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GUIDELINES FOR DESIGN OF INTEGRAL BRIDGES

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GUIDELINES FOR DESIGN OF INTEGRAL BRIDGES

This guidelines has been prepared by the IRC Committee (B-9) on 'Specialized Bridge Structures including Sea links' during its term 2015-2017. The B-9 Committee comprises of the following members:

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Raina, Dr. V.K.	……	Co-Convenor
Joglekar, S.G.	……	Member-Secretary

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Secretary General, IRC
(Nirmal, S.K.)

After due deliberations the B-9 Committee has taken a considered view that as there are no standards for Integral Bridges, there is a need to bring out these guidelines titled 'Guidelines for Design of Integral Bridges', for the design, detailing and construction of Integral Bridges in India. Considering the fact that Integral Bridges worldwide have shown saving in initial cost and life cycle cost through reduced maintenance. As Integral Bridges have demonstrated better performance under earthquake loads, their use needs to be encouraged. In addition, Integral Bridges eliminate expansion joints and provide better riding quality thereby adding comfort to the road users. Because of advantage of reduced initial cost and maintenance cost and better service performance/riding quality, the engineer's worldwide in countries like USA, UK, New Zealand, Australia, Japan etc. are preferring to use Integral Bridges. In UK, bridges up to a length of 60 m are mandatory to be of integral type[1]. However, because of complexity in design of long Integral Bridges, their use is generally limited in length to about 100 m, though there are examples of Integral Bridges with length more than 300 m in some of the countries.

Keeping this objective in mind, a sub-committee consisting of following members was formed to prepare the initial draft of the guidelines.

a) Mr Alok Bhowmick (Convener)
b) Mr G L Verma
c) Dr. Lakshmy Parameswaran
d) Mr V N Heggade
e) Dr. Krishna Sandepudi
f) Dr. Harshavardhan Subbarao
g) Mr Faqir Chand

The initial draft prepared by the sub-committee was discussed by the B-9 committee at several meetings and finalized in its meeting held on 26th May 2017. The draft document was approved by Bridges Specifications and Standards Committee in its meeting held on 23.10.2017. The document was considered by IRC Council in its 213th meeting held on 03.11.2017 at IRC Session held at Bengaluru and approved the document for publication.

1 INTRODUCTION

1.1 General

An Integral Bridge (IB) is a structure where there are no bearings over the abutments and no expansion joints in the superstructure. IB's are characterized by monolithic connection between the superstructure and the substructure (piers and abutments), unlike the traditional bridge construction, where the superstructure is supported on bearings and transfers all the forces to substructure and foundation through bearings. Provision of expansion joints and bearings in traditional bridges allows movement and rotation of the bridge deck, without transferring any force to abutment / pier and foundation due to thermal / creep / shrinkage induced movements. In case of IB's, the deck carries the movement of deck to the abutment as well as to the backfill soil behind the abutment. The approach slab between the bridge end and the pavements accommodate the necessary movements, which leads to a strong soil-structure interaction.

Apart from the fully integral solutions without expansion joints or bearings, it is also possible to have structural solution, where only the expansion joints at Abutments are omitted, but the bearings are provided. The back-wall portion of the substructure is directly connected with the superstructure in such case and the superstructure, back-wall and approach slab moves together 'towards' and 'away' from the backfill during the thermal expansion and contraction. Such solutions, known as 'Semi-Integral Bridges' (SIB's), are often appropriate particularly for the rehabilitation of bridges.

Another structural form, which is commonly used is 'Framed-Type Bridges' (FTB's), where the bridge deck is monolithic at intermediate pier locations but have bearings as well as expansion joints at the abutment locations. In this case there is no interaction of the structure with the backfill soil. Design of FTB's are well covered in existing IRC codes and therefore not covered in this guideline.

Fig.1.1 shows the different type of bridges, classified based on the connection of deck at the ends. This guideline covers design of fully Integral Bridges (IB's) only as shown in **Fig. 1.1(b)** and **(c)**.

There are four basic ways that a bridge can be made integral, depending on the abutment detail. These four forms can be referred to as: Bank seat abutments, Framed abutments (fully integral bridges); Embedded wall abutments and Flexible support abutments. **Fig.1.2** shows typical details of these different type of IB's possible.

1.2 Advantages and Disadvantages of using Integral Bridges

Some of the advantages of adopting integral bridge concept as against the conventional bridge concept are summarized below:

- Added redundancy with improved seismic performance
- Improved structural reliability and redundancy

- Improved ride-quality and noise reduction
- Improved durability due to absence of expansion joints, which is the source of moisture ingress
- Potential for reduced initial cost
- Reduced maintenance requirement
- Reduced traffic disruption
- Lower whole-of-life cost and
- Improvement of bridge appearance
- Simplified Widening & Replacement detail
- Useful concept for strengthening of existing bridges

Some of the disadvantages of adopting integral bridge concept are summarized below:

- Limited span range due to restraints to movements caused by thermal, creep and shrinkage.
- Differential settlement between foundations resting on varying strata or varying scour conditions in case of river bridges.
- Climatic conditions with large variation in maximum and minimum ambient temperatures.
- Need for complex structural analysis involving soil-structure interaction.

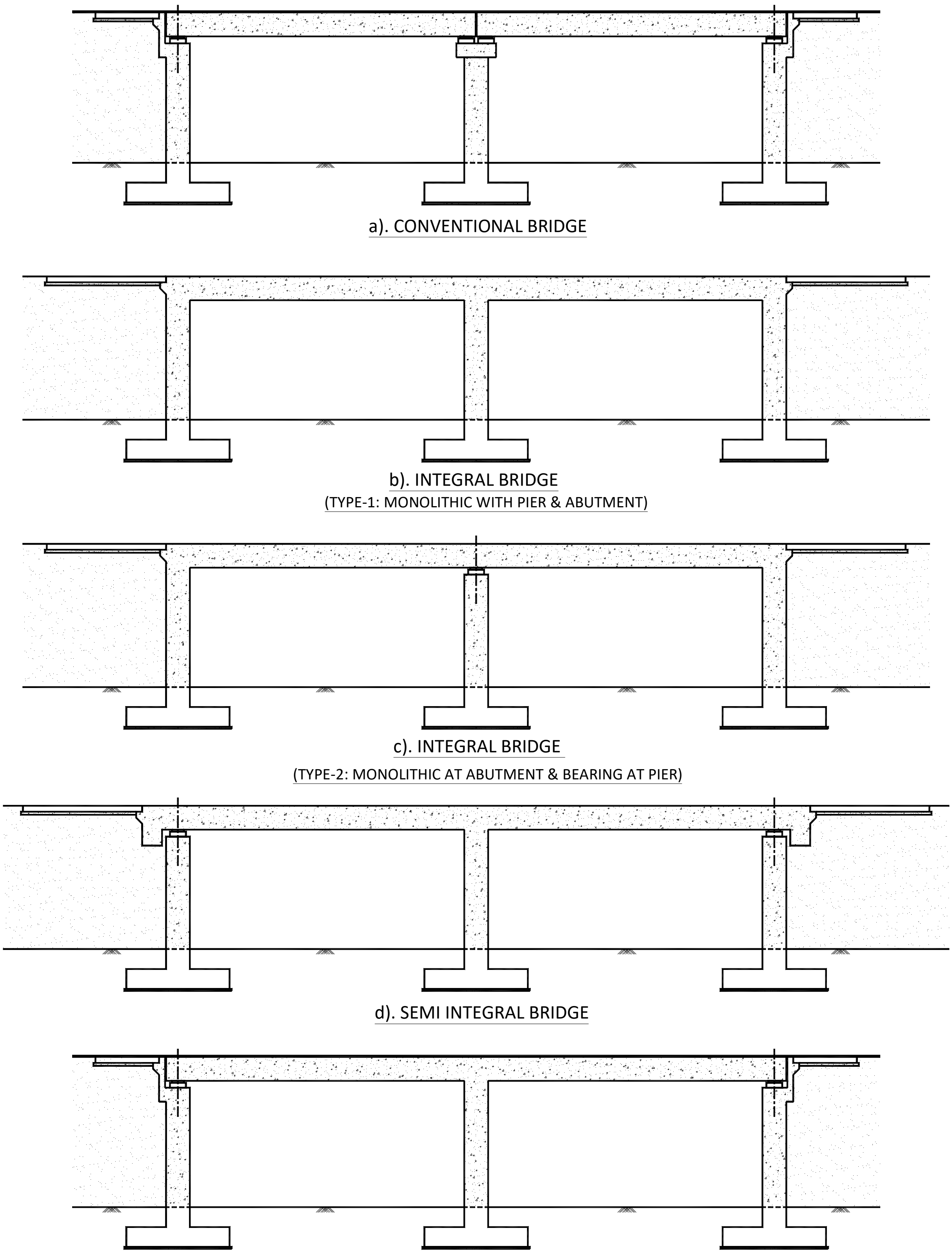
1.3 Integral Bridge Practices in various parts of the World

Experience on construction of Integral Bridges in the United States of America dates back to late 1930's and early 1940's. Ohio, South Dakota, and Oregon were the first states to routinely use continuous construction with integral abutments. California followed suit in 1950's. Tennessee and other states in USA began moving toward integral bridges from 1960's.

