CIVIL ENGINEERING

Highway Engineering

Comprehensive Theory
with Solved Examples *and* Practice Questions

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Highway Engineering

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1

Introduction

1.1 TRANSPORTATION

Transportation is the movement of goods and persons from place to place and the various means by which such movement is accomplished. The importance of transportation in the development of a country is multidimensional i.e. economic, industrial, social and cultural development of any country. Transportation is vital for the economic development of any region, since every product produced such as food, clothing, industrial products or medicine needs transport at all stages from production to distribution. The inadequate transportation facilities retard the process of socio- economic development of a country. All human beings are interacting over distance and time for food, shelter, work, business, recreation and security. All agricultural and industrial raw materials, products and equipment's are needed to be transported from one place to other place to other place.

1.2 TRANSPORTATION ENGINEERING

Transportation engineering is a branch of civil engineering that involves planning, designing, operating, and maintaining transportation systems to help build smart, safe, and livable communities. Any system that moves people and goods from one place to another falls under the scope of transportation engineering, which includes:

- Highways and roadways
- Railways
- Oil pipelines
- Public transport systems
- Traffic control systems
- Automated transport systems
- Space transport systems

The three basic mode of transports are:

(*i*) Land: Road Transport, Railway Transport

(*ii*) Water: Water ways

(*iii*) Air: Airways

1.3 HIGHWAY ENGINEERING

The planning, designing, construction and maintenance of road and roadway facilities and necessity of road traffic are covered under Highway Engineering. Highway engineering deals with the following broad elements:

(*i*) Planning and Location
(*ii*) Alignment selection and Geometric design
(*iii*) Pavement design
(*iv*) Materials, Construction and Maintenance
(*v*) Traffic operations and it's control
(*vi*) Economics, Finance and Administration
(*vii*) Environmental and Social aspects

Scope of Highway Engineering

PHASES	DETAILS
Development, Planning and Location	Historical background; Basis for Planning; Master Plan; Engineering surveys and highway alignment.
Highway Design, Geometrics and Structures	Road Geometrics and their Design; Rigid and Flexible Pavements; Design factors and thickness design; Overlay design; Design of drainage system.
Traffic Performance and its Control	Traffic studies analysis; Need for new road links; Traffic regulation and control; Intersection design and their controls with signs, signals, islands and markings.
Materials, Construction and Maintenance	Highway Materials and mix design; Highway construction; Earth work, construction of different types of pavements; Earthen, soil stabilized, water bound macadam, bituminous surfaces and cement concrete roads; pavement failures; pavement evaluation, maintenance of pavements and drainage system.
Economics, Finance and Administration	Road user cost and economic analysis of highway projects; pavement types and maintenance measures; Highway Finance and phasing of expenditures; Administration.

1.4 ROAD TRANSPORT

Road transport is one of the most common mode of transport. The transportation by road is the only mode which could give maximum service to one and all. This mode of transportation also has the maximum flexibility for travel with reference to route, direction, time and speed of travel etc. through any mode of road vehicle. Door to door service can only be provided by road transport.

In this book, we will discussed about the roadways or highways in the succeeding units.

1.5 CHARACTERISTICS OF ROAD TRANSPORT

(*i*) Roads have ability to accommodate various types of vehicles at a time, like passenger cars, trucks, pedal cycles and animal drawn vehicles.
(*ii*) Road transport requires a relatively low capital investment for the government.
(*iii*) Road transport offers a complete freedom to road users to transfer the vehicle from one lane to another and from one road to another according to the need and convenience.

(*iv*) In particular for short distance travels, road transport saves time.

(*v*) Road transport is the only means of transport that offers door to door service.

1.6 IMPORTANCE OF ROADS IN INDIA

Road development in India has contributed greatly to the increment in agricultural, commercial and industrial sectors. It is essential to provide road links between the villages and market centres.

Overall economic progress can be achieved, only if reasonably adequate transport facilities are made available between the villages and commercial centres. Road development also generates considerable employment potential.

Revenue from the road transport in India has been much higher than the investment made on road development plans.

1.7 CLASSIFICATION OF RURAL ROADS

The rural roads are classified on the basis of:

(i) Traffic volume:
   (a) Heavy (b) Medium (c) Light

(ii) Load Transport:
   (a) Class A (b) Class B etc.

