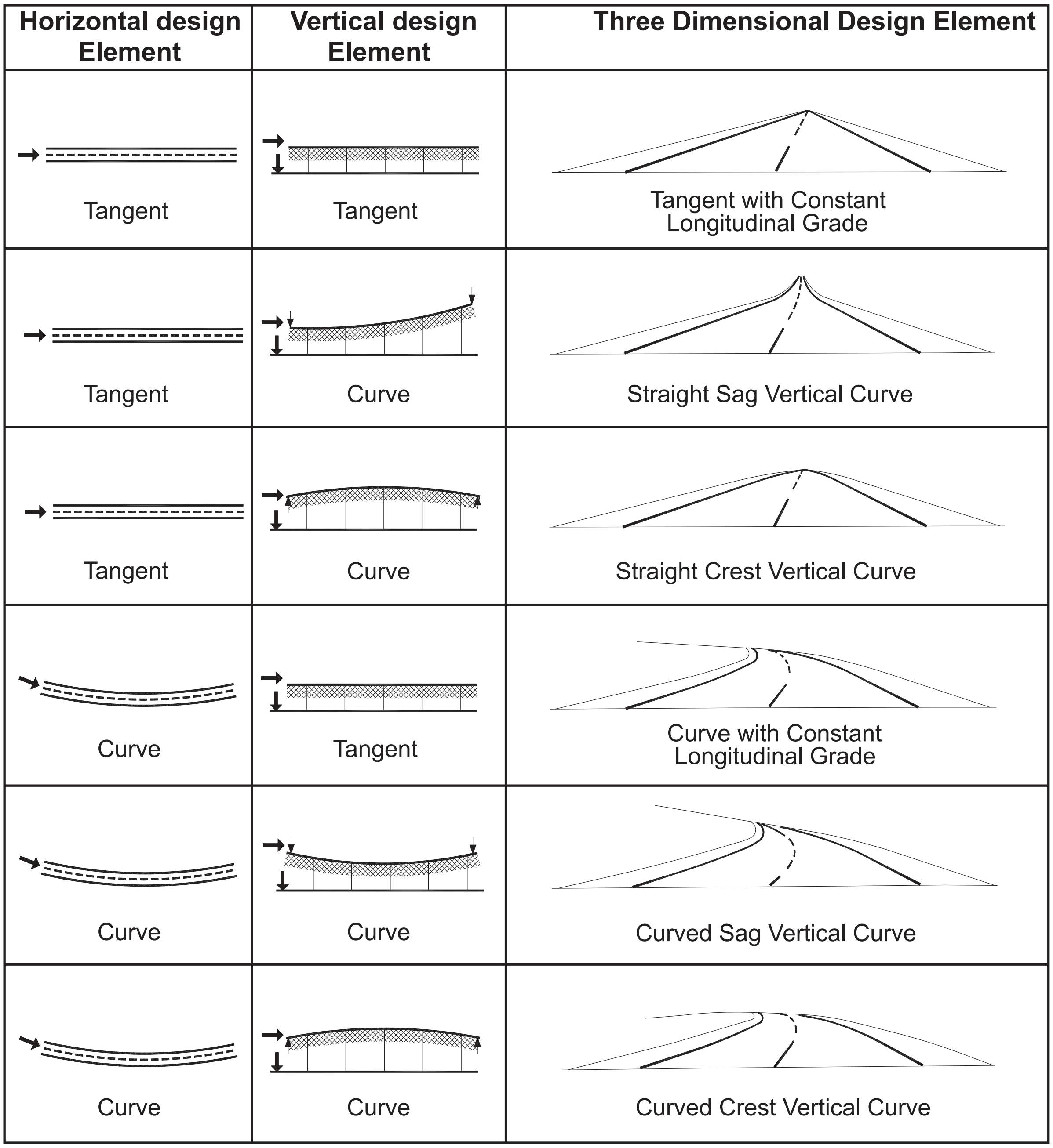


Fig 1.11 Desirable Plan & Profile Combination
Not To Scale

1.11.2 Horizontal design elements

Tangents: Long tangent sections of expressways are monotonous and fatiguing. They can lead the driver into traveling at excessive speeds and increase the danger from headlight glare at night. Therefore, long tangents with constant grades must be avoided, and the maximum length should be limited to numerical value, in meters, of approximately 20 times the design speed, in kilometers per hour. (Source: Vic Roads Australia)

The unfavorable impression caused by long tangents in mountainous topography can be reduced by the use of a sag vertical curve with a long length and large radius.

Short tangent segments between two horizontal curves in the same direction should be avoided (**Fig. 1.12a**). If such designs cannot be eliminated, it is important that a minimum length be used between the two curves. The minimum length of the tangent segment should correspond to a numerical value, in meters, of approximately 6 times the design speed, in kilometers per hour, to maintain consistency of the optical guidance.

Curves: Short circular curves between tangents appear as optical brakes from the perspective view of the driver. Such an optical break can be avoided (**Fig. 1.12b and 1.12c**) by connecting the two tangents with a long horizontal curve.

1.11.3 Vertical design elements

Tangents: The tangent in profile is a segment with constant grade. With respect to the three-dimensional alignment, this part of the alignment is not critical.

A short tangent used between two succeeding sag vertical curves can give the impression of a crest vertical curve (**Fig. 1.12d**) and should be avoided. A better solution, using a long sag vertical curve, is shown in **Fig. 1.12e**. The same is true for a short tangent between two succeeding crest vertical curves. Such a design may give the impression of a sag vertical curve (**Fig. 1.12f**) and should be avoided. A better solution, using a long crest vertical curve, is shown in **Fig. 1.12g**. In addition, the greater the distance a driver can see ahead on the road, the longer a sag vertical curve should be to eliminate visual breaks.

Sag Vertical Curves: The sag vertical curve is the three-dimensional design element with the best visual qualities and optical guidance. However, there is one exception: the use of a short sag vertical curve between long sections with constant grades should be avoided. In this case, it does not matter whether the horizontal alignment is on a tangent section or on a curve (**Fig. 1.13a** and **Fig. 1.13b** respectively). In both cases, a visual break in the perspective view occurs. The length of sag vertical curves on embankments usually can be increased considerably notwithstanding the situation that it will result in expensive earthwork.

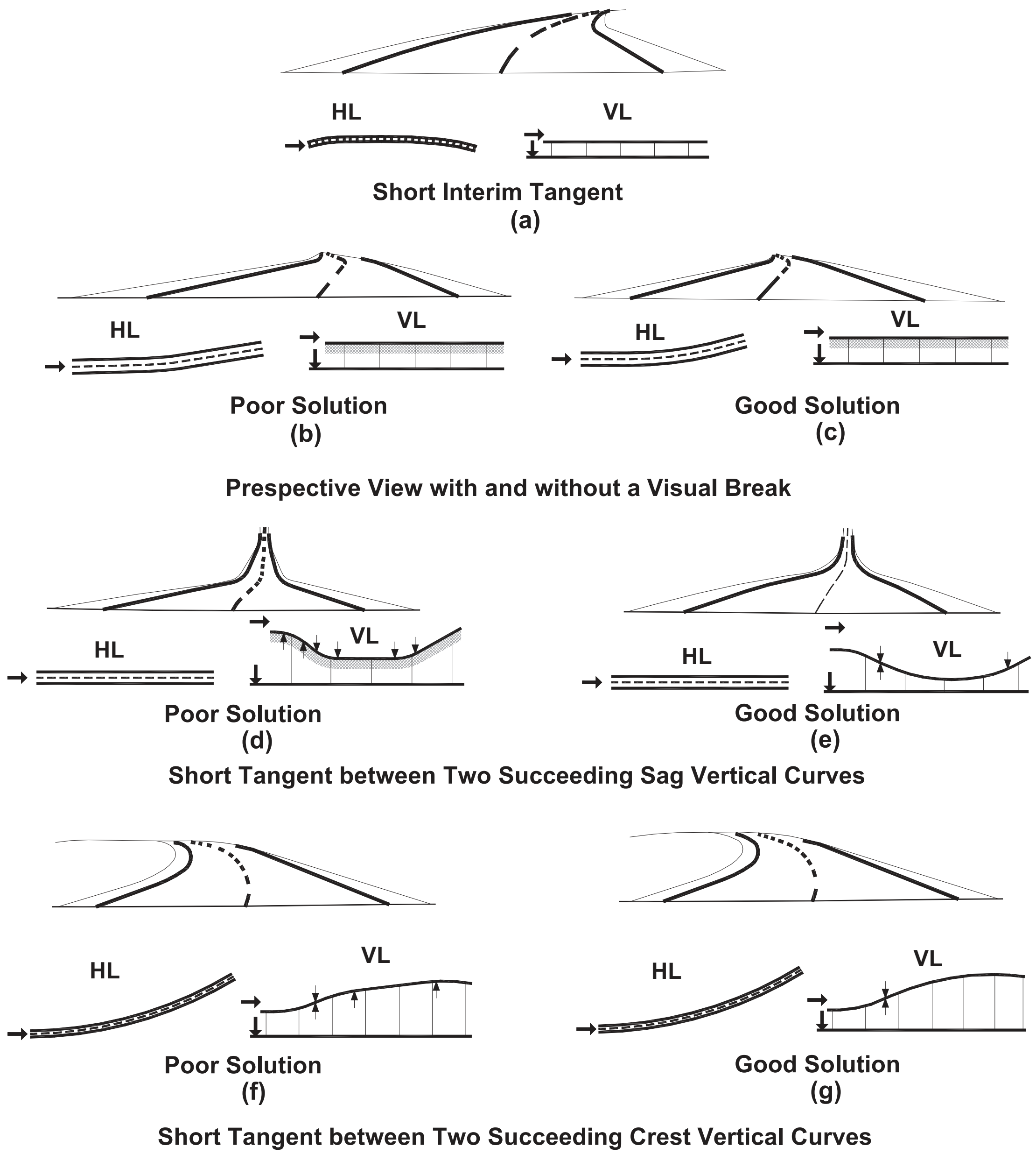
Crest Vertical Curves: The crest vertical curve represents the most critical design element when considering good visual qualities. The influence of a crest vertical curve is especially critical with short lengths that cause insufficient sight distances (**Fig. 1.13c**). Crest vertical curves with minimum stopping sight distances should be avoided on the mainline roadway if possible. The main consideration in using longer lengths is earthwork costs. With the availability of user-friendly earthwork programs and the perspective plot capabilities with the programs, it is now easy to design and test many alternative profiles.

Consequences: On main rodway sections, visual breaks that are the result of short horizontal and vertical curves or their combination should be avoided. Instead, strive to use longer design elements. Short curves lead to inconsistencies at the roaway's edge. These statements are better understood by comparing **Fig.1.12a** and **Fig.1.12b** (poor soluction) with **Fig.1.12c** (good solution and **Figs. 1.12d** and **1.12e** (poor solution) with **Figs. 1.12f** and **1.12g** (good solution). In addition, **Fig. 1.13b** and **1.13c** also show designs that should be avoided.

The following should also be avoided :

- Diving: The partial disapperance of the road from the driver's view with reappearance in the extension of the just-passed roadway section (**Fig. 1.13d)**.
- Jumpint: Similar to diving but with displaced reappearance (**Fig. 1.13e)**.
- Fluttering: Multiple diving or a rapidly rolling profile **(Fig. 1.13f)**.
- Broken-back vertical curve: A short tangent section between two sag vertical curves(**Fig. 1.12d)**.

Most of these designs may lead to critical driving manoeuvres because of visual misconceptions, since portions of the alignments become hidden from the driver's view, which may, in turn, mislead the driver about the course of the roadway and opposing traffic. These visual misconceptins are especially dangerous in the case of passing manoeuvres.



Legend:
HL = Plan View **VL = Profile**

Fig 1.12 Example of Poor and Good Solutions
Not to scale

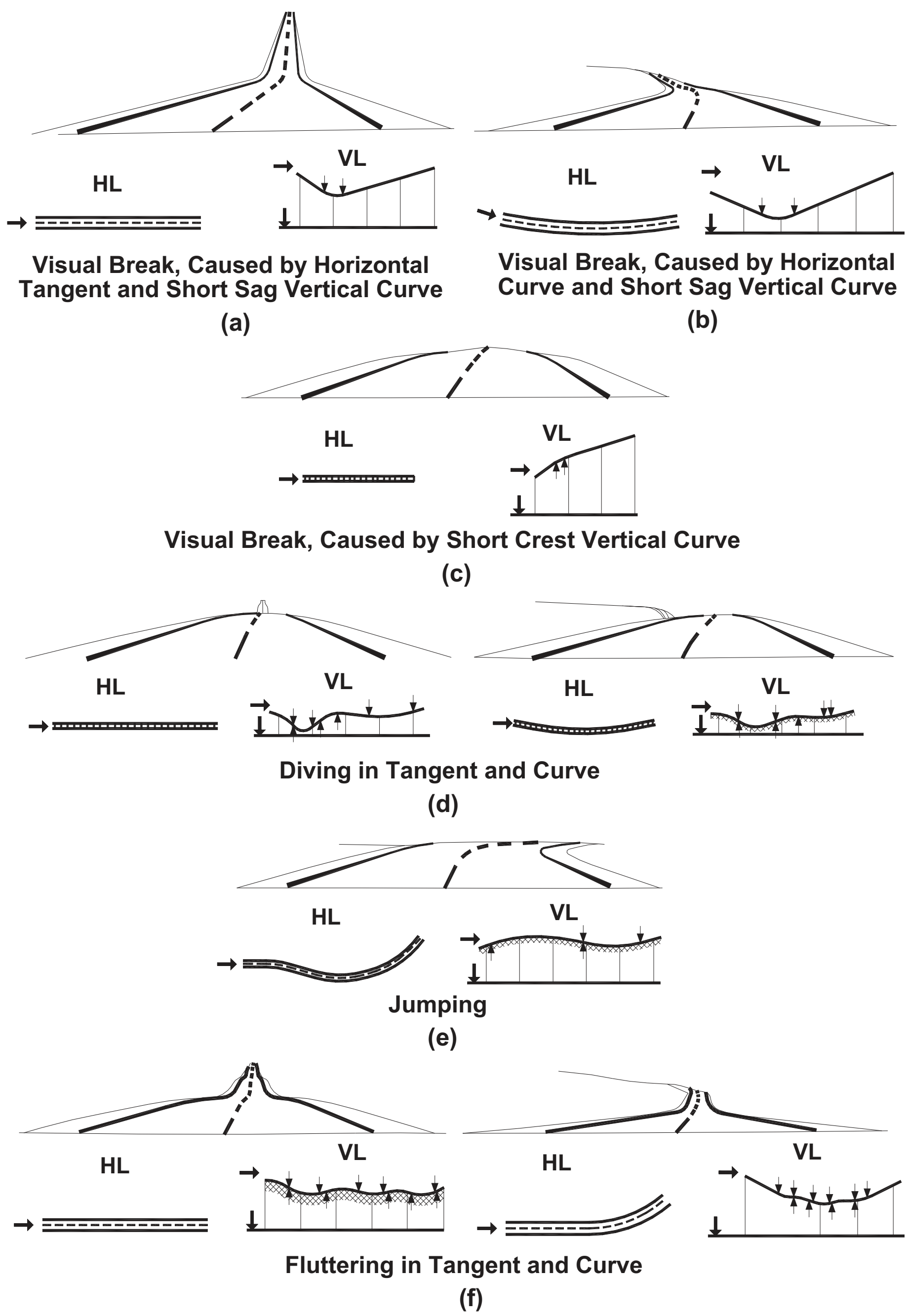


Fig 1.13 Design Cases to be Avoided
Not to scale

1.12 LATERAL AND VERTICAL CLEARANCE AT UNDERPASSES

1.12.1 *Vehicular underpasses*

Vechicular underpasses shall be provided for all cross roads. If the interesction is staggered, the underpass shall be provided in such a manner that no vehicle is required to travel more than 2 km on connecting road for crossing over to the other side.

1.12.2 *Facilities for pederstrians and cyclists*

Facilities shall also be planned and provided for crossing of pedestrians and cyclists through underpasses. The crossing facilities shall be provided such that pedestrians do not have to work for more than 0.5 km to reach the crossing point. The slab culverts and minor bridges with span length equivalent or more than 5 m and not catering to perennial flow, can aslo be used for pedestrian and cycle crossings by providing necessary flooring. In rural stretches pedestrian/cycle underpasses shall be provided at the locations of the existing crossing points.

1.12.3 *Cattle crossings*

Facitlitiesf for crossing of cattle through underpasses shall be provided at locations required for the purpose.

1.12.4 *Lateral clearance*

Lateral clearance for an expressway is the distance between edge of the carriageway and the face of nearest support which may be a solid abutment, pier or column.

Desirably, the full roadway width at the approaches shall be carried through the underpass. However, the minimum lateral clearance shall be 10.5 m for vehicular underpasses and 4 m for pedestrian/cattle underpasses.

Where the expressway will be in underpass requiring continuation of safety barriers, the safety barriers must be located at distance of 0.60 m from the face of the nearest support and 0.25 m from the edge of paved shoulder.

1.12.5 *Vertical clearance*

Vertical clearance for vehicular underpasses shall be minimum 5 m. pedestrian/cattle under passes, the vertical clearance shall be minimum 3.0 m, which may be increased to 4.5 m in case of such animals as elephant/camel expected to cross.

Traffic composition shall be kept in view in planning and design of underpasses, over bridges and at interchanges to effect economy. Availability of other routesf with higher clearances should also be kept in view.

The above recommended values are the standard minima; where it is economical and/or topographically/environmentally acceptable, higher values should be provided.

Considering the maximum permissible height of Road Design vehicles as per IRC:3-1983 and Motor Vehicles Act, 1989, the following **minimum** values of vertical clearances may be maintained/adopted under special consideration with additional provisions as necessary.

Table 1.21 Vertical Clearances

Traffic Composition	Vertical Clearance (m)
Comprise passenger vehicles, buses (single deck) and	4.70
freight carrier and container trucks including over height consignments	
Including Double deck buses, Trms and Trolley buses	5.50

Because of their lesser resistance to impacts, foot bridges and over carriageway gantry signs shall have a minimum vertical clearance of 5.5 m. For access to roadside amenity centres, the underpass shall be provided with a vertical clearance of 4.7 m as desirable and 4.3 m, a absolute minimum.

CHAPTER - 2

INTERCHANGE DESIGN

CHAPTER - 2

INTERCHANGE DESIGN

2.1 INTRODUCTION

Fundamentally, an interchange simply provides an opportunity for traffic to transfer from one road to another. Design of an interchange is required to provide safe and efficient movement of vehicles. This allows for the greatest capacity and level-of-service that can be achieved by providing uninterrupted travel for expressway users. Naturally, the type of interchange proposed must be adequately designed to accommodate the anticipated traffic in order for the entire expressway section or segment to achieve the desired results.

2.1.1 *Justification for interchanges*

There shall be no at-grade intersection of any road with the project expressway. The intersection of the Project Expressway with another expressway or other highway (NH) shall be through interchanges.

All traffic without exception, needing access to the project highway shall join the project highway through an acceleration lane. Similarly, all traffic exiting the project highway shall be through an exit ramp from where it would distribute to the local road network for various destinations.

Each situation is required to be analysed in respect of the traffic, terrain, hazards etc. Therefore, provision of an interchange shall be analysed with regard to the following major factors:

i) **Elimination of congestion:** Traffic operation analysis at the intersection may indicate the need for an interchange to provide for the traffic demands. Insufficient capacity at an intersection of two high volume expressways or of one road and the expressway results in delay and increased operating expenses.

ii) **Elimination of hazard:** Some intersections have a high accident rate even though lightly travelled. The provision of an interchange at such locations can be justified to prevent/minimise potential for fatal accidents.

iii) **Topography:** There are some sites where existing topography creates a condition where the only rationale is to provide a grade separation. These sites may be such that dictate provision of an interchange.

iv) **Traffic volumes:** This is most tangible of all factors for justification of an interchange. Although it is difficult for the designers to decide specific volumes warranting the provision of an interchange, it is an important guide when combined with the traffic distribution patterns and the likely effect of traffic behaviour.

2.2 LOCATION PLANNING

The locations of individual interchanges are determined primarily to reduce detour considering regional network and nearness to places of importance. Location of interchange is guided by

i) At crossing or nearest points of other Expressways, National Highways, State Highways and important arterial roads.
ii) At crossing or nearest points of major roads to important ports, airports, material transport facilities, commercial and industrial areas, and places of tourist interest.

The exact location should consider the gradient of intersecting roads which shall desirably be flat not exceeding 2 percent. Special measures shall be considered for mountainous topography steeper than 3 percent, since combination of 6 percent super elevation and gradient steeper than 3 percent would lead to difficult manoeuvre.

2.3 INTERCHANGE SPACING

2.3.1 *General*

Generally interchange spacing is based upon demand for access from the important cross roads, adequate distance to provide for signing and weaving, and adequate distance to permit sufficient lengths of speed change lanes for the respective adjacent interchanges to operate safely and efficiently at the desirable level of service. As a general guide the following may be provided for preliminary design consideration of interchanges spacing.

a) Between cities - a spacing of 20 – 30 km would be desirable
b) City outskirt areas - a spacing of 15 – 25 km would be desirable
c) Urban areas – In areas of concentrated urban development where the habitation and development is considerable : a spacing of 5 – 10 km would be desirable

The desirable minimum spacing shall be 4 km and absolute minimum as 3 km from deceleration, weaving and acceleration considerations. Special consideration for lane balance and provision of additional lanes should be studied for closely spaced interchanges. For spacing less than 3 km, both the interchanges shall be considered as a combined one.

2.3.2 *Route continuity*

Route continuity is another consideration which refers to the provision of a directional path along and throughout the length of a designated route. The designation pertains to a route number or a name of a major expressway. Route continuity is an extension of the principle of operational uniformity coupled with the application of proper lane balance and the principle of maintaining basic number of lanes.

The principle of route continuity simplifies the driving task in that it reduces lane changes, simplifies signing, delineates the through route, and reduces the driver's search for directional signing.

Desirably, the through driver, especially the unfamiliar driver, should be provided with a continuous through route on which changing lanes is not necessary.

In the process of maintaining route continuity, particularly through cities and bypasses, interchange configurations need not always favour the higher volume of traffic but rather the through route. In this situation, higher volume of traffics can be designed on flat curves with reasonably direct connections and auxiliary lanes, which is operationally equivalent to through movement.

2.4 TYPES AND FORMS OF INTERCHANGES

2.4.1 *Types of interchanges*

There are two broad categories of Interchanges, based on traffic exchange:

i) **Service Interchanges:** This refers to an interchange of the Expressway with a road less in importance than Expressway.

   For this category, it is considered that Expressway shall be toll roads, and the other intersecting road shall be a "non-tolled" road or a road with open system of tolling with the toll plaza on the other road minimum 2 km away. This requires the consideration of tolling system which considers a barrier system as well as toll booths on the interchange ramps. This requires consideration for appropriate deceleration and acceleration lengths and operating speed limitations in the interchange areas.

ii) **System Interchanges:** This refers to an interchange between two Expressways

For this category, since both the intersecting routes are toll roads under closed system, the aspects of toll booths on ramps are not required. The system need to cater for high speed operation. The toll aspect needs to be considered on integrated basis between the two involved concessionaires. The modalities need to be suitably addressed.

2.4.2 *Forms of interchanges*

In selection of basic forms, the following aspects need consideration:

i) The nature of terrain and availability of land;
ii) The geometrics of the intersecting roadways and the prioritized turning and through traffic movement on the cross-road;
iii) Coordinated traffic handling, to ensure safety during travelling as well;
iv) Economic factors such as initial cost, operation and maintenance costs, and vehicle operating costs;
v) Environmental considerations including mitigation measures against adverse impact both permanent and temporary during construction;
vi) The effect/impact of noise level during and after the construction of interchange;

Each interchange site should be studied and alternate designs made to determine the most fitting arrangement of structures and ramps. **Fig. 2.01** presents typical forms of Interchanges.

For toll expressways in India, the form of interchange will be such that all traffic will pass through a single point for collection of toll at one place. Advantages of integrated toll plaza are: (i) less numbers of toll lanes, (ii) higher level of security, (iii) efficient operation and maintenance, and (iv) quick response to incident management.

2.4.2.1 Service interchanges

Generally, trumpet and T-interchange are the preferred configuration. The advantages are

(a) suitable for three way junction with no weaving, (b) limited requirement of ROW area, (c) single point toll booth ,and (d) provides a relatively high speed (compared to loops) semi-directional turning movement.

Diamond and Cloverleaf Interchanges require a number of toll plazas on ingress/egress ramps. Whereas Trumpet or T-interchange require single toll plaza. **Fig. 2.02** presents typical Diamond and Trumpet interchanges.

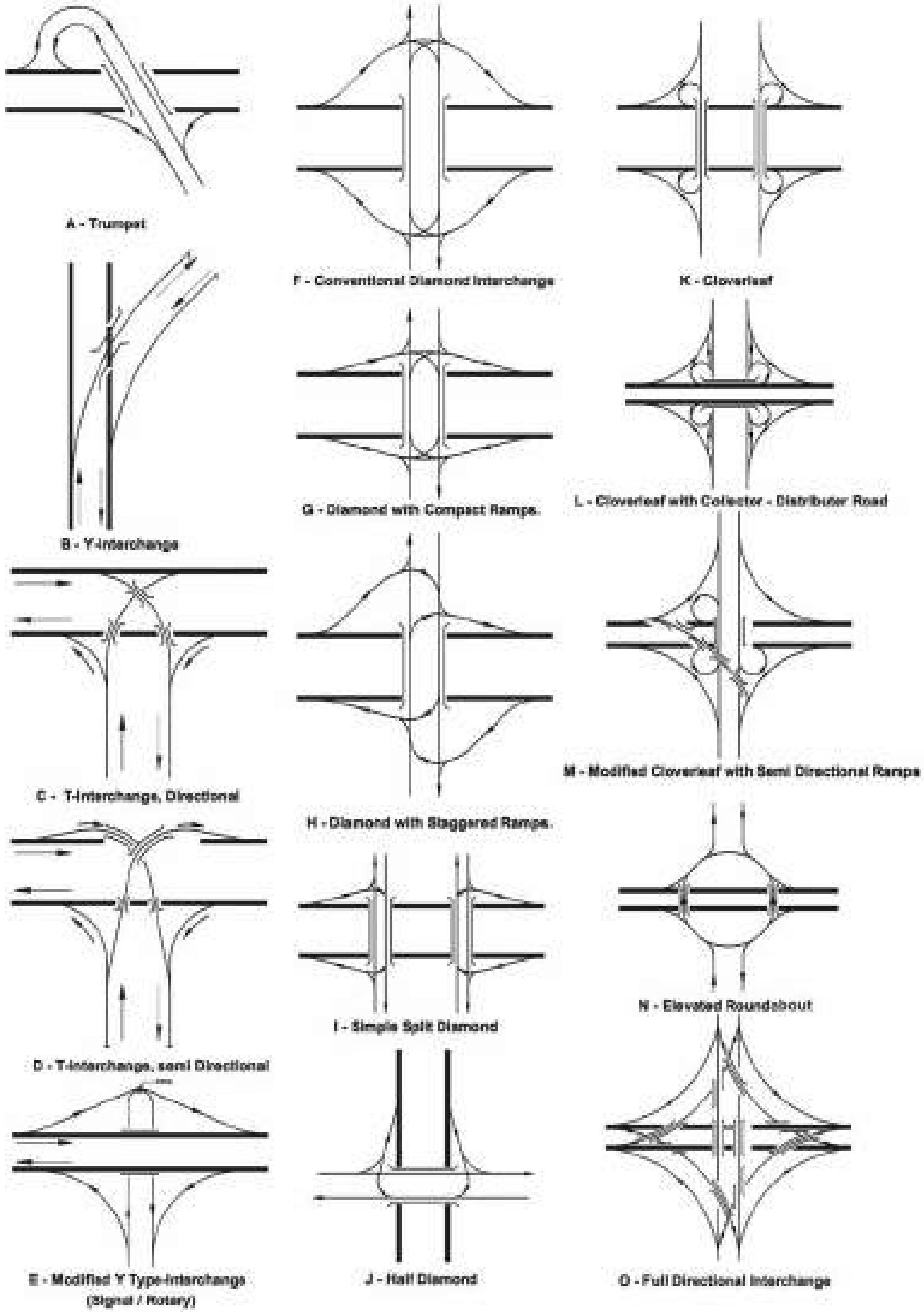


Fig. 2.01 Typical forms of Interchange

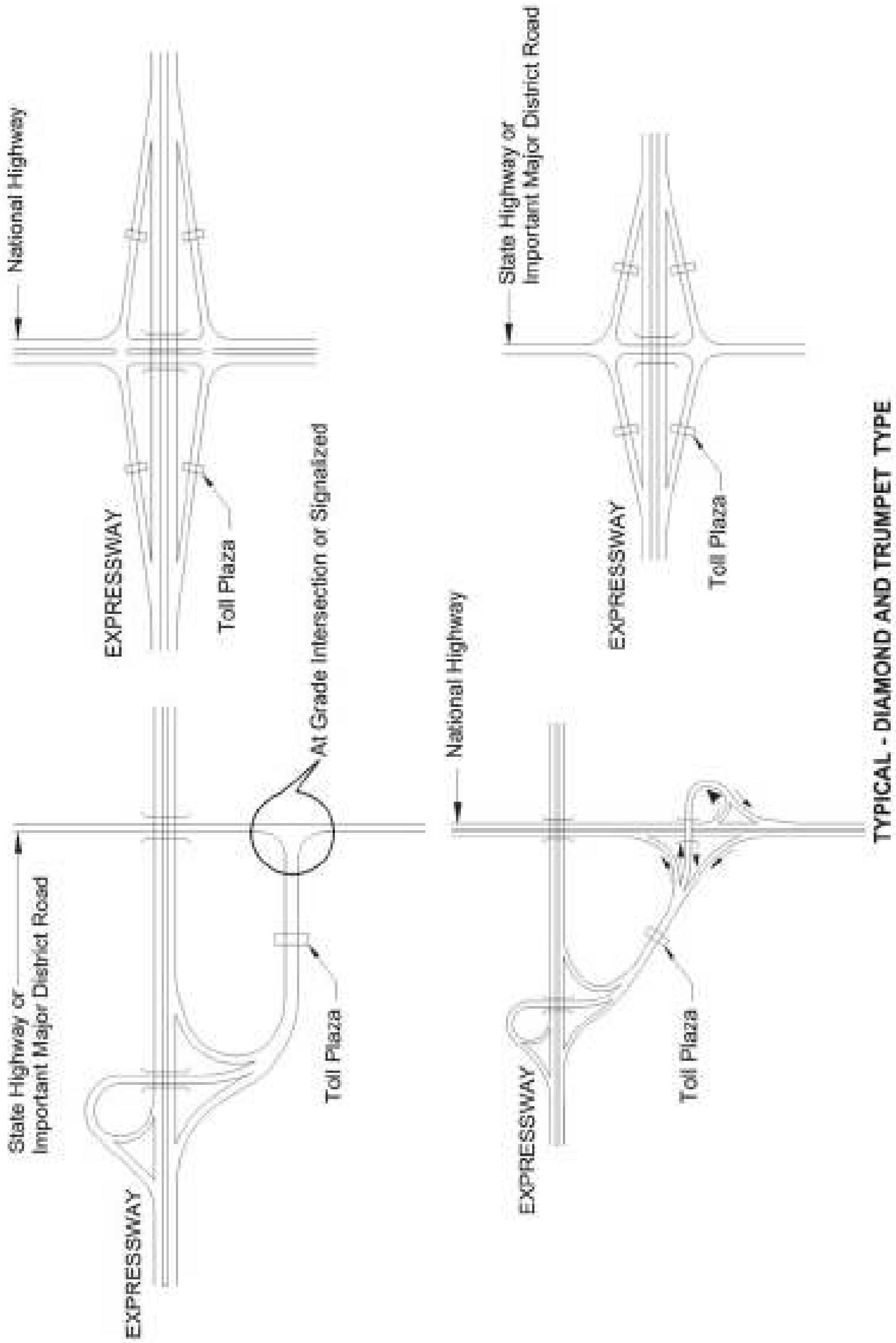


Fig. 2.02 Typical Service Interchange (with Toll Plaza)

2.4.2.2 System interchanges

As mentioned earlier, system interchanges to handle high volume of traffic. The connecting ramps can be directional, semi-directional and large radius loops as well. The aspect of toll sharing between adjacent concessionaires shall be integrated. For system interchanges also, the basic forms may comprise of three legs or four legs.

For Three Leg Interchanges, the T type configuration would require larger loops and semi directional ramps of larger radius based on traffic volumes. This may also require catering for frontage road consideration.

For Four Leg Interchanges, the forms may be Diamond, clover leafs directional and semi directional interchanges and composite interchanges requiring combinations of straight, curved or with loops and weaving. These configurations generally require multi level structures. **Fig. 2.03** presents services and system interchanges.

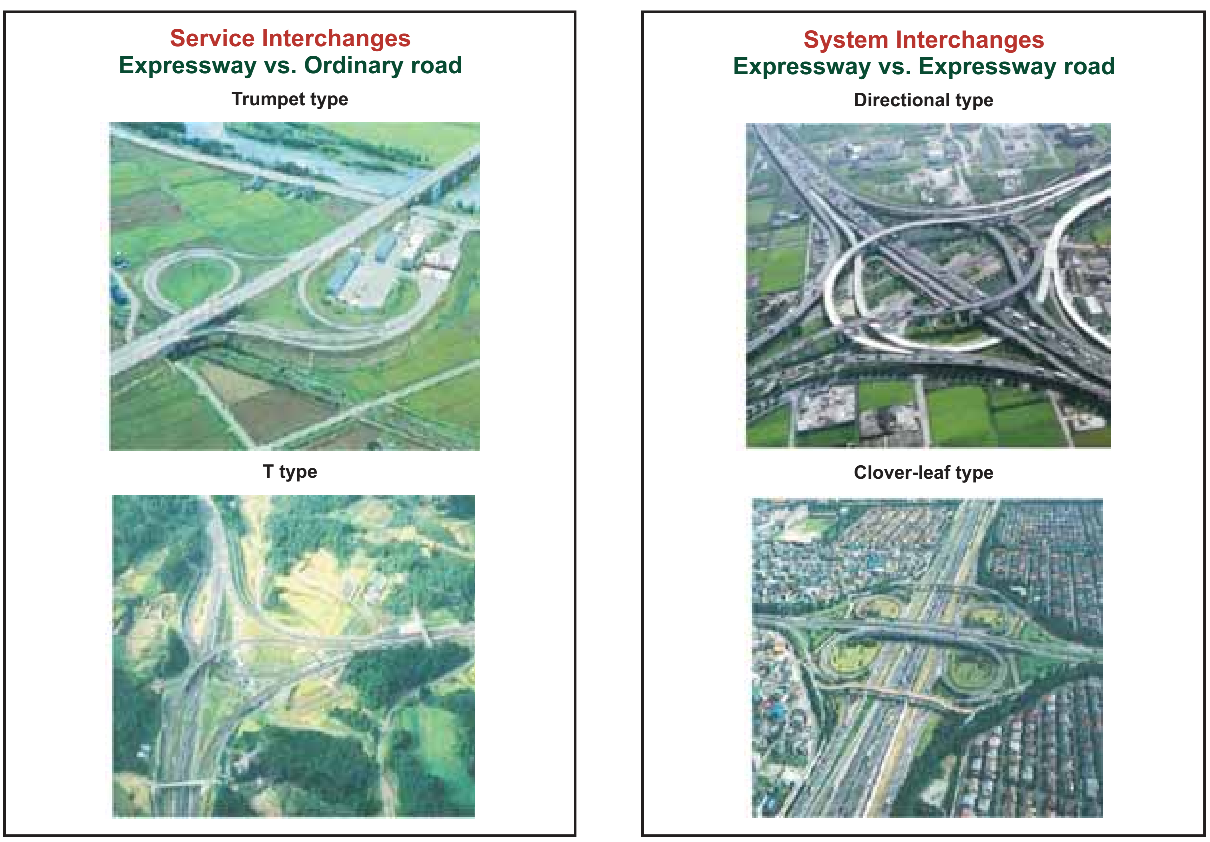


Fig. 2.03 Services and System Interchanges

2.4.2.3 Typical interchanges

Fig 2.01(A) shows a trumpet interchange at the junction of an expressway and a major local road in a rural area. This pattern also explains the relatively sharp radius on the loop. The design favours the heavier traffic movement that is provided by the semi-direct connection, and loop handles the lighter volume.

The Y configuration interchange (shown in **Fig 2.01(B)**) may be provided when all three intersection legs have a through character or the intersection angle with the third intersection leg is small.

Fig 2.01(C) shows a directional, T-interchange crossing between two expressways. The turning roadways are liberally designed to permit high-speed operation. All movements are directional, three structures are needed, and weaving is avoided. This plan is suitable for the intersection of a through expressway with the terminal of another major expressway. Some or all of the interchanging movements will need at least two-lane roadways. All entrances and exits are designed as branch connections or major forks.

Fig 2.01(D) shows a semi directional T-interchange between two expressways in a rural area. The directional design with large radii permits high-speed operation for all movements. The frontage roads provide desirable one-way operations with connections from the interchange roadways being as long as practical. The separation distance between major forks and the ramp terminals that follow should be sufficient to provide for smooth traffic operations.

Fig. 2.01(E) presents a minor T-interchange with at grade intersection (rotary/signal).

A Diamond Interchange (shown in **Fig 2.01(F and G)**) is formed when a one-way diagonal ramp is provided in each quadrant. The ramps are aligned with free-flow terminals on the major expressway, and the left turns at grade are confined to the crossroad.

Fig. 2.01(H) is similar to **Fig. 2.01(G)** with staggered ramp provisions - suitable for land constraint situtation.

A Simple Split diamond is one in which each pair of ramps connected to a separate crossroad about a block apart. As shown in **Fig 2.01(I),** conflicts are minimized by handling the same traffic at four rather than two crossroad intersections, reducing the left-turn movements at each intersection from two to one. A disadvantage with this arrangement is that traffic leaving the expressway cannot return to the expressway at the same interchange.

Fig. 2.01(J) is a partial/half diamond type - used at minor intersections.

Cloverleafs (shown in **Fig 2.01(K and M)**) are four-leg interchanges that employ loop ramps to accommodate left-turning movements. Interchanges with loops in all four quadrants are referred to as “full cloverleafs” and all others are referred to as “partial cloverleafs.” A full cloverleaf may not be warranted at major-minor crossings where, with the provision of only two loops, freedom of movement for traffic on the major road can be maintained by confining the direct at-grade left turns to the minor road. The principal disadvantages of the cloverleaf are the additional travel distance for left-turning traffic, the weaving manoeuvre generated, the very short weaving on the main line, the double exit on the main line, and problems associated with signing for the second exit. Because cloverleafs are considerably more expensive than diamond interchanges, they are less common in urban areas and are better adapted to suburban or rural areas where space is available. This type forms symmetrical and beautiful geometry and requires only one grade separation structure.

Collector-distributor roads are to be provided along the expressway in expectation of heavy weaving volumes. Because of the high unit cost of right-of-way, this design was more economical with the collector-distributor roads and loop ramps with smaller radii. A design with ramps of larger radii would have been used if the collector-distributor roads had not been provided. The grades are relatively flat, with three percent being maximum. **(Fig 2.01(L)).**

Elevated Roundabout (as shown in **Fig 2.01(N)**) provides a relatively simple solution with four or more approaches where speed and volumes are not high. Generally on a split level structure, the main expressway is taken at ground level and the roundabout with weaving movements is taken at high upper level. It requires large land area. The weaving sections limit the speed and capacity. The directional signing is difficult unless the diameter of the circle is large enough to provide adequate length in the weaving sections. The weaving type does not contain at-grade intersections, where all ramps are not independently provided and two or more carriageway (through traffic lane or ramps) are partially overlapped and weaved.

Fully Directional Interchanges (as shown in **Fig 2.01(O)**) are generally preferred where two high-volume expressways intersect. Since traffic movements between the two expressways are free-flow with this interchange configuration, there are no at-grade intersections, only direct ramp connections from one expressway to the other.

2.5 CAPACITY CONSIDERATIONS

The design of interchanges must be coordinated with the design of the expressway. The design process consists of the following:

- preliminary design to set the locations of the ramps
- calculation of ramp and intersection capacity
- check of the design geometrics to ensure adequate sight distances
- preliminary design inspection to make sure all concepts are feasible

Capacity analysis of an interchange is a complex phenomenon and depends on the geometric configuration of the ramp i.e. direct, semi direct or loop and the gradient available for operation.

A thumb rule and for a preliminary design, as considered by various authorities, consider loop ramps for 800 – 1200 vehicles per hour (vph) semi direct ramps for 1200-1500 vph and direct ramps for more than 1500 vph.

The reduction/avoidance of the effects of ingress and egress traffic on the through lanes at the interchange is a prime requirement. These facilities require capacity analysis for vehicle manoeuvres, which include merging, diverging, weaving and angular crossings.

The capacity analysis for these complex movements are dependent on the horizontal and vertical alignment, composition of classified traffic, weaving and turning volume. “Highway Capacity Manual - 2000 (HCM-2000) of Transportation Research Board, National Research Council, Washington DC is most widely accepted document. Till the formulation of Indian Highway Capacity Manual, HCM-2000 of USA may be used for such analysis with considerations for Indian situation. More details on capacity analysis have been given in “Volume-I : Planning”.

2.6 DESIGN CONSIDERATIONS

2.6.1 *Ramp types*

Ramps are provided at interchanges for desired turning movements. Based on movement requirements, the connecting ramps may be classified as Direct, Semi-direct and Loop ramps.

Loop ramp is for right turns accomplished by a left exit and turn to the left through about 270^0. A loop ramp may have single turning movement (left or right or double turning movements (left and right) at either or both ends.

Semi-directional ramp for right turns accomplished through a partial duration from the intended path. With semi-directional connection, the driver makes a left turn first, heading away from the intended direction, gradually changing, and then completing the movement by following directly abound and entering the other road.

Directional ramp (also known as diagonal connections) which may be

a) A connection between the expressway and the cross road. The driver takes off the expressway on left and merges with the cross road.

b) For entry to expressway from cross road, the driver takes off on left and merges with the expressway.

Fig. 2.04 presents different types of Ramps.

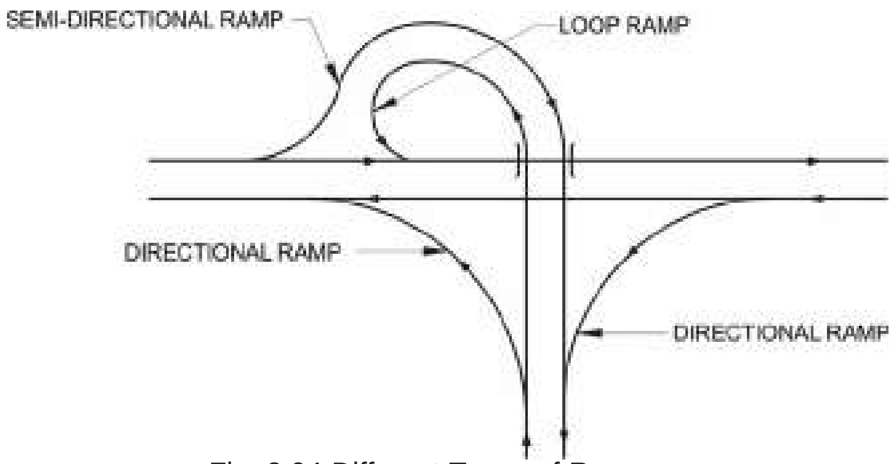


Fig. 2.04 Different Types of Ramps
Source: IRC : 92 - 1985

2.6.2 *Design speed*

Desirably, ramp design speed should approximate the low-volume running speed on the intersecting expressways. As mentioned in AASHTO – 2004, this design speed is not always practical and lower design speeds may be selected. Policy for Geometric Design of Rural Road by AUSTROAD (earlier NAASRA) recommends the Design Speed for interchange elements as given in **Table 2.01**. For expressways in India, these speeds can be adopted.

Table: 2.01 Recommended Design Speeds for Interchange Ramps

Configuration	Type of Ramps	Range of Expressway Design Speed (kmph)		
		100-120	**80-100**	**60-80**
		Range of Ramp Design Speeds (kmph)		
1. System Interchange	Loop	50-70	40-60	40-60
	Semi-Direct	70-90	60-80	60-70
	Direct	80-100	70-90	60-80
2. Service Interchange	Loop	40-60	40-60	40-60
	Semi-Direct	60-80	60-70	50-70
	Direct	60-90	60-80	60-80

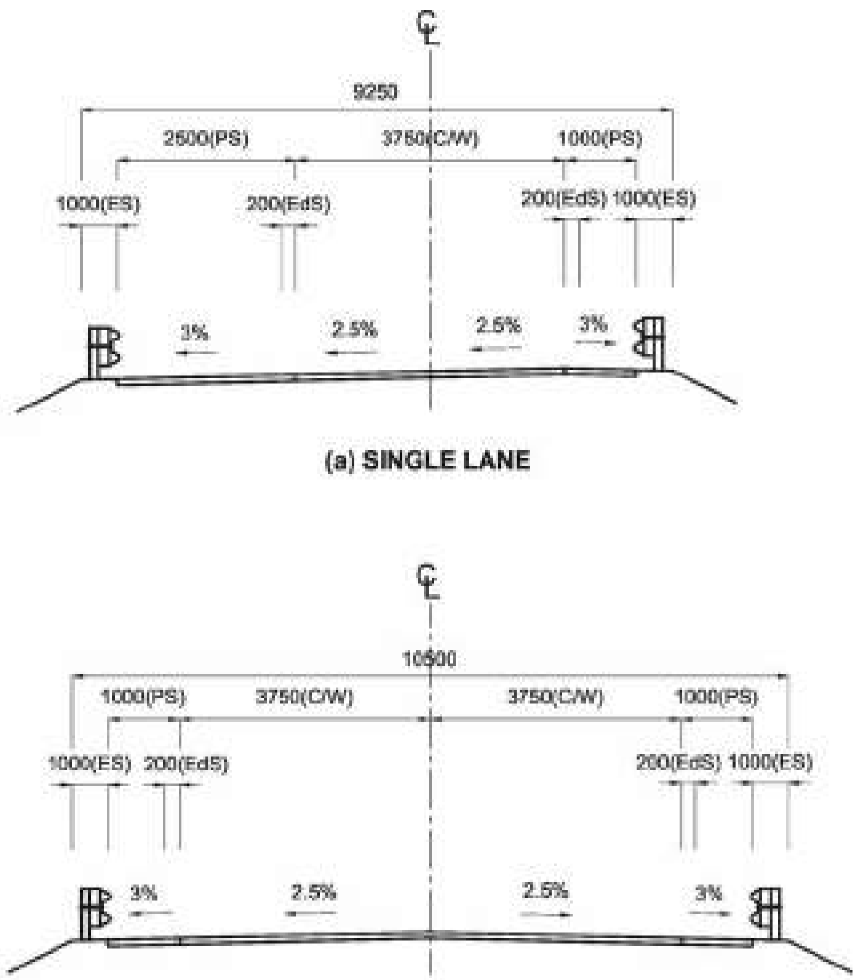
NOTE: *The above values from both AASHTO – 2004 & AUSTROAD document*

Ramp design speeds above 50 kmph for loops require longer length and large areas, which are expensive and require additional travel distance. For these reasons, ramp speed may have to be limited for Service Interchanges to keep the requirement of interchange area to a reasonable limit. Speed shall be reduced from around 120 kmph to stopping requirement at Toll Plaza, if provided on ramp.

For System Interchanges direct, semi direct or loops (with larger radius) may be considered.

2.6.3 *Width and cross-section*

The ramp cross-section showing carriageway width and shoulder (both paved and earthen) is given in **Fig. 2.05** for single lane and two way two lane ramps on **tangent** alignment. The width of paved and earthen shoulders considered here are for interchange ramp design only. Applicable extra wide carriageway shall be provided, as needed from ramp radius consideration.



(b) TWO LANE

LEGEND:

C/W - Carriageway
PS - Paved Shoulder
ES - Earthen Shoulder
EdS - Edge Strip

NOTE: All Dimensions shown are in millimeters unless otherwise noted.

Fig. 2.05 Typical Ramp Cross-Section
(on Tangent Alignment)
(Source : Interurban Toll Expressway System of Malaysia)

The extra width of carriageway to be provided at horizontal curves on single and two-lane roads is given in **Table 2.02**. In bracket (Bold) values indicates the rounded values. For multi-lane roads, the pavement widening may be calculated by adding half the widening for two-lane roads to each lane. As an illustration on a curve of 30 m radius for a six lane expressway, the extra width shall be 3.0 m for each carriageway

Table 2.02 Extra Width of Pavement at Horizontal Curves at Ramps
(For Semi-Trailer WB-12.0 Design vehicle)

Radius of Curve (m)	**15**	**25**	**30**	**50**	**75**	**100**	**125**	**150**	**>150**
Extra Width (m)									
Two-lane	6.95 (**7.0**)	4.45 (**4.5**)	3.95 (**4.0**)	2.85 (**2.9**)	2.25 (**2.3**)	2.05 (**2.10**)	1.85 (**1.9**)	1.7 (**1.8**)	1.25 (**1.3**)
***Single-lane**	2.55 (**2.6**)	1.25 (**1.3**)	0.95 (**1.0**)	0.35 (**0.4**)	0.05 (**0.1**)	Nil	Nil	Nil	Nil

Source: Compiled from ASSHTO-2004 Geometric Design
NOTE: * Single lane- with provision for passing a stalled vehicle.

On simple (unspiraled) curves, widening should be applied on the inside edge of the travelled way only. On curves designed with spirals, widening may be applied on the inside edge or divided equally on either side of the centreline.

Curve widening should transition gradually over a length sufficient to make the whole of the travelled way fully usable.

Preferably, widening should transition over the superelevation runoff length, but shorter lengths are sometimes used.

2.7 GEOMETRIC DESIGN CONSIDERATIONS

For interchange ramps, due to low volume (compared to main expressway lane), different parameter values on sight distance (both stopping and decision making consideration), maximum super elevation, side friction coefficients and longitudinal gradients shall be adopted.

2.7.1 *Sight distance*

Stopping and decision making sight distances depend on the manoeuvring time required. Stopping involves brake reaction time, braking distance depending on driver's deceleration rate while decision sight distance is a combination of speed/ path/direction change and driver's unexpected incidents. The **Table 2.03A** provides the recommended values.

Table 2.03A Decision Sight Distance

	Decision Sight distance for Avoidance manoeuvres (m)	
Design Speed (km/h)	**Stopping**	**Speed/Path/Direction change**
120	265	360
100	200	315
80	140	230
60	95	170

2.7.2 *Super elevation and side friction factor*

Most of the ramps have curvilinear alignment which may comprise tangent, transition, compound and simple curved. Considering the likely high percentage of trucks in traffic mix and the alignment curvature it is recommended to limit the super elevation and side friction values. **Table 2.03B** presents the minimum radius values for various combinations of speed, super elevation and side friction. Computed from $e + f = V^2/127R$

The length of vertical curves shall be checked against decision sight distance (Refer to Chapter-1: Geometric Design Section).

Table 2.03B Minimum Ramp Radius Recommended

V (kmph)	e%	F	R min (m) Comput-ed	R (m) Recomm-ended	V (kmph)	e%	F	R min (m) Comput-ed	R (m) Recomm-ended
40	0.02	0.15	74	75	80	0.02	0.14	315	315
40	0.025	0.15	72	70	80	0.025	0.14	305	305
40	0.03	0.15	70	70	80	0.03	0.14	296	295
40	0.04	0.15	66	65	80	0.04	0.14	280	280
40	0.05	0.15	63	65	80	0.05	0.14	265	265
40	0.06	0.15	60	60	80	0.06	0.14	252	250
50	0.02	0.15	116	120	90	0.02	0.12	456	455
50	0.025	0.15	112	115	90	0.025	0.12	440	440
50	0.03	0.15	109	110	90	0.03	0.12	425	425
50	0.04	0.15	104	105	90	0.04	0.12	399	400
50	0.05	0.15	98	100	90	0.05	0.12	375	375
50	0.06	0.15	94	95	90	0.06	0.12	354	355
60	0.02	0.15	167	170	100	0.02	0.11	606	605
60	0.025	0.15	162	165	100	0.025	0.11	583	585
60	0.03	0.15	157	160	100	0.03	0.11	562	560
60	0.04	0.15	149	150	100	0.04	0.11	525	525
60	0.05	0.15	142	140	100	0.05	0.11	492	490
60	0.06	0.15	135	135	100	0.06	0.11	463	465
70	0.02	0.15	227	230					
70	0.025	0.15	220	220					
70	0.03	0.15	214	215					
70	0.04	0.15	203	205					
70	0.05	0.15	193	195					
70	0.06	0.15	184	185					

2.8 LANE BALANCE

To ensure efficient operation and to realise the capacity potential where merging, diverging and weaving take place, an additional lane may be required in addition to capacity analysis. The following basic principles should be considered.

2.8.1 *Exit from expressway*

Beyond **Exit** i.e. point of divergence from expressway, the number of through traffic lanes on expressway may be

a) **Same number**, or

b) **Reduced by one**

2.8.2 Entry to expressway

Beyond the **Entry** i.e. the point of merging the number of through traffic lane on expressway may be

a) **Same number**, or
b) **Increased by one**

Fig 2.06 presents typical lane balance arrangements (Source: AASHTO – 2004)

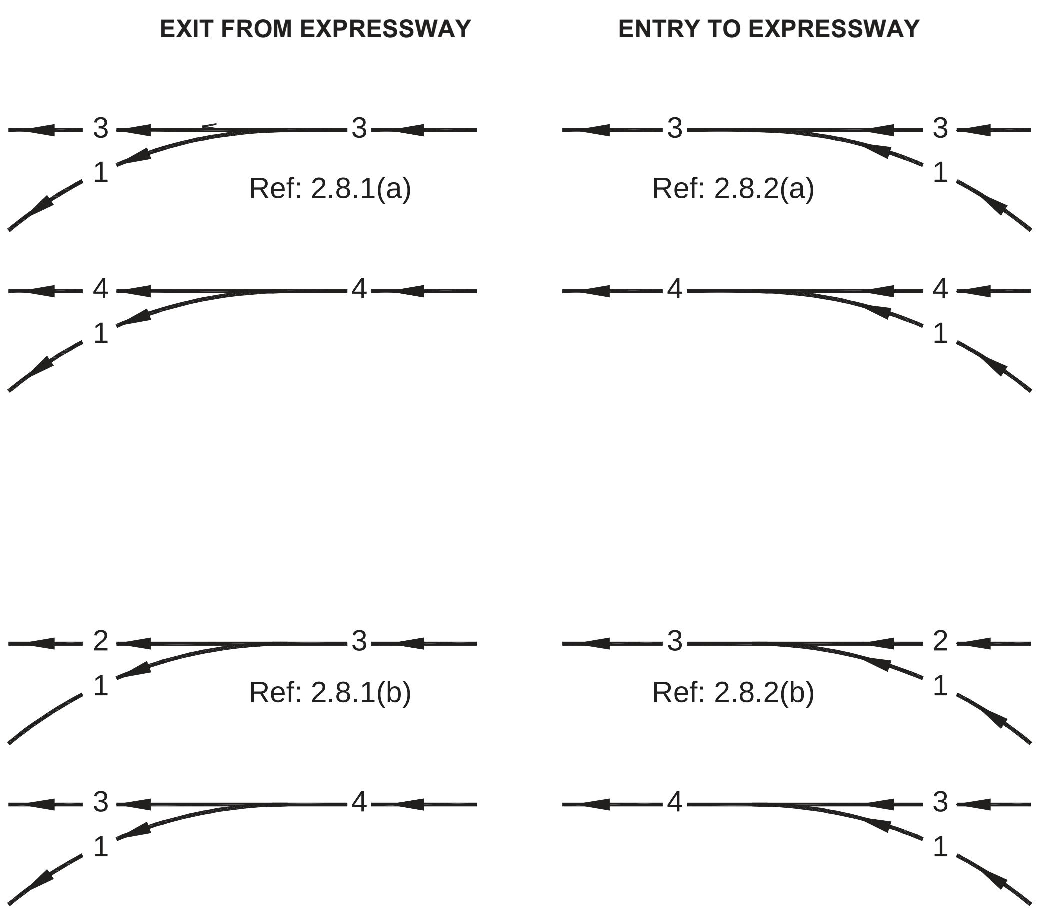


Fig. 2.06 Typical Examples of Lane Balance
Source : AASHTO - 2004

2.9 WEAVING SECTIONS

The high traffic demand near urban / outskirt areas may require construction of a number of interchanges. This may necessitate the establishment of a minimum spacing distance considering, deceleration, weaving and acceleration. The deceleration and acceleration lengths may be considered as given in this section. Weaving length may be considered on the following principles:

a) Weaving sections not on the principal carriageway should have a minimum length of 0.2 times Q (in metres). Q being the total weaving traffic in PCU/hour. The number of lanes necessary (i.e. provision of *auxiliary lane*) on this hypothesis is calculated by multiplying the smaller weaving flow by a factor of 3.
b) If, in exceptional situations, a weaving section cannot be avoided on the expressway, the length Q metres shall be a minimum of 600 m (based on Japanese standard).
c) The interchange should be so designed that, within its limit, the total weaving traffic is less than 2,000 PCU/hour.

2.10 EXIT AND ENTRANCE TERMINALS

Interchange ramps are made of three distinct components - two terminal ends and a connecting roadway. The connecting roadway is often referred to as the ramp proper, or simply the ramp. Based on operational aspects, taper and parallel or a combination design of ramp terminals are common practice in almost all countries. (**Fig. 2.04)**.

The taper design works on the principle of direct egress and ingress from/to Expressway at flat angle. The taper type design reduces the amount of driver steering control and, especially on exit ramps, fits well the direct path preferred by most drivers. However, taper design used on entrance ramps requires the drivers to time share between the tasks of accelerating, searching for an acceptable gap, and steering along the lane.

In India parallel type is preferable, especially for entrances. The parallel type designs require a reverse-curve manoeuvre and provide the driver with full view from side or rear view mirror to adjust with the following traffic.

2.11 ACCELERATION/DECELERATION LANES

Each entry and exit ramp shall have acceleration/deceleration lane for the project expressway. The length of the acceleration/deceleration lanes shall be decided on the basis of speed differentials of the project highway traffic and the speed permitted on the ramps.

Drivers exiting an interchange are required to reduce speed to meet with toll payment where such a scheme exists. Drivers entering an expressway from a ramp accelerate until the adjacent through lane speed is reached.

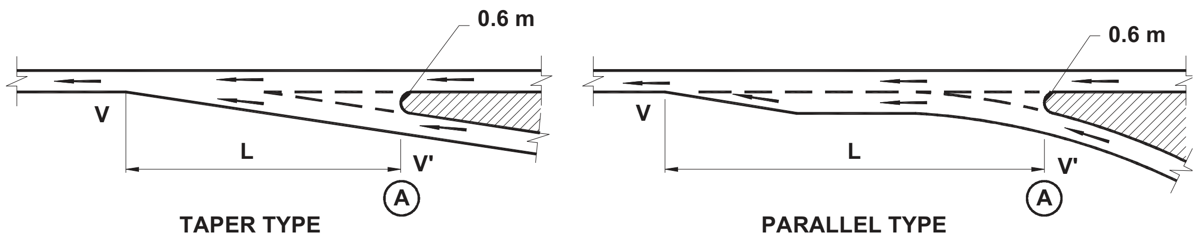
Provision should be made for acceleration and deceleration to be accomplished on additional lanes to minimize interference with through traffic and to reduce accident potential. Such an auxiliary lane is called speed change lane.

For safety, expressway exits should be located on tangent sections, wherever possible to provide maximum sight distance and optimum traffic manoeuvrability operation .The following recommendations should be considered from safety aspect.

Typical requirements of Acceleration length and Deceleration length and speed change length adjustment factors are presented in **Tables 2.04, 2.05 & 2.06 A, B and C** respectively.

Tables 2.04 Minimum Acceleration Lengths for Entrance to Expressway With Flat Grades of 2 Percent or Less

Expressway Design Speed, V (kmph)	Acceleration Length, L(m)							
	Speed on Entry Curve (kmph) at A							
	Stop Condition	20	30	40	50	60	70	80 or more
60	95	80	65	45	-	-	-	-
70	150	130	110	90	65	-	-	-
80	200	180	165	145	115	65	-	-
90	260	245	225	205	175	125	35	-
100	345	325	305	285	255	205	110	40
110	430	410	390	370	340	290	200	125
120	545	530	515	490	460	410	325	245



V = Design speed of expressway

V' = Design speed of entry curve

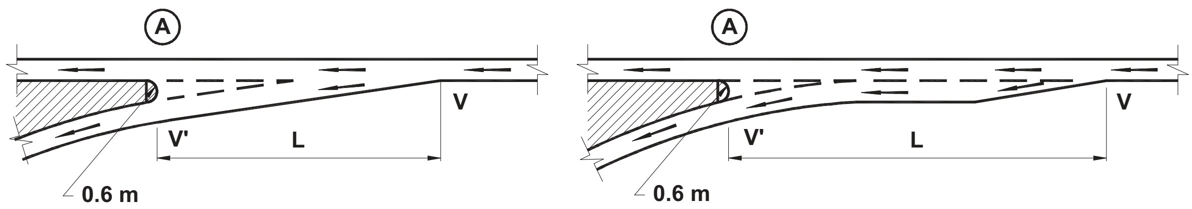
NOTE:
i) Values inside box are indicative only

ii) Uniform 50:1 to 70:1 tapers are recommended where length of acceleration lane exceeds 400 m

iii) For Parallel type, on high-speed expressways, it is common practice to use a taper rate that is between 8:1 and 15:1 (longitudinal : transverse or L:T)**.** The taper rate may be 8:1 [L:T] for design speeds up to 50 km/h and 15:1 [L:T] for design speeds of 80 km/h. For speed between 50 kmph and 80 kmph suitable taper rate may be adopted.

Table 2.05 Minimum Deceleration Lengths for Exit with Flat Grades of 2 Percent or Less

Expressway Design Speed, V (kmph)	Deceleration Length, L(m)							
	Speed on Exit Curve (kmph) on A							
	Stop Condition	20	30	40	50	60	70	80 or More
60	95	90	80	65	55	-	-	-
70	110	105	95	85	70	55	-	-
80	130	125	115	100	90	80	55	-
90	145	140	135	120	110	100	75	60
100	170	165	155	145	135	120	100	85
110	180	180	170	160	150	140	120	105
120	200	195	185	175	170	155	140	120



TAPER TYPE PARALLEL TYPE

V = Design speed of expressway

V' = Design speed of exit ramp

NOTE: i) Values inside box are indicative only.

ii) For Parallel type, on high-speed expressways, it is common practice to use a taper rate that is between 8:1 and 15:1 (longitudinal : transverse or L:T)**.** The taper rate may be 8:1 [L:T] for design speeds up to 50 km/h and 15:1 [L:T] for design speeds of 80 km/h. For speed between 50 kmph and 80 kmph suitable taper rate may be adopted.

Table 2.06A Deceleration Length (Table 2.05) Adjustment Factor

	Value	Factor
Upgrade	3 to 4%	0.90
	5 to 6%	0.80
Downgrade	3 to 4%	1.20
	5 to 6%	1.35

Table 2.06B Acceleration Length (Table 2.04) Adjustment Factor for Down Grade

Design Speed of Expressway (kmph)	Down Grade (All Speeds on Ramp)	
	3 to 4%	5 to 6%
60	0.70	0.60
70	0.65	0.60
80	0.65	0.55
90	0.60	0.55
100	0.60	0.50
110	0.60	0.50
120	0.60	0.50

Table 2.06C Acceleration Lengths (Table 2.04) Adjustment Factor for Up Grade

Design Speed of Expressway (kmph)	Design Speed of Ramp (kmph)				
	40	50	60	70	80
	3 to 4% Up Grade				
60	1.30	1.40	1.40	-	-
70	1.30	1.40	1.40	1.50	-
80	1.40	1.50	1.50	1.50	1.60
90	1.40	1.50	1.50	1.50	1.60
100	1.50	1.60	1.70	1.70	1.80
110	1.50	1.60	1.70	1.70	1.80
120	1.50	1.60	1.70	1.70	1.80
5 to 6% Up Grade					
60	1.50	1.50	-	-	-
70	1.50	1.60	1.70	-	-
80	1.50	1.70	1.90	1.80	-
90	1.60	1.80	2.00	2.10	2.20
100	1.70	1.90	2.20	2.40	2.50
110	2.00	2.20	2.60	2.80	3.00
120	2.30	2.50	3.00	3.20	3.50

NOTE: Adjustment Factor from this table, multiplied by the length in Table 2.04 or Table 2.05 gives length of speed change lane on various grades.

2.12 TRAFFIC DISPERSAL SCHEMES

2.12.1 *Introduction*

On Access Controlled Expressways, the services of collection and distribution of traffic is provided through specially designed interchanges at selected locations along the route and at the terminal ends. The high volume of ingress and egress traffic at the interchanges as well as at the terminals would require considerations of local road network, its present capacity, physical condition of road, possibilities of improvements etc. This total complex system may be addressed under Traffic Dispersal Schemes. In real terms, the benefit of high level investments on expressway can be appreciated only through an effective and efficient traffic dispersal scheme. After enjoying a high level of service, the users should not be pressed into nerve-raking delays due to over congested roads and signals at the dispersal point.

2.12.2 *General considerations*

Generally provision of an access or interchange shall be made on economic considerations. An expressway without intermediate access would be efficient for through traffic, but it could not be considered efficient in an overall sense. Sometimes, physical barriers or adverse topographical conditions dictate location of an access.

Normally at traffic collection/dispersal locations, connections are made to the surface street system either directly to or in close proximity to a major surface artery which is of carrying the traffic to the distributor road network system and also of feeding the expressway with ingress traffic.

The regional town planning/highway department shall be involved in improvement of the road network system to provide ingress traffic to expressway as well as to disperse the egress traffic from the expressway.

This is a complex planning process involving various States and concerned authorities. A thematic arrangement of ring road or peripheral road has been presented in **Fig. 2.07**. Construction of ring roads should precede the connection of the expressway

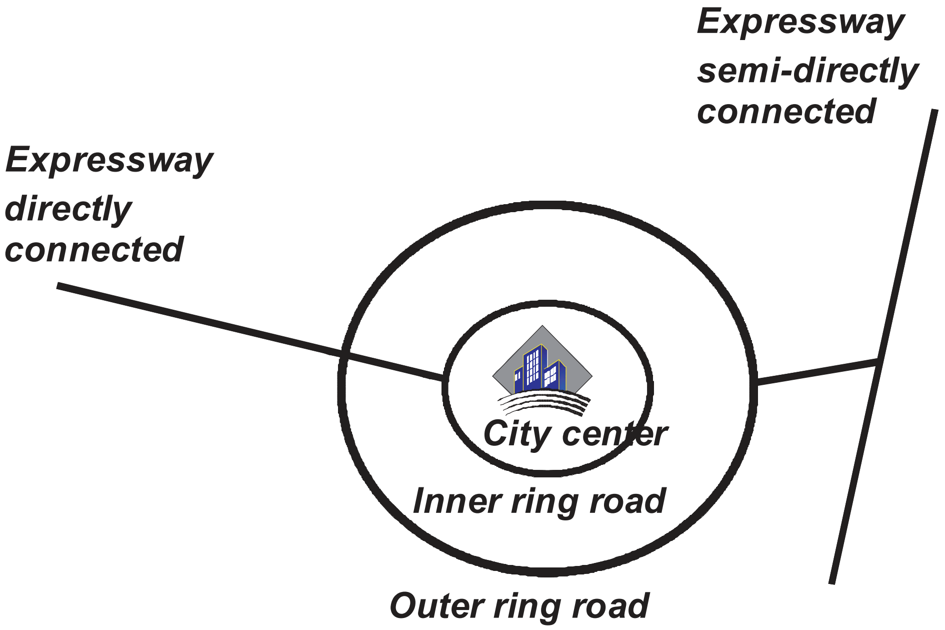


Fig. 2.07 Thematic Traffic Dispersal Arrangement
Not to Scale

CHAPTER - 3

EMBANKMENT AND CUTTING

CHAPTER – 3

EMBANKMENT AND CUTTING

3.1 GENERAL CONSIDERATIONS

The expressway alignment is intended to provide for high level of safety and efficiency in movement with large volumes of traffic at high speeds. These facilities are designed to be access controlled, requiring provision of grade separated structures to allow/maintain cross road traffic services.

All these involve the expressway to be built in embankment, or cutting or on long elevated structures.

Desirably, a minimum height of 3.5 m shall be considered to accommodate animals, pedestrians, agricultural vehicles etc requiring a minimum vertical clearance of 2.5 m. The Finished Road Levels (FRL) shall be finalised with this minimum value as datum.

The height of embankment shall be based on the final road levels. The following principles shall be followed for fixing the road level:

i) The top of the sub-grade is at least 1.0 m above the high flood level/high water Table/pond level. However, in exceptional circumstances where it is found difficult to fulfil this criterion, a minimum difference of 0.6 m between the top of sub-grade and HFL/high water Table/pond level shall be ensured.
ii) To fulfil the minimum free board requirement and provide smooth vertical profile for portions forming approaches to structures.

Structural Features and Design of Embankment

Embankment shall be designed to ensure that stability of the roadway and shall incorporate only those materials, which are suitable for embankment construction.

Embankment instability may result from a variety of causes, and the modes of failure can be numerous. Failure can occur in almost every conceivable manner, slowly or suddenly, and with or without any apparent provocation. Failures within the body of the embankment may arise due to adoption of incorrect design. When a high embankment is made up of sandy soil, one of the possible measures against erosion is to have a blanket cover of cohesive soil over the sandy core.

Embankment Slope

Flat, rounded side-slopes, fitting with the topography and consistent with available right-of-way, shall be provided on rural Expressways. Embankment slopes shall not be steeper than 1V:2H. Slopes of 1V:4H or flatter are desirable for embankments of moderate height. For high embankments, steeper slopes protected by safety barriers may be needed.

For embankment heights more than 6.0 m, slope stability of embankment will dictate the side slopes. High embankment (height 6 m or above) in all soils shall be designed from stability considerations. For design of high embankments IRC:75 and MORTH – Guidelines for Deign of High Embankment may be referred. This has been further elaborated later on.

Most slips occur in cohesive materials because of weakening of soil with increase in moisture content. Reduction in moisture in such cases can result in substantial improvement in stress-resisting properties of the soil. Efficient surface, sub-surface and interceptor drains fulfil the function of supporting the slope against failure by preventing the entry of surface water which would have caused softening of the soil.

The side slopes shall be protected against erosion by providing turfing/vegetative cover, stone/CC block pitching, geo-synthetics, gabion walls or any other measures depending on the height of the embankment, type of soil involved and susceptibility of soil to erosion as per IRC:56. Pitching works on slopes shall be as per MORTH Specifications.

Retaining Structures

The embankment shall be retained by the retaining structures conforming to site conditions. The type of earth retaining structures shall be aesthetically pleasing and compatible with adjoining structures. This has been further elaborated later on.

3.2 EXPRESSWAY ON EMBANKMENT

3.2.1 *General*

The purpose of this section is to outline the general requirements associated in fixing the finished road levels on various topography with varied geological and geomorphological conditions.

For design of embankment involving internal and global stability, various methods are available in documents published by Indian Roads Congress (IRC) and the Bureau of Indian Standards (BIS).

A brief list (not necessarily exhaustive) is presented below.

3.2.2 *Relevant Indian Roads Congress publications*

	Specifications for road and bridge works
IRC:10	Recommended practice for borrow pits for road embankment constructed by manual operation
IRC:34	Recommendations for road construction in waterlogged areas
IRC:36	Recommended practice for the construction of earth embankment for road works
IRC:56	Recommended practice for treatment of embankment slopes for erosion control
IRC:75	Guidelines for the design of high embankments
IRC:78	Standard specifications and code of practice for road bridges – Section VII : Foundations and substructures
IRC:89	Guidelines for the design of river training and control works for road bridges
IRC:SP:42	Guidelines on road drainage
IRC:SP:58	Guidelines for use of fly ash in road embankments

3.2.3 *Relevant Bureau of Indian Standards publications*

IS 1498	Classification and identification of soils for general engineering purposes
IS 8408	Planning and Design of Groynes in alluvial river guidelines (First revision)
IS 8835	Planning & Design of Surface Drains
IS 14262	Planning & Design of Revetment
IS 10751	Planning & Design of Guide Banks for alluvial rivers Guidelines (First revision)
IS 12094	Guidelines for Planning and Design of River Embankment (levees)
IS 11532	Constructions and Maintenance of River Embankment (levees) Guidelines
IS 12926	Construction and maintenance of guide banks in alluvial rivers - Guidelines

Note: Use latest versions.

3.3 SALIENT STRUCTURAL FEATURES ON EMBANKMENT DESIGN

The embankment height governs the types of material to be used. The nature of foundation materials has a significant influence on the design of embankment.

The basic requirement involves

a) Stability Analysis, and
b) Settlement Analysis

3.3.1 Stability analysis

The calculation of slope stability is well described in the guidelines for the design of high embankments (IRC:75-1979). Different cases of calculation using total stresses and effective stresses are presented. However, manual computations are laborious and also not desirable to carryout for a bigger project, because it is important to test quickly a wide range of parameters. There are softwares available for such calculations capable of simulating the flow of water through soil and embankment and so constitute a help to improve stability by designing any appropriate measure for drainage.

Any software available for slope stability may be used.

