Indian Roads Congress
Special Publication 24

GUIDELINES ON THE CHOICE AND PLANNING OF APPROPRIATE TECHNOLOGY IN ROAD CONSTRUCTION

NEW DELHI 1984

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FOREWORD

The resources for the development of roads continue to be limited and far short of the demand because of the phenomenal growth of traffic on our roads. Highway Engineers are thus pressed to evolve the most economical design and construction practices to match the specific technical requirements compatible with the overall socio-economic needs. Though there have been remarkable advancements in the use of equipment based technology in the field of road construction, such technology may not be suitable for use in entirety in our country in view of the large surplus manpower available with us. Hence, there is need for going in for intermediate technology which perhaps is best suited to our country.

The Highway Engineers have been quite conscious of this requirement and keeping this in view, the "Guidelines on the Choice and Planning of Appropriate Technology in Road Construction" have been evolved by the Indian Roads Congress through a Special Committee. These guidelines were approved by the Council in their 109th meeting held at Nagpur on the 8th January, 1984 for being issued as a Special Publication of the Indian Roads Congress.

I hope that this publication will prove to be a very useful guide to the Highway Engineers of our country. We would, however, welcome feed back data from the field engineers in order to know their difficulties, if any, so that the same could be given due consideration.

New Delhi
June, 1984

K K. SARIN
Director General (Road Development) &
Addl. Secretary to the Govt. of India

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GUIDELINES ON THE CHOICE AND PLANNING OF APPROPRIATE TECHNOLOGY IN ROAD CONSTRUCTION

1. INTRODUCTION

1.1. The fundamental principle of alignment, design and construction of any road is to achieve the least overall cost of transportation having regard to the cost of initial construction of the facility, its periodic maintenance and vehicle operation, while at the same time satisfying the social and environmental requirements. Once a road project has been prepared on this principle, the prime objective of the Site Engineer will be to complete the construction to the stipulated requirements at the minimum cost, and within the time schedule. Fulfilment of this objective will involve several steps which will include, *inter alia*, the choice of the appropriate construction technology which is economically viable and technically suitable for the type of work and for which the necessary input resources are readily available or can be made available in time. Once the construction method is chosen, whatever method it may be, the Site Engineer should arrange for the needed resources in time and take all measures for their efficient and economical working.

1.2. In the interest of better planning of works at site and economical execution of highway projects, this publication provides guidelines for the choice of appropriate construction methods under different situations, and discusses the ways and means for improving the efficiency and productivity of these methods. A large number of worked out examples have been included for assisting the Site Engineers in this regard.

1.3. These guidelines were initially prepared by K. Arunachalam, Deputy Secretary (Research), Indian Roads Congress. These were considered and approved by the Special Committee for Mechanised Road Construction in their meeting held at New Delhi on the 2nd December, 1983. These were later approved by the Executive Committee by circulation and then by the Council in their meeting held at Nagpur on the 8th January, 1984 for being issued as a Special Publication of the Indian Roads Congress

2. SCOPE

2.1. The choice of the appropriate construction method for a work or task is governed by several factors such as terrain, climate, available resources, technical feasibility for the nature of operations and relative economy. While for some operations, there can be more than one method that could be feasible and the choice will mostly be dictated by the availability of the needed resources, for some other technical requirements or the time factor will dictate the adoption of only one type of method. For example, compaction of aggregates for WBM can be done only by a power roller even in cases where the aggregates are broken and hauled to site of work by purely manual methods. Similarly, even though the manual methods might be the most economical alternative for earthworks within short leads, equipment-intensive methods might have to be resorted to in cases where time of completion is the crucial factor.

2.2. This document gives guidelines for helping the Site Engineer in choosing the appropriate methods for the various tasks involved in road construction under different situations and discusses the ways and means of improving the efficiency and productivity of these methods. It should be understood that these guidelines are neither absolute nor static and would need changes from time to time depending on the relative cost of materials, equipment and services involved. It is, therefore, suggested that road construction departments should collect, compile and analyse the productivity data along with the governing parameters at least for major road construction projects so that the guidelines could be up-dated in the years to come.

2.3. The construction methods are generally classified into three categories, namely :

(i) Labour-intensive methods which depend mostly on unskilled labour who may use nothing more than simple hand tools.

(ii) Intermediate methods which employ certain simple equipment or non-human resources for aiding the manual operations, such as pack of animals, wheeled carts, small mixing machines, etc.

(iii) Equipment—intensive methods in which the operations are executed by a single or series of machines and where no unskilled labour is employed except in purely ancillary capacity.

Thus for any task, a broad spectrum of methods is available with the labour-intensive and equipment-intensive methods falling at either extreme and the intermediate methods falling in-between In actual practice, however, for certain ranges of site parameters, it will be inevitable even for the labour-intensive methods to use some simple equipment or devices. For example, haulage for a distance of over 100 m for which pack animals, cart and the like will necessarily have to be inducted though use of unskilled labour will be predominant. Such cases almost merge with the intermediate methods because of physical inevitability. From this consideration, as also to avoid any confusion in the classification of the different methods, both the labour-intensive and the intermediate methods which are practiced extensively in the country will be dealt with together in these guidelines under the broad heading 'Labour-based methods'.

3. SITE PLANNING

Site planning forms the forerunner to the starting of any construction operation. It is at this stage that the site engineer decides on the appropriate construction method for the various tasks to be accomplished, plans the needed resources and takes measures for improving the productivity at task/activity level for economical working. All this involves a step by step procedure which will include the following :

(i) Listing out all the required tasks along with the quantities split according to critical site parameters (e. g. hardness of soil to be excavated, haulage distance, etc.) and the possible construction methods. A typical list is shown in Table 1 for illustration.

(ii) Selecting the most appropriate method of working for each task from angles of technical feasibility, economic viability and social desirability. This will require a good understanding and relevant information relating to the specification requirements and the capabilities of the different methods in achieving these, the productivity and cost of operation with these, the advantage and disadvantage of adopting a method peculiar to a particular site, etc. This exercise will involve the listing out of all the possible methods, and choosing the most approriate one through a process of rational and

TABLE 1. LISTING OF TASKS AND AVAILABLE CONSTRUCTION METHODS

Activity/task	Site/job parameter	Quantity	Available construction methods	
			Labour-based	Equipment-intensive
1	2	3	4	5
1. Excavation	Soft soil Hard soil		Hoe, pick, pre-wetting ripping with plough	Dozer, scraper, tracked excavator
	Soft rock		Crowbar, wedging tools	Dozer—ripper
	Hard rock		Hand drilling & blasting	Machine drilling & blasting
2. Loading, hauling unloading	Haul 0—100 m		Headbasket, wheel barrow, pack animals	Dozer, wheeled loader
	100—1000 m		Pack animals, animal cart, tractor-trailer, flat-bed truck	Scraper with or without pusher, loader/excavator into dump truck
	Over 1 km		Tractor-trailer, flat-bed truck	Loader/excavator into dump truck
3. Watering			Animal/tractor drawn water tanker	Self propelled water tanker
4. Spreading soil or aggregate			Hoe or rake	Grader or dozer

5. Production of stone aggregate		Hammer, mobile crushing plant with manual loading	Crushing plant with integral screens and conveyor, loaded by wheeled loader
6. Loading, hauling unloading aggregate	Haul over 1 km	Animal cart, tractor-trailer, flat-bed truck with manual loading/unloading	Loader—dump truck
7. Rolling	Embankment/ base/surfacing	Power roller	Power roller
8. Bitumen carpet	Dense-graded		Hot-mix plant, paver-finisher
	Open-graded	Tar boiler, mechanical mixer, hand laid	Hot-mix plant, paver-finisher

systematic elimination. This aspect is dealt with in more detail in para 4.

(iii) Calculations for the quantity of resource inputs for each task based on productivity norms for the chosen method and the laid-down time schedule.

(iv) Preparation of a draft work plan showing the calendar of activities along with the required resources. This plan is examined in light of the resources which are readily available or which can be made available. If the resources are sufficient or more than sufficient for the target production, the work plan can be finalised accordingly. If otherwise, the Site Engineer should explore the feasibility of improving the productivity through management measures, or by extending the working season, or by introducing an additional shift. If these are of no avail, he should inform his Senior Officers of the position and demand more resources or extension of the time schedule.

4. CONSIDERATIONS IN THE CHOICE OF THE APPROPRIATE CONSTRUCTION METHOD

4.1. General

In broad terms, the choice of appropriate construction method should be based on the following considerations :

(i) Technical feasibility

(ii) Economic viability

(iii) Social desirability

(iv) Compatibility in working

This would show that the choice of the appropriate construction method should be based not on a single consideration or in isolation but in the light of a combination of factors. Also, the governing factors will not have the same importance for each and every task. A realistic approach in this regard would be to identify in the first instance all the technically feasible methods for each major task without regard to cost of construction and then choose the most appropriate method through a framework of rational and systematic elimination. For this purpose, it would be useful to make a listing of the type shown in Table 1. The step by step procedure for elimination of the inappropriate methods as illustrated in Table 2 can then be followed for choosing the optimum method.

TABLE 2. PROCESS OF CHOOSING OPTIMUM CONSTRUCTION METHOD

LOCAL/JOB CONDITIONS

1. Terrain
2. Rainfall and rainfall season
3. Harvest/local festival season
4. Effective working days in the working season
5. Labour available locally or to be brought from outside
6. Stone quarry/pavement material source
7. General type of soil
8. Average height of embankment depth of cutting
9. Condition of haul roads
10. Nearest base mechanical workshop
11. Range of equipment available
12. Any other condition affecting choice of method

PROCEDURE

1. List all technically feasible methods (see Table 1). Exclude methods obviously unsuitable in light of local conditions.
2. Estimate task level productivities for each remaining method. Exclude methods where productivity is too low.
3. Estimate resources needed for each remaining method. Exclude methods for which available resources are insufficient.
4. Estimate unit cost of each remaining methods. Exclude methods with unit costs 25 per cent higher than the cheapest.
5. Check for compatibility of the remaining methods with those considered for the other related tasks of the project. Exclude incompatible methods.
6. Estimate task/project cost for each remaining method. Tabulate the results and choose the most appropriate method taking all other tasks of the project into account.

4.2. Technical Feasibility

Many of the tasks involved in road construction can be executed either by labour or equipment-intensive methods. However, there are some others which can be accomplished by either of these methods alone with no other alternative. This situation may arise because of the following factors :

(i) **Specification requirements**—for example, high-type asphaltic concrete which has to be mixed, laid and compacted to a specified quality and within a stringent temperature range will call for equipment intensive methods. Another example is subgrade compaction and compaction of pavement courses which can be effected to the specified degree only with power rollers even where labour-intensive methods are adopted for other tasks.

(ii) **Physical constraints of energy of worker**—production of aggregates by manual breaking is possible, but when the required sizes are small, say less than 25 mm, and the rock is hard as is warranted for bituminous surfacings, effort required will be too considerable for the human energy to cope with, particularly when the aggregates are required in large quantities. Employment of mechanical crushers will be inevitable in such cases.

(iii) **Size of work**—at some works because of sheer size, such as high embankments in long lengths for major highways, or mass production of aggregates, or those which have to be completed within a tight time schedule, there will be no alternative but to adopt equipment-intensive methods. The labour-intensive alternative would entail the deployment of a very large labour force in a concentrated way and even if such labour could be mobilised, it would be physically impossible to have a good control either over the productivity or quality.

(iv) **Restricted site conditions**—large but concentrated works will not have sufficient space for working of a large labour force, and for such cases, labour methods may have to be ruled out. On the other hand at certain restricted locations, machines cannot operate or manoeuvre and labour methods will be the only alternative.

4.3. Economic Viability

4.3 1. Economic viability is an important factor in the choice among technically feasible construction methods. The exercise involves the comparison of costs by the various possible methods and choosing the least cost alternative. The viability of any method will depend on its productivity and the relative prices of labour and equipment. One method of comparing the relative economy of equipment-intensive method *vis-a-vis* a labour-intensive alternative for the same task is through the concept of break-even wages for unskilled labour. This is done by calculating the cost of the task by assuming different wage rates for labour and comparing the same with that by the equipment-intensive alternative. Break-even wage rate is that wage at which the cost of carrying out a task by labour is equal to the cost by equipment. A labour method will be economical when the actual labour rate is less than the break-even wage rate.

4.3.2. The basic data required for cost comparison is the productivity by the different methods for various tasks. The detailed World Bank Study* conducted in the country during early seventies had shown that labour productivity can vary in a large range, depending on parameters such as method of payment (daily-paid, taskwork or piecework), and the quality of supervision and site organisation. For example, the productivity on an earthwork job was 3-4 times when the incentive piecework payment method was adopted compared to daily-paid wage method. This is not to say that the piecework method will be cheaper by 3-4 times since the pieceworker will be earning almost two times that of a daily-paid labourer. Better site supervision will also involve some additional cost.

4.3.3. The studies have also shown that besides the incentive wage system, further improvement in the productivity could be achieved through improved tools, project organization and site management. Examples in this regard are avoidance of double handling, balancing of tools and labour gangs, and taking measures for reducing human effort like pre-ripping and pre-wetting of hard soil prior to excavation.

