THE FUNDAMENTAL PRINCIPLES OF ROAD ENGINEERING

A BASIC TEXT BOOK FOR ENGINEERING STUDENTS]

by

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THE FUNDAMENTAL PRINCIPLES OF ROAD ENGINEERING

In this edition, Metric system of units has been used side by side with British system of units

By the same author:

The Fundamental Principles
of
Irrigation Engineering

•

The Fundamental Principles
of
Hydraulics Vol. I

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With many loves
dedicated
to
my dream, my hope, my refuge

FOREWORD

Road development is gaining increasing importance in the planned economy of our country. This is evident from the allocation of Rs. 5,200 crores proposed by the Chief Engineers of the States for the next twenty years (1961-81) which I had the honour to announce as the Second Road Plan for India, presiding over the Silver Jubilee Session of the Indian Roads Congress early this year in Bangalore.

The first milestone of road development in India is known as Nagpur Plan and was conceived in 1943. It is gratifying to know that the targets proposed in this Plan will have been realised by 1961, two years earlier than anticipated. The Second Plan envisages the total increase in mileage in the country from 379,000 miles to 657,000 miles. The target proposed is not too ambitious even when fully implemented: many villages of our country will still be 4 miles from a metalled road and 1½ miles from any road, and it will take considerably a bigger effort to bring all villages on the road.

In the New Plan, while thousands of miles of new roads will have to be constructed, it will be nonetheless necessary to upgrade the surfacing of thousands of miles of existing roads which are crumbling under speed, weight and intensity of traffic as were never anticipated before the war.

Examined in this context, it will hardly be necessary to emphasise the need of adequate training in the basic principles of road-making in our engineering institutions. In my opinion, Prof. V. B. Priyani's book *admirably* fulfills this purpose. Covering (as it does) syllabii of various universities, Prof. Priyani has done a good turn to the students of engineering in general and Western India in particular.

The lucid exposition of the fundamentals and presentation of the *present* practice and *modern* trend is an asset of this text-book. It is also refreshing to see the progressive approach and *constant* revision in the later editions. The author has adopted standards as advocated by the Indian Roads Congress. Prof. Priyani has added sufficient material in chapters on Traffic Engineering, Airport Engineering and Earthwork Computations in his latest edition. I would request him further to add a chapter on Express Highways with limited access and grade-separation which have now come to stay. In fact, we have made a beginning in Bombay to take out the through traffic for national highways leading to Bombay, Delhi and Madras by Eastern Express Highway and, Bombay-Ahmedabad-Rajasthan-Delhi to the North and Okha to the West by the Western Express Highway. In Calcutta, the projects are under way of Express Highways for connecting Calcutta with the steel cities of Durgapur in one direction and Jamshedpur and Rourkhela in the other. It will also be useful to add a chapter on road research and the necessity of preparing the structural-designs for pavements.

I welcome this treatise on highway engineering and practice which, I am sure, will be *extremely useful* to the students of engineering and also the professional engineers in the field.

September 30, 1960

U. J. Bhatt

Chief Engineer (Roads, Buildings and Ports) and Joint Secretary to the Government of Gujarat, Public Works Department.

PREFACE TO FIRST EDITION

Road Engineering is a science regarding roads and who has not seen a road? In fact our association with road is since the day we learnt to walk and we shall have association with it as long as there is breath in us. It stands to reason therefore that an object of life-long association must be of great importance to us; who can deny that a number of books must have been written on so common and so important an object as road? All the same, it is a well-known fact that many books miss their mark when they are not restricted to a particular class of readers. Mixed traffic (i.e. vehicles, cyclists and pedestrians etc.) if allowed on an important road invariably results in sad accidents and, will not a book written for mixed readers (i.e. readers of different classes, different tastes and different understanding) inevitably result in ill-understanding and ill-digestion on the part of many? The present book is different from other books on road engineering in this respect that it presents only the *basic* principles of road engineering and, as such, will have its great utility to beginners namely, the student community of engineering polytechnics and colleges. Also the treatment of the subject matter is step by step and hence systematic as it should be presented to a beginner. This has been possible because the author has experience of teaching road engineering to both the degree and diploma classes of his college.

The book offers sufficient material to the student to prepare himself for the entire syllabus in road engineering prescribed by the Universities of Bombay, Gujarat, Vallabh Vidyanagar, Poona, Baroda and Karnatak. It also covers the syllabii in road engineering prescribed by *practically all* other Indian Universities. The syllabus treated in this book is given at the end of the book.

The author gratefully acknowledges the help received, in writing this book, from many standard works on road engineering including text books by Indian and foreign authors and the technical papers and journals published by learned professional bodies on road engineering. Special mention must be made of the books, journals, technical papers and other literature published by Indian Roads Congress. The Indian Roads Congress has indeed done admirable work in connection with the development of roads in India. The principles and practices mentioned in

this book are mostly based on the recommendations of Indian Roads Congress.

The author is highly indebted to Mr. B. D. Patel, the retired road engineer and the present Vice-Chancellor of Sardar Vallabhbhai Vidyapeeth, Vallabh Vidyanagar for using his notes on road engineering which were written by him soon after his retirement. These notes incorporate his rich and praise-worthy practical experience of over 15 years in the design, construction and maintenance of all types of roads in the States of Bombay and Sind. His meritorious services as an eminent road engineer in Bombay and Sind were duly recognised and appreciated by the then governments of these two States. The rich experience of this practical road engineer thus finds outlet in the pages of this book.

The author is also thankful to all those *good* men who helped in the preparation of this book.

May the book serve those for whom it is written!

Vallabh Vidyanagar
15th March, 1956

V. B. Priyani

PREFACE TO SECOND EDITION

Following are the *additional* features of this revised and enlarged second edition:

(i) Chapter on Airport Engineering.
(ii) Chapter on Earthwork Computations.

With the growing importance of air-transport, it was felt necessary to add a chapter on the elements of this important subject of airports. Also, a chapter on earthwork computations is added to make the subject matter of earthwork, already treated in the book, complete. The matter of the first edition has also been revised and enlarged.

The author heartily thanks 'The Associated Cement Co. of India, Bombay' for their courtesy shown in allowing him to print the photo of Marine Drive, Bombay on the jacket of this book.

With these new features, may the book be more useful!

Vallabh Vidyanagar
25th March, 1958 **V. B. Priyani**

PREFACE TO THIRD EDITION

The text of second edition has been revised and a few additions have been made in the matter of that edition. Special additions have been made in the chapters on:

(i) Traffic engineering.
(ii) Airport engineering.
(iii) Earthwork computations.

It is hoped that this new edition will prove more useful to the students of road engineering.

Vallabh Vidyanagar
5th April, 1960 **V. B. Priyani**

PREFACE TO FOURTH EDITION

The text of third edition has been revised and a few additions have been made in the matter of that edition so as to make the book uptodate; a few additions have been made in practically all chapters. Following are the *additional* features of this revised and enlarged fourth edition:

(i) Chapter on 'Elementary Problems and Designs in Road Engineering'.

(ii) Appendix on 'Geometric Road Standards'.

With these additions, the book will *undoubtedly* be of more utility to those for whom it is meant. Be it so!

Vallabh Vidyanagar
6th December, 1961 **V. B. Priyani**

PREFACE TO FIFTH EDITION

In this new edition, Metric system of units has been used along with the British system of units. Also one more chapter by title 'Metric system of units in Road Engineering' has been added at the end of the book.

It is hoped that the new additions will make the book still more popular.

Vallabh Vidyanagar
23rd June, 1964 **V. B. Priyani**

PREFACE TO SIXTH EDITION

Following are the *additional* features of this revised and enlarged sixth edition:

(i) The text of fifth edition has been revised and a few additions have been made in the matter of that edition.

(ii) Chapter on 'Road Research' has been added. It is hoped that this chapter will prove useful and thought-provoking.

That the present book has gone through *six* editions in just *one* decade shows that its judicious readers have acclaimed and adopted it as *their basic book* on Road Engineering.

Vallabh Vidyanagar
12th April, 1966 **V. B. Priyani**

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THE FUNDAMENTAL PRINCIPLES OF ROAD ENGINEERING

ROAD ENGINEERING

CHAPTER I

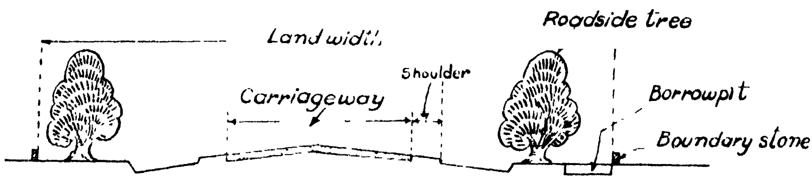
DEFINITIONS AND GENERAL

1. Introduction: This chapter will deal with a few articles of general interest. The study of these articles will broaden our outlook regarding roads and will fill us with interest and enthusiasm to study the subsequent chapters.

Note: Readers are advised to study chapter XXIV on Metric system before reading any further articles of chapter I.

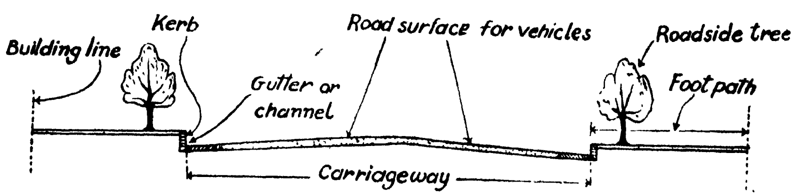
2. Definitions: To define a road will be to make an easy and familiar thing more easy and more familiar; but then the function of any book worth its name is to make difficult things easy and easy things easier still. Throughout this treatise, this main function of a book is kept in view. We will therefore make our conception of road more clear by saying that a *road* is a convenient way over which vehicles, cyclists, pedestrians etc. may lawfully pass for going from one place to another. The vehicles, cyclists and pedestrians are together known as *traffic* on the road. Traffic has *right-of-way* over the road. Right-of-way is defined as the privilege of use of a way; this privilege is acquired by the traffic by law, custom or usage. Usually the term '*highway*' is used in place of '*road*' but it is better to define highway as an important and special road in a road system. The science concerning roads is called *road engineering* and the gentleman who looks after the design, construction and maintenance of roads is called a *road engineer.*

A road connecting one town with another is called a *country road* (see fig. 1) or a road in open country while a road within a town or city is called a road in *urban area* (see fig. 2) or a road in built-up area. It is but natural that the requirements of these two kinds of roads will be different according to the needs of traffic using them. A *street* may be defined as a road, within a town or other centre of habitation, which has become partly or wholly defined by buildings constructed along one or both of its sides (i.e. frontages). It is thus a road in built-up area. Where the traffic is heavy (as in the case of city streets) and there is danger of accidents in allowing mixed traffic (i.e. traffic consisting of vehicles, cyclists and pedestrians) on a road, the way or path for each class of traffic is separately demarcated to avoid accidents. The portion of roadway used by vehicular traffic (i.e. bullock cart and motor traffic etc.) only is called a *carriageway* (see fig. 1). In the case of country road, carriage-



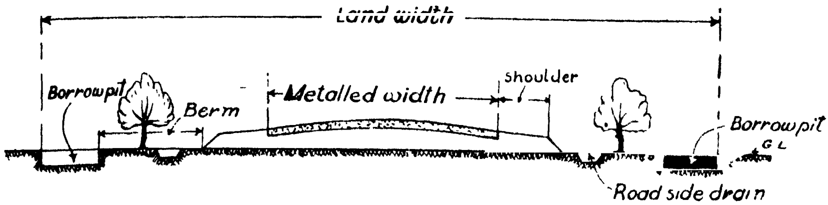
Cross section of country road
FIG. 1

way is protected by 1·20 m to 1·80 m (4′ to 6′) wide shoulder of good soil or other material on each side of the carriageway. This shoulder provides lateral stability to carriageway; it also allows a vehicle to be accommodated on it in case of emergency. The portion of traffic-way or road-way used by



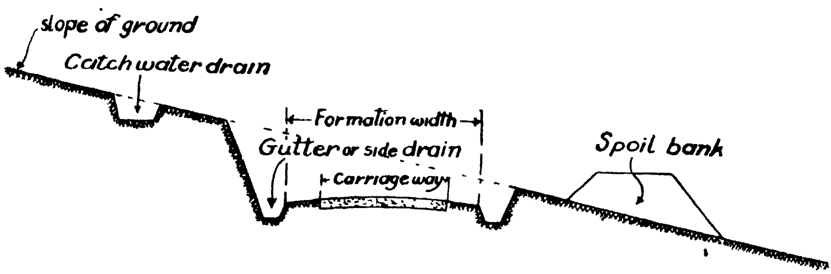
Cross section of road in urban area
FIG. 2

pedal bicycles only is called a *cycle track* and that used by pedestrians only is called a *foot path* or *foot way* or *side walk* (see fig. 2) Sometimes a carriageway is reserved for use by high speed power-driven vehicles *only*. It is then called a *motorway* or *express highway* or *super highway.* A road (see fig. 3)



Cross-section of road in plain country;
the ground has no appreciable cross slope.
FIG. 3

may be in a plain country like that of Gujarat, Uttar Pradesh or it may be in an undulating country like that of Deccan, Kashmir or Himalayan regions. The road in an undulating area is called a *hill road* or *ghat road* (see fig. 4).



Cross-section of road in a hilly area;
the ground has appreciable cross slope.
FIG. 4

3. Benefits of roads: Following are some of the advantages of roads:

(a) Roads facilitate communication on land i.e. they make it easy for traffic to go from one place to another.

(b) They are essential for economic prosperity and *general* development of a country. The country having *comparatively* more mileage of good roads is said to be more advanced and prosperous country.

(c) Roads help in the growth of trade and other economic activities in and outside the villages and towns.

(d) Roads help in keeping the cultural and educational contact with strangers and thus they broaden the outlook of the population keeping such contact.

(e) Roads serve as feeder lines for railways, waterways and airways and thus they help the development of these classes of transport.

(f) Good net-work of roads helps in the defence of a country during war time, not to talk of the facility that it affords in the time of aggression.

(g) Better law and order can be kept within the country itself if it has a good system of roads.

Thus we see that the progress and well-being of a nation, interalia, depend on roads. Indeed, roads are the life lines of a nation's economy.

4. Importance of roads in India: "A country pays for the roads whether it has them or not -- and it pays more for those roads which it does not yet have." This stresses the urgent and dire necessity of the planning and development of adequate road system in any country. Indeed, roads are an imperative economic necessity to-day. Likewise, the importance of roads in a vast country like India can scarcely be exaggerated. A system of well designed, well constructed and well maintained roads is essential for India's economic and cultural progress. The roads have also a vital role to play in the defence of India. India's deficiency in the matter of roads has contributed very largely to her agricultural, commercial and industrial draw-backs to-day. In India, the total length of all classes of roads is round about 6 lakhs kilometres. The most serious defect however is the improper and inadequate road transport between villages and, between villages and markets. Another drawback of our present-day road system is that it is unbalanced and top-heavy. The national highways (i.e. roads of national importance) are, for example, comparatively more highly developed than the district and village roads. India is a country of villages and it is the village and district roads that will help in the development of her economic progress. Unfortunately, this day, most of the village roads are only *fair-weather roads* i.e. roads which can be used by traffic in fair weather (or non-monsoon season) only. With the arrival of monsoon, these roads are turned into mud and pools of dirty water and, they become unpassable. India lags behind many other countries so far as the length of roads is concerned. Let us hope, and in all earnestness, that not only will India wipe out this deficiency in near future but that it will lead many other countries in this respect as it does now in the field of irrigation.

5. **Classification of roads in India:** This day, the country roads in India are classified as:

(a) National highway.
(b) Provincial highway or State highway.
(c) Major district road.
(d) Other district road.
(e) Village road.

National highways are the important roads connecting capital cities of states (i.e. provinces) and, the capital cities to the ports. They constitute the main arteries of transport in the country and are of military importance. Roads connecting the neighbouring countries are also called national highways. National highway should have 2 lanes of traffic and should be about 7·30 m (24′) wide. It should have a modern type surfacing.

Provincial highways or *State highways* are the main roads within the state and they connect important towns and cities of the state. They also connect the cities of a state with national highways. Provincial highway should preferably be 7·30 m (24′) wide. Where it be only 3·70 m (12′) wide, it should have 1·80 m (6′) wide shoulder on each side. The surfacing should be modern type.

Major district roads connect areas of production and markets with either a state highway or a railway. They also form the main connections between head quarters of the neighbouring districts. Major district road should have atleast metalled single-lane carriageway. The surfacing should preferably be modern type.

Other district roads and *village roads* mostly meet the requirements of rural population. They connect a village with other villages, with nearest district road, with river ghat etc. From the traffic point of view, other district roads are of greater importance than village roads. They should be all-weather roads. These roads have single-lane width of stabilised soil or gravel.

Of late, *expressways* (or express highways) are being constructed in India. Expressway should have atleast a 4-lane modern type surfacing (i.e. concrete or bituminous surfacing) with controlled access, and grade separation at all road and rail crossings.

6. Brief review of the development of roads in India: It is said that the primitive and prehistoric man had non-vegetarian habits. He used to live on prey of animals. Early morning, he would leave his abode in search of some animal which he might kill; by evening he would bring his prey to his abode, roast it and share it with his wife. By going out every morning and coming back every evening, he made a narrow way known as *field path.* Birth control and family planning of to-day were unknown then. The biological necessity on the part of the primitive pair resulted in about half a dozen issues in due course of time. Like a good father, the primitive man used to treat his children with a joy-ride on a wooden plank (made from trunk of a tree) which was dragged by him by means of a stout rope tied to the plank. The children used to feel uncomfortable and sometimes used to be tossed off the plank. The *practical* wife of the primitive man gave the suggestion that the plank be mounted on wheels for the safety of her children. With the design of this crude wheel, started the first vehicle. This vehicle, for its plying, required a greater width of passage and thus a *cart track* came into existence. With the passage of time, the traffic necessitated the development of good earth roads. And as more and more time passed, the other types of roads were evolved due to the needs of the new and changing traffic. Road bridge was constructed where a road came across a stream or river.

History tells us that long long ago, Indians were adept in the science of road construction. Excavations of Mohan-jo-daro and Harappa have established, without doubt, that even 3500 years B.C., Indians knew this science. About 600 years B.C., a pucca road 6·1 m to 7·3 m (20′ to 24′) wide existed in Rajgir of Patna district; this road was made of stone. About 300 years B.C., Kautilya — the celebrated prime minister of the Mauryan dynasty — wrote a book entitled Arth Shastra. In that book he has given specifications for road widths, road surfaces, traffic control etc. He has also laid down punishment for those who would not observe the rules of traffic. At one point, he has mentioned that the profile or cross section of road should be like the back of a tortoise; and we very well know this day that the top surface of every road has convexity upwards. How nicely, Kautilya has compared this upward convexity of road surface to the back of a tortoise! Chandragupta Maurya had special communication department for looking after roads. He got fixed some pillars and sign boards on the road-side for the guidance of traffic as is also the practice nowadays. He got constructed a national highway connecting N.W.F. province to his capital city of Patna. The historian Strato confirms that along this highway, two Greek travellers Magasthenes and Irastathenes travelled to northern India. About 269 years B.C., during the regime of Ashoka, there was a good network of roads in India; the mention of these roads has been made by Chinese traveller Fahien. In the days of Ashoka, trees were planted on either side of roads for providing shade to the travellers and, the rest houses were constructed at about 4·80 km to 6·40 km (3 to 4 miles) distance along the road so that the tired travellers might take rest for a while.

Muslim ruler Mohmed Tughlaq constructed a road connecting Delhi to Daulatabad. Shershah was very famous for construction of several roads. In the book by title 'Tarikhe Shershahi', it is mentioned that in Shershah's days, roads were well looked after and were well managed by the government. The longest road that he constructed was from Lahore in Punjab to Sunargaon in Bengal. In all, he constructed about 1700 rest houses and planted a number of fruit trees along the roads.

Book by title 'Chahar Gulshan' describes Moghul period and it makes a mention of 24 long roads connecting distant towns and cities.

The East India Company did not evince any interest in road construction. It was Lord William Bentinck who revived the idea of constructing roads. In his days, military boards used to look after the roads. It was only during the time of Lord Dalhousie that a Central P.W.D. was created, for the first time, to look after the roads. In 1855, such departments were created in other provinces also. The progressive policies of Lord Mayo and Lord Rippon acted as a good stimulus to the road development because the local affairs came directly under the control of local boards.

The present road system is a superstructure raised on the old roads. Its development began about 100 years ago. But the Government of India's entire energy being directed towards the opening of new railways, the roads came to be regarded as of little importance. The culmination of the lack of interest on the part of central government was reached in the passing of Government of India Act of 1919 which transferred the subject of roads from the central government to the provincial governments; the central government began to look after the roads of military importance only. The provincial governments, in their turn, placed greater part of road length in the charge of local bodies and they began looking after a few roads of provincial importance only. But the circumstances changed after world war I. Motor transport came to the forefront. The result was that the existing roads deteriorated and the development of the roads, adequate for fast motor traffic, could not keep pace with the increase of this type of traffic. Central government became conscious of this and, in 1927, it appointed a committee under the chairmanship of Dr. M. R. Jayakar to investigate and report about the then-existing roads and about the road development in India. In 1928, Jayakar Committee reported that the provincial governments and the local bodies were unable to look after all the roads and hence the central government should look after the important roads of national importance at least. The committee recommended to impose a petrol tax surcharge of 2 annas per gallon (12 p. per 4·55 l) of petrol consumed by motor traffic and thus build up a Central Road Fund from this revenue. One-sixth of this revenue was to be retained by the central government for the administration purpose, the research and the development of roads under its care and, the annual block grants were to be given to provinces from the remaining 5/6th of the Central Road Fund. Accordingly, the Government of India created a *Central Road Fund* in 1929. The Committee also suggested the setting up of,

(i) A separate Road Development Committee in the central government.

(ii) A Transport Advisory Committee consisting of the representatives of central and provincial governments.

(iii) A Central Organization of Information and Research.

According to these recommendations, a Central Road Organization was set up in 1930 and a Transport Advisory Committee in 1935. Also a Road Conference, for the first time, met in 1931 to discuss the road development in India. A semi-official body named as *Indian Roads Congress* (I.R.C.) was also set up in 1934 to provide a forum for the regular pooling of experiences and ideas on all matters affecting the design, construction and maintenance of roads, to recommend standard specifications for roads and, to provide a platform for the expression of professional opinion on the matters relating to road engineering.

Due to the road deficiency caused by the second world war, a conference of Chief Engineers of all provinces was convened by the Government of India in December 1943, at the instance of I.R.C. This conference met at Nagpur and it is an important land mark in the history of road development in India. It drew a 10 years plan of the road development, known as *Nagpur Plan*, for the construction and development of about 3,31,000 miles of all classes of roads and necessary road bridges at an estimated cost of Rs. 448 crores. This programme however could not be properly translated into action due to the lack of funds and the partition of India in 1947. It was this conference which, for the first time, classified the roads as national highways, provincial highways, major district roads, other district roads and village roads.

Note: 1 mile = 1·6093 kilometres.

In September 1950, *Central Road Research Institute* (C.R.R.I.) was started at Okhla (near Delhi) for the research on road engineering, in all its aspects. Technical advice is also given by it, to the state governments, on various problems concerning roads. This institute is financed and controlled by the Central Transport Ministry and it co-ordinates the activities of *State Road Boards* located at Madras, Calcutta, Lucknow and Patna.

The First Five Year Plan (1951-56) of India earmarked Rs. 109 crores for the development of 3000 miles of new high-type roads and for the construction of 17,000 miles of *kutcha* village roads through the community effort. In case of these village roads, 1/3rd of the cost of roads was to be borne by villagers by doing voluntary labour or otherwise and the balance 2/3rd was to be borne by the central and the state governments. At the beginning of the first plan, India had 97000 miles of surfaced and 151000 miles of unsurfaced roads. By 1956, 24000 miles of new surfaced roads and 44000 miles of low-type unsurfaced roads were constructed. Still greater provision, to the tune of 269·5 crores of rupees, was made under the Second Five Year Plan (1956-61) for the development of roads in India.

The *aim* of the framework of Second Five Year Plan was to step up the target for national highways from 12,500 miles in 1955-56 to 20,000 miles by 1960-61 and, of state highways from 20,600 miles in 1955-56 to 40,600 miles by 1960-61. It was expected that by the end of Second Five Year Plan period, the lengths of surfaced and unsurfaced roads would be about 1,44,000 and 2,35,000 miles respectively. This would yield about 30 miles of roads per 100 sq. miles (18·60 km per 100 km^2) of the area of Indian territory. While the Nagpur Plan targets have been mostly attained, we are still short of these targets in respect of surfaced roads and road bridges. The net-work of village roads will also have to be extended. The aim is that no village with a population of more than 1000 souls should remain unconnected with the marketing centre and no such village should be farther than 8 km (5 miles) from a pucca *all-weather road.* On this basis, it is estimated that the system of village roads only will need an investment of about 100 crores of rupees. But as the voluntary labour by the villagers is forthcoming for road construction, the financial outlay required will be substantially less. Thus, an adequate development of road transport will require an outlay of Rs. 350 crores for the national and the state highways and, at least Rs. 50 crores for the village roads after taking credit for the co-operative effort on the part of local population.

A new All-India road development plan which will cover the economic and social needs of the country for the period of 20 years (1961 to 1981) was submitted to Government of India by a committee of road engineers. This plan envisages the increasing of the road mileage from 3·79 lakhs in 1961 to 6·57 lakhs in 1981. National highways and state highways will be a little over one lakh miles and the balance will be district and village roads. The targets envisaged in this new plan will give 52 miles of roads for 100 sq. miles (32·3 km per 100 km^2) of area. The plan aims at bringing every village (a) in a well-developed agricultural area, within 4·80 km (3 miles) of pucca road (b) in a semi-developed area, within 8·85 km (5·5 miles) of pucca road and (c) in an undeveloped area, within 14·50 km (9 miles) of pucca road.

The tentative expenditure of the plan will be Rs. 5200 crores in 20 years.

The table shown below indicates the targets aimed at under the Nagpur Plan, the position expected at the end of Second Five Year Plan and the targets laid down in the newly envisaged 20-Year Plan:

Type of road	Nagpur Plan mileage	Mileage expected at the end of Second Five Year Plan (1960-61)	Mileage targets proposed in 20-Year Plan (1961-81)
1. National highways	20,000	13,800	32,000
2. State highways	53,000	35,000	70,000
3. Major district roads	50,000	95,200	150,000
4. Other district roads	70,000	78,300	180,000
5. Village roads	138,000	156,700	225,000
Total mileage	331,000 (5,32,700 km)	379,000 (6,06,900 km)	657,000 (10,57,300 km)

The 20-year plan is under the active consideration of the Government of India.

The draft outline of the Third Five Year Plan (1961-66) envisages a *total* outlay of rupees 10,200 crores which is nearly twice the provision for the Second Five Year Plan. Outlay on roads and road transport is rupees 350 crores which is nearly the same amount as that provided in the Second Five Year Plan.

The road programme in Third Five Year Plan provides for the addition of about 25000 miles of surfaced roads and improvement in the existing road system. By the end of 1966, the total length of surfaced roads in India will be about 170000 miles.

The draft outline of the Fourth Five Year Plan (1966-71) makes a provision of a total of rupees 21500 crores. In this plan also sufficient emphasis is given to road development. Thus, the future picture of our roads is quite rosy. May it be more rosy!

7. Road administration and finance in India: The road authorities in India are:

(a) Central Government.

(b) State Government.

(c) District Local Board.

(d) Municipality, Corporation or the like.

Since April 1947 (according to the recommendation of Nagpur Plan), the national highways are the responsibility of central government. There is a *Central Roads Organization*, under Consulting Engineer (Roads) to the Government of India, which looks after the national highways and other problems concerning the road development in general; it also decides about the block grants to the state governments for the road development, the expenditure on road research, the overseas training of Indian road engineers and, the bulk procurement of road-making plant and machinery. There is a Central Drawing Office of this organization which deals with the type designs of roads and its ancillary works. Nowadays, the central government levies a *petrol tax surcharge* of 2½ annas per gallon (15 p. per 4·55 l) of petrol to build the Central Road Fund; 1/5th of this fund is retained by the central government and 4/5th is given to the state governments in the form of block grants. Central government also taxes motor transport in the form of import duty.

In each state, there is P.W.D. with Chief Engineer and his elaborate staff who look after the state highways and most of the major district roads. In bigger states, there is a separate Chief Engineer (with his establishment) for irrigation and a separate one for roads and buildings. Each state government charges the direct tax on vehicles and the sales tax on petrol to build up the *State Road Fund.*

Other district roads and village roads are looked after by the district local boards which partly depend on the state government grant and partly depend on their own funds collected in the form of tolls and other local taxes.

Roads in built-up areas are looked after by the municipalities. Only through-roads, passing within municipal limits, are looked after by the state government or the district local board. Some municipalities (for example, those in the states of Bombay and Madhya Pradesh) levy *wheel tax* on the vehicles which use the roads constructed by these municipalities.

8. Road transport in India: Under the Indian Motor Vehicles Act of 1939, each state is divided into two or more regions with a *Regional Transport Authority* in each region. To co-ordinate the work of regional transport authority, there is (in addition) a *State Transport Authority* is each state. For securing the effective co-ordination between the road and the rail transport in India, it has been agreed that there should be a fusion of the financial interests between the railways and the large road-transport undertakings; this has been done in the states of Maharashtra, Madhya Pradesh, Punjab and Orissa.

9. Types of roads: Every engineering structure has a superstructure and a foundation, so has every road. A road is named after the material of its superstructure which can be seen on its top surface. Thus we have the following types of roads or road surfacings:

(a) Earth roads.

(b) Gravel roads and Murum roads.

(c) Waterbound macadam roads including kankar roads and lime-stone roads.

(d) Bituminous roads or black-top roads (i.e. tar and asphalt roads).

(e) Cement concrete roads.

(f) Paving of,

(i) Stone blocks or Stone setts.

(ii) Bricks.

(iii) Wooden blocks.

(iv) Rubber blocks.

(v) Metal blocks.

(g) Special surfacing of glass etc.

Roads mentioned in (a), (b) and (c) above prove suitable and sufficient for the village roads which carry a light traffic. Roads mentioned in (a) and (b) are called *low type* or *low cost* roads. They are also known as *unmetalled* roads. Those mentioned in (c), (d) and (e) are known as metalled roads. Those mentioned in (d) and (e) are suitable for major district roads, state highways, national highways and city streets which carry a heavy and fast traffic; they are known as *modern* or superior or high-cost *roads*. Pavings mentioned in (f) (i), (ii) and (iii) are used in special situations. The roads mentioned in (f) (iv), (v) and, (g) are yet in the experimental stage.

In subsequent chapters, we shall learn about these types of roads in details.

10. Scope of road engineering: As said before, the reader is already familiar with roads. After going through the previous articles, he has been more familiar with the roads. At this stage, it is worth while to know the items which we have to study and learn in road engineering. It may be said in nut-shell that:

Road Enginering deals with the design, location, methods of construction and maintenance of all types of roads in plain country as well as in hilly country. The other items to be learnt in road engineering are:

(a) Road administration and finance.

(b) Road economics.

(c) Traffic surveys, traffic safety and traffic control.

(d) Road-making plant and machinery.

(e) Road-making materials and their testing.

(f) Road-side tree planting.

(g) Preparation of plans, estimates and specifications for road construction.

A road engineer should also have some working idea about Soil Mechanics as applied to road design and construction.

For a comprehensive and successful road planning and development, all the above-said knowledge is expected of a modern road engineer.

CHAPTER II

ROAD STANDARDS AND THE DESIGN OF GEOMETRIC ELEMENTS OF ROADS

1. Introduction: In this most important chapter we shall learn about the design and standards of roads on which depends the success or failure of a road system. With proper design and layout, the roads can properly serve the purpose for which they are constructed. Details of design depend upon the type and intensity of traffic for which the road is intended and, the form of construction is indicated partly by local geological conditions and partly by traffic conditions.

2. Requirements of a good road: In order that a road may be satisfactory for traffic,

(i) It should be dry and unyielding.

(ii) It should have easy gradients, smooth curves of large radii and a good wearing surface.

(iii) It should be durable and cheap.

3. Road design and layout: 'Road design and layout' is a comprehensive phrase. In the proper design and layout of a road, some or all (as the situation requires) of the following points should be considered so that the road may give adequate and safe movement of all traffic and it may meet the social and industrial requirements of the locality served by it:

(a) Road structure.

(b) Road alignment and road surveys.

(c) Road capacity and road widths.

(d) Camber and gradient.

(e) Superelevation and visibility at curves.

(f) Road junctions or crossings or intersections.

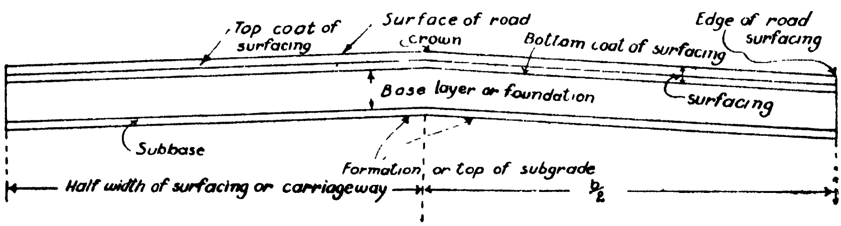
(g) Money available for road work.

(h) Miscellaneous items like,

(i) Kerbs, footpaths, cycle tracks, grass verges, service roads, road arboriculture.

(ii) Pedestrian crossings, refuges and islands, subways and over-bridges, restriction of ribbon development, parking places, lighting of roads, means of ingress and egress; all these come under the general heading 'traffic safety and traffic control'.

Points (a) to (f) refer to the technical perfection of a road and hence they are to be considered practically in all roads; these are treated in this chapter. Miscellaneous items also refer to the technical perfection of a road but they are considered where they apply. These miscellaneous points are treated in subsequent chapters in their proper place.



Cross section of road structure showing the surfacing, foundation, etc.
FIG. 5

4. **Road structure** (see fig. 5): Every building has superstructure and structural foundation; similarly a road has also the superstructure and the structural foundation. And as the structural foundation of a building rests on natural foundation, similarly the structural foundation of road also rests on natural foundation which may be soil in situ. The top of natural foundation on which the entire road structure rests is called a road bed or *subgrade*. The top of subgrade should be about 0·61 m (2′) above the high flood level at that site. The structural foundation of road is called a *base* or *foundation* or *soling* and the superstructure of road is called a *wearing course* or *wearing layer* or *road surfacing*.

The top of this layer is the road surface which is in direct contact with traffic. In some roads there may be additional layer between subgrade and base course; such a layer is called *sub-base* and is used only when the bearing capacity of subgrade is poor or when the subgrade has poor drainage properties as happens when it is made of fine-grained soils; sub-base also helps in distributing the traffic load over a greater area of the subgrade. Sometimes when the subgrade is hard and rocky, only surfacing layer is placed on it and even the base layer is omitted. Base layer is not necessary also in case of low-type roads carrying light traffic, and in case of rigid pavement of concrete.

Sub-base usually consists of a 7·5 cm to 15 cm (3″ to 6″) layer of granular material like broken stone, gravel, coarse sand, cinders, soil-cement, etc. It is rarely built in India.

Base consists of a layer of either hard murum or hand-packed big size stones called rubble; bricks on edge or flat bricks, as required, or even brick bats made from over-burnt bricks are used when stones cannot be had in the vicinity of road; rubble base is specially useful when the subgrade is of black cotton soil. Lean concrete slab is used as a base for some types of bituminous roads. Soil-cement as a base may be used in some cases.

Surfacing consists of earth, gravel, kankar, limestone, laterite, small pieces of hard stone, bituminous layer, concrete layer or blocks of various road-making materials like stone, wood, rubber, metal etc. In case of concrete and sheet asphalt, the surfacing may be in two layers — the top layer and the bottom layer.

The thicknesses of sub-base, base and surfacing are governed by certain rules of design, given in chapter XXIII.

The life of road depends primarily on stable and dry subgrade. When the subgrade fails, the base and the surfacing cannot perform their functions satisfactorily and the reconstruction of entire road structure becomes necessary. The support given to the road structure by the subgrade is an important factor which should be taken into account while designing the road structure. For this reason, considerable attention should be paid to the proper preparation of subgrade before the road structure is laid on it. Where the subgrade has a very low bearing capacity, some process is adopted for increasing its bearing capacity; such a process is called *soil stabilization.* The subgrade must be such that it provides an adequate and uniform support to the entire road structure. The soils, the bearing capacity of which is below 5·5 mt/m² ($\frac{1}{2}$ ton/sq. ft.), are usually not suitable for serving as subgrade. When the bearing capacity of the soil of subgrade is between 5·5 to 8·2 mt/m² ($\frac{1}{2}$ to $\frac{3}{4}$ ton/sq. ft.), it should be increased by the methods of soil stabilization. To ensure proper and uniform supporting power of the subgrade, resort should be made to the following operations:

(a) All patches of soft soil should be excavated and removed and should be substituted by good granular soil properly rammed in place.

(b) Where the subgrade is likely to remain wet, the subsurface drainage should be provided to keep it dry. This drainage is treated in chapter III of this book.

(c) Subgrade should be compacted thoroughly by means of road rollers. These road rollers are described in chapter VI.

(d) Clayey soils should be stabilized if they are present in the subgrade.

The function of road base is to transmit a load from the surfacing to the subgrade directly or through the sub-base where a sub-base is used. Ordinarily, the flexible type (i.e. of big stone pieces or bricks) foundation is used and hence the subgrade should have a uniform bearing capacity as already said. In case of very heavy traffic or where the block paving is constructed, rigid type (i.e. of cement concrete) foundation is used. In such case, the subgrade need not have uniform bearing capacity because the concrete slab can work as a beam over the soft patches of subgrade and therefore the surfacing will not be disturbed due to non-uniform bearing capacity of the subgrade. The thickness of road structure in case of waterbound macadam road is found from the empirical formula,

$$d = \sqrt{\frac{W}{3p} + \frac{T^2}{9}} - \frac{T}{3} \text{ inches}$$

where, d — Thickness of surfacing + thickness of base course, in inches.

T — Width of wheel (in contact with road surface) in inches.

W — Maximum (single tyre) wheel load in lb., including 50% impact i.e. W is $1\frac{1}{2}$ times the maximum static wheel load W_1 on the surfacing. In India, usually, a wheel load of 5000 lb. (2268 kg) is considered to be the limit for the design of pavement thickness and, a tyre width of 4·5″ (about 11·4 cm) is assumed; for only bullock cart traffic, wheel load equal to 2800 lb. (1270 kg) and T equal to 1·75″ (about 4·4 cm) mav be used.

p = Safe intensity of pressure, in lbs per sq. inch, which the subgrade can bear without yielding.

Note: 1 inch = 2·54 cm; 1 pound = 0·4536 kg; 1 lb/in² = 0·0703 kg/cm².

Thickness of the surfacing is decided by keeping in view the material of surfacing and the nature and quantity of traffic expected to go on the road after its construction. Then, the thickness of base = (d — thickness of the surfacing). The thickness of base is *usually* kept not more than 25·5 cm (12 inches). If this thickness works out to be more than 25·5 cm, the subgrade soil should be stabilized and improved so that the base thickness does not exceed 25·5 cm. For flexible bituminous pavement,

$$d = 0{\cdot}564 \sqrt{\frac{W_1}{p}} \text{ inches}$$

where, W_1 = Static wheel load in lb.

For rigid pavement (e.g. cement concrete surfacing),

$$d = \sqrt{\frac{2{\cdot}4W_1 \times C}{M}} \text{ inches}$$

where, d = Thickness of plain concrete slab in inches.

W_1 = Static wheel load in lb.

C = Coefficient of subgrade support
= 0·77 to 1·1 according to soil; C is less for hard and compact subgrade and vice versa.

M = Safe modulus of rupture of concrete, in lb/in^2. It is equal to $\frac{1}{10}$th of the ultimate crushing strength of concrete after 28 days and it is usually assumed as 24·5 kg/cm^2 (350 lb/in^2).

The main function of road surfacing is to provide a smooth and stable running surface suitable for the type and intensity of traffic anticipated on the road. The surfacing should be impervious and should protect the base and the subgrade from the action of weather and rain water. The desirable properties of a surfacing are:

(a) *Durability:* The road surfacing should have a long life i.e. it should resist very well the weather and, the abrasion and impact of traffic. The surface should not show waves and distortions.

(b) *Stability:* Road surfacing should transmit the load of traffic to the base without undue deformation occuring in the surfacing. All the same, it should be sufficiently flexible to adjust itself to a slight settlement of the base if it occurs.

(c) *Non-slipperiness:* Road surface should be non-slippery for all types of traffic.

(d) *Economy:* Road surfacing should be economical in its initial cost and also in the subsequent cost of maintenance.

(e) *Dustlessness:* Road surface should be dust-proof, as far as possible.

Road surfacing should be of such material and of such thickness that it proves strong enough from the point of view of the type of traffic, the intensity of traffic and the length of service required of it.

Both the foundation and the surfacing permit the use of a great variety of materials and many details of construction but the choice is limited by the location of road (i.e. whether the road is in town or in country), by the intensity and type of traffic and, by the nature of subgrade.

For a detailed note on 'pavement design', see Chapter XXIII.

5. **Road alignment:** Before a road is constructed, the direction of its centre line is fixed or located. The course or route along which the centre line of a road is located in plan is called the *road alignment.* The act of selecting and defining on the site or on the plan the route of a proposed road is called the *road location.* Sometimes, the term road location is also used in place of road alignment. The following points should be considered while fixing the alignment of a new or proposed road:

(a) Road line between any two points *A* and *B* should be as straight as possible because such road will be of shortest length and hence less costly; in the following circumstances, however, we have to deviate or make a *reasonable* detour from the straight alignment:

(i) When the road has to pass through a previously fixed or *obligatory point* between *A* and *B* so as to give to that point the benefit of road. This obligatory point may be an important village or town between *A* and *B*.

(ii) When the road has to cross another road, railway or a stream. It is desirable that another road, railway or stream should be crossed at right angles; a stream should further be crossed at a suitable point where a road bridge can be safely and economically constructed. In doing so, a detour from straight alignment may be necessary.

(iii) If the ground between *A* and *B* is marshy in some places, it should be avoided because such ground cannot prove as a good and stable subgrade. The alignment will therefore deviate from such marshy places. Similarly, the areas of poor soil and poor natural drainage should be avoided.

(iv) Straight alignment may come across gardens, cultivated agricultural land or thick forest. Now the land through which a road passes has to be acquired or purchased from the private owners. This acquisition of land will be costly in case of a *lengthy* stretch of the gardens and the agricultural lands. Also, cutting down of a thick and productive forest will be costly and undesirable unless the road is a forest road. A detour is therefore necessary.

(v) The alignment should be near the source of materials to be used for the construction and maintenance of road. Thus, if stone quarry is not far away from the straight alignment, we may make a detour and take the road by its side so that the cost of construction and maintenance of the metalled road will be less.

(b) The alignment should ensure an easy longitudinal gradient of the road surface and, the flat curves where the curves are necessary. Steep gradients and sharp curves prove difficult and dangerous for the traffic.

(c) Alignment should ensure the minimum cutting and embankment work for the road construction. As far as practicable the cutting should balance the embankment so as to avoid the borrow pits or the spoil banks. The significance of borrow pit and spoil bank is given in chapter IV.

(d) As far as possible, the road alignment should be on a high ground or ridge. This will ensure that the road surface will remain in dry state even in rainy season or in other words such an alignment ensures a good natural drainage of water from the road surface Thus, the road will be passable in all seasons and its life will also be more.

(e) As far as possible, the alignment should be such that it comes across very few streams and rivers; with such alignment, very few road bridges will have to be constructed and the road work will be cheap.

(f) The alignment of a country road should not go through the habitated area of a village or town but it must pass by the side of the village or town. This ensures less number of accidents; also, the future widening of the road will be possible if there are no built-up areas on its two sides.

(g) The alignment should serve very well the needs of the area through which the road passes.

In hilly country, the following *special* points should be considered:

(i) The ascents and descents should be easy and not very steep as far as practicable. Unnecessary ascents and descents should be avoided. Very steep reaches should not be continuous for very long distances and they should be interposed by easy and gently sloping reaches of short length.

(ii) Very deep cuttings should be avoided as they are very costly in hilly area.

(iii) Alignment should be on that side of a hill which is sound and solid. The dip of strata in the side of hill should not be towards the road otherwise a land-slide of these strata may occur and the road may be blocked by the land-slide. Also, there should be no inclined fissures in the hill side as they may bring subsoil water to the road side.

(iv) Unnecessary zig-zags in the alignment should be avoided, as far as practicable.

6. Road surveys: To determine the location of a proposed road and to collect the necessary data for the design and construction of a road, the following road surveys are undertaken:

(a) Reconnaissance survey and preliminary soil survey.

(b) Preliminary location survey and land acquisition.

(c) Final location survey and final soil survey.

(d) Construction survey.

A preliminary and usually rapid examination or survey of a region with reference to its natural features or other local conditions to determine the location of a road is called *reconnaissance survey.* Before this survey is done, the topo sheets, showing the area connecting two points *A* and *B* (between which road is to be located) and round about *A* and *B*, should be taken and on these topo sheets the *possible* routes from *A* to *B* should be marked. A *rough and rapid survey* of all the *possible* routes will be done by the plane table and the prismatic compass. While this survey work is done on the site, the following information should also be collected:

(i) The nature of the top or surface soil along the possible routes should be noted. If the geological sections for the area are available, they should be studied to know the nature of sub-soil. If some road bridges have to be constructed, it should be verified on the site whether the suitable and safe natural foundations are available for them at their sites or not.

(ii) The sources of water and materials required for the construction and maintenance of the road should be noted.

If due to the terrain of the country, land survey with the plane table and the compass is not practicable, aerial survey may be done where facilities for such survey exist. In this type of survey, it is always preferable to take direct photos of the land. Oblique views are not advisable. The information collected from all survey work should be compared with the principles governing the alignment of a road and the undesirable routes should be dropped for the purposes of doing *further* survey work.

Preliminary location survey is then done along the remaining desirable routes only. Traverse survey is carried out along these routes. Steel tape or chain is used in survey according to the accuracy required in measuring the distance and the offsets. For taking angles, a transit theodolite is used. For filling in details, tacheometric survey is done. The total land width to be acquired for each desirable route is then decided . *Land width* (see figs. 1 to 4) is the total width required to accommodate the roadway for traffic and the necessary adjuncts (i.e. ancillary works) of roadway in the form of road side berms, road side drains, width reserved for future development and for making spoil banks, etc. Following are the land widths (or right-of-ways) recommended for the various classes of *country* roads; these land widths are exclusive of temporary land acquired for excavating borrow pits:

Class of road	Recommended land width	
	Normal width	Minimum width
National highway	200′ (60 m)	150′ (45 m)
State highway	150′ (45 m)	100′ (30 m)
Major district road	100′ (30 m)	66′ (20 m)
Other district road	80′ (25 m)	50′ (15 m)
Village road	66′ (20 m)	44′ (15 m)

Note: Approximate desirable widths in metres are shown in brackets.

After this, the necessary plans (i.e. drawings) are prepared corresponding to the survey work etc. and a rough estimate of the cost of the road and its ancillary works (for each desirable route) is prepared. The economic and the best route, out of all the desirable routes, is then selected.

For the final location survey, the centre line of the finally selected road is marked on the ground and the longitudinal levelling is done along it. Fly levelling is done to check this work. After this, the cross sectional levelling is done at the required points of the centre line of the road. From this detailed survey work, the final plans, final designs and final estimates are prepared to know the probable cost of the road and its adjuncts or necessary works.

In the final location of the centre line of road, horizontal curves shall have to be laid out where a change in the direction of road is necessary. Curves should be as few as practicable and should be of large radius, specially for fast moving traffic.

The usual types of horizontal curves are:

(i) Simple curve.

(ii) Compound curve including *S* curve or Reverse curve.

(iii) Transition curve or Curve of easement or Radiod. This may be:

(a) Cubic parabola.

(b) Bernoulli's lemniscate.

(c) Scartes' spiral.

Cubic parabola is mostly used for railway transition curves. For road transition curves, the lemniscate and the spiral are used, specially the former. In hilly road, spiral is used for sharp curves of smaller radii. The curves can be laid out by the following methods:

(i) One theodolite method.

(ii) Two theodolites method.

(iii) Method of laying offsets from tangent.

(iv) Method of laying external offsets from chords produced.

The various types of horizontal curves and the methods of their layout are fully described in any standard book on surveying and as such they are not described here at length.

Where there is a change of longitudinal gradient of the road, a simple parabolic curve is introduced in the vertical plane at the point where the two gradients join. Vertical curve may be on *summit* or in *valley* and it is used to effect easy change in the gradient. These curves are also well known to the student of surveying and their detailed description can be found in text books on surveying.

For the final soil survey, it is necessary to get an idea about the nature of soil below the ground by actually drilling the bore holes (with soil auger) at required points along the route of the road. The observations regarding subsoil strata are recorded in a book. The subsoil samples obtained at various depths below the ground level are preserved and are sent to a Soil Mechanics Laboratory for tests so as to know the properties of the subsoil at various depths. Information about the depth of subsoil water table in each bore hole is also noted.

Construction surveys will be descripted in chapter IV.

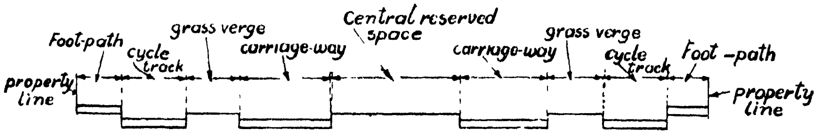
7. Road capacity: A certain width of wearing surface of a road can accommodate a certain quantity or volume of moving traffic (at certain speed) without accidents or undue congesion and delay. The width of road surface actually provided depends on the peak intensity of traffic. Greater the width of road surface, greater will be its road capacity to accommodate the traffic. The capacity of a traffic lane is thus the ability of the lane to accommodate certain traffic under some specified operating conditions. In general, road capacity is defined as the maximum number of vehicles etc. that can pass a given point on a lane or a carriageway during one hour under the prevailing roadway and traffic conditions, without unreasonable delay or restriction to the driver's freedom to manoeuvre. Carriageway may have one lane, two lanes or three lanes of traffic. The number of lanes to be provided on a carriageway

$$= \frac{\text{peak volume of traffic, in vehicles per hour}}{\text{capacity of single lane of traffic}}.$$

Traffic lane of a carriageway is defined as a longitudinal strip of the carriageway, regarded as a unit of width, to accommodate safely the forward movement of a single line of vehicular traffic. One such traffic lane is equal to 3·0m to 3·7m (10′ – 12′) in width. Such traffic lane can safely accommodate one-way traffic only. At peak hours, a traffic-lane can accommodate per hour about 200 slow-moving vehicles and 250 fast-moving vehicles if they move in one direction only, without overtaking. On important roads having a heavy traffic, two-way traffic requires two lanes of traffic with a total width of carriageway equal to 6·7 m (22 feet) and three lanes of traffic should have a total width of

9·7m (32 feet). A very busy road (see fig. 6) may have dual carriageways, each carriageway having two or three traffic lanes.

Note: It is desirable to have widths of 3·5 m, 7 m and 10 m for one, two and three lanes of traffic respectively.



A busy urban road showing two carriageways, cycle tracks and foot paths

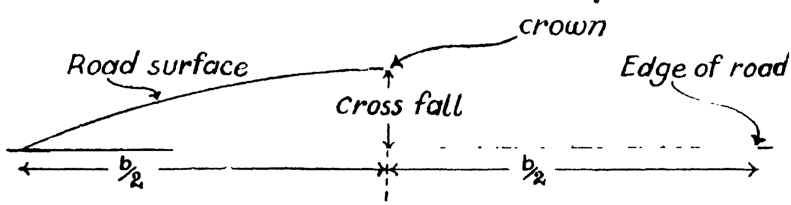
FIG. 6

Number of lanes required for motor traffic is as follows:

(i) Upto 300 vehicles per hour, 2 lanes in a single carriageway.

(ii) For 300-600 ,, ,, , 3 lanes in a single carriageway.

(iii) For 600-1500 ,, ,, , 2 lanes in each of the dual carriageway.



Cross section of a road showing the crown and the parabolic profile of the road surface

FIG. 7(*a*)

8. Road camber: [see figs. 7(*a*), 7(*b*) and 7(*c*)]. In the cross section of straight portion of a road, the highest point on the curved road surface is called *crown*. The level of crown is called the *road surface level*. The curved road surface has its convexity upwards like the back of a tortoise. This convexity can be seen in the cross section of a road surfacing and it is usually called *camber* of the road. Camber is expressed as the slope of line joining the crown with the edge of carriageway. Thus, a camber of 1 in 60 in a carriageway 10 m wide shows that the crown is 8·33 cm above the two edges of the carriageway. The road surface of such carriageway is said to have a *cross fall* $8\frac{1}{3}$ cm. The cross fall (i.e. amount of camber) is mainly given to take away rain water from the road surface and the amount of cross fall or camber depends on the material of which the road surfacing is made i.e. it depends on the type of road. It is steep for soft and permeable material and, flat for hard and impermeable material. The camber should be just sufficient for the efficient drainage of rain water from the surface of the road. Excessive camber induces the drivers of vehicles to keep near the crown and increases the tendency of the vehicles to side-slipping; also, the central portion of road gets tracked and easily worn out. Following are the cambers recommended for various types of roads:

Type of road	Recommended camber
Earth road	1 in 20
Gravel road	1 in 24
Moorum and Kankar roads	1 in 24 to 1 in 30
Waterbound macadam road	1 in 30 to 1 in 48
{Bituminous painting and Bituminous semi-grout road	1 in 48
Bituminous concrete or Sheet asphalt	1 in 60
Cement concrete road	1 in 70 to 1 in 80
Pavings	1 in 48 to 1 in 60

In actual construction, the barrel is given to the road profile by filling the surfacing material between camber-templates fixed at 15 m to 30 m (50′ to 100′) apart, across the centre line of the road.

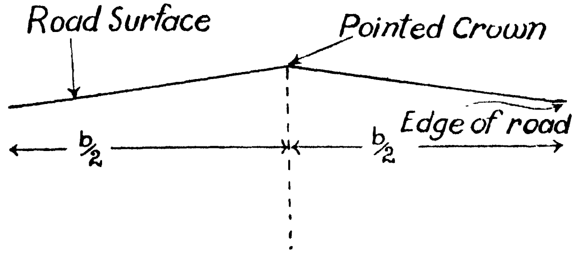
Three types of camber are commonly used on single carriageway roads. They are:

(a) Barrel camber.

(b) Sloped camber

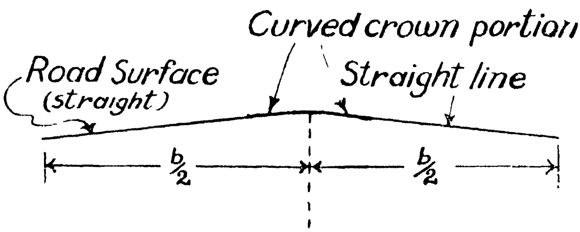
(c) Composite camber

Barrel camber consists of a continuous curve as shown in fig. 7(*a*). Sloped camber consists of two straight slopes joining at crown as shown in fig. 7(*b*). Composite camber consists of two straight slopes with a parabolic crown portion as shown in fig. 7(*c*)



Cross section of a road showing the crown and the straight profile of the road surface

FIG. 7(*b*)



Cross section of a road showing the crown and the road surface having a composite (i.e. parabolic and straight) profile

FIG. 7(*c*)

9. Road gradient: No ground surface is dead flat and level and because of this, the road surface also rises and falls along the length of the road. The rate of this rise or fall is called road *gradient* or *grade* and is usually expressed as a ratio of *1* vertical in *n* horizontal (i.e. *1* in *n*). Thus, if the road surface fall 2 m in 200 m horizontal distance measured along the length of a road, the road gradient in that reach of the road is 1 in 100. The gradient of a road is regulated by the nature of traffic, nature of country and partly by the kind of the surfacing material. It should not cause difficulty and danger to traffic, specially the draught animals pulling the slow moving vehicles like carts, tongas etc. It should therefore be gentle as far as practicable; such a procedure entails less consumption of energy on the part of traffic using the road. A gradient which must never be exceeded in any part of a road is called the *limiting gradient* or *maximum allowable gradient*. Its value is fixed at 1 in 20 in plain country and 1 in 15 in hilly country. It is however desirable to give the gradient upto a certain desirable upper limit below the limiting gradient. Such a desirable upper limit of the gradient is called the *ruling gradient*. Its value is fixed at 1 in 30 in plain country and 1 in 20 in hilly country. Where it is not feasible to keep within the ruling gradient, it should be seen that the gradient is not steeper than the limiting gradient at least. Even in that case, the limiting gradient should not be given over very long lengths of a road and, it is desirable to interpose short and flatter reach between the steeper reaches having the limiting gradient. It has also been found that for the efficient drainage of water from the surface of a road, a certain minimum gradient should be given to the road. Such a gradient is called *minimum gradient* and its value is *usually* fixed at 1 in 200, though it depends on the nature of road surface also.

When gradient occurs on a horizontal curve of less than 300m (1000′) radius, gradient may be reduced throughout the length of curve and also for 15 m (50′) on either side of curve by a percentage which is given by the formula,

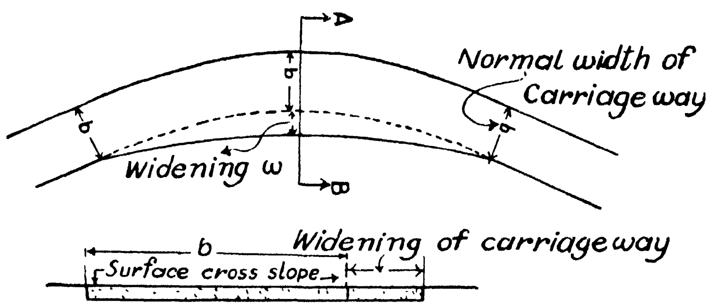
gradient compensation $= \left(\frac{75}{R} \times 100\right)\%$, where R is the radius of curve in metres.

The recommendation of I.R.C. regarding gradient on straight length of road is given in the table below:

Type of country	Ruling gradient	Maximum gradient	Limiting gradient or Exceptional gradient
Plain	1 in 50	1 in 33	1 in 20
Hilly	1 in 20	1 in 15	1 in 12

The limiting gradient given on a road should be in the least number of places, well separated from each other and, at each place, this gradient should not be used for a distance of more than 90 m (about 300′).

10. Widening of the carriageway on curves: [see figs. 8 and 10(*a*)]. On curved portion of a road, the steering wheels turn sideways so that the width of carriageway occupied by a vehicle is more than the width of carriageway occupied by the vehicle on straight portion of the road. Hence the width of carriageway is increased, on the entire curved portion, usually on the inside or concave side of carriageway. This widening is necessary in case of that curve only, the radius of which is less than 460 m (about 1500 feet). A certain uniform width is added on the inside of the entire circular curve as shown in fig. 10(*a*). This width gradually decreases towards those ends of the two transition curves (on the inside of carriageway) which meet the straight portions of road.



Cross section of road showing the widening provided on the inside of curved portion of the road

FIG. 8

The value of uniform width added to the inside of the entire circular curve corresponding to the radii of curves is as shown below:

Radius of circular curve in metres	300 to 460 (1001′ to 1500′)	150 to 300 (501′ to 1000′)	60 to 150 (201′ to 500′)	less than 60 (200′ and less)
Value of uniform width in metres, for each traffic lane of the carriageway having one or two traffic lanes	0·3 (1′)	0·6 (2′)	0·9 (3′)	1·25 (4′)

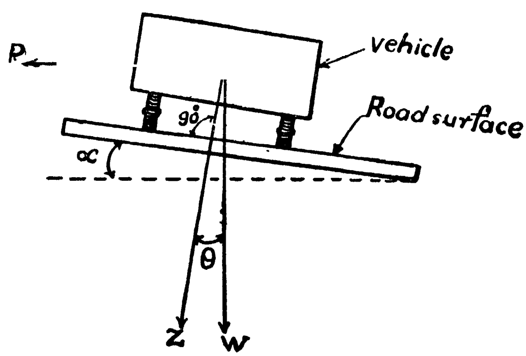
The following are the formulae which are sometimes used for calculating the widening w in metres to be provided for each traffic lane:

(i) $w = \frac{L^2}{R}$, where R is the radius of curve in metres and L is the length of vehicle in metres.

(ii) $w = \frac{(3D)^{\frac{1}{3}}}{3 \cdot 3}$, where D is the degree of curve in Metric system.

Note: In British system, $W = D^{\frac{1}{3}}$.

11. Superelevation: (see fig. 9). When the fast moving traffic, say a motor car, negotiates a horizontal curve, the centrifugal force acts on the car and hence its lateral (or sideway) stability is affected. Value of this centrifugal



Cross section of road showing the superelevated road surface which is *B* metres wide. The superelevation is *h* metres

FIG. 9

force P is given by the formula, $P = \frac{Wv^2}{gR}$ kg.

Hence, $\frac{P}{W} = \frac{v^2}{gR}$

where W = weight of motor car in kg.

v = speed of motor in m/sec while it is moving on the curve; this speed on curve is usually taken as 0·7 times the design speed allowable on the straight portion of the road.

g = 9·81 m/sec^2.

R = radius of the horizontal curve in metres.

Note: (i) 1 ft/sec = 0·3048 m/sec = 1·0973 km/hour.
(ii) 1 mile/hour = 1·6093 km/hour.

This force is experienced by the wheels at right angles to the direction of their motion and if its value is greater than the frictional resistance between the wheels and the road surface (i.e. top of the carriageway), side-slip of the wheels will take place. If the speed is not lowered after the side-slip occurs, the car may topple over. To avoid this, the outer edge of the carriageway on a curve is superelevated i.e. raised above the inner edge. *Superelevation* is thus provided on all sharp curves and it provides a factor of safety for the drivers who misjudge the curve and negotiate it too fast. When the road cross-section is superelevated, the centrifugal force (parallel to road surface) trying to push the wheels towards the outer edge of road will be equal to $P\cos\alpha$, where α is the cross inclination of the road surface to the horizontal. Also due to this inclination, the component of W parallel to the road surface (namely $W\sin\alpha$) tries to pull the wheels towards the inner edge of road or towards the centre of the curve. For no side-slip to occur, we should have,

$P\cos\alpha = W\sin\alpha$ + frictional resistance between the wheels and the road surface.

To be on safe side, this frictional resistance is not taken into account and hence for no side-slip we should have,

$$P\cos\alpha = W\sin\alpha$$

or, $$\frac{P}{W} = \tan\alpha.$$

Also, $\tan\theta = \frac{P}{W}$, where θ is the angle between the vertical line and the line normal to the superelevated inclined surface. Hence $\theta = \alpha$ i.e. the cross surface of the road should be inclined to such an extent that the resultant Z of P and W should be normal to the inclined or superelevated surface of the road.

Now, $\sin\theta = \sin\alpha = \frac{h}{B}$

where, h = vertical distance in metres through which the outer edge of the road has been raised above the inner edge, and

B = width of the inclined road surface, in metres.

As α is very small, $\sin\alpha = \tan\alpha$.

Hence we get,

$\frac{h}{B} = \frac{P}{W} = \frac{v^2}{gR}$, where $\frac{h}{B}$ is called the rate of superelevation or the superelevation per metre width of the carriageway and h is called the *superelevation* or *banking* or *cant.*

If friction between the wheels and the road surface be considered, we have,

$P\cos\alpha = W\sin\alpha + \mu W\cos\alpha$, where μ is the coefficient of friction between the wheels and road surface

i.e. $\frac{Wv^2}{gR}.\cos\alpha = W\sin\alpha + \mu W\cos\alpha$

or, $\frac{v^2}{gR} = \tan\alpha + \mu \simeq \sin\alpha + \mu$

or, $\sin\alpha = \frac{v^2}{gR} - \mu$

i.e. $\frac{h}{B} = \frac{v^2}{gR} - \mu$, where the value of μ is usually taken as 0·15.

Greater the superelevation, more the inconvenience to the slow moving traffic. Hence the maximum value of $\frac{h}{B}$ is fixed at 0·067. This gives a maximum cross slope of 1 in 15; also the formula becomes, $\frac{v^2}{gR} = 0{\cdot}067 + 0{\cdot}15$ or,

$\frac{v^2}{gR} = 0{\cdot}217$. The maximum allowable centrifugal ratio $\frac{v^2}{gR}$ is thus 0·217. From this, we get the minimum value of radius R given to a curve when the speed v is specified. When the maximum banking of 1 in 15 given to a road surface is less than the theoretical banking worked from the formula, part of the centrifugal force is counter-balanced by the horizontal component of the weight of vehicle, and the remainder of the centrifugal force is opposed by the lateral friction between the wheels and the road surface. If the superelevation works out to be less than the value of camber of a road, it should be kept equal to the camber of the road for drainage purposes. In cross section, the surface of a superelevated road appears as an inclined straight line. Superelevation is therefore also defined as the inward tilt or transverse inclination given to the road surface on a horizontal curve to reduce or check the evil effects of the centrifugal force on a fast moving traffic. Superelevation is then expressed as cross slope which is very approximately equal to 1 in $\frac{B}{h}$.

The table below gives the radius in metres (for various roads and various design speeds) beyond which no superelevation is necessary; for no superelevation, $\frac{v^2}{gR} = \mu = 0{\cdot}15$.

Design speed in km.p.h.	W.B.M. road		Bituminous road	C.C. road
	Camber 1 in 36	Camber 1 in 48	Camber 1 in 60	Camber 1 in 72
	Radius in metres	Radius in metres	Radius in metres	Radius in metres
24 (15 m.p.h.)	90 (300′)	120 (400′)	150 (500′)	180 (600′)
32 (20 m.p.h.)	170 (550′)	210 (700′)	270 (900′)	300 (1000′)
40 (25 m.p.h.)	260 (850′)	340 (1100′)	430 (1400′)	520 (1700′)
48 (30 m.p.h.)	360 (1200′)	490 (1600′)	610 (2000′)	950 (2450′)
64 (40 m.p.h.)	660 (2150′)	880 (2900′)	1100 (3600′)	1310 (4300′)
80 (50 m.p.h.)	1040 (3400′)	1370 (4500′)	1710 (5600′)	2040 (6750′)

From this article we learn that the design of horizontal curve on a road is influenced by (i) Design speed (ii) Safe allowable friction (iii) Maximum allowable superelevation and (iv) Permissible centrifugal ratio.

Note: (i) It is desirable to round off the design speed in km/h to the figures, 25, 30, 40, 50, 60 and 80.

(ii) Radius given in metres, has been rounded off.

12. Method of introducing superelevation on curve: [see figs. 10(*a*) and 10(*b*)]. A superelevated curve will have a circular curve, with transition curve on each of its two sides. A transition curve thus joins the straight portion of road with one end of the circular curve. Reckoning in the direction of forward movement of traffic, at the end of straight portion (which is also the beginning of transition

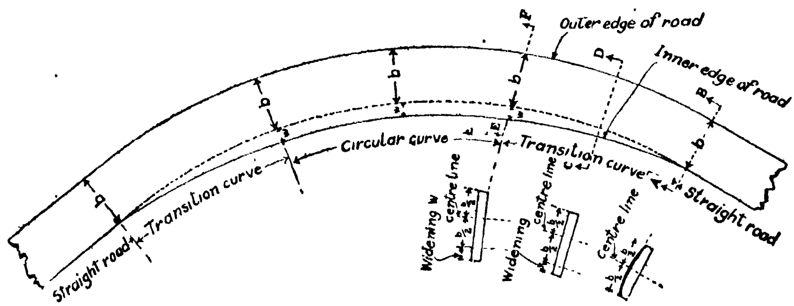
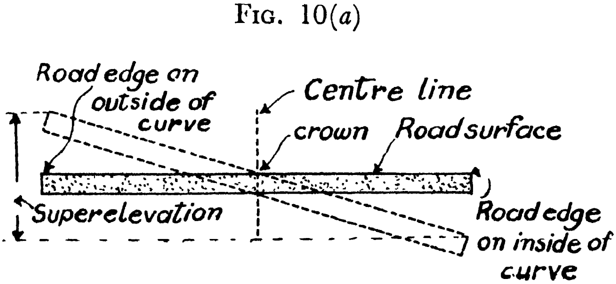


Figure shows the plan of road with curved portion and, straight portions on both sides of the curved portion. It also shows the cross sections of road at the beginning, the middle and the end of the transition curve.

FIG. 10(*a*)



Cross section of road showing the superelevation *h* metres and the straight profile of the road surface which is *B* metres wide.

FIG. 10(*b*)

curve), there will be usual camber to the road surface. On a single carriageway, superelevation is now gradually introduced on the outer half-width of the road surface till this surface has an inward cross fall represented by the road camber. Now the entire road surface is revolved about the crown till the inclination of the entire width of the road surface represents the required superelevation or inward tilt. This is so gradually done that the required superelevation is obtained at the end of the transition curve which is also the beginning of the circular curve. This full and required superelevation is maintained on the entire circular curve upto its end which is also the beginning of the next transition curve. On this transition curve, superelevation must be gradually removed and the cross slope should be gradually changed to the cambered road surface in the manner reverse to that in which the superelevation was developed from a cambered surface. This should be so done that at the end of the transition curve which is also the beginning of the other straight portion of road, the road surface should have the required camber resembling the back of a tortoise.

13. **Length of transition curve on roads:** [see fig. 10(*a*)]. Let a fast moving vehicle move with a speed of v m/sec on the curved portion of road and cover a distance of L metres in t seconds, L being the required length of transition curve. To avoid shock or inconvenience to the passengers, the rate of change of radial acceleration of the vehicle (while it is going on the transition curve) should be constant and of reasonable value. Let f_r be the radial acceleration of vehicle at that end of the transition curve which is also the beginning of the circular curve and, let f_r' be the constant rate of change of radial acceleration. Then we have,

$$f_r = f_r' \times t$$
$$= f_r' \times \frac{L}{v}.$$

But the radial acceleration of vehicle at the same point (when that point is considered to be on the circular curve) is given by $\frac{v^2}{R}$ which remains constant along the entire circular curve. Equating the two values of radial acceleration at the same point we get,

$$f_r' \times \frac{L}{v} = \frac{v^2}{R}$$

$$\therefore \qquad L = \frac{v^3}{f_r' \times R} \text{ metres} \qquad \ldots\ldots\ldots\ldots\ldots(i)$$

In the above formula for the required length of the transition curve, f_r' may be taken equal to $\frac{46}{40 + \frac{49}{22} v}$.