3.3.2 Settlement analysis

Settlements are of two types: embankment settlement and ground settlement.

The embankment settlement is more or less controlled during the construction and should be reduced by strict application of specifications about compaction rate. According to the specifications of MORTH, expansive clay may be used in embankment and the minimum required relative compaction is only 90 percent. These materials should therefore be avoided as much as possible because of risk of delayed settlement especially because of the cycle of wet/dry conditions.

3.3.3 Fill slopes

i) From safety consideration slopes steeper than 1V:3H are not generally used. With road side barrier, slopes steeper than 1V:3H may be permitted with the following considerations:

- For clayey sand to sandy clay fill materials a slope of 1V:3-4H may be used for height more than 5.0 m and 1V:2-3H for heights below 5.0 m.
- For sandy and gravely fill materials, a slope of 1V:2H may be used.

ii) In case of scarcity of fill materials or where land availability is a problem, use of retaining structures including reinforced earth construction may be made.

The Reinforced Earth Structure shall be designed in conformity with MORTH – Specifications for Road and Bridge Works : Fourth Revision, Section 703 and in accordance with

i) BS:8006-1995 "Strengthen/Reinforced Soils and Other fills"
ii) FHWA-NHI-00-043 Mechanically Stabilised Earth Walls and Reinforced Soil Slopes – Design and Construction Guidelines.
iii) Design Manual for Segmental Retaining Walls published by the National Concrete Masonry Association (NCMA) Washington, DC, meeting the ultimate and serviceability limit state requirements.

The reinforcing elements may be hot dip galvanised steel strips, or Geosynthetic Material (i.e. geogrid reinforcement or geotextiles reinforcement) or any other proprietary material conforming to MORTH Specifications.

3.3.4 *Cut slopes*

Generally the slope is decided by the stability and erosion prevention consideration and the soil / rock formation through which the road passes.

i) On impervious Soils

A slope of 1V:2H for heights up to 5.0 m and 1V:2.5H for heights above 5.0 m may be used.

ii) In Rocky Areas

The recommended values are for normal slope conditions where minimising or preventing rock falls are major concern and massive land sliding is not a problem. The generally adopted values are given in **Table 3.01**.

Table 3.01 Cut Slope in Rocky Area

Rock Types		Slope (H:V)
a)	Igneous Rocks Granite, Trap, Basalt, Lava	 1:4 to 1:2
b)	Sedimentary Rocks - Massive sand stone and lime stone - Interbedded sand stones, shales and lime stones - Massive clay stone and silt stone	 1:4 to 1:2 1:2 to 3:4 3:4 to 1:1
c)	Metamorphic Rocks - Gneiss, Schist and Marble - Slate	 1:4 to 1:1 1:2 to 3:4

3.3.5 Ground improvement

3.3.5.1 Requirements and investigations

Where the embankment is to be supported on a weak stratum, it may be necessary to adopt remedial/ground improvement measures to provide the safe bearing capacity. This would require detailed geotechnical investigations to evaluate the soil profile, ground water levels and soil properties.

The appropriate measures for ground improvement will depend on these investigations. Further analysis is required if there is evidence of any of the following

a) Difficult soils, such as expansive or collapsing soil and sensitive or dispersive clay
b) Potential for liquefaction
c) Potential for slope instability
d) Potential for excess seepage, high uplift pressures or erosion and piping

3.3.5.2 Methods of ground improvement

Many methods for ground modification and improvement are available, including dewatering, compaction, preloading with and without vertical drains, admixture stabilization, grouting of several types, deep mixing, deep densification, and soil reinforcement.

Methods (not exhaustive) generally adopted for ground treatment are as follows:

a) Soil Replacement

Soil replacement involves excavating the soil that needs to be improved and replacing it. The excavated soil can sometimes be recompacted to a satisfactory state or it may be treated with admixtures and then be replaced in a controlled manner. It can also be replaced with a different soil with more suitable properties for the proposed application

b) Roller Compacted Concrete

Roller compacted concrete (RCC) is a material that has useful applications for ground improvement. Roller compacted concrete is essentially no-slump concrete composed of a blend of coarse aggregate, fine aggregate, cement and water. It is placed and spread using conventional earth moving equipment, compacted with vibratory rollers and allowed to cure. During curing, the Roller compacted concrete hydrates and hardens into weak concrete.

c) Vibrocompaction and Vibrorod

Vibrocompaction methods use vibrating probes (typically having a diameter of about 0.4 m) to densify the soil. The probe is usually jetted into the ground to the desired depth of improvement and vibrated during withdrawal, causing densification. The soil densifies as the probe is repeatedly inserted and withdrawn in about 1 m increments. The cavity that forms at the surface is backfilled with sand or gravel to form a column of densified soil. Vibrocompaction methods are most effective for sands and gravels with fines less than about 20 percent.

d) Stone Columns (Vibro-replacement)

Stone columns are installed using a process similar to Vibrocompaction, except that a gravel backfill is used, and they are usually installed in slightly cohesive soils or silty sands rather than clean sands. In the dry process, a cylindrical cavity is formed by the vibrator, that is filled from the bottom up with gravel or crushed rock. Compaction is by vibration and displacement during repeated 0.5 m withdrawals and insertions of the vibrator. Stone columns are usually about 1 m in diameter, depending on the soil conditions, equipment and construction procedures. They are usually installed in square or triangular grid patterns, but may also be used in clusters and rows to support footings and walls. Center-to-center column spacings of 1.5 to 3.5 m are typical.

e) Gravel Drains

Gravel drains are a type of stone column proposed for use in liquefiable soils to mitigate liquefaction risk by dissipation of excess pore water pressures generated during earthquakes. These are for use in two ways: (1) as the sole treatment method for liquefiable zones and (2) as a perimeter treatment around improved zones to intercept pore pressure plumes from adjacent untreated ground. Gravel drains are constructed in the same manner as stone columns, but are installed in cohesionless deposits. As the gravel is densified during vibro-replacement, there is mixing of the sand with the gravel in the drain. The degree of mixing has a strong influence on the final permeability of the gravel drain.

f) Compaction Grouting

Compaction grouting consists of injecting a very-low slump mortar into loose soils and cavities. The grout forms a bulb which expands against the surrounding soil, causing densification and displacement to occur. The grout acts as a radial hydraulic jack to compress the surrounding soil. The grout is usually a mix of sandy soil with enough fines to bind the mix together, cement, and water. A typical compaction grout mix consists of about 3 parts sand to 1 part cement, although cement is not always used. The grout forms a bulb up to about 1 m in diameter that is relatively strong and incompressible after it hardens. The process causes an overall decrease in the void ratio of the formation. Compaction grouting is most effective for loose granular soils, collapsible soils, and loose, grained soils.

g) Prefabricated Vertical (PV) Drains, With or Without Surcharge Fills

Prefabricated vertical (PV) drains, also known as wick drains, are typically installed in soft, cohesive soil deposits to increase the rate of consolidation settlement and corresponding strength gain. The rate of consolidation settlement is proportional to the square of the length of the drainage path to the drain. Installing vertical drains shortens the drainage path which causes an increase in the rate of settlement. Geocomposites are widely used as drains because they are relatively inexpensive, economical to install and have a high flow capacity. Geocomposite drains consist of a plastic waffle core which conveys the water and a geotextile filter to protect the core from clogging. In selecting a drain, it is important to choose one with enough capacity. Drains are typically spaced in a triangular or rectangular configuration. A sand blanket is usually placed on the surface of the consolidating layer to facilitate drainage. Surcharge preloading can be used in conjunction with vertical drains to increase the magnitude of settlement prior to construction.

3.3.6 *Use of fly ash for embankment construction*

i) Fly ash shall be used for construction of embankment in accordance with guidelines of MORTH. The embankment shall be designed and constructed in accordance with IRC:SP-58. The thickness of soil cover shall be not less than 1 m for embankments upto 3 m height. For high embankments, the thickness of soil cover shall be increased as per design.
ii) The side slopes of the embankment shall be protected against erosion.
iii) The stability analysis of the embankment shall be carried out as per IRC:75.

CHAPTER - 4

PAVEMENT DESIGN

CHAPTER – 4

PAVEMENT DESIGN

4.1 GENERAL CONSIDERATIONS

Expressways are intended to serve high volume traffic and cater for highest safety and comfort in driving. These basic requirements demand minimum maintenance limiting traffic disruption to lowest. This would require

a) Adequately designed pavement from structural strength considerations, and
b) Safety and comfort of users

While the structural aspects are generally well covered in IRC design standards coupled with MORTH policy, the safety and comfort aspects are related more to surface characteristics. This chapter deals with these aspects i.e. Traffic Safety and Driving Comfort.

Imported elements are:

i) Enhanced safety requirements, compatible with high traffic speeds and volumes;
ii) Adequate driving comfort for long distance high speed travel;
iii) Provision of the needed safety and comfort levels on a sustained basis without any dislocation, disturbance or inconvenience to the traffic.

Traffic Safety depends on a number of factors including pavement surface characteristics, the vehicles and the drivers. Safe vehicle pavement interaction at high speeds, apart from adequacy of geometric design for the traffic speeds and volumes, needs special attention to the aspect of skid resistance and hydro-planing. These properties of the pavement are related to its surface texture and surface drainage characteristics.

Driving Comfort considerations call for increasingly more even surface with increase in speed. More stringent norms need to be adopted as compared to other highways. The choice of construction and quality control techniques, compatible with the assurance of the needed level of surface evenness, becomes particularly significant in this context.

The three main characteristics expected of an expressway pavement surface from the users' point of view are:

i) Good riding quality (low roughness value);
ii) Skid-resistance i.e. good pavement - tyre friction including under wet weather situation;
iii) Absence or limitation of rutting on wheel tracks.

The new expressway pavement may be designed as flexible pavement in accordance with IRC:37 or rigid pavement in accordance with IRC:58.

4.2 RIDING QUALITY

Roughness of road is a major determinant of safety, cost of vehicle operation, comfort and speed of travel. Its accurate measurements are of vital importance to a highway engineer. The important uses of roughness measurements are:

i) To assess maintenance needs;
ii) To assess quality of construction.

The riding quality of a pavement is determined to a large extent by its functional and structural adequacy, the cumulative axle load repetitions, specification adopted for the surface initially, and the maintenance inputs. Hence pavement performance can be assessed through monitoring roughness.

Roughness of a road surface is expressed in mm/km or m/km. The former is known as BI (Bump Integrator) value and the latter one is known as IRI (International Roughness Index) value. In India it is common to use BI value.

4.2.1 *Measurement of riding quality*

Type C i.e. APL Inertial profilometres is recommended for measurement of roughness or a suitable method may be adopted from World Bank Technical Paper No. 46 – Guidelines for Conducting and Calibrating Road Roughness Measurement.

For assessment of surface roughness, two main approaches are available as mentioned below:

a) **Response-type equipment** recording relative movement between a single-wheel trailer and its standardized chassis, when towed at or corrected to a standard speed. The TRL Fifth wheel Bump Integrator is one such equipment. Calibrated vehicle mounted bump integrator is convenient for long stretch survey.

b) **Profile characterization and characterizing equipment**. This can range from rod and level measurements at close intervals, to high-speed laser-based profilometers. The first significant automated equipment to be developed was the CHLOE Profilometer developed for the AASHTO Road Test for monitoring of slope variance. Slope variance was subsequently correlated with unevenness index as assessed by the Bump Integrator, for more expeditious assessment.

c) **APL Inertial Profilometre** – The LCPC Longitudinal Profile Analyzer (APL) is designed for continuous high speed evaluation of 100 to 300 km of the expressway per day. The APL consists of a special towed trailer that has one bicycle type wheel, a chassis with ballast, and a special low frequency inertial pendulum that serves as a pseudo-horizontal reference. The trailer is designed to be sensitive to only the profile of the traveled wheel track over the frequency band of 0.5 to 20 Hz and towed at any constant speed between 50 and 100 kmph.

Proper calibration of the riding quality monitoring equipment is a precondition for any roughness measurement.

An overview of the riding quality monitoring equipment is given in **Fig. 4.01**.

4.3 SKID RESISTANCE

For improved traffic safety, attention is required to be paid to skid resistance of the pavement surface.

The potential for an accident from skidding depends mainly on:

i) Speed of the vehicles;
ii) Cornering path i.e. minimum/near minimum curvature;
iii) Magnitude of acceleration or deceleration;
iv) Condition of vehicle tyres;
v) Pavement Surface characteristics

Speed is the most significant parameter on wet pavements not only because the frictional demand increase in proportion with the square of the speed but also because the skid

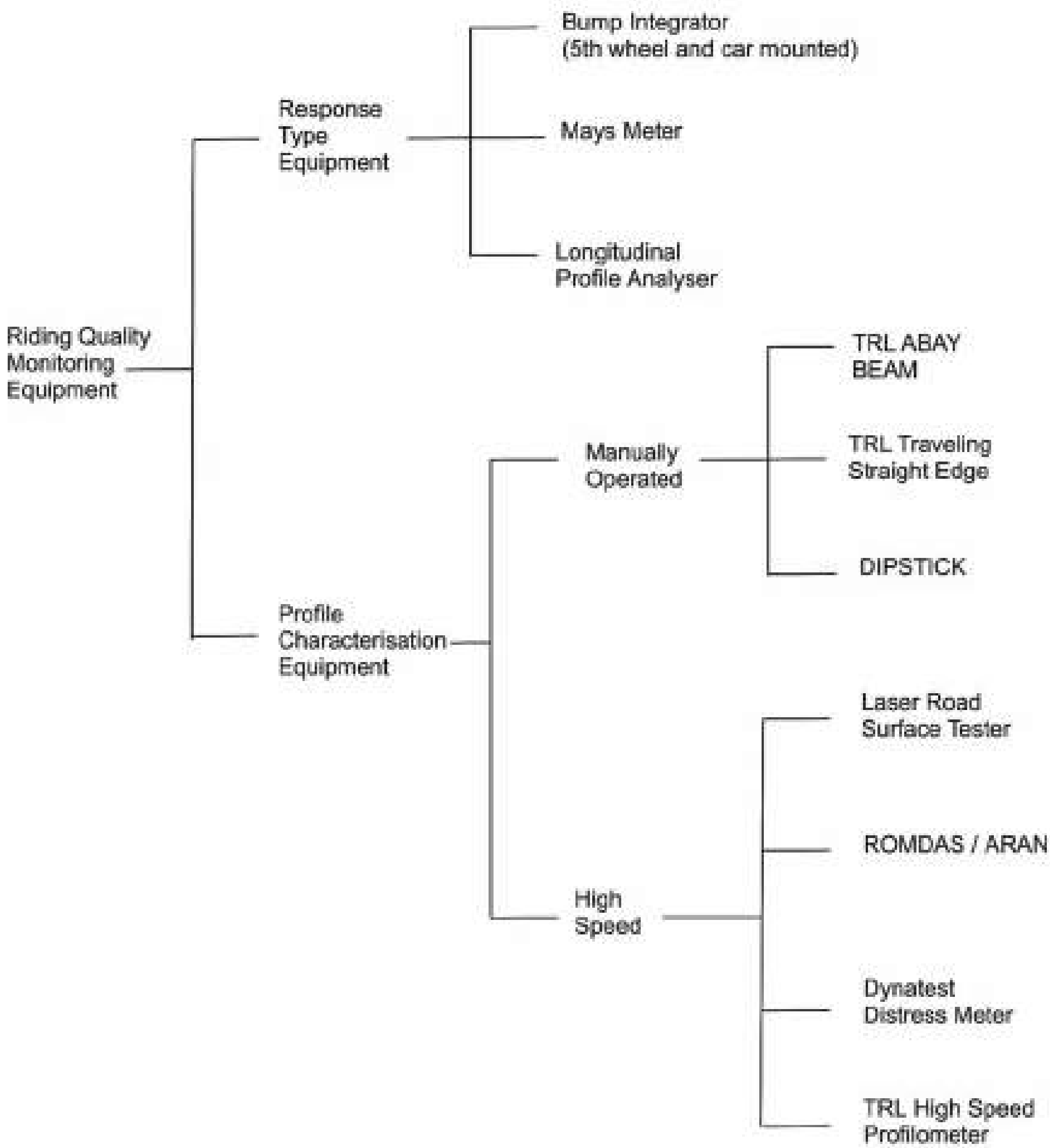


Fig. 4.01 Riding Quality Monitoring Equipment

resistance at the tyre-pavement interface decreases with increasing speed. When the depth of water on a pavement is excessive, skidding and/or hydro-planing effect can occur even when the wet friction required by a particular manoeuvre does not exceed the pavement skid number. In order to reduce the potential for hydro-planing at sites where climatic or geometric conditions are likely to produce excessive water depths on the pavement, it is necessary to understand the role of pavement surface properties in skid resistance.

The pavement surface properties that influence skid resistance can be divided into two categories, micro texture and macro texture.

Pavement micro texture consists of the microscopic texture on the surface of the individual pieces of aggregate, and to a lesser extent on the surface of the pavement binder (asphalt or portland cement). Micro-texture is what makes a piece of aggregate feel smooth or rough to the touch.

Pavement macro-texture consists of the large scale roughness or harshness associated with voids on the pavement surface between pieces of aggregate.

In simpler terms, micro-texture is determined by the aggregate sizes and the manner in which the individual pieces of aggregate are assembled to form a pavement surface. Micro-texture has wavelengths from 0.5 mm to 50 mm and vertical amplitudes ranging from 0.1 mm to 20 mm. Micro-texture plays a major role in wet weather friction characteristics of pavement surfaces, especially at high vehicle speeds. Therefore, pavements that are constructed to accommodate vehicles traveling at speeds of 80 kmph or greater require good macro-texture to help prevent hydroplaning. In addition to providing wet weather friction, macro-texture is the pavement surface characteristic with the strongest impact (reduction) on tyre-pavement noise and splash and spray.

It is important to understand that hydroplaning is different from skidding on wet pavement. When hydroplaning occurs, the entire tyre footprint is separated (i.e. complete loss of contact) from the pavement by a thin layer of water and the pavement surface texture no longer plays a role in the friction process. When a rolling tyre encounters a film of water on the roadway, the water is channeled through the tyre tread pattern and through the surface texture of the pavement. Hydroplaning occurs when the drainage capacity of the tyre tread pattern and pavement surface is exceeded and the water begins to build up in front of the tyre, creating a wedge of water that lifts the tyre off the pavement surface.

Research has not clearly defined the depth of water at which hydro-planing occurs because this phenomenon depends on a range of vehicle speeds, tyre tread patterns, tyre pressure, and pavement surface textures. However, there is considerable agreement on the water depth required to produce wheel "spin down" with sufficient loss of tyre friction to present a major driving hazard. This approximate depth is in the range of 1.5 to 5.0 mm.

It is quite a difficult task to prevent water from exceeding this depth specially on wide pavements during high intensity rainfalls. Speed management in such situations would be a preferable solution.

4.3.1 *Measurement of pavement skid resistance*

A number of methods are available for measurement of skid resistance of the pavement surface. An overview is given in **Fig. 4.02.**

The skid resistance is determined using portable skid resistance tester after 6 (Six) hours of polishing designed to produce a state similar to that which the aggregate would be subjected to under actual traffic when equilibrium conditions are reached. This is termed as Polished Stone Value (PSV). The aggregate durability is measured by Aggregate Abrasion Value (AAV).

4.3.2 *Practice in various countries*

Various standards have been set for **Polished Stone Value (PSV)** requirements of stone aggregates and minimum requirement of skid resistance by different organisations.

USA specifies the PSV depending on the traffic volume as given in **Table 4.01:**

Table 4.01 Recommended PSV in USA

Present Average Daily Traffic Grouping	Minimum PSV
0 – 749	None
750 – 1999	50
2000 – 4999	55
5000 – over	58
Interstate Expressway	58

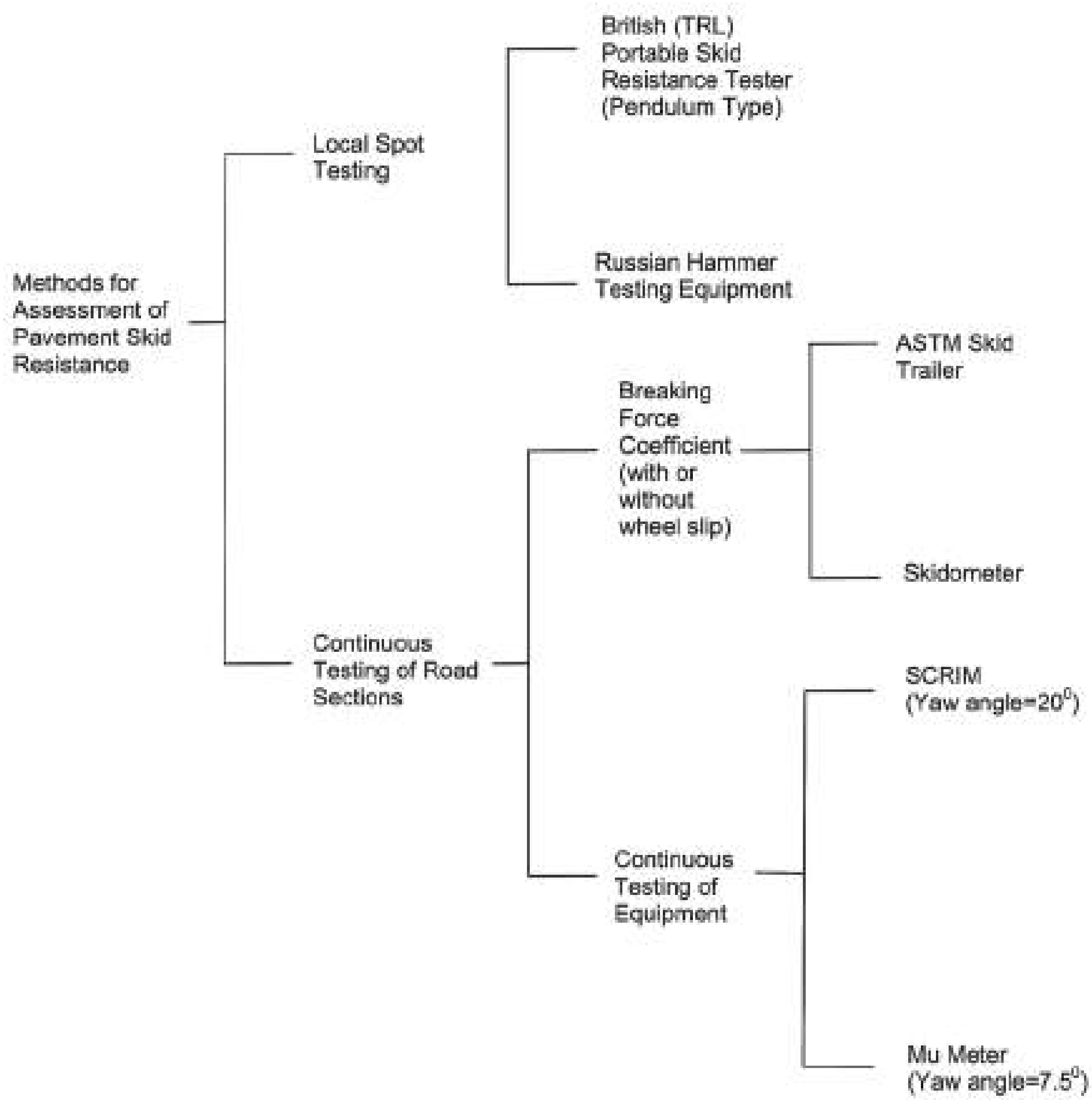


Fig. 4.02 Methods for Assessment of Pavement Skid Resistance

In the **UK,** selecting the minimum PSV and maximum of the road aggregate AAV are done iteratively. The design engineer selects a road stone with the required PSV in order to maintain the desired skid resistance under the given traffic condition using value given in **Table 4.02** and **Table 4.03.**

Table 4.02 Minimum PSV of Chippings for Flexible Pavement (For Motorway and Dual Carriageway Roads)

Traffic CV/Lane/Day	Minimum PSV
Less than 1750	55
1751 – 2250	57
2251 – 2750	60
2751 – 3250	65
Greater than 3250	68

Table 4.03 Maximum Aggregate Abrasion Value (AAV)

Traffic CV/Lane/Day	<250	251-1000	1001-1750	1751-2500	2501-3250	>3250
Maximum AAV for chippings	14	12	12	10	10	10
Maximum AAV for coated aggregate	16	16	14	14	12	12

Belgium has recommended minimum PSV as 50 for aggregate larger than 8 mm in wearing course.

France suggests that aggregate with PSV between 45 and 55 is considered ‘good’ and higher than 55 “very good”. Use of PSV 55 is recommended when alignment and traffic conditions are not favourable.

Spain recommends that for bituminous pavement, the minimum PSV is from 40 to 45 depending on traffic volume and it can be from 50 to 55 in special cases.

Skid resistance guidelines adopted in some countries in Europe and Japan are presented in **Table 4.04.**

Table 4.04 Skid Resistances in some European Countries and Japan

Country	Equipment Used	Parameter Monitored	Guidelines Stipulated
Germany	Stuttgarter Reibungsmesser (for testing existing pavements)	Braking Force Coefficient (BFC) Locked wheel patterned tyre	BFC min 0.42 at 40 kmph 0.33 at 60 kmph 0.26 at 80 kmph
Netherlands	-	Braking Force Coefficient with 86 percent slipping and a patterned radial tyre. Water film thickness 0.5 mm, test speed 50 kmph (for special requirements, speeds of 70 and 90 kmph also used)	Existing Pavements: Improvement measures generally recommended when BFC<0.51 and immediate measures to be taken when BFC<0.46 New Pavements: Min. acceptable BFC=0.56, to be measured within 4 weeks after construction.
Poland	Cobirdt Trailer	Locked wheel Braking Force Coefficient with patterned tyre and a load of 400 kg at a speed of 60 kmph	BFC > 0.35 considered satisfactory in most cases.
Japan	Japanese heavy test vehicle (of braking force tyre) British Pendulum Tester	Braking Force Coefficient at 60 kmph -	Existing Pavements: Min. BFC=0.40 for normal roads and 0.45 for difficult locations New Pavements: Recently built roads should have a coefficient higher than 0.60

4.3.3 *Anti skid measures*

Source: “Surface Characteristics” – TCR XVIII World Road Congress.

A very innovative and promising introduction is permeable wearing course over an impervious surfacing. The permeable wearing course substantially reduces spray and hydro-planing during heavy rains. However, this technique has still to overcome problems of durability and is in restricted use for critical expressway sections though research development continues in several countries to widen the scope of application.

For concrete pavements, choice of aggregate and construction techniques are utilized to improve the skid resistance for a new surface. Belgium, with its good background of concrete pavement construction, uses the following techniques for heavily trafficked highways:

i) Chemical aggregate exposure using a setting retarder (where the aggregate is non-polishing);

ii) Chipping of fresh concrete (where the aggregate used in the main pavement course is of polishing type);

iii) Deep transverse grooving (less used since 1980 because of the resultant high level of rolling noise).

In **Japan**, "steel line grooving technique" (following FHWA specification) has been used with groove spacing 30 mm and target groove depth 3 mm. Additionally the concrete mix is so designed that the mortar on the surface wears faster than the aggregate, thus exposing aggregates and enhancing macro-texture. This essentially involves keeping down the cement content of the mix which, however, can be in conflict with strength development objective. For Sanyo Expressway project in Japan, the cement content of concrete mix was kept at 280 kg/m^3 and the design was based on the strength development not at 28 days but at 91 days.

Skid resistances of expressways are to be checked after construction and periodically during service. Different highway research organizations have produced appropriate equipments. The equipment developed by **TRL,** known as SCRIM (Sideway-force Coefficient Routine Investigation Machine) is very well-known and has been in use in several countries. The skidding resistance norms, based on SCRIM measurements and as prescribed for UK motorways, are given in **Table 4.05.**

Table 4.05 Warning Levels of Skidding Resistance Below Which Investigation Required

Site	Definition	Skid Friction Coefficient, SFC (at 50 km/h) Min. Value of Skidding Resistance
A1 (very difficult)	i) Approaches to traffic signals on roads with a speed limit greater than 64 km/h. ii) Approaches to traffic signals, pedestrian crossings and similar hazards on main urban roads.	0.55 – 0.75
A2 (difficult)	i) Approaches to major junctions on roads carrying more than 250 commercial vehicles per lane per day ii) Roundabouts and their approaches iii) Bends with radius less than 150 m on roads with a speed limit greater than 64 km/h iv) Gradients of 5% or steeper, longer than 100 m	0.45 – 0.65
B (average)	Generally straight sections of large radius curves on: i) Motorways ii) Primary Routes iii) Other roads carrying more than 250 commercial vehicles per lane per day	0.30 – 0.55
C (easy)	i) Generally straight sections of lightly trafficked roads ii) Other roads where wet accidents are unlikely to be a problem	0.30 – 0.45

4.4 RUT DEPTH

The effect of chanelised heavy vehicles movement is to form corrugations or more frequently, to create longitudinal ruts (deformations) along the wheel tracks. The formation of ruts leads to accumulation of water increasing the danger of skidding and hydro-planing. Moreover, ruts make driving dangerous, specially when vehicles change lanes.

In some developed countries, limitation of the absolute or relative depth of ruts in the transverse profiles is the design criterion, or it is used as a standard of judgment to decide whether a road needs repair.

Generally, repair is recommended based on formation of rut (depth) measured using 1.2 m long straight edge. The practice in various countries is given below.

Country	Rut Depth for Repair (mm)
Belgium	10 – 15
Canada	18 – 25
Spain	10 – 20
UK	More than 15
USSR	10 – 20
Japan	10 – 20
Netherlands	More than 20
AASHTO	10 – 20

MORTH Report of the Committee on Norms for Maintenance of roads in India, 2001, recommends a maximum 20 mm rut depth upto 1 percent on wheel path is recommended as good.

It has been reported that ruts present a serious risk of rainwater accumulation and enhance hydro-planing even when the depth is less than 10 mm. In general, it is also felt that the ruts of 5 - 6 mm depth affect high speed traffic. For rut depths more than 10 mm, the effects are fairly troublesome for fast traffic.

Jabatan Kerja Raya (JKR) PWD Malaysia developed the following criteria **Table 4.06** to assess current functional condition of expressways in terms of rutting, texture depth and roughness.

Tale 4.06 Pavement Functional Condition Criteria

Condition	Rutting (mm)	Texture Depth (mm)	Roughness	
			IRI (m/km)	BI (mm/km)
Good	2 – 3	> 0.5	< 3	< 2150
Fair	3 – 5	0.5 – 0.3	3 – 5	2150 – 3800
Poor	5 – 10	< 0.3	5 – 7	3821 – 5570
Bad	> 10	-	> 7	> 5570

4.5 RECOMMENDATION FOR PAVEMENT SURFACE CHARACTERISTICS

Based on above deliberations, the pavement surface characteristics for expressways, immediately after construction (or overlay) and at any time during the service life should be followed as under:

i) The pavement performance and structural capacity shall be measured in terms of objective measurable performance and strength indictors, i.e. roughness, rutting, cracking and deflection.

ii) The new flexible pavement surface on completion shall satisfy the follwooing standards.

a) Roughness

In each lane measured by Bump Integrator (BI)	Not more than 2000 mm/km for each lane in a km length

b) Rutting

In wheel path measured By 3 m Straight Edge	No rutting

c) Cracking — No cracking

d) Defletion — Not more than 0.5 mm characteristics deflection to be determined as per IRC:81.

iii) The new rigid pavemtn surface on completion shall satisfy the following standards:

a) Roughness

In each lane measured by Bump Integrator (BI)	Not more than 2000 mm/km for each lane in a km length

b) Cracking — No cracks other than shrinkage cracks

c) Other distresses such as Scaling, raveling, spalling at edges — Nil

The other aspect which requires attention is to ensure sufficient macro-texture for safe driving and day-night visibility. The recomended texture depth (determined by sand patching method).

a) For satisfactory skid resistance
   - 1.00 mm for bituminous surfacing.
   - 0.50 mm for concrete surfacing.

b) For Day and Night Visibility
   - General requirement is a pronounced macro texture depth of 1.0 to 1.5 mm, alongwith use of angular chippings, use of impervious materials and ‘avoidance of smooth or polished areas of surface.

CHAPTER - 5

DESIGN OF STRUCTURES

CHAPTER – 5

DESIGN OF STRUCTURES

5.1 INTRODUCTION

An expressway alignment would meet various obstacles in the form of cross roads, railways, rivers/waterways, canals, topographical features such as dips, gorges, valleys, lakes and water bodies and other physical barriers. These obstacles are generally grouped as follows:

Group – 1 : Rivers, streams, rivulets, canals and water bodies (natural or man made)

Group – 2 : Cross Roads – Major and important which cannot be closed or diverted based on service provided and community requirements.

Group – 3 : Crossing facilities required for agricultural activities, pedestrian, animals movement.

Group – 4 : Depressions and short valley between two elevated plateau i.e. the locations where the change in expressway vertical profile is not warranted.

Group – 5 : Railway crossings

Group – 6 : Interchange locations (both service and system)

All the six groups need grade separated structures and shall generally meet the followings:

i) The complete structure shall be designed to be safe against collapse and to maintain at all times an acceptable serviceability level. These shall also be designed to be durable to withstand the deteriorating effects of climate and environment.

ii) All bridges shall have independent superstructure for each direction of travel. Culverts may have single or independent structure. Width of median in structural portion shall be kept at least equal to that in the approaches.

iii) In cases where median is kept open to sky, suitable provision shall be made for retaining the earth likely to spill from median portion of immediate embankment behind abutment either by extending the abutment wall or constructing a new retaining wall. Adequate safety measures shall also be provided for errant vehicles on the median. Care shall also be taken to merge the wing wall / return wall.

iv) All bridges shall provide for carriageway width as below.

v) Utility service, if any, shall be taken on the structures.

Type of Structures

i) The concessionaire may choose any type of structure and structural system. Design and layout of structures shall be aesthetically pleasing to local environment.

ii) Bridge superstructure, substructure and foundation may be of plain or reinforced concrete, pre-stressed concrete, steel or steel-concrete composite construction.

iii) The following types of structures shall not be accepted in general,

   a) Drop in spans with halved joints (articulation).
   b) Trestle type frames for substructures.

Pipe Culverts

i) Minimum diameter of pipes of pipe culverts shall be 1200 mm.

ii) Minimum depth of earth cushion over pipe including road pavement shall not be less than 1000 mm.

Design Period

The design discharge shall be evaluated for flood of 50-year return period for calculation of waterway and design of foundations.

Width of Structures

The width of the culverts and bridges shall generally be adopted as below:

i) The pipe/slab/box bridges/culverts shall have the same overall width as of the approach road. Overall width of these structures shall be such that the outer face of railing/parapet shall be in line with the outer edge of the shoulder. The median side inner edge of the safety barrier/kerb shall be similar to approaches.

ii) All bridges shall be constructed to accommodate minimum six lanes. Width of immediate approaches (if any) shall be adjusted to provide smooth transition from approaches to bridge.

Design loading and stresses

i) The design loads shall be as per IRC:6 approaches for the width of carriageway, type and properties of stream, location, altitude, etc.

ii) In Seismic Zones IV & V, necessary precautions against dislodgement of superstructure shall be taken by provision of reaction blocks or other type of seismic arresters and increased width of pier/abutment cap. The design shall conform to the latest requirement on regional or global basis.

Analysis and design of structures

All structures and the individual components shall be analyzed and designed as per IRC:5, IRC:18, IRC:21, IRC:22, IRC:24, IRC:40, IRC:78 and IRC:83 (all parts) depending upon the proposed type of structure/individual components. The cross sectional dimensions of each component shall be provided to satisfy the requirements specified in relevant IRC codes. The design shall take into account long term durability, serviceability, constructability, construction methodology and environmental factors.

All river training and protection works shall be deigned in accordance with IRC:89.

5.2 OVERPASS VERSUS UNDERPASS: Considerations

5.2.1 *General design considerations*

The green field expressway alignments are being planned generally as elevated carriageways around 3.5 m above the adjoining ground levels. This considerations of elevated platform is based on the premises of likely number of puncture to be provided for which the vertical profile can not be configured.

For **Group-1 through 4**, the expressway needs to be carried on structures desirably fulfilling the functional requirements of expressway users.

Group-5, Railway Crossings: Generally the railways are carried at higher elevation compared to adjacent land. At such crossings i.e. where both expressways and railways are at higher level, the high level structures may warrant considerations. Underpass for the expressway (being a new facility) may be considered. The construction shall not stop the railway services and the expressway shall be provided with safety facilities. Alternatively, the expressway alignment may be shifted to a location where the railway levels are near ground. This would require several alignment planning exercises.

Group-6: Interchanges are formed by the entry and exit ramps between the expressway and cross road. At such locations, the expressway alignment dominates and the interchange ramp geometrics works as connectors/facility providers. In cases, where the topography of cross roads is considerably at higher level compared to expressway, then underpass facility for the expressway may need to be examined.

With the above considerations, the planning exercise for underpass vis-à-vis overpass shall be carried out. Based on literature survey, the followings are presented as guidelines for the designer.

At any site, the issues governing whether a road should be carried over or under usually fall into one of three groups: (1) the influence of topography predominates and, therefore, the design should be closely fitted to it; (2) the topography does not favour any one arrangement; and (3) the alignment and gradeline controls of one highway predominate and, therefore, the design should accommodate that highway's alignment instead of the site topography.

As a rule, a design that best fits the existing topography is the most pleasing and economical to construct and maintain, and this factor becomes the first consideration in design. Where topography does not govern, as is common in the case of flat topography, it may be appropriate to study secondary factors, and the following general guidelines should be examined:

- For the most part, designers are governed by the need for economy, which is obtained by designs that fit existing topography, not only along the intersecting highways but also for the whole of the area to be used for ramps and slopes. Thus, it is appropriate to consider alternatives in the interchange area as a whole to decide whether the major road should go over or under the crossroad.

- An undercrossing highway has a general advantage in that an approaching interchange may be easily seen by drivers. As a driver approaches, the structure appears ahead, making the presence of the upper-level crossroad obvious, and providing advance warning of the likely presence of interchange ramps.
- Through traffic is given aesthetic preference by a layout in which the more important road is the overpass. A wide overlook can be provided from the structure and its approaches, giving drivers a minimum feeling of restriction.
- Where turning traffic is significant, the ramp profiles are best fitted when the major road is at the lower level.
- In rolling topography or in rugged terrain, major-road overcrossings may be attainable only by a forced alignment and rolling gradeline. Where, otherwise there is no pronounced advantage to the selection of either underpass or an overpass, the design that provides the better sight distance on the Expressway should be preferred.
- Where topography control is secondary, the cost of bridges and approaches may determine whether the major roadway underpasses or overpasses the minor facility. A cost analysis that takes into account the bridge type, span length, roadway cross section, angle of skew, soil conditions, and cost of approaches will determine which of the two should be placed on structure.
- An underpass may be more advantageous where the major road can be built close to the existing ground, with continuous gradient and with no pronounced grade changes.
- Where a new highway crosses an expressway carrying a large volume of traffic, an overcrossing by the new highway causes fewer disturbances to the existing route and a detour is usually not needed.

- In some instances, the lower volume facility should be carried over if there is a pronounced economic advantage.

5.2.2 *Additional design considerations for underpass*

For each underpass, the type of structure used should be determined by the dimensional, load, foundation, and general site needs for that particular location. Only the dimensional details are reviewed herein.

Although it is an expensive element, an underpass is only one component of the total facility and should, therefore, be consistent with the design standards of the rest of the facility to the extent practical. It is desirable that the entire highway cross section, including the median, carriageway, shoulders, and clear roadside areas, be carried through the structure without change. However, several possible limitations may require some reduction in the basic carriageway cross section: structural design limitations; vertical clearance limitations; controls on grades and vertical clearance; limitations due to skewed crossings, appearance, or aesthetic dimension relations; and cost factors.

5.3 TYPES OF STRUCTURES

The structures are identified by three general types: i) Deck type; ii) Through type and iii) Partial through type. The deck type is the most commonly used. However, through and partially through types are appropriate at rail road and interchange locations.

For the overpass highway, the deck-type structure is most suitable. Although the supports may present both lateral and vertical clearance problems on the lower highway, they are out of sight for motorists on the Expressway. The deck-type bridge at the upper level has unlimited vertical clearance; lateral clearance is controlled only by location of the protective barrier. The parapet system should provide a freedom of view from the passing vehicles insofar as practical; however, capability to redirect errant vehicles should have precedence over preserving the motorist’s view. The parapet and railing should have an appearance of strength and the ability to safely redirect the design vehicle(s) under the design impact conditions. Consideration should also be given to containing and redirecting larger vehicles crossing the structure. In special cases where spans are long and the difference in elevation between the two highways is to be limited, all practical designs should be compared for suitability, including economic and aesthetic considerations.

For the underpass highway, the most desirable structure from the standpoint of vehicular operation is one that will span the entire highway cross section and provide a lateral clearance of structural supports from the edge of roadway that is consistent with good roadside design. The lateral clearance between the edge of roadway and the structural supports should be as wide and flat as practical to provide usable recovery space for errant vehicles and to prevent distraction in the motorist's peripheral field of vision. On divided highways, center supports should be used only where the median is wide enough to provide sufficient lateral clearance or narrow enough to need protective barriers. The usual lateral clearance of an underpass at piers or abutments may allow sufficient room to construct additional lanes under the structure in the future, but at a sacrifice of recovery space. In anticipation of future widening, the piers or abutment design should provide footings with sufficient cover after widening.

On **elevated facilities** with viaduct construction, cross streets are relatively undisturbed; however, on all other types of roadways, considerable savings can be achieved by terminating some of the less important cross streets. Special consideration is needed relative to the spacing and treatment of cross streets on these roadways. Major cross streets should continue across the main line without interruption or deviation. Grade separations should be of sufficient number and capacity to accommodate not only the normal cross traffic but also the traffic diverted from the other cross roads terminated by the expressway and the traffic generated by access connections to and from the expressway.

5.3.1 *Location of bridge*

The location of a bridge structure is governed by the expressway alignment, which could be one of several aspects under consideration. The bridge location should be selected to suit the particular obstacle being crossed. Stream crossings should be located with regard to initial capital cost of bridge works and the minimization of total cost including river training works and the maintenance measures necessary to reduce erosion. Highway and railroad crossings should provide for possible future upgradation works such as road widening.

5.3.2 *Structural integrity*

The design procedure for structures are extensive and of varying requirement. These have been dealt with in various literatures, text books. IRC practices and BIS code of practices. Individual design of a structure, commands specialized knowledge and expertise. Therefore, detailed design procedures have not been dealt with in this document. However, some considerations which may required to be ckecked at planning design stage are indicated here.

Design and details for new bridges should address structural integrity by considering relevant codal requirements.

The following elements of design for Bridges and other Grade Separator Structures shall be considered:

i) Loading and hydraulic considerations;
ii) Cross-section (Bridge type and Geometry);
iii) Parapets and safety barriers;
iv) Transition of protection system from road to bridge;
v) Overpasses;
vi) Underpasses;
vii) Other crossings;
viii) Clubbing of grade separation facilities;
ix) Aesthetics;
x) Durability and maintenance.

5.3.3 *Loading and hydraulic considerations*

The loading conditions for the bridges and other grade separator structures as well as the hydraulic regulation for those structures crossing waterways are of prime concern. For interchange structures, the traffic entry, exit and gore areas need considerations.

The load carrying capacity is one of the relevant elements of an expressway system considering high percentage of transport of freight vehicles.

Indian loading conditions meet all the possible present day loading. These are specified in IRC:6 and shall be used for expressways in India. For impact of safety barriers, it may require considerations from specialized literatures.

Hydraulic Regulation

The IRC codes for the design of cross-drainage structures, including type designs, have seen periodic refinements. However, the concept of flood return period (varied accordingly to the importance of the project) has not been explicitly or consistently incorporated in the IRC guidelines and this will be an important requirement in cross-drainage structures design for expressways, considering the need for performance reliability at a predetermined level of assurance. A flood return period of i) 25 years for culverts; ii) 50 years for ventages upto 30 m and iii) 100 years for wider openings (i.e. > 30 m).

5.3.4 *Bridge type*

The following types of structures are commonly used:

i) Simply supported structures with various types of superstructure elements;
ii) Cantilever construction with suspended span;
iii) Continuous structures with simple supports over piers or having fixity with piers;
iv) Other long span structures requiring suspension, cable stayed, extradoses cable system etc. which require special expertise for both design and construction.

Simply supported structures, the most common type of structure, are the easiest to construct and require relatively simple techniques for construction and installations; As there are gaps between the ends of superstructure, considerable number of expansion joints are to be installed which impair the riding quality. Expansion joints shall be kept as minimum and designed with rider comfort considerations.

Superstructures with cantilever arms should preferably have simply supported suspended spans. These spans should be between 10 and 12 m to increase rider comfort.

Continuous structures are preferred over normal ground i.e. mainly for land crossings involving other roads or railways i.e. for viaducts. Continuous structures can be constructed on waterways where foundation can be rested on rock or very hard stratum involving very low differential settlements.

5.3.5 *Cross-section (basic geometry)*

a) ***Expressway Carried on Structure***

The expressway is being conceived primarily of 2 x 3 lane carriageway configuration. The users (drivers) shall not feel a difference in driving comfort.

All the features of expressway, prior to or after the bridge shall be carried over the bridge.

On expressway bridges, by regulation pedestrians are not permitted. Hence provision of walkways/footways is not made. In case directional split structure is required, a special treatment may be necessary from drivers comfort and the provisions made similar (or close to) expressway.

b) ***Other Roads over Expressways***

The cross-section shall consider the cross road geometric features including the additional safety features such as pedestrian facilities, railings and more importantly barrier screens of sufficient height (desirably around 2 m) to prevent falling objects on expressway. The details have been dealt with in Chapter-8:Safety Barrier in this Guideline.

c) ***Other Roads under Expressway***

The cross-road under passing expressway shall have similar features of the cross-road in addition to safety arrangements for the abutments and piers of the expressway. Pedestrian facilities shall be provided with guard railing to segregate from vehicles. Vertical clearance for vehicles is of prime importance. The cross sectional features have been included elsewhere in this guideline.

5.3.6 *Transverse width of bridge*

Roads with all expressway features are the safest and give the driver a sense of freedom. Bridge railing, and parapets located close to the vehicular carriageway are potential hazards and cause drivers to shy away from them. For long bridges which are generally costly, some trade off may be necessary.

In arriving at a decision as to the width of the roadway over or under a grade separation, in determining the dimensions, location, and design of the structure as a whole, and in detailing features adjacent to the road, the designer should aim at providing a facility on which driver reaction and vehicle placement will essentially be the same as that of the approaching expressway.

5.3.7 *Safety barriers on structures*

Safety barriers consisting of longitudinal barriers (i.e. guide rail) and/or energy attenuation devices are used where errant vehicles leaving the traveled roadway would be subjected to a hazard that may cause excessive bodily harm or death to the vehicle occupants. Barriers must contain and redirect vehicles to the carriageway.

Types

The safety barriers are broadly classed into three groups, according to the rigidity of their horizontal elements: flexible, semi-rigid and rigid barrier.

Flexible barriers, in which the horizontal elements consist of cables under tension, are quite safe in the case of collisions by light vehicles, but are not capable of withstanding the impact of a heavy vehicle; the use of this type of barrier is generally not favoured in expressways.

Semi-rigid barriers, with horizontal elements made up of simple steel sections, are less prone to buckle than flexible type, but they offer otherwise limited guarantees of resistance in the case of impact by heavy vehicles; they shall thus be used only in the cases specified (See Chapter-8:Safety Barriers).

Rigid barriers, which include both those with horizontal elements of steel sections reinforced by very sturdy spacers, and those of suitably shaped reinforced concrete, should generally be used on expressway structures.

More details are presented in Safety Barrier Chapter-8 of this Guideline.

5.4 CLUBBING OF GRADE SEPARATION FACILITIES

An expressway, specially adjacent to habitations necessarily has several cross-roads within short distance intervals.

The local cross roads interrupted by the expressway require either an overpass or underpass facility. As such, this is a specific planning exercise and general recommendations on either location or spacing are not available. Provision of an overbridge and underpass is expensive. The cost generally compels merger of several cross-roads to a single crossing facility. It may be mentioned that the expressway is of elevated viaduct construction, the cross roads are relatively undisturbed.

5.4.1 *Considerations for merger of cross roads*

The merging of cross roads may be based on the following considerations (not necessarily meant to be exhaustive).

i) When the cross roads are to be carried over the expressway, considerable savings can be effected by terminating some of the less important cross roads and to club their crossing facility to a single location. The additional travel or detour may preferably be limited to 1.0 km;

ii) Determination of the number and location of cross roads to be grade separated requires a thorough analysis of traffic on the road network. Grade separation should be of sufficient number and capacity to handle adequately not only the normal cross traffic but also lack of the traffic generated by access connecting to and from the expressway and the traffic diverted to cross road from other streets terminated due to cost effectiveness;

iii) Arterial and other major channels of cross traffic should continue across the expressway without interruption or significant deviation;

iv) In so far the expressway operation is concerned there is no minimum spacing or limit to the number of grade separated structures of cross roads as this is generally governed by the local street system, planned or existing. In addition to the importance of the cross roads, other factors that may affect the number and spacing of the grade separation structure are the location of schools, recreational areas, other public facilities, school bus routes and fire fighting equipment routes;

v) The provision for pedestrians require special attention and it may be appropriate to add separate pedestrian crossings particularly where there are large number of pedestrians, such as proximity of schools, places of religious worship and factories. For the most cases, pedestrians are accommodated on the same structure which serve the vehicular traffic;

vi) Whenever the expressway is on elevated structure, the clubbing of cross traffic facilities may require additional spans to accommodate future development.

5.5 AESTHETICS

The bridge structures carrying elevated expressway and highways pose some aesthetic problems and the engineers skill is required to make them aesthetically pleasant and functionally efficient.

Aesthetic expression is an important factor which goes into determining the built form. Architectural aesthetics is the quality or sense of beauty achieved by the interplay of space, form, structure, light and shadow, proportions and materials. The external appearance of a built form is dependant on various parameters. In the case of expressway bridging structure, this encompasses the configuration, pattern and landscaping.

Some Aspects for Consideration of Aesthetics

While considering built form aesthetics, the following aspects are significant:

i) Through traffic is generally given aesthetic preference by a layout in which the more important highway is on the overpass. Drivers have minimum sense of restriction when they have wide angle view from the structure and its approaches;

ii) Where drivers take practically no notice of a structure over which they are crossing, their behaviour is the same or nearly the same as at other points on the highway. On the other hand, it is virtually impossible not to notice a structure overpassing the roadway being used. For this reason, every effort should be made to design the structure so that it fits with the surrounding in a pleasing and functional manner without drawing unnecessary or distracting attention;

iii) Interchange design is simple in flat terrain, but it may be necessary to introduce grades that may not favour vehicle operation. Interchanges in flat terrain generally are not as pleasing in appearance as those fitted to rolling terrain. When it is possible to regrade the whole of the interchange area and to landscape it properly, most of the deficiency in appearance can be overcome;

iv) Interchanges provide areas suitable for landscape development. For some conditions, the necessary two-level development is a disadvantage in regard to appearance and may block the view. On the other hand, due regard to the architectural features in the structural design and to the flattening and rounding of slopes for erosion control and landscape treatment can provide a development that will almost always prove aesthetically pleasing. Attention to such aspects may require the use of above minimum layouts rather than the use of the simplest or least costly type of structure or the development of ramps with a minimum of grades/gradients;

v) Where a city road underpasses a major roadway, the underside of the structure is a design feature that deserves special treatment for aesthetics. Because of numerous pedestrians and slower moving traffic, the underside of a structure as viewed from the cross road is especially noticeable to the local citizens. It should be as open as feasible to allow the maximum amount of light and air below. An open-type structural design is also needed to improve the sight distance, especially if there are intersections adjacent to the structure.

5.6 DURABILITY AND MAINTENANCE

Durability of the structure is one of the major aspects for a bridge intended to carry an expressway through it. Minimum cement content as specified in various **IS, IRC, ASTM and BS** reference codes may be taken care of. Suitable method of concrete mix design should be adhered to so as to promote minimum voids and high yield of the mix, keeping addition of water to a minimum to ensure smooth workability.

Maintenance

This aspect requires extensive deliberation and is addressed in a separate Volume. The current practices need to be studied and integrated with improvement measures.

Adequate maintenance planning and organisation are the requirements for the expressway structures. Planned maintenance which is defined as the work organised with forethought, control and records comprises two essential elements:

i) Planned preventive maintenance;
ii) Planned corrective maintenance.

Both of these must be organised in a proper way and should be mutually balanced and capable of simultaneous execution.

The main objectives of maintenance planning are:

i) To preserve the investment;
ii) To provide adequate level of safety to users;
iii) To provide adequate level of driving comfort to users;
iv) To ensure economy in expenditure and resources.

5.7 INSPECTION FACILITIES FOR MAINTENANCE

For preventive maintenance, visual inspection of the bridging structure is an important component. Visual inspection is effective when it is carried from close quarters often referred as hand shaking distance. For long span structure, moving inspection platforms suspended from the underside of the bridge are employed. However, most of the bridges for the expressway will be related with grade separator for the cross traffic where these suspended moving platforms are not suitable as these are likely to foul with the vertical clearances available. Moreover, as the length for these grade separating structures will generally be less than 50 m, the conventional system with access ladder and stairs may be both economical and practical.

CHAPTER - 6

TUNNELS

CHAPTER – 6

TUNNELS

6.1 EXPRESSWAY – IN TUNNELS

Expressways may require sections to be constructed in tunnels either to carry the alignment under or through a natural obstacle or to minimize the impact on the community.

The general conditions under which tunnel construction may be warranted are:

- Long, narrow mountainous terrain where a cut section may be expensive or leads to environmental consequences.
- Narrow right-of-way, where all the surface area must be retained for road purpose
- Railroad yard, airport and runways, or similar facilities
- Parks or other land uses, existing or planned
- Right-of-way acquisition costs exceed cost of tunnel construction and operation

6.2 CLASSIFICATION OF TUNNELS

The classification of tunnels, based on Traffic volume and length of tunnel is given in **Fig. 6.01** and the standards for installation of the emergency facilities according to this classification are given in tabular form.

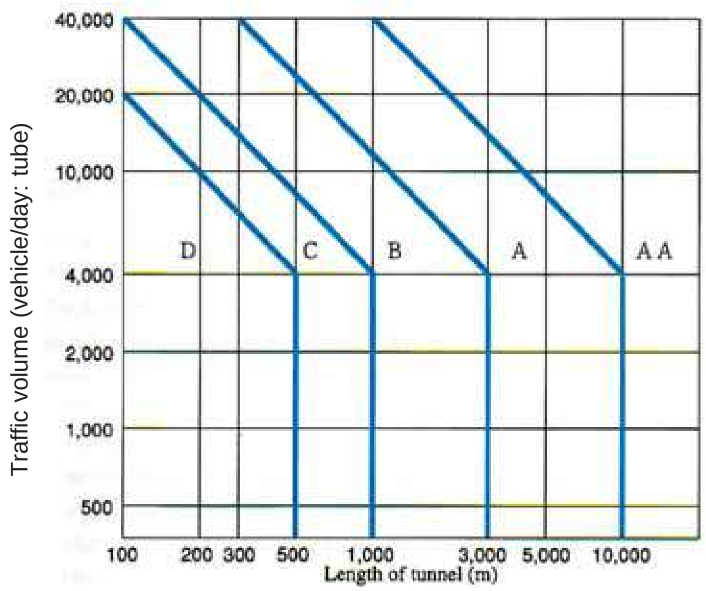


Fig. 6.01 Classification of Tunnels
(Source : NEXCO Practices)

6.3 DESIGNING A TUNNEL

The planning and design of a tunnel shall study various conditions along the road including the topography, geology, meterology, environment, locations and traffic volumes with due considerations for economical maintenance, safe and secure operation in service.

i) Horizontal alignment on safety considerations, the alignment of the tunnel shall preferably be straight and in difficult situations curves with large radius may be adopted.
ii) Vertical alignment on safety ventilation considerations, the ascending grade in tunnel shall be limited to 3 percent or less.
iii) Distance between tunnels (refer 'Tunnel Cross Sections' dealt in this chapter)

6.4 EMERGENCY FACILITIES

6.4.1 *General*

Tunnel emergency facilities are designed for mitigating damage in the event when fire or any other accident arises in the tunnel.

Emergency facilities are provided according to occurrence of tunnel disaster probabilities which are influenced by the length of the tunnel and the traffic volume. **Fig. 6.01** gives the classification of tunnels while **Table 6.01** gives installation guidelines of emergency facilities for each tunnel classification.

6.4.2 *Types of details of emergency facilities*

Emergency facilities are categorized as Information and Alarm Equipment, Fire Extinguishing Equipment, Escape and Guidance facilities and other equipment.

Information and Alarm Equipment

- Emergency Telephone: to be used exclusively for dispatching information regarding the occurrence of an accident to the highway authorities by persons involved in or discovering the accident (installed at intervals of 200 m).

- Pushbutton type information equipment: to be pressed by persons involved in or discovering an accident in order to inform the highway authorities etc. of the occurrence of the accident (installed at intervals of 50 m).

- Fire Detectors: detect fires and automatically notify their location to the highway authorities etc. (installed at interval of 25 m).

- Emergency Alarm Equipment: when something goes out of order in the tunnel, drivers running in the access zone as well as in tunnel promptly notified through this alarm equipment. The system includes entrance information boards at tunnel entrances and the in-tunnel information boards in emergency parking areas in tunnels.

Fire Extinguishing Equipment

- Fire Extinguishers: installed for initial control of small-scale fires. Portable powder-type fire extinguisher, two per set, are equipped (installed at intervals of 50 m).

- Fire Plug: hose-reel water plugs are installed for initial control of ordinary fires. Designed even for road users to be able to handle them (installed at intervals of 50 m).

- Smoke Discharge Equipment: when a fire arises, this device keeps the spread of smoke to a minimum level and also functions to force smoke to be discharged. Usually, ventilation equipment (working in reverse mode) is used as a smoke remover.

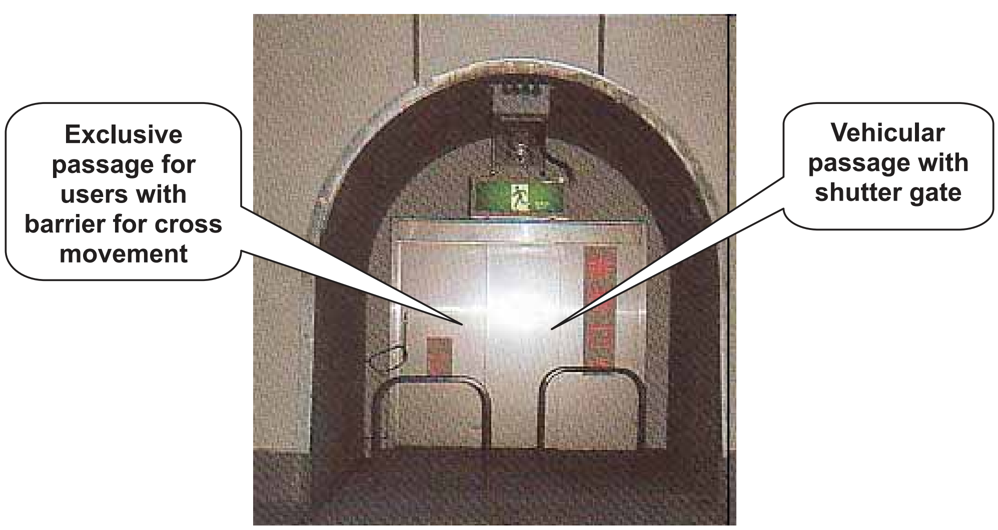
Table 6.01 Installation Standards of Emergency Facilities
(Source : NEXCO Practices)

Emergency Facilities		Classification of Tunnel	AA	A	B	C	D	Remarks
Information alarm equipment	Emergency telephone		O	O	O	O	O	Omitted in Class D tunnels less than 200 m in length
	Pushbutton type information equipment		O	O	O	O		
	Fire detector		O	O				Omitted in tunnels without ventilation system
	Emergency alarm equipment	Tunnel entrance information board	O	O	O	O	O	Can be omitted in tunnels less than 200 m in length
		In-tunnel information board	O	•				To be installed in Class A tunnels 3,000 m or more in length
Fire extinguishing	Fire extinguisher		O	O	O	O	O	
	Fire plug		O	O	•			To be installed in Class B tunnel 1,000 m or more in length
Escape and guidance equipment	Guide board	Emergency exit lamps	To be installed in tunnels with evacuation adits					
		Guide board	To be installed in tunnels with evacuation adits					
		Emergency exit direction board	To be installed in tunnels with evacuation adits					
		Guide board	O	O	O			To be installed in tunnels without evacuation adits
	Smoke discharge equipment and Escape passage		• Evacuation adits to be provided in tunnels of around 750 m or more in length. • Smoke discharge equipment to be provided in tunnels of around 1,500 m or more in length. • Evacuation tunnels provided for those Class AA tunnels and Class A tunnels of a length of 3,000 m or more which employ a two-way traffic system and a longitudinal ventilation system. • Either evacuation adits or smoke discharge to be provided for Class AA tunnels less than above length.					
Other equipment	Hydrant		O	O	•			To be provided in Class B tunnels 1,000 m or more in length. Tunnels equipped with hydrants are to be provided with water supply ports near the entrance.
	Radio communication auxiliary equipment	Coaxial cables	O	•				To be provided in Class A tunnels 3,000 m or more in length
		Entrance/exit telephone	O	O				
	Radio rebroadcasting equipment	Interrupt function provided	O	•				To be provided in Class A tunnels 3,000 m or more in length
	Cell phone connectivity		O	O	O	O	O	To be provided.
	Loudspeaker equipment		To be provided in tunnels equipped with a radio rebroadcasting equipment (with interruption function)					
	Water sprinkler system		O	•				To be provided in Class A tunnels 3,000 m or more in length, and serviced in two way traffic.
	CCTV		O	•				To be provided in Class A tunnels 3,000 m or more in length
	Lighting equipment for power failure		To be provided in tunnels 200 m or more in length					
	Emergency Power supply equipment	Independent power plant	To be provided in tunnels 500 m or more in length					
		Non-failure power supply equipment	To be provided in tunnels 200 m or more in length					

LEGEND : **O** – Mandatory ∆ **-** use with consideration

Escape and Guidance Facilities

- Guide board: in an emergency, these direct road users in the tunnel the distance/direction to an exit or evacuation route, the current position, and other information.
- Escape Passage: there are evacuation tunnels and evacuation exits for the road users in the tunnel to a safe place. The former is built for escape, separately from the main tunnel, while the latter connects the main tunnel to an evacuation tunnel which runs in parallel with it, or two main tunnels. The evacuation tunnel may have a vertical clearance of 4.5 m. The exit for evacuation shall be shutter type of light weight and inflammable materials. Adequate signage for direction of movement and easy opening mechanism shall be provided. Separate escape tunnel may be considered only for long tunnel. Providing escape tunnel below the tunnel operating surface may be considered only for the tunnel constructed by the shield tunneling method. Evacuation tunnel shall be used only by the evacuating persons and emergency vehicles. A typical example of ‘adit’ in Japan is shown below:



Typical ‘adit’ in Japan

Other Equipment

- Hydrant: supply water for fire fighting activities by fire service crew. The storage capacity of tank is designed to supply water to the following firefighting measures for at least 40 minutes simultaneously. Design allowance shall be 20 percent extra.

- three fire hydrants (with fire hose)
- two sections of sprinkler
- two hydrants

- Radio Communication Auxiliary Equipment: used for communication with the fire squads engaged in rescue or fire-fighting activities in the tunnel.
- Mobile Connectivity: Arrangements for mobile connectivity shall be provided.
- Radio Rebroadcasting Equipment: This is installed in the tunnel so that radio broadcasting can be made by the authorities to transmit information in an emergency.
- Loudspeaker Equipment: reliable information is supplied to those who have alighted from their vehicles.
- Water Sprinkler System: Sprinkle fine particles of water from water spray heads in order to prevent fire from spreading, support fire-fighting activities.
- Observation Equipment: CCTV with zoom function are installed at intervals of 200 m.
- Lighting Equipment for Power Failure: maintains minimum lighting required during power failure or a fire.
- Emergency Power Supply Equipment: used to keep emergency facilities functioning during power failure. There are two kinds, storage cell type and an independent power plant.

Fig. 6.02 presents typical Tunnel Emergency Facilities in Japan.

6.5 TUNNEL CROSS SECTIONS

There can be two types of tunnel cross sections based on construction practices:

i) Tunnels constructed by mining method;
ii) Tunnels constructed by cut-and-cover method.

Road tunnel cross sections contain “in breadth” a certain number of elements which need considerations during an optimization study of the geometric characteristics of the profile.

Two unidirectional tunnels (tubes) are spaced at minimum three times the dimension of the tunnel at carriageway level as shown in **Fig. 6.03.**

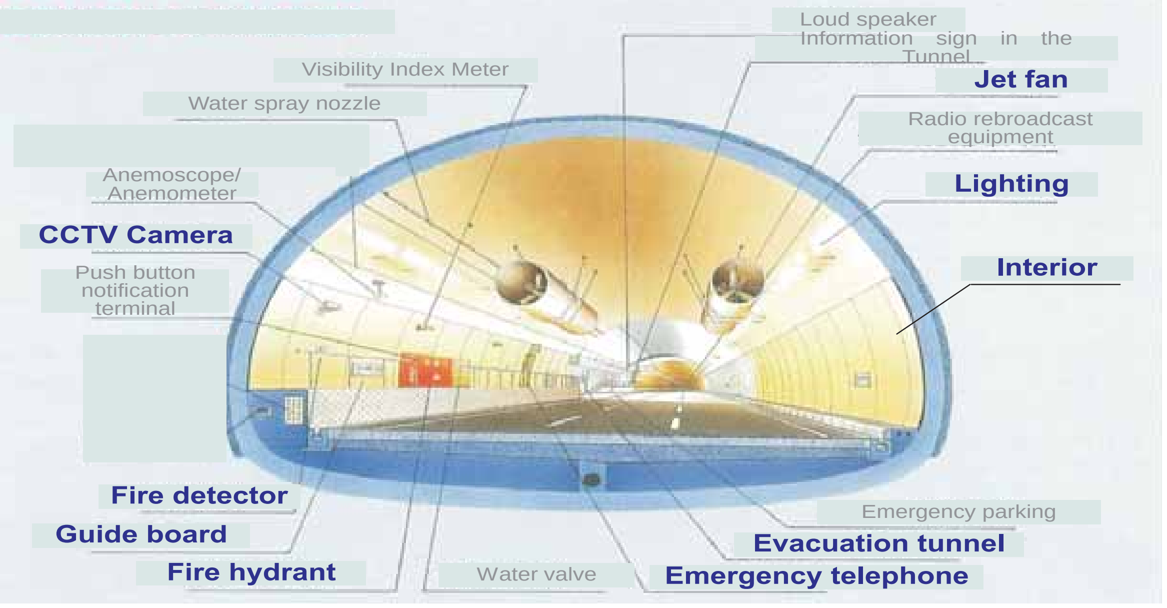
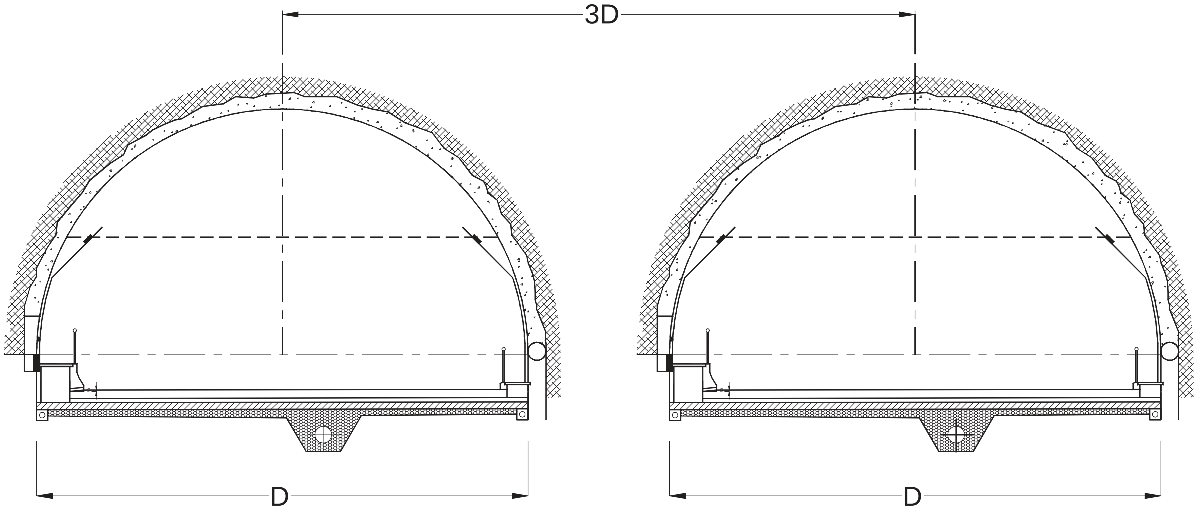


Fig. 6.02 Typical Tunnel Emergency Facilities



D = Maximum dimension at Carriageway level
3D = Minimum spacing between two Tunnels

Fig. 6.03 Typical Spacing between two Tunnels (Tubes)

From safety considerations, paved shoulder width of 3.0 m on left and 0.75 m on right, as provided on expressway sections other than tunnel shall desirably be carried through the tunnel. However, on cost considerations, for long tunnels (more than 500 m) the 3.0 m wide paved shoulder on left side may be reduced to 1.0 m with provisions for layby of 2.0 m width at 750 m interval. The escape footway shall continue adjacent to the layby. The layby is intended for maintenance vehicles as well as damaged vehicles. **Fig. 6.03** and **6.04** present typical cross-sections.

Users consider tunnel as a hazard and therefore, deserves all considerations.

The following considerations would be useful.

- A smoothly aligned tunnel approach has no major impact on the transverse positions of vehicles.
- However, a sudden narrowing of the tunnel wall has a significant impact upon the transverse position of vehicles, resulting in a shift from the tunnel wall.
- Inside tunnels, after a period of adoption to the adjacent tunnel walls, the mean transverse position of light vehicles does not significantly differ from the mean transverse position on the open road. However, inside a tunnel, transverse positions show a relatively small spread compared with the open road.
- Heavy vehicles drive closer to the left side lane compared to light vehicles.
- Inside tunnel overtaking shall be prohibited.
- The maximum permissible gradient shall be 3 percent considering emission effect and safety considerations on down grade.

The above considerations lead to the following important aspects**:**

a) **Tunnel Approach** shall have the following characteristics

- Smoothly aligned tunnel walls without any sudden narrowing to avoid a shift from the tunnel wall

- A good day/night visibility of the edge lines and inside the tunnel will eliminate hazard feeling of users. The tunnel wall lining shall be of white colour with high luminous reflectance.

b) Inside Tunnel

- The same cross section (carriageway and paved shoulder) of the expressway before and after the tunnel location shall desirably be continued as stated earlier.

Dimensions of Road Tunnels

The internal cross sectional dimensions of road tunnel shall consider the followings:

- the number and width of traffic lanes
- the lateral and vertical clearances for vehicles
- the space to be provided for ventilation ducts, escape footway, emergency layby lighting and drainage, and fire and other services

The above aspects also require consideration on method of construction i.e. by mining or cut-and-cover method.

Lateral Clearance

The most currently used forms of lateral clearances are footways (low or high), raised edges and emergency stopping layby at the same level as the carriageways.

Raised Walkways

Raised walkways are at a higher level relative to the carriageway (around 1.00 m) and therefore remain very useful for the maintenance as inspection gallery as well as escape footway. Near the escape door, steps shall be provided along the tunnel for user convenience.

Raised Edges and Safety Fences

The function of raised edges and safety fances is basically protection of the tunnel walls and vehicles from damage. They are not intended to be used by the pedestrians. Their width is normally about 0.75 m.

c) Traffic Regulations

Overhead Traffic Signage

It is necessary to provide traffic lights above each lane at the entry portal end as well as inside, to be able to inform the traffic of lane blockage due to serious accident or maintenance operations/activities.

It is useful to complement the signage system with a yellow light, above each lane, to announce an abnormal situation, which should not necessarily lead to a reduction of the number of lanes (breakdown or damaged car parked along the wall) but to warn of possible hazards ahead.

Markings

To provide markings consisting of a discontinuous line separating the traffic lanes and a continuous line separating the lateral traffic lane from the paved shoulder and emergency laybye. These lane markings shall be of such material as to provide good day/night visibility.

Over and above, the space for the service ducts, lighting, ventilation and other utility services such as communication facilities, emergency fire fighting arrangement are to be provided in considering the size of the tunnel.

Emergency utility power and waterline shall be provided encased in fireproof arrangement. For Rectangular sections (for cut and cover method), a special configuration for urban area with limitations to go deeper, the size may be decided enveloping all the requirements mentioned above.