4.4. Social Desirability

In a developing country like India, provision of gainful employment to a large number of people is an important matter of social desirability which cannot be overlooked in road construction which is known to be capable of engaging large labour force. For this reason, it is a commom practice in the economic analysis of development projects in the country to shadow price the cost of unskilled labour to the extent of 50 per cent. This feature, if taken into account in the choice of the method, will show the

*Summary of the Study and its findings may be seen in the following two Papers published by the Indian Roads Congress in November, 1976. The First Paper also lists out the Reports and Technical Memoranda of the World Bank where more details of the various aspects of the Study can be found.

(i) Sud, I.K., Harral, C.G. & Coukis, B.P., Scope for the Substitution of Labour and Equipment in Civil Construction.

(ii) Green, P.A. & Brown Peter D., Some Aspects of the Use of Labour-intensive Methods for Road Construction.

labour methods in better colour for most of the road construction tasks.

4.5. Compatibility in Working

The tasks involved in road construction can be accomplished adopting a wide range of methods from the most labour-intensive to the most equipment intensive, but the method chosen for one task may dictate the use of similar technology for some or all other tasks in the project. For example, loading of a large capacity dump truck should be by mechanical loaders, as resorting to labour loading, even if less costly for this activity, will entail idle time for the expensive dump truck and consequently result in an overall uneconomic operation.

4.6. Overall Philosophy in the Choice of Appropriate Technology

4.6.1. Paras 4.1. through 4.5. have broadly discussed the factors that should be considered in the choice of the most appropriate method(s) for road construction projects. Of these, economic viability among the technically feasible methods emerges as the most important parameter. An objective exercise for evaluating this parameter will require realistic productivity norms of the various methods under different site conditions. Productivity norms adopted by the different State P.W.Ds in the country for working out the schedule of rates vary considerably from place to place and cannot therefore be generalised.

4.6.2. Factual productivity data qualified by site and management parameters for road projects in the country are not available except in the case of labour methods observed in the World Bank Study. The picture of relative economy of the various methods (both labour-intensive and equipment-intensive) for the earthwork operation as emerging from the Study is shown in Fig. 1. While the data for the labour methods were actually measured, those for equipment-intensive methods where derived from the ideal productivity norms given in manufacturers' manuals. The equipment costs were at 1976 prices and the wages for unskilled labour were taken to be Rs 4.5 for daily-paid worker and Rs 9 for pieceworker. Break-even wage rates (see para 4.3.1. for definition) for some selected tasks as emerging from the Study

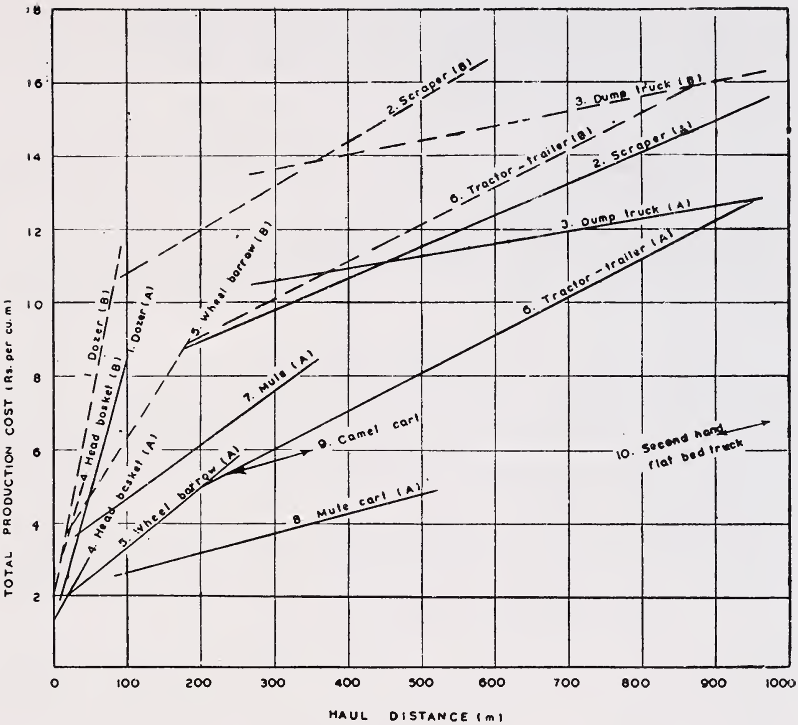

Fig. 1. Cost of earthwork task in borrow-to-fill (Based on World Bank Study)

Notes :

1. Line A corres onds to piecework payment with good supervision while Line B is for daily paid work with poor supervision

2: Assumed unskilled Labour daily wage (Line B) Rs 4.5, daily piecework earnings (Line A) Rs 9

3. Details of the methods are as follows :
   (1) .D7 dozer for all activities
   (2) Cat 621 motor scraper, D8 pusher, 12G grader
   (3) Cat 769B (35-tonne) dump truck, 988 wheeled loader, excavation by D8 dozer, speading by 12G grader
   (4) Headbasket and labour
   (5) Wheelbarrow and labour
   (6) 35 hp tractor and 3-tonne tipping trailers, manual excavation, loading and spreading
   (7) Mule with panniers and labour
   (8) Mule-cart and labour
   (9) Camel-cart and labour
   (10) Second-hand truck of 5-tonne capacity and labour

4. Total production cost includes overhead and supervision

are given in Table 3. Till more realistic indigenous data are available, these can be consulted to get a broad idea on the economically feasible methods.

4.6.3. Besides knowledge about the most economical method, the Site Engineer will be interested in working out the needed resources for the various tasks For this purpose, the productivity information relating to certain important tasks abstracted from the World Bank Study are given in Tables 4 through 9.

4.6.4. It may be noted that productivity of both labour and equipment is strongly influenced by various conditions or parameters. For example, in the case of earth excavation by labour, the productivity will depend on age, sex, traditional skill, health and nutritional standards of labour; the terrain and climatic conditions; the hardness of soil; the payment method; the type of management and supervision, etc. Similarly, for working with machines, the specific parameters affecting productivity are the age and standard of maintenance of the equipment, the operator efficiency and the job efficiency. In view of the interplay of several parameters and the large variations in the productivity from site to site, it will be convenient to express the productivity in the form of two enveloping lines, the upper one (line A) representing the most favourable conditions (i.e. high incentive wages, good supervision, etc.) and the lower one (line B) denoting poor conditions (i.e. daily wages, poor supervision, etc.). In Tables 4 to 9 relating to labour-based methods, the input coefficients which are inverse of productivity are given for both line A and line B conditions. On similar considerations, productivity of equipment can also be expressed in terms of lines A and B as discussed in para 6.4.

4.6.5. The selection of the most appropriate method for the different road construction tasks is not just sufficient, and for efficient and economical completion of a road project the Site Engineer will have to look for improvements in planning and organization of the works. Guidelines in this regard are given in para 5 for labour based methods and in para 6 for equipment-intensive methods.

TABLE 3. BREAK-EVEN WAGE RATES FOR SELECTED TASKS

Task		Method 1 (Equipment-intensive)	Method 2 (Labour-based)	Break-even wage rate (Rs/day)	
				B_1B_2	A_1A_2
1		2	3	4	5
1. Earthwork, borrow to fill	30 m haul	Dozer	Labour, head-basket	5.5	7 (14)
	60 m haul	Dozer	Labour, wheelborrow	8	10.5 (21)
	240 m haul	Motor scraper, dozer pusher, grader	Labour, tractor-trailer	6.5	10.5 (21)
	960 m haul	Dozer, wheeled loader, dump truck	Labour, tractor-trailer	2.5	4.5 (9)
2. Road material haulage	1 m haul	Wheeled loader, tipping truck	Labour, tractor-trailer	8	10 (20)
	5 m haul	Wheeled loader, tipping truck	Labour, flat-bed truck	0.2	4.5 (9)
3. Aggregate production	50 mm size	6-8 tonne/hr crusher	Hand breaking	6	9.5 (19)
	10 mm size	6-8 tonne/hr crusher	Hand breaking	2.5	3.5 (7)

Notes: 1. The analysis is based on 1976 rates (World Bank Study).

2. The figures in columns 4 and 5 are in terms of daily-paid wage rate. Corresponding piece rate earnings are given in brackets in column 5.

3. B_1B_2 corresponds to daily-paid payment method with poor supervision. A_1A_2 corresponds to piecework payment method with good supervision.

TABLE 4. PRODUCTIVITY DATA FOR MANUAL EXCAVATION USING HAND TOOLS

Material	Input coefficient Man-hour (WT) per cu.m.	
	A	B
1. Ordinary soil	0.3	0.8
2. Hard soil	0.9	2.3
3: Soft rock	1.3	3.3

Correction to input coefficient for loading height

Loading height (m)	A	B
—0.3	—0.04	—0.10
0.5	0.08	0.19
1.0	0.16	0.43
1.5	0.26	0.70
2.0	0.38	1.02

Notes : 1. 'A' corresponds to piecework payment and good supervision while 'B' is for daily-paid method and poor supervision.

2. Ordinary soil and hard soil are taken to correspond to soil parameters 2 and 5 respectively of the World Bank Study.

3. All negative loading heights may be taken as —0.3 m.

4. Output in cu.m. pertains to in-situ volume prior to excavation.

5. 'WT' means working time which can be taken as 8 hrs/day and 5.5 hrs/day for conditions A and B respectively.

6. The correction coefficients for the appropriate loading heights are to be added to the excavation input coefficient.

TABLE 5. PRODUCTIVITY DATA FOR MANUAL LOADING OR UNLOADING

Loading or unloading height (m)	Input coefficient Man-hour (WT)/tonne	
	A	B
0.3	0.20	0.52
0	0.22	0.58
0.5	0.26	0.69
1.0	0.31	0.82
1.5	0.37	0.98
2.0	0.44	1.16

Notes : 1. Loading or unloading means moving broken-up earth, aggregates or loose materials into or out of a haulage vehicle by hand or with hand tools.

2. For definition of A, B and WT, see notes under Table 4.

TABLE 6. PRODUCTIVITY DATA FOR MANUAL SPREADING IN EARTHWORKS

Haulage mode	Input coefficient Man-hour (WT)/cu.m.	
	A	B
1. Headbasket	0.17	0.33
2. Wheel-barrows/animals	0.25	0.50
3. Animal carts, tractors, trucks	0.33	0.67

Notes : 1. Spreading means distribute deposited loose soil in a uniform layer 200-400 mm loose thickness, breaking up any large lumps and removing organic matter.

2. Output in cu.m. is measured in-situ in the borrow area.

TABLE 7. PRODUCTIVITY DATA FOR MANUAL HAUL AND UNLOAD OPERATIONS

Methods	Equations for input-coefficient Man-hour (WT)/cu.m.	
	A	B
1. Headbasket	0.07 + 0.021 L	0.68 + 0.047 L
2. Wheel-barrow	0.25 + 0.0076 L	0.67 + 0.0186 H
3. Donkey	0.1 + 0.009 L	**
4. Mules	0.1 + 0.004 L	**
5. Ox cart	0.1 + 0.001 L	**
6. Tractor-trailer (35 HP tractor & 3 tonne tipping trailor)	0.014 + 0.00017 L	0.04 + 0.00033 L

Notes : 1. 'L' is the equivalent haul distance. One-metre rise may be taken as equivalent to 10 m additional haul distance.

2. ** Input coefficient may be taken as twice that for condition 'A'.

3. For definition of A, B and WT, see notes under Table 4.

TABLE 8. PRODUCTIVITY DATA FOR MANUAL SPREADING OF PAVEMENT MATERIALS

Material	Layer thickness (mm)	Input coefficient Man-hour (WT)/tonne	
		A	B
1. Aggregates for base or sub-base	100 60	0.25 0.45	0.4 0.7
2. Filler for WBM	8	2.5	4.0

Notes : 1. For definition of A, B and WT, see notes under Table 4.

2. Spreading does not include associated loading and hauling from stockpiles.

TABLE 9. PRODUCTIVITY DATA FOR MANUAL PRODUCTION OF AGGREGATES

Activity	Input coefficient Man-hour (WT)/tonne	
	A	B
1. Production of 50 mm aggregate—reduction factor 4	4	12
2. Production of 10 mm chippings—reduction factor 10	11	30

5. GUIDELINES ON PLANNING AND ORGANISATION OF LABOUR-BASED METHODS

5.1. General

A large number of resources will be required for executing a road project. The Site Engineer should arrange for these in the required quantities and in time so that the work could be completed within the time schedule. The major resources for labour based construction methods are :

(i) Labour

(ii) Earth for earthwork

(iii) Aggregates and other pavement construction materials.

Besides these, tools and small equipment for the different operations and water will be required, and these are discussed alongwith the above resources as relevant. Provision of cross-drainage structures are not dealt with in this publication.

5.2. Labour

5.2.1. The number of labourers required for a task is given by :

$$\text{Number of labourers} = \frac{\text{Volume of task}}{\text{Labour effective days} \times \text{Productivity}}$$

Where productivity is measured in terms of output per day per person.

5.2.2. The labour effective days are affected by a number of factors such as :

(i) Length of construction season

(ii) Weekly or periodical rest days and other holidays

(iii). Absenteeism because of illness or local crop planting/harvesting

(iv) Time lost in recruiting labour at start of the season

(v) Time lost due to bad weather during the working season

(vi) Time lost due to labour unrest.

While items (i) to (iv) can be estimated to a reasonable degree of accuracy based on local experience, some *ad hoc* allowance will have to be provided for the other two items.