(iii) Nagpur road plan: The plan classified roads into following 5 categories based on location and function
   (a) National Highway
   (b) State Highway
   (c) Major District Roads
   (d) Other District Roads
   (e) Village Roads

1.8 CLASSIFICATION OF URBAN ROADS

The urban roads are classified as:

(i) Arterial roads

(ii) Sub arterial roads

(iii) Collector streets

(iv) Local streets

(v) Expressways

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CHAPTER

2

Highway Development and Planning

2.1 INTRODUCTION

In this chapter, we will discuss about history of development of roads. We will discuss about how the road development in India has taken place over past few decades and the various authorities and committees discuss that were formed which gave guidelines and planning for development of roads in India. At last, we will about a system that helps to choose a particular design of road system from the others based on their utility.

The first mode of travel was on the footpaths. Animals were also used to transport men and materials. Later animal drawn vehicles were developed and it became a popular mode of transportation after the invention of wheel. This brought up the necessity of providing a hard surface for such a wheeled vehicles to move on. Some terms like highways, roads and streets have precise meaning but they are often used casually in practice. A highway is designed for high speed and high volume traffic in the urban areas like National Highway. A road is of low order facility, designed for relatively lower speed and lower volume traffic in non - urban areas like village roads while a street is an urban road facility.

2.2 DEVELOPMENT OF ROADS

2.2.1 Roman Roads

Firstly Roman started construction of roads in large scale. In 312 BC they constructed the Appian way of length extending over 580 km.

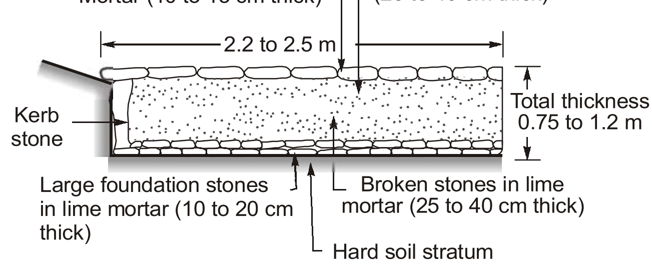


Fig. Typical cross section of Roman Road

Main features of roman roads are:

(*i*) They were built straight regardless of gradients.
(*ii*) Total thickness of the construction was as high as 0.75 m to 1.2 m.
(*iii*) They were built after the soft soil was removed and a hard stratum was reached.
(*iv*) The wearing course consisted of dressed large stone blocks set in lime mortar.

2.2.2 Tresaguet Construction

Pierre Tresaguet developed an improved method of construction in France during 1764 A.D.

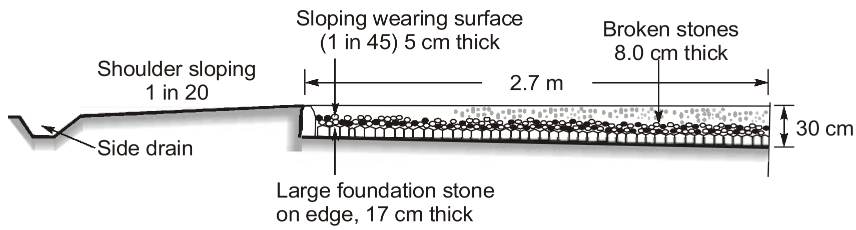


Fig. Typical cross-section of Tresaguet's construction

Main features of Tresaguet construction

(*i*) Thickness of the road was in the order of 30 cm.
(*ii*) Consideration was given to subgrade moisture condition and drainage of surface water.
(*iii*) The top wearing course was made up of smaller slope having a cross slope of 1 in 45 to the surface to provide surface drainage.
(*iv*) Shoulder sloping was also provided in the order of 1 in 20 to drain the surface water to the side drain.

2.2.3 Telford Construction

Thomas Telford began his work in early 19th century in England.