In addition to the consideration of the radial acceleration, it should be seen that the value of centrifugal ratio is kept about $\frac{1}{4}$. Now we know that,

$$\text{centrifugal ratio} = \frac{\text{centrifugal force}}{\text{weight of vehicle}}$$

$$= \frac{P}{W} = \frac{v^2}{gR}$$

Putting this equal to $\frac{1}{4}$ we get,

$$\frac{v^2}{gR} = \frac{1}{4}$$

$$v = \sqrt{\frac{gR}{4}} \simeq \sqrt{2{\cdot}45R}$$

or, $$\text{minimum } R = \frac{4v^2}{g} \simeq \frac{v^2}{2{\cdot}45} \qquad \ldots\ldots\ldots\ldots(ii)$$

But $L = \frac{v^3}{f_r' \times R}$

$$\therefore \quad L = \frac{2{\cdot}45\sqrt{2{\cdot}45R}}{f_r'}, \text{ by putting } v = \sqrt{2{\cdot}45R} \quad \ldots\ldots(iii)$$

Also $$L = \frac{2{\cdot}45v}{f_r'}, \text{ by putting } R = \frac{v^2}{2{\cdot}45} \qquad \ldots\ldots\ldots\ldots\ldots(iv)$$

Thus, we see that the length of transition curve is governed by the rate of change of radial acceleration and, by the centrifugal ratio or superelevation per metre width of the carriageway.

14. Sight distance required at curve: In consequence of the intensive use of the roads by fast-moving traffic, visibility has become very essential requirement if loss of life is to be avoided. This visibility is of greater urgency on sharp curves. When fast-moving vehicles negotiate a horizontal (or a vertical) curve at the same time but from opposite directions, a good sight or *visibility* of the vehicle coming from opposite direction is necessary to avoid accidents. For vehicles to be able to travel at a specified speed with safety and without difficulty, the road should be so designed that the drivers can see far enough, ahead of them, at all times to be able to bring the vehicles from their speed to a dead stop before meeting any accident. *Sight distance* or *visibility* is defined as the distance (measured along the centre line of road) over which a driver can see the opposite object on road surface and the provision of this distance is necessary to avoid accidents. It may also be defined as the ability to see over such a distance on the road that the drivers and the pedestrians are given sufficient time to react to an emergency and thus they can avoid impact or accident. In short, sight distance is the length of road visible, ahead, to the driver of a vehicle. When this distance is not long enough to enable one fast-moving vehicle to overtake and pass another slow-moving vehicle moving in the same direction, it is known as 'non-passing sight distance' or 'non-overtaking sight distance'. When it is long enough to enable this overtaking on a two-lane carriageway, it is known as 'passing or overtaking sight distance'. In particular, a non-passing sight distance is defined as the longest distance over which a driver, whose eyes are 1·22 m (4′) high above the road surface, can see ahead the top of an object about 10 cm (4″) high above the road surface. Let us consider this type of sight distance. Let two vehicles, each moving with a speed of v m/sec. on a horizontal curve, approach each other from opposite directions. Let us say that the drivers apprehend danger of head-long collision of vehicles and hence they apply brakes to bring their vehicles to rest. Let us consider one of the two vehicles. The driver of this vehicle saw the vehicle from opposite direction and *instantly* applied brakes; but some interval of time must have elapsed between the instant of his seeing the opposite vehicle and the instant of his effectively applying the brakes. This time lag or brief interval of time is called the total *brake reaction time* of driver and its average value is taken as 1 second. During this time, his vehicle must have moved through a distance known as *lag distance* which will be equal to $v \times 1$ metres (some authorities recommend 2 to 3 seconds as the brake reaction time; in that case, lag distance will be $2v$ to $3v$ metres). After the effective application of brakes, the vehicle will move with a uniform retardation and will come to a stand-still after another interval of time. During this interval of time, the vehicle must have moved through a further distance which is known as the *braking distance.* The total stopping distance of this vehicle will be equal to sum of the lag distance and the braking distance. Practically same will be the stopping distance for the opposite vehicle. To avoid accidents, it is therefore necessary that the horizontal sight distance or visibility measured along the centre line of road should be greater than twice the stopping distance of each vehicle, stopping distance being the total distance travelled by a vehicle from the instant a danger is apprehended by the driver to the instant of actual stopping of the vehicle.

At the instant of applying brakes, the kinetic energy of vehicles is $\frac{Wv^2}{2g}$ m-kg; let μ be the coefficient of skid friction between the wheels of vehicle and the road surface; let l metres be the braking distance of the vehicle; then, considering the road surface to be level (i.e. with no gradient) we have,

$$\left\{\begin{matrix}\text{frictional resistance between}\\ \text{the wheels and the road surface}\end{matrix}\right\} \times l = \frac{Wv^2}{2g}$$

i.e.

$$\mu W \times l = \frac{Wv^2}{2g}$$

or,

$$l = \frac{v^2}{2g.\mu}.$$

Here $\mu = 0{\cdot}4$ to $0{\cdot}5$, allowing for the brake inefficiency and some slipperiness of the road surface.

$\therefore$ The required sight distance $\not< 2(l + v)$

$$\not< 2\left(\frac{v^2}{2g.\mu} + v\right) \text{ metres.}$$

Note: 1 ft-lb = 0·1383 m-kg.

If instead of two moving vehicles, there were one vehicle moving towards some stationary object ahead, the required sight distance should be greater than the expression $\left(\frac{v^2}{2g.\mu} + v\right)$.

The horizontal curve should be flat enough to ensure the necessary sight distance. If necessary, the obstructions like trees, buildings etc. on the inside of the curve may be removed sufficiently away from the roadway to secure the required sight distance.

Sight distance on vertical curve is defined as the distance over which a driver whose eyes are assumed to be 1·14 m (3′9″) above the road surface can just see the top of an opposite object 1·14 m high above the road surface. If vehicle is moving upgrade or uphill, the braking distance is decreased because the gravity force helps in slowing the vehicle and vice versa. Hence when two vehicles approach each other from opposite directions and both vehicles are moving uphill, the required vertical sight distance should be greater than $2\left\{\frac{v^2}{2g\,(\mu + s)} + v\right\}$, where s is the longitudinal gradient of the road surface. When a vehicle moves down grade, its braking distance l will be equal to $\left\{\frac{v^2}{2g\,(\mu - s)}\right\}$. Minimum sight distance of about 300 m (1000′) on single carriageway and about 150 m (500′) on dual carriageway should be provided on horizontal as well as vertical curves.

The recommendations of I.R.C. regarding sight distances are given below:

A. Table for nonpassing sight distance

Class of road	Plain country		Hilly country	
	Design speed	Nonpassing sight distance	Design speed	Nonpassing sight distanc
National Highway and Provincial Highway	80 km/h (50 m.p.h.)	270 m (900 feet)	48 km/h (30 m.p.h.)	150 m (500 feet)
Major District Road	64 km/h (40)	210 m (700)	40 km/h (25)	120 m (400)
Other District Road	48 km/h (30)	150 m (500)	32 km/h (20)	90 m (300)
Village Road	32 km/h (20)	90 m (300)	24 km/h (15)	60 m (200)

B. Table for overtaking sight distance

Class of road	Speed in km.p.h.	Overtaking sight distance in metres
N.H. & P.H.	80 (50 m.p.h.)	430 (1400′)
M.D.R.	64 (40)	290 (950′)
O.D.R.	48 (30)	170 (550′)
V.R.	32 (20)	90 (300′)

Note: The sight distances given in metres, have been rounded off.

15. Standards for design speed and radius of curve: In the previous articles, the speed v in m/sec has been used in deriving many formulae; such speed is called *design speed.* The design speed may be defined as the maximum safe speed assumed for design purposes. The following design speeds are recommended for various classes of *straight* portion of road in plain and hilly countries; these speeds should not be exceeded. Safe design speed on *curves* may be taken as 0·7 times the design speed on the straight portion of the road.

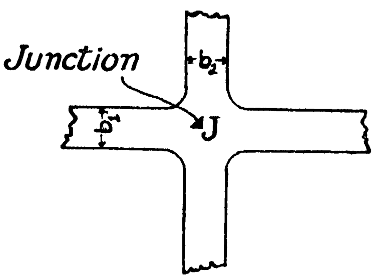
Class of road	Design speed, in km per hour, in plain country	Design speed, in km per hour, in hilly country
National highway	80 (50 m.p.h.)	48 (30 m.p.h.)
Provincial highway	80 (50)	48 (30)
Major district road	64 (40)	40 (25)
Other district road	48 (30)	32 (20)
Village road	32 (20)	24 (15)

The radius given to a circular curve depends on the design speed. The following minimum radii of curves (known as *ruling radii*) are recommended in plain and hilly countries, corresponding to the design speeds shown. As far as possible, the radius given to a curve should be more than the recommended value. Radius less than this value will not provide safe and comfortable travel along the curve and may cause skidding when the road surface is wet.

Design speed, in km per hour, on the circular curve	Ruling minimum radius (in m) of the circular curve in plain country	Ruling minimum radius (in m) of the circular curve in hilly country
80 (50 m.p.h.)	300 (1000 ft.)	This speed is not allowed
64 (40)	240 (800)	..do ..do..
48 (30)	150 (500)	120 (400 ft.)
40 (25)	120 (400)	90 (300)
32 (20)	90 (300)	60 (200)
24 (15)	90 (300)	45 (150)

Note: The radius given in metres, is rounded off.

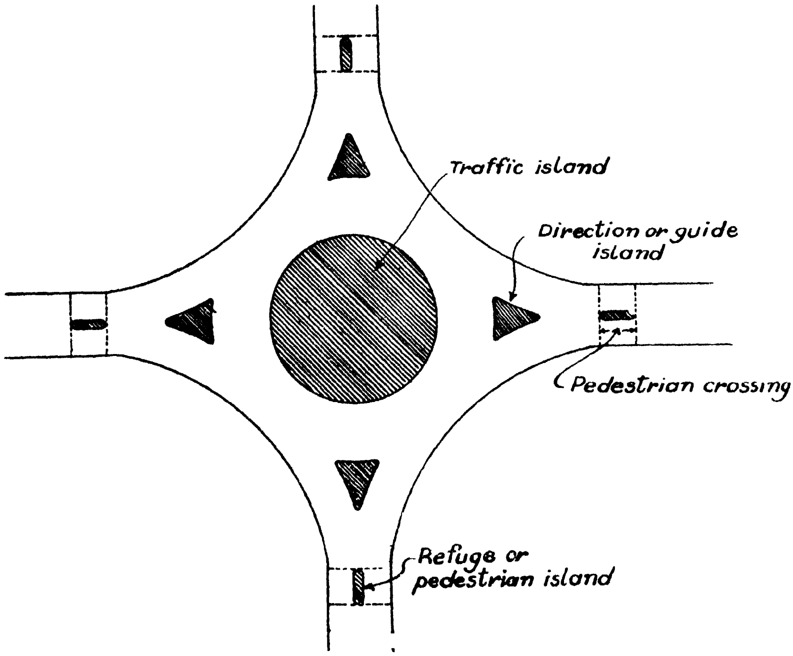
16. Road junctions and crossings: (see fig. 11). The most important feature in road design and layout is the *road junction* or *road crossing*. It is defined as an area common to two or more roads which meet at an angle. Same is the definition of *road intersection* with only this difference that in the case of road intersection, a road may or may not cross another road at the same level. It has been found that many accidents occur at road junctions in built-up areas. The aim should be to provide a junction which will avoid accidents as well as the delay and congestion of traffic. The following main principles should be considered in the design and layout of a road junction:



Road junction
FIG. 11

(a) The number of crossings on main road should be as few as possible and should be spaced at least 460 m (about 1500 feet) apart.

(b) Where necessity arises, the main road carrying a very heavy and fast traffic should be separated from the



Rotary level junction showing traffic island and refuge

FIG. 12(*a*)

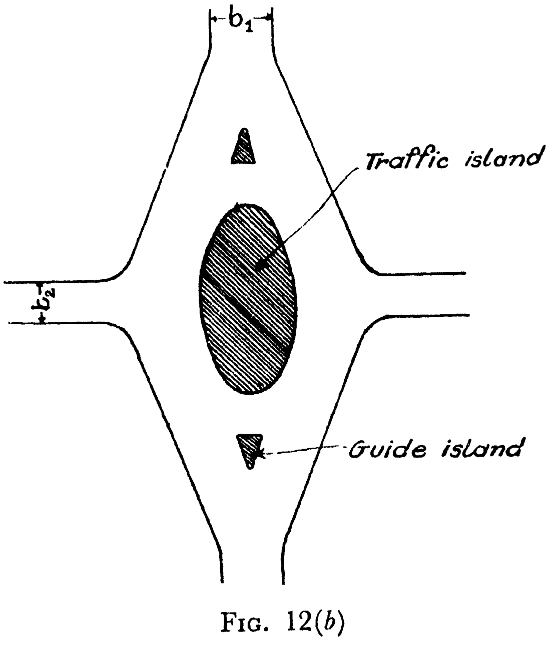


FIG. 12(*b*)

intersecting unimportant road by means of a bridge. Thus, one road will be going over another.

(c) Road junction of more than four intersecting roads should be avoided as far as possible.

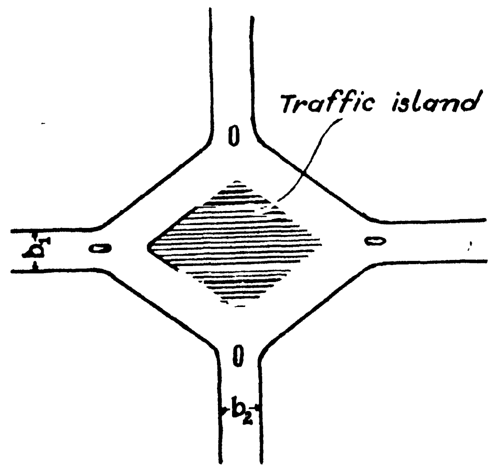


FIG. 12(*c*)

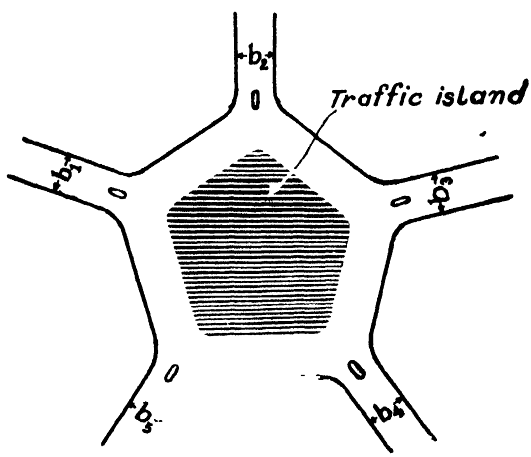


FIG. 12(*d*)

(d) As far as possible, the minor roads should cross a main road at right angles.

(e) Where three or more roads meet, they should be equally spaced round the junction.

(f) Where major roads of equal importance meet or intersect, the necessary traffic islands and refuges {see figs. 12(*a*) to 12(*f*)} should be provided for the safety of traffic.

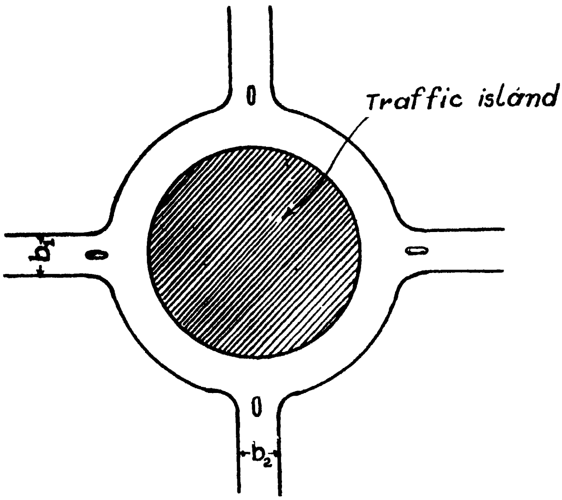


FIG. 12(*e*)

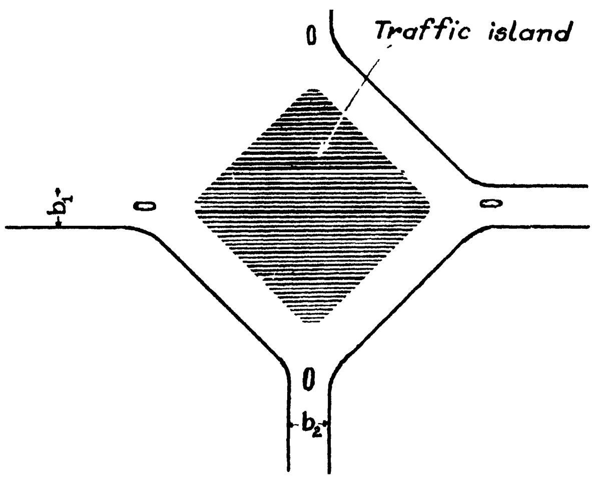


FIG. 12(*f*)

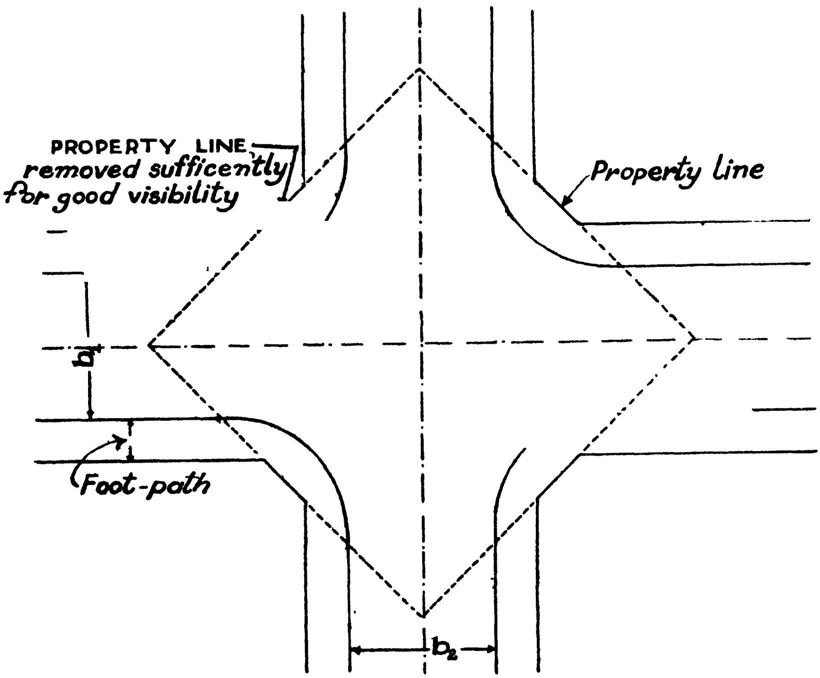
Traffic island is a *central island* (at a junction) having a circular, oval, etc. shape. It regulates the traffic to avoid accidents. *Refuge* is a raised space like central island (and near it) where pedestrians take refuge from the vehicular traffic, while crossing the carriageway from one footpath to the other. It is also known as *pedestrian island* or raised safety zone for pedestrians and is of less area than a central island.

(g) At all junctions (see fig. 13), there should be proper provision for visibility so as to avoid accidents.

(h) Requirements of non-vehicular traffic should be examined and proper provision should be made for it.

(i) To reduce conflicts and to provide the desirable angles of crossing and intersection, the traffic streams may be channelized by means of guide islands constructed at the entrances to a junction.

(j) Two main roads, carrying very heavy and fast traffic, may cross at different levels; such an intersection lay-



Level junction showing the building property removed far inside at the corners so as to improve visibility

FIG. 13

out is known as *highway grade separation* or *fly-over junction* or *overhead crossing*. In this type of junction, one road goes over another, by means of a bridge.

17. Types of road junctions: Following are the *usual* types of road junctions:

(a) Square junction or Straight-over junction (fig. 11).

(b) Acute junction including staggered acute junction [figs. 14(*a*) and 14(*b*)].

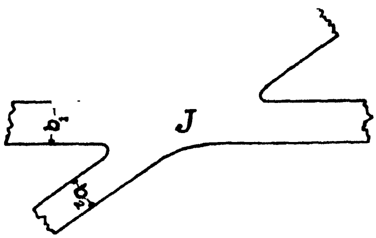


FIG. 14(*a*) Acute junction

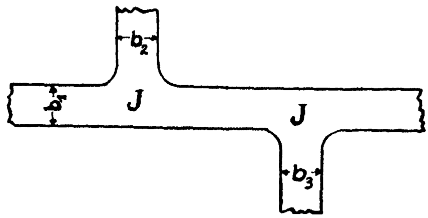


FIG. 14(*b*) Staggered junction

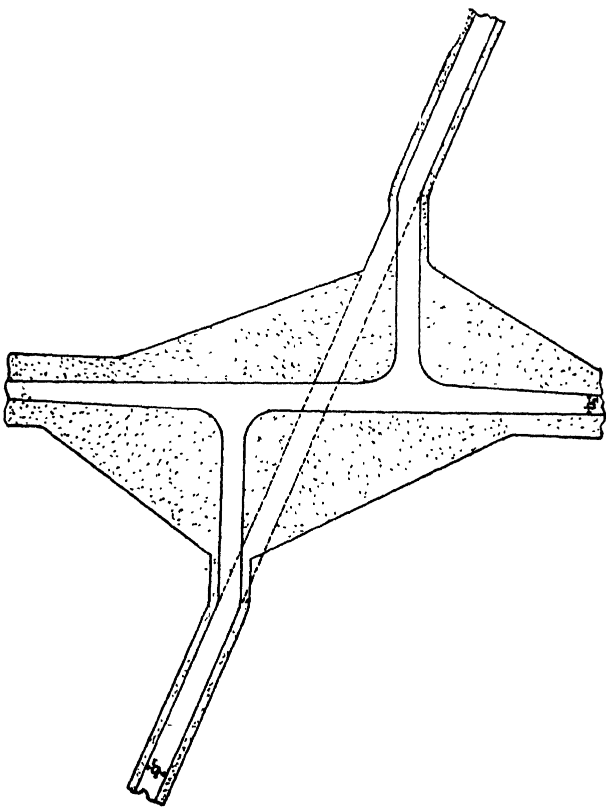


FIG. 14(*b*) Staggered junction

(c) T-junction [fig. 14(*c*)].

(d) Y-junction [fig. 14(*d*)].

(e) Multi-junction [fig. 14(*e*)].

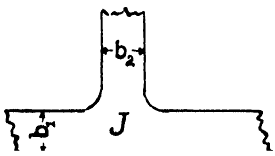


FIG. 14(*c*)

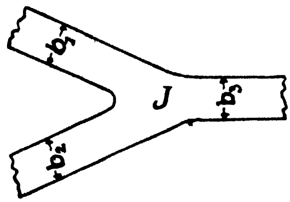


FIG. 14(*d*)

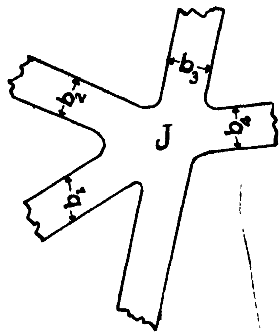


FIG. 14(*e*)

18. Miscellaneous points shown in article 2(h), will be described in subsequent chapters in their proper and more suitable places.

19. Funds available for road construction: After all has been said about the principles of design and the layout of roads, it may be remarked that the final design must be a compromise between the technical perfection and the utmost economy. The design is also to a great extent governed by the funds available for the construction of road. However it may be noted that it is a sound economy to spend money in the initial stage, with a view to future saving on the maintenance etc. of the road.

Note: Road standards, recommended by I.R.C., are shown in tabular form, in Appendix.

CHAPTER III

ROAD DRAINAGE AND THE DRAINAGE STRUCTURES

1. **Introduction:** Road drainage is very important because with the efficient road drainage, the life and efficiency of road can be increased. In this chapter we shall learn about this important item and also about certain road structures which effect some of this drainage.

2. **Road drainage:** Drainage may be defined as the interception and removal of water from, over, or under an area. *Road drainage* therefore means the removal of water from road surface and also from road subgrade. The removal of rain water from road surface and roadside ground is called *surface drainage* and that from the subgrade is called *sub-surface drainage.* For removal of water from the surface of road, proper camber and gradient are given to the road surface. The water coming down from road surface collects in *ditches* or *side drains* (of required cross-section area as shown in figs. 3 and 4), cut below the ground surface. These road ditches should be at least 1·80 m (6′) away from the edge of roadway so that there may be no danger to the traffic. There is one side drain on each side of the roadway and it is parallel to the road alignment. It has certain longitudinal gradient and discharges its water into a nearby nallah or stream. Side drains are absolutely necessary when the formation is in cutting and these drains are then excavated immediately after the formation width. In case of the formation in bank, the side drains are excavated a little away from the lower edges of side slopes of the bank. The strip of land between side drain and the lower edge of bank is called the *berm.* The cross section of side drain may be trapezoidal (see fig. 3) and sometimes triangular (see fig. 1). From the point of view of surface drainage, the road in cutting is not desirable as the surface water of the adjoining land *also* comes to the side drains and the road is in danger

of remaining wet in rainy season. The side drains, in the case of road on embankment, have to receive the rain water from the road surface and berm. To cut down cost, the height of road embankment should be low; it should be just sufficient to keep the road above high flood water on the adjoining land. The height of bank may *ordinarily* be 0·3 m to 0·60 m (1′ to 2′) above ground and more than 0·60 m (2′) near the masonry structures like bridges. In addition to the extra cost in case of high banks, such high banks may prove dangerous to the traffic under certain circumstances.

What will happen if there is defective or inadequate surface drainage due to inadequate camber and grade and due to the deficiency of side drains? The answer is that due to the inadequate camber and grade, some rain water will remain on the road surface and will soften it; the traffic will produce ruts in soft surface and the road surface will go on deteriorating. Also, some water may pass through the surfacing to the base and the subgrade below and may make them weak, resulting in the failure of road structure.

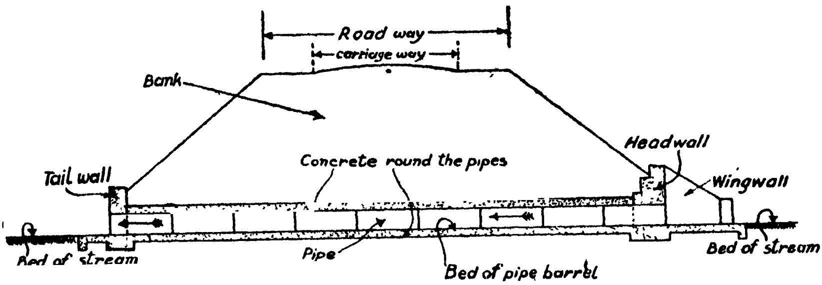
3. **Drainage structures:** There is another aspect of the drainage of surface water and that arises when a low lying area or a stream or river crosses the alignment of road. At the point of crossing, the water of stream or river is made to pass on the other side of the road by means of a masonry work known as *cross drainage work* or *drainage structure.* The *usual* types of cross drainage works for roads are:

(a) Road culvert and Road bridge. In these cases, water passes under the road surface.

(b) Low level causeway and High level causeway. In these cases, water may pass over the road for some time.

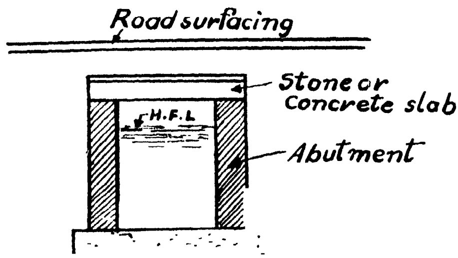
Floating bridges and suspension bridges are not common nowad.ys.

A small bridged passage/passages for the conveyance of water (under a road) from one side of roadway to the other is/are known as culvert. When the lineal waterway between the inside faces of abutments of a drainage structure is less than 6·0 m (20 feet), it is called a *culvert.* When this lineal waterway is greater than 6·0 m (20 feet), the cross drainage structure will be called a *bridge.* Thus, a culvert



Longitudinal section through a pipe culvert. Road in embankment goes, over it, at right angles.

FIG. 15



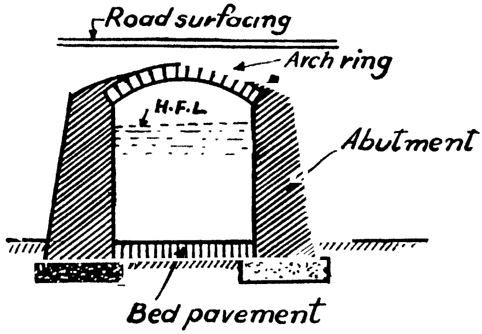
Cross section through abutments of slab culvert. Road goes over, at right angles to the cross section.

FIG. 16

can be called a bridge of smaller proportions. The culverts are usually constructed across small streams and, the bridges are constructed across wide streams and rivers. The following are the various types of culverts:

(a) Pipe culvert (fig. 15).
(b) Box culvert.
(c) Slab culvert (fig. 16).
(d) Arch culvert (fig. 17).

In case of pipe culvert, water passes under the road (and from one side of the roadway to the other) through slightly inclined pipes of cast iron or corrugated sheet iron or prefabricated R.C.C. The maximum diameter of each pipe may be kept as 1·50 m (5 feet).



Cross section through abutments of arch culvert.
Road goes over, at right angles to the cross section.

FIG. 17

Box culvert is a rectangular passage of concrete through which water passes from one side of roadway to the other. It may be defined as a monolithic drainage structure rectangular in cross section. The rectangular passage should not be less than 0·60 m × 0·60 m (2′ × 2′) so that it can be cleaned of debris etc. periodically by a man, after getting into the passage.

Slab culvert has abutments and a slab over them. Roadway is taken over this slab and, the drainage water passes below the slab and between the abutments. For small span (between abutments) of 0·90 m (3′) or so, hard stone slab can be used but for bigger span, a R.C.C. slab is constructed. As a rule, each span (if there are more than one span) of slab culvert should be less than 3·0 m (10 feet).

In case of arch culvert, there is arch from abutment to abutment or there may be arches from abutment to pier and from pier to pier. Roadway goes over the arch or arches. Each span of an arch culvert (if there be more than one span) should be less than 3·0 m (10 feet).

The following are the *usual* types of road bridges:

(a) Masonry arch bridge of brick or stone.

(b) R.C.C. slab and beam bridge.

(c) Steel girder bridge or Steel built-up section bridge.
(d) R.C.C. girder bridge.
(e) Prestressed concrete girder bridge.

In case of bridges, each span can be greater than 3·0 m (10 feet). High flood discharge of a stream or river at the point of crossing is calculated and sufficient waterway should be provided for the high flood discharge while it passes through the vents or passages of a culvert or a bridge. The choice of the type of bridge or culvert depends on the amount of high flood discharge and on the economical dimension or width of individual vent (or passage) to be constructed. Bridges and culverts should be constructed when the road is an important one and, therefore, is required to be passable in *all* seasons.

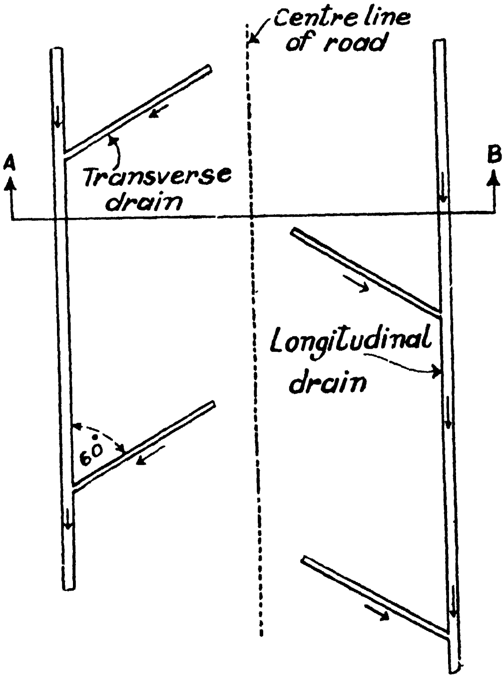
Sometimes, a horizontal pavement is constructed across a wide and shallow stream to pass the traffic during fair weather season only; such pavement is called *Irish bridge* or *Causeway*. A causeway may be defined as a road built across a natural drainage and it is constructed so as to resist the erosive action of stream flow across and over it. If the drainage has a protracted low water flow, the road surface may be kept free of this flow by constructing it at a somewhat high level and passing the flow through culverts built under the road surface. A short road length on each side of this pavement is in the form of a ramp. Causeway is, in essence, a paved dip in a road constructed across a shallow drainage at or about the bed level of drainage. Causeway may be a *low-level causeway* or a *high-level causeway* (i.e. raised causeway with culverts below it). *Low level causeway* or Flush causeway has a paved dip at bed level of the stream which is dry for most part of the year during which traffic can go over the causeway; for a short time in the year, this causeway may be under water and may not be used by the traffic. Low level causeway is used for very unimportant roads. In case of roads of ordinary importance, a high level causeway or *submersible bridge* is constructed. It is a paved dip appreciably above the bed of stream and is usually provided with vents (below it) to allow the normal floods to pass through the vents, from upstream side to the downstream side of the causeway. During high flood, however, the causeway is under water and therefore it cannot be used for some time till the flood water goes below the paved dip. High level causeway is quite suitable for wide stream in which there is no flow after October end.

Causeways and culverts are ordinarily sufficient for unimportant village roads. They are feasible when the stream is wide and has low banks. Causeways should not be constructed in the case of important roads like highways as they will cause serious interruption to the traffic during high floods; such interruption can be tolerated on village roads and other unimportant roads. Causeways are very cheap as compared to the culverts and bridges.

The design, construction and maintenance of bridges forms the subject matter of Bridge Engineering and hence they are not treated here. However, the elements of small road bridges and culverts are briefly treated in chapter XIX.

4. **Sub-surface drainage:** Water affecting the subgrade of road may be either surface water soaking in through road surfacing and road side, or it may be subsoil water. Subsoil water may be free water when water table is high or it may come up by capillary action to the subgrade when water table is low. The subgrade of a road should be of self-draining material so that it may pass off the percolation water (that comes to it) and thus it may remain dry. If, however, the subgrade is of soft and retentive soil or, there are underground springs bringing free water to the subgrade, the *subsoil drains* or *sub-surface drains* [see fig. 18(*a*)] should be constructed about 0·45 m to 0·60 m (18″ to 24″) below the formation level (and the subgrade soil) to carry away water from the subgrade and thus keep the subgrade dry. These subsurface drains are called the cross drains or *lateral drains* and have a small downward inclination (say 1 in 60 or so) from the centre of road towards the two side drains in which they discharge the water drained from the wet subgrade. Subsoil drains are also constructed to lower the water table to a safe depth below road surface so that water does not come by capillary action to the subgrade. (Water

table, in easily drainable soils, can also be lowered by deep and open side-drains to which water from water table percolates; such deep side-drains also take rain water from the road surface). If the subgrade is allowed to remain wet and soft, the whole road structure will fail. The cross drains [fig. 18(*a*)] may be in the form of trapezoidal trenches filled



Plan showing the lateral and the longitudinal pipe drains used under a seepage area in a through cutting

FIG. 18(*a*)

with selected rubble or stone and are then called rubble drains or *stone drains;* they are also known as French drains or blind drains. These are used when the depth is not much and the discharge is small. They discharge the water (percolating to them) into the deep side drains filled with rubble. The cross drains may also be *pipe drains.* A pipe drain [fig. 18(*c*)] consists of a trench in which earthenware or C.C. pipes are laid in line, with the joints between two adjoining pipes open; the pipes have a little inclination towards the side drains. The pipes are surrounded by the filter material and the remaining of this cross trench is filled with graded rubble, the bigger size rubble being nearer the pipe. Water of the wet subgrade passes through the open joints of pipes and enters

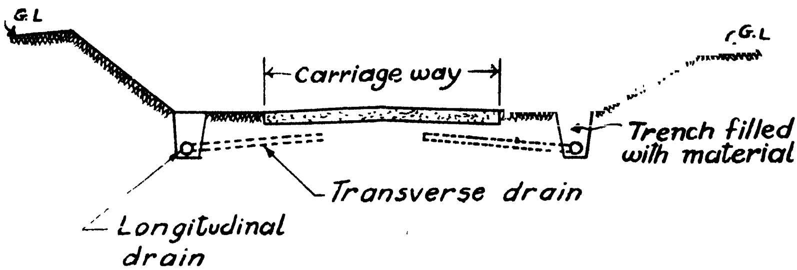


FIG. 18(*b*)

the lateral drains which discharge into two longitudinal pipe drains laid (with a little inclination) in the two longitudinal side trenches. The space above the longitudinal pipe drain is filled with graded rubble as is done in the case of lateral pipe drain.

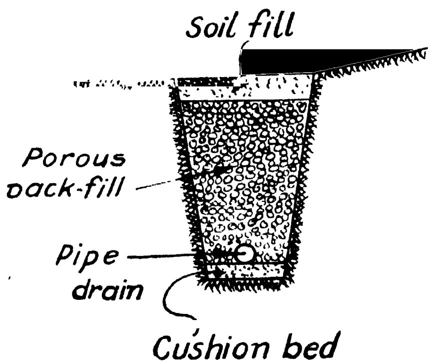


FIG. 18(*c*)

The longitudinal drains carry away water to the nearby stream or nallah. The diameter of the lateral pipe drain may be 7·5 cm to 10 cm (3″ to 4″). The diameter of the longitudinal pipe drain may be from 15 cm to 20 cm (6″ to 8″) or more according to design. The cross drains, as seen in plan, are placed staggered in the herring-bone fashion [see fig. 18(*a*)]. Spacing of lateral drains is less in impermeable soil and more in permeable soil. For clay sub-soil, the maximum spacing may be *about* 7·5 m (25 feet).

When a road is taken through swampy area, the sub-surface drains should invariably be provided at 0·90 m to 1·20 m (3′ to 4′) below the formation level of road.

It is usual to classify the subsoil drains as follows:

(a) Those which intercept the subsoil water before it comes to the subgrade. They are also known as intercepting drains and are generally used in cuttings and in the side-long ground.

(b) Those which bring down the water table to a safe depth below the subgrade and keep the water table there.

Note: In Metric system, diameter of pipe may also be reckoned in centimetres.

CHAPTER IV

ROAD SETTING OUT AND EARTHWORK

1. Introduction: Before a road is constructed, construction surveys are done and the road line is set out on the site of work. Then the subgrade is prepared to place the road structure on it. While preparing subgrade, some excavation of the natural ground or, the bankwork on the natural ground shall have to be done. The process of cutting excavations and/or preparing embankments is called *earthwork*. In this chapter we shall learn about setting out a road line and doing the earthwork.

2. Construction surveys: The construction survey is necessary for setting out a road on the site. It mainly consists in:

(i) Clearning the site of work by removing grass, weeds, brushwood and the objectionable material.

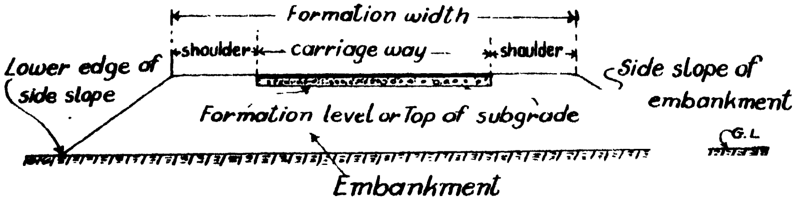
(ii) Setting out the centre line and the edges of the roadway.

(iii) Setting out areas for borrow pits and spoil banks before earthwork is done.

(iv) Fixing bamboo and string profiles for doing embankment work.

(v) Setting out road bridges and other ancillary works of a road.

After clearing the site, centre line (straight and/or curved) of the proposed road is defined on the ground by means of *alignment pegs* fixed at certain distance centre to centre on straight portions of the road. On curves, the pegs will be fixed closer to each other. These pegs are known as *centre pegs* also. The line between these pegs is clearly demarcated by making a narrow continuous V-shaped cut in the ground surface along this line. Such a cut is called *lockspit* or *dagbel.* Next, the formation widths and the side slopes of the excavation or bankwork (as the case may be) are decided. *Formation width* or roadway (see fig. 19 and fig. 20) is defined as the finished top width of an embank-



Cross section showing the formation width of road carried on embankment

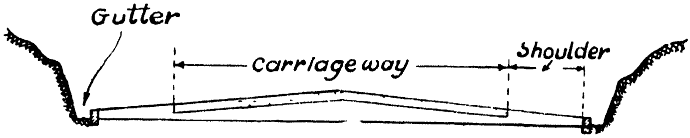
FIG. 19

ment or cutting which forms the subgrade for the road structure; it will be a little more than the width of road-base. The portion of formation width on each side of the road-base is called road *shoulder* or berm. It should be about 1·50 m to 2·45 m (5′-8′) wide to permit vehicles swerving or parking off the road in emergencies; it should be hard and dustless. The following are the formation widths recommended for the various classes of roads in plain and hilly areas:

Class of road	Minimum formation width, in m, in plain country	Minimum formation width, in m, in hilly country
National highway	12 (40ft)	8 (26ft)
Provincial highway	9·75 (32)	8 (26)
Major district road	7·25 (24)	6·75 (22)
Other district road	7·25 (24)	6·75 (22)
Village road	5·5 (18)	4·25 (14)

Note: Formation width given in metres, is rounded off.

The level of this formation (in the form of bank or cutting) is called the *formation level.* The side slopes of the formation will be such as the material of the formation can safely stand without slip or failure. The usual side slopes in the case of ordinary soils are $1\frac{1}{2}$:1 and 2:1; in rocky soil, steeper side slopes of $\frac{3}{4}$: 1 or $\frac{1}{2}$: 1 can be given. While treating the road gradient in chapter II, we fixed the gradient of longitudinal line passing through the crown of cross section of the road. After fixing the thickness of *entire* road structure, we can get the formation level by deducting the thickness of road structure from the level of crown at that point of the road. Like the centre pegs, other pegs are fixed to demarcate the formation width and the ends of the side slopes of embankment or cutting as the case may be. Lockspitting is done along these four lines of the pegs also.

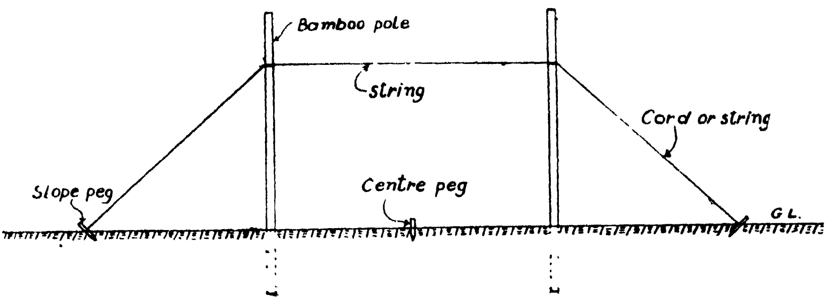


Cross section of road carried in cutting. The formation width is the total width between side gutters.
FIG. 20

When the road is on embankment, the earth is taken from pits (excavated on road side) to form the embankment; these pits are known as *borrow pits* (see fig. 3) and they are of regular and specified length, breadth and depth. When the work is done by contract, the excavators are asked to leave a narrow diagonal wall unexcavated in the borrow pits; such a diagonal wall is called *witness* and by examining it, one can say if the fresh borrow pit has been actually excavated by the contractor's labour or not.

When the road is on excavated formation, the excavated earth is utilized for making the formation in bank if it is required in the vicinity of the excavated formation. If after forming this bankwork, there is still some surplus earth, it is *dumped* in the form of a bank on the road side and parallel to the alignment of road; this surplus earth is called *spoil* and such a bank is called *spoil bank* (see fig. 4). The location of borrow pits and spoil banks should be within the temporary land acquired for the road. The areas for locating borrow pits and spoil banks are set out by the responsible official of the road authority.

3. Earthwork: The earthwork (i.e. excavation and/or embankment) is done by manual labour (as is *usual* in India) or by suitable road machinery. On bigger jobs, road machinery should preferably be used for economy and efficiency of work. The earthwork is done according to the standard specifications. The equipment usually used for manual labour consists of mamoty or phaorah, shovel, spade, pickaxe, baskets, rammers, rollers and surveying instruments like level, boning rods, plumb rule etc. Before earth filling is done to form a hiah bank, the *bamboo-and-string profiles* (see fig. 21) are fixed across the road at certain distance centre



Bamboo and string profile

FIG. 21

to centre. A bamboo profile consists of two vertical bamboo poles fixed vertically at the two ends of the formation width. A string is taken and it is tied to the slope-peg and the adjoining vertical bamboo so as to correspond to one slope of the bank; it is then taken horizontally from this bamboo to the next vertical bamboo to correspond to the top of the bank and it is finally tied to the slope-peg on the other side of the bank to correspond to the other slope of the bank. Thus, the thread tied to the two slope pegs and the two vertical bamboos presents a trapezoidal cross-section or profile. It is a well known fact that even though the earth filling to form a bank is properly rolled in layers, the bank material *does* settle to some extent after the construction of bank. This settlement of bank depends on the material of bank but the *average* allowance for this settlement may be made at the rate of *about* 1 metre for every 12 metres height of the bank. It therefore stands to reason that the height of the finished bank should be more in the first instance so that it gives the required height (and therefore required formation level) after its settlement. The horizontal thread (of bamboo profile) between the vertical bamboos is therefore fixed at a level above the required formation level to the extent of this allowance for settlement of the bank. After fixing these bamboo profiles, the earth brought from borrow pits and/or excavated formation is filled between them to the trapezoidal profile represented by the thread. This earth filling is done in 15 to 23 cm (about 6″ to 9″) layers and the rolling of each layer is done at *optimum moisture content* of the soil. *Optimum Moisture Content* (i.e. O.M.C.) of the soil is that amount of moisture or water in the soil which, when present in it at the time of its being rolled, gives the most dense and compact embankment. If the rolling of soil is done at any other moisture content which is either more or less than that represented by O.M.C. of the soil, the bank will not be so dense and compact. The soil will generally consolidate to about $\frac{2}{3}$ rds of its loose thickness. The finished embankment is finally trimmed on the top and the side slopes to give it a trapezoidal profile. The desired longitudinal gradient is given to the formation in cutting or bank by means of boning rods.

Setting out of the road bridges etc. is beyond the scope of this book. This information can be found in any standard book on surveying.

Calculations for the volume of cuttings and embankments are usually based on cross sections taken at regular intervals along the centre line of the road. After the cross sectional areas of these sections are computed, the volume of earthwork to be done is calculated by average end-area method or by prismoidal formula. These earthwork calculations are shown in chapter XXII of this book.

CHAPTER V

ROAD MAKING MATERIALS AND THEIR TESTING

1. General: In this chapter all the materials required in all types of roads are described. In chapter VI, all the machinery used in the construction of all types of roads is described. In the few chapters that follow viz. chapter VII to chapter XI, the *current* practices for the construction of all types of roads are given. Chapters V and VI should therefore be read in conjunction with the chapters on current construction practices. Thus, when chapter VII on earth roads is taken up for study, the characteristics and tests of soils (which form earth road) should be read from chapter V and the machinery that is used for the construction of earth roads should be read from chapter VI. Study on these lines will be *more* instructive than the isolated study of the chapters V and VI. Hence, before studying the current practice of construction of any type of road, the materials and the machinery used in the construction of that type of road should be studied from chapters V and VI.

2. Introduction: For the purposes of this chapter, road making materials may be defined as the materials that are used for constructing and/or supporting the road structure. Such materials are:

(a) All types of soils.

(b) Gravel.

(c) Moorum.

(d) Stones.

(e) Tar and asphalt.

(f) Cement, sand and aggregate.

(g) Miscellaneous materials like brick, wood, rubber, metal, glass etc.

In this chapter, however, only the following materials will be described with reference to roads:

(i) Soils.
(ii) Gravel.
(iii) Moorum.
(iv) Stones.
(v) Tar and asphalt.

Also, the tests will be described for the following materials only:

(i) Soils.
(ii) Road stones.
(iii) Tar and asphalt.

3. Soils: A *soil* is defined as a mixture of earthy materials, with particles differing physically in size, shape and structure and, varying in chemical composition. It forms the top layer of ground. The undisturbed strata lying below this natural top soil are known as *sub-soil.* The common soils used in road-making are:

(a) Clay.
(b) Silt.
(c) Sand.
(d) Loam.
(e) Marl.
(f) Peat.
(g) Shale etc.
(h) Mixture of these soils i.e. composite soils.

Clay is a fine-grained hygroscopic silicate of alumina mixed usually with impurities. It becomes plastic when moist.

Silt is a mud consisting of fine and barely visible grains, of specified size, with little or no plasticity and no cohesion; it is usually deposited as a sediment in water.

Sand consists of granular, gritty, loose grains of silicious origin, the grain size being from 0·002 to 2·00 millimetres.

It is free from appreciable quantities of clay and silt and hence it is non-plastic and cohesionless.

A loam is a soil having a relatively even mixture of the different grades of sand and, of silt and clay. It is mellow with a somewhat gritty feel and is yet fairly smooth and slightly plastic. Some loamy soils contain a considerable proportion of organic matter.

Marl is an earthy mixture of minerals consisting of quartz, clay, calcite and sometimes glauconitic sands. It is quite often found in swamps and lakes.

Peat is a dark fibrous spongy soil showing evidence of vegetable origin.

Shale is a compressed and laminated clay not so hard as slate. It may be with or without organic matter.

Black cotton soil is a composite soil formed by the decomposition of rocks like trap, basalt etc. after long and continued weathering. The clay content in it is from 40 to 50 percent. It is black or blue-black in colour and is found in tropical countries. This soil contains 4 to 8 percent humus. It has great affinity for water and attracts water, from all directions, by capillarity. It is extremely sticky when wet and has a high coefficient of shrinkage. It has a better bearing capacity when dry but becomes almost a fluid when wet. It is generally suitable for cotton crop and hence it is called black cotton soil. It is very unsuitable as a subgrade for road structure and other engineering structures because of its great change in volume when it is allowed to dry after first being wetted. If used as a subgrade, it must be properly treated before putting the road structure on it.

We have also composite soils like sandy-clay, clayey-sand etc. having sand and clay in certain proportions. In sandy-clay, the clay content is more but in clayey-sand, the sand content is more. In fact, in nature, we have mostly the composite soils.

All road structures are supported by the soil of subgrade. Knowledge of the soils is therefore of great importance to a Road Engineer. This science about soils pertaining to roads is called *Road Soil Engineering*; in road soil engineering, we learn about the origin and formation of soils, common soil types, basic soil properties, tests for the identification and classification of soils, soil surveys, soil moistures and various other items connected with soils. This study enables the road engineer,

(i) to decide the best location of a road and of the drainage structures,

(ii) to select suitable soils for the construction of the embankment of the road,

(iii) to decide whether or not the subsurface drainage for the road will be necessary,

(iv) to determine whether or not the subgrade soil requires to be improved so as to increase its bearing capacity.

The properties and the characteristics of soils are affected by the size of their constituent particles and by the relative proportions of these particles. A convenient method of classifying soil particles is by their grain size. This is known as *mechanical analysis of soils* and is given in the following table for a few soils:

Kind of soil	Grain-size of the particles of soil, in millimetres	Significant properties of the soil
Gravel	2 or more	There is internal friction between particles.
Coarse sand	0·25 to 2	..do.. ..do..
Fine sand	0·05 to 0·25	It is inert.
Silt	0·005 to 0·05	It is non-cohesive.
Clay	0·002 to 0·005	It is cohesive and plastic.

A satisfactory soil for the earth road will be one in which the main properties of cohesion, plasticity and internal friction are present in the *required* proportions. The ideal surface layer of earth road should consist of the following:

(i) Clay — 9 to 18%
(ii) Silt — 5 to 15%
(iii) Sand — 65 to 80%

It will be sufficient to have 70% of sand and 30% of silt and clay together.

4. Soil characteristics: The characteristics of soil may be classified as:

(a) *Physical constants* of soil like:

(i) Internal friction.
(ii) Cohesion i.e. internal molecular attraction which opposes the rupture of soil.
(iii) Compressibility and permeability.
(iv) Elasticity.

(b) *Physical characteristics:* These characteristics are shown by soil on the addition of water to a dry soil or, on drying a wet soil. For knowing these characteristics, following tests are performed in Soil Mechanics Laboratory:

(i) Shrinkage limit test.
(ii) Liquid limit test.
(iii) Plastic limit test.
(iv) Plasticity index.
(v) Field moisture equivalent test.
(vi) Shrinkage ratio test.
(vii) Centrifuge Moisture Equivalent test.
(viii) Volume change or Volume shrinkage test.
(ix) Lineal shrinkage test.

The first four tests are known as *Atterburg Limit Tests.* These tests are *usually* described in books on Soil Mechanics.

(c) *Textural characteristics:* These characteristics show the size and grading of the individual particles of the soil.

5. Soil stabilization: It is the process of treating a soil in such a manner as to improve or alter its physical properties so that it may become more stable and durable. The soil so stabilized may form the subgrade or the wearing layer of a road. Following are the methods of soil stabilization:

(a) Mechanical stabilization method.
(b) Cement stabilization method.
(c) Lime stabilization method.
(d) Bituminous stabilization method.
(e) Chemical stabilization method.

In mechanical stabilization method, we verify whether the soil to be stabilized is fine-grained or coarse-grained. If the soil is fine-grained like clay, it is ploughed, coarse-grained soil is mixed with it in proper proportion (usually in the ratio of 2 parts of coarse-grained to 1 part of fine-grained), requisite water is also added and the mixture is rolled to compaction. If the soil is coarse-grained, it is ploughed to a depth of about 15 to 20 cm (about 6″ to 8″) fine-grained soil is mixed with it in proper proportion, water is also added if necessary and in the case of banks more than 1·2 m (4′) high, the mixture is rolled to compaction first by sheep's foot roller and finally by smooth wheeled roller Sheep's foot roller need not be used for low banks. These rollers are described in chapter VI. This method of soil stabilization is becoming *common* in India. The object of this method is to improve the grading of local soil and thus make it more stable. Clay should be just sufficient to fill the voids in sand.

In cement stabilization method, the soil to be stabilized is ploughed to a depth of about 10 to 15 cm (4″ to 6″), proper quantity of cement (usually 8 to 12% of the soil by weight) is mixed with it, also requisite water is added and the mixture is compacted first by sheep's foot roller and finally by smooth wheeled roller. The compacted surface is cured for about a week.

In case of lime stabilization, the process of stabilization is similar to that in cement stabilization except that the hydrated lime is used in place of cement. The compacted surface is kept moist for a few days. Lime (5 to 10%) helps in checking the shrinkage of soil like clay.

In bituminous stabilization, the soil is treated with required quantity of bituminous oils or, bituminous solutions known as *emulsions* and medium curing *cutbacks.* About

4·50 litres (1 gallon) of solution is applied per square yard (0·84g m^2) of road surface to penetrate 1·25 to 2·5 cm (½″ to 1″) in the soil. The object is to bind together the granular particles of soil more firmly. The significance of emulsion and cutback is given in articles that follow.

In chemical stabilization, the hygroscopic chemicals like NaCl, $CaCl_2$ etc. are used. $CaCl_2$ helps to retain *proper* amount of moisture in the soil as this is necessary for its stability. In some cases, molasses mixed with CaO (i.e. quick lime) is used to stabilize the soil.

6. Gravel: It consists of small stones of irregular shape and size which are usually water-worn and are sometimes mixed with finer materials. It occurs in river beds or open beaches and is also called shingle.

7. Moorum: It is a gritty silicious material with big size lumps or, stones not exceeding about 18 mm (¾″) in size and with a natural mixture of clay of the calcareous or laterite origin, usually of the former origin. Hard moorum is broken to about 72 mm (3″) size; it is used as soling under waterbound macadam road and also as the wearing surface on shoulders of the trafficway. Soft moorum is used as blindage on most of the metalled road surfaces and as a casing for the side slopes and for the top of bank made of black cotton soil.

8. Stones: Various types of stones are used for road construction. Following are some of the *common* types of stones used for that purpose:

(a) Gneiss.
(b) Granite.
(c) Laterite (hard variety).
(d) Lime stone (hard variety).
(e) Sand stone.
(f) Basalt.
(g) Kankar.
(h) Trap.

Gneiss is a banded or foliated rock of metamorphic origin. It has the mineral composition of granite. The principal minerals contained in it are quartz and feldspar with a black or white mica. It yields good road metal.

Granite is a coarse-grained, holocrystalline, plutonic rock which is composed of quartz, orthoclase, subordinate plagioclase, ferromagnesian mineral and accessories. It yields good road metal.

Laterite is a mixture of red and yellow residual soils or surface products that have originated in situ from the atmospheric weathering of rocks and the infiltration of iron compounds. Tough variety should be used for road metal.

Lime stone is a rock consisting essentially of $CaCO_3$. Hard variety should be used. It forms dust on road when traffic goes over it.

Sand stone is a stone which is formed by consolidation of sand, predominantly of quartz. It forms dust when traffic goes over it.

Basalt is a dark coloured, fine-grained igneous rock composed essentially of calcic plagioclase, augite and iron ores usually from olivine. It yields good road metal.

Kankar is a nodular form of carbonate of lime and its bajri makes very good blindage for waterbound macadam roads. Its hard variety is used for road surfacing. When so used, it is broken in pieces of bigger size.

Trap is a mixture of feldspar and hornblende. It is often compact and fine-grained. It is fairly hard and tough and makes good road stone.

In most situations, road stone is used in road construction in the form of crushed or broken stone of regular sizes below 3 inches. Such broken stone of size 1″, 1½″, 2″, 2½″ or 3″ is called *road metal.* It is desirable that in Metric system, these sizes may be *approximately* shown as 24 mm, 36 mm, 48 mm, 60 mm and 72 mm respectively. Stone is also used in the form of small stone chips, boulders, dressed blocks and setts. Stone is quarried from quarries by various methods and it is then broken to the required size. This may be done by heavy hand hammers or, mechanically by stone crushing machines.

In places where the road stone is not available, pieces of over-burnt bricks are used as road metal in the case of unimportant roads.

9. Desirable qualities of road stone: The road stone should have the following desirable qualities:

(a) Hardness to resist rubbing due to moving traffic.

(b) Toughness to resist fracture under impact of traffic.

(c) Resistance to attrition and wear (i.e. resistance to mutual rubbing or grinding of stone pieces under the action of traffic).

(d) Good binding or cementing value.

(e) Low absorption of water or Less pore space.

(f) Hardness to resist crushing under the load of traffic.

(g) Durability against weather.

A road stone should be able to resist the crushing and abrasion caused by traffic, it should be able to take up the blows or impact from the wheels of traffic without breaking, it should weather well, rain water should not have any adverse effect upon it and, it should have good binding value. Granite is very hard but granite dust or powder has no good binding value. Lime stone is not a hard stone but its dust has very good cementing property.

10. Physical tests for road stone: In order to know whether or not a stone has the qualities mentioned in article 9, the stone is put to the following tests:

(a) Hardness test or Abrasion test for wear.

(b) Impact test for toughness.

(c) Attrition test.

(d) Cementation test.

(e) 'Absorption of water' test.

(f) Crushing strength test for compression.

For hardness test, a specimen of 2·5 cm (1″) diameter and 2·5 cm (1″) height is made from the stone to be tested. The specimen is weighed and then it is made to press on the top of annular steel disc of Dorry's testing machine with a pressure of 1250 gm; the steel disc is then made to rotate at 28 R.P.M. While the disc rotates, coarse sand of certain specification is sprinkled over the disc. The specimen is kept in contact with the disc till the latter has completed 1000 revolutions. During this interval, the bottom of specimen rubs and wears against the surface of steel disc which is made rough by the sprinkling of coarse sand on it. After this interval, the worn-out specimen is weighed and the coefficient of hardness is found from the formula,

$$C = 20 - \frac{\text{loss in weight of specimen, in gm}}{3}$$

Value of C should not be less than 14 if the stone is to be used for road work. This test is specially useful in finding the resistance of stone to traffic when stone is used in the form of stone blocks or setts in stone paving. When the value of C is between 14 and 17, the stone is said to be of medium hardness and when C is greater than 17, the hardness is said to be satisfactory.

In impact test, a specimen of 2·5 cm (1″) diameter and 2·5 cm (1″) height is prepared from the stone to be tested. The specimen is tested for impact in Page impact machine. Specimen is put on C.I. anvil (of the machine) weighing 50 kg. Over the specimen, is placed a steel plunger of certain design and weighing 1 kg; plunger has circular bottom and hence it touches the top of specimen at one point only. A steel hammer weighing 2 kg. is made to fall vertically and axially, on the plunger, from a height of 1 cm. The axial blow of hammer is passed by plunger to the specimen. The hammer is raised and, in the second blow, it is made to fall from height of 2 cm; in the third blow, from height of 3 cm. and so on. The specimen will break after some n^{th} blow of the hammer. The value of n represents the toughness index of the stone. If $n < 13$, the stone is not tough enough; when $n = 13$ to 19, it is called moderately tough and when $n > 19$, the toughness is said to be high.

Attrition test is used to determine the rate of wear due to the grinding action under the traffic. The given stone is broken to pieces of about 60 mm (2½″) size and about 5 kg (11 pounds) of these pieces are put in both the cylinders (20 cm diam and 34 cm long i.e. 8″ diam. and 13½″ long) of Deval's attrition test machine. The cylinders, whose axes are inclined at 30° to the horizontal, are then closed and are made to rotate about horizontal axis for 5 hours at the rate of 30 R.P.M. After that, the contents of the cylinders are taken out and are sifted over 1·5 mm ($\frac{1}{16}''$) mesh. The material remaining on the mesh after sifting is weighed.

$$\text{Percentage wear} = \frac{\text{loss in weight of stone pieces}}{\text{initial weight of stone pieces}} \times 100\,\%.$$

If wear $\lesssim$ 2%, the stone is quite good.

If wear = 3%, it is tolerable.

When wear > 3%, the stone is not satisfactory.

To know the cementing value of the dust of a given stone, about 500 gm. of it are pulverised and mixed with 90 c.c of water to form a thick paste. From this paste, a cylinder 2·5 cm diameter and 2·5 cm high (i.e. 1″ diam. and 1″ high) is made under a hydraulic pressure of 130 kg/cm^2 (1880 lbs/in^2). The cylinder is dried in atmosphere for 20 hours and it is then put in an oven box for about 4 hours, the temperature of oven being maintained at about 93°C (200°F). The cylinder is afterwards taken out of oven and put into dessicator for about 20 minutes. It is then put to the impact test in Page impact machine; in this test, however, all the blows of falling hammer are given from a *constant* height of 1 cm. The number n of blows required to break the cylinder gives the cementing value of the powder of the given stone. If $n < 10$, the cementing value of stone is poor. If $n = 10$ to 25, the cementing value is fair. When $n = 25$ to 75, the cementing value is said to be good and when $n > 75$, it is very good.

For absorption test, a cubical sample weighing about 50 gm is prepared out of the given stone. It is weighed; let its weight be W_1 gm. The cube is then immersed in a trough full of distilled water and it is allowed to absorb water for 72 hours. It is then taken out, wiped dry with cloth and weighed again; let its weight be W_2 gm. Then,

$$\text{absorption} = \frac{\text{weight of water absorbed}}{\text{original weight of dry sample}} \times 100\,\%$$

$$= \frac{W_2 - W_1}{W_1} \times 100\,\%.$$

Absorption should not exceed 0·6%.

In the crushing test, the sample in the form of cube is put to axial load in the crushing test machine; load is *gradually* increased till the sample crushes under the load. Crushing strength should be greater than 1050 kg/cm^2 (15000 lbs/in^2). Crushing strengths of 1750 kg/cm^2 (25000 lbs/in^2) and 2800 kg/cm^2 (40000 lbs/in^2) are corresponding to the stones of medium and good qualities respectively.

11. Tar and asphalt: *Crude tar* is a viscous product which results from the destructive distillation of organic materials and it has adhesive properties. The word tar should be preceded by the name of the material from which it is produced e.g. crude coal tar shows that the tar is produced from coal. Crude coal tar is dehydrated and then put to fractional distillation at a maximum temperature of 204 to 232°C (400° to 450°F). Various light oils like phenol etc. are given out, leaving *refined tar* which is useful for road work and is therefore known as *road tar.* A non-crystalline solid or a viscous material (having adhesive properties) which is derived from crude petroleum either by natural or artificial distillation process and which is substantially soluble in CS_2 is called *bitumen.* Bitumen is a mixture of hydrocarbons and is black or brown in colour. It is viscous fluid or semi-solid with a capacity for adhering to rock surfaces. It can be produced in a variety of grades in respect of softness, volatility, etc. to suit particular requirements in various types of road surfacings. Though it may occur naturally, it is usually obtained artificially as the last residual and highly viscous product from the distillation of, or as extract from, crude petroleum oil; this product is known as *petroleum asphalt* or *asphaltic bitumen* and its grade can be varied by varying the temperature during processing. When asphaltic bitumen is of such consistency that it can be directly used for making bituminous roads, it is called *asphalt cement.* The word asphalt should always be qualified by the indication of its origin or nature. Thus, we have lake asphalt, mastic asphalt and rock asphalt. *Lake asphalt* is a solid or semi-solid *natural* asphalt existing naturally in well defined surface deposits. *Mastic asphalt* is the asphalt heated and mixed with mineral fillers, sand and/or stone chippings so as to form a coherent, voidless and impermeable mass which is solid or semi-solid under normal temperature but which becomes sufficiently fluid when brought to a suitable high temperature. *Rock asphalt* is a *natural* asphalt and consists of lime stone or sand stone, impregnated with 4 to 11 % of bitumen throughout its mass. A *natural* asphalt from which water and the coarser mineral matter have been separated by the application of heat is called *refined asphalt*.

The word bitumen covers both the tar and asphalt; but, *conventionally*, bitumen stands for asphalt. Of the two bituminous materials namely tar and asphalt, the latter is more used in road construction than the former.

12. Some terms: When fractional distillation of crude coal tar is done at higher temperatures (above 450°C), a residue remains which is called *coal tar pitch*. It is a black or dark-brown solid and fusible residue. It can be softened by adding to it a fluxing agent or flux (e.g. nonvolatile oil like petroleum oil or kerosene oil) and heating the mixture; the soft material, obtained as a result of fluxing, is useful for road purposes. The process is known as *fluxing* of the pitch. *Road oils* are slow-curing liquid bitumens and are prepared by fluxing solid bituminous material with light nonvolatile oil. Similarly a solid bituminous material, the consistency of which has been thinned by adding a volatile dilutant (e.g. kerosene, white spirit, creosote etc.) and heating it, is called *cut-back bitumen* or *cut-back asphalt;* it contains 80 % bitumen and 20 % dilutant. It is usually a medium or rapid curing liquid bituminous material. A cut-back of bitumen which sets or stabilizes neither very quickly nor very slowly is called a *medium* cut-back bitumen. Rapid curing cut-back has liquid naptha as solvent while slow-curing cut-back has kerosene as solvent. A liquid product in which a substantial amount of bitumen (tar or asphalt) is suspended, in a finely divided condition, in an aqueous medium and which is stabilized by means of suitable stabilizer, is called a *bitumen emulsion* or road emulsion. Thus, molten tar or asphalt is mixed with hot water; to this mixture, is added an emulsifying agent or *emulsifier* which is usually the ordinary soap. Due to this emulsifier, tar or bitumen is kept in suspension (in water) in a finely divided state. This is how emulsion is prepared. Emulsion contains 55% bitumen and 45% water; or it may contain 75% tar and 25% water. It may be quick breaking, medium breaking or slow breaking. Quick breaking emulsion is used for inferior bituminous surfacings and slow breaking one is used for superior surfacings.

Cut-backs and emulsions of various consistencies and stabilities are supplied under various patented names by Burmah Shell Co., Esso, Indian Oil Corporation Ltd., etc.

The forms in which an artificial bitumen is used for road work are:

(i) Straight-run bitumen: this is solid or semi solid bitumen which is made fluid by heating and it is then used for road work. It cannot be used on wet surface.

(ii) Cut-back: when of thin consistency it is usually used cold; if of thicker consistency, it may be slightly heated before use. Cut-back cannot be used on wet surface.

(iii) Emulsion: this is applied cold on the road surface. It has the advantage that it can be applied on wet surface.

13. Tests for bituminous materials: In this article will be described the standard tests for tar and asphalt to know their utility as binders in road construction. Following are the tests for road tar:

(a) Specific gravity test.
(b) Consistency test.
(c) Softening point test.
(d) Distillation test for,
 (i) Water content. (ii) Phenol content.
 (iii) Napthalene content.

According to old practice, tars were classified as tar No. 1, tar No. 2, and tar No. 3 This classification was according to the viscosity of tar. Modern practice is to classify tars according to their setting property i.e. whether a tar is quick setting tar or a slow setting tar. Thus, we have tar type *A*, tar type *B* and tar type *C*; type *A* sets quickly while type *C* sets slowly. For all road tars, the above-said tests are carried out.

Specific gravity of tar is found by the following methods:

(i) Pyknometer method.

(ii) Water displacement method.

Pyknometer method is used for semi-solid tars. *Pyknometer* is a glass flask of 25 c.c capacity. Let the weight of clean and dry pyknometer with its stopper be *A* gm. It is then filled with distilled water at 15·5°C (60°F) and its stopper is placed in position. The flask is wiped dry on its outside and weighed; let its weight with water be equal to *B* gm. Water is next poured out, flask is dried from inside and liquid tar is put in it so that it becomes *about* half full. Flask is put in a water bath (at 15·5°C) for some time, it is then taken out of bath, wiped dry from outside and weighed again. Let the weight of flask plus tar at 15·5°C be equal to *C* gm. Distilled water 15·5° C is put over the tar (in the remaining capacity of flask), stopper is put in position, flask is wiped dry from outside and weighed again. Let the weight of flask with tar and water be equal to *D* gm. Then we have,

$$\text{sp. gravity of tar} = \frac{\text{weight of tar}}{\text{weigh of an equal volume of water}}$$

$$= \frac{C - A}{(B - A) - (D - C)}.$$

In case of solid tars, weigh the tar in air and then in water and find its sp. gravity by applying Archimedes principle for solid substances immersed in water.

By the *consistency* of a tar, we mean the degree or extent to which the tar is viscous. To determine the consistency of tar, a standard *Viscometer* surrounded by bath at 15·5°C (60°F) is used. Tar is heated to about 18°C and is put in viscometer, the standard orifice in the bottom of which is kept closed by a spherical ball fixed to the bottom of a rod. When the temperature of tar comes down to 15·5°C, the rod is moved up to open the orifice and the tar (coming out of orifice) is collected into a graduated glass flask. The time required for 50 c.c of tar to come out of the orifice into the measuring glass flask is found out. This time, expressed in seconds, is known as the consistency (i.e. viscosity) of tar at 15·5°C. The viscosity of cut-backs, road oils and emulsions can be similarly found.