5.2.3. Ideally, a constant number of labour should work together in perfect balance to maximise utilisation of resources. This, however, is not generally possible in actual practice as there will be build-up of labour at the start of a job and a run-down towards the end. Taking all these into account, an example for working out the effective labour days for a typical road project is illustrated in Table 10. Once this is calculated, the average number of labour to be employed in a task can be computed by the formula given in para 5.2.1. In cases, where a work is required to be speeded up or where additional work volumes not originally anticipated crop up, the labour resources should be augmented in the non-agricultural periods where labour can be mobilised with greater ease.

5.2.4. In harvest and other periods specific to the area, a heavy run-down of labour availability will be a general feature. On works where equipment like trucks, etc. are used alongwith labour, any idling of the equipment during such periods would add to the cost of the project. One way to avoid this is to take away available labour from the tasks being carried out by labour alone and put them to work with the equipment for ensuring their full utilisation. Alternatively, import of labour from outside by paying higher wages could be considered. However, the measure adopted should be based on the relative costs of paying higher wages or of having the equipment standing idle.

TABLE 10. CALCULATIONS FOR NUMBER OF EFFECTIVE DAYS FOR LABOUR - AN EXAMPLE

1. NUMBER OF DAYS ON WHICH WORK IS DONE	
(a) Length of season	... 8 months
(b) Length of working week	... 6 days
(c) Number of working days in the season $= 8 \times 30 \times \frac{6}{7}$	... 206 days
(d) Number of official/local holidays during the season	... 10 days
(e) Likely loss of time in recruiting labour at start of season	... 10 days
(f) Likely loss of time owing to bad weather	... 15 days
(g) Likely loss of time owing to labour disputes	... 5 days
(h) Total days on which work will be done $= 206 - (10+10+15+5)$	... 166 days
2. LOSS OF TIME OWING TO LABOUR FLUCTUATION	
(i) 50% Labour present during the first and last weeks (assumed)	
Reduction factor $= \frac{0.5 \times 2 \times 6}{166}$	... 0.036
(j) 25% Labour present during four weeks of harvest (assumed)	
Reduction factor $= \frac{0.75 \times 4 \times 6}{166}$	... 0.108
(k) 5% time lost due to labour turnover	
Reduction factor	... 0.050
(l) Total reduction factor	... 0.194
(m) Loss of time $= 166 \times 0.194$	... 32 days
3. NUMBER OF EFFECTIVE DAYS = 166—32	... 134 days

5.3. Site Clearance

5.3 1. Site clearance which forms the first stage of any construction activity may consist of removing and disposing/storing/stacking of one or more of the following :

(i) Trees, bushes and shrubs

(ii) Grass and other vegetation

(iii) Stumps, rubbish, loose stones, etc.

(iv) Top soil from embankment, cut and borrow areas (removed and stored for re-application)

Site clearance should proceed well ahead of construction so that the construction lines can be set out and the precise nature of the ground can be known for planning the earthwork operations. It will be a good practice to carry out all major clearance work and to set out alignments, etc. for a whole season's work before construction begins.

5.3.2. The project drawings would generally show the clearing limits. If not, the limits should extend over the area which in one way or the other affect the construction activities. In either case, the following guidelines may be helpful during the operations :

(i) All trees and stumps falling within the excavation/fill toe lines should be cut to such depths that these do not fall within 0.5 m of the subgrade level.

(ii) In all other cases, the vegetation which protects the ground soil against erosion should not be cut out unless their removal is warranted either for facilitating construction operations, or for haul roads, or for improving the visibility, etc. In such cases, the trees etc. should be removed only upto the ground level leaving the roots to remain in place.

(iii) Removal of top soil should be to the depth containing organic matter, and this may generally be to the depth of 50—150 mm.

5.3.3. Labour methods are well suited for site clearance work. Labour can distinguish between the trees and plants to be removed and to be left in place, and the actual depth of organic top soil to be cleared. They should be provided with good quality axes, saws and grubbing mattocks, portable tree pulling devices like winches, etc Animals or tractors can be used for removing the felled trees to the stackyard.

5.4. **Earthwork**

5.4.1. **General**

(1) Earthwork constitutes a major component in the cost of any road project, and on the overall basis, the cost of earthwork may amount to 25—30 per cent of the project cost. For lower category roads, this percentage will be even more. Careful planning and efficient operation of the involved activities is therefore necessary for economising road construction cost.

(2) Earthwork can be broken down into the activities of ripping (if required), excavation, loading of excavated material into the haulage mechanism, hauling, unloading, spreading and compaction, although more than one of these activities can be combined into a single operation All these operations can be economically performed by labour-based methods which include use of some simple equipment like tractor-trailer, flat-bed trucks, etc.

5.4.2. Excavation

(1) Excavation in road construction may be for cutting the natural ground for roadway or drain construction, or for winning earth from borrow areas for embankments, or for founding highway structures. In all cases if excavation can be combined with loading, the combined operation becomes more efficient. However, in hard materials like moorum. soft rock, etc. excavation and loading generally will have to be done separately in labour based methods.

(2) The hardness of the material excavated is an important factor affecting productivity of excavation tasks. The Ministry of Transport Specification divides soil into two categories, namely, ordinary soil and hard soil with the following description :

(a) Ordinary Soil

This shall comprise vegetable or organic soil, turf, sand, silt, loam, clay, mud, peat, black cotton soil, soft shale or loose moorum, a mixture of these and similar material which yields to the ordinary application of pick and shovel, rake or other ordinary digging implement. Removal of gravel or any other nodular material having diameter in any one direction not exceeding 75 mm occurring in such strata shall be deemed to be covered under this category.

(b) Hard Soil

This shall include :

(i) stiff heavy clay, hard shale, or compact moorum requiring grafting tool or pick or both and shovel, closely applied;

(ii) gravel and cobble stone having maximum diameter in any one direction between 75 and 300 mm;

(iii) soling of roads, paths, etc., and hard core;

(iv) macadam surfaces such as water bound, and bitumen/tar bound;

(v) lime concrete, stone masonry in lime mortar and brick-work in lime/cement mortar below ground level;

(vi) soft conglomerate, where the stones may be detached from the matrix with picks; and

(vii) generally any material which requires the close application of picks, or scarifiers to loosen and not affording resistance to digging greater than the hardest of any soil mentioned in (i) to (vi) above.

Available data show that hard soils require 2-3 times the manpower inputs compared to that for softer soils. Effort required for hard soils can be reduced and the productivity increased to the extent of 50-100 per cent by :

(i) Pre-ripping, and

(ii) Wetting

(3) Pre-ripping may be by tractor/animal drawn ploughs. Ripping is started on a narrow strip which after the process is excavated and the material removed to form working space with vertical faces. The adjoining strip is then ripped and the excavation is continued on the vertical faces which has the advantage that the cut material falls away from the face aided by gravity. Also, the vertical face reduces drying cut and hardening of soil in hot climates.

(4) Wetting prior to excavation softens the material and makes the excavation task easier. However, over-wetting of clay soils should be guarded against as this may make the materials slushy and un-workable. It will be advantageous to time the earthwork operation when the soil is fairly moist so that not only the excavation effort is less but also not much water will be required to be added for compaction. The best time for the purpose is at the beginning of construction season, i.e. soon after the monsoons when every opportunity should be taken to plan the bulk of the earthwork.

(5) The higher the material has to be lifted for loading, the greater will be the amount of effort expended, see Table 4. A low or negative loading height will make the operation much easier. The excavation should be so organised that as far as possible, all haulage containers can be loaded within small lifts, if negative lifts are not possible. For this purpose, a strip of width sufficient to pass the haulage vehicle is first cut. Excavation is proceeded with on the vertical faces so that the haulage system can be loaded without much lift. Fig. 2, illustrates the sequence of short-haul earthwork by headbasket method while Fig. 3, shows possible arrangements for medium hauls using carts/vehicles.

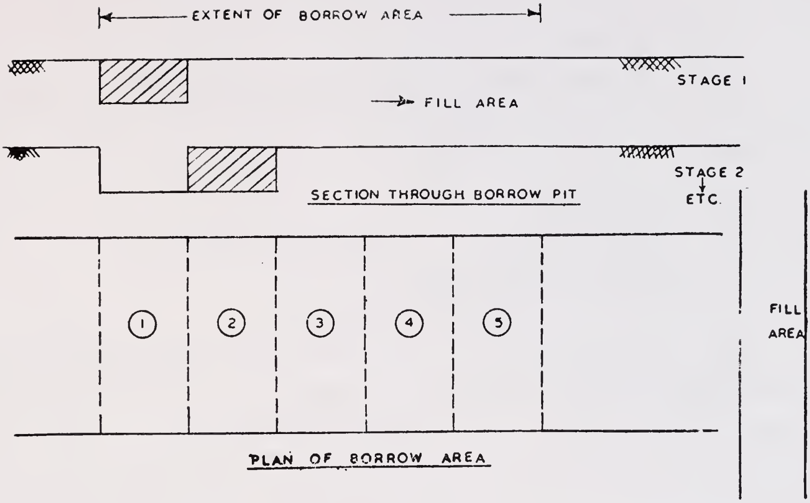

Fig. 2. Sequence of borrow excavation—short hauls by headbasket method

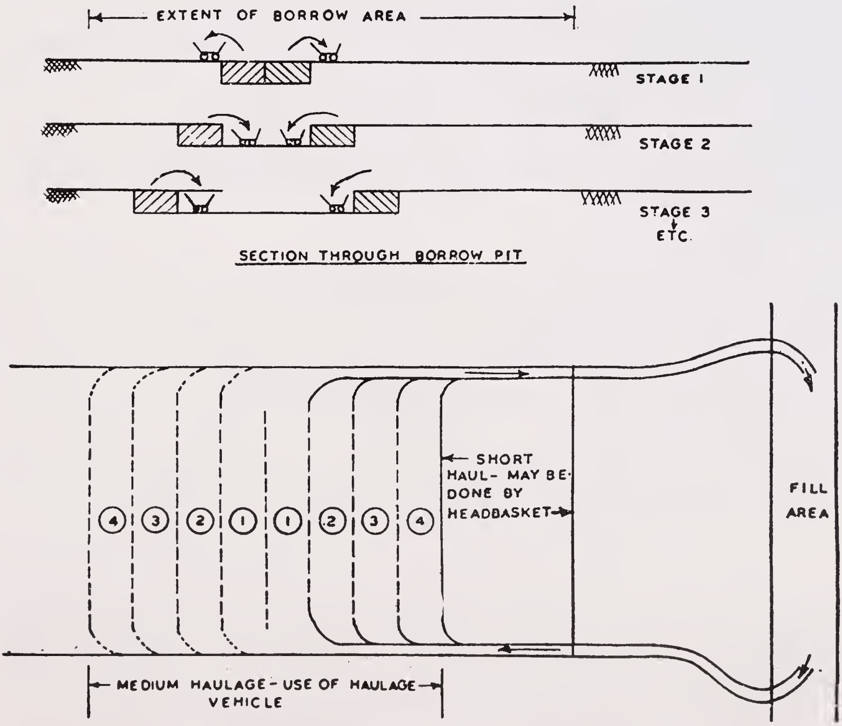

Fig. 3. Sequence of borrow excavation—haulage by carts/vehicles

5.4.3. **Hauling**

(1) A variety of labour based methods are possible for hauling soil for earthwork. In general, the choice of the method and the cost of hauling are governed by :

(i) Haulage distance

(ii) Rise/fall from the source to place of deposition

(iii) Conditions of the haulage routes such as roughness, firmness, uniformity, slope, etc.

(2) For embankment construction, the soil is generally obtained either from roadway and drainage excavation or borrow areas, or from both. At the stage of designing the grade line for the road, it will be expected that the cut and fill quantities are balanced to the maximum extent possible. Balancing is possible both in the lateral and longitudinal directions as depicted in Fig. 4. Lateral balancing involves a half-cut, half-fill cross section with or without retaining wall, but this will not be feasible when the ground slope is very steep in which case the road may have to be in full cutting. Lateral balancing, where possible will not involve much haulage, but in longitudinal balancing, the distance may vary from case to case. When the haulage distance is more than 150-200 m, it will be more economical to go in for roadside borrow if available.

(3) Winning earth from roadside borrow areas which involves short haulage distances is ideally suited for manual methods. The borrow pits should preferably be located on both sides of the line of work. Guidance on the location of roadside borrowpits can be had from IRC : 10 "Recommended Practice for Borrowpits for Road Embankments Constructed by Manual Operation". Roadside borrowpits may, however, be not possible in the case of high embankments involving large earthwork quantities and in certain other cases, for example, sections falling on low lying areas.