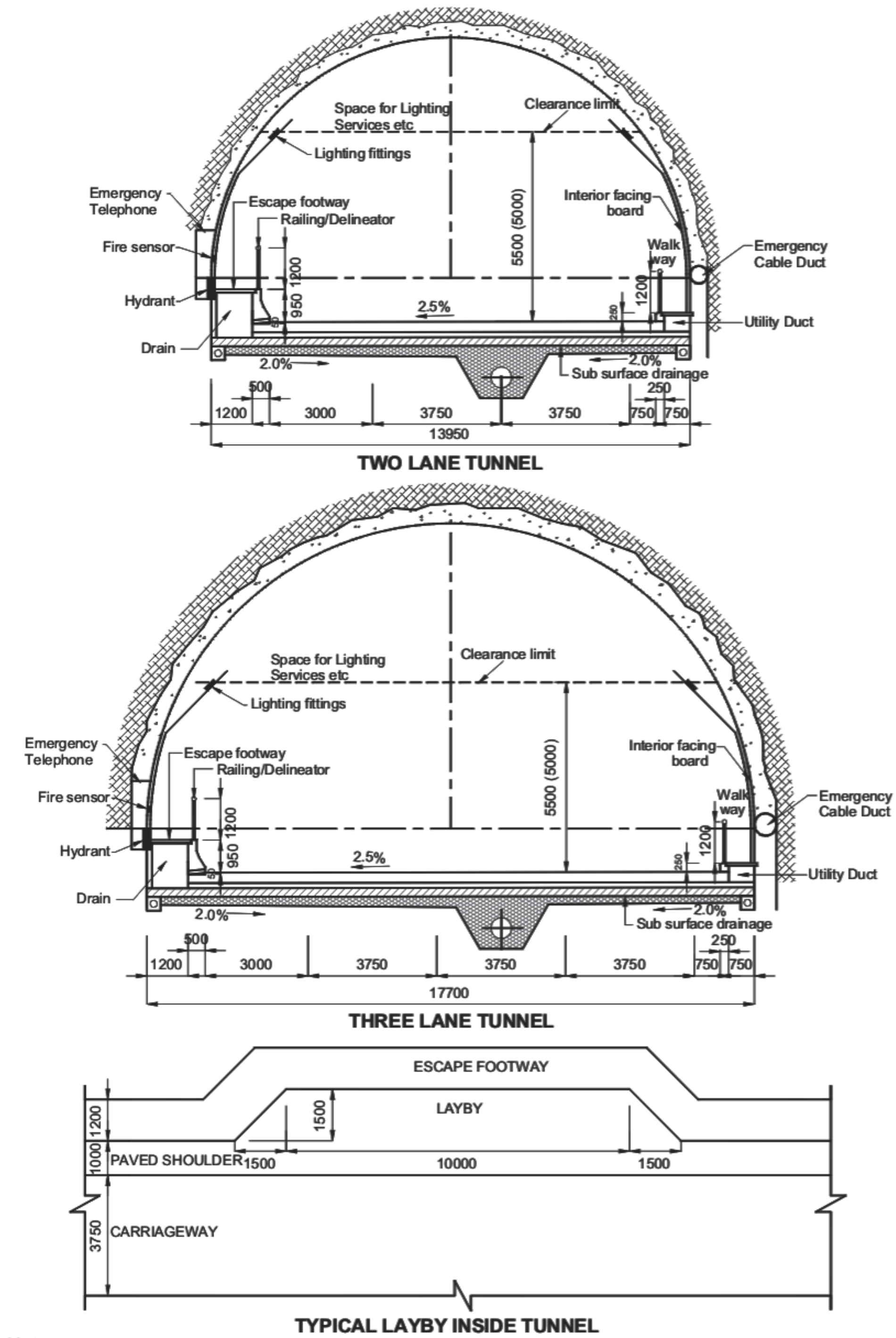
Based on the above, tunnel cross-sections are given in **Fig. 6.04** and **Fig. 6.05**.

6.6 TUNNEL WATERPROOFING AND DRAINAGE

An efficient and effective water proofing and drainage system is required in all road tunnels for removal of water from rainfall, seepage, tunnel washing operations, vehicle drippings/ spillage or fire-fighting operations. To economize on cost, the drainage of tunnels is generally achieved by gravity flow system. The roadway is generally drained by draining water on one side and provision of series of catch-basins to pick-up any run-off water. In addition, subsurface trench drains are provided under the roadway to remove any hydrostatic pressures that could damage the pavement. Good water proofing of tunnels is essential from operational consideration as also for structural protection from surrounding weathering effects. To accomplish this, various interior and exterior water proofing techniques are used to resist hydrostatic and earth pressures. This can be provided through appropriate lining.

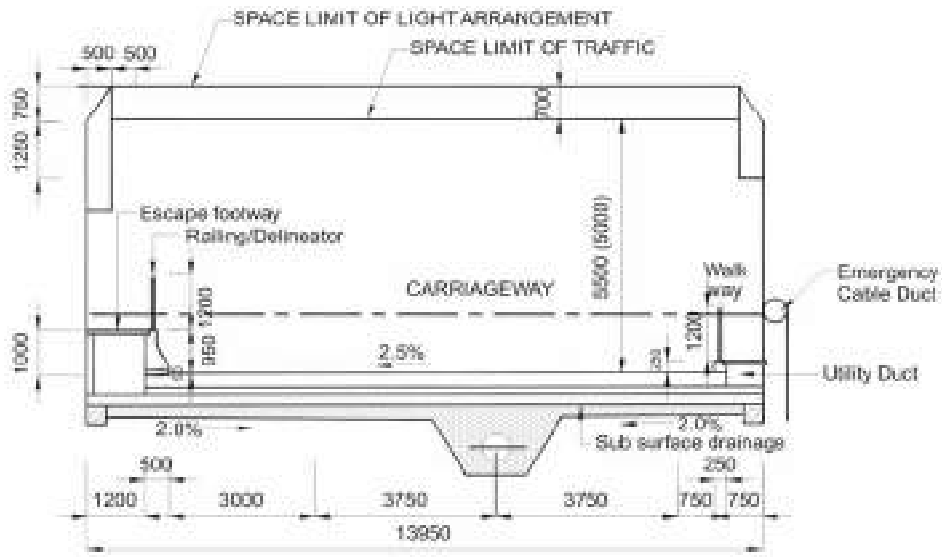
6.6.1 *Lining*

Tunnel secondary lining and interior lighting improves visibility inside the tunnel. This beautifies tunnel interior and gives comfortable vision to the drivers, improves visibility for safe driving, and lighting inside the tunnel.

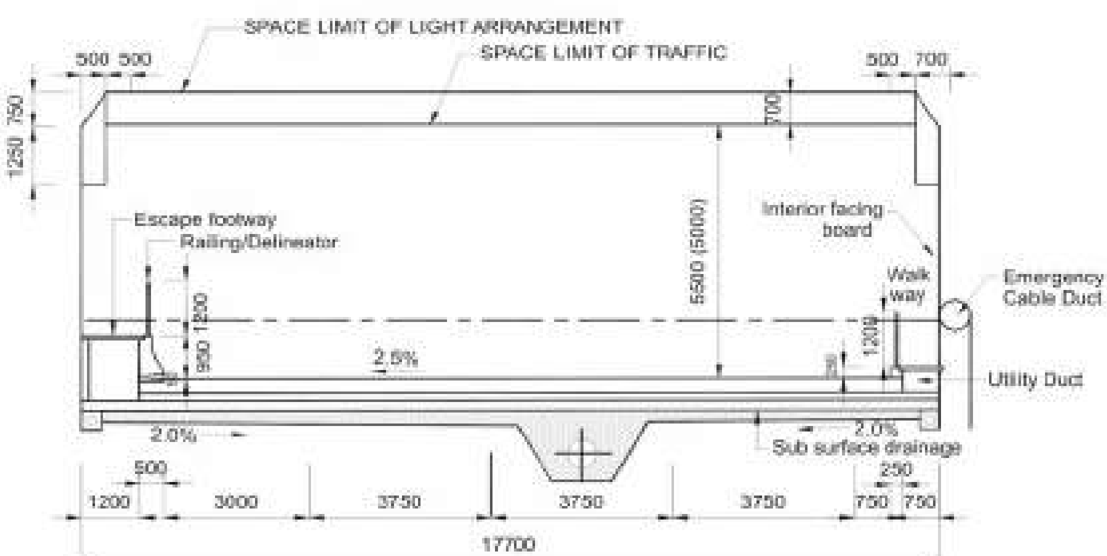


Note: All Dimensions are in millimeters

Fig. 6.04 Two and Three Lane Tunnels (Mining Method)



TWO LANE TUNNEL



THREE LANE TUNNEL

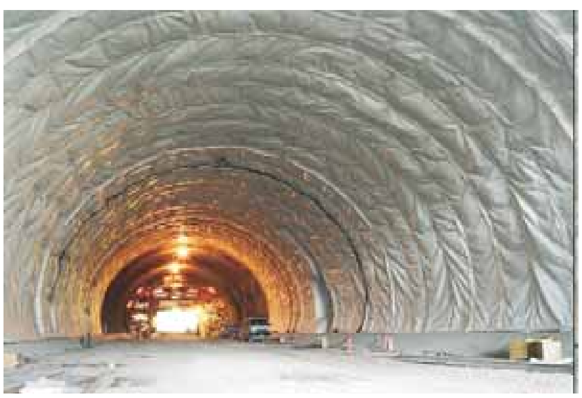
Note: All Dimensions are in millimeters

Fig. 6.05 Typical Two and Three Lane Tunnels (Cut and Cover Method)

6.6.2 *Tunnel drainage*

Typical arrangements of tunnel drainage for expressway are presented in **Fig. 6.04** and **Fig. 6.05.**

To prevent water leaks in road tunnels and cracks in lining, waterproofing comprising a waterproof sheet of at least 0.8 mm thick with synthetic textile buffer, is provided between shotcrete and lining. Cast-in-place unreinforced concrete is used as the material for lining though reinforced concrete is employed and places under high earth pressure or close to the portals. Typical arrangements are shown below:




Waterproof memberane of 0.8 mm on both sides of sprayed concrete

6.7 TUNNEL VENTILATION

The objective of ventilation in tunnels is to provide fresh air so as to reduce the effect of contaminants so that they are within permissible limits both during construction and operation of expressway facility. The ventilation during construction of facility termed as “temporary ventilation” is required to reduce air pollution due to explosives, smoke, fumes, dust and spillage caused by operating equipment and vehicles. This pollution adversely affects the health, working conditions and efficiency of crew and other supervisory staff. The ventilation during operation of highway/expressway facility termed as permanent ventilation is required to reduce the effect of contaminants such as Carbon Monoxide (CO), Nitric Oxide (NO), Nitrogen Dioxide (NO_2), Lead Sulphur Dioxide (SO_2) and other obnoxious gases and substances caused by vehicle emissions together with soots and spillage during operation. These contaminants while present beyond allowable limits adversely affect health (headache, faintness and unconsciousness), visual performance of motorists, efficiency and safety of users.

6.7.1 *Vehicle emissions, exhaust emissions and emission rates*

Usually, CO (which adversely affects the human body) and soot (which reduces visibility) are the prime considerations for tunnel ventilation. NOx, which is less harmful and have lower concentration in exhaust than CO, will also be removed with ventilation of CO. Sometimes the soot concentration triggers for ventilation.

The majority of the soot is discharged from commercial vehicles. The design concentration of soot is expressed by means of the visibility index (the larger the number, the cleaner the air). It is also noted that its values are fixed corresponding to combinations of design speeds and traffic volumes.

Commercial and passenger vehicles discharge CO equally and the design concentration does not depend on design speed or traffic volume. **Table 6.02** presents typical values for Design Concentration Soot and CO, which triggers for ventilation provisions.

Table 6.02 Design Concentration of Soot and CO
(Source : NEXCO Practice)

Design Speed of Road	For Soot (visibility)		For CO Gas
	When reached estimated hourly traffic volume	When reached potential traffic capacity	
100 km/h	τ = 50%	τ = 50%	K = 100 ppm
80 km/h	τ = 50%	τ = 45%	
60 km/h	τ = 40%	τ = 40%	

6.7.2 *Tunnel ventilation systems*

The objective of ventilation is to dilute or remove the harmful substances in exhaust gas from vehicles, in order to prevent the harmful substances from producing biologically adverse effects on users and maintenance personnel and to maintain good visibility in the tunnel.

There are two ventilation systems: the natural ventilation system that depends only on traffic ventilation power, and the mechanical ventilation system using machines. The mechanical ventilation system is divided into four basic systems according to the direction of ventilation wind relative to the axial direction of the tunnel: the longitudinal flow system, the transverse flow system, the semi-transverse flow system, and combinations of these.

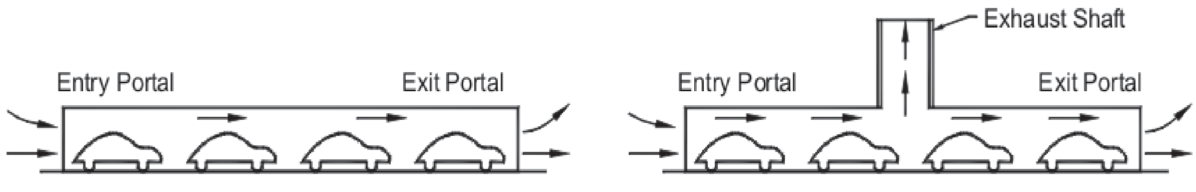
- Mechanical Ventilation System
  - Longitudinal ventilation system
    - Jet fan type
    - Saccardo type
    - Intake/exhaust shafts type
    - Concentrated exhaust type
    - Electrostatic precipitator type
  - Semi-transverse ventilation system
    - Air supply type
    - Exhaust type
  - Transverse ventiltion system
  - Combined ventilation system

Longitudinal System: using the space in the roadway as a duct for ventilation, the system ventilates through traffic ventilation power and mechanical air supply power.

Transverse System: exclusive ducts for the supply and discharge of air are provided separate from roadway space. Ventilation is carried out by sending fresh air across the roadway space from the air supply duct to the exhaust duct.

Natural Ventilation: naturally ventilated tunnels rely primarily on meteorological conditions and the piston effect of the moving traffic to maintain satisfactory environmental conditions within the tunnel. The prime meteorological condition affecting the tunnel is the pressure differential between the two tunnel portals created by differences in elevation, ambient temperatures, or wind. *Unfortunately*, none of these factors can be relied on for consistent results. A sudden change in wind direction or velocity can rapidly negate all of these natural effects including, to some extent, the piston effect. The total of all pressures must be of sufficient magnitude to overcome the tunnel resistance, which is influenced by tunnel longitudinal coefficient of friction, hydraulic diameter, and air density. None of the natural effects defined above can be considered when addressing emergency ventilation.

Air flow through a naturally ventilated tunnel can be portal to portal (**Fig. 6.06A(i)**) or portal to shaft (**Fig. 6.06A(ii)**). The portal-to-portal flow-type system functions with unidirectional traffic, which produces a consistent, positive air flow.



(i) PORTAL TO PORTAL (ii) WITH SHAFT AT CENTER

Fig. 6.06A Natural Ventilation Systems
(Mechanical Ventilation)

The naturally ventilated tunnel with an intermediate shaft (**Fig. 6.06A (ii)**) is best suited for bidirectional traffic. However, the air flow through such a shafted tunnel is also at the mercy of the elements. The added benefit of the “stack effect” of the shaft depends on air temperature differentials, rock temperatures, wind direction and velocity, and shaft height.

Because of the numerous uncertainties outlined above, the reliance on natural ventilation for tunnels more than 240 m (PIARC-1999) long should be thoroughly evaluated, specifically the effect of adverse meteorological and operating conditions.

Longitudinal Ventilation. A longitudinal ventilation system is a system where the air is introduced to or removed from the tunnel roadway at a limited number of points, thus creating a longitudinal air flow within the roadway (**Fig. 6.06B (i)**). The injection-type longitudinal system developed for (**Fig. 6.06B (ii)**) railroad tunnels; has also found application in highway tunnels. Air is injected into the tunnel roadway at one end of the tunnel, where it mixes with the air brought in by the piston effect of the incoming traffic. This system is most effective in a tunnel with unidirectional traffic. The air velocity within the roadway is uniform throughout the tunnel, and the concentration of contaminants increases from ambient at the entering portal to maximum at the exiting portal. Adverse external atmospheric conditions can reduce the effectiveness of this system. The concentration of contaminants increases as the air flow decreases or the tunnel length increases.

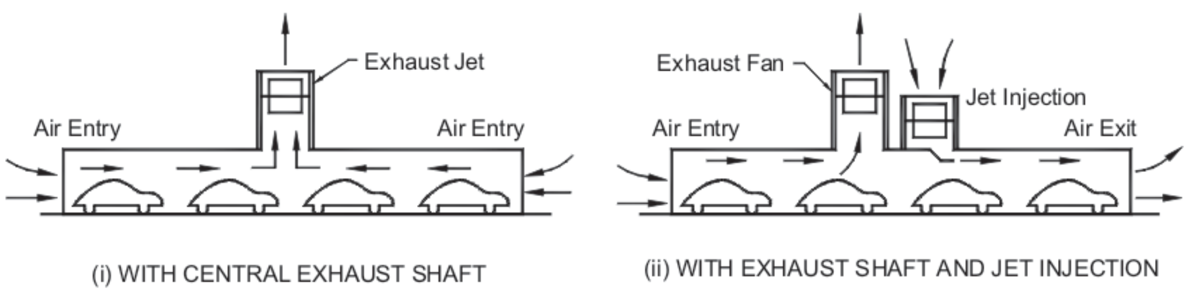


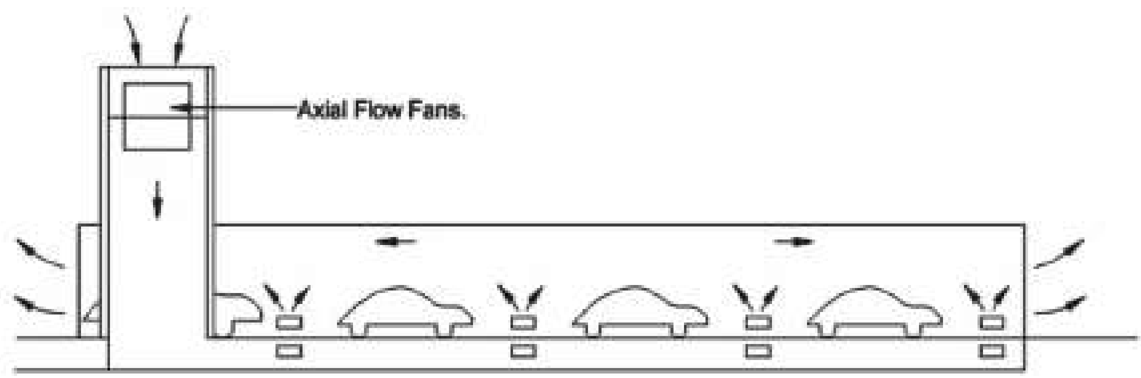
Fig. 6.06B Longitudinal Ventilation System
(Mechnical Ventilation)

The longitudinal system with a shaft (**Fig. 6.06B(i)**) is similar to the naturally ventilated system with a shaft except that it provides a positive stack effect (fan induced). With bidirectional traffic, peak contaminant concentration occurs near the shaft location. This system is generally not used for unidirectional tunnels, because the contaminant levels become unbalanced and excessive amounts of air will therefore be required for ventilation.

An alternative longitudinal system uses two shafts located near the center of the tunnel, one for exhausting and one for supplying, **Fig. 6.06B(ii)**. This configuration will provide a reduction of contaminant concentration in the second half, because a portion of the tunnel air flow is exchanged with ambient air at the shaft. Adverse wind conditions can cause a reduction of air flow, a rise in contaminant concentration in the second half of the tunnel, and "short circuiting" of the fan air flows.

Semi-transverse Ventilation using Axial-flow Fans

As a general rule, semi-transverse ventilation systems using Axial-flow-fans, introduce sufficient fresh air into the tunnel to dilute the emitted pollutant loads. Thus diluted, the tunnel air exits through both portals. A controlled flow of fresh air is introduced continuously into a separate air duct from which the requisite partial volumes are forced into the roadway tunnel via so-called secondary ducts. (**Fig. 6.07A**)



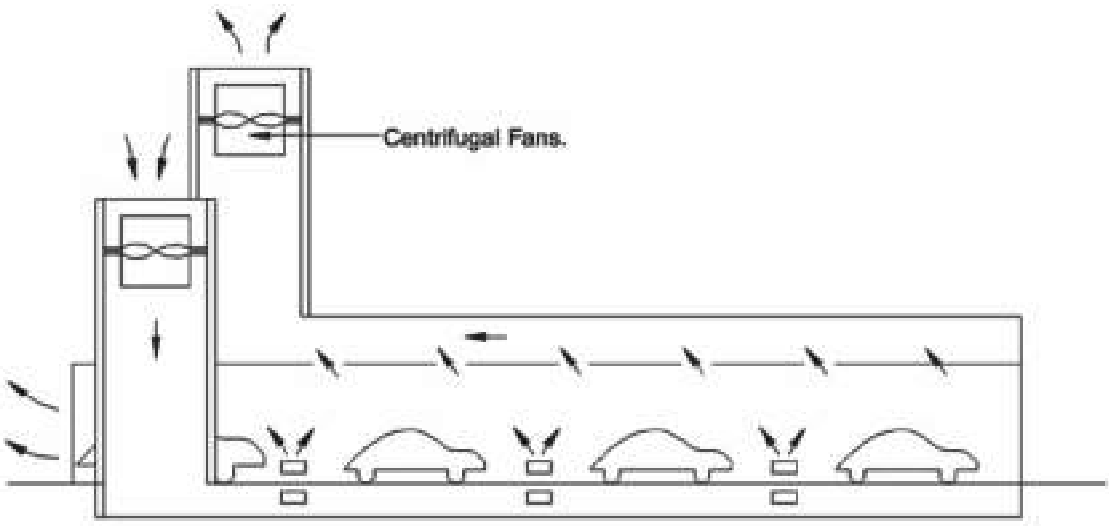
WITH SUPPLY DUCT
Fig. 6.07A Semi Transverse Ventilation System

To ensure that the direction of flow can be controlled in the case of a fire, reversible axial-flow fan systems are employed. Under normal conditions, these units operate as supply fans. If necessary, during fire, these axial fans can be switched to exhaust mode, extracting air via the ducts.

Compared with longitudinal ventilation using jet fans, such systems offer the advantage of producing lower longitudinal airflow velocities since the air can exit through both portals. In the semi transverse system, the air supply to the tunnel is not affected by adverse meteorological conditions or opposing traffic. With this advantage, the semi transverse ventilation system can be used for long tunnels and its successful use has been reported for tunnels upto **2 km** in length.

Fully Transverse Ventilation using Centrifugal Fans

With fully transverse ventilation, fresh air is supplied to each point of the roadway in exactly the extracted quantity. Fresh air is introduced into distribution ducts extending along each tube's length and blown into the tunnel through air-supply openings (**Fig. 6.07B**).



WITH SUPPLY AND EXHAUST DUCT
Fig. 6.07B Transverse Ventilation System

The exhaust air carrying pollutant loads is continuously extracted over the length of the tunnel via exhaust vents. The individual exhaust air flows are combined in plenums running parallel to the tunnel, then discharged via exhaust stacks.

In one variant of the fully transverse ventilation method, referred to as “reduced transverse ventilation”, the rated exhaust air flows are less than the supply-air volume. The excess of air leaves the tunnel via the portals.

Forced Ventilation

In recent years, a clear trend towards longitudinal ventilation has emerged for medium tunnel lengths of around 3 km.

The success of this ventilation method is partly attributable to the lower capital outlay, operating overhead and maintenance cost involved.

Jet fans arranged individually or in groups (**Fig. 6.08**) at specified distances along the tunnel’s to impart energy pulses to the air column, thus including airflow movement. With this design, care must be taken in determining fan spacing along the tunnel axis to ensure good intermixing of the jet discharge and the remaining tunnel airflow, as well as an optimum flow distribution across the tunnel.

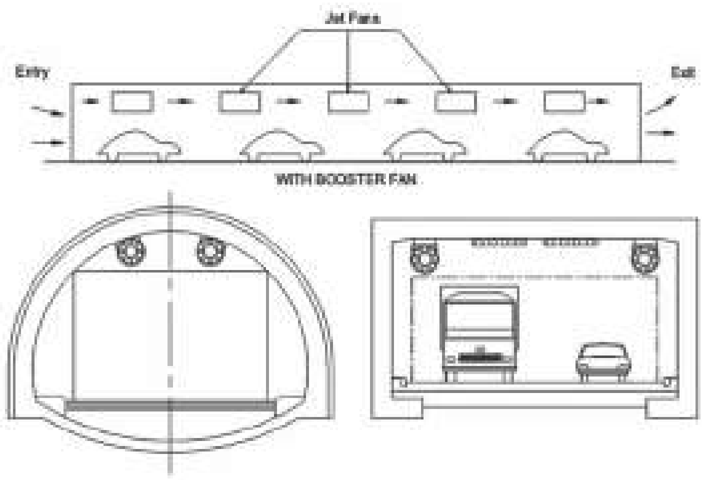


Fig. 6.08 Forced Ventilation Systems with Jet Fans

The length of jet fan ventilated tunnels is limited by the maximum longitudinal air velocity, since the speed of the airflow must not exceed accepted safety and comfort levels. For the sake of completeness, the longitudinal air management method based on Saccardo nozzles should likewise be mentioned here.

Saccardo nozzles (**Fig. 6.09A**) are fed by axial-flow fans mounted at the tunnel portal. The nozzle injects the fan intake into the roadway tube at a 15 to 20-degree angle to the tunnel axis and air speeds between 25 and 30 m/sec via a circular gap in the upper portal area.

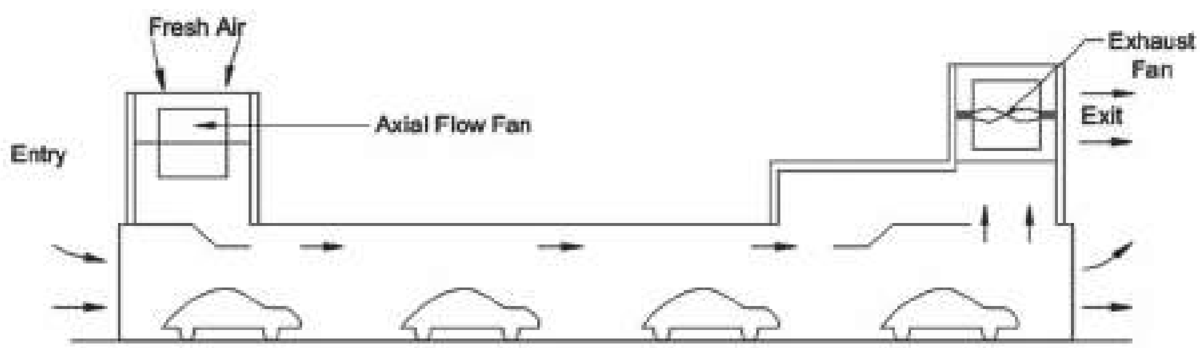


Fig. 6.09A Longitudinal Ventilation Using Exhaust Air Fans
(Shafts at Entry and Exit)

Another interesting recent development in longitudinal road ventilation is the use of exhaust air fans mounted in caverns and operating via central ducting (**Fig. 6.09B**). In this system, fresh air is drawn in from both portals by large axial-flow fans arranged in caverns near the middle of the tunnel. Exhaust air is extracted and discharged via an outlet shaft. A benefit of this system lies in the fact that on exhaust, air exits from the portals and that the length of the ventilation air-way is virtually reduced by half, with the advantageous reduction on tunnel CO and improved visibility levels. It is often combined with additional jet fans inside the tunnel which are activated in the case of a fire to keep escape routes clear of smoke.

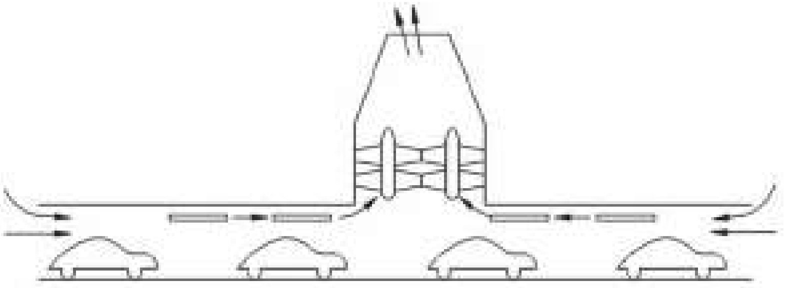


Fig. 6.09B Longitudinal Ventilation Using Exhaust Air Fans
(Shaft at Mid Way Between Entry and Exit)

Irrespective of the foregoing, the other ventilation techniques, viz.

- reduced semi-transverse ventilation
- semi-transverse ventilation
- fully transverse ventilation

each have their own specific advantages over all-longitudinal ventilation in terms of fire safety, ride comfort and environmental compatibility and will therefore be adopted or specified on a case-by-case basis. Needless to say, combinations between longitudinal and semi-transverse ventilation may be found effective both under normal operating conditions and in the event of a fire.

Summary Selection Criteria for Ventilation Systems

The choice of a tunnel ventilation system is essentially determined by the following factors:

- fresh-air demand as a function of CO, NOx and opacity-inducting emissions, taking into account legal requirements and the anticipated trend in emission levels and control thresholds over the next few years;
- reliability of the system;
- safety in case of fire;
- energy consumption;
- investment cost;
- maintenance;
- service friendliness

For short (around 240 m) tunnels, either natural or traffic-induced ventilation may prove adequate. Longer tunnels will require one of the three basic types of mechanical ventilation. Longitudinal ventilation is the simplest form. Fresh air enters one portal and exhaust air flows out at the other portal. Booster fans may be installed at points along the tunnel length to increase the air flow. Practical limitations to this system include the maximum air speed that can be tolerated by maintenance workers and the increase in fire hazards. Transverse ventilation is the most common mechanical system for long tunnels. Two separate air ducts with fan systems are required, one forcing fresh air into the tunnel and one drawing exhaust air out. Both ducts are connected to the traffic space at regular intervals to minimize the longitudinal flow of contaminated air. Semi-transverse ventilation requires a single fresh air duct connected to the traffic space at regular intervals. Exhaust air is forced out at the portals or drawn from the traffic space at intermediate shafts.

Ventilation requirements for long tunnels should be thoroughly evaluated at an early point in the design phase. The energy requirement for mechanical ventilation varies in direct proportion to the fourth power of tunnel length and in inverse proportion to the square of the duct area.

6.8 FIRE RESISTANCE OF TUNNEL STRUCTURE AND APPURTENANCES

6.8.1 *Tunnel structures*

The objectives for fire resistance of tunnel structures are:

- To make evacuation or protection of tunnel users possible.
- To make rescue and firefighting operations possible and ensure their safety.
- To limit damage to tunnel structure and equipment, and to surrounding buildings.

It is generally acceptable that repairs are necessary after a large fire, but not that whole tunnel is lost.

In the tunnel with two lanes constructed by the New Austrian Tunnelling Method (NATM), unreinforced concrete lining with a thickness of **300 mm** was normally installed inside the tunnel. In the tunnel constructed by the conventional tunneling method, unreinforced concrete lining with a thickness of more than **450 mm** was used as the main structure of the tunnel. For these tunnels, no special fire resistant protection has been provided, because a local collapse of concrete lining caused by a fire will generally have much smaller consequences on safety and property of the rock tunnels and it will be repaired more easily and in a short time.

6.8.2 *Tunnel appurtenances*

6.8.2.1 Evacuation Exit Doors are made of light inflammable material and user friendly system for opening. The doors are provided also to arrest spreading of fire.

6.8.2.2 Jet Fans provided in Japan are not designed as fireproof. In Europe, the Jet fans are designed to withstand fire for two hours at **400^0 C.**

6.9 PORTALS

Functionally, the portal is regarded as a sort of retaining wall to protect at entrance and exit. Its purpose is to reduce the luminance of facing walls. These days, importance is attached to harmony with the surrounding environment, and portals are designed and constructed to convey drivers about the presence of a tunnel.

The commonly-employed method of building portals avoids making cuts near the entrance as much as possible, to limit/protect loose soil/rocks. In some cases, entrance have to be built in unfavorable positions which are threatened by the possibility of landslide or slope failure, are under uneven earth pressure, or poor ground bearing capacity. Dealing with these construction problems is another important task.

Wing Wall Type

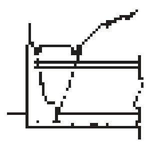
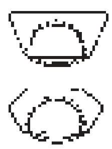
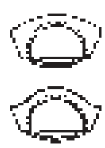
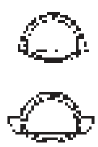
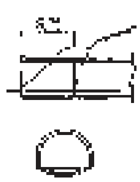
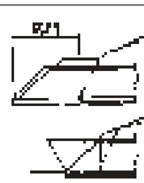
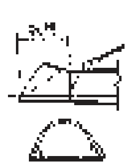
Arch Shape – Wing Wall

Protruded Type

Protruded Type (Split Bamboo Type)

Moreover, on aesthetic considerations, a tunnel portal becomes a locational feature also. The users may refer the portal shape to locate the tunnel. **Table 6.03** presents Typical Tunnel Portals used in Japan combining functional as well as visual aesthetics for different ground conditions.

Table 6.03 Typical Tunnel Portal

Item	Type	Shape	Applicability to Ground Condition	Workability	Landscape
Gravity Type	Gravity/Semi-gravity type		• When land feature is rather steep or structure like earth retaining wall is required. • When frequent rock fall is expected. • Back drainage is easily dealt with.	• As poor ground increases the amount of cut, sufficient protection to stabilize back cut slope is necessary.	• Wider area of wall necessitates some means of reducing brightness (for example, chipping of wall). • Looks substantial but drivers tend to have an oppressive feeling
Upright Wall Type	Wing Type		• When cut works on both sides are required • When fully subjected to earth pressure • Snow protection works should be added wh ere heavy snowfall is expected.	As above • Should be jointed to tunnel	As above
	Arch Wing Type		• When land feature is relatively gentle. • When cut works on both sides are relatively minor.	• In some cases, artificial tube is built (particularly in the arch position) • Some protection earth blanket is necessary.	• Attention should be paid so as to avoid curves in the arch portion causing a sense of in harmony.
Protruded Type	Half Protruded Type (Parapet Type)		• When a ridge -like land feature or when no structure exists on both sides. • Applicable even in snowy districts.	• Several-meter long artificial tube is required and tiny retaining walls may be built against back fill. • Rational structure as portal, though.	• As wall area of portal concrete is reduced, no sense of visual in harmony is caused.
	Protruded Type		• When counterweight embankment is set. • Ground condition of portal area is poor. • Applicable even in snowy districts. • When reshaping such as cutting the land feature around the portal is somehow possible.	• Most economical when land feature and nature of ground are stable, but if ground is geologically poor and needs counterweight embankment artificial tube should be built in advance.	As above
	Spilt bamboo (cut) Type		• When area adjacent to portal is topographically gentle. • In the case of inverted split bamboo type, full consideration should be given to bearing capacity in view of the position of the center of gravity.	• Form, reinforcing bar arrangement and th e like are time -consuming and troublesome as well as being costly.	• Harmony with the entrance is attained by beautification of the surrounded area.
	Bell-mouse type		• Applicable in places that are topographically and geologically favorable and are op en around the portal. • Snow is blown in and cornices tend to be formed in snowy districts	As above	• Less influence is induced on the running of vehicles. • Matches well with land feature adjacent to entrance.

CHAPTER - 7

DRAINAGE AND EROSION PROTECTION

CHAPTER – 7

DRAINAGE AND EROSION PROTECTION

7.1 INTRODUCTION

Water is always present in soil and granular pavement materials in some form, but the forms that concern the pavement design are free water, capillary water, bound moisture, and water vapour.

Free water in the base, subbase and subgrade is of particular concern because it can decrease the pavement strength in the following ways:

i) Reducing the apparent cohesion by lowering the capillary forces;
ii) Reducing the friction by reducing the effective mass of the materials below the water table;
iii) For quickly applied loads, possibly reducing the strength by the development of increased and/or oscillating pore pressures.

Since water is the prime factor causing failure of pavements, attempts should be made to keep the water away from the road-bed. This can be achieved by undertaking the following measures:

i) The surface run-off over the pavement surface and the shoulders should be drained away as quickly as possible, preventing ingress of the water into the pavement layers;
ii) Precipitation over the open land adjoining the highway should be led away from the highway through natural drainage channels or artificial drains. Suitable cross-drainage structure should be provided to lead the natural drainage channel across the highway embankment;
iii) Consideration should be given to deal with the precipitation and surface flow on the embankment and cut slopes to minimise/eliminate erosion;
iv) Seepage and sub-surface water is detrimental to the stability of cut slopes and bearing power of subgrades. Similarly, it can be of great importance in preventing frost action. An effective system of sub-surface drainage is a guarantee against such failures;

v) Alignment of the road can have a vital bearing on the problem of drainage. So in case of new road, surface drainage should be one of the criteria in fixing proper alignment;

vi) Landslide-prone zones deserve special investigations for improving uphill drainage;

vii) Poor embankment soils can be made to perform satisfactorily with adequate drainage provision;

viii) Water-logged and flood-prone areas require special consideration for improving the overall drainage pattern of the area. An alternative alignment may also be explored to avoid complex and expensive drainage arrangements through such areas.

Highway drainage design should incorporate safety, appearance, control of pollutant, and economy in maintenance. The interrelationship between the drainage channel and the side slopes is important for safety aspects of vehicles leaving the roadway.

Drainage Channels include:

i) Road side channels in cut sections to remove water from the roadway;

ii) Toe-of-slope channels to convey the water from any cut section and from adjacent slopes to natural water courses;

iii) Intercepting channels placed uphill at the back of the top of cut slopes to intercept surface waters;

iv) Chutes to carry collected water down steep cut or fill slopes.

In rural and urban situation, the shape and size may be changed to meet the specific requirements.

Road Side Channels

For an efficient road channel from hydraulics consideration, the open channel ditches with steep slopes are generally used.

Considering the safety of errant vehicles sides slope of 1V:4H or flatter and a 3.0 m shoulder with rounded edge are generally considered. Side slope of 1V:5H to 1V:6H are recommended to reduce snow drifts. The depth and hydraulic gradient of channel should be sufficient to remove the water without saturation of subgrade. The channel grade does not have to follow the road profile. Not only can the depth and breadth of the channel be varied to meet different amounts of runoff, slopes of channel, types of lining, and distances between discharge points, but also the lateral distance between the channel and the edge of the carriageway can also be varied.

The cross-sections are presented in **Fig. 7.01** and **Fig. 7.02**.

7.2 ROAD SIDE AND MEDIAN DRAINS

7.2.1 *Road side drains - rural expressways*

Roadside drainage channels should be economical to construct and require a minimum of maintenance, in addition to adequately performing their primary function as conveyance facilities.

These channels, depending on topography and terrain will discharge into either natural streams or open area. The practice suggests on:

a) Preservation of natural valleys, ravines, stream channels, flood plains and wetlands to the extent possible;
b) Minimizing the provision of storm sewers where other alternatives such as open channels are feasible.

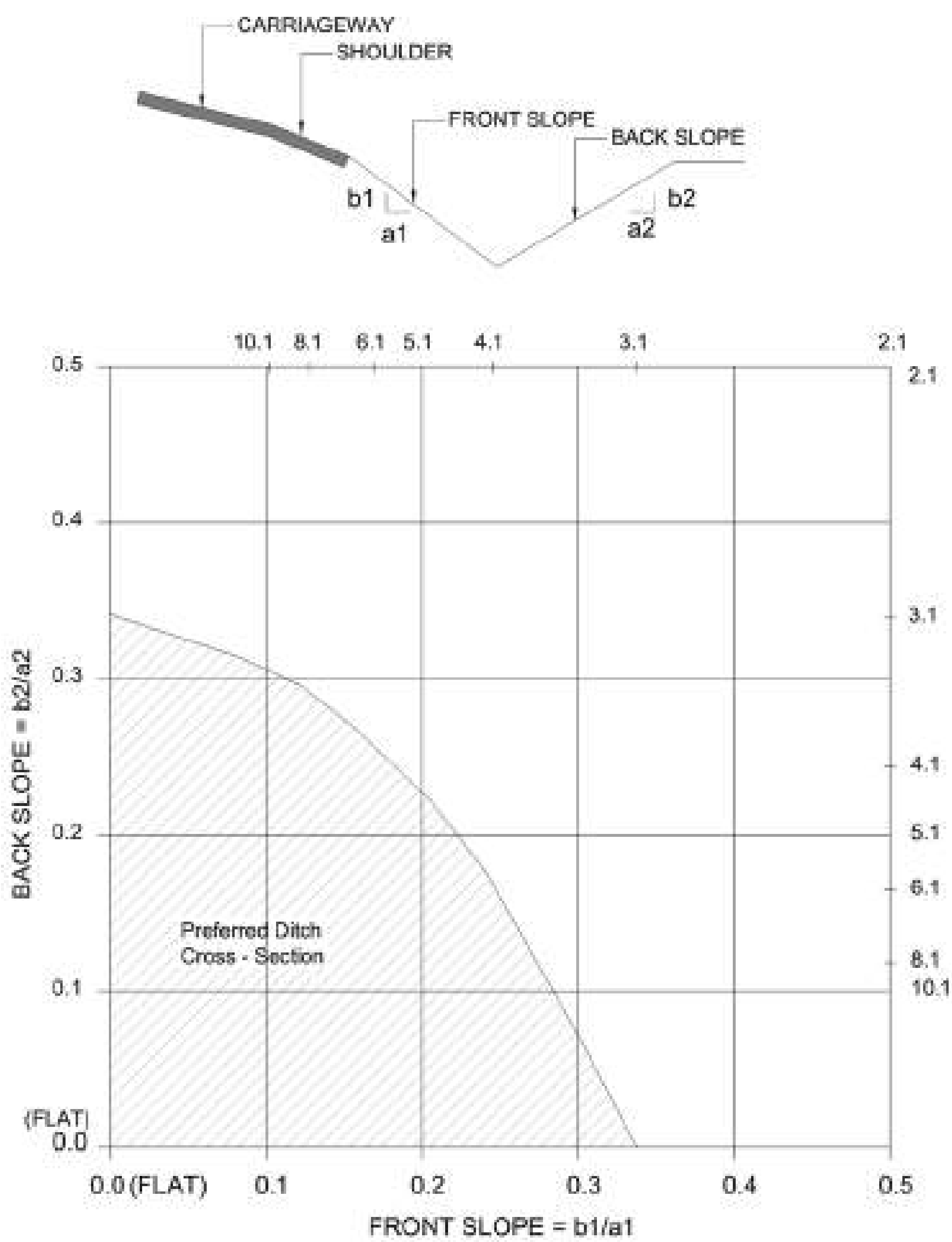
7.2.2 *Kerbs and channels (for wayside amenities and other areas)*

Expressways in general do not require the provision of kerb and channel except for drainage at valley curve locations, provision of raised medians on emergency median openings, at gore area locations, on exit ramps, on median terminal areas at the commencement of toll plaza, on raised footway at the periphery of toll plaza etc.

In such situations, on road safety considerations, mountable type barriers are desirable. The typical details are presented in **Figs. 7.03A, 7.03B and 7.03C**.

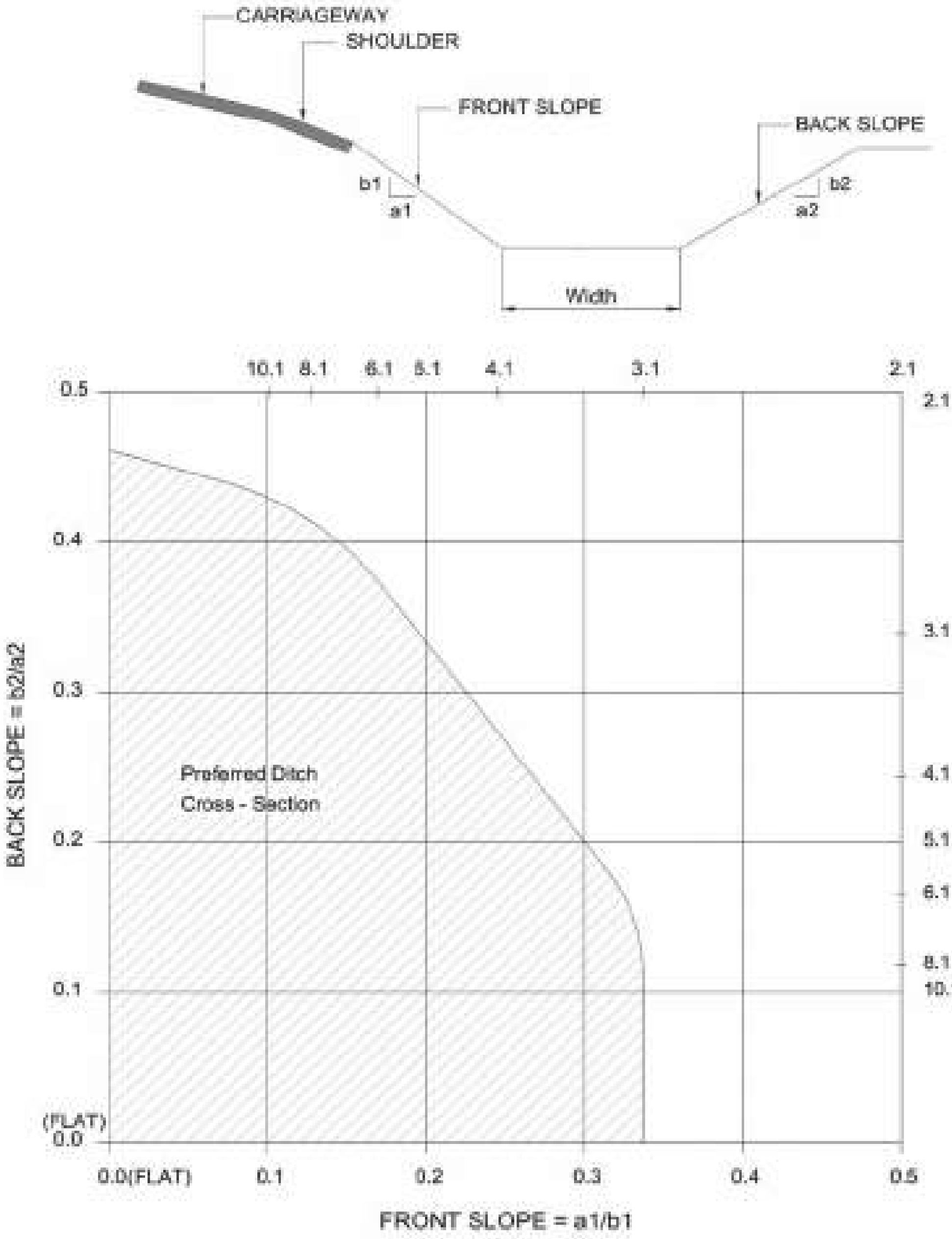
Kerbs with or without channels along entrance roadways and around parking lots in rest areas provide excellent traffic delineation. The raised walkway and footpath provides visual and aesthetic benefits.

Many sources are available that recommend the types of kerb requirement on parking area lot dimensions, types of drainage system etc. Site specific appropriate details may be developed.



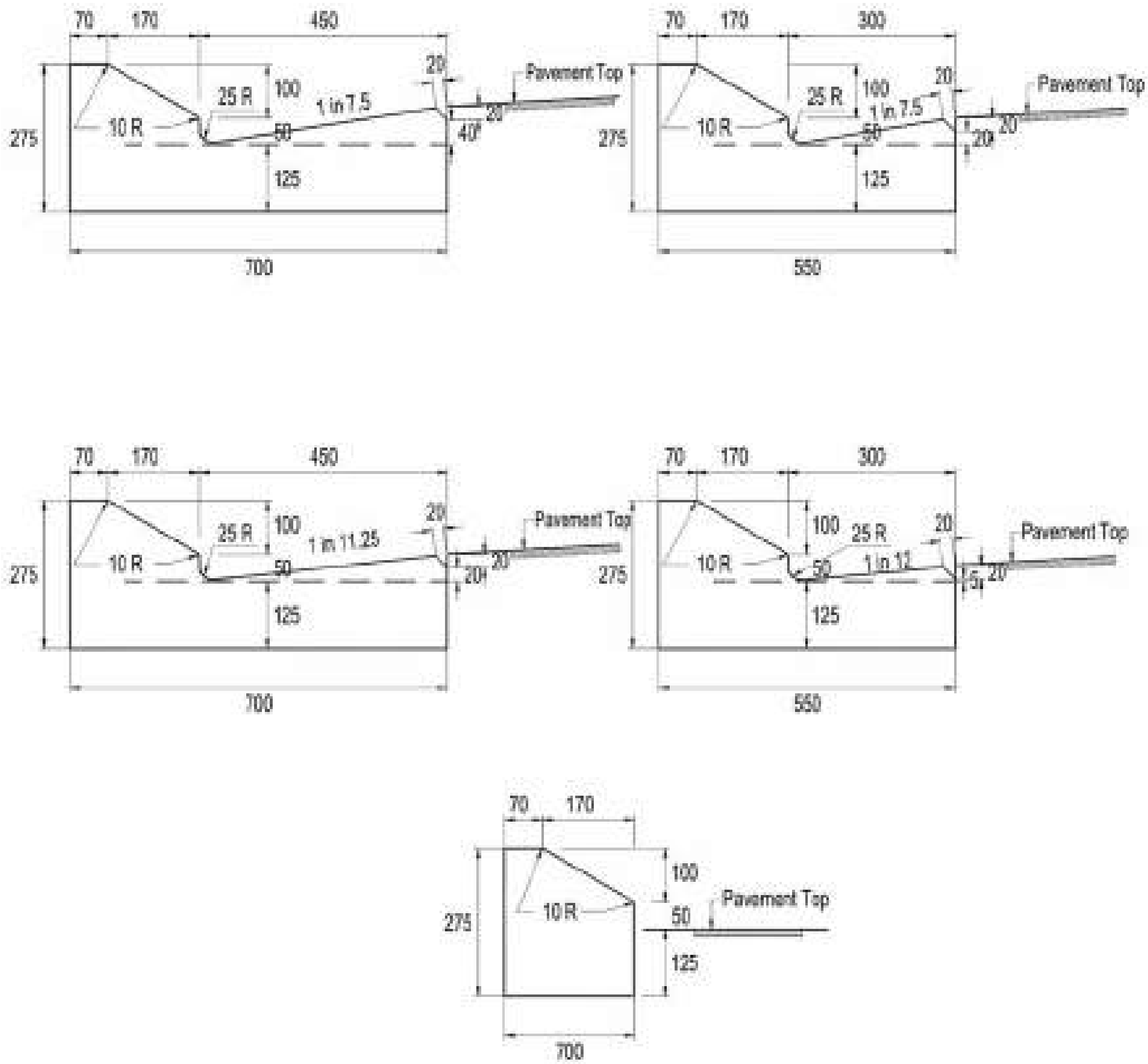
NOTE: **This chart is applicable to all vee ditches, rounded ditches with a bottom width less than 2.4m and trapezoidal ditches with bottom widths less than 1.2 m.**

Fig. 7.01 Typical Cross-Section for Ditches with Abrupt Slope Change



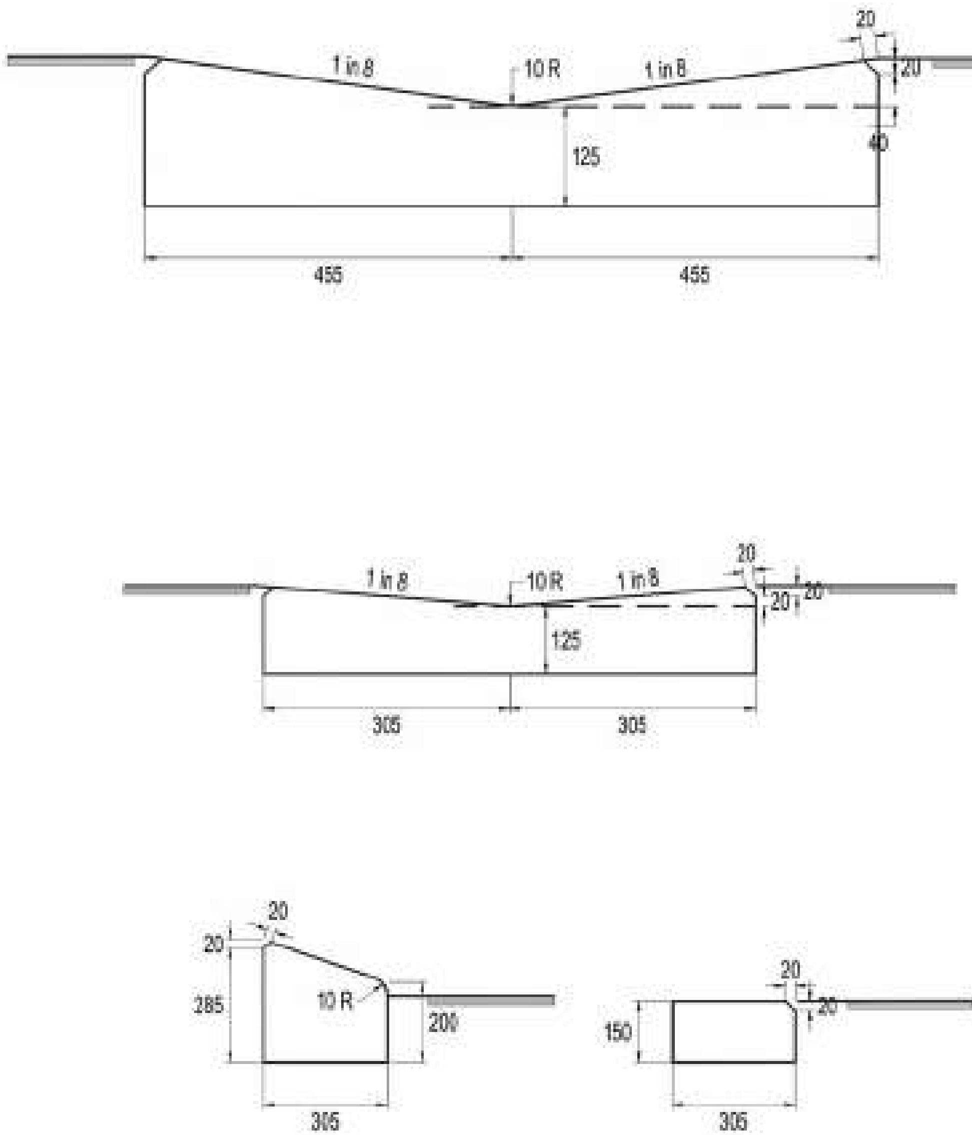
NOTE: This chart is applicable to all vee ditches, rounded ditches with a bottom width less than 2.4 m and trapezoidal ditches with bottom widths less than 1.2 m.

Fig. 7.02 Typical Cross-Section for Ditches with Gradual Slope Change



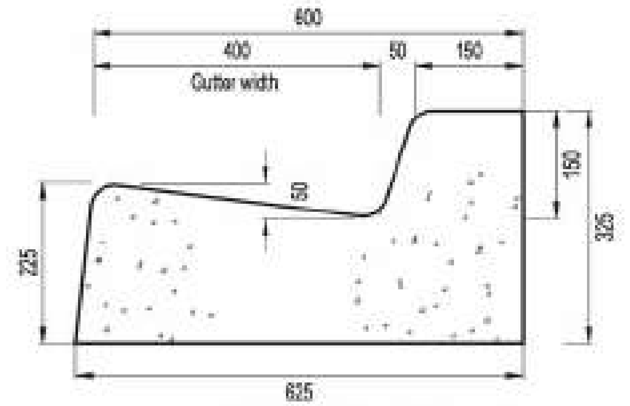
Note: All Dimensions are in millimetres

Fig. 7.03A Typical Concrete Kerb and Channel (Semi-Mountable Types)

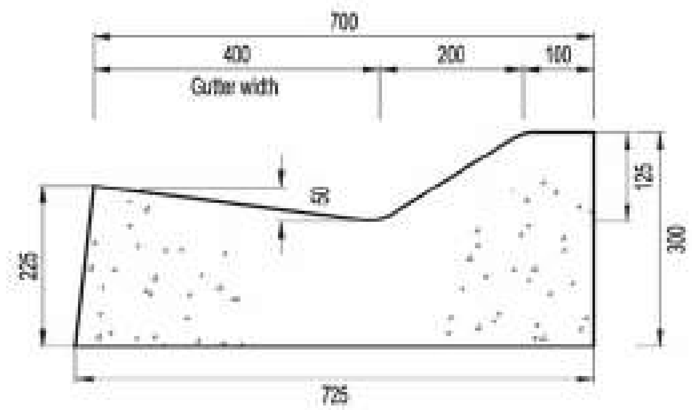


Note: All Dimensions are in millimeters

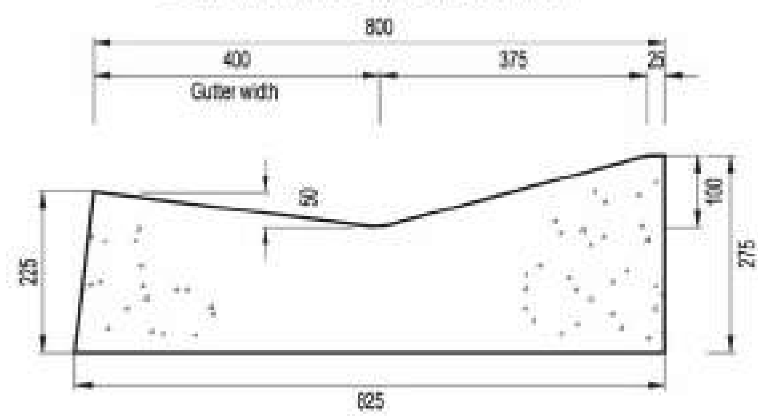
Fig. 7.03B Typical Concrete Kerb and Channel (Mountable Types)



Barrier Kerb and Channel



Semi - Mountable Kerb and Channel



Mountable Kerb and Channel

Note: All Dimensions are in millimeters

Fig. 7.03C Typical Kerb and Channel Dimensions

7.2.3 *Chutes and flumes*

In high embankment and approaches to bridge, if water is allowed to leave the carriageway at undefined spots, it may do serious damage to the embankment and eventually undermines the pavement.

In each location, rain water is collected through longitudinal kerb channel and brought down through chute. The chute may be lined with cement concrete on stable supports and may be located at 10 to 15 m interval depending upon rainfall, width, cross slope and longitudinal gradient of carriageway.

Some provision for energy dissipation or scour protection may be necessary at the outlet end. On long slopes, closed (pipe) flumes are generally desirable to open sections because the high velocity flow may overtop the open channel, erode the adjacent earth slope beyond the protection measures and destroy the entire structure.

The inlet of all chutes and flumes, open or closed, must be designed to guide the approaching flow from bypassing the flume or overtopping the structure occurred on steep longitudinal gradient. The other design requirements shall satisfy IRC:SP:42-1994 and IRC:SP:50-1999.

Typical cross-sections for chute are shown in **Figs. 7.03D and 7.03E.**

7.2.4 *Median drainage*

A depressed median is generally preferred on expressway for more efficient drainage and snow removal. Median slopes should preferably be 1:6 but slopes of 1:4 may be adequate.

Inlet spacing can be determined by the design discharge, longitudinal slope, capacity of the median channel and the flow velocity in the median channel.

Typical median drainage out fall through cross-drainage works and detail of median drainage arrangement with catch pit are shown in **Figs. 7.04A** and **7.04B**.

7.3 DESIGN OF DRAINAGE

The design of drainage system such as surface and sub-surface drainge for pavement, median, shoulder, high embankment shall be carried out in accordance with IRC:SP:42 and IRC:SP:50. Surface runoff from the project highway, embankment slopes and the service roads shall be

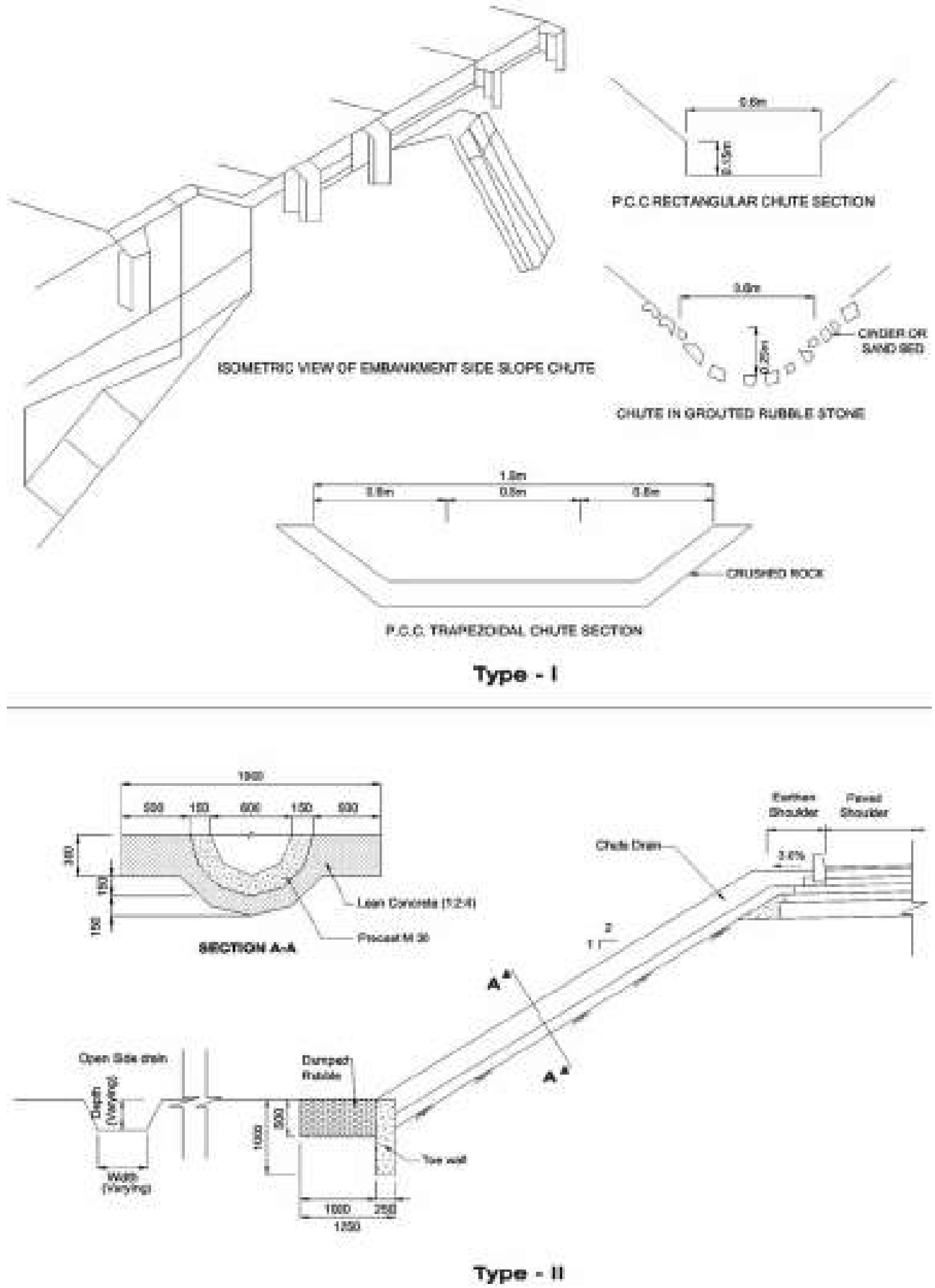


Fig. 7.03D Typical Chute Sections

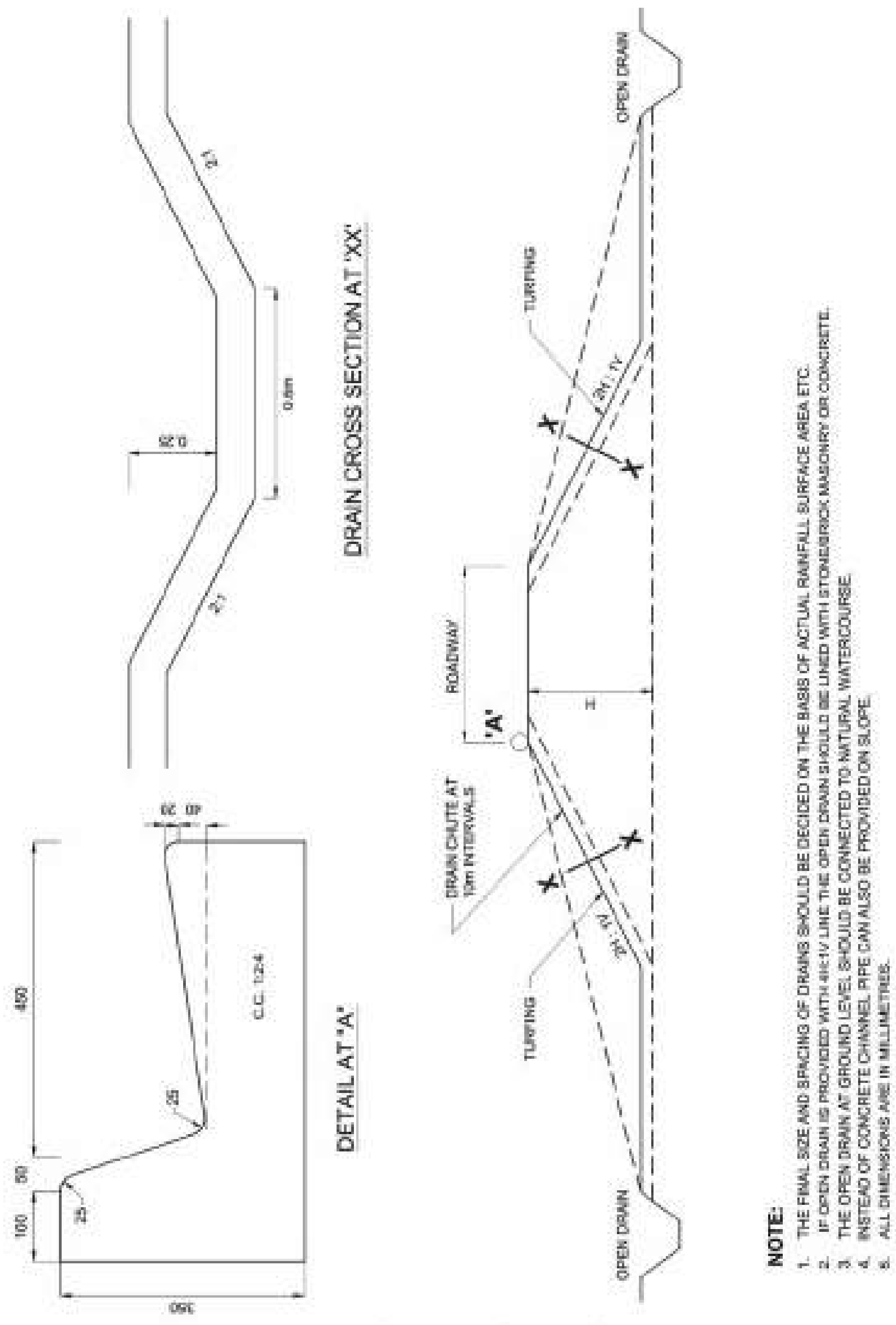


Fig. 7.03E Typical Details of Drainage System for High Embankment

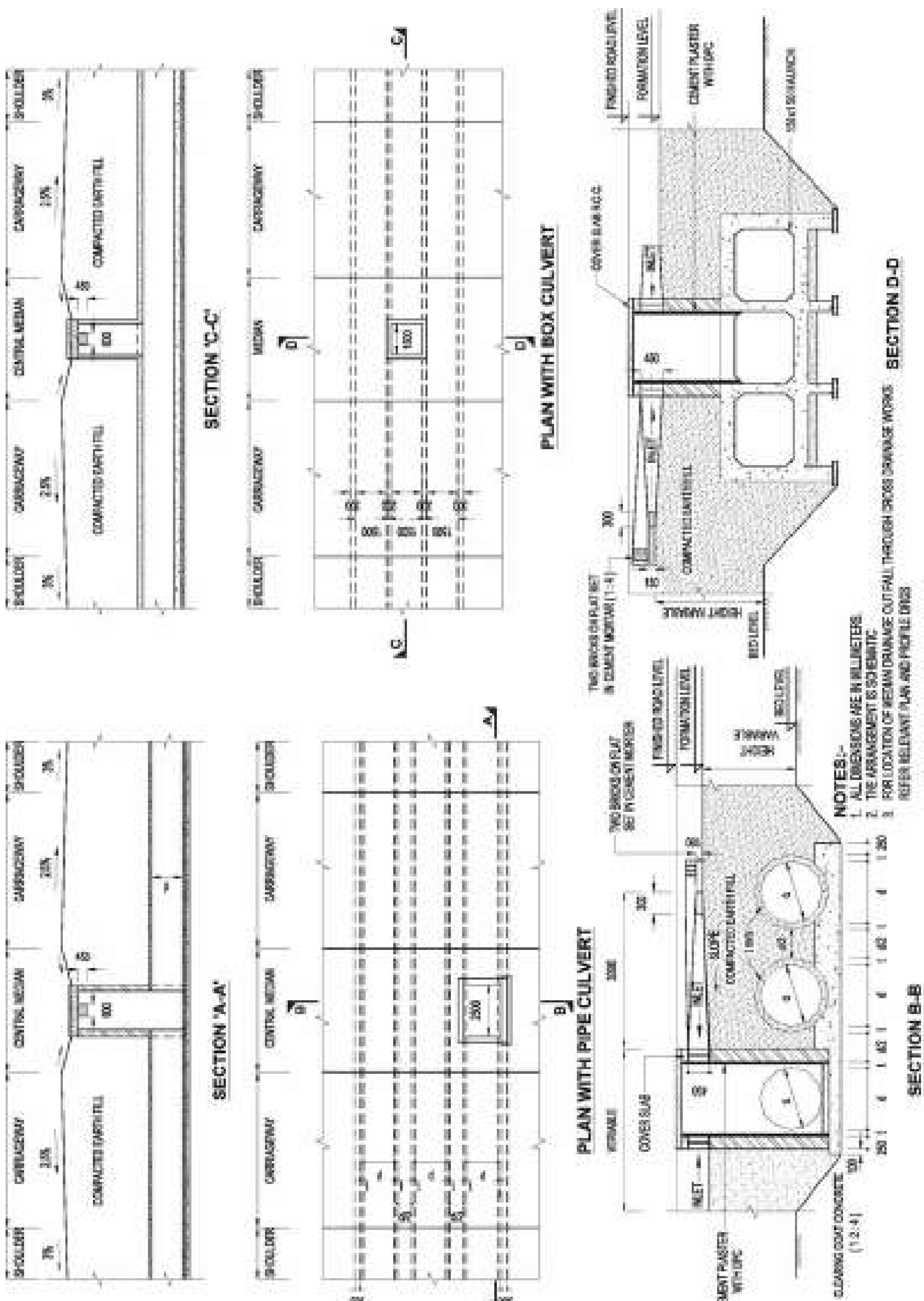


Fig. 7.04A Typical Median Drainage Outfall at Cross Drainage Structures

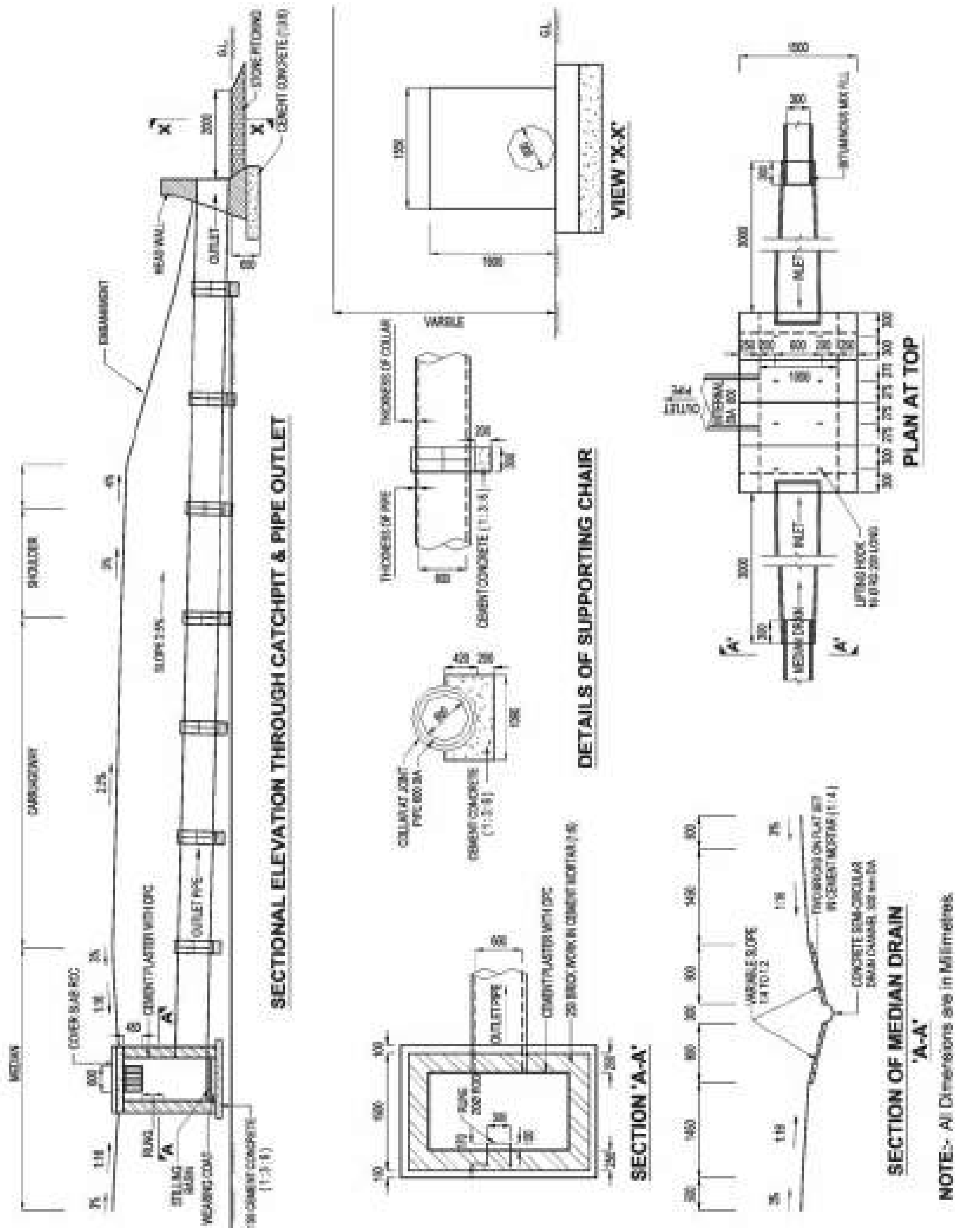


Fig. 7.04B Typical Median Drainage Arrangement with Catchpit

discharged through longitudinal drains, which shall be designed for adequate cross-section, bed slopes, invert levels and the outfalls. If necessary, the walls of the drains shall be designed to retain the adjoining earth. Where drains are required to be the covered, the cover of the drain shall be designed for carrying the maximum expected wheel load. The covered drains shall be provided with iron gratings, strong enough to withstand expected loading.