In the softening point method, tar is melted and a cube of tar 1·25 cm × 1·25 cm × 1·25 cm (½″ × ½″ × ½″) is prepared, from it, in a mould. A beaker is filled with water at i.e. 25° C (77° F) and it is surrounded by a water bath. The tar-cube is immersed in water of the beaker by hanging it from a metal wire pierced through the body of cube. The temperature of bath (and hence of the water in the beaker) is *gradually* increased till the cube, which is held about 1·25 cm (½″) above the base of beaker, softens and touches the base of the beaker. As soon as this happens, the temperature of water in the beaker is noted; this temperature represents the softening point of the tar. This method is also known as *cube-in-water method.*

For the distillation test, tar of known weight and volume is put into a distillation flask and its temperature is raised to 93°C (200°F), then to 132°C (270°F) and finally to 149°C (300°F). The distillates collected upto 93°C, between 93°C and 132°C and, between 132°C and 149°C are collected *separately.* These distillates are expressed as percentages of the weight or volume of the distilled tar. Distillate number one gives the idea of water content in tar; second distillate gives clue to the phenol and napthalene content. Phenol content is expressed as percent of the original volume of tar while the napthalene content is expressed as percent of the original weight of tar. The third distillate gives idea about heavy oils in the tar.

For tar, tests (b) and (c) are comparatively more important.

The following are the tests for road asphalt:

(a) Specific gravity test.
(b) Consistency test.
(c) Softening point test.

(d) Flash point test.
(e) Ductility test.
(f) 'Solubility in CS_2' test.
(g) 'Loss on heating' test.

Sp. gravity test is done as for tar.

Consistency or grade of asphalt is measured by doing the penetration test by means of a *penetrometer.* Asphalt at 25°C is put in a dish and the surface of the asphalt is made to be penetrated by the point of needle (of penetrometer) of standard dimensions. The needle is weighted by 100 gm and it is allowed to penetrate the asphalt surface under this weight for 5 seconds. The vertical distance (expressed as multiple of 0·1 mm) penetrated through the asphalt in this time is called the consistency (i.e. penetration) of asphalt at the temperature of asphalt. This penetration can be directly read on the dial (of penetrometer) which is provided with a pointer for taking a reading on the dial.

At this stage we may define the consistency of a bituminous material as its resistance to deformation or flow when this bituminous material is in a semi-fluid or plastic state. In case of tar, the consistency is expressed by the viscosity of tar while in the case of asphalt, it is expressed by the penetration of asphalt.

Softening point test is done as for tar.

For the flash point test, asphalt is heated and its temperature is gradually raised till the vapour, coming out of it, takes fire *momentarily* when the vapour is brought in contact with a flame. The temperature at which this happens is called the flash point of asphalt. *Flash point* of asphalt is thus defined as the lowest temperature of asphalt at which its vapour *momentarily* takes fire but does not continue to burn. It is thus different from the ignition point of asphalt. The asphalt therefore should not be heated upto flash point if it is to be used in road construction.

Ductility may be defined as the physical property of a material which permits its permanent distortion without rupture. In ductility test, a standard briquette of asphalt at 25°C is stretched at the rate of 5 cm/minute by two tensile forces applied at its two ends. The distance, in cm, through which the briquette stretches without rupture or breaking is known as its ductility.

For the solubility test, the asphalt is dissolved in pure CS_2 at ordinary room temperature and the residue is collected. This residue should *wholly* consist of mineral matter only and should not be more than 1%.

In the 'loss on heating' test, 50 gm of asphalt are heated at 163°C for 5 hours. The loss in weight due to this protracted heating is expressed as percentage of the weight of sample and this loss should be less than 3%.

After all these tests for tar and asphalt are performed, the results of the tests are compared with the standard requirements which are expected of tar and asphalt for a particular type of road work. These standard requirements are issued by the manufacturers and suppliers of tar and asphalt.

For asphalt, tests (b), (c) and (e) are comparatively more helpful in selecting the suitable grade for a particular job.

14. Consistency of bitumen: We have already discussed the viscosity of tar or the penetration of asphalt i.e. we have learnt about the consistency (viscosity or penetration) of the bituminous binder. For different types of bituminous roads, binders of different consistency or prade are used. The suitability of asphalt of a certain penetration for the corresponding types of bituminous roads can be found from the table given at the end of this article. The consistency used depends on climate and traffic conditions; thicker consistency is used for heavier traffic and hot climate of the place where the road is constructed:

The asphalts and tars of various grades are supplied by Burmah Shell Co. and other oil companies under various patented names. On the whole, tars have better fluidity and penetrating power than asphalts. Use of a primer coat with asphalt ensures better penetrating power of the asphalt. Tars make harder surface than asphalts but such surface is brittle. Asphalts make more elastic surface and are better suited for penumatic-tyre traffic. The volume of tar required is about 10 % less than that of asphalt for the same type of road work. Asphalts of hard and soft grades can be mixed together. Similarly asphalts and tars can be mixed together and used; such bituminous mixtures are required for road work in many cases.

TABLE

Penetration of asphalt		Types of bituminous roads for which the asphalt of given penetration is suitable
Hard grade asphalt	30/40	Grouted roads; premixed roads; heavy application of surface dressing.
Do-	60/70	Used instead of 80/100 penetration asphalt in the places of very hot climate.
Medium grade asphalt	80/100	Such an asphalt of standard grade is used for surface dressing, premixing and seal coat work.
Soft grade asphalt	180/120	For light surface dressing; such an asphalt of soft grade is also used in the places of very cold climate.

CHAPTER VI

ROAD MAKING PLANT AND MACHINERY

1. Introduction: This is the age of machinery. The old, crude and slow methods of construction and maintenance with the help of hand tools are being replaced very fast by modern, refined and quick methods by the use of machinery. In many cases, these modern methods effect economy in construction, in addition to the saving in the time of construction. When the road work is of big magnitude, the use of machinery is highly desirable. In this chapter, therefore, we shall learn the *common* types of plant and machinery which is used for the construction of all types of roads.

2. Road making plant and machinery: The following is the *major* machinery which is commonly used in the construction of roads:

(a) Scraper.

(b) Grader.

(c) Tractor.

(d) Dozer.

(e) Road roller.

(f) Scarifier.

(g) Power excavator.

(h) Road drill or Road breaker.

(i) Hauling machinery like motor lorries, tip-wagons, disel locomotives etc.

(j) Stone breaker and Screens.

(k) Granulators for producing chippings.

(l) Mixer for mixing bitumen and aggregate; machinery for laying bituminous materials on road bed and for gritting afterwards the surface so treated.

(m) Mixer for batching and mixing concrete; machinery for laying, consolidating and finishing the concrete for concrete roads.

Excavating machinery consists of items (a), (b), (d), (f), (g) and (h).

The reduction of natural ground to conform to the desired gradient and cross-section of earth road is technically called *grading*. The operations to be performed in grading include:

(i) Clearing the site.
(ii) Cutting dhwn high spots and filing up low spots.
(iii) Making road-side drains and forming the shape or profile of the road.

The grading equipment used in modern road construction includes the following:

(i) Scraper.
(ii) Grader.
(iii) Tractor.
(iv) Dozer and Rooter.
(v) Road roller.

3. Wheeled scraper: (fig. 22). It provides one of the most economical machines used during earthwork operations of a road. Scraper is a machine mounted on two or four pneumatic tyred wheels and consists essentially of a

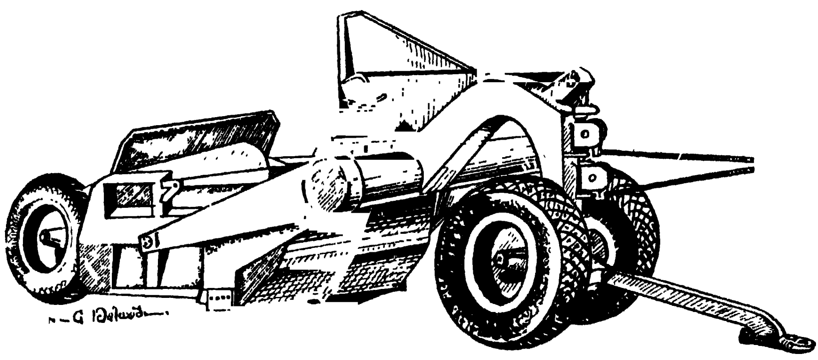


FIG. 22

large scoop with a cutting edge; scoop is designed to excavate, load and transport the material over relatively short distances upto about 460 m (1500 feet) and dump the material at the site of road. The capacity of scraper is *usually* between 3 m^3 and 9 m^3 (i.e. 4 cubic yards and 12 cubic yards). It is drawn by a tractor. The scoop of scraper consists essentially of a bucket or shallow container of steel known as bowl or body which excavates, transports and dumps the material where required. The cutting edge of the scoop does the excavating work and the excavated material goes on collecting in the scraper body or bucket from the front gate of the bucket. The material is taken out, at the site of dumping, from the rear gate of the bucket.

4. Grader: A *grader* is a machine which is either self-propelled or is towed by tractor and has a blade within the wheel base. It is used for shaping a subgrade, constructing earth roads, and for spreading loose material. A *blade grader* (fig. 23) consists of an angled blade about 2·40 m to

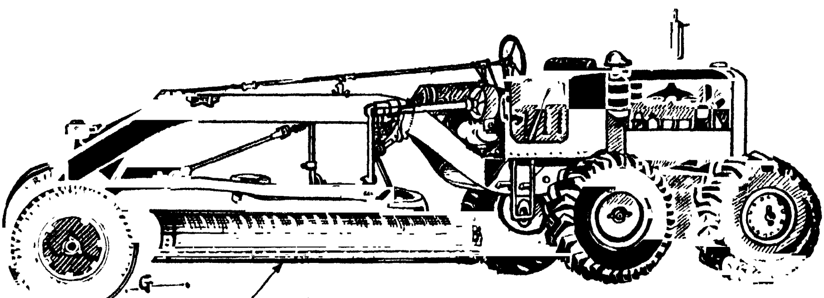


FIG. 23

3·70 m (8′ to 12′) long supported on a frame work which is mounted on wheels. The blade can be tilted, turned round and raised or lowered. Blade grader is chiefly used for levelling and grading the earth roads. When the blade grader has got its own motive power i.e. when it is self-propelled, it is called a *motor grader*. The other type of grader is called an *elevating grader*. In case of the latter type, a plough at the bottom excavates the earth and throws it on the conveyor belt which, in its turn, throws it into a wagon moving parallel to the elevating grader and with the same speed as the elevating grader. The wagon will transport the material and dump on the site of work.

Drag, which is used for maintaining profile of earth road, is described in chapter XVI on the maintenance of roads.

5. Tractor: A *tractor* is a self-propelled machine carried either on crawler tracks or on wheels. A crawler

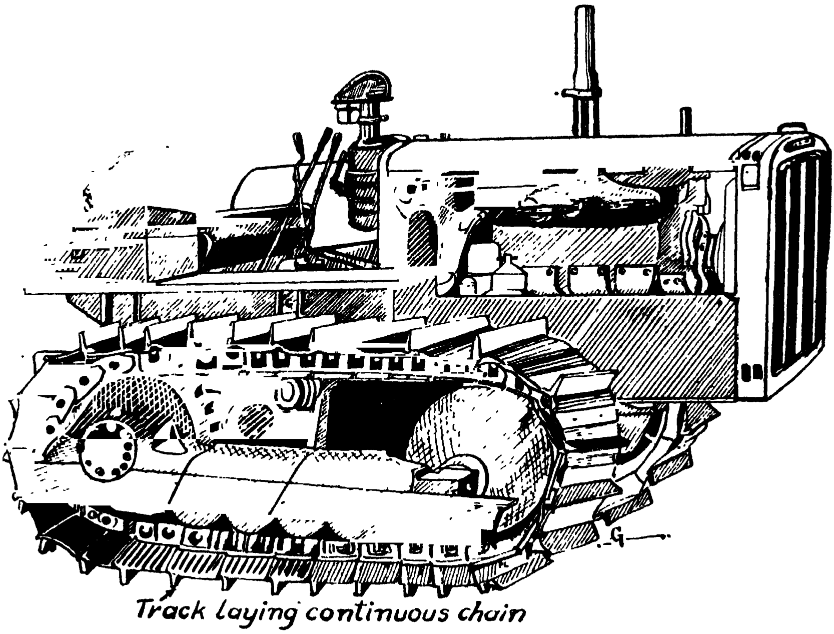


Fig. 24

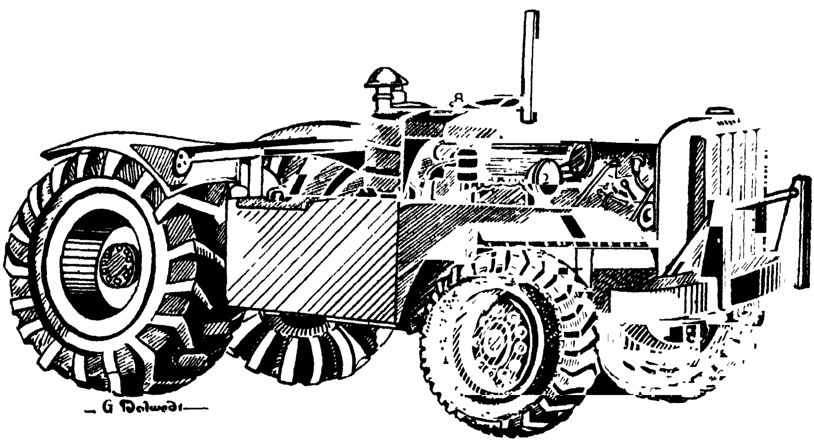


Fig. 25

track is a device consisting of an endless chain of plates which bear upon the ground and this device is used instead of wheels; when on track, the tractor is called a *track type tractor* (fig. 24) and is used when country is uneven and rough; *wheel type tractor* (fig. 25) is used in even country; tractor is intended primarily to exert a powerful tractive force for towing other machines but it is often capable of serving as a mount for other equipment like bull dozer, winch etc. Such a combination forms a self-sufficient unit.

6. Dozer: A *dozer* is a machine which is used for grading purposes. The three types of dozers are: bull dozer, angle dozer and tree dozer. A *bull dozer* is a tractor on the front of which is mounted a suitable straight and wide blade of steel at right angles to the direction of movement of the machine. The blade can be raised or lowered. Bull dozer is used for pushing the material in the forward direction.

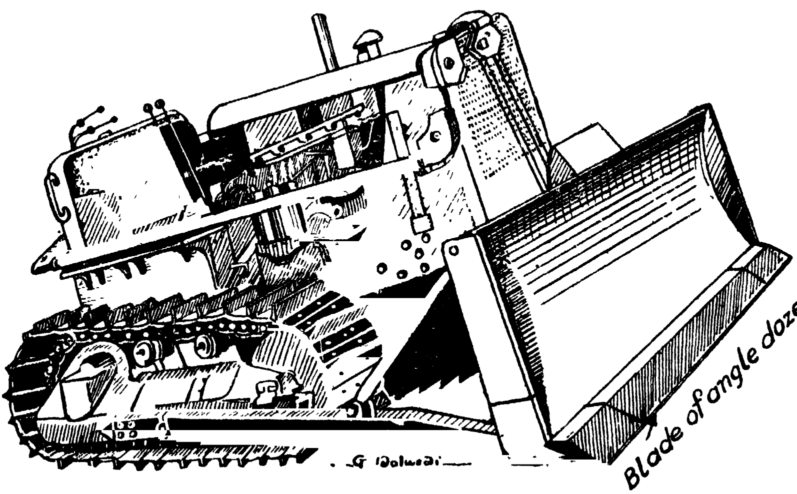


FIG. 26

The word bull dozer is also used *only* for that equipment (viz. straight blade) which is mounted on the tractor. Bull dozer is economical upto a maximum haul of 45 m (150 feet), It is used for pushing and levelling a heap of excavated earth. *Angle dozer* (fig. 26) is a tractor on the front of which is mounted a suitable blade which can be set obliquely to the direction of movement of the machine. The maximum possible angle of inclination of the blade to the front face of tractor is 30°. Due to this inclination, angle dozer is used to push the material sideways, to the right or the left. The word angle dozer is also used *only* for the equipment (viz. angled blade) which is mounted on the tractor. A *tree dozer* or *stumper* is a bull dozer with a slightly curved blade; the concavity of blade is in the forward direction of motion of the dozer and the blade is specially designed for felling trees and for unrooting the stumps. The word tree dozer is also used *only* for the equipment (for felling trees) which

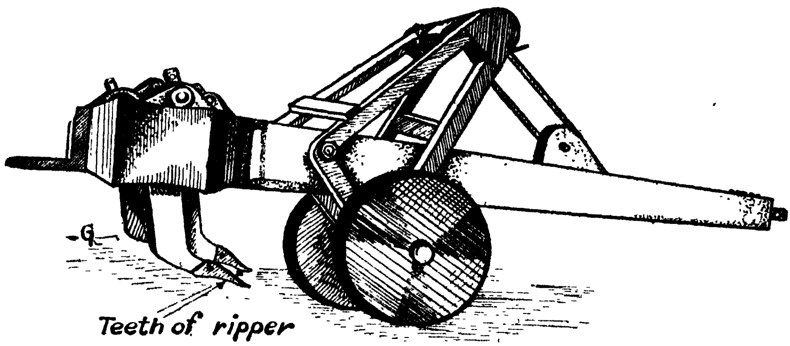


Fig. 27

is mounted on the tractor. Sometimes a *rooter* or *ripper* (fig. 27) is used for loosening the ground and for pulling up roots. A rooter is a machine mounted on wheels and is towed by a tractor. It has one or more tynes or teeth which are driven through the ground to loosen it and to pull out the roots.

7. **Road roller:** It is used for rolling and compacting the subgrade, the base and the surfacing of many types of roads. It is a towed or power-driven machine having wheels or rolls for rolling and compacting the road-making material. Following are the *common* types of road rollers:

(a) Smooth wheeled roller: This is a multipurpose roller used for various purposes and for practically all types of roads.

(b) Sheep's foot roller: This is used for rolling soils only and is towed by a tractor.

(c) Rubber-tyred roller or Pneumatic roller.

Smooth wheeled roller has smooth wheel or wheels and it may be (i) hand or animal driven (fig. 28), (ii) power driven. The former may be of one roll of stone or iron, about 0·90 m (3′) diameter and 1·20 m to 1·50 m (4′ to 5′) long and of adout 2 mt (2 tons) weight; consolidation with

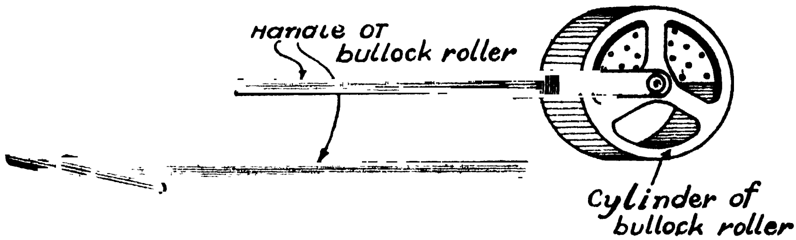
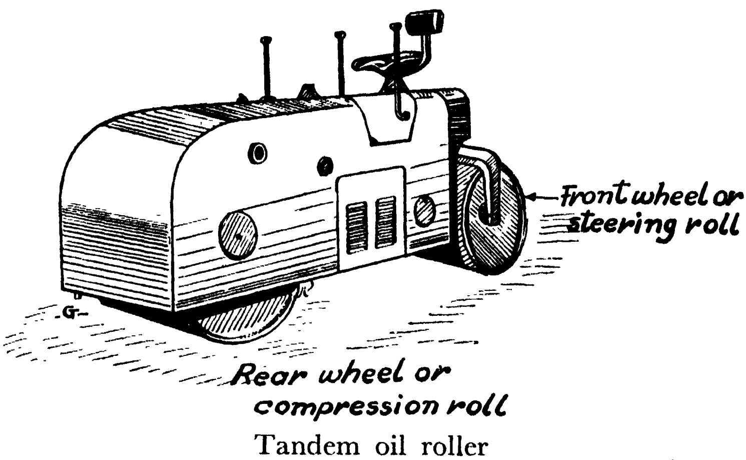


Fig. 28

such rolleı is not good and it takes more time than other rollers to do a job. The latter may be a steam roller or oil roller. The power driven roller may have two or three wheels; one with two wheels is called a *Tandem roller* (fig. 29) and is of about 6 mt to 8 mt (6 to 8 tons) weight; that with three wheels is called *three-wheeled roller* (fig. 30) and is from



Tandem oil roller
Fig. 29

10 mt to 15 mt (about 10 to 15 tons) weight. Rolling is done in longitudinal diıection and first the longitudinal strip of surface near the edge of a roadway is rolled. Then the roller is gradually taken to the crown. Rolling should

be slow and without jerks. Different weights of roller are required for different types of work, according to the size and hardness of stone rolled and according to the thickness of layer of material to be consolidated, as shown in the table below:

Type of work	Approximate nominal (i.e. static) weight of the road roller required
(i) Foot-path	75 kg to 125 kg (about $1\frac{1}{2}$ to $2\frac{1}{2}$ cwts.)
(ii) Surface dressing (soft aggregates)	2 mt (2 tons)
(iii))Surface dressing (hard aggregates)	6–10 mt (6–10 tons)
(iv) Waterbound macadam road (soft road metal)	6–8 mt (6–8 tons)
(v) ....do.... (hard road metal)	12–15 mt (12–15 tons)
(vi) Bituminuous surfaces	8–10 mt (8–10 tons)

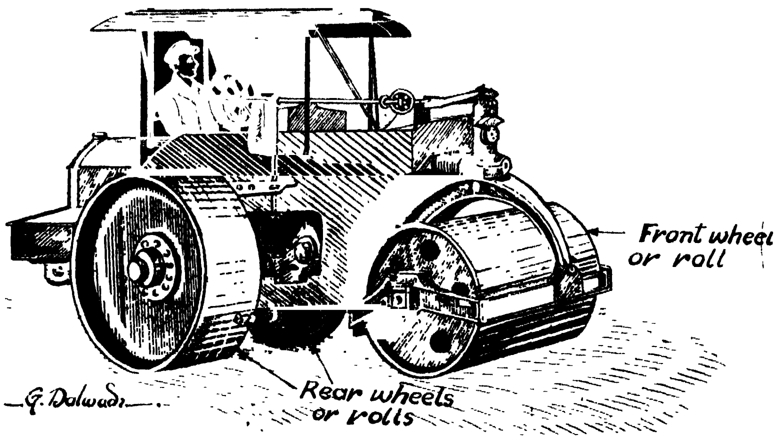
Note: (i) 1 British ton = 1·016 metric tons, or 1·016 tonnes.
(ii) Metric ton is shortly written as mt.

The power driven roller may be *oil roller* or *steam roller.* Oil (or motor) roller is superior to steam roller due to the following reasons:

(i) There is greater ease in handling an oil roller.
(ii) There is no fuel wastage in the intermittent jobs.
(iii) It can be put into action without waste of time; whereas in the case of steam roller, time is required to raise the steam which works the steam roller.
(iv) It is economical from the point of view of output of work; its output is about 50% more than that of the steam roller.
(v) It does not create smoke or ashes which are the by-products of a steam roller.

However, the initial cost of a motor roller is more and to run it, skilled driver is required. Steam and motor rollers are worked for about 8-10 hours per day and in this period, each consumes a certain quantity of materials for its working.

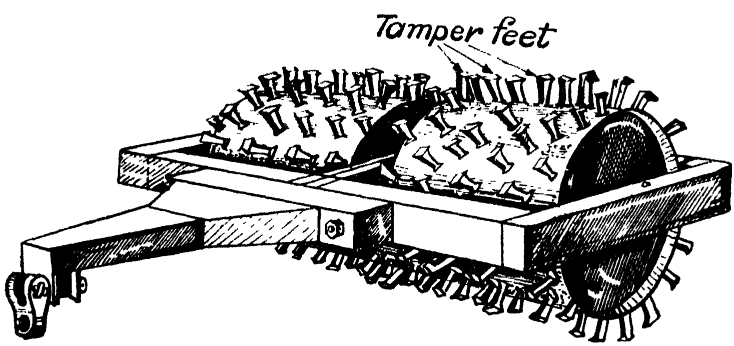
The best method of compacting many kinds of soils (usually *cohesive*) is by means of a sheep's foot roller (figs. 31 and 32). This roller consists of heavy hollow cylinder or cylinders, each about 1·20 m (4′) long and 1·2 m diameter with 18 cm



Three-wheeled oil roller

FIG. 30

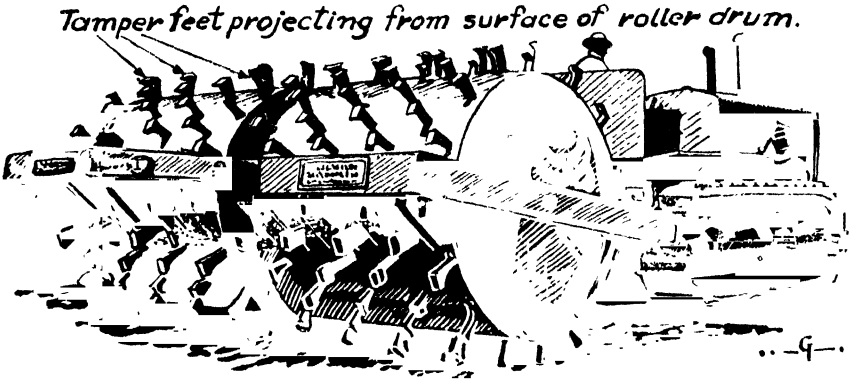
to 23 cm (about 7″ to 9″) projections extending out from the curved surface of the cylinder. These projections are in the form of sheep's feet and are arranged in rows round the cylinders, the projections in successive rows being staggered.



Two rolls of sheep's foot roller

FIG. 31

The maximum thickness of layer which can be compacted by a sheep's foot roller is about double the thickness of layer which can be satisfactorily compacted by a smooth wheeled roller. The roller is made in sections which can be connected together one behind another or in series. A single section usually weighs 1350 to 1600 kg (3000 to 3500 lbs). As the roller is pulled forward over a layer of loose material, the projections penetrate the layer and after a few rollings, the layer becomes more and more compact and the projections penetrate less and less in the rolled material. The roller is pulled by a tractor at a speed of *about* 3·0 to 5 km/h (2 to 3 miles per hour).



Sheep's foot roller towed by a tractor

FIG. 32

Pneumatic roller consists of one or two axles on which are placed a number of smooth rubber-tyred wheels above which is a flat platform; on this platform, sand bags or some other weight is placed. This type of roller is very efficient in the consolidation of earth subgrades, *granular* soils in base course and in the final operations for bituminous surface dressings etc.

8. As already said, road metal is used for road making. A lump of rock is fed into a *stone breaker* or *stone crusher* and it is reduced to road metal of the required size. The different sizes of road metal are sorted by the *screens.* For producing stone chippings, a *granulator* is used. These stone chippings are used for bituminous surface dressings.

9. Scarifier: *Scarifier* is used to score and loosen hard soil or macadam surface or old road surfacing to a uniform predetermined depth. The teeth of a scarifier, which are known as tynes, are set with a forward slant so that they may enter the surface and loosen it. They can be adjusted in vertical direction. Ordinarily, the tynes are fitted at the rear of a smooth wheeled road roller (fig. 33). As the road roller moves forward, the surface is loosened by the tynes. Another form of scarifier consists of a heavy iron frame holding a few tynes and it is dragged by a roller.

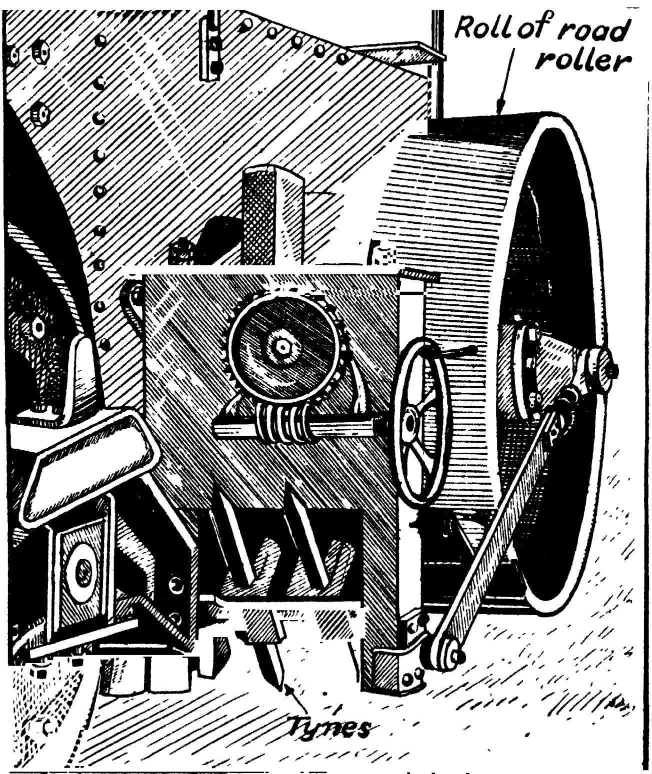


FIG. 33

10. The machinery for mixing bitumen and aggregate, for applying bituminous materials on road bed and for gritting the road surface afterwards consists of:

(i) Bitumen (tar or asphalt) boiler (fig. 34).
(ii) Bitumen sprayer.
(iii) Bitumen mixer and Bitumen spreader.
(iv) Gritter or Gritting machine.

In hot process, bitumen is heated in a *boiler* before applying it on the road surface. The hot bitumen is uniformly applied, under pressure, on the road surface by means of a *bitumen sprayer*. Heating and spraying is done by a bitumen distributor or pressure distributor. It is a pneumatic tyred lorry on which is mounted a tank with a heating system. It is further supplied with a pump to handle a cold emulsion or hot bitumen. At the rear end of the tank is attached a spray bar unit on which are fitted nozzles through which the bitumen jets are forced out under pressure onto the road

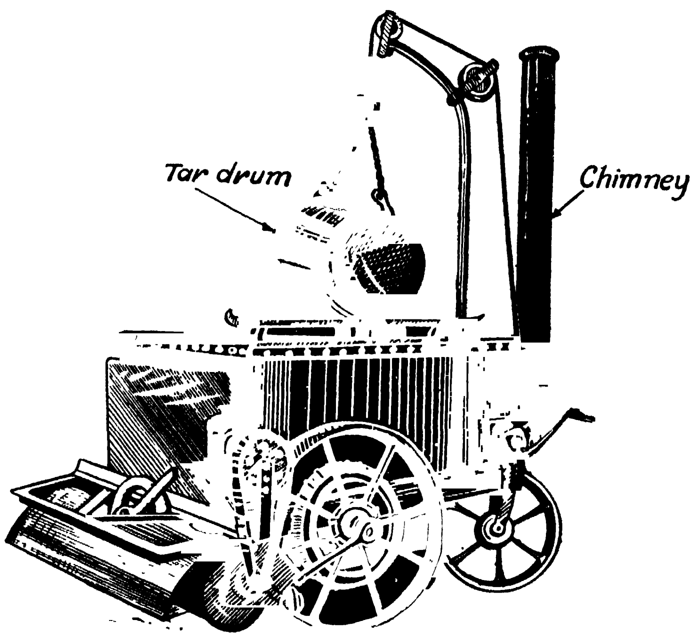


FIG. 34

surface. Bitumen is also poured by labour on the road surface through *pouring pots* [fig. 35(*a*) and fig. 35(*b*)]. In case of some bituminous surfaces, the aggregate is first mixed with hot bitumen in a *bitumen mixer* (fig. 36) and the mixture is then spread on the road bed and rolled by spreader and finisher. For mixing, there may be,

(i) Machines for mix-in-place surfacings
(ii) Travel plants.
(iii) Hot-mix plants.

(iv) Hand drum mixer for small jobs, near the site of work.

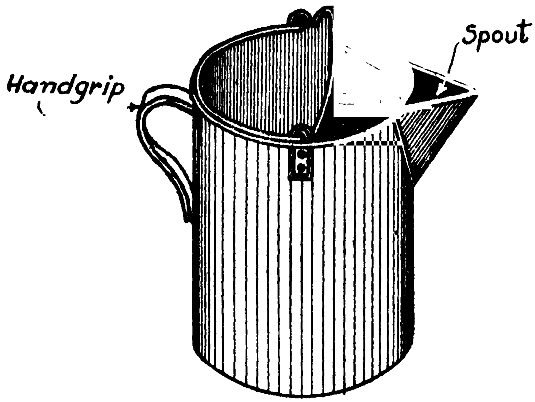


FIG. 35(*a*)

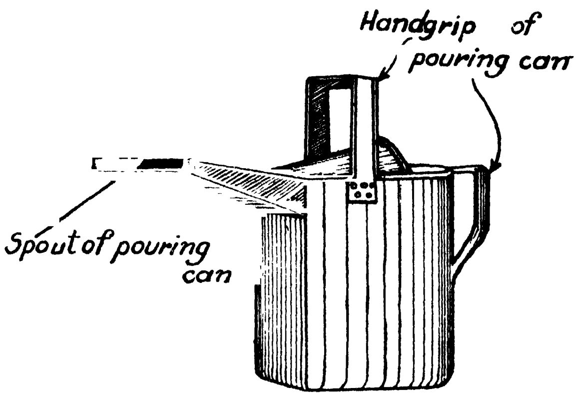


FIG. 35(*b*)

Hot-mix plant consists of five principal parts, namely,

(a) An aggregate heater known as drier.

(b) Screens and bins for separating and storing the various sizes of heated aggregate.

(c) Bitumen storage and heating tanks.

(d) Devices for accurately proportioning each constituent of mix.

(e) Mechanical mixer.

Spreaders and finishers may be for,

(i) Mix-in-place and cold-laid plant mix.

(ii) Hot plant mix.

In case of hot-mix the equipment consists of distributing hopper, strike off screed and finishing screed. In bituminous surface dressings, after the appication of hot bitumen on road surface, the surface is gritted evenly with stone chips etc. by means of a *gritting machine* or aggregate spreader.

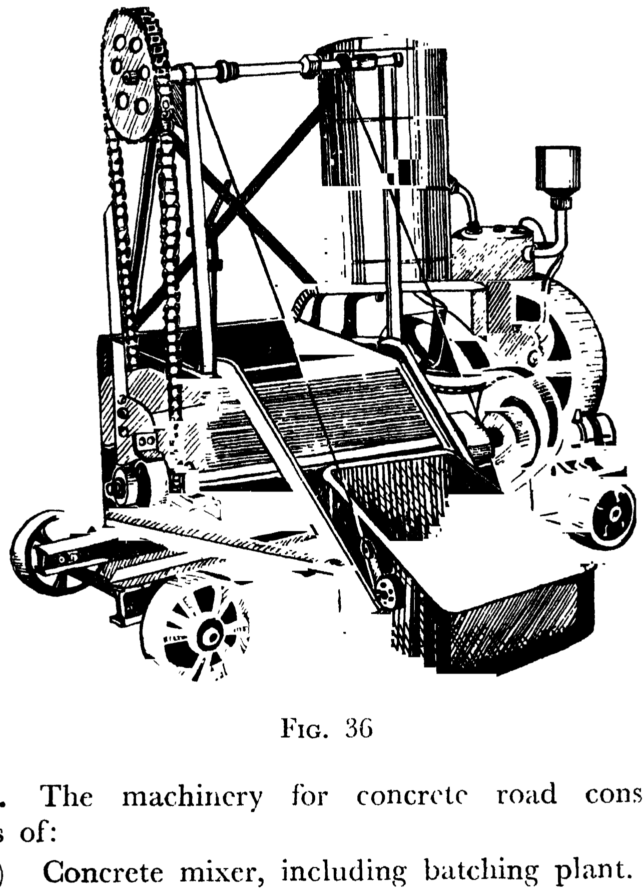


FIG. 36

11. The machinery for concrete road construction consists of:

(a) Concrete mixer, including batching plant.

(b) Concrete laying machine or Concrete paver.

(c) Concrete screed; it is used near concrete joints.

(d) Concrete vibrator; it is used on concrete surface in place of concrete tamper.

(e) Concrete finisher.

(f) Pressure grouting machine.

The ingredients, for making the concrete, come from a *batching plant* in the required proportions and are mixed in a *concrete mixer* (fig. 37) to prepare concrete of the required specifications. Batching plant is a mechanical equipment for measuring, either by weight or by volume, the quantities of different ingredients required to make up each complete charge of a concrete mixer. The batching plant in which the quantities of different materials are measured by weight is called a *weigh-batcher.* Concrete so prepared is spread on the roadway in a required loose layer by the *concrete laying machine.* This loose layer when consolidated will give the required thickness of the finished concrete surfacnig. The

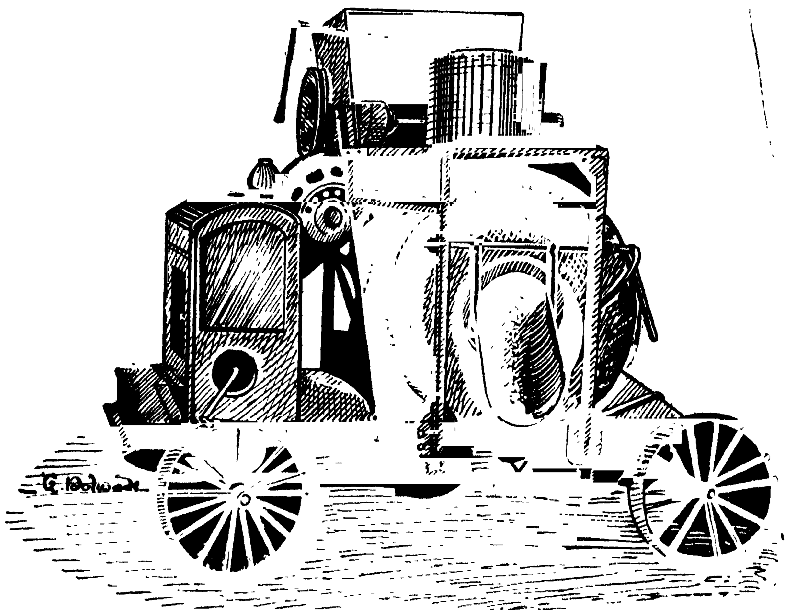


FIG. 37

loose concrete is consolidated by means of a *surface vibrator* and the top surface of the consolidated concrete is finished by a *concrete finisher.* Now-a-days, on large scale work, the loose concrete can be spread, compacted and its surface finished by a travelling plant running slowly on the top of the steel side-forms which are used as side shuttering for the concrete surfacing. One plant is required for spreading the concrete in required position and another for consolidating it and finishing its surface. The latter plant consists of a *screed* in its front, a vibrating beam in the centre and a finishing beam at its rear. After the loose concrete is spread, the surface of concrete is struck off by the front screed to the required thickness; screed is a 10 cm (4″) wide strip of metal used as a guide for striking off the loose concrete to a required thickness. The compacting unit consists of a surface vibrator which vibrates with a frequency of about 3000 vibrations per minute, the amplitude of vibration being 6·5 mm ($\frac{1}{4}$ inch); these vibrations compact the layer of freshly mixed and freshly spread concrete. The finishing beam smoothens the surface which is compacted by the surface vibrator. In case of such plant, the consolidation is better than when it is done by manual labour; also, stiffer concrete can be used than that which is used in case of manual labour. If necessary, *hand float* may be used for the proper finish after the mechanical finishing is over.

12. The machinery (e.g. *drag*, *road drill*, etc.) used during the maintenance of roads will be described in its proper place. Thus, drag is used for maintaining earth roads and as such it will be described in the chapter on the maintenance of roads.

Smaller tools and plant used during construction by manual labour will also be described elsewhere in their proper places.

Hauling machinery is very common and well known and it is therefore not described here.

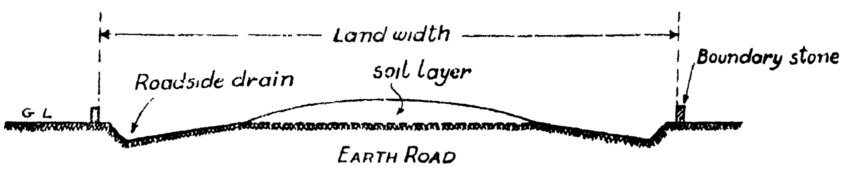
LOW TYPE ROADS LIKE EARTH, GRAVEL AND MOORUM ROADS

[UNMETALLED ROADS]

A. EARTH ROADS

1. General: In chapters VII to XII, the *current* practices followed for constructing the road surfacing of all types of roads are described. When a certain length and width of a road is under construction or repairs, that area should be blocked so that the traffic may not go over that area when the road is under construction or repairs. The traffic in case of existing road under repair or reconstruction is diverted on the alternative parallel and nearby route as a temporary expediency till the road repair or construction is over. Such an alternative temporary route is called a *diversion.*

2. Introduction: When the traffic-way of a road has the surfacing of soil, the road is called an *earth road* (fig. 38). It is a low type of road and can carry only light traffic. In the figure, land width to be acquired is shown between the



Cross section of an earth road showing V-shaped side drains

FIG. 38

boundary stones. If it is economically possible, a berm on each side should be left between the road-side drain and the boundary stone; such a procedure will increase the land width to be acquired. As most of the village roads in India are earth roads and as India is a country of villages, earth roads are of very great importance in India. As far as practicable every earth road should be made as stable and durable as possible and it should be passable and useful in *all* seasons. Unfortunately most of the earth roads in India are only fair-weather roads. These should be made all-weather roads and, in future, special attention should be paid to the design, construction and maintenance of earth roads in India.

3. Classes of earth roads: Earth roads may be classified as:

(a) Natural (or Native) earth roads.

(b) Stabilized earth roads, 10 cm to 20 cm (4″ to 8″) thick.

Natural earth road is one which is made of soil like clay, sand, loam etc. available naturally along the alignment of road. The natural soil along the alignment is compacted and given the proper gradient and proper camber in the length and the width respectively of the traffic-way when it becomes a natural earth road. The earth road may be in bank or in cutting; *usually*, earth road in cutting is avoided. The usual shoulders, berms and side drains are provided—one shoulder, one berm and one side drain being on each side of the prepared traffic-way of natural soil. This type of road is not durable and is highly unsatisfactory. It gets worn out under the traffic very easily. The road may be constructed either by manual labour when the tools like shovel, spade, mamoty, pickaxe, baskets etc. are used; alternatively, it may be prepared by road machinery like scrapers and graders.

The usual type of *stabilized earth road* constructed in India is the *sand-clay road.* Clay particles provide cohesion and bind the sand particles together while the sand particles provide stability and reduce the shrinkage of soil. If the soil along the alignment of road is clay, sand is brought from some nearby place and is mixed with clay of the proposed traffic-way in proper proportions (usually 1 part of clay with 2 parts of sand); the percentage of clay to be mixed with sand should be equal to the percentage of voids in the sand. If the soil along the alignment of road is sand, clay is brought from elsewhere and is mixed with sand of the proposed traffic-way in proper proportions. In each case, the original surface is first ploughed to a depth sufficient to furnish the required amount of in-place material for the desired thickness of surfacing to be constructed. Also in each case, the mixture of sand and clay is spread in a loose layer of about 11·25 cm ($4\frac{1}{2}''$) and the layer is compacted by light rollers to a thickness of about 7·5 cm (3″). It may be remarked that a soil will generally get compacted to about $\frac{2}{3}$rd of its loose thickness. A little water is used during rolling so that the rolling is done at O.M.C. of the soil. During rolling, the required camber and gradient are maintained. Similarly we can have 15 cm (6″) finished thickness of the sand-clay layer rolled in two layers if greater thickness is required. The road should have 1·20 to 1·50 m (4′ to 5′) wide shoulder of good earth on each side. This type of earth road is more durable and better than the first type and can take a maximum *composite traffic* consisting of 50 mt (about 50 tons) of rubber-tyre traffic and 30 mt (about 30 tons) of steel-tyre traffic per one traffic lane per day. As it is an earth road, after some use the deep ruts and pot holes are formed in its surface, specially due to steel-tyre traffic. These ruts and pot holes should be filled in periodically. For durability of road, the longitudinal grade and the camber must be maintained to their original standards, by means of a drag which is described in chapter XVI. Side drains should be properly constructed and maintained. In fact, the surface drainage is very important in case of earth roads. If it is efficient, the life of road increases and the road remains passable in all seasons.

B. GRAVEL AND MOORUM ROADS

4. Introduction: Gravel road is also a low type and low cost road like earth road and it is also essentially a village road. Hence great care should be given to the design, construction and maintenance of this type of road also.

5. Gravel road: The surface layer of traffic-way of a gravel road [figs. 39(*a*) and 39(*b*)] is made of:

(a) about 6 mm to 36 mm ($\frac{1}{4}''$ to $1\frac{1}{2}''$) size gravel.

(b) Binder (or bindage) to bind the gravel pieces together.

Gravel can be had from river bed when it is called the *pit-run* gravel; we can use *crushed gravel* also. Gravel is mixed with required quantity of binder which consists of sand and clay in proper proportions. Usually, the mixture consists of 26% of sand and 13% of clay. The binder not

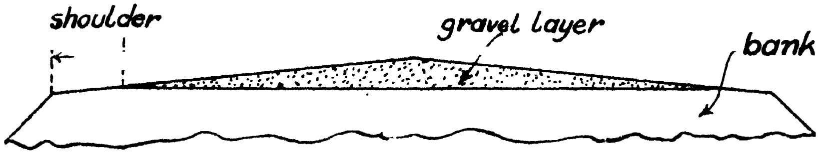


FIG. 39(*a*)

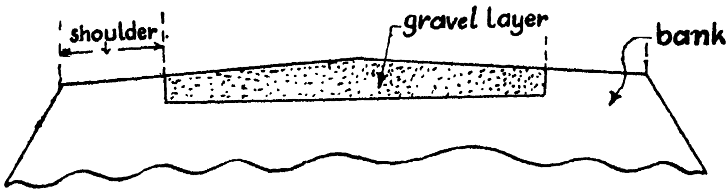


FIG. 39(*b*)

only binds the gravel together but it also fills the voids between pebbles. The mixture is spread on the prepared and rolled subgrade (the foundation layer is not necessary for gravel roads) and is rolled by means of a light (3 to 5 mt) roller to get a rolled thickness of 15 to 30 cm (6″ to 12″) according to the requirements of traffic More traffic and the weaker subgrade need greater finished thickness of the gravel surfacing. During rolling, proper grade and camber must be maintained. The mixture is usually spread in a loose layer of 11·25 cm ($4\frac{1}{2}''$) thickness, at a time, which is compacted by light (8 mt) roller to a finished thickness of 7·5 cm (3″). Surface is slightly sprinkled with water during rolling. If we want 15 cm (6″) thick finished surfacing, it will be constructed in two layers, each layer being rolled separately. Similarly we can have greater compacted thickness if necessary. During rolling, it should be seen that the surface becomes compact but the pebbles do not get crushed under the roller. Before opening the road to traffic, the rolled surface should be lightly sanded so as to obtain a cover of about 6 to 12 mm ($\frac{1}{4}''$ to $\frac{1}{2}''$) over the whole surface.

As in earth roads, the surface drainage should be efficient and the grade and camber should be maintained by periodical repairs. In dry weather, clay particles of the binder get blown off, hence the surface is slightly sprinkled with water in dry weather to keep the binder in position; if this were not done, the pebbles, in absence of binder, will become loose under the traffic. The surface becomes somewhat muddy in rainy season.

This type of road, if properly maintained, can take double the composite traffic carried by a sand-clay road.

6. Moorum road: This is also a low type road and resembles gravel road in durability and service. In this type, the traffic-way has the surfacing of moorum which is consolidated in layer or layers to get the required finished thickness of surfacing; the surfacing is directly laid on the prepared subgrade. Blindage is not usually required; however, the top dressing of sand may be given to the rolled surface. This is also essentially a village road and requires same care and attention as the other village roads.

CHAPTER VIII

WATERBOUND MACADAM ROADS

[UNTREATED METALLED ROADS]

1. Introduction: Waterbound macadam (W.B.M.) road is better than earth, gravel and moorum roads. Some of the good village roads are W.B.M. roads. It is a good plan to have *at least* W.B.M. road as a village road; W.B.M. road is becoming more common as a village road in India.

2. Waterbound macadam road: W.B.M. road [fig. 40] is that type of low cost road which may be laid on soil subgrade or gravel subgrade. It *may* have foundation layer of rubble stone in addition to the surfacing. Its surfacing consists of:

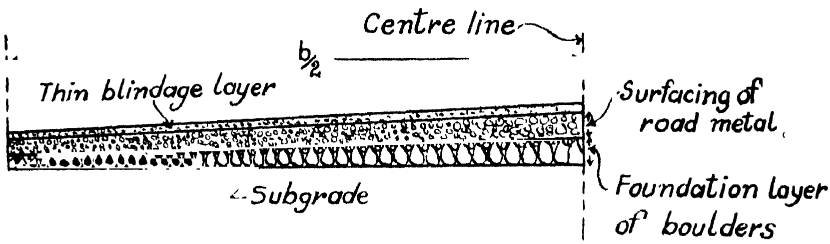


FIG. 40

(a) Stone pieces of about 24, 36, 48, 60 or 72 mm (1″, 1½″, 2″, 2½″ or 3″) size. These pieces are called *road metal* or *macadam*; hence the road is called macadam road. Also, during its construction water is copiously used to help in interlocking the stone pieces together; hence the road is called waterbound macadam road. If the road metal is made from *hard* stone, *small* size of metal is used and vice versa.

(b) Bindage in the form of stone chips or soft moorum or even kankar bajri. Sometimes, small size gravel and coarse sand are used as bindage. *Bindage* or *binder* fills the voids at the top of the rolled layer of macadam and binds the stone pieces together.

(c) Blindage in the form of thin layer of coarse sand.

3. Construction: The subgrade or road bed is shaped to the required grade and camber. If the subgrade is weak, as it is when it is of soft clay or black cotton soil, the foundation layer of required thickness is laid on the subgrade and rolled with 8-10 mt roller to proper grade and camber. Foundation layer which is 0·3 m (1′) wider than the surfacing layer usually consists of 13-23 cm (5″ to 9″) size stones which are hand-packed in a 23 cm (9″) thick layer; they are bedded on their broadest face, with their pointed portions upwards. The voids between these big-size stones are filled with smaller spawls about 36-72 mm (1½″ to 3″) size. This layer is also called *Telford base* because it was first suggested by English road engineer named Telford. Scotch road engineer by name Macadam had suggested only a surfacing layer of road metal. Waterbound macadam is a type of surfacing in which the road metal is first interlocked by rolling and then it is bound and blinded (at top) with stone chips, gravel or kankar bajri which is forced in, at the top, by watering and rolling. The details about the construction of the surfacing or *wearing course* are as follows:

Subgrade is properly compacted and prepared to required grade and camber; 1·50 m (5′) wide road shoulders of good earth or moorum are prepared and rolled so as to retain the road structure between them. *If required*, the soling of stone, brick or hard moorum is spread and compacted by rolling. On the top of this soling, 11·25 cm (4½″) layer of metal of specified size is spread between camber templates fixed at about 7·5 — 15 m (25′ to 50′) c/c to get a 7·5 cm (3″) rolled layer after the rolling; the width of soling layer will be 15 cm (6″) more, on either side, than the specified width of the metalled surface which forms the traffic-way. During rolling, the required grade and camber should be maintained. The grade can be checked by stretching a longitudinal string between the adjacent templates. If greater finished thickness is required, another layer is similarly spread and rolled dry so that the pieces of stone get interlocked. Rolling should begin at the edges of traffic-way and the 12 mt road roller should move backwards and forwards along the length of road; then the roller should move slightly sideways towards the centre of traffic-way and should again move backwards and forwards till half the width of traffic-way is rolled *dry*. Similarly other half-width of the surfacing should be rolled dry, beginning with the other edge of traffic-way and progressing towards the crown of traffic-way. Roller should move smoothly at a maximum speed of 30 m/minute (100 ft/min) and without jerks; road surface will be wavy when roller moves with jerks. Water is *lightly* sprinkled on the rolled surface and the surface is rolled again till the stone pieces are *nicely* interlocked and the surface becomes hard. After this, 6-12 mm ($\frac{1}{4}''$ to $\frac{1}{2}''$) layer of bindage of soft moorum or kankar bajri or fine chippings is spread uniformly on the hard and open-textured surface to seal it and bind the stone pieces at the top; water is copiously used on top of this bindage and the surface is again rolled till the surface become hard, smooth and impervious. Next day, the surface is again rolled and covered with 6 mm ($\frac{1}{4}''$) blindage layer of coarse sand to prevent the wet bindage from sticking to the wheels of the vehicular traffic. Thereafter, the rolled surface is kept moist for about 7 days by light sprinkling of water. When the road has set properly and is dry, it is opened to the traffic.

During rolling of the base, the surface of base may become uneven and may show humps and hollows which should be corrected by removing the humps or filling in the hollows with extra material. Similarly, while rolling the road metal, unevenness in the surface, if any, should be corrected to get the surface of required grade and camber and, the surfacing of required thickness. The unevenness can be readily detected by stretching a piece of string between two points on the surface.

W.B.M. road in good condition can take a composite traffic of 910 mt (900 tons) per traffic lane per day; this traffic may consist of 460 mt (450 tons) of rubber-tyre traffic and 460 mt of iron-tyre traffic. For good service and better life of road, the W.B.M. surfacing should be maintained to its designed profile and grade by regular repairs when they are found necessary.

W.B.M. road surfacing should be constructed with road metal obtained from hard stone; but in many cases the soft stone available near the road alignment is used for making

W.B.M. surfacing. Thus, we have laterite road, kankar road and lime stone road. Laterite road is a W.B.M. road with the surfacing formed of roed metal obtained from laterite stone. Kankar road is a W.B.M. road with the surfacing formed of road metal 60 mm to 72 mm (2½″ to 3″) size obtained from kankar stone; limestone road is a W.B.M. road with the surfacing formed of road metal obtained from limestone. Laterite, kankar and limestone are soft and hence in the case of roads made from these stones, the road metal of bigger size is used. Also, in case of roads made of soft road metal, light (6 to 8 mt) roller should be used for the consolidation purposes. In case of kankar, sometimes, hand rammers are used instead of roller if the kankar gets crushed under the roller. In case of kankar roads, bindage and blindage may not be used as, while being consolidated, kankar road metal forms its own bindage and blindage to seal the top surface; when it is absolutely essential to use blindage, kankar bajri is used as bindage for such roads.

4. W.B.M. road in service: The W.B.M. road can take the bullock cart traffic better; under motor traffic, it wears away easily. The bindage is sucked up by fast-moving motor traffic and is blown off; the road surface without bindage disintegrates in no time. Also, the surfacing gives way in isolated patches; such worn-out local patches or depressions of the road surfacing are known as *pot holes.* These should be repaired as soon as they appear on the surface. If, however, pot holes occur on more than one-third area of a road surface in a particular reach, this area should be repaired by scarifying the surface, rolling the old road metal so scarified, spreading the required fresh layer of loose metal, rolling it and, preparing the surface as is done while constructing a new W.B.M. surfacing. This sort of repair is called *partial resurfacing* of the W.B.M. road. When the entire thickness of the surfacing is allowed to be worn out, due to negligence shown in the maintenance of road, the entire surfacing is said to have died and the life of road then ends. The entire thickness of surfacing should be renewed and the process is called *renewal* or *resurfacing* of the road. The road is then said to have been given a new life after its death. It is a good practice to keep the road in good and immediate repair because when the road surfacing becomes badly worn, the repairs become costlier; also till the surfacing is repaired, it causes inconvenience and danger to the traffic.

5. Dust nuisance and its prevention: The low type of roads like earth, gravel, moorum and W.B.M. roads produce dust when in service and they create more dust when they get badly worn and are not kept in good repair. Unmetalled roads like earth, gravel and moorum roads create more dust nuisance than the metalled road like W.B.M. road. To lay down dust, unmetalled and W.B.M. roads are *lightly* sprinkled with water when it is found necessary; too much water, if sprinkled, will create muddy surface and the wet or drenched road surfacing will get worn quickly under the traffic. This remedy for dust nuisance is however temporary. The other remedies are:

(i) A coat of road oil may be given to the surface of earth, gravel or W.B.M. road. This oil coat keeps down the dust and increases the load carrying capacity as well as the life of road to some extent. Also the surface of earth road is lightly bladed, $CaCl_2$ powder in required quantity is added and the surface rolled to get a dust-proof and stable surfacing. Various other methods of soil-stabilization may be used to make the earth roads dust-proof and more stable.

(ii) At times, a light coating of tar or asphalt is given to the surface of gravel road to lay down dust and to increase its load carrying capacity as well as its life to some extent.

(iii) Powder of $CaCl_2$ is sprinkled on the surface of W.B.M. road. This powder takes up the moisture from atmosphere and thus the bindage remains always moist and therefore intact in its place; the result of this is that the stone pieces remain bound together. The bindage gets blown off only when it becomes dry in the dry weather. Sometimes, solution of $CaCl_2$ in water is applied on the road surface.

(iv) A light surfacing of tar or asphalt (known as surface dressing) is given to the surface of W.B.M. road. This is the best remedy to remove dust nuisance permanently. Such a surfacing also increases the load carrying capacity and the life of road to a *considerable* extent.

(v) Dust-proof surfacings like bituminous carpets or bituminous pavements, concrete pavements and block pavings may be constructed. These are good dust-proof roads but they are constructed when the traffic is heavy; they are also costly. All these roads are known as modern roads or high-cost roads or superior roads. These roads are described in subsequent chapters.

CHAPTER IX

BITUMINOUS ROADS

1. Introduction: Bituminous road is a road in the surfacing of which bitumen (i.e. tar or asphalt) is used as a binder which binds together the coarse ingredients (i.e. stone metal) of the surfacing. Such a road is also known as *black top* road because the surface of this road presents a black appearance due to bitumen. These roads are common in cities and towns; also roads like national highways may be bituminous roads.

2. Classification of bituminous roads: There are various types of bituminous roads which are useful for different intensities of traffic and different character or composition of traffic. Some of the *common* types of bituminous surfacings are as follows:

(a) Surface dressing or Surface painting. This is a type of bituminous surface treatment which may be either of single coat or double coat.

(b) Bituminous (i.e. tar or asphalt) macadam.

(c) Bituminous (i.e. tar or asphalt) concrete.

(d) Sheet asphalt.

In each case, bitumen (i.e. tar or asphalt) as a binder can be used hot or cold. In hot process, bitumen has to be heated to the *required* temperature before it can act as a binder on the stone metal which has also to be heated; over-heating of binder will destroy its physical properties. In different classes of work, different consistency of bitumen is used. In case of light traffic and in cold climate, bitumen of thin consistency and in case of heavy traffic and in hot climate, one of thick consistency is used. A tar of thin consistency means a tar of low viscosity; asphalt of thin consistency means an asphalt of high penetration. A tar of thick consistency means a tar of high viscosity; asphalt of thick consistency means an asphalt of low penetration.

Also, in a particular type of work, bitumen having the required *setting quality* (i.e. quality of being hard) is used. Tars and asphalts are available in market under various trade names. In cold process, bitumen in liquid state is used and it does not require heating before use as a binder on the stone metal which is used cold and is not to be heated. Such solutions of bitumen are known as:

(a) Bitumen (i.e. tar or asphalt) emulsion. This can be used in wet weather also.

(b) Bitumen (i.e. tar or asphalt) cut-back of thin consistency. When bitumen cut-back is of thicker consistency, it may be heated to about 120°C (250°F) before use.

Also, in each process, the coarse ingredients of surfacing may be first mixed with binder and then the mixture is laid, on prepared layer of base, in the form of a continuous surfacing known as *pavement*. Such a method is called *premix method.* The premix may be prepared in a plant when it is known as *plant-mix;* it may also be prepared at the site of work on the road-side, when it is known as *road-mix.* Premix method is invariably used in case of bituminous concrete and sheet asphalt roads. In some other cases, in each process, the coarse ingredient is laid in the form of surfacing layer and the binder is introduced from the surface of this layer to penetrate the surfacing layer. This is called *penetration method* or *grouting method.* And yet there are cases, in each process, in which the binder is first applied on road bed and the coarse ingredient is spread immediately after this; such method of construction is known as *surface treatment.*

3. **Surface dressing or Surface painting:** It is a kind of bituminous surface treatment in which a film of tar or asphalt is first applied on the prepared top of road foundation and then, on this film, is spread a thin layer of stone chippings or other fine mineral aggregate and the surfacing is then rolled. The thickness of this surfacing is *usually* 2 cm (about $\frac{3}{4}''$) and its main purpose is to seal the surface of foundation layer and make it impervious, smooth and durable. Foundation layer may be W.B.M. surfacing, stabilized gravel layer or a layer of stabilized soil. In hot

process, hot tar or hot asphalt is used; in cold process, emulsion like colas or, cut-back like shelmac or shelspar is used. Surface dressing is usually given on the top of W.B.M. road which may be either existing one or it may have been just newly constructed. In case of new W.B.M. road, if the surface dressing is to be put on the top of W.B.M. road, the bindage (which is used as a final process in the construction of W.B.M. road) should not be used. Thus, after the perfect interlocking of road metal, the surface dressing is given to the top of new W.B.M. road. In case of existing W.B.M. road, the surfacing of W.B.M. road is first brought to proper grade and profile by the necessary repairs which may be in the form of patch work or resurfacing. Surface is then cleaned of dung, dust, dirt etc. and is made *absolutely clean* by means of wire brushes [see fig. 41], soft brushes and gunny bags.

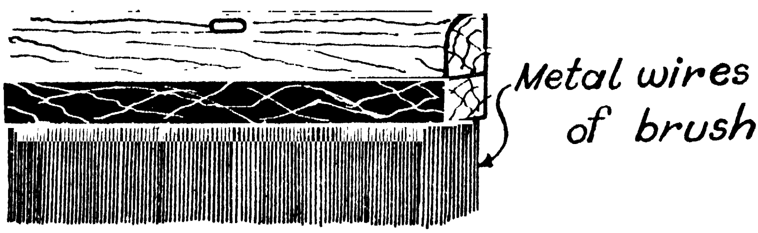


FIG. 41

Surface should also be *dry*. In hot process, the binder (tar or asphalt) is heated in either bitumen boiler or in heating kettle. Tar, if used, is heated to *about* 120°C (250°F) and asphalt, if used, is heated to *about* 180° C (350°F). The actual temperature to which tar or asphalt should be heated depends on the type and grade of tar or asphalt; this temperature is fixed by manufacturers for each type. For surface dressing, tar or asphlat of thin consistency is required so that it can be applied easily on the surface. A *uniform* thin film of hot binder is laid over the *clean and dry* surface of W.B.M. road either by spraying machine or by hand pouring from a pouring can, having a spout. The laying of hot binder is done in strips, in the longitudinal direction of road, beginning with the edges of road. The binder is brushed evenly over the surface by brushes. About 35 to 50 lbs (av. about

40 lb.) of binder are used per 100 sq. feet of the road surface i.e. an average of 2·0 kg of binder per one sq. metre of the road surface. It should be noted that the life of road can be increased by using less (but reasonable) quantity of binder. Mechanical sprayers and spreaders should be used for economy, even distribution and better life of the surfacing. After the binder becomes tacky, ungraded stone chippings of 12-18 mm ($\frac{1}{2}''$ - $\frac{3}{4}''$) size are spread *uniformly* over the applied binder, in a thin one-chip layer, at the rate of about 1·5 — 1·8 m^3 per 100 m^2 (i.e. 5-6 c.ft. of stone chippings per 100 sq. feet) of road surface. The spreading of stone chippings is known as *gritting* the surface with chippings or broadcasting the chippings on the surface. After the gritting process, the surface is lightly hand-broomed and is then rolled by a 6-8 mt Tandem roller so that the chippings get fixed into the binder which, after setting, will hold them firm on their bottom and sides; there should be no free binder on the top of chippings. During rolling, the *usual* precautions (as are taken while constructing a W.B.M. road) are taken. Also, where necessary, more chippings are broadcast during rolling; this becomes necessary where more binder shows itself and where depressions appear on the surface. Traffic is normally kept off the road until at least 24 hours elapse after the completion of the work.

In case of cold process, the rapid-setting emulsion from a pouring can or a spraying machine is applied on the clean and dry surface at the rate of $\frac{1}{4}$-$\frac{1}{2}$ gallon per 9 sq. feet of the surface or 33-39 lb. of emulsion per 100 ft^2 of road surface or 1·60 — 2·0 kg per one sq. metre of the surface. The surface is then gritted with 1·0 m^3/100 m^2 ($3\frac{1}{2}$ c.ft/100 ft^2) of 6 mm ($\frac{1}{4}''$) size stone chippings before the emulsion breaks; emulsion is said to have broken when it *just* changes its colour from brown to black. As the time passes on, the emulsion will become thicker and thicker due to the evaporation of water and the bitumen of emulsion will ultimately harden and hold the chippings firm. Cut-back, if used, may be applied at the rate of 1·5 kg/m^2 (30 lb. per 100 ft^2) of road surface.

Note: 1 gallon = 4·55 litres. Hence $\frac{1}{4}-\frac{1}{2}$ gallon/9ft^2= 1·3 to 2·7 litres/m^2.

In the case of W.B.M. road made from soft stone like kankar, laterite etc., it is not possible to make the surface perfectly clean before putting the surface dressing on it. For such roads, after cleaning the surface to the *maximum possible extent*, a *priming coat* of a primer (i.e. a binder of low viscosity) is given on the cleaned surface so as to penetrate and bind the loose particles; thus, a film of primer like road-oil is applied on the surface to fix the dust of soft stone. On this film of primer, is put the surface dressing, as usual, after 24 hours when the primed surface becomes dry. Primer is also put where there is an absorbing base of gravel etc.

The above type of surfacing over W.B.M. road is called a *single-coat surface dressing* because the binder and the chippings are laid in *one* layer which is thin also; about 2 — 2·5 cm ($\frac{3}{4}''$ to 1″) thick single coat surface dressing is *useful* for a mixed traffic consisting of 1020 mt (1000 tons) of motor traffic and 510 mt (500 tons) of iron-tyred traffic; this surfacing is however better fitted for motor traffic.

For heavier traffic consisting of more bullock cart traffic, *two-coats surface dressing* 3 cm (about $1\frac{1}{4}''$) thick will be suitable and desirable. Two-coats surface dressing is sometimes known as *armour coat.* Both the coats are either given one after another or, one coat is given as explained above and the road is opened to traffic for some days; the road surface is then cleaned and made dry *as usual* and the second coat is given like the first coat with only this difference that the materials (viz. binder and chippings) required for the second coat are *less* than those required for the first coat. Thus, in hot process second coat will require about 1·5 kg of bitumen per m^2 (30 lb. per 100 sq. feet) of road surface and 1·2 to 1·5 m^3 of *finer* chippings of 9 mm ($\frac{3}{8}''$) size per 100 sq. m. of the road surface or 4 to 5 c.ft./100 ft^2. In case of two-coats dressing, the thickness of first coat may be about 2 cm ($\frac{3}{4}''$) and that of the second coat may be about 1·25 cm ($\frac{1}{2}''$). Similarly two-coats surface dressing can be given with emulsion like colas. Surface dressing can also be given with premix which is prepared by mixing the stone chippings and bitumen. The mix so prepared is laid and rolled. The bitumen for mixing is taken at the rate of about 64 kg/m^3 (4 lbs.

per c.ft.) of the stone chippings used; the chippings may be of 12 mm ($\frac{1}{2}''$) size and are used at the rate of 2·5 $m^3/100\ m^2$ or $8\frac{1}{3}$ c.ft. per 100 ft^2 of road surface.

Tar is generally not satisfactory for making good roads. Tar becomes brittle in cold weather and it *bleeds* in hot weather specially when due to negligence, a little more quantity of tar is used in the surfacing than what is absolutely necessary. To overcome this defect of bleeding, *tar mixtures* are used. Heated tar at 120° C (250° F) may be mixed with 10 to 20% of bitumen and the mixture may be mixed well to form a tar mixture. Also, one part of tar may be mixed with $1\frac{1}{2}$ to 2 parts of the heated tar-pitch to form a tar mixture.

If a renewal coat is to be given to a worn out existing surface-dressed road, the quantities used will be approximately the same as used for the second coat of a two-coats surface-dressed road.

4. Bitumen-bound macadam 2·5 to 7·5 cm thick (1″ to 3″ thick): It is a type of construction in which the coarse aggregate is *bound* together by asphalt or tar which is used either by premix method or by grouting method. In the grouting method, the macadam is first laid on the prepared foundation and then the binder is introduced from the top to penetrate through the thickness of the layer of macadam. The surfacing is therefore also called the *bituminous penetration macadam* or *bituminous grouted macadam*. Grouting can be done with tar or asphalt as required. When the penetration of binder is for a very small depth (about 2 — 2·5 cm or $\frac{3}{4}''$ to 1″) below the surface of macadam, the method is called *semigrouting;* in this case, cold process may be used. When the penetration is substantial (i.e. 5 to 7·5 cm, or 2″ to 3″) it is called *full grouting*. Thus, we may have bituminous macadam full grout road and bituminous macadam semi-grout road. Cold process is *usually* not preferred in the case of bituminous macadam roads because the road surfacing constructed by hot process is superior to that constructed by cold process. Bituminous macadam surfacing is laid on the existing W.B.M. surfacing which serves as a foundation layer for it. It may also be laid over a 15 cm (6″) thick metal base prepared for the purpose.

In case of bituminous macadam full grout surfacing, the surface of existing W.B.M. road is brought to proper profile and grade by the necessary repairs; this is known as *reconditioning* of the existing worn-out surfacing of W.B.M. and the old surfacing is said to have been reconditioned. There should be atleast 15 cm (6″) thick base of W.B.M. The side kerbs of brick etc. are then constructed so that the bituminous surfacing may be laid between them. Road metal of 36—48 mm ($1\frac{1}{2}$″ to 2″) size is spread between these kerbs in a 8·75 cm ($3\frac{1}{2}$″) loose layer and is *lightly* rolled by a 10-12 mt roller to get a *partial* consolidation of this metal to about 7·5 cm (3″) thick layer. Partial consolidation and the ungraded road metal used leave sufficient voids (in the layer) for the binder to penetiate. Asphalt or tar of the *required* consistency is heated to the *required* temperature and is sprayed on the surface of layer by a spraying machine at the rate of about 7·5 kg/m^2 (150 lb. per 100 sq. feet) of the surface. It penetrates the layer to a depth of about 5—7·5 cm (2″ to 3″). For keying the big size stones, stone chippings of 2 cm ($\frac{3}{4}$″) size are at once broadcast on the surface at the rate of 1·8m^3 /100 m^2 (6 c.ft. per 100 sq. feet) of the surface. The surfacing is then rolled to compaction and is opened to the traffic. The top surface of such surfacing will be rough, open-textured and pervious. To make the surface smooth and impervious, a *seal coat* is given on the top after allowing the traffic on the road for about 7 days. This coat is a kind of surface treatment and is nothing but a 1·25—2 cm ($\frac{1}{2}$″-$\frac{3}{4}$″) thick surface dressing; since it is required to seal the open texture at the top of grouted macadam, it is called a seal coat. It is given for imperviousness and for improving the riding quality of the surface. Before this coat is applied, the surface of grouted macadam is cleaned and dried. For the seal coat, binder is used at the rate of 1·5 kg/m^2 (30 lb. per 100 sq. feet) and the stone chippings of 9 mm ($\frac{3}{8}$″) size are used at the rate of 1·2 m^3 /100 m^2 (4 c.ft. per 100 sq. feet) of the surface which is then rolled with 6 to 8 mt roller. The road is opened to traffic after 24 hours when the binder sets and the surface becomes hard.