(4) The volume occupied by soil in compacted fill will usually differ from in-situ volume in borrow areas because of difference in densities. The correction factor for converting in-situ volume into compacted volume is given by :

$$\text{Earthwork correction factor} = \frac{\text{In-situ density of borrow}}{\text{Compacted density of fill}}$$

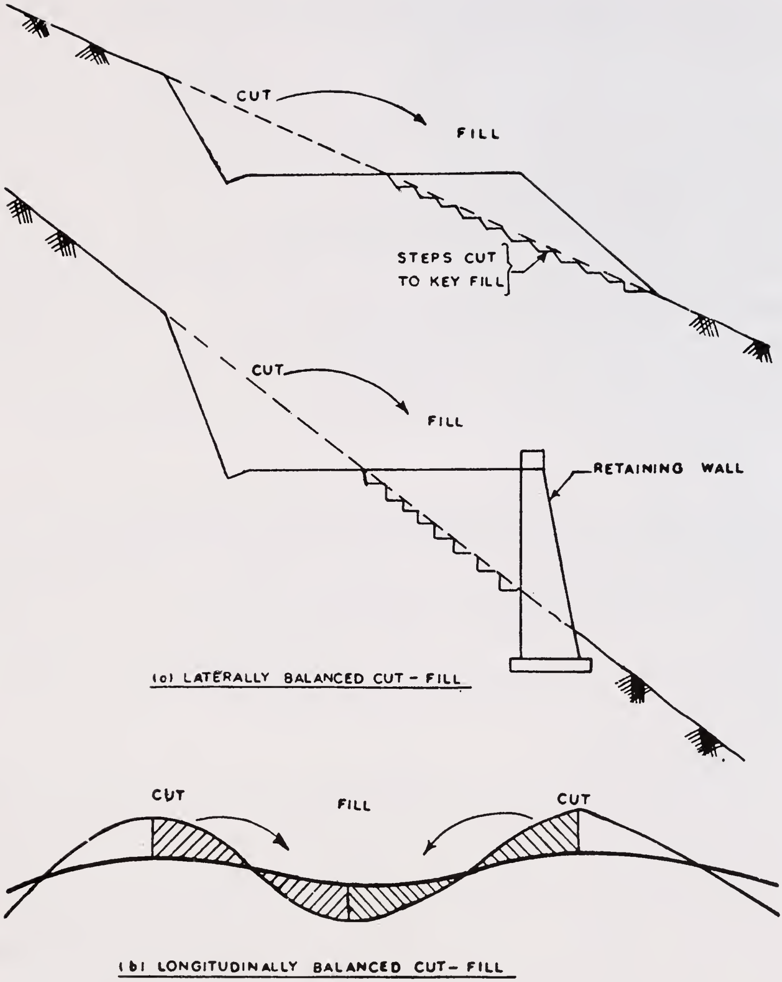

Fig. 4. Balancing of cut and fill in road construction

Where vehicles are used for haulage, the output will be a function of loose volume carried by the vehicle and therefore a knowledge of the loose density of bulking factor of the soil will be required. Bulking factor is given by :

$$\text{Bulking factor} = \frac{\text{In-situ density in borrow}}{\text{Loose density in haulage}}$$

The loose dry density of most of the soils will be in the range of 1.4 and 1.5 tonnes/m^3.

(5) Rise or lift from source to place of deposition involves additional effort, and roughly 1 metre rise can be taken as equivalent to 10 m haulage distance. Similarly, a rough haul route involves additional effort, but the extent varies from method to method. The different methods, therefore, require different treatment to the haulage routes. While men and pack animals can negotiate rough routes with steeper gradients, wheel barrow, animal cart and other similar devices are highly sensitive to these parameters. This aspect is discussed in subsequent paragraphs under respective method of hauling.

Head Baskets

(6) Head baskets are one of the most common form of manpower haulage and are efficient for distances upto 50-60 m. It is reasonably independent of the route condition. Unloading is a simple operation and little spreading is needed after unloading. Load carried varies between 15 and 40 kg and speeds from 50 to 70 m/minute. Use should be made of spare baskets for excavators to fill the basket by the time the hauler returns.

Wheel Barrows

(7) Wheel barrows can be used for haulage between 25 and 100 m, and can be highly economical if a smooth and firm haul route can be made. The most common method is by building a barrow way usually made of planks if a hard and smooth surface cannot be formed on the ground. Barrow has a triangular body with a single wheel fitted in the forward part. With improved barrows fitted with pneumatic tyres, pay loads in the range of 70-120 kg are possible at speeds 50-80 m/minute.

Pack Animals

(8) A variety of animals like donkeys, mules, ponies and camels can be used for pack work. Haulage by pack animals becomes relatively advantageous where steep gradients and poor haul routes are encountered. The load usually of the order of 100-200 kg, is carried on panniers made of woven rope. Loading is by hoe or shovel and emptying is by tipping. This method can

be found workable for distance upto 300 m and rise upto about 10 m. Usually gangs of 10-12 animals are loaded, led and unloaded 4-5 labourers.

Animal Carts

(9) Wooden-wheeled or pneumatic tyred carts pulled by bullock or buffalo can be used for haul distance upto 100 m. While large diameter solid-wheeled carts can negotiate uneven or slushy tracks, pneumatic tyred carts can work only on firm and even ground. The load carried per trip varies between 500 and 1000 kg. Haul speeds vary from 48-60 m/min depending on haul route condition. Loading is by headbaskets while unloading is by tipping the cart (after unyoking the animals) and using a hoe.

Tractor-trailer and Flat-bed Truck

(10) Manual and animal haulage methods usually are uneconomical on hauls of over 500 m. The most common form of equipment for longer hauls in combination with manual loading is either the tractor-trailer combination or the flat-bed truck.

(11) Tractors are easily available during slack times in the farmwork cycle. They have the advantage of being a basic and robust machine and are more likely to have a well developed repair facility. Two or more trailers may be used depending on haul length so that when one is being hauled, the other may be loaded. The labour for a tractor may be divided into three groups, two at the borrow area (one for excavation and the other for loading) and the third at the fill site for unloading and spreading. The suggested load capacity of trailers are :

Tractor HP	*Trailer Capacity*
35 HP	3 tonnes
45 ,,	4 ,,
60 ,,	5 ,,
75 ,,	6 ,,

(12) Two-axle trailers are capable of carrying a greater load than a single axle trailer of the same size and are easier to hitch and unhitch. Single axle trailer is much easier to manoeuvre and can transfer load to the back axle of the tractor thereby

greatly increasing the traction which may be required for haul on poor routes or steep ramps.

(13) The lower the loading height, the quicker the trailer may be loaded. The lie of the land can be utilised to ensure a downhill approach for the loaders, or loading benches can be excavated. Separate team of unloaders should be provided at the unloading point. If tipping trailers are used, unloaders will not be needed but the cost of the equipment will be high. The nature of the haul route has an important effect on the productivity as rough or rutted route will cut the travel speed and up gradients will reduce the pay load. Ideally the route should not have a gradient steeper than 10 per cent and should be well maintained.

(14) For flat-bed trucks, the economical haulage distance varies between 1 and 5 km. The haul route should be good and the loading and unloading operations should be quick. The labour gang may be divided into three groups, one at the borrow area (for excavation when the truck is hauling and for assisting in loading when the truck returns) the second moving with the truck for loading and unloading, and the third at fill site for spreading.

5.4.4. **Gang balance** : Gang balance is the distribution of activities within a task so that all the men in a gang can work at much the same pace In planning, the resources, this aspect must be considered in any task which consists of a number of inter-related activities. If the excavation-load-haul-unload task is considered, the excavators and loaders should be able to work at an even pace without having to wait for a hauler, while the hauler should not have to wait for the haulage container to be filled. Calculations for gang balance for the earthwork task with the headbasket and flat-bed truck for haulage are given in Tables 11 and 12 respectively.

5.5. Road Construction Aggregates

5.5.1. **General** : Stone aggregates are required for the construction of road pavement and structures. Low-grade aggregates like moorum, gravel and kankar can also be used in sub-base of main roads and in sub-base/base/surfacing of low-volume roads. Generally, cost of loading, hauling and unloading will form a

TABLE 11. GANG BALANCE CALCULATIONS FOR EARTHWORK BY HEADBASKET

1. SITE PARAMETERS		
Task	...	excavate, load into headbaskets, haul and unload
Soil	...	ordinary soil
Haul distance	...	20 m
Rise of haul route	...	1 m
Management	...	good
Payment method	...	piecework
Gang strength	...	20
2. CALCULATIONS		
(i) Activity level inputs		
(a) Excavate input (Table 4)	...	0.3 man-hr/cu.m.
(b) Correction for loading height (assuming 1.5 m)	...	0.26 man-hr/cu.m.
(c) Equivalent haul length $= 20+10\times1$	...	30 m
(d) Haul/unload input (Table 7)	...	0.7 man-hr/cu.m.
(ii) Output for perfectly balanced gang		
(a) Total input $= 0.3+0.26+0.7 = 1.26$ man-hr/cu.m.		
(b) Gang output (20 men) $= 20/1.26 = 15.9$ cu.m/hr		
(iii) Best feasible gang proportion		
(a) Rates of excavator/loader to hauler $= (0.3+0.26) : 0.7 = 1:1.25$		
(b) Optimum gang proportion = 9 excavators to 11 loaders		
(iv) Actual output		
(a) 9 excavators excavate	...	$9/0.56 = 15.5$ cu.m/hr
(b) 11 haulers haul	...	$11/0.7 = 15.7$ cu.m/hr
(c) Actual output of gang	...	15.5 cu.m/hr

TABLE 12. GANG BALANCE CALCULATIONS FOR EARTHWORK USING FLAT-BED TRUCK FOR HAULAGE

1. SITE CONDITIONS AND ASSUMPTIONS

Task	...	excavate, load into flat-bed truck, haul, unload and spread
Soil	...	hard soil
Haul distance	...	3 km
Loading height	...	0.5 m
In-situ density of soil	...	1.7 gm/cc
Management	...	good
Payment method	...	piecework
Truck capacity	...	5 t or 3 cu. m (in-situ volume)
Truck speed, loaded	...	15 km/hr
Truck speed, empty	...	20 km/hr

For operational convenience, 8 men load the truck, and 8 men who travel with the truck perform unloading.

2. CALCULATIONS

(i) Truck cycle time

Hormonic mean truck speed $= \dfrac{2}{\dfrac{1}{15}+\dfrac{1}{20}} = 17.1$ km/hr

Haul time (out and return) $= \dfrac{2\times3\times60}{17.1} = 21$ min

Collapsing truck sides and remaking $= 1$ min

Loading input (Table 5) $= 0.26$ man-hr/tonne
$= 0.44$ man-hr/cu. m.

Loading time with 8 men $= \dfrac{3\times0.44}{8}\times60 = 9.9$ min

Unloading input (Table 5) $= 0.20$ man-hr/tonne
$= 0.34$ man-hr/cu. m.

Unloading time with 8 men $= \dfrac{3\times0.34}{8}\times60 = 7.7$ min

Total cycle time for truck $= 21+1+9.9+7.7 = 39.6$ min or say 40 min

(ii) Excavators

Excavate input (Table 4) $= 0.9$ man-hr/cu. m.

Time available for excavation $= 40-9.9 = 30.1$ min

Number of excavators required $= \dfrac{3\times0.9\times60}{30.1} = 5.4$ or say 6

(iii) Spreaders

Spreading input (Table 6)	=	0.33 man-hr/cu.m.
Time available for spreading	=	$40-7.7-1 = 31.3$ min
Number of spreaders required	=	$\frac{3 \times 0.33 \times 60}{31.3} = 1.9$ or say 2

Note : **These spreaders and excavators can also help in unloading so that the number of loaders/unloaders travelling with the truck can be reduced to 6.**

(iv) Output

Output per hour	=	$\frac{3 \times 60}{40} = 4.5$ cu.m.
Output per truck per day of 8 hours effective working time	=	$8 \times 4.5 = 36$ cu. m.

(v) Conclusion

A gang of 22 men (6 excavators, 8 loaders, 6 unloaders and 2 spreaders) working with a 5 tonne flat-bed truck can turn out 36 cu.m. of excavate-load-haul-unload-spread operation

Note ; **If the haul distance is less or the speed of travel is more, the productivity will be more and will warrant more excavators and spreaders for balanced working.**

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sizeable portion of the aggregate cost at the work site. Arranging for gravity loading from a higher level at quarry site, cutting down the idle time of haulage vehicle by providing adequate number of labourers for loading-unloading, maintaining the haul route in good condition and unloading the material at the pre-planned locations at work site to avoid double handling are some of the measures for improving productivity and reducing cost. Flat-bed trucks are extensively used in the country for aggregate haulage through animal carts are also employed for shorter hauls and where only small quantities are required.

5.5.2. **Stone quarries** : Generally, stone aggregates for road works are supplied from well established running quarries. Side by side, developmental work in identifying new quarry sources is also going on, and it will be worthwhile considering opening up of new quarries for greater economy particularly in the case of major civil engineering works where the demands will be large and continuous. The first step in the process will be to test samples of rock from the prospective quarries for conformity with specification requirements. If the material is suitable, the main factors to be taken into account in choosing the best alternative would be :

(i) Cost of removal of overburden and opening up the quarry.

(ii) Ease of excavation through blasting or other means.

(iii) Existance of suitable areas for installing the crushers, the cost thereof and the distance of the quarry point to the crusher or vehicle loading point.

(iv) Cost of providing vehicle manoeuvring area in the quarry and of access routes.

(v) Haul length, haul route condition and rise/fall of haul route.

(vi) The quantity of stones required to be extracted to assess the economy of opening up the quarry, providing access roads, etc.

Generally, the initial cost of opening a quarry, constructing haul roads, installation of crushing equipment, etc. will be considerable and outweigh the operating cost unless the quantities to be extracted are large, and the quarry could be put to use in future for other works.