New Zealand's experience with joint-less bridges began in 1930's. Standardized design drawings for concrete bridges of this type have been developed by the New Zealand Ministry of Works and Development (NZMWD) as far back as 1950's.

In the 1970's, Britain started to research on IB's. Currently in UK, the bridges with span length less than 60 m and skew not exceeding 30º are generally required to be continuous over intermediate piers and integral at abutments[2]. The thermally induced cyclic movement at each abutment is restricted to ± 20 mm in case of IB's as per the British Advisory Note.

In Japan, the first integral bridge was built in 1996. Generally the integral bridge length in Japan is restricted to 30 m. In Australia, the integral bridge construction is practiced by Queensland Main Roads Department (QMRD) since 1975. China began to build Integral bridges since 1990's.



a). CONVENTIONAL BRIDGE

b). INTEGRAL BRIDGE
(TYPE-1: MONOLITHIC WITH PIER & ABUTMENT)

c). INTEGRAL BRIDGE
(TYPE-2: MONOLITHIC AT ABUTMENT & BEARING AT PIER)

d). SEMI INTEGRAL BRIDGE

e). FRAMED BRIDGE

Fig 1.1 Different Bridge Types Classified Based on Connection of Deck at Ends

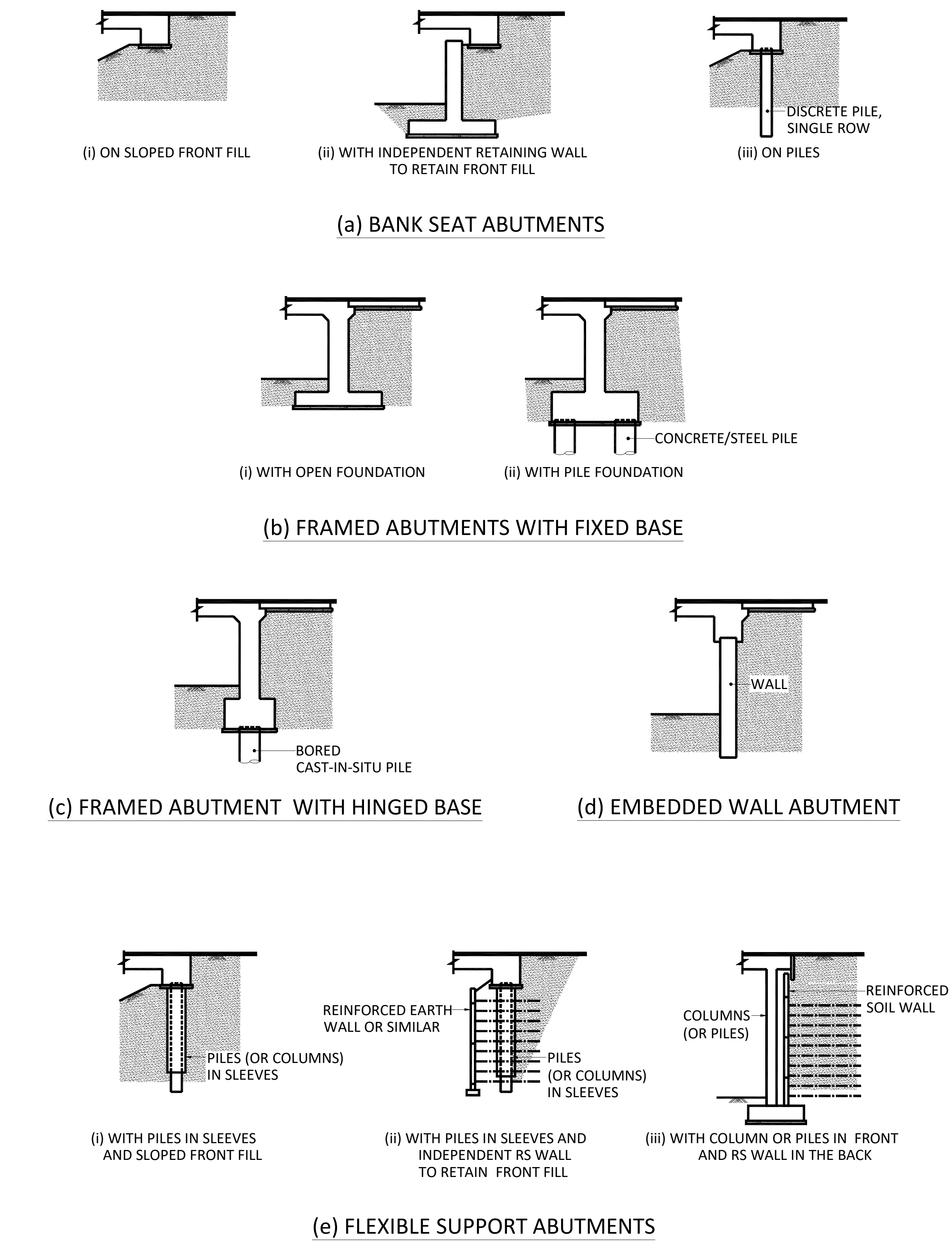


Fig 1.2 : Typical Details of Different Ntegral Abutment Types

European experience of integral bridge is significantly less and dates back to 1960 onwards. However the experience gained by Europe has been positive and as a result, the trend is towards making integral bridges a larger percentage of all newly constructed bridges in Europe. In Switzerland, many integral bridges were constructed on the national motorway network during the period 1960-85. The long term experiences of these structures have been overwhelmingly positive, both in terms of construction and maintenance. More than 40% of the existing bridges on FEDRO (Federal Roads Office of Switzerland) network are integral or semi integral structures[2]. The scientists at EPFL (Ecole Polytechnique Federale de Lausanne) are currently conducting research program on abutment and approach slab construction techniques, with the challenge to build long span bridges with integral concepts (i,e. bridges of length > 200m).

Table 1.1 below gives the recorded longest integral bridges in the world.

Table 1.1 Longest Integral Bridges in the World

Sr. No.	Bridge Location	Bridge Length	Type of Superstructure
1	Isola Della Scala, Verona, Veneto, Italy	400.8 m	Precast U-Girder with in-situ deck
2	SR 50 (over Happy Hollow Creek), Tennessee, USA	358.4 m	Precast, prestressed concrete bulb-T girders, curved in plan
3	Colorado, USA	339.2 m	Precast girder with in-situ deck
4	Oregon, USA	335.5 m	Precast girder with in-situ deck
5	Colorado, USA	318.4 m	Steel girder with in-situ deck
6	SR 249 (over US 12), Indiana, USA	302 m	Composite prestressed bulb-tee girder
7	Colorado, USA	290.4 m	Cast-in-place Deck
8	SR 34 (over Southern Railway &Whitehorn Creek), Tennessee, USA	250 m	Precast/prestressed box beams with composite concrete deck
9	Virginia, USA	235.5 m	Precast girder, composite with in-situ deck

2 SCOPE

2.1 This guidelines is applicable to fully Integral Bridges, with structural deck made of steel, concrete or composite construction, including precast and prestressed concrete.

2.2 Semi Integral Bridges and Framed Type Bridges are not covered in this guideline. For framed bridges, provisions of current IRC code are sufficient and for semiintegral bridges, specialist literature may be referred.

2.3 In order to use the simplified design methods as per this guideline, the structure should satisfy the following requirements :

a. the characteristic thermal movement at the end of the deck does not exceed ±20 mm under normal case from the position at the time of restraints during construction[1].

b. shall have a skew angle less than or equal to 30 degrees;

c. shall be a straight bridge or a curved bridge with radius of curvature exceeding 100 m.

d. shall not have connected splayed wing wall.

2.4 A structure that falls outside of the criteria given above may require more detailed analysis, for which specialist literature may be referred.

3 DEFINITIONS & SYMBOLS

3.1 Definitions

3.1.1 *Asphaltic Plug Joint*

An in situ joint in the pavement, comprising a band of specially formulated flexible material which may also form the surfacing.

3.1.2 *Abutment*

Abutment is a sub-structure component which supports the end of a Superstructure and retains some or all of the bridge approach fills.

3.1.3 *Bank Seat Abutment*

Bank seat end support for bridge constructed integrally with deck, acting as a shallow foundation for end span and as a shallow retaining wall for adjoining pavements and embankment.

3.1.4 *Embedded Wall Abutment*

End support for bridge comprising a diaphragm wall (contiguous, or secant or sheet pile walls) with toe embedded in ground below lower ground surface.

3.1.5 *End Screen Abutment*

Wall structure cast monolithic with and supported off the end of bridge deck providing retaining wall for adjoining ground, but not acting as a support for vertical loads.

3.1.6 *Frame Abutment*

End support for bridge constructed integrally with the deck and acting as a retaining wall for adjoining pavement and ground below.

3.1.7 *Flexible Support Abutment*

Abutments supported on flexible piles or columns with the earth pressure mainly taken by the reinforced soil wall. The piles or columns are either enclosed in sleeves to allow them to flex without displacing the surrounding soil or they are located in front of the surrounding reinforced soil wall.

3.1.8 *Granular Backfill*

Selected granular material placed adjacent to the abutment wall and forming the subgrade for the adjoining pavement construction.

3.1.9 *Integral Abutment*

Bridge abutment which is connected to the bridge deck without any movement joint for expansion or contraction of the deck.

3.1.10 *Integral Bridge*

A bridge with integral abutments.