When a seal coat is applied like surface dressing, it is known as *liquid* seal coat. In case of pre-mix roads, seal coat is applied as a thin pre-mix layer; it is then known as *premix* seal coat.

In case of cold full-grout process, emulsion is used at the rate of 8 to 11 litres/m^2 ($1\frac{1}{2}$ to 2 gallons per 9 sq. feet) of the road surface for grouting the 7·5 cm (3″) layer of macadam and at the rate of 1·25 lit/m^2 for the sealing coat. Road metal will be of 18 - 48 mm ($\frac{3}{4}$″ - 2″) size stone and the keying stones will be 1·8 m^3/100 m^2 of 12 mm size. Seal coat will consist of 1·2 m^3/m^2, of 18 mm size chippings.

In semi-grout method, 2·5 - 5 cm (1″ to 2″) layer of coarse sand or moorum containing a very high content of clay is laid on the surface of reconditioned existing surfacing of W.B.M. Over this, stone metal of 24 - 36 mm (1″ - $1\frac{1}{2}$″) size is laid in a 6 cm ($2\frac{1}{2}$″) thick layer; the surface of this layer is freely sprinkled with water and is rolled with 6 to 8 mt roller to about 5 cm (2″) thickness. While rolling is done, the sand or moorum will form a slurry with water and will work up and, it should come within about 2 - 2·5 cm ($\frac{3}{4}$″ to 1″) distance from the surface of rolled layer. *The rolled surface is allowed to dry.* This 2 to 2·5 cm depth at the top is then grouted with heated tar or asphalt at the rate of 2·5 kg of binder/m^2 (50 lb per 100 sq. feet) of the surface. Immediately after grouting, 12 mm ($\frac{1}{2}$″) size stone chippings are broadcast on the surface at the rate of 1·2 - 1·8 m^3 of chippings/100 m^2 (4 to 6 c.ft. per 100 sq. ft) of the surface. The surfacing is then rolled and allowed to traffic for some time. Seal coat is given, as usual, after a few days. In case of cold process for semi-grout method, the emulsion for semi-grouting is used at the rate of 4 litres per sq. m of the surface. The consumption of emulsion for sealing coat will be the same as in the case of full-grout method. However the size of road metal used will be 12 - 36 mm ($\frac{1}{2}$″ to $1\frac{1}{2}$″).

Full-grouted bituminous macadam can take a traffic of 5080 mt (5000 tons) per day/traffic lane. Semi-grouted bituminous macadam can take a traffic of 3050 mt (3000 tons)/day/traffic lane.

In premix method, the usual surfacing constructed is called *tar macadam* or *tar carpet.* In it, the coarse aggregate is heated to 120° C (250° F); similarly the refined tar (at the rate of 56 kg/m³ or 3½ lb/c.ft. of stone used) is heated to 120° C and both are mixed in a power-driven mixing plant or country-made drum mixers till each piece of stone gets coated with the tar. The hot mixture is then laid over the prepared road bed between kerbs and is rolled with at 8 mt roller; surface is then checked and the depression, if any, rectified. Over this, a thin premix sealing coat 1·25 cm (½″) thick is given with a premix of tar and 6 mm (¼″) size chippings, the latter being precoated with tar. Full-grout work is more costly than premix macadam but is superior to it. The premix layer of bituminous surfacing more than 2·5 cm (1″) thick is known as *premix carpet* or *premix mat*, e.g. bituminous concrete surfacing, sheet asphalt surfacing etc. When the thickness of this carpet is less than 5 cm (2″), it is called a *thin carpet;* when it is greater than 5 cm, it is called a *thick carpet.* Tar macadam surfacing is briefly known as *tarmac* surfacing.

In the premix method, we may also have a surfacing known as *asphalt macadam.* This is described in the next article.

Premix may be either hot mix or cold mix. In hot mix, both the binder and aggregate are heated. In cold mix, only binder is heated and aggregate is not heated before mixing with binder. Hot mix removes the moisture from aggregate so that there is good bond between the binder and aggregate. In summer season, cold mix may be used in the hot parts of India.

5(a). **Premix asphalt macadam** 5 - 7·5 cm (2″ to 3″): The W.B.M. base is prepared as usual. Stone or concrete or brick-on-edge kerbing is constructed so that the asphalt macadam surfacing may be laid between the side kerbs. For 7·5 cm (3″) asphalt macadam, the road metal of 24 - 36 mm (1″ - 1½″) size is heated to about 180°C (350°F); bitumen is taken at the rate of about 56 kg/m³ (3½ lb. per c.ft.) of the road metal used and is heated to about 180°C. The two are mixed in a bitumen mixer. The hot mix is laid between the side kerbs in loose layer and is rolled by 8-10 mt roller to 6 cm (2½″) thickness. Roller wheels are damped to prevent the premix from adhering to the surface of wheels. The rolled surface is opened to traffic for a few days after it becomes hard; 1·25 cm ($\frac{1}{2}''$) seal coat is then given on it as usual. For seal coat, 6 mm ($\frac{1}{4}''$) size stone chippings are taken and are mixed with bitumen which is used at the rate of 64 kg of bitumen per m^3 (4 lb per c.ft.) of the stone chippings. This hot-mix is spread and rolled to 1·25 cm ($\frac{1}{2}''$) thickness. Shell macadam is a patented type of asphalt macadam.

For 5 cm (2″) asphalt macadam, road metal of 18 - 24 mm ($\frac{3}{4}''$ - 1″) size will be used and the hot-mix will be rolled to 3·75 cm ($1\frac{1}{2}''$) thickness. Over this, 1·25 cm ($\frac{1}{2}''$) seal coat will be given as shown above.

5(**b**). **Premix asphalt macadam** 2·5 cm (or 1″): For this surfacing, the W.B.M. base is prepared as usual. On the prepared base, a *tack coat* of bitumen is given so that there may be proper bond between the base and the thin surfacing. As soon as the tack coat slightly thickens and becomes tacky, the pre-mix surfacing is laid on it. The bitumen used for tack coat will be 1 kg/m^2 (20 lb/100 sq. ft) of the surface. The kerbing is constructed as usual. 9 mm ($\frac{3}{8}''$) size hard stone chippings are mixed (in paddle mixer or drum mixer operated by hand) with bitumen which is taken at the rate of 64 kg/m^3 (4 lb per c.ft.) of chippings used. The hot-mix is laid between kerbs and is rolled with 6 to 8 mt roller. Over this, after some time, a pre-mix seal coal $\frac{1}{2}$ cm ($\frac{1}{4}''$) thick is given of coarse sand, pre-mixed with bitumen which is taken at the rate of 128 kg/m^3 (8 lb per c.ft.) of sand used; this hot-mix of seal coat is laid and rolled with 6 to 8 mt roller so that the total thickness of surfacing is about 2·5 cm (1″). The road is opened to traffic 24 hours after the application of premix seal coat.

Note: Tack coat is also applied on old concrete pavement, bituminous pavement or brick-paving which require to be resurfaced; this tack coat will ensure a proper bond between the old base of concrete, bitumen or brick and the layer of new surfacing which is to be put on the old base. Tack coat is not ordinarily applied unless the succeeding bituminous surfacing is 2·5 cm (1″), or less in compacted thickness. Unless mentioned otherwise, the bituminous material which is used in preparing the mixture for succeeding bituminous surfacing, shall be used for giving the tack coat also.

6. Bituminous concrete pavement 3·75 to 6·25 cm (1½″ to 2½″ thick): It is a surfacing in which the coarse and fine mineral aggregates are premixed with hot bitumen (usually asphalt) and the mixture is laid hot in a layer of the required thickness. This thickness of layer is always greater than 2·5 cm (1″); hence the layer is also called *premix carpet.* This type of surfacing includes a considerable variety of mixtures, using a wide range of aggregate grading, sand and asphaltic cement or heavier grades of refined tar. Since this is a superior type of surfacing, asphalt is used in preference to heavy grade tar as a binder; also, hot process is usually used. The old surface of existing W.B.M. road is reconditioned, dried, cleaned and the side kerbs are provided to give lateral support to the bituminous surfacing. The thickness of W.B.M. base should be at least 15 cm (6″). Road metal of 6 – 30 mm (¼″ to 1¼″) size and well-graded is heated to 180°C (350° F) in the drier of mixing plant; sand of 3 to 0·12 mm (1/8″ to 1/200″) size and well graded is also heated to 180°C and the road metal and sand are taken in the ratio of 2:1. The binder of thicker consistency is taken at the rate of 48 kg/m^3 (3 lb/c.ft.) of road metal used and 128 kg/m^3 (8 lb/c.ft.) of sand used and it is heated in the boiler of mixing plant. For proper coating, two thirds of the quantity of binder is mixed with the hot road metal in bituminous mixer of the plant; then, sand should be added and finally the remaining 1/3rd of the binder is added and all the ingredients are mixed to get the hot mix. The metal and sand get coated with binder. This premix of metal, sand and asphalt is conveyed in wheel barrows and is spread *hot* on the prepared foundation (between kerbs, coated with hot bitumen) by meanr of hot rakes [figs. 42(*a*) and 42(*b*)] to the required thickness which on rolling wiht 6 to 8 mt roller will give about 3·75-6·25 cm (1½″ to 2½″) thick layer. Spreading and finishing of hot mix can be done mechanically by pavers. After rolling and when surface becomes hard, the road is opened to traffic for a few days; premix seal coat of sand premixed with bitumen is then given as usual and the surface is finally opened to traffic after it becomes hard. On small jobs, instead of mixing plant, crude appliances are used for preparing the premix. Cut-backs and emulsions are not preferred and are not *generally* used for carpets more than 2·5 cm (1″) thick.

This surfacing can carry traffic which is much heavier than the one carried by the grouted macadam surfacing. It is also economical than the grouted macadam. It is quite good for bullock cart and other iron-tyred traffic. Shelcrete mix is a patented type of bituminous concrete.

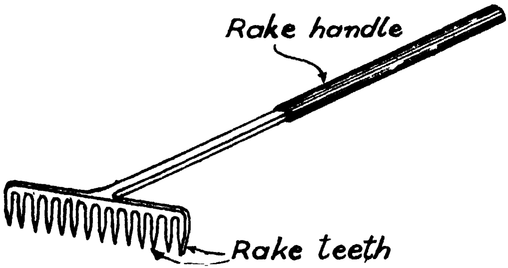
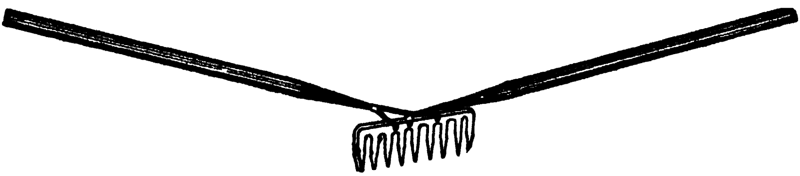


FIG. 42(*a*)



Rake having two handles so that it can be worked by two persons

FIG. 42(*b*)

7. Sheet asphalt pavement 2·5-3·75 cm (1″ to $1\frac{1}{2}$″ thick) : This surfacing is also known as *rolled asphalt pavement* and it gives dense, stable, durable and non-skid surfacing. In this surfacing, asphalt is used as a binder; there are different names patented for the asphalt used e.g. Maxphalt, Spramax, Caltax road asphalt etc. The surfacing is laid on a binder layer serving as cushion between the surfacing layer and the rigid concrete foundation below the binder layer; it will also assure a firm bond with the old surface and will, in addition, provide substantial resistance to the rutting and creeping of the wearing surface on its top. Because of two layers, this surfacing is also known as *two-coats asphalt carpet.* Bituminous concrete surfacing described in article 6 above is known as *single-coat asphalt carpet* because the asphalt concrete forms only one coat or layer and it has no binder layer below it. Both layers of sheet asphalt are laid between side kerbs of concrete.

The top coat or wearing coat of sheet asphalt road is about 2·5-3·75 cm (1" to 1½") thick and is made of asphalt mortar; the bottom coat or base course or binder course is about 3·75-6·5 cm (1½" to 3") thick or more and is made of asphalt concrete. The total thickness of both layers which is *usually* about 3·75 cm i.e. 2½" (or sometimes more, upto 11·25 cm i.e. 4½") is generally laid on 15 cm (6") foundation layer of cement concrete (1:3:6 or 1:2½:5) which is given proper grade and camber. The binder layer consists of well-graded 6 to 24 mm (¼" to 1") size stone, 0·12-2·4 mm (1/200" to 1/10") well-graded sand of volume equal to that of the stone and, asphalt at the rate of 48 kg/m³ (3 lb/c.ft) of stone metal used plus 128 kg/m³ (8 lb/c.ft.) of sand used. The asphalt concrete for base course is prepared as usual and is laid to the required thickness and profile (by means of hot rakes) on c.c. foundation as usual and is rolled, both longitudinally and across, to 3·75 cm (1½") thickness or so. The top surfacing coat consists of sand, filler (like limestone dust or, better still the portland cement) of volume equal to 1/4th of the volume of sand and, the asphalt at the rate of 128 kg/m³ (8 lb/c.ft.) of sand used plus 192 kg/m³ (12 lb/c.ft.) of filler used. Filler makes the mix more dense and it also stabilizes the asphalt. Sand and asphalt are first heated to the required temperature and they are then mixed in the mixer of the mixing plant. Filler is then put in the mixer of the plant. The asphalt mortar so prepared is laid on the top of binder course while the latter is still hot. The top coat of asphalt mortar is rolled with 10 mt roller to a thickness of 2·5 cm (about 1"). The top 2·5 cm thick surfacing is known as *sheet asphalt pavement* or *sheet asphalt carpet.* Sometimes the aggregate thickness of both layers is known as the thickness of sheet asphalt pavement. Shelsheet is a patented type of sheet asphalt. This surfacing is superior to all other bituminous surfacings and can take fairly good intensity of traffic. It is therefore common surfacing for roads in cities like Delhi, Bombay, Calcutta, Madras, etc.

8. Rubber-bitumen pavement: The use of rubber combined with bituminous material for the construction of highway pavements is being studied on experimental basis in many parts of the world; the results reported are encouraging as to the feasibility of this type of construction in terms of performance. In 1960, U. K. Road Research Laboratory (London) developed a method of preparing a rubberised cut-back bitumen. By this means, an economic binder has been evolved. Argentina and parts of Australia too have favoured such roads. In India, we have an enormous road development programme and it might be worthwhile ascertaining whether this new type of road surfacing will prove economical for village and district roads in near future.

CHAPTER X

CEMENT CONCRETE ROADS

1. Introduction: Concrete roads are superior to bituminous roads. They can carry greater intensity of traffic and are also more economical in the long run. Their initial cost is however more than the initial cost of bituminous roads. Concrete road is dustless, durable, without corrugations and requires low maintenance cost; it is however noisy and less resilient.

2. Kinds of concrete roads: Concrete roads may be classified as:

(i) Premix concrete road.

(ii) Cement-bound macadam road.

In case of premix concrete road, the premix is prepared by mixing the proper proportions of coarse aggregate, fine aggregate, cement and water in a concrete mixer or a central batching plant. This concrete is laid on the prepared road bed and is consolidated and finished to a slab of required thickness. Unlike cement-bound macadam roads, roller is not used for consolidation of premix concrete. The premix concrete road may be:

(a) All concrete road.

(b) Bonded concrete road.

All concrete road is ordinarily called only concrete road. In this, the concrete slab is laid on the prepared subgrade of natural soil. This slab serves the purpose of the surfacing as well as the foundation, *all in* one.

In case of cement-bound macadam, the road metal is laid and rolled by roller; the stone pieces are bound together by cement slurry or fluid cement mortar and the consolidation is effected by roller. The cement-bound macadam may be:

(a) Cement-grouted macadam.
(b) Cement-bound macadam (sandwich type).
(c) Colloidal concrete. It is a special type of cement grouted macadam.

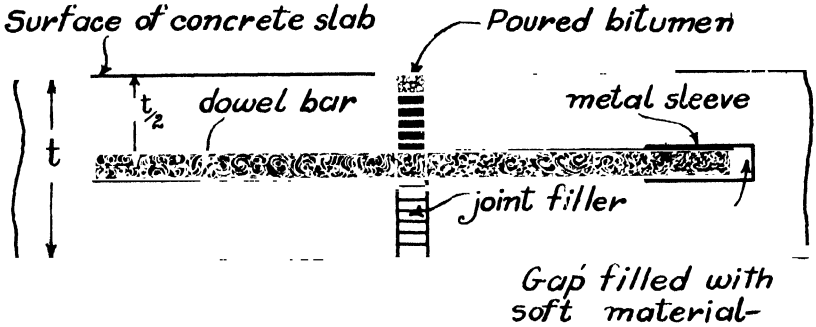
Cement-bound macadam surfaces are nonskid and are often preferred on hilly roads.

3. All concrete road: The concrete slab is laid in various ways. The following are the *usual* methods of construction of a concrete slab:

(i) Full width method.
(ii) Strip method.

In full width method, slab of certain length is laid at a time for the full width of the traffic-way. This is done when the width of traffic-way is less than 4·5 m (15 feet). The slab is laid in successive lengths (i.e. bays) or, usually in alternate lengths. *Transverse expansion joints* 9 to 12·5 mm (3/8″ to 1/2″) thick are provided between the successive lengths of slabs. Full width construction is not desirable in hot countries.

When the width of traffic-way is greater than 4·5 m, the slab is laid in longitudinal strips, of certain length, the width of strip being 2·4 to 3·6 m (8′ to 12′). Thus, a 6·0 m (20′) wide traffic-way may be laid in two strips of 3 m (10′) width each; there will be a longitudinal joint (between these two strips) which is called a *construction joint.* Thus, longitudinal construction joints are provided between strips which may be two or many, depending on the width of traffic-way. The slab along each strip may be laid in successive bays or in alternate bays. Usually the construction in alternate bays is preferred as it gives, to each slab length, the time (about 48 hours) to experience an initial expansion and contraction before the other slab is laid in the adjoining bay. The *usual* length of each bay is kept at 18·0 m (60 feet). During expansion, the 18 m long slab shows cracks at about 6 m (20′) intervals; to avoid this cracking of slab due to warping, two *transverse contraction joints* of dummy type are provided in 18 m length between the two transverse expansion joints; they allow free contraction of concrete due to its shrinkage or warping. Each of these contraction joints is 6 m from its neighbouring expansion joint. The longitudinal joints, which serxe as contraction joints also, are constructed as simple butt joints with tie-bars between two lanes of traffic or the two widths of slabs laid on two sides of each joint; they are sealed with poured bitumen. Sometimes (as when the subgrade is poor), the longitudinal joint is constructed as tongue and groove joint; the transverse contraction joint may be plain butt type also.



Transverse expansion joint
FIG. 43

In case of expansion joint (fig. 43), a premoulded joint-filler is used in the 9 to 12·5 mm (3/8″ to 1/2″) gap of joint between the two 18 m long slabs in the adjoining bays. The thickness of this filler will be 9 to 12·5 mm its length will be equal to the width of bay and the depth of filler will be equal to the thickness of slab minus 18 mm. Thus the top of filler is 18 mm (3/4″) below the top of slab. Dowel bars 0·3 to 0·6 m (1′ to 2′) long and 15 to 18 mm (5/8″ to 3/4″) diameter are used across each expansion joint and at about 37·5 to 50 cm (15″ to 20″) centre to centre. One end of this bar is in one slab and the other end is in the adjoining slab on the other side of the joint. Dowel bars penetrate through the filler also; they help in transferring the traffic load from one slab to the other and prevent the differential vertical movement of adjoining slabs near the joint as may otherwise happen in case of poor subgrade of low bearing capacity. Dowel bar is thus used when subgrade is weak or the traffic is very heavy; each bar is fixed as follows:

One end of the dowel bar is fixed in the concrete of slab on one side of the joint while the other end of dowel bar is free to move (in and out) in a 10 cm (4″) long metal sleeve fixed in the other adjoining slab. There are holes in the filler at 37·5 to 50 cm centre to centre to allow the dowel bars to go through them. At the base of sleeve, there is about 1·25 cm (½″) clearance between that end of dowel bar and the inside of the base of sleeve. During expansion of the slab, this end of dowel bar will move through this clearance towards the base of sleeve and the thickness of expansion joint will be less to that extent. This is possible as the filler of the joint is compressible, the filler being usually a thin slab made of bitumen, cork and rubber. After the concrete slabs are laid in alternate bays and they harden, the top 18 mm (3/4″) depth of joint, above the premoulded filler, is filled with poured asphalt which is first heated to the required temperature.

In case of transverse contraction (butt type) joint, the face of one slab is painted with two coats of bitumen all along the thickness of slab before another slab is laid in the adjoining bay. Thus, there will be no bond between the adjoining slabs which can therefore contract freely. This type of joint may also be a dummy type joint.

Thus the joints classified according to their position are: (i) Longitudinal and (ii) Transverse. When classified according to their function they are: (i) Expansion (ii) Contraction (iii) Construction (iv) Warping.

The use of longitudinal expansion joints is not necessary on road pavements but it might be necessary on wide runways of an airport.

4. Cross section of all-concrete slab: The section of slab, as seen in the profile of all-concrete road, may have uniform thickness {fig. 44(*a*)} or the thickness at the edges of slab {fig. 44(*b*)} may be slightly more than what it is in the remaining width of slab. Also, the camber may be a *straight camber* (fig. 45) or *composite camber* (fig. 46). In case of straight camber, the slab top is straight line from crown to each edge of the slab. *This camber is used when the road has more than one traffic lane.* This practice is common.

In case of composite camber, the surface of slab is parabolic for a small width equal to $b/10$ on each side of the crown and, beyond that, it is a straight line upto each edge of the

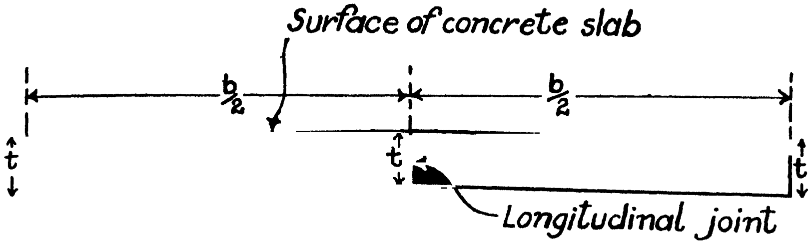


FIG. 44(*a*)

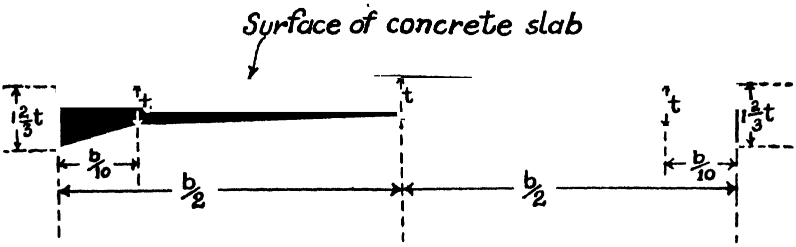


FIG. 44(*b*)

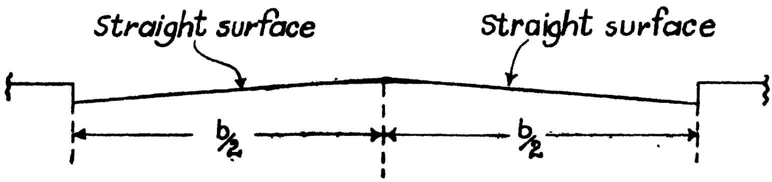


FIG. 45

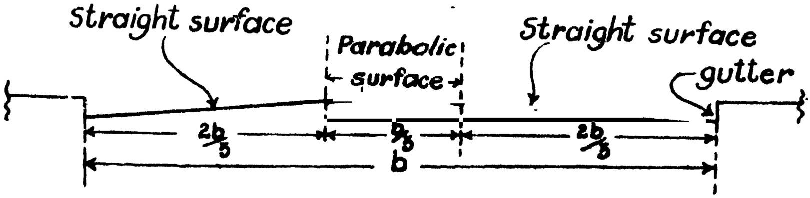


FIG. 46

entire slab width b of the traffic-way. The uniform thickness of slab may be found from the formula (Note: one formula is already given in chapter II, article 4),

$$t = \sqrt{\frac{3W_1}{M}} \text{ cm}$$

where, t = Uniform thickness of slab in cm; a minimum of 12·5 to 15 cm (5″ to 6″) is usually used.

W_1 = Static load on road at one wheel, in kg. It varies with situation e.g. whether the road is a street or a national highway.

M = Safe modulus of rupture of concrete in kg/cm² say, 24·6 kg/cm² (350 lbs/in²) when concrete has an ultimate crushing strength of 246 kg/cm² after 28 days.

The thickness at thickened edges of slab {fig. 44(*b*)}, where such construction is used, may be $1\frac{2}{3}t$ cm. In this construction, uniform thickness t is provided in the central $\frac{4}{5}b$ of slab and, in a width of $\frac{b}{10}$ on each side of this central portion the thickness increases gradually from t to $1\frac{2}{3}t$ at the edge of the slab. In such construction, the slab is designated as $1\frac{2}{3}t$ cm: t cm: $1\frac{2}{3}t$ cm concrete slab.

Usually, all-concrete slab of *minimum* uniform thickness of 12·5 to 15 cm (5″ to 6″) is constructed; this thickness is increased if the traffic is heavy. Heavier the traffic, more will be the thickness. The slab is usually of plain concrete but when the traffic is very heavy or when the subgrade is poor, a *nominal* reinforcement is provided in the slab. This reinforcement is used in both directions in the form of welded wire fabrics which are obtainable in rolls (fig. 47) of different widths and lengths, upto 2·1 m (7′) width and 73 m (240′) length. Similarly bar mats may be used; wire fabric is however better than bar mat. No calculations are necessary for the amount of reinforcement to be used; it is usually used at the rate of 2·7 to 5·4 kg/m² (5 to 10 lb per 9 sq. feet) of the surface. Usually one layer of reinforcement is provided at the bottom of slab, the reinforcement having a clear cover of 3·75 cm ($1\frac{1}{2}$″). Sometimes when the traffic is very heavy or the subgrade soil is unstable, it is also provided at the top of slab with a clear cover of 3·75–5 cm ($1\frac{1}{2}$″ to 2″). The *main* function of reinforcement is that it prevents the cracks developing due to warping etc. in the body of slab; it also holds the cracked portions together and does not allow the cracks to open up. It further increases *slightly* the load carrying capacity of the slab. It is useful when subgrade has non-uniform bearing capacity. Also by the use of reinforcement, thinner slab can be used; a reduction of 5 cm (2″) in the thickness of slab will usually pay for the reinforcement used in the slab.

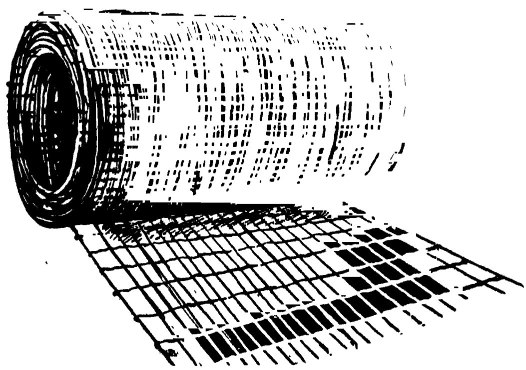


FIG. 47

The slab is usually laid in one course or one layer 12·5 to 25 cm (5″ to 10″) thick according to the traffic requirements. In some cases, to cut down the cost, the slab thickness is laid in two courses, the top course being 3·75 to 5 cm ($1\frac{1}{2}$″ to 2″) thick and of richer concrete (say 1:2:4) while the bottom course is of the balance thickness and of less rich concrete (say 1:3:6). Top course should have the aggregate of harder stone. In two-course work, the interval between the time of mixing the bottom course and that of laying the top course should not exceed 45 minutes.

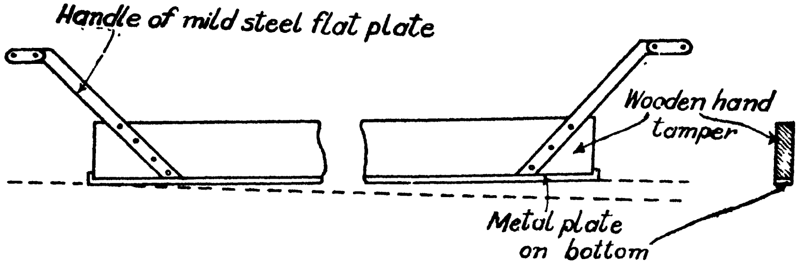
5. Subgrade treatment: Before laying concrete on the subgrade, the latter is treated as follows:

The subgrade is properly compacted with 10 mt roller and is brought to the true grade and profile.

A thin 7·5 cm (3″) layer of sand is spread on the subgrade and thoroughly wetted so that it may not absorb the water of concrete; this layer is called *insulating layer.* It also allows easy creep of the concrete slab on top of the layer. Sometimes, special water-proof paper is used (instead of sand layer) as an insulating material. In case of subgrade of black cotton soil, a 7·5 cm layer of road metal is laid and rammed over 22·5 cm (9″) thick rubble foundation and then the concrete is laid on specially prepared paper spread over the metal. In case of all-concrete road, a subgrade having the reasonably *uniform bearing capacity* is essential; subgrade for concrete road need not necessarily have a high bearing capacity.

6. Materials of construction and form work: The coarse aggregate will be well-graded and of size 6 to $\frac{10t}{3}$ mm ($\frac{1}{4}''$ to $\frac{t''}{7\cdot5}$) where t cm is the thickness of slab. Sand used will be of size 3 mm (1/8″) and below; it will also be well-graded and should be dry. If wet sand is used, allowance should be made for the *bulking* of sand. Good cement of the usual specifications will be used and the mixing of concrete will be done in concrete mixers, using just the *required* quantity of water. The mixed concrete is at once laid between the side forms or side shuttering which may be of timber or steel. The loose concrete so laid should protrude 2·5 cm (1″) above the side forms. Timber forms (coated with boiled linseed oil) are not so desirable and, when used, the thickness of form work should be at least equal to $\frac{t}{3}$ cm so that the form work does not bulge out when concrete, that is laid between the forms, is consolidated. The timber forms should be fixed in truly vertical position and they should have supports of pegs 5 cm × 5 cm × 0·6 m long i.e. 2″ × 2″ × 2′ long, fixed at 1·2 m (4′) centre to centre at the back of side forms. Also, cross forms are fixed at the ends of bays. When the consolidation is to be done by mechanical means (and not by manual labour), steel forms should be invariably used. They are usually in 3 m (10 feet) lengths and are fixed in position by 3 spikes at the back of each 3 m length. On the top of these steel forms, the mechanical appliance can move along the length of road and do its work of consolidation. The form work is to be removed after the lapse of 24 hours, reckoned after the consolidation process.

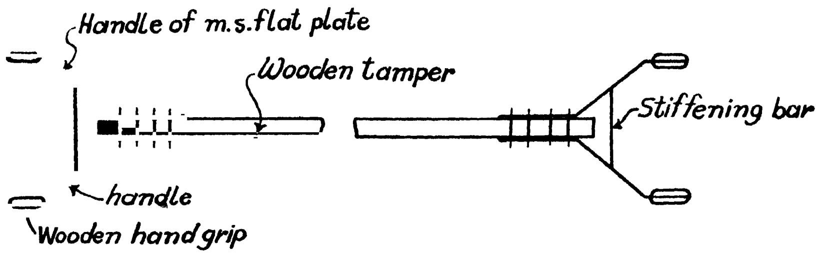
7. Consolidation, finishing and curing of all-concrete slab: The consolidation of concrete laid between the foıms may be done with a *hand tamper* [figs. 48(*a*) and 48(*b*)] worked by the manual labour. It should weigh



Longitudinal view of hand tamper

Fig. 48(*a*)

about 10·4 kg/m (7 lb/R ft). Consolidation may also be done by a *mechanical vibrator.* A hand tamper is also known as wooden tamping beam and it consists of a wooden beam 7·5 cm (3″) wide by 22·5 cm (9″) deep and of length equal to the width of bay plus one foot. The under-side of this beam has a metal plate 7·5 cm (3″) wide by 4·5 mm (3/16″) thick



Plan of hand tamper

Fig. 48(*b*)

attached to it. The beam has handles at is ends which are gripped by the men who use the tamper while standing. The tamper is used across the bay and the tamping progress is made along the length of bay. The surface is then tamped longitudinally by a hand tamper 15 cm (6″) wide by 22·5 cm (9″) deep and 5 m (16 feet) long. To its under side, metal plate 15 cm wide by 4·5 mm thick is attached. The irregularities appearing on the surface due to tamping are rectified. The surface tamped with the underside of beams is then finished smooth by a *hand float* (fig. 49). Hand float is a beam 7·5 cm by 7·5 cm in cross-section and 0·75 m (2½ feet) long. It has a hand-grip on the top by means of which it can be pressed and rubbed on the tamped surface to finish it smooth. While using it, men sit on portable timber bridges which span the

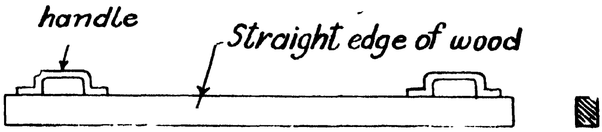


FIG. 49

width of surfacing to be rubbed. The trueness and straightness of the finished surface in longitudinal direction is checked by means of a wooden beam 7·5 cm (3″) deep, 3·75 cm (1½″) wide and 3 m (10 feet) long, known as *straight edge*. Irregularities in the surface, if any, are rectified. Similarly the trueness of surface in the cross direction is checked and the irregularities in the surface, if any, are rectified. The edges of concrete slab near expansion joints are rounded to 9 mm (3/8″) radius with a *joint tool* (or edging tool or rounding tool) before the concrete becomes hard and stiff. After this, the surface of concrete is cured as follows:

The finished surface, after 12 hours, is covered with gunny bags which are kept wet for a duration of 24 hours. Then the gunny bags are removed, 3·75 to 5 cm (1½″ to 2″) layer of sand is spread on the surface and the sand layer is kept moist for 14 days; as an alternative to this, the surface is divided into a number of bays by forming small 5 cm (2″) high earthen ridges and the bays are filled with 3·75 cm (1½″) depth of water and the surface is kept moist for 14 days. After this curing, the surface is cleaned and the top 18 mm (¾″) depth of expansion joints is also cleaned and filled with poured bitumen which is then blinded with sand. Joints may be lipped at the top.

Sometimes, to make the surface of slab hard, a wash of the solution of sodium silicate in water is given to the surface. The surface is opened to traffic 21 days after the consolidation and the finishing of concrete.

The concrete road will have 0·6 m (2′) wide metalled shoulder on each side which will be properly compacted and blinded. The shoulders will consist of 5 cm (2″) thick layer of macadam laid on 10 cm (4″) layer of hard moorum. Instead of metalled shoulders, we may have hard moorum shoulders. Beyond the 0·6 m (2′) width, there will be 0·9 m (3′) more width of shoulder on each side; this 0·9 m width of shoulder will be of 15 cm (6″) layer of gritty material.

8. Bonded concrete road: It is a thin layer of concrete of 1:2:4 proportion laid on existing W.B.M. which serves as its foundation. The *existing* W.B.M. surfacing is reconditioned; a wash of cement grout is given on the reconditioned surface to have a proper bond between this surface and the bottom of bonded concrete layer. One

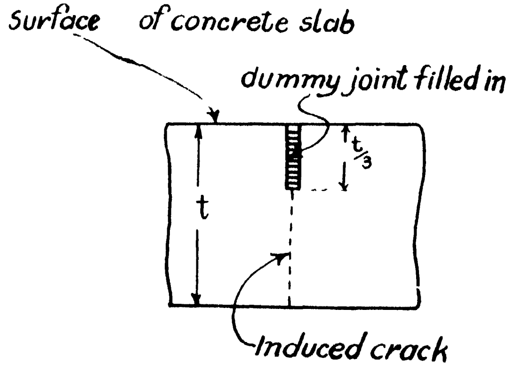


Fig. 50

layer of bricks is laid flat on each side of roadway to serve as side shuttering. A 5 cm (2″) layer of freshly prepared 1:2:4 concrete is laid on the wash-given surface and, between the side shuttering of bricks; this thin layer is reinforced by B.R.C. wire fabric placed in the middle of layer. This layer is consolidated as usual but in the present case, only longitudinal consoiidation is done by means of a 5 m (16′) long tamper weighing 14·9 to 22·3 kg/m (10 to 15 lb/R.ft.) of the tamper. The surface is finished, checked for trueness and rectified as usual. Curing of surface is also done in the usual way.

Only dummy joints (fig. 50) 6 mm or $\frac{1}{4}''$ wide and $\frac{10t}{3}$ mm or $\frac{t''}{7 \cdot 5}$ deep from the surface of slab are constructed transversely at about 6 to 9 m (20′ to 30′) centre to centre; the joints are filled with poured bitumen. These joints act as contraction joints.

This type of road is a *cheap* concrete road and is quite suitable for the bullock cart traffic and wears well under this type of traffic. The thickness of concrete layer may be increased to 7·5 cm (3″) or even 10 cm (4″) if necessary. It can then take the traffic intensity of 2030 mt/day i.e. 2000 tons/day, with 50% iron-tyred traffic.

9. Cement grouted macadam: On the reconditioned surface of existing W.B.M. road, a 12·5 cm (5″) layer of road metal of 36–48 mm (1½″ to 2″) size is laid and rolled *lightly* with 8 mt roller to get a partially consolidatd layer of 10 cm (4″) thickness. Cement and sand are taken in the ratio of 1:2; 5 bags of cement are used per cub. m of macadam i.e. about 14 bags of cement per 100 cubic ft of macadam and 34 litres (7½ gallons) of water are added per 1 bag of cement used to form a fluid mortar or a grout of cement and sand. This grout is poured over the lightly rolled surface of macadam. After grouting operation, stone chippings of size 1·5 to 18 mm (3/16″ to 3/4″) are spread on the surface and are forced into the mortar on the surface by longitudinal tamping or rolling. The grout penetrates the surface layer which gets consolidated also. The consolidated surface is checked for trueness and is then cured like other concrete roads. Longitudinal joints and transverse joints are provided as in an all-concrete road.

This type of road is not so common in India.

Note: 1 gallon = 4·55 litres.

10. Sandwich type cement macadam: The surfacing of existing W.B.M. road is reconditioned to serve as foundation for this type of road. On the reconditioned surface, 6·25 cm (2½″) layer of road metal of 36 to 48 mm (1½″ to 2″) size is laid and rolled properly to get a consolidated layer 5 cm (2″) thick. Cement and sand in the ratio of 1:2 are mixed with 32 litres (about 7 gallons) of water per

50·8 kg (1 c.wt) of cement used to form a thick or stiff mortar. This mortar is laid on the rolled surface in a 3·75 cm (1½″) thick layer and, over this, a 6·25 cm (2½″) layer of 36 to 48 mm (1½″ to 2″) size road metal is spread and the surface is rolled with 12 mt roller. During rolling, the mortar between the two layers of road metal gets squeezed into the voids of road metal and we get *about* 10 cm (4″) thick layer of surfacing which consists of road metal bound together by cement-sand mortar. Rolling is stopped when the mortar works up and just comes to the surface. After this, a hand tamper is used for tamping the surface longitudinally. Surface is checked and cured as usual. Joints are provided as in an all-concrete road.

This type of road is better than the grouted cement road and as it has rough texture on the surface, it is usually constructed in hilly country where all-concrete road may prove slippery and therefore dangerous to traffic as the gradients in hilly country are very steep.

Note: 50·8 kg are approximately equal to ½ quintal.

11. Colloidal concrete: This is a special type of cement grouted macadam road. This surfacing, if laid on natural subgrade, will require insulating layer between it and the subgrade. Sometimes this surfacing is also laid on a reconditioned existing W.B.M. which then serves as its foundation. Road metal of 36 to 72 mm (1½″ to 3″) size is laid in a 17·5 cm (7″) thick loose layer on a prepared bed of sand or W.B.M. as the case may be and is partially consolidated to 15 cm (6″) thickness. Grout of cement, sand and water is then prepared; cement and sand are taken in the ratio of 1: 1¼ by weight (or sometimes in the ratio of 1:1) and 34 litres of water are added per one bag of cement used to form the required grout; 4·25 bags of cement are required per m^3 (12 bags per 100 c.ft.) of macadam used in the surfacing. The grout is poured on the surface, which is then gritted and tamped by a tamper in the longitudinal direction. The checking of surface and its curing is done as usual. Joints are provided as in an all-concrete road.

Since the bigger size of stone and less cement are used, this road surfacing is cheaper.

12. Creteway: Village road has mostly the bullock cart traffic to carry. India is a country of villages and it is most important to have such village roads as prove durable under steel-tyre traffic. At present, the following types of roads are *commonly* constructed as village roads:

(a) Earth road.

(b) Gravel road.

(c) Moorum road.

(d) Brick-on-edge road. (This is described in chapter XI.)

(e) W.B.M. road of hard stone or of soft stone like kankar, lime stone, laterite etc.

These types of roads give way easily under the bullock cart traffic and hence their maintenance is very costly. They have to be reconstructed after a very short duration. Bituminous roads and concrete roads will be durable but they will prove very costly for a village road. A type of *track-way* or *wheeler* of concrete is however devised for the bullock cart traffic. This trackway of concrete is called a *creteway* (fig. 51) and it is quite cheap and durable. The trackway can

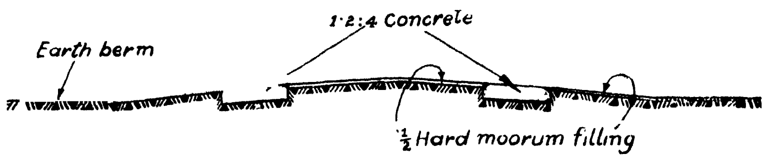


FIG. 51

also be of stone slabs or of 7·5 cm (3″) thick asphalt surfacing; such trackway is however not so common. Trackway, in essence, consists of two narrow longitudinal strips of road surface on which the two wheels of bullock cart or any vehicle can move. When these strips are made of concrete, the trackway is called a creteway. In case of creteway, the width of each concrete strip is 0·6 to 0·75 m (2′ to 2½′) and the thickness 10 to 15 cm (4″ to 6″). The centre to centre of the two strips should be such that the two wheels of the bullock cart will be just in the middle of the two strips. This distance is about 1·36 to 1·52 m (4½′ to 5′) depending on the design of bullock cart using the trackway. Since, nowadays, the motor-lorry traffic is becoming common in villages, the centre to centre of the two strips may be 1·67 m ($5\frac{1}{2}'$) so that the motor traffic can also use the creteway. The concrete strips may be cast-in-situ or they may be of precast slabs; the latter construction is more speedy and more common.

When the slab is cast-in-situ, the natural soil is prepared to the required grade; the camber of the subgrade may be from 1 in 24 to 1 in 32. In this subgrade, two strip-trenches, 0·6 to 0·75 m ($2'$ to $2\frac{1}{2}'$) wide and 10 to 15 cm ($4''$ to $6''$) deep, are excavated; the centre to centre of the trenches will be equal to the required distance as said already. The bed of trenches will be given the grade of the creteway and it is well watered and rammed. Cement concrete 1:2:4 with 6 mm to $\frac{10t}{3}$ mm size coarse aggregate is prepared and is laid on the prepared bed of trenches in 9 m ($30'$) lengths, filling the width and the depth of trenches and 1·25 cm ($\frac{1}{2}''$) above the top of trenches; the alternate bay construction of laying the concrete slabs is used and 9 mm ($\frac{3}{8}''$) expansion joint is kept between the adjacent slabs. The forms at ends of the slab are used as usual and the consolidation, finishing and curing of the concrete slab is done as for all-concrete roads. In some cases (e.g. when slab is thin, say 10 cm i.e. $4''$ thick or so), transverse dummy joint 6 mm wide by $\frac{10t}{3}$ mm deep is provided in the middle of each slab. This joint is filled with hot bitumen.

The cast-in-situ construction takes more time hence the precast slab construction is preferred. Precast slab is usually 1·8 m ($6'$) long, 0·6 m ($2'$) wide and 7·5 cm ($3''$) thick; in the lower 3·75 cm ($1\frac{1}{2}''$) thickness of the slab, there are frogs of size 28·75 cm $\times$ 15 cm ($11\frac{1}{2}''$ by $6''$) each; at one end of each slab, there is a tongue and at its other end there is a groove. Thus the adjoining slabs placed in 6·25 cm ($2\frac{1}{2}''$) deep trenches, interlock due to the tongue and groove joints. Slab being 7·5 cm ($3''$) thick, protrudes by 1·25 cm ($\frac{1}{2}''$) above the prepared ground; hence on each side of the slab, moorum filling is done so that the top of moorum filling is in level with the top of the slab. Life of creteway under bullock cart traffic is about 20 years.

In case of some city roads carrying mixed traffic like motor traffic and bullock cart traffic, the central portion of the road may be asphalt surfacing to carry motor traffic and on each side of the asphalt surfacing, there may be one creteway for carrying bullock cart traffic. Such a composite roadway is known as *conphalt* (i.e. concrete and asphalt) road.

13. Selection of road surfacing: The most important part of the road which requires a very careful consideration, a good deal of forethought and a right technical knowledge is the surfacing of the road. While deciding the type of road to be constructed, the following points are considered:

(a) Intensity and character of traffic.
(b) Initial cost and the subsequent cost of maintenance.
(c) Action of climate and traffic on the surfacing.
(d) Life of the surfacing.
(e) Smoothness, cleanliness and dustlessness of the road surface.

We already know that the volume of traffic is expressed as so many vehicles (of all types) passing a given point on the road in a given duration of time On the peak volume of traffic depends the width to be provided for the traffic-way. More the peak volume of traffic, more the lanes of traffic to be provided on the traffic-way. Volume of traffic per foot width of a traffic-way is called the *density* or *concentration of traffic*. *Intensity of traffic* is expressed as so many tonnes of traffic per metre-width of a traffic-way (or road surface) per day. Greater the intensity of traffic expected on a road, superior and stronger should be the surfacing to be constructed. By the *character* of traffic we mean whether the traffic is motor traffic or steel-tyre traffic or both. Bituminous roads are eminently suitable for motor traffic. Steel-tyre traffic requires a hard surface which should not develop cuts or ruts under the wheels of the steel-tyre traffic.

In the case of superior type of roads, the initial cost is more and sometimes the available funds do not permit their construction though their construction is otherwise justified looking to the intensity and the character of traffic on these roads. Such roads should preferably be constructed as require the less maintenance charges. A road the initial cost of which may be less but which requires heavy maintenance charges may, in the long run, be not economical.

Road surfacing should be able to fare well in hot and cold weathers and the rain should not have any adverse effect on it. It should be able to take the impact of wheels of traffic without yielding or without fracture.

Road surfacing should have long life and good durability. Life of a road depends on the nature and stability of subgrade, foundation, and wearing surface and to some extent, on the camber and gradient of the wearing surface. The average life of some of the common types of roads is as follows:

Type of road	Average life, in years, under the mixed or composite traffic
(i) All concrete	20 to 30
(ii) Bituminous carpets (excluding Sheet asphalt)	} ...... 7½ to 15
(iii) Surface dressing (single coat)	} ...... 2 to 3
(iv) Bitumen grouted macadam	...... 7½
(v) Sheet asphalt	 15
(vi) W.B.M.	...... 1½ to 2 (with good and regular maintenance)

Road surface should be smooth to offer less resistance to the moving traffic. It should be such as can be kept clean and tidy and it should be dust-proof.

The benefits of superior type of roads are: (i) improved vehicle performance (ii) less fuel, oil and tyre costs (iii) more comfort to the driver and passengers.

14. Intensity of traffic: This point is more important and is mostly considered while selecting the suitable type of road. In the table given below, the intensity of traffic and the corresponding suitable road surfacings are shown. The traffic is also said to be light, medium, heavy and very heavy. Light traffic suggests that the volume, density and hence the intensity of traffic are low.

Nature of traffic	The intensity of traffic in tonnes/metre width/day	Suitable roads
(i) Light (as on country and urban roads)	<160 (<50)	Earth, Moorum, Stabilized soil roads, Gravel, Kankar roads; Creteway.
(ii) Medium (as on country and urban roads)	160-330 (50–100)	W.B.M. (of hard road metal), Surface dressing (single coat), Creteway, 15 cm (6″) plain concrete road; Bonded concrete 5 cm (2″) thick laid on existing W.B.M. surface.
(iii) Heavy (as on country and urban roads with 2 or 3 lanes of traffic)	330-500 (100–150)	Surface dressing (two coats), Bituminous grouted macadam, 15 cm (6″) plain concrete road, Bituminous carpet.
(iv) Very heavy (as on city roads with dual carriageways) (a)	500-1300 (150–400)	Bituminous grouted macadam; Asphalt concrete road; 17·5 cm (7″) reinforced concrete road.
— do — (b)	1300-3300 (400–1000)	Sheet asphalt; 20 cm (8″) reinforced concrete road.
— do — (c)	3300-5000 (1000–1500)	22·5 cm (9″) reinforced concrete road; Granite setts paving (this will be described in chapter XI).

It will be seen that for a particular intensity of traffic, there is some choice of the roads to be constructed. A particular type of road will be decided upon, keeping in view the character of traffic, available funds and the *ultimate* economy. As a general rule, concrete roads prove more economical than bituminous roads in the long run though their initial cost of construction is more.

Note: (i) 1 ton/foot width/day = 3·33 metric tonnes/metre width/day.
(ii) The intensity of traffic shown within brackets in above table is in tons/foot width/day.

15. Superior Bituminous road versus Concrete road: Flexible pavement like sheet asphalt road compares favourably with the rigid pavement like premix c.c. road and if we have to decide between the two, we must consider the following points:

(a) Economy.

(b) Satisfaction of the road after its construction.

To know which road will be economical on the whole we must consider the initial cost, the cost of maintenance and the life of each road. Initial cost will be on survey, design and construction work. The maintenance cost of each road during the average life of more durable of the two roads should be worked out. This cost is parctically negligible for concrete road but it is appreciable for the sheet asphalt road. Also, as the life of concrete road is more, the sheet asphalt surfacing may have to be done once again during the life-span of the concrete road. This extra cost should also be debited on the side of sheet asphalt road. It will be found that the concrete road is economical *on the whole.* It may also be noted that after the life span of sheet asphalt road is over, the salvage value of such a road is nil whereas the dead and discarded concrete road can serve as a foundation for the bituminous surfacings.

After construction, the riding comfort and the wear of the surfacing are to be considered. Sheet asphalt may prove more comfortable specially for the rubber-tyre traffic as it is a resilient surfacing. The wear of sheet asphalt is however more. The asphalt surface may become plastic in very hot weather and therefore may lose its camber and grade and may develop corrugations under a heavy traffic. This surface also becomes more smooth as it wears, resulting in the slipping of draught animals. Sheet asphalt necessarily requires side kerbs and also a good foundation. All these drawbacks are absent in case of concrete road. In addition, c.c. road offers less tractive resistance and has good visibility at night time.

The above-said treatment gives *just* a glimpse into what is called the *economics of roads.* Elements of Road Economics are given in chapter XX.

16. Prestressed concrete roads: This chapter will be incomplete if a reference is not made to the prestressed concrete roads with which a beginning was made in 1945 and which are nowadays being constructed in Britain and elsewhere abroad. The surfacing slab is made of high grade and high strength concrete which can take a safe compressive stress of 105 kg/cm^2 (1500 lbs/in^2). The reinforcement used in the slab consists of the cold-drawn steel wires of high tensile strength. It is possible to construct the slab upto a length of 120 m (400 feet) without providing expansion or construction joints. Longitudinal joint for every 4·5 m (15′) width of surfacing is desirable. The slab thickness may be 12·5 to 15 cm (5″—6″), with a prestress of 17·5 kg/cm^2 (250 lbs/in^2).

The concrete of slab is prestressed and the compressive stresses are initially induced in it. The longitudinal prestress may be applied by: (a) post-tensioned cables (b) post-tensioned bars (c) pre-tensioned wires. The tensile stresses caused by traffic, the variation of temperature and the subgrade restraint are off-set by the initial compressive stresses induced due to prestressing. Thus, the slab will not show cracks under the tensile stresses caused by traffic, temperature variations, subgrade restraint etc. Experience so far has shown that the cost of prestressed concrete slab in roads is approximately equal to the cost of ordinary concrete slab. The prestressed concrete slab is however more durable, there is reduction in the number of transverse joints, reduction in slab thickness and hence in the quantity of concrete used. The cost of maintenance is less and the riding qualities of the surface are better.

Prestressed concrete construction has proved very economical in the case of bridges and buildings and therefore it is being increasingly used in these fields.

CHAPTER XI

PAVINGS

1. Introduction: In this chapter will be described those surfacings which are not so common; they are used in *special* situations only. Some of these surfacings are in the experimental stage.

2. Paving and its kinds: A *paving* is a road surfacing which is made of loose blocks or units placed side by side to form a traffic way; the joints between blocks or units are filled with suitable binder to hold the blocks or units together. A paving may also be called *block pavement* when blocks are used to form it. Following are the various kinds of pavings:

(a) Stone paving. This may be:

(i) Stone block pavement.

(ii) Stone sett pavement.

(b) Brick paving.

(c) Wood paving or Wood block pavement.

(d) Rubber paving or Rubber block pavement.

(e) Metal (C.I.) paving or Metal block pavement.

(f) Asphaltic paving or Asphalt block pavement.

3. Stone block pavement: (see fig. 52). It is a form of paving in which stone blocks are laid flat with their vertical faces carefully dressed so as to give fine joints which are filled with binder. Stone sett pavement is a paving like stone block pavement with this difference that the rectangular stone setts (of size less than the stone blocks) are laid in regular courses.

In stone block pavment, stone blocks 17·5 to 25 cm (7″-10″) long, 7·5 to 10 cm (3″-4″) wide and 12·5 cm (5″) high are used. A 15 to 20 cm (6″-8″) thick foundation of concrete is prepared with the required grade and camber. Over this, 2·5 cm (1″) layer of sand is spread to serve as a cushioning between the foundation and the surfacing of stone blocks.

On both edges of the traffic way, longitudinal edging of stone or plain c.c. blocks is first constructed to protect the paving from the danger of dislocation caused by traffic. The stone blocks are dressed on all faces, except the bottom which is left rough. Between edgings, these stones are laid on the sand layer to form the staggered joints, the thickness of ver-

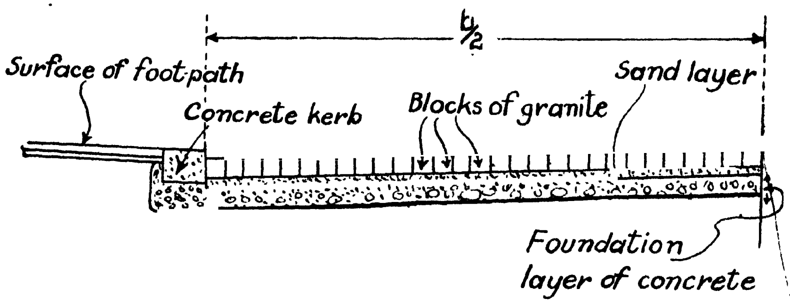


FIG. 52

tical joints being 3 to 9 mm (1/8″-3/8″). The joints are filled with 3 mm (1/8″) size stone chips upto half their depth and are then grouted with cement; in some cases, the upper half depth of the joints is filled with hot bitumen.

The blocks are usually of hard stone like granite; sometimes the blocks of trap or sand stone are used. This type of road presents a hard surface and is therefore used for very heavy traffic on roads like those leading to a dock yard or a railway goods yard; even if such roads were built of concrete, they will be badly cut up under the severe traffic. The road however is non-resilient and gives some discomfort to the occupants of vehicles; also, the traffic produces noise when going over the hard and non-resilient surfacing. This road surfacing is appreciably affected by weather changes and rain water; it is costly and is more or less obsolete now-a-days.

4. **Brick paving:** It is a paving composed of units of bricks which are laid in regular courses, the joints being filled with binder to hold the bricks together. This paving is useful in the streets (of town) having a light traffic on them.

The bricks may be laid on a base consisting of 5 to 7·5 cm (2″—3″) of rammed ballast or lime concrete, well consolidated and prepared to the required grade and camber. They may also be laid on the existing W.B.M. as foundation; in the latter case, 2·5 cm (1″) layer of sand is first spread on the prepared bed to serve as cushion. Bricks are laid on edge over this sand layer, the vertical joints being staggered. Bricks may be laid in straight or herring bone pattern. The joints are grouted with cement mortar (1:2) or they are filled with hot bitumen, the latter being usually preferred for its resilience. Expansion joints 1·25 to 2·5 cm (½″-1″) wide are usually left between the edgings and the brick paving and they are filled with hot bitumen.

As all the bricks may not be of uniform quality, the wear of this surfacing is non-uniform and where the bricks are not hard, pits and pot-holes are formed. In such places, new bricks should be laid. The surface is, however, impermeable, nonslippery and comparatively less noisy. It offers more resistance to traffic as it is not smooth. The weather-changes and the rain water have no appreciable effect on the surfacing. In case of this paving, the labour cost is high.

5. **Wood paving:** (fig. 53). It is a kind of paving which is formed of the rectangular blocks of wood; the blocks are laid in regular rows on a prepared foundation and the vertical joints are filled with binder. The wood blocks used are usually 20—22·5 cm (8″—9″) long, 7·5 cm (3″) wide and 10—12·5 cm (4″—5″) high. Hard timber presents slippery surface hence the soft timber is used for preparing the blocks. The timber is creosoted by using 160—240 kg of creosote oil per cubic metre (i.e. 10-15 lb per one c.ft.) of timber; this preservation treatment of timber is necessary to make it more durable.

The blocks are laid on a 22·5—30 cm (9″—12″) thick foundation bed of concrete, taking care to stagger the vertical joints which should be only 3 mm (1/8″) thick. These joints are filled with hot bitumen. Expansion joints 2·5 — 3·75 cm (1″ — 1½″) wide are usually left between the kerbs and the paving and, they are filled with hot bitumen. In some cases, the surface dressing (single coat) is given on the top of blocks to make the surface impermeable, resilient, noiseless and non-skid; also the life of road increases thereby. Surface dressing is renewed after 2 to 3 years.

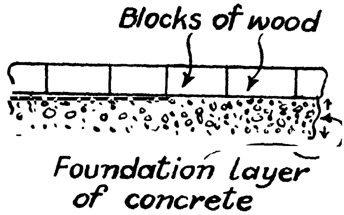


FIG. 53

This paving is used in those business centres where the noise due to traffic is to be kept down. It has a life of about 15 years and can carry heavy traffic. It is costly in the initial stage but the maintenance charges are less. This paving also is more or less obsolete now-a-days.

6. **Rubber paving:** This paving is as yet in the experimental stage. It, in essence, consists of the blocks of wood, concrete or even brick-units with 9--15 mm (3/8″ to 5/8″) thick rubber working as tread or capping and stuck on the top of each such block or unit. The blocks or units are laid on a foundation bed of concrete with a cushion layer of sand in-between; the joints are filled with hot bitumen. This paving is absolutely noiseless. It is fairly dustless and non-slippery. Weather and rain have no adverse effect on it and the wear of the rubber surfacing, due to the traffic, is negligible. It is costly and the difficulty arises in fixing the rubber pad to the top of each block or unit. The relatively high initial cost is the disadvantage due to which the more general use of rubber paving is handicapped.

7. **Metal paving:** This paving is also in the experimental stage. Hollow cast iron blocks are laid on a concrete bed and the 3 mm (1/8″) thick vertical joints are filled with hot bitumen. The blocks are triangular in plan, with each side of the triangle equal to 30 cm (12″) and they are 30 cm (12″) high. The thickness of the walls of block is 5 cm (2″). The top of the block shows 7·5 mm (5/16″) high

studs or projections (diamond-like in plan) which make the surface non-slippery.

8. Asphaltic blocks: These blocks are 22·5—30 cm (9″—12″) long, 11·25—12·5 cm (4½″—5″) wide and 1½″—3″ (3·75—7·5 cm) high. They are formed from the mixture of bitumen, crushed stone and filler. The mixture is put into moulds and it is subjected to a pressure of about 420 kg/cm² (6000 lb/in²) by means of the hydraulic machine. The blocks so prepared are laid on a concrete bed with 1·25 cm (½″) thick cement mortar layer between the concrete and the bottom of blocks. The cement mortar used will be of 1:4 composition. This paving is obsolete now-a-days.

ROAD ARBORICULTURE

1. Introduction: It is a usual practice to grow trees on both sides of a road, *specially* in case of the road in country or non-built-up area. This growing of the road-side trees is called *road arboriculture.* These trees are planted due to the following reasons:

(a) They improve the appearance of road and break monotony of long road.

(b) They provide shade to the road users and thus make their journey comfortable in hot weather.

(c) They yield wood and, in some cases, fruit and thus they prove a source of some income to the road authorities.

2. Kinds of trees and their methods of planting: Only such trees should be planted as will naturally thrive in the local soil, climate (available in the locality of road) and with the available facility of watering them. The trees to be grown should be quick-growing, hardy and tall-growing so as to have headway of 4·5—6 m (15′—20′).

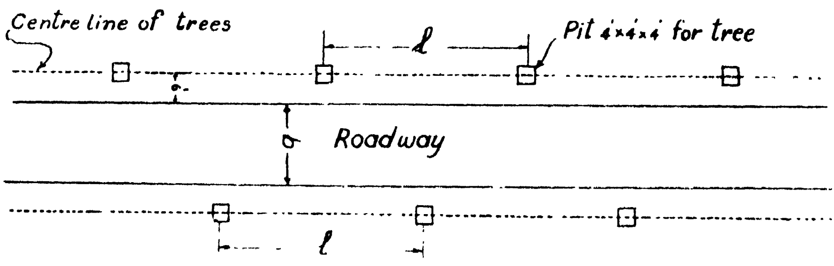


FIG. 54

The *common* avenue trees grown on the sides of roads in India are the following:

Banyan, mango, neem, pipal, tali, siris, tamarind etc.

Along hill road, oak, pine wood, sal, walnut are generally planted.

The centre to centre of trees may be from 9 – 18 m (30 – 60 feet); the trees which grow luxuriantly will be spaced further apart within this limit. Trees should be at least 1·8 m (6 feet) away from the edge of roadway so that the branches may not overhang the roadway and thus they may not cause obstruction to the vehicular traffic. When the trees are grown on both sides, the trees on one side should stagger with those on the other side; this arrangement (fig. 54) will provide better shade to the road.

The healthy seedlings about 1·5 m (5 feet) high, are taken from nursery and are transplanted, on the road side, in pits of size 1·2 m × 1·2 m × 1·2 m (4′ × 4′ × 4′) each. Best season for planting is after the first heavy shower of rain when the soil has been fairly soaked with water. Manured soil is put in each pit, tree is planted in it, the pit is partly filled with manured soil and the rest of the pit is back-filled with rough stones, having a layer of porous soil on the top.

To protect each such young tree from stray cattle like buffalo, cow, goat etc., a tree-guard of circular mud wall 1·5 m (5′) high may be put around it. Tree guards of wood, wire-netting, thorny hedge etc. are also used. This care of young trees for a few years is necessary. It is also necessary to water them periodically, weed out the grass around the tree and to hoe the soil occasionally around the tree.

The branches, over-hanging the roadway, should be periodically pruned so that they do not cause obstruction to the traffic.

HILL ROADS

1. Introduction: In this chapter only those points will be treated which are peculiar to hill or ghat roads only. Ghat roads present more difficulties in their alignment, design, layout, construction and maintenance. Such roads are more costly than roads in plain country and prove more dangerous and sometimes fatal to the traffic when accidents occur. Surface drainage is important because of heavy rainfall in hilly area and because of quick flow due to steep gradients prevalent in such region. Subsurface drainage problem does not exist in hilly area.

2. Alignment of ghat roads: Great care should be given to the fixing of alignment because on it depends the cost as well as the success and utility of the hill road on the whole. The alignment should be such that the road should be as short as possible and the gradient should be as easy as possible; also the alignment should give a stable and safe road. To achieve this object, the alignment will necessarily have a number of sharp curves of very small radius.

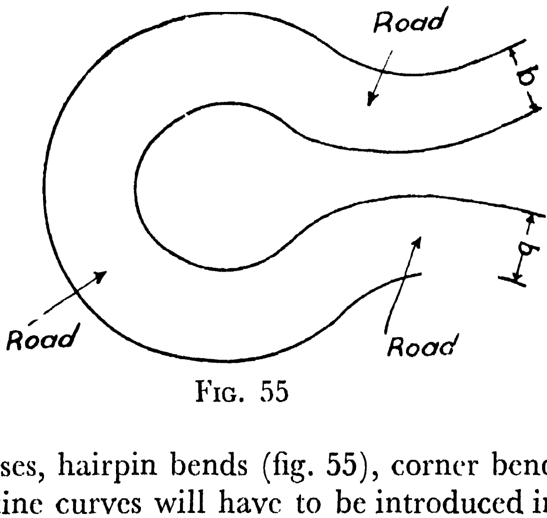


FIG. 55

In many cases, hairpin bends (fig. 55), corner bends (fig. 56), and serpentine curves will have to be introduced in the alignment. While the road goes round and on the side of a hillock (fig. 57), it will have convex curve (with its convexity on the outer edge of the road) at the ridge of hillock; this curve is known as *salient curve;* at the valley of the hillock, the road

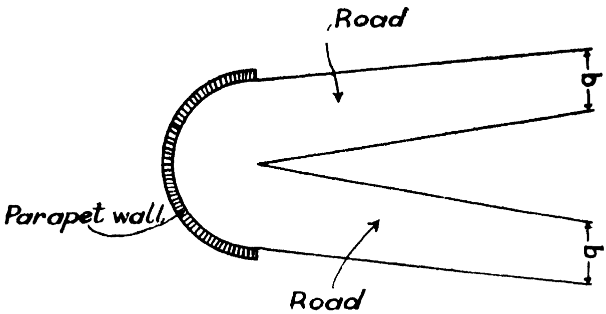


FIG. 56

will have a concave curve known as *re-entrant curve.* Due to these ridges and valleys on the side of hillock, the visibility on a hill road is less and the traffic has to be very careful while negotiating the salient and re-entrant curves in succession otherwise there will be a danger of fatal accidents. To improve the visibility at a salient curve, a portion of the jutting-out hill side is cut down [figs. 58(*a*) and 58(*b*)].

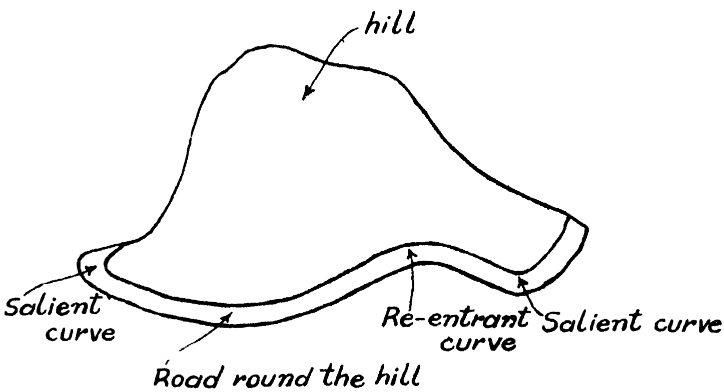


FIG. 57

3. Road gradient, Camber, and Cross section: The following are the maximum and average gradients adopted for hill paths and hill roads:

Type of road or, path	Maximum gradient	Average gradient
Path for pedestrians	1 in 5	1 in 7·5
Path for pack horses	1 in 7·5	1 in 10
Path for loaded mules	1 in 10	1 in 15
Path for loaded camels	1 in 15	1 in 20
Road for vehicular traffic	1 in 20	1 in 30

In case of hilly area, a path or way limited to the use of led, driven or ridden animals is known as *bridle path* or *briddle way*. It is 2·4 m (8′) wide and serves as feeder road to the motor road.

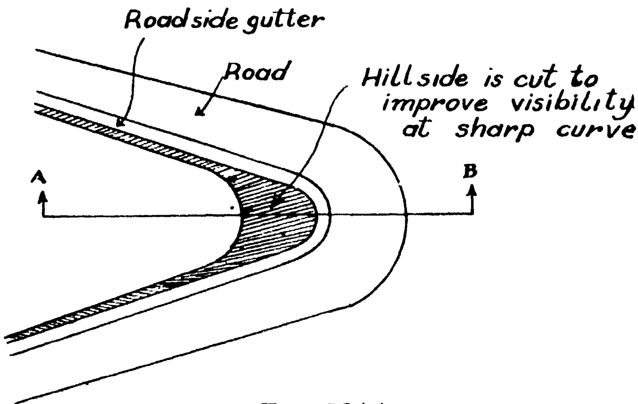
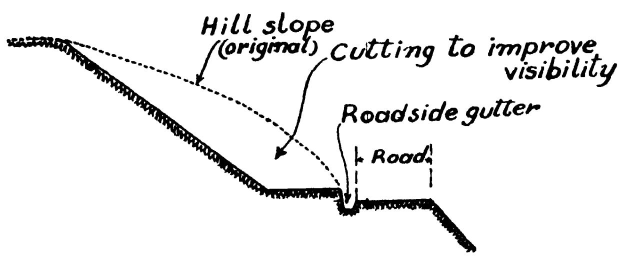


FIG. 58(*a*)



Section on AB

FIG. 58(*b*)

The cross section of hill road going round a hillock may be wholly in cutting (fig. 4 and fig. 59) as is done when the hill side slope is steep; when the side slope is very steep and material is hard rock, the cross section for narrow roads is wholly in cutting as shown in fig. 60 and the road is said to be the road in half tunnelling. Half tunnel is used where the

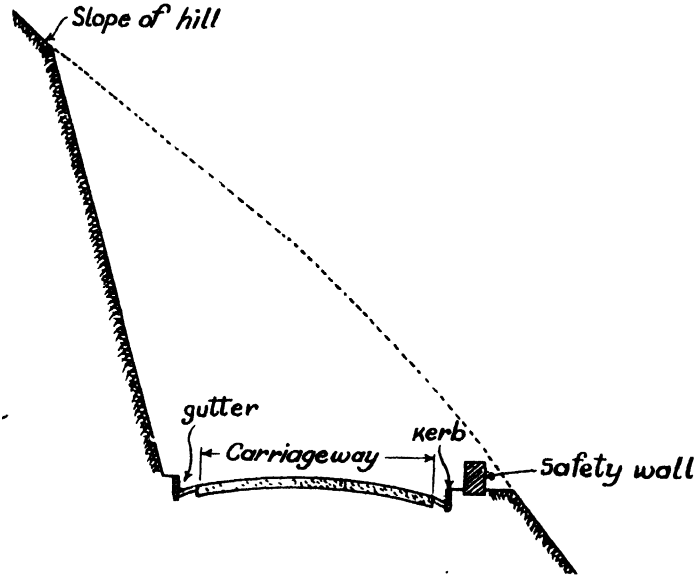


FIG. 59

strata of rock dip away from the road side and when the rock is sound and hard. In some rare cases, road is carried in full

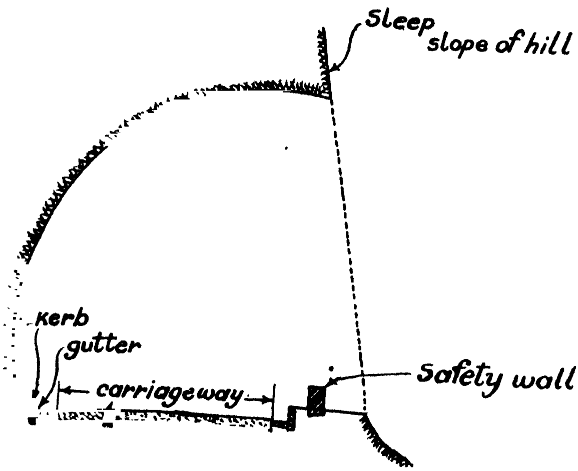


FIG. 60

tunnelling in the form of a horse-shoe. A road tunnel is however very costly and is therefore rarely constructed.

