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Highway Engineering

Civil Engineering

Comprehensive Theory *with* Solved Examples

Civil Services Examination

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Contents

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01

CHAPTER

Highway Planning & Geometric Design

1.1 ROLE OF TRANSPORTATION

The importance of transportation in the development of a country is multidimensional. 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 are needed to be transported from one place to another.

1.2 DIFFERENT MODES OF TRANSPORTATION

Three basic mode of transports are:

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

(*ii*) *Water*: Water ways

(*iii*) *Air*: Airways

The four major modes of transportation are:

(a) Roadways
(b) Railways
(c) Waterways
(d) Airways

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

1.3 ROADWAYS OR HIGHWAYS

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 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.

The planning, design, construction, maintenance of road, roadway facilities and need of road traffic are covered under Highway Engineering.

1.4 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.

1.5 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.

1.6 CLASSIFICATION OF RURAL ROADS

The roads are classified on the basis of:

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

(ii) Nagpur road 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

1.7 CLASSIFICATION OF URBAN ROADS

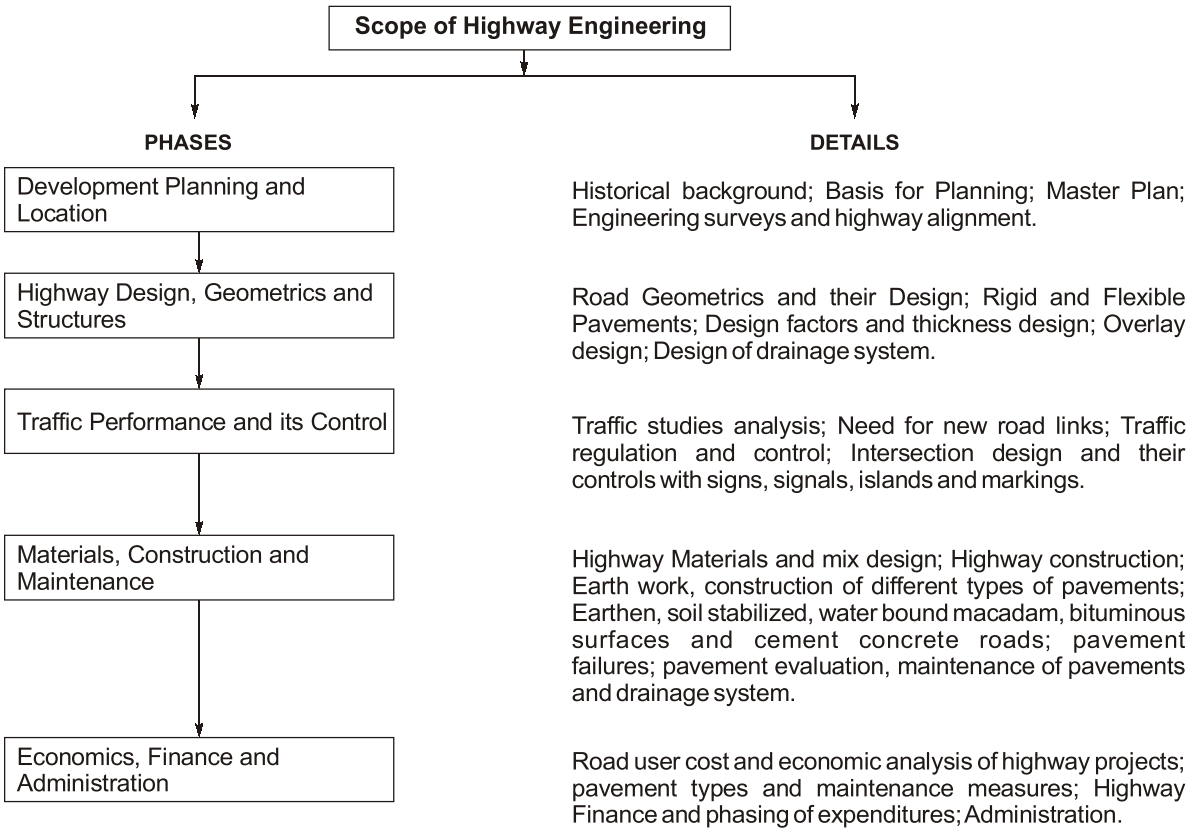
The urban roads are classified as:

(i) National Highways (NHs) (ii) State Highways (SHs)
(iii) Major District Roads (MDRs) (iv) Other District Roads (ODRs)
(v) Village Roads (VRs)

1.8 SCOPE OF 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 its control (*vi*) Economics, Finance and Administration
(*vii*) Environmental and Social aspects



1.9 HISTORY OF ROAD TRANSPORT

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 nonurban areas like National Highway. A road is of lower 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.

1.10 DEVELOPMENT OF ROADS

A. Roman Roads
B. Tresaguet Construction
C. Telford Construction
D. Metcalf Construction
E. Macadam Construction

1.11 MACADAM ROADS CONSTRUCTION

John macadam (surveyor general of roads in england) proposed entirely new method of road construction are given under:

(i) He suggested that subgrade should be prepared property kept drained so as to carry the load transmitted through the pavement. Therefore the subgrade was prepared with a cross slope of 1 in 36.

(ii) Macadam suggested that instead of placing large foundation stones, broken small size stones should be spread over subgrade and properly compacted.

(iii) Due to improved load dispersion of small size broken stone aggregates, total thickness of construction reduces.

(iv) Top layer aggregates size decided on the stability under animal drawn vehicles.

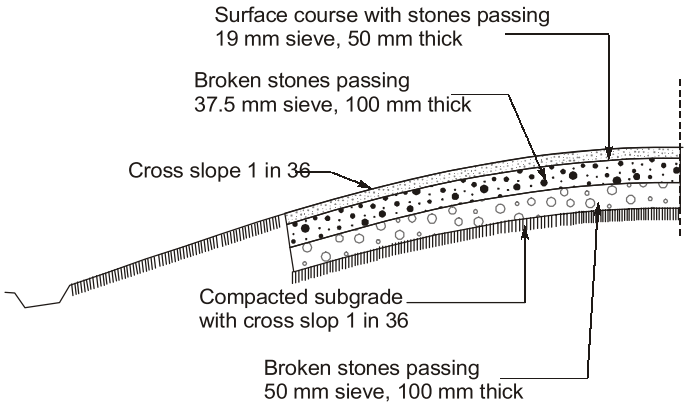


Fig. Typical cross section of macadam's construction (1827 A.D.)

1.12 MODERN ROAD DEVELOPMENT IN INDIA

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

After the first world war, motor vehicles using the roads increased and demanded a better road network. So, British government passed a resolution in 1927, in response to which Jayakar committee was consulted in 1927.

1.12.1 Recommendations Made by 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.

(*iv*) A research organisation should be started to carry out research and development work and to be available for consultations.

(*v*) They gave more preference to the long term planning programme, for a period of 20 years.

At present, an extra tax on speed diesel and petrol is Rs. 2 per litre, out of which 50 paise is kept aside for construction, maintenance and developments of NH and 1.5/- paise is distributed among states according to their collection.

1.12.2 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 last three 20 years road development plan in India.

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

1.12.3 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.

1.12.4 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 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)

They recommended the construction of star and grid pattern of roads throughout the country. They recommended the development allowance of 15%.

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

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

Features:

(*i*) At the end of plan, the target road length aimed was 32 km per 100 sq. 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.

The total achievement was higher than the targeted but NH and SH were constructed lesser than targeted.

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

Features:

(*i*) In this plan roads are 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 sq. km area.

(*iv*) The 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 NH.

(