3.1.11 *Pavement/Abutment interface*

The interface between the pavement construction and the back face of the abutment.

3.1.12 *Range*

Change (of temperature, strain) between extreme minimum and extreme maximum.

3.1.13 *Sleeper Slab*

A horizontal slab placed beneath the joint at the end of approach slab that is joined to the other side of roadway pavement.

3.1.14 *Strain Ratcheting*

Repeated backward and forward movement of an abutment caused by expansion and contraction of the deck of an integral bridge or the application of live load surcharge behind a bridge abutment which, with time, causes a change in the properties of granular backfill.

3.1.15 *Sub-surface Drainage*

A system for draining water from within the surfacing.

3.1.16 *Surface*

The carriageway or footway surface.

3.1.17 *Surfacing*

Carriageway or footway wearing course and base course materials.

3.1.18 *Zero Movement Point*

The point on a bridge in plan which does not move when the bridge experiences expansion or contraction during changes in bridge temperature.

3.2 Symbols

d	thermal movement of the end of a bridge deck at top of Abutment
d'	deflection of an integral bridge abutment at a depth H/2 below ground level
E	Young's modulus
H	retained height of wall or end screen
H'	depth of soil influenced by abutment movement and used in a soil–structure interaction analysis of an integral bridge
H_c	depth of earth cover between ground level and the top surface of the roof of a buried structure
K	earth pressure coefficient
K_a	coefficient of active earth pressure
K_d	design value of K based on j'd and including a model factor γ_{Sd}; K if relevant
K_o	coefficient of earth pressure at rest
K_{max}	coefficient of earth pressure applied to buried structures which takes account of pressure increases caused by expansion of the structure
K_{min}	coefficient of minimum earth pressure applied when earth pressure is favourable
K_p	coefficient of passive earth pressure
$K_{p;t}$	coefficient of passive earth pressure used in the calculation of K^* and determined using the design value of the triaxial j',
K_r	coefficient of earth pressure resisting overturning or sliding
K*	design earth pressure coefficient applied to integral bridge abutments
Lx	expansion length measured from the end of the bridge to the position on the deck that remains stationary when the bridge expands
z	depth below ground level or top of wall
α	Coefficient of thermal expansion
β	Angle of inclination of backfill
γ^*_M	Partial safety factor on passive earth pressure coefficient
$\gamma_{Sd;K}$	model factor to be applied to earth pressure at ULS
$\gamma_{Sd;ec}$	model factor to be applied to the weight of earth cover at SLS and ULS
δ	structure–ground interface friction angle or friction angle on a vertical or inclined virtual face
θ	Skew angle of bridge
φ'	angle of shearing resistance in terms of effective stress

3.3 Abbreviations

EQU	Ultimate limit State of Equilibrium
GEO	Geotechnical Ultimate Limit State

SLS	Serviceability Limit State
STR	Ultimate Limit State of Strength
ULS	Ultimate Limit State
IB	Integral Bridge
SIB	Semi-Integral Bridge
FTB	Framed Type Bridge
IRC	Indian Roads Congress
RS	Wall Reinforced Soil Wall
FRL	Finished Road Level

4 PLANNING CONSIDERATIONS

It is important to ensure that the feasibility of the IB concept for any project is established in the early planning stage. Every site is not necessarily suitable for this type of structure and hence indiscriminate use of this concept in situations where it is not suitable, should be avoided. Factors that influence the feasibility of adopting integral type of structure include:

a) Length of Structure
b) Climatic condition
c) Seismic zone
d) Type of superstructure
e) Type of abutments
f) Type of foundations and sub-soil conditions
g) Geometry of the structure
h) Complexity in analysis and design

4.1 Length of Structure

The limitation in the length of the bridge, upto which an integral bridge can be built, depends upon:

a) The climatic conditions
b) Range of temperature variation (‘daily’ as well as ‘seasonal’)
c) Material of the structure, geometry of the structure
d) Abutment and pier heights and the sub-soil conditions
e) Differential settlements and scour conditions in river bridges

4.2 Climatic Condition

IBs are sensitive to daily and seasonal changes in temperature and humidity. Lesser the variation in temperature, lesser will be the force induced in the structure. In the long term, creep in the deck, abutment and approaches will reduce the forces induced in the deck. For daily variation, the beneficial effect of creep should not be considered. Integral bridge with longer length is possible in regions where the difference between maximum and minimum shade air temperature is minimal.

4.3 Seismic Zone

Integral bridges perform better under seismic induced forces due to the fixity and restraints at the abutments. The multiple degree of redundancy in the structure helps to minimize the risk of failure of the structure. Therefore in high seismic zone, integral bridges are preferred.

4.4 Type of Superstructure

The type of superstructure has a significant influence on the design of integral bridges. The following types of superstructure are usually adopted :

- Cast in-situ RC solid slab/voided slab deck
- Precast Prestressed/RCC girder with in-situ composite deck.
- Steel girder with in-situ concrete composite deck

IB's with steel decking are more responsive to temperature than with concrete deck. IB's with cast-in-situ post tensioned bridge decks suffer large movements resulting from shrinkage and creep, which needs to be absorbed by the structure.

4.5 Type of Abutments

Various types of integral abutment types are possible, as given below[7]:

a) Bank Seat Abutments
b) Framed Abutments with fixed base (i,e. With open foundation or foundation with multi-row piles)
c) Framed Abutments with hinged base (i,e. foundation with single row piles)
d) Embedded Wall Abutments
e) Flexible support abutments

Fig.1.2 shows the various types of Abutments generally adopted for IBs.

Bank seat abutments: These are effectively extensions to the deck that are seated on the backfill and act as end supports for the bridge as shown in **Fig. 1.2(a)(i)** and **Fig. 1.2(a) (ii)**. These bank pads slide on top of the foundation soil in response to thermal expansion and contraction of the deck and can rotate under live loading. The bank pad should have adequate weight to provide stability to the structure, and in multi-span structures, the end span should have adequate flexibility to accommodate differential settlement and to avoid uplift when remote spans are subject to traffic loading.

Bank pad abutments on piles: These are bank pad abutments founded on a single row of discrete vertical piles, as shown in **Fig. 1.2(a)(iii)**, which are driven or bored through an embankment or cutting slope. The top of the piles are integral with the deck. When the deck expands, the pile cap and the end of the deck move into the backfill without significant rotation, whereas the piles flex backward into the fill.

Framed abutments: These abutments support the bridge deck and act as retaining walls for the backfill. They are connected structurally to the deck and are supported on spread footings or piled foundations as shown in **Fig. 1.2 (c)**.

Embedded wall abutments: These include contiguous or secant pile, sheet pile or diaphragm wall abutments, which extend to a depth below the retained fill as shown in **Fig. 1.2(d)**. The walls are integral with the bridge deck. These type of abutments are popular for short span underpasses in congested urban areas where top-down construction is envisaged.

Flexible support abutments: These are abutments in which the deck is supported on flexible piles or columns. The piles or columns are either enclosed in sleeves to allow them to flex without displacing the surrounding soil as shown in **Fig. 1.2 (e)(i)** and **Fig. 1.2(e)(ii)**, or they are located in front of a reinforced soil or similar abutment as shown in **Fig. 1.2(e)(iii)**. In these types of abutments, only the end screen, which is attached to the end of the deck, moves into the fill.

4.6 Type of Foundations and Sub-Soil Conditions

Sub-soil condition is an important consideration while choosing the type of foundation and for ascertaining the feasibility of integral structures. The primary criterion is the need to support the piers and abutments on relatively flexible foundation. It is desirable to have 'flexible' abutment and foundations, which allow movement of the structure under thermal loadings without much restraint. For footings founded on soft or compressible soil, mechanical stabilization of the soil may be required to avoid large total and differential settlements.

Single row of Steel 'H' piles are commonly considered as the best foundation practice in integral bridges, in many countries, including USA, UK, Ireland. Single row of pile allows the abutment stem to translate into and out of the soil as it provides maximum ductility and flexibility in cyclic bending. Piles may be oriented with bending to occur about the strong or weak axis (relative stiffness between abutment and piles is so large that piles attract little moment regardless of orientation. For large movements, pile can be installed in permanent steel casings. The steel casing in such cases shall be designed to have the same design life as that of the bridge and an appropriate sacrificial corrosion thickness should be allowed for in the pile section.

Alternative to steel H-piles, single row of reinforced concrete piles / pre-stressed spun piles or steel pipe piles filled with concrete are also used for integral bridges in Europe. The use of Reinforced Concrete (RC) piles in IBs has not been widespread due to concerns over pile flexibility and the potential for concrete cracking. More than one row of piles in foundation can be used in IBs provided the piles can absorb the thermally induced high bending stresses, which may be caused due to increased stiffness of the foundation system in such cases.

Some of the countries (e,g. UK, Sweden)[2] use sleeves around the piles to prevent soil from restraining the free bending of the piles during superstructure translation. The pile theoretically distributes any longitudinal translation along a greater length of freestanding pile, thereby reducing the moment induced in the pile.

Spread footing, by their very nature, restrain the rotation of the abutment stem and therefore attracts larger forces in the base, in case of IBs. However depending upon the length and geometry of the IB, spread footings can also be used.