Road section may usually be $\frac{2}{3}$rd in cutting and $\frac{1}{3}$rd in bank

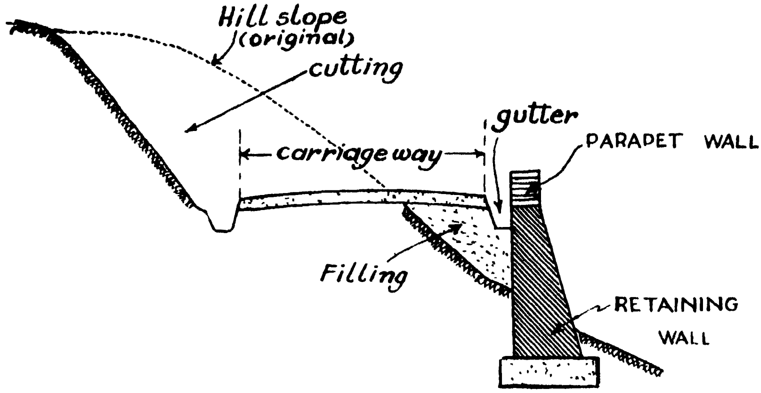


FIG. 61

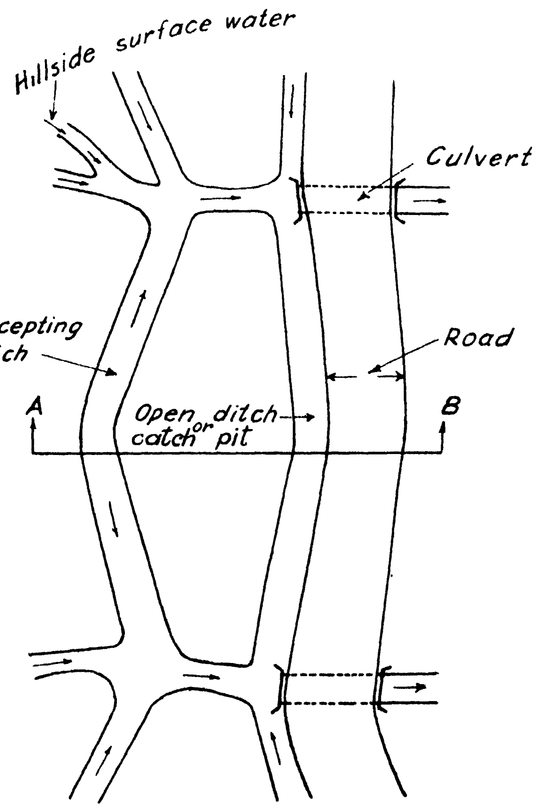
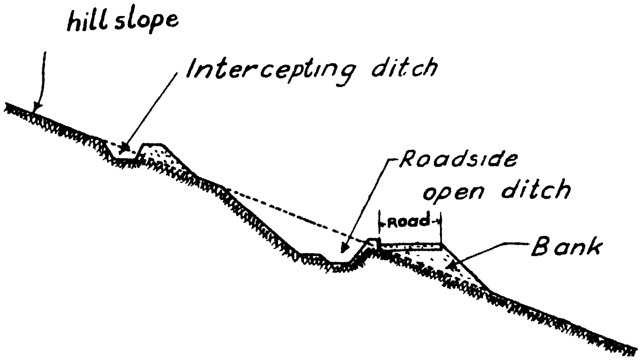


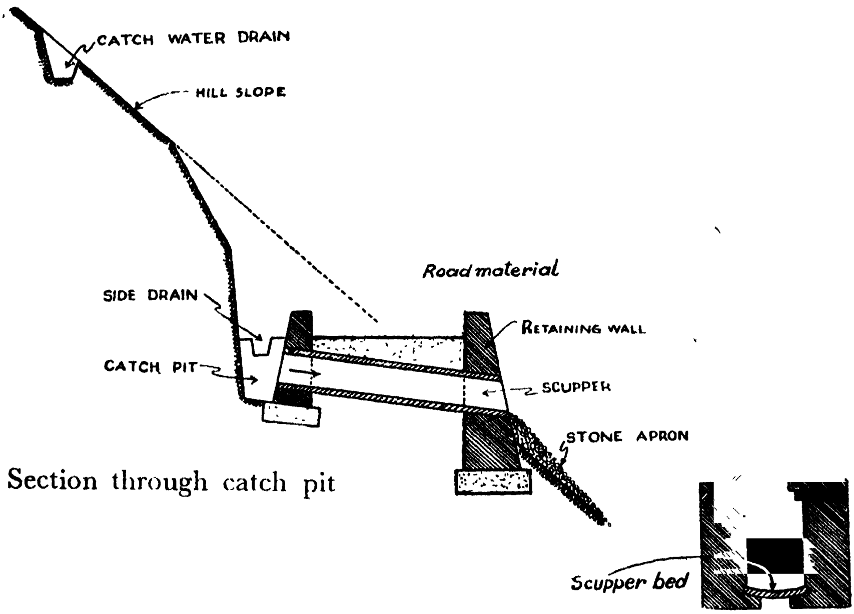
FIG. 62(*a*)

(fig. 61) when the side slope is not very steep and the cost of cutting through rock is too much. In the straight reach of the road, the camber will be hog-shaped (fig. 61) as usual. There will be one side-gutter on each side of the carriage way; also on the sloping side of the hillock [figs. 62(*a*) and 62(*b*)], there will be a catch water drain parallel to the



Section on AB
FIG. 62(*b*)

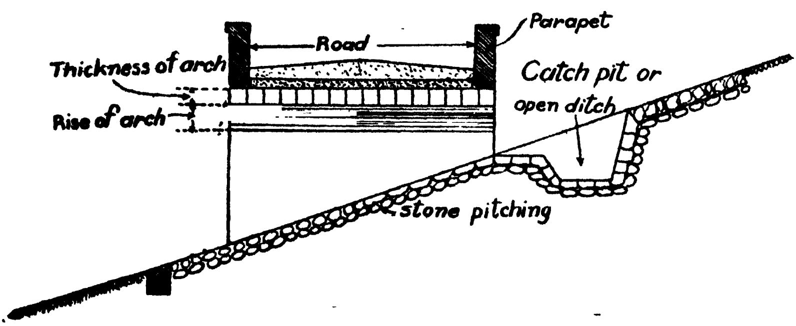
alignment of road; this catch water drain will catch all the drainage water running down from the hill side above it and it will discharge this drainage into the nearby valley in the side of hillock. Catch water drain may be 60 cm (24″) wide and 45 cm (18″) deep, with pitched bed and sides. It is located about 4·5 to 9 m (15′ to 30′) above road level and has a longitudinal gradient of 1 in 50. Thus the major portion of water coming down the hill is intercepted by catch water drain and is not allowed to go to the road side drain or side gutter; the latter may therefore be of smaller size. Where this valley cuts the road alignment, road culvert [figs. 63(*a*) and 63(*b*)] and suspension bridges will be constructed to pass the water (from the valley) below the road and to the outer side of the road. The side-gutter on inner side will collect drainage from hill side (between catch water drain and catch pit) and from the surface of road; this drainage will be disposed off in a catch pit at the base of the above-said valley and will be taken out through the above-mentioned road culvert. All the debris brought by the water running down the valley or coming from the inner side-gutter to the catch pit will get deposited in the catch pit with depressed bed and, the debris-free water will go through culvert openings to the outer side of the road. The side-gutter on the outer side of the carriageway will collect drainage from the surface of road only. Due to the peculiar terrain of hilly country, there will be a number of culverts etc. in every kilometre of the road,



Section through catch pit

Cross section of culvert in the form of scupper for small streams

FIG. 63(*a*)

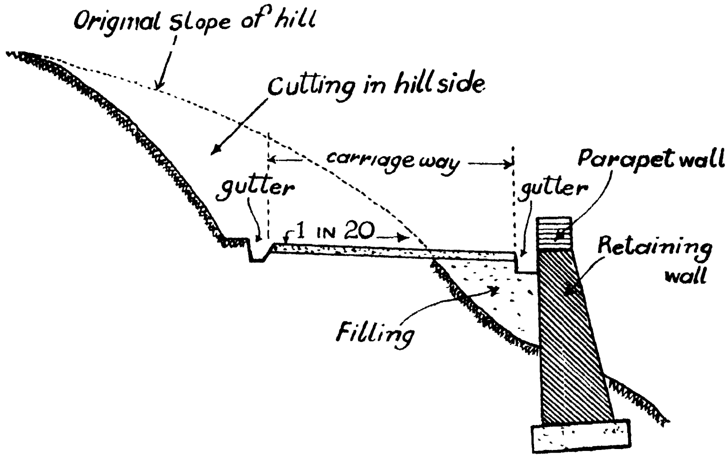


Section through catch pit and arch culvert

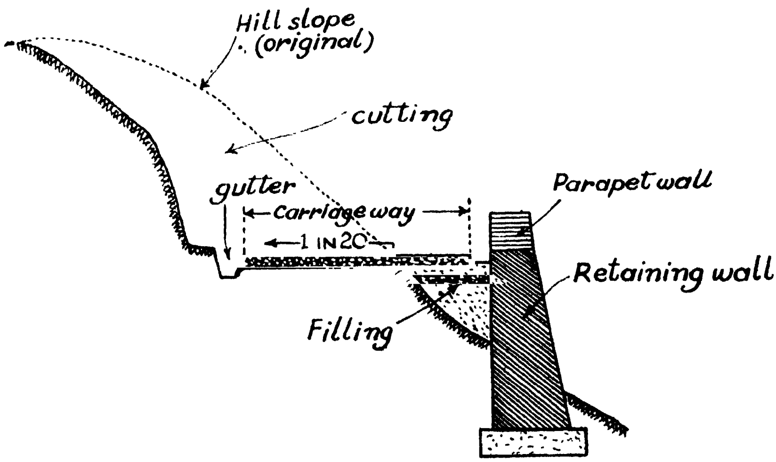
FIG. 63(*b*)

The cross section of carriageway at re-entrant curve (fig. 64), will show a straight cross fall of the road surface from its inner edge to the outer edge. Thus the camber will not be hog-shaped at re-entrant curve.

The cross-section of carriageway at salient curve (fig. 65), will show a straight cross fall of the road surface from its outer edge to the inner edge. The camber will thus not be hog-shaped here also.



Cross section at re-entrant curve
FIG. 64



Cross section at salient curve
FIG. 65

When the cross section of a road is partly in cutting and partly in bank, a retaining wall is used to retain the filling on the outer side of the road. On the top of this retaining wall, a parapet wall 45 cm (18″) thick and 60 to

67·5 cm (24″ to 27″) high is invariably provided on the outside of road at salient curve as this ensures safety of the fast moving traffic. After every 6 m (20′) length of the parapet wall, there may be 0·6 m (2′) gap to dispose off the drainage water from the outer gutter. Parapet walls with gaps are also provided, on the outside of road, at the hairpin corner or hairpin bend. For safety of traffic, a parapet wall may also be provided on the outside of road even at straight reaches of the road where there is a likelihood of danger and accidents. Breast walls (fig. 66), with vertical back

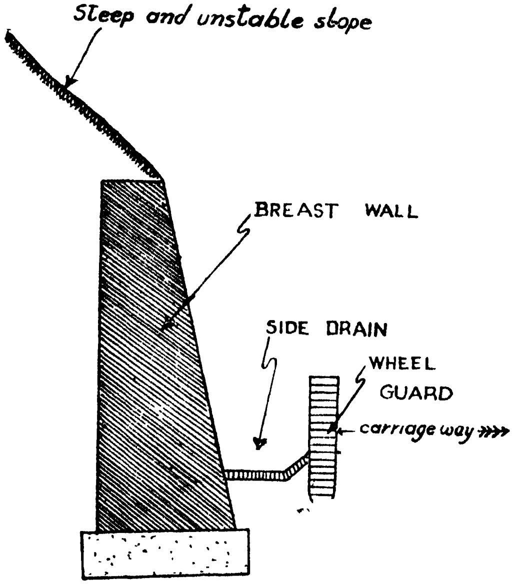


FIG. 66

and a face batter, are sometimes used on the inner side of the road to support the loose and unreliable soil of the hill side and thus prevent the land slides which may otherwise cause accidents to traffic and also may block the road width. The breast wall may be 0·6 m (2′) thick at its top and there should be a number of weep holes to relieve the saturated earth pressure at the back of the wall.

Where the side drain is deep, wheel guard (fig. 66) is fixed between the side gutter and the adjoining end of the carriageway to prevent the wheels of the vehicular traffic from rolling into the side drain.

URBAN ROADS

1. Introduction: The requirements of urban roads are slightly different from those of the roads in an open country hence their design and layout will also be slightly different. The *general* principles are same for both classes of roads.

2. Classification of urban roads: Urban roads shall be classified according to the traffic movement and importance as follows:

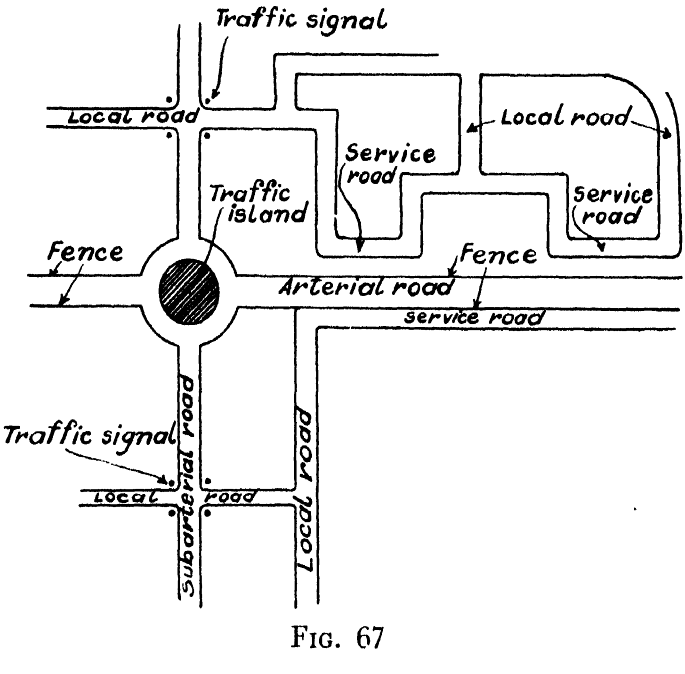


FIG. 67

(a) Arterial roads.
(b) Major roads or Sub-arterial roads.
(c) Minor roads or Local roads.
(d) Streets (residential, shopping, industrial etc.)
(e) Pathways or Pedestrian ways.

see figs. 67, 68 and 69.

An arterial road passes within the city limits and links the State or National highway system, with a limited access.

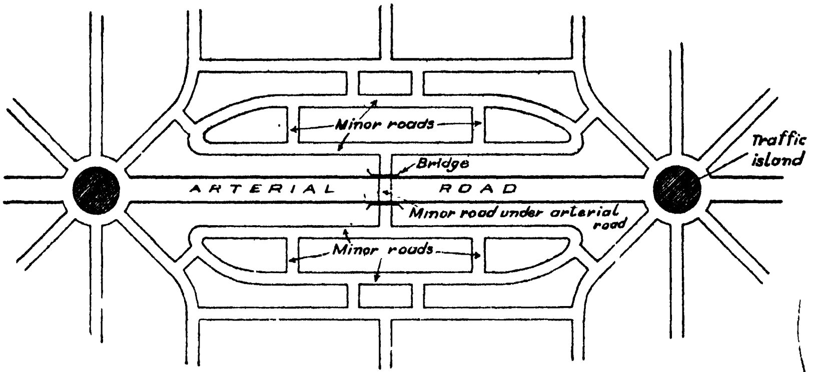


FIG. 68

It includes ring road, by-pass road etc. No residential buildings are allowed along this road.

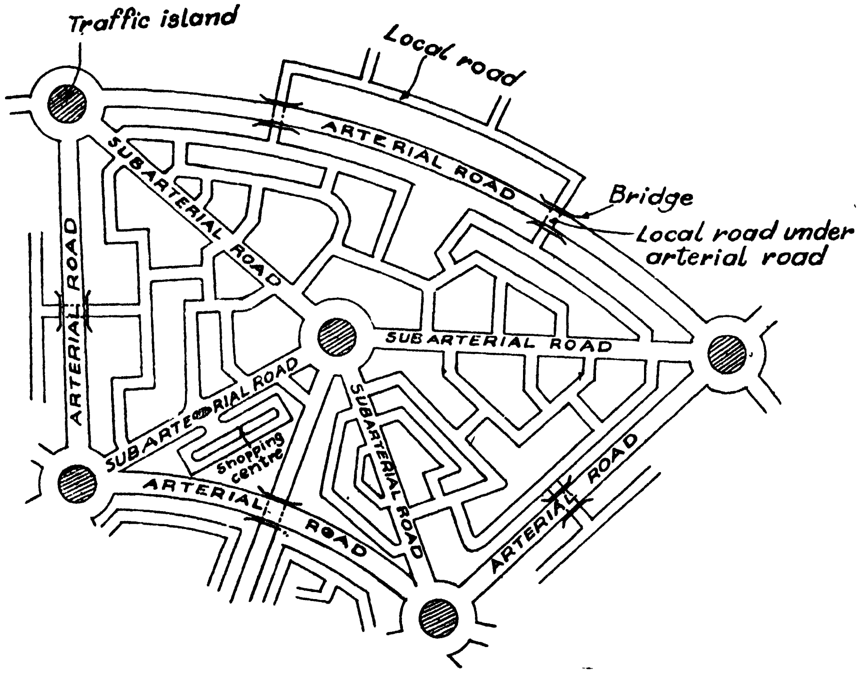


FIG. 69

Major road is one, within city, which connects the important places. In the design of (a) and (b) classes of roads, much importance is not given to the non-vehicular traffic.

Minor road collects the traffic from different parts of the town and links with other minor road and/or with major road. On this road, importance is given to non-vehicular traffic. Minor road is not made to touch an arterial road; the two are separated by a bridge and one goes over the other.

Street (fig. 2) is a road which caters for the internal communication of a local area which may be residential, commercial or industrial. While designing a street, special attention is paid to the social, commercial and other requirements of the local community. Shopping street is wider than a residential street and it has wider footpaths.

Pathway is the access-way intended to give access to the individual premises or shops in the shopping streets and, the vehicular traffic is forbidden to come in this access-way.

3. Standards for urban roads: The following standards are recommended for the different classes of urban roads. The widths and other details will be as shown in the following table:

Class of Urban road or, Pathway	Single or Dual carriage-way	Number of vehicular traffic lanes per single carriage-way	Width of cycle track in m	Width of footpath in m	Overall width of road land in m	Distance between the edge of road land and the building line on each side, in m
(i) Arterial road	Dual, with 3m median strip.	2, each 6·7m wide	No cycle-track or footpath to be provided; shoulders 3m wide to be provided; service roads (i.e. frontage roads) to be provided where developments are likely.			
(ii) Major road	—do— with tramway in between	2	2·7	4·5 on each side	34	1·5
(iii) Minor road	Single	2	1·8, if provided	1·5 to 3 on each side	13 to 20	1·5
(iv) Street	—do—	1 to 2	—	1·5 to 4·5 on each side	10 to 13	1·5
(v) Pathway	—	One lane of 1·8 to 3m for pedestrians	—	—	3·7 to 4·9	1·5

Note: To convert widths in m to widths in feet in the above table, pu 1 m = 3·28 ft, and round off the width as required.

In case of streets of 9·75 m (32′) aggregate width, the width of carriageway between kerbs shall not be less than 6 m (20′), with a minimum pavement width of 3·6 m (12′).

Kerbs (fig. 70) shall be of height 10—20 cm (4″—8″) and shall be chamfered or rounded off. The functions of kerbs are to give side support to the road surfacing and to prevent the traffic from getting off the carriageway.

Adequate street facilities or adornments such as lighting, traffic signs and signals, lane markings, street names, directional signs, pedestrian-crossing markings, parking of vehicles etc. shall be provided and they shall be suitably displayed. The significance of all these street facilities is shown in chapter XV by title 'Elements of Traffic Engineering'.

Water-supply, sewer, gas and other service lines shall be so laid below the ground level as to avoid the frequent opening up of the roads for repairs, maintenance and for putting new connections of these service lines.

4. **Side channel and kerb:** (fig. 70). In urban area, every road shall have one kerb of stone or concrete at

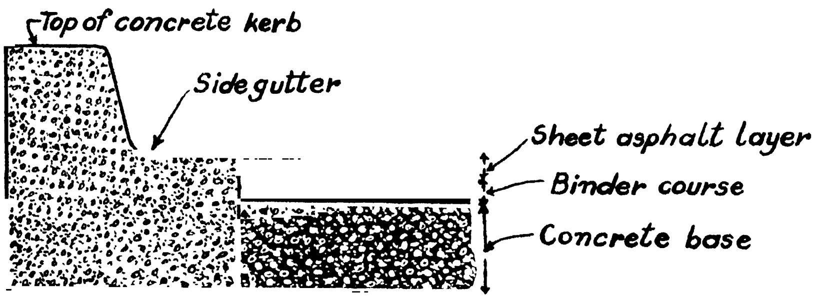


FIG. 70

each end of the roadway. Important function of the kerb is to indicate the limits of roadway. The top of kerb may be about 10—20 cm (4″—8″) above the edge of roadway when footpath is next to the edge of roadway. The kerb and the road surface near the edge together form a side channel which carries away water that comes to it from the surface of the road. The concrete kerb and channel are usually cast as one piece, having a length equal to 0·9 m

(3 feet). The thickness of this precast kerb piece may be 10—15 cm (4″—6″) and the width of the channel may be about 0·45 m ($1\frac{1}{2}'$). These precast kerb pieces are laid side by side in a line to form a length of the channel and kerb line at one and the same time. The water of channel (which is given some longitudinal gradient) goes into gullies which are placed at certain interval along the length of channel and at the back of kerb line. Just near the gulley, kerb is discontinued and water enters the gulley from the kerb inlet and through a grating which covers the top of gulley. From the gulley, water is taken away by the underground drainage pipes.

Where a foot path is provided, the top of foot path near the kerb shall be flush with the top of the kerb. Foot path has a little inclination towards the side of kerb so that the water from its surface may flow into the side channel.

5. **Foot path or Side walk or Foot way:** (fig. 71). If a road passes through a built-up area, the safety of pedestrians has to be considered. A pedestrian is one who does *pada yatra* on the road. Hat off to that brilliant and imaginative chap who defined pedestrian as 'A gentleman who has a luscious, dominating wife and a modern group-up lass but is unfortunately the owner of two cars *only*.' In case of urban roads in built-up area (including streets), one foot path should be provided on each side of the roadway. This is absolutely necessary in case of busy roads and streets. The usual widths of foot paths provided are 1·5 m, 2·25 m, 3 m, 3·75 m, etc. (5′, $7\frac{1}{2}'$, 10′, $12\frac{1}{2}'$ etc), the increment in width being by 0·75 m ($2\frac{1}{2}'$) which is considered as a measure of one lane of pedestrian traffic. In case of busy shopping centres, foot path may be as wide as 4·5—6 m (15′—20′). Foot path may be constructed of stone slabs, bricks, tar macadam, asphalt concrete or cement concrete. Concrete foot path of about 5 cm (2″) thick surfacing is common now-a-days. It should however be seen that the foot path should be of the material not inferior to the material used for road surfacing as otherwise the pedestrians would be tempted to use the road surface in preference to the foot paths. There is little justification to provide the

paved foot paths in rural roads except in the vicinity of villages, towns and habitated areas.

6. Cycle track: (fig. 71). It is provided on those urban roads on which the volume of pedal cycle traffic is such that it warrants the construction of cycle track for the

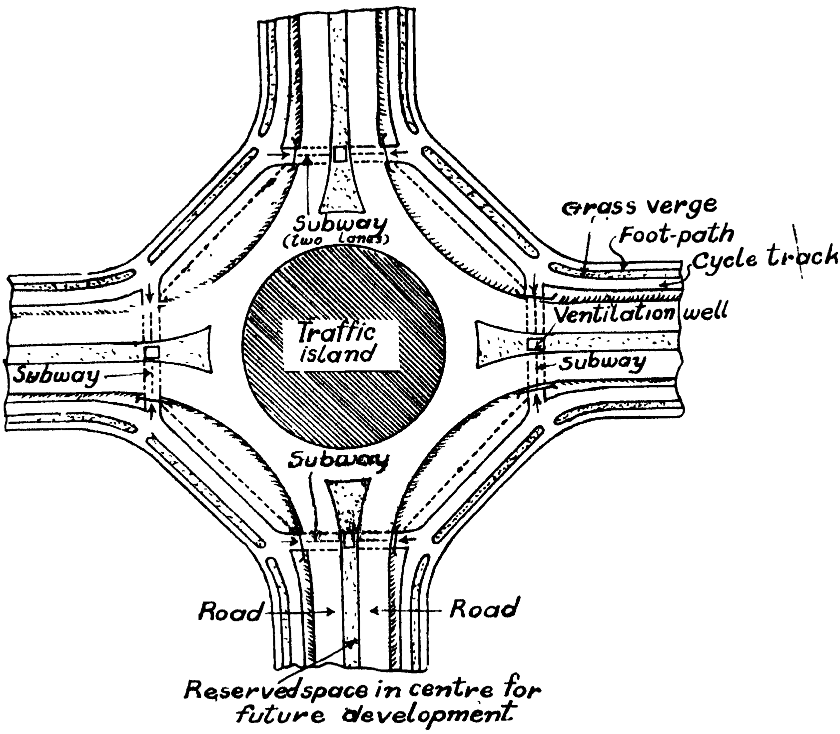


FIG. 71

safety of pedal cyclists. As a rule, when the number of cycles passing a given point of a road is 500 -- 2000 per hour, separate cycle track is provided. The usual widths provided for cycle track are 1·8 m, 2·7 m, 3·6 m etc (i.e. 6′, 9′, 12′ etc), the increment in width being by 0·9 m (3′) which is considered as a measure of one lane of pedal cycle traffic. More the volume of traffic, greater the width of cycle track provided. In case of main industrial streets, there may be even one cycle track on each side of the street. The cycle track surfacing material should be the same as that of the carriageway of the road. If of concrete, 10 cm (4″) thickness is sufficient as a surfacing of cycle track. Grass verge of 1·8 m (6′) width is provided between the carriageway and the cycle track; similar verge 0·9 m (3′) wide may be provided between the foot path and the cycle track. Verges are provided to avoid collision of the different kinds of traffic moving on the adjoining paths.

7. Underground mains and services: For the purpose of preventing interference with the carriageway, adequate verge accommodation should be provided on all new roads for the laying of drains, underground mains, cables etc. and their relative positions should be determined at the very outset. When the grass verges have to be disturbed for repairs to these services, turf and top soil should be cut, stacked and then filled back after the repairs are over. Where no verges are provided, the services may be sited below the foot paths and not below the carriageway so that when the repairs etc. to these services are to be done, the carriageway has not to be disturbed.

8. Special types of roadways: The following are the special types of roadways which are constructed in built-up area under certain conditions:

(a) Open subsurface roadway.
(b) Overhead roadway.
(c) Parkway.
(d) Boulevard.

In case of subsurface roadway, the road surface is below the ground level. Thus, when a through traffic roadway has a parallel local traffic roadway on each side, it is a better plan to separate the through traffic-way from the local traffic-ways by constructing the through traffic-way in a strip of land depressed below the ground. Hence, there will be two-level roadways side by side. Interconnection of the two local trafficways is done by over-bridges across the through trafficway. Subsurface road may be in open as stated above or, it may be in the form of an underground road tunnel.

Road tunnel may be taken below a river when the road comes across the river or, it may be taken through a hill when the road comes across the hill and when a detour becomes costlier in this latter case. Road tunnels are rare and are avoided as far as possible.

An overhead or elevated roadway is created parallel to the existing road and over a portion of the existing roadway when a particular length of the existing road cannot be widened to take the entire volume of the present traffic. The overhead roadway is taken in the form of a viaduct on pillars with ramps at its ends. The space below such a road can be used for the parking of cars.

Parkway is a roadway which has parks on both sides or one side, for a certain length. Such road is restricted to the private traffic only; no commercial traffic is allowed on this road. Parkway may also be circular in shape and in that case, the lengths of parks are arranged along its inner circumference. A parkway has no building frontage.

Boulevard is a very wide road ar street with avenue on each side. It is used as a processional road.

9. Through route and by-pass: Sometimes, a through road between two places passes through the heart of a village or small town on its way. In such cases, the through and local traffic are carried by the same portion of

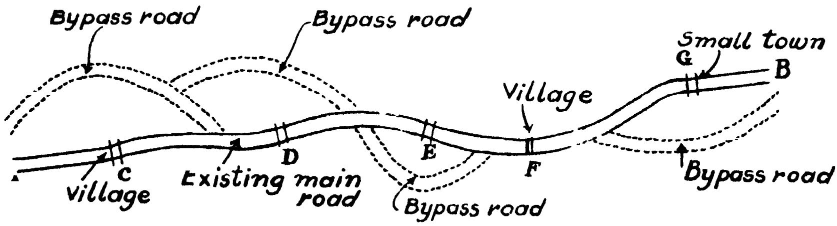


FIG. 72

the through road which lies within the limits of the village. This may cause accidents if there is not sufficient space to provide the foot paths on both sides of the road length which lies within the village limits. To avoid such accidents, a by-pass road (fig. 72) is constructed which diverts the through traffic from that reach of the through road which lies within the village limits. This by-pass road takes off from a point, on the through road, on one side of the village; it skirts round the village and again joins the through road on the other side of the village, outside the habitated area of the village. A by-pass road or loop-road thus enables the through traffic to avoid congested areas of villages or small towns.

10. Service road: (fig. 67). It is a subsidiary road which is constructed parallel to the main road and lies between the main traffic road and the roadside buildings; it is connected with the main road at selected points only. It is used for servicing and for providing the means of access to the roadside property. The indiscriminate provision of service roads should be discouraged since the service roads imply that the ribbon development rather than group development is taking place. Nevertheless there may be particular cases where the development fronting the road is unavoidable; in such cases, service roads should be provided and they should be effectively fenced from the roadway where practicable. Access from roadway to the service road should be provided at intervals of not less than 400 m (1320 feet).

11. Shopping centre: (fig. 73). In good city planning, some area is demarcated for locating the shopping centres. A shopping centre, in essence, consists of an oval-shaped raised island or platform on which the shops are constructed; a wide road goes right round this island and the shops have frontages on this road. Parking facility

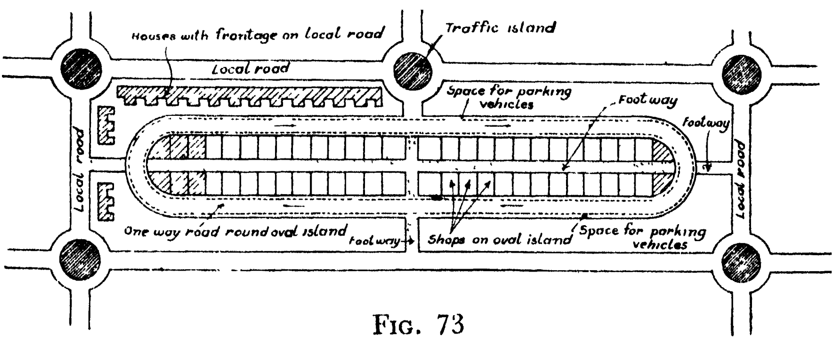


FIG. 73

is provided on that extreme edge of the road which is away from the shop frontages. Footways are provided along the longitudinal and transverse axes of the island. The oval road is connected to one local road; it may also be connected to other nearby local roads by footways.

ELEMENTS OF TRAFFIC ENGINEERING

1. **Introduction:** Road is constructed not for mere use but for its safe and free use. How to ensure its use without congestion and without occurrence of accidents is the duty of every road engineer to know. This is a science in itself and is developing very rapidly due to the phenomenal growth in motor traffic; this science is called traffic engineering and it deals partly with the proper design and layout of road and partly with other means to ensure easy and safe flow of traffic. Traffic engineering includes the analysis of traffic characteristics, the planning of regulatory measures, the design and application of control devices and, the geometric design and functional planning of routes, terminals etc. Traffic engineering thus deals with the regulation, direction and control of vehicular and pedestrian traffic on a road so as to ensure safe and free use of the road. In this chapter, only the elements of this rapidly developing science will be treated; this knowledge is of immense use to a modern road engineer.

2. **Definitions and general:** *Traffic engineering* may be defined as that phase of engineering which deals with the planning and the geometric design of roads and adjoining lands; it also deals with certain traffic operations which are necessary to have the safe, convenient, rapid and economic transport of persons and goods. An engineer well versed in traffic engineering is called a *traffic engineer.*

For the road-traffic planning, operation and administration, the road traffic treatments are based on restrictive (i.e. regulating and controlling) methods applied to the existing facilities on a road on the one hand and, to the proper planning and design of the new constructive measures on the other hand; both of these take place in the environment of administration and planning.

3. Road traffic problems: The problems of road traffic are concerned with the achievement of more efficient system of road transport on the one hand and the conservation of community resources on the other. These two aspects of road traffic are inseparable and they result from the requirement and performance of the following three components:

(i) Human beings as road users (i.e. pedestrians and drivers of vehicles).

(ii) Moving vehicular traffic.

(iii) Fixed facilities for the accommodation of traffic on the road.

All traffic problems and all traffic improvements are concerned with these three components and they must recognize the qualifications and limitations imposed by these components. Road traffic is complex for it involves the inter-relationships of human nature on one hand and physical laws of time, space and motion on the other.

In striving for the road-traffic improvements, two fundamental methods of approach are:

(a) To adjust human behaviour to the environment of the traffic stream and to the fixed facilities for traffic stream on the road.

(b) To accept human behaviour and seek to contrive the ways and means of better traffic accommodation on the road.

Experience has shown that both methods are required and that each method supplements the other. Thus, educational methods to be adopted are necessary to improve the road user's behaviour through persuation, explanation etc. Wide-spread and well organized propaganda by means of lectures, films, radio talks and organization of road-safety weeks shall prove effective and useful. Enforcement methods to be adopted are necessary to change the road user's attitude and behaviour through the supervision of road use according to certain road-code, finding out those who disobey this code and punishing them. Engineering methods are concerned with the qualities of the vehicles and with the fixed facilities on road and they seek to design and construct these to fit the road user's demands and limitations more ideally.

4. Traffic regulations and control: To avoid unnecessary interruptions, detentions, congestions and accidents, traffic regulation is necessary. Regulation of traffic covers all aspects of the control of vehicle, driver and pedestrian. This is necessary to ensure the safety and convenience of traffic. Certain basic rules of road use and conduct concerning the lateral placement, speed, overtaking, starting, turning, stopping, right-of-way, pedestrian rights, pedestrian duties, general parking rules, vehicle size, vehicle weight and such other regulations are formulated to form a *road code.* Then it is seen by the traffic-police that the road-code is observed by traffic. The defaulters are punished through the courts of law. The regulations should be rational as far as practicable; then only they will be effective and will ensure speedy and smooth flow of traffic.

Then there is another class of regulations which specially applies to the particular times and particular places; to aid in the implementation of these regulations, the traffic control devices are used which warn or inform the traffic near those places. Such devices (described later in this chapter) are:

(i) Traffic signs and Road markings.

(ii) Traffic signals (power-operated).

(iii) Road lighting.

From time to time, effort has been made to standardize all these devices either on a regional or on global basis.

5. Traffic control by design and layout: The construction of fixed facilities on a road is of special concern to the traffic engineer since these facilities *virtually* affect the traffic operations. Reconstruction or new construction of road should therefore be designed so as to suit the traffic requirements on that road. Following are some of the traffic factors which influence the road design:

(i) Composition (i.e. nature and character) of traffic.

(ii) Volume of traffic.

(iii) Speed of traffic.

(iv) Performance values of traffic.

This aspect of the road design is called functional (or geometric) traffic design and it keeps the traffic values of a road in view. This traffic design is concerned with the following items:

(a) Road surface because of its functional value and light-reflecting properties.

(b) Cross section of the road showing width, kerbs etc.

(c) Vertical alignment of the road.

(d) Curves, corners and sight distance (or visibility).

(e) Kerbs.

(f) Lighting of road.

(g) Parking places.

(h) Foot crossings.

(i) Subways and over-bridges.

(j) Restriction of ribbon development.

(k) Means of ingress and egress to and from road-side premises.

(l) Pedestrian refuges and traffic islands.

(m) Road intersections or crossings or junctions.

Some of these points have been already treated elsewhere in this book. Here, these points will be touched from the point of view of the traffic requirements.

The road width should be sufficient to satisfy the volume of traffic going on the road. On busy road, a minimum of two lanes of traffic are necessary to avoid accidents. The minimum required camber should be provided according to the surfacing of the road. Too much camber causes skidding and side-slip. The road surface should be such that it should afford sufficient grip to the running vehicles in dry as well as in wet weather. Also the colour of surface should be such that it should not cause glare in sunlight and should be visible during night. In vertical alignment, the gradient should be as easy as possible. The humps of vertical curves should be as low as possible so that the vision may not be obstructed.

In horizontal alignment, the curves should be of sufficient radii so that the fast moving traffic can negotiate them with safety. The corners in roadway should be rounded off with minimum radius of 9 m (30 feet) as this will provide facility to the traffic turning round them. A minimum sight distance of 150 m (500′) should be provided at all curves.

The kerbs should be neither too high not too low. Average height of the kerb is from 10 to 15 cm (4″ to 6″) above the edge of road. If the kerb is too high, the pedestrians will find it difficult in coming down from the foot path. The kerbs should have distinct colour so that they can be distinguished from the roadway.

The road surface should be fully and uniformly lighted. There should be no patchy lighting nor should the light cause dazzle to the road users. The road lighting should provide pleasant and accurate seeing conditions at night time so that the traffic movement may occur safely and easily. At road junctions and round-abouts, it is particularly important to ensure that a driver can see the junction from far off and can appreciate the route which he has to follow.

The standing vehicles on a road obstruct the road space and for them the parking places, off the road, should be provided wherever necessary. Parking place is an area, off the road, set apart for temporarily accommodating the stationary vehicles. Parking places should thus be provided near business centres, shopping streets, offices, markets, cinema houses, restaurants, places of worship etc. so that the owners of cars may temporarily park their cars there till their business is transacted. On roads, parallel parking is preferred to angle parking. Parking places should have easy access to the main road. Parking meters are an effective means for regulating on-street parking. They offer an accurate time check on parkers, thus discouraging over-time and all-day parking.

The minimum width of foot crossing or pedestrian crossing or cross walk (see figs. 74, 75 and 76) should be about 2·4 m (8 feet) and it is demarcated on the road surface. Foot crossing is the transverse strip of the carriageway for the pedestrians to cross from one foot path to the other, across the road. At a pedestrian crossing, the guard rails should be erected to induce the persons crossing the street to do so *only* at the crossing provided for them. At busy places, guard rails also prevent the pedestrians from roaming on the road.

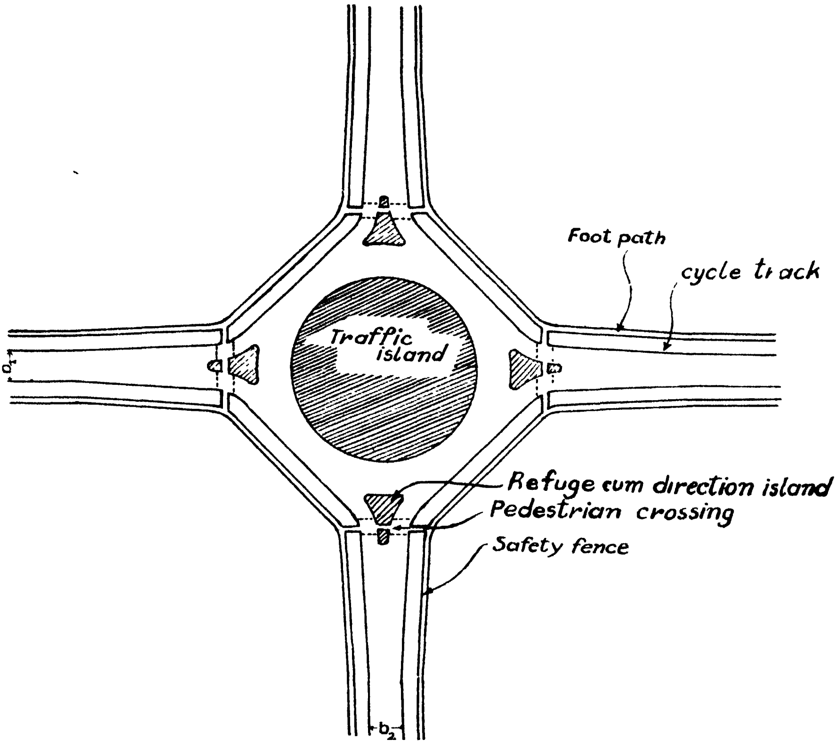


FIG. 74

Subways {see figs. 77, 78(*a*) and 78(*b*)} and over-bridges are necessary for the pedestrians for safe crossing across the congested roads or where the traffic on the road is very fast and is moving in more or less continuous stream. The subways are preferred to over-bridges if a passage could be had undergound immediately below the road junction at about 2·7–3 m (9′ to 10′) below the road surface. Such passage can be had if there are no sewers and water supply mains below the junction. The steps are provided to come down from the foot path to the floor of subway. Subway may also be used by cyclist and then it will be wide enough to

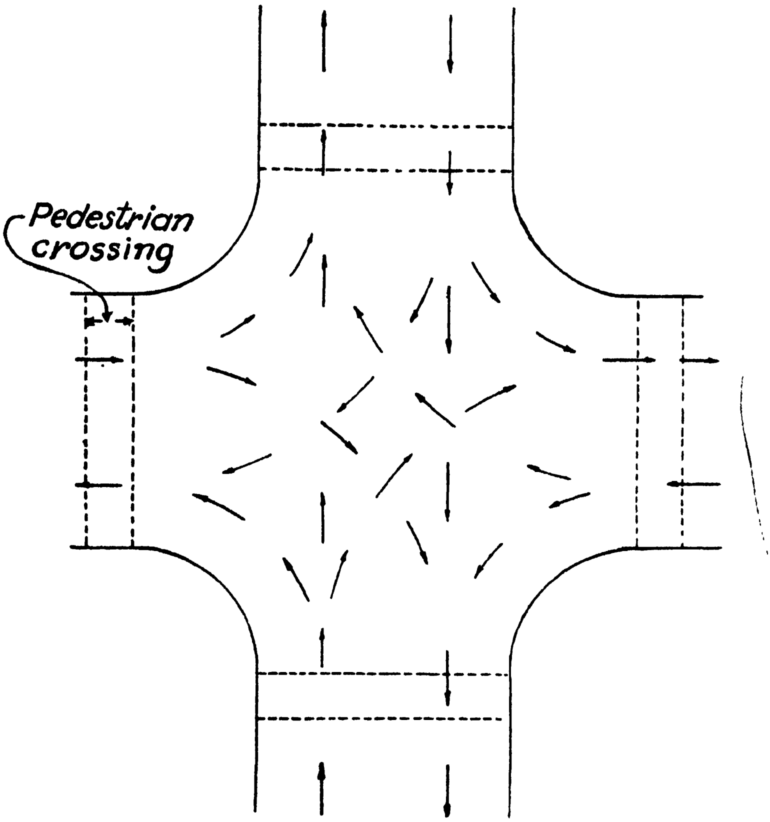

Pedestrian crossing

FIG. 75

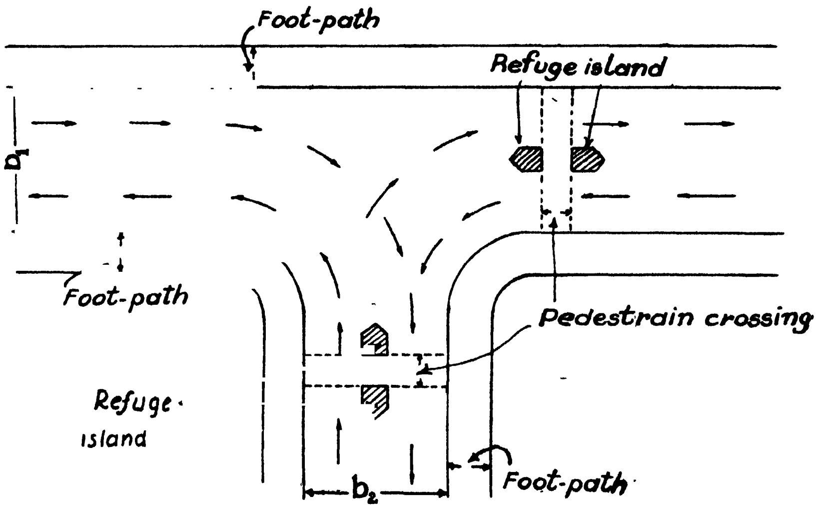

Foot-path
Refuge island
b_1
Foot-path
Pedestrain crossing
Refuge island
Foot-path
b_2

FIG. 76

accommodate both the pedestrian traffic and the pedal cycle traffic. When the cyclists have to use the subway, a ramp is provided instead of the steps. When an over-bridge is adopted, the bottom of the over-bridge should be about 4·8—5·1m (16′ to 17′) above the road surface. The over-bridge is used only by the pedestrians.

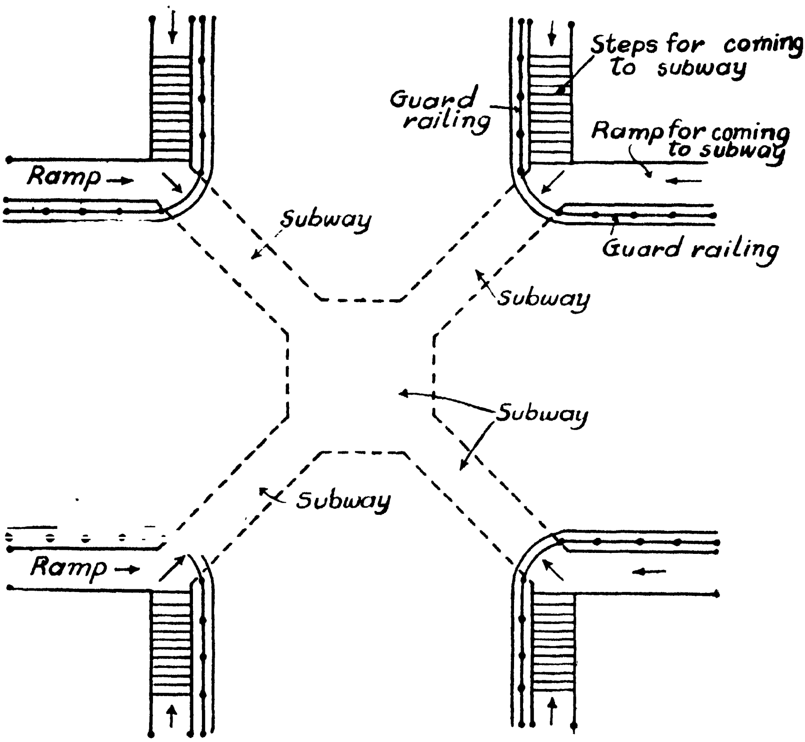


Fig. 77

The ribbon development along the sides of a road is undesirable as the adjoining population is subject to a danger while crossing such road; hence the British Government passed the restriction of ribbon development act which came into force from 1935. According to this act, the road authorities are empowered to control this sort of development. In India, the revenue authorities are empowered to control this sort of development; it is desirable that the road authorities should be empowered to control it. According to this act, no body can construct the means of ingress and egress from the road to the road-side premises without the prior consent of the authorities. Authorities can reject plans of the means of ingress and egress if such plans interfere with the road-side traffic. Also, no building can be constructed within 67 m (220′) from the centre of the road. According to some town-planning act, the authorities are empowered to see that the new building is so designed and situated as not to cause interference with the traffic on the road.

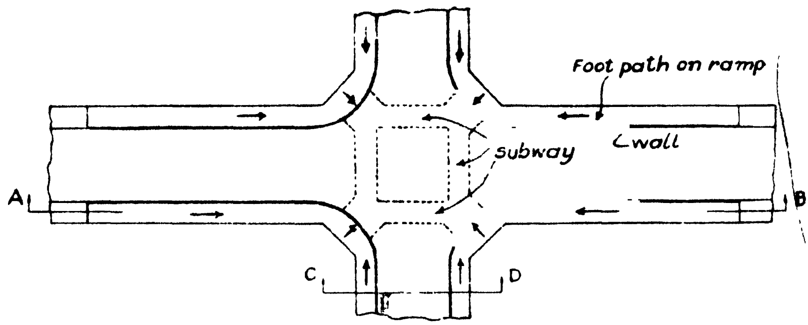
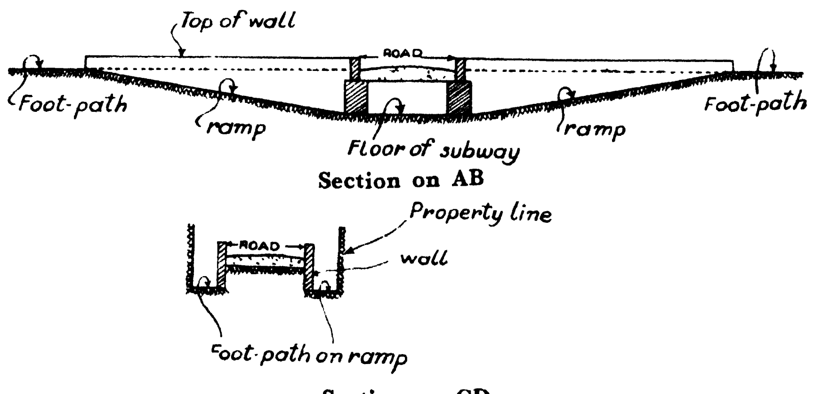


FIG. 78(*a*)



Section on CD

FIG. 78(*b*)

To ensure safety, the traffic at the road junctions in built-up area is controlled by means of the following:

(a) Traffic (light) signals on the roads carrying less traffic.

(b) Traffic island and refuges on the roads having a fairly good traffic. This provision ensures a continuous flow of traffic.

(c) Fly-over junction or grade separation on the roads of heavy traffic. In U.S.A., this junction is more common than level crossing. This junction ensures a continuous flow of traffic.

Road signal or traffic light signal(for vehicle drivers or pedestrians) is a device for the control, warning or guidance of traffic. It provides for orderly movement of traffic, reduces the frequency of accidents and, warns and controls the traffic at railroad crossings and other points of hazards to traffic. It may be operated manually, electrically or mechanically. It assigns the right-of-way *alternately* to diverse traffic flows at the junction. Road signals are usually provided at the corner of a junction and slightly on the inside of the kerb line. Stop lines (fig. 79) are marked on

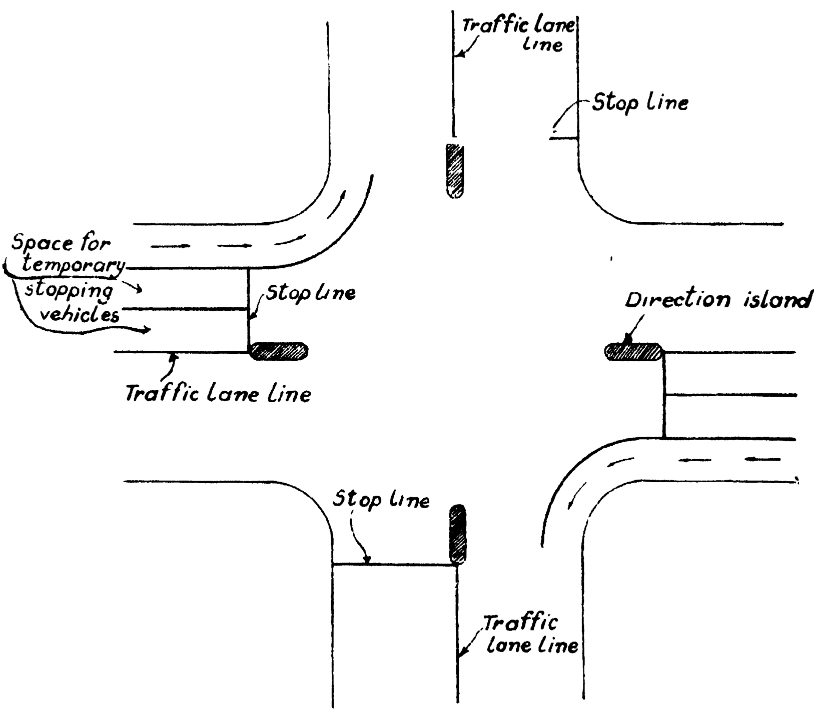


FIG. 79

road surface at the entrance to a junction. Signal shows red, green and yellow colours. If opposite signal shows red colours, the vehicle must stop at the stop line; when it shows yellow or amber colour, the vehicle should be ready to proceed; when it shows green colour, vehicle must proceed further, enter the junction and go to the required road taking off the junction. Signals may be:

(i) Automatic time-spaced signals or Automatic fixed-time signal.

(ii) Vehicle-actuated or traffic-actuated signal.

Automatic signal shows different colours at regular intervals of time. The three lights are fixed one above another on a post such that the lowest green light is 2·25 m ($7\frac{1}{2}'$) above the bottom of the post. The placing of signal posts may be as follows:

(a) One signal at each of the diagonally opposite corners for four-way lights: This is common.

(b) One signal at each of the four corners for one-way or two-way light: Signals should be placed at the far corner so that they can be seen properly.

(c) One four-way signal at the traffic island site: This is used in case of very wide roads only.

Automatic signals repeat regularly a given colour sequence of signal indications. Cycle length (i.e. the time required for a complete sequence of indications) is between 20 and 120 seconds. With high volumes of traffic, cycle length is greater. At intersections, signals must be timed to accommodate pedestrian traffic movement for 5 seconds.

The draw-back of automatic signal is that a vehicle must stop at the stop line on seeing the red colour even though there may be no traffic along the road crossing at right angles. This signal is useful where the volume of traffic is fairly constant.

In the case of vehicle-actuated signal, 20 cm (8″) thick rubber pad is fixed in the road surfacing, the top of pad being flush with the road surface. Each pad is fixed across the roadway and about 30 m (100′) away from the road junction. As the vehicle passes over the pad, the wheels of vehicle press it and by means of an electrical connection, the arrival of the vehicle near the junction is recorded in a control box which is located on foot path near one corner of the junction. From the control box, the required colour is then shown. Thus, if there is no traffic on the cross road, green colour will be shown so that the vehicle can proceed further. This signal is costly.

Where the roads intersect at one level i.e. in the case of an intersection at grade, a 7·5—15 cm (3″ – 6″) high traffic island (fig. 74) is provided in the centre of the important junction. At a little distance before the entrances to this traffic island, refuges or pedestrian islands are provided to guide the pedestrian traffic into the proper channel and thus ensure the safety of pedestrians. These pedestrian crossings become absolutely necessary when the road to be crossed by the pedestrians is wide, say 9 m (30′) or more. A bollard or guard-post (fig. 80) should be provided at each end of a

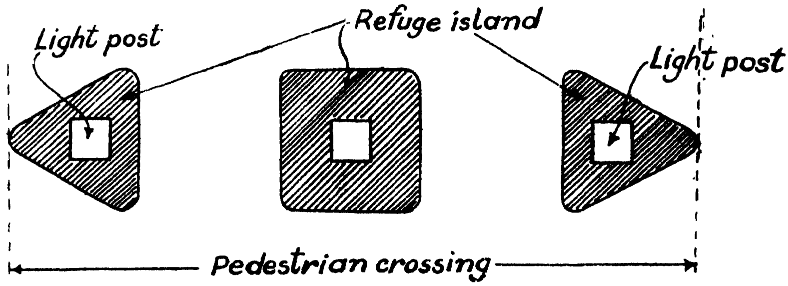


FIG. 80

refuge so that the refuge can be readily seen by the road users. The guiding of the vehicular traffic into proper channels is known as *channelizing* of the traffic and is effected at entrances to a junction by means of direction islands. The strip of roadway round the traffic island is called a *round-about;* width of this strip should be from 7·2—9 m (24′ to 30′) and at any rate it should be sufficient to take up the traffic safely. Sometimes the island itself is called a round-about. The combination of the interlacing movements of vehicles at the island is known as *weaving* and the distance between the entrances of adjacent radial roads of a junction is called the *weaving length.* Weaving length of a traffic island may be equal to three times the width of the widest way or limb of the round-about and should not be less than 45 m (150′). Weaving distance should be sufficient so that the smooth flow of traffic is maintained. The side width of a polygonal island should be slightly greater than the widest limb mentioned above. A vehicle has to give a round (about this island) before it can go to the road on which it has to go; it is therefore compelled automatically to slow down at the round-about. The advantages of such rotary treatment of the junction are the following:

(i) A steady one-way traffic movement is ensured.

(ii) Weaving is facilitated for all classes of traffic.

(iii) A considerable volume of traffic can be kept moving in safety.

(iv) The passage of traffic is quicker than by the use of traffic signals only.

All the roads should be equally spaced round the junction. At the junction where four roads meet, the island may be of the shape of a circle, oval, square, rhombus etc. [see figs. 12(*a*), (*b*), (*c*) and (*f*)]. Where more than four roads meet at a junction, the island may be of the shape of a circle or a polygon [see fig. 12(*d*)]. Ample direction signs should be placed on the radial roads and the traffic island to guide and help the traffic; the usual warning signs are essential. Vehicles should enter the junction cautiously and slowly and should leave it with a speed so as to ensure safety.

When two roads carry a very fast traffic and intersect or cross each other, their grabes can be separated by carrying one road over another by means of a bridge; further, these roads can be interconnected by means of *link roads* and *loop roads* so that the traffic can go from one road to the other. Such a junction is known as a *flyover junction* or *grade separation.* Following are the *usual* types of such junctions according to their geometrical pattern:

(a) Clover leaf pattern (fig. 81).

(b) Diamond pattern (fig. 82).

Grade separation serves the following purposes:

(i) It assists the rapid and un-interrupted movement of a large volume of traffic.

(ii) It removes the bottle-necks and the peak-period congestion.

(iii) It creates the road safety conditions of the high-speed traffic.

Flyover junction is costly to construct and occupies large area of land. It, however, causes less hazard and less delay to traffic.

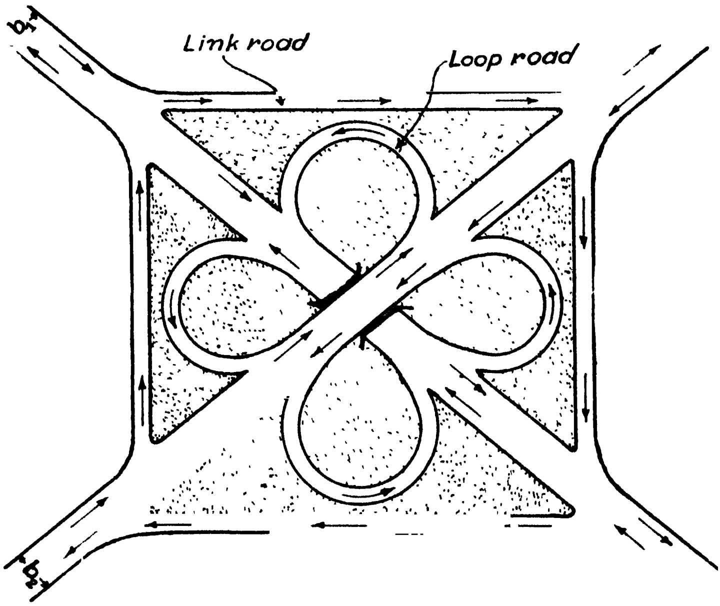


FIG. 81

6. Problems of road traffic: Following are the problems of road traffic which are to be tackled by a traffic engineer:

(i) Problem of road safety.
(ii) Problem of segregation of traffic.
(iii) Problem of cross traffic.
(iv) Problem of road obstruction.
(v) Problem of road census.

Road safety depends on the following factors:

(a) Safe speed of vehicles.
(b) Physical condition of driver.
(c) Condition of vehicle.

The driver should drive the vehicle with speeds that are within the allowable limits; the unusually high speeds are dangerous to other traffic and to the high-speed vehicles themselves. Every motorist must drive slowly and cautiously *so that his car license expires before he (expires)*. He should know that accidents begin where caution ends. His res-

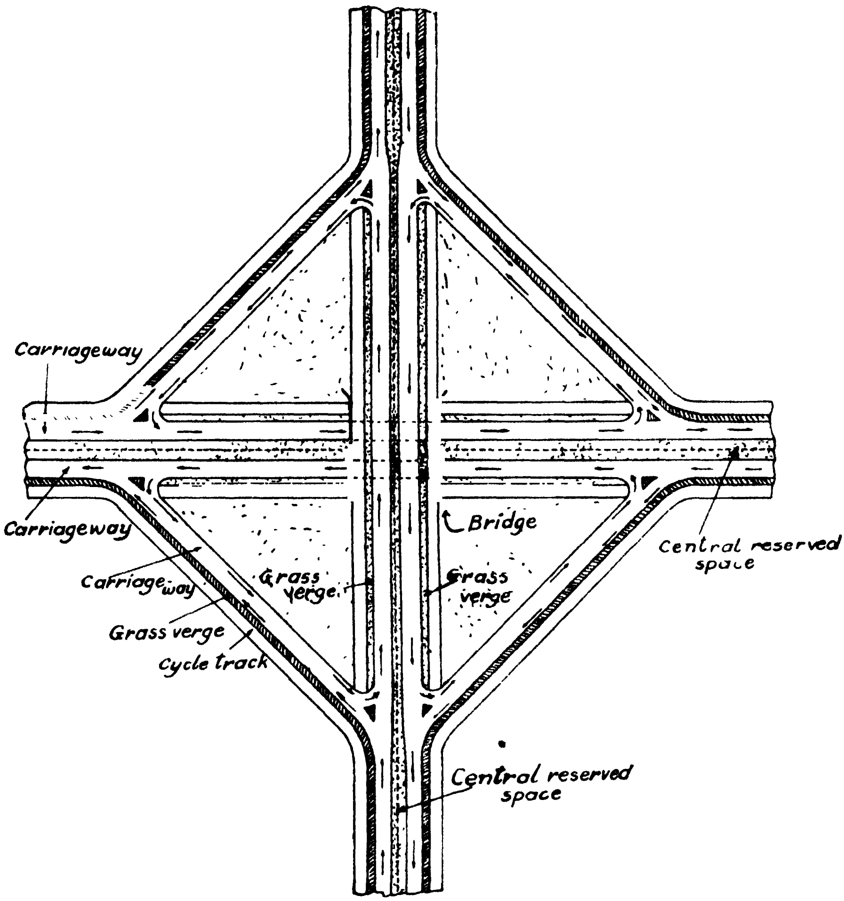


FIG. 82

ponsibility does not end by merely blowing his horn at pedestrians. Indeed, the driver who *often* is blowing his horn is the kind of fool called natural-born. Driver should be fully qualified to drive the vehicle. Every driver of vehicle must remember the following poem for his own benefit and for the benefit of all other concerned:

Save yourself and save them pal,
Make the roads safe for all.
Reckless drivers kill and die,
Leaving kith and kin to cry.
Dazzle him not — he may dash into you;
Puzzle him not — he may crash into you.
Be more cautious on bend and curve,
The laws and rules of the road observe.

For safety, every driver must keep the following points in view:

(i) Come to a complete stop at the stop points.
(ii) Dim the head lights on the road at night.
(iii) Follow other vehicles at a safe distance.
(iv) Slow down in bad weather and adjust to all climatic conditions.
(v) Stay alert and concentrate on driving only.
(vi) Yield right-of-way to pedestrians at pedestrian-crossings.
(vii) And, above all, be a Human Being.

Every driver should also know that if he has any plans for *to-morrow*, he should be careful on the road *to-day*. He should be conscious of the fact that life may start at 40 (years) but death begins to approach at 50 (miles per hour). With such caution and care, highway shall not prove a deathway nor shall a road prove to be a highway to Heaven.

Also he should be physically fit in all respects to drive the vehicle safely. He should not drive after drinking or when he is tired. Drinking, driving and disaster usually go in good sequence. Road safety instructions may be given to the children in primary schools; also, the general public should be informed about the road safety, by propaganda. The machinery of vehicle should be sound and reliable. Brakes of vehicle should be in order; front and rear lights of vehicle should also be in order so that they can be used at night time. These lights are necessary to define the position and the dimensions of vehicle, at night time. In short, the vehicle should be *road-worthy*.

The fast traffic is sometimes segregated from the pedestrians by providing foot paths, subways and over-bridges for the pedestrians. Also, the cycle tracks may be provided for the cyclists to segregate them from the fast-moving traffic.

When two roads carrying a heavy traffic cross each other then, at the point of crossing, the round-baouts and flyover junctions should be provided to ensure a continuous flow of the traffic from either side; otherwise the traffic from the two directions will interfere with each other and will cause delay.

The obstruction and consequent delay on a road is the direct result of the following:

(i) Inadequate road width.

(ii) Waiting vehicles or standing vehicles on the road; this is called kerb-side parking.

(iii) Slow-moving vehicles.

(iv) Pedestrians, crossing the road in a continuous stream.

Road-side parking is undersirable and hence the parking facilities form an important feature for the regulation of traffic in urban and city areas. These facilities may be provided as follows:

(a) In wide streets (b) In open spaces (c) In one-way streets (d) Parking for specified periods (e) Parking around public buildings. Location and layout of the parking facilities must be suited to the traffic conditions on adjacent roads.

In case of road-side parking, a parking lane is separate and distinct from the traffic lane.

The first part of the traffic engineer's work is to make a survey of the existing traffic flows. This will include a census of traffic taken at various points of the road, over a period, so as to find the peak rates of flow. A traffic census gives the engineer an idea about the maximum quantity of traffic and the type of traffic which occur on the existing road and, this census becomes useful to him when he has, in his mind, the widening or improvement of the existing road at a future date. It is also useful for better planning and design of new roads. Traffic surveys are useful for the following particular purposes:

(i) To find the average daily volume of traffic and, its nature and destructive effect on the road.

(ii) To determine the variation in volume of traffic and, the congestion at different periods.

(iii) To help the road engineer in designing, constructing and maintaining a road.

(iv) To enable the traffic-police in selecting the signals or other controlling points for controlling the traffic.

(v) To enable a town-planner in the preparation of town-planning schemes.

These traffic surveys are conducted by enumeration at control points or they are conducted mechanically at these selected points of the road.

7. Traffic directions for safety: The traffic direction or traffic control devices may be:

(i) For drivers and vehicles.

(ii) For pedestrians.

The vehicular traffic is directed by providing the roadside traffic signs along the road. Road sign or traffic sign is a device mounted on a support to give (in the prescribed form and/or symbol) the warning, direction or guidance to the traffic. The support is fixed in a prominent position near the kerb so that the road sign can be clearly seen by the road users.

8. Road-side traffic signs: Properly designed and placed road signs are a *must* for safe and efficient movement of traffic. They should be so located as to be clearly visible. These signs have particular purpose, shape, dimensions and colour. Following are the road-side traffic signs commonly used:

(i) Warning signs or Cautionary signs (fig. 83).

(ii) Prohibitory signs [figs. 84(*a*), (*b*) and (*c*)].

(iii) Mandatory signs or Regulatory signs (fig. 85).

(iv) Informatory signs or Guiding signs (fig. 86).

Warning or cautionary sign indicates to the traffic, usually by means of an appropriate symbol, the approach of the traffic to a place where some caution is required. Warning signs are used to show the hairpin bend, steep hill, level crossing, round-about, school, hospital, cross road, T-junction, pedestrian crossing, narrow road, bridge, winding road, etc. These signs are put along the road-side, a little distance before the hairpin bend etc., to warn the driver that the hairpin bend etc. is ahead, he should be cautious and, should drive slowly and safely.

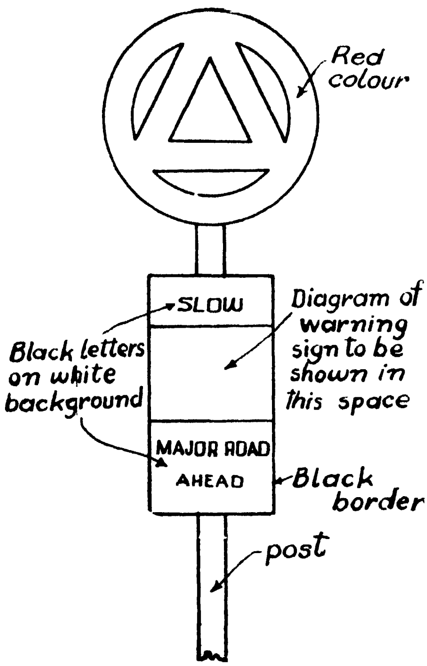


FIG. 83

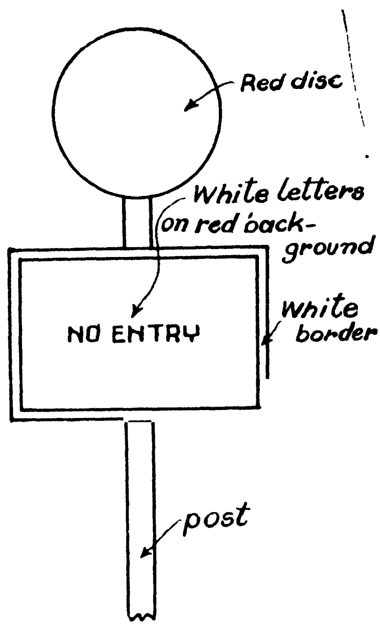


FIG. 84(*a*)

Prohibitory sign indicates to the traffic that the use of a road by a specified class of traffic is forbidden or prohibited. The prohibitory signs prohibit the drivers from exceeding the safe limits of speed or from parking at certain places or from entering certain roads. They are fixed at the required places along the road-side.