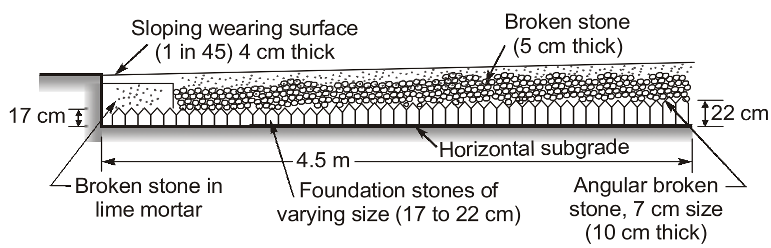


Fig. Typical cross-section of Telford's construction

Main Features of Telford Construction

(*i*) He proposed a level subgrade of width 9 m.
(*ii*) Thickness of foundation stone varied from 17 cm at edges to 22 cm at the centre.
(*iii*) A binding layer of wearing course 4 cm thick was provided with cross slope of 1 in 45.
(*iv*) The central portion of about 5.5 m width was covered with two layers of angular broken stones to compacted thickness of 10 cm and 5 cm.

2.2.4 Metcalf Construction

John Metcalf (1717-1810) was the first of the great road builders during the Transport Revolution. He was a remarkable man, who had been blind since the age of six, but went on to build about 300 km of turnpike road, mainly in Lancashire, Derbyshire, Cheshire and Yorkshire, in the period 1765-1792.

Metcalf believed that a good road should have good foundations, should be well drained and have a smooth convex (rounded) surface to allow rainwater to drain quickly into ditches at the side of the road. Metcalf established his reputation as a road builder, particularly, by building a good dry road across marshland. Other engineers thought it could not be done, but Metcalf accomplished the task by first making a foundation of brushwood and heather. He showed the importance of good drainage, since it was rain which caused most of the problems on the roads. During that time when Metcalf was working, his roads needed to repair and could be used for several years.

2.2.5 Macadam Construction

John Macadam (1756 -1836) started an entirely new method of road construction in 1815. This was the first method based on scientific thinking.

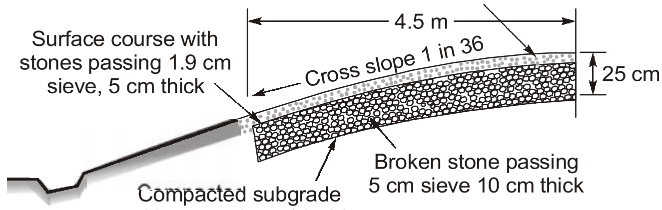


Fig. Typical cross-section of Macadam's construction

Main features of Macadam construction

(*i*) Macadam was the first person who suggested that heavy foundation stones are not at all required to be placed at the bottom layer. He provided stones of size less than 5 cm to a uniform thickness of 10 cm.

(*ii*) The importance was given to subgrade drainage and compacted subgrade, so, the subgrade was compacted and prepared with cross slope of 1 in 36.

(*iii*) The size of broken stone for the top layers was decided on the basis of stability under animal drawn vehicles.

(*iv*) Total thickness was kept uniform from edge to centre to a minimum value of 25 cm.

The macadam and Telford methods of construction differ considerably though both the methods were put forward in the early 19th century.

	Macadam method	Telford method
1.	The subgrade was given a cross slope of 1 in 36 to facilitate subgrade drainage.	The subgrade was kept horizontal and hence subgrade drainage was not proper.
2.	The bottom layer of pavement or the sub-base course consisted of broken stones of less than 5cm size to uniform thickness equal to 10 cm only.	Heavy foundation stones of varying size, about 17cm towards the edges and 22 cm towards the centre were hand picked and prepared to serve as sub-base course.
3.	Base and surface courses consisted of broken stones of smaller sizes to compacted thickness of 10 and 5 cm respectively and the top surface was given a cross slope of 1 in 36.	Two layers of broken stones were compacted over the foundation stones before laying the wearing course, 4 cm thick with a cross slope of 1 in 45.
4.	The total thickness of pavement construction was kept uniform from edge to centre to a minimum value of only 25 cm.	The total thickness of construction varied from about 35 cm at the edge to about 41 cm at the centre.

2.2.6 Water Bound Macadam (WBM)

In this method the broken stones of the base course and surface course are bounded by the stone dust in the presence of moisture.

2.3 MODERN ROAD DEVELOPMENT IN INDIA

At the beginning of British rule, the conditions of roads were deteriorated and more importance was given to the railways. In 1865, Lord Dalhousie, Governor General formed the Public Work Department in the same form that exists today.

After the first world war, motor vehicles using the roads increased and this demanded a better road network. So, British government passed a resolution in 1927 and in response to which Jayakar committee was appointed with **M.R. Jayakar as Chairman in 1927**.