4.7 Geometry of the Structure

A complex geometry creates problems in the design of integral bridges. Irregular structures, sharply skewed structures and structures with sharp curvatures (that is, where there are abrupt or unusual changes in the mass, stiffness or geometry along the span) should be avoided.

For an integral structure, it is preferable that the spans are symmetrically placed and the adjacent pier stiffness does not differ substantially (say by more than 25 percent). Though curvature and skew can be accommodated, it would be desirable to avoid large skew (say, more than 30º) and high degree of curvature (Say R<100 m).

Bridges with tall piers are ideally suitable for integral bridges. The frame action greatly *helps* to reduce the lateral loads being transferred to the foundation. Preferably abutment heights on either side shall be the same. A difference in abutment height will cause unbalanced lateral loads resulting in side sway, which should be considered in the design by balancing the earth pressure which is consistent with the direction of sway, at the abutments. This procedure is a complex, iterative process and should be avoided.

4.8 Complexity in Analysis and Design

Integral Bridges, for all their simplicity of construction, are complicated structural systems. To thoroughly analyze a given structure, the designer must not only design for primary loads (dead, live, wind, etc.) but must also accurately account for secondary loads (creep, shrinkage, settlement, temperature effects, etc.). To additionally complicate the analysis, the response of a structure to a given set of external forces is very dependent on the geometry, materials, configuration, soil-structure interaction, and construction details of the individual system.

5 CONSTRUCTION CONSIDERATIONS

The sequence of construction for integral bridges should be specified in the Good for Construction (GFC) drawings. Following requirements should be adhered to :

5.1 Durability, Workmanship & Specific Requirements

5.1.1 *Concrete Quality*

Minimum grades of concrete, minimum cement content, maximum water cement ratio, cover to reinforcement and other durability and workmanship requirement shall be same as given in IRC:112.

5.1.2 *Backfill*

The densely compacted coarse gravel should be used as backfill material when this type of material is available. The material should be free draining and granular. Backfill material shall be compacted to the order of 95% modified Proctor density or 75% relative density.

The log-spiral approach with curved failure surface can be used when the soil friction angle is 40º or above and wall friction /soil friction ratio 0.60 to 0.75, to determine the passive resistance. These parameters should give a lower bound solution of the passive response of backfill, when subjected to static, cyclic and dynamic loadings. The designer who has performed field shear strength testing and is confident in the resulting parameters can use them in determining a larger earth resistance noting that calculated passive earth pressure coefficients increase by 10% to 15% for each one degree increase in the soil friction angle beyond 40º.The length of the compacted zone of backfill should extend for at least the height of the wall beyond the back face of the abutment and vertically below the bottom of the wall by about 25% of the height of the wall.

5.1.3 *Road Pavements*

Road Pavements should be constructed in accordance with the specifications for Highway works and IRC codes right up to the back faces of integral abutment. The surfacing can be laid as continuous layer over the approach roads and over the deck water proofing.

5.2 Sequence of Construction and its Influence in Design.

5.2.1 The abutments and the wing walls shall be constructed first to seating level elevation.

5.2.2 In case precast / prefabricated girders are used, they shall be placed on a support that allows rotation and deflection of girders due to self-weight of the deck. A 20 mm thick natural rubber sheet is generally provided to accommodate rotation of girders.

5.2.3 The deck and the portion of the abutment above bearing seat elevation shall be cast integrally with the girders.

5.2.4 There is a possibility that during construction, the superstructure will be subject to thermal movements when the freshly placed concrete of the abutment diaphragm is not fully set. This can be a serious concern with steel beam bridges that are more responsive to rapid changes in ambient temperatures. As such, casting of the closing pour of the abutment should be timed such that the initial set of the abutment diaphragm concrete occurs when the superstructure is at a relatively constant temperature. As bridge temperatures are dissimilar to ambient air temperatures, casting after midnight or in the very early hours of the morning is preferred.

5.2.5 In the case of steel girder bridges, their thermal movements are modified after casting the concrete deck slab. Therefore the best results can be achieved by casting the closing abutment joint after the deck slab has been cast, and preferably whilst the deck slab is cooled with water spraying or flooding, which is also beneficial for curing.

5.2.6 The construction of deck and abutment to the seating level shall be in sequence so that the structure becomes integral, with no residual stress. This may require careful consideration of concrete-pouring sequence and sometimes even the use of a retarder. The ends of the deck and the abutments shall be placed last unless setting of concrete can be retarded sufficiently to allow the placement from one end to the other in a single pour.

5.2.7 The stability and the integrity of the structure shall be maintained at all stages of construction.

5.2.8 Backfill shall not be placed behind the abutment until the concrete deck has attained 75% of its specified strength. Backfill shall be placed simultaneously behind both abutments, keeping the height of backfill appropriately same. At no time the difference in height of backfill shall be greater than 500 mm. The sequence of placement of backfill shall be taken into account in design.

6 LOADS AND LOAD COMBINATIONS

6.1 Introduction:

6.1.1 Bridge structures and abutments in particular of integral Bridges must be designed for the movements due to thermal strains, both increasing and decreasing, and the decreasing strains due to shrinkage of the superstructure if it is concrete, and in addition the decreasing strains due to creep in case of pre-stressed concrete decks. The forces developed in the structural system are a function of the relative stiffness of the elements, their foundations, their interaction with the surrounding soils and sequence of construction.

6.1.2 The forces due to applied loads must also be accommodated, and these are the dead loads, the vehicular live loads plus impact, the horizontal force due to wind, vehicle braking and centrifugal force and seismic force as applicable.

6.1.3 The connection between the superstructure and the substructure must also be designed for a Minimum Lateral Restraint Capacity to ensure that the superstructure has sufficient lateral restraint to resist unaccounted lateral forces notwithstanding that has been catered for in the design. Integral Bridges therefore should also be designed for a force of 500kN or 5% of the superstructure dead load, whichever is the greater acting at the junction of superstructure and substructure in addition to the actual forces. This force is to be considered at Ultimate Limit State.

6.2 Longitudinal Movement:

6.2.1 Integral Bridges should be designed to accommodate the effects of thermal expansion and other longitudinal forces, with thrusts from structural restraints, earth pressures and friction. They should also be designed for the effects of thermal contraction, with axial tension from structural constraint and sliding.

6.2.2 The effects of temperature difference, shrinkage, and creep should also be considered in accordance with relevant clauses of IRC:6 and IRC:112.

6.2.3 The temperature variation for Integral Bridges is to be taken assuming that during construction the bridge is made monolithic at following temperature ranges as given in IRC:6.

Bridge Location having difference between maximum and minimum air shade temperature	Bridge Temperature to be assumed when the structure is effectively restrained
>20 °C	Mean of maximum and minimum air shade temperature + 10 °C
<20 °C	Mean of maximum and minimum air shade temperature + 5 °C

6.2.4 The longitudinal movements calculated above as per IRC:6 and IRC:112 are serviceability Limit State values and should be multiplied by a factor of 1.25 to convert them to Ultimate Limit State Values.

6.3 Thermal Effects:

6.3.1 The Integral Bridges shall be designed for seasonal variation of temperature and shrinkage strains duly taking into account the sympathetic effects due to creep of concrete. In case of concrete structures when long term temperature movement is considered due to seasonal variation of temperature, the thermal modulus of elasticity may be taken as one-half that used for dynamic loads. Such benefits however shall not be considered for short-term movements caused due to daily variation in temperature (gradient effect).

6.3.2 The temperature gradient loading shall be considered in line with provisions of IRC:6. The effect of sympathetic creep shall not be considered for temperature gradient effects.

6.3.3 Special attention should be given to prevent early thermal and shrinkage cracking resulting from restraint to the longitudinal movement of deck slabs, by integral abutments.

6.3.4 Bridges which are curved, or not symmetric, experience thermal movements relative to a zero movement point. The position of the zero movement point can be determined from a stiffness analysis employing horizontal stiffness at supports and abutments.

6.4 Earth Pressure

6.4.1 The earth pressure coefficient is a function of the displacement or rotation of the earth retaining structure. An integral abutment bridge will experience elongation and contraction of superstructure due to temperature variations during its service life. Thus the earth pressure at the abutments should be considered in correlation with temperature variations.

6.4.2 A small displacement of the bridge away from the backfill soil can cause development of active earth pressure conditions. Therefore when the bridge contracts, due to fall in temperature, shrinkage, creep etc., active earth pressure will be developed behind the abutment.

Active earth pressure on abutments due to thermal contraction of decks are usually very small as compared to passive pressure and may be ignored.

6.4.3 At rest earth pressure condition behind the abutment may be assumed when there is no thermal movement.

6.4.4 When the bridge expands due to rise in temperature, the intensity of the earth pressure behind the abutment depends on the magnitude of the bridge displacement towards the backfill soil. The actual earth pressure coefficient may change between at rest 'Ko' and passive 'Kp' depending upon the amount of displacement of the abutment.

6.4.5 Live load surcharge on backfill shall be ignored while calculating the passive earth pressure mobilised by thermal expansion of the deck.

6.4.6 A summary of the proposed design earth pressure distributions with depth for the different structural form is as follows:

i) **Shallow height bank seat abutments**

The typical height of a bank seat abutment is up to 3.0 metres, and therefore the total force generated by passive excitation is usually readily accommodated within the design. The following equation to calculate the relationship between K*, the retained height (H) and thermal displacement of the top of the abutment (d), should be used.