Basic steps in the design of roadway drainage and storm sewer are as follows:

i) The rainfall for the desired return period is adopted for design;
ii) The maximum allowable encroachment of gutter flow onto the traffic lanes for the design runoff is selected;
iii) The locations and spacing of sewer inlets are established;
iv) The storm sewer is designed to accommodate the design runoff;
v) The flow path followed by the major [50 (special case 100 year)] flood is examined to ensure that no significant damage or hazard will occur;
vi) The outfall is designed to minimize erosion problems;
vii) The effect of the drainage system on the receiving channel is evaluated and erosion control measures introduced where necessary.

7.3.1 *Hydraulics of storm sewers*

The most common type of flow in storm sewer systems is open channel flow, i.e. flow exposed to atmospheric pressure.

In steady uniform flow in drains of all shapes flowing either full or partially full, the mean velocity of flow is calculated from the Manning's formula as :

$$V = \frac{R^{2/3} S^{1/3}}{n} \qquad Eq....2.01$$

where

n = Mannings roughness coefficient
S = The slope of lined open channel (m/m)
R = The hydraulic radius (m)
A = Cross-sectional area of flow (sqm)
P = Wetted perimeter (m)
R = A/P

The discharge flow i.e. capacity (Q) is calculated using **Equation 2.01**.

$$Q = A\,V$$

Where Q = Discharge in m^3/s

For shallow triangular channels where the flow width may exceed 40 times the maximum depth, the Manning's formula gives inaccurate result. The following modified formula may be adopted for better assessment.

$$Q = \frac{0.375\, S_o^{0.5}\, d^{2.667}}{n S_x} \qquad Eq....2.02$$

where

Q = Discharge in (m^3/s)
S_o = Slope (m/m)
S_x = Crossfall
n = Mannings roughness coefficient
d = Maximum flow depth (m)

The values of n are given in **Table 7.01** and the solution of the **Equation 2.02** can be obtained by the nomogram given in **Fig. 7.05A**.

7.3.2 *Runoff*

The rate of runoff largely governs the cost of the drainage works. Various methods are available for estimating run-off for storm drain design, ranging from simple empirical formulae to hydrograph techniques and complex computer models. Highway drain systems draining areas up to 50 Ha are generally based on the Rational Method.

7.3.3 *The rational method*

This method states that the peak flow Q equals a fraction C of the rate of supply of water to the water shed area A

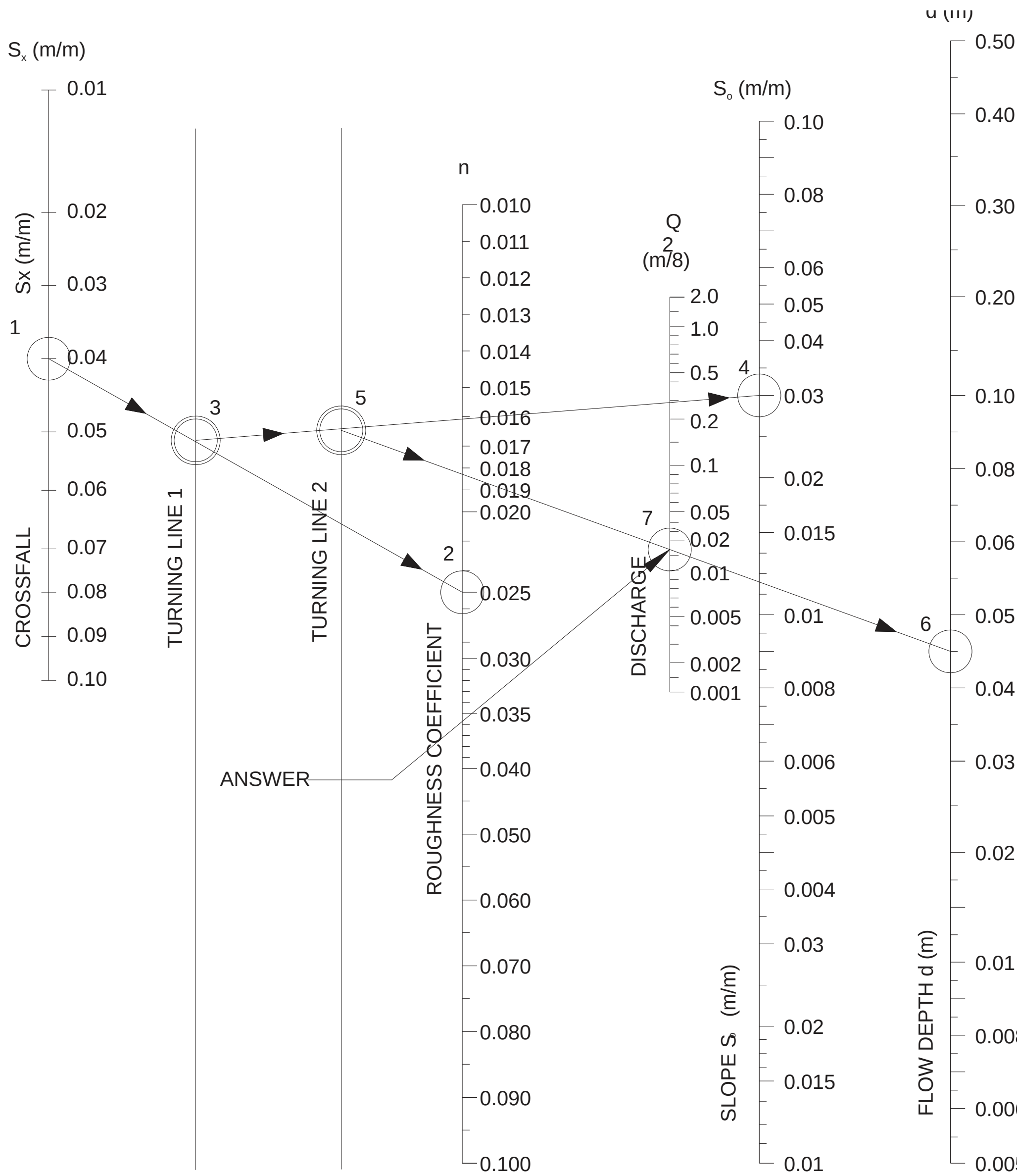
$$Q = 0.0028\, A.C.i \qquad Eq.... 2.03$$

where

Q = Peak flow (m^3/s),
C = Run-off coefficient
i = Rainfall intensity (mm/h) and
A = Drainage area (Ha)

Table 7.01 Manning's Roughness Coefficients

Sl.	Item	Roughness Coefficient
A.	**Wall/Surface Type**	
	a) Concrete pipe storm sewers	0.011 - 0.013
	b) Vitrified clay pipe	0.012 - 0.014
	c) Steel pipe (smooth)	0.009 - 0.011
	d) Monolithic concrete:	
	1) Wood forms, rough	0.015 - 0.017
	2) Wood forms, smooth	0.012 - 0.014
	3) Steel forms	0.012 - 0.013
	e) Cemented rubble masonry walls:	
	1) Concrete floor and top	0.017 - 0.022
	2) Natural floor	0.019 - 0.025
	f) Laminated treated wood	0.015 - 0.017
	g) Smooth walled pbyethylene pipe	0.011 - 0.013
	h) Corrugated interior polyethylene pipe	0.024
B.	**Road Gutters**	
	a) Concrete gutter, troweledfinish	0.012
	b) Asphalt pavement:	
	1) Smooth texture	0.013
	2) Rough texture	0.016
	c) Concrete gutter with asphalt pavement:	
	1) Smooth texture	0.013
	2) Rough texture	0.015
	d) Concrete pavement:	
	1) Float finish	0.014
	2) Broom finish	0.016
	e) Brick	0.016
C.	**Grassed Channels**	
	a) Average turf	
	i) Erosion resistant soil	0.050 – 0.070
	ii) Easily eroded soil	0.030 – 0.050
	b) Dense turf	
	i) Erosion resistant soil	0.070 – 0.090
	ii) Easily eroded soil	0.040 – 0.050
	iii) Bushes only both sides	0.050 – 0.080
	iv) Dense weeds	0.080 – 0.120
	v) Dense brush	0.100 – 0.140
	vi) Dense willows	0.150 – 0.200



EXAMPLE

<u>GIVEN</u> S_x = 0.04 m/m, n= 0.025, S_o =0.03m/m, d = 0.045m.

<u>REQUIRED</u> DETERMINE Q.

<u>SOLUTION</u> JOIN 1 TO 2, CROSSING TURNING LINE 1 AT 3.
JOIN 3 TO 4, CROSSING TURNING LINE 2 AT 5.
JOIN 5 TO 6, READ Q= 0.017 AT 7.

Fig. 7.05A Nomogram to Calculate Discharge

7.3.4 *Watershed area*

The area of the watershed may be determined from project plans, municipal drainage maps (for urban arterials), contour maps and maps of the watershed.

7.3.5 *Runoff coefficient*

The runoff coefficient may range from 0.05 or less for open sand to 0.95 for steep paved surfaces. Values of C may be taken from **Table 7.02**. The table considers topography, vegetation, soil, landuse and storm frequency to some extent, but does not consider surface detention or storage. The choice of C must be based on experience. Normally, the runoff coefficient should be based on existing conditions.

If the area to be drained comprises several types of surfaces, a composite runoff coefficient may be calculated as:

$$C = \frac{A_1 C_1 + A_2 C_2 + \ldots\ldots A_n C_n}{A} \qquad \textit{Eq...2.04}$$

where

A = Total areas of watershed

C_1, C_2, …C_n = Corresponding runoff coefficient

C = Overall runoff coefficient

7.3.6 *Time of concentration*

In storm sewer systems, the time of concentration “Tc” consists of the time taken for storm water to reach the inlet, termed the inlet time “Ti”, plus the time of flow in the sewer to the point in question. Inlet time varies accordingly to the slope, permeability and ground cover of the surfaces, the length of the flow path, and rainfall intensity. Typical inlet times that may be used in the design are given in **Table 7.03.**

7.3.7 *Rainfall frequency and intensity*

The rainfall intensity “i” to be used in the Rational formula depends on the selected design storm frequency, the time of concentrations of the watershed and the intensity - frequency relationship of rainfall at the location of the project.

The design storm frequency should be selected on the basis of road classification and other factors. Rainfall intensities corresponding to a given storm frequency. Tc should be obtained from intensity, duration frequency curves that may be available with meteorological stations.

Table 7.02 Runoff Coefficients for Return Period of 10 Years

Description			Runoff Coefficient	
			Min.	Max.
Pavement	-	asphalt or concrete	0.80	0.95
	-	brick	0.70	0.85
Gravel roads and shoulders			0.40	0.60
Roofs			0.70	0.95
Business	-	downtown	0.70	0.95
	-	neighbourhood	0.50	0.70
	-	light	0.50	0.80
	-	heavy	0.60	0.90
Industrial	-	single family urban	0.30	0.50
	-	multiple, detached	0.40	0.60
	-	multiple, attached	0.60	0.75
	-	suburban	0.25	0.40
Apartments			0.50	0.70
Parks, cemeteries			0.10	0.25
Playgrounds (unpaved)			0.20	0.35
Railroad yards			0.20	0.35
Unimproved areas			0.10	0.30
Lawns	-	Sandy soil		
	-	flat, upto 2%	0.05	0.10
	-	average, from 2 to 7%	0.10	0.15
	-	steep, over 7%	0.15	0.20
	-	Clayey soil		
	-	flat, upto 2%	0.13	0.17
	-	average, from 2 to 7%	0.18	0.22
	-	steep, over 7%	0.25	0.35

Note : For storms having return period of more than 10 years, increase the listed values of runoff coefficient as follows subject to a maximum coefficient of 0.95.

25 yr - add 10%
50 yr - add 20%
100yr - add 25%

Table 7.03 Sewer Inlet Times

Paved areas draining directly to closely spaced inlets..	5 to 10 minutes
Paved areas with small unpaved areas more widely spaced inlets..	10 minutes
Largely impervious areas with some pervious, fairly flat slopes......................................	10 to 15 minutes
Mixed impervious and pervious areas, flat grades, widely spaced inlets......................................	20 to 30 minutes

7.3.8 *Road geometrics*

Road geometric elements such as longitudinal gradient, pavement cross-slope/camber, shoulder crossfall, allowable spreads etc. play a very vital role in roadway drainage. These have been dealt with in **Chapter-1**, cross-sectional elements. Additional information is given in **Tables 7.04** and **7.05**.

Table 7.04 Minimum Gradient on Road and Road Side Drain

Design Element	Grade	
	Desirable minimum	Absolute minimum
Kerbed roads (gutter grade)	0.5%	0.3%*
Roads with adequate crossfall	0.5%	0.3%
Earth or grassed ditches	1.0%	0.5%

* *With kerb and channel section only*

Table 7.05 Minimum Crossfalls

Type of Surface	Minimum Crossfall %
Traffic Lanes	
Concrete pavement	2 %
Bituminous pavement	2 to 2.5 %
Shoulders	
Paved or treated	2 to 2.5 %
Gravel or crushed stone	3 %
Earth or turf	3 to 4 %
Grassed Areas	5 %
Sidewalks	2 %

7.4 CULVERTS AND CROSS DRAINAGE STRUCTURES

The function of a culvert is to convey surface water across or from the highway right-of-way. In addition to this hydraulic function, it must also carry construction and highway traffic and earth loads; therefore, culvert design involves both hydraulic and structural design. The hydraulic and structural designs must be such that risks to traffic, of property damage and of failure from floods are consistent with good engineering practice and economics.

Structures measuring more than 6.0 m along the roadway centreline are conventionally classified as bridges in IRC: 5.

7.4.1 *Culvert location, plan and type*

Location

Culvert locations are fixed considering the alignment of both the stream and the highway.

The horizontal and vertical alignment are important in maintaining a sediment-free culvert. The following factors contribute to deposition in culverts:

i) At moderate flow rates, the culvert cross section is larger than that of the stream, thus the flow depth and sediment transport capacity is reduced;

ii) Point bars form on the inside of stream bends and culvert inlets placed at bends in the stream will be subjected to deposition in the same manner. This effect is most pronounced in multiple-barrel culverts with the barrel on the inside of the curve often becoming almost totally plugged with sediment deposits;

iii) Abrupt changes to a flatter grade in the culvert or in the channel adjacent to the culvert will induce deposition. Gravel and cobble deposits are common downstream from the break in grade because of the reduced transport capacity in the flatter section.

Plan

Location plan deals basically with the route that the flow takes in crossing the right-of-way. Regardless of the degree of skew/meandering of the natural channel within the right-of-way, a crossing is generally accomplished by using a straight culvert either normal to or skewed with the roadway centreline preferably placed in the natural channel.

Where location in the natural channel would require a long culvert, channelisation of some stream may be required with adequate inlet and outlet design.

Culvert Type

Selection of Culvert type includes the choice of material, shape and cross section and the number of culvert barrels combined with fill height, terrain, foundation condition, fish passage, shape of the existing channel, roadway profile, allowable head-water, stream stage discharge and frequency discharge relationships, cost and service life.

Several commonly used culvert shapes are:

i) Circular;
ii) Pipes of arch and elliptical shape;
iii) Rectangular or square box;
iv) Arches.

7.4.2 *Cross drainage structures*

Cross-drainage structures are designed to carry water underneath the roadway and vary in size from 900 mm concrete or corrugated metal pipes to multi-barreled concrete box culverts or structural plate pipes. Typically, their inlets and outlets consist of concrete head walls and wing walls for the larger structures and bevelled end sections.

Traversable Designs

A roadside designed with optimal safety features could be defined as the one that is almost flat, completely traversable from the edge of the carriageway to the right of way line, and would include sufficient area for all desirable clear zone distance requirements.

If a slope is generally traversable, the preferred treatment for any cross drainage structure is to extend (or shorten) it to intercept the roadway embankment and to match the inlet or outlet slope to the embankment slope. For cross drainage structure, a small pipe culvert is defined as a single round pipe or multiple round pipes of 900 mm diameter. Extending or shortening culverts to locate the inlets/outlets a fixed distance from the traveled way is not recommended if such treatment introduces discontinuities in an otherwise traversable slope.

Extension of Structures

For intermediate sized pipes and culverts whose inlets and outlets cannot readily be made traversable, an option often exercised by the highway designer is to extend the structure so that the obstacle is located at or just beyond the appropriate clear zone. While this practice reduces the likelihood of the pipe end being hit, it does not completely eliminate its possibility. The clear zone distance should not be viewed as a discrete, exact distance, but as the center of a zone which should then be analysed on a site specific basis.

If the extended culvert headwall remains the only significant man-made fixed object immediately at the edge of the clear zone along the section of roadway under design, and the roadside is generally traversable to the right of way line elsewhere, simply extending the culvert to the edge of the clear zone may not be the best alternative, particularly on freeways and other high speed, access controlled facilities. On the other hand, if the roadway has numerous fixed objects, both natural and man-made, at the edge of the clear zone, extending individual structures to the same minimum distance from traffic may be appropriate. However, redesigning the inlet/outlet so that it is no longer an obstacle is usually the preferred safety treatment.

Shielding

For major drainage structures which are costly to extend and whose end sections cannot be made traversable, shielding with an appropriate traffic barrier is the most effective safety treatment. Although the traffic barrier is longer and closer to the roadway than the structure opening and is likely to be hit more often than an unshielded culvert located further from the traveled way, a properly designed, installed and maintained barrier system may provide an increased level of safety for the errant motorist.

7.4.3 *Catch water drain*

Catch water drains, are also known as interceptor drains located on the high side of cuttings clear of the top of batters to intercept the flow of surface water and upper soil seepage water. These are generally located at level of 2.0 m from the edge of the cutting to minimise possible under cutting of the top of the batter.

These are lined, if necessary, depending upon hydraulic design (velocity) and soil type. The discharge from the drain will be led to the nearest natural channel.

7.4.4 *Rainwater harvesting and conservation*

To dispose of the rainwater from the road surface and the embankment slope, toe drains are provided unless the topography is such that the runoff can flow to natural outfalls.

These toe drains, once provided, have their outfall in the waterway or natural basin. To conserve these runoffs as an alternative proposed to be conserved. The details have been explained in **Appendix-7**.

7.5 SUB-SURFACE DRAINAGE

Sub-surface drainage systems will only remove water from soils in which gravity is the primary energy gradient. Sub-surface drains may not remove all of this moisture. Darcy's law is applicable for the design of sub-drainage systems, but it should be emphasized that only "free" water (the quantity sometimes referred to as the specific yield) can be removed by a sub-surface drainage system.

7.5.1 *Horizontal drains*

Groundwater problems frequently involve water trapped on an impermeable layer above the actual water table. These problems often can be solved with horizontal drains (**Fig. 7.05B**). Horizontal drains are either perforated or slotted pipes wrapped with geotextile placed in holes which have been bored into the aquifer or water bearing formation. Usually, these are installed in cut slopes and under fills to guard against slide and slip-outs by relieving hydrostatic pressure, though they may be used to prevent saturation of the roadbed material. A collection system to remove the intercepted water shall be provided.

A trench loosely backfilled with graded stones in which the space between the stones serve as a passageway for sub-surface water. Drains of this general type are known as "French Drains". While "French Drains" provide a degree of crude sub-surface drainage with naturally occurring materials, they have recently given way to the more effective pipe under drains surrounded by geomembranes/geotextile.

7.6 PIPE UNDER DRAINS

Longitudinal pipe under drains are often used in regions of high groundwater to intercept sub-surface water before it can reach and enter the structural materials supporting the pavement. In sloping terrain, when slope stability is not a problem, a trench may be excavated along the uphill side of the roadbed near the toe of the cut slope. In areas where the ground is nearly level, longitudinal pipe under drains may be necessary along both sides of the roadbed near the toe of cut slopes. Longitudinal pipe under drains are also placed along the toe of fills to intercept high groundwater.

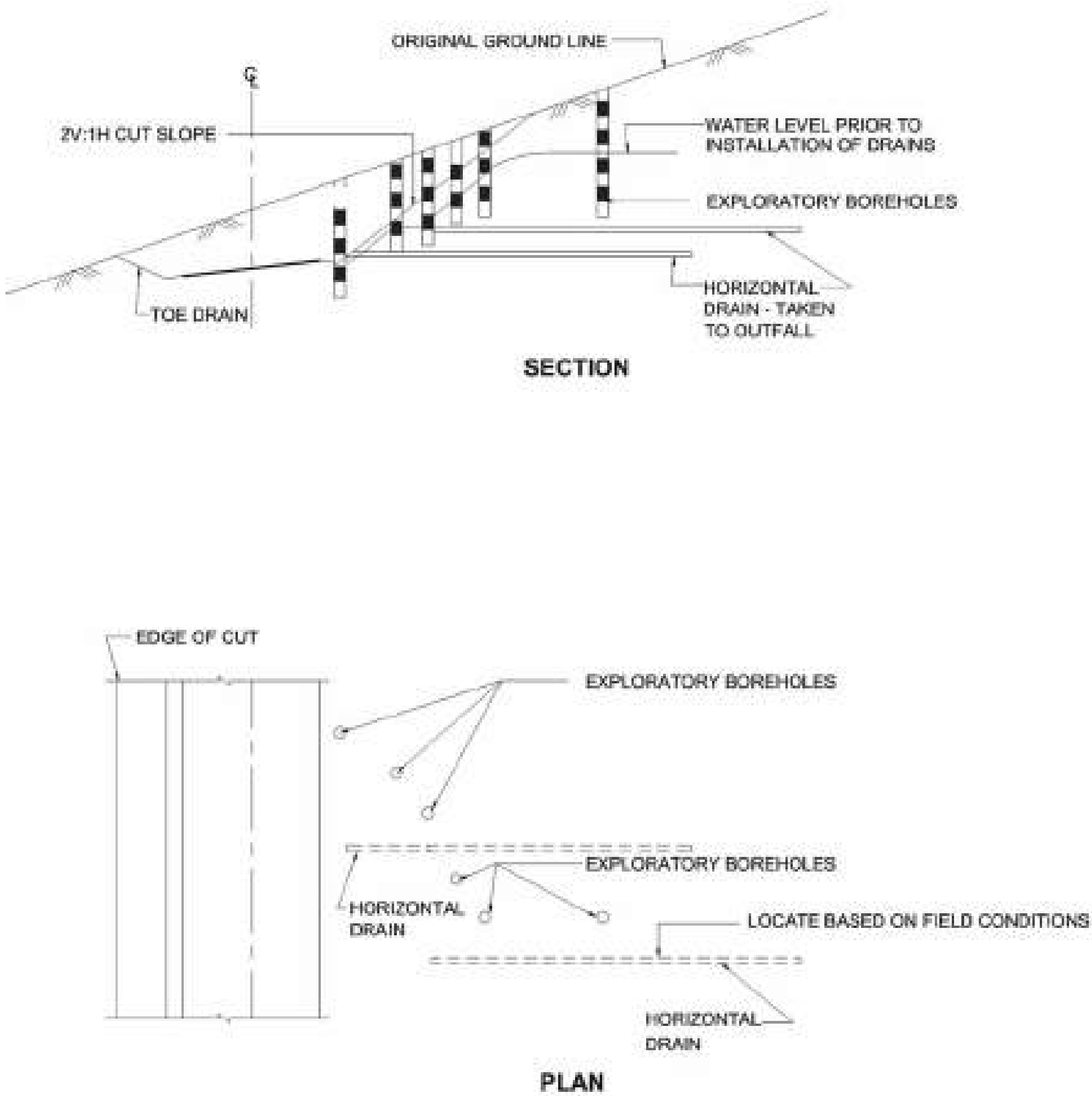


Fig. 7.05B Typical Horizontal Drains.
(TO LOWER WATER TABLE)

In hilly or mountainous terrain, a transverse interceptor pipe under drain may be necessary to prevent groundwater seepage from flowing down the grade out of cut sections and into the fills which can cause subsidence and slip outs. Shallow transverse drains are also constructed in conjunction with treated and untreated permeable base layers for rapid removal of surface water infiltration.

The locations and depths of pipe under drain trenches depend largely on hydrostatic pressures and soil permeabilities. Whenever practicable, under drain pipe should be placed at a depth so as to be in the impervious zone below the aquifer.

Outlets for longitudinal pipe under drains shall preferably be placed at intervals of not more than 300 m.

7.7 SUBGRADE DRAINAGE SYSTEMS

Natural elements constantly work to create cracks and open joints in almost all pavements. While every effort should be made to minimize the amount of water that enters pavements, the roadbed structural layers should be designed to accommodate occasional wetting and still prevent water damage.

Water infiltrating through the pavement surface is the most common cause of damage to highway pavements. Even on regularly maintained roads surfaces, infiltration of water is at considerable rates and the rapid removal of water from the pavement section is essential. The inclusion of a positive sub-grade drainage system is the best insurance against water-caused distress in both flexible and rigid pavements.

The function of a subgrade drainage system is to rapidly remove water entrapped under the pavement. The basic components of such a drainage system are:

i) A permeable base drainage layer;
ii) A collector and outlet system.

Typical cross-sections for sub-grade drainage system are given in **Fig. 7.05C.**

7.8 EDGE DRAIN COLLECTOR SYSTEMS

An adequate collector and outlet system must be used with a permeable drainage layer under the pavement. These collector drains are typically longitudinal drains located at or near the edge of pavement, hence they are commonly called edge drains. Some of the various types of pavement edge drains are given in **Fig. 7.05D**.

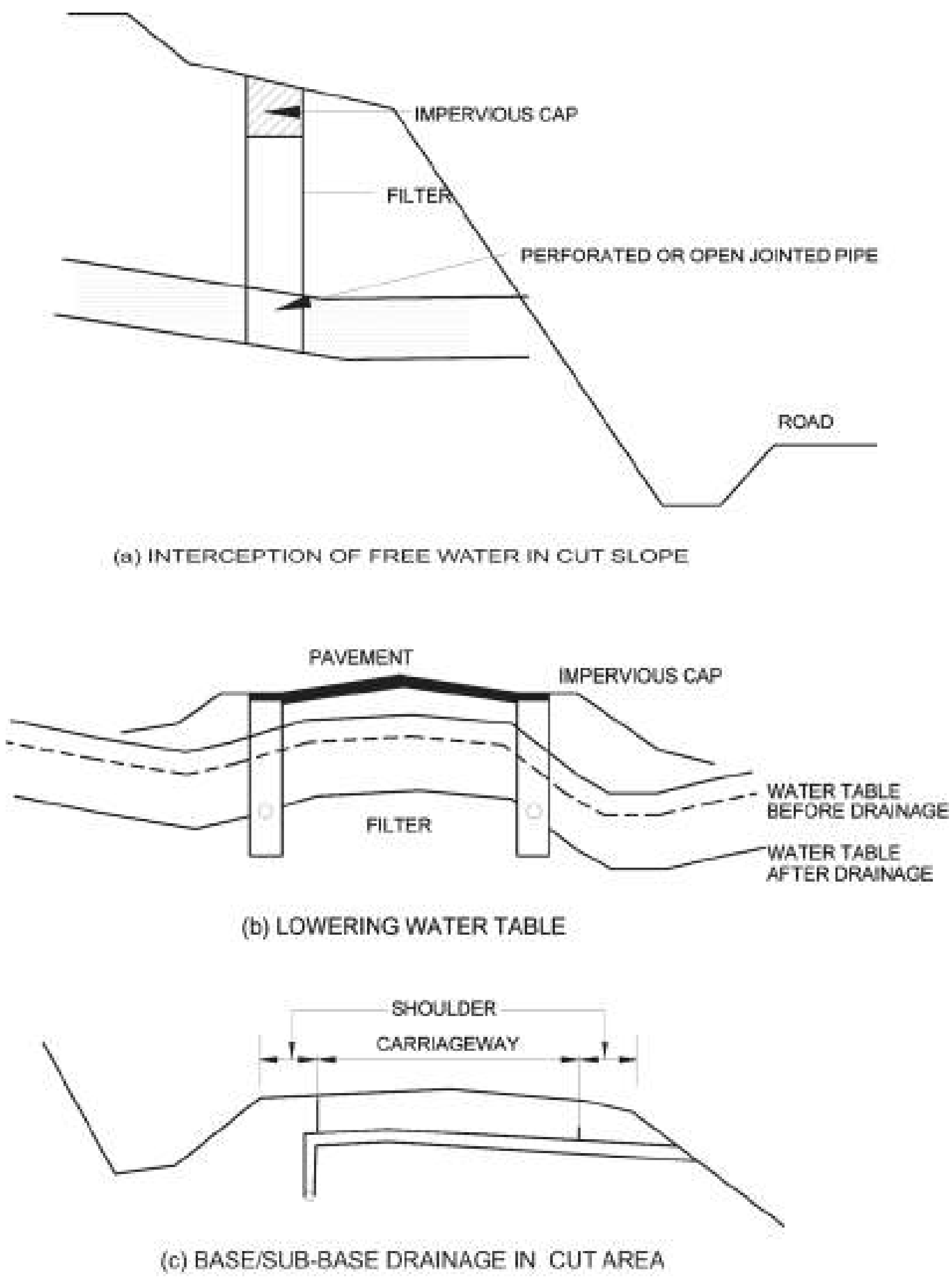


Fig. 7.05C Example of Typical Sub Surface Drains

The basic function of an edge drain system is the rapid removal of water entrapped beneath the pavement. Although longitudinal pipe under drains may be, on occasion, located close enough to the edge of pavement so that they intercept surface water infiltration, their primary function is to prevent groundwater from reaching the roadbed.

Typically, the dimensions of an edge drain system are less than those required for a longitudinal under drains. Since the required size of conduit and the width and depth of edge drain trench are smaller, the cost per linear meter of edge drain is less than that for pipe under drains.

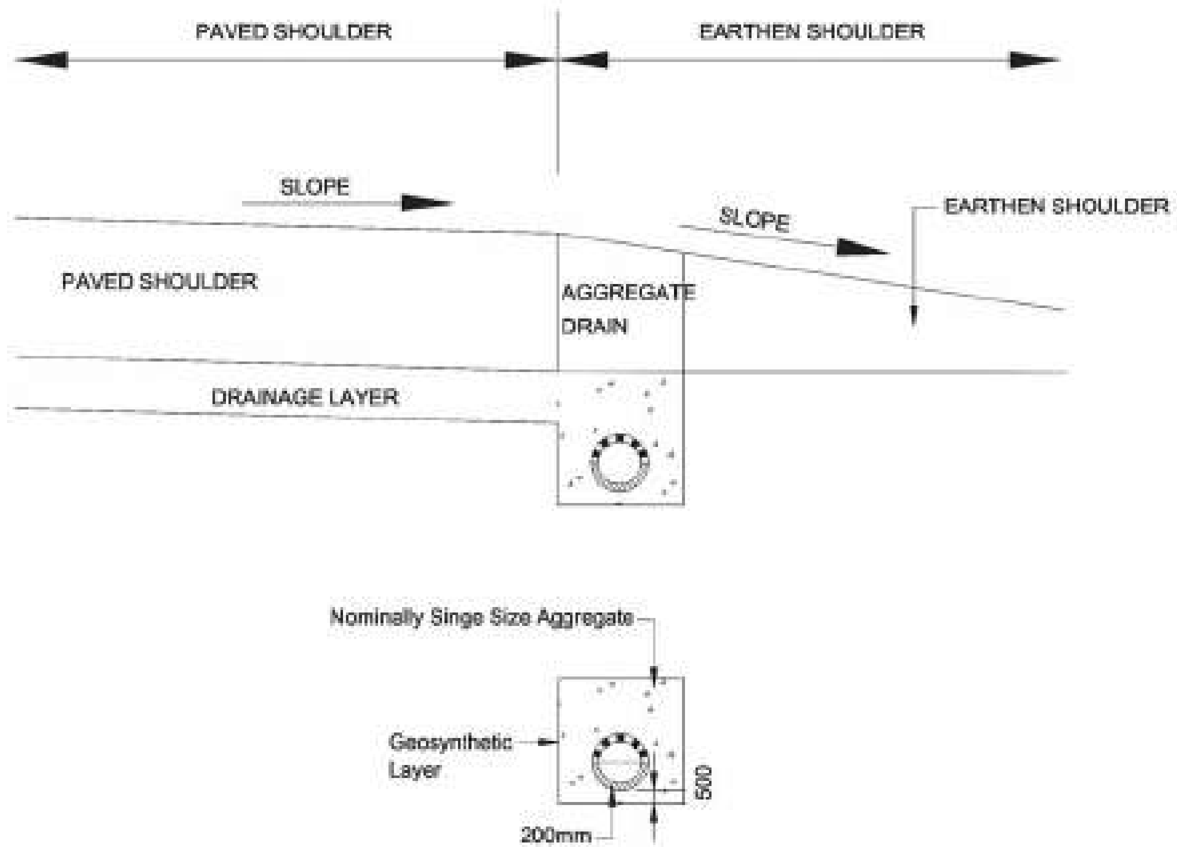


Fig. 7.05D Typical Pavement Edge Drains

7.9 EROSION CONTROL MEASURES

Erosion controls in one form or another is required for virtually every highway construction project. They may range from simple grass cover to elaborate channel protection measures.

Function

In general, erosion controls perform one or more of the following functions:

i) Reducing the impact of raindrops on exposed soil;
ii) Binding the soil particles together;
iii) Preventing uncontrolled flow down slope;
iv) Preventing the velocity of sheet and channel flows;
v) Protecting of soils from high flow velocities;
vi) Protecting soil against the impact of ice flows, debris or waves.

Measures

The various categories of erosion control measures used in highway construction are given below:

i) Vegetative Cover;
ii) Non-vegetative Cover - temporary;
iii) Non-Vegetative Cover - permanent;
iv) Slope Modification;
v) Temporary Runoff Controls;
vi) Retaining Walls;
vii) Control of Wind Erosion;
viii) Permanent Drainage Erosion Controls.

Only some of these are recommended for expressways as described below:

7.9.1 *Vegetative cover*

Vegetative methods of controlling erosion are vital to highway construction, since they are effective in the long term, relatively inexpensive, and visually pleasing. Their main drawbacks are that vegetation grown from seed is totally ineffective in its initial stages of development unless supplemented by application of a mulch and vegetative cover is unable to withstand high flow velocities.

7.9.2 *Permanent non-vegetative cover*

For growth of turfs, grass or vegetative cover over silty sand or fly ash type of fill materials require a thick layer of (around 300 mm) good earth (with substantial clay content). In places where “good earth” is not easily available, rubble stone, dry stone masonry, bricks, soft-stone, slabs, blocks, lateritic stone blocks, grouted stone masonry and concrete blocks are used. These are termed as non-vegetative covers and are permanent (requiring less maintenance) in nature.

7.9.3 *Slope modification*

Slope erosion can be reduced to some extent by flattening the gradient or by reducing the effective slope length by breaking it up into segments with benches or serrations.

This reduces the amount of runoff travelling down slope, reduces the flow velocity, increases infiltration and intercepts some of the sediment before it reaches the toe of slope.

7.9.4 *Temporary runoff control*

As most sheet and small trench with erosion is caused by flowing water, it is essential that overland flow be controlled at all stages of the project, especially before the soil cover is applied. This may be achieved by intercepting sheet flow and safely conveying it to a satisfactory outlet, or in some cases by storing it.

7.9.5 *Temporary check dams*

A check dam is a small barrier constructed in a ditch or other channel to reduce the hydraulic gradient and flow-velocity, thereby minimizing erosion of the channel and preventing degradation and gulling.

Temporary check dams are used to reduce channel flow velocity until grass lining has become fully established.

It suffers from a major disadvantage that they are vulnerable to washouts caused by end cutting, under cutting and hydrostatic pressure, and if they fail, may cause more sedimentation down stream than it would have occurred without them.

7.10 EXISTING DRAINS, CANALS AND MINOR WATERWAYS

The expressway will pass over the existing drains, canals and waterways. These are to be provided with adequate crossing facility depending on their requirements. Draining provisions for these must be maintained and the consequences of prolonged heavy rainfall must be allowed for.

Particular attention should be given to the drainage channels carrying factory waste and effluent. Special attention is required for chloride contaminated effluents which are likely to affect the RCC structures.

While crossing irrigation canals, sufficient care shall be taken so that the spillage from expressway does not contaminate the flow in the canal.

When the existing channels and the expressway runs parallel, adequate precautions in the form of bank protection and channel alignment should be taken so that there is no stagnation or water build up against the expressway slope endangering pavement drainage. The drainage channels at the toe of the expressway may have to be adequately protected or reshaped for discharge into these channels. Where discharge from road drainage is not permitted, separate cross drainage structures are to be provided on both the sides of such channels.

APPENDIX-7

RAINWATER HARVESTING AND CONSERVATION

Source: (i) *Rain Water Harvesting and Conservation Manual, Government of India, Consultancy Services Organisation, Central Public Works Department, Nirman Bhawan, New Delhi – 110011, and*

(ii) *IRC:SP:50 Guidelines on Urban Drainage.*

Rain water harvesting and Conservation, is the activity of direct collection of rain water. The conservation of rain water so collected can be stored for use or can be re-charged into the aquifer. The main goal is to minimize flow of rain water through drains to the outfall without making any use of the same. It is well known that the groundwater level is depleting and getting lower and lower in the last decades.

The Artificial recharge technique should normally address the following issues:

i) Enhance the sustainable yield in areas where over development has depleted the aquifer.

ii) Enhance the rainfall runoff, since this is going to sewer or storm Water drain.

iii) Conservation and storage of excess surface water for future requirements, since these requirements often change within a season or a period.

iv) Surface water is inadequate to meet our demand and we have to depend on ground water.

These issues can be addressed by adopting the following forms.

(A) Recharge Pit

i) Recharge pits are constructed recharging the shallow aquifer.

ii) These are constructed generally 1 to 2 m wide and 2 to 3 m deep.

iii) After excavation, the pits are refilled with pebbles and boulders.

iv) Water to be recharged should be silt free as far as possible.

v) Cleaning of the pit should preferably be done once a year.

vi) It is suitable for small buildings having roof top area upto 100 sqm.

vii) Recharge pit may be of any shape i.e. circular, square or rectangular.

viii) The run off of 1st rain should not be allowed to percolate to the rain water harvesting structure and it be allowed to go to the drain by making suitable bypass arrangement in water carrying pipe systems.

ix) If the pit is of trapezoidal shape, the side slopes should be steep enough to avoid silt deposition.

(B) Recharge Trench

i) It is constructed when permeable strata of adequate thickness are available at shallow depth.

ii) It is a trench of shallow depth filled with pebbles and boulders.

iii) These are constructed across the land slope.

iv) The trench may be 0.5 to 1 m wide, 1 to 1.5 m deep and 10 to 20 m long depending upon the availability of land and roof top area.

v) It is suitable for the buildings having roof area of 200 to 300 sqm.

vi) Cleaning of trench should be done periodically.

(C) Gravity Head Recharge Well

i) Bore wells/tube wells can be used as recharge structure.

ii) This technique is suitable where

a) Land availability is limited

b) When aquifer is deep and over land by impermeable strata (clay)

iii) The roof top Rain Water is channelised to the well and recharges under gravity flow condition.

iv) Recharge water should be silt free as far as possible.

v) The well can also be used for pumping.

vi) Most suitable for the areas where Ground Water levels are deep.

vii) The number of recharging structures can be determined in limited area around the buildings depending upon roof top area and aquifer characteristics.

viii) The run off of 1st rain should not be allowed to percolate to the rain water harvesting structure and it be allowed it to go to the drain by making suitable bypass arrangement in water carrying pipe systems.

(D) Recharge Shaft

i) A recharge shaft is dug manually or drilled by the reverse/direct rotary method.

ii) Diameter or recharge shaft varies from 0.5 to 3 m depending upon the availability of water to be recharged.

iii) It is constructed where the shallow aquifer is located below clayey surface.

iv) Recharge shaft is back filled with boulders, gravels and coarse sand.

v) It should end in more permeable strata (sand).

vi) Depth of recharge shaft varies from 10 – 15 m below ground level.

vii) Recharge shaft should be constructed 10 to 15 m away from buildings for the safety of building

viii) It should be cleaned annually preferably by scrapping the top layer of sand and refilling it accordingly.

Any of the above system can be integrated with the roadside surface drainage. A typical arrangement is shown in **Fig. 7-A-1 Rainwater Harvesting Arrangement**.

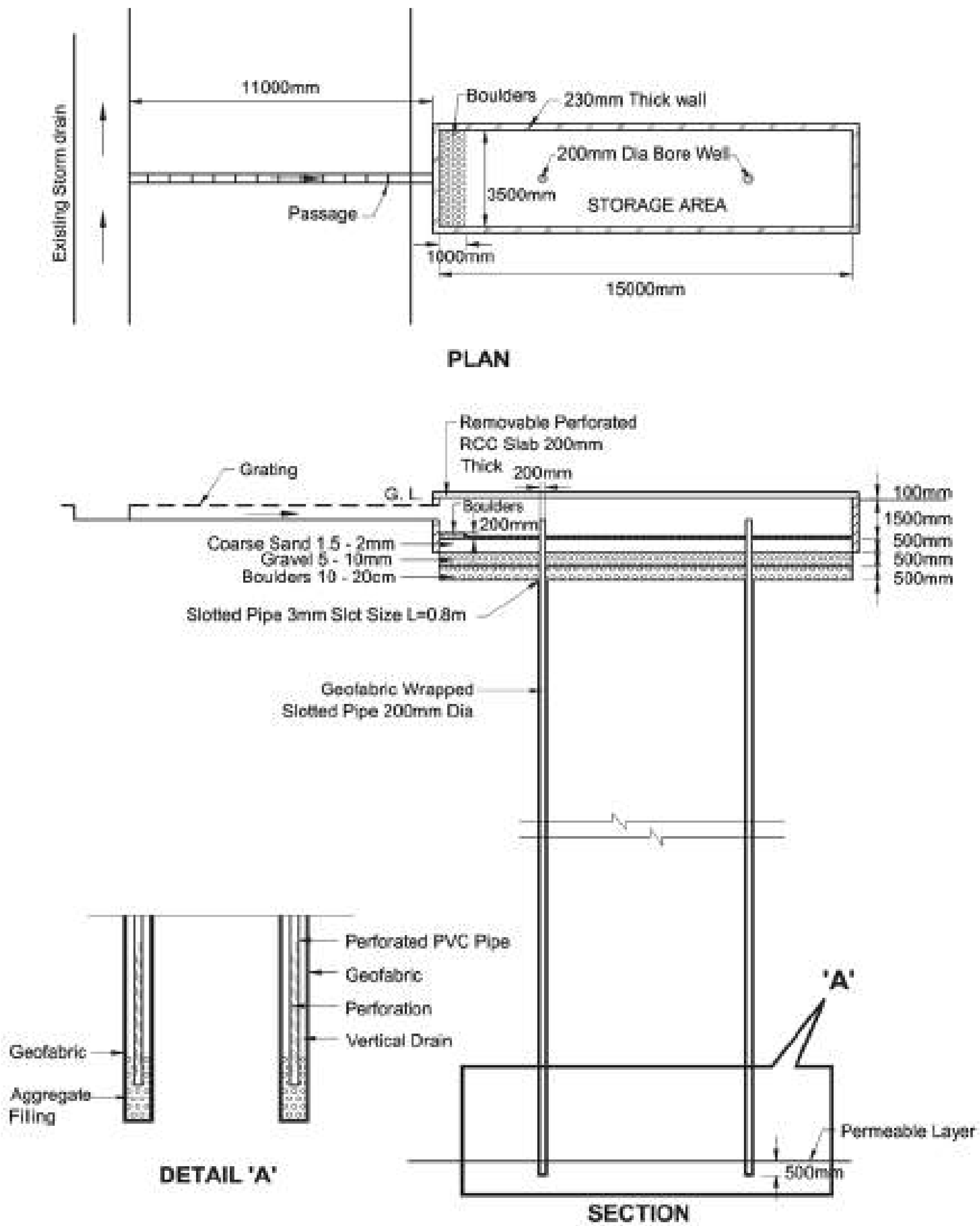


Fig. 7-A-1 Rain Water Harvesting Arrangement

CHAPTER - 8

SAFETY BARRIERS

CHAPTER – 8

SAFETY BARRIERS

8.1 INTRODUCTION

The ideal roadway would be entirely free of any roadside obstructions or other hazardous conditions. This is rarely practical because of natural, economic, and environmental factors. The consistent application of geometric design standard for expressway provides motorist with a high degree of safety. For safety reasons, technological development and adequate regulations requires to develop new safety barriers for the expressways. This technology of such barriers absorbs the impacts and redirects the vehicles back into carriageway.

8.2 BARRIER ACCEPTANCE STANDARDS

Mechanistic design of barrier system involving vehicle barrier impact mechanism is a complex process. Therefore, the barrier effectiveness is evaluated from the "crash tests" performed on representative vehicles.

To be effective a barrier must be capable of restraining a vehicle from:

- i) a) Penetrating, vaulting over or wedging under the installation;
  - b) Unless otherwise designed the barrier must also remain intact so that detached elements and debris will not create hazards for vehicle occupants or other traffic;
  - c) The system must be designed and installed so that spearing does not occur;
- ii) The vehicle/barrier collision should result in smooth redirection of the vehicle at an angle so that the vehicle will not create hazard to trailing or oncoming vehicles;
- iii) The collision must not result in excessive damage to the vehicle occupants.

"NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features" is accepted as standards almost universally. An abridged content of NCHRP Report 350 is presented below:

The procedures are directed at the safety performance of roadside safety features; other service requirements such as economics and aesthetics are not considered here.

In accordance with **NCHRP Report 350**, Indicative Test Levels are:

Test Level	Vehicle mass (kg)	Speed (km/h)	Impact Angle (degrees)
TL-5	820 (small car)	100	20
	36000 (tanker type semi-trailer)	80	15
TL-4	820 (small car)	100	20
	8000 (rigid chassis truck)	80	15
TL-3	820 (small car)	100	20
	2000 (utility)	100	25
TL-2	820 (small car)	70	20
	2000 (utility)	70	25
TL-1	820 (small car)	50	20
	2000 (utility)	50	25
TL-0	820 (small car)	50	20
	1600 (small car)	50	25

8.2.1 *Selection criteria*

Highway safety features, including longitudinal barriers, anchor assemblies, bridge terminal assemblies and impact attenuators, installed on the Expressway must demonstrate satisfactory crash worthy performance.

A given feature, placed on expressway, must be tested to one of six different test levels (TL) mentioned earlier.

Once geometric and traffic control deficiencies are addressed and these do not fully rectify the issue, then the installation of barriers should be considered. Although objective warrants for the use of these performance barriers do not presently exist, subjective factors most often be considered for new construction or for upgrading safety. Based on literature survey, suggestive criteria are stated below:

Barrier Type	**Placement**
TL-3	On mainline expressway as identified in warrant.
TL – 4 and TL – 5	• On stretches with significant percentage of trucks; • Where third party injury risk is high; • Likely places affecting other railway, important highway and important utility lines and places; • Adjacent to water bodies of importance.
TL – 2	For all other places such as interchange ramps, connection to local roads, protection of bridge piers on median and roadside etc.

8.2.2 *Barrier warrants*

A warrant is an empirical expression, which combines the degree of need in terms of accident severity of a single accident with the frequency of errant vehicle accidents and average cost. Warrants are the criteria by which the need for a safety treatment or improvement can be determined.

Barrier warrants are based on the premise that a traffic barrier should be installed to reduce the severity of potential accidents.

Embankments

Embankment height and side slope are the basic factors considered in determining barrier need as shown in **Fig. 8.01**. These criteria are based on studies of relative severity of encroachments on embankments versus impact with roadside barriers. Embankments with slope and height combinations on or below the curve do not warrant shielding unless they contain obstacles within the clear zone that presents a serious hazard to errant motorists.

Roadside Obstacles

Roadside obstacles may be non-traversable hazards on fixed object and may be either man made or natural. Barrier warrants for roadside obstacles are a function of the obstacle itself and the likelihood that it will be hit. However, a barrier should be installed only if it is clear that the result of a vehicle striking the barrier will be less severe than the accident resulting from hitting the un-shielding object. Non-traversable and fixed object hazards, which normally warrant shielding are listed in **Table 8.01**.

Median Barriers

A median barrier should be installed only if striking the barrier is less severe than the consequence that would result if no barrier existed. **Fig. 8.02** suggests warrants for median barriers on high speed, controlled access roadways which have relatively flat, traversable medians. Barriers are typically considered for combination of average daily traffic (ADT)

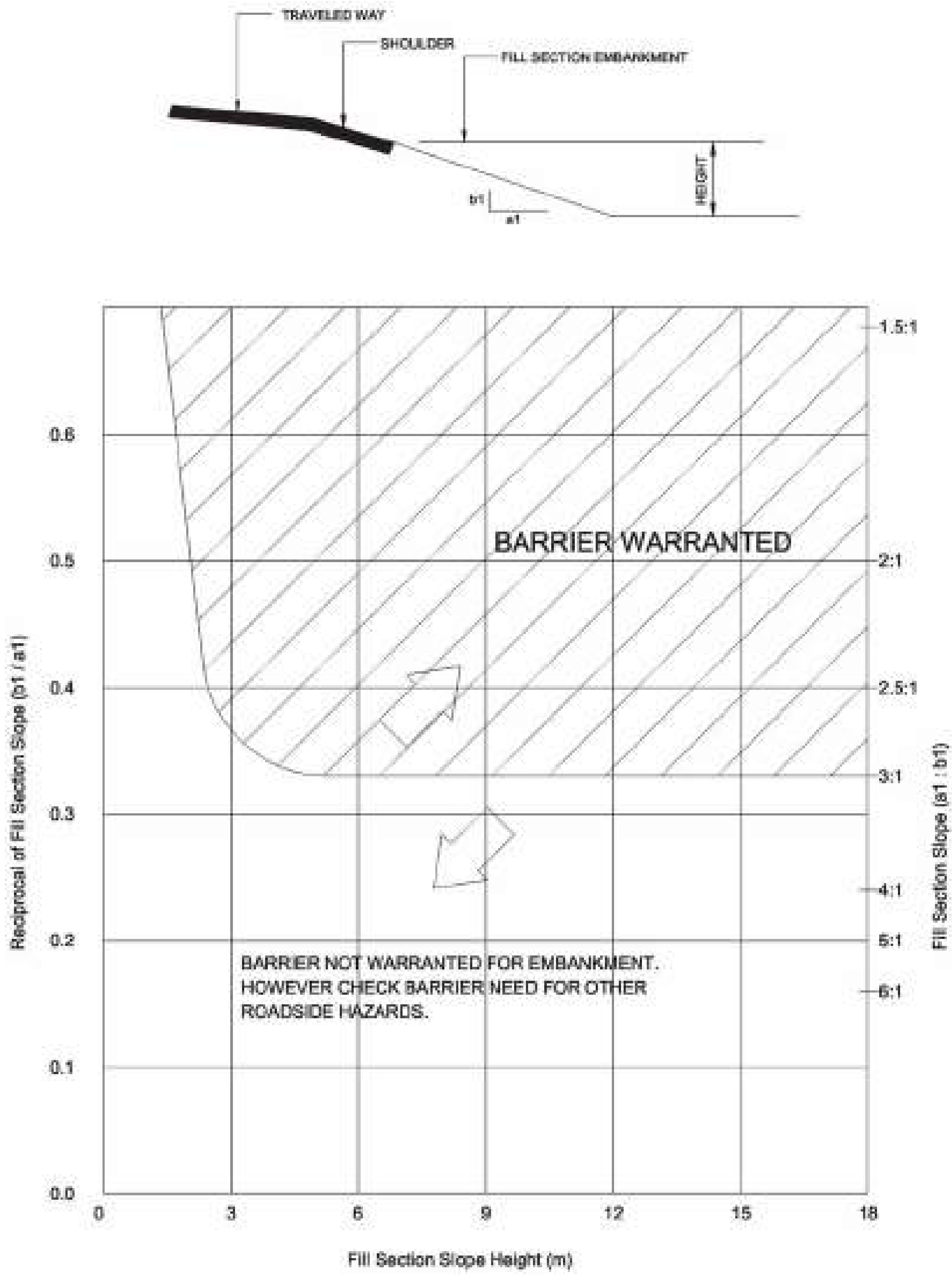


Fig. 8.01 Comprative Risk Warrants for Embankment

(Source: AASHTO-Roadside Design Guide-2006

Table 8.01 Barrier Warrants for Non-Traversable and Fixed Object Hazards

Bridge piers, abutments and railing ends	Shielding generally required
Boulders	A judgement decision based on nature of hazard and likelihood of impact
Culverts, pipes, headwalls	A judgement decision based on size, shape and location of hazard
Cut slopes (smooth)	Shielding not generally required
Cut slope (rough)	A judgement decision based on likelihood of impact
Ditches (transverse)	Shielding generally required if likelihood of head-on-impact is high
Embankment	A judgement decision based on fill length and slope
Retaining walls	A judgement decision based on relative smoothness of wall and anticipated maximum angle of impact
Sign/luminaire supports	Shielding generally required for non-breakaway supports
Traffic signal supports	Isolated traffic signals within clear zone on high-speed rural facilities may warrant shielding
Trees	A judgement decision based on site specific circumstances
Utility poles	Shielding may be warranted on a case-by-case basis
Permanent bodies of water	A judgement decision based on location and depth of water and likelihood of encroachment

and median widths that fall within the dotted area. For ADT less than 20,000 and median widths within the optional areas of **Fig. 8.02**, a barrier is warranted only if there has been a history of cross median accidents. For median width greater than 9 m and within the optional area of the figure, a barrier may or may not be warranted. The criteria used for **Fig. 8.02** is relatively subjective and does not specifically address the cost-effectiveness issue.

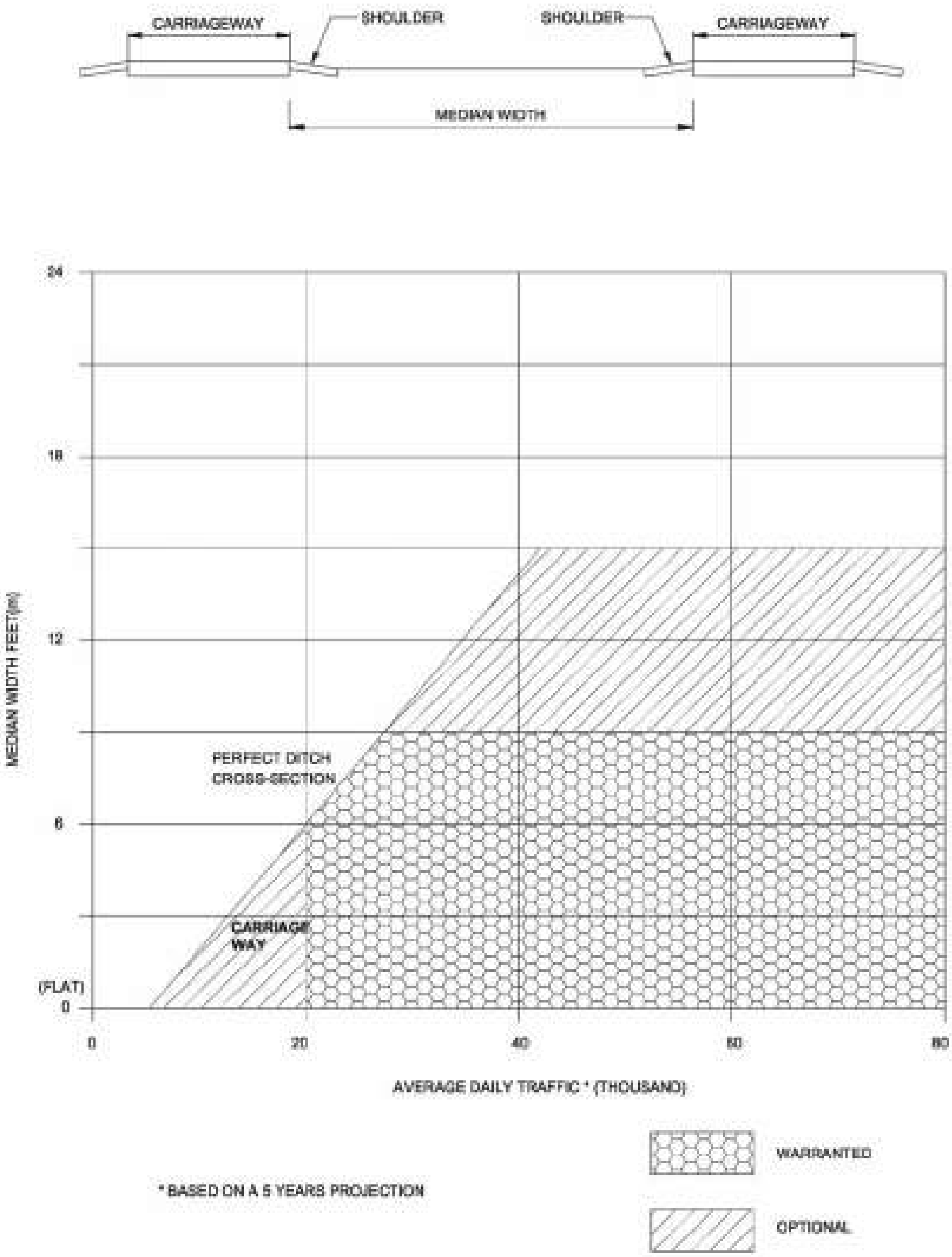


Fig. 8.02 Median Barrier Warrants for Expressways

(Source: AASHTO-Roadside Design Guide-2006)

8.2.3 *Types of safety barriers*

Based on the type of protection, barriers can be classified as:

- i) Longitudinal barriers
  - a) Verge side/Edge barriers
  - b) Median barriers
- ii) Crash cushions
  - a) For temporary installations in construction zones
  - b) Precast barriers

8.2.4 *Verge/edge barrier selection*

The barrier performance-level requirements must be considered when selecting an appropriate roadside barrier. Traditionally, most barriers have been developed and tested for passenger cars and offer marginal protection when struck by heavier vehicles at high speeds and at other than flat angles of impact. Therefore, if passenger vehicles are the primary concern, the steel plate beam system will normally be selected. However, locations with high traffic volumes, high speeds, high-crash experience, and/or a significant volume of heavy trucks and buses may warrant a higher performance level barrier (e.g., the concrete barrier). This is especially important if barrier penetration by a vehicle is likely to have serious consequences.

The dynamic deflection must also be considered in barrier selection. **Fig. 8.03** presents typical barriers with important dimensions and the dynamic deflection values. NCHRP-350 test requirements and their probable usages have also been described.

Another consideration in selecting the barrier type depends on maintenance of the system. Although the steel plate beam guardrail can often sustain second hits, it will need to be repaired with some frequency. In areas of restricted geometry, high speeds, high traffic volumes, and/or where railing repair creates hazardous conditions for both the repair crew and for motorists using the roadway, a rigid barrier should be considered.

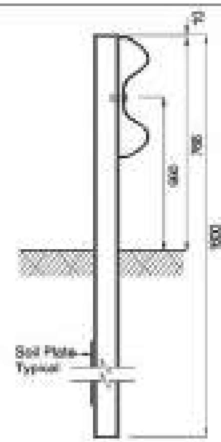
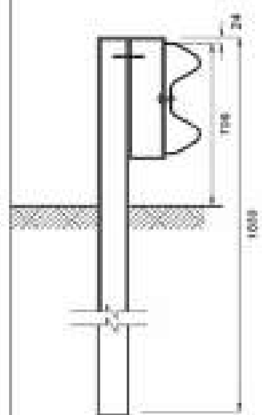
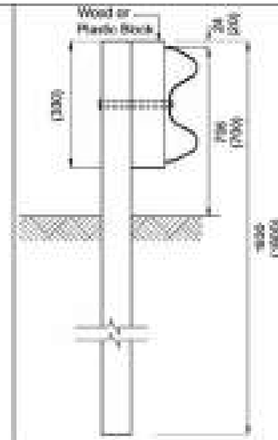
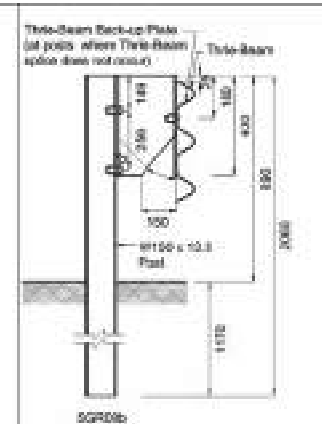
Figure				
AASHTO Designation	SGR02	SGR09a	SGR04b	SGR09b
System	W-beam (weak post)	Block out thrie beam (strong post)	Blocked out W-beam (strong post)	Modified thrie beam
Test Level	TL3	TL-3	TL-3	TL3
Type	Flexible barrier	Semi-rigid barrier	Semi-rigid barrier	Semi-rigid barrier
Post Spacing	3810 mm	1905 mm	1905 mm	1905 mm
Total Height	1600 mm	1980 mm	1830 mm	2060 mm
Height above G.L.	776 mm	730 mm	730 mm	890 mm
Maximum Deflection	Approximately 2 m	Approximately 0.6 m	Approximately 0.9 m	Approximately 0.9 m
General Remarks	Barrier as shown is TL -3, TL -2 design is 610 mm to centre of rail with W -beam rail splices located midway between posts.	Used with steel or wood posts and wood or plastic blocks.	TL-2 with steel blocks. **Note: The values shown in the bracket are as per MORTH Circular.**	This barrier can accommodate vehicles ranging in size from 800 kg subcompacts to a 15000kg intercity bus.

Fig. 8.03 Longitudinal Barriers

(Source: Roadside Design Guide - AASHTO 2006)

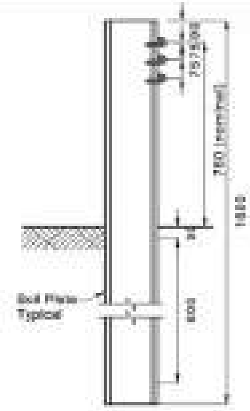
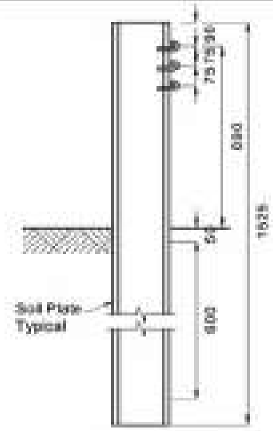
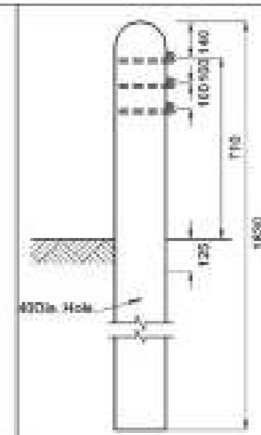
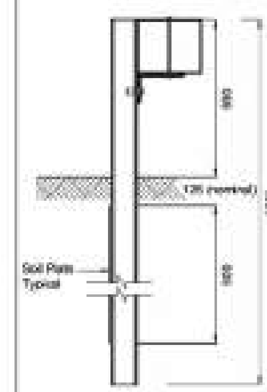
Figure				
AASHTO Designation	SGR01a	SGR01b	SGR01c	SGR03
System	Three Strand Cable (weak post)	Three Strand Cable (weak post)	Three Strand Cable (weak post)	Weak post box beam
Test Level	TL3	TL3	TL3	TL-3
Type	Flexible barrier	Flexible barrier	Flexible barrier	Semi-rigid barrier
Post Spacing	5000 mm	5000 mm	3800 mm	1830 mm
Total Height	1600 mm	1525 mm	1830 mm	1600 mm
Height above G.L.	850 mm	780 mm	850 mm	690 mm
Maximum Deflection	3.5 m	3.5 m	3.5 m	Approximately 1.5 m
General Remarks	For shallow angle impacts, barrier damage is usually limited to several posts, which must be replaced. Cable damage is rare except in severe crashes. A crashworthy end terminal is critical in each of the cable system, both to provide adequate anchorage to develop full tensile strength in the cable and to minimise vehicle decelerations for impacts on either end of an installation.			For use in Interchange Ramps

Fig. 8.03 Longitudinal Barriers
(Source: Roadside Design Guide-AASHTO 2006)

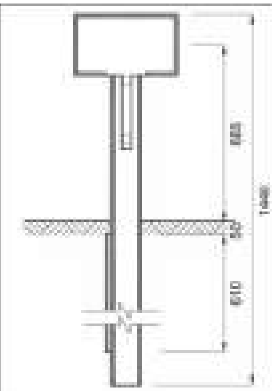
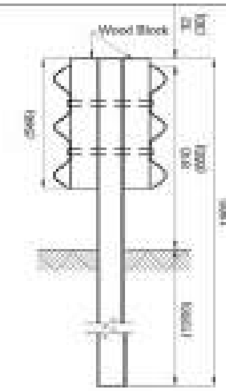
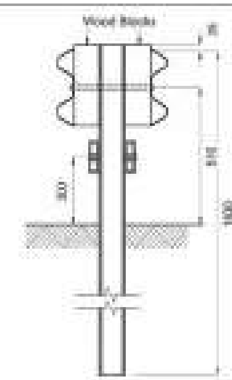
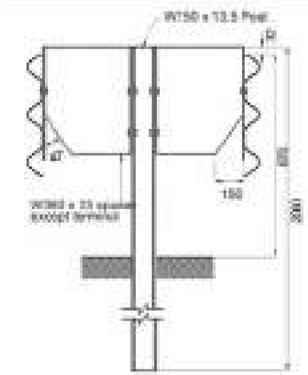
Figure				
AASHTO Designation	SGM03	SGM09a	SGM05a	SGM09b
System	Weak-post box beam median	Strong post thrie beam median barrier	Strong-post W-Beam	Strong post – thrie beam median barrier
Test Level	TL-3	TL-3	TL-3	TL-4
Type	Flexible barrier	Semi rigid barrier	Semi rigid barrier	Semi-rigid barrier
Post Spacing	1830 mm	1905 mm	1905 mm	1905 mm
Total Height	1440 mm	1980 mm	1830 mm	2060 mm
Height above G.L.	760 mm	842 mm	625 mm	902 mm
Maximum Deflection	1.7 m	Approximately 0.5 m	Approximately 0.6 m	Approximately 0.5 m
General Remarks	The barrier system is suitable for both wide and narrow medians.	Used in narrow medians. Normal impacts do little damage to the rail. **Note: The values shown in the bracket are as per MORTH Circular.**	This system is satisfactory for use in narrow medians. After typical impacts, the system remains serviceable.	These systems are satisfactory for use in narrow medians.

Fig 8.03 Longitudinal Barriers

(Source: Roadside Design Guide – AASHTO 2006)

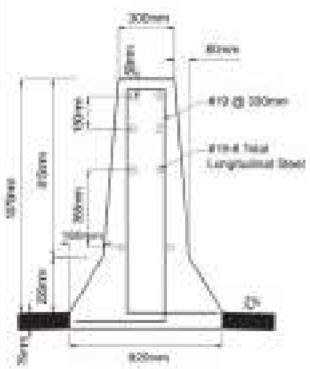
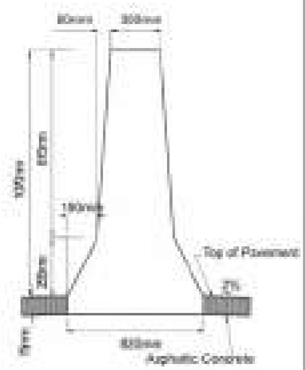
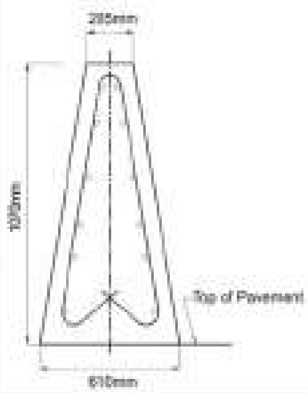
Figure				
AASHTO Designation	SGM12	SGM11B	SGM11b	SGM11a
System	Tall wall concrete safety shape (reinforced)	Tall wall concrete safety shape (non-reinforced)	Single slope concrete barrier	Concrete Safety Shape (NJ-Shape)
Test Level	TL-5	TL-5	TL-5	TL-4
Type	Rigid barrier	Rigid barrier	Rigid barrier	Rigid Barrier
Post Spacing	-	-	-	-
Total Height	1145 mm	1145 mm	1070 mm	810 mm
Height above G.L.	1070 mm	1070 mm	1070 mm	740 mm
Maximum Deflection	0 m	0 m	0 m	0 m
General Remarks	This is also New Jersey Type with higher heights and used where truck traffic is high.		This barrier is suitable for both permanent and tem porary applications.	The safety -shape barrier is suitable for narrow medians. Both faces can be flared away from the centreline to provide room for rigid objects to be installed in medians.

Fig 8.03 Longitudinal Barriers

(Source: Roadside Design Guide – AASHTO 2006)

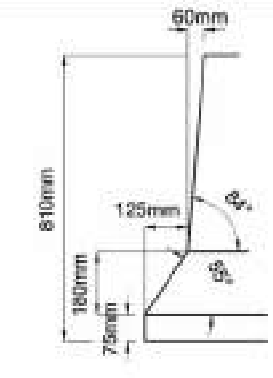
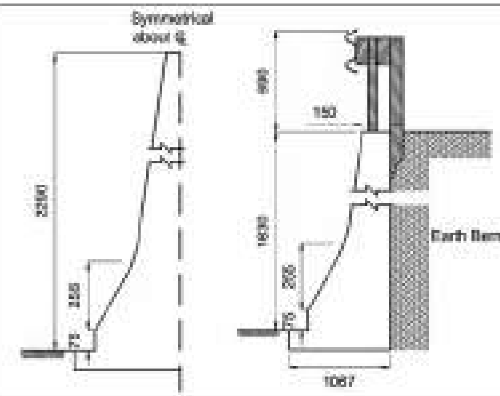
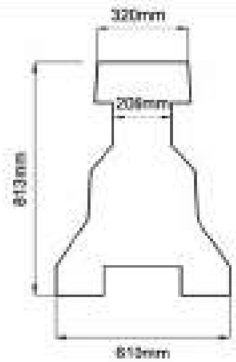
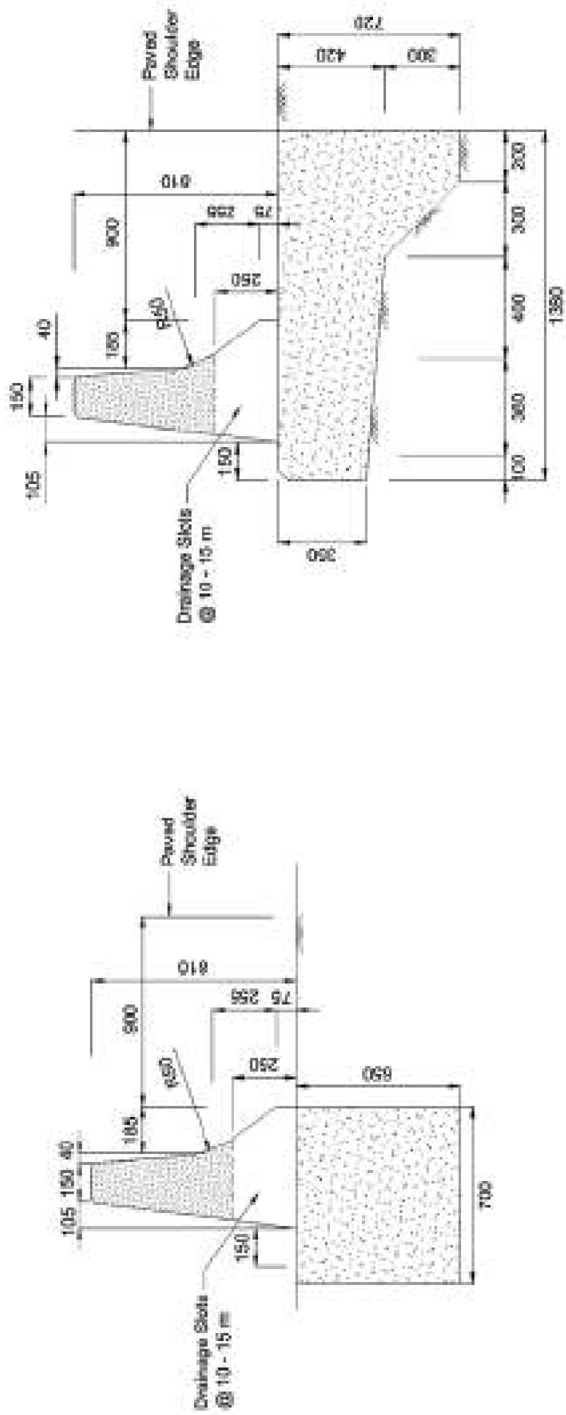
Figure			
AASHTO Designation	SGM11b	MB5	SWC01
System	Concrete Safety Shape (F-Shape)	Concrete Safety Shape	Movable concrete barrier
Test Level	TL-4	TL-4	TL-3
Type	Rigid Barrier	Rigid Barrier	Rigid barrier
Post Spacing	-	-	
Total Height	810 mm	2320 mm	813 mm
Height above G.L.	740 mm	2320 mm	813 mm
Maximum Deflection	0 m	0 m	0 m
General Remarks	The safety-shape barrier is suitable for narrow medians. Both faces can be flared away from the centreline to provide room for rigid objects to be installed in medians.	The standard New Jersey shape with extended upper stem serve as a maintenance -free glar e screen. Used at bridge railing, roadside and on median	May be used on Toll plaza.