Mandatory sign indicates to the traffic an obligation to comply with a statutory regulation. The mandatory signs are provided usually at round-abouts. They carry directions to the traffic to keep or move in a particular direction. Thus, the signs like 'Keep to left' and 'Turn to right' are mandatory signs.

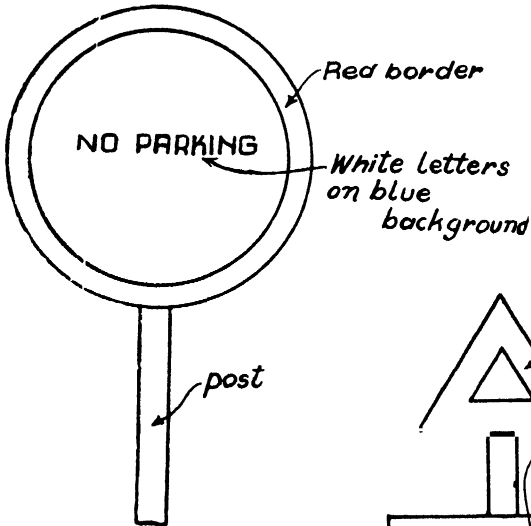


FIG. 84(*b*)

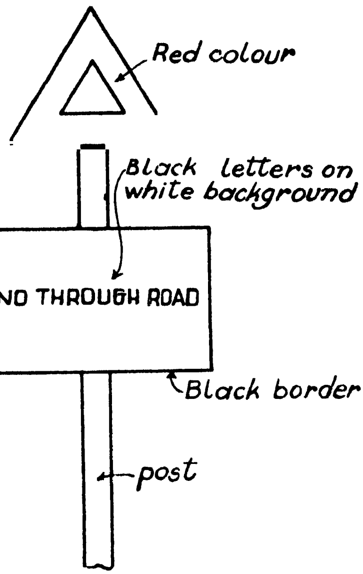


FIG. 84(*c*)

The informatory signs provide certain information and guidance for the driver. Thus, 'Parking for 4 vehicles' and 'Major road ahead' are informatory signs; so are the street name signs, distance signs, directory signs, etc.

9. Directions for pedestrians: In our life, we cannot live without crossing a road and infact the road itself will be utterly useless unless we cross it and use it. Crossing a *busy* road requires certain qualifications on the part of a pedestrian. He should have:

(i) The courage and determination of a hero.
(ii) The eyesight of an eagle.
(iii) The strength of a horse to pull himself across the road.
(iv) The agility of a squirrel to clear the road as swiftly as possible.
(v) The cunningness of a cat to come on the other side of road, without being run over.

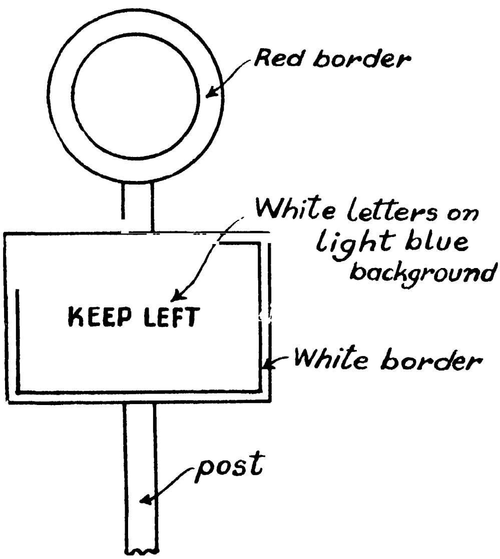


FIG. 85

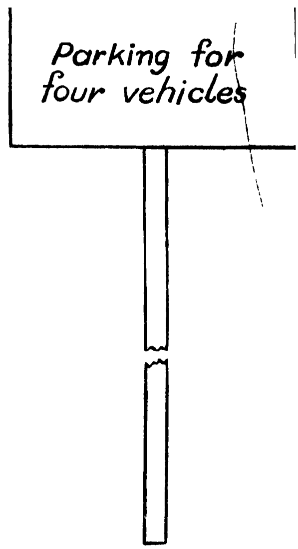


FIG. 86

It is very difficult to find a pedestrian having all the above-said qualifications. He however need not despair if he follows certain out-lined rules of the road while he has an occasion to cross it and use it. Thus, all the pedestrians are directed to observe certain rules. They must keep to the foot paths. In case of congested roads carrying very heavy and fast traffic, *pedestrian guard rails* or pedestrian safety fences (see figs. 74 and 77) are provided on the foot paths, at a distance of about 45 cm (18″) from the kerbs, in conjunction with the pedestrian crossings. These are barriers consisting of rails (or pipes) supported on posts and they pevent the pedestrians from crossing the road (near junction) at any other point except at the foot crossing where the guard rails have openings; the topmost rail may be about 1 m (3′ 6″) above road surface. Now-a-days special light signals for the pedestrian control are being used. They are operated by pedestrians.

In their own interest and in the interest of others, the pedestrians would do well to commit the following poem to memory:

Cart, cycle and other vehicles
Must use their own road;
Foot paths are meant for pedestrians
Thus says the traffic code.

Gentleman, keep to the left,
Safe is the left extreme,
As you go, you should not read,
Nor walk as though in dream.

While walking, look not to your feet,
Nor look too often behind;
Lest you should bump into one
Who may shout, "Are you blind"?

To reach the opposite side,
Hastily you should not cross;
Look to right and left and wait
And let the vehicles pass.

At the junction, a policeman
Gives signals with his hand;
Obey his directions or else
Into trouble you shall land.

When the way is clear, it is time
For you to run a race;
Across onto the foot path there
And back to normal pace.

This done, go on, and in good manner
To all your brethren bow;
That you are a well-mannered pedestrian,
Your every step **must** *show.*

The statistics of one International Agency show that unmarried persons are more prone to road accidents. Bachelors, please beware! Ah, nothing like married bliss!!

93(*a*) and 93(*b*)] is 0·75 m ($2\frac{1}{2}'$) high above ground, 0·75 m ($2\frac{1}{2}'$) below ground and is fixed at every kilometre. It also shows the distance to and from other places. Both the kilometre and $\frac{1}{5}$ kilometre stones are to be located on the left

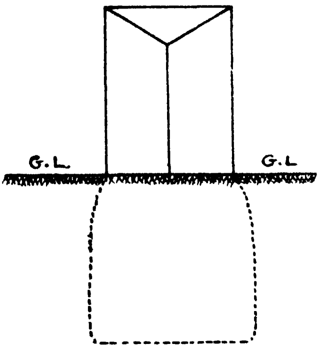


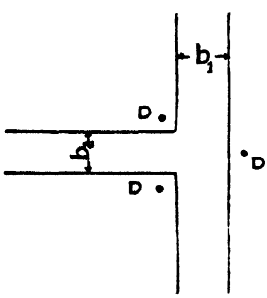
FIG. 93(*a*)

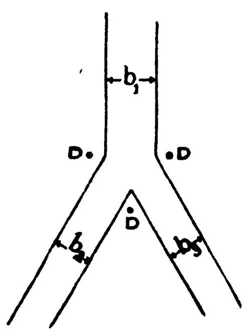
Plan of kilometre stone

FIG. 93(*b*)

hand side of a road as one proceeds from the station from which the distance is counted. Such stones should be about 0·75 m ($2\frac{1}{2}'$) clear of the outer edge of the berm.

Note: In Metric system, the existing mile and furlong stones may be changed to Kilometre and 0·2 kilometre stones. Since 1 km ≃ 5 furlongs, a kilometre stone may be put after a distance of every 5 furlongs. Distance between two kilometre stones, may be subdivided into 5 equal parts, each part being equal to 0·2 km or 1 furlong. Since 0·2 km = 2 hectometres, there will be four numbers of two-hectometre stones between two kilometre stones.





D. Signifies direction post

FIG. 94 FIG. 95

Direction posts (fig. 94 and fig. 95) at a junction of road in open country are used to guide the traffic in proper directions.

are called *guide white lines* or *lane lines* (fig. 89) and they may be noncontinuous lines 10 cm (4″) wide and 0·9 m (3′) long, with the gaps of 3 – 4·5 m (10′ – 15′) between the lines. White lines may be marked with paint or the plastic material.

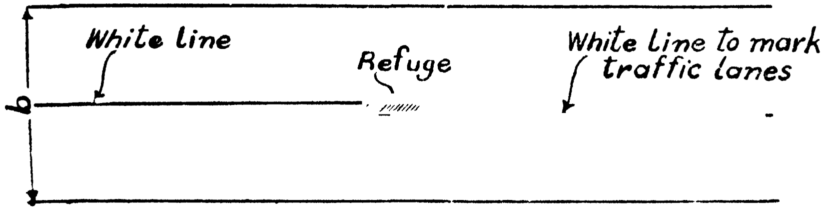


FIG. 89

The stop lines near the entrance to a junction, route markings, foot crossing lines, centre lines etc. are all known as traffic markings.

11. Women Motorists: The Delhi traffic authorities have given a clean chit to '*fair motorists*'. According to these authorities, Delhi roads would become far more safe if more women were to take to driving. A survey carried-out recently by the capital's traffic police has revealed that very few women motorists were involved in road accidents. The traffic officials state that, once at the wheel, women are far more cautious than men. From this finding of the Delhi traffic police the author feels that the women have really proved to be *fair* and the men *unfair*. He also earnestly wishes that in the interest of road safety, men should have their main occupation inside the kitchen!

12. The Purport: It was Abraham Lincoln who had, on one occasion, said:

"That this nation, under God, shall have a new birth of freedom, and that Government *of* the people, *by* the people, *for* the people, shall not perish from the earth".

Likewise every traffic engineer should earnestly wish:

"That our men and women, on earth, may have a better sense of road-use and that driving by the people, *through* the people, *over* the people may shortly perish from our good earth."

93(*a*) and 93(*b*)] is 0·75 m ($2\frac{1}{2}'$) high above ground, 0·75 m ($2\frac{1}{2}'$) below ground and is fixed at every kilometre. It also shows the distance to and from other places. Both the kilometre and $\frac{1}{5}$ kilometre stones are to be located on the left

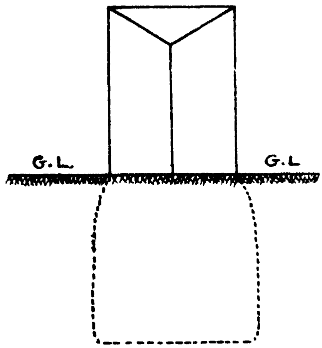


FIG. 93(*a*)

Plan of kilometre stone

FIG. 93(*b*)

hand side of a road as one proceeds from the station from which the distance is counted. Such stones should be about 0·75 m ($2\frac{1}{2}'$) clear of the outer edge of the berm.

Note: In Metric system, the existing mile and furlong stones may be changed to Kilometre and 0·2 kilometre stones. Since 1 km = 5 furlongs, a kilometre stone may be put after a distance of every 5 furlongs. Distance between two kilometre stones, may be subdivided into 5 equal parts, each part being equal to 0·2 km or 1 furlong. Since 0·2 km = 2 hectometres, there will be four numbers of two-hectometre stones between two kilometre stones.

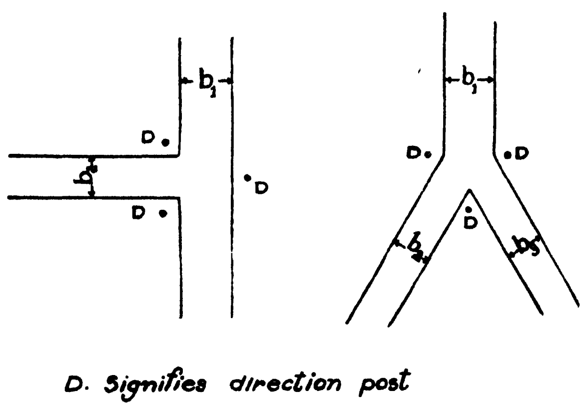


FIG. 94 FIG. 95

Direction posts (fig. 94 and fig. 95) at a junction of road in open country are used to guide the traffic in proper directions.

3. **Road maintenance:** The maintenance of a road may be considered under the following heads:

(a) Repairs to earth-work of road bank.

(b) Repairs to bridges and culverts.

(c) Clearing of the side drains, cutting of over-hanging branches of the road-side trees and controlling the weed growth on the land acquired foı the road.

(d) Keeping the traffic-direction and traffic-control devices to the required standards.

(e) Repairs to road surfacing, foot paths etc.

For roads in open country, gangs of lower establishment are maintained (by the road authorities) to look after the roads. Duties of these cooly-gangs are as under:

(i) Repairing the road shoulders to keep them stable, smooth and at proper elevation and cross slope.

(ii) Cleaning the side drains; cleaning the culvert openings and bridge openings so as to provide a free passage for flood water; taking care of scour around bridge piers and abutments.

(iii) Removing the land-slides from the road surface.

(iv) Cutting of the over-hanging branches of trees.

(v) Doing the petty repairs to the road surfacing.

(vi) Reporting to the officials, in charge of road, about any major defects which these coolies cannot rectify.

4. **Repairs to road surfacing:** Traffic actually moves on the road surface hence the repairs to road surfacing are more frequent and costly than repairs to the road adjuncts. The pot holes or ruts appearing on the road surface should be repaired as soon as they appear or develop. Pot hole should be picked or excavated to the depth of pot hole and space round the pot hole should be excavated to the regular length and breadth so that the pot hole resembles a rectangular cutting below the surface. The two sides of cutting should be parallel to the road alignment. Repairs and maintenance of road surfacing will now be treated separately for different kinds of roads:

(*I*) *Earth and gravel roads:* As said above, the rectangular cutting is prepared round the pot hole and it is then filled with fresh material which should be of the same composition as is of the road surfacing. The material is then consolidated by means of hand rammer after moistening it with water. The patched portion should be brought to such shape as will fit in the original profile and grade of the road. The camber and grade of an earth road can be maintained by means of a *road-drag* which can be used on the road surface when necessary. Dragging is the operation of smoothening out and reshaping the irregularities in the surface of earth by means of a road-drag. Following are the usual types of road-drag:

(i) Split log drag.
(ii) Sawn plank drag.
(iii) Steel plate drag.

The first two types are more efficient than the third type. The first type is common in India.

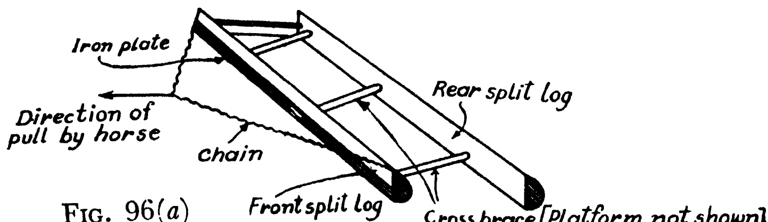


FIG. 96(*a*)

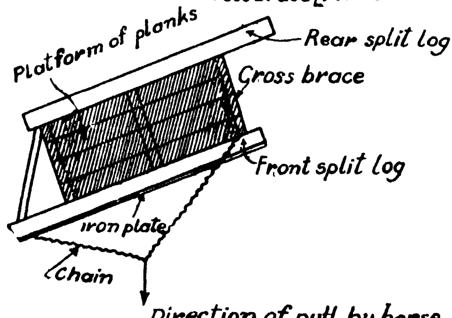


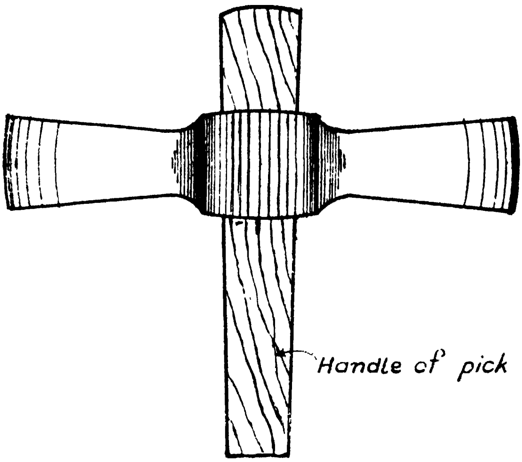
FIG. 96(*b*)

Split log drag [fig. 96(*a*) and fig. 96(*b*)] consists of a timber log 20 to 25 cm (8″ to 10″) in diameter and 1·8 to 2·4 m (6′ to 8′) long, cut into two halves along its longitudinal axis. These two split logs are braced together by 0·9 m (3′)

long cross-braces and on the top of these braces, a platform of wooden planks its constructed. An iron plate 1·8 to 2·4 m (6′ to 8′) long, 5 cm (2″) high and 6 mm ($\frac{1}{4}$″) thick is fixed to the vertical face of the split log (which is on the front of the drag) such that the plate projects about 12 mm ($\frac{1}{2}$″) below the bottom of this split log. Ropes or chains are tied to this front split log and an animal (usually horse or sometimes two bullocks) is yoked to the ropes to pull the drag on the surface of road. The man controlling the reins of horse should stand on the platform of drag. The iron plate will cut the road surface and the depth of cut can be regulated, by the man, by moving on one or the other side of the platform. The ropes tied to the front log are so adjusted that when the horse moves along the alignment of road, the drag-log makes an angle of 30° to 45° with the line normal to the road alignment. Due to this inclination of the drag-log, the material excavated on one side of the road will be dragged on the other side; the surface will be smoothened by the split log at the rear. Thus, the correct camber is maintained by dragging the earth to or away from the crown of road. This work of dragging should preferably be done every month to maintain the road properly. For better workability of the earth, NaCl should be sprinkled on the road surface so that the earth remains moist and as such it can be worked in the best possible manner.

Where a blade grader is used, earth roads are generally regraded twice a year. Regrading of earth road is usually carried out at the end of the rainy season when the soil is still damp but not too wet and, as such, can be worked properly. For better maintenance, dust palliatives and, soil stabilization methods may be used.

(*II*) *Waterbound macadam roads:* To repair a pot hole, the hole is picked as usual to form a small rectangular trench or excavation. The road metal of the required size will be put into this trench till the material protrudes slightly above the road surface; the metal is consolidated as usual by means of a hand rammer. The surface of the consolidated metal will be blinded and finished as is done while constructing a new W.B.M. surfacing. The finished surface must fit in the original profile and grabe of the road surface. Blindage is periodically put on the W.B.M. road when necessary; thus, the blindage is used as a protection after very heavy rain and occasionally during the dry weather. The road metal required for patch work etc. is collected in stacks, on the berm, on one side of the road. Deep ruts, where they appear, should be filled with blindage so that the bullock carts leave these ruts and move on the remaining surface of the road. For better maintenance, dust palliatives may be used.



Pick-axe used in the hand-picking of road surface
FIG. 97

(*III*) *Bituminous roads:* The inside surface of the picked pot hole is cleaned of all dust and dirt and it is then coated with asphalt. After that, the small rectangular trench in the surfacing will be filled with the material of the same composition as that of the original surfacing. The material will be consolidated with hand rammer and finished, as is done in case of the original bituminous surfacing under question. It may be necessary to seal the surface of coarse textured surfacings. Also, cracks in bituminous concrete surfacing and sheet asphalt surfacing may have to be filled with asphaltic cement.

(*IV*) *Cement concrete roads:* If the pot hole is less than 2·5 cm (1″) deep, it will be filled with the material used for bituminous concrete or sheet asphalt road; if it is more than 2·5 cm (1″) deep, it will be cleaned of all dust and dirt, the inside surface will be moistened with water and it will be given a wash of cement grout. After that, the small trench of the pot hole will be filled with the material of the same

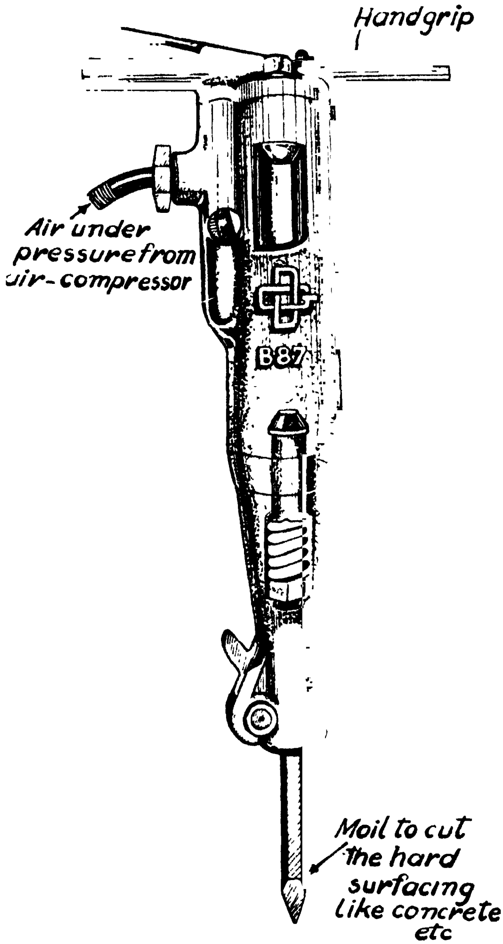


FIG. 98

composition as that of the original surfacing and the surface will be consolidated, finished with wooden float and cured as usual. Concrete joints require special care; they should be inspected periodically and racked out and, refilled with sealing compound of poured bitumen as and when necessary.

Hot bitumen is to be poured in the cracks when they develop on the surface.

(*V*) *Pavings:* In case of paving, the damaged units of the paving will be replaced by new ones.

Similarly the ruts and the worn-out patches, appearing on the road surface, should be repaired immediately.

For repairs, the picking of hard surface of all types of roads is done either by hand picking (fig. 97) or by scarifier tynes fixed to the road roller (fig. 33). The hard surface of concrete is usually broken by road drill (fig. 98) worked by pneumatic pressure supplied from a pneumatic machine.

5. **Road corrugations:** After a W.B.M. or bituminous surfacing is opened to traffic, it may develop waves on its surface; these waves are known as *road corrugations* (fig. 99). Road corrugations are thus wave-like deformations

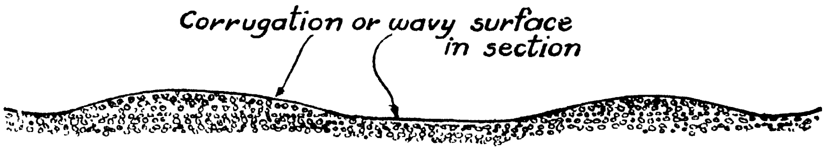


FIG. 99

on a road and, the crest and the bottom of these corrugations are transverse to the alignment of road. Road corrugations cause discomfort to the traffic and the road deteriorates as the corrugations go on developing more and more. These corrugations are due to the following causes:

(i) Weak and poor subgrade and its unequal settlement.

(ii) Defective construction.

(iii) Imperfect grading of coarse aggregate.

(iv) Use of too much binder like tar or asphalt.

If the subgrade is weak, it may settle unevenly and thus cause the corresponding uneven settlement of the road structure, resulting in corrugations on the surface.

If, during construction, a very heavy roller is used or the rolling is done with jerks or the consolidation of metal is bone in very thick layer, the surface shows corrugations when opened to the traffic. Also, the road surface should not be allowed to the traffic till it sets or becomes hard after its construction.

Similarly, the imperfect grading of coarse aggregate may cause an uneven displacement of stones in the surfacing and cause the corrugations under the load of traffic.

Too much binder, if used, will invariably result in corrugations under the load of traffic, specially when the road surface bleeds in very hot climate.

There are more chances of the corrugations appearing on rough road surface than on smooth one; thus, there are more chances of corrugations on W.B.M. surface than on bituminous surface. Surface corrugations also occur on gravel or stabilized earth roads, specially in dry weather, when the fast motor traffic goes over them.

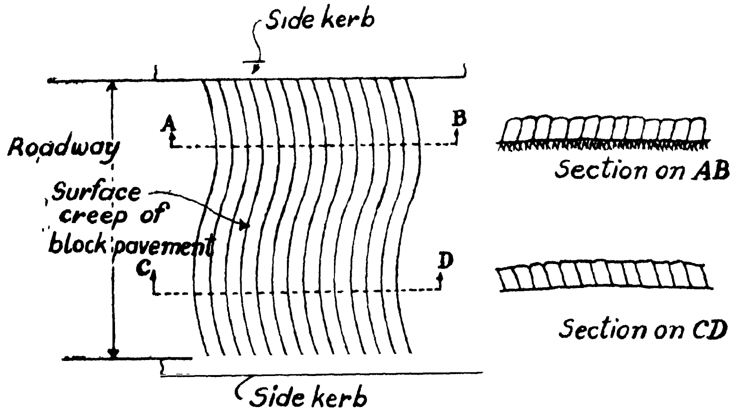


FIG. 100

Sometimes when the surfacing material (as in case of block paving) is loose, the individual units of paving move or creep under the force of traffic. Such a movement of paving is called the *creep* and is shown in fig. 100. Asphalt surfacing is sometimes liable to a slight creep in summer season.

PREPARATION OF ROAD PROJECT

1. Introductory: It is a well-known fact that whenever an engineering job of some magnitude is to be done, the engineer-in-charge always prepares a scheme or plan for executing that job successfully and economically. Thus, if a road is to be constructed, the road engineer will first prepare a scheme for that road; this scheme is called the *road project*. The preparation of a road project consists in:

(a) Doing the investigation work, including surveys on the field, along and round about the alignment of road. Data is collected for the safe and correct design of the roadway and its adjuncts.

(b) Doing the design work from the data so collected.

(c) Preparing the plans (i e. engineering drawings) of road works corresponding to the design.

(d) Preparing the estimates from the plans and, working out the probable cost of the project.

(e) Writing a brief report on the project.

After the project is sanctioned by a competent sanctioning authority, the construction work is started. For construction work (as a matter of fact, for constructing any engineering scheme) men, machinery and money are necessary.

2. Investigation of road project: A preliminary reconnaissance should first be made to determine:

(a) The generally best alignment.

(b) The ruling points such as the crossing of hill spurs and drainages, canals, etc. on which the value of road-gradient depends.

(c) The places from where the materials of construction can be had.

(d) The climatic conditions along the alignment of road.

(e) The amount and the character of traffic which is likely to use the road and, the periods when the traffic will be the heaviest and the lightest.
(f) Full details of roads, railways, canals etc. crossing the road alignment and round about the site of road.
(g) Any special requirements to be fulfilled by the proposed road.

After the alignment is roughly fixed, the detailed survey should be carried out. Longitudinal section and cross sections will be taken; also, the longitudinal section and cross sections of drainages, spurs and, the sections of side-long ground will be taken. The positions and the distances of quarries for getting the construction materials will be located and determined. The nature of soil and subsoil along the alignment of road will be noted. Trial pits at the cross drainage sites will be excavated to know the nature of foundation for the proposed bridges or culverts. The levels of the highest flood level and low water level of stream at the point of crossing with the road alignment shall be ascertained.

3. **Designs, plans, estimates and cost:** The designs, plans and estimates are prepared and the probable cost of the project is worked out. Plans will consist of the following:
(a) Index plan on scale of 1 cm = 0·5 km (i.e. about 1″ = 1 mile).
(b) Detailed plans on scales of 1 cm = 50 m (i.e. about 1″ = 400′) horizontally and, 1 cm = 5 m (i.e. about 1″ = 40′) vertically.
(c) Longitudinal section on scale of 1 cm = 20 m (i.e. about 1″ = 200′) and, cross sections of road on sacles of 1 cm = 10 m (i.e. about 1″ = 100′) horizontally and 1 cm = 1 m (i.e. about 1″ = 10′) vertically.
(d) Detailed soil surveys.
(e) Plans of all adjuncts like bridges, culverts, road-side trees, road junctions etc. Cross drainage works may be drawn on scale of 1 cm = 1 m (i.e. about 1″ = 8′).

Index plan should show the general topography of the road, important towns and the existing means of communication, canals, etc.

Detailed plans should show the horizontal alignment of road, road widths, contour lines, natural drainages etc.

Longitudinal section should show the ground levels, formation levels, longitudinal gradients, height of bank and depth of cut, drainage crossings etc. Cross sections should show the ground levels, formation levels, side drains, catch-water drains, land widths etc.

Estimates are prepared for the following items of work:

(a) Survey work.

(b) Earthwork, road structure and minor items coming within the road width.

(c) Cross drainage works like bridges and culverts.

(d) Road arboriculture.

(e) Land acquisition.

(f) Materials. labour and, the road plant and machinery required for construction.

The report should give the details regarding the following items:

(i) Early history of the road project; the topography and geological features of the site of road.

(ii) Possible future developments of the area round about the road.

(iii) Rainfall on the area and the high flood discharges of streams crossing the road alignment.

(iv) Details of the proposed alignment and the justification for its selection.

(v) Details of the design speeds, grades, cambers, curves, sight distances etc.

(vi) Formation widths and land widths.

(vii) Cross drainage works and other masonry structures; road surface drainage; subsurface drainage.

(viii) Miscellaneous minor works and the roadway adjuncts.

(ix) Traffic safety devices.

(x) Availability of materials, labour etc.

CHAPTER XVIII

ROAD SPECIFICATIONS AND ESTIMATES OF MATERIALS, LABOUR, ROAD PLANT AND MACHINERY

1. Introduction: Construction of every engineering job is done according to certain standards which are known as *specifications* for that job or work. While preparing a project, the detailed statement of particulars for carrying out the road-work are drawn by the road engineer; such detailed particulars are known as *road specifications* and are of special importance when the work is to be done by a contractor. Truly speaking, the specifications prepared in P.W.D. for any work are drawn in a careful, comprehensive and more or less legal language so that the contractor may not find any loop hole to play; as such, these specifications are usually bulky and full of verbosity and voluminous language. In this chapter, however, these specifications will be given in a *direct* language shorn of all verbosity. This is all that a student is expected to know, in general, regarding these road specifications. After giving brief specifications for each type of road, the material, labour and, plant and machinery required for the construction of such road are also given so that the student can prepare a rough estimate of the material, labour and machinery required for any type of road.

2. Specifications for C.C. road 15 cm (6″) thick laid in single layer:

(i) The cement used shall be of approved quality.

(ii) The required quantity of sand, according to the mix of concrete, shall be used and both the water and the sand used for preparing concrete shall be quite clean.

(iii) Steel reinforcement (if used) shall be free from oil-stains or rust and shall be placed in proper place with

3·75 to 5 cm ($1\frac{1}{2}''$ to 2″) clear cover of concrete. The reinforcement should not get displaced during the concreting operations.

(iv) On an already prepared firm subgrade, 5 to 7·5 cm (2″ to 3″) layer of sand shall be spread, rammed and wetted.

(v) All forms used shall be clean before use and shall be firmly fixed so as not to give way while doing the concreting operations. The forms shall be removed after a lapse of 24 hours, counted from the instant of depositing the concrete against them.

(vi) In case of hand-mixing, the required quantities of sand and coarse aggregate shall first be mixed dry, then the required quantity of cement will be added and all the ingredients will again be mixed dry. The required quantity of water will then be added and the mixture will be mixed thoroughly so that it may have the *required* consistency. In case of machine-mixing, coarse aggregate, sand and cement shall be put in *required* proportions into the concrete mixer and they will be mixed dry for a few seconds. Then the *required* quantity of water will be added and the mixing will be continued for about 1 minute.

(vii) After being mixed, the concrete will be placed on the prepared sand-bed as rapidly as possible.

(viii) The surface of the deposited concrete shall be tamped with hand tamper weighing 10·4 kg/m (7 lb per R.ft.) and having the tamping bottom about 7·5 cm (3″) wide; while finishing the surface, the camber of surface should be maintained.

(ix) Trueness of the tamped surface shall be checked with a straight edge and the defects in the surface, if any, will be rectified.

(x) Expansion and contraction joints will be provided as required.

(xi) As soon as the concrete sets, its surface shall be kept moist for about 14 - 21 days. After this period, the surface shall be cleaned of all dust and dirt.

(xii) The surface shall be opened to the traffic after the lapse of 28 days reckoned from the instant of the finishing of the surface.

The above is a *specimen* showing how the specifications are drawn. It may be noted that in the above specimen, phrases like 'approved quality', 'required quality', 'required consistency', 'required proportions', 'as required' etc. have been used. In the actual specifications drawn by officers in P.W.D., these phrases are also *clearly* defined so that there is absolutely no vagueness or ambiguity about the specifications. The above specimen is therefore in its most *general* form and gives a fairly good idea to the student as to what the specifications can be like. It may also be noted that the technique of road design and construction goes on changing rapidly from time to time and, more than that, the technique of construction changes from place to place according to the available materials, labour etc. and according to the different requirements of traffic. One cannot therefore say that a particular technique in road construction will have an all-India application, not to talk of the universal application. It is with this view that only the basic and general principles of specification-drawing have been given. This must be clearly borne in mind by the reader.

3. Materials, labour and machinery required for C.C. road:

Let us calculate the quantities of materials required for concrete road 1 mile long, 12′ wide and 6″ thick; the slab is laid in single layer and the mix of concrete is 1:2:4.

Cubic contents of *finished* c.c. slab $= 5280 \times 12 \times \frac{6}{12}$

$= 31680$ c.ft.

Cubic contents of *loose* concrete to be deposited on the road bed $= (5280 \times 12 \times \frac{6 \cdot 5}{12}) = 34320$ c.ft.

It is assumed that 6·5″ layer of *loose* concrete depgsited will give about 6″ *finished* layer after consalidation.

Now 100 c.ft. of loose 1:2:4 cement concrete can be had by mixing the following *approximate* quantities of the nigredients:

90 c.ft. of coarse aggregate.

45 c.ft. of *dry* sand.

22·5 c.ft. of cement i.e. $\frac{22 \cdot 5}{1 \cdot 2}$ or 18·75 bags of cement.

∴ Quantity of coarse aggregate required

$$= 34320 \times \frac{90}{100} = 30888 \text{ c.ft.}$$

Quantity of dry sand required $= 34320 \times \frac{45}{100}$

$= 15444$ c.ft.

Quantity of cement required $= 34320 \times \frac{22 \cdot 5}{100}$

$= 7722$ c.ft.

∴ Number of cement bags required

$$= \frac{\text{quantity of cement in c.ft.}}{1 \cdot 2}$$

$$\frac{7722}{1 \cdot 2}$$

$= 6435$, on the assumption that *one bag of cement contains 1·2 c.ft. of cement.*

If the sand used is *damp*, the *bulking* of sand shall have to be considered while working out the quantity of *damp* sand required. The increase in volume of sand due to water content is known as bulking. The average extent of bulking is 30% for fine sand and 20% for coarse sand. Let us say that we have to use damp sand of *bulking factor* 1·2 or a sand having 20% bulking. Then,

The quantity of such damp sand required

$= 15444 \times 1 \cdot 2 = 18533$ c.ft.

Water for mixing the concrete will be used at the rate of *about* 6 gallons per one bag of cement used.

Allowing 5% wastage, the quantities of aggregates required will be as under:

$$\text{Coarse aggregate} = 30888 \times \frac{100}{95} = 32514 \text{ c.ft.}$$

$$\text{Dry sand} = 15444 \times \frac{100}{95} = 16257 \text{ c.ft.}$$

We will also require premoulded joint filler, dowel bars etc.

The quantity of labour required to do a certain job also varies from place to place. However, on the average, about 15 - 20 coolie-days may be required for finishing 100 sq. feet of concrete road and for doing the following operations involved therein:

(a) Preparation of subgrade.
(b) Mixing and laying of concrete.
(c) Fixing and removing of side forms.
(d) Tamping and finishing of concrete.
(e) Fixing reinforcement if any.
(f) Finishing the joints.
(g) Curing of concrete etc.

Equipment required for construction will be,

(i) Side forms.
(ii) Tamping and finishing implements (or tools).
(iii) Jointing tool.
(iv) Danger lights and road barriers.
(v) Road roller.
(vi) Other petty equipment.

Exercise: Work out quantities of materials for concrete road 1 km long, 3·5 m wide and 15 cm thick.

4. Specifications for 2·5 cm (1″) thick sheet asphalt laid on 3·75 cm (1½″) binder layer:

(i) The foundation bed of concrete shall be clean and shall be brought to the proper camber and gradient.

(ii) Binder course shall be 3·75 cm (1½″) thick and shall consist of the coarse aggregate 6—24 mm (¼″ — 1″) size well graded and the sand of required grade; the quantities of these two ingredients will be in the ratio of 1:1. Asphalt of *required* penetration shall be heated to about 180°C (350°F) and shall be added to the mixer in which the sand and coarse aggregate have been already mixed at 180°C. Asphalt shall be required at the rate of 48 kg/m³ (3 lb/c.ft.) of coarse aggregate and 128 kg/m³ (8 lb/c.ft.) of fine aggregate used.

The hot mix of coarse aggregate, fine aggregate and asphalt shall be uniformly spread to the required depth over the clean foundation bed by means of hot rakes and between the side kerbs which must be constructed before spreading the mix. The surface of the deposited mix shall be compacted by 10 mt roller. Any humps and hollows occuring in the surface during the rolling operations shall be rectified.

(iii) The wearing course or sheet asphalt layer shall be 2·5 cm (1″) thick and shall consist of graded sand, asphalt and the filler like cement. Sand and asphalt, in required quantities, shall be mixed in an asphalt mixer at a temperature of about 180°C. Asphalt shall be used at the rate of 128 kg/m^3 (8 lb/c.ft.) of sand used plus 192 kg/m^3 (12 lb/c.ft) of filler used. Filler to the extent of 25% of the volume of sand used will then be added to the mixer and all the ingredients will be mixed again. The hot mix so formed shall be spread evenly by means of hot rakes over the top of binder course while the top of this binder course is still warm. The surface of wearing course shall be rolled slowly and uniformly with 10 mt roller till it becomes compact. All the irregularities, occuring in the surface during the operation of rolling, shall be made good.

5. Materials required for 1″ sheet asphalt road, 12′ wide and 1 mile long laid on $1\frac{1}{2}$″ binder layer:

(a) Materials for binder course $1\frac{1}{2}$″ thick:

$\frac{1}{4}$″-1″ size well graded stone

$$= 5280 \times 12 \times \frac{1 \cdot 75}{12}$$

$$= 9240 \text{ c.ft.}$$

$\frac{1}{200}$″ to $\frac{1}{10}$″ size well graded sand

$$= 5280 \times 12 \times \frac{1 \cdot 75}{12}$$

$$= 9240 \text{ c.ft.}$$

Asphalt of required penetration

$$= 3(9240) + 8(9240) = 101640 \text{ lb.}$$

Concrete kerbing $= 5280 \times 2 = 10560$ R.ft.

(b) Materials for wearing course 1″ thick:

Sand $= 5280 \times 12 \times \frac{1}{12} = 5280$ c.ft.

Cement used as filler $= (5280) \times 12 \times \frac{1}{12}) \times \frac{25}{100}$

$= 1320$ c.ft.

$= \frac{1320}{1 \cdot 2}$ or 1100 cement bags.

Asphalt of required penetration

$= 8(5280) + 12(1320)$

$= 58080$ lb.

Exercise: *Work out quantities of materials for 2·5 cm sheet asphalt road, 3·5 m wide and 1 km long laid on 3·75 cm binder layer.*

6. Specifications for asphalt concrete road 6·25 cm (2½″) thick:

(i) The foundation bed shall be brought to the proper camber and grade and shall be cleaned of dust and dirt.

(ii) The asphalt concrete layer shall consist of coarse aggregate of 6—30 mm (¼″ – 1¼″) size well graded, 0·12 to 3 mm ($\frac{1}{200}$″ to ⅛″) size clean and well graded sand and, the asphalt. The coarse aggregate and sand shall be heated to a temperature of about 180°C (350°F). They will then be put into a mixer in the proportion of 2:1 and shall be well mixed. Asphalt of required grade and penetration shall be heated to about 180°C and shall be added to the mixer in the required quantity which is at the rate of 48 kg of asphalt per m^3 (3 lb per c.ft.) of coarse aggregate and 128 kg of asphalt per m^3 (8 lb per c.ft.) of sand used. The mixing is continued so that the coarse aggregate and sand get coated with asphalt. The hot mix is then taken from mixer, is transported to the site of work and is spread on the clean foundation bed (by means of hot rakes) to the required thickness between the side kerbs already constructed. The surface of hot mix shall be compacted slowly by means of 8 mt roller; humps and hollows, that may occur in the surface during rolling operation, shall be rectified. The consolidated surface is opened to the traffic after it cools and hardens.

(iii) After some time, a sealing coat shall be applied over the previously laid layer as shown below:

The surface shall first be cleaned of all loose material and the hot asphalt shall be evenly laid over the surface at the rate of 1 kg/m^2 (20 lb/100 sq. feet) of the road surface. Immediately after, the dry clean chippings of 6 to 9 mm ($\frac{1}{4}''$ to $\frac{3}{8}''$) size shall be evenly spread over the surface at the rate of 1·2 to 1·8 m^3/100m^2 (4 to 6 c.ft./100 sq.ft.) of the surface and the chippings shall be rolled thoroughly.

(iv) The surface is opened to the traffic one day after the final rolling.

7. Materials, labour and equipment required for 1 mile long, 12′ wide and 2½″ thick asphalt concrete road:

(a) Materials for asphalt concrete layer:

Coarse aggregate of $\frac{1}{4}''$ to $1\frac{1}{4}''$ size, well graded $= 5280 \times 12 \times \frac{3}{12} = 15840$ c.ft.

Sand of $\frac{1}{200}''$ to $\frac{1}{8}''$ size, well graded

$$= (5280 \times 12 \times \frac{2{\cdot}75}{12}) \times \frac{1}{2} = 7260 \text{ c.ft.}$$

Asphalt of required penetration

$$= 3(15840) + 8(7260) = 105600 \text{ lb.}$$

Concrete kerbing $= 5280 \times 2 = 10560$ R.ft.

(b) Materials for sealing coat:

$\frac{1}{4}''$ to $\frac{3}{8}''$ size stone chipping

$$= (5280 \times 12 \times \frac{6}{100}) = 3802 \text{ c.ft.}$$

Asphalt of required grade and penetration

$$= (5280 \times 12 \times \frac{20}{100})$$

$$= 12672 \text{ lb.}$$

Labour is required for cleaning the surface, heating and mixing the ingredients, spreading and consolidating the hot mix, laying of seal coat, attending to road roller etc.

Equipment will be in the form of 10 mt road roller, road barriers, danger lights, rakes, caution boards etc.

Exercise: Work out quantities of materials for 1 km long, 3·5 m wide and 6·25 cm thick asphalt concrete road.

8. Specifications for 19 mm ($\frac{3}{4}''$) thick asphalt surface dressing, single coat (hot process):

(i) The wearing surface of W.B.M. road shall be brought to the proper grade and camber by necessary repairs.

(ii) The surface shall be cleaned of all dust and dirt and shall be kept dry.

(iii) Asphalt of the required grade and penetration shall be heated to about 180°C and shall be applied evenly in strips, parallel to the road alignment, either from a sprayer of from the hand cans; the rate of application will be 1·75 to 2·5 kg/m^2 (35 to 50 lb/100 sq.ft.) of the surface.

(iv) Immediately after this, the dry clean chippings of 12 to 18 mm ($\frac{1}{2}''$ to $\frac{3}{4}''$) size shall be evenly spread on the surface at the rate of 1·5 to 1·8 m^3/100 m^2 (5 to 6 c.ft. per 100 sq.ft.) of road surface and the surface shall be rolled by 6 to 8 mt roller; the irregularities, appearing on the surface during rolling, shall be made good.

(v) The road surface shall be opened to the traffic after a lapse of 24 hours, reckoned from the instant of final rolling.

9. Materials, labour and equipment required for $\frac{3}{4}''$ thick asphalt surface dressing (single coat) for 1 mile long and 12′ wide road (hot process):

$\frac{1}{2}''$ to $\frac{3}{4}''$ size stone chippings

$$= (5280 \times 12 \times \frac{6}{100}) = 3802 \text{ c.ft.}$$

Asphalt of required grade and penetration

$$= 5280 \times 12 \times \frac{40}{100} = 25344 \text{ lb.}$$

Labour will be required for reconditioning the old surface of W.B.M., cleaning it, heating and laying asphalt, spreading and rolling the chippings etc.

Equipment required will be pickaxe or scarifier for picking the surface, wire brushes and brooms for cleaning the surface, boilers for heating the asphalt, asphalt sprayer or the pouring hand cans, tandem roller etc.

Exercise: Work out quantities of materials for 19 mm thick asphalt surface drsssing (hot process) for 1 km long and 3·5 m wide road.

10. Specifications for 15 cm (6″) thick W.B.M. surfacing:

(i) The foundation, if any, shall be properly prepared to the required grade and camber.

(ii) The 1·5 m (5′) wide side-berms or shoulders of moorum shall be prepared to receive the road metal between them.

(iii) Road metal shall be uniformly laid over the prepared foundation bed to a thickness of 11·25 cm ($4\frac{1}{2}$″) and rolled *dry* to a 7·5 cm (3″) consolidated thickness. The usual care shall be taken in rolling and the surface shall be *slightly* sprinkled with water to help the interlocking of stone pieces.

(iv) Another 11·25 cm ($4\frac{1}{2}$″) layer of road metal shall be spread uniformly on the previous consolidated layer and this, in turn, shall be rolled *dry* to a thickness of 7·5 cm (3″). Water shall then be sprinkled over the surface and the rolling shall be continued to get the proper interlocking of stones of the top layer. During rolling, the camber and grade of the road shall be maintained.

(v) When the surface becomes very hard, *and not till then*, a thin 1·25 cm ($\frac{1}{2}$″) layer of bindage of approved material shall be evenly spread over the surface which shall be watered copiously and rolled so that the bindage seals the unevenness at the top of the surfacing and binds the stone pieces together. The final rolling should give a smooth, hard and impervious surface.

(vi) Next day, the surface shall be again rolled and covered with 6 mm ($\frac{1}{4}$″) thick blindage layer of coarse sand to prevent the wet bindage from sticking to the wheels of vehicular traffic.

(vii) After final consolidation, the surface shall be kept moist for a few days.

(viii) Surface shall be opened to the traffic after it sets and becomes hard.

11. Materials, labour and equipment required for 1 mile long, 12′ wide and 6″ thick W.B.M. road:

Coorse aggregate of 1″ size $= 5280 \times 12 \times \frac{9}{12}$
$= 4720$ c.ft.

Bindage $= (5280 \times 12 \times \frac{1}{2 \times 12}) = 2640$ c.ft.

Coarse sand $= (5280 \times 12 \times \frac{1}{4 \times 12}) = 1320$ c.ft.

Moorum for shoulders $= (5280 \times 5 \times \frac{9}{12}) = 19800$ c.ft.

Labour will be required for preparing the foundation bed, spreading and rolling the road metal, sprinkling the surface with water, spreading blindage etc.

Equipment required will be a 12 mt road roller, road signs and road barriers, danger lights, camber templates, strings and stakes, boning rods, 50′ tape, 10″ straight edge, equipment for spreading metal and sprinkling water, etc.

Exercise: Work out quantities of materials for 1 km long, 3·5 m wide and 15 cm thick W.B.M. road.

12. Thus, the specifications can be written for other types of roads also. The general principle to be kept in view while drawing these road specifications is that 'the specifications should be precise, clear, without ambiguity and unwanting even in the minor detail of the work to be done'.

ELEMENTS OF SMALL ROAD BRIDGES AND CULVERTS

1. Introduction: As already said in chapter IV, there are various types of cross drainage works across a road. Out of all these types, the small bridges and culverts are of *common* occurrence and many of the cross drainage works constructed across the road alignment belong to this category. Hence only this category of cross drainage works is dealt with here. The big-size bridges which are not of common occurrence are excluded from treatment in this chapter. In fact, as already pointed out in chapter IV, the detailed treatment of all types of bridges can be studied from the standard works on Bridge Engineering; however, as the cross drainage works form the important adjuncts of road, the description about the most common types of these adjuncts is given in this chapter.

2. Selection of the site for road bridges and culverts: Selection of site depends on the following factors:

(a) Nature of river banks and approaches.

(b) Width of river to be bridged.

(c) Depth of river at site.

(d) The road alignment should cross the stream at right angles as far as practicable. This is obligatory in case of big rivers only.

(e) Availability of good and safe foundation for bridge.

At the site, the bed and banks should be stable as far as possible; the width at site should be small to get less length of the bridge as this will be economical.

3. Data to be collected for the design of bridges and culverts: Following data should be collected:

(i) We should have an idea about the catchment area for a particular site of bridge or culvert. *Catchment area* for a particular site is that area from which the rain water (falling on that area) drains to that site; it is therefore also called the *drainage area.* This area starts from the site and lies entirely on the upstream side of the site. It is an area within the water-shed line or ridge line which starts from one bank of river at the site and ends at the other bank of the river. The rough idea of this area can be had from topo sheets for the land on the upstream side of the site.

(ii) The longitudinal section of the river or stream should be taken for a distance of about 300 m to 900 m (1000′ – 3000′) on each side of the site. Cross sections of the stream should be taken -- one at the site, other at 300 to 900 m on the upstream side and third at 300 m to 900 m on the downstream side of the site. Greater the catchment area, greater should be the distance that will be taken within the limits of 300 m to 900 m stated above.

(iii) The high flood level (i.e. H.F.L.) at the site should be investigated by an inquiry, from the people living near the site; H.F.L. is the level of water in the stream when high flood discharge (i.e. maximum possible dicharge) flows in the stream due to the intense rainfall on the catchment area.

(iv) A few trial pits should be excavated in river bed at the site so as to have an idea of the nature and thickness of the subsoil strata. This is necessary so that the foundation of bridge or culvert can be placed safely at the required depth below the river bed.

4. High flood discharge and its determination: The maximum rate at which the flood water flows at the site of a bridge or culvert is known as high flood discharge (i.e. H.F.Q.) at that site. It also represents the maximum rate of run off from the catchment area due to the highest intensity of rainfall on the catchment. The idea about H.F.Q. at the site of a bridge or culvert is *absolutely* necessary so that the sufficient number of vents or passages may be provided below the bridge or culvert for the H.F.Q. to pass through them *safely* and without causing damage to the bridge or culvert or the adjoining land or other property. Following are *some* of the methods for determining H.F.Q. at the site of a bridge or culvert:

(i) Dicken's flood formula:

$Q = CA^n$ c.ft./sec. where

Q = H.F.Q. in cusecs.

A = Catchment area in sq. miles and,

C and n are constants depending on the factors affecting the H.F.Q.; $n = \frac{3}{4}$.

C = 800 to 1600, more value being for hilly catchment. Also, for the same type of catchment, greater the rainfall on the catchment, greater the value of C. The value of C should therefore be ascertained for a particular catchment (under consideration) according to the nature of the catchment and the intensity of rainfall on it.

Note: 1 ft^3/sec = 0·0283 m^3/sec; 1 sq. mile = 2·59 km^2.

(ii) Ryves' flood formula:

$Q = CA^n$ c.ft./sec.

where Q, C, A and n have the usual significance; here $n = \frac{2}{3}$.

C = 450 to 673, with less value for flat catchment and more for hilly catchment. As in Dicken's formula, the value of C should first be ascertained for the catchment under consideration.

There are many other flood formulae given by other Indian engineers and by many foreign engineers but all the formulae give only a *general* (and not specific) idea about H.F.Q. and, that too, when the correct value of the constants (like the constant C in Dicken's and Ryves' formulae) involved are inserted in the formula. Only a few good and experienced engineers can hit upon the probable values of these constants after studying the hydrographic conditions regarding the site and the catchment area under consideration.

(iii) Rational flood formula: this is used for *small* catchment area less than 1200 acres.

Note: 1 acre = 0·4047 hectare; 1 hectare = 0·01 km^2.

It is already pointed out in Dicken's formula that the H.F.Q. depends on the nature of rainfall on catchment and on the characteristics of catchment. A *general* formula connecting the peak intensity of rainfall with the precipitation and the duration of precipitation is as follows:

$$i_1 = \frac{P}{T}\left(\frac{T+1}{t+1}\right) \text{ inches/hour} \quad \ldots\ldots\ldots\ldots\ldots \quad \text{(i)}$$

where i_1 = Intensity of rainfall in inches/hour.

P = Total precipitation or rainfall in inches, on the catchment, in T hours.

T = Duration, in hours, in which the *severest* or *peak* intensity rainfall of P inches occurs on the catchment. This severest shower is such that it occurs once in 35 years.

t = *Small* duration of time (less than T and within the duration T) during which the precipitation of intensity i_1 inches/hour occurs.

Note: 1 inch of rainfall/hour = 25 mm of rainfall per hour.

Now, if t be taken equal to one hour we shall have,

$$i_2 = \frac{P}{2}\left(1 + \frac{1}{T}\right) \text{ inches/hour} \quad \ldots\ldots\ldots\ldots \quad \text{(ii)}$$

This i_2 is known as '*one hour rainfall*' on the catchment. For designing small bridges and culverts in India, i_2 may be approximately taken as 4 to 5 inches/hour in case of catchment areas having the intense and prolonged rainfall; i_2 may be taken as 2 to 3 inches/hour for other catchment areas in India.

In the above treatment, the value of t has been approximately taken as one hour for convenience. Actually, t should be taken equal to the *concentration time* of the catchment area. The concentration time of catchment area is defined as the time (in hours) taken by the run-off from the farthest point on the outline of catchment area to reach the site of a bridge or culvert. This farthest point is known as the *critical point.* When t is put equal to the concentration time of catchment, we will have,

$$i_3 = \frac{P}{T}\left(\frac{T+1}{t_1+1}\right) \text{ inches/hour} \quad \ldots\ldots\ldots\ldots \quad \text{(iii)}$$

Here i_3 = maximum or critical intensity of rainfall in inches/hour; P and T have the usual significance and, t_1 = concentration time in hours. This t_1 can, in turn, be calculated from the following formula:

$$t_1 = \left(11{\cdot}9 \times \frac{L^3}{Y}\right)^{0{\cdot}385} \text{ hours}$$

where L = Distance, in miles, from the critical point to the site of a bridge or culvert.

Y = Difference, in feet, between the reduced levels of the critical point and the bridge or culvert site.

After finding i_3, H.F.Q. can be calculated from the formula:

$$\text{H.F.Q.} = \left(\frac{i_3}{12 \times 60 \times 60} \times A \times K\right) \text{ c.ft/sec}$$

where A = Area of catchment in sq. feet.

K = Run-off coefficient. Value of K depends on the characteristics of the catchment. Its value may be from 0·1 to 0·9, greater value being for hilly and good catchments giving more run-off.

(iv) Calculation of H.F.Q. from high flood level, longitudinal section and cross sections of a river:

(a) When H.F.Q. flows at a site, the level of water is called high flood level (i.e. H.F.L.). In case of a river with stable (i.e. unerodible) bed and banks, the H.F.L. is marked on the cross section of river at the site; then the area between H.F.L. and, the bed and sides of river below H.F.L. is worked out. This is called *waterway* when H.F.Q. flows at the site. *Waterway* is the area through which water flows. *Wetted border* below H.F.L. can be measured from the cross section. Bed slope can be found from the longitudinal section of the river. Then, Manning formula is used to calculate mean velocity of flow when H.F.Q. flows through the waterway at the site of bridge or culvert. Thus,

$$v = \frac{1{\cdot}49}{N}\, m^{2/3}\, i^{1/2} \text{ ft/sec}$$

where v = Mean velocity of high flood in ft/sec.

m = Hydraulic mean depth in feet

$$= \frac{\text{area of waterway } a \text{ in sq. feet}}{\text{wetted border } P \text{ in feet}}$$

$$= \frac{a}{P} \text{ feet.}$$

i = Hydraulic slope; it may *approximately* be taken equal to the bed slope which is calculated from the longitudinal section.

N = Rugosity coefficient; it depends on the material of bed and sides of the river at the bridge site. More rough the bed and sides, greater the value of N and vice versa. Values of N can be found from Volume I on Hydraulics by the author.

After finding v, H.F.Q. can be found from the formula:

$$\text{H.F.Q.} = (a \times v) \text{ c.ft/sec.}$$

$$= \left(a \times \frac{1\cdot49}{N} \times m^{2/3}\, i^{1/2}\right)$$

$$= K.\, i^{1/2} \text{ where } K \left(\text{i.e. } a \times \frac{1\cdot49}{N} \times m^{2/3}\right) \text{ is called}$$

the *conveyance factor* of the stream.

Note: In Metric system, Manning formula will be,

$v = \frac{1}{N} . m^{2/3} . i^{1/2}$ m/sec, where hydraulic mean depth m is in metres.

(b) In case of river with erodible bed and banks (as in alluvial area), for finding the waterway, the average scoured bed line likely to be existing during H.F.Q. should first be drawn on the cross section. Lacey's formula is usually used to find the depth of scour and to locate this scoured bed line. Lacey's regime equations govern the flow of water in alluvial rivers and these equations can be found in book on 'Irrigation Engineering' by the author. As they do not fall within the scope of this book, they are not given here.

5. Design of the lineal waterway of bridges and culverts:

(a) In case of rivers in non-alluvial and unerodible soil, the lineal waterway of a bridge or culvert may be taken equal to the width of water surface measured along H.F.L. *Lineal waterway* may be defined as the width of water (in cross section of river) which is obtained by dividing the area of waterway by the average depth of flow in the river. The clear distance between the end abutments of a bridge should be equal to the lineal waterway as calculated above.

(b) The effective lineal waterway between the end abutments of a bridge across a river in alluvial soil is found from Lacey's formula which is as under:

$P_w = 2{\cdot}67 Q^{1/2}$ feet

where P_w = The effective lineal waterway, in feet, under the bridge.

Q = H.F.Q., flowing at the bridge site.

6. Talbot formula for superficial waterway: For *small* cross drainage works, Talbot has given a formula which directly gives the area of waterway to be provided. Thus,

$a = C_1 A^{3/4}$ sq. feet, where

a = Area of waterway of the cross drainage in sq.ft.

A = Catchment area in acres.

C_1 = A coefficient which varies from 0·2 to 1·0, depending on the nature of soil and the slope of catchment, etc; $C_1 = 0{\cdot}2$, if catchment is a flat plain area; $C_1 = 1{\cdot}0$, if catchment has a steep rocky soil.

7. Depth of the foundation of piers and abutments: (see fig. 101). The end supports of a bridge superstructure (i.e. floor etc.) are known as abutments. One abutment is constructed near each bank or river. In case of wide rivers, the bridge superstructure will have some intermediate supports known as piers. The clear distance between two adjacent piers is called one span of the bridge. A bridge may have one span (fig. 102) and then there will be no piers but only two abutments; the width of this span will be the clear distance between the abutments. If there be n piers (fig. 101), the number of bridge spans will be $(n + 1)$; then, the clear lineal waterway P_w under the bridge will be $(n + 1) \times s$ feet where s is the width of each span in feet. The length of such bridge between the abutments will be equal to $\{(n + 1)s + t_1 n\}$ feet where t_1 is the thickness of each pier in feet. The rules for the depth of foundation etc. are as follows:

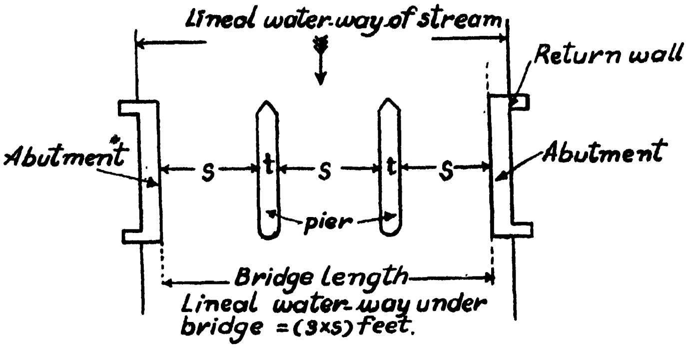
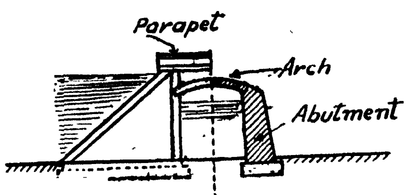


FIG. 101

(a) If hard and unerodible sub-stratum is available at river bed level or at a *little* distance below river bed, the foundations of piers and abutments should go into such stratum for a depth of about 1′ to 2′.



Cross section of one-span bridge, half in section and half in elevation.

FIG. 102

(b) (see fig. 103). If the stratum below river bed is soft and erodible and the thickness of this stratum is considerable, the bottom of the foundation of piers and abutments should be laid at the maximum possible depth (measured below H.F.L.) of scour which is equal to 1·34 times the maximum depth of scour (at the site) after the bridge is constructed. Maximum depth of scour is taken as 1·5 to 2 times the normal depth of scour. The latter is defined as the depth, below H.F.L., upto which the bed of river will get eroded when there is no bridge. The normal depth of scour is found from Lacey's formula given below:

$$R = 0{\cdot}473\left(\frac{Q}{f}\right)^{1/3} \text{ feet}$$

where R = Normal depth of scour, measured below H.F.L., on the downstream side of bridge i.e. below H.F.L at the site when no bridge existed.

Q = High flood discharge in cusecs.

f = A constant known as Lacey's *silt factor;* it depends on the nature, grade, charge and other attributes of the silt held in suspension by the river water.

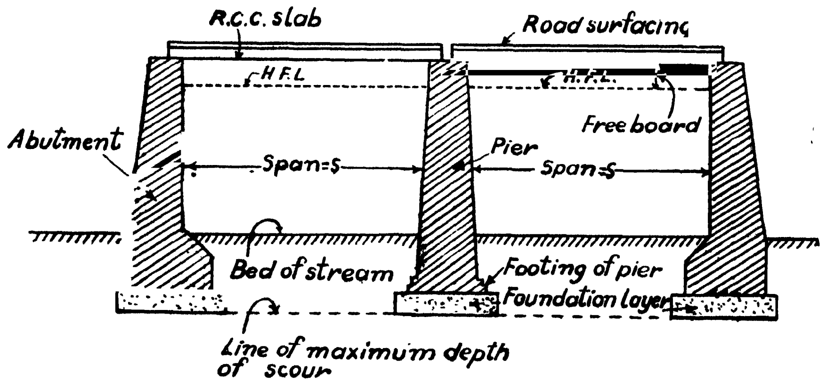


FIG. 103

It should be noted that the bottom of foundation should be *at least* 4′ to 6′ below the bed scour line corresponding to the normal depth of scour R when the usual rule mentioned in opening para of (b) above gives less than 4′ depth of foundation below the bed scour line.

8. Number of spans or openings to be provided for a bridge: The number of spans should be as small as possible because greater the number of spans, greater the number of piers and hence more the obstruction to the flow of water under the bridge. Superstructure of a bridge consists of floor etc. supported by piers and abutments. Substructure of a bridge consists of piers, abutments, wing walls and their foundations. As a rule, the most economical width s of span is that which gives the cost of superstructure equal to the cost of substructure. The number n of spans can be found from the relation,

$$n = \frac{\text{clear lineal waterway between abutments} + t_1}{(s + t_1)};$$

here t_1 is the thickness of each pier in feet and s is the economical width of span; s should be slightly altered from the economical width of span to get the whole number of spans.

For small bridges, the rule for finding the economic width of span need not be applied. In such cases, the following practice is adopted:

(a) For masonry arch bridges,

$$s = 2H$$

where H = Total height of pier including its foundation and, s has the usual significance.

(b) For R.C.C. slab bridges,

$$s = 1 \cdot 5H.$$

9. Allowance for vertical clearance: As the high flood water flows under the bridge, the underside of the superstructure should be some distance above the water level under the bridge. This distance is called *free board* or *vertical clearance* (fig. 103). It is necessary to allow the floating debris to pass through the bridge spans without striking against the underside of the bridge superstructure. The clearance for non-arch openings is kept at the rate shown in the following table:

H.F.Q., in cusecs, flowing at the site of bridge	Minimum vertical clearance required in feet
< 10	0·5
10 — 100	1·0
101 — 1000	2·0
1001 — 10000	3·0

For arched openings, the clearance below crown of the introdos of arch shall not be less than 1/10 of the maximum depth of water plus 1/3rd of the rise of the introdos of the arch.

10. Abutments, piers, wing walls, return walls etc. of bridges and culverts:

(a) Bridges without arches or, non-arch bridges (fig. 103):

The base width of abutments and piers should be sufficient so that the compressive stress caused on the foundation soil does not exceed the safe bearing capacity of the foundation soil.

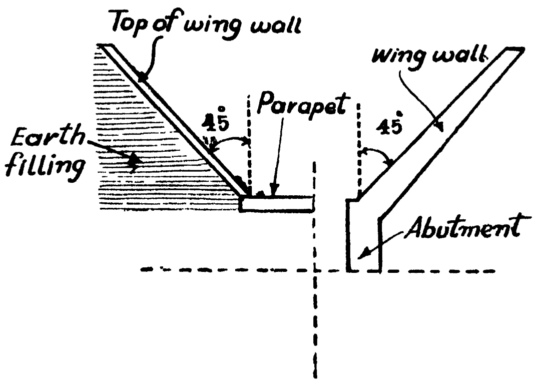
The thickness at the top of abutments and piers constructed of masonry in cement mortar may be found from the following table:

Clear span *s* in m	Thickness, in cm, at the top of abutment on which the bridge superstructure rests	Thickness, in cm, at the top of pier on which the bridge superstructure rests
3·0 (10′)	38 (15″)	46 (18″)
6·0 (20′)	46 (18″)	56 (22″)
9·0 (30′)	56 (22″)	66 (26″)
12·0 (40′)	66 (26″)	76 (30″)
15·0 (50′)	76 (30″)	89 (35″)

Note: Spans in Metric system may be 3 m, 4·5 m, 6 m, 7·5 m, 9 m, 10·5 m, 12 m, 13·5 m, 15 m, 16·5 m, 18 m and so on.

Base width of abutment may be about 0·67 of the height of abutment, the abutment having the necessary back batter. The pier thickness will be uniform throughout the height of pier. In case of high piers, a side batter of 1 in 12 may be provided on both sides of the thickness of piers.

Return walls or wing walls, as the case may be, are provided at the ends of abutments. A return wall (fig. 101) is a wall at each end of the abutment and goes in the river bank and at right angles to the abutments; it supports earth fill at its back. A wing wall (fig. 104) is also a wall at each end of the abutment but it goes into the river bank at a splay (usually 45°) to the length of the abutment. Wing wall, in addition to supporting the earth fill at its back, provides smooth entry and exit to the water passing through the bridge spans. Wing walls for slab drains and culverts upto 10′ span have water face vertical, a back batter of 1 in 4, and a top thickness of 15″. Wing walls for small bridges from 15′ to 30′ span have water face with batter of 1 in 12, back batter of 1 in 6 and the top thickness of 18″. The foundations of wing walls and return walls may be stepped if such a procedure ensures a substantial economy.



The plan at top and the plan at foundation of the abutment and wing wall.

FIG. 104

R.C.C. slab resting on the piers and abutments is designed as usual, considering the dead load and live load on it. The live load is the I.R.C. standard class *A* wheel load train. The slab is designed as freely supported with proper bearing on the supports (i.e. piers) on two sides of it. The allowable stresses etc. used in the design are: $c = 750$ lb/in², $t = 18000$ lb/in² and $m = 15$ where c, t and m have the usual significance. The necessary main reinforcement and distribution reinforcement are provided, keeping a proper cover of concrete over the reinforcement. Bond stress and shear stress are checked for small spans only upto 4 or 5 feet. For bigger spans, these stresses induced are usually within the safe limits for R.C.C. slabs and, as such, they need not be checked.

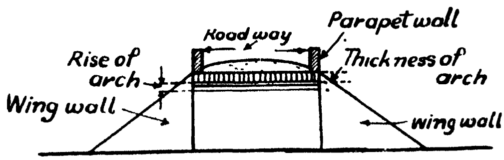
Note:- 1 kg/cm² = 14·22 lb/in².

(b) Small bridges with arches or, arch-bridges (fig. 105):

The live load will be as for slab bridges mentioned in (a) above. The arch may be segmental and its rise may be taken equal to $\frac{s}{4}$. Thickness t_2 of arch may be from 1′ to 3′, depending on span and the type of masonry; t_2 is less for good masonry and smaller spans. A rough rule for thickness t of arch ring is as follows:

$$t_2 = \frac{\sqrt{R_i + \frac{s}{2}}}{4} + 0{\cdot}2 \text{ feet}$$

where R_i = radius of introdos of the arch.



Cross section through arched bridge, showing wing walls in elevation and road in cross section
• FIG. 105

The cover over crown of the arch, upto the road level, may be from $1\frac{1}{2}'$ to $2\frac{1}{2}'$; greater the span, greater the cover to be provided.

Pier thickness t_1 may be taken as $\frac{1}{6}$ to $\frac{1}{8}$ of the span. As in case of slab bridges, the high piers may have a batter of 1 in 12 on both sides. In long arch-bridges, one pier in every 4 or 5 piers should be thicker than the other piers; such a pier is called the *abutment pier.*

The reduced level of each end of an arch is called the *springing level*; at this level, the arches rest on the piers and abutments. When the height of abutment or abutment-pier does not exceed $1\frac{1}{2}$ times its base width, the thickness T of the abutment or abutment-pier at the springing level is found from the following formula:

$$T = \left(\frac{R_i}{5} + \frac{\text{rise of arch}}{10} + 2\right) \text{ feet.}$$

The back batter of abutment in such case will be equal to 1 in $\left(\frac{24 \times \text{rise of arch}}{\text{span}}\right)$.

The wing walls or return walls are provided as for the slab bridges.

11. Roadway over a bridge or culvert: In case of culverts across a national highway, provincial highway or major district road, the roadway between parapets (provided over culverts) shall be equal to the formation width of the road minus the thickness of the two parapets; the roadway should be equal to 3·8 metres (about 12′).

In case of bridges across a national highway, provincial highway or major district road, the roadway over bridges should be equal to 7·5 m (about 22 feet) between wheel guards fixed on the inside of the parapets; in case of bridges across other district road or village road, the roadway should be equal to 3·8 m (about 12′) between the wheel guards.

12. Formulae to compute the discharge passing under a bridge or culvert:

(a) When the bridge or culvert openings do not run full i.e. when there is a vertical clearance, as is usual. Further,

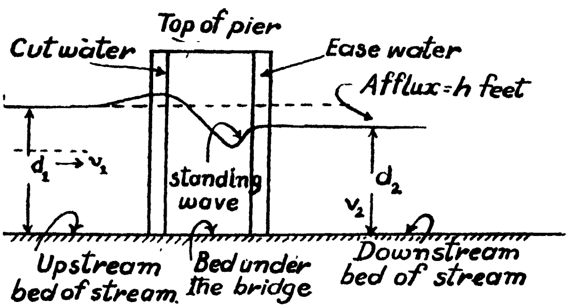


FIG. 106

(i) when the afflux h (fig. 106) at the bridge site is greater than $\frac{d_2}{4}$ we have,

$$Q = C_d \times 3{\cdot}09L\left(d_1 + \frac{v_1^2}{2g}\right)^{3/2} \text{ c.ft/sec}$$

where h = Afflux, in feet, caused at the bridge.

d_2 = Depth of water, in feet, on the downstream side of bridge

= depth of flow in river at the bridge site before the bridge is constructed.