$K^*=Ko+ (d/0.025H)^{0.4} \times Kp$

Where :

K*= Design earth pressure coefficient

Ko= At rest earth pressure coefficient

Kp= Passive earth pressure coefficient

The passive earth pressure coefficient shall be taken based on wall friction. $\delta=\varphi/2$.

ii) **Full height frame abutments with fixity at base**

With the increase in the height of abutment, the magnitude of passive pressure acting on the back of the wall is likely to be significant. Careful design of the abutment is therefore important to ensure that the structure is strong enough to resist lateral pressures that could build up behind the wall, and yet flexible enough to accommodate movement. The earth pressure coefficient, being a function of abutment displacement, the following distribution of earth pressure coefficient is assumed:

- Earth Pressure with uniform value of K* over the top half of the retained height of the wall.
- Earth pressure then remaining constant with depth as K* drops towards Ko.
- Below this depth, pressures are according to the in-situ value Ko.

For framed abutments with fixity at base, the following equation which is based on wall friction, $\delta=\varphi/2$ has been used to calculate the relationship between K*, the retained height (H) and thermal displacement of the top of abutment, (d):

$K^* = (d/0.05H)^{0.4} \times Kp$

K* shall however not be taken less than the 'at-rest' earth pressure 'Ko'.

iii) **Full height frame abutments with hinge at the base**

For framed abutments with hinge at base, the earth pressure distribution as given in 6.3.5 (ii) above shall be applicable except that the relationship between K*, the retained height (H) and thermal displacement of the top of abutment, (d) will be given by :

$K^*=Ko+ (d/0.03H)^{0.6} \times Kp$

iv) **Full height embedded wall type abutment**

Embedded wall type abutments are installed in undisturbed ground. For embedded walls, the earth pressure distribution may be represented by:

- Earth Pressure with uniform value of K* over the top two-thirds of the retained height of the wall.
- Earth pressure then varying from K* to Ko upto retained height of wall.
- Below that depth, pressures are according to the in-situ value Ko.

For wall type abutments with fixity at base, the following equation which is based on wall friction, $\delta= \varphi/2$ has been used to calculate the relationship between K*, the retained height (H) and thermal displacement of the top of abutment,(d) :

$K^* = (d/0.05H)^{0.4} \times Kp$

K* shall however not be taken less than the 'at-rest' earth pressure 'Ko'

v) **Flexible Support Abutments :**

For flexible support abutments, the earth pressure shall be taken from the details as given above as per the chosen structural arrangement. For combined behaviour with RS wall, the relevant provision of IRC guideline on RS wall shall be referred.

6.5 Partial Load Factors

6.5.1 Integral bridges should be designed for limit state design approach for load combinations and corresponding partial load factors as shown in Annex B of IRC:6.

6.5.2 Earth pressure coefficients on abutments should be multiplied by a material partial safety factor, $\gamma_m = 1.0$

6.5.3 Passive earth resistance forces on abutments should be calculated in accordance with **clause 6.4** and treated as a permanent load effect with partial safety factors of:

FOR ULS 1.5
FOR SLS 1.0

7 ANALYSIS

7.1 The IBs, are complicated structural systems for design. Apart from considering the primary loads (i,e. dead, live, wind …etc.), secondary loads (such as creep, shrinkage, settlement, temperature effects ..etc.) need also to be considered under serviceability limit state as well as ultimate limit state.

7.2 Methods of analysis, methods of modelling of structure for analysis, as given in existing code IRC:112 (For reinforced/prestressed concrete structures), IRC:22 (For composite structures) and IRC:24 (For steel structures) will be applicable for integral bridges as well. Linear Elastic analysis may be used for both the serviceability and ultimate limit states.

7.3 For the determination of action effects, linear analysis may be carried out assuming:

i) Uncracked cross sections

ii) Linear stress-strain relationship and

iii) Value of the modulus of elasticity as per IRC:112.

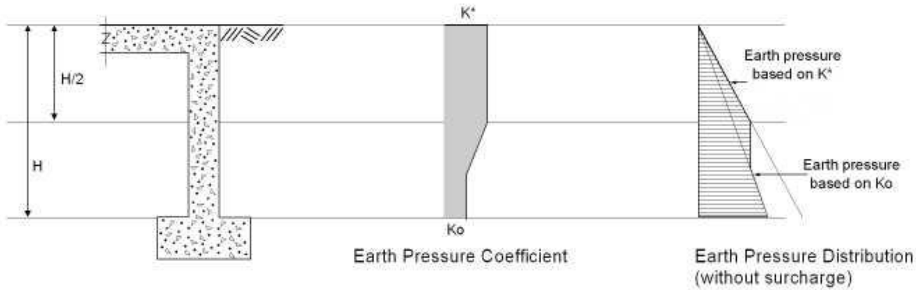


Fig. 6.1 Earth Pressure Distribution for Frame Abutment

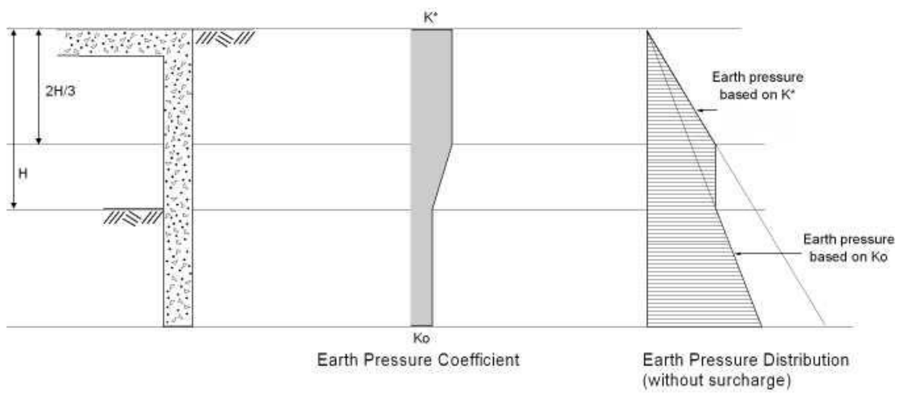


Fig. 6.2 Earth Pressure Distribution for Full height Embedded Wall Abutments

For the thermal deformation, settlement and shrinkage effects at the Ultimate Limit State (ULS), a reduced stiffness corresponding to the cracked section neglecting tension stiffening but including the effects of creep, may be assumed. For the Serviceability Limit State (SLS) a gradual evolution of cracking should be considered.

7.4 Limit Equilibrium method of analysis :

For full height abutments on spread footings which accommodate thermal movements by rotation and/or flexure, the design value of the earth pressure coefficient for expansion K* may be calculated from the equation, as given in Clause 6.4.6 in this guideline.

For abutments that accommodate thermal movements by translation without rotation, such as bank pad and semi-integral end screen abutments, the earth pressure coefficient for expansion, K*, maybe calculated from the equation, as given in Clause 6.4.6 in this guideline.

7.5 Soil-Structure interaction analysis needs to be performed for analysis of integral bridges under following situations :

a. abutments and piers founded on single row of piles;

b. embedded wall abutments;
c. abutments with over-consolidated backfill material;
d. abutment on cohesive soil
e. abutment in layered soil

As an alternative to the limit equilibrium method described in 7.4 and for bridges excluded by the requirements of 7.4 such as piled abutments and embedded wall abutments, the horizontal earth pressures on integral abutments may be evaluated using recognized soil–structure interaction methods incorporating an appropriate numerical model of the soil properties.

In situations where limit equilibrium method is not applicable, specialist literature may be referred incorporating appropriate soil structure interaction matrix. In all other cases, where abutments or piers are founded on spread footing or on pile cap with more than one row of piles, the simplified 'limit equilibrium analysis' method can be used for the design of integral bridges. However for the design of pile foundation proper, soil structure interaction may be considered. The sensitivity analysis also shall be carried out using upper and lower bound modulus of subgrade reaction.

8 DESIGN AND DETAILING ASPECTS

8.1 General

Integral bridges should be designed to resist all the vertical and lateral loads acting on them individually and in combination. The combined load effects on the structure at various stages of construction and stage by stage development of stresses in structural members should be considered in the design. The stages at which the structure is simply supported, then made integral with abutments, and backfilling are of primary importance. Design should be carried out according to the limit state provisions of current IRC codes, using the same limit state principles as any other bridge type, taking appropriate partial safety factors.

8.2 Structural Forms

All types of structural forms can be adopted with Integral abutments. The possible types commonly used are :

a) Precast RCC/PSC Girder with in-situ RCC deck slab for composite action.
b) Steel Girder with RCC in-situ RCC deck slab for composite action.
c) Cast-in-place Solid Slab/Voided Slab deck
d) RCC/Prestressed Box Girder deck

The selection is governed by the project economics and functional requirements, in the same manner as for the traditional bridges.

Integral abutment forms such as piled abutments, spread footings, full-height abutments, and RS walls are mainly dictated by geotechnical considerations.

Detailing of the connection between Superstructure and Substructure requires special considerations when precast concrete superstructure is adopted. Particular attention is required for the following:

a) Embedment of precast concrete beams into the abutment
b) The reinforcement detail for the moment connection between the abutment and the precast beams
c) Detailed construction staging consideration of beams and abutments for prediction of beam end rotations due to creep and shrinkage.