Fig 8.03 Longitudinal Barriers
(Source: Roadside Design Guide – AASHTO 2006)



ON CURVE ALIGNMENT
(Near Minimum Readius)

NORMAL CONDITION
(Comfortable Alignment)

Fig. 8.03 Longitudinal Barriers
(Source : Roadside Design Guide - AASHTO 2006)

Table 8.02 summarizes the advantages and disadvantages of the roadside barriers and provides their typical usage. **Table 8.03** summarizes the general selection criteria which apply to a roadside barrier.

Table 8.02 Barrier Selections

System	Advantages	Disadvantages	Typical Usage
Steel Plate Beam Guardrail	1) High level of familiarity by maintenance personnel. 2) Can safely accommodate wide range of impact conditions for passenger vehicles. 3) Relatively easy installation. 4) Remains functional after moderate collisions.	1) Cannot accommodate impacts by large vehicles at other than flat angles of impact. 2) At high -impact locations, will require frequent maintenance. 3) Susceptible to veh icular under ride and override.	1) Wider medians. 2) Low to medium volume of traffic.
Concrete Barrier	1) Can accommodate most vehicular impacts without penetration, especially the 1070 mm concrete barrier. 2) Little or no deflection distance required behind barrier. 3) Little or no damage sustained for most vehicular impacts; therefore, least need for maintenance. 4) No vehicular under ride/ override potential or snagging potential. 5) Light supports, sign supports, glare screens, etc., may be mounted on top.	1) Can induce vehicular rollover. 2) For given impact conditions, highest occupant decelerations; therefore, least forgiving of barrier systems. 3) Reduced performance where offset between carriageway way and barrier exceeds 3.6 m.	1) Where high traffic volumes are present. 2) Where high volumes of large vehicles are present. 3) Where maintenance operations will require lane closure. 4) Where poor geometrics exist. 5) Where snagging is a concern.

(Source: "Bureau of Design and Environment Manual" Illinois, December 2002)

Table 8.03 Selection Criteria for Roadside Barriers

1) Performance Capability	Barrier must be structurally able to contain and redirect design vehicle.
2) Deflection	Expected deflection of barrier should not exceed available room to deflect.
3) Site Conditions	Slope approaching on the barrier, and distance from traveled way, may preclude use of some barrier types.
4) Compatibility	Barrier must be compatible with planned terminal treatment and capable of transition to other carrier systems (such as bridge railing).
5) Cost	Standard barrier systems are relatively consistent in cost, but high -performance railings can cost significantly more.
6) Maintenance	
(a) Routine	Few systems require a significant amount of routine maintenance.
(b) Collision	Generally, flexible or semi -rigid systems require significantly more maintenance after a collision than rigid or high performance railings.
(c) Materials Storage	The fewer the number of different systems used, the fewer inventory items/storage space required.
(d) Simplicity	Simpler designs, in addition to costing less, are more likely to be reconstructed properly by field personnel.
7) Aesthetics	Occasionally, barrier aesthetics is an important consideration in selection.
8) Field Experience	The performance and maintenance requirements of existing systems should be monitored to identify problems that could be lessened or eliminated by using a different barrier type.

(Source: "Bureau of Design and Environment Manual" Illinois, December 2002)

8.2.4.1 Cost considerations for use of concrete barrier on roadside

New Jersey Safety Side Barrier (AASHTO designation - SGM 11a & b) of height 810 mm above the adjacent pavement or F-shape (AASHTO designation - SGM 10a & b) of height 1070 mm above the adjacent pavement are acceptable as roadside concrete barrier. The sloped front (traffic side) face and vertical back makes it more vulnerable to over turn. Therefore, the roadside version usually contains more reinforcing steel and/or a more elaborating footing design unless earth support is available on the backside of the barrier.

Moreover, the presence of continuous concrete barrier on the shoulder side will be a hindrance for drainage of the runoff from the carriageway. This would require providing drainage on the shoulder side using kerb and channel coupled with drainage slots/ openings as outlets on the crash barrier at 10 to 15 m intervals. This is required to be followed by provision of chute drains over the embankment for safe passage of the runoff from the carriageway.

Typical arrangement is shown in Fig. 8.04.

The provision of continuous concrete barrier may produce tunnel effect on the road users. However, where it is necessary to provide Noise Barriers, the concrete crash barrier shall provide a good foundation for the purpose.

Compared to metal beam barriers, the concrete barriers require less maintenance and less attendance. The concrete barriers can also sustain more amounts of minor to medium collisions, without maintenance, compared to metal beam barriers which require immediate attention and replacement of the damaged elements. The initial costs of concrete barriers are more than metal beam barriers. A rough cost estimate for comparative purposes is indicated below:

- Roadside concrete crash barrier with chutes — Rs 18,000 per meter
- Roadside concrete crash barrier without chutes — Rs. 15,000 per meter
- Roadside Metal beam barrier (W – shape) — Rs 3,000 per meter
- Median side concrete crash barrier — Rs 5,500 per meter

8.2.5 *Median barrier selection*

For expressway median (4.5 m), the centrally placed double faced concrete barriers or double faced steel plate – W-beam type are the two alternatives. A 4.5 m wide median

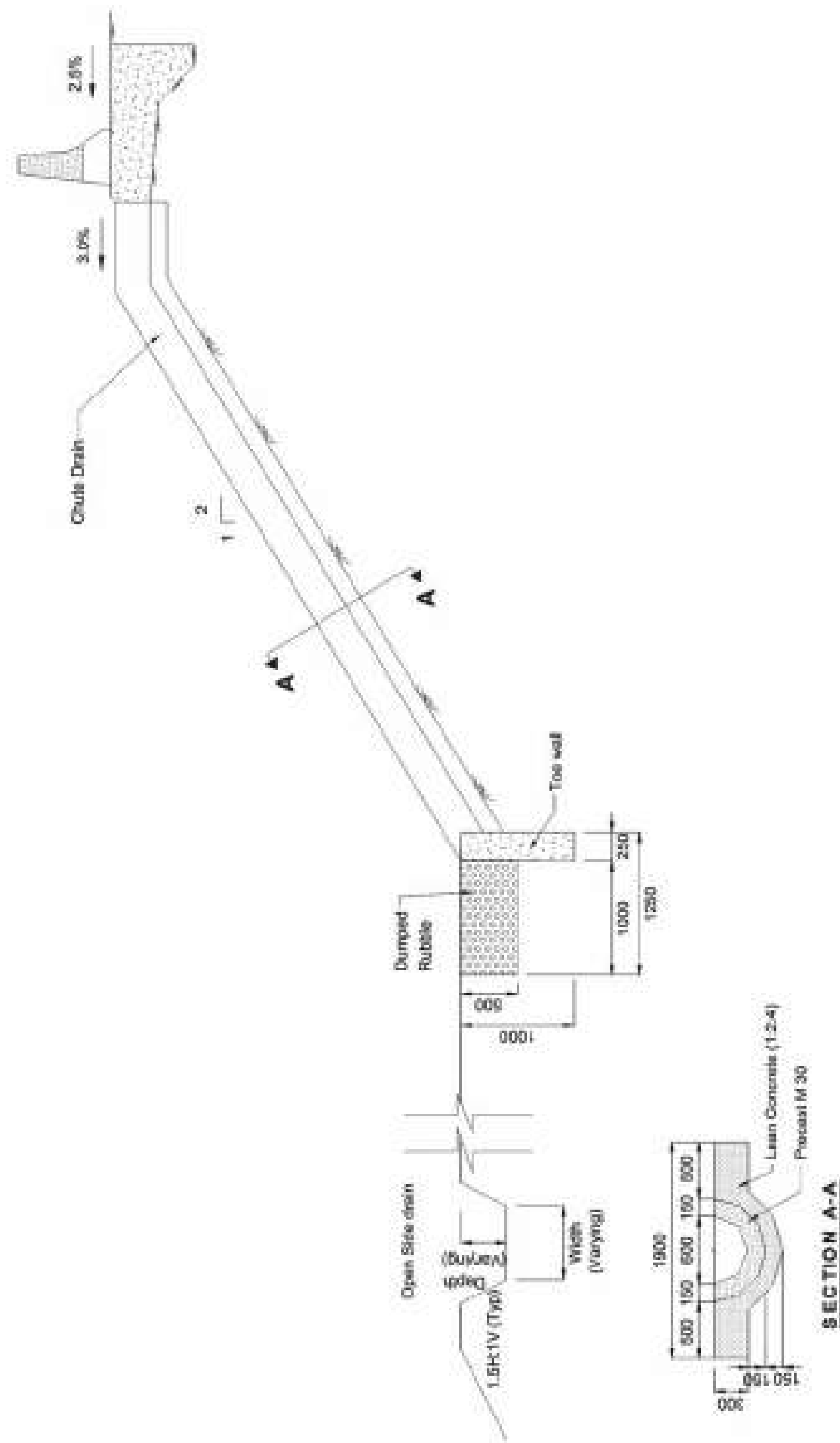


Fig. 8.04 Typical Arrangement Concrete Barrier on Shoulder Side

sufficiently meets the dynamic deflection requirement to arrest and redirect the errant vehicle. Compared to concrete barriers, the metal beam barriers are maintenance prone requiring periodic attention. Such maintenance is also a safety hazard.

In spite of initial higher cost, on maintenance consideration, concrete barrier on median is preferred in Indian context.

On wide medians, where the barriers used to be placed wide apart, the cost aspect may require trade off for the selection of median barrier systems. These involve a subjective evaluation of the many trade-offs between systems:

Median Width. The median width will significantly affect the probability of impact (i.e., the number of hits) and the likely angles of impact. The former will influence maintenance costs; the latter influences safety. The greater the offset to the barrier, the higher the likely angle of impact. Therefore, considering both maintenance and safety, this favours the use of the concrete barrier on narrow median widths and the steel plate double faced guardrail system for wider medians. The concrete barrier may be used on wider median widths on high-volume roadways where crossover crashes would be catastrophic.

Heavy Vehicle Traffic. The concrete barrier is more likely to restrain and redirect heavy vehicles (trucks and buses) than the steel plate double faced guardrail system. Therefore, where there is a high volume of heavy vehicles, this may favour the concrete barrier even on medians wider than 8 m. If there has been an adverse history of heavy-vehicle cross over crashes, the 1070 mm concrete barrier should be considered.

Costs. The initial cost of the concrete barrier will exceed, perhaps by a wide margin, the initial cost of the steel plate double faced guardrail system median barrier. The concrete barrier may also require a closed drainage system in the median, further increasing initial costs. However, the maintenance costs per impact on the concrete barrier will probably be far less, which favours the concrete barrier in narrow medians and/or on high-volume highways.

Maintenance Operations. Two factors are important. First, maintenance response time will influence safety. The longer a damaged section of median barrier is present, the greater the likelihood of a second impact on a substandard barrier. This observation favours the use of the concrete barrier which normally sustains far less damage when impacted. Second, the maintenance operations for repairing damaged barrier can interrupt traffic operations. It is particularly undesirable to close a traffic lane to repair a barrier. The consideration of maintenance operations generally favours the use of the concrete barrier in narrow medians and/or on high-volume highways.

Appurtenances. A roadway with a median barrier may also warrant other appurtenances in the median (e.g., highway lighting, signs, and glare screens). Since such appurtenances are warranted, this favours the use of the concrete barrier.

Table 8.04 summarizes the advantages and disadvantages of the median barriers and provides their typical usage.

The barriers discussed above may also be used in locations other than median. This would typically occur where a barrier is needed to separate lanes of traffic moving in the same direction, or beginning to diverge.

Table 8.04 Median Barrier Selection

Note: Same as Table 8.02

8.3 VERGE SIDE/EDGE BARRIER: PLACEMENT AND END TREATMENTS

A verge side/edge barrier is a longitudinal barrier used to shield roadside obstacles or non-traversable terrain features. It may occasionally be used to protect pedestrians, bystanders from vehicular traffic.

8.3.1 *Placement considerations*

The Verge side/Edge barriers shall be placed on the earthen shoulder with a minimum clearance of 250 mm from the paved shoulder edge.

This placement/provision of longitudinal barrier shall be continuous with exceptions/ adjustment near structures or any other hazards which may be unsafe for the vehicular traffic.

8.3.2 *End treatments*

A crashworthy end treatment is considered essential. To be crashworthy, the end treatment should not spear, vault, or roll a vehicle for head-on or angled impacts. For impacts within the length of need, the end treatment should have the same re-directional characteristics as the standard verge side/edge barrier.

For Expressways, the barriers may be provided for the entire length. However near the

Toll plaza and at Gore areas, end treatment may be required to be provided. In addition this may also be required to protect bridge piers, utility poles and foundation of overhead sign boards.

An untreated end of the roadside barrier can be hazardous, because the barrier can penetrate the passenger compartment and cause the impact vehicle to stop abruptly. End treatments should therefore form an integral part of safety barriers. And end treatment should not spear, vault or roll a vehicle for head-on or angled impacts.

For the expressway, turn down end treatment shall not be used. On the other hand the same height is maintained parallel to carriageway or paved shoulder edge for around 10-15 m with crash cushion at the end. The layout may also be flared for additional safety.

A typical arrangement of embankment guardrail end treatment and a typical connection between two types of safety fences are presented in **Fig. 8.05** and **Fig. 8.06** respectively. **Fig. 8.07** presents a typical layout of crash cushion at Gore areas and near Toll plaza.

A typical pictorial view of crash cushions can be seen in **Fig. 8.08**.

8.4 MEDIAN BARRIERS: PLACEMENT AND END TREATMENTS

Median barrier can be defined as a longitudinal barrier used to prevent an errant vehicle from crossing the highway median.

8.4.1 *Placement recommendations*

All traffic barriers perform best when an impacting vehicle has all its wheels on the ground at the time of impact, and its suspension system is neither compressed nor extended. Thus, major factors to consider in the lateral placement of a median barrier are the effects of the terrain between the edge of the travelled way and the barrier on the vehicle trajectory. The lateral offset from safety barrier to the edge of the carriageway is given in "**Fig.1.06** Location of Safety Barrier and **Table 1.07** Width of Paved Shoulder - **Chapter-1** Geometric Design". Other significant factors affecting barrier performance are as follows:

Terrain Effects

Terrain conditions between the carriageway and the barrier can have significant effects on the barriers impact performance. Kerbs and sloped medians (including super-elevated sections) are two prominent features, which deserve special attention.

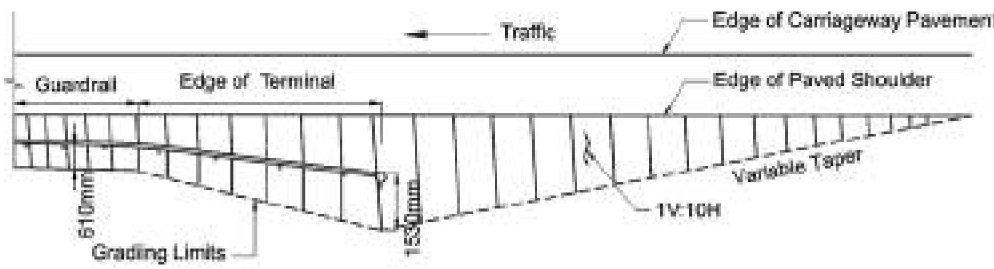


Fig 8.05 Embankment Guardrail End Treatment

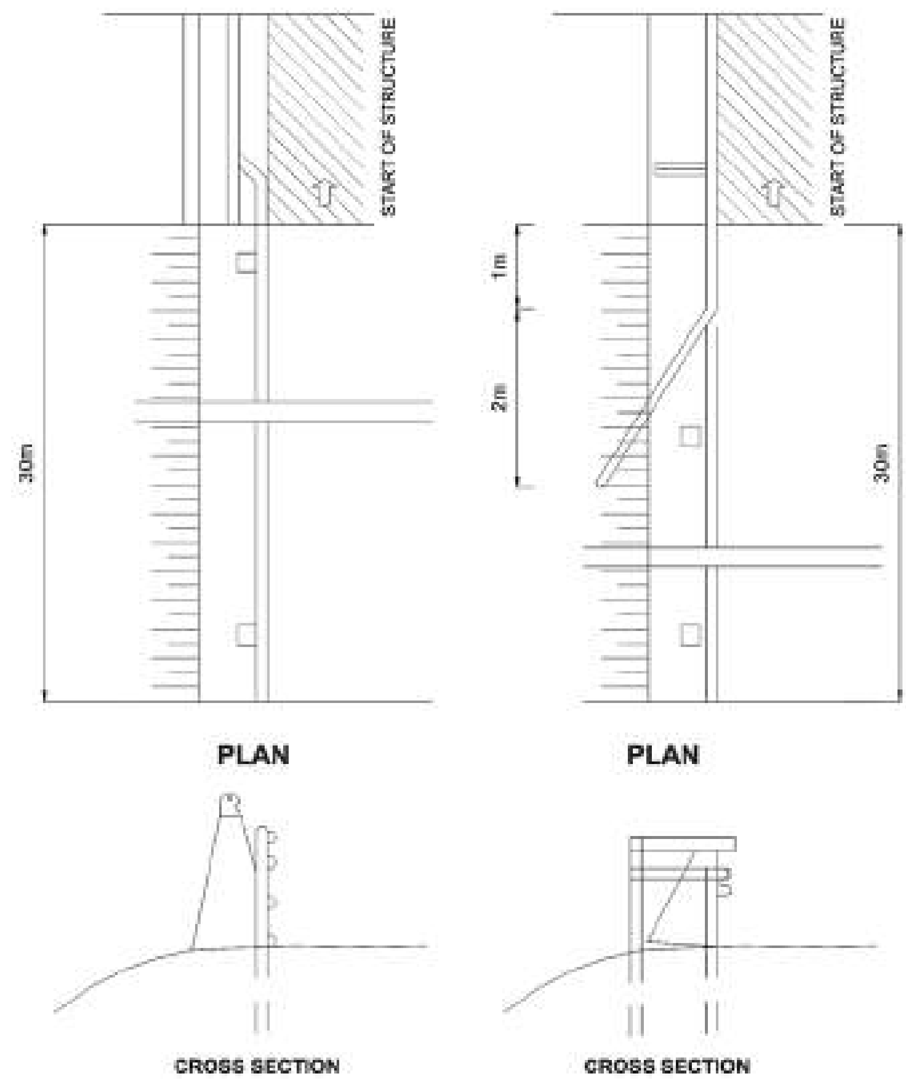


Fig. 8.06 Connection between two types of Safety Fences

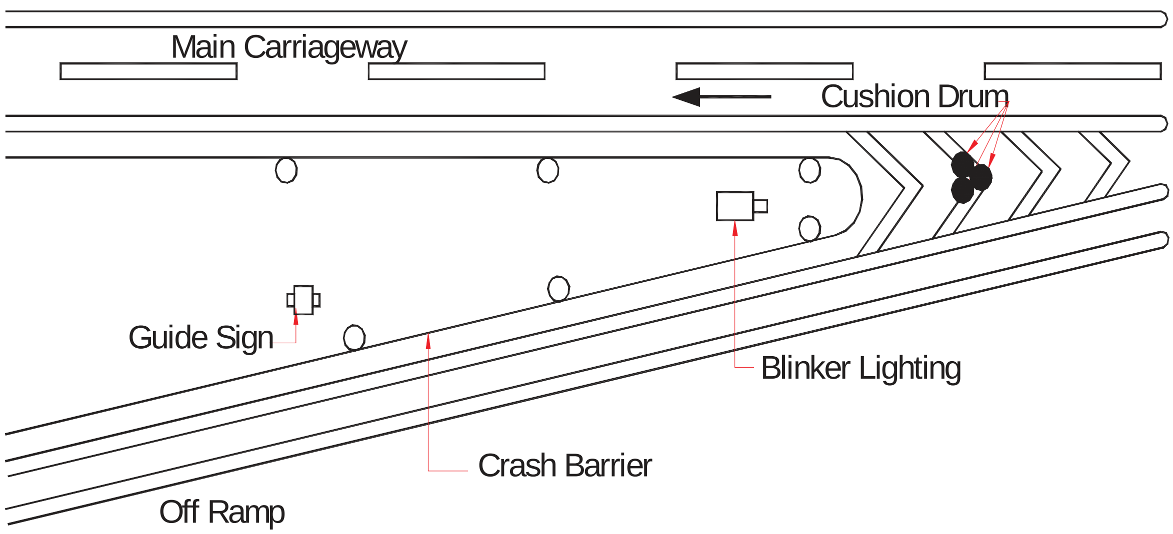


Fig. 8.07 Crash Cushion at Gore Area

Fig. 8.08 Crash Cushion

Sloped Medians

The most desirable median is one that is relatively flat (slopes of 10:1 or less) and free of rigid objects. If warranted, the barrier can then be placed at the centre of the median. When these conditions cannot be met, placement guidelines are necessary.

Fig. 8.09 shows three basic median sections for which placement guidelines are presented. In each section, it is assumed that a median barrier is warranted. Section I applies to depressed medians or medians with a ditch section. Section II applies to stepped medians or medians that separate travel ways with significant differences in elevation and Section III applies to raised medians, or median berms.

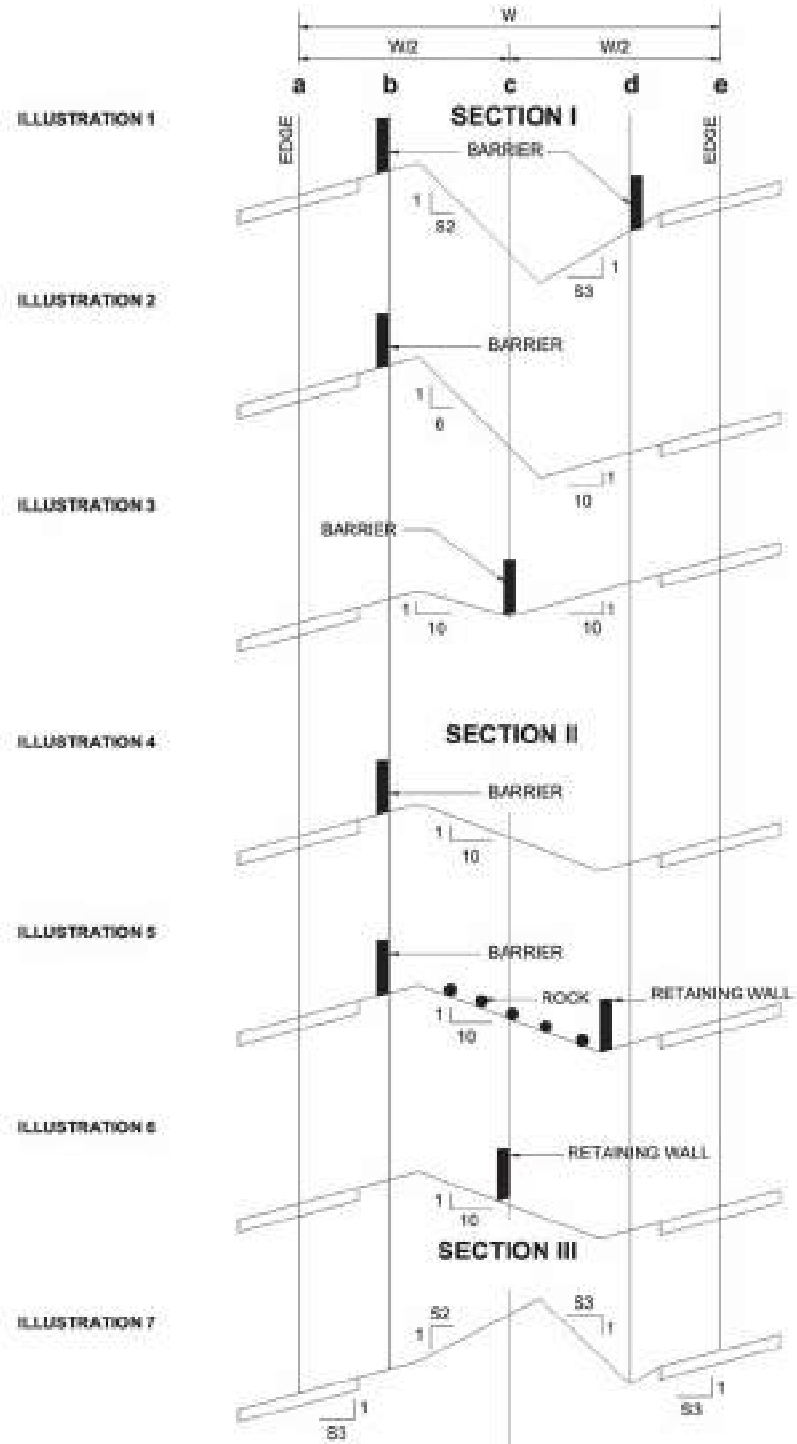


Fig. 8.09 Recomended Barrier Placement in Sloped Median
(Source: AASHTO-Roadside Design Guide-2006)

Section I - The slopes and the ditch section should first be checked to determine if a roadside barrier is warranted. If both slopes require shielding (Illustration) a roadside barrier should be placed near the shoulder on each side of the median (“b” and “d”). If only one slope requires shielding eg. a median barrier should be placed at “d”. In this situation, a rigid or semi-rigid barrier is suggested and a kerb rail should be installed on the ditch side of the barrier to prevent vehicles that have crossed the ditch from snagging on a post and beam railing system.

If neither slope requires shielding but both are steeper than 10:1(Illustration a median barrier should be placed on the side with the steeper slope when warranted.

For example, if: S_2 = 6:1 and S_3 = 10:1

The barrier would be placed at “b”. A rigid or semi-rigid system is suggested in this situation. If both slopes are relatively flat (Illustration 3), a median barrier may be placed at or near the centre of the median (at “c”) if vehicle override is not likely. Any type of median barrier can be used, provided its deflection is not greater than one half the median width.

Section II - If the embankment slope is steeper than approximately 10:1 (Illustration 4), a median barrier should be placed at “b”. If the slope is not traversable (rough rock cut, etc.) a roadside barrier should be placed at both “b” and “d” (Illustration 5)). It is not unusual for this section to have a retaining wall at “d”. If so, it is suggested that the base of the wall be contoured to the exterior shape of a concrete median barrier. If the cross slope is flatter than approximately 10:1, a barrier could be placed at or near the centre of the median (Illustration 6).

Section III - Placement criteria for median barriers on this cross-section (Illustration 7) are not clearly defined. Research has shown that such a cross-section, if high enough and wide enough can itself redirect vehicles impacting at relatively shallow angles.

As a general rule, if the cross-section itself is inadequate for redirecting errant vehicle, i.e. the slopes are relatively flat, a semi-rigid median barrier should be placed at the apex of the cross-section.

If the slopes are not traversable (rough rock cut, etc.) a roadside barrier should be placed at “b” and “d”. If retaining walls are used at “b” and “d”, it is recommended that the base of the wall be contoured to the exterior shape of a standard concrete barrier.

When a median barrier is warranted, it is desirable that the same barrier be used throughout the length of need, and that the barrier be placed in the middle of a flat median.

8.5 BARRIERS ON BRIDGES

Concrete Barriers should be used on Bridges. IRC: 5-1998 recommends suitably designed crash barriers shall be provided at the following situations to safeguard against errant vehicles:

- i) Multi-lane bridges and bridges on expressways
- ii) Flyovers and interchanges in urban situations
- iii) ROBs across railway lines
- iv) Open sea, breakwaters, deep valleys/gorges

For other cases, decision may be taken by the appropriate authority duly considering the importance of the structure and the level of safety warranted.

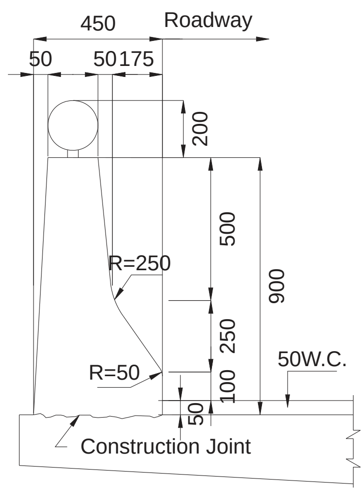
Crash barriers, when provided, shall be essentially of the following types:

Typical shapes and dimensional details of Crash Barriers and their locations on the bridge decks are given in **Fig. 8.10A**. These crash barriers are stronger compared to NCHRP-350 test criteria. The dimensions of these barriers meet the requirements of AASHTO as well as high containment requirements for TL-4 and TL-5 of NCHRP-350.

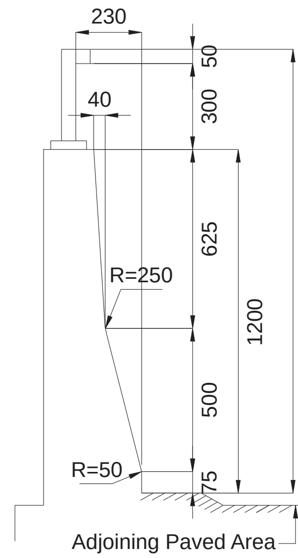
End Treatment of Bridge and Tunnel

For expressways, concrete barriers have generally been considered. However, in some places, provision of metal beam barriers may have to be adopted, as for example protecting hazards. Sometimes, it may not be economical to adjust the longitudinal concrete barriers.

In such circumstances, the two types of barriers need to be connected for example with concrete barrier on bridges and tunnels as shown in **Fig. 8.10B** and **Fig. 8.10C**. At the junction points, the flexible metal beam barrier has to be stiffened by reducing the spacing of supports and finally the W-beam is connected with the face of the concrete barrier. This stiffness on flexible metal beam barrier may be progressively met over a length of 10 to15 m.



Vehicle Crash Barrier
(Bridge without Footpath)



High Containment Crash Barrier

NOTE: ALL dimensions are in Millimeters.

Fig 8.10A Typical Crash Barrier

Source : IRC:5-1998 Standard Specifications & Code of Practice for Road Bridges, Section 1-General Features of Design(Seventh Revision)

Fig. 8.10B End Treatment at Bridge Barrier

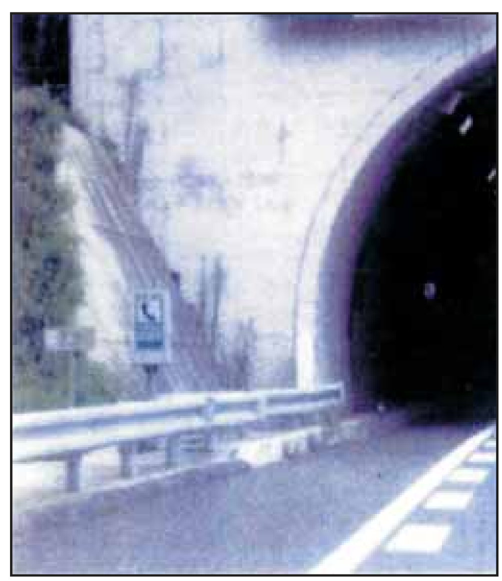


Fig. 8.10C End Treatment at Tunnel

8.6 OTHER BARRIERS

8.6.1 *Barriers to shield hazards*

General

- Hazards on expressways may include
- Foundations of gantry signs
- Piers and abutments of overpass structures
- Permanent structures
- Utility poles or allied structures

These may have to be accommodated on the median or on verge side. Such hazards from safety considerations need to be shielded or protected from vehicular collision.

Since on expressways, by policy decisions, continuous longitudinal safety barriers need to be provided, minor adjustment to the layout can provide desired safety against such hazards.

Verge Side/Edge Side Locations

The typical placement of barriers or deviations in longitudinal barriers are presented in **Fig. 8.11A**. The treatments are required to be provided for traffic in one direction only.

Median Side Locations

When the hazard is on median, the protection measures have to consider traffic in both directions. The layout becomes similar to verge side one but are extended with mirror image on the other side. A typical location is shown in **Fig. 8.11B**.

Removable Barrier

These are longitudinal barriers of high impact resistance. These are useful in toll plaza area, maintenance work zones, for temporary closures etc. These channelise the vehicles around hazardous areas, reducing exposure to liability and worker injury.

These may be made of concrete blocks connected by metal pipes or chain links or hollow polymer containers. These should preferably be light weight for easy manual handling.

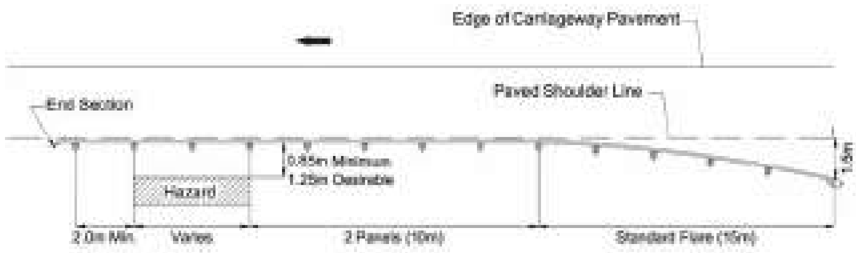


Fig. 8.11A Barrier Layout at Hazard Location

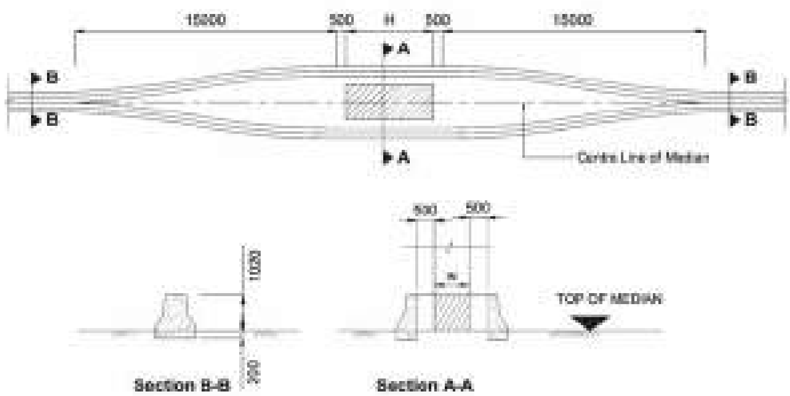


Fig. 8.11B Hazard at Median (with Concrete Barrier)

Fig. 8.11C Protection at Road Lighting Post

Currently in India water ballasted polyethylene barriers are being manufactured and used as removable barriers. Its lightweight allows one or two workers to quickly erect and the water inside provide greater degree of safety compared to conventional drums and cones. **Fig. 8.12A** and **B** show such barriers.

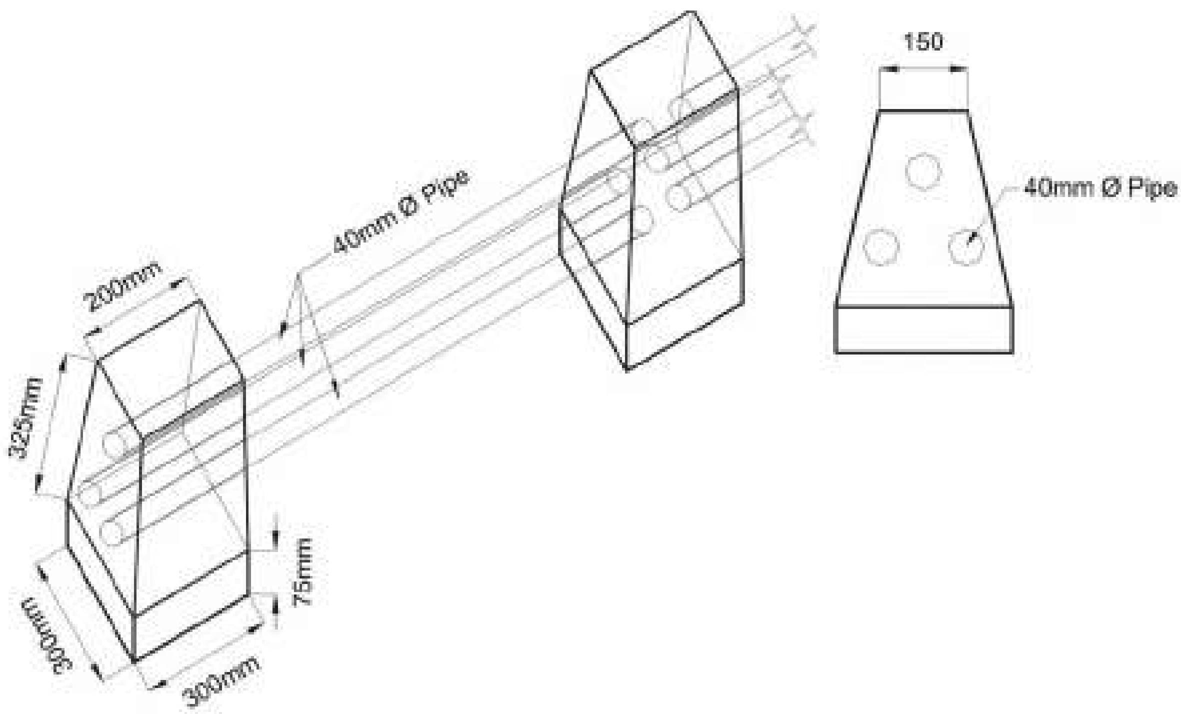


Fig. 8.12A Removable Concrete Barrier

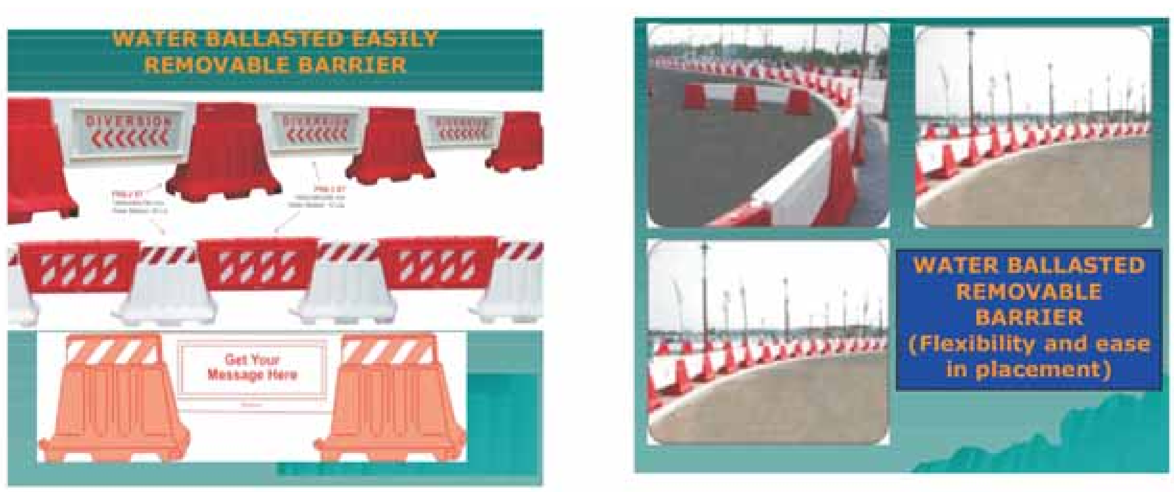


Fig. 8.12B Water Ballasted Removable

8.6.2 *Fences against falling objects*

The purpose of installation of fences against falling objects is the prevention of objects from falling from over-bridges down to expressways or the prevention of objects from jumping beyond the vehicles on expressways to areas out of the expressways, to ensure traffic safety.

1) ***Types***

Fences to prevent falling objects are grouped into the following two types according to their purposes.

i) Fences to prevent objects dropping from other roads over expressway.
ii) Fences to prevent objects falling off expressways into railway, major highway and canal: Installed along roadsides of expressways.

This fencing shall be installed vertically adjacent to the uprights of the parapets or crash barriers, starting from the base in the case of parapets with horizontal elements of metal, or starting from the top of the structure in the case of reinforced concrete parapets crash barrier. In any case the fencing should be a minimum of 2.20 m in height, starting from the pavement surface, and shall extend along the whole length of the overpass as per computation given in the following para. The grill shall be supported by stiff frameworks of suitable dimensions.

2) ***Places of Installation***

i) Fences to prevent objects dropping from over-bridges
   a) National Highways and State Highways.
   b) Over-bridges in densely populated areas used by a large number of people and vehicles.
   c) Over-bridges designated as school-commuting roads.
   d) Other sections where installation of fences is deemed necessary.
ii) Fences to prevent objects falling off expressways
   a) Sections crossing or nearing railway tracks.
   b) Sections crossing or nearing heavily trafficked truck roads.
   c) Sections in the vicinity of housing areas.
   d) Other sections where installation of fences is deemed necessary.

3) *Area of Installation*

The area of installation fences to prevent objects falling of expressways include the area crossing the facility to be protected and the adjacent allowance area. The adjacent allowance area is shown below.

The adjacent allowance area is represented by the following equation.

Length of adjacent allowance area

$$L = V_o \sqrt{\frac{2(H+3)}{g}} \left[\cos 15^o + \frac{\sin 15^o}{\tan \alpha} \right]$$

where

V_o = Speed of object jumping out of the expressway (m/s)

H = Height from the base of the facility to be protected to the road surface of the expressway (m)

α = rossing angle between the facility and the expressway (between 0 and 180 degrees) (a = 90 degrees is assumed in the case of proximity)

g = Gravity acceleration = 9.8 m/s^2

Typical arrangements of such fencings are shown in **Fig. 8.13**.

8.7 CRASH CUSHIONS

A crash cushion's major contribution to highway safety is its ability to absorbs energy at a controlled rate, thus stopping an impacting vehicle in such a way that its occupants may avoid serious injuries. There are basically two concepts, either of which is followed, to accomplish this task. These are:

- Kinetic Energy Principle
- Conservation of Momentum Principle

8.7.1 *Application of crash cushions*

Fixed objects as listed in **Table 8.01** require shielding when located within the designated clear zone for expressways. Some of these objects can be shielded only with crash cushion,

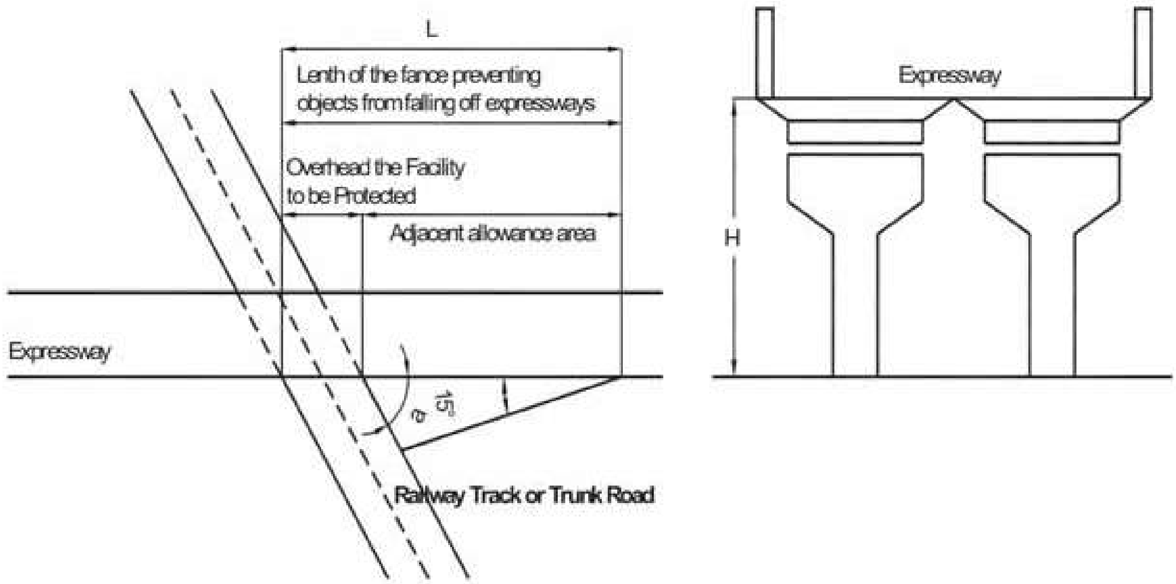


Fig. 8.13 Typical Fences against Failing Objects

but most can also be shielded with a properly designed longitudinal barrier with crashworthy end terminals. A common application of a crash cushion is in an exit ramp gore on an elevated or depressed structure where a bridge rail end or a pier requires shielding. Crash cushions are also frequently used to shield the ends of median barriers.

Special condition for which crash cushions are applicable is the protection of construction and maintenance personnel as well as motorists in work zones. Portable and temporary crash cushions have been developed for use in such situations. These shall be installed at Toll Plaza and Gore area.

CHAPTER - 9

TRAFFIC SIGNS AND PAVEMENT MARKINGS

CHAPTER - 9

TRAFFIC SIGNS AND PAVEMENT MARKINGS

9.1 GENERAL

9.1.1 *Introduction*

To maintain value added services, signs should be used to provide guidance, warnings, notice and regulatory information to road in well designed formats for ensuring comfortable, safe and smooth driving. Signs are also essential where hazards are not self-evident. These also provide information on entry/exit directions, destinations and points of interest. Clear, ample and effective signing is at places to provide adequate reaction time for the driver. Signs are designed so that they are legible to road users approaching them and readable in time to permit proper responses. Desired design characteristics include:

- Long visibility distances,
- Large lettering and symbols, and
- Short legends for quick comprehension

In general, the signage shall follow IRC: 67 code of practice for road signs and reference may be made to clause 800: traffic signs, markings and other appurtenances in MORTH – Specifications for road and bridge works.

In general, this chapter describes the Mandatory/Regulatory signs, Cautionary/ Warning signs and Informatory/Guide signs illustrated in this chapter for use only on Expressways. **Functional usage classifications are** generally defined as follows:

- Mandatory/Regulatory (Circular) signs:

These signs are used to impose legal restrictions applicable to particular locations and unenforceable without such signs. These include all signs, such as, Speed Limits, No Entry, etc. which give notice of special obligations, prohibitions or restrictions for traffic control, which the road users must comply. The violation of the rules and regulations conveyed by these signs is a legal offence and shall attract penalty.

- Cautionary/Warning Tringular signs:

These signs are used to call attention to actual or potentially hazardous conditions, so that the users can become cautious and take the desired action. These signs also advise drivers to exercise caution.

- Informatory/Guide (Rectangular) signs:

These signs are used to provide directions to motorists, including route designations, destinations, available services, points of interest, and other geographic, recreational, or cultural sites. These also inform drivers of traffic regulations and information on the points necessary for traffic operation.

9.1.2 *Expressway signing principles and classes*

As mentioned above, on Expressways (a high volume-high speed facility) the road signs require to provide adequate information on lane driving, advance information for exit, location of facilities for emergency need for vehicles, users and vehicles.

Therefore traffic signs on Expressways should serve distinct functions as follows:

- Give directions to destinations, or highway routes, or to another Expressway interchanges and toll plazas;
- Furnish advance notice of the approach to interchanges or toll plazas;
- Direct road users into appropriate lanes in advance of diverging or merging movements;
- Identify routes and directions for important destination on those routes;
- Show distances to destinations;
- Indicate access to general motorist services, rest, scenic, and recreational areas; and
- Provide other information of value to the road user such as weather, maintenance works and occurrence of incidents.

9.1.3 *Siting of signs with respect to the carriageway*

It shall be ensure that any sign, signal or any other device erected for traffic control, traffic guidance and/or traffic information shall not obscure any other traffic sign and shall not carry any advertisement.

Signs requiring decisions and choices (e.g. Guide signs) need to be located sufficiently far in advance of the decision point to permit drivers to position the vehicle in the appropriate lane or take other preparatory action. Signs shall be mounted on gantries, cantilevers, and butterfly or on over bridges with vertical clearances as applicable for vehicular operations.

Considering the Expressway configuration with 3.0 m wide paved shoulder, the sign supports need to be provided on the earthen shoulder. From the drivers' visibility considerations, the information which is applicable for all traffic lanes, general informations, lane distribution information shall generally be placed on overhead gantry or on over bridges (if available at the desired site). The exit or entry signs may be placed on cantilever. Placement of foundation and supporting structures shall be sufficiently away from paved shoulder edge on verge side maintaining stipulated vertical clearance for vehicle movements.

Overhead gantry and cantilever supports within the clear zone on expressways shall always be shielded by a safety barrier system.

Overhead guide signs may be, where practicable, mounted on overpass structures above the expressway to minimise the number of potentially hazardous roadside structures. Special designs for the signboard and/or its mounting may be required where an overpass structure is skewed in plan to the line of the Expressway.

For Cantilever mounted signs, the centre of the sign is typically located over the carriageway edge line; however the left edge of the sign shall be positioned no further left than the left edge of paved shoulder. On exit ramps, guide signs shall be located over the relevant lanes. Where number of signs are erected on a gantry, the outer edges of signs shall not extend beyond the outer edges of paved shoulders.

The desirable minimum distance over which signs should be seen is the legibility distance of the principal legend size, plus an additional one third of this distance to allow sufficient time for the driver to see the sign prior to reading its text.

9.1.4 *Mounting height and clearance*

All signs for through traffic shall be provided by overhead gantry / cantilever gantry. Kerb mounted signs supported on GI pipes shall be used at entry / exit of the Expressway or in wayside amenity / toll plaza areas. Overhead signs shall be placed on a structurally sound gantry or cantilever structure made of GI pipes. Its height, lateral clearance and installation shall be as per this “Guidelines for Expressways”.

Overhead Gantry

Shall be mounted at 5.5 m height above the highest point on the carriageway keeping 0.5 m additional clearance and shall be extended over the entire carriageway width of Expressway plus paved shoulder width.

Cantilever Gantry

Shall be mounted at a height of 5.5 m measured from the carriageway of the sign to the verge side of the paved shoulder.

Fig. 9.01A and **Fig. 9.01B** presents typical sign which may be placed on side mounted or overhead gantry structures. Overhead signage on gantry is preferable on the 2x3 expressways.

9.1.5 *Visibility of signs*

In order to make the signs more visible at night, in particular danger/warning signs and regulatory signs on expressway shall be provided with reflective materials. Care shall be taken that this does not result in road users becoming dazzled. The material shall be of high intensity micro prismatic grade sheeting conforming to MORTH Specifications.

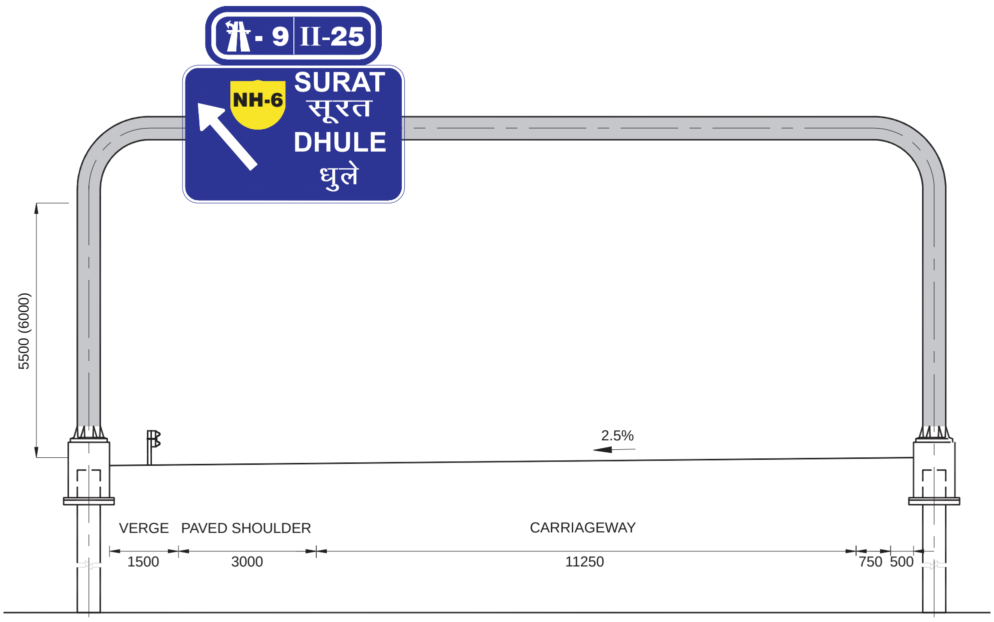
9.2 EXPRESSWAY TERMINALS AND INTERCHANGES: SIGN AND LANE MARKING LAYOUTS

This section illustrates typical signing and marking treatments for expressways and interchanges.

9.2.1 *Interchange exit numbering*

Interchange exit numbering provides valuable orientation for the road user on an Expressway. The feasibility of numbering interchanges or exits on an expressway will depend largely on the extent to which grade separations are provided. Where there is appreciable continuity of interchange facilities, interrupted only by an occasional intersection at grade, the numbering will be helpful to Expressway user.

Interchange numbering shall be used in signing each expressway exit. Interchange exit numbers shall be displayed with each advance Guide sign, Exit direction sign and Gore



NOTE: All Dimensions are in mm. and Typical Design may change to suit the site condition.

Fig 9.01A Typical Overhead Mounted Structure

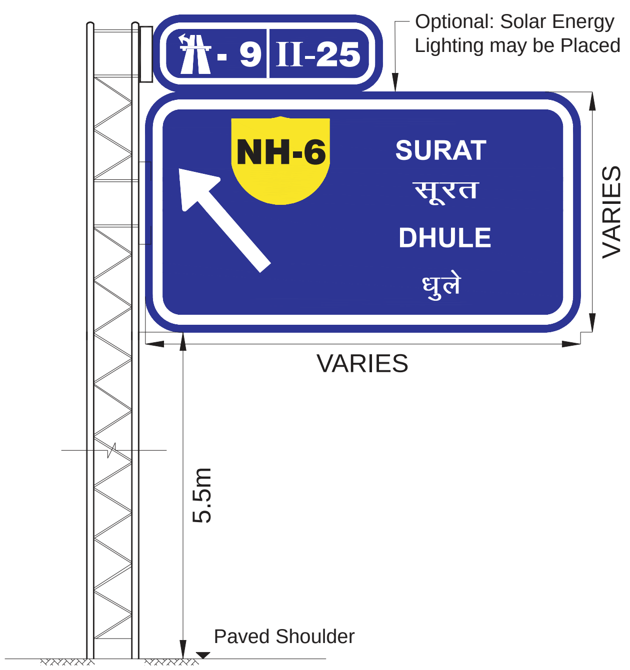


Fig. 9.01B Typical Exit Gore Sign

sign. The exit number shall be displayed on a separate plaque at the top of the advance Guide or Exit direction sign.

There are two approaches to interchange exit numbering: (1) Reference location sign numbering (km-base) or (2) Consecutive numbering

- km – basis is recommended in Indian situation since it is flexible for future additional interchanges.
- The start point (0 km) of the numbering shall be the start of the BOT project. Each BOT project shall be identified such as I, II, III etc. along the national Expressway (such as NE-9)
- It would be optional for the BOT concessionaire whether naming the Interchange or not.

Fig. 9.02 presents below a typical Exit (km) numbering sign

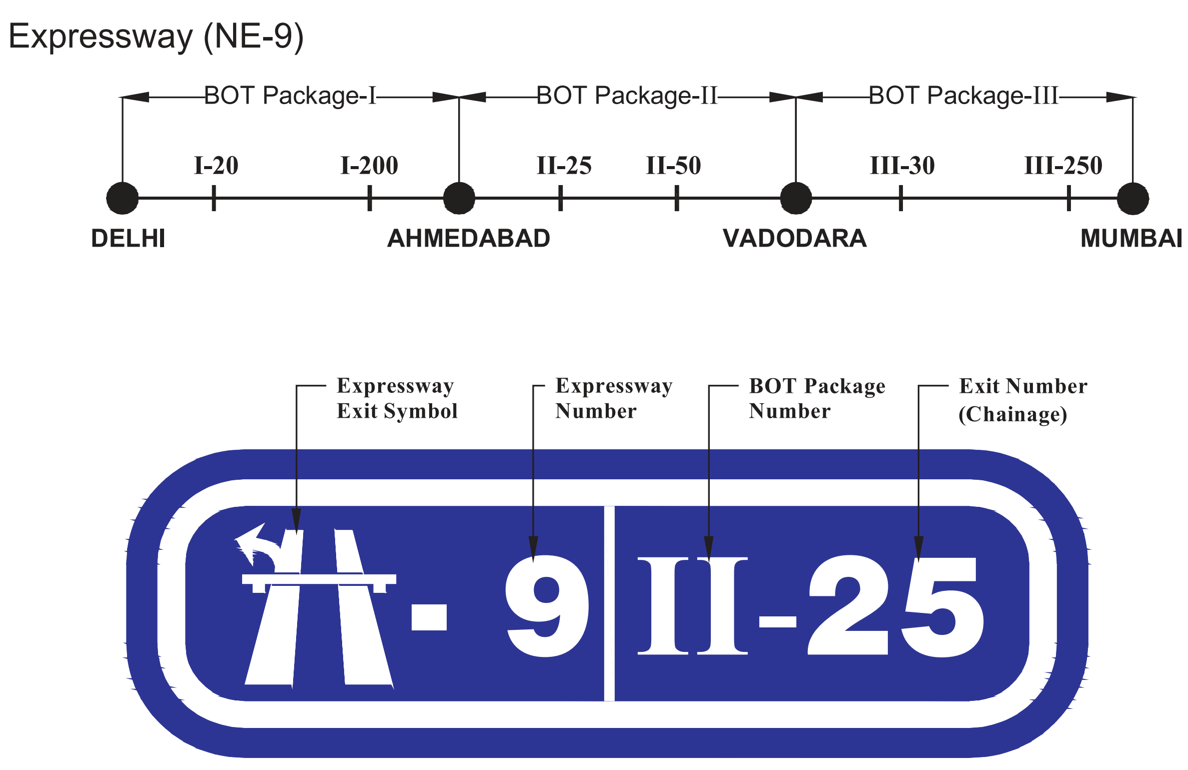


Fig. 9.02 km - Numbering

9.2.2 *Interchange guide signs*

The signs at interchanges and on their approaches shall include advance guide sign, Exit direction sign and Exit gore sign. Consistent destination messages shall be displayed on these signs.

9.2.2.1 Advance guide signs

The Advance Guide sign gives notice well in advance of the exit point of the principal destinations served by the next interchange and the distance to that interchange. Advance Guide signs should be placed at 500m, 1 km and at 2 km in advance of the exit . Fractions of kilometers or decimals of kilometers should not be used. Where Advance Guide signs are provided for a right exit, diagram signs should be used.

Fig. 9.03 Shows typical Interchange advance guide sign.

9.2.2.2 Exit direction signs

The exit direction sign repeats the route and destination information that was shown on the advance guide signs for the next exit, and thereby assures road users of the destination served and indicates whether they exit to the right or the left for that destination.

The message EXIT ONLY in black on a yellow panel shall be used on the overhead exit direction sign to advise road users of a lane drop situation.

Fig. 9.04 Shows typical Exit direction sign.

9.2.2.3 Exit gore signs

The Exit Gore sign in the gore indicates the exiting point or the place of departure from the main roadway. Consistent application of this sign at each exit is important.

The gore shall be defined as the area located between the main roadway and the ramp just beyond where the ramp branches from the main expressway.

Fig. 9.05 Shows typical Exit Gore sign.

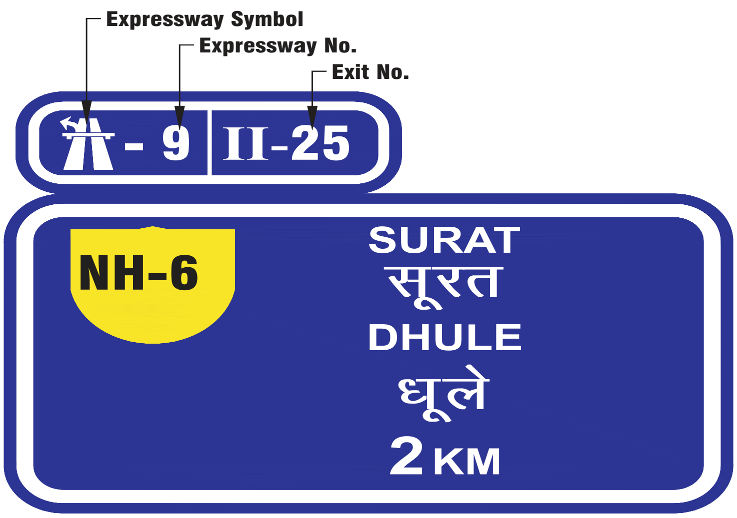


Fig. 9.03 Typical Interchange Advance Guide

Fig. 9.04 Typical Exit Direction Sign

Fig. 9.05 Typical Exit Gore Sign

9.2.3 *Next exit supplemental signs*

Where the distance to the next interchange is unusually long, Next Exit supplemental signs may be installed to inform road users of the next interchange. The Next Exit supplemental sign shall carry the legend NEXT EXIT X km. If the Next Exit supplemental sign is used, it shall be placed below the advance guide sign nearest the interchange.

Fig. 9.06 shows typical next exit supplemental sign.

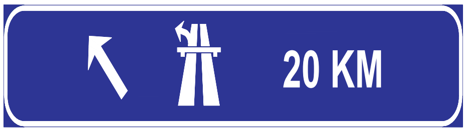


Fig. 9.06 Next Exit Supplemental Sign

9.2.4 *Expressway symbol sign*

Two, three wheelers shall be banned for expressway. One identical sign for expressway should be useful such as Germany or UK in order to avoid listing too many "not allowed vehicles". Fig. 9.07 shows expressway symbol sign.

Fig. 9.07 Expressway Symbol Sign

9.2.5 *End of expressway*

The minimum treatment for advance direction signing and conditions may warrant cantilever or overhead signing. In the case where an interchange is located near the start or end of expressway, the roads leading to expressway are treated with expressway type advance exit signs. The advance exit signs are placed on the non-expressway section of the route. Fig. 9.08.

Fig. 9.08 End of Expressway

9.2.6 *Characteristics of rural signing*

The tendency to group all signing in the immediate vicinity of rural interchanges should be avoided by considering the entire route in the development of sign plans. Extra effort should be given to the placement of signs at natural tangent locations to command the attention of the road user, particularly when the message requires an action by the road user.

9.2.7 *Post-Interchange signs*

If space between interchanges permits, as in rural areas, and where undue repetition of messages will not occur, a fixed sequence of signs should be displayed beginning 150 m beyond the end of the acceleration lane. At this point a Route sign assembly should be installed followed by a Distance sign as indicated in **Fig. 9.09**, at a spacing of 300 m. If space between interchanges does not permit placement of these three post-interchange signs without encroaching on or overlapping the Advance Guide signs necessary for the next interchange, or in rural areas where the interchanging traffic is primarily local, one or more of the post-interchange signs should be omitted.

Fig. 9.09 Distance Sign (Reassurance Sign)

9.2.8 *Distance sign*

The post-interchange Distance sign shall consist of a two- or three-line sign carrying the names of significant destination points and the distances to those points. The top line of the sign shall identify the next interchange with the name of the community near or through which the route passes and exit number, or if there is no community, the route number or name of the intersected highway.

Second line is second next exit. The third, or bottom line, shall contain the name and distance to a control city (if any) that has national significance for travelers using the route. When Interchange spacing is more than 10 km, the distance sign shall be provided in between at appropriate location. The distances displayed on these signs should be the actual distance to the destination points and not to the exit from the expressway or expressway.

Fig. 9.09 shows typical distance sign.

9.2.9 *Signing by class of interchange*

Full signing of the interchange should also cover all approaches and ramp. For Expressway there are two classes of interchange configurations i) System Interchange and ii) Service Interchange.

- System Interchange may be Cloverleaf or T-type
- Service Interchange may be Diamond or Trumpet type

Fig. 9.10 and **9.11** presents significant features of signing plan for Trumpet and Diamond Interchanges.

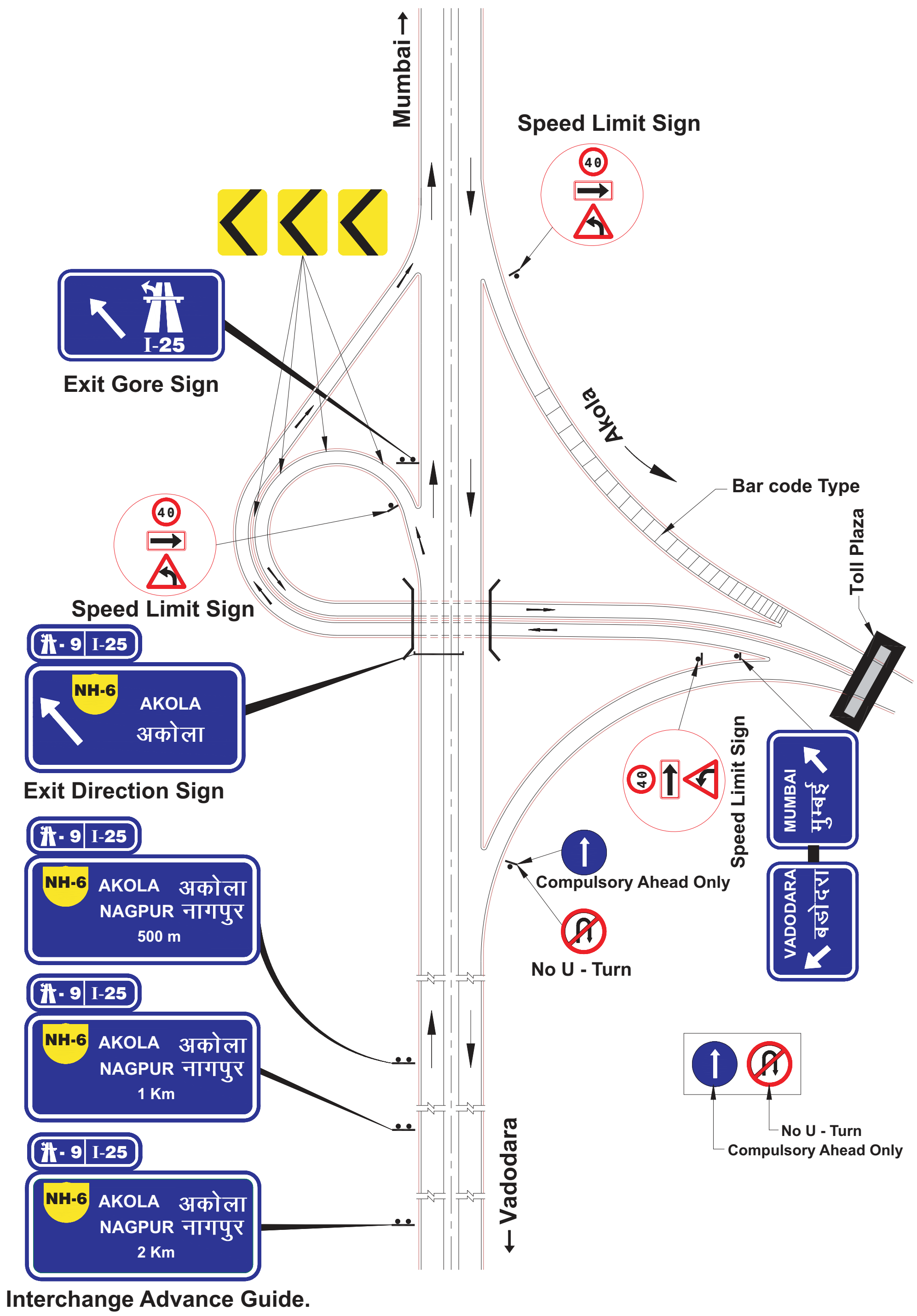


Fig. 9.10 Typical Layout for Trumpet Interchange

(Note: One side only, other side will be similar)

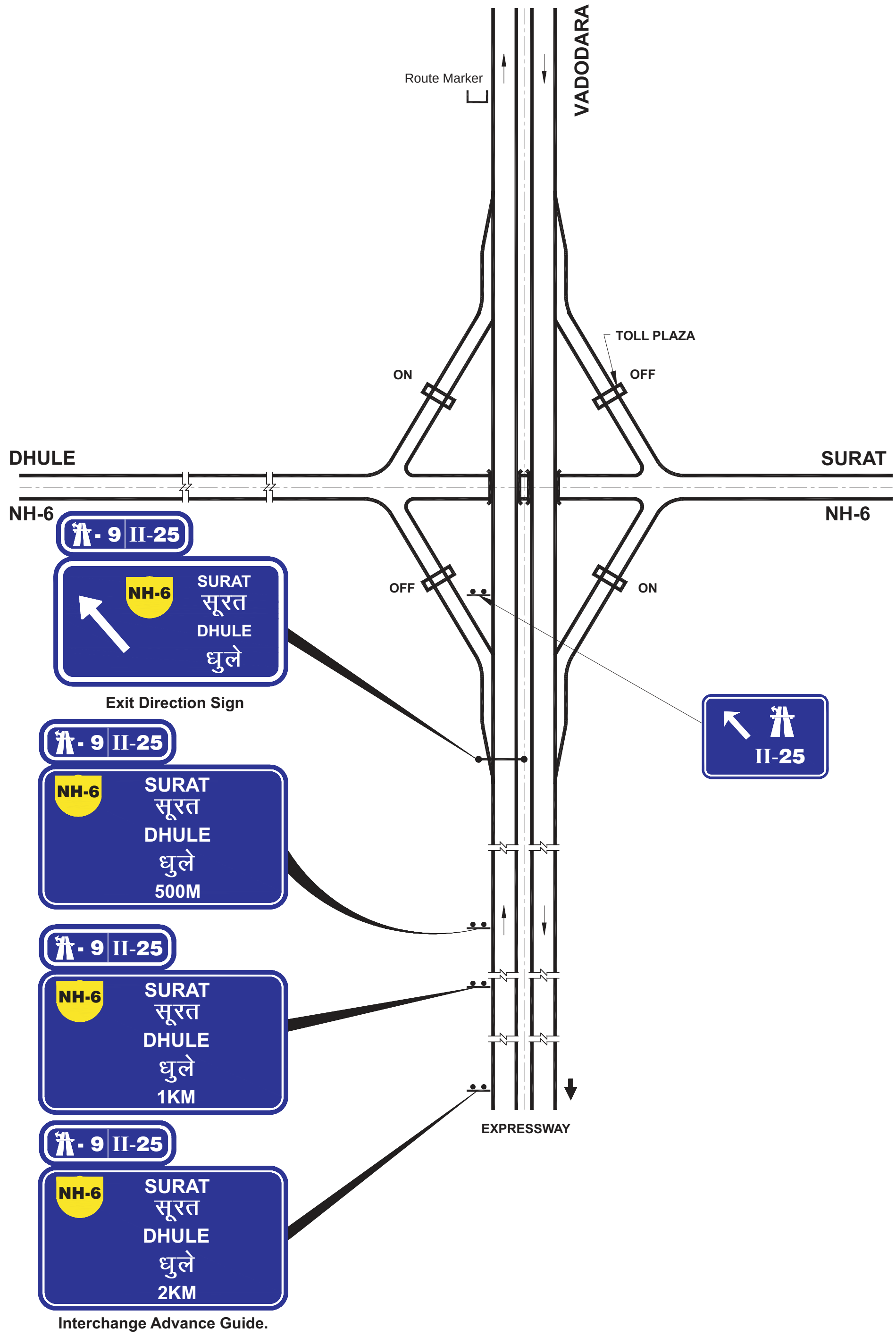
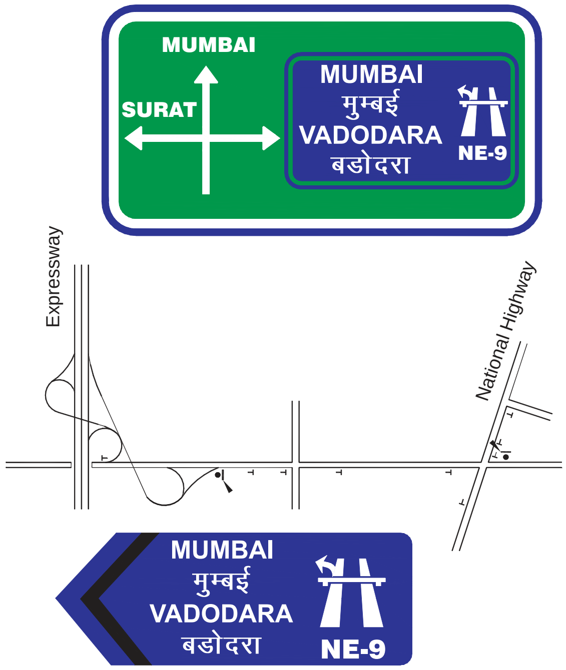


Fig. 9.11 Typical Layout of Diamond Interchange Sign

(Note: One side only, other side will be similar)

9.2.10 *Entry to service interchange*

Service interchange by design accommodates ingress and egress traffic between the expressway and non-expressway. A typical arrangement is shown in **Fig. 9.12.**



Service Interchange

Fig. 9.12 Service Interchange

9.2.11 *Direction sign at system interchange*

The direction signs are rectangular with arrows and letters. The inscriptions should be in English and other languages as necessary. The signs of this group include destination signs, direction signs, Re-assurance signs, route marker and place identification signs.

Fig. 9.13 and 9.14 show typical system interchanges.