2.3.1 Recommendations of Jayakar Committee

(*i*) The road development in the country should be considered as a national interest because it has become beyond the capacity of provincial government and local bodies.
(*ii*) An extra tax should be levied on petrol from the road users to develop a road development fund called **Central Road Fund.**
(*iii*) A semiofficial technical body should be formed to pool technical, know how from various parts of the country and to act as an advisory body on various aspects of roads.
(*iv*) A research organisation should be started to carry out research and development work and to be available for consultations.
(*v*) The long term planning programme must be performed, for a period of 20 years.

NOTE

- As per central road fund (CRF) Act, 2000, an extra tax charged on speed diesel and petrol (Road cess) was Rs. 2 per litre. Under the 2000 Act, the fund can be utilized for projects including national highways, state roads including roads of economic importance and rural roads.
- Now, as per the CRF (Amendment) Act, 2017, an extra tax charged on speed diesel and petrol (Road and Infrastructure cess) can be distributed among the four ministries i.e. Ministry Of Road Transport and Highway (MORTH), Ministry of Rural Development, Ministry of Railways and Ministry or shipping (for National waterways).

Accepted Recommendations of Jayakar Committee

(*i*) The Central Road Fund was formed in 1929.
(*ii*) A semi official technical body known as Indian Road Congress (IRC) was formed in 1934.
(*iii*) Motor Vehicle Act started in 1939.
(*iv*) In 1950, Central Road Research Institute (CRRI) was started.
(*v*) IRC has played an important role in the formulation of the three 20 years road development plan in India.

NOTE: Highway Research Board (HRB) was setup in 1973, with view to give proper direction and guidance to road research activities in India.

2.3.2 Objectives of Indian Road Congress

(*i*) To provide a forum for regular pooling of experiences and ideas affecting the planning , construction and maintenance of roads.
(*ii*) To promote the construction of road building.
(*iii*) To advise the authorities regarding the experiments and research connected with roads.
(*iv*) To hold periodic meetings to discuss technical things regarding roads.

2.3.3 First 20 year Road Plan (Nagpur Road Plan) (1943 - 63)

Features: This plan was a major attempt in planning for road development in a scientific manner. The total road length of 5,32,700 km with a density of 16 km of road length per 100 km^2 area would be available by 1963. All the roads were classified into five categories

(*i*) National Highway (NH)
(*ii*) State Highway (SH)
(*iii*) Major District Roads (MDR)
(*iv*) Other District Roads (ODR)
(*v*) Village Roads (VR)

This plan recommended the construction of star and grid pattern of roads throughout the country and a development allowance of 15%. The Nagpur Plan gave formulae for road length of different classes, considering the geographical, agricultural and population conditions.

(*i*) Length of National Highway and State Highway and Major District Roads (in km)

$$= \left[\frac{A}{8} + \frac{B}{32} + 1.6\,N + 85\,T\right] + D - R$$

where,
A = Agricultural area (km^2)
B = Non - agricultural area (km^2)
N = Number of towns and villages having a population of 2000 - 5000
T = Number of towns and villages having a population of over 5,000
D = An allowance for agricultural and industrial development during the next 20 years.
R = Existing length of railway track (km)

(*ii*) Length of other District and Village Roads (in km)

$$= [0.32V + 0.82 + 1.6P + 3.25] + D$$

where,
V = Number of villages with population 500 or less.
Q = Number of Villages with Population 501 - 1000
R = Number of Villages with Population 1001 - 2000
S = Number of Villages with Population 2001 - 5000
D = An allowance for agricultural and industrial development during the next 20 years

RESULT: Though the total achievement was higher than the targeted value, but the lengths of NH and SH achieved were lesser than the plan targets.

2.3.4 Second 20 year Road Plan (Bombay Road Plan) (1961 - 81)

Some of the feature of Bombay Road plan are as follows:

(*i*) At the end of plan, the target road length aimed was 32 km per 100 square km area.
(*ii*) Maximum distance of any place in a developed or agricultural area would be 6.4 km from a metalled road and 2.4 km from any category of roads.