8.3 Component Design Considerations

8.3.1 *Girder Design*

a) Precast Girders (bare and composite) may be designed conservatively assuming no fixity at abutments for DL, LL and SDL assuming conventional approach.
b) The connection between deck and abutment can be considered to be 'fixed' or 'pinned' somewhere between 'fixed' and 'pinned', depending upon the sequence and stage of construction.
c) The beneficial effects of axial compression induced in the girders due to earth pressure should not be included in the design of the girders.
d) The design details used to achieve a rigid connection between the superstructure and the substructure vary for different types of superstructures. In addition, specific considerations may be required to reflect other design aspects, such as lateral movements, vibrations, sub surface soil conditions, backfill requirements …etc. These aspects may have a considerable effect on the performance, integrity, and durability of the integral abutment design. Typical details generally adopted are shown in **Fig. 8.1 & Fig. 8.2.**
e) In case precast girders / steel girders are used, natural / elastomeric rubber pads, supported on 150 mm high concrete pedestal may be used to support the girder initially. This will allow for rotation of girder end to take place before attaining fixity with abutment. The rubber pad can be eventually embedded into concrete, as shown in **Fig. 8.1 & Fig. 8.2.**
f) The longitudinal forces induced in the superstructure due to movements are directly related to the lateral resistance of the integral abutment. In designing the substructure, attention should be paid to details that provide flexibility and reduce unwanted restraints. Where piles are bored into stiff soils, pre-drilled oversized holes filled with loose sand should be provided to reduce resistance to lateral movements and reduce pile stresses.

8.3.2 *Abutment Design*

a) It is recommended to have a symmetrical structural arrangement with both the abutments of same height. A difference in abutment height causes unbalanced lateral loads resulting in side sway.
b) The distribution of moments from wing walls to the abutments should be considered in the design of horizontal reinforcement in the abutment.

c) The maximum bending moment obtained from frame analysis should be assumed to act at the corner of the idealized frame at the junction of abutment and deck. The design bending moment at the critical section, located at the soffit of deck, should be derived from frame analysis.

8.3.3 *Foundation Design*

a) Spread footings, Single row as well as double row of piles can be used at abutments. The top of the pile should be suitably embedded into the abutment walls/capping beam and should be adequately reinforced to transfer the forces.

b) In stiff soils, piles should preferably be placed in pre-augured holes filled with loose sand.

c) Wherever settlement of soil is likely, adopt appropriate ground improvement measures.

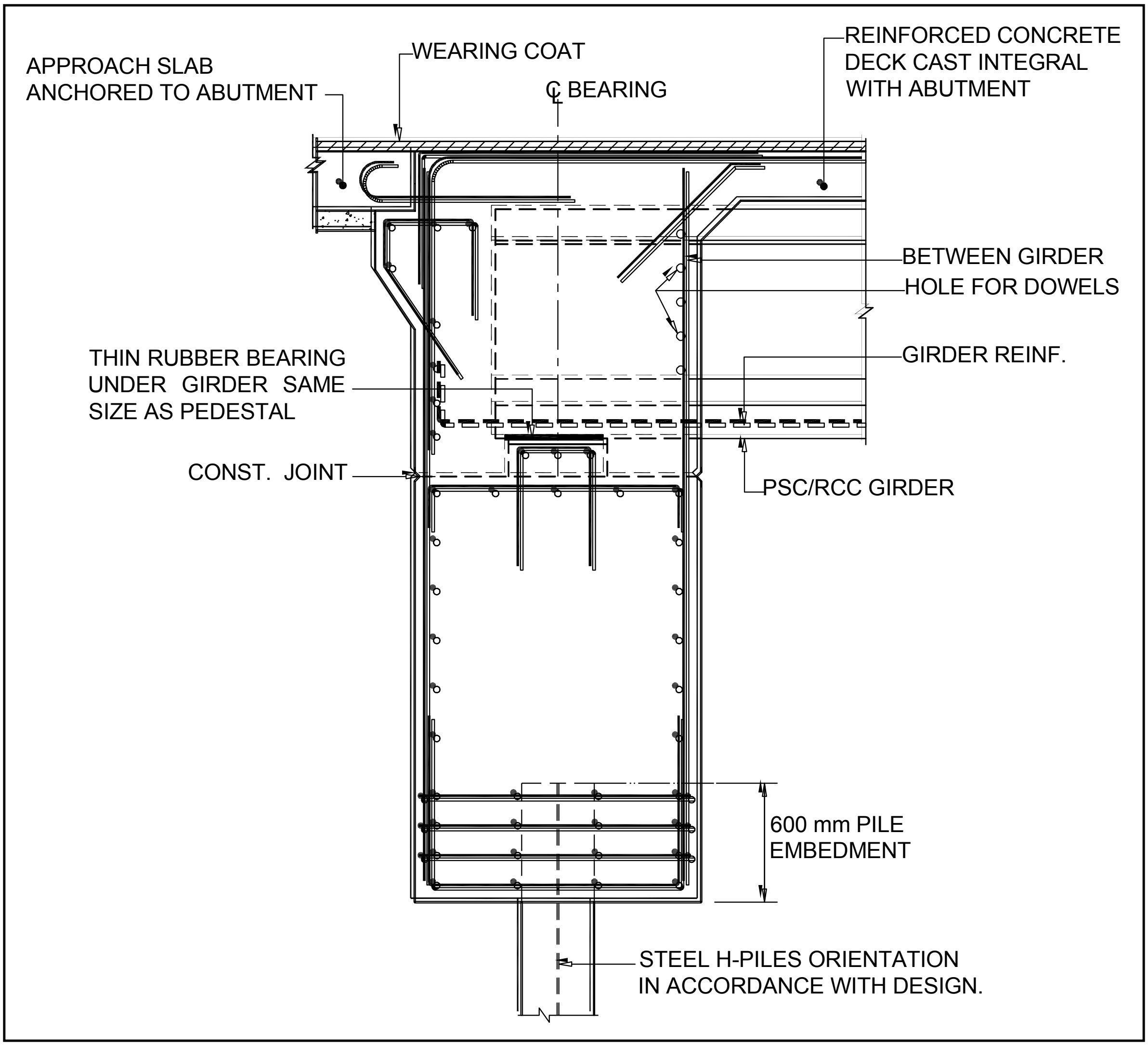


Fig. 8.1 : Typical Precast RCC/PSC Girder made Integral with single row of Steel H-Pile

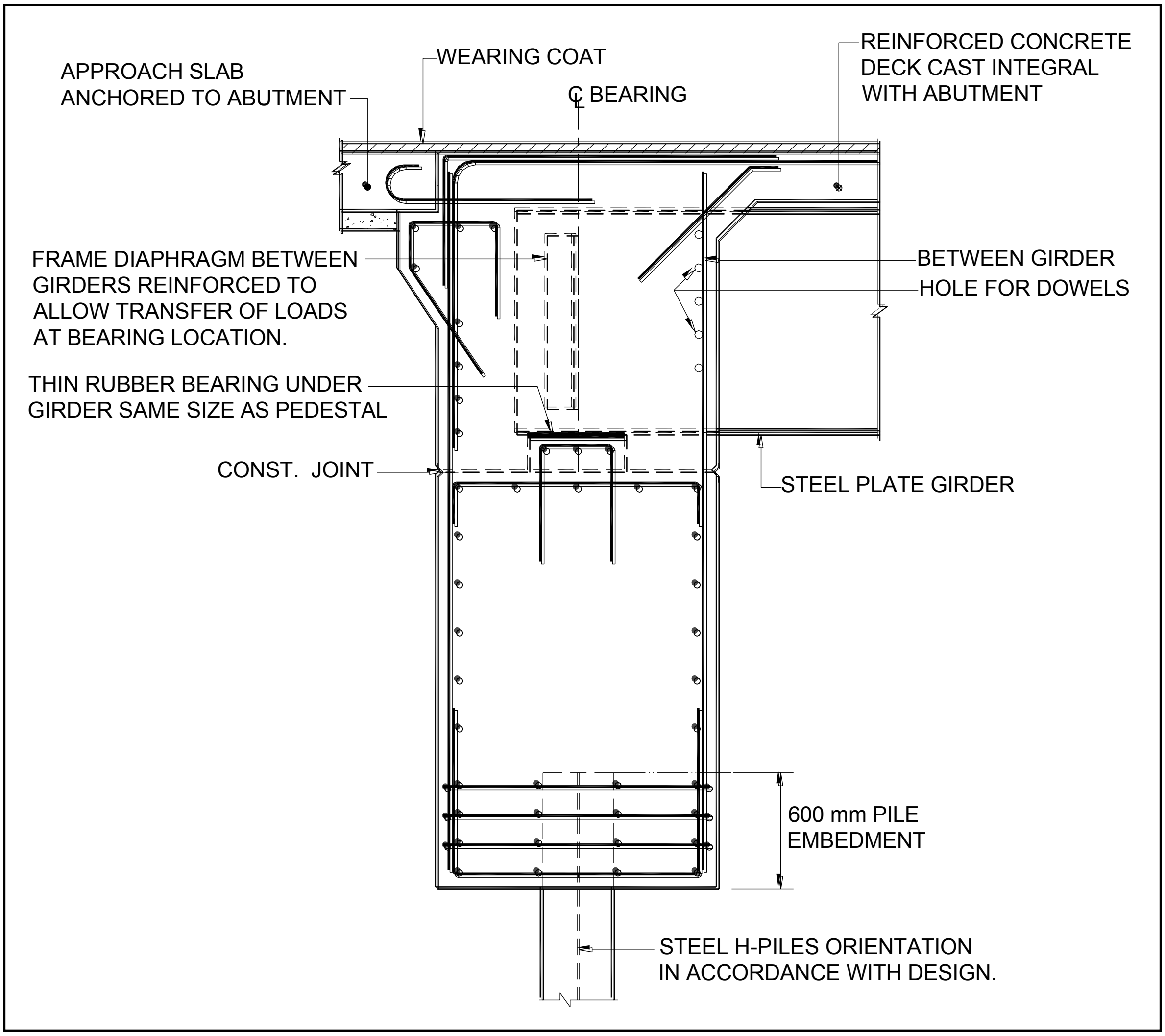


Fig. 8.2 : Typical Steel Girder composite with RCC deck, made Integral with single row of Steel H-Pile