9.2.12 *Lane drop exit type*

Major guide signs for all the lane drops at interchange shall be mounted overhead. An exit only panel shall be used for all interchange lane drops at which the through route is carried on the mainline. Advance Guide signs for lane drops within 2 km of the interchange should not contain the distance message. Wherever the dropped lane carries the through route,

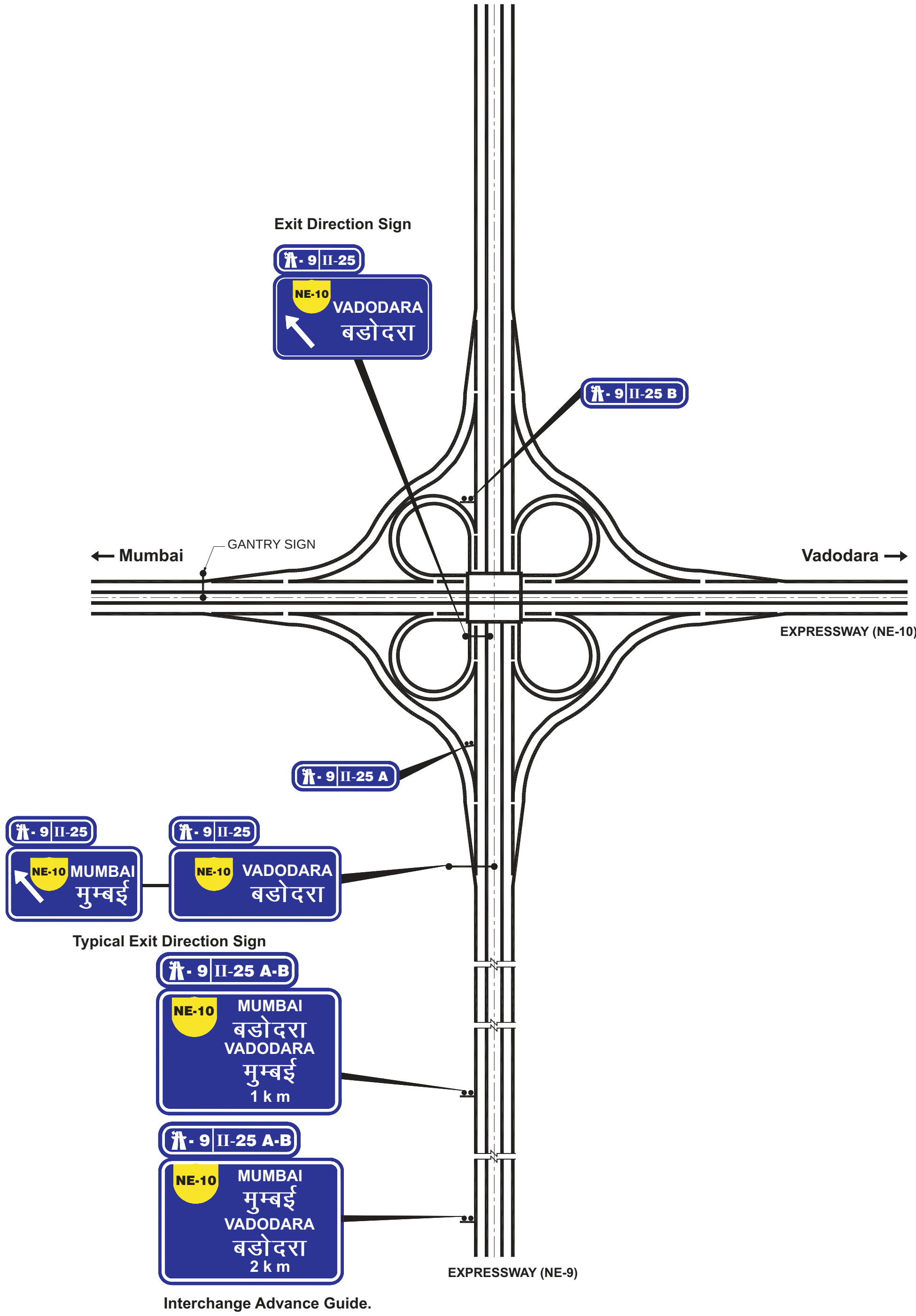


Fig. 9.13 Typical Layout for Full Cloverleaf Interchange Sign
(System Interchange)
(Note: One side only)

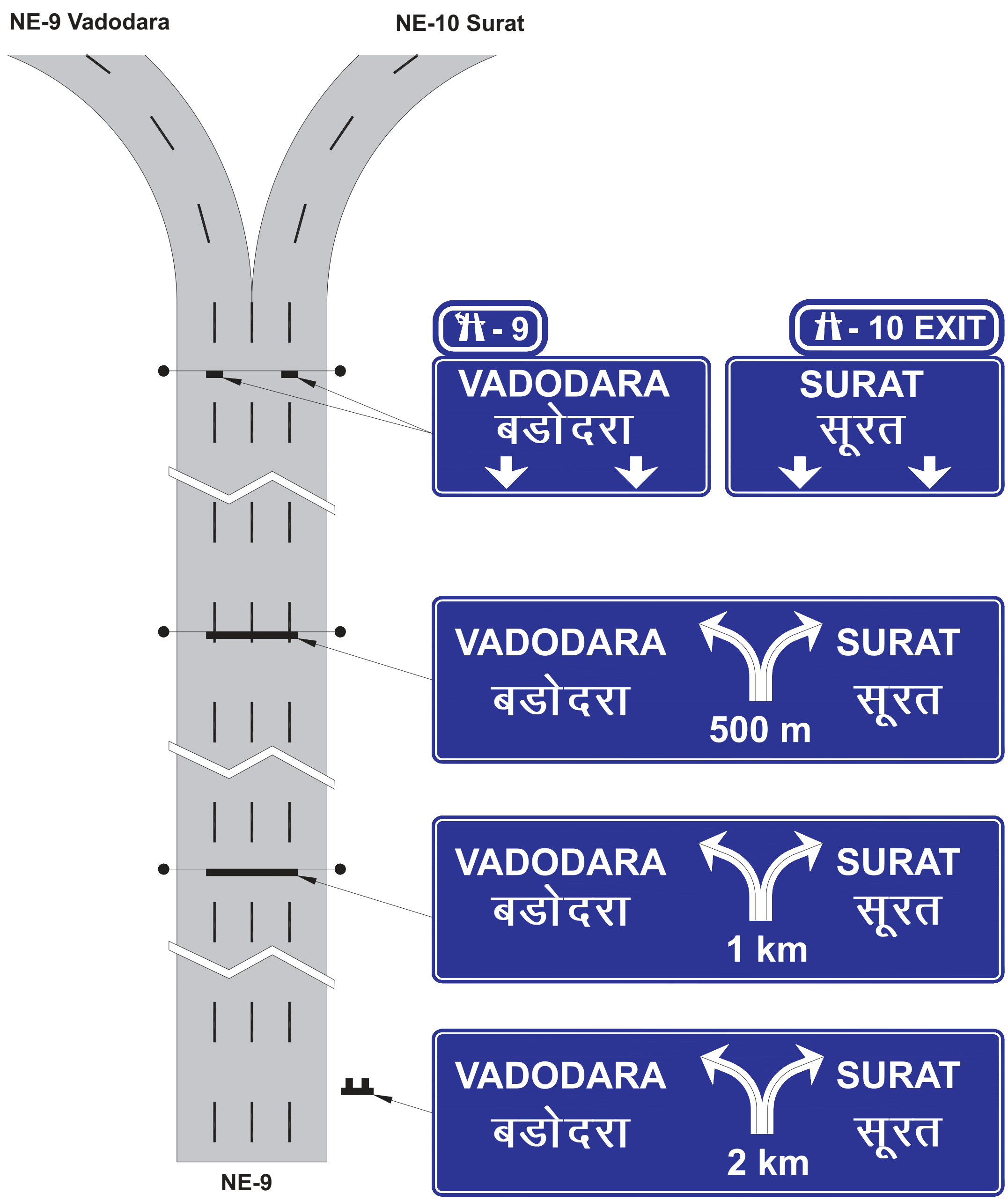


Fig. 9.14 Diagrammatic Signs for Split with Dedicated Lanes (System Interchange)

diagrammatic signs should be used without the EXIT ONLY panel. **Fig. 9.15** shows Exit only Panels for Left Lane Drop at an Interchange.

9.2.13 *Wrong-way traffic control at interchange ramps*

At interchange exit ramp terminals where the ramp intersects a cross road in such a manner that wrong way entry could inadvertently be made, the following signs shall be used.

On interchange entrance ramps where the ramp merges with the through roadways and the design of the interchange does not clearly make evident the direction of traffic on the separate roadways or ramps, a ONE WAY sign visible to traffic on the entrance ramp and through roadway should be placed on each side of the through roadway near the entrance ramp merging point as illustrated in **Fig. 9.16.**

9.2.14 *Keep adequate headways*

Keep adequate headway distance is a safety signage for the drivers to maintain safe manoeuvering stopping distance. These are generally placed between interchanges and at around 5 km interval on long stretches

Fig. 9.17 shows typical keep adequate headway sign.

9.2.15 *Miscellaneous guide signs*

Miscellaneous Guide signs are used to point out geographical features, such as rivers and summits, and other jurisdictional boundaries. Miscellaneous Guide signs may be used if they do not interfere with signing for interchanges or other critical points.

9.3 REST AREA AND GENERAL SERVICE SIGN

To provide the motorist with information on the location of succeeding rest areas, a sign with the word message NEXT REST AREA XX km may be installed independently or as a supplemental panel mounted below one of the advance rest area guide signs. Rest area signs shall be provided at 2 km, 1 km and 500 m ahead of rest area.

When symbols are used for the road user services, they should be displayed as follows:

A. *Six services:*

1) Top row – FUEL, FOOD and LODGING

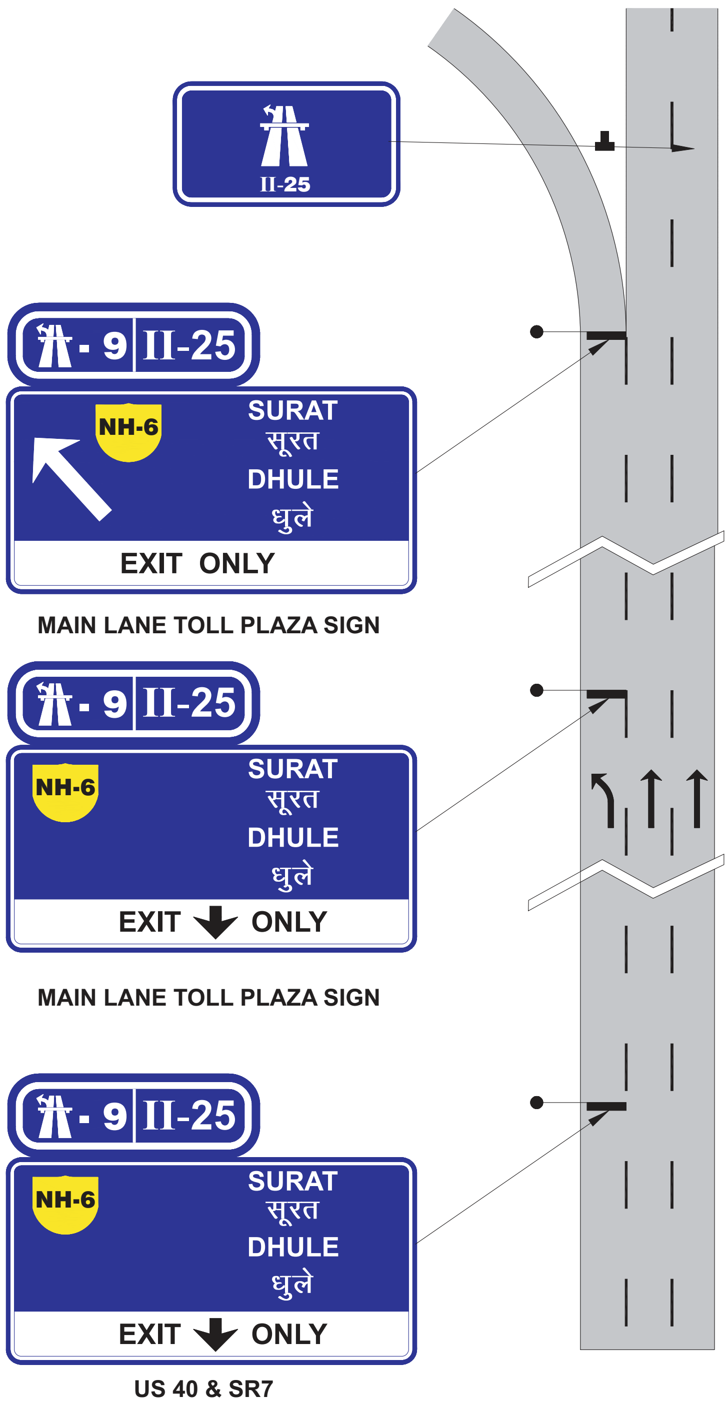


Fig 9.15 Exit Only Panels for Left Lane Dropped at an Interchange (Service Interchange)

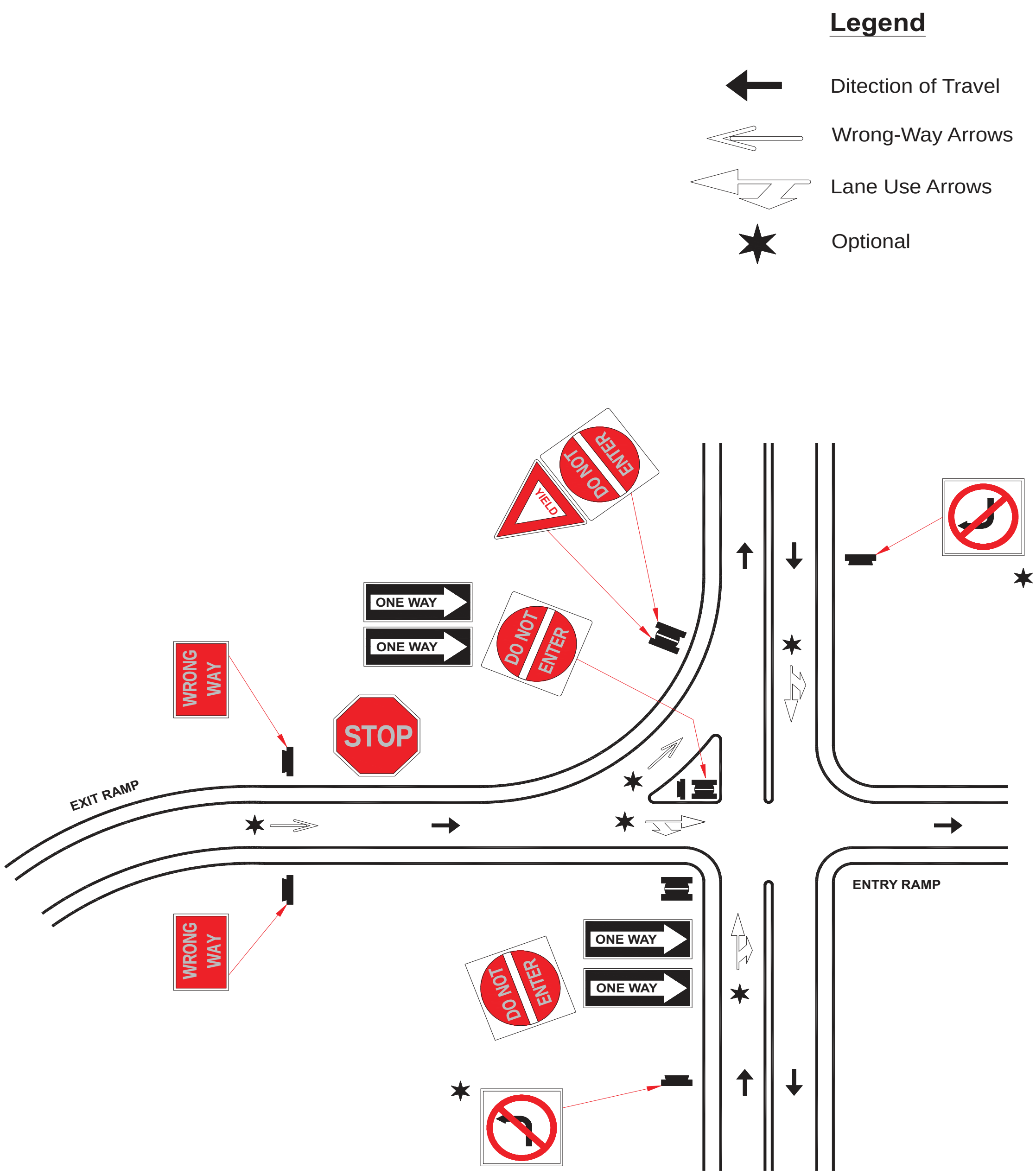


Fig. 9.16 Deter Wrong-way Entry

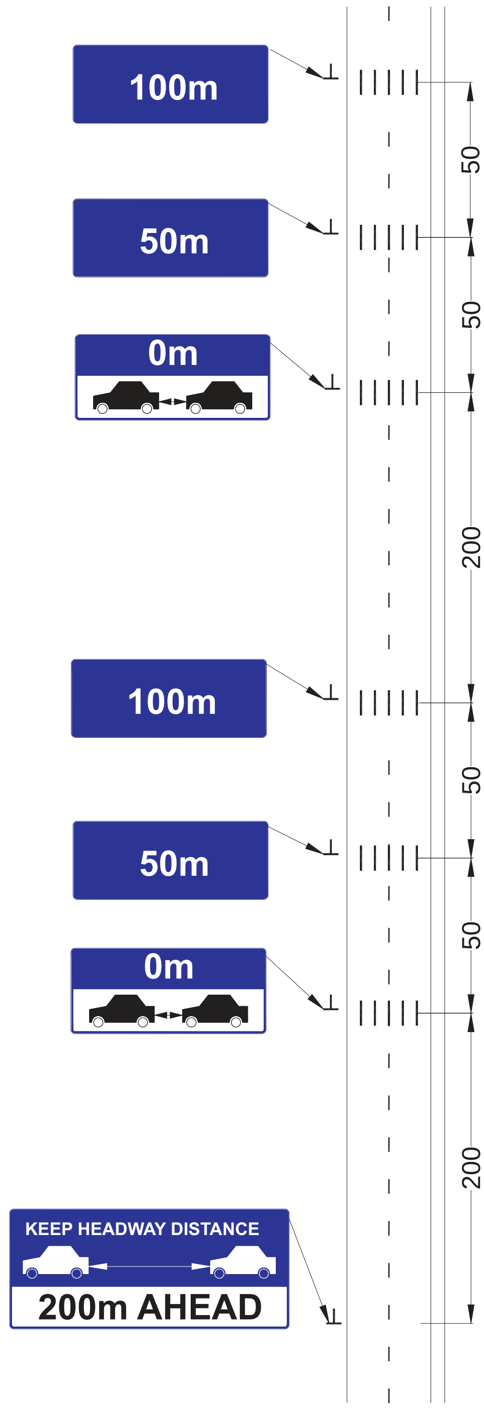


Fig. 9.17 Keep Adequate Headway Distance

2) Bottom row – TELEPHONE, HOSPITAL, and CAMPING

B. *Four services:*

1) Top row – FUEL and FOOD
2) Bottom row - LODGING and TELEPHONE

C. *Three services:*

1) Top row – FUEL, FOOD and LODGING

Substitutions of other services for any of the services shown above may be made by placing the substitution in the lower left (four or six services) or extreme left (three services) portion of the sign panel. An action message or an interchange number may be used for symbol signs in the same manner as they are used for word message signs.

If more than three services become available at rural interchange areas where limited road user services were anticipated, replaced with an independently mounted general service sign.

A separate Telephone service sign may be installed if telephone facilities are located adjacent to the route at places where public telephones would not normally be expected.

Chemical toilet sign may be used as needed to indicate the availability of facilities designed for dumping wastes from recreational vehicle holding tanks.

A TRUCK PARKING sign may be used on a separate sign panel below the other general road user services to direct truck drivers to designated parking areas.

Fig. 9.18 show typical rest area signs for six services.

9.4 TOLL PLAZA

Installed at the entrance of a toll gate, this board displays traffic and weather information over broad areas.

For toll plaza(s), advance direction signs shall be provided at 1 km and 500 m ahead of toll plaza. These signs are rectangular in shape, bilingual, gantry, cantilever mounted as illustrated in **Chapter-10** on Toll Plaza Design.

At the start of flare of the toll plaza, a sign displaying the fee rates shall be erected.

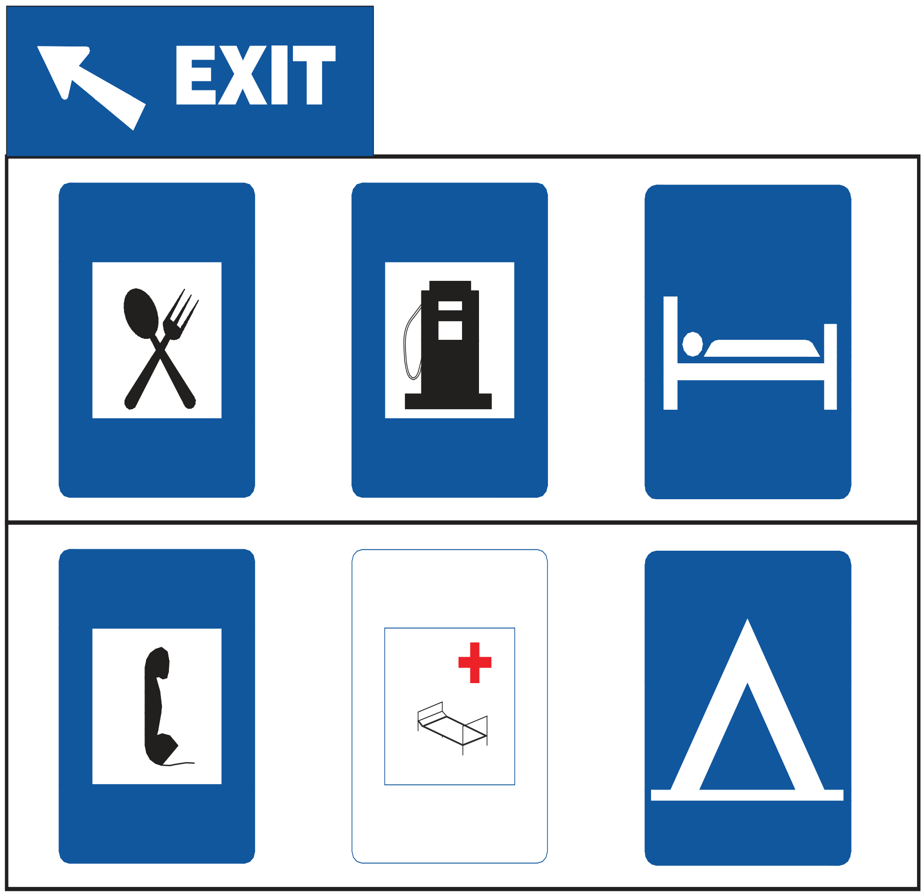


Fig. 9.18 Signing for Service Area

9.5 ROUTE MARKERS

Route markers on expressways are normally incorporated as shields or other distinctive shapes in large directional guide signs.

Trail blazers erected at strategic locations, usually along major urban road, to indicate the direction to the nearest or most convenient point of access. The use of the word to indicates that the road where marker to posted is not part of the indicated route, and that a driver is merely being directed progressively to the route.

A trail blazer assembly shall consist of two markers, a cardinal direction marker if needed symbol and a single headed directional arrow pointed along the route leading to the facility.

Trail blazer assemblies may be erected with or without other route marker assemblies, in the immediate vicinity of designated facilities.

Route markers and auxiliary markers showing junctions and turns should be used for guidance on approach roads, for route confirmation just beyond entrances and exits, and for reassurance along the expressway. When used along the expressway, the markers should be suitably enlarged 10-20 percent more than for main roads.

IRC: 67-2010 provides guidelines on route marker for Expressways. This guideline shall be followed for expressway. Important points are as mentioned below:

- i) The sign may be either enamelled or painted steel plate
- ii) An expressway route marker sign shall consist of a shield painted on a rectangular plate 600 mm x 900 mm;
- iii) The sign background and the lettering and border shall conform to "IRC: 67";
- iv) For letter, legend and numeral shall be NE;
- v) Word messages shall be NE(X). Where (x) is Number of National Highways

Typical route marker sign is shown in **Fig. 9.19.**

9.6 DISTANCE MARKER (Kilometer and 100 m Marking)

These markers will be required for the expressway drivers to identify his location enroute as well as to assess the distances to his destinations, service areas, location of emergency incidents etc. These also help the operation and maintenance persons to locate the places of incidents and/or pavement distress and maintenance requirements.

The distance numberings shall desirably be continuous. A typical arrangement as practiced in Japan showing kilometer and 100m marking is shown in **Fig. 9.20**. These may be placed/ attached/embedded in crash barriers or on individual foundations.

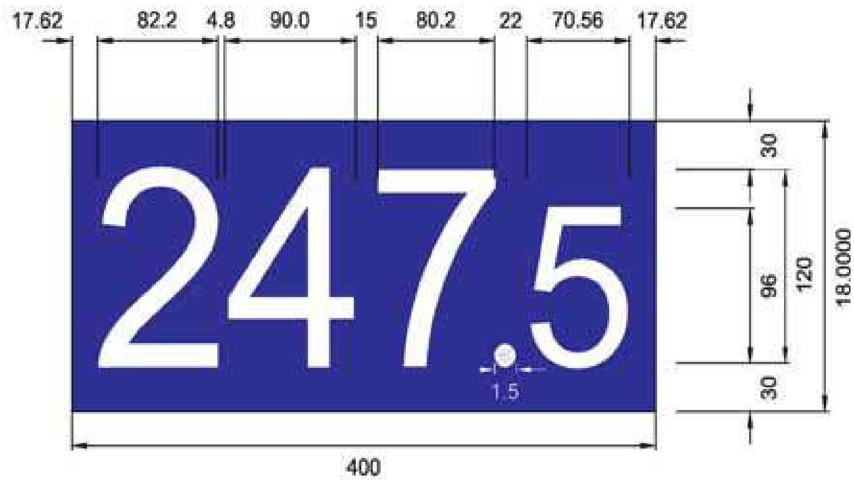
9.7 REGULATORY (MANDATORY) SIGNS

These signs inform road users of roads closed, parking prohibition, the speed limit and other prohibitions, regulations and special duties to be observed by users.

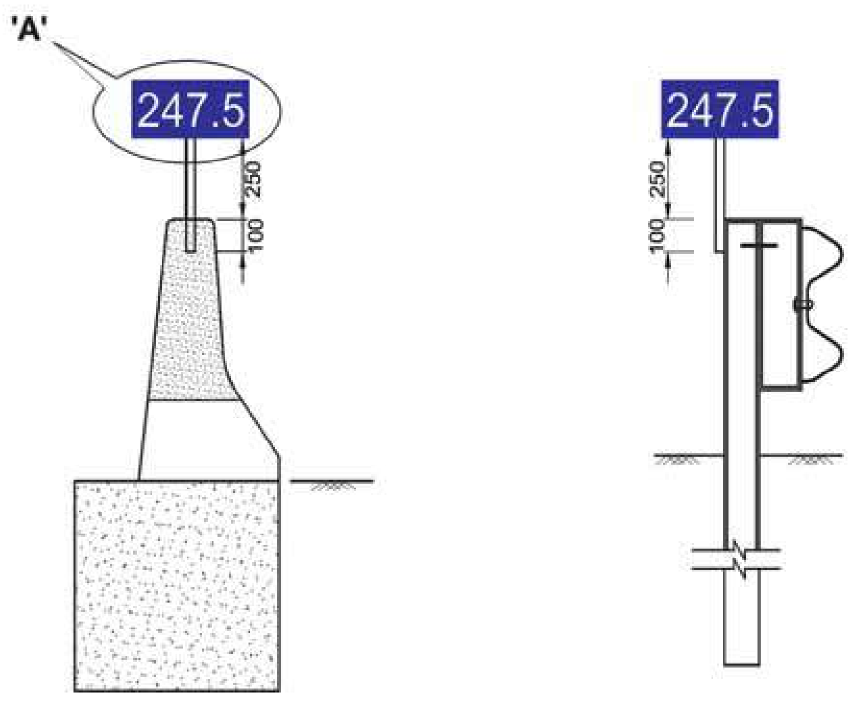
Table 9.01 gives the specified mandatory signs for use on expressways.

NOTES: 1. All dimensions are in millimetres.
2. Dimension of Number shall be taken from IRC : 67-2010
3. Dimension of letter shall be taken as from IRC : 8 -1980 and Enlarge Suitably.(Around 10 - 20%)

Fig. 9.19 Route Marker for Expressways



Detail 'A'



NOTE : All Dimensions are in Milimeters
Fig. 9.20 Type Design for 100 m markers on Expressway

Table 9.01 Various Types of Mandatory Signs

Mandatory Signs
1) Speed series • Speed limit sign • No overtaking
2) Movement series • Slower traffic keep left
3) Parking series • Parking, Standing/Stoppage prohibition sign

9.7.1 *Speed limit sign*

The speed limit sign shall display the limit established by law or by regulation after an engineering and traffic investigation. Maximum speed rates shall be multiple of 10 kmph or 5 kmph.

Proper numerical values for a speed zone should be determined considering following traffic engineering investigation:

i) Road surface characteristics, shoulder condition, grade, alignment and sight distance;
ii) The 85th percentile speed and space mean speed;
iii) Roadside development and environment;
iv) Safe speed for curves.
v) Reported crash experience for at least previous 12-month period

9.7.2 *Movement series*

The sign shall be a single arrow and the regulatory word messaged ONLY. The optional movement sign shall show a straight through and a curve arrow with lower ends of their shafts superimposed, to indicate that either of the lower ends movements symbolized is permissible. The mandatory turn sign designed for post mounting shall carry the message left lane must turn left.

9.7.3 *Parking series*

Stopping of vehicles on expressway can be exceedingly hazardous. If an emergency stop is necessary, it should be made on the shoulder, well off the pavement. Except where adequate paved turnouts are provided, the road shoulders should be reserved for emergency use by vehicles that must leave the roadway to stop because of mechanical breakdown, tyre trouble, lack of fuel, or other emergencies involving their occupants.

These signs are not generally used on expressway but Emergency Parking signs should be used on expressways a short distance beyond on interchange entrance at random intervals as needed. If necessary the word stopping may be replaced by parking.

Typical Mandatory Signs:

Various mandatory signs for use on the expressways are given in **Fig. 9.21.**

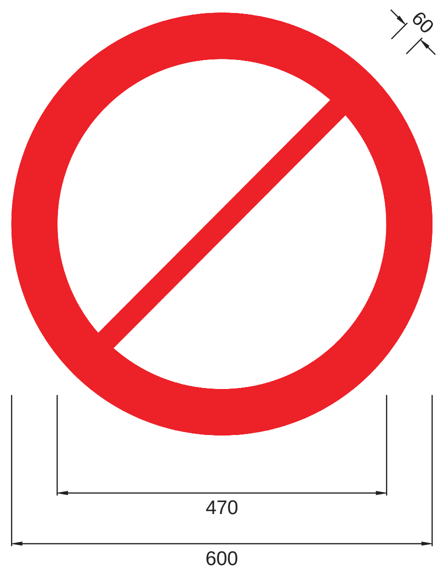
9.8 CAUTIONARY/WARNING SIGNS

These signs inform road users of hazardous sites or potentially hazardous conditions. Such as interchange locations, exit and entry ramp locations, toll areas.

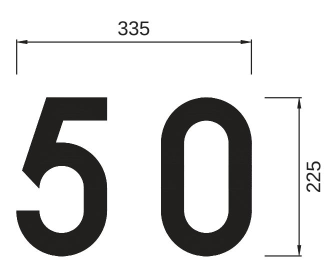
Typical locations and hazards that may warrant the use of warning signs are:

- i) Changes in horizontal alignment;
- ii) Intersections;
- iii) Advance warning of control devices;
- iv) Converging traffic lanes;
- v) Narrow roadways;
- vi) Changes in highway design;
- vii) Grades;
- viii) Roadway surface conditions;
- ix) Railroad crossings;
- x) Miscellaneous;
- xi) Entrances and crossing.

Table 9.02 shows various types of warning signs useful for expressways.



NO PARKING



SPEED LIMIT

1. Dimensions showns are for normal sized signs.
2. All dimensions are in millimetres.
3. A definition plate may be attached with the No Parking signs carrying the message in English and other languages as necessary, as also any additional information such as the period for which restrictions will be in force or the particular class of vehicle to which it applies.
4. Speed limits for different classes of vehicles may be indicated in a separate definition plate attached to the Speed limit sign.
5. Colour and Border as Per IRC Practice.

Fig. 9.21 Various Types of Regulatory Signs

Table 9.02 Various Types of Useable Warning Signs

Classes of Signs
1) Changes in horizontal alignment • Turn and curve sign • Large arrow sign
2) Intersection Sign • Cross road sign • T symbol sign • Y symbol sign • Chevron alignment sign • Merge sign • Roadway narrow sign • Lane reduction transition sign • Hill sign • Slipping when wet sign • Advance crossing sign • Advisory exit speed sign

9.8.1 *Turn and curve sign*

Both signs are used where engineering investigations of roadway, geometric and operating conditions show that recommended speed on the curve to be greater than 48 kmph and equal to or less than the speed limit established by law or by regulation for that section of the highway.

These signs are generally avoided as far as possible because of reduction of speed but turn sign may be provided at interchange or ramp. This sign is necessary to warn motorist of the existence of sharp change of alignment such as at a turn or sharp curve to avoid accident.

9.8.2 *Large arrow sign*

A Large Arrow sign may be used to delineate a change in horizontal alignment. The Large Arrow sign **(Fig. 9.22)** shall be a horizontal rectangle with an arrow pointing to the left or right. If used, the Large Arrow sign shall be installed on the outside of a turn or curve in line with and at approximately a right angle to approaching traffic. The Large Arrow sign shall not be used where there is no alignment change in the direction of travel, such as at the beginnings and ends of medians or at center piers**.** The Large Arrow sign should be visible for a sufficient distance to provide the road user with adequate time to react to the change in alignment.

Fig. 9.22 Large Arrow Sign

9.8.3 *Chevron alignment signs*

This sign may be used as an alternative or supplement to standard delineators and to the large arrow sign as in **Fig. 9.23**. This is intended to be used to give notice of a sharp change of alignment with the direction of travel. This sign is intended to provide additional emphasis and guidance for vehicle operator as to changes in horizontal alignment at roadway.

Chevron Alignment signs shall be installed on the outside of a turn or curve, in line with and at approximately a right angle to approaching traffic. A Chevron Alignment sign may be used on the far side of an intersection to inform drivers of a change of horizontal alignment for through traffic. Spacing of Chevron Alignment signs should be such that the road user always has at least two in view, until the change in alignment eliminates the need for the signs. It should be visible for at least 150 m. Final position may be determined by trial runs by day and night. This sign is used on interchange ramp and sharp curve on main carriageway

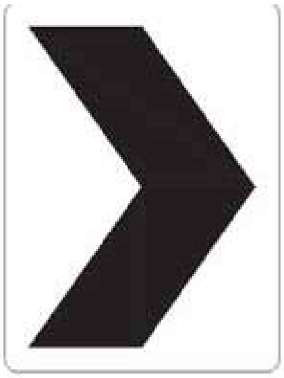


Fig. 9.23 Chevron Alignment

9.8.4 *Merge sign*

The merge sign is placed in advance of a point where two roadways (expressway and other road) converge and where traffic from these roadways is moving in the same direction of travel and must merge into one lane as given in **Fig. 9.24**.

The sign should be erected on the side of the encountered and in such entering roadway. Where two roadways are of equal importance, a sign should be placed on each roadway.

Fig. 9.24 Merge Sign

9.8.5 *Hill sign*

The hill sign is used in advance of a downgrade/upgrade where the length, percent of grade, horizontal curvature or other physical features requires special precautions on the part of drivers. When the percent grade is shown within the hill sign, the message X percent shall be placed below the inclined ramp/vehicle symbol, **Fig. 9.25**.

Fig. 9.25 Hill Sign

9.8.6 *Slippery when wet sign*

Calculated safe wet speed is considered to be at least 10 percent lower than the posted maximum speed. This sign should be installed in advance of the beginning of the slippery section and at appropriate intervals on long section of such pavement.

The Slippery When Wet sign **(Fig. 9.26)** may be used to warn that a slippery condition might exist. When used, a Slippery When Wet sign should be placed in advance of the beginning of the affected section and additional signs should be placed at appropriate intervals along the road where the condition exists.

Fig. 9.26 Slippery When Wet Sign

9.8.7 *Warning for animal crossing*

The sign should be erected where there is danger due to farm animals or cattle crossing on the road. The sign should not be used simply because animals are driven along or across the road at frequent intervals. If an unexpected hazard is seasonal or temporary, these signs shall be removed when the hazardous condition terminates, **Fig. 9.27**.

Fig. 9.27 Animal Crossing

9.8.8 *Slow traffic keep left sign*

This sign, **Fig. 9.28** is placed to maintain the traffic movement and to provide right of way to faster vehicles.

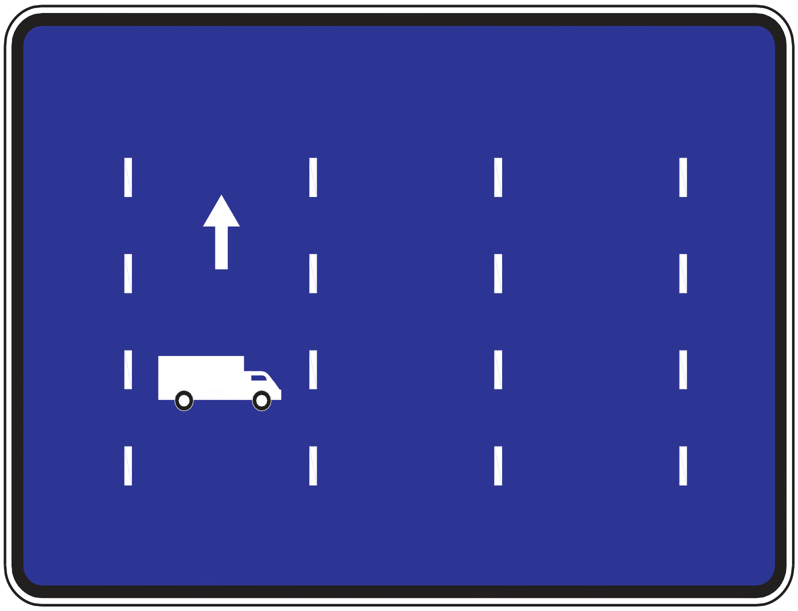


Fig. 9.28 Slow Traffic Keep Left

9.8.9 *Climbing lane/overtaking lane sign*

At steep gradients when the heavy vehicles slow down, creating reduced platoon speed. It is necessary to provide additional lanes for these heavy vehicles as shown in **Fig. 9.29**.

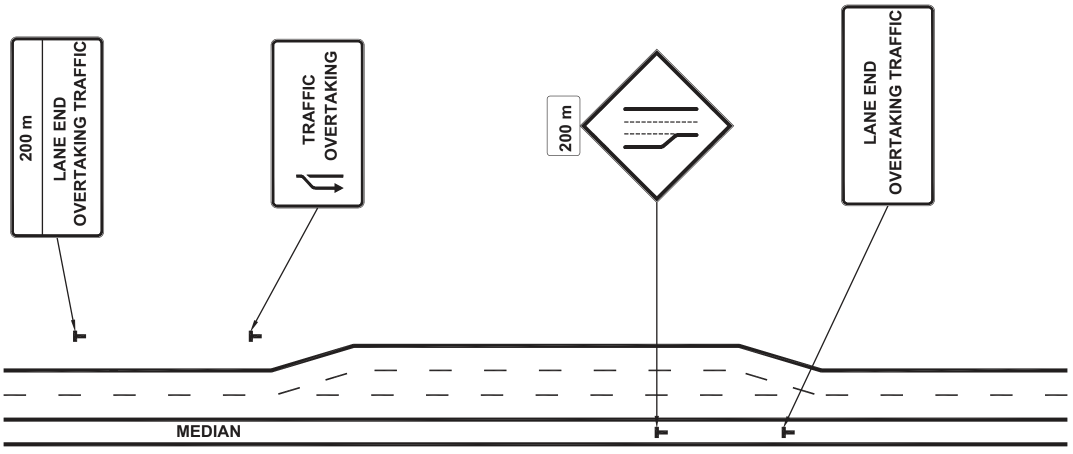


Fig. 9.29 Climbing Lane

9.9 DESIGN

9.9.1 *Legend size, letter series, legend limits and sign size*

a) General

The basic requirement shall meet IRC: 67-2010 code of practice for road signs and IRC: 30-1968 standard letters and numerals of different heights for use on expressway signs

Expressways require a higher standard of signing than other roads. This means large signs with clear layouts and large letter sizes, as well as the repetition of important information.

The larger legends used on expressway signs result in larger total sign sizes which makes them more conspicuous and helps drivers identify signs in the first place. The ease of reading signs (their legibility) is affected by:

- Colour: Blue background with white letters to be adopted.
- Letter height: The larger the lettering, the greater the distance over which the text is legible.
- Letter series: Standard highway sign alphabets given in IRC: 67 and IRC: 30, the wider the letter series, the easier it is to read.
- Spacing of legend: It is important that adequate spacing between letters, spacing between words and spacing between words and the edge of signs is provided. Drivers' eyes search for recognisable words and messages. This is difficult to do if inadequate spacing leads to letters merging into each other or words merging into other words or the sign's border.
- Amount of legend: There is a limit to how much can be read from a sign within the legibility distance. The amount of information presented to the driver therefore should be minimised. Also, many sign types which can vary in the amount of legend (e.g. reassurance of direction signs) have limits on the number of lines of text permitted. Similarly, signs with large amounts of text or which require different responses, need to be separated by distance along a road if these are to be read and acted upon appropriately.
- Spacing of signs: The spacing between signs is also a critical factor in managing the release of information to drivers. Drivers on expressways require larger spacing than on arterial roads.

- Consistency: The information presented on signs should be in a consistent location and form so that drivers seeking specific information on signs know where to look and what to look for, e.g. Route numbers should be located in a prominent and standard location on the sign face.
- Effective diagrams: The solution to excessive amounts of text may be to put the information in diagrammatic form. All graphic symbols on road signs need to be tested in accordance with IRC:67 and IRC:30.

b) Sign Size

As outlined above, the size of a sign face is determined by the amount of legend, the letter size, the legend series and spacing. These factors enable the sign firstly to be noticed, and then read.

If overhead signs are warranted, the number of signs at these locations should be limited to only those essential in communicating pertinent destination information to the road user. Exit direction signs for a single exit and the advance guide signs should have only one panel with one or two destinations. Regulatory signs, such as speed limits, should not be used in conjunction with overhead guide sign installations. Because road users have limited time to read and comprehend sign messages, there should not be more than three guide signs displayed at any one location either on the overhead structure or its support.

At overhead locations, more than one sign may be installed to provide advice of a multiple exit condition at an interchange. If the roadway ramp or crossing roadway has complex or unusual geometrics, additional signs with conforming messages may be provided to properly guide the road user.

In some cases it may be desired that signs erected on overhead structures are designed to fit in the depth of structure for aesthetic reasons. However, sign size must not be reduced in a way which results in reduction in letter heights, letter series or spacing.

Letter size of regulatory and mandatory signs should be enlarged suitably as per requirement. For these two types' signs, minimum letter size 20 cm as per IRC: 67-2010 is applicable for expressways. For this purpose IRC:30-1968 “Standard Letters and numeral of different heights for use on highway signs” shall be useful guideline.

For the benefit of the drivers who are not conversant with English language, important sign may carry the message in the regional language/Hindi besides English. Height of every regional/Hindi letter may be kept same. Letter of Hindi and other regional languages may not be keeping same height because of different script.

9.9.2 *Establishment*

Overhead Sign Installations:

Overhead sign installations will have value at many locations on expressways.

Over crossing structures can often serve for the support of overhead signs, and may be the only practical location that will provide adequate viewing distance. Use of these structures as sign supports will eliminate the need for sign supports along the roadside. Where overhead crossings are closely spaced, it is desirable to place signs on the bridges to enhance safety and economy. Butterfly-type signs, and other overhead sign supports shall not be erected in gores or other exposed locations in new signing projects.

9.9.3 *Material*

The traffic sign plate may be made of stove-enamelled metal plate, or other suitable local materials. Nothing should be interpreted to exclude any new material that meets the standard requirements for colour and visibility.

9.9.4 *Variable Message Signs*

This has been dealt with in detail under Operation and Maintenance Section.

9.10 PAVEMENT MARKINGS AND RAISED PAVEMENT MARKERS

Pavement markings may be defined as markings on the surface of the road for the control, warning, guidance or information of road users.

The principles to be borne in mind are:

i) Markings must be visible under all circumstances and they must have a good contrast with the road surface;
ii) Markings must be durable;
iii) Markings must not be so thick that these become a hazard in themselves.

Pavement markings on the expressway shall be in accordance with IRC:35. These markings shall be applied to road centre line, edge line, continuity line, stop line, give way lines, diagonal/chevron markings, zebra crossing and at parking areas using a self propelled machine with satisfactory cut off value capable of applying broken line automatically.

9.10.1 *Visibility of pavement markings*

Pavement markings must be clearly visible in all conditions at day and night, wet and dry conditions. The colour should be clear and bright, have a matt finish and contrast well with the road surface on which the markings are laid.

Reflectorization is a very valuable aid to night time visibility. This depends for its action on the refraction (or bending) of light entering glass at an angle.

9.10.2 *Classes of markings*

Pavement markings shall be classified as:

i) ***Longitudinal line****:* Lane lines and edge markings oblique connecting and channel lines;

ii) ***Other line road markings****:* Chevron markings, lettering, directional arrows etc.

i) Longitudinal Lines

Longitudinal lines are further classified as:

a) Lane lines;
b) Carriageway edge markings;
c) Oblique connecting and channeling lanes.

These may be continuous or broken lines.

Minimum width of longitudinal marking is 20 cm and the following colours should be considered:

a) White colour shall be used for carriageway markings except the ones indicating parking restrictions; for the latter the colour used shall be yellow conforming to IS colour No.356 as given in IS 164-1951;

b) White together with black colour shall be used for kerb and object markings;

c) Yellow colour may also be used for the continuous centre and barrier line markings.

ii) Other Road Markings

a) Directional Arrows and Lettering

Lane selection arrows on pavement may be used for purpose of guiding, warning or regulating traffic to change correct lane for driving.

It shall be white colour. Large numerals and letters should be used,

Fig. 9.15 shows typical directional arrows and lettering.

b) Chevron Markings

A series of parallel chevron markings on a pavement zone, surrounded by continuous line, is indicating closed to traffic.

On deceleration and acceleration lanes and ramps, delineators shall be provided for both median side and shoulder where no lighting facilities. These should be used in the area of lane reduction. For detail information on Delineators, refer **Section 13.5.3.**

Length and Gap

The length and gap ratios used for centre line markings often vary according to the type, location, forward visibility and design speed of the road.

Length and gap shall be 1.5 m and 4.5 m on straight reaches and 1.5 m and 1.5m on curve to avoid accident and better visibility of the drivers for markings.

9.11 COLOUR AND MATERIAL

The following recommendations are to be considered:

i) Carriageway edge lines are in reflectorised hot spray thermoplastic supplemented by stick-on reflective markers;

ii) Lane lines are in unreflectorised hot spray thermoplastic supplemented by reflectors;

iii) All other markings, e.g. at gore areas, junctions, main roads, state highways, stop lines, painted islands etc., are by reflectorised hot spray thermoplastic;

iv) All paint markings are in white colour and some time yellow colour;

v) Red for use in the lane lines and median edge line.

Also for use on right hand side of ramps and at entry ramp in the continuity line wherever the taper lane has reached a full lane width;

vi) White colour on median side edge lane marking and yellow colour on shoulder side edge lane marking.

vii) Other Markings

All other markings, arrows, stop lines shall accord with current national highway standards as preliminary guidelines or to be set out during detailed engineering stage.

Fig. 9.30 Lane Indication Arrows

CHAPTER - 10

TOLL PLAZA DESIGN

CHAPTER – 10

TOLL PLAZA DESIGN

10.1 INTRODUCTION

Some of the primary goals of tolling are to provide value added service, expedite the maintenance process, and generate revenue. To maintain toll rates at reasonable levels and provide a high standard of service, a toll system must be efficient for enabling the vehicles to pass through toll plazas with least hazards of toll payment.

Toll plaza configurations are a function of the type of toll collection method, the type and volume of traffic served by the plaza, toll rate schedules and the physical and environmental constraints of the site.

For inter-city network, a closed ticketing system has been generally adopted. Toll Plazas are located on the Main lane, at the beginning and end of the project and at interchange ramps in between. The users get the ticket at the entry and pay the toll at the exit according to the distance traveled.

Signage and lane markings are important aspects of toll plaza design as well. They are the primary means of conveying information and instructions to drivers. It is important that signage and lane markings are clear and easy to understand in order to avoid confusion at toll plazas, such as inadvertent mix-ups between manual and electronic toll collection lanes.

The use of electronic toll collection (ETC) is becoming a more preferred and accepted method of collecting tolls at main lane and interchange toll plazas. ETC is a system that automatically recognizes a vehicle using a valid encoded data tag, called a transponder, and allows the vehicle admittance through the toll plaza without stopping, which, in turn, decreases the congestion at toll plazas. The ETC lanes are usually split from cash and smart card transaction lanes because of the difference in travel speeds, and the users of the ETC lanes expect to receive more efficient services.

10.2 TOLL SYSTEM

For intercity expressway network, “Closed system with ticketing payment mode” shall be adopted. Ticketing System of tolling means that payment need to be made only at the exit by depositing the ticket collected at the entry.

Trumpet type interchange shall be provided to connect the Expressway with the Toll Plaza and road beyond.

Various Toll Collection Systems are:

10.2.1 *Closed ticket system*

A closed-ticket toll system has an entrance and exit booth for the toll system and captures all users and revenue of the system. Toll plazas are located at every interchange preventing diversion around main lane toll plazas. Upon entering the toll system, the user receives a ticket. When exiting, the user gives the ticket to the toll collector and is charged a set fee as per policy decision and notification. Rates on this type of toll system are variable, depending on how long a user has been traveling on the toll facility.

Some instances where usage of a closed-barrier toll system provides benefits include the following:

- To capture toll from all facility users;
- To capture the entire revenue stream;
- To provide better enforcement for toll collection; and
- To ensure users pay tolls that are directly related to the distance traveled on the system.

10.2.2 *Closed – cash system*

A closed-cash system is similar, except that a cash toll is typically paid upon entering and/or exiting and at strategically placed main lane toll plazas throughout the toll system. This toll assessed to users is also based on vehicle classification and distance traveled on the toll system. This system is suitable for intra – city / urban expressway.

10.2.3 *Open system*

An **Open toll system** is where users pay a **fixed toll** at set main lane toll plaza locations, but ramp plazas are not located at each point of entry and exit from the toll system. It is important to note that this type of system does not account for how long a user has been traveling on the expressway and does not capture all users and revenue on the expressway. Some instances where usage of an open-barrier toll system provides benefits include the following:

- To retrofit an existing transportation corridor with tolls;
- To capture the longer distance users, including national and regional traffic, but allow the opportunity for local traffic to be toll-free, such as on the fringes of urban areas; and

- To minimize implementation, operating and toll collection labour costs for the toll system.

Fig. 10.01 presents the Closed and Open Toll Collection System.

10.3 PAYMENT TYPE

a) Semi Automatic Toll Collection

The semi automatic toll collection system shall be equipped in each entry lane with a vehicle detector for counting the number of vehicles and their axle number and for identification of the category of vehicle. The system shall also have a ticket issuing machine for issue of the tickets for user fee at the press of a button on a touch panel and entry lane controller for controlling the equipment of the entry lane and for sending the data to the data processing equipment at toll plaza office. Each toll lane shall have electronically operated boom barrier along with synchronized system for traffic lights.

b) Smart Card

The smart card system would comprise the system for vehicle identification, barrier and synchronize traffic light and payment through smart card. The smart card would comprise reader/ writer conforming to ISO Standards: 1443-A sealed to a National Electrical Manufacturers Association (NEMA) for Ingress Protection (IP-65) having transmission frequency of 13.56 MHz.

Smart Card and Reader Device

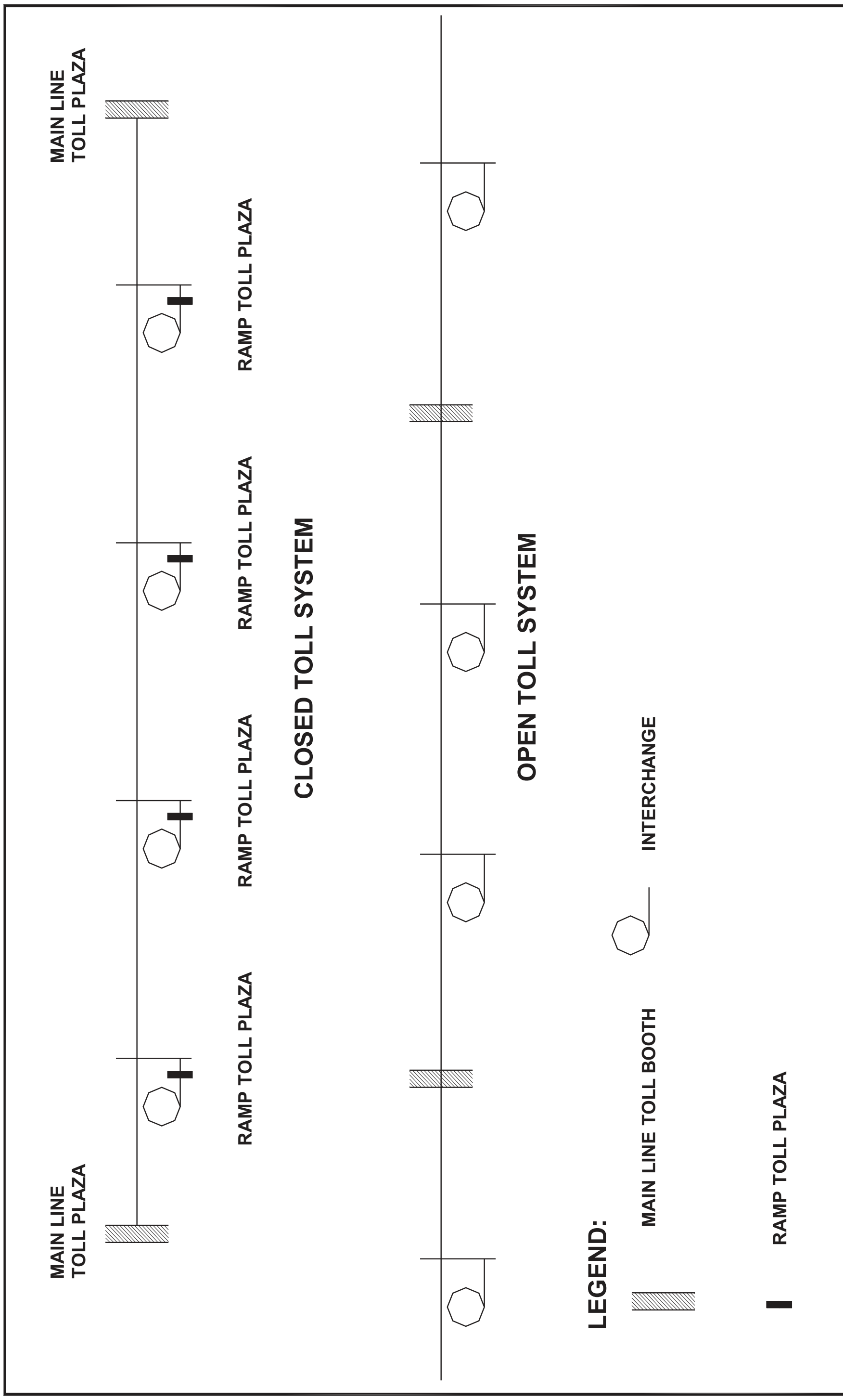


Fig 10.01 Toll Collection System

A smart card is a plastic card, usually about the same size as a magnetic stripe card that has electronic logic to store data and in some case a microprocessor that can process data.

Smart card users have to stop on the “Touch & Go” reader in order to go through the Toll Plaza.

The physical components of a smart card system are:

i) a card;
ii) a reader device (or a target for contactless cards);
iii) a terminal;
iv) a host computer; and
v) the connections which link the components of the system

c) Electronic Toll Collection (ETC)

The Electronic Toll Collection system shall consist of an On Board Unit (OBU) fitted on a vehicle and an antenna to receive communication for identification of its code and other stored data and a system for transmitting the data from the on board unit to the reader and from reader to the customer information management system.

10.4 TOLL PLAZA ELEMENTS

All toll plaza essential elements are broadly classified as.

- Toll collection sites – either attended toll booths or toll collection equipment such as cash, smart card and ETC facility.
- Toll islands – an elevated platform, typically made of concrete, which provides crash protection devices on the traffic approach side of the toll plaza for toll booths and violation cameras and other equipment.
- Toll canopy – shall be wide enough to provide weather protection to toll operators, drivers, and facilities. The canopy shall be of aesthetically pleasing design with cylindrical support columns located at traffic island so that there is no restriction on the visibility and traffic movement. The canopy may also provide mounting for signage and ETC equipment, utility access to the toll booths and ETC lanes.

The toll plaza consists of the following components:

- i) Lane width at toll booth;
- ii) Transition zone
- iii) Removable barrier;
- iv) Traffic signs;
- v) Road markings;
- vi) Toll booth facility;
- vii) Office building;
- viii) Barrier gate.
- ix) Toll Plaza lanes
- x) Utility Tunnel or overbridge – for utility services and safe movement of cash collections
- xi) Turn around vehicular underpass

Fig. 10.02 presents Schematic Arrangement of Services facilities at toll plaza. **Fig. 10.03A** and **Fig. 10.03B** present Typical Layout of Toll Plaza.

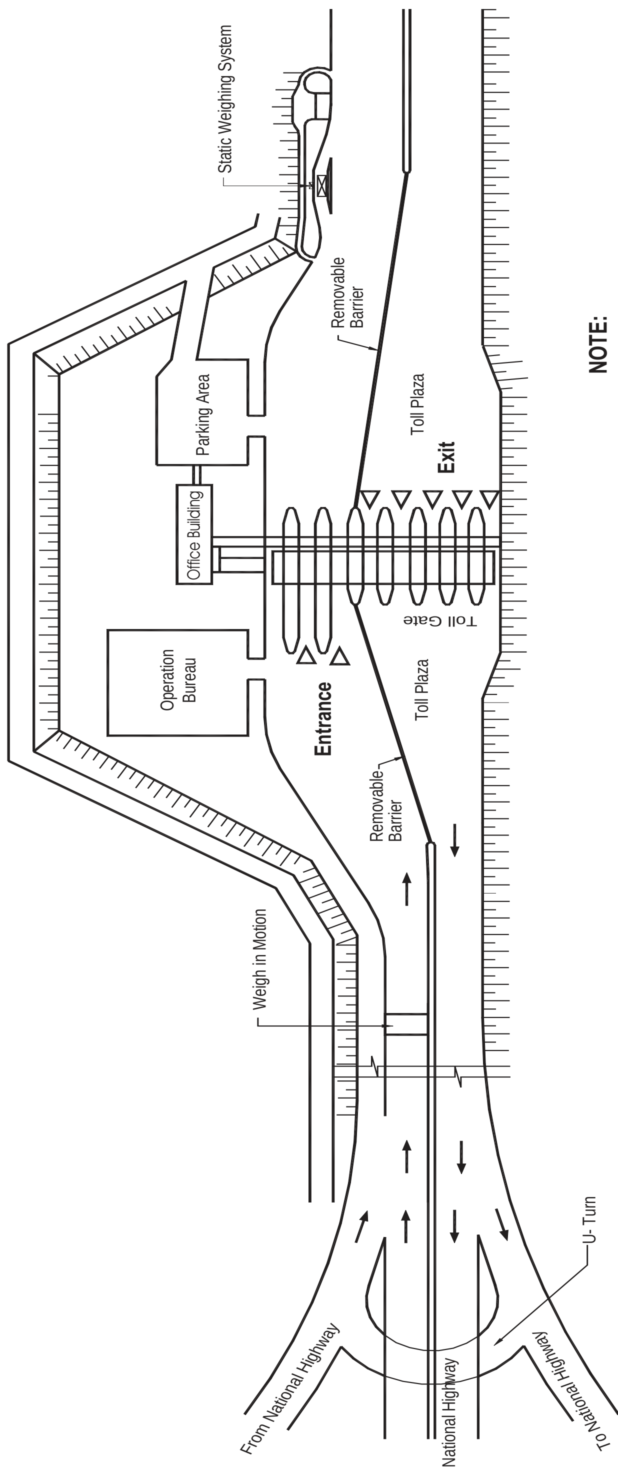
10.4.1 *Lane width at toll booth*

The width of each toll lane shall be 3.2 m, except for the ETC lanes (which shall be 3.5 m) and the lane for over dimensioned vehicles (which shall be 4.5 m).

Between each toll lane of the toll plaza, traffic islands are required to accommodate toll booth. These islands shall be of minimum 25 m length and 1.8 m width. Protective barriers of reinforced concrete shall be placed at the front of each island to prevent out of control approaching vehicles crashing into the toll booth. These would be painted with reflective chevron markings.

10.4.2 *Transition zone*

Number of lanes at toll plaza location is generally double or more of the through lane. At the entry to select the appropriate toll lanes, the driver has to perform a complex manoeuvre of deceleration and weaving for divergence. While at the exit, the combined manoeuvre of acceleration and weaving for merging is required to be performed.



NOTE:
The U - Turn shown in the sketch is an indicative one Location shall be merged with the nearby Underpass Structure.

Fig. 10.02 Schematic Arrangement: Service Facilities at Toll Plaza (Ramp Toll Plaza
(Not To Scale)

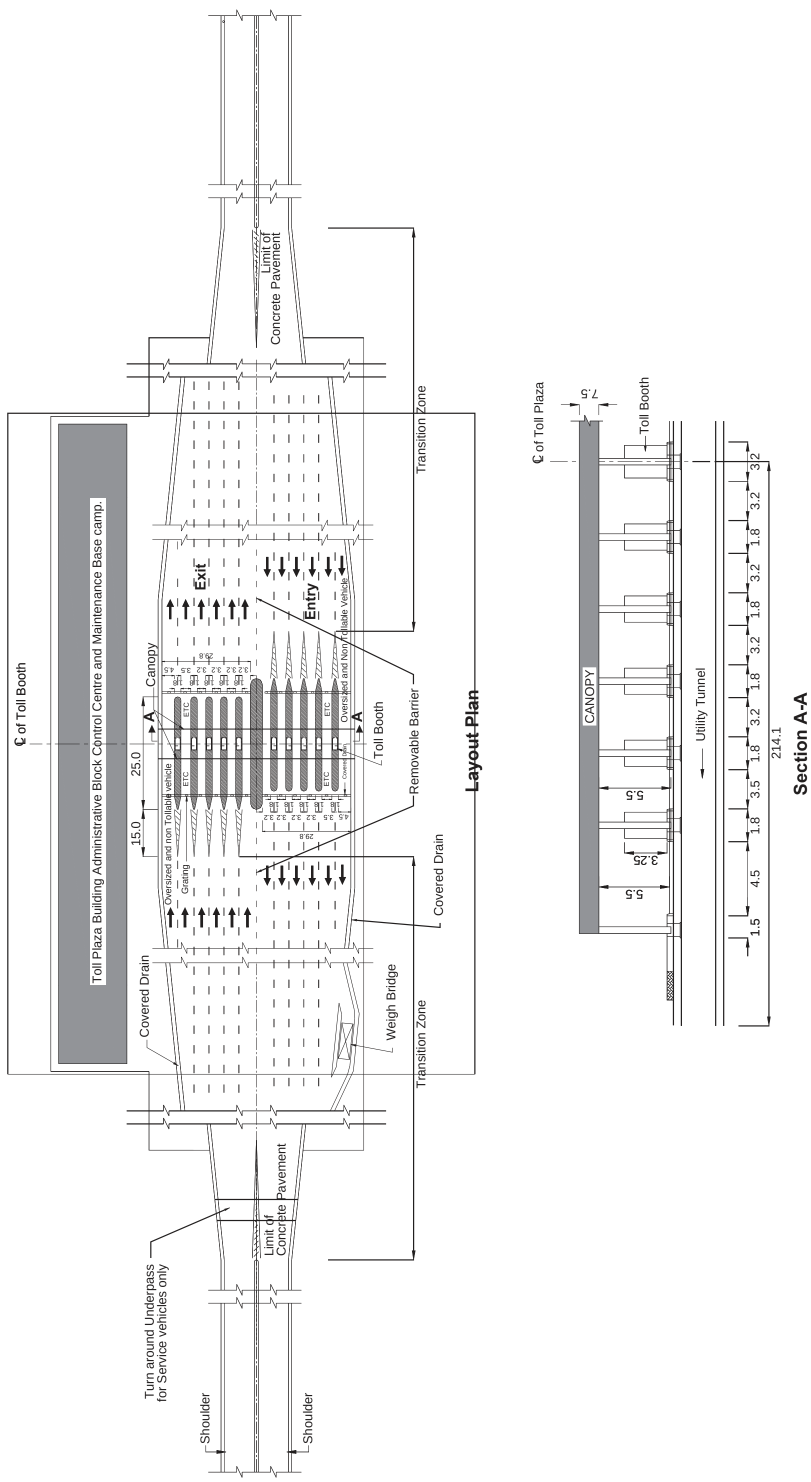
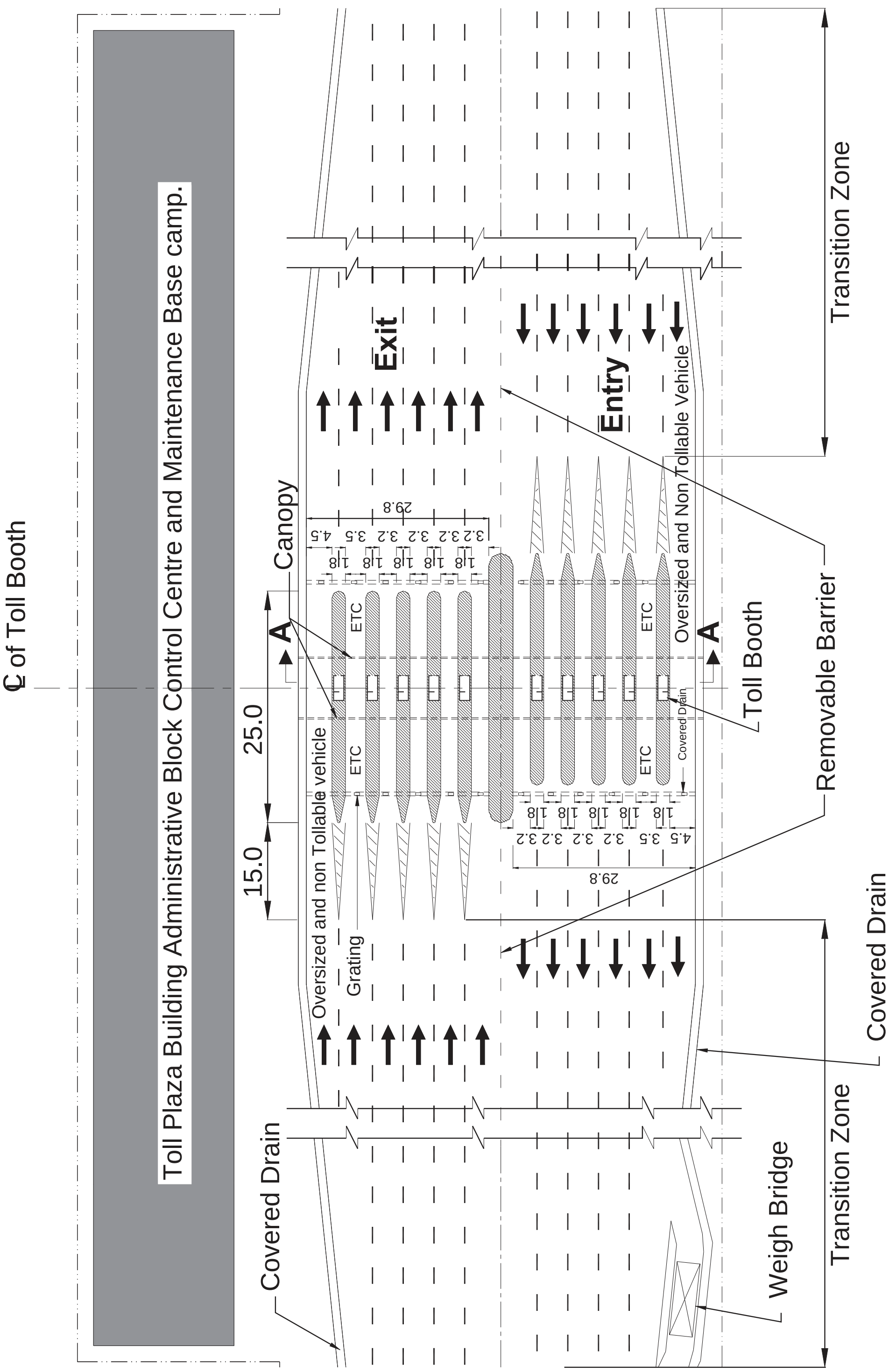


Fig. 10.03 A Typical Layout of Toll Plaza (Main Lane Toll Plaza)

NOTE: All Dimensions are in Meters Unless Specified Otherwise

NOT TO SCALE



NOT TO SCALE

Fig. 10.03 B Toll Plaza Area (ETC Lane at Centre)

All these operations will take place in the transition zone. However, the complexity of those operations will vary depending upon the toll plaza location i.e. on the expressway or on the interchange ramp. Accordingly the length of transition will depend on the acceptable rate of taper. Keeping all these in mind, the following taper rates are recommended for both acceleration and deceleration lane.

Toll Plaza Location	Rate of Taper for Transition Length		
	Desirable	Minimum	Exceptional
On Expressway	1 in 25	1 in 15	1 in 10
On Interchange Ramp	1 in 15	1 in 10	1 in 3*

** To be used in restricted situation coupled with low volume of traffic.*

10.4.3 *Removable barrier*

Removable type barriers shall be provided for emergency or maintenance area cross over and to accommodate reversible toll lanes.

10.4.4 *Traffic signs*

For expressways, closed system is considered, where toll plazas are provided along the main roadway, advance guide signs should be provided at 1 km and 0.5 km in advance of the area. Signs for toll plaza should be in white letters on a reflectorized blue background and should carry the message **TOLL GATE 1 km Fig. 10.04A** presents details of traffic signs and distance based toll rates shown in **Fig. 10.04B**.

Fig. 10.04 A Toll Plaza Sign

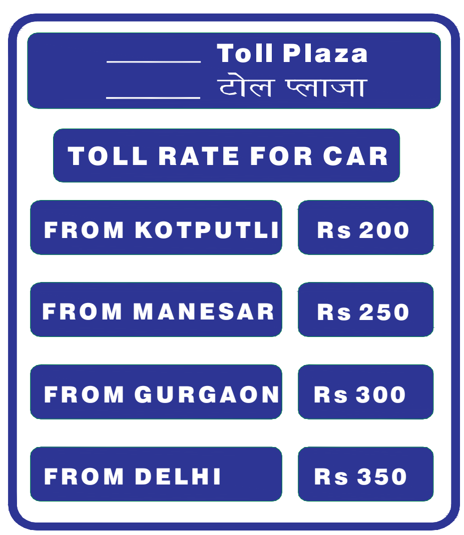


Fig. 10.04B Toll Rate Sign at Exit Ramp
(Assumed : Sign Placed at Jaipur)

Stop signs shall always be used in combination with certain road markings such as stop line and the word "STOP" marked on the pavement vide IRC:35 "Code of Practice for Road Markings" and IRC:67 "Code of Practice for Road Signs" should be followed.

10.4.5 *Road markings*

The road markings for the toll plaza area are designed to provide lane markings diagonal, chevron markings. In the flared zone provided in place of dismantled centre median to indicate segregation of the traffic in two directions. Single lane was provided at the centre of carriageway at toll gate to demarcate each service lane. Diagonal markings for central traffic island and chevron markings at side traffic island shall be provided to guide the approaching and separating traffic.

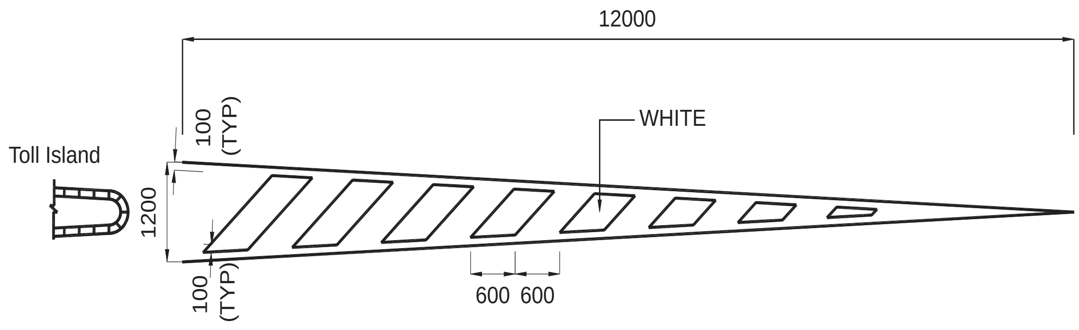
Relevant markings are shown in **Fig. 10.05**. The road markings are generally proposed in accordance with IRC:35, "Code of practice for road markings".