The productivity of road aggregates by hand breaking depends to a great extent on the hardness of stone and the reduction factor. Normally 200-250 mm sized rubble are collected after blasting and used for hand breaking with a 0.5-0.9 kg hand hammer. The productivity of breaking to 25-50 mm size aggregate used for Water Bound Macadam (i.e. a reduction ratio of about 4) will be of the order of 0.5 to 1.0 cu. m./man day. For higher reduction ratio, the effort required will be higher, and the productivity will be correspondingly less. The effort required for breaking into smaller sizes goes up steeply, and it will be more economical to go in for mechanical crushing for such cases.

5.5.3. **Moorum and gravel quarries :** As in the case of stone quarries, the suitability of the available material will be the first consideration in the choice of moorum/gravel quarries. Generally, the installation cost for such quarries will only be nominal, and for choice among the suitable alternatives, the most significant factor will be the haulage cost. The factors affecting haulage productivity and cost such as loading height and time, haul distance, condition of the haul route, etc. equally apply to this case.

5.6. Compaction

5.6.1. For the embankments, compaction is generally specified in terms of standard Proctor density - 95 per cent for body of embankment and 100 per cent for subgrade portion and shoulders. The compaction is to be done in 250 mm thick loose layers. This will be possible only with power rollers which is capital intensive. Different types of soils require different types of rollers, but the 8/10 tonne three-wheeled roller will be found to be useful for most cases. Where a power roller is used for compaction, it should be ensured that the hauling and spreading activities are balanced to provide adequate work to the roller so that it does not remain idle. Light-weight (0.5 — 2 tonne) tractor/animal drawn rollers are also available but these should not be used unless the road is a minor one and there is no other alternative.

5.6.2. Compaction of sub-bases of moorum/gravel, etc. will be on the same lines as of subgrade compaction. Water bound macadam requires large compactive effort for getting the aggregates properly interlocked and this is possible only with power rollers.

5.6.3. Compaction of bituminous layers can be done conveniently with 8/10 tonne three wheeled roller. The roller wheels have to be kept moist to prevent the mix from being picked up. Bituminous Macadam and asphaltic concrete surfacing will require 3-wheeled roller for break down rolling and tandem roller for finishing.

5.6.4. The normally observed productivities of 8/10 tonne roller in compacting different materials are given in Table 13.

5.7. Soil Stabilisation

5.7.1. Adequate pulverisation of soil, and thorough and uniform mixing of stabilizer constitute essential requirements to the success of soil stabilisation works. From this angle, it would be preferable to use mechanical equipment wherever possible.

5.7.2. Lime stabilisation which is commonly adopted in the country is applicable for clayey soils where pulverization of the soil

Table 13. Characteristics and Output of 8/10T Three-Wheeled Roller

CHARACTERISTICS

Width compacted	... 1.78 m
Speed of rolling	... 50 m/min
Applicability	... Suitable for (i) all soil types except soft wet clay and uniformly graded sand, (ii) all bituminous layers through pnuematic tyred is preferable for surface dressing

	Type of material	Average output/day
1.	Earthwork in embankment in 150 mm thick compacted layers	400 cu.m
2.	Moorum/gravel sub-base in 150 mm thick compacted layers	300 cu.m
3.	Moorum/gravel sub-base in 100 mm thick compacted layers	250 cu.m
4.	WBM over-size metal sub-base in 100 mm thick layer (compact)	35 cu.m
5.	WBM base in 75 mm thick layer (compact)	30 cu.m
6.	Surface dressing, single coat	770 sq.m
7.	Surface dressing, two-coat	550 sq.m
8.	Premix carpet, 25 mm thick	600 sq.m
9.	Premix carpet, 20 mm thick	740 sq.m
10.	Liquid seal coat for premix carpet	1000 sq.m
11.	Sand seal for premix carpet	2000 sq.m
12.	Bituminous macadam, 50-75 mm thick	280 sq.m
13.	Asphaltic concrete 25-40 mm thick	370 sq.m

prior to mixing is an important requirement. For such soils, mould-board ploughs, disc harrows and off-set harrows hitched to agricultural tractor which is often used for agricultural operations can be used. The tractor should be of about 50 HP for depth of processing upto 200 mm and 110 HP where the depth goes upto 400 mm. Mould-board plough is used first for loosening the soil. The disc harrow is then passed over the ploughed soil to break down clods further. The soil is then processed further with off-set harrow. After achieving the required degree of pulverisation, the soil is levelled, moisture content adjusted, and the stabilizer is spread over it manually. The off-set harrow is then used for 4-6 passes for mixing. After levelling, the layer is compacted with power roller. For heavy clays, pre-treatment with lime may be adopted for aiding pulverisation.

5.7.3. The purely manual method consists of cutting the soil several time with hoe/spade for pulverising it, then forming a stack and adjusting the moisture, spreading the stabilizer on the stack, and turning over the material 4·6 times till it is uniformally mixed. This method should be adopted only where the needed equipment is not avilable.

5.8. **Bituminous Works**

5.8.1. A variety of bituminous constructions from thin surface dressing to dense asphaltic concrete are practiced in the country. Surface dressing though apparently simpler to construct require uniform spreading of bitumen and even spreading of aggregates before rolling. The quick succession of the operations is important to ensure that the aggregate get properly embedded in the binder before the latter becomes hard, as otherwise the aggregates will whip-off. All this can be possible and a good quality surfacing constructed only if mechanical sprayers and chip spreaders are used. In the absence of truck-mounted sprayers, hand operated sprayers attached to a tar boiler may be used.

5.8.2. Open-graded premix carpet construction requires uniform coating of aggregates, and preferably hot mix plant is used for the purpose though laying may be done manually. Mini hot mix plant of 6-8 tonne capacity will be found suitable. Where such plant is not available, the aggregates can be heated in stacks with fire through empty bitumen drums embedded in them, and mixing done in a concrete mixer or improvised mixer. A sample calculation for working out the resources for laying 20 mm thick premix carpet with mini hot mix plant is given in Table 14.

5.8.3. Bituminous macadam and asphaltic concrete mixes should invariably be prepared in hot mix plant and laid with

TABLE 14. RESOURCE CALCULATION FOR 20 mm THICK PREMIX CARPET WORK USING MINI HOT MIX PLANT

DATA

1.	Output of mixing plant	... 6 tonne/hr
2.	Output/day (effective working time = 6 hrs)	... 36 tonnes
3.	Cycle time for each batch	... 3 min
4.	Weight of each batch of mix $\left(\frac{6000 \times 3}{60}\right)$	... 300 kg

5. Haulage of mix by large wheel barrow pushed by two persons :

Speed loaded	... 50 m/min
Speed empty	... 60 m/min
Unloading time	... 0.5 min

6.	Width of paving	... 7 m
7.	Aggregate dumped within an average distance of 10 m from plant. Loading the bin is by headbasket method	
8.	Bulk density of aggregate	... 1.5 tonne/cu.m.
9.	Binder content by weight of total mix	... 4.45%

10. Calculations are done for two cases :

(a) The plant at one location will cater for the work for a distance of 600 m on either side

(b) The plant at one location will cater for the work for a distance of 1000 m on either side. On completion of the work, the plant will be shifted to a new location.

CALCULATIONS

A. Plant to cater for 600 m length on either side

1. Output of plant/day $= 6 \times 6 = 36$ tonnes

2. Aggregate to be dumped at plant site (@ 0.27 cu.m/10 sq.m) $= \frac{2 \times 600 \times 7 \times 0.27}{10} = 226$ cu.m

3. Bitumen to be brought to plant site (@ 14.6 kg/10 sq.m) $= \frac{2 \times 600 \times 7 \times 14.6}{10 \times 1000} = 12.2$ tonne

4. Volume of aggregate used per day $= \frac{36(100-4.45)}{1.5} = 22.8$ cu.m

5. Area of spread of mix/day (0.27 cu m/10 sq.m) $= \frac{22.8}{0.27} \times 10 = 850$ sq.m

6. Length of road paved/day $= \frac{850}{7} = 120$ m

7. Labour for hauling mix :

Average lead	= 300 m
Time for loaded trip	= 300/50 = 6 min
Time for empty return	= 300/60 = 5 min
Unloading/turning time	= 0.5 min
Time per cycle	= 11.5 min
As each batch will be at 3 minutes, provide four teams of two persons each for hauling	

8. Labour for spreading mix :

Spreading input coefficient	= 0.5 man-hr/tonne
Number of persons required	$= 6 \times 0.5 = 3$

9. Labour for loading bin :

Hauling/unloading input coefficient (10 m lead)	= 0.28 man-hr/cu.m.
Quantity of aggregate to be loaded/hr	$= \frac{22.8}{6} = 3.8$ cu m.
Number of persons required for hauling	$= 0.28 \times 3.8 = 1.05$ or say 1
Provide one extra for loading baskets	

10. Provide 2 persons for loading bitumen into boiler

11. Total number of labour required $= 8 + 3 + 2 + 2 = 15$ persons

12. Output of roller (Table 13) = 740 sq. m

13. Provide one roller for rolling

14. Number of working days required for completing the job $= \frac{2 \times 600}{120} = 10$ days

B. Plant to cater for 1000 m on either side

1. The other resources required will be the same as for case. A except that number of teams hauling the mix will have to be increased.

Average lead	= 500 m
Time for loaded trip	= 500/50 = 10 min
Time for empty return	= 500/60 = 8.3 min
Unloading/turning time	= 0.5 min
Time per cycle	= 18.8 min or say 18 min
Number of teams of haulers	= 18/3 = 6
	= 12 persons

2. Number of working days required for completing the job $= \frac{2 \times 1000}{120} = 17$ days

mechanical paver. The operation, therefore, has to be equipment-intensive for obtaining the best results.

6. GUIDELINES ON PLANNING AND ORGANISATION OF EQUIPMENT-INTENSIVE METHODS

6.1. General

As discussed in para 4, the choice of the most appropriate technology for road works has several ramifications, and is not to be based on micro-level cost comparsion alone. For example, for the task of earthwork within a lead of 25 m, the labour intensive headbasket method will be the most economical, but if the work is of large magnitude to be completed within a stringent time schedule, or the required labour force is not available, the job may dictate the adoption of equipment-intensive methods particularly where the needed equipment are readily available at site. The choice will, therefore, have to be judicious taking all the related parameters into account. In this Section, considerations in the choice of the appropriate equipment for the major tasks involved in road construction and guidelines on their efficient utilisation are given irrespective of the fact whether the job may be done equally well or not with labour based methods.

6.2. General Principles Governing the Selection of Machinery

6.2.1. It will generally be necessary to have a good experience in the operation and upkeep of equipment for satisfactory selection and handling. The records which have been kept for operating and maintenance of the various types of equipment and the actual output obtained under comparable conditions of previous projects will greatly assist in this regard. The types and sizes of equipment available to accomplish a job are in wide variety and range, and for selecting the best suited one, it would be advantageous to consider the following factors :

(i) The equipment already available in the project may be used even though it may not be the ideal choice. The heavy ownership cost involved in keeping the available equipment idle may offset the increasd cost involved in its operation cost *vis-a-vis* the ideal alternative.

(ii) The capabilities of each type of equipment and the conditions under which they can work efficiently.

(iii) The likely output of each machine and how this is affected by the site conditions.

(iv) Co-ordination of the different machines employed on a job and matching of their sizes and types so that all the machines work to full capacity.

(v) Organisation available/required for the efficient operation and maintenance of the machines.

(vi) Easy mobility of the plant particularly for cases where it has to be shifted from place to place.

(vii) The type of work such as nature of soil, haulage distance, restricted space for working, etc.

(viii) Indigenous availabiliy.

6.3. Equipment Suitable for Earthwork

6.3.1. **Site clearance :** The equipment suitable for preparation of site, clearing and grubbing including removal of trees, stumps and bushes is the crawler tractor with dozer blade attachment. Other attachments like rooter, stumper, tree stinger, etc. facilitate removal of trees and stumps. The draw-bar horse power (DHP) of the tractor should be 90-120 for light clearance and 160-200 per heavy clearance.

6.3.2. Earthwork

(1) For cutting earth and pushing the cut material to short leads, a bulldozer of about 100 DHP is suitable. For major dozing and removal of excavated rock, a larger sized dozer of 160-200 DHP would be necessary. The economic lead for dozer operation is about 100 m for crawler dozer and 130 m for wheeled dozer. While the crawler dozer is more appropriate for working on soft/muddy soil or rough/rocky formations, the wheeled dozer has higher travel speeds which is of advantage for longer hauls and in easy shifting from site to site. If the material to be excavated in too hard but not rock, it will be advantageous to rip it by the hydraulic ripper attachment at the back of the tractor before dozing is done.

(2) For leads ranging between 100—1000 m, a scraper would be preferable. The scraper does the entire work of excavation,

loading hauling and spreading by itself without the help of any other equipment except perhaps a pusher tractor. Scrapers can be towed or motorised. For relatively short haul distances upto about 300 m, the crawler tractor pulling self-loading scraper can move earth economically. Scrapers commonly used for road works have 10-13 cu.m. heaped capacity. The tractor pulling the scraper should have 180—250 DHP. These can negotiate steeper grades, require less haul road maintenance and can work under more adverse conditions.