(*iii*) 1600 km Expressways have been considered in this plan within proposed target of NH.
(*iv*) Every town with a population above 2000 in plains and above 1000 in semi hilly areas and above 500 in hilly areas should be connected by metalled road.
(*v*) A development allowance of 5% is provided for future developments.
(*vi*) Traffic Engineering Cells should be established in each state.

> **RESULT:** The total achievement was higher than the targeted value but NH and SH were constructed lesser than targeted.

2.3.5 Third 20 Year Road Plan (Lucknow Road Plan) (1981 - 2001)

Some of the features of Lucknow Road Plan are as follows:
(*i*) In this plan, roads were classified into primary, secondary and tertiary road systems.
(*ii*) All villages with over 500 population should be connected by all weather roads.
(*iii*) The overall road density was targeted as 82 km per 100 square km area.
(*iv*) The National Highway (NH) network should be expanded to form square grids of 100 km sides so that no part of the country is more than 50 km away from a National Highway (NH).
(*v*) A length of 2000 km for expressways have been considered in this plan along with major traffic corridors to provide fast travels.

The classification as per Third 20 Year Road Plan is as follows:

- **Primary Road System:** This system of road includes expressways of total length 2000 km and NH based on the concept of 100 km square grids. Thus, 100 + 100 = 200 km of NH length were provided per 100 × 100 = 10000 sq. km area. This means 1 km per 50 km^2 area. Total length of NH according to this concept in the country is 66000 km.
- **Secondary Road System:** This system of road includes state highway (SH) and major district road (MDR).
- **Tertiary Road System:** This system of roads includes other district roads and village road.

The length of these roads is calculated as follows:
(*i*) Total length of road = 4.74 × [No. of towns and villages] or Road density × Area
(*ii*) National Highway and State Highway

$$\text{Length of National Highway (NH) in km} = \frac{\text{Total area of state (km}^2)}{50}$$

$$\text{Length of State Highway (SH) in km} = \left(\frac{\text{Area of state (km}^2)}{25}\right)$$

or (62.5 × number of towns in state – length of NH), whichever is maximum

(*iii*) Major District Road:

$$\text{Length of Major District Road (MDR) in km} = \frac{\text{Area of state (km}^2)}{12.5}$$ or (90 × number of towns in state), whichever is maximum

2.4 CLASSIFICATION OF ROADS

On the basis of weather, roads are classified into two categories:

(i) All Weather Roads: These are the roads negotiable during all weather except at major river crossings.

(ii) Fair Weather Roads: These roads are those on which traffic may be interrupted during monsoon season at causeways where streams may overflow across the road.

On the basis of carriageway, roads are classified as follows :

(i) Paved Roads: They are provided with a hard pavement course which should be atleast a water bound macadam (WBM) layer.

(ii) Unpaved Roads: They are not provided with a hard pavement course of atleast a WBM layer. The earth roads and gravel roads may be called as unpaved roads.

Classification of roads on the basis of type of pavement surface provided:

(i) Surface Roads: These roads are provided with a bituminous or cement concrete surfacing.

(ii) Unsurfaced Roads: These roads are not provided with bituminous or cement concrete surfacing. The roads provided with bituminous surfacing are also called as black topped roads.

Example 2.1 The area of a certain district in India is 13,400 sq. km and there are 12 towns as per 1981 census. Determine the lengths of different categories of roads to be provided in this district by the year 2001.

Solution :

(*i*) Length of NH $= \dfrac{13400}{50} = 268$ km

(*ii*) Length of SH:

(a) By area, SH $= \dfrac{13400}{25} = 536$ km

(b) By area and number of towns, SH $= 62.5 \times 12 - \dfrac{13400}{50} = 482$ km

Adopt length of SH (Higher of the two criteria) = 536 km

(*iii*) Length of MDR in the District:

(a) By area, MDR $= \dfrac{13400}{12.5} = 1072$ km

(b) By number of towns, MDR = 90 × 12 = 1080 km

Provide length of MDR (higher of the two criteria) = 1080 km

(*iv*) Total length of all categories of roads may be assumed to provide an overall density of road length equal to 82 km per 100 sq. km area by the year 2001.

$$\text{NH + SH + MDR + ODR + VR} = 13400 \times \frac{82}{100} = 10988 \text{ km}$$