10.4.6 *Toll booth*

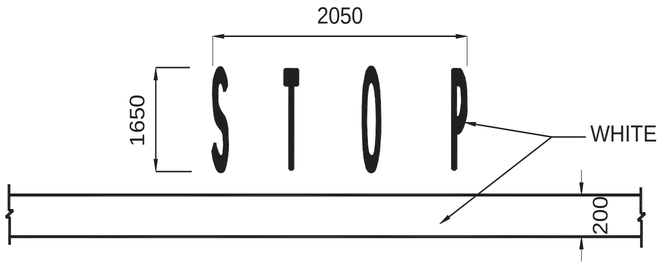
Toll booth shall be placed at the centre of each traffic island with dimensions to accommodate toll collector's desk for toll equipment such as key board and console, video screen, card reader, note and coin storage, telephone and environmental control system. The toll booth shall have large glass window to provide the toll collector with good visibility of approaching vehicles. The bottom of the toll window should be placed at such a height (0.9 m) above ground level so as to provide convenience of operation. The Toll booths shall be ergonomically designed and vandal proof. There shall be CCTV camera installed at each booth. The design of toll booths is guided by the functional requirement, climate, regional architectural characteristics, as well as expected duration of its operation and reusability. The height of toll booth shall be kept as 3.6 m so as to provide sufficient head room for ventilation, ceiling fans and cool air facility.

10.4.7 *Office building*

Toll plaza shall have a separate office building so as to provide comfortable office space for manager, cashier and other staff. There shall be separate rooms for T.V. monitors, toilets, and for the sale of passes, smart cards, on board units and public interaction. The building shall have a strong room for keeping the money and a garage to accommodate the security van (during operation of loading the collected revenue). There shall be parking space in the same campus for vehicles for the staff and workers and other vehicles engaged in the operation of the Project Highway.



Toll Island at Approach



STOP MARKING (Plan View)

NOTES :

1. ALL DIMENSIONS ARE IN MILLIMETRES.
2. ROAD MARKING SHOULD BE PROVIDED IN ACCORDANCE WITH IRC-35

Fig. 10.05 Road Marking in Toll Plazas

For the movement between toll office and toll booth of each toll lane, an underground tunnel across all toll lanes shall be provided. Its dimension would be sufficient to accommodate the required wiring/cable system and for convenient movement of personnel. It should also be provided with lighting and ventilation system so that the movement is convenient. This has been further discussed under management and operations facilities.

10.4.8 *Barrier gate*

To prevent passing out of any vehicle without payment of toll, normally swing barriers are generally placed at the exit of each lane. These barriers will normally remain closed and on payment of toll by the passing vehicle, the barrier will be opened by the collectors through their key board command. Normally these can be operated by the master booth operator and in his absence, master booth can be operated with the instruction of supervisor. Also there will be a provision for keeping swing barrier open if necessary. Generally, electrically operated barrier gate is used. For ETC, the barrier gate opens automatically controlled by ETC system.

10.4.9 *Toll plaza lane length*

Toll plaza length consists of two components:

i) Straight length: This length is required to accommodate toll lane and the space for waiting vehicles. A 100 m length would be desirable for the purpose.
ii) Taper length: This facilitates the merging and diverging manoeuvres required by the vehicles. Varying taper length is to be provided at both ends.

10.4.10 *Utility tunnel/overbridge*

For the movement between toll office and toll booth of each toll lane, an underground tunnel / overbridge across all toll lanes shall be provided. Its dimension would be sufficient to accommodate the required wiring/cable system and for convenient movement of personnel. It should also be provided with lighting and ventilation system so that the movement is convenient.

10.4.11 *Turn around provisions*

Emergency and patrol vehicles are required to have U-turn provisions for effective mitigation of emergent incident. **Fig.10.06** presents the indicative arrangement. The actual configuration may be designed based on site conditions and locations of other underpass structure and it is desirable to club this with other requirements for underpasses.

Fig. 10.06 U-Turn Ramp Near Toll Plaza

10.5 NUMBER OF TOLL LANES

10.5.1 *Recommendation in the "Manual of 4/6-laning by MORTH"*

Toll plazas shall be designed for projected peak hour traffic of 20 years. The total number of toll booths and lanes shall be such as to ensure the service time of not more than 10 seconds per vehicle at peak flow regardless of methodology adopted for fee collection. For purpose of guidance, following parameters are suggested as capacity of individual toll lane for design purpose:

For Open System

i) **Semi-automatic toll lane** **240 veh/hour**

(Automatic vehicle identification but manual money transaction)

ii) **Automatic toll lanes** **360 veh/hour**

(Automatic vehicle identification and money transaction – smart card)

iii) **Electronic toll collection (ETC lanes)** **1200 veh/hour**

(Toll collection through on board unit and no stoppage of vehicles)

10.5.2 **Japanese** method of deciding lane capacity (number of vehicles) number of toll lane based on service time desired and queuing on lane permitted as presented in **Table 10.01**:

Table 10.01 Lane Capacity (Number of Vehicles) Service Time and Queuing Permitted

Service	6 Sec		8 Sec		10 Sec		14 Sec		18 Sec		20 Sec	
Queuing	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0
Lane Nos.												
1	300	450	230	340	180	270	130	190	100	150	90	140
2	850	1,040	640	780	510	620	360	440	280	350	250	310
3	1,420	1,630	1,070	1,230	850	980	610	700	480	550	430	490
4	2,000	2,230	1,500	1,670	1,200	1,340	860	960	670	740	600	670
5	2,590	2,830	1,940	2,120	1,550	1,700	1,110	1,210	860	940	780	850
6	3,180	3,430	2,380	2,570	1,910	2,060	1,360	1,470	1,060	1,140	950	1,030
7	3,770	4,020	2,830	3,020	2,260	2,410	1,620	1,720	1,260	1,340	1,130	1,210
8	4,360	4,630	3,270	3,470	2,620	2,780	1,870	1,980	1,450	1,540	1,310	1,390
9	4,960	5,220	3,720	3,920	2,980	3,130	2,130	2,240	1,650	1,740	1,490	1,570
10	5,560	5,820	4,170	4,320	3,330	3,490	2,380	2,490	1,850	1,940	1,670	1,750
11	6,150	6,420	4,610	4,820	3,690	3,850	2,640	2,750	2,050	2,140	1,850	1,930
12	6,740	7,020	5,050	5,270	4,040	4,210	2,890	3,010	2,250	2,340	2,020	2,110
13	7,340	7,620	5,510	5,720	4,400	4,570	3,150	3,270	2,450	2,540	2,200	2,290
14	7,940	8,220	5,954	6,170	4,760	4,930	3,400	3,520	2,650	2,740	2,380	2,470
15	8,530	8,820	6,400	6,620	5,120	5,290	3,660	3,780	2,840	2,940	2,560	2,650

Determination of number of lanes in a toll plaza is a complex process which can be dealt using the above table as in Japan. The required number of lanes at a toll gate is calculated by the access traffic volume at the interchange, the time required for collection at the toll gate (average service time) and the number of vehicles waiting to pay (service standard).

With close ticketing system, a service time of **6** seconds at the entry and **14** seconds at the exit may be considered. A queuing number of vehicles may be up to **3** (three).

However at each toll plaza, an investigation should be made of the directional distribution of flow throughout all hours of day and night. Where unbalanced flow is observed or projected to occur, reversible toll lanes may be warranted. As a general guide – minimum two toll lanes in each direction of travel shall be provided with the system of payment through smart card and their configuration would be such that one lane in each direction could be upgraded in future to the system of Electronic Toll Collection (ETC). Not less than 2 middle toll lanes shall be capable of being used as reversible lane to meet the demand of tidal flow.

10.6 ETC (ELECTRONIC TOLL COLLECTION) SYSTEM

10.6.1 *General*

ETC is a modern high efficiency toll collection system placed at entry of a toll lane. The vehicle can pass at reduced speed (i.e. non-stop) thus minimizing toll lane congestion. The road side wireless system (Antenna) communicates with the On-Board-Unit (OBU) i.e. Transponder placed on the passing vehicle.

ETC – Antenna

This antenna is conveniently installed in the ETC lane of toll gate. This instantaneously obtains requisite travel information from OBU (transponder), computes the required payment needed and debit the system for the toll amount.

OBU – Transponder

This transponder is installed in the bottom corner of the vehicle wind screen or behind the rear view mirror. A two piece combination of OBU and smart Integrated Chips (IC) card is sometimes adopted to establish a common link with the cards used for motors, buses and other public transport facilities, as well as parking charges or similar other utility charges.

Fig. 10.07 presents the concepts of ETC system configuration.

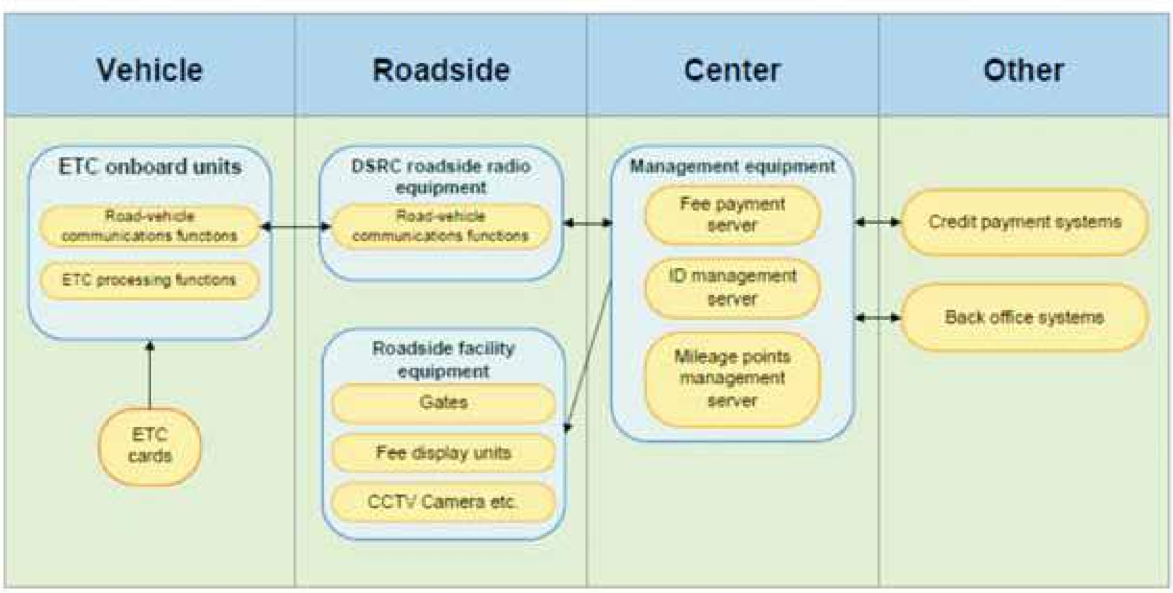


Fig. 10.07 ETC System Configuration

10.6.2 *Available technologies*

Characteristics of Available Technologies

All present automatic vehicle identification (AVI) technologies operate by (1) intercepting modulated electromagnetic radiation from a vehicle, (2) recovering the information contained in the signal, and (3) using a computer to identify the Tag from a database.

Technologies may be divided according to the frequency of the electromagnetic radiation, the method by which the signal is modulated (tuned or adjusted), and whether the vehicle Tag generates or simply reflects electromagnetic radiation. There are three frequency ranges in use:(1) very low frequencies (below 200 KHz), which are employed in inductively coupled systems; (2) microwave frequencies (500 to 8,000 MHz); and (3) optical or near-optical frequencies (30 GHz to 1,000 GHz), which include infrared.

This radio wave communication is known as Dedicated Short Range Communication System (DSRC) and broadly classified as:

a) Active RF DSRC
b) Passive RF DSRC and
c) Infrared Ray (IR) Radiation

Comparison of Active DSRC with others are presented in **Fig. 10.08** and **Tables 10.02 and 10.03.** Active DSRC is suitable for Intelligent Transport Systems (ITS) expandability

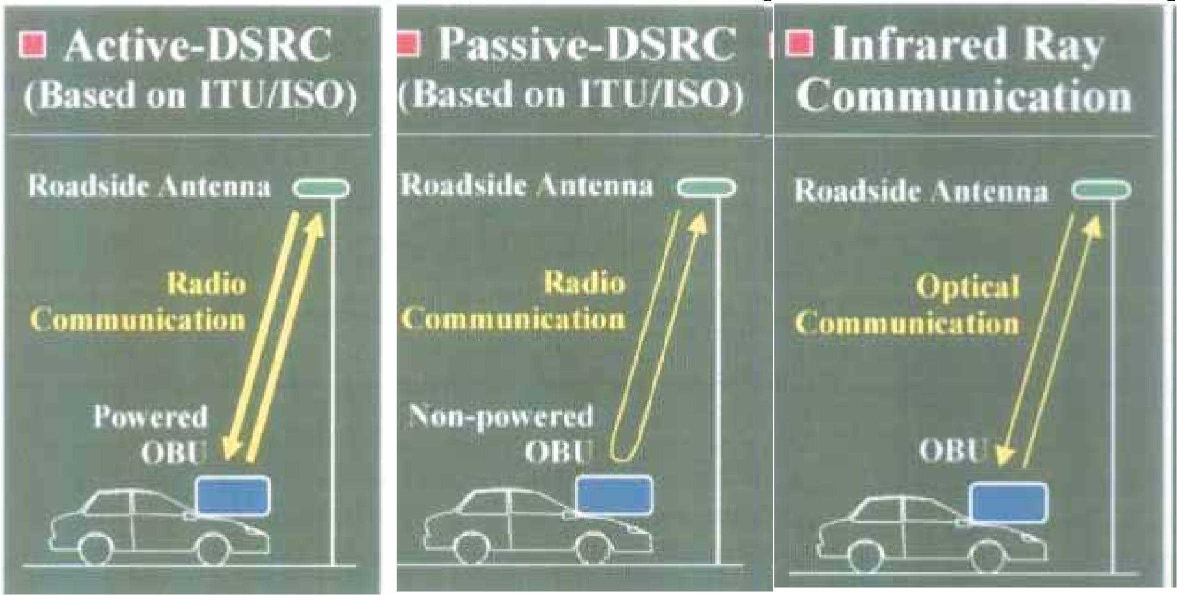


Fig. 10.08 DSRC System Classes

Table 10.02 Comparison of ETC Technologies

	Infrared Radiation with Active OBU	DSRC with Passive OBU	DSRC with Active OBU
System Performance	Satisfactory except during heavy rain	Satisfactory	Satisfactory
System Economy	Satisfactory except monopoly nature on the supply side	Satisfactory	Satisfactory
System Expansion & Upgrade for ITS	Limited	Limited	Abundant
Adopted areas	Malaysia, India (Noida)	European Countries, India (Gurgaon)	Japan, USA, Korea, China
Manufacturers	EFKON (Austria)	Many	Many

Note: Compared by SAPI (Supplementary Assistance for Project Implementation)Team

Table 10.03 Toll Payment Methods with Shares in 2008

	Manual	Touch & Go (Smart Card)	ETC (OBU-equipped Vehicle)
Noida	75%	21%	4%
Gurgaon	60%	40%	
Mumbai – Pune	80%	20%	N.A.
NEXCO Japan	25%	N.A.	75%

Source: Data compiled by SAPI Team

10.6.3 *ETC facilities*

10.6.3.1 System configuration

i) ***Lane Operation***

1) The passing mode of vehicles is “non-stop”.

2) Basically it is “exclusive”, limiting the passage of vehicles only to ETC vehicles. “Mixed” lane operation that allows non-ETC vehicles to pass the lane is taken into consideration separately.

3) The System is basically operated for 24-hour, 365 days basis.

4) ETC lane clearance is shown in **Fig. 10.09**.

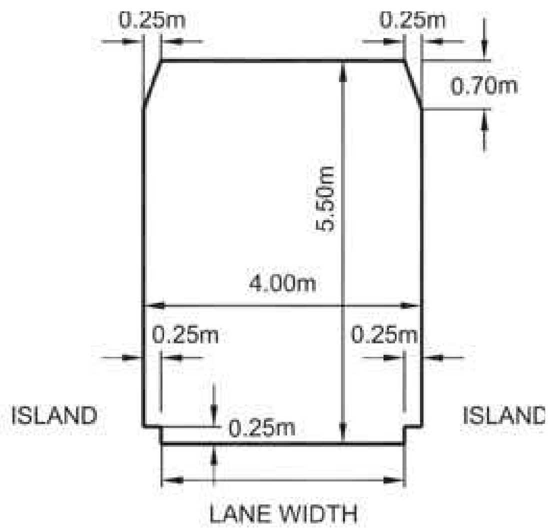


Fig. 10.09 ETC Clearance Diagram

ii) ***IC Card Outline (Applicable for Some Types of OBU)***

1) The IC card is basically a contact-less IC card conforming to the ISO/ IEC14443 Type A or Type B standard while contact and combined type of IC cards based on the ISO/IEC7816 standard are offered as optional.
2) Interoperability with services other than ETC is offered as optional.

iii) ***Payment Methods***

1) Payment method should be basically prepaid.
2) Re-charge and account balance view opportunities should be provided to users through IC card issuance and re-charging units at toll plazas and through other means internet or automatically by credit card similar to VISA card developed for DMRC (Delhi Metro Rail Corporation).

iv) ***On-Board Unit Outline***

1) The on-board unit should be basically a two-piece type or one-piece type
2) Power is basically sourced from battery or the vehicle's power plug.
3) The unit should be able to withstand in-vehicle environment.

Fig. 10.10A presents ETC OBU with an IC Card.

Fig. 10.10A ETC OBU with an IC Card

v) ***Road Side Equipment Outline***

1) Antenna system should be employed in the road side equipment.
2) The roadside system does not employ vehicle classification feature. Tolls are determined based on information including vehicle class registered to the on-board unit.
3) Enforcement cameras should be installed to check vehicle license plates. **Fig. 10.10B** present of Roadside Radio Unit

Fig. 10.10B Roadside Radio Unit

vi) ***Security***

1) To ensure the security of all data transfers, data should be protected by encryption, decryption and other means.

2) Data transferred over radio communication and stored in IC card should be encrypted, and mutual authentication between road side equipment and IC card should be performed.

vii) ***Toll Evasion Countermeasures***

1) Enforcement cameras are mounted on the gantries or roadside to store images data of vehicle license plates.

2) To detect vehicles that evaded payment of toll, license plate information obtained through road-to-vehicle communication and license plate images as explained in above (1) are matched.

10.6.3.2 ETC layout

In a toll plaza, the operating speed of vehicles with ETC payment would be higher than that with Cash payment which could increase the possibility of road accidents. Therefore ETC lane should be implemented to avoid unnecessary crossing movement. **Fig. 10.10C** presents typical layout of ETC Mechanism. Schematic arrangement of ETC lanes is given in **Fig. 10.10D**.

10.6.4 *Signages and markings*

ETC being a non-stop lane would require signages in advance for traffic lane guidance to avoid complex weaving manoeuvre at toll plaza. **Fig. 10.11A** presents Guide sign for ETC.

The ETC lane at the plaza shall have a distinct identification signage adequately illuminated and placed over the dedicated lane. **Fig. 10.11B** presents Guide Sign on Toll Lane Portal.

The portal over the ETC lane shall also have purpose oriented informative features. For easy identification by driver, the pavement surface of the ETC lane shall be marked with special type, such as, white chevron marking on blue background and the word ETC is written on the pavement surface. **Fig. 10.11C** presents ETC Lane Marking.

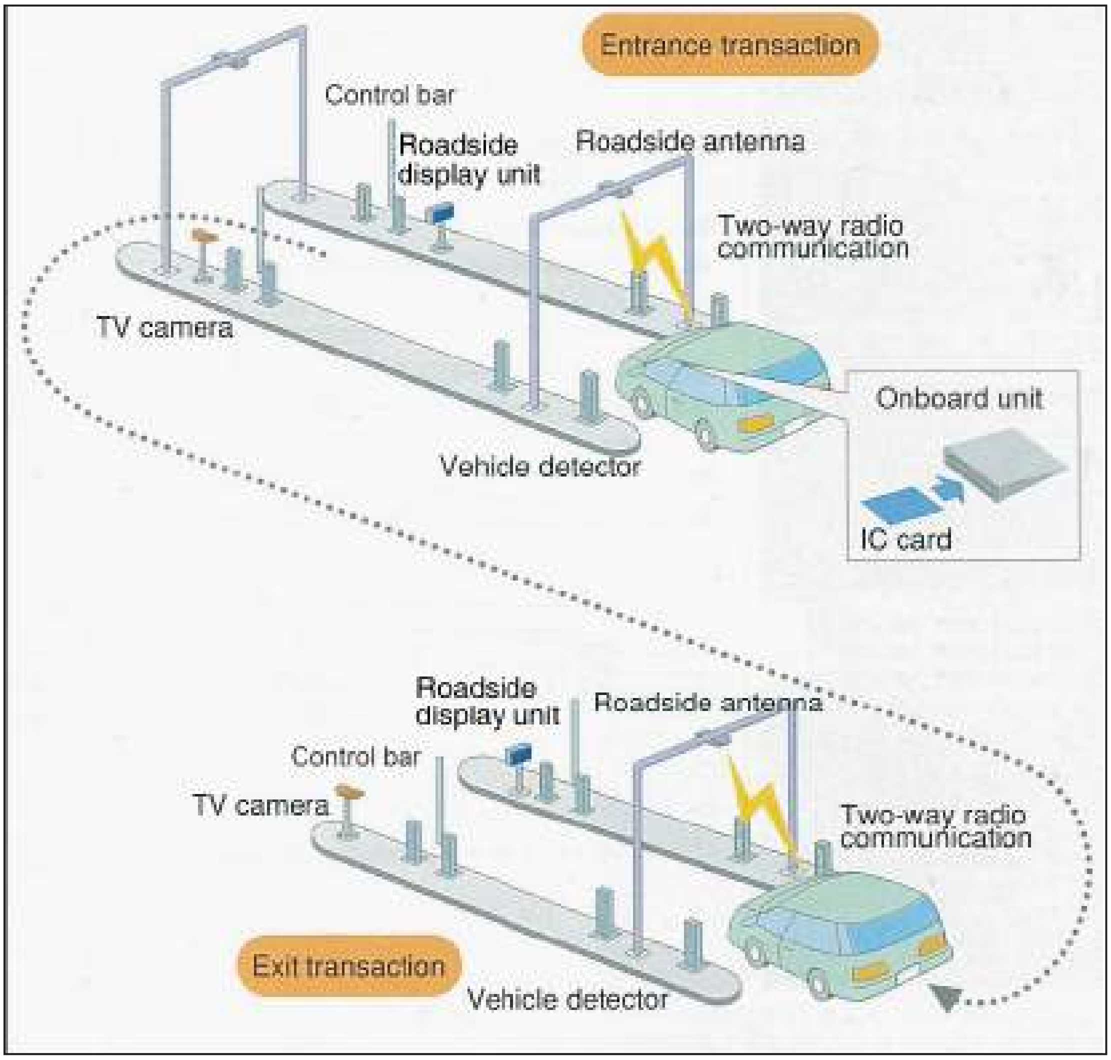
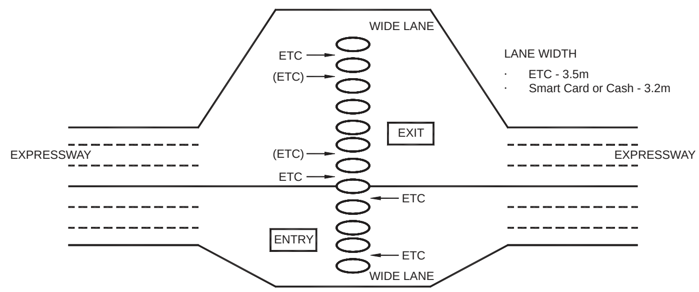
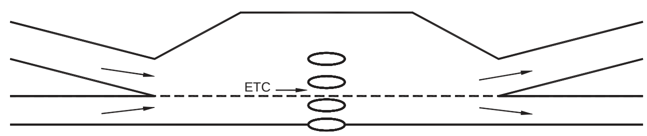


Fig. 10.10C Typical Layout of ETC Mechanism

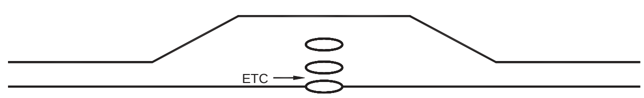
Typical arrangements in Japan are shown below.



Layout of ETC (Main Carriageway)



Layout of ETC (IC with merging diverging)



Layout of ETC (Ramp Interchange)

Fig. 10.10D Schematic Arrangement of ETC Lanes

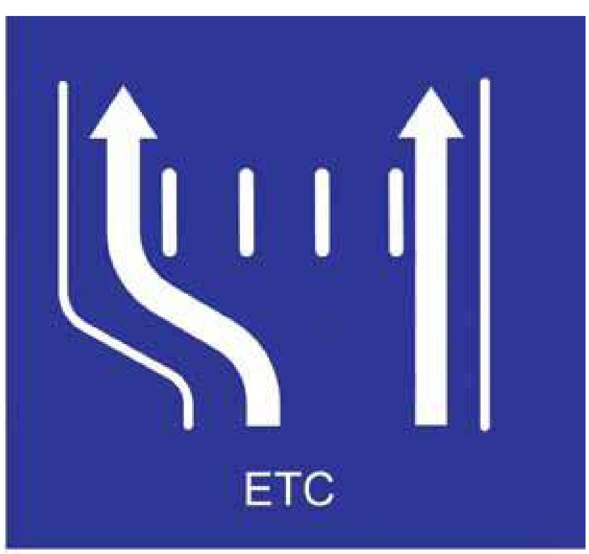


Fig. 10.11A Advance Gantry Sign

Fig. 10.11B Guide Sign on Toll Lane Portal

Fig. 10.11C ETC Lane Marking

10.7 OPERATIONS AND MAINTENANCE CENTER

There shall be operation and maintenance center(s) either at the toll plaza (s) or at any other location along the highway as identified by the concessionaire. The land for the same shall be acquired by the concessionaire at his cost and risk. The operation and maintenance centre would have following minimum facilities.

i) Main control center and Administrative block
ii) Equipment for operation and maintenance and storage space for them
iii) Storage space for equipment and material for traffic signs and markings
iv) Workshop
v) General garage and repair shop
vi) Testing laboratory
vii) Parking space for minimum 4 numbers of large vehicles and for other expected vehicles during peak hours including those for working and visitors.

All building works shall be designed to meet the functional requirements and shall be compatible with regional architecture and micro climate. Locally available materials shall be given preference but not at the cost of construction quality.

The circulation roads and parking spaces in the O&M center shall be paved to withstand vehicles loads and forces due to frequent acceleration and deceleration of vehicles. Parking bays/ lots shall have proper cross slope and drainage. The marking of the parking bays shall be as per IRC:35 to demarcate parking and circulation space. Parking lots shall have illumination as provided in IS 1944 (Parts I and II).

The whole campus of operation and maintenance center shall have system for security with safe entry and exit.

10.7.1 *Operation center*

Each operation centre may be in charge of preferably, and the site of each one including the administration building, warehouse, electrical systems, etc. occupies approximately 20,000 – 30,000 m^2, although this varies according to the location, size of the site, etc. **Table 10.04** presents an outline.

Table 10.04 Facility Outline at Operation Centre

Facility	Facility Outline
Administration Building	Traffic Control Center, Facility Control Center, offices, and other rooms where related business is conducted, police related facilities.
Garage	Parking of vehicles required by the operation bureau.
Electric Room	Houses the power receiving and distributing equipment and the non-utility power generator.
Auxiliary Facilities	Other facilities needed for the operation bureau to function normally, these include bicycle parking, propane storage, flag pole etc.

10.7.1.1 General administration and functional areas

Senior officers room, general offices, traffic control centres (office, accident response room, communication and command room, monitoring and control machinery room, communication equipment room, rest room, storehouse, locker rooms), facility control centre (office, control room, rest room, storage, changing room), conference room, document room, storage for office supplies, account books, technical materials, emergency supplies, spare room, reception room, rest room, locker room, welfare room, drivers' waiting room. Shall also provide space for crane, trucks, ambulances and the rest/working space.

10.7.1.2 Common areas

Dining room, kitchen, telephone switchboard room, first-aid room, kitchen, bathroom, toilet.

10.7.1.3 Equipment areas

Air-conditioning room, boiler room, electrical utility room (including non-utility generator).

10.7.1.4 Other areas which include

i) Computer Room: Data Management

Office, computer room, stock room, rest room, locker room, air-conditioning room.

ii) Expressway Traffic Police and security personnel

Office, changing room, communications room, firearm control and storage, investigation room, dark room, resting room, storeroom.

iii) Contractors

Traffic management contractor's room, housekeeping contractor's room, water quality control contractor's room, property management contractor's room, road maintenance inspection contractor's room, toll office machinery maintenance room, equipment maintenance contractor's room, and road communication maintenance contractor's room.

iv) Building Management, Equipment management – equipment maintenance contractor's room.

10.7.2 *Maintenance office*

An Operation office, an organization assigned the task of properly managing an expressway, is generally responsible for about 50 km of expressway. For a 100 km sketch, two offices can be considered and its site including office space, garage, air-conditioning room, and snow removal and ice control base, occupies between 12,000 and 18,000 m^2, but this varies according to the size and the topography of the site.

It provides centralized control of toll offices and rest areas on the expressway under its jurisdiction. **Table 10.05** presents an outline of the facilities at an Operation office.

Table 10.05 Facility Outline at Operation Office

Facility	Facility Outline
Operation Office Buildings	The area should be sufficient so that all the agencies such as road authorities, police, contractors, utility agencies, regional transport authority, and emergency rescue team can be located at these sites.
Garage	Vehicles needed by the operation office are stored here. Snow removal and ice control vehicles are also kept in the garage at operation offices where these types of work are done.
Utility	Houses the power receiving and distributing equipment and the non-utility power generator.
Snow Removal and Ice Control Facilities (where required)	Chemical storage, office, de-icing solution storage tanks, alt dissolution storage tanks (in areas to remove snow and control ice only).
Auxiliary Facilities	Vehicle parking, propane storage, oil storage, accident processing room, incinerator, flagpole, flammable chemical storage, filling facilities, water storage tank.

10.7.2.1 Administration and functional areas

Senior officers room, office, communication equipment room, accident, disaster and snow and ice counter-measure room, conference room, rest room, housekeeper's room, changing room, storeroom, drying room (only in regions where snow removal and ice control is performed), auxiliary traffic management rooms (liaison and consulting room, storeroom).

10.7.2.2 Common areas

Water heating room, food service rooms (dining room and kitchen), toilets, bathroom, corridors, stairs, air-conditioning room.

10.7.2.3 Other areas

i) Expressway Traffic Police and Security Personnel

Office, changing room, communications room, firearm control and storage, investigation room, dark room, resting room, storeroom.

ii) Contractors

Traffic management contractor's room, housekeeping contractor's room, water quality control contractor's room, property management contractor's room, road maintenance inspection contractor's room, toll office machinery maintenance room, equipment maintenance contractor's room, and road communication maintenance contractor's room.

10.7.2.4 Garage related areas

Garage, materials storage, vehicle repair equipment/parts storeroom, accident processing room.

Electrical Utilities Room Related

Power reception/distribution room, non-utility generator room, machinery and materials storeroom.

Snow Removal and Ice Control Related

Chemical storeroom, crew members room, de-icing solution tanks, salt dissolving tank.

10.7.3 *Toll office*

Toll plaza shall have a separate office building so as to provide comfortable office space for manager, cashier and other staff. There shall be separate rooms for TV monitors, meetings, toilets, and for the sale of passes, smart cards, on board units and public interaction. The building shall have a strong room for keeping the money and a garage to accommodate the security van (during operation of loading the collected revenue). There shall be parking space in the same campus for vehicles for the staff and workers and other vehicles engaged in the operation of the Expressway.

Toll offices are facilities provided to issue tickets and to collect toll fees from drivers using the expressway. There are two types: expressway barrier toll offices on expressways and interchange toll offices constructed at interchanges. **Table 10.06** presents an outline of the facilities at toll office.

Table 10.06 Facility Outline at Toll Office

Facility	Facility Outline
Office Building	Rooms used for toll fee collection related work, police related rooms.
Toll Gate	Facilities where expressway tickets are issued and toll fees for expressway use collected. Some are located at boundaries between expressways and ordinary roads to psychologically re-orient drivers.
Electrical Utilities Room	Houses the power reception receiving and distributing equipment, the non-utility power generator, and the communication equipment.
Snow Removal and Ice Control Facilities	As necessary, chemical storage or de-icing solution tanks.
Auxiliary Facilities	Bicycle parking, propane tanks, incinerator, flagpole.

10.8 OTHER FACILITIES

10.8.1 *Vehicle weighing system and associated storage space*

Toll plaza location shall also be provided with system for checking and preventing overloading of vehicles. For this purpose, Weigh in Motion Systems (WIM) one to be untalled at entry. Separate space for static weigh bridge and accommodation to store off-loaded goods from overloaded vehicles shall be provided after the toll barriers for each direction of travel.

10.8.2 *Electrical*

The efficient functioning of toll plaza complex for toll collection, maintenance of records of vehicles, control of regulated movement of vehicle through Lane Control Signs etc. are centrally operated from the shift supervisor’s room in facility building and this requires continuous and reliable electric supply system. Power supply shall be from public power supply system but stand by generating set of the capacity to supply the required power shall be provided at toll plaza.

10.8.3 *Interior lighting*

The inside toll booths and facility building office will all be illuminated to a level of approximately 200 to 300 lux as per IS: 3646 Part II. Indoor lighting will be fluorescent lamps. Lighting should be provided in such a manner that glare should be avoided or minimized.

10.8.3.1 Canopy lighting

The area of toll plaza covering the flared portion shall be provided with concrete pavement. All the toll lanes and toll booths shall be covered with a canopy. The canopy shall be wide enough to provide weather protection to toll operators, drivers and facilities. The canopy shall be of aesthetically pleasing design with cylindrical support columns located at traffic island so that there is no restriction on visibility and traffic movement.

For higher level of illumination up to 100 lux, for convenient reading, at the toll gate area beneath the canopy and at the toll booth locations, require use of metal halide lamps and halogen lamps. Normal fluorescent tubes inside toll booths may also be provided.

10.8.4 *Exterior lighting*

Lighting of the toll plaza is one of the important features for enhancing the night visibility, so that drivers and truck/bus drivers are able to see objects on their travel path from a distance in a comfortable manner without suffering any type of discomfort or disability glare. The lighting system has two major components:

- i) High mast lighting
- ii) Highway lighting

10.8.4.1 High mast lighting

The toll plaza shall have lighting system to provide visibility to drivers for the use of facility especially to access the correct service lane and also to the toll collector. Indian Standard IS 1944 shall be followed. The minimum requirement of illumination on the road surface of 30 lux shall be ensured. This would be done by providing high-mast lighting (minimum 25 m height), lighting at canopy, and lighting inside toll booths. Street lighting shall also be provided on both side approaches of toll plaza for a minimum length of 500 m beyond toll plaza area on each side.

10.8.4.2 Highway lighting

Lighting in 1 km length beyond both approaches of toll plaza shall be provided to enhance the safety on highway and to make the drivers conscious of their approaching the toll gate. These shall be provided on the mild steel welded tubular poles of 10 m height from road surface and with 2 m over hand on both sides. Sodium vapour lamp luminaries of 250 watt shall be provided for these poles, erected in the center of the central median at the spacing of 50 m.

10.8.5 *Water supply*

On the basis of water requirement, following arrangements are proposed for:

- Water supply from municipal main;
- Water supply from bore well.

10.8.6 *Drainage*

The toll plaza shall be provided with surface and sub surface drainage system so that all the storm water is drained off efficiently and no ponding or stagnation of water takes place at any area of the toll plaza. Drainage gratings across the toll lanes shall be provided and connected to covered drain at the periphery of toll plaza area. ***Ref. Fig. 10.03A and B.***

10.8.7 *Fire fighting system*

Toll Plaza shall have fire fighting equipment including smoke detectors and audio visual alarm system as per National Building Code so that the personnel working in the complex and the office are not subjected to hazardous situation due to fire.

10.8.8 *Air conditioning*

Air Conditioning shall be provided in toll booths, offices, computer rooms and all areas of works. Ceiling fans and AC unit should also be provided in selected areas.

10.9 AUDIT SYSTEM

The toll plaza shall have toll audit system and fraud protection measures. The operations for toll collection, supervision, auditing and money handling shall be done through the qualified personnel so that each operation is efficiently handled.

The toll audit unit would be responsible for the audit of all toll attendants. Toll attendants must be audited for every hour of duty in order to prevent theft. The people in this unit will audit a seven day work week for toll collection in a five day period. It is extremely important that this unit not be understaffed. The toll collection system should provide these individuals with terminals and a method for making corrections or adjustments to data entered by toll attendants. It is anticipated that diskettes received from the toll plazas would be loaded on a central computer for processing. These diskettes would contain information entered by toll attendants and independent information recorded by treadles and loops regarding axle counts and transactions. This applies to entry lanes as well as exit lanes. Amounts to be deposited by attendants would be calculated by the equipment at the toll plaza from the information contained on toll tickets processed through the exit lane terminal. The treadles and loops should balance with the axles and transactions accounted for by the toll tickets processed by the attendant.

The entry-lane audit is as important as the exit lane audit even though no cash is involved. Transaction and axle counts should be balanced with the tickets issued so as to be certain that the automatic traffic issuing machine is not issuing extra tickets that can be given to a friend working at exit-lane or at another toll plaza.

CHAPTER - 11

SERVICE AREAS

CHAPTER – 11

SERVICE AREAS

11.1 INTRODUCTION

Service Areas (SA) are an integral part of access controlled closed – toll system expressway. The users of expressway under close toll system need to be provided with service areas for the users who stop for rest, refreshment and fuelling or for some emergency requirement.

These service area facilities are expected to rejuvenate during fatigue and thus reducing accident possibilities.

It is mandatory that facilities provided on expressways should take into account the needs of the provisions for Persons with Disabilities (PwD). These have been comprehensively considered and are indicated in **Appendix – 11.**

11.2 SERVICE AREAS

For the closed toll system, the SAs are planned to be integrated with toll plaza and interchanges.

11.2.1 *Locations*

Various research studies have indicated that the drivers would prefer to stop at around 100 km after say one hour drive on high density, high speed corridor like expressway.

Expressway shall have Rest Area(s) planned such that they are spaced at intervals of 30 minutes to one hour of driving time between two important cities/towns, which corresponds to around 50 – 100 km spacing. They would not be located between 5 km of a town or city or near interchange if entrance and exit ramps could cause weaving conflict.

Rest areas shall be planned to cater for traffic moving in both directions such that there is no need for the vehicles on one carriageway to cross over to the other carriageway. The entry to this Rest Area(s) would be through deceleration lane and exit through acceleration lane. The minimum width of these lanes shall be 5.5 m.

Rest area(s) shall be designed for the expected peak hour long term clientage and shall provide facilities for parking, restaurant, cafeteria, toilets, telephone and shops for selling items normally required for traveling, fuel and garage for minor repair, telephone, first aid.

The parking should include parking for expected peak hour truck traffic and cafeteria suitable for fulfilling the need for Indian truck drivers and shall be paved by CC blocks strong enough to withstand expected loadings. The whole area shall be elaborately landscaped to provide a pleasing environment.

However, the option of integrating a service area with the facilities around an interchange point require special care / resources when the expressway is implemented under PPP (Public Private Partnership) format. Additional precautions need to be exercised on evasion of tolls or misappropriate use of toll tickets.

In combination with functional requirements of man and machines, utilization of scenic spots along the expressway corridor shall be considered, but not in total wilderness. These have to be sufficiently close to localities to provide for operation and maintenance of service facilities, otherwise locality need to developed.

From security considerations, it is of prime consideration that service areas will be provided near interchanges and at intermediate locations where the distance between successive interchanges is more than 100 km. In such cases, Wayside Amenities are to be provided at a point approximately mid way between interchanges.

11.3 SIZE

The process of developing on adequate service area to meet the needs of Heavy Commercial Vehicle (HCV) drivers, Passenger Car Users, expressway bus users, is a complex process. Non availability of such database makes the process more complex. “AASHTO – Guide for Development of Service Areas on Major Arterials and Freeways – third edition” – recommends:

a) Number of parking spaces will dictate minimum size of the site required at each location;

b) A minimum size of 5 (five) hectares (50,000 sqm) is required;

c) Sites upto 15 (fifteen) hectares (150,000 sqm) area are considered generally manageable and provide ample room for such site development as picnic areas, children’s playing arena and landscaping. Some additional area may also be considered to provide emergency services such as medical centre, trauma centre and even heliports as SoS measures;

d) Sites with areas around 35 hectares (350,000 sqm) are considered too large from maintenance, operation and security considerations. Unless dictated by topography and other natural barriers such as hillocks, water bodies, historical monuments and ecologically sensitive areas etc. such a large size should be avoided. Otherwise such large sites may be considered for integrated planning.

The size and composition of the service areas would vary according to the expected peak traffic (during lunch and dinner times), dwelling/resting time, location, proximity to facilities and places of special interest. Currently, in India many sources/authorities/ institutions are available that recommend parking – area dimensions. The sizing of the service area shall also take care of local regulations on solid waste management, waste disposal, sewerage, drainage and erosion control aspects. The scenic beauties, natural greeneries and view points shall be given due consideration. Land grading shall be kept to minimum. In summary, in sizing of service areas, wide spectrum vision is a necessity.

11.4 AMENITIES/SERVICE FACILITIES

Service Facilities are to be determined depending upon the distance between successive service areas. As a general guidance ADT related spacing of Facilities/Services are given in **Table 11.01**. The facility provisions shall include

a) Parking space for large vehicles including commercial trucks and expressway buses;

b) Parking space for small vehicles including cars and minibuses;

c) Filling stations for petrol, diesel & CNG including compressed air facility for tyres;

d) Vehicle servicing areas

e) Amenity Facilities such as

- Toilets/Service rooms with separate provisions for ladies, gents, nursing mothers and Persons with Disabilities (PwD);
- Dormitory – separate for commercial trucks and light vehicles with provision for beds, chairs, sitting provisions and place for keeping luggage’s, toilet may be common;

- Cubicles – are for longtime service and desirably shall be provided with bed, small writing desk, attached toilet and cup board with spaces for luggage;
- Fast Foods and Restaurants with provision for serving and eating places besides food counters;
- Shops for essential needs, local area mementos, first aid and essential medicines, magazines, photo films, batteries, toiletries and other tit bits

f) Walkway, service way and circulation space for Persons with Disabilities (PwD), mothers with lap babies and pregnant women;

g) Pickup Bus Stop

h) Parking facility for emergency vehicles including office, service areas and toilets;

i) Space for security personnel with watch towers (optional);

j) Provisions for medical care and trauma centre and helipad for emergency evacuation;

k) Liberal space for land space, children play areas and walk ways;

l) Other facilities may include travel information centres (including person oriented or digitally displayed fixed or movable types), interpretive and educational displays, do's and dont's while driving on expressways;

- Free informative hand outs about service centres along the expressway (like Highway Walkers – in Japan)
- Smart driving tips (audio – visual)
- Computerized tourist information kiosk
- Mobile phone recharging/tapping up facility
- Current news bulletin, display board
- Recreational vehicle dump stations
- Vending machines
- Weather information display
- Road condition (for driver's usage)

Table 11.01 Typical Spacing of Facility/Services

Sl. No.	Facility/Service	Distance (km)		
		ADT 20,000-30,000 Vehicles	ADT 30,000-40,000 Vehicles	ADT 40,000 Vehicles and above
1)	Parking Area and Rest Facilities	60	40	40 (15-25 in Japan)
2)	Fuel cum service station	40	40	40 (50-100 in Japan)
3)	Work Shop	80	80	40
4)	Restaurant	60	40	40
5)	Dormitory	160	80	80
6)	Motel	160	160	160
7)	Tourist Information Centre	160	160	160

11.5 DEVELOPMENT CONTROL

It is desirable that the service areas with amenities be designed, to blend with the surrounding landscape. Preference should be given for the use of local architectures and planning considerations. These should be made attractive as value added place through proper design, landscaping and provision of neatly maintained facilities. Consideration may be given that land for provision of amenities and service areas is acquired by the authority. However, these areas could be leased out to the concessionaire or private developers and entrepreneurs for construction, operation and maintenance of services. Sufficient space must be earmarked, to allow for anticipated future expansion, with development of expressway traffic.

11.6 CONCEPTUAL LAYOUT

The basic consideration should be to integrate interchange, service area and bus stop. This may produce a combined effect of attraction. However, the ramp configuration may become complex. Other consideration is to separate the parking area for large vehicles and the parking area for small vehicles. This separation has been planned with the provision of building with various amenities. With this as basic consideration, a few conceptual layouts have been developed and are presented as **Fig. 11.01A** through **Fig. 11.01F.**

Conceptual Drawing of IC cum SA cum BS

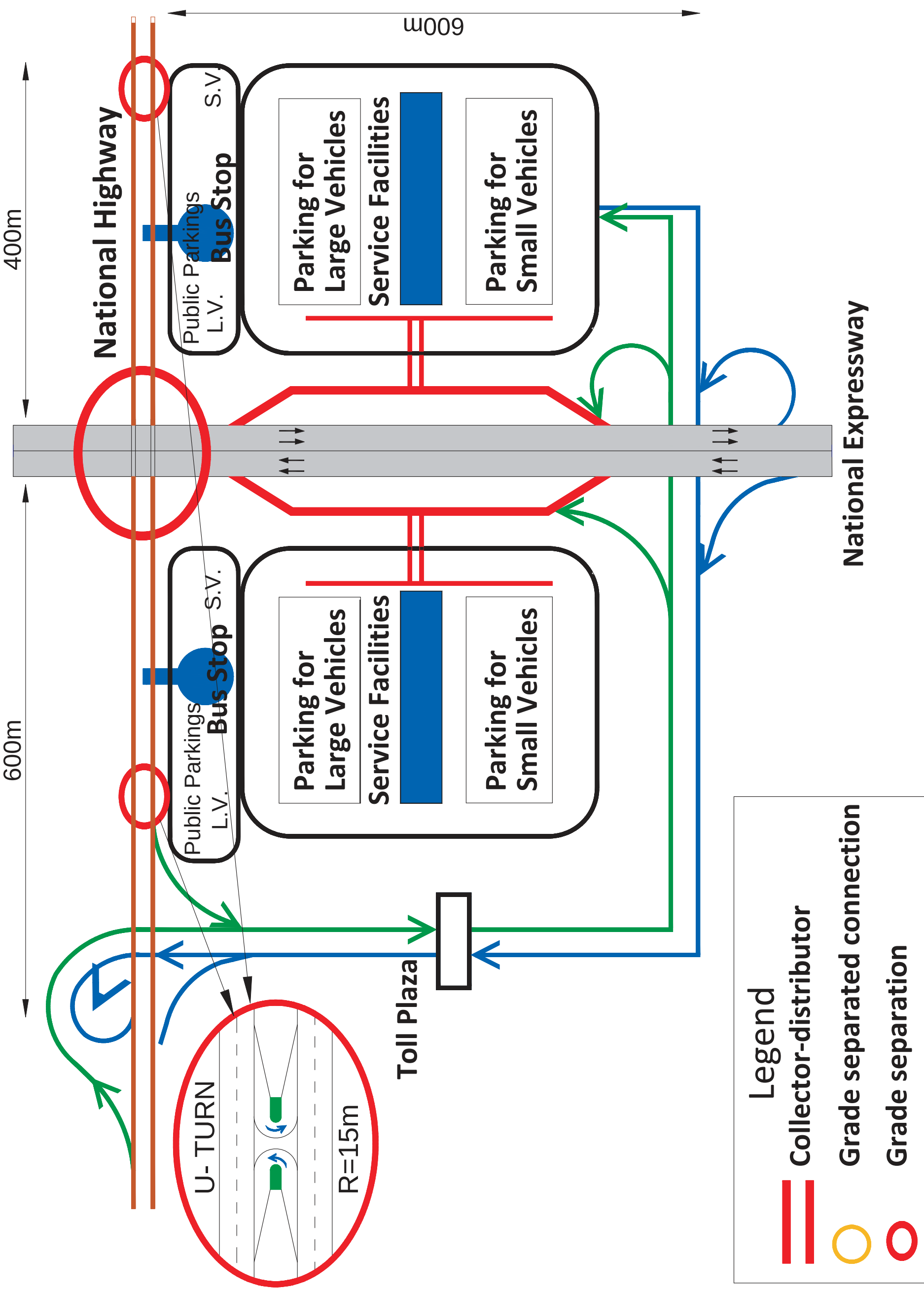


Fig. 11. 01A

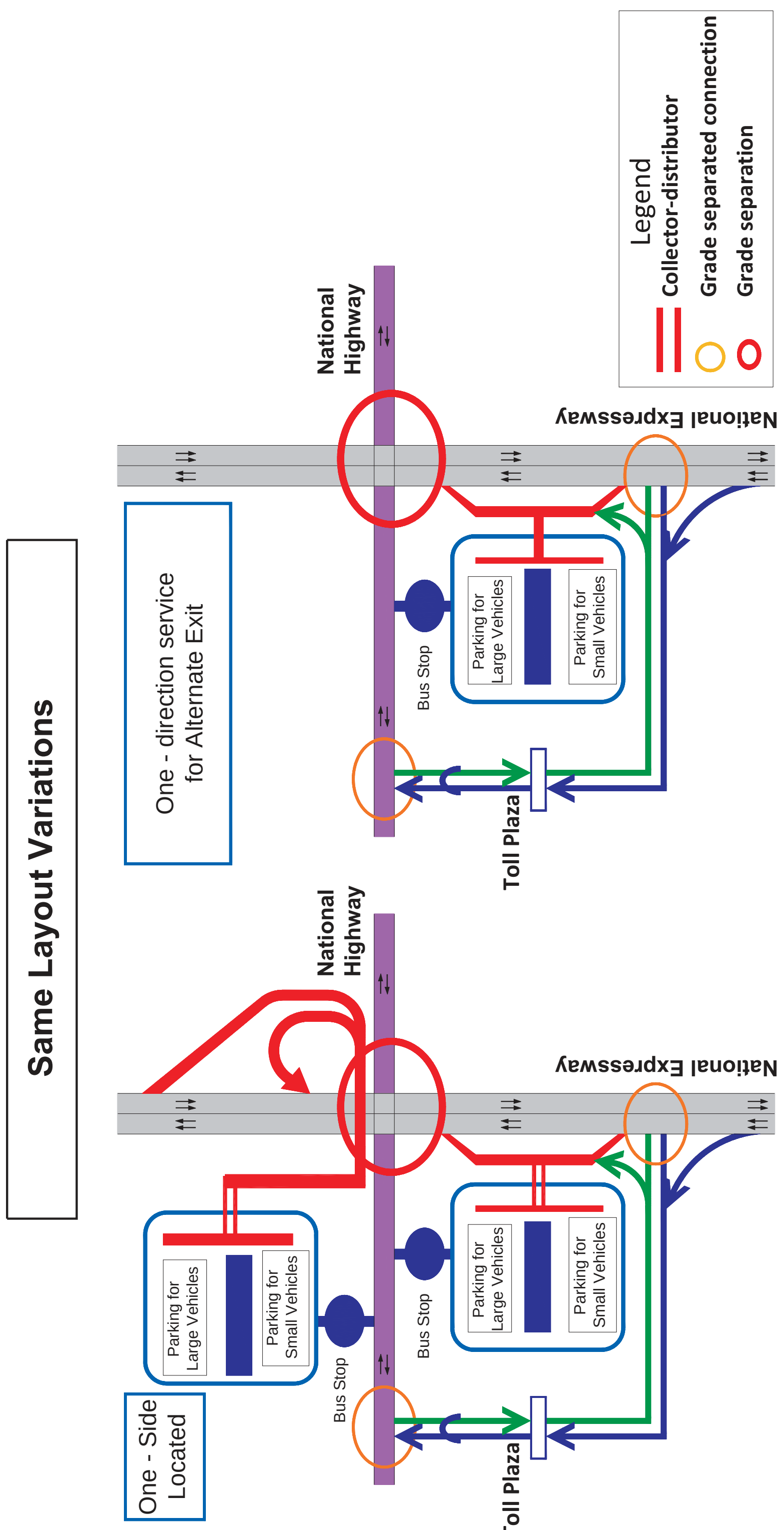


Fig. 11.01C

Fig. 11.01B

Typical Layout of Full-size and Small-size

Full-sized Amenity

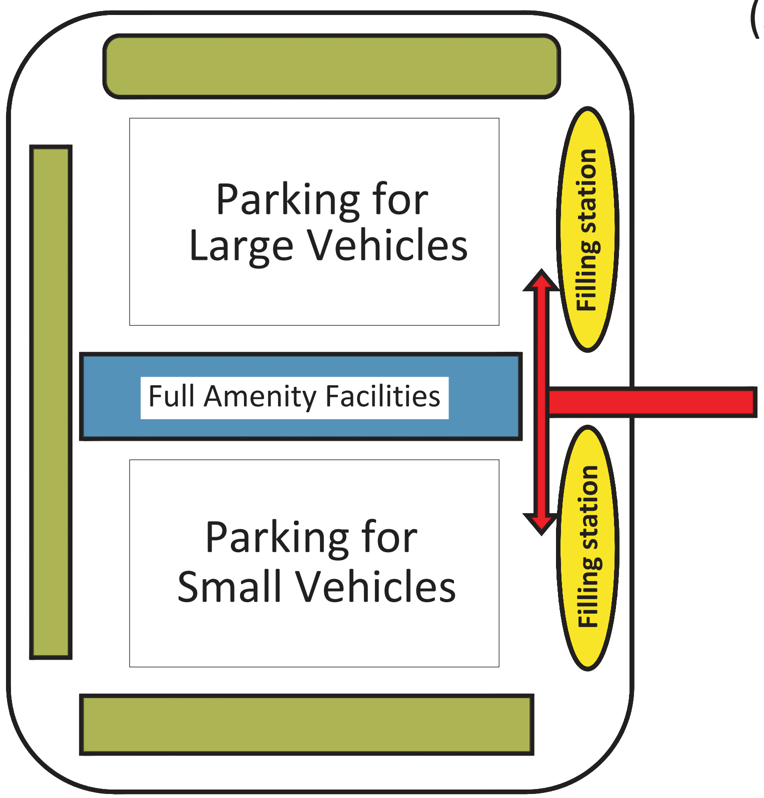


Fig. 11.01D

Small-sized Amenity
(Stand-alone when spacing of
IC > 40km)

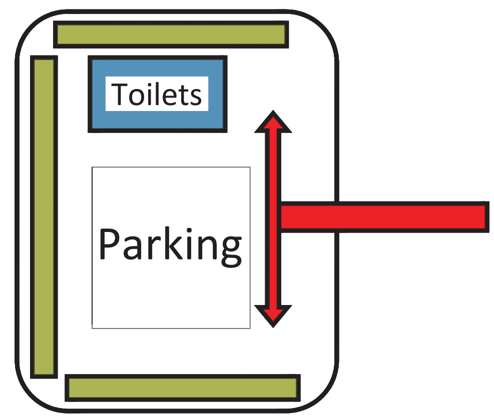


Fig. 11.01E

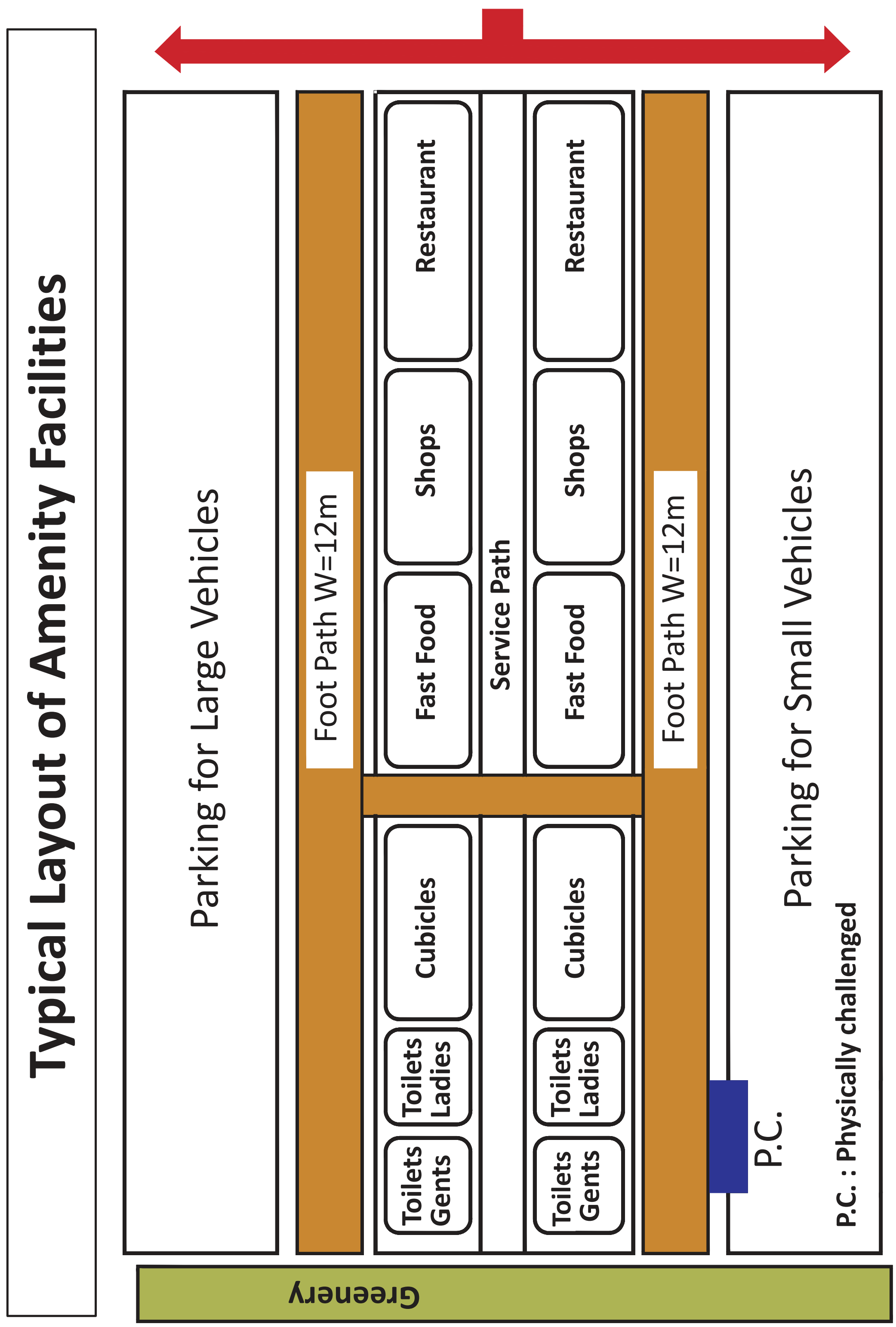

Typical Layout of Amenity Facilities
Parking for Large Vehicles
Foot Path W=12m
Restaurant
Shops
Fast Food
Cubicles
Toilets Ladies
Toilets Gents
Service Path
Restaurant
Shops
Fast Food
Cubicles
Toilets Ladies
Toilets Gents
Foot Path W=12m
Parking for Small Vehicles
P.C.
P.C. : Physically challenged
Greenery

Fig. 11.01F

Fig. 11.01A : Presents service area built in pairs to meet the directional users separately. The pairs are interrelated as near to each other as possible from operation, maintenance and security considerations. This has also been provided with C-D roads to avoid restrictive weaving. The facility requires large area and includes all possible needs of the users of closed toll expressway corridor.

Fig. 11.01B : This a down sized version of the layout of **Fig. 11.01A**. In case of difficult terrain/topographyly or physical constraint for the land requirement. The land may be available on one side of the expressway. For the other directional users are brought to the service area through an appropriate grade separated passage (depending on ground conditions).

Fig. 11.01C : Presents the limited facility service area to cater for one direction traffic. This layout may be adopted for places with secure land constraint. Such facilities may be provided for alternate exits to cater for the other direction traffic.

Fig. 11.01D : Presents a relational diagram for locating filling stations for petrol, diesel and CNG.

Fig. 11.01E : Presents a small facility where the Interchanges (IC) are more than 40 km apart. This provides bare minimum urgent requirement. Such facilities are seldom used since this becomes a standalone facility and leads to higher cost of maintenance, operation and security provisions.

Fig. 11.01F : Presents the relational layout of the amenities planned to be provided at various locations. While providing the facilities, the building blocks are planned in a scalable fashion in modular units – so that the furniture, interiors can be made in modular configuration. This helps standardizing the service at various centers.

A few pictorial views are presented in **Fig. 11.01G** for appreciation of the facilities.

11.7 DESIGN CONSIDERATIONS FOR THE SERVICE AREAS AND AMENITIES

Source: 1. "Service Areas", NCHRP Synthesis of Highway Practice 20, HRB, 1973

2. "Roadside Features", Departmental Advice Note TA 57/87, Highways and Traffic, Department of Transport, UK.

3. *"AASHTO": Guide for Development of Service Areas on Major Arterials and Freeways –Third Edition.*

ECHIGO-KAWAGUCHI IC, KANETSU Expressway

TATSUNO-NISHI IC, SANYO Expressway

AKAGI IC, KANETSU Expressway

NADACHI – TANIHAMA IC, HOKURIKU Expressway

Fig. 11.01G Some Examples of IC cum SA in JAPAN

The broad elements of design are:

- Capacity of Facilities
- Acceleration and deceleration lanes
- Internal circulation and distribution of sites equipped for parking
- Entry and Exit
- Electrical Systems
- Road markings, road signs and safety
- Water supply and sanitary systems

While designing such service area, it is first necessary to take into account the following considerations:

i) The distribution of facilities along the expressway
ii) Topography of the site selected
iii) Provisions for future expansions

11.7.1 *Capacity of facilities*

The capacity of facilities at a Service Area shall be arrived at based on anticipated demand for such facilities. The number of facility users, and hence the scale of the facility depends upon the following factors:

- The AADT (Annual Average Daily Traffic)
- The composition of traffic
- The types of services offered
- The distance from other similar services
- The potential ability of the service area management to render the stop a pleasant one
- Proximity to facilities and places of special interest

• **Type of parking lots**

- The type of parking lots is generally equal to three. They are:

- Car parking lot
- Bus parking lot
- Goods vehicle parking lot

- **Number of parking places**

  Number of parking spaces shall be assessed based on facility spacings.

Number of parking spaces dictate the size of the service areas. Deciding parking space requirement is a complex process specially in absence of adequate data base. In order to break through “chicken and egg” situation we have to adopt other country practices. AASHTO – Guidelines on service area have recommended a system – Analysis procedure. This requires parameters to be established from statistical data base. For this Guideline – some decision rules have been adopted for the emerging transportation scenario in India.

Using the systems approach, the followings are generated as Interim Guidelines for the designers and planners.

While **Table 11.02** has been adopted from Japan documents, **Table 11.03** has been computed using System – Analysis – Procedure with the assumptions for Indian traffic situations. Computations are presented below:

For this guideline, we may assume **Table 11.02** as **Minimum** values while **Table 11.03** as **Desirable.**

Table 11.02 No. of Parking Spaces Required at Service Areas (Japan Standards)

% of HCV	AADT									
	30,000		35,000		40,000		45,000		50,000	
	Car	HV	Car	HV	Car	HV	Car	HV	Car	HV
30	100	40	110	45	125	50	135	55	145	55
40	85	50	95	55	105	60	115	65	125	70
50	70	55	80	65	90	70	100	80	100	85
60	55	65	65	75	70	85	75	90	80	95

Source: Japan Documents

Table 11.03 No. of Parking Spaces Required at Service areas (AASHTO)

% of HCV	AADT									
	30,000		35,000		40,000		45,000		50,000	
	Car	HV	Car	HV	Car	HV	Car	HV	Car	HV
30	101	54	118	63	134	72	151	81	168	90
40	86	72	101	84	115	96	130	108	144	120
50	72	90	84	105	96	120	108	135	120	150
60	57	108	67	126	77	144	86	162	96	180

Systems-Analysis Procedure: Decision Rules

Traffic volumes, usage surveys, the spacing intervals can be included in a systems analysis formula to determine parking needs for cars and trucks within a highway section being studied. Once parking needs have been established, existing areas within that section can be examined. Analysis of existing parking spaces along a route, size of existing sites, and other factors will determine whether a new service area is built or an existing site is upgraded. Similarly, each highway section (package) can be analyzed.

The first step in systems analysis is to identify study sections along a specific highway route. Each study section is referred to as a design section length (DSL taken as 250 m). The base spacing interval of 50 m is referred to as the base section length (BSL). Current and 20-year projected ADTs are established for each DSL to determine parking and sizing needs. If several ADTs are involved within the section being investigated, then these are collectively averaged into a single ADT. The forecast design hourly volumes for each section are similarly determined and averaged. The following equations may then be used to determine parking needs at each site:

$$N_c = \frac{ADT \times P \times DH \times D_c \times PF \times VHS}{60} = car\ parking\ spaces\ required$$

and

$$N_t = \frac{ADT \times P \times DH \times D_t \times PF \times VHS}{60} = truck\ parking\ spaces\ required$$

where

N_c = number of car parking spaces required,

N_t = number of truck parking spaces required,

P = proportion of maintenance stopping (considered as one percent) x DSL/

BSL (150/50) (the adjusted proportion of mainline stopping in the overall corridor), established on a case-by-case basis by usage surveys,

DH = design hourly factor (DHV/ADT) considered as 0.08

D_c = proportion of cars using the facility, normally assumed to be varying between 70 to 40 percent,

D_t = proportion of trucks and oversized vehicles using the facility, assumed to bev varying between 30 to 60 percent

PF = peak factor, the ratio of the average day usage during the five summer months compared with the average day usage over the entire year, normally assumed to be 1.8, and

VHS = average length of stay for cars and trucks determined on an hourly basis, normally assumed to be 40 minutes for cars, and 50 minutes for trucks.

11.7.2 *Toilet and washing facilities*

11.7.2.1 Planning

These are the most essential and prime requirement of expressway users. The frequent cleaning and maintenance operations shall be considered in planning. To keep toilet clean and bright, special care shall be given to ventilation and natural light intake and lighting facilities. Cleaning and maintenance operations shall be carried out without closing the services. In other words, the facilities shall be planned in compartment/enclosures so that the facility is available while the other portion is being cleaned/maintained.

The toilet shall desirably have an entrance hall which will work as waiting place and through this hall users can get the entrance door to men and women toilet enclosures. Separate enclosures shall be provided with baby care and cradle facilities.

Separate toilet shall be provided for Persons with Disabilities (PwD) as brought out in ***Appendix-11***.

Toilet Facilities

The number of toilet facilities in a public lavatory is depended on the number of users. No standard guideline is available. The number of toilets and the standard sizes for general application are given in **Tables 11.04** and **11.05** as designers guide. These are considered as “free facility”. The “pay facility” planning requirements may be different.

Passenger Car Parking Area (Indicative)

Table 11.04 Number of Toilet Facilities for Car Users

Number of Parking stalls	Number of Toilet Facilities			
	Urinals	Men’s Toilet	Women’s Toilet	For Persons with Disabilities (PwD)
Over 251	30	10	30	4
250-201	25	8	25	4
200-151	20	7	20	2
150-101	15	5	15	2
Under 100	10	3	10	2

Commercial Vehicle Area (Indicative)

Table 11.05 Number of Toilet Facilities for CV Users

Number of Truck Parking Stalls	Number of Toilet Facilities			
	Urinals	Men’s Toilet	Women’s Toilet	Shower Facility
Over 100	20	10	10	2
71-100	15	7	5	2
45-70	10	5	5	1
Under 45	5	3	3	1

Washing Facilities

Wash basins may be planned at the lobby space in separate compartment for ladies, gents and special provisions for children and Persons with Disabilities (PwD).

Vending Machines for drinking water, soft drinks and coffee/tea (hot and cold) shall be placed in a separate kiosk adjacent to toilet blocks.

11.7.3 Restaurants and fast food centres

11.7.3.1 Planning

Restaurants and fast food centres shall display the available foods with price tag and numbering to place the order vending machines for drinking water, soft drinks and coffee/tea (hot or cold) shall be placed in separate kiosks.

The planning should be liberal for display, movement walkways for users as well as serving/facilitators. The pathways shall be smooth finished for the trolley users, wheel chairs. Tactile surfacing stripe shall be placed to facilitate visually challenged persons.

The eating places shall be placed nearby the counters with user friendly table and chairs. Special/separate areas shall be marked for families and children; for mothers with lap babies to be provided with moving cradles. The entire planning exercise shall be liberal considering the requirements and shall not look “congested”. Various layouts are possible and innovative ideas of the planners will bring the variety. Such places are rated by the users as value added places.

Needless to mention, the area should be eco-friendly and blend with surrounding landscapes, greeneries and scenic spots.

The following area requirements are generally considered. Special provisions shall be kept for the Persons with Disabilities (PwD).

11.7.3.2 Area requirements

The practices vary from place to place. However, as a broad guideline related to the number of seats needed. for each parking areas are provided below.

Unit necessary space for 1 seat is 1.6 m^2, Kitchen space (may be optional for cooked/ semi cooked foods)shall be 40 percent of the dining area floor size. The space for other related activities is around 150-200 percent of the total eating area floor size.

Generally considered floor size corresponding to the parking spaces provided is shown in **Table 11.06**.

Table 11.06 Reasonably Comfortable Area

Number of Parking lots	Lots Number of seats	Area (m^2)
Over 251	190	950
250-201	160	800
200-151	130	650
150-101	100	500
Under 100	70	400

For the future extension, additional space for around 50 percent be preserved. or provisions shall be kept for adding floors.

11.7.4 *Dormitories and cubicles*

These are rest places for longer stay, generally more than four (4) hours or those who want to have a short sleep and/or night stay.

- Dormitories are provided with beds and some storage space with locking facility. Facility for TV and telephone may be provided. Generally three (3) beds are provided in a dormitory room. Two such rooms have common toilets. For one such two rooms unit with common toilet, an area of 70 m^2 is generally comfortable.
- Cubicles are small units provided with privacy. TV, telephone (intercom), toilet facility and storage space with locking provision is provided. An area of 12 – 15 m^2 is generally comfortable.

11.7.5 *Filling station*

The area shall cater for Petrol/Diesel/CNG and Electrical/Compressed Air facilities.

The area requirement depends on the number of flowmeters provided to service the visiting vehicles. A standard station generally has four to six flowmeters.

Refueling space	Office	Car wash area	Others	Total
300 m^2	120 m^2	60 m^2	50 m^2	530 m^2

11.7.6 *Mechanical repairing service*

The area shall provide repair shops for trucks, buses and cars and washing ramps alongwith space for towing vehicles and the affected vehicles.

Standard sizes normally followed are:

Repair Shops : 800 – 900 m^2
Washing Ramps : 100 m^2
Parking Space : 500 m^2

Additional communication facilities may be installed in Service Areas. In such cases communication equipment room shall be installed within the power house separated by concrete wall. Standard size of the room generally kept is 15 m^2 (6 m x 2.5 m).

11.7.7 *Sewerage facility*

If the local sewerage disposal system is not available then provision of single septic tank serving two adjacent service areas shall be provided. The size is determined according to the number of persons served or local area norms, if any. **Tables 11.07** and **11.08** give standard sizes of septic tanks.

Table 11.07 Sewerage Facility *(Passenger Area)*

Planned number of parking stalls on one side	Lavatory (ton)	Restaurant (ton)	Stand (ton)	Gas station (ton)	Total on one side (ton)	Total (ton/day)
250	175	140	37	20	352	724
200	140	112	29	20	281	582
150	105	84	22	20	211	442
100	70	56	15	20	141	302

Table 11.08 Sewerage Facility *(Commercial Vehicles Area)*

Planned number of parking stalls on one side	Lavatory (ton)	Stand (ton)	Total on one side (ton)	Total (ton/day)
100	82	17	99	198
70	58	11	69	138
45	37	9	46	92
30	25	9	34	68

11.7.8 *Waste and recycling receptacles*

A key component of cleanliness and public health, use of receptacles shall be used and placed at convenient locations for all restaurants, food plaza, vending machines as well as along walkway and parking corners and islands. Such receptacles must be functional, accessible, durable and easily maintained. The most common materials used are plastics, fibre glass and non-corrosive light metals. These should be present in sufficient numbers at every convenient place, and large enough to accommodate trash volumes.

11.7.9 *Other facilities*

- The scale of water tank shall be decided complying local regulations of the area.
- The indicative floor space for minor facilities are given in **Table 11.09.**
- Consideration shall be given for the future extension.
- In cold snowing area, deposit for deicing material shall be prepared facing to the parking place.

Table 11.09 Area Recommended for Minor Facilities

Facility	Area
Ware House	50-100 m^2
LPG Storage	20-30 m^2
Incinerator	15-30 m^2
Temporary Waste Stock Yard	4-20 m^2

11.7.10 *Internal circulation and distribution of sites for parking*

The following standards should be followed in the design:

i) Circulation should be in the same direction as that of the carriageway to which the area is connected

ii) Normally the roads and the parts reserved for passenger cars, separated from those for heavy vehicles, should be located in the Service Area/Service Area Zone nearest to the Expressway in such a way that visibility of the facilities is not impeded. The zone reserved for heavy vehicles, on the other hand, should be located in the rear zone of the area. This principle can be reversed in the case of service areas where ordinarily the zone farthest from the expressway is the most suitable for passenger cars

iii) The parking in the service area should be located in the immediate vicinity of the refreshment facilities. This would serve to reduce walking distance to a minimum and permits keeping an eye on the unattended vehicle.

The best arrangement of the parking places is at a 45° angle with respect to the transit lanes. This involves the minimum space necessary for parking manoeuvres. The parking places for 2/3 axle goods vehicles should be Diagonal Pull Through (DPT) or Diagonal Non-Pull through type (DNPT). The parking places for articulated/semi-articulated vehicles should however be Diagonal Pull Through-type.