8.4 Drainage

a) An efficient drainage system as per relevant IRC Code/Guideline should be incorporated in the design. To avoid water intrusion behind the abutment, the approach slab should be connected directly to the abutment and appropriate provisions made to provide for drainage of any entrapped water.

b) Integral abutments should have permeable backing as specified for earth retaining structures in relevant IRC codes. The permeable backing should be drained with a pipe of at least 150 mm diameter which has a suitable slope for outfall.

8.5 Bridge Approach System

The approach system of an integral bridge, comprising of the backfill, the approach fill, the approach slab, the sleeper slab and the foundation soil, are important elements for the long term performance and serviceability behavior of integral bridges. Imposed deformations from the bridge deck are transferred to the abutment and the approach slab, which leads to a strong soil-structure interaction in the approach zone. **Fig. 8.3** below shows various elements of an approach system.

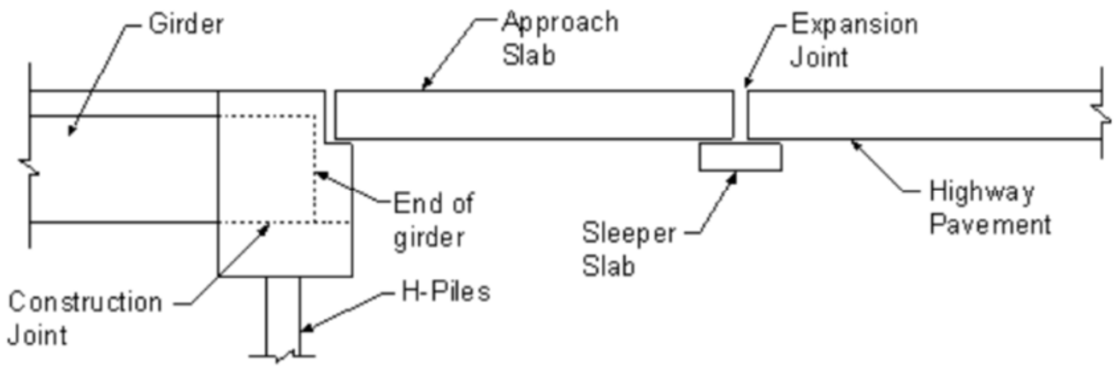


Fig. 8.3 Elements of Bridge Approach System for Integral Bridge

To ensure efficient performance of the approach system, the following guidelines should be followed :

a. Minimum recommended length of approach slab is 6 m. The approach slab should be positively attached to the back-wall by reinforcing bars (**Fig. 8.4**).

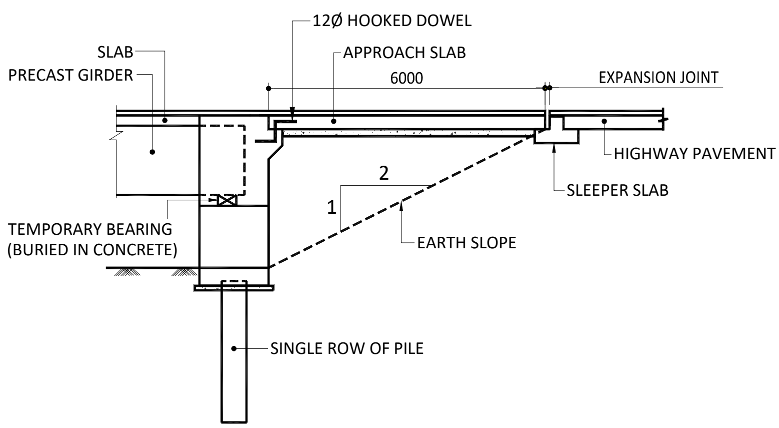


Fig 8.4: Positive Connection of Approach Slab to Back Wall

b. The connection between approach slab and bracket should be detailed to act as a pin with tension steel transferred across the approach span into the back-wall of integral abutments. The detail should allow for some tolerance between the approach slab and the bracket of back wall such that no damage occurs due to settlement.

c. A sleeper slab is placed at the roadway end of the approach slab. The intent of this slab is to provide a relatively solid foundation for the far end of the approach slab and to provide a location for limited expansion and contraction (**Fig. 8.5**). Sufficient allowance for expansion of the super-structure must be accommodated in the sleeper slab. Otherwise compression can be introduced into the slab by closing the expansion gap and subsequently activating the passive pressure behind the sleeper slab, or from contact with the adjacent roadway pavement. The latter can often be a major issue for spalling and heaving of the adjacent pavement.

d. Crash barrier and kerbs should have a clear discontinuity with joint at the junction of bridge proper and its approaches.

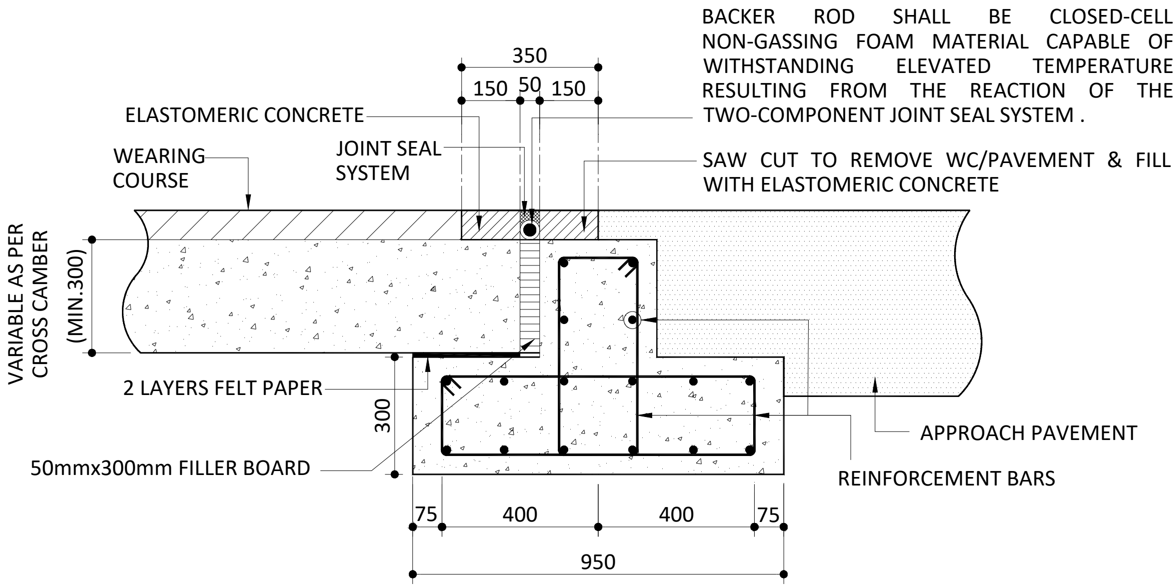


Fig 8.5 : Typical Sleeper Slab Detail

8.6 Wing Walls

Wing Walls, wherever required, should preferably be independently supported and should not be a part of the integral bridge structure.

8.7 Expansion Joints

To cater for the cyclic movements of the bridge abutments / approach slabs, a suitable type of expansion joint (buried, asphalt plug, compression seal, or strip seal type) shall be provided as per IRC:SP:69 at the location of sleeper slab between end of approach slab and pavement as shown in **Fig. 8.3.**

9 INSPECTION AND MAINTENANCE CONSIDERATIONS

9.1 General

Generally, from the performance of integral bridges built in different countries, it is seen that though most of them are performing well, they require regular inspection, but reduced maintenance. To have a comprehensive maintenance strategy, it is important to inspect the bridge periodically with the understanding and knowledge of strategic bridge elements and locations which are vulnerable to distress.

9.2 Inspection

During inspection of integral bridges, the inspector should look for distress in following vulnerable areas:

a. Crack at the connection between abutment/pier and bridge superstructure: Significant change in temperature during initial concrete setting may cause distress at the junction.
b. Cracks in deck slab: In the case of skew integral bridges, diagonal cracks are often seen at the acute corner of bridge deck. Straight cracks may be seen over previously placed concrete end diaphragms. Transverse cracks at relatively uniform spacing, may occur as a result of insufficient continuous and temperature/shrinkage reinforcement on deck slab over end diaphragm.
c. Cracks in abutment, piers, girders, crash barrier…etc.
d. Longitudinal and transverse cracking of approach slab: Longitudinal cracking develops when voids are formed under approach slabs. If the backfill material is not perfectly elastic, voids are formed with cyclic movement due to diurnal temperature fluctuations.
e. Wet areas around seating level
f. Condition of expansion joints at the end of approach slab
g. Differential settlement between approach system and bridge abutments
h. Performance of drainage system at backfill.