Q = Discharge, in cusecs, passing through the bridge openings.

C_d = Coefficient of discharge for the bridge openings; its value is from 0·94 to 0·98; less value is used when a floor is provided on river bed between the piers and abutments.

L = Lineal waterway, in feet, of the bridge openings

= No. of spans × width of each span, if the end contractions are neglected

= $n \times s$.

When end contractions are considered, L should denote the effective lineal waterway, under the bridge, through which water *actually* passes. It shall be less than $(n \times s)$ feet.

d_1 = Depth of water on the upstream side of bridge after the bridge is constructed. Due to afflux, it is greater than d_2.

v_1 = Mean velocity of flow, in ft/sec., where the depth of flow is d_2 feet.

Afflux is defined as the heading-up of water on the upstream side of a bridge due to the obstruction caused by the bridge piers and due to the passing of water through the bridge with effective or artificial lineal waterway less than the natural width of stream immediately on upstream side of the bridge. Afflux is equal to the difference of water levels on the upstream and downstream sides of bridge after the bridge is constructed. The above formula for discharge is similar to the formula for broad-crested weir with free discharge and holds good on the assumption that a standing wave or hydraulic jump forms while the water passes through the bridge openings.

(ii) when $h < \frac{d_2}{4}$ and hence no standing wave forms (fig. 107): This condition is more often prevalent than condition no. (1) above.

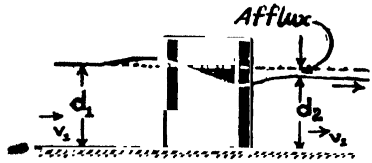


FIG. 107

In such case,

$$Q = C_d\, L\, d_2 \sqrt{2g} \left\{ h + (1 + e) \cdot \frac{v_1^2}{2g} \right\}^{1/2} \text{ c.ft/sec}$$

where Q, C_d, L, d_2, h and v_1 have the usual significance and e is a constant depending on the ratio of artificial lineal waterway under the bridge and the natural width of stream immediately on the upstream side of the bridge; $e = 0$ when this ratio is unity; $e = 1$ when this ratio is about 0·5; thus e increases when the lineal waterway provided under the bridge becomes less as compared to the width of stream on the immediate upstream side of the bridge.

C_d = 0·90 to 0·96; value of C_d decreases as the above-said ratio decreases and vice versa.

(iii) when $h = \frac{d_2}{4}$:

In such case, Q may be worked out by both the formulae given in a(*i*) and a(*ii*) above and the *safer* value should be adopted.

(b) Small culverts across wide and shallow rivers in alluvial soil:

In case of above-said small culverts, the culvert openings usually run full. The water level on upstream side is always above the top of the opening of culvert; thus, the inlets of culvert remain submerged under water. The outlets of culvert-barrels may be submerged (fig. 108) or, they may discharge partly freely into atmosphere (fig. 109). When the outlets remain submerged, the head H operating across the culvert will be equal to the difference of water levels on the upstream and downstream sides of the culvert. When the

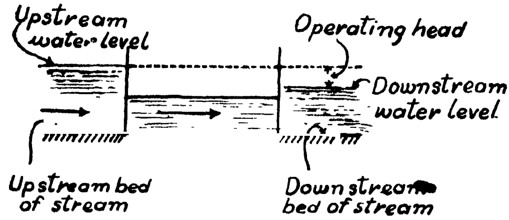


FIG. 108

culvert outlets discharge freely i.e. when the downstream water level is below the crown of culvert outlets, the operating head will be equal to the water level on upstream side minus the level of top or crown of the outlets. In both the cases,

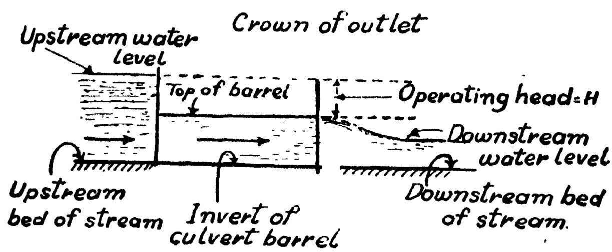


FIG. 109

$$H = \left(h_i + h_f + \frac{v^2}{2g}\right) \text{ feet}$$

where H = Operating head in feet.

h_i = Loss of head at inlet

$= 0{\cdot}05 \dfrac{v^2}{2g}$ when the inlet is bell-mouthed

$= 0{\cdot}5 \dfrac{v^2}{2g}$ when the inlet has a sharp entry.

h_f = Loss of head due to friction as water passes through the barrel of culvert

$= \left\{ \frac{f\,l}{m} \times \frac{v^2}{2g} \right\}$, in which l is the length of each barrel in feet, m is hydraulic mean depth of the cross section (circular, rectangular etc.) of barrel, v is the mean velocity of flow through barrel and, f is the coefficient of friction which depends on the material of which the barrel is made. More rough the inside surface of barrel, greater the value of f.

Note: h_f may also be found from the equation,

$h_f = \frac{v^2 N^2 l}{2{\cdot}2(m)^{4/3}}$ feet; here l and m have the usual significance and N is the rugosity coefficient depending on the character of the inside surface of barrel in contact with water.

The values of f and N for different materials can be found from tables which are usually given in books on Hydraulics. For the significance of various notations used in the hydraulic formulae for bridges and culverts, the reader may refer the author's 'Fundamental Hydraulics Vol. I.'

From the above equation for H, the velocity v can be calculated. Then the discharge Q passing through the culvert barrels will be,

$Q = x\ (A \times v)$ cusecs

where A = Cross section area of each barrel, in sq. feet.

x = Number of barrels of the culvert.

13. Formulae for determining afflux: The amount of afflux caused at a bridge-site has a great importance. Greater the afflux, (i) more the velocity through bridge spans, causing the likely scour of the downstream river bed (ii) higher the roadway to be provided (iii) higher the top of the flood banks, if provided to confine the water on the upstream side of the bridge (iv) more the land that is likely to be submerged due to the higher upstream water level caused by the afflux. Also, as said in article 12 above, the idea about the likely afflux is necessary to find out the discharge passing under the bridge. Following are some of the *approximate* formulae for calculating the afflux:

(a) $h = \left(\frac{v_2^2}{58 \cdot 6} + 0 \cdot 05\right)\left\{\left(\frac{a_2}{a}\right)^2 - 1\right\}$ feet

where h = Afflux in feet.

v_2 = Normal velocity of water on the downstream side of bridge, or velocity before the bridge was constructed.

a_2 = Natural waterway of river, immediately on the downstream side of the bridge, or waterway before the bridge was constructed.

a = Area of artificial waterway provided *under* the bridge.

(b) $h = \frac{v_1^2}{2g}\left\{\left(\frac{a_2}{C_d \times a}\right)^2 - \left(\frac{a_2}{a_1}\right)\right\}$ feet

where v_1 = Mean velocity immediately on the upstream side of the bridge i.e. velocity of approach. It is slightly less than v_2 but approximately equal to v_2 if the obstruction of waterway is not much.

a_1 = Area of waterway immediately on the upstream side of bridge; a_1 is evidently greater than a_2.

C_d = Coefficient of discharge

$$\simeq 0 \cdot 75 + 0 \cdot 35\left(\frac{a}{a_2}\right) - 0 \cdot 1\left(\frac{a}{a_2}\right)^2$$

and, a_2 and a have the usual significance.

Note: Various hydraulic formulae have been used in this chapter. For these formulae in metric system, students may refer 'Hydraulics Vol. I' 3rd edition by the Author.

CHAPTER XX

ELEMENTS OF ROAD ECONOMICS

1. General: What a qualified engineer does, a trained man with a little common sense may as well be able to do but the only difference between the two is that a qualified engineer *should* be able to execute his scheme most economically, consistent with the maximum utility accruing from the scheme. In fact the *engineering economy* is defined as 'getting the most, in the long run, for the money spent on an engineering job or scheme'. The principles of *road economics* will help a road engineer to spend the public funds on road construction or improvement in such a way as will serve the purpose properly and will ensure the lowest possible cost. For this purpose, various alternatives for the *entire* road scheme are to be compared and the best alternative, consistent with the maximum possible economy, is to be selected.

2. Principles of road economics: These principles will be treated under the following heads:

(a) The cost of road transportation which, in turn, consists of:

(i) Road costs.

(ii) Vehicle costs.

(b) Benefits and utility, resulting from the road construction or improvement This consists of:

(i) Benefits to traffic.

(ii) Benefits to property adjacent to the road.

(iii) Benefits to general public.

3. Costs of road transportation: The road costs and vehicle costs are expressed on annual basis. *Road costs* for a road are defined as the annual costs due to construction, maintenance and operation of that road. *Vehicle costs* on.

a road are defined as the annual costs due to ownership and operation of vehicles, in a year, on that road. Sum of these two costs determines the yearly costs of road transportation for that road. Maximum economy is obtained when this sum is a minimum, consistent with the convenience and safety of the traffic using that road. Annual road costs can be worked out from the relation,

Annual road costs = Annual interest on the capital investment at the prevailing rate of interest
+ Road depreciation, in a year
+ Cost of the road maintenance, in a year
+ Yearly cost of the administration and the operation of road.

The initial amount spent for constructing a road and all its adjuncts is called the *capital investment.* If this amount had not been spent, it would have fetched some interest every year; this interest therefore forms, indirectly, a part of the annual road costs.

As after construction the road comes in use, its value goes on decreasing every year; this decrease in its value is called the *yearly depreciation.* After a certain number of years of service, the road will lose its utility as a road for traffic; at the end of this period (in years) the road, after undergoing yearly depreciation in its value for these years, will have certain remnant value known as its *salvage value.*

As already said in the chapter on maintenance, the road in use has to be looked after properly. Maintenance consists of the frequent minor repairs during the economic life of the road; it also consists of the major repairs after a number of years when the road proves unserviceable and is said to have retired at the end of its economic life. Both types of maintenance are necessary to maintain the road at an appreciable level of safe and efficient utility. The cost due to the minor and major maintenances is worked out per year.

For the administration of road, some personnel is necessary; also for the proper operation, policemen etc. are engaged. The annual cost due to the administration and the operation is worked out.

All these annual costs are added to get the annual road costs.

Vehicle costs are due to the annual costs of owning and operating a vehicle. These annual costs consist of:

(i) Annual interest on the investment.

(ii) Annual depreciation value.

(iii) Annual maintenance cost due to the repairs and the upkeep of vehicle including the major overhauls.

(iv) Annual operation charges due to the cost of supervision, operator's wages if any etc.

(v) Annual licence fees, taxes, insurance charges, storage charges etc.

In case of vehicles, the annual costs are transformed into one of the units viz. vehicle-mile and ton-mile. The former unit is used for the passenger vehicles and the latter unit is used for the commercial vehicles or trucks. In Metric system, these units will be vehicle-kilometre and tonne-kilometre.

4. Benefits resulting from road construction or improvement: Some traffic benefits are those which are enjoyed by the owner or operator of vehicle. These benefits consist of:

(i) Reduction in the operation costs of vehicle due to (a) less distance to be covered by vehicle (b) flatter longitudinal gradient of road and (c) improved type of road surfacing.

(ii) Saving in time due to the road facilities provided.

(iii) Reduction in accidents and the consequent reduction in the loss of life and property.

Due to the construction of road, the value of land and property in the vicinity of road increases. This is a benefit to the owner of that land or property.

Many benefits are enjoyed by the general public using the road. These benefits are:

(i) Better fire protection in case of fires and, police protection in case of disturbed conditions.

(ii) Rapid postal delivery.

(iii) Rapid access to the education, recreation and social centres.

(iv) Less cost of the commodities due to the efficient transport.

(v) Better national defence in the time of war.

5. **The tail-piece:** For construction or improvement of any road, the principles of road economics require that '*the highest possible ratio of the utility to the cost should be secured by a road engineer*'.

CHAPTER XXI

ELEMENTS OF AIRPORT ENGINEERING

1. Introduction: Man has always been a discontented and inquisitive creature but these are the very attributes which serve as impelling forces for him to show more development and progress in various spheres of existence. It is no wonder therefore that this day, airports and airport engineering have come into sufficient prominence. Railways and roads are essential for the development of any country but in the modern world when the people are more time-conscious, air transport — the fastest of all the transport systems of our times — plays a vital role in the life of a nation.

The design, layout and construction of airports are generally carried out by a road engineer and hence the basic principles of airport engineering are given in this chapter.

2. Some definitions: In this article, are given definitions of a few terms which are of common use in airport engineering.

(a) *Airfield:* An aerodrome, other than an airport, is called an airfield. Landing strip forms a part of an airfield.

(b) *Land aerodrome:* It is a defined area on land (including any buildings and installations) which is normally used for the take-off and landing of aircraft.

(c) *Airport:* It is an aerodrome at which the facilities available to the public are provided for shelter, servicing or repair of aircraft and, for receiving or discharging the passengers or cargo.

(d) *Landing area:* It is the part of the movement area which is *primarily* intended for landing or take-off of the aircraft. It may or may not be provided with facilities for shelter, servicing, etc.

(e) *Runway:* It is a hard-surfaced straight path (within a landing strip) which is normally used for the take-off and landing of aircraft.

(f) *Terminal area:* It is the entire portion of airport except that occupied by the landing area.

(g) *Taxiway:* It is a defined path on an aerodrome for the use of taxiing aircraft. It is a prepared strip over which an aircraft may taxy to and from the runway and the apron.

(h) *Aircraft:* It is a general term and includes glider, aeroplane, helicopter, rocket, etc. It may be lighter or heavier than air.

3. The modern airport: The modern large airport is indeed a city in itself, having all the amenities of life and having the normal transactions as carried out in a city. Such airport is laid out over a vast area in acres and has a fairly great population on it. An airport may be a civil or military airport. The complete description of an airport should ordinarily include the description of all the elements forming the city-like airport. As this is beyond the scope of this book, only the following elements of an airport will be briefly treated in this chapter.

(a) Location, size and layout of airport.

(b) Runways — their lengths, patterns etc.

(c) Airport drainage.

(d) Airport pavements.

(e) Marking and lighting of airport.

4. Location and layout of airport: The following considerations are generally kept in view while fixing the site of an airport:

(i) Aeronautical (ii) Geographic (iii) Political (iv) Military (v) Constructional and future development (vi) Economic (vii) Accessibility to the public of area served by the airport, to minimize the time required by passengers to reach the airport.

In particular, the air space within a 2-mile (about 3 km) radius of the site should not be limited by natural or irremovable man-made obstructions which may prove hazardous to aircraft in flight. Also, the site should not be subject to weather or industrial conditions, thus limiting the operations because of poor visibility due to fog, smoke etc. Flat areas requiring excessive drainage and hilly land requiring a large amount of grading are less desirable than free-draining and moderately rolling terrain.

The size and location of airport are closely inter-related. The size is largely determined by economic factors which establish the need for a definite type of air service; this air service, in turn, fixes the types of aircraft which will use the airport. Each type of aircraft requires certain minimum landing area and other facilities.

After the site selection, a master plan lay-out is prepared showing the relative location of runways, taxiways, aprons, hangars, terminal buildings, access roadways, parking areas and other airport facilities.

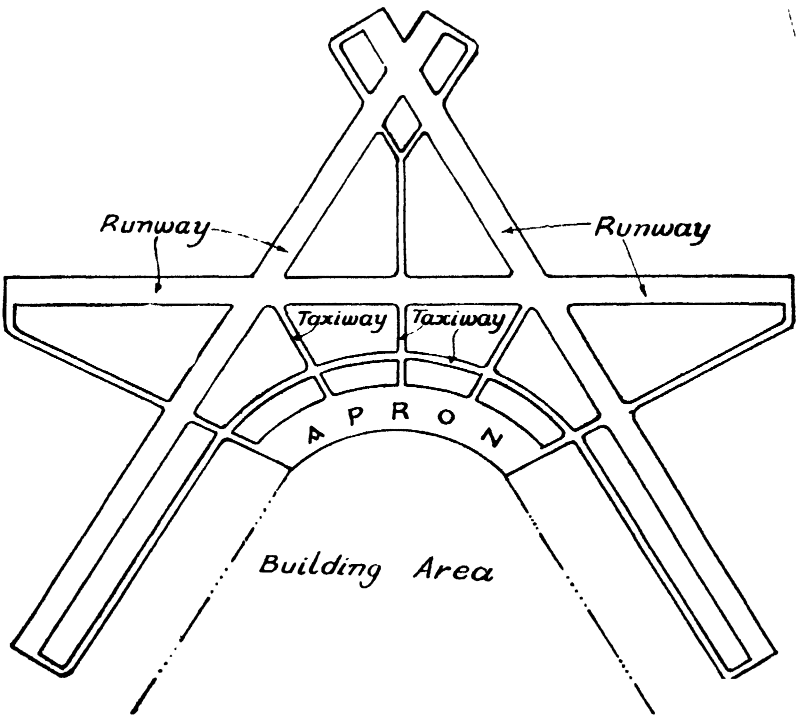
In the lay-out of an airport, we have generally to consider the following *main* items:

(i) Intensity of traffic and number of runways (ii) Orientation of runways (iii) Runway patterns (iv) Loading bays (v) Lay-out of taxiways, buildings, etc.

In particular, a large airport should be laid out, as far as possible, in such a manner as to reduce the amount of aircraft taxiing to a minimum. Taxiways must be provided to permit the speedy clearing of the runway and give direct access to the loading apron. The building area should contain sufficient space for the handling of passengers, freight and mail; it should provide for the needs and comforts of travellers; it should include the facilities for the servicing and repairing of aircraft; finally it should provide facilities for surface transportation.

Where an airport is to be adjacent to a road or a railway, it is necessary to provide adequate clearances to permit the landing and take-off of aircraft without interference from the traffic of road or railway.

The airports are classified according to the type of service and this classification varies from country to country. In India, they are classified as minor airports, intermediate airports, major airports and international airports. In India, at present, their number is 38, 33, 8 and 3 respectively; some of these are shown in fig. 109(A). In India, the air services were nationalized in 1953 to ensure their planned development and, to this end, two corporations were set up — The Indian Air Lines Corporation for internal services and The Air India International for foreign services. The Second Five Year Plan provided Rs. 30·5 crores for the development of air services in India. In Third Five Year Plan, provision was made of 75 crores of rupees for civil aviation, broadcasting and tourism.



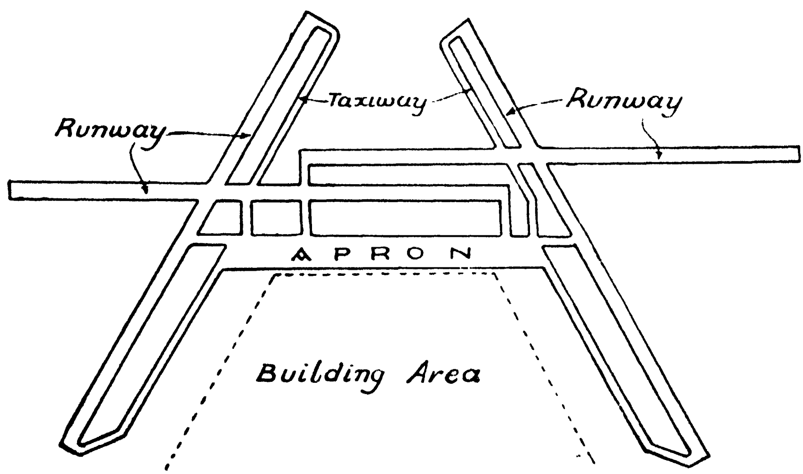
Layout of airport showing runways, taxiways, aprons etc.
FIG. 110

Intensity of traffic: In good weather, thirty movements per hour can be reasonably achieved on a single runway and about sixty movements per hour on adequately spaced dual runways. If more movements are required, more runways can be arranged in different patterns.

Orientation or layout of runways: This depends on the type and intensity of traffic and on meteorological conditions. The number and direction of runways are largely dependent on the direction and speed of prevailing winds and the physical limitations of the site. The landing and take-off are done in a direction opposite to the direction of wind. Small aeroplanes having light wing loads are much more sensitive to cross winds than are the large commercial aircrafts which are capable of negotiating a landing or take-off even though the cross component of the wind be large. Cross component of any wind is equal to wind velocity multiplied by the sine of angle between wind direction and the centre line of runway. Enough runways, which are properly oriented into the prevailing winds, should be provided to permit aircrafts to be operated with the cross component of the wind as 24 kilometres per hour. To determine the necessary orientation of runways, records of wind directions and velocities should be obtained for as long a period as possible. The analysis of winds generally results in a three-directional or four-directional layout. With certain assumptions, a two-directional or even one-directional layout may result and a very satisfactory operation is sometimes achieved in this way, particularly when there is a steady prevailing wind.

Runway pattern: The simplest runway layout consists of a single strip. This may be modified to the shape of an L, V, X or T to provide two runways which will allow greater use with respect to wind direction. From any of these basic shapes, a variety of additional modifications can be made to increase the capacity and also the use with respect to wind direction. The A-type pattern shown in fig. 110 is a good example of runway layout which reduces the amount of aircraft taxiing to minimum and provides for a maximum of 40 aeroplane operations or movements (i.e. landings and take-offs) per hour. Airports having higher intensity of traffic require parallel or non-intersecting runways permitting the simultaneous landings and take-offs as shown in figure 111. In a multi-runway layout, the main runway is set in the direction of the most frequent winds of moderate and greater force and subsidiary runways are laid in the direction which yields for the whole system the required maximum cross wind component and percentage visibility.

Loading bays in aprons: In civil aerodromes, a long-haul aircraft takes an average of 40 minutes for departure or transit (including refuelling). Aircraft, requiring longer time than this, would normally be removed from loading bay to the parking area or hangar area for storage and repairs. The average width of loading bay is kept about 45 m (150 feet). The size and shape of the apron depends on the number of aircraft stands and the temporary parking system to be adopted. The number of aircraft stands depends on traffic intensity and the size of the stands is determined from the consideration of the size and turning circle of the aircraft, allowing a nominal clearance of 7·5 m (25′) between adjacent aircrafts and between aircraft and terminal building. Three types of parking systems may be adopted: (i) Immediately adjacent to the terminal building (ii) Finger system according to which the stands are adjacent to a pier, tunnel or fenced passenger walkway. (iii) Open apron system.



Layout of airport showing runways, taxiways, apron etc.
FIG. 111

Layout of taxiways, buildings etc: Taxiways, which link runways with parking apron, should be located at various points along the runway to permit the landing aircraft to turn off the runways as quickly as possible so as to clear it for other aircraft. According to present practice, both ends and the two-third points of runways are usually connected with the adjoining parallel taxiways. Distance between the centre lines of taxiways may be from 38 m to 100 m (125′ to 325′) and that between the centre line of taxiway and any fixed obstruction may be from 24 m to 55 m (80′ to 180′). Width of taxiways may be from 12 m to 30 m (40′ to 100′). Airport buildings should be located and planned with respect to runways and taxiways so that a rapid exchange will be achieved between air and ground transportations. Building area provides for the transition of persons and luggage between ground and air services. This area includes access roads, walkways, loading aprons and various buildings like administration (or terminal) building, maintenance building, etc. The location of administration building in the building area is important because this building is the centre of airport activity. All managerial, operational and service functions are performed in this building. It serves as processing centre for passengers and luggage between ground and air services; it also provides facilities for the comfort and convenience of passengers.

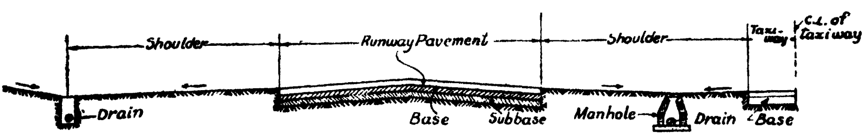
Apron is the area of transition between the landing field and the administration building. It is used for loading, unloading, temporary parking and servicing of aircraft. Minimum apron depth is kept as 90 m (300′). Length of apron will be determined by the amount of traffic. Facilities for servicing and fuelling of aircraft are generally provided at one end of the apron. Layover parking areas may be provided close to the aprons so that aircraft can be moved to this area, from gate position, during extended layover. Hangars, warehouses, buildings for airport maintenance are also constructed in building area. Hangars may be for repairs and maintenance or, for storage. The buildings should be near the centre of gravity of runways for minimum taxi distances; however, where there is a prevailing wind, it may be desirable to site the buildings near the up-wind end of the main runway.

5. Runway lengths and other design standards: The runway length depends on the type of service and, to some extent, on elevation of the site above sea level, on temperature at site and on runway gradient. Runway length may be from 910 m to 2560 m (3000′ to 8400′) according to the type of service or the classification of aerodrome. Width of runway may be from 30 m to 60 m (100′ to 200′). The longitudinal gradient of runway may be about 1% to 1·5%. For safety during take-off and landing operations, abrupt gradient-changes (at summits and valleys) on runways should be avoided. Transverse slope of runway should be just sufficient to prevent the accumulation of rain water on the surface but it should not exceed 1·5%.

The length of landing strip should be greater than the length of runway by 60 m (200′) on each end of the runway. The width of landing strip may be from 90 m to 150 m (300′ to 500′).

The distance between centre lines of parallel runways may be from 150 m to 210 m (500′ to 700′). The distance between centre lines of runway and taxiway may also be from 150 m to 210 m. Theminimum clearance between the centre line of runway and any building line varies from 45 m to 200 m (150′ to 650′) for different types of airports.

6. Airport drainage: It is desirable to provide separate drainage systems for the following (see fig. 112):



Cross section of landing strip showing runway, surface drainage, turfed shoulders, etc.

FIG. 112

(i) Surface water from the runway.
(ii) Surface water from the grass margins.
(iii) Subsoil drainage under runways, taxiways and aprons where necessary.

The entire grading (in longitudinal and transverse directions) and drainage design of the airport should be directed towards efficient disposal of surface and sub-surface water.

Surface water from the runways is usually collected at the edge of runway either in shallow channels formed in the surface and provided with gullies at 90 m (300′) c/c or, it is collected at the edge in deeper channels covered with continuous metal gratings or having a continuous narrow slit. These are tapped off at intervals by outlet drains going away at right angles to the edge of the runway. The outlet drains have silt traps at their heads and they tail into the closed drains (usually of earthenware or concrete pipes) which are led to a suitable outfall. Elevated site of airport ensures adequate surface drainage.

The sub-surface drainage is effected as in the case of roads.

7. Airport pavements: The general principles and methods for the design of road surfacings are applicable to the design of airport surfacings used on runways, taxiways, parking aprons etc. In addition, the particular requirements of airport surfacings are the following:

(i) The surface of pavement of runways should be fairly smooth and hence, where a seal coat is used in case of certain bituminous surfacings, the coarse aggregate of the seal coat should be finer and of size not more than 6 mm ($\frac{1}{4}''$).

(ii) To resist abrasive and dynamic action properly, the surface of pavement at the parking aprons and at the ends of runway lengths should be more hard, thick and stable. Such thicker runway-ends may be 10% of the length of runway.

(iii) The surfacing of runways and parking aprons should be such as can resist the action of gasoline and oil droppings on it.

The pavements may be rigid pavements of concrete or the flexible pavements of bitumen. The rigid pavement may have a sub-base of lean mix (12:1) of concrete. The concrete slab may be of uniform thickness, with or without reinforcement. Transverse expansion joints 2·5 cm (1″)

thick, with dowel bars, may be kept at 36 m (120′) c/c, with a top seal of 3·75 cm (1½″). Transverse dummy joints, between expansion joints, may be at 4·5 m to 6 m (15′-20′) c/c. The longitudinal construction joints (with tie bars) may be at 3·6 m to 4·5 m (12′ to 15′) c/c, with a seal of 3·75 cm (1½″) at the top. Longitudinal expansion joints are not necessary when the width of pavement is less than 60 m (200′). The flexible pavement may consist of a bituminous surfacing on a granular or other suitable base. The thickness of flexible pavement may be a little more than that of rigid pavement. To determine the pavement thickness, it is necessary to know (i) the maximum static load of aircraft (ii) properties of sub-soil below pavement and (iii) the facility for drainage. Minimum thickness of concrete pavement shall be 15 cm (6″). The gradings of aggregates suitable for bituminous roads prove usually too open-textured for bituminous runways and this fact must be kept in view while designing a flexible pavement. On the whole, a rigid pavement is preferred to a flexible pavement.

Note: Turf is used on airports as a wearing surface for traffic areas to control the dust and soil erosion and to improve the appearance of airports, specially that of the ground around buildings, drives and parking areas.

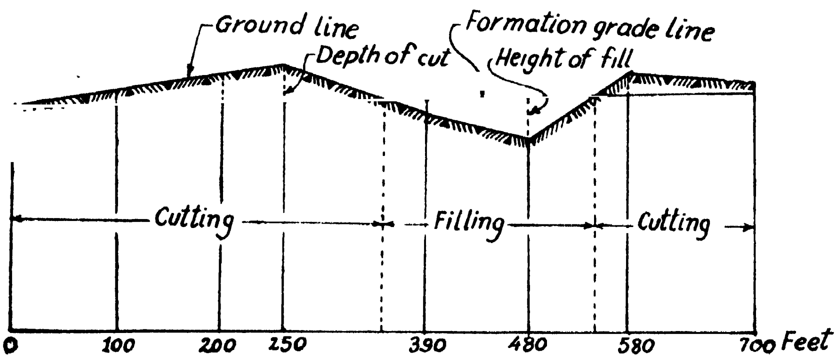
8. Airport marking and lighting: In the interest of safety to air navigation, certain requirements for marking and lighting of the airport are necessary. The airport runways, taxiways, etc. should be marked so that the pilots may easily spot it and may be able to identify clearly the landing area, ascertain the direction of wind and avoid hazards while landing. All markings on runways are white; taxiways markings are yellow. On small airports which are unpaved and unlighted, the airport boundary markers should indicate clearly the landing and take-off areas. For safe landing and take-off at night or during the restricted visibility periods at day-time, a system of signal lights on both sides of runways, taxiways and elsewhere on port area is used to convey, by colour, the proper information to the pilots. The essential basic elements of all airport lighting systems are: (i) beacons (ii) runway, strip or boundary lights (iii) taxiway lights

(iv) obstruction lights (v) illuminated wind indicators. A beacon tells the pilot the location of the lighted airport. The runway, strip or boundary lights outline the area which the pilot must use in landing the aircraft on the ground. The obstruction lights warn the pilot of hazards (in the vicinity of airport or on airport itself) which should be avoided while making a landing. The illuminated indicator shows him the necessary wind-direction information which he needs in making his final approach to airport for making a landing.

EARTHWORK COMPUTATIONS

1. Introduction: As already pointed out in chapter III, in the construction of roads and railways, the irregularities of the surface of natural ground must first be removed by cutting through high spots and filling in the low spots; this cutting and filling is called *earthwork.* The loose soil or rock which is excavated to permit the placing of a road or railway below the high natural surface of ground is called the cut or *excavation.* Similarly the bank of loose soil or rock which is constructed above the low natural surface of the ground to permit the placing of a road or railway is known as fill or *embankment.*

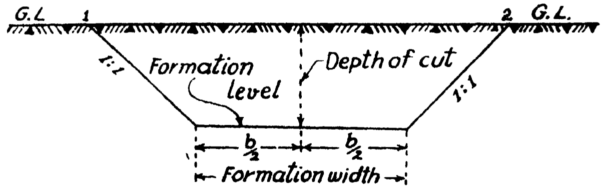
2. Earthwork computation: In a particular length, the formation (or bed) in cut or on bank has first to be prepared before placing the road or railway along its central portion. For preparing the formation width, (which is



Longitudinal profile of proposed road or railway showing natural ground, formation line etc.

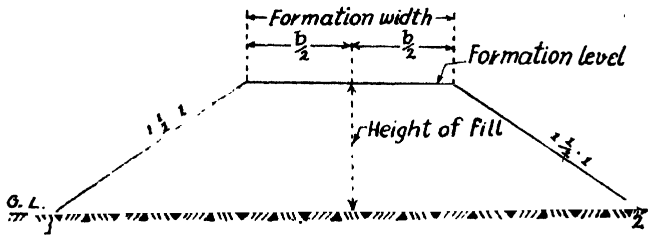
FIG. 113

slightly greater than the width occupied by road or railway) certain cutting or filling or both cutting and filling shall have to be done in that length. Finding out the quantity of earthwork (in excavation, or in filling or in both) which is to be done is called the *earthwork computation.* To be able to compute the earthwork, it is evident that we should take the longitudinal section of that length (taken along the centre line of road or railway); on this longitudinal section, we must show the formation grade line to find the depth of cut



Cross section at chainage 250′
FIG. 114

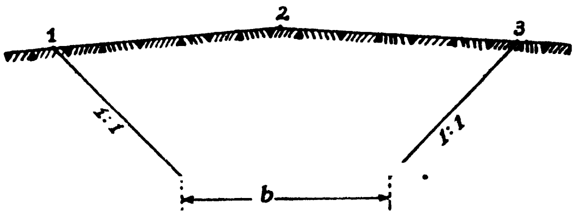
or the height of fill at the centre of formation width as shown in fig. 113. We should also take a number of cross sections along this centre line and at right angles to the centre line. A cross section should be taken at certain interval and also at every point where the longitudinal slope of the ground along the centre line of proposed road or railway changes *sufficiently* to affect the volume of earthwork appreciably;



Cross section at chainage 480′
FIG. 115

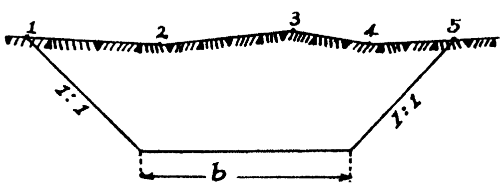
also, spot levels should be taken at every point (along the cross section) where the transverse slope changes sufficiently enough to affect the area of cross section appreciably. On this cross section, will be shown the width of formation (in cut or in fill as required) and the necessary side slopes at the ends of the formation width. Two such cross sections, at chainages 250′ (75 m) and 480′ (144 m) of longitudinal profile, are shown in figs. 114 and 115 respectively. The area of cross section between ground line, formation width and the two side slopes will be worked out. Knowing the areas of cross sections and the distances between cross sections, we can find out the quantity of earthwork in a given length of the proposed road or railway.

3. Cross sections: In a cross section, the natural ground may be level across (i.e. ground may be horizontal in a direction at right angles to the centre line of road or railway) or the ground may have transverse (i.e. cross) slope.



Three-level cross section
FIG. 116

When the ground has transverse slope, this slope may be uniform from one end to the other end of cross section or the slope may change at one or more places between these two



Multi-level cross section
FIG. 117

ends of the cross section. When the slope is uniform, the cross section is called *two-level* cross section (see figs. 114 and 115) because this slope can be obtained by joining the points at the *two* ends of the cross section. When the slope is not uniform, we may have *three-level* cross section (see fig. 116) or *multi-level* cross section (see fig. 117). In *three-level* cross section, there will be *two* transverse slopes between the two ends of the cross section.

4. Areas and side-widths of two-level cross section: Unless mentioned otherwise or unless so found from the data given for cross section, a cross section should be assumed as a two-level cross section. In this article let us find the area etc. of such cross section. The ground at cross section may be:

(a) Level across or,

(b) It may have a transverse or side-long or cross slope m:1 (i.e. for every m horizontal, there is 1 vertical). Thus the cross slope may be 10 : 1, 8 : 1 and so on.

When the ground is level across (i.e. formation width is parallel to ground and $m = \infty$), the cross section may be either wholly in cutting or wholly in bank. When there is a cross slope, the cross slope may cut the formation width or it may not cut it. When the cross slope does not cut it, the cross section may be either wholly in cutting or wholly in bank. When the cross slope cuts it, the cross section will be partly in cutting and partly in bank.

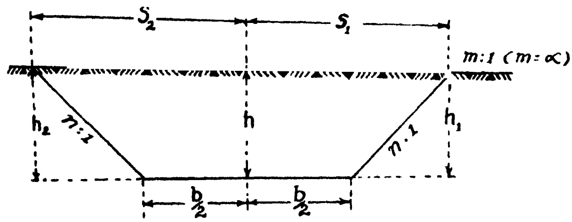


FIG. 118

I. Ground is level across and the cross section is wholly in cutting (see fig. 118):

Let b metres be the formation width or width of bed on which a road or railway will be placed, n:1 be the side slopes of cutting, h metres be the depth at centre of cross section; h_1, h_2 be the depths of cutting at two ends of the cross section: h_1 and h_2 are therefore known as side depths or side heights of a cross section; s_1, s_2 be the side-widths of the cross section; A sq.metres be the area of cross section in cutting.

Then from the geometry of figure, we have,

$$A = (b + nh)h \text{ sq.metres} \quad \ldots\ldots\ldots\ldots\ldots \text{(i)}$$

$$s_1 = s_2 = \left(\frac{b}{2} + nh\right) \text{ metres} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

$$h_1 = h_2 = h \text{ metres} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

The formulae (i), (ii) and (iii) also hold good when the cross section is wholly in bank i.e. when ground is below the formation width.

II. Ground has cross slope of m:1 and it does not cut the formation width: further, the cross section is wholly in cutting (see fig. 119). The notations used are the same as those used in I above.

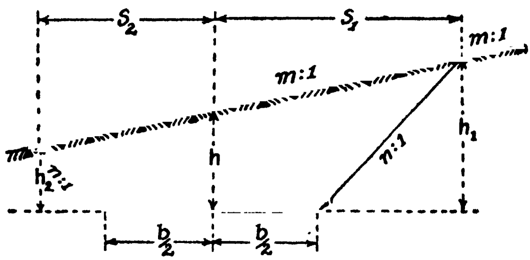


FIG. 119

From the geometry of figure, we have,

$$A = \tfrac{1}{2}\left\{(s_1 + s_2)\ \left(h + \frac{b}{2n}\right) - \frac{b^2}{2n}\right\} \text{ sq. metres} \quad \ldots\ldots \text{(i)}$$

or, $$A = \tfrac{1}{2}\left\{\frac{b}{2}(h_1 + h_2) + h\ (s_1 + s_2)\right\} \text{ sq. metres}$$

$$s_1 = \frac{b}{2} + \left(h + \frac{b}{2m}\right)\left(\frac{mn}{m-n}\right) \text{ metres} \quad \ldots\ldots\ldots\ldots \text{(ii)}$$

$$s_2 = \frac{b}{2} + \left(h - \frac{b}{2m}\right)\left(\frac{mn}{m+n}\right) \text{ metres} \quad \ldots\ldots\ldots\ldots \text{(iii)}$$

$< s_1$.

$$h_1 = h + \frac{s_1}{m} \text{ metres} \quad \ldots\ldots\ldots\ldots \text{(iv)}$$

$$h_2 = h - \frac{s_2}{m} \text{ metres} \quad \ldots\ldots\ldots\ldots \text{(v)}$$

$< h_1$.

All the above-said formulae also hold good when the cross section is wholly in bank.

III. Ground has steep cross slope of $m : 1$ and it cuts the formation width (see fig. 120). Thus the cross section is partly in cutting and partly in bank; this section is common in hilly country. Let the area of cutting be more than the area of filling i.e. h is the depth of *cutting*.

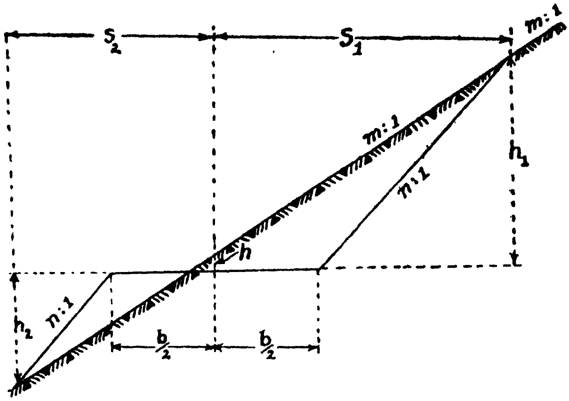


FIG. 120

From the geometry of figure, and using the same notations as before, we have,

$$\text{Area of fill } A_F = \left\{ \left(\frac{b}{2n} - h\right)(s_2 - mh) - \frac{b}{2n}(b - mh) \right\} \text{ sq. metres} \quad \text{(i)}$$

or
$$A_F = \tfrac{1}{2}\left(\frac{b}{2} - mh\right)h_2 \text{ sq. metres.}$$

$$\text{Area of cut } A_C = \tfrac{1}{2}\left\{ \left(\frac{b}{2n} + h\right)(s_1 + mh) - \frac{b}{2n}\left(\frac{b}{2} + mh\right) \right\} \text{ sq. metres} \quad \text{(ii)}$$

or
$$A_C = \tfrac{1}{2}\left(\frac{b}{2} + mh\right)h_1 \text{ sq. metres.}$$

$$s_1 = \frac{b}{2} + \left(h + \frac{b}{2m}\right)\left(\frac{mn}{m-n}\right) \text{ metres} \quad \ldots\ldots \quad \text{(iii)}$$

$$s_2 = \frac{b}{2} + \left(\frac{b}{2m} - h\right)\left(\frac{mn}{m-n}\right) \text{ metres} \quad \ldots\ldots \quad \text{(iv)}$$

$$< s_1.$$

$$h_1 = h + \frac{s_1}{m} \text{ metres} \quad \ldots\ldots\ldots\ldots \quad \text{(v)}$$

$$h_2 = h - \frac{s_2}{m} \text{ metres} \qquad \ldots\ldots\ldots\ldots \quad \text{(vi)}$$

$$< h_1.$$

The negative answer for h_2 shows that h_2 is measured on the side which is opposite to that on which h and h_1 are measured. In some cases, A_C may be less than A_F i.e. h may be the height of *fill*. The necessary equations can be written when this is the case.

5. Three-level and multi-level cross sections: As already said, in case of these cross sections, there is no uniform cross slope; as such, complete data must be given regarding the cross section so that it can be plotted corresponding to this data and its area may be found out by finding the area of trapeziums etc. of which such cross section is composed. The data for such cross sections is usually recorded in the table shown on page 261.

From this data, three cross sections can be plotted; on each cross section, the formation width and side slopes will be shown and then the irregular area of each cross section can be found out. It may be noted that the *minus* sign before figures in the above-said table shows *cut* and *plus* sign shows *fill*.

6. Volume of earthwork: The following methods are used for finding the volume of earthwork between regular or two-level cross sections:

(a) Average end-area formula.

(b) Middle area formula.

(c) Prismoidal formula.

Let there be two parallel cross sections of areas A_1 and A_2 sq. metres and let L metres be the longitudinal or axial distance between them. If V be the volume of earthwork between these two cross sections, we have,

(a) According to average end-area formula,

$$V = \frac{A_1 + A_2}{2} \times L \quad \text{c.metres}$$

Table showing data for multi-level cross sections

Number of cross section	Chainage of cross section in feet	R. L. of ground at the point of that chainage	R.L. of subgrade or formation at the point of that chainage	Data of cross section at that chainage		
				Left of centre	Centre	Right of centre
3	300	130·1	130·4	$\frac{-4\cdot1}{17}, \frac{-2\cdot2}{11}, \frac{0}{2\cdot3}$	$\frac{+0\cdot3}{0}$	$\frac{+2\cdot0}{7}, \frac{+3\cdot9}{17\cdot4}$
2	200	129·0	129·6	$\frac{-5\cdot7}{19}, \frac{0}{3\cdot3}$	$\frac{+0\cdot6}{0}$	$\frac{+2\cdot9}{13}, \frac{+3\cdot5}{16\cdot3}$
1	100	127·2	128·8	$\frac{-6\cdot5}{21}, \frac{-4\cdot1}{14}, \frac{0}{4\cdot4}$	$\frac{+1\cdot6}{0}$	$\frac{+2\cdot3}{9}, \frac{+3\cdot8}{17\cdot2}$

(b) According to middle area formula,

$V = A_m \times L$ c.metres where A_m is the area of section *midway* between A_1 and A_2, i.e. $\frac{L}{2}$ metres away from each of the two end-sections; value of A_m can be calculated if the values of A_1 and A_2 are given.

(c) According to prismoidal formula,

$V = \frac{L}{6}(A_1 + 4A_m + A_2)$ c.metres where L, A_1 and A_2 are given and A_m is calculated midway between the locations of A_1 and A_2.

Formulae (a) and (c) are usually used; formula (a) gives slightly greater result than what is obtained by formula (c) which is more accurate than formula (a). The results of these two formulae are very nearly equal when A_1 is not much different from A_2.

When there are a number of equidistant and parallel sections of areas A_1, A_2, A_3, A_4 ......A_n, and L is small, the volume of earthwork between A_1 and A_n will be,

(i) According to average end-area formula,

$$V = \frac{L}{2}\{A_1 + A_n + 2(A_2 + A_3 + A_4 + \ldots + A_{n-1})\} \text{ c.metres.}$$

(ii) According to prismoidal formula, we have,

$$V = \frac{L}{3}\{A_1 + A_n + 2(A_3 + A_5 + A_7 + \ldots A_{n-2}) + 4(A_2 + A_4 + A_6 + \ldots + A_{n-1})\} \text{ c.metres.}$$

The formula in (ii) above is applicable when there are true prismoids between successive sections and the number of sections is *odd*. If there be *even* number of sections, the above formula will be applied to a number of sections equal to the given even number minus one; the volume of last prismoid between the last section and last-but-one section will be found separately according to formula (c) shown above and the two results will be added to get the volume between the first section and the last *even* number of section.

Note: The earthwork formulae derived above can be shown in the British system of units if metres, sq. metres and cubic metres are changed to feet, sq. feet and cubic feet respectively.

7. Illustrative examples: In this article, a few typical problems are solved to illustrate the principles outlined already for the computation of earthwork.

Example 1.

A straight and level roadway, 20′ wide, is cut through a plane hill side which slopes at 1 in 9 at right angles to the road, although it is level in the direction of road. The side slopes of the cutting are 1:1 and the depth of cutting at centre is 10′. Calculate the quantity of earthwork in a horizontal length of 100 feet.

Solution:

Here we have,

$$b = 20', \; h = 10', \; n = 1, \; m = 9 \text{ and } L = 100'.$$

Now,

$$s_1 = \frac{b}{2} + \left(h + \frac{b}{2m}\right)\left(\frac{mn}{m-n}\right)$$

$$= \frac{20}{2} + \left(10 + \frac{20}{2 \times 9}\right)\left(\frac{9 \times 1}{9 - 1}\right)$$

$$= 10 + (10 + 1{\cdot}11)\,(1{\cdot}125)$$

$$= 10 + 12{\cdot}55$$

$$= 22{\cdot}55 \text{ feet.}$$

$$s_2 = \frac{b}{2} + \left(h - \frac{b}{2m}\right)\left(\frac{mn}{m+n}\right)$$

$$= 10 + (10 - 1{\cdot}11)\,(\tfrac{9}{10})$$

$$= 10 + 8$$

$$= 18 \text{ feet.}$$

And,

$$A = \tfrac{1}{2}\left\{\left(s_1 + s_2\right)\left(h + \frac{b}{2n}\right) - \frac{b^2}{2n}\right\}$$

$$= \tfrac{1}{2}\left\{(22{\cdot}55 + 18)\,(10 + 10) - \frac{20 \times 20}{2 \times 1}\right\}$$

$$= \tfrac{1}{2}\{(40{\cdot}55 \times 20) - 200\}$$

$$= 305{\cdot}5 \text{ sq.ft.}$$

$$\therefore \quad V = A \times L$$

$$= 305{\cdot}5 \times 100$$

$$= 30550 \text{ c.ft., excavation} \quad \textit{Ans.}$$

Example 2.

Find the volume of earthwork required for embankment from the following data when the ground is level across:

Height of bank at near end	....	= *3 m*
Upward gradient of formation level (or top of bank)	....	= *1 in 150*
The down-gradient of the ground from the near to the far end of embankment	....	= *1 in 30*
Horizontal length of bank between the sections		= *120 m*
Formation width or Top of bank	......	= *9 m*
Side slopes of bank	....	= *2:1.*

Solution:

Here we have,

$b = 9$ m, $n = 2$, $m = 0$, $L = 120$ m and h for near section $= 3$ m.

$$h \text{ for distant section} = 3 + \frac{120}{150} + \frac{120}{30}$$
$$= 3 + 0{\cdot}8 + 4$$
$$= 7{\cdot}8 \text{ m.}$$

$$A_1 \text{ for near section} = (b + nh)h$$
$$= \{9 + 2(3)\} \times 3$$
$$= 45 \text{ m}^2.$$

$$A_2 \text{ for distant section} = \{9 + 2(7{\cdot}8)\} \times 7{\cdot}8$$
$$= 191{\cdot}9 \text{ m}^2.$$

A_m for section midway between A_1 and A_2

$$= \{9 + 2\ (5{\cdot}4)\} \times 5{\cdot}4$$
$$= 106{\cdot}9 \text{ m}^2.$$

Now by prismoidal formula, we have,

$$V = \frac{L}{6}\{A_1 + 4A_m + A_2\}$$
$$= \frac{120}{6}\{45 + 4(106{\cdot}9) + 191{\cdot}9\}$$
$$= 13290 \text{ cu.m, fill.} \quad \textit{Ans.}$$

Example 3.

A railway embankment has top width of 30′, side slopes of 1½:1 and centre height of 12′. The ground has a cross slope of 1 in 10.

Calculate the cubic contents of earthwork when the length of bank is 200 feet.

Solution:

Here we have,

$b = 30'$, $n = 1{\cdot}5$, $h = 12'$, $m = 10$ and $L = 200'$.

Now, $$s_1 = \frac{b}{2} + \left(h + \frac{b}{2m}\right)\left(\frac{mn}{m-n}\right)$$

$$= 15 + \left(12 + \frac{30}{20}\right)\left(\frac{10 \times 1{\cdot}5}{10 - 1{\cdot}5}\right)$$

$$= 15 + 23{\cdot}8$$

$$= 38{\cdot}8 \text{ feet.}$$

$$s_2 = \frac{b}{2} + \left(h - \frac{b}{2m}\right)\left(\frac{mn}{m+n}\right)$$

$$= 15 + \left(12 - \frac{30}{20}\right)\left(\frac{10 \times 1{\cdot}5}{10 + 1{\cdot}5}\right)$$

$$= 15 + 13{\cdot}7$$

$$= 28{\cdot}7 \text{ feet.}$$

And, $$A = \tfrac{1}{2}\left\{(s_1 + s_2)\left(h + \frac{b}{2n}\right) - \frac{b^2}{2n}\right\}$$

$$= \tfrac{1}{2}\left\{(38{\cdot}8 + 28{\cdot}7)\left(12 + \frac{30}{3}\right) - \frac{30 \times 30}{3}\right\}$$

$$= \tfrac{1}{2}\{(67{\cdot}5)(22) - 300\}$$

$$= 592{\cdot}5 \text{ sq.feet.}$$

$$\therefore \quad V = A \times L$$

$$= 592{\cdot}5 \times 200 = 1{,}18{,}500 \text{ c.ft., fill.} \quad \textit{Ans.}$$

Example 4.

From the following data, determine by prismoidal and average end-area formulae the amount of cut between two sections 90 m apart when the ground is level across:

Formation width = 9 m

Side slopes of formation = 2:1

Centre depth of first section = 7·5 m

Centre depth of second section = 4·5 m.

Solution :

Here we have,

$b = 9$ m, $n = 2$, $m = 0$, $L = 90$ m, h at first section $=$ 7·5 m and h at second section $= 4·5$ m.

Now, $A_1 = \{9 + 2\ (7·5)\} \times 7·5$

$= 180\ \text{m}^2.$

$A_2 = \{9 + 2\ (4·5)\} \times 4·5$

$= 81\ \text{m}^2.$

$A_m = \{9 + 2\ (6)\} \times 6$

$= 126\ \text{m}^2.$

$\therefore$ By prismoidal formula,

$$V = \frac{90}{6}\{180 + 4\ (126) + 81\}$$

$$= 15 \times 765$$

$= 11475\ \text{m}^3$, cut or excavation. *Ans.*

Also, by average end-area formula,

$$V = L\left(\frac{A_1 + A_2}{2}\right)$$

$$= 90\left(\frac{180 + 81}{2}\right)$$

$= 11745\ \text{m}^3$, cut. *Ans.*

Example 5.

A railway embankment has formation width of 30′ and side slopes of 2:1. The ground is level across and the distance between successive sections is 100′. Find by prismoidal and average end-area formula the quantity of earthwork when the centre heights at various sections are 0, 7′, 12′, 14′, 13′, 9′, 8′, 4′, 0.

Solution :

Here we have,

$b = 30'$, $n = 2$, $m = 0$, $L = 100'$ and the centre heights h at successive sections are 0, 7, 12, 14, 13, 9, 8, 4, 0 feet respectively.

Now,

$A_1 = 0$, where $h = 0$

$A_2 = \{30 + 2\ (7)\} \times 7 = 308\ \text{ft}^2.$

$A_3 = \{30 + 2\ (12)\} \times 12 = 684$ ft².
$A_4 = \{30 + 2\ (14)\} \times 14 = 812$ ft².
$A_5 = \{30 + 2\ (13)\} \times 13 = 728$ ft².
$A_6 = \{30 + 2\ (9)\} \times 9 = 432$ ft².
$A_7 = \{30 + 2\ (8)\} \times 8 = 368$ ft².
$A_8 = \{30 + 2\ (4)\} \times 4 = 152$ ft².
$A_9 = 0$, where $h = 0$.

$\therefore$ By prismoidal formula for *odd* number of sections,

$$V = \frac{L}{3}\{A_1 + A_9 + 2\ (A_3 + A_5 + A_7) + 4\ (A_2 + A_4 + A_6 + A_8)\}$$

$$= \frac{100}{3}\{0 + 0 + 2\ (648 + 728 + 368) + 4\ (308 + 812 + 432 + 152)\}$$

$$= \frac{100}{3} \times 10304$$

$= 3{,}43{,}466$ c.ft., fill. *Ans.*

Also, by average end-area formula,

$$V = \frac{L}{2}\{A_1 + A_9 + 2\ (A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8)\}$$

$$= \frac{100}{2}\{0 + 0 + 2(308 + 648 + 812 + 728 + 432 + 368 + 152)\}$$

$= 50 \times 6896$

$= 3{,}44{,}800$ c.ft., fill. *Ans.*

Example 6.

The straight centre line of a proposed railway is located by 100′ chainage pegs and the cross sections have been taken at these pegs. In the longitudinal profile, the formation level is in cutting from chainage 76 + 60′ to chainage 83 + 78′. The cross section areas of excavation at various chainages are as shown below:

Chainage of peg (in ft)	*Area of excavation (in ft²)*
77 + 00	*16*
78 + 00	*304*
79 + 00	*656*
80 + 00	*768*
81 + 00	*640*
82 + 00	*320*
83 + 00	*176*

Compute the cubic contents of cut by using (a) average end-area formula (b) prismoidal formula.

Solution :

Earthwork will be found between,

(i) chainages 76 + 60′ and 77 + 00

(ii) chainages 77 + 00 and 83 + 00

(iii) chainages 83 + 00 and 83 + 78′.

The sum of (i), (ii) and (iii) gives the required answer.

V_1 in (i) above by average end-area formula

$$= \frac{16}{2} \times 40 = 320 \text{ c.ft.}$$

V_3 in (iii) above by average end-area formula

$$= \frac{176}{2} \times 78 = 6{,}864 \text{ c.ft.}$$

V_2 in (ii) above by average end-area formula

$$= \frac{100}{2} \{16 + 176 + 2(304 + 656 + 768 + 640 + 320)\}$$

$$= 50 \times 5920$$

$$= 2{,}96{,}000 \text{ c.ft.}$$

∴ Total volume of cut by average end-area formula

$$= 320 + 2{,}96{,}000 + 6{,}864$$

$$= 3{,}03{,}184 \text{ c.ft.} \quad \textit{Ans.}$$

Now, V_2 in (ii) above by prismoidal formula will be,

$$V_2 = \frac{100}{3}\{16 + 176 + 2(656 + 640) + 4(304 + 768 + 320)\}$$

$$= \frac{100}{3} \times 8352$$

$$= 2{,}78{,}400 \text{ c.ft.}$$

V_1 by prismoidal formula will be,

$$V_1 = \frac{40}{6}\{0 + 4(4) + 16\}$$

$$= \frac{40}{6} \times 32$$

$$= 213 \text{ c.ft.}$$

V_3 by prismoidal formula will be,

$$V_3 = \frac{78}{6}\{176 + 4(44) + 0\}$$
$$= 4{,}567 \text{ c.ft.}$$

$\therefore$ Total volume of cut by prismoidal formula

$$= V_1 + V_2 + V_3$$
$$= 213 + 2{,}78{,}400 + 4{,}567$$
$$= 2{,}83{,}180 \text{ c.ft.} \quad \textit{Ans.}$$

Example 7.

A road having a formation width of 9m and side slope of 1½ : 1 is to be constructed on side-long ground. At adjacent cross sections, 30 m apart, the depths of cutting at the centre line of road are 0·6 m and 0·3 m respectively. The original ground surface between the cross sections has a side-long slope of 4 : 1. Calculate the volume of cutting and the excess of the volume of cutting over the volume of embankment between these two cross sections.

Solution:

Here we have,

$b = 9$ m, $n = 1{\cdot}5$, $m = 4$, $L = 30$ m, and the centre-height h at the two sections is 0·6 m and 0·3 m respectively (see fig. 120).

(i) For cross section with $h = 0{\cdot}6$ m, the formation width b is divided by ground line into two portions 2·1 m and 6·9 m each, 2·1 m being on the bank-side and 6·9 m being on the cutting-side.

Now, h_2 on bank-side $= \dfrac{2{\cdot}1}{4 - 1{\cdot}5} = \dfrac{2{\cdot}1}{2{\cdot}5} = 0{\cdot}84$ m

OR, $\dfrac{h_2}{2{\cdot}1 + 1{\cdot}5\,h_2} = \dfrac{1}{4}$

$\therefore$ $h_2 = 0{\cdot}84$ m, as before.

Also, h_1 on cutting-side $= \dfrac{6{\cdot}9}{2{\cdot}5} = 2{\cdot}76$ m.

$\therefore$ area of fill $A_F = \frac{1}{2} \times 2{\cdot}1 \times 0{\cdot}84 = 0{\cdot}88$ m^2;

and area of cut $A_C = \frac{1}{2} \times 6{\cdot}9 \times 2{\cdot}76 = 9{\cdot}50$ m^2.

Note: Alternatively, the formulae of article 4(III) may be used to find A_F and A_C.

(ii) For cross section with $h = 0{\cdot}3$ m, the formation width b is divided by ground line into two portions 3·3 m and 5·7 m each, 3·3 m being on the bank-side and 5·7 m being on the cutting-side.

$$h_2 = \frac{3{\cdot}3}{2{\cdot}5} = 1{\cdot}32 \text{ m}$$

and $h_1 = \dfrac{5{\cdot}7}{2{\cdot}5} = 2{\cdot}28$ m

$\therefore \quad A_F = \frac{1}{2} \times 3{\cdot}3 \times 1{\cdot}32 = 2{\cdot}18 \text{ m}^2$

and $A_C = \frac{1}{2} \times 5{\cdot}7 \times 2{\cdot}28 = 6{\cdot}5 \text{ m}^2$.

Hence the required volume of embankment

$$= \frac{0{\cdot}88 + 2{\cdot}18}{2} \times 30 = 45{\cdot}9 \text{ m}^3, \text{ say } 46 \text{ m}^3.$$

And the volume of cutting

$$= \frac{9{\cdot}50 + 6{\cdot}5}{2} \times 30 = 240 \text{ m}^3 \quad \textit{Ans.}$$

Also, excess of cutting over embankment $= 240 - 46$
$= 194 \text{ m}^3$ *Ans.*

Example 8.

The centre line of a railway embankment, circular in plan and having a radius of 3000′, subtends an angle of 45° at the centre of the curve. The ground has a side-long slope of 1 in 10 towards the centre of the curve. Calculate the quantity of filling required for making the embankment if it has to be 30′ wide at its top and 10′ high along its centre line; the embankment has 2:1 side slopes.

Solution:

Here we have,

$R = 3000'$, $\theta = 45°$, $m = 10$, $b = 30'$, $h = 10'$, $n = 2$.

Now,

$$s_1 = \frac{b}{2} + \left(h + \frac{b}{2m}\right)\left(\frac{mn}{m-n}\right)$$

$$= \frac{30}{2} + \left(10 + \frac{30}{2 \times 10}\right)\left(\frac{10 \times 2}{10 - 2}\right)$$

$$= 15 + (10 + 1{\cdot}5)\ (2{\cdot}5)$$

$$= 15 + 28{\cdot}75$$

$= 43{\cdot}75$ ft.

$$s_2 = \frac{b}{2} + \left(h - \frac{b}{2m}\right)\left(\frac{mn}{m+n}\right)$$

$$= 15 + (10 - 1{\cdot}5)\left(\frac{20}{12}\right)$$

$$= 15 + (8{\cdot}5)\left(\frac{5}{3}\right)$$

$$= 15 + 14{\cdot}17$$

$$= 29{\cdot}17 \text{ ft.}$$

Cross-sectional area of bank throughout the curve

$$= \tfrac{1}{2}\left\{(s_1 + s_2)\left(h + \frac{b}{2n}\right) - \frac{b^2}{2n}\right\}$$

$$= \tfrac{1}{2}\left\{(43{\cdot}75 + 29{\cdot}17)\left(10 + \frac{30}{2 \times 2}\right) - \frac{900}{2 \times 2}\right\}$$

$$= \tfrac{1}{2}\{(72{\cdot}92)\ (17{\cdot}5) - 225\}$$

$$= \tfrac{1}{2}\{1276 - 225\}$$

$$= \tfrac{1}{2} \times 1051$$

$$= 525{\cdot}5 \text{ ft}^2.$$

Hence, quantity of filling $= A \times L$ c.ft., where L is the curved length of bank along centre of its top width

$$= 525{\cdot}5\left(2\pi R \times \frac{45}{360}\right)$$

$$= 525{\cdot}5\ (2\pi \times 3000 \times \tfrac{1}{8})$$

$$= 525{\cdot}5(750\pi)$$

$= 12{,}39{,}000$ c.ft. *Ans.*

Problems for practice:

(*1*) *In a certain railway cutting, the formation width is 6 m side slopes of cutting are 1½ : 1 and the ground has a cross slope of 1 in 10. Estimate the quantity of cutting between two cross sections 90 m apart when the centre-depth of cutting at first section is 7·5 m, at second section it is 9 m and at the point mid-way between these two sections, it is 8 m.* (*Ans.* 13500 m^3.)

(*2*) *Find the quantity of earthwork for the embankment for which the following data are given:*

Upward gradient of formation level	......	*1 in 150*
Height of bank at nearest end	......	*10′*
Side slopes of bank	......	*2:1*
Width of bank at formation level	......	*30′*
Longitudinal downward slope of ground from the nearest end	....	*1 in 30*
Cross slope of the ground	....	*nil*
Distance between two cross sections	......	*400′*

(*Ans.* *4,92,260 c.ft.*)

(3) *Find the side-widths and cross-section area of a railway embankment having formation width of 9 m, side slopes of 1½:1 and centre-height of 3·6 m. The ground has a cross slope of 1 in 10.*

(*Ans.* $s_1 = 11{\cdot}6\,m$, $s_2 = 8{\cdot}6\,m$, $A = 54{\cdot}5\ m^2$.)

(4) *Calculate the quantity of excavation between chainages 800′ and 1000′ from the following data which refer to the cross sections taken across the centre line of a road. The formation width is 30 feet.*

Chainage in feet	*Left*	*Centre*	*Right*
800	$\frac{15\cdot5}{30\cdot5}$	$\frac{12\cdot6}{0}$	$\frac{3\cdot2}{18\cdot2}$
900	$\frac{10\cdot6}{25\cdot6}$	$\frac{4\cdot4}{0}$	$\frac{2\cdot3}{17\cdot5}$
1000	$\frac{7\cdot5}{22\cdot5}$	$\frac{2\cdot6}{0}$	$\frac{1\cdot8}{16\cdot8}$

(*Ans.* *47,260 c.ft.*)

(5) *The ground levels along the centre of a road are as follows:*

Chainage in feet	*400*	*500*	*600*	*700*	*800*	*900*	*1000*
Reduced level in feet	*56*	*59*	*64*	*68*	*72*	*70*	*74*

A cutting is to be made in this length of the road. The formation width is 36′ and side-slopes of cutting are 2:1. The reduced level of the formation level is 50 at chainage 400 and the longitudinal upward gradient of the formation is 1 in 50. If the ground surface is level across, find the quantity of excavation. (*Ans. 3,48,000 c.ft.*)

(6) *Find the volume of a road embankment from the following data:*

Formation width	*6 m*
Height of bank at zero chainage	*0·6 m*
Longitudinal downward slope of ground	*1 in 50*
Longitudinal downward slope of formation	*1 in 100*
Side slopes of bank	*2:1*
Transverse slope of ground	*nil*
Length of bank	*120 m*

(*Ans. 1240 m^3*)

(7) *In a certain railway cutting, the width at formation level is 30 ft., the side slopes of cutting are 1:1 and the ground surface has a uniform side-long slope of 1 in 8. Find the quantity of earthwork in a length of 400 feet, the depths of cutting at chainages 0,200′ and 400′ being 10′, 12′ and 16′ respectively.*

(*Ans. 2,19,400 c.ft.*)

8. Disposal of cut and fill: The cost of excavation depends not only on the volume of material excavated but also upon its disposal. In case of road or railway, it is a common practice to use the material excavated (from cutting) for making the embankment in the vicinity of the cutting. For economic earthwork, the 'cut' should just *balance* the 'fill'; to achieve this object, care is taken while fixing the formation grade line on the longitudinal profile of natural ground which exists along the centre line of the proposed road or railway. Also, for economy, the *horizontal* haul length (i.e. *lead*) from 'cut' to 'fill' should be as short as possible. For all practical purposes, it is sufficient to determine economic haulage graphically by means of mass-diagram. In fact the mass-haul curves show graphically the haul length, the economic direction of haul and the position along the route where the cut balances the fill. The method of constructing a mass-diagram is however not shown here.

9. Rates for earthwork: The earthwork being cheap is generally paid for at the rate of so many rupees per 1000 c.ft. of earthwork for soil and per 100 c.ft. of earthwork for rock. If, in the same cross section in cutting, strata of radically different hardness are encountered, the volume of earthwork for each type of soil must be found separately as the rate of payment for excavating soft soil is less than that for excavating hard soil or rock. The rate of excavation includes a certain *free lead* i.e. the excavating party will excavate and move the excavated material over a certain free distance which will not be charged for; also, during the process of removal or disposal of excavated material, it shall have to be lifted *vertically* through certain height or lift; a certain lift is not charged for and is known as *free lift*. If the lead and lift are greater than the free lead and free lift included in the initial rate for excavation and its disposal, the extra lead and extra lift will be paid for at some extra rate, in addition to the initial rate. In India, the free lead and free lift are usually 100′ and 5′ respectively.

Note: In Metric system, unit for earthwork may be taken as 10 m^3 instead of 1000 ft^3. Free lead and lift may be taken as 30 m and 1·5 m respectively.

CHAPTER XXIII

ELEMENTARY PROBLEMS AND DESIGNS IN ROAD ENGINEERING

Design problem 1: A car is travelling at 60 miles per hour on a concrete road for which the coefficient of friction may be taken as 0·5. If the perception time and reaction time of the driver are 1·5 seconds and 0·5 second respectively, find the distance in which the car can be brought to a standstill after apprehension of the trouble when (a) the longitudinal gradient of the road is negligible (b) the car is moving up a 5% grade (c) the car is moving down a 5% grade.

Solution:

Here we have,

$v = \dfrac{60 \times 5280}{60 \times 60} = 88$ ft/sec, $\mu = 0{\cdot}5$, total brake-reaction time $= 1{\cdot}5 + 0{\cdot}5 = 2$ seconds; $s = \dfrac{5}{100} = 0{\cdot}05$.

(a) Lag distance $= 2 \times 88 = 176$ feet.

Braking distance, $l = \dfrac{v^2}{2g.\mu} = \dfrac{88 \times 88}{64{\cdot}4 \times 0{\cdot}5} = 240{\cdot}5$, say 241 feet

$\therefore$ Total stopping distance $= 176 + 241 = 417$ feet, Ans.

(b) Lag distance $= 176$ feet.

$$\text{Braking distance, } l = \frac{v^2}{2g\,(\mu + s)} = \frac{88 \times 88}{64{\cdot}4\,(0{\cdot}5 + 0{\cdot}05)}$$
$$= 219 \text{ feet}$$

$\therefore$ Total stopping distance $= 176 + 219 = 395$ feet, Ans.

(c) Lag distance $= 176$ feet.

$$l = \frac{v^2}{2g\,(\mu - s)} = \frac{88 \times 88}{64{\cdot}4\,(0{\cdot}5 - 0{\cdot}05)} = 267 \text{ feet}$$

$\therefore$ Total stopping distance $= 176 + 267 = 443$ feet, Ans.

Design problem 2: Work out the above problem when the speed of car is 50 kilometres per hour, all other data remaining the same.

Design problem 3: A fast-moving vehicle is going along a wet road surface at a speed of 30 miles per hour. If $\mu = 0{\cdot}2$ and the total brake reaction time of driver is one second, find the safe non-overtaking sight distance corresponding to these conditions. Take the road to be practically level.

Solution:

Here we have,

$v = 30$ m.p.h. $= 44$ ft/sec, $\mu = 0{\cdot}2$, total brake-reaction time $= 1$ second.

Now, lag distance $= 1 \times 44 = 44'$.

$$\text{Braking distance} = \frac{v^2}{2g\,\mu} = \frac{44 \times 44}{64{\cdot}4 \times 0{\cdot}2} = 150'.$$

$\therefore$ Safe non-overtaking distance $= 44 + 150 = 194$ feet.

Design problem 4: A vehicle moving at a speed of 20 m/sec is stopped in a distance of 75 m after the application of brakes by the driver. Find the coefficient of friction induced between the tyres of the vehicle and the road surface.

Solution:

$$\text{Braking distance} = \frac{v^2}{2g\,\mu}$$

i.e. $$75 = \frac{20 \times 20}{2 \times 9{\cdot}81 \times \mu}$$

$\therefore$ $$\mu = \frac{20 \times 20}{19{\cdot}62 \times 75} = 0{\cdot}27.$$

Design problem 5: A car is moving along a 4° circular curve at a speed of 60 miles per hour. If the curve is not superelevated, find the coefficient of side friction so that car may not skid.