Parking places for buses should be located near the refreshment facilities and set up in such a way as to ensure sufficient safety for the passengers (possibly surrounded by green zones). The bus parking places should preferably be DPT-type.

iv) The access roads to the area and the internal circulation roads shall be one-way, and have a cross-section not less than 9 m in width, including the edge markings and shoulders.

All the zones, both for traffic and for stopping, should be separated from the expressway by a buffer zone not less than 10 m. This zone should be planted with vegetation (grass and bushes of limited height). The internal roads of the service areas should be planned in such a way as to avoid creating points of conflict. The service area may be connected to adjoining service persons area, local habitations by a road of a minimum width of 5.5 m to provide for the supply of the area with gates and security arrangement for safety and toll slippage.

v) The entire service area shall be with boundary walls. Access gates shall be with security persons.

11.7.11 *Entry and exit*

The entry and exit to service area should be located separately independent from each other and wide enough with as large turning radius as possible. Ramp design shall follow Chapter-2: Interchange Design 2.6. Collector – Distributor (C-D) roads shall be provided for the service area traffic to avoid weaving through expressway traffic. This will improve the ingress and egress facility for the service area.

11.7.12 *Lighting*

There should be high level of illumination in the parking areas, on the walkways, restaurants, food plazas and filling stations and surrounding areas for safe and efficient operation. It is desirable to have the following minimum levels

- for indoor areas 150-200 lux
- for closed corridors 100-150 lux
- for walkways and parking areas 30-40 lux

The lighting requirement shall be planned based on following guidelines

- IS 3646 (Part II) for Interior Illumination
- National Electrical Code Published by Bureau of Indian Standards

11.7.13 *Electrical systems*

The design of the electrical system must take into account the needs of the area in its final stage. It is not absolutely necessary to have an electrical system in the service area. The electrical power will be used for internal and external lighting, cooling and for all the systems and equipment. All closed convenient areas shall be air conditioned and adequate ventilation system and full lighting. Full back-up facilities shall be there to meet emergency during power failure.

11.7.14 *Road markings, signs and safety*

Besides the warning signs along the expressway, the service areas should be equipped with road markings and signs for the following purposes.

i) to limit speeds to 40 kmph

ii) to give advance warning of junctions

iii) to prevent stopping outside the zones specifically designated for parking

iv) to advertise the various services offered by the service area

Service Area Sign shall be provided to inform the driver for exiting of this facility. Sign may be placed 2 km, 1 km and 500 m advance and information sign i.e. availability of facilities. Typical service area signs are given in **Fig. 11.02A** and **11.02B**.

Fig. 11.02A Sign for Service Area

Fig. 11.02B Distance Assurance Sign for Service Area

11.7.15 *Water supply and sanitary systems*

The areas should be provided with a water system both for drinking and for industrial purposes (washing, irrigation, WC), preferably connected with the public networks. A water system should also be provided for service areas.

The water requirements including all possible uses, can be estimated at 50 litres per user. The service areas and service areas should be equipped with drainage for the disposal of rain and waste water, connected with the expressway drainage system. Where it is impossible to arrange a connection with the public sewerage network, the foul water will have to be treated.

11.7.16 *Landscaping*

Landscaping assumes particular importance in service areas. The greenery contributes greatly to provision of a relaxed atmosphere. The vegetation should necessarily be characteristic of the local terrain and presenting as wide a variety as possible. Refreshment and assistance facilities, fuel station facilities and parking lots should be separated by green zones. The parking lots, in particular, should be arranged in such a way as to be shaded by trees or high shrubbery. The whole zone separating the area from the expressway carriageway should be planted with greenery, preferably with plants which require little maintenance but of a consistency such as to constitute a protection against vehicles possibly running off the road and to prevent pedestrians from attempting to cross the carriageway. In the vicinity of the nose of the entrance or the exit, the plants must be of limited height so as not to interfere with driver vision.

11.7.17 *Pick-up bus stops*

This section has been dealt with in **Chapter-12 : Pick-up Bus Stops**.

11.7.18 *External parking*

Wherever an area is connected with the ordinary road system, it will be necessary to construct a parking lot in the vicinity of the area, outside the fencing and communicating with it via a passage closed by a gate, but which permits free access to pedestrians. This parking lot will permit the following:

i) Parking of vehicles belonging to service personnel or to those who wish to enter the area to take advantage of the facilities located there
ii) The transit of passengers on bus lines with stops at the area in question
iii) The location of those installations (electrical transformers, water purifying plants, water tanks, trash bins) generally serviced by external personnel

APPENDIX-11
(Clause 11.1)

PROVISIONS FOR PERSONS WITH DISABILITIES (PwD)

For this Guideline, the disabilities mean which confine individuals to wheel chair for mobility. The standard size of wheel chair as generally considered is **1,050 mm x 750 mm**.

At the wayside amenity centres/rest areas, the level of the roads, access paths and parking areas require special considerations as described below:

Access Path/Walk Way: Access path from entry to parking lot and to facility centre shall be minimum of 1,800 mm wide having even surface without any steps. Slope, if any, shall not have gradient greater than 5 percent. Finishes shall have a non slip surface with a texture traversable by a wheel chair as well as for trolley baggage. Kerbs wherever provided should blend to a common level.

Parking*:* For parking of vehicles, the following provisions are desirable:

- Surface parking for at least two Car Spaces shall be provided near entrance, with maximum travel distance of 30 m from facility entrance.

- The width of parking bay shall be minimum 3.6 m.

- The signage for reserved space for wheel chair users shall be conspicuously displayed using large sign boards.

- The slope of parking spaces reserved for **Persons with Disabilities (PwD)** on wheel chair especially should not exceed 1 (one) percent gradient. **Fig. 11A-01** presents typical layout.

- Ramp should be complemented by flights of steps, as many people (crutch users) have more difficulty coping with ramps than steps, particularly when descending.

- Landings – every 750 mm of vertical rise, width should be 1800 mm wide to permit wheelchairs to pass. Over short lengths, a minimum width of 1200 mm can be accepted. **Fig. 11A-02** presents typical arrangement.

Ramped Facilities: Ramp shall be finished with non slip material to enter the facility. Minimum width of ramp shall be 1,800 mm with maximum gradient 1V:20H.

Exit/Entrance Door: Minimum clear opening of the entrance door shall be 900 mm and it shall not be provided with a step that obstructs the passage of a wheel chair.

Entrance Landing: Entrance landing shall be provided adjacent to ramp with the minimum dimension 1,800 mm x 2,000 mm. The entrance landing that adjoin the top end of a slope shall be provided with floor materials to attract the attention of persons (limited to coloured floor material whose colour and brightness is conspicuously different from that of the surrounding floor materials). Finishes shall have a non slip surface with a texture traversable by a wheel chair.

Flooring:

- Tactile floor blocks should be provided to orient persons with low vision, vision impairment and deaf blind. These blocks should have a colour (preferably canary yellow), which contrasts with the surrounding surface.

- Guide path (line blocks) has straight continuous line and indicate the correct path/route to follow, leading to building entrances, an amenity, bus stop etc. and should not be located close to manholes or drains, to avoid confusion for persons with vision impairments.

- Warning (dot/blistered blocks) strip provides warning signal to screen off obstacles, drop-offs or other hazards, to discourage movement in an incorrect direction and to warn of a corner or junction. Should be placed 300 mm at the beginning and end of the ramps, stairs and entrance.

Lifts: Wherever lift is required, provision shall be kept for at least one space for the wheel chair, with the following cage dimensions (Bureau of Indian Standards). Clear internal depth of 1,100 mm, Internal width of 2,000 mm and Entrance door width of 900 mm.

- A hand rail not less than 600 mm long at 1,000 mm above floor level shall be fixed adjacent to the control panel.

- The lift lobby shall be of an inside measurement of 1,800 mm x 1,800 mm or more.

- The time of an automatically closing door should be minimum 5 seconds and the closing speed should not exceed 0.25 m/s.

- The interior of the cage shall be provided with a device that audibly indicated the floor the cage has reached and indicates that the door of the cage for entrance/exit is either open or closed.

Toilets: At least one special WC in a set of toilet shall be provided for the use of handicapped with essential provision of wash basin near the entrance.

- The minimum size shall be 1,500 mm x 1,750 mm
- Minimum clear opening of the door shall be 900 mm and the door shall swing out.
- Suitable arrangement of vertical/horizontal handrails with 50 mm clearance from wall shall be made in the toilet.
- The WC seat shall be 500 mm from the door.

Drinking Water: Suitable provision for drinking water shall be made for the handicapped near the special toilet provided for them.

Signage

Appropriate identification of specific facilities within a building for the handicapped persons should be done with proper signages. Signs should be designed and located so that they are easily legible. To ensure safe walking, there should not be any protruding sign which creates obstruction in walking. Public Address System shall be provided.

The symbols/informations should be in contrasting colour and properly illuminated. A symbol for wheel chair shall be installed at the lift, toilet, staircase, parking areas etc., that have been kept specially for the purpose. **Fig. 11A-04** presents typical signages.

Other Facilities:

Fig. 11A-03, Fig. 11A-05, Fig. 11A-06 and a page of exhibit courtesy – SAMARTHYAM presents the necessary other facility requirements at various usage places.

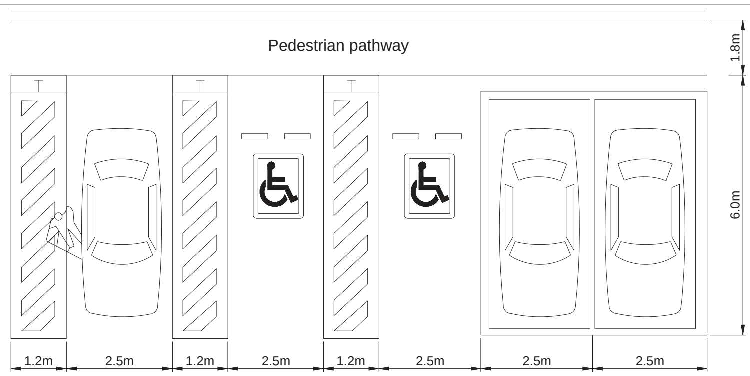


Fig. 11A-01 Parking Facilities

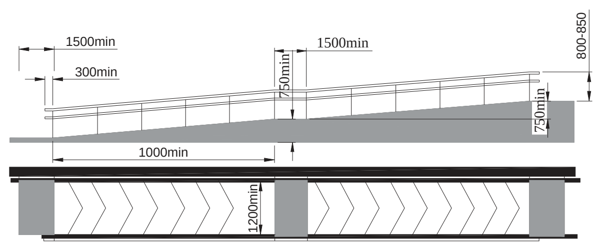
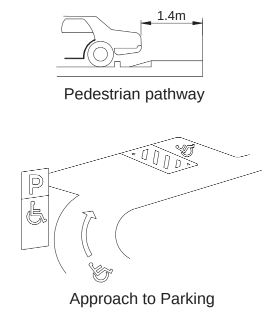


Fig. 11A-02 Ramp Facilities



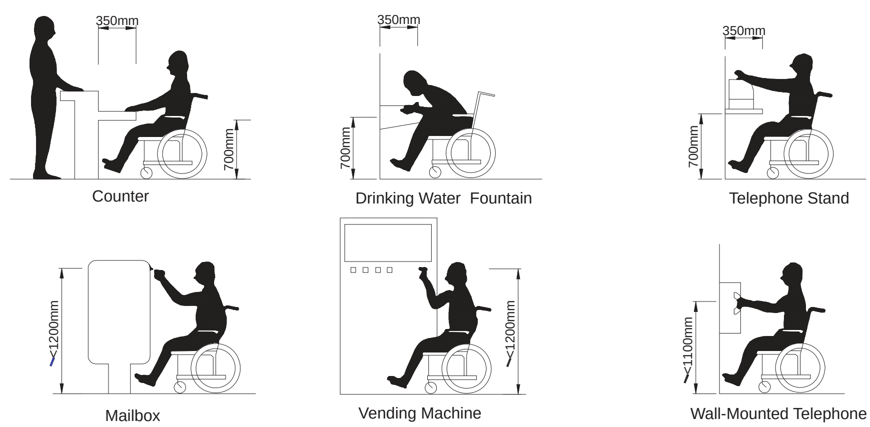


Fig. 11A-03 Other Facilities

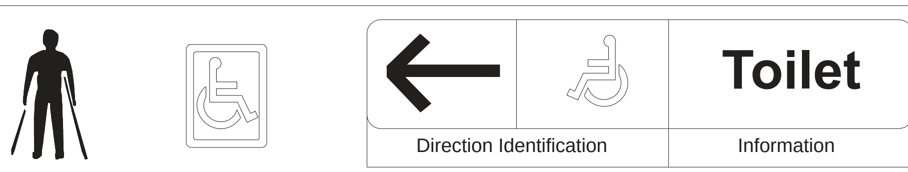


Fig. 11A-04 Signage Facilities

PROVISIONS FOR PHYSICALLY CHALLENGED PERSONS

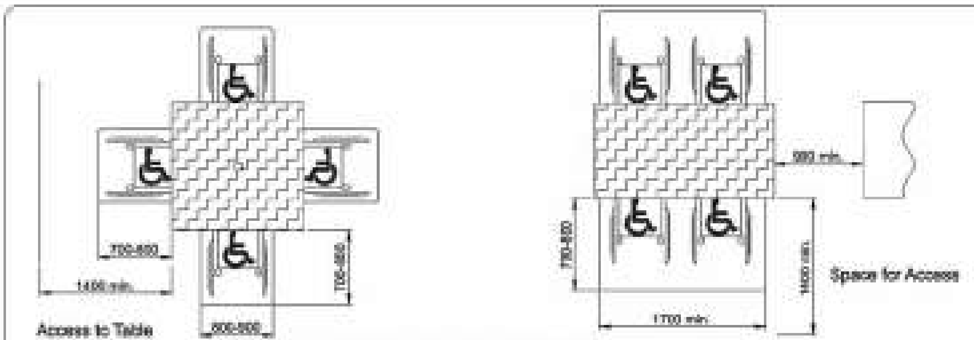


Fig. 11A-05 Restaurant Facilities

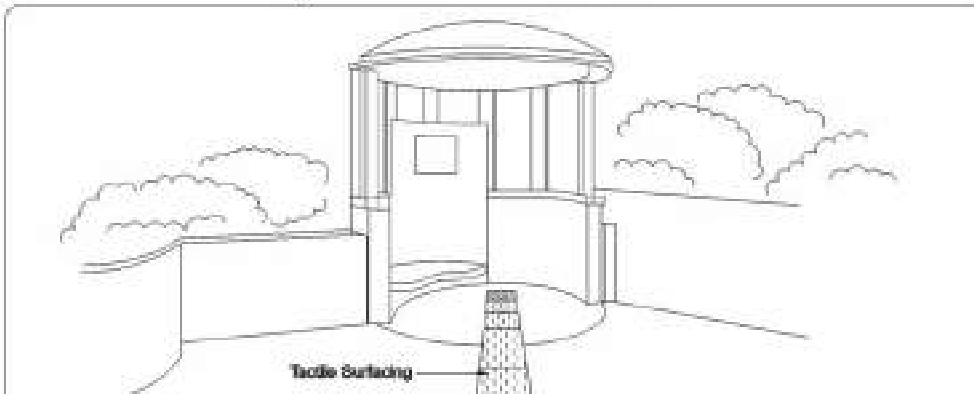


Fig. 11A-06 To Restaurant or Toilet

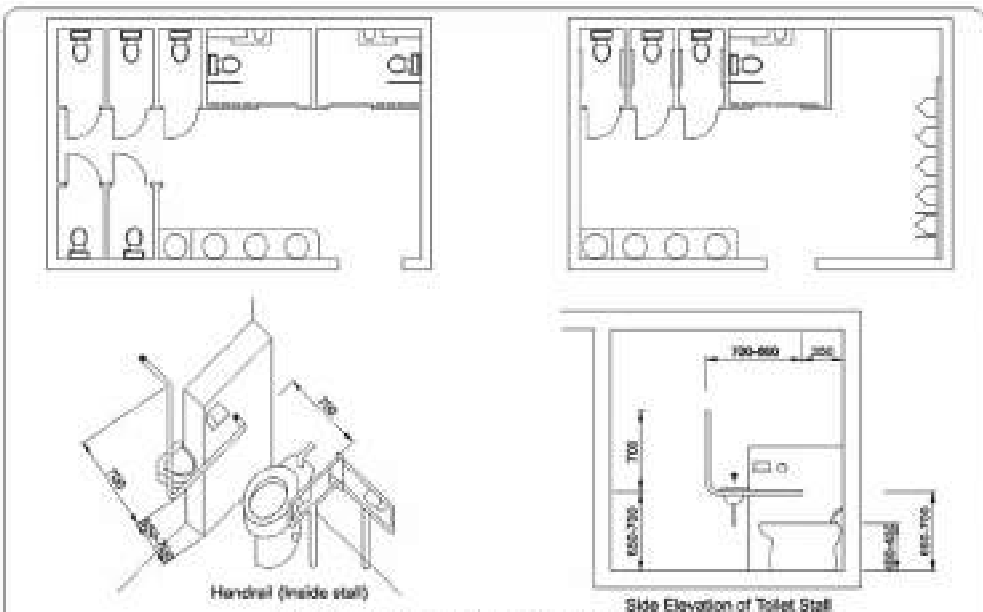
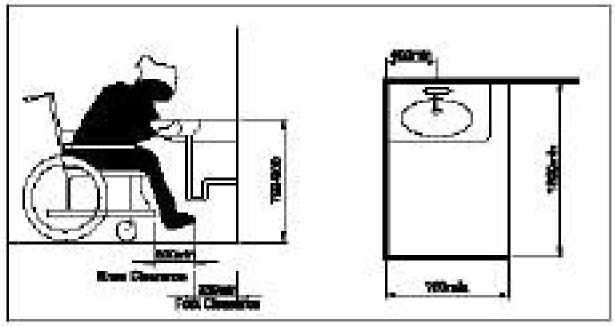
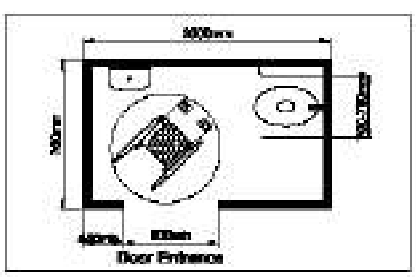
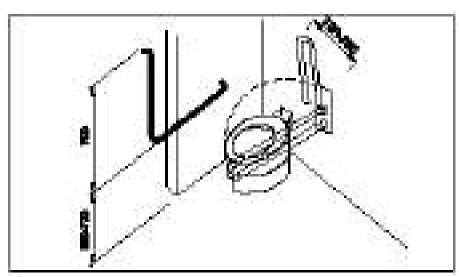


Fig. 11A-07 Toilet Facilities

PROVISIONS FOR PHYSICALLY CHALLENGED PERSONS







Courtesy :

SAMARTHYAM: National Centre for Accessible Environments, New Delhi

CHAPTER - 12

PICK-UP BUS STOPS

CHAPTER – 12

PICK-UP BUS STOPS

12.1 INTRODUCTION

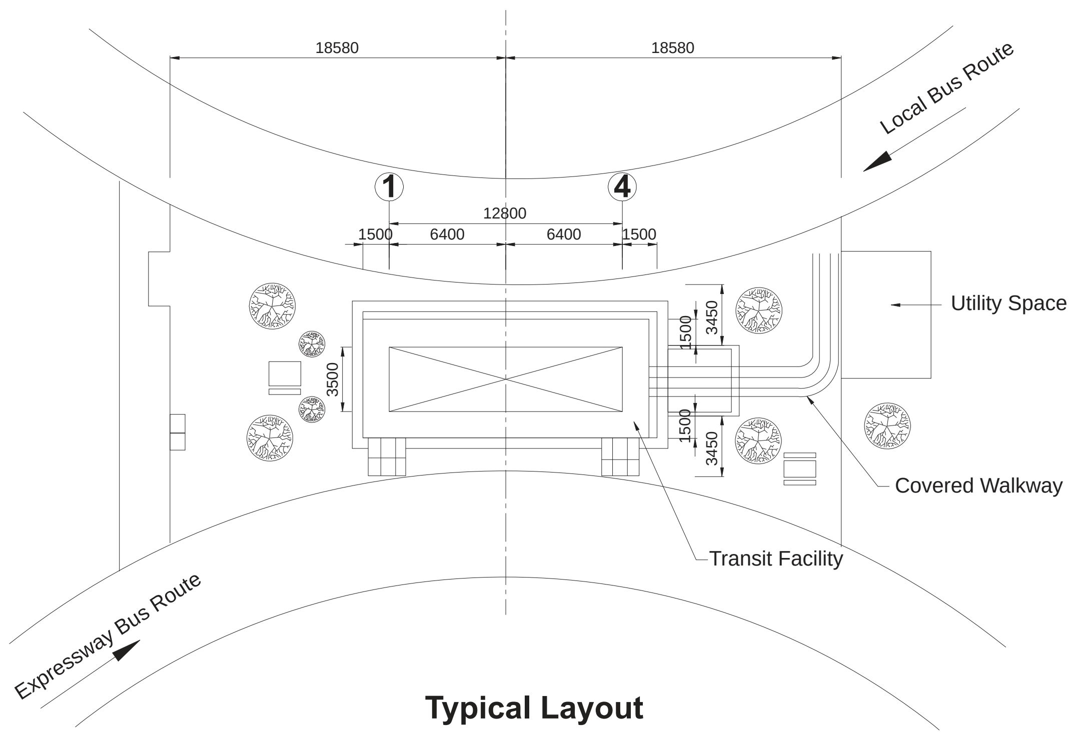
Combining mass transit in the form of Bus Services is a means for providing optimum transportation services between metropolitan (important) cities. On the other hand, express bus operation with few, if any, stops along the expressway provides superior transit service for outer urban areas and affects expressway operation the least.

12.2 PICK-UP BUS STOPS

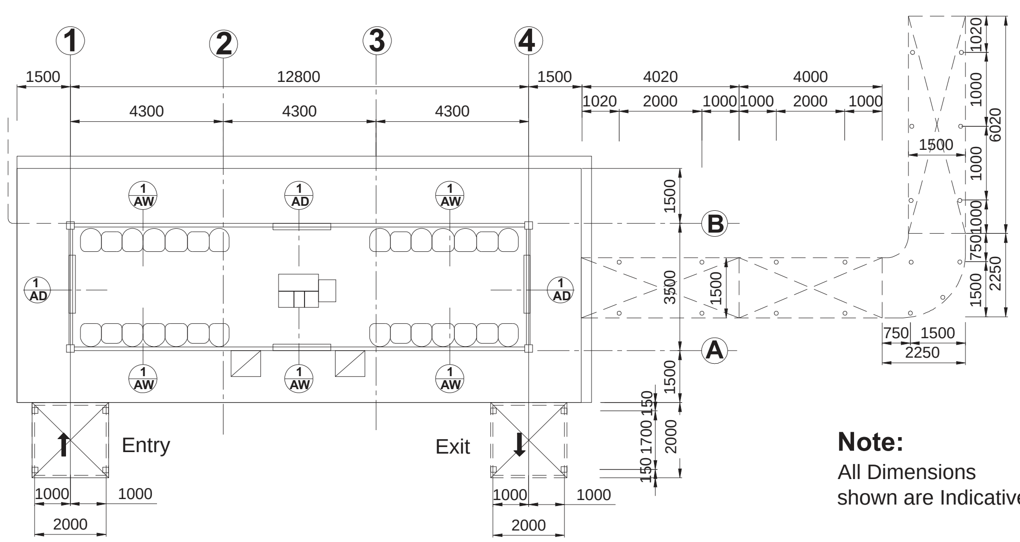
The expressway is likely to have regular movement of buses either through Government or private sector, pickup bus stops shall be planned designed and provided for the convenience of bus commuters and safe and unimpeded travel on Expressways. These facilities shall be provided away from the Expressway, connected through properly designed exit and entry ramps from Expressways.

The expressway bus stops shall be located in the service area adjacent to local bus routes. For a closed toll system of expressway, the basic philosophy of design is to provide layout convenient for both local and expressway bus services and not to involve passing through toll plaza. Typical location of pick-up bus stops in Service Area is shown in **Fig. 11.01A through Fig. 11.01C.**

Adequate passenger transit facility shall be provided between the Expressway Bus service and Local Bus Service. **Fig. 12.01** presents typical functional arrangements of Expressway and local bus routes with indicative dimensions for passenger transit facility. **Fig. 12.02** presents a pictorial view for appreciation of the designer.



Typical Layout



Note:
All Dimensions
shown are Indicative

ExpresswayTransit Facility

Fig. 12.01 Typical Functional Arrangement of Expressway and other Highway at Bus Stop in JAPAN

Pick-up Bus Stops

Fig. 12.02 Typical Pick-up Bus Stop in Japan

CHAPTER - 13

LIGHTING

CHAPTER – 13

LIGHTING

13.1 GENERAL

The expressway provides an alignment and profile that, together with other factors, encourages high operating speeds. Although improved design will generate significant benefits, it has also potential problems. For example, driving at night at high speeds may lead to reduced forward vision – that is, the inability of headlights to illuminate objects in the driver's path in sufficient time for some drivers to respond.

The addition or enhancement of lighting can improve visibility at night, thereby improving throughout (higher night speeds are possible) and safety. The objectives of roadway lighting are as follows:

- Promotion of safety at night by providing quick, accurate and comfortable vision for drivers and users.
- Improvement of traffic flow at night by providing light, beyond that provided by vehicle lights, which aids drivers in orienting themselves, delineating roadway geometrics and obstructions, and judging opportunities for overtaking.
- Illumination in long underpasses and tunnels during the day to permit drivers entering such structures from the open to have adequate visibility for safe vehicle operation.

13.2 WARRANTS FOR EXPRESSWAY LIGHTING

The primary purpose of warrants is to assist designers in evaluating locations or lighting needs and selecting locations for installing. Meeting these warrants does not obligate to provide lighting. Conversely, information in addition to that reflected by the warrants, such as roadway geometry, ambient lighting, sight distance, crash barriers, signages, or frequent occurrences of fog, ice, or snow, may influence the decision in favour of lighting.

AASHTO - Warrants for expressway lighting may be comprehensively brought out as indicated below:

13.2.1 *Continuous expressway lighting*

- Continuous expressway lighting is considered to be warranted on those sections near cities where the current ADT is 40,000 or more.
- Continuous expressway lighting is considered to be warranted on those sections where three or more successive interchanges and cross road are located with an average spacing of 2.5 km or less, and adjacent areas outside the right-of-way are substantially urban in character.
- Continuous expressway lighting is considered to be warranted where for a length of 3 km or more, the expressway passes near a substantially developed suburban or urban area in which one or more of the following conditions exists:

  a) local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the expressway.

  b) the expressway passes near a series of developments such as residential, commercial, industrial and civic areas, colleges, parks, terminals, etc., which includes roads, streets and parking areas, yards, etc. that are lighted.

  c) the expressway cross section elements, such as median and paved shoulder, are substantially reduced in width locally below desirable sections used.

In rural areas each location must be individually evaluated as to its need for illumination.

13.2.2 Interchange lighting

Complete Interchange Lighting

Complete interchange lighting generally is warranted only if the mainline expressway has continuous lighting and the adjacent areas of interchange are commercially developed and illuminated.

Partial Interchange Lighting

- Partial interchange lighting is considered to be warranted where the total current ADT of ramp traffic entering and leaving the expressway within the interchange areas exceeds 5,000 for urban conditions, 5,000 for suburban conditions, or 2,500 for rural conditions.

- Partial interchange lighting is considered to be warranted where the current ADT on the expressway through traffic lanes exceed 25,000 for urban conditions, 20,000 for suburban conditions, or 10,000 for rural conditions.

13.2.3 *Bridge structures and underpasses*

Where justified, underpass lighting level and uniformity ratios should duplicate, to the extent practical, the lighting level on the adjacent facility. On continuously lighted expressways and lighted interchanges, the lighting of bridges and overpasses should be of the same level and uniformity as the roadway.

An underpass is a portion of roadway extending through or beneath some natural or man-made structure. Supplementary lighting might be required during the daytime as well as at night. Guidance provided by AASHTO (An information guide for Roadway Lighting) is summarized below:

- Length to height ratios of 10:1 or lower will not, under normal conditions, require underpass lighting during the daytime. When this ratio is exceeded, it is necessary to analyze the specific geometry and pavement conditions, including penetration of daylight on the alignment to determine the need for daytime lighting. The transition from bright daylight to lower level of lighting, and back again to daylight must also be considered.
- Underpasses that are part of an expressway section with continuous lighting, warrant the use of (night time) illumination; with the lighting levels and uniformities duplicating to the extent practical, the lighting values of the expressway. If continuous lighting is not provided along the adjacent expressway sections, underpass lighting may still be warranted for night time conditions where unusual or critical roadway geometry occurs under or adjacent to the underpass area.

13.2.4 *Special situations*

- Long tunnels (defined in Tunnel Lighting section) require the use of lighting or equivalent means to provide adequate roadway and tunnel user visibility necessary for safe and efficient traffic operations.
- All Service Areas offering complete rest facilities should be lighted, including the entrance and exit, the interior roadways, parking areas, and activity areas.
- Lighting of other specialized areas should be considered with respect to the needs of the users as well as the requirements of others interacting with the

users. These other specialized areas include truck weighing stations, inspections and enforcement areas, park-and-ride lots, toll plazas, and escape ramps.

13.3 TRANSITION LIGHTING

Transition lighting is a technique intended to provide the user with a gradual reduction in lighting levels and glare when leaving an illuminated area. In addition, the designer also may consider extending delineation 300 m beyond the last luminary for traffic lanes emerging from a lighted area. This will provide an additional measure of effectiveness. Vision adjustment when approaching a lighted area is not impacted greatly and therefore requires no special consideration.

13.4 LIGHTING STANDARDS

The overall quality of an installation for lighting has several components:

- Average luminance level: This is all-important, as it not only impinges on the safety benefits but also largely determines the power requirements and hence the running costs. In most simpler design processes, and for checking the performance of an installation, this translates into average illuminance level.
- Overall uniformity of luminance, or illuminance, both across and along the roadway. Defined as the minimum divided by the average, and design at U_0.
- Uniformity of luminance, or illuminance, along the axis of the road, usually an axis which coincides with a typical driver's eye position. Defined as the ratio of the minimum to the maximum, and designated U_1.
- Glare: As glare has the effect of reducing contrast, a luminary's "glare performance", or optical control, can be expressed in terms of the increase in background luminance necessary to compensate (threshold increment, TI). The lower this figure the better. In highly motorised countries 10 percent is specified for motorways, with 15 percent and even 30 percent allowed for general traffic routes. These percentages are determined by the amount of light the luminaries project near the horizontal. This light also causes problems of sky-glow.
- Guidance: Whilst glare must be kept under control, a small amount of direct light from the luminaries gives a useful sense of the "run" of the road ahead, and can forewarn the approach of junctions or roundabouts.

Category	Average level	U_0	U_1	TI
Expressway, high-speed roads with dual carriageways	1.5 cd/m^2 (~ 25 lux)	0.4	0.7	15 %

(Source : CIE 180:2007 Road Transport Lighting for Developing Countries)

13.5 TUNNEL LIGHTING

(Source : CIE 88:2004 Guide for the Lighting of Road Tunnels and Underpasses)

13.5.1 *General*

The basic objective of tunnel lighting is to ensure that traffic both during day and night times can approach, pass through and leave the tunnel at the designated speed with adequate safety and comfort not less than that of expressway section before and after the tunnel. The lighting in tunnels, especially during day time, poses number of technical and financial problems. On bright sunlit days, a great difference in luminance level exists between exterior and interior luminance which seriously impairs the visual performance of drivers in adaptation of such abrupt light changes and may lead to hazardous situations. It is also true that the human eye takes longer time in adaptation from light to dark than from dark to light. In other words, the design of lighting at entrance zone of tunnel should be given more attention than at exit zone.

13.5.1.1 Long and short tunnels: defined

A tunnel is a covering over the road. The lighting requirements for long and short tunnels differ according to the degree to which the approaching driver can see through the tunnel. The ability to see through the tunnel depends primarily on the length of the tunnel but also on other design parameters (width, height, horizontal and/or vertical profile of the tunnel, etc).

For lighting and illumination purpose, tunnels are usually subdivided into “long tunnels” and “short tunnels”. This designation refers primarily to the length of the tunnels (typically measured along the tunnel axis). Some tunnels – where the drivers cannot see the exit from a point in front of the tunnel – need to be illuminated like a long tunnel, even if their lengths would seem to make a “short” one. These tunnels are designated as “optically long tunnels”, contrary to those where approaching motorists can see through the tunnel (“optically short tunnels”). With regard to the lighting, tunnels are subdivided into three classes:

- geometrically long tunnels;

- optically long tunnels;
- short tunnels.

The distinction can be made on the basis of the diagram given in **Fig. 13.01.**

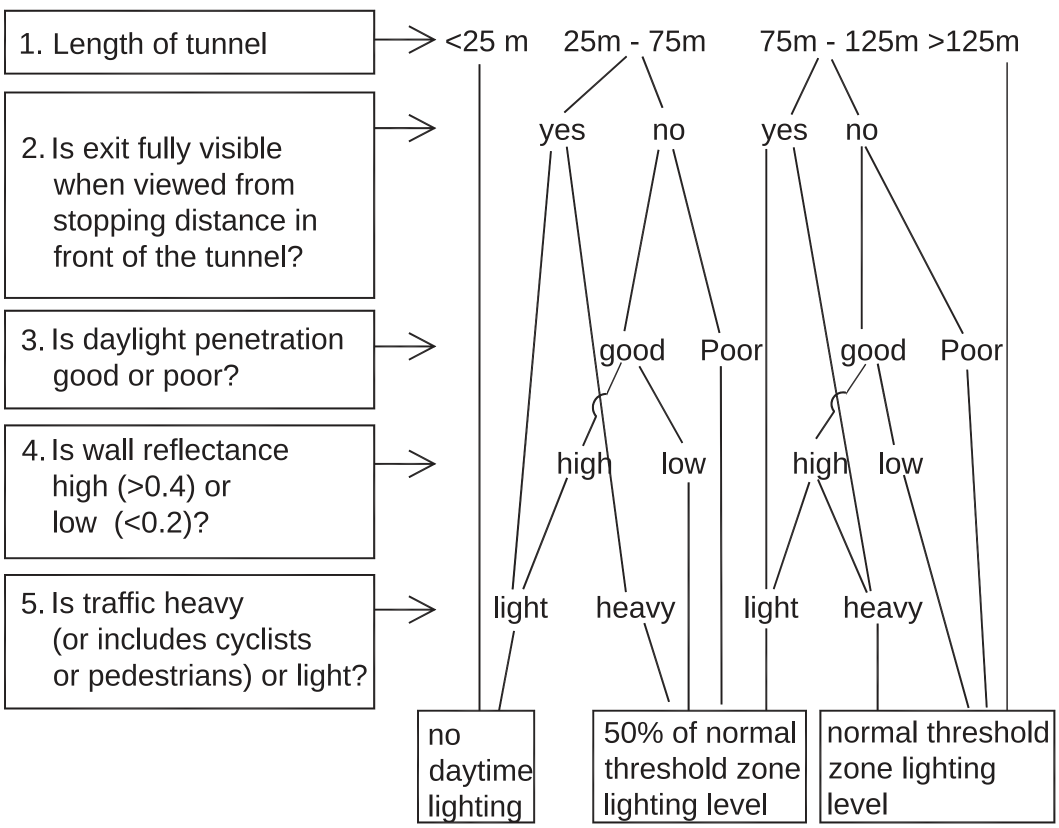


Fig. 13.01 Daytime Lighting of Tunnels for Different Tunnel Lengths

Fig. 13.01 offers a first approximation. For a detailed lighting design, the possibilities to look through the tunnel must be determined graphically. *(Source: CIE 88:2004 Guide for the Lighting of Road Tunnels and Underpasses)*

Note: for tunnel lengths up to 75 m where no daytime lighting is recommended in **Fig. 13.01,** it is to be noted that at least one hour before sunset and one hour after sunrise a lighting level equal to the recommended values for the interior zone of a long tunnel should be achieved. At night, only the recommended value for night-time lighting is needed.

13.5.1.2 Tunnel related zones

(Source: CIE 88:2004 Guide for the Lighting of Road Tunnels and Underpasses)

For tunnel lighting, the tunnel length is divided into various zones to determine the longitudinal lighting level at daytime lighting. Those are the access zone, the threshold zone, the transition zone, the interior zone and the exit zone. **Fig. 13.02** presents various zones in tunnel.

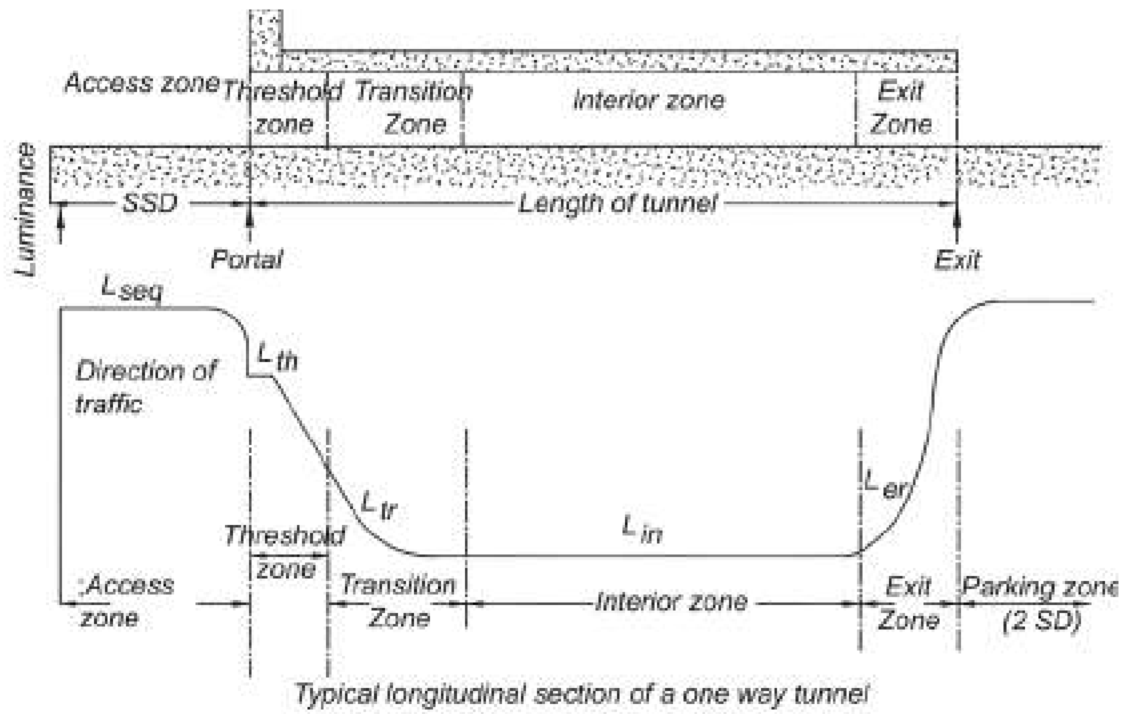


Fig. 13.02 Zones in a Tunnel
(Source : CIE 88:2004)

Access zone: the part of the open road immediately outside (in front of) the tunnel portal, covering the distance over which an approaching driver must be able to see into the tunnel. The access zone begins at the stopping distance point ahead of the portal and it ends at the portal.

Threshold zone: the first part of the tunnel, directly after the portal. The threshold zone starts either at the bringing of the tunnel or at the beginning of the daylight sunscreens when occurring. The length of the threshold zone is at least equal to the stopping distance.

Transition zone: the part of the tunnel following directly after the threshold zone. The transition zone begins at the end of the threshold zone. It ends at the beginning of the interior zone. In the transition zone, the lighting level is decreasing from the level at the end of the threshold zone to the level of the interior zone.

Interior zone: the part of the tunnel following directly after the transition zone. It stretches from the end of the transition zone to the beginning of the exit zone.

Exit zone: the part of the tunnel where, during the day-time, the vision of a driver approaching the exit is predominantly influenced by the brightness outside the tunnel. The exit zone begins at the end of the interior zone. It ends at the exit portal of the tunnel.

Parting zone: the first part of the open road directly after the exit portal of the tunnel. The parting zone is not a part of the tunnel, but it is closely related to the tunnel lighting. The parting zone begins at the exit portal and a length of more than 200 m is not generally necessary for lighting.

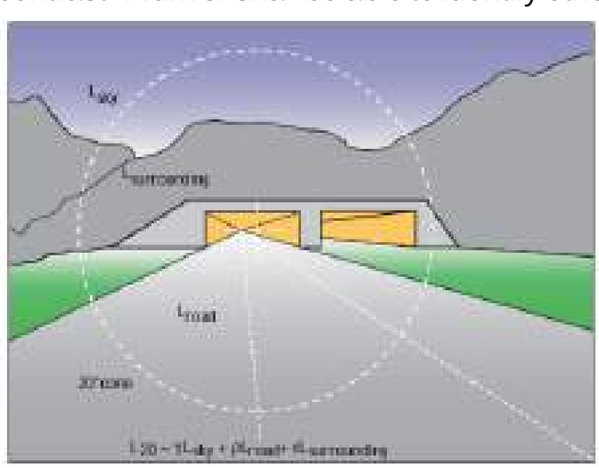
Entrance portal: the part of the tunnel construction that corresponds to the beginning of the covered part of the tunnel, or – when open sub-screens are used – to the beginning of the sun-screens.

Exit portal: the part of the tunnel construction that corresponds to the end of the covered part of the tunnel, or – when open sub-screens are used – to the end of the sub-screens.

13.6 DAYTIME LIGHTING FOR LONG TUNNELS

13.6.1 *General*

The necessary lighting level in the threshold zone is determined by visibility criteria or, in other words, by enough contrast. A driver shall be able to identify other vehicles or objects



Sketch showing the 20° conical field of view referred to in the text in the threshold zone from the stopping distance ahead of tunnel portal.

The luminance in the access zone (defined as L_{20}, is measured in a conical field of view, subtending an angle of 20^0, by a driver located at safe stopping distance from the tunnel portal and looking towards a cantered point at a height equal to one quarter of the height of the tunnel opening.

13.6.2 *Length of the threshold zone*

The total length of the threshold zone must be at least equal to the stopping distance. Over the first half of the distance, the luminance level must be equal to L_{th} (the value at the beginning of the threshold zone). It is recommended that from half the stopping distance onwards, the lighting level may gradually and linearly decrease (linear scale) to a value, at the end of the threshold zone, equal to 0.4 L_{th}. See **Fig. 13.03.** The gradual reduction over the last half of the threshold zone may also be in steps. However, the luminance levels should not fall below the values corresponding to a gradually decrease, as shown in the Figure.

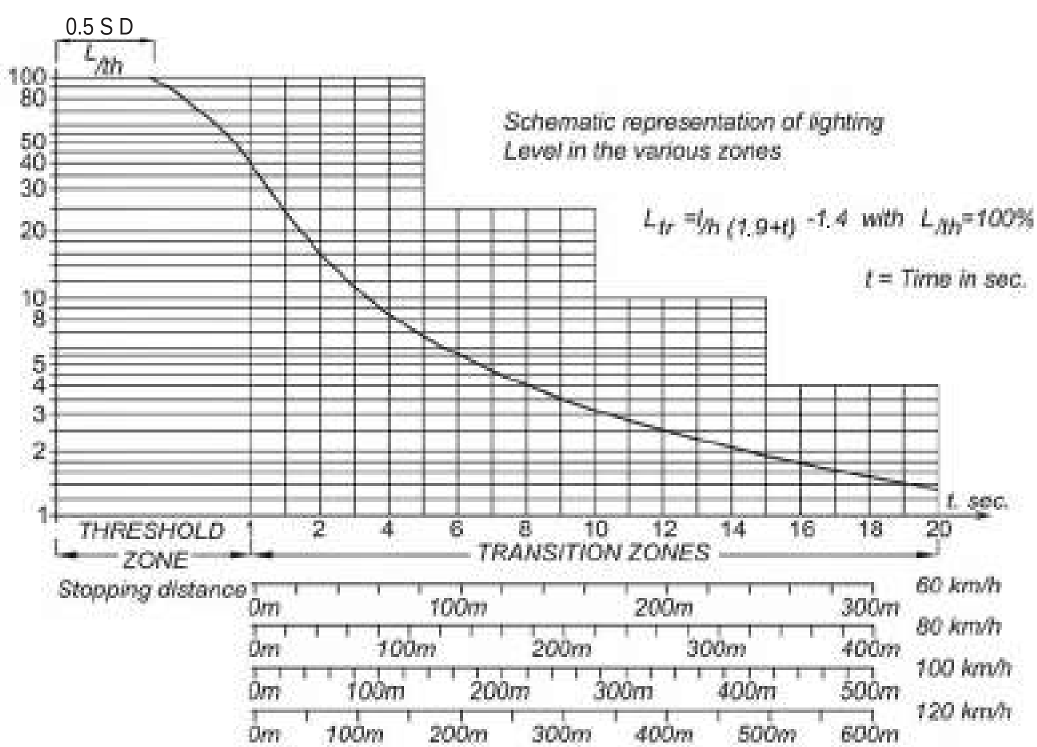


Fig. 13.03 Luminance Evolution Along the Tunnel
(Source : CIE 88:2004)

13.6.3 *Luminance in the transition zone*

The reduction of the luminance of the road in the transition zone follows, in principle, the curve shown in **Fig. 13.03.**

The transition zone starts at the end of the threshold zone (t=0).

This curve can be replaced by a stepped curve with levels that should never fall below the continuous curve. The maximum luminance ratio permitted on passing from one step to another is 3. The last step should not be greater than 2 times the interior zone luminance.

As the field of view of the driver is made up by the tunnel interior, a longer transition zone may be advisable in order to counteract a second black hole effect.

For additional driving comfort, in the case of the stepped curve, the length of the transition zone may, at its end, be extended for 1 to 2 seconds over the length that follows from the CIE-curve.

13.6.4 *Daytime luminance in the interior zone*

The average luminance of the road in the interior zone of the tunnel is given below as a function of the stopping sight distance (SSD) and of the traffic flow. Very long tunnel's interior zone consists of two different sub zones. The first sub zone corresponds to the length which is covered in 30 seconds and should be illuminated with the "long tunnels" levels. The second sub zone corresponds to the remaining length and should be illuminated with the "very long tunnels" levels.

a) A Luminance value of 10 cd/m^2 in the interior zone for long tunnels and in first part of very long tunnels may be considered.
b) A Luminance value of 5 cd/m^2 in the second part of the interior zone for very long tunnels.

13.6.5 *Luminance in the exit zone*

In order to ensure adequate direct illumination of small vehicles and sufficient rear vision via mirrors, the exit zone should be illuminated in the same way as the interior zone of the tunnel. In situation where additional hazards are expected near the exit of the tunnel and in tunnels where the interior zone is long, it is recommended that the daytime luminance in the exit zone increases linearly over a length equal to the SSD (before that exit portal), from the level of the interior zone to a level five times that of the interior zone at a distance of 20 m from the exit portal.

13.6.6 *Parting zone lighting*

In case the tunnel is part of an unlit road and the speed of driving is higher than 50 km/h, night-time lighting of the parting zone is recommended:

- if the night-time lighting level in the tunnel is more than 1 cd/m^2;
- if different weather conditions are likely to occur at the entrance and at the exit of the tunnel.

Road lighting in the parting zone shall be provided over the length of two stopping distances with road luminance not lower than 1/3 of the night-time luminance in the interior zone of the tunnel.

13.6.7 *Lighting of the walls and the ceiling in all zones*

Tunnel walls form part of the background for the detection of obstacles in the tunnel; they contribute to the adaptation level and to the visual guidance. Therefore, the luminance of the tunnel walls is an important component for the quality of the tunnel lighting. The average luminance of the tunnel walls, up to at least of 2 m, must be at least 60 percent of the average road surface luminance at the relevant locations.

13.6.8 *Uniformity of luminance*

Good uniformity of luminance must be provided on the road surface and on the walls up to a height of 2 m. The lower parts of the walls act as a background for traffic, as does the road. So both must be considered in the same way. A ratio of 0.4 for the minimum to the average value of luminance on the road surface and on the walls up to 2 m lean conditions of the tunnel is recommended. A longitudinal uniformity of 0.6 along the centre of each lane is recommended for the road. Such values of uniformity must be verified for all dimming steps of the lighting installation. Moreover, in the transition zone, as well as in the second half of the threshold zone (and in the exit zone if existing), the luminance uniformity shall be calculated and measured in the central part of each step replacing the continuous variation curve.

13.6.9 *Daylight variation and lighting control*

The access zone luminance varies with changes in daylight conditions.

As the luminance levels in the threshold and transition zones are constant percentages of the access zone luminance, it is necessary to provide control of the lighting in these zones. The control may be done through continuously dimming devices or by switching in separate steps.

For adequate light control, the access zone light level must be monitored continuously. The method used for lighting control can be different from the method for the lighting design.

13.6.10 *Glare restriction*

As glare reduces visibility, it is important to minimize it. In tunnel lighting, the physiological (disability) glare has to be considered. Disability glare effects are quantified by the Threshold Increment TI as described in CIE 31-1976 "Glare and Uniformity in Street Lighting)".

The threshold increment TI must be less than 15 percent for the threshold, the transition and the interior zones of the tunnel at daytime and night-time. For the exit zone during daytime no restriction is given. The following formula shall be used to calculate TI:

$$TI = 65 (L_v / L_r^{0.8}) \text{ for } L_r \leq 5 \text{ cd/m}^2$$

$$TI = 95 (L_v / L_r^{1.05}) \text{ for } L_r > 5 \text{ cd/m}^2$$

with : L_r - average road surface luminance

L_v - veiling luminance created by all luminaries in the field of view where the axis of fixation is 1^0 down from the horizontal at the relevant location. The calculations shall be made on the base of the initial values and with a full cut-off angle of 20^0 above the axis of observation due to the roof of the car. At present, it is not possible to give a numerical value for the restriction of the glare in the transition zone.

13.6.11 *Restriction of the flicker effect*

Flicker sensations are seen when driving through spatially periodic changes in luminance, such as those produced by daylight screens (both sun-tight and non-sun-tight) or luminaries that are mounted separately. Under specific conditions, the flicker may cause discomfort that sometimes can be severe.

The degree of visual discomfort experienced due to flicker depends upon:

a) the number of luminance changes per second (flicker frequency)
b) the total duration of the experience;
c) the ratio of peak (light) to trough (dark) luminance within each period (luminance modulation depth) and the steepness in the increase (rise-time).

(a), (b) and (c) depend upon vehicle speed and luminance spacing. (c) also depends upon the photometric characteristics and the spacing of the luminaries.

In general, the flicker effect is negligible at frequencies below 2.5 Hz and above 15 Hz. When the frequency is between 4 Hz and 11 Hz, and has duration of more than 20 s, discomfort may arise provided no other measures are taken. It is recommended that, in installation where the duration is more than 20 s, the frequency range between 4 Hz and 11 Hz should be avoided.

13.6.12 *Night-time lighting*

a) If the tunnel is on a section of an illuminated road, the quality of the lighting inside the tunnel should be at least equal to the level, uniformities and glare of the access road. The uniformity at night of tunnels shall fulfil the same requirements as the daytime lighting.
b) If the tunnel is a part of an unlit road, the average road surface luminance inside must be around 4-5 cd/m^2, the overall uniformity at least 40 percent and the longitudinal uniformity at least 60 percent.

13.6.13 *Emergency lighting*

In the event of a failure in the normal power source that supplies the lighting system, it is recommended that an emergency on interruptible power supply is employed to energize sufficient system luminaries. Conventionally the “emergency” luminaries form a part of stage 1 being the normal night-time level throughout the tunnel. The emergency configuration by example could consist of : one lamp from a selection of the system luminaries, forming a linear symmetrical and inter spaced series of emergency luminaries, being energized from the uninterruptible power supply source. It is recommended that the average illuminance level of the emergency lighting should be at least 10 lux with 2 lux being the minimum level at any location within the tunnel. For recommendations relating to escape lighting in the event of a fire, appropriate references and standards should be sought by the designer (e.g. EN 1838), as it is not intended for this document to cover the specific demands required by such circumstances.

13.6.14 Lighting in other places

At other places associated with the expressways, the lighting shall be provided on individual considerations of the functional requirements. Japan practices are given below:

- **Interchange lighting**

  Interchange lighting, which is installed at convergence/divergence points and at ramps on expressways, is required to provide an average road surface luminance of 1 cd/m^2 (average road surface luminance of approx. 15 lux).

  The number of lights installed depends on the traffic volumes of the expressway and interchange.

- **Toll booth plaza lighting**

  Toll booth plaza lighting is installed to provide an average road surface luminance of 20 lux in the plaza, and it provides an average vertical surface luminance of 40 lux where it is necessary to identify the type of motor vehicle.

- **Service and Parking area lighting**

  Service and parking area lighting is installed at convergence and divergence points and ramp ways on the expressway and provides an average road surface luminance of 1 cd/m^2.

  The number of lights installed depends on the traffic volumes on the expressway and the volume of vehicles entering/leaving the area.

  Lighting inside parking areas has an average road surface luminance of 10 lux, and suitable lighting is also installed along sidewalks.

- **Pick-up Bus Stop lighting**

  Pick-up bus stop lighting provides an average road surface luminance of 10 lux at and near the platform.

13.7 GUIDANCE FACILITIES DURING NIGHT TIME

13.7.1 *Interior/exterior illuminated signs*

As interior illuminated signs provides night time visibility and guidance superior to that of externally illuminated signs, they are used as important signs such as expressway exit signs.

13.7.2 *Blinker lights*

Blinker lights are yellow flashing light to alert drivers to the existence of interchanges and parking area entries or branch points etc. to prevent collisions and merging accidents.

13.7.3 *Delineators*

This is erected along the roadsides and indicates the road alignment. It functions mainly at night to guide the drivers. The delineator is effective in promoting safe driving by providing advance information of the alignment, which serves to prevent traffic accidents.

The colour and number of delineators are determined by the location, as in **Table 13.01A and 13.01B**. The arrangement Horizontal Vertical too is fixed in cases of more than two reflectors on the post to indicate where expressway runs and locating of interchange and facilities at night.

It is standard practice to locate delineators on the left side of the carriageway, at a distance of 120 cm from road surface to the center of the reflector and with 50 cm clearance.

The delineator is installed 90 cm from the road surface on the median side of the main roadway and on an interchange ramp way. It is attached directly on the front surface of guard rails, it is installed 60 cm away from the marginal strip. Installation methods of Delineator and Delineator for concrete Barrier are shown in **Table 13.01A and 13.01B**.

Table 13.01A Location and Kind of Delineator *(Japan Condition)*

Location	Colour	Number	Remarks
Left shoulder of Main Roadway	White	1	
Median of Main Roadway	Orange	1	
Ramp at Interchange and Service Area	Orange	1	
Speed Changing Lane	Orange	2	Longitudinal Arrangement
Start of Merging lane and End	Orange	3	Longitudinal Arrangement
Start of Separation Lane and Start of Deceleration Lane	Orange	3	Parallel Arrangement

Table 13.01B Location and Kind of Delineator *(Indian Condition)*

Location	Colour	Number	Remarks
Left shoulder of Main Roadway	Yellow	1	
Median of Main Roadway	White	1	
Ramp at Interchange and Service Area	White	1	
Speed Changing Lane	White	2	Longitudinal Arrangement
Start of Merging Lane and End	White	3	Longitudinal Arrangement
Start of Separation Lane and Start of Deceleration Lane	White	3	Parallel Arrangement

Spacing and Placement of Delineators

The spacing of delineators depends on the alignment radius. For expressways and ramps on interchanges, the speed values range between 40 – 120 kmph and the corresponding minimum/desirable radius varies from 60 m to 1000 m.

IRC:79-1981 recommended spacing values compared fairly to MUTCD-2003 values. Moreover, MUTCD-2003 has recommend a formula for spacing computation as

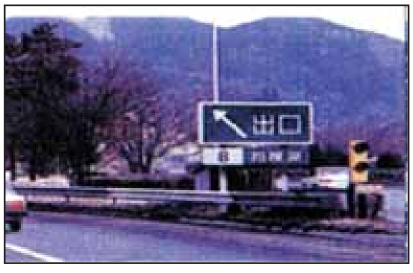
$S = 1.7\sqrt{R-15}$ where: S = Delineator Spacing in meter, R = Radius in meter

For expressway on tangent/transition section, the spacing of the first (for the beginning of curve) delineator shall be 2S, the second at 3S and the third at 6S limited to maximum of 50 m.

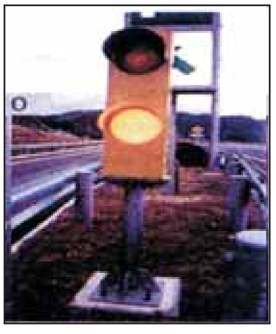
On Expressway tangent sections, Delineators should be spaced 50 to 70 m apart.

On merging, diverging areas and in tunnels, desirably the spacing may be reduced to 50 percent of normal sections.

For this Guideline, the above recommendations shall be used.



Blinker Light Installation



Blinker Light

Delineators

13.8 GLARE REDUCTION

1) *Purpose*

Glare reduction devices are installed for reducing the headlight glare of opposing traffic at night which may distract from driving tasks.

2) *Place of Installation*

Installation of glare reduction devices depends on many factors such as accident experience, high night-time traffic volumes and complaints from the public or highway geometry. Additional factors include distance between opposing traffic, lane width restrictions, narrow median, barrier type, vertical and horizontal curvature.

Glare reduction devices are generally installed on the median strips, in bridge and overpass sections, on horizontal curves and in cut and embankment sections without vegetation. Generally these shall be placed at 4 to 6 m spacing. However, 4 m spacing would be desirable.

Installation of glare reduction devices can be omitted in the sections with the following characteristics.

a) The median strip has a width of 7 m or larger.
b) The difference in the elevation of centreline in opposing directions is 2 m or greater.
c) Lighting devices are installed continuously, which regulate use of head lights on high beam.

3) *Structural Specifications*

i) *Height*

The height of a glare reduction device is set at 1.4 to 1.5 m on the assumption of combinations of opposing passenger vehicles and of a passenger car and a large-size vehicle running in the opposite directions.

ii) *Shading Angle*

For 2 x 3 lane dual carriageway with 5.5 m median and 3.75 m lane width, the shading angle θ in the case where passenger vehicles passing other vehicles are moving in opposing directions with a 50 m gap between them is calculated by the following equation.

$$\theta = \tan^{-1} \frac{9.25}{50} = 10^{\circ}\ 30^{'}$$

In order to reduce the headlight glare of a vehicle passing other vehicles for another vehicle travelling in the opposite direction, greater shading angle is required. Full shading, however, narrows the view of the driver and restricts view of opposing traffic for the authorized personnel in patrol vehicle. Therefore, a shading angle of approximately 5 to 10 degrees has been selected to provide partial shading.

iii) Desirable characteristics of a glare screen shall generally be the following:

- Will not penetrate the passenger compartment or present an undue risk to workers and other traffic when hit
- Performs in a predictable manner when hit
- Effectively reduces glare
- Is resistant to vandalism and vehicle damage and
- Is easy to repair

Fig. 13.04 shows the concrete visual barrier.

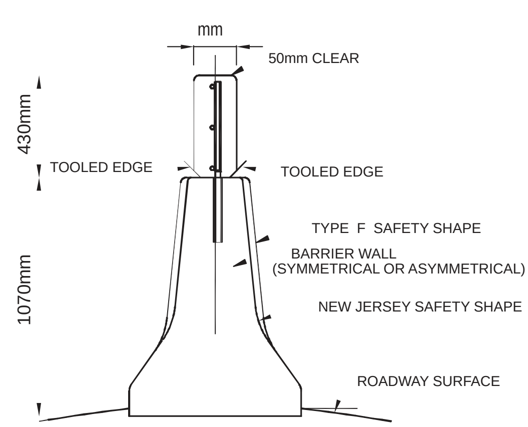


Fig. 13.04 Visual Barrier

CHAPTER - 14

NOISE BARRIERS

CHAPTER – 14

NOISE BARRIERS

14.1 NOISE BARRIERS

14.1.1 *General*

Noise barriers are solid obstructions (acoustically) built between the expressway and the receptors. It is reported that effective noise barriers can reduce noise levels by 10 to 15 decibels, cutting the loudness of traffic to half.

Barriers can be formed from earth mounds, reinforced earthen embankment or high vertical walls. Noise walls can be built of wood, stucco, concrete, masonry, metal and other materials. New designs are developing fast that are pleasing, that blend with surroundings and reduce tunnel effect with visually transparent materials.

As a broad guidelines, FHWA considers a minimum 10 dB insertion loss (IL) is to be considered for the provision of Noise barrier.

14.1.2 *Noise barriers for expressways*

Most of the barriers are either made of concrete (pre-cast or cast-in-situ), metal panels and these reduce noise passing through such walls. But these may block sunlight, road side vision and may produce tunnel / prison wall effect. The large flat surfaces attract graffiti and screenings that can create loud echoes otherwise which were meant to make the environment quiet.

The noise barrier material selection process shall broadly consider

i) Pleasant Aesthetics

To break monotony and tunnel effect, combined with considerations of safety, it is desirable to combine the concrete or metal forms with transparent (see through) materials. The combination shall create unique architectural alternative alongwith desirable noise control.

ii) Impact Resistance

Sound barriers are often subjected to impacts caused by stones or other debris thrown up by vehicle tyres. Therefore, barrier materials are desirable to withstand these impact forces. Concrete and metal have negligible effect, whereas transparent material need special considerations.

iii) Graffiti Resistance

The surfaces need to be textured so that no mark (i.e. graffiti work) could be made on the surface. Even if some marks are there, the same shall be washable with (hot / cold) water.

iv) Durability

Compared to clear plastics and glasses, the poly-carbonate based materials are reported to offer greater resistances to impact and maintains durability against wide range of temperature such as from -20^0 C to +90^0 C.

v) Safety

Being transparent, the wall reduces the risk of vandals hiding behind the wall. The material surface is generally corrugated which minimizes hazardous glare from sunlight or head lights from opposing vehicles.

vi) Low Maintenance Cost

Concrete, metals or transparent materials shall be easy to clean and shall require minimum maintenance attention.

14.1.3 *Noise barrier placement and reduction effect*

The degree of attenuation provided by a noise barrier is mainly a function of (1) the diffraction angle α through which the sound path must be bent in order to get from source to receiver and (2) the frequency of the sound source.

Five main factors that influence the acoustic effectiveness of a barrier are: (1) distance (offset), (2) height, (3) continuity, (4) length, and (5) mass.

An additional factor influencing the acoustic effectiveness of a barrier is the sound absorption capability of the barrier, i.e., the degree to which it minimizes reflection of sound.

Distance (Placement of Barrier):

A sound barrier should be erected as close as possible to either the noise source or the receiving position in order to maximize the diffraction angle.

Height of Barrier:

The minimum height of the barrier should be such that the line of sight between source and receiver is interrupted.

Continuity of Barrier:

No gaps or holes should be present in a noise barrier. It must be effectively airtight.

Length of Barrier:

As a guideline, the length of a noise barrier should be at least 2 to 3 times the distance between the barrier and the protection structure to minimize sound diffraction around the ends of the barrier.

Noise reduction effect: Generated noise generally dissipates with distance, land use and the nature of vegetation, forests etc. **Table 14.01** Highway Noise at various distances from source of the noise and **Fig. 14.01** Typical Effect of Noise Barrier – presents the noise reduction effect of the barrier and **Fig. 14.02** presents extents of barrier requirement. These two help designers in selection / fixation of alignment. Needed length of barrier to protect the target / receptor are i) desirably three times the distance of the targets / receptor, from the highway edge and ii) minimum two times the distance or 50 m whichever is more.

Table 14.01 Highway Noise Various Distances from Source

Abatement Measures		**Distance from Noise Source (m)**				
		15	**30**	**60**	**90**	**100**
		Noise Levels in Decibels (dB)				
Noise Abatement Measures	No Barrier	76	72	66	63	60
	Landscaping of 30 m width with dense overlapping crowns	-	67	61	58	55
	2 m height of Barriers on Edge of Verge	64	60	54	51	48
	4m height of Barriers on Edge of Verge	61	57	51	48	45
	3 m Depressed Expressway	74	68	58	55	52

Note: Source is emitting noise of 100 dB

Source: Handbook of Highway Engineering – by Robert F Baker et.al

14.1.4 *Type of noise barriers*

As designers aid, some typical arrangements of noise barriers (mostly from Japan) have been included. These include some typical arrangements on embankment and structures (bridges) in the form of sketches and pictorial views.

Fig. 14.03 presents typical noise barriers while **Fig. 14.04** and **Fig. 14.05** presents typical arrangement of metal panel on pile foundation and on bridges respectively. **Fig. 14.06** presents typical pictorial views of transparent type noise barriers. Transparent type is preferable for the drivers as it provides view of the adjoining areas. However, periodic cleaning is necessary to maintain the transparency.

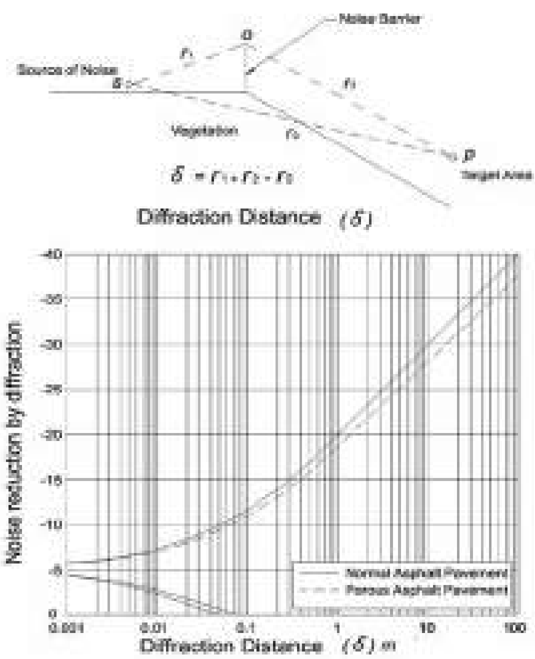
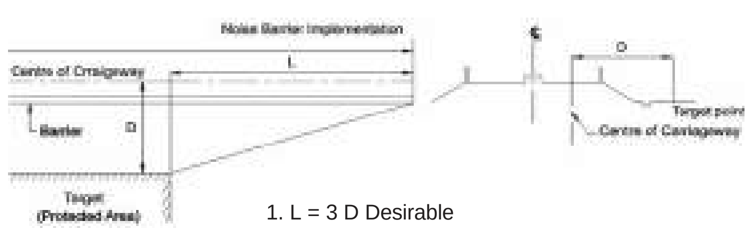
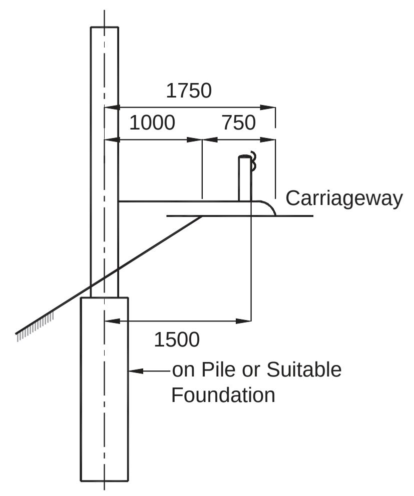


Fig. 14.01 Effect of Noise Barrier



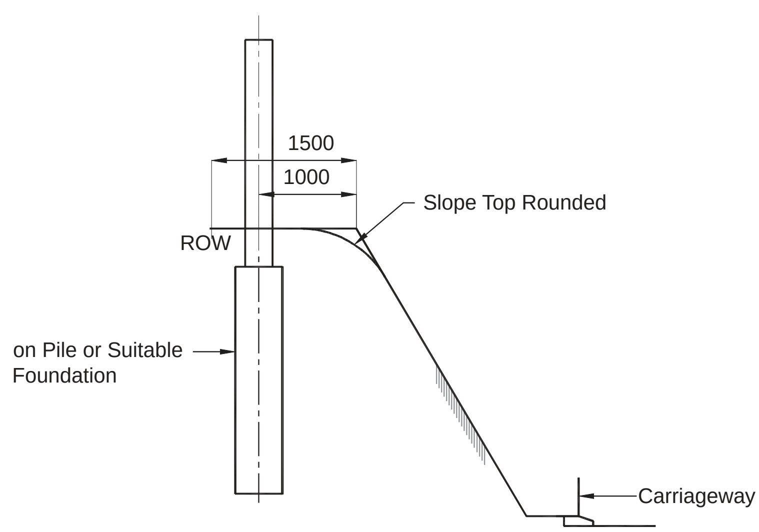
1. L = 3 D Desirable
2. L = 2 D Minimum or 50 m whichever is more

Fig. 14.02 Typical Noise Barrier Extent
(Source: Japan Standards)



At Embankment Slope

Location on Embankment



Location on Cut Slopes

Note:

- Embankment Slopes shall be provided with appropriate erosion control Measures.
- Cut slopes shall be stable and may require Protection with breast walls.

Fig. 14.03 Typical Noise Barrier Locations
(Source: Japan Standards)

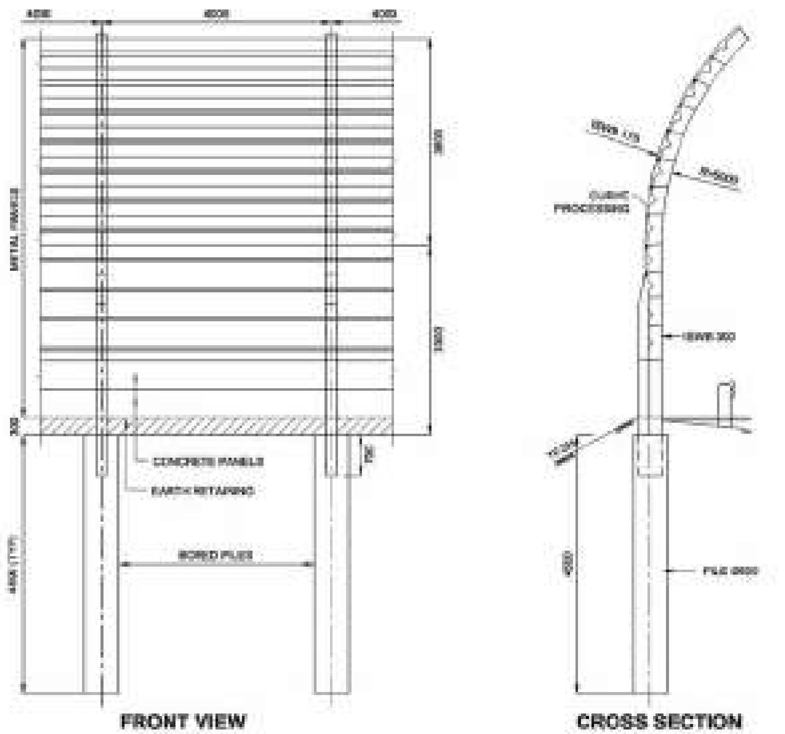


Fig. 14.04 Typical Arrangement Metal Panel on Pile Foundation

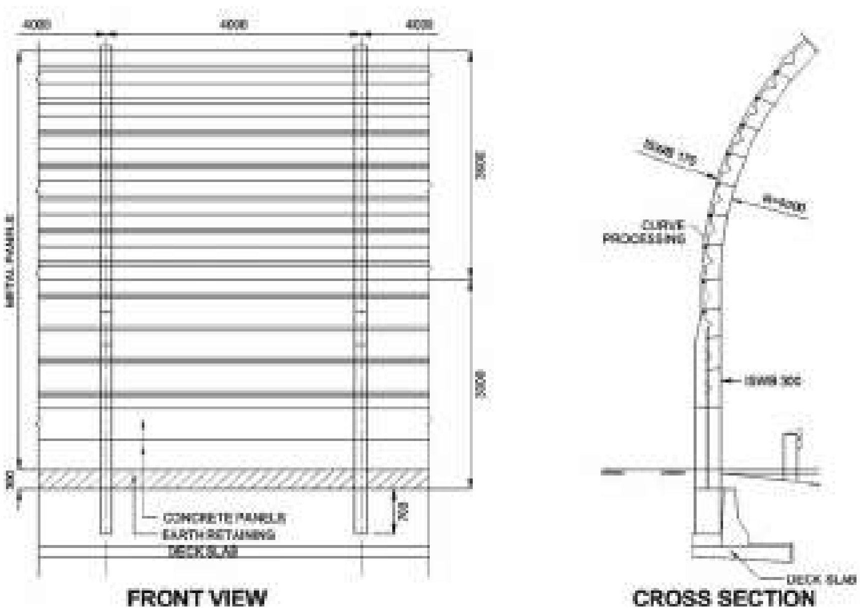


Fig. 14.05 Typical Arrangement (Metal Panel on Bridge)

1) Full height transparent acrylic panel noise barrier with vertical metal posts on embankment with top portion of acrylic panel bent inwards – noise deflected back.

2) Full height transparent acrylic panel with inside metal posts on bridge – Noise deflected back.

3) Placed on bridge – a combination of acrylic panel and metal panel noise barrier.

4) Placed on bridge crash barrier – the noise barrier similar to (1).

5) Placed on bridge deck –noise barrier similar to (2) but curved towards sea.

Fig. 14.06 Pictorial Views of Transparent Type Noise Barriers
Source: http:\\www.tokyorope.co.jp/eg/