(3) For longer haul distances, the low speed of the crawler tractor becomes a bottleneck, and it would be preferable to go in for self-propelled motorised scraper. Normally, motorised scraper requires a pusher while loading. A heavy duty tractor of 230—300 DHP would be suitable for the purpose. One pusher can help load several scrapers, the number depending on the loading time and the cycle time of the scraper.

4 Some of the aspects involved in scraper operation are :

(i) The scraper can excavate the material in layers and require a fairly long loading distance.

(ii) The scrapers can work successfully only where the material is not mixed with boulders or there are no rock outcrops. If the scrapers are to be used with very hard material (not rock or boulders), it will be necessary to have the area ripped by using ripper attachment on the crawler tractor.

(iii) The productivity of a scraper heavily hinges on the condition of haul roads. The haul roads should be firm, dust-free and should not have steep gradients to be negotiated on the loaded portion of the haul cycle.

(iv) Scrapers are generally used in groups at a location depending on the haul distance. This is from the angle that the expenses of operating the pusher tractor at the borrow area and the levelling tractor/grader at the fill area are distributed over a large volume of earthwork and the equipment are not kept idle.

(5) For leads beyond 1000 m, shovel-dumper or front end loader-dumper combination will be found suitable. Front end loaders are either tracked or wheeled type and are economical for a range upto 30 m. This piece of equipment can be used for light excavation, truck/dumper loading as also for loading hoppers or bins of hot mix plants. Loaders of 0 5 to 2 cu m. capacity are made indigenously.

(6) Motor grader is useful for spreading and grading of earth. As the scraper blade can be adjusted to any angle in vertical plane, the grader can be effectively used of trimming and maintaining the side slope of embankments. Grader is also useful for road surface maintenance, ditching, stripping, scarifying and finishing operations. However, for spreading and levelling earth dumped by rear or bottom dumpers, dozers would be required. Motor graders of 110 HP are manufactured indigenously.

6.4. Output of Earthmoving Equipment

6.4.1. General

(1) Equipment operation essentially comprises a series of cyclic operations or cycles. The probable output of an equipment per hour can be computed by multiplying the average net output per cycle by the number of cycles per hour. The cycle time for a machine is composed of two components—fixed time and variable time. The variable time is the time actually spent on travelling and is a function of the distance travelled and the speed of the unit. The speed of travel depends on several job factors such as rolling resistance, grade resistance, altitude and power rating of the equipment. The fixed time comprises the time spent in the performance of all operations other than travelling, such as loading, dumping, turning, gear shifting, accelerating, etc.

(2) In production operations, the labour and equipment do not work all the 60 minutes in an hour, and a value of 45-50 min/hr. will be appropriate for day working and 40-45 min/hr for night operation. The cycle time will, therefore, need to be corrected for taking this aspect into account. Besides this, the output is also affected by job and management factors. The job factors which are inherent in the job itself relate to site topography, available working space, climatic conditions, geology of the area affecting method of excavation, specification of the work, etc. Management factors pertain to efficiency of the organisation and operating staff, appropriateness of the equipment for the job, job planning, supervision, maintenance of plants and haul roads, etc. It is on the management aspects that the Site Engineer should apply all his effort for improving the efficiency and productivity of the operations.

(3) The output of earthmoving equipment is generally expressed in terms of 'bank measure' which is a measure of the soil in-situ. When the soil is excavated, its volume increases and it is in this loose state that the machines have to move the earth. The capacity ratings of machines, struck or heaped, relate to loose excavated material. The loose volume can be converted into bank measure by applying the swell factor which is given by :

$$\text{Swell factor} = \frac{100}{100 + \%\text{Swell}}$$

The swell factor may vary from 0.75 to 0.85 depending on the type of the soil and its compactness in-situ.

6.4.2. **Bulldozer :** The loose volume excavated/dozed per trip can be estimated by measuring the area of the load profile in front of the blade and multiplying it by the blade length. The output may be estimated from :

$$\text{Output (bank volume)/hr} = \frac{\text{(Loose volume/trip)} \times \text{swell factor} \times 60 \times \text{efficiency}}{\text{Cycle time in minutes}}$$

The efficiency factor in the equation has three components, namely, operator efficiency (0.6—0.9), job efficiency (0.6—0 8) and soil hardness. Generally manufacturers of the equipment indicate the productivity of the machines under ideal conditions. Taking the efficiency factors into account, it will generally be seen that the actual productivity will be between 30 per cent (line B for poorly managed jobs) and 50 per cent (Line A for well managed jobs) of the ideal productivity. The corresponding values (Lines B and A) for dozers of 3 different capacities are plotted against haul distance upto 100 m in Fig 5. Mean of the values could be adopted for planning purposes while the attempt during actual working should be to achieve productivities corresponding to Line A.

6.4.3. **Scrapers—General**

(1) Scrapers are rated according to volume capacity, struck or heaped volume, and the load capability. Two scraper bowls having the same struck capacity may have different heaped capa-

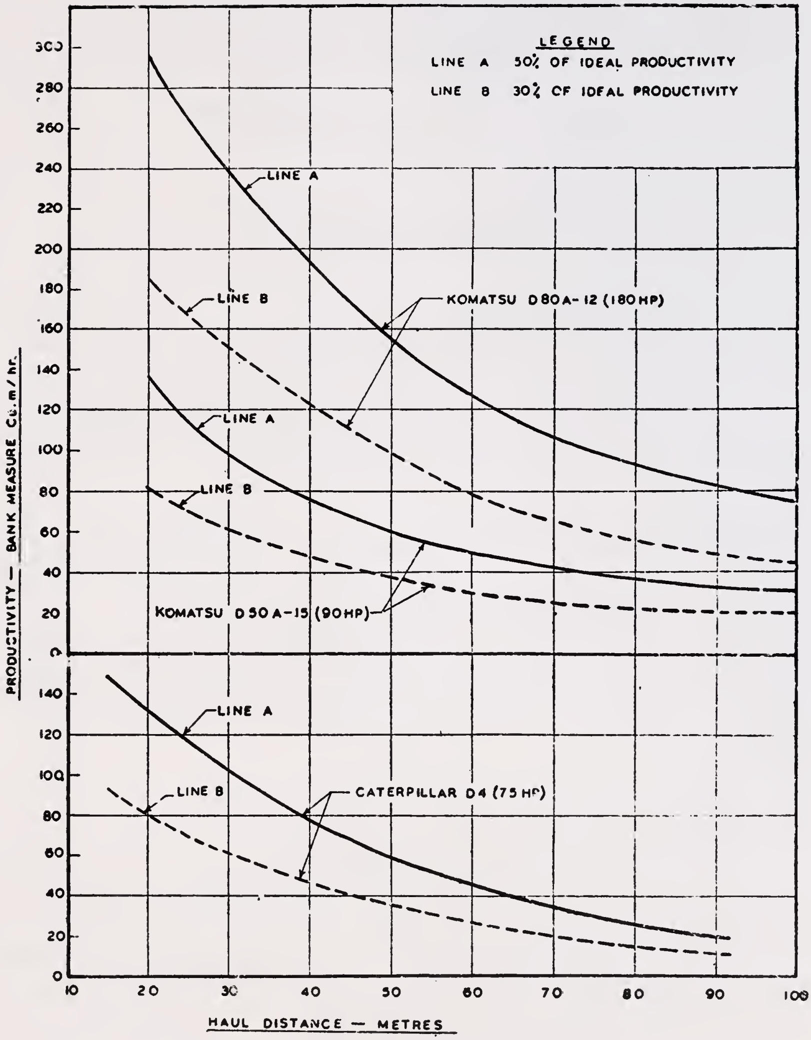

Fig. 5. Productivity of bulldozer

cities, depending upon the ratio of the base area of the bowl to its height.

(2) A major share of cycle time for scrapers goes for travelling. Proper maintenance of haul roads is therefore of prime importance for better productivity and reduced maintenance cost.

(3) In scraper loading, the rate of filling the bowl diminishes rapidly with the quantity of already loaded material, and it will be preferable to keep the loading time to less than one minute.

(4) The output can be determined from the following equation :

$$\text{Output (bank measured)/hr} = \frac{\text{Optimum (loose) load} \times \text{swell factor} \times 60 \times \text{efficiency}}{\text{Total cycle time in minutes}}$$

In the cycle time, the fixed time includes the time of loading and unloading (done at the first gear) turning, gear shifting, acceleration and deacceleration, all totalling to 4-5 minutes. Variables time is a function of speed of the unit and haul distance. The speed depends on the available drawbar pull *vis-a-vis* the required pull which depends on rolling resistance and grade.

6.4.4. **Towed scraper :** As in the case of dozers, the actual output will be 30-50 per cent of ideal output indicated by the manufacturers depending on the job/operator efficiency and soil condition. These values are plotted (lines A and B) for scrapers of three struck capacities, viz. 9.2 cu.m., 11.5 cu.m. and 13.8 cu.m. in Fig. 6. Average of these lines may be used for planning purposes.

6.4.5. **Motorised scraper**

(1) Motorised scrapers are assisted by pusher tractor during loading operation. The combined tractive effort of the scraper tractor and the pusher tractor, after allowing for resistances (grade and rolling) should be adequate to load the scraper by the desired amount. Number of scrapers that can be served by one pusher tractor can be estimated by the equation :

$$\text{No. of scrapers per pusher} = \frac{\text{Total cycle time of scraper}}{\text{Total cycle time of pusher}}$$

For a scraper loading time of 1 minute, the pusher cycle time will be of the order of 2-3 minutes, depending upon the scraper volume and job conditions.

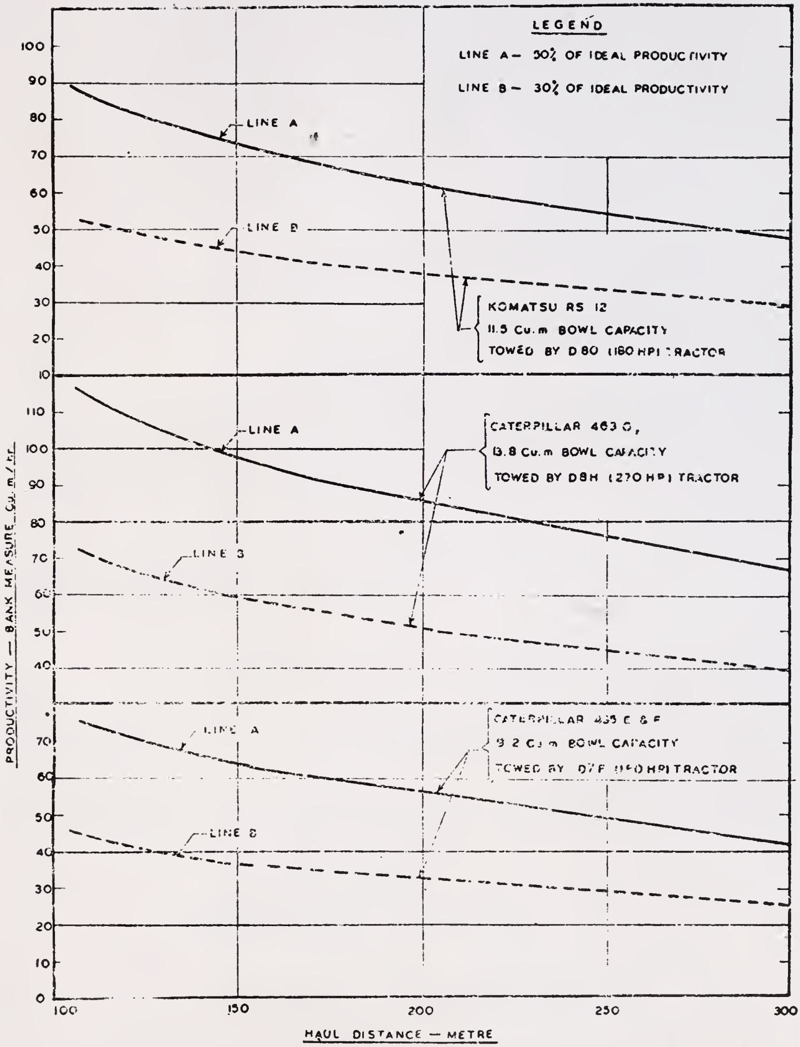

Fig. 6. Productivity of towed scraper

(2) Practical productivities of scrapers of 7, 12 and 12.8 cu.m. bowl (struck) capacity corresponding to 30 per cent (line B) and 50 per cent (Line A) of the ideal productivities are plotted against haul distance in Fig. 7. Average of the Lines A and B may be used for planning purposes.