Length of NH + SH + MDR = 268 + 536 + 1080 = 1884 km

Therefore length of Rural roads consisting of ODR + VR = 10988 – 1884 = 9104 km

(*i*) Primary system consisting of NH = 268 km

(*ii*) Secondary system consisting of SH = 536 km and MDR = 1080 km

(*iii*) Tertiary system of Rural Road consisting of ODR and VR of length = 9104 km

(*iv*) Total road length = 10,988 km

2.5 ROAD PATTERNS

The various road patterns may be classified as follows:

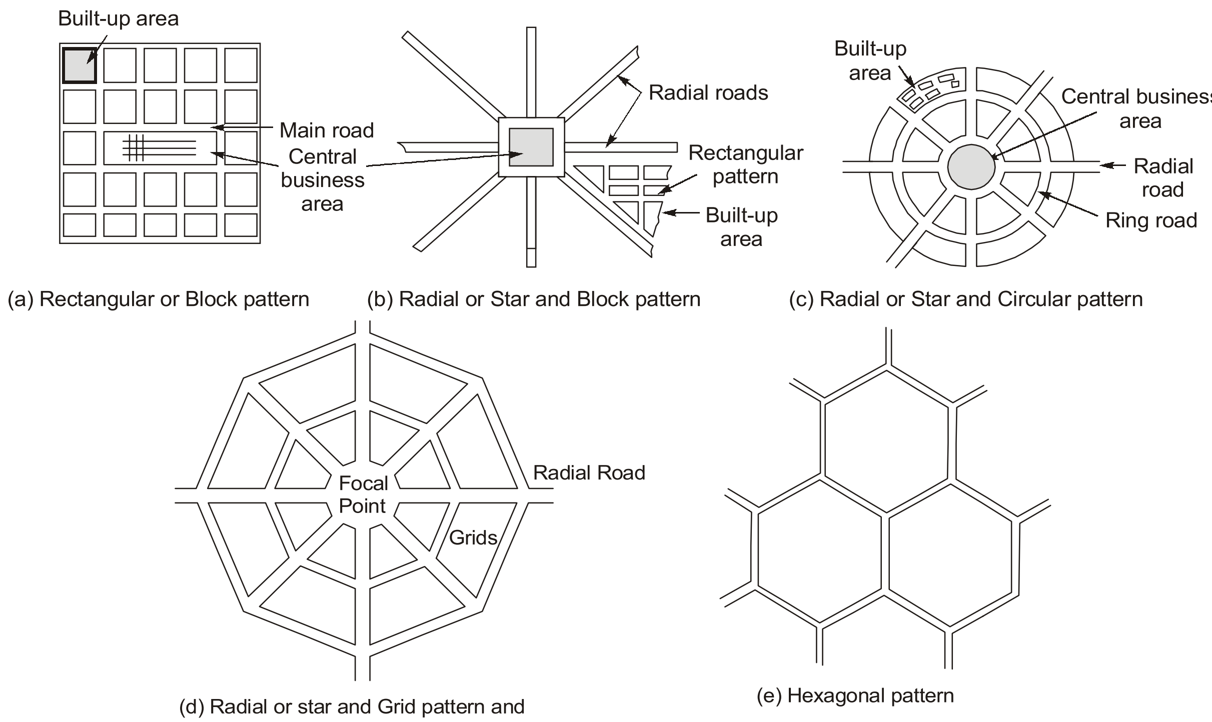


Fig. Road Pattern

The rectangular pattern has been adopted in the city roads of Chandigarh. Radial and circular pattern is the road network of Cannaught Place in New Delhi .

2.6 ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

Before highway alignment is finalized in highway project, the engineering surveys are to be carried out. The stages of engineering surveys are:

(a) Map study
(b) Reconnaissance
(c) Preliminary survey
(d) Final location and Detailed survey

2.6.1 Map Study

By the topographic map of the area likely routes of the road can be suggested. The main features like rivers, hills, valleys etc., are also shown on these maps. The probable alignment can be located on the map from the following details available on the map:

(*i*) Alignment avoiding valleys, ponds or lakes.
(*ii*) When the road has to cross a row of hills, possibility of crossing through a mountain.
(*iii*) Approximate location of bridge site for crossing rivers, avoiding bend of the river, if any.
(*iv*) When road is to be connected between two stations, one at the top and other on the foot of the hill, then alternate routes can be suggested keeping in view of the permissible gradient.