9.3 Maintenance

The preventive maintenance measures for integral bridges are similar to conventional bridges.

a. Crack repair of abutment wall, wing wall, deck slab, crash barrier, approach slab and at junction between abutment and bridge superstructure.
b. Overlaying, grouting or replacement of approach slab or backfill adjustments. when it settles excessively.
c. Repair or replacement of expansion joint at the location of sleeper slab.
d. Repair/replacement of damaged kerbs, crash barriers.
e. Periodic cleaning of clogged drains and drainage spouts.

For more details of repair and maintenance strategy of bridge elements, IRC: SP:35 and IRC: SP:40 shall be referred.

10 PERFORMANCE MONITORING

This Section deals with performance monitoring of integral bridges. Condition assessment is generally carried out during service through visual inspection, as discussed in Section 9, which involves subjective judgment of inspectors and which enables detection of only local and visible defects. However, visual inspection cannot evaluate the reserved strength or deformation capacity of a bridge. In many situations local defects might not have significant effect on the global performance.

Sensor based Structural Health Monitoring (SHM) has revolutionized the traditional bridge inspection in a more timely, objective and quantitative manner. Performance monitoring of bridges can be used to verify the current design approaches and suggest future improvement in design. The results of monitoring can be used for making scientific decisions in terms of prioritization of bridges for strengthening or retrofitting.

From the design practices of integral bridges around the world, it is seen that geotechnical considerations and thermal effects have vital role in the performance and in deciding the span limit upto which this type of bridges with reduced maintenance requirements can be adopted. More insight can be obtained through performance monitoring of some of the integral bridges being constructed in our country in line with international practices. A very brief discussion on performance parameters and sensor type that can be used for monitoring of bridge is included in this guideline.

10.1 Performance Parameters

While planning the instrumentation scheme due attention is to be paid to measure the parameters required to capture behavior of various bridge components. Number and type of sensors and its locations are to be decided carefully based on mathematical modeling and analysis under the loading conditions which are very important for the design. Therefore, to understand the performance, the parameters to be measured and sensors that can be used are given in **Table 10.1** as some of these sensors will have to be embedded during different construction stages of a bridge. Also, location of bridge, span length, height of abutment, geotechnical parameters and so on will have to be considered in deciding the instrumentation scheme.

Table 10.1 Performance Parameters of Various Bridge Components

Bridge Component	**Performance Parameters**	**Sensors**
Integral abutment	• Longitudinal displacement • Transverse displacement • Rotational displacement • Tilt	Extensometer, displacement transducer, LVDT, tilt meter,
Pile foundation	• Strain, • deformation, • temperature in steel piles • bending moment	Strain guages
Backfill	• Soil pressure, • soil temperature	Pressure Cells
Girders of bridge deck, deck slab	• Thermal gradient, • ambient air temperature, • longitudinal movement, • vertical displacement, • strain, • Tilt of web of girder • bending moment, axial force	Vibrating Wire temperature gauge, strain gauge, thermocouple, LVDT, displacement transducer, tilt meter

Bridge Component	Performance Parameters	Sensors
Approach slab	• Strain, • Displacement at the ends • Temperature	Vibrating wire strain gauge Vibrating wire temperature gauge, extensometer
End screen	• Gap and earth pressure between end screen and embankment • Displacement of end screen • Soil temperature of embankment • Displacement between approach slab and end screen	Pressure cells, extensometer, vibrating wire temperature gauge

For more details of performance evaluation of integral bridges using sensor technologies specialist literature shall be referred.

11 REFERENCES

1. BA 42 (Highways Agency) (1996)., The design of Integral Bridges; Design manual for Roads and Bridges.
2. Harry White (2nd); Special Report No. FHWA/NY/SR-07/152; Integral Bridges: Comparison of Current Practice Between European Countries and the United States of America; (July 2007)
3. Cheng Lan; Thesis on the Performance of Super-Long Integral Abutment Bridges – Parametric Analysis & Design Optimisation, University of Trento, Brescia, Padova, Trieste, Udine & Venezia (Italy) (April 2012)
4. Hussain, I., and Bagnariol, D.; Report No. SO-96-01 : Integral Abutment Bridges; (1996). Ontario Ministry of Transportation.
5. Walter Kaufmann; Swiss Federal Roads Office Guidelines for Integral Bridges; published by IABSE in SEI 2/2011
6. Hideaki Nishida, Hirokazu Miyata, Shinya Kimura, Tetsuya Kohno, Toshiaki Nanazawa & Shoichi Nakatani; Design & Construction Guideline of Integral Abutment Bridges for Japanese Highways.
7. PD-6694-1: 2011 : Recommendations for the design of structures subject to traffic loading to BS EN 1997-1:2004; BSI Standards Publication
8. EN 1992-1-1:2004 : Eurocode 2 : Design of Concrete Structures – Part 1-1:General Rules for Buildings
9. John Wood, Alexai Murashev, Alessandro Palermo, Moustafa Al-Ani, Kaveh Andisheh and Darren Godall; Criteria and guidance for the design of integral bridges in New Zealand; (November 2015)," NZ Transport Agency research report 577
10. Sami Arsoy, R.M. Barker and J. Michael Duncan.(1999). The Behaviour of Integral Abutment Bridges, Virginia Transportation Research Council, VTRC00-CR3.
11. Fennema, J.L., Laman, J.A., and Linzell, D.J.(2005), Predicted and Measured Response of an Integral Abutment Bridge, Journal of Bridge Engineering, ASCE, Vol. 10, No. 6, pp. 666-677.

12. Laaksonen, A. (2011),Structural Behaviour of Long Concrete Integral Bridges, Thesis for Doctor of Science in Technology, Tampere University of Technology, Finland.
13. Olson, S.M., Holloway, K.P., Buenker, J.M., Long, J.H. and La Fave, J.M. (2013), Thermal behavior of IDOT integral abutment bridges and proposed design modifications, Research Report FHWA-ICT-12-022, Illinois Center for Transportation, University of Illinois at Urbana–Champaign.
14. Pétursson and Kerokoski(2013), Monitoring and Analysis of Abutment-Soil Interaction of Two Integral Bridges, Journal of Bridge Engineering, ASCE, Vol. 18, No. 1, pp. 54- 64.
15. Damien Dreier; Olivier Burdet; Aurelio Muttoni, Transition Slabs of Integral Abutment Bridges, Structural Engineering International, Vol. 2/2011.
16. Stergios A. Mitoulis; Prof.Ioannis A. Tegos, Two new Earthquake resistance Integral Abutment for medium to long span Bridges, Structural Engineering International, Vol. 2/2011.
17. Murat Dicleli; Semih Erhan, Effect of Foundation soil stiffness on the Seismic performance of Integral Bridges, Structural Engineering International, Vol. 2/2011.
18. F Gajanan N. Wagle; Doug Watt, Design of Integral bridges on M50, Ireland, Structural Engineering International, Vol. 2/2011.
19. Nobumasa Iwasaki; Shinji Tenma; Akimitsu Kurita, Portal frame Bridges in Japan: State of the Art Report, Structural Engineering International, Vol. 3/2011.
20. Jimin Huang; Carol Shield; Catherine French, Behavior on an Integral Abutment Bridges in Minnesota, US, Structural Engineering International, Vol. 3/2011.
21. Steffen Marx; Gunter Seidl, Integral Railway Bridges in Germany, Structural Engineering International, Vol. 3/2011.
22. Edward P. Wasserman, Integral abutment practices in the United State, The Indian Concrete Journal, Sept. 2005, Vol. 79, No. 9.
23. Satinder P. Singh, Integral abutments for bridges in Seismic regions: California practice, The Indian Concrete Journal, Sept. 2005, Vol. 79, No. 9.
24. V.V. Nori; B.S. Joshi; M. N. Patel, Integral Bridges: Examples from quarter century experience, The Indian Concrete Journal, Sept. 2005, Vol. 79, No. 9.
25. Alok Panday; Mahesh Tandon, Integral Flyovers in Delhi, The Indian Concrete Journal, Sept. 2005, Vol. 79, No. 9.
26. Alok Bhowmick, Design and Detailing of Integral Bridges: Suggested Guidelines, The Indian Concrete Journal, Sept. 2005, Vol. 79, No. 9.
27. Alok Bhowmick, Design and construction of Integral Bridges – An innovative concept, The Indian Concrete Journal, July 2003, Vol. 77, No. 7.
28. S.C. Gupta; S.D. Limaye; M.K. Gupta; V.L. Dodeja; V.V. Nori, Integral bridges on the Konkan Railway, The Indian Concrete Journal, Sept. 2005, Vol. 79, No. 9.
29. George L. England; Neil C. M. Tsang; David I. Bush, Integral Bridges – A Fundamental approach to the time-dependent loading problem, Thomas Telford Publication, 2000.
30. Edward P. Wasserman; John Houston Walker : “Integral Abutment for Steel Bridges”, Vol.-II, Chap.-5 of Highway Structures Design Handbook

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