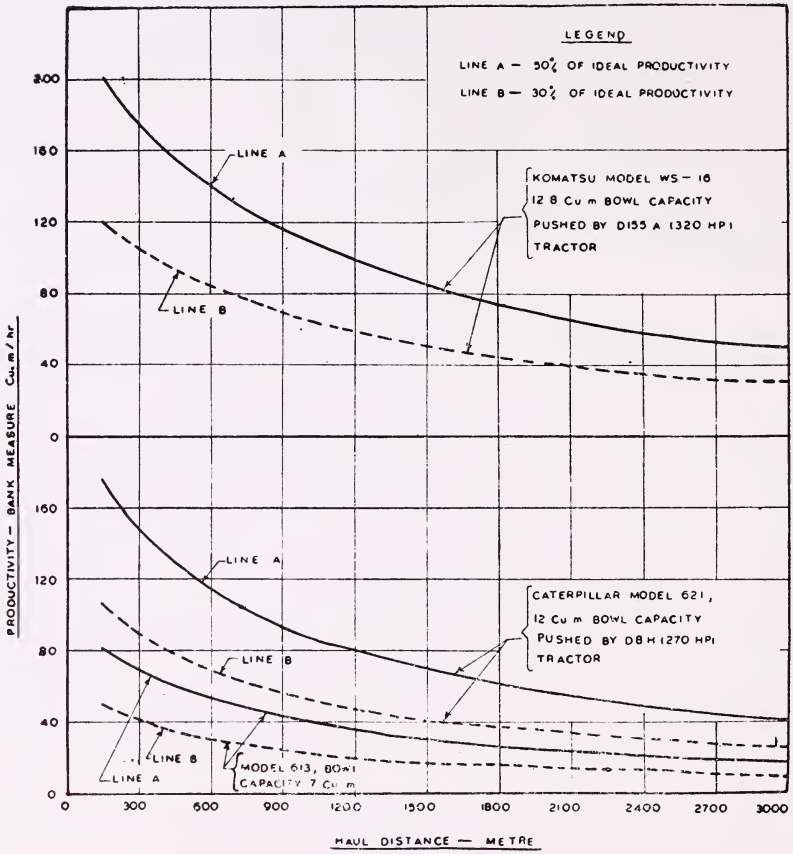

Fig. 7. Productivity of motorised scraper

6.4.6. Shovel/front end loader—dump truck

(1) Shovel/front end loader—dumper combination can be used for picking up blasted/excavated material and dumping in fill areas, picking up materials like moorum/gravel/sand, etc. from the sources and hauling to work site, or for digging earth from inclined faces and hauling, or hauling earth over distances beyond the economic leads of scrapers. Front end loaders by themselves can also be used for feeding hoppers of hot mix plants with aggregates.

(2) Productivity of front end loaders depends on the bucket size and haul distance, and can be taken to be 50-80 per cent (Line B and Line A) of the ideal output. The corresponding productivities for front end loaders of 0.8, 1.15 and 1.3 cu. m. capacity are plotted in Fig. 8. The mean of lines A and B may be taken for planning purposes.

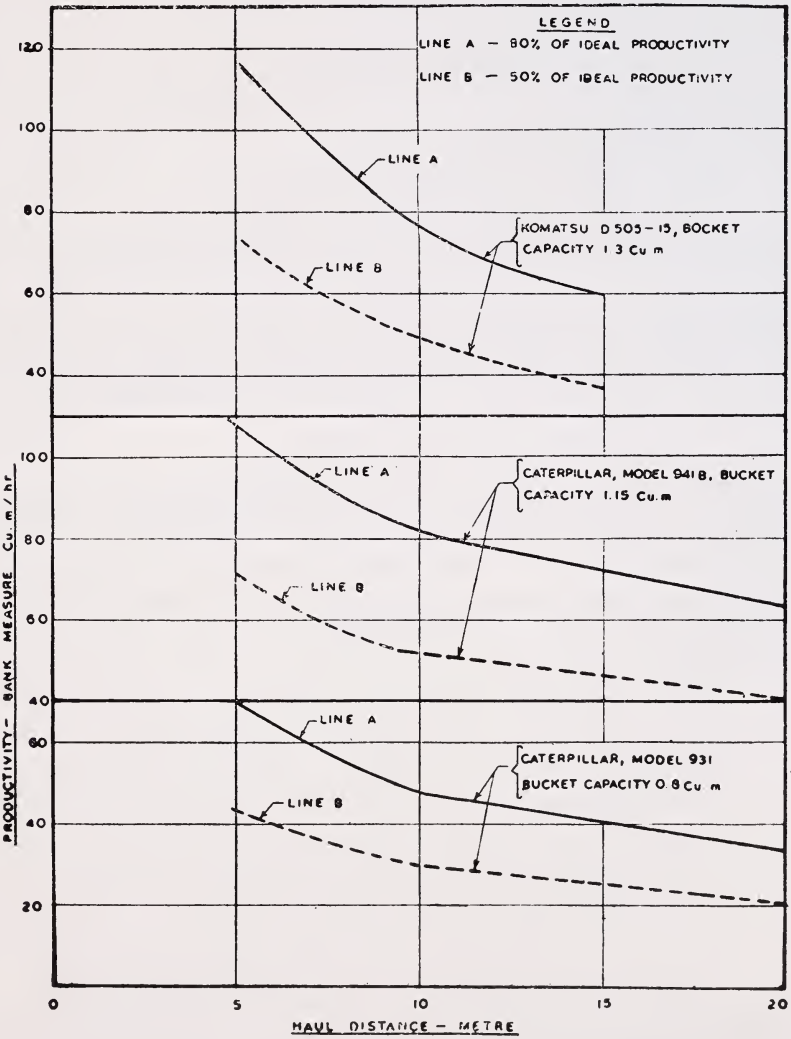

Fig. 8. Productivity of front end loader/excavator

(3) The excavator/loader and the hauling units should be properly matched in size and number for optimum working. As a rough guide, the size of hauling unit may be fixed to provide a capacity of 4 to 6 times the capacity of the loader bucket. After selecting two or three possible sizes, the number of haul units per loader as also the unit cost of handling the job are calculated for choosing the most economical alternative.

(4) Sample calculations for finding the matching number of haulage units for a job of earth excavation from side-hill and dumping over a distance of 3 km are given in Table 15.

TABLE 15. SAMPLE CALCULATIONS FOR EARTHWORK WITH FRONT END LOADER AND DUMP TRUCKS

DATA

Ordinary earth is to be excavated from sloping face. Haul distance of loading 10 m. Dump trucks 7-tonne capacity are available. Haulage for dumper is 3 km. Speed loaded = 15 km/h. Speed empty = 20 km/h. Swell factor = 0.8.

CALCULATIONS

1. Capacity of dumper = 7 tonne = 4.7 cu.m. loose choose excavator/loader bucket capacity of 1.15 cu.m. (1.5 cyd) which is about one – fourth the capacity of the hauling unit.
2. Productivity of loader for average of lines A & B (Fig. 8) = 67 cu.m (bank)
3. Bank volume carried by truck per trip = 4.7 × 0.8 = 3.76 cu.m.
4. Productivity of truck :

   Truck loading time $= \frac{3.76}{67} \times 60 = 3.4$ min.

   Travel time (loaded) $= \frac{3}{15} \times 60 = 12$ min.

   Travel time (return) $= \frac{3}{20} \times 60 = 9$ min.

   Truck fixed time (turning, dumping) = 2 min.

   Total cycle time = 3.4 + 12 + 9 + 2 = 26.4 min.

   No. of cycles made by truck/hr = 60/26.4 = 2.27

   Productivity of one truck = 2.27 × 3.76 = 8.6 cu.m (bank)

   Number of trucks required for each loader = 67/8.6 = 7.8 or 8
5. The productivity of one excavator/loader and 8 dump trucks will be 67 cu.m/hour (bank measure).

6.5. Other Road Construction Equipment

6.5.1. Compaction plant

(1) Whether the job is labour-based or equipment intensive, power rollers are required. For mechanisation of major highway or airfield jobs, it will be advantageous to go in for heavier and higher efficiency compaction plants in place of the traditional three-wheeled static rollers, for achieving better compaction and higher productivity.

(2) One such plant is the 8-10 tonne vibratory roller which is equivalent in compactive effort to 20-25 tonne static rollers. The principle is that the vibrations imparted by the roller drum causes the particles of material to shift themselves into the tightest arrangement. This type of roller is suitable for compacting granular soils, granular base and sub-base materials and in the break-down rolling of bituminous mixes. Because of the higher compacting efficiency, higher degree of compaction can be achieved, or a deeper lift can be constructed with the same number of passes.

(3) Another specialised compaction plant is the pneumatic tyred roller which compacts by the principle of kneading action. This type of roller generally has two axles with four to nine wheels each. The wheels are arranged so that the rear ones run in the spaces between the front ones, thus leaving no ruts. The chassis of the vehicle is also a container for solid or liquid ballast. The rollers which may be towed or self-propelled can be of different weights. A 8-10 tonne capacity roller is ideally suited for compacting surface dressings without crushing the aggregate. As regards soil compaction, pneumatic tyred rollers will work on most types of soils except heavy clays. A heavier 40-50 tonne roller is appropriate for achieving higher densities corresponding to modified AASHO density as is required for airfields and also for proof rolling.

(4) For compacting cohesive soils, sheepfoot roller is the suitable equipment. It can be towed or self-propelled, and the units range in weight from 2 to 20 tonnes with feet projecting from 175 to 225 mm. Compaction starts from lower layers and proceeds

upwards and the roller is removed when the compaction is complete. The maximum depth which the roller can compact is about 5 cm more than the length of the feet.

(5) For optimum utilisation of the compaction plant, it is essential that the capacities of the hauling and spreading plants must be matched and be adequate so that none of the equipment remains idle.

6.5 2. Watering for compaction

(1) For earth compaction and compaction of similar materials like moorum, the moisture content of the material before compaction will have to be adjusted so as to bring it near about the optimum moisture content. Water bound macadam construction will require a lot of water during compaction for driving in the filler material. This water will have to be arranged by pumping from suitable locations and brought to site for sprinkling on the soil/material to be compacted.

(2) Usually, two types of water tankers are used, truck mounted and trailer mounted The tankers may be of 4000-5000 litre capacity fitted with sprinkler arrangement. Where water is to be used continuously, truck-mounted tankers which have higher travel speeds may be convenient. Trailer mounted type has the advantage that the tractor can be used in conjunction with 2 or 3 trailers so that the power unit dces not remain idle during filling. The tractor can also be put to some other use at times when watering is not required.

(3) Productivity of water tankers can be calculated from the unit capacity and cycle time. As in the case of other hauling equipment, the cycle time comprises two components, fixed time involved in filling, turning and spraying, and variable time which depends on speed and haul distance.

(4) Table 16 illustrates the working of tractor-drawn water tanker for earthwork job.

6.5.3. Air compressor

(1) Air compressors of 3-4.5 cu.m/min capacity operating a single jack hammer will be very useful for exploratory work on

TABLE 16. SAMPLE CALCULATIONS FOR WORKING OF TRACTOR-DRAWN WATER TANKER ON EARTHWORK JOB

DATA

Capacity of water tanker = 4000 litres

Haul length for water = 2 km

Speed of tractor – loaded 5 km/hr and empty 8 km/hr

Quantity of earthwork = 60 cu m./day (bank volume)

Swell factor for soil = 0.8

Moisture content of borrow = 6%

Optimum moisture content = 15%

CALCULATIONS

1. Additional moisture to be added (including 1% extra for evaporation losses) $= 15 - 6 + 1 = 10\%$

2. Quantity of soil catered for by one round of tanker $= \frac{4000 \times 100}{10 \times 1000} = 40$ tonnes or 25 cu m loose

3. Length of soil spread covered by one run of tanker for 2.5 m width and 250 mm loose thickness $= \frac{25}{2.5 \times 0.25} = 40$ m

4. Cycle time of tractor

   Haul time loaded $= \frac{2}{5} \times 60 = 24$ min

   Haul time empty $= \frac{2}{8} \times 60 = 15$ min.

   Spraying time (speed = 3 km/hr) $= \frac{60}{3000} \times 40 = 0.8$ min.

   Time for hitching/unhitching tanker, turning, etc. = 2 min.

   Total cycle time $= 24 + 15 + 0.8 + 2 = 41.8$ min.

5. Productivity of tractor/hr $= \frac{60}{41.8} \times 4000 = 5750$ litres

6. Volume of earth catered for by one tractor tanker $= \frac{5750}{4000} \times 25 \times 0.8 = 28.6$ cu.m (bank)

7. Number of watering units required $= 60/28.6$ = say 2 nos.

hill road construction. This unit can be transported by manual labour or by animals from one site to another For subsequent development work, air compressors of 6-10 cu.m/min capacity operating two jack hammers would be found suitable.

(2) The output of a compressor and the air consumption of pneumatic tools are affected by altitude and humidity, while performance is affected by the loss of pressure in the pipelines. Adequate care should be taken to ensure that all the connections are tight and there is no leakage in the system.

6.5.4. **Stone crushing plant :** For production of aggregate, stone crushers of 400 mm × 225 mm and 400 mm × 280 mm capable of producing 14—18 tonnes/hr are suitable. Granulators of sizes 300 mm × 175 mm and 300 mm × 100 mm are capable of yielding 5—8 tonnes/hr, and are suitable for producing smaller size aggregates. For major construction jobs requiring large quantities of aggregates, it will be advantageous to install 100—150 t/hr capacity base crushers and 50—100 t/hr secondary crushers.

6.5.5. **Hot mix plant :** Hot-mix plants of 20—30 tonne/hr or 30—45 tonne/hr capacity can be used for mechanised paving works in conjunction with tipper trucks and paver-finisher. Generally. such plants in one location can cater for 20—30 km of road on either side. For optimum working of the system, the following points need attention :

(i) All the materials needed for the plant must be available at site in time. It will be preferable if aggregates required for atleast 15 days are stock piled at site.

(ii) The number of tipper trucks must be matched with the plant output.

(iii) The work of cleaning the road surface and applying tack coat should proceed sufficiently in advance so that the paving work need not have to stop on this account.

(iv) Front end loaders of adequate capacity should be employed for loading cold feed bins.