2.6.2 Reconnaissance

The second stage of surveys for highway location is the reconnaissance to examine the general character of the area for deciding the most feasible routes for detailed studies. In this survey very simple instrument like abney level, tangent clinometer, barometer etc. are used.

All relevant details are not available in the map are collected and noted down. Some of the details to be collected during reconnaissance are given below :

(*i*) Valleys, Ponds, lakes, marshy land, ridge, hills, permanent structures and other obstructions along the route which are not available in the map.

(*ii*) Approximate values of gradient, length of gradients and radius of curves of alternate alignments.

(*iii*) Number and type of cross drainage structures, maximum flood level and natural ground water level along the probable routes.

(*iv*) Soil type along the routes from field identification tests and observation of geological features.

(*v*) Sources of construction materials, water and location of stone quarries.

A rapid reconnaissance of the vast area is difficult and may be done by an aerial survey.

2.6.3 Preliminary Survey

The main objective of the preliminary survey are:

(*i*) To survey the various alternate alignments proposed after the reconnaissance and to collect all the necessary physical information and details of topography, drainage and soil.

(*ii*) To compare the different proposals in view of the requirements of a good alignment.

(*iii*) To estimate quantity of earth work materials and other construction aspects and to workout the cost of alternate proposals.

(*iv*) To finalise the best alignment from all considerations.

2.6.4 Final Location and Detailed Survey

The alignment finalized at the design office after the preliminary survey is to be first located on the field by establishing the centre line. The centre line of the road finalized is to be translated on the ground during the location survey. Detailed survey is done to fix temporary bench mark and levelling work is used for drainage and earthwork calculations.

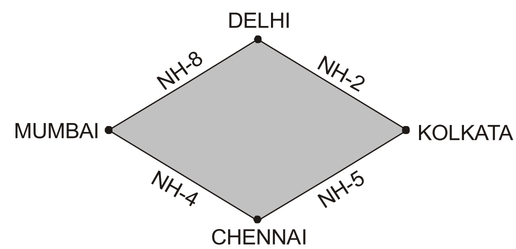
NOTE

- The highway alignment is the position or the layout of the centre line of the highway on the ground.
- A new road should be aligned very carefully as improper alignment would result in many disadvantages such as:
  i) Increase in construction and maintenance cost.
  ii) Increase in vehicle operation cost.
  iii) Increae in accident rate.
- The various factors which control the highway alignment may be listed as:
  (a) Obligatory points (The control points governing the alignment of highways).
  (b) Traffic
  (c) Geometric design
  (d) Economic considerations.
- In hilly roads, additional care has to be given for
  (a) Stability
  (b) Drainage
  (c) Geometric standards of hilly roads
  (d) Resisting length

2.7 NATIONAL HIGHWAY DEVELOPMENT PROGRAM (NHDP)

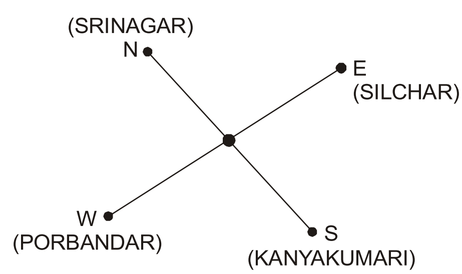
It consists the following program:

(i) Golden Quadrilateral: Delhi-Mumbai-Chennai-Kolkata



Total length of Highway in Golden Quadrilateral is approximately 4500 km.

(ii) North - South and East-West Corridor: Srinagar to Kanyakumari (North-South) and Silchar to Porbandar (East – West).



Total length of Highway is N-S and E-W corridor is approximately 7250 km.

2.8 MAXIMUM UTILITY SYSTEM

It is useful in arriving at the best road system out of the alternative proposals. In this system optimum road length is calculated for the area, based on the maximum utility per unit length of road. Factors considered in this system are:

(a) Population

(b) Agricultural and industrial productivity

The following steps may be followed to find the road network having maximum utility per unit length by the saturation system:

(i) Population units: Since the area under consideration may consist of villages and towns with different populations, it is required to group these into some convenient population ranges and to assign some reasonable values of utility units to each range of populations served.

(ii) Productivity units: The total agricultural and industrial products served by each road system should be worked out. The productivity served may be assigned appropriate values of utility units per unit weight.