Solution:

$50 = R.\sin\frac{D}{2}$, where R is the radius of horizontal curve in feet and D is the degree of curve

i.e. $50 = R\sin 2$

$\therefore$ $$R = \frac{50}{\sin 2} = \frac{50}{0{\cdot}0349} = 1433 \text{ feet}.$$

For no superelevation on the curve, we should have,
Centrifugal force developed $\lesseqgtr$ The frictional force developed between tyres and the road surface

i.e. $W.\frac{v^2}{gR} \lesseqgtr \mu W$, where W is the weight of car

or, $\frac{v^2}{gR} \lesseqgtr \mu$

i.e. $\mu \gtrless \frac{v^2}{gR}$

$\therefore$ min. $\mu = \frac{v^2}{gR} = \frac{88 \times 88}{32{\cdot}2 \times 1433} = 0{\cdot}168$, say $0{\cdot}17$.

Design problem 6: Find the degree of the sharpest horizontal curve along which a vehicle can move without skidding when the speed of the vehicle is 96 km/h and the coefficient of side-friction is 0·15. The curve is not superelevated.

Solution:

$$\mu = \frac{v^2}{gR}$$

i.e. $0{\cdot}15 \gtrless \frac{26{\cdot}67 \times 26{\cdot}67}{9{\cdot}81 \times R}$, since 96 km/h = 26·67 m/sec

$\therefore$ min. $R = \frac{26{\cdot}67 \times 26{\cdot}67}{9{\cdot}81 \times 0{\cdot}15} = 483$ m.

Now, $10 = R.\sin\frac{D}{2}$

i.e. $10 = 483 \sin\frac{D}{2}$

$\therefore \quad \sin\frac{D}{2} = \frac{10}{483} = 0{\cdot}0207 \quad \therefore \quad \frac{D}{2} = 1°12'$

$\therefore$ lowest degree of curve = 1° 12′.

Note: In Metric system degree of curve is half of the angle subtended at centre by a chord of 20 m length.

Design problem 7: The design speed allowable on a horizontal curve is 60 m.p.h. If $\mu = 0{\cdot}15$ and the maximum permissible superelevation is given on the curve, find the minimum permissible degree of the curve.

Solution:

Here we have,

$v = 88$ ft/sec; $\mu = 0{\cdot}15$; $\frac{h}{B}$ (being of maximum permissible value) $= 0{\cdot}067$ feet per foot-width of the carriageway.

Now, $$\frac{h}{B} = \frac{v^2}{gR} - \mu$$

i.e. $$0{\cdot}067 = \frac{88 \times 88}{32{\cdot}2 \times R} - 0{\cdot}15$$

or, $$0{\cdot}217 = \frac{88 \times 88}{32{\cdot}2 \times R}$$

$\therefore$ $$R = \frac{88 \times 88}{32{\cdot}2 \times 0{\cdot}217} = 1110 \text{ feet.}$$

Now, $$50 = R \sin \frac{D}{2}$$

$\therefore$ $$\sin \frac{D}{2} = \frac{50}{1110} = 0{\cdot}045$$

$\therefore$ $$\frac{D}{2} = 2° \ 36' \quad \text{or,} \quad D = 5° \ 12'.$$

Note: In F.P.S system, degree of curve is the angle subtended at centre by a chord of 100′ length.

Design problem 8: Solve the above problem when design speed is 80 kilometres per hour, all other data remaining the same.

Design problem 9: The design speed allowable on a horizontal curve is 60 m.p.h. If $\mu = 0{\cdot}13$ and the curve is a 4° curve, find the necessary superelevation to be given on the curve.

Solution:

Here we have,

$v = 88$ ft/sec, $\mu = 0{\cdot}13$ and $D = 4°$.

Now, $$50 = R \sin \frac{D}{2}$$

$\therefore$ $$R = \frac{50}{\sin 2} = \frac{50}{0{\cdot}0349} = 1433 \text{ feet.}$$

Also, $$\frac{h}{B} = \frac{v^2}{gR} - \mu$$

$$= \frac{88 \times 88}{32{\cdot}2 \times 1433} - 0{\cdot}13$$

$$= 0{\cdot}168 - 0{\cdot}13$$

$= 0{\cdot}038$ feet per foot-width of the carriageway.

Design problem 10: Work out the above problem when the design speed is 64 kilometres per hour, all other data remaining the same.

Design problem 11: Work out design problem No. 9 for a 6° curve, all other data remaining the same.

Design problem 12: A two-lane road has a 10° curve. On the inside of the curve, there is an obstruction in the form of an existing building. The corner of this building is 26′ from the centre line of the curve. Considering the horizontal sight distance at the curve, find the safe design speed on the curve.

Solution: See fig. 121.

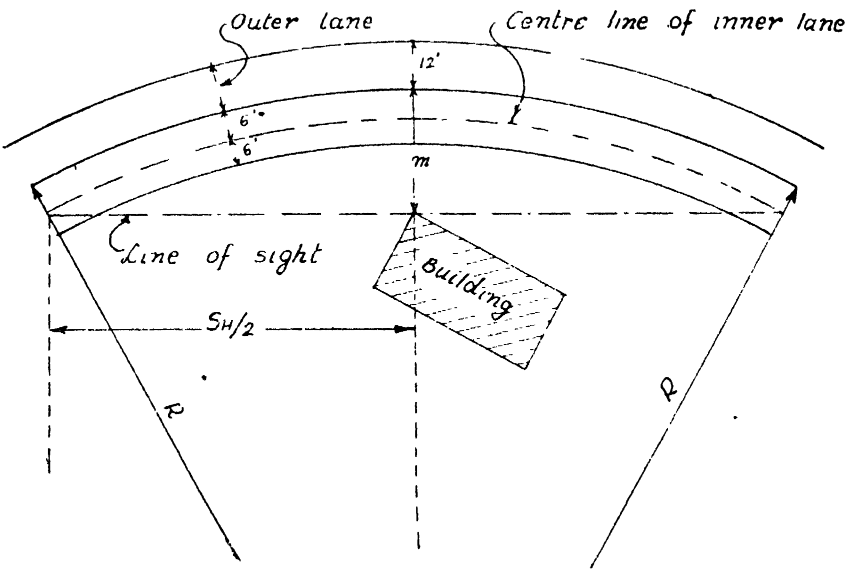


FIG. 121

Here we have,

$D = 10°$; $B = 24$ feet, as the carriageway has two lanes, each lane being 12′ wide, say; m = clearance from the centre of the curve to the corner of the obstruction = 26′.

Safe total stopping distance along the centre line of the inside lane of the curve $= (2v + \frac{v^2}{2g\mu})$ feet, taking the perception plus reaction time of the driver to be 2 seconds.

From the figure, the horizontal sight distance S_H at the curve is,

$$S_H = 2\sqrt{(R-6)^2 - (R-m)^2}$$
$$= 2\sqrt{(R-6)^2 - (R-26)^2} \text{ feet.}$$

Now, $50 = R.\sin\frac{D}{2}$

$= R \sin 5$

$\therefore \quad R = \frac{50}{\sin 5} = \frac{50}{0{\cdot}0872} = 574$ feet.

Hence, $S_H = 2\sqrt{(574-6)^2 - (574-26)^2}$

$= 2\sqrt{20 \times 1116}$

$= 299$, say 300 feet.

Now S_H is slightly less than the total stopping distance measured along the centre line of the inside lane of the curve; but for all practical purposes, S_H may be considered equal to the total stopping distance.

Hence, $S_H = 2v + \frac{v^2}{2g.\mu}$

i.e. $300 = 2v + \frac{v^2}{64{\cdot}4 \times 0{\cdot}5}$, taking $\mu = 0{\cdot}5$

or, $300 = 2v + \frac{v^2}{32{\cdot}2}$

$\therefore \quad v^2 + 64{\cdot}4\, v - 9660 = 0$

or, $v = \frac{-64{\cdot}4 + \sqrt{(64{\cdot}4)^2 + (4 \times 1 \times 9660)}}{2}$

$= 71$ ft/sec or, 48·4 miles/hour. Ans.

Design problem 13: Solve the above problem for a 8° curve; also, m = 8 metres and μ = 0·4.

Design problem 14: A 8° horizontal curve has 2 lanes, each 11′ wide. If the design speed on this curve is 60 m.p.h., find the *widening of carriageway which will be necessary on the inside of this curve.*

Solution:

Here we have,

$D = 8°$, $B = 22'$ and $v = 60$ m.p.h. 88 ft/sec.

Now for each traffic lane we have,

$$\text{widening } w = D^{1/3} = (8)^{1/3} = 2 \text{ feet}$$

$\therefore$ the widening for 2 traffic lanes $= 2 \times 2 = 4$ feet, Ans.

Also, $50 = R \sin \frac{D}{2}$

$$\therefore \quad R = \frac{50}{\sin 4} = \frac{50}{0{\cdot}0698} = 716 \text{ feet}$$

$$> 500 \text{ feet}$$

$$< 1000 \text{ feet.}$$

According to I.R.C. practice, for radius R of curve between $501'$ and $1000'$, widening should be $2'$ per traffic lane. Hence the widening should be $2 \times 2 = 4'$, as obtained before.

Design problem 15: A vehicle is moving over a 6° metric curve which is superelevated to the maximum permissible limit. Find the design speed when (a) friction between the road surface and the tyres allowable of vehicle is neglected (b) friction is considered. Use Metric system of units.

Solution:

Here we have,

$D = 6°$; $\frac{h}{B}$ is maximum i.e. $\frac{h}{B} = 0{\cdot}067 = \frac{1}{15}$.

(a) Neglecting friction, we have,

$$\frac{h}{B} = \frac{v^2}{gR}$$

i.e.
$$\frac{1}{15} = \frac{v^2}{9{\cdot}81 \times R}$$

$$\therefore \quad v^2 = \frac{9{\cdot}81}{15} R.$$

Now, $10 = R \sin \frac{D}{2}$

$\therefore$ $R = \frac{10}{\sin 6} = \frac{10}{0{\cdot}1045} = 95{\cdot}7$ m.

Hence, $v^2 = \frac{9{\cdot}81}{15} \times 95{\cdot}7$

$\therefore$ $v = 7{\cdot}9$ m/sec $= 28{\cdot}4$ km/h., Ans.

(b) Considering friction, we have,

$$\frac{h}{B} + \mu = \frac{v^2}{gR}$$

i.e. $0{\cdot}067 + 0{\cdot}15 = \frac{v^2}{9{\cdot}81 \times 95{\cdot}7}$

or, $v^2 = 0{\cdot}217 \times 9{\cdot}81 \times 95{\cdot}7$

$\therefore$ $v = 14{\cdot}3$ m/sec $= 51{\cdot}5$ km/h., Ans.

Design problem 16: Give the standards recommended by Indian Roads Congress for the type and width of road corresponding to the given nature of traffic and its intensity.

Solution:

The factors governing the lane-width of a carriageway and the number of lanes in a carriageway are the following:

(i) Maximum overall width of vthe ehicles using the road.

(ii) Transverse placement of vehicles while travelling free, passing other vehicles in opposite direction or, over-taking other vehicles in the same direction.

(iii) Speed of different types of traffic.

(iv) Minimum width for safe driving of the heaviest vehicle using the road.

(v) Existing and expected traffic in type, total volume, peak-hour intensity and daily average.

The capacity of traffic lane of a carriageway is influenced by:

(a) Variations in speed and, composition of traffic.

(b) The hold-up at the intersections.

At peak hours, a traffic lane may accommodate about 200 slow-moving vehicles and 250 fast-moving vehicles if these move *only* in one direction with no overtaking or passing-by vehicles. With the traffic in both directions, this will further be reduced. There will be a still further reduction at intersections and cross roads.

Dual carriageways should be constructed where an existing road carries or a proposed road is expected to carry 400 vehicles at the peak hour. Where it is necessary to provide more than 2 traffic lanes in a carriageway, the construction of a dual carriageway (if practicable) is preferable to the widening of a single carriageway by providing more than 2 traffic lanes in it.

Where the single lane carriageway proves inadequate, the next stage should be either to increase the width of carriageway to that of 2 lanes of traffic or to provide suitable shoulders of adequate width to make an overall width (of carriageway) of at least 18′ (5·5 m). The latter alternative is only a palliative and should be resorted to when the funds for proper widening to the 2 lanes of traffic are not available.

As already said, where the traffic warrants the provision of more than 2 traffic lanes in a carriageway, it is desirable to have dual carriageways, each carriageway having 2 lanes of traffic; the construction of 3 lanes of traffic in a carriageway is hazardous and should be avoided even though a dual carriageway (with 4 lanes of traffic in all) may be more costly than a single carriageway having 3 lanes of traffic.

Separate cycle tracks should be provided near urban areas, industrial centres, etc. where the peak hour cycle-traffic is of the order of 500 or more. The minimum width of cycle track should be 6′ and may increase by 3′ or a multiple of 3′.

Foot paths are recommended where the pedestrian traffic-density per day is sufficient.

Considering the mixed traffic which is obtained on roads in India, the lane width and the types of surfaces recommended (as rough guide) as suitable, are shown in the table on pages 284 and 285.

TABLE

S. No.	Nature of traffic	Average daily tonnage (tons)	No. of lanes	Width of lane and total width of pavement (feet)	Type of pavement suggested	Shoulders for occasional traffic in lieu of additional lane
1	Slow bullock cart traffic up to 200 vehicles, with only occasional cars and no commercial vehicles.	Up to 200	1	10 feet minimum; 12 feet desirable.	Earth, moorum or stabilized soil.	Nil
2	Mainly slow traffic, with a low percentage of motor cars.	201-500	1	12	Water-bound macadam	Nil
3	Slow-moving traffic, mixed with light motor traffic and a few commercial vehicles.	501-750	1	12	Water-bound macadam; bituminous surfacing desirable.	Nil
4	Mixed traffic, with a fair amount of both cars and commercial vehicles.	751-1000	1	12	Waterbound macadam, surfaced. Separate trackways for slow traffic desirable.	Where no trackways are provided, moorum shoulders 3 ft on either side.
5	Mixed traffic as in 4 above.	1001-1500	1	12	Cement concrete or Bituminous carpets depending on the economics of construction.	3 ft. metalled shoulders.
6	Mixed	1501-2500	2	22	(a) Cement concrete.	Nil
			1 + 2	32	(b) Bituminous carpet 12 ft. in the centre, with 2 concrete haunches 10 ft. for slow traffic.	

S. No.	Nature of traffic	Average daily tonnage (tons)	No. of lanes	Width of lane and total width of pavement (feet)	Type of pavement suggested	Shoulders for occasional traffic in lieu of additional lane
			2 + 1	32	(c) Bituminous carpet 22 ft. with one concrete haunch 10 ft. for heavy slow traffic in one direction depending on the proportion of mixed traffic.	
7	Mixed traffic	2501-5000 (exclusive of cycles) Cycle track where cycles exceed 500 at peak hour.	Dual carriageways, each consisting of (a) 1 lane 12 ft. for fast traffic (b) 1 lane 12 ft. for slow traffic (c) cycle track 9 ft. All segregated.		(a) Cement concrete or, Bituminous carpet. (b) Cement concrete. (c) Macadam, surface painted or, thin cement concrete.	Nil Foot paths 9 ft. wide desirable
8	Mixed traffic	Over 5000, exclusive of cycles.	Dual carriageways, each consisting of (a) 2 lanes 22 ft. for fast traffic (b) 1 lane 12 ft. for slow traffic (c) cycle track 9 ft. (d) foot paths 9 ft. All segregated.		(a) Cement concrete or, Bituminous carpet. (b) Cement concrete. (c) Macadam, surface painted or, thin cement concrete.	Nil

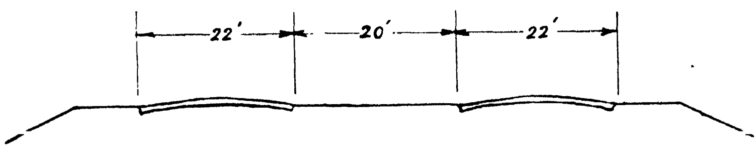
Note: The quantities in the table can be converted to Metric system by putting 1 ft = 0·3048 m and 1 ton = 1·016 mt.

Design problem 17: Write a note on 'Motorway' or 'Express Highway'.

Solution:

A motorway or express highway is defined as a highway reserved *exclusively* for express motor (or fast-moving) traffic which is bound for long-distance journey.

On a road carrying mixed traffic (with large volume of motor traffic), many accidents occur and also a lot of delay is caused to the fast-moving traffic. This can be avoided by segregation of the different classes of traffic. It can also be avoided by segregating the opposing streams of traffic by having dual carriageways with the central dividing strip. By the latter method, one carriageway is reserved for up traffic and the other carriageway is reserved for down traffic and thus the head-on collisions with the traffic from opposite directions are avoided. When these dual carriageways exclude slow traffic and other miscellaneous traffic but carry *only* fast motor traffic, the highway is known as a motorway. In case of motorway, each carriageway should have atleast two lanes of motor traffic and the central strip dividing the carriageways should be continuous i.e. the central dividing strip should not allow change-over of motor traffic from one carriageway to the other. Such an arrangement promotes an efficient long-distance transport. The cross section of a motorway is shown in fig. 122.



Cross section of express highway showing
dual carriageways and central strip
FIG. 122

A motorway should have easy curves of large radius. The curves should have good visibility and should be properly superelevated. Access of cross traffic to a motorway is restricted. The cross traffic of other minor roads does not cross a motorway at any level crossing; the minor roads are negotiated either by fly-overs (i.e. grade-separation crossings) and over-bridges going over the motorway or by sub-ways going below the motorway. This is the essential feature of all motorways. Where some essential cross traffic has to enter the main traffic on the carriageway of a motorway, it must enter in the direction of flow of the main traffic. A motorway is thus a *distinct* type of arterial road which is reserved for high-speed and long-distance traffic *only*. It promotes quick transport and safety against accidents as each carriageway of the motorway allows one-way traffic only.

No ribbon development is allowed along a motorway.

To reduce tractive effort, steep longitudinal gradients should be avoided. The road surface of carriageways should be smooth and skid-proof.

Motorway is the most practical solution of the economics of the long-distance transport along highways. All advanced countries have therefore motorways and further they have new schemes for constructing more motorways. In India, also, a beginning has been made with the construction of a few motorways or express highways.

Design problem 18: Write a note on the structural design of road pavements.

Solution:

(A) General:

So far, mostly, the design of road pavements has been empirical and guided largely by experience and experiment. With the rapid increase in the wheel loads on roads and runways, attention is now directed to the scientific and rational design of the road and runway pavements. Here, the word 'pavement' is used in a slightly different way than its common use. Ordinarily, pavement means the surfacing layer only; but in this article, pavement means the total thickness of road including surfacing, base and sub-base (if any). Thus, pavement includes all the structural layers of road-structure, lying on the sub-grade of the road.

In road-structure, the thickness of each layer should be sufficient to ensure that the layer immediately below is not overstressed. The total thickness of the pavement depends on the magnitude of the applied load, its area of contact with the surface of the road, and the safe bearing capacity of the sub-grade which is of the natural soil in situ. The problem of the pavement-design therefore resolves into:

(i) Treatment to be applied to the natural sub-grade in order to improve its bearing capacity, if necessary.

(ii) The economical design of the pavement in order to exploit fully the properties of materials used in the pavement and to ensure the adequate distribution of the load on the sub-grade.

The fundamental technique by which the properties of natural soils of sub-grade can be improved are: drainage, grading, compaction and stabilization. Of these, the compaction is frequently adopted and the stabilization is occasionally resorted to.

Since the percolation of water has a weakening effect on natural soils, a well-graded soil which can be compacted to a high density (and soil therefore offers maximum resistance to percolation) is the most suitable for the sub-grade. The object of compaction is to improve the desirable qualities of the sub-grade by reducing the voids.

Three of the properties (of sub-grade soils) which are of importance in road and runway construction are:

(i) High shear strength.

(ii) Low permeability and low water absorption.

(iii) Little tendency to settle under repeated loading.

(B) Design of pavement thickness:

The thickness of pavement should be such that no layer of the pavement is overstressed nor is the sub-grade overloaded. Pavement is classified as:

(i) Flexible (or non-tensile) pavement.

(ii) Rigid (or tensile) pavement.

Flexible pavement cannot take tensile stresses caused by load, while the rigid pavement can take such tensile stresses. Flexible pavement consists of stabilized gravel, rolled stone, mixtures of sand and clay, soil and bitumen, soil and lime and, some such materials. This material of flexible pavement may or may not be covered by bituminous surfacing. Rigid pavement consists of a concrete slab which may serve as surfacing layer; in case of superior bituminous road, it may serve as foundation or base layer when it is covered by a bituminous layer on the top. Rigid pavement resists the applied load partly by the development of tensile stress. Mixture of soil and cement is often termed as semi-flexible material and has the load bearing property midway between the properties of flexible and rigid materials. For the flexible pavement, failure usually follows the movement of the sub-grade while for the rigid pavement, the initial crack of the concrete slab is more likely to be the main cause of failure.

There are various methods of design of the flexible and rigid pavements but the following are more rational and hence are widely accepted and used:

(a) California Bearing Ratio (CBR) method for flexible pavement.

(b) Westergaard's modified formulae for rigid pavement.

California Bearing Ratio Method:

The CBR is a property of the sub-grade soil which is measured by an empirical test devised by California State Highways Department, U.S.A. The test is made on a sample of the subgrade soil in a standard loading device which measures the load required to cause 2·5 mm (0·1″) penetration of a plunger (of 4·87 cm or 1·95″ diameter) having cross-section area of 19·36 cm^2 (or 3 in^2). The plunger is made to penetrate the sample at the rate of approximately 1·25 mm (0·05″) per minute until the required penetration of 2·5 mm (0·1″) is obtained. The load on plunger, necessary to get this penetration, is expressed as a percentage of the load (namely 1360 kg or a pressure of 70·3 kg/cm^2) which is required to cause the similar penetration in a standard sample of compacted crushed stone. This percentage is known as CBR of the subgrade soil, the sample of which is tested. The test is also performed for 5 mm (0·2″) penetration at the rate of 1·25 mm (0·05″) per minute and the load on plunger is again expressed as the percentage of load (namely 2040 kg or 105·5 kg/cm²) which is required for similar penetration in a standard sample of compacted crushed stone. The value of CBR for 5 mm (0·2″) penetration is compared with that for 2·5 mm (0·1″) penetration and the higher value is taken as the CBR for the subgrade soil under test. The test, though empirical, gives a comparative measure of the bearing capacity of the subgrade. Greater the value of CBR for subgrade, less the total thickness of pavement necessary to cover it and vice-versa. By the same method, CBR of the soils of sub-base and base can be found out.

For each value of CBR from 0 to 80 %, the combined thickness (in cm) of surfacing layer, base layer and sub-base layer if any, has been recorded as suitable for the wheel loads (e.g. 3180 kg, 4080 kg, 5440 kg, etc. or, 7000 lb, 9000 lb, 12000 lb, etc.) which are likely to be encountered on road or runway. The curves (see fig. 123) are plotted showing the CBR of soils as abscissa and total thickness of pavement (in inches) as ordinate, corresponding to various wheel loads in lb. Knowing the maximum wheel load for the road and the CBR of the subgrade soil, the total thickness of pavement can be obtained from these curves. The thickness of surfacing may then be decided, depending on the type of construction; total thickness minus the thickness of surfacing will give the thickness of base or, base and sub-base if any. The suitable material of suitable CBR is used for base or, base and sub-base. If both the base and sub-base are to be used, the material of sub-base should have higher CBR than that of the sub-grade soil; also the material of base, which comes directly under surfacing, should have higher CBR than that of the sub-base material. In many cases, only base is used. This base may be of uniform material or the base itself may consist of two or three layers to make up the requird thickness of the base. In the latter case, the CBR values of different layers should be in ascending order, the lowest value being of the lowest layer and higher value being of the top-most layer of the base.

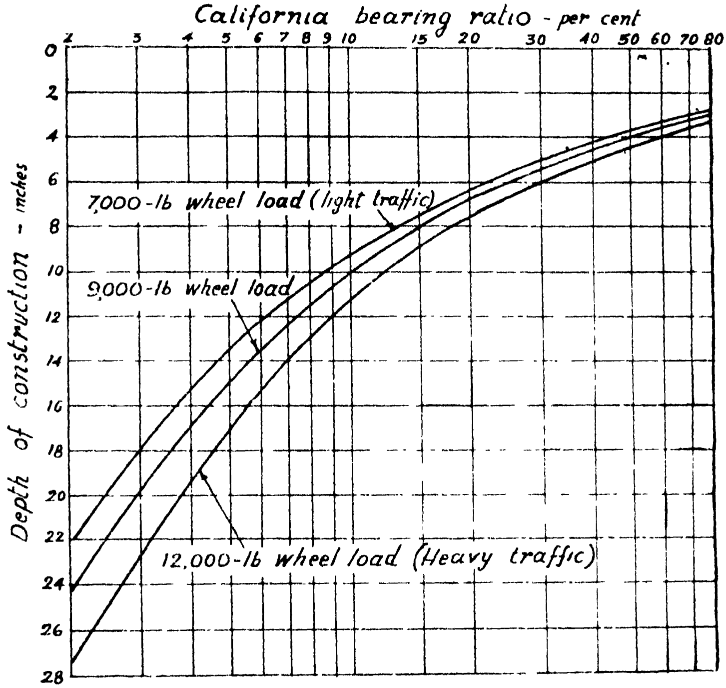


FIG. 123

Instead of deciding the thickness of surfacing layer first, sometimes the materials of given CBR values are given for the sub-base and base. In that case, proceed as follows (see fig. 124):

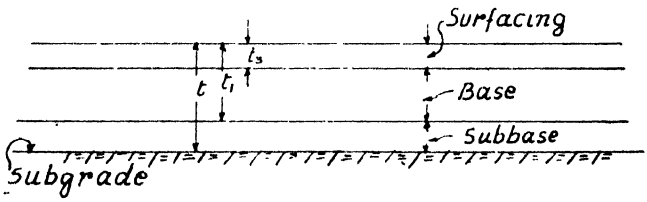


FIG. 124

(i) First find the total thickness t of pavement, corresponding to the given value of CBR for the sub-grade.

(ii) Next find the thickness t_1 of protective cover required to lie over the sub-base of given CBR. Deduct this cover

t_1 from the total thickness t of pavement to get the thickness of sub-base layer of given CBR.

(iii) Finally find the thickness t_3 of the protective cover (namely, surfacing) required to lie on the base of given CBR. Deduct this from the thickness t_1 to get the thickness of base layer of given CBR.

(iv) Thus we have,

thickness of sub-base $= (t - t_1)$ inches

thickness of base $= (t_1 - t_3)$ inches

thickness of surfacing $= t_3$ inches.

$\therefore$ Total thickness of pavement $= (t - t_1) + (t_1 - t_3) + t_3$

$= t$ inches.

Thus, the same curves help not only to know the total thickness of pavement which is to lie on the subgrade but they also help to know the thickness in inches of various layers of the pavement if their CBR values are given. The general design principle to be kept in view is that each layer should be sufficiently resistant to sustain the stress imposed from the layer above and should be thick enough to spread the load sufficiently so as to cause pressure of a value within the safe bearing capacity of the layer below it.

Note: (1) For common sub-grade soils, CBR is usually from 2 to 10%.
(2) For sandy-clay subgrade, CBR = 8%.
(3) For silty-sand sub-base, CBR = 15%.
(4) Any material which has CBR value more than 80% when compacted and which remains stable in presence of water, is suitable for road base. More the CBR value of base material, less the thickness of base and vice versa. Granular material, soil-cement and dry lean concrete are good for the base of a road; usually 15 cm (6″) thickness of these materials is used as a base.

Westergaard Method:

The thickness of rigid pavement (i.e. concrete slab) depends on the following factors:

(i) The properties of the sub-grade soil.

(ii) The weight or tonnage of traffic and the intensity of traffic.

(iii) The use or otherwise of steel reinforcement in the slab.

(iv) The inclusion or otherwise of the base layer between the sub-grade and the concrete slab.

The bearing value of sub-grade soil has little effect on the stresses (due to wheel loads) in a concrete slab when the slab is *uniformly* supported by the sub-grade. The load carrying capacity of a concrete road lies in the structural rigidity of the concrete slab and unless suitable base material can be obtained very cheaply, it will usually be uneconomical to increase the structural strength of the road by the provision of a base. A base is therefore usually used on clay or silt sub-grade to provide a levelling coarse; the thickness of such a base is usually 7·5 cm (3″).

Stresses produced in a concrete slab are due to:

(i) Traffic loads or wheel loads.

(ii) Restrained warping.

(iii) Expansion and contraction of slab due to changes in the temperature and moisture content of the concrete of the slab.

Westergaard has given some formulae to find the suitable thickness of concrete slab so that it may take safely the stresses caused by wheel loads. In this method, a new constant known as the *modulus of sub-grade reaction k* has been introduced. This constant takes into consideration the type of sub-grade. It represents the resistance of the sub-grade to displacement under the wheel load. It is defined as the pressure required to produce on the soil, *in situ*, a deflection or displacement of 2·5 cm (1″) and is measured in kg/cm^2 per cm (or lb/in^2 per inch) of penetration (or deflection or displacement) in the soil of the subgrade. In practice, a 45 cm (18″) diameter plate is put on the sub-grade and loaded to produce a deflection of 1·25 mm (0·05″); modulus of sub-grade reaction is then obtained for 2·5 cm (1″) deflection by mere proportion. Thus, if a load of 1·4 kg/cm^2 (20 lb/in^2) causes a deflection of 0·125 cm (0·05″) in the sub-grade, the value of k for the sub-grade will be $\frac{1{\cdot}4}{0{\cdot}125} = 11{\cdot}2$ kg/cm^2 per cm (or 400 lb/in^2 per inch) of deflection. Value of the modulus of sub-grade reaction k varies from 3·9 kg/cm²/cm (or 140 lb/in² per inch) deflection for silty material to 61·6 kg/cm²/cm (or 2200 lb/in² per inch) deflection for gravel. Corresponding to the formulae given by Westergaard, design curves have been plotted giving the modulus of sub-grade reaction as abscissa and total thickness of rigid pavement as ordinate. If we know CBR for a sub-grade, we can have modulus of sub-grade reaction from curves (not shown) of CBR against modulus of sub-grade reaction; corresponding to this modulus of sub-grade reaction and a given wheel load, total thickness of rigid pavement can be found from curves (not shown) of the modulus of sub-grade reaction against the total thickness of rigid pavement. Higher the value of k, less will be the thickness of pavement.

Design wheel load for the design of flexible or rigid pavement is found as follows:

From the total weight of the heaviest vehicle which is expected to use the pavement, the rear axle load can be worked out; this rear axle load is usually from 60 to 80% of the total weight of the vehicle. Wheel load will be half of the axle load. This wheel load may be on one tyre or two tyres. Usually when the wheel load is heavy, it is taken on two tyres; by so doing, the area of contact between the road surface and tyres will be more and the wheel load will be distributed over greater area of the layers below the surfacing. When the load is distributed over a greater area, these layers will not be overstressed. In general, a wheel load of 3180 kg (7000 lb) is used for the design of an ordinary street pavement; a wheel load of 4080 kg (9000 lb) is used for pavement carrying many heavy vehicles and a wheel load of 5440 kg (12000 lb) is used for a road intended primarily for heavy trucks.

Westergaard formulae:

These formulae are used for calculating stresses in concrete slabs; they are semi-empirical. The assumption is that the *entire* slab is in contact with the sub-grade and that the reactions of the sub-grade are vertical and directly proportional to the slab deflections.

A rigid pavement slab resists deflection not only because of the sub-grade reaction but also because of its own stiffness. The relation between the stiffness of the subgrade and that of the concrete slab is expressed by Westergaard as a linear dimension l which is called the *radius of relative stiffness* of the slab and the sub-grade and is given by the following formula:

$$l = \sqrt[4]{\frac{E\,d^3}{12\,(1-\mu^2)\,k}} \text{ inches}$$

where, E = modulus of elasticity of concrete, in lb/in².

d = *uniform* thickness of concrete slab, in inches.

μ = Poisson's ratio for concrete. It is from 0·1 to 0·2, average value being 0·15.

k = modulus of sub-grade reaction, in lb/in² per inch deflection.

The basic modified Westergaard formulae for tensile stress in concrete slab are as follows:

(i) For protected corner of slab (see fig. 125):

$$S = \frac{3{\cdot}36\,W}{d^2}\left[1 - \frac{\sqrt{a/l}}{0{\cdot}925 + 0{\cdot}22\,\frac{a}{l}}\right] \text{ lb/in}^2$$

where, S = max. tensile stress in lb/in², induced at the top of the slab.

W = effective wheel load, in lb, placed on the corner of slab; it is 20% more than the static wheel load so as to make allowance for the impact.

a = radius, in inches, of circular area equivalent to the area of contact of the tyre (or tyres) with the surface of slab near the corner. This area is said to be loaded by the wheel load.

l = radius (in inches) of relative stiffness of the slab and the sub-grade; its value can be found from the formula already given.

(ii) For unprotected corner of slab (see fig. 125):

$$S = \frac{4{\cdot}2W}{d^2}\left[1 - \frac{\sqrt{a/l}}{0{\cdot}925 + 0{\cdot}22\,\frac{a}{l}}\right] \text{ lb/in}^2.$$

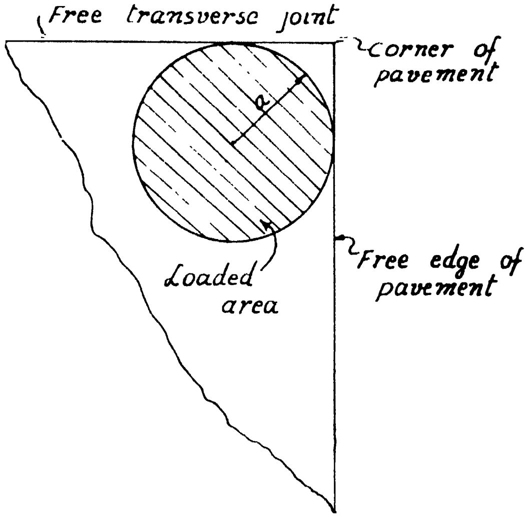


FIG. 125

Note: (1) A corner is said to be protected when it is connected to the corner of the adjoining slab by dowel bars or tie bars so that the load is transferred from one corner to the other; thus, the two adjacent corners help each other in carrying the load and hence the value of S is less as shown in formula (i) above.

(2) When dowel or tie bars are not provided, the corner is said to be unprotected one. In such case, value of S is more as shown in formula (ii) above.

(3) The stress in slab will be critical when the wheel load is near the corner of the slab; hence the formulae for such condition are only considered. Stress will be less when the wheel load is at one edge of slab; it will be still less when the wheel load is at the centre of the slab.

(4) In Metric system, l can be found in cm and S in kg/cm² by using similar suitable formulae.

Design problem 19: The materials described below are available for a road carrying a heavy traffic corresponding to a wheel load of 12000 lb:

Types of material	Intensity of pressure, in lbs/in², causing 0·1″ penetration or deflection	CBR (%)
1. Sub-grade of compacted soil	95	$\frac{95}{1000} \times 100 = 9{\cdot}5\%$
2. Lower layer of base	250	$\frac{250}{1000} \times 100 = 25\%$
3. Upper layer of base	700	$\frac{700}{1000} \times 100 = 70\%$

Determine the suitable thickness of each layer of the base.

Solution: (see fig. 126).

A material of certain CBR requires a certain minimum thickness of construction (or, overlying cover) above it to protect it from failure. Further, as it should be, the material having lower CBR of 25 % is used in the lower layer of base and one having higher CBR of 70 % is used in the upper layer of base.

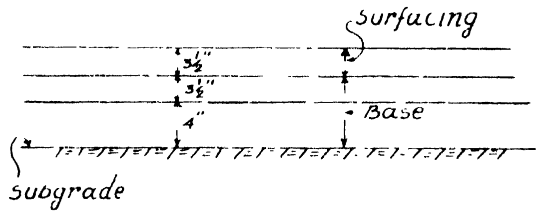


FIG. 126

From curves of fig. 123, for CBR = 70 % and wheel load = 12000 lb, the overlying cover (i.e. surfacing) is obtained as $3\frac{1}{2}''$.

From these curves, for CBR = 25 % and wheel load = 12000 lb, the overlying cover (i.e. surfacing + upper layer of base) is obtained as 7″. Hence the upper layer of base, lying directly below the surfacing, will be $7 - 3\frac{1}{2} = 3\frac{1}{2}''$.

From the same curves, for CBR = 9·5 % and wheel load = 12000 lb, the overlying cover (i.e. surfacing + upper layer of base + lower layer of base) is obtained as $11\frac{1}{2}''$. Hence the lower layer of base, lying directly above the sub-grade, will be $11\frac{1}{2} - 7 = 4\frac{1}{2}''$.

The various layers of the road structure are shown in fig. 126.

Design problem 20: A concrete road slab is to be laid on the sub-grade, the value of k for which is 250 lb/in² per inch deflection. The ultimate strength of the concrete is 3500 lb/in² and the modulus of elasticity E for the concrete is 4 × 10⁶ lb/in². The maximum weight of the heaviest vehicle which will use this road is 23000 lb; 75% of this weight is on the rear axle. There are dual tyres at each end of the rear axle. Find the necessary uniform thickness of the slab when a = 7·5″ for dual tyres and μ = 0·15 for concrete. The corners of the slab are provided with dowel bars for load transfer.

Solution:

Here we have,

$k = 250$; allowable tensile stress $S = \frac{1}{10}(3500) = 350$ lb/in²; $E = 4 \times 10^6$ lb/in²; design wheel load W

$$= \frac{23000 \times \frac{75}{100}}{2} \times 1{\cdot}2 = 10350 \text{ lb}; \; a = 7{\cdot}5''; \; \mu = 0{\cdot}15.$$

Now assume $d = 7''$. Then,

$$l = \left\{\frac{E\,d^3}{12\,(1-\mu^2)\,k}\right\}^{1/4}$$

$$= \left[\frac{4 \times 10^6 \times (7)^3}{12\,\{1-(0{\cdot}15)^2\} \times 250}\right]^{1/4}$$

$$= 26{\cdot}3''.$$

For protected corner,

$$\text{induced } S = \frac{3{\cdot}36W}{d^2}\left[1 - \frac{\sqrt{a/l}}{0{\cdot}925 + 0{\cdot}22\,\frac{a}{l}}\right] \text{lb/in}^2$$

$$= \frac{3{\cdot}36 \times 10350}{(7)^2}\left[1 - \frac{\left(\frac{7{\cdot}5}{26{\cdot}3}\right)^{\frac{1}{2}}}{0{\cdot}925 + 0{\cdot}22\left(\frac{7{\cdot}5}{26{\cdot}3}\right)}\right]$$

$$= 326{\cdot}4 \text{ lb/in}^2.$$

Induced tensile stress is 326·4 lb/in² which is less than the maximum allowable of 350 lb/in²; hence the slab is safe against failure. Also, the induced stress is slightly less than the maximum allowable stress; hence the thickness of 7″ is not extravagant. It is just sufficient. To stress the slab upto 350 lb/in², a slightly less thickness will do. In that case, a second assumption of d less than 7″ (say 6½″) shall have to be made and the induced S worked out again. This S should be less than 350 lb/in². If it works out to be more than 350 lb/in², it will show that 6½″ thickness is less than what is necessary and a little higher value may be assumed, say 6·75″ or better still the thickness of 7″ may be kept.

Design problem 21: Work out problem No. 20 when $E = 21 \times 10^4$ kg/cm², all other data remaining the same, but in the equivalent Metric units.

Design problem 22: Work out problem No. 20 when $k = 5{\cdot}6$ kg/cm² per cm deflection, all other data remaining the same, but in the equivalent Metric units.

Design problem 23: Work out problem No. 19 when it is decided to have surfacing layer of 3½″, upper layer of base is to be kept as 3½″ thick and the layer of base is to be kept as 3″ thick.

Hint:

Here the total thickness of pavement $= 3\frac{1}{2} + 3\frac{1}{2} + 3$
$= 10''$.

For thickness of pavement = 10″, find the required CBR of the sub-grade. Improve the existing sub-grade till its CBR of 9·5 % rises to the required CBR corresponding to the total overlying cover of 10″

For CBR of 70 % of the upper layer of base, 3½″ of surfacing is sufficient. Similarly for CBR of 25 % of the lower layer of base, 3½″ thickness of the upper layer is sufficient.

CHAPTER XXIV

METRIC SYSTEM OF UNITS
IN
ROAD ENGINEERING

1. Introduction: Indian parliament passed a bill on the 8th December 1956 to introduce in India the new or rationalized Metric (i.e. M.K.S.) system of units from the year 1958. According to this form of Metric system, the unit of length is *metre*, unit of mass is *kilogram* and unit of time is *second.*

So far, in India, we were using British (i.e. F.P.S.) system of units. According to this system, the unit of length is *foot*, unit of mass is *pound* and unit of time is *second.*

In India, the M.K.S. form of Metric system has already been started in various fields of activity of man. For a transition period of a few years, *both* the systems have *necessarily* to be used side by side with each other. After this period, complete switch-over is possible to the Metric system of units.

2. Physical quantities and their units: In the table given below a few physical quantities, of use in Road Engineering, are given. For these quantities the units, to be used in both the F.P.S. and M.K.S. systems, are given. Also the conversion factors are given in brackets; by means of these factors, units can be converted from F.P.S. system to M.K.S. system and vice versa. Thus, in the table, the unit of length in F.P.S. system is shown as 1 foot; it is also clear from the brackets that 1 foot = 0·3048 metre. Similarly, the unit of length in M.K.S. system is shown as 1 metre; it is also clear from the brackets that 1 metre = 3·2808 feet.

Table showing physical quantities and their units

Quantity	System of units F. P. S	 M.K.S.
Length	Foot (0·3048 m) Inch (2·54 cm) Mile (1·6093 km)	Metre (3·2808 ft.) Centimetre (0·3937 in.) Kilometre (0·6214 mile) Note: 1 km = 10 hectometres (hm).
Area	Square foot (0·0929 m^2) Square inch (6·452 cm^2) Square mile (2·59 km^2) Acre {0·4047 ha; 4047 m^2}	Square metre (10·7639 ft^2) Square centimetre (0·155 in^2) Square kilometre (0·386 sq.mile) Hectare (2·471 acres) Note: 1 hectare (ha) =0·01 km^2=10000 m^2.
Volume	Cubic foot (0·02832 m^3) Imperial gallon (4·546 l) Note: 1 ft^3 = 6·24 imp. gal. 1 acre-foot = 0·1234 ha-m.	Cubic metre (35·314 ft^3) Litre (0·22 imp. gal. 0·0353 ft^3) Note: 1m^3=1 kl=1000 lit 1 hectare-metre =8·104 acre-feet.
Weight	Pound (0·4536 kg) Ton (1·016 mt) Note: 1 cwt=50·8 kg$\simeq\frac{1}{2}$ q	Kilogram (2·2046 lb) Metric tonne (0·9842 ton) Note: 1 mt=1000 kg = 10 quintals (q).
Weight Density	Pound per cu. foot (16·019 kg/m^3)	Kilogram per cu. metre (0·06243 lb/ft^3)
Velocity	Foot per second Mile per hour	Metre per second Kilometre per hour
Acceleration	Foot/sec^2	Metre/sec^2 Note: g = 9·81 m/sec^2.
Discharge	Cu. foot/sec Gallon/sec	Cu. metre/sec. Litre/sec
Pressure or, Force per unit area	Pound per sq. foot {47·88 Nw/m^2; 4·882 kg/m^2} Pound per sq. inch (0·0703 kg/cm^2 Ton per sq. foot (10·937 mt/m^2	Newton per sq. metre (0·02089 lb/ft^2) Kilogram per sq. centimetre (14·22 lb/in^2) Metric tonne per sq. metre (0·0914 ton/ft^2 Note: 1 kg/m^2 = 0·2048 lb/ft^2.
Work	Foot-pound {1·3565 m-Nw; 0·1383 m-kg}	Metre-Newton (0·7376 ft-lb) Note: 1 m-kg=7·233 ft-lb.
Bending moment	Foot-pound (0·1383 m-kg) Inch-pound (1·15 cm-kg)	Metre-kilogram (7·233 ft-lb) Centimetre-kilogram (0·8676 in-lb)

3. Suggested Metric units: Until the Metric units for various materials or trades, used in Road Engineering, are finally standardized and adopted by Indian Roads Congress, the Metric units in the following table are *suggested* to be used for the materials/trades shown against these units. *The suggestions are based on the practical utility and feasibility.*

TABLE

Material/trade	F.P.S. units used at present	Suggested unit in Metric system
Concrete	ft^3	m^3
Cement	cwt	q
Steel	lb	kg
Road metal (size)	inch	mm
Gravel (size)	inch	mm
Brick (all dimensions)	inch	cm
Stone block (all dimensions)	inch	cm
Pipe:		
(a) length	ft	m
(b) other dimensions	inch	cm
Gutter:		
(a) length	ft	m
(b) other dimensions	inch	cm
Earthwork	1000 ft^3	10 m^3
Expansion joint:		
(a) length	ft	m
(b) width	inch	mm

Note: (i) For working out quantities of all materials, length, area and volume may be measured correct to 0·01 m, 0·01 m^2 and 0·01 m^3 respectively.

(ii) For working out quantities in earth work, the length, area and volume may be measured correct to 0·1 m, 0·1 m^2 and 0·1 m^3 respectively.

CHAPTER XXV

ROAD RESEARCH

1. 'Oh Research! I am in your search.'
— *Gautam Budha*
2. 'Nothing is so difficult that it may not be found out by research.' — *A Scientist*

1. Introduction: Oxford Dictionary defines research as 'careful search or inquiry'. Yes, research is an endeavour to discover *new* facts by scientific study of a subject. It is a course of critical investigation. Indeed, man is a thinking animal. His intelligence begins to have doubts and hence he tries to question the universe, he explores its secrets and finds out the hidden meaning.

Is such a critical study and investigation *always* fruitful? Unfortunately, not. *But it does not matter.* The research scholar should do research work out of keen desire for research. The end may be kept in view *but the chase is all that matters.*[1] This view point is also stressed in all ancient scriptures and the ancient wisdom says quite emphatically, "Work for the work and let not the idea of fruit unnerve and unsettle you."

In this sense, research is 'nishkam karma' and research scholar is a true and enlightened 'karma yogi'.

2. Research — why?: They say: "*Necessity* is the mother of invention." Quite so.

Once upon a time there was a young sanskrit pundit (i.e. scholar) who was well-versed in all the ancient scriptural literature but who could not carry on smoothly with his young, good and sensible wife. As a consequence, there often used to be (between the couple) hot words and hotter discussions which invariably resulted in frayed tempers, A wise neighbour, who used to watch this bad show, once advised young pundit to try hard and know the virtues of woman whom our good God, certainly, did not create out of mere idleness or wrong judgement. He also indicated, to pundit, the literature to be explored for that purpose. The pundit took that advice seriously and did a lot of reading on the indicated subject. He investigated, explored, analysed and wrote a big size treatise which, in modern language, is known as dissertation or thesis. The synopsis of his *praiseworthy* treatise read as under:

'Woman has the beauty of flowers, the charm of full moon, the song of cuckoo, the colours of rainbow, the coolness of breeze, the laughter of gurgling brook and the gentleness of lamb. She is sister or daughter and she is wife; ***but, above all, she is mother.*** For man, she is God's greatest blessing, bliss, fortune and joy. Indeed, woman is a worthy object of praise and divine perfection on our good Earth.'

And it is said that after this much-wanted research done by the young sanskrit pundit, all sweetness prevailed in his home. He and his good wife lived happily, thereafter.

Necessity impelled the sanskrit scholar to do research which indeed paid the young couple rich dividends. This day, thousands of research workers are engaged in various types of study in India and elsewhere. Surely, there is a necessity for it and these research pundits are motivated by this necessity.

3. Who is a research scholar? Said poet Keats:

"Beauty is truth, truth beauty — that is all,
Ye know on Earth, and all ye need to know."

A research scholar is after finding some truth (about some thing) and since truth is beauty, the research scholar is truly a *seeker* of truth and beauty. He is therefore a high-grade man. Verily, it is so!

4. Qualifications of a research scholar: A good research worker should be one with a missionary zeal and he should have a very active, enterprising and inquisitive mind. He must have keenness of observation. He should be very eager to explore and know something *new*, with the basic idea of being more helpful to the society around him. He has always in mind that his findings may be of some use to men, women and children. He constantly desires that his research work may make their burden a little lighter, the odd circumstances a bit easier and their life somewhat sweeter.

Infact, research (scientific, engineering or of any kind) may be defined as a careful investigation which is solely undertaken *for the benefit of mankind.* Such a high and praiseworthy ideal in life requires a very hard labour and relentless effort on the part of every research worker.

5. Method of Research: One wise guy has said, and rightly too, "Even in one's madness, there should be a method." Therefore it stands to reason that for conducting a difficult (and at the same time noble) job of research, a certain well-defined method or technique should be followed. This method is outlined below in the good hope that it may prove helpful to the prospective research workers:

(i) First of all, the research worker should define very carefully the object of his study. This object of study should preferably be one about which less is so far known and more is yet to be known. The object of study should also be one which the research worker literally loves. For, then only, can he set his heart on the object of his study. Once the heart is set and attached, it will release a tremendous amount of energy to do the hard labour involved in doing research. It is therefore obligatory to spend some time in choosing the object of study. It will be comparatively easy to define the research problem if the necessity, utility and ultimate aim of the research are kept in view.

(ii) After choosing the object of study, it is incumbent for research workers to indulge in very wide and extensive reading of all available literature (in form of text books, technical papers, journals, etc.) on the subject so as to collect the most uptodate information which already exists on the subject. More study of this sort should continue throughout the research period.

(iii) The effort of research worker shall have to be persistent, continuous, pretty hard and sincere. He can ill-afford to work by fits and starts, or to put in a half-hearted attempt. He should preferably chalk out a tentative monthly programme of his work, well in advance.

(iv) The research worker will, very carefully, analyse the data collected by him and shall have to do a lot of hard and *reflective* thinking to find out something *new and useful.*

(v) From time to time, the research worker may have to resort to experimentation in a well-equipped and modern laboratory so as to test the correctness of his new ideas.

(vi) The research worker should be a well-read man. Above all, he should know the *modern* methods and techniques of attacking his research problem.

(vii) He should not isolate himself from other research workers in the *same* field of work and he should often compare his notes with them either by correspondence or by personal contact or by both.

(viii) He should be virtually wedded to his work.

(ix) But this does not mean that a research worker shall be a narrow specialist, knowing only about one topic under the sun. He should not have a one-track mind. The author is reminded of a glutton (i.e. specialist in over-eating) who, at one interview, was asked to add two to three; and this specialist replied, with a lot of satisfaction: "Two and three make five *loaves*, sir. *Only* five loaves."

Perhaps some absent-minded and narrow specialist on Road Research may say: "Two and three make five kilogrammes of *road tar!*"

(x) To strike a balance, it is absolutely necessary for a research worker to do sufficient *general* reading *as well* so that if need be, he can take intelligent part in discussion on topics in the fields of economics, politics, sociology, civics, current history, literature and art. And, if on some occasions, he cannot quote a line from Shakespeare or Shelly, Brown or Byron, Tagore or Iqbal, he should not be called an *accomplished* research worker. This general reading, in addition, refreshes the mind and gives it necessary vigour and resilience which are *badly* needed by a research worker.

Infact, in the interests of fruitful research itself, it is necessary that he has had sufficient general reading and that he knows enough about life and living. Therefore, in his spare time, let the research worker arm himself with this *useful* weapon and tackle his research problem with vigour, fresh mind and two-pronged attack. A boxer who uses *only* his right fist is a *mere* pugilist. But the one who gives *both* the right and left knocks, in quick succession, is likely to be declared a champion!

6. Road Research: Having known the definition and scope of research and also the requirements for it, it should be easy to define road research. It is a research in which the *broad* object of study is road. This study is undertaken by a road research worker *for the benefit of mankind.* It was indeed an exhilarating experience for the author to enter the very first capacious hall of the Central Road Research Institute (CRRI), New Delhi and read on the opposite wall:

> 'Did you meet him on the road,
> Did you lighten some of his load?'

Verily, such slogans and mottoes touch one's heart, they warm it and make it throb much better. One does not know, how many other research stations on our good Earth have this *very apt* meaning of research written on their walls. Indeed, the function of research is to make the burden of our fellow-travellers a little lighter and their life a little better.

7. Road research organisations in India: The main object of any road research organisation (like CRRI, New Delhi) is to study problems which arise in design, construction and maintenance of roads. The significant aims are as shown below:

(i) To reduce the cost of construction and maintenance.

(ii) To make the roads durable.

(iii) To cut down the time for construction, by evolving suitable road-making equipment.

(iv) To promote traffic safety.

(v) To ensure comfort in travel on roads.

To cut down road accidents and to promote speedy, comfortable and cheap travel, constitute the best types of social service known to mankind and it is heartening to know that the road research organisations are engaged in such humanitarian work.

Following are some of the road research organisations in India:

(a) Central Road Research Institute, New Delhi-20. This institute is situated at 7th mile of Delhi-Mathura road and is near Okhla. Its foundation stone was laid on 6th September 1950 and it was formally opened by late Prime Minister Jawahar Lal Nehru on 16th July 1952. The head of the institute is known as Director. At present, Prof. S. R. Mehra is the Director. He is assisted by a Deputy Director.

The institute is divided into seven research divisions as shown below:

(i) Soils division.
(ii) Rigid pavements division.
(iii) Flexible pavements division.
(iv) Roads (general) division.
(v) Traffic engineering, Economics & Statistics division.
(vi) Bridges division.
(vii) Workshop division.

Each division is headed by an Assistant Director. He is assisted by the requisite number of Senior Scientific Officers (SSO), Junior Scientific Officers (JSO), Senior Scientific Assistants (SSA) and other technical members of staff.

CRRI is indeed a *premier* road research organisation in India and it has been rendering much valuable service to highway departments of various States, Municipal Corporations of many cities in India, Traffic Authorities of big cities which have complicated traffic problems and to various other bodies connected with road work.

CRRI has, by now, published *many* research papers and other technical literature (connected with roads) which are worth studying as they show research results, keeping in view the local conditions, local soils and road materials, local climate, local traffic, etc. The research conducted in this institute is both fundamental and applied.

In addition, CRRI has been providing training and refresher courses for practising road engineers so as to keep them acquainted with the latest techniques and developments in road engineering. Short term training in Road Engineering is also given to the teachers and students from engineering colleges in India.

(b) Besides the CRRI New Delhi, there are road research stations and laboratories in some States of India. Only three of them are shown below:

(i) Highway Research Station, Guindy, Madras.

(ii) Building and Road Research Laboratory, Karnal, Punjab.

(iii) Roads and Building Research Institute, Alipore, Calcutta.

These laboratories and a few more which exist in some other States, strive hard to give techniques for cheaper, better and safer roads. The author has been regularly getting some publications of Highway Research Station Madras and he finds the work, done by this station, to be of really good quality and standard.

8. Road Research review in India:

The research stations in States give the review of the research work done by them, in their periodical publications.

CRRI also publishes its Annual Report which gives the activities of all the research divisions of this institute, during the year under review.

Indian Roads Congress (I.R.C.) New Delhi, in its journal, publishes a yearly feature by title 'General report on road research in India'. In this feature, is highlighted the road research work done during the year under review, by *all* the road research organisations in India.

9. Road Research—a global review:

A few years back, Indian Roads Congress (I.R.C.) requested Road Research Laboratories in the various countries of world to send brief accounts of road research as it was being carried out in those laboratories. The following 19 countries supplied such information:

U.S.A., Australia, Brazil, Canada, Czechoslovakia, France, India, Japan, Mexico, Netherlands, New Zealand, Norway, Pakistan, Poland, Spain, Sweden, Switzerland, Turkey and UAR.

All road research workers will be very much benefited by study of the brief information sent by these 19 countries to I.R.C. This information was published by I.R.C. in 1964 and it runs in about 34 pages. After this preliminary study, the road research workers can get further information on any particular topic of their interest, by carrying on correspondence with the pertinent road authorities of these countries. It will surely be a fruitful study.

10. Gautam Budha—the greatest research scholar:

Blessed Sidhartha (this was Budha's personal name) was perhaps the best research scholar that our World has ever known.

It was all dead silence. His darling wife Yasodhara was fast asleep. Sidhartha rose up for, the distant stars were calling him. Before leaving his house on unknown journey, he desired to have the last full look at those fond sleeping eyes. The entire scene was so grim, so sad, so pathetic! The learned prince bent low and, with his brow, he touched very tenderly Yasodhara's feet; he bade farewell to his sleeping queen and their *unborn* babe in womb. Then, he started to go. The great sanskrit scholar, Sir Edwin Arnold, records in 'The Light of Asia':

'And thrice prince made to go, but thrice came back,
So strong the sleeping Beauty was, so large his love:
Then, over his head, drawing his cloth, he departed!
His tearful eyes raised to the stars, and lips
Close-set *with purpose of mankind's welfare.*'

It was at this historic moment that the blessed Sidhartha —the greatest yogi—uttered: "Oh Research! I am in your search".

Thus spoke Sidhartha—the Saviour of the World:

> 'Now the hour is come when I should quit
> To find the truth; which henceforth I will seek,
> *For all men's sake*, until the truth is found.'

And he did make wonderful and abiding research and his findings have benefited humanity at large, through all these hundreds of years and shall continue to do so. To mention *only three* of his findings:

(i) It was Gautam Budha who explained lucidly and forcefully the 'theory of cause and effect'. The enlightened yogi said: "Know ye men that every cause has a corresponding effect. A *good* cause has *good* effect and a *bad* cause has a *bad* one. If we do not want bad effect, the only thing which we have got to do is to remove the bad cause. Our *entire* life is rigidly governed by this basic theory".

And scientist Newton, *much later*, put this basic theory of cause and effect in scientific language when he said: "Every action has a corresponding reaction which is just equal and opposite." And how could there be reaction if we take away the action?

(ii) It was again Gautam Budha who, *very convincingly*, enunciated a marvellous theorem namely:

"Truly artistic living is, above all, a *balanced* living. Let, therefore, all earthly beings follow the life of *moderation*, middle path or golden mean."

And on this basic theory of moderation, was *subsequently* built (by a great economist) the well known economics principle of 'Marginal Utility'.

(iii) It was also Gautam Budha who said like a great mathematician and a man of great vision:

"Love is an *integrating* force; it increases our power. Hate or *differentiation* decreases our power."

And have not the *later* mathematicians shown in integral calculus that the *integration* of a quantity invariably *increases* its power? Thus:

$$\int x = \frac{x^2}{2}$$

$$\int x^2 = \frac{x^3}{3}$$

$$\int x^3 = \frac{x^4}{4}, \text{ and so on.}$$

This shows that, *because of integration*, the power of x goes on increasing.

Similarly these mathematicians have shown in differential calculus that the *differentiation* of a quantity invariably *decreases* its power. Thus:

$$\frac{d}{dx}(x^4) = 4x^3$$

$$\frac{d}{dx}(x^3) = 3x^2$$

$$\frac{d}{dx}(x^2) = 2x, \text{ and so on.}$$

This shows that, *because of differentiation*, the power of x goes on decreasing.

Thus, many of the *basic* thoughts of Gautam Budha have been translated by scientists, economists, mathematicians, etc. in their own language and notation and, they find applications in various fields of man's activity.

Every research worker will do well to read extensively the life and work of Gautam Budha who was the *original* and *reflective* thinker. He was indeed research scholar of high repute. And before starting on his *noble* mission of research, let the research worker exclaim, like Budha, "Oh Research! I am in your search."

11. The curtain drops:

Before closing this chapter on Road Research, the author feels like putting his *personal* views and convictions as under:

(a) The work done by CRRI is *really fine*. Special mention may be made of the *significant* work done by Soils division and Traffic engineering division.

A new soil-stabilization technique for low-cost road construction has been evolved by Prof. S. R. Mehra—the present Director of CRRI. This method is popularly known as 'Mehra method of soil-stabilization'. It provides a *cheap* alternative to W.B.M. road and has been successfully tried in some rural areas of various States in India.

Likewise, the members of Traffic Engineering division have sampled traffic statistics of some of the big cities in India and, concrete suggestions to cut down the road accidents and to make the congested roads safe for travel have been outlined. Such statistical studies will go a long way to help in solving the complicated traffic problems which have now come to the forefront and need *immediate* suitalbe solutions in most of the congested cities of India.

(b) Looking to the present-day road problems in India, the CRRI would do well to strengthen the above-said two divisions, still further, so as to have still greater benefits for mankind.

(c) Perhaps, it is also the time for CRRI to introduce one *new* division entitled 'Metric Standards' division. The work of this division will be to coordinate the work of other seven divisions in F.P.S. system, and disseminate this information in Metric system. With India's adopting the Metric system of units since 1958, this is a clear and urgent necessity.

(d) *Good work never dies.* Hence, a good research is of *enduring* value. A good research worker will be remembered by the public, with enough love and esteem, long after he is dead and gone. This love and esteem, of generations to come, is indeed a *matchless prize* which every research worker should endeavour to bag.

APPENDIX

IN WHAT FOLLOWS, THE GEOMETRIC ROAD STANDARDS (PREVALENT IN INDIA) ARE GIVEN IN A TABULAR FORM. THESE STANDARDS ARE ACCORDING TO THE INDIAN ROADS CONGRESS PRACTICE AND ARE TAKEN FROM THE PUBLICATIONS ISSUED BY I.R.C.

ROAD STANDARDS

Classes of highways		Village Road	Other District Road	Major District Road		State Highway	National Highway		
1. Design capacity	Traffic classification	Very light	Light	**Medium** A	B	Heavy	**Very** A	**heavy** B	C
	Average daily tonnage	Upto 200	201 to 500	501 to 750	751 to 1000	1001 to 1500	1501 to 2500	2501 to 5000	Over 5000
2. Number of traffic lanes for each class of highway	Traffic classification	Very light	Light	**Medium** A	B	Heavy	**Very** A	**heavy** B	C
	No. of lanes	1	1	1	1	1	2 or 3*	4-lane divided	6-lane** divided

* In addition, 9 ft. wide cycle track on each side, where required.
** In addition, 9 ft. wide cycle track and 9 ft. wide foot path, where required.

	National Highway	State Highway	Major District Road	Other District Road	Village Road
3. Design speed in miles per hour (a) Flat and rolling topography	50	50	40	30	20
(b) Mountainous topo raphy	30*	30*	25*	20	15
4. Pavement width per traffic lane	..................12 ft. per lane..................			10 ft.; desirable 12 ft.	10 ft.; desirable 12 ft.

* Where practicable.

5. Min. width of shoulders (a) Flat and rolling topography (b) Mountainous topography	Not specified							

6. Width of roadway in ft.	NH	SH	MDR	ODR	VR
(a) Flat topography	38	32	24	24	16
(b) Rolling ,,	38	32	24	24	16
(c) Mountainous ,,	26	26	22	22	14
7. Side slopes of road embankment and cutting	Not specified				

8. Minimum width of right-of-way	Class of road	Open areas and agricultural country: Width of road land, Normal ft.	Open areas and agricultural country: Width of road land, Range ft.	Open areas and agricultural country: Building lines (overall width) ft.	Open areas and agricultural country: Control lines (overall width) ft.	Urban (built-up) and industrial areas: Width of road land, Normal ft.	Urban (built-up) and industrial areas: Width of road land, Range ft.	Urban (built-up) and industrial areas: Building (or set back) line width of strip beyond road boundary ft.
	1	2	3	4	5	6	7	8
	NH & SH	100	100-200	200	440	80	80-200	10-20
	MDR	80	80-100	160	300	40	40-60	10
	ODR	40	40-80	80	120	30	30-50	—
	VR	40	40-60	80	100	30	30-50	—

9. Road camber or cross fall	
(a) Water-bound macadam road	(a) 1 in 48 1 in 36 in heavy rainfall regions
(b) Black top ,,	(b) 1 in 60
(c) Concrete ,,	(c) 1 in 72
(d) Shoulders	(d) 1 in 48 (Earth)

10. Gradient maximum	Ruling	Limiting	Exceptional	
(a) Flat topography	(a) 1 in 30	1 in 20	1 in 15	
(b) Rolling topography	(b) 1 in 30	1 in 20	1 in 15	
(c) Mountainous ,,	(c) 1 in 20	1 in 15	1 in 12	
	Lengths in exceptional gradients should not exceed 300 ft. in a mile.			
11. Max. length of road permissible with grades (a) 3 to 4 per cent (b) More than 4 per cent of	Not specified			
12. Minimum distance between brake points of grades	Not specified			
	Design speed	Minimum overtaking sight distance: Divided carriageway	Minimum overtaking sight distance: Un-divided carriageway	Stopping sight distance
13. Sight distances (stopping and overtaking)	m.p.h.	ft.	ft.	ft.
	50	850	1550	400
	40	550	1000	300
	30	350	600	200
	25	250	450	160
	20	200	300	120
	15	—	—	90
Increase in sight distance on down-grade Decrease on upgrade	Increase and decrease in sight distance due to grades not specified.			

	Design speed	Plain and rolling topography: Ruling	Plain and rolling topography: Absolute maximum	Mountainous topography: Ruling	Mountainous topography: Absolute minimum
14. Minimum radius of horizontal curve	m.p.h.	ft.	ft.	ft.	ft.
	50	1,000	800	—	—
	40	800	500	—	—
	30	500	300	400	300
	25	—	—	300	200
	20	300	150	200	150
	15	—	—	150	100

15. Minimum length of transition curve	Design speed in m.p.h.	15	20	25	30	40	50
	Min. length of transition curve in ft.	50	50	50	50	75	100

16. Extra width of carriageway on curve	Radius of curve in ft.	Upto 200	201-500	501-1000	1001-1500	Above 1500
	Extra width in ft.	4	3	2	1	Nil

17. Superelevation (a) When necessary	Design speed m.p.h.	(a) Radius of curve (in feet) less than: W.B.M. 1/36 cross fall	W.B.M. 1/48 cross fall	B.T. 1 in 60 cross fall	C.C. 1 in 70 cross fall
	15	300	400	500	600
	20	550	700	900	1000
	25	850	1100	1400	1700
	30	1200	1600	2000	2450
	40	2150	2900	3600	4300
	50	3400	4500	5600	6750
(b) Rate of superelevation	(b) $3v^2/80R$, with maximum of 1 in 15. v = speed in m.p.h., R = radius in feet.				

18. Minimum distance between two serpentine curves	Not specified							
19. Minimum radius of vertical curve:	Design speed m.p.h.	15	20	25	30	40	50	60
(a) Summit or convex curve.	(a)	195	350	540	780	1380	2160	3110
(b) Valley or concave or sag curve.	(b) Min. radius should be such that the rate of radial acceleration doe; not exceed 2 ft/sec^2.							
20. Design standards for hairpin bends: (a) Maximum radius of basic curve (b) Minimum crossfall (c) Minimum length of transition curve (d) Extra width of carriageway (e) Maximum grade (f) Maximum speed	Not specified							
21. Minimum clearance								
(a) Horizontal	(a) —							
(b) Vertical	(b) 16 ft. 6 in.							

22. **Bridges:**		
(a) Loading	(i) Single lane of I.R.C. Class 'AA' loading, checked for 2 lanes of I.R.C. class 'A' loading.	Within certain municipal limits in certain existing or contemplated industrial areas, and along certain specified highways.
	(ii) I.R.C. Class 'A' loading for permanent bridges and culverts in other localities.	
	(iii) Temporary bridges: I.R.C. Class 'B' loading.	
(b) Minimum width between wheel guards	(b) 12′ for single lane bridge; 22′ for 2-lane bridge; 24′ on National and State highway bridges.	
23. (a) Axle load	(a) 18000 lb.	
(b) Max. permissible wheel load	(b) 9000 lb.	

Note: With the help of tables on Metric system given in chapter XXIV, the above-said road standards in F.P.S. system may be converted to Metric system and rounded off.

SYLLABUS IN ROAD ENGINEERING

(*a*) **Administration and finance:** Early roads; road development in India.

Road classification: Inter-provincial, provincial, district and village roads. Town roads and municipal streets.

Road widths and traffic lanes.

Road authorities: Provincial Governments, District Local Boards, Municipalities. Transport Advisory Council. Provincial Boards of Communication. Regional Transport Authorities.

Petrol tax fund, provincial road fund, road tolls, wheel tax.

Financing for road improvement; evaluation of road benefits. Traffic operation costs and the effect of road conditions and traffic delays on these.

(*b*) **Alignment of roads:** Relative importance of length of road, height of bank, depth of cutting, road grades, cross-drainage works, value of land, nearness to quarries and sources of water supply in alignment. Traffic arteries, bye-pass roads. Main shopping or business streets; special types of roads. Road tunnels. Sub-grades, road foundations and road surfacings; under-drainage; camber; gradients.

Masonry cross-drainage works.

Hill roads. Road arboriculture.

Curves: Simple, compound, parabolic, spiral, and leminiscate. Widening of roads and super-elevation on curves; vertical curves; sight distance; road intersections and crossings.

(*c*) **Road surfacings:** Earth roads and their stabilisation.

Sand-clay, gravel and moorum roads; kankar, laterite and broken-stone roads. Waterbound Macadam and Telford roads. Testing of road metal.

Effect of grading of metal; consolidation with power-driven rollers and bullock rollers; bindage and blindage.

Modernisation of roads; surface painting, semi-grouting, grouting with tar and bituminous compounds. Premix with tar and bituminous carpets; seal coats. Cold treatment with bituminous emulsions. Asphalt, tar and asphalt mixtures. Testing of tars and asphalts.

Cement concrete roads: All-concrete slab — section and reinforcement; cement macadam, colloidal concrete, bonded concrete roads. Joints, dowel bars.

Paving with stone setts, bricks, wood blocks etc; special roads; cycle tracks.

(*d*) **Road repairs and maintenance:** Waves, corrugations, creep. Maintenance of all types of roads.

(*e*) **Road plant and machinery:** Graders, drags, scarifiers, scapers, road rollers, tar and asphalt boilers, sprinklers, mixers, screeders, vibrators, road drills, etc.

(*f*) **Traffic engineering:** Traffic problems—Traffic census, cross traffic, inadequate road space, waiting vehicles, slow-moving vehicles, vehicles of large size, pedestrians, peak-load periods. Segregation of traffic.

Traffic control: Width, layout, camber, gradient, surface, curves, corners and sight lines; kerbs, refuges and islands; lighting of roads; parking spaces; means of ingress and egress of road-side premises; restriction of ribbon development; junctions and intersections, round-abouts, fly-over junctions.

Foot paths, guard rails, foot-crossings; subways and overbridges for pedestrians; cycle tracks.

Traffic signs: Standard warning signs, prohibitory signs, mandatory signs, informative signs, white lines.

(*g*) **Road specifications.**

(*h*) **Preparation of road projects.**

(*i*) **Road economics.**

(*j*) **Elements of Airport Engineering.**

(*k*) **Earthwork computations.**

(*l*) **Problems and designs in road engineering.**

(*m*) **Road Research.**

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