Sample calculations for paving 50 mm thick bituminous macadam using 30—45 tonne capacity hot-mix plant are given in Table 17.

TABLE 17. SAMPLE CALCULATIONS FOR PAVING 50 mm THICK BITUMINOUS MACADAM

DATA

Length of road to be paved with 50 mm BM	= 40 km
Width of paving	= 7 m
Hot-mix plant output	= 30 tonnes/hr
Binder content of mix	= 3.5%
Compact density of layer	= 2.1 gm/cc
Capacity of tipper truck	= 5 tonnes
Speed of truck—loaded 20 km/hr, empty 30 km/hr	
Average haul distance for mix	= 10 km

CALCULATIONS

1. Time for hot-mix plant to produce 5 tonnes of mix $= \frac{5}{30} \times 60 = 10$ min.

2. Cycle time for tipper truck
   - Loading time = 10 min.
   - Haul time loaded $= \frac{10}{20} \times 60 = 30$ min.
   - Haul time empty $= \frac{10}{30} \times 60 = 20$ min.
   - Time for discharging into paver = 2 min.
   - Time for turning = 2 min.
   - Total cycle time = 64 min.

3. Productivity of tipper/hr $= \frac{5}{64} \times 60 = 4.7$ tonnes

4. Number of tippers required = 30/4.7 = 6.4 or say 7

5. Provide a paver-finisher of 50 tonne/hr capacity

6. Assuming effective working time of 7 hrs/day, output/day $= 7 \times 30 = 210$ tonnes

7. Area paved/day $= \frac{210}{0.05 \times 2\ 1} = 2000$ sq.m. or 285 m length

8. Number of working days for plant $= \frac{40 \times 1000}{285} = 140$

9. Bitumen consumption/day $= \frac{210 \times 3.5}{100} = 7.35$ tonne

10. Aggregate consumption/day $= 210 - 7.35 = 202.65$ tonne
    = 135 cu.m (loose)

6.5.6. **Soil stabilisation :** Single pass stabilizer capable of cutting the soil to the desired depth, pulverising and mixing it with the stabiliser and laying the mix to level and regularity in a single pass can be used for soil stabilisation.

7. COST CALCULATIONS

7.1. General

7.1.1. Cost calculations in road construction projects are necessary for the following purposes :

(i) Cost comparison at the task level for the different technically feasible construction methods for selecting the least cost method. The costing is usually done in terms of unit costs, i.e. the cost per unit of output, for example, cost per cu.m. of earthwork.

(ii) Cost comparison for the choice of pavement materials. For example, prospecting of aggregates from a quarry may involve higher initial installation cost but lower haulage cost compared to another alternative. Similarly comparison may be required for the use of permissible but poorer locally available pavement material which has to be used in larger thickness *vis-a-vis* a better material available from longer distances.

(iii) Costing of the total job for the preparation of financial estimates for processing and sanction by the appropriate authorities.

7.1.2. For all the purposes mentioned above, the starting point will be the unit cost. The unit cost of a task can be calculated by multiplying the input coefficient for the resources performing the task by the rate for the resource. The rate is the cost of the resource per unit of time, e.g. per hour or per day, except in the case of construction materials when it is the cost per cu.m. tonne, etc. If two or more resources are involved in the task, the product of input coefficient and rate should be calculated separately for each item and the products added.

7.2. Costing of Labour-based Methods

7.2.1. Tables 4 through 9 give the input coefficients for different labour-based activities as derived from the World Bank Study. The input coefficients are in terms of working time in ours, and their reciprocals give the output per man-hour (working time). The output per man-day can be calculated by knowing the working hours in a day which may be 5.5—6 hours for daily-paid wage system and 8 hours for the incentive piecework system.

7.2.2. The cost of unit output of an activity can be computed by multiplying the input coefficient and the rate per working hour. The rate for daily paid labour which is on day basis is governed by statutory minimum wages. The day wage can be converted into working hourly wage by dividing the former by the effective working hours in a day. For example, unit cost of excavation can be calculated as follows :

Input coefficient (ordy. soil, daily paid labour, Table 4)	= 0.8 man/hr (WT/cu.m)
Working hours in a day	= 6 hrs
Wage rate	= Rs 6/day
Working hourly rate	= 6/6 = Re 1
Cost of activity	= 0.8 × 1 = Rs 0.8/cu.m.
Output per labourer	= $\frac{1}{0.8} \times 6 = 7.5$ cu.m./day

7.2.3. For tasks involving more than one resource, e.g. labour, animal cart, etc., the unit cost for each resource is calculated and added together for finding the total unit cost. An example of excavation, loading, hauling and unloading earth using animal cart is illustrated below :

Excavation input coefficient	= 0.8 man-hr/cu.m.
Loading input coefficient (height of loading 1.5 m)	= 0.98 man-hr/cu.m.
Excavation + Loading	= 1.78 man-hr/cu.m.
Input coefficient for hauling and unloading by animal cart (assumed)	= 0.75 cart hr/cu.m.
Labour rate	= Re 1/hr (WT)
Cart rate (including driver)	= Rs 3/hr (WT)
Unit cost of labour	= 1.78 × 1 = Rs 1.78/c.um.
Unit cost of cart	= 0.75 × 3 = Rs 2.25/cu.m.
Unit cost of task	= 1.78 + 2.25 = Rs 4.03/cu.m.

7.3. Costing of Equipment-intensive Methods

7.3.1 The cost of using capital equipment is usually divided into four broad heads, namely :

(i) Ownership charges relating to the cost of the equipment brought to site spread over the expected working hours during its life till it is sold out or scrapped.

(ii) Repair charges.

(iii) Running charges which include wages of operators and cost of P.O.L. etc.

(iv) Overhead charges.

The usually accepted norms for calculating the usage charges of equipment are given in Table 18.

TABLE 18. NORMS FOR CALCULATING USAGE CHARGES OF MACHINES

I. OWNERSHIP CHARGES	
(A) Total investment at site of work (This includes cost of equipment, sales tax, excise and other duties, transport expenses consisting of freight, insurance, loading/unloading, erection and commissioning)	= A
(B) Deduct salvage value @ 15% of A	= 0.15A
(C) Total investment to be depreciated	= A-B = 0.85A
(D) Economic life of the machine (Working hours)	= varies by type of machine and operating conditions from 10,000 to 15,000 hrs
(E) Depreciation per hour	$= \frac{C}{D}$
For the case of 10,000 hrs	$= \frac{0.85\ A}{10{,}000}$
(F) Storage charges (1% of E)	$= \frac{0.0085\ A}{10{,}000}$
(G) Total cwnership charges = E + F	$= \frac{0.8585\ A}{10{,}000}$
II. REPAIR CHARGES	
(H) Repair charges per hour including maintenance and replacement of tyres	$= 1.5\ \frac{C}{D} = \frac{1.275A}{10{,}000}$
III. HIRE CHARGES = G + H	$= \frac{1{,}1335\ A}{10{,}000}$

Note : The fixed hire charges per hour can be directly computed by dividing 1.1335 times the investment cost by the useful life in hours.

IV. RUNNING CHARGES

(a) Diesel oil consumption

$$= \frac{\text{BHP} \times \text{load factor (0.6)} \times 0.5}{7.4} \times 3.785 \text{ litres/hour}$$

$$= 0.154 \times \text{BHP litres/hour (Approx.)}$$

(b) Lubricating oil consumption

$$= \frac{BHP \times 0.6 \times 0.006}{7.4} \times \frac{C}{t} \times 3.785 \text{ litres/hour}$$

Where $C = 0.06 \times BHP$

t = time for changing oil = 100 hrs

(c) Other lubricants, grease, cotton waste etc. are assumed to cost twice the cost of lubricating oil in the case of heavy machinery and the same cost in the case of others.

(d) Wages for operating staff—For staff on regular strength, the annual wages is divided by the annual utilisation in hours in a year.

V. **OVERHEAD CHARGES**

Taken as 5% of the total charges per hour.

Notes : 1. Repair charges (H) taken as equal to 150 per cent of depreciation reflects the average for both wheeled and tracked vehicles considered together. This can also be calculated in one other way. namely, by separating out the cost of replacement tyres and the repair charges for other items.

2. The diesel oil consumption depends on the condition and age of the engine, and the equation given in IV (a) is for average conditions. The load factor for different machines also varies, and the value 0.6 represents average conditions. The oil consumption is for the prime mover and does not include that for heating aggregates etc. as in the case of hot mix plants.

3. Interest charges have not been added in the calculations. These will, however, have to be included where a machine is given out to contractors or for economic analysis.

7.3.2. The usage charges for some of the commonly used earth moving equipment are worked out in Table 19. For other equipment too, the charges can be computed on similar lines.

7.4. Comparison of Cost of Road Construction Jobs by Different Methods

7.4.1. The following cases of earthwork have been taken to illustrate cost comparison :

(i) *Short haul of 20 m*

(a) Labour intensive method of headbasket

(b) Equipment intensive method using 90 HP dozer

(ii) *Long haul of 3 km*

(a) Manual excavation, loading, hauling by flat-bde truck and manual unloading/spreading.

TABLE 19. USAGE CHARGES FOR SOME EARTHMOVING EQUIPMENT

Sl. No.	Equipment	Cost at site Rs lakhs	Econo-mic life 000' hrs	Hire charges Rs/hr	Fuel consump-tion litre/hr	Running charges Rs/hr				Usage charges col. 5 + col. 10+ overhead @ 5%
						Fuel cost	Oil+other lubricants	Opera-tor wages	Total running cost	
1	2	3	4	5	6	7	8	9	10	11
1.	Dozer, 90 HP	10.2	10	115	16	48	9	10	67	190
2.	Front end loader—1.15 cu.m (1.5 cyd) bucket	9.0	10	112	10	30	8	10	48	168
3.	Tipper truck 7-8 t capacity	2.5	10	28	6	18	6	8	32	63
4.	Flat-bed truck, 5 t	1.75	10	20	5	15	5	8	28	50

Notes: 1. Cost of diesel is taken as Rs 3/litre.

2. Operator wages per hour has been computed by dividing the total annual wages by 1200 which is taken as utilisation hours in a year.

3. Hire charges = ownership charges + repair charges. See Table 18 for the norms.

(b) 1.15 cu m. bucket loader/excavator, tipper trucks for hauling and spreading by 90 HP dozer.

The calculations for the labour and equipment methods are given in Tables 20 and 21 below :

TABLE 20. COST OF EARTHWORK BY MANUAL METHODS

A. **SHORT HAUL** (20 m)

The same case as worked out in Table 11 is taken.

The productivity for a gang of 20 persons = 15.5 cu.m/hr
= 124 cu.m/day

Usually a pieceworker earns about twice that of a daily paid worker. Assuming the daily earnings as Rs 12/day, cost per cu.m (bank measure) $= \frac{12 \times 20}{124} =$ *Rs 2*

B. **LONG HAUL** (3 km)

The same case as worked out in Table 12 is taken.
The productivity of a gang of 22 men plus one 5-t flat-bed truck was 36 cu.m/day.

Wages for Labour	= 22 × 12 = Rs 264/day
Usage charges for truck	= Rs 50/hr
—for 8 working hrs.	= Rs 400

Cost per cu.m. (bank measure) = 664/36 = *Rs 18.4*

Note : The cost figures do not take into account incidental expenses such as those on labour mobilisation, provision of health, travel and accommodation facilities to labour, small tools and plant, etc. Also, it should be understood that the unit wage rate assumed is only for the purposes of this example, and the actual prevailing/statutory wage rates should be applied for actual cases.

TABLE 21. COST OF EARTHWORK BY EQUIPMENT — INTENSIVE METHOD

A. **SHORT HAUL** (20 m)

Job details	: Excavation in ordinary soil by dozer : and hauling/spreading at an effective haul distance of 30 m	
Equipment	: 90 BHP Dozer	
Productivity	: Taken as mean of lines A and B (average conditions) in Fig. 5	
Calculations	: Productivity of dozer	= 80 cu.m/hr (from Fig. 5)
	Usage charges for dozer	= Rs 190/hr (from Table 19)
	Cost per cu.m	= 190/80 = *Rs 2.4*

B. **LONG HAUL** (3 km)

The same case as worked out in Table 15 is considered. The productivity of 1.15 cu.m loader/excavator and 8 tipper trucks will be 67 cu.m/hr.

Usage charges for loader	= Rs 168
Usage charges for 8 trucks	= 8 × 63 = Rs 504
Cost of spreading (using 90 HP Dozer)	= Rs 190
Total usage cost/hr	= Rs 862
Cost per cu.m	= 862/67 = Rs 12.9

The picture emerging is :

Cost/cu.m (bank measure) Rupees

	Haul 20 m	*Haul 3 km*
(i) Labour method	2.0	18.4
(ii) Equipment method	2.4	12.9

This would show that while the labour methods will be generally cheaper for shorter hauls, equipment methods would be more economical for longer hauls.

7.4.2. As discussed in detail in the earleir sections, each method has its own advantages and disadvantages, and the choice has to be judicious taking all the factors into account. Whatever be the method chosen, the objective should be to look for measures for improving the productivity through organisational and managerial measures. While motivation of a large labour force for improved productivity will be a crucial factor for labour methods, for equipment intensive methods it will be better training of operators and prompt and better maintenance facilities for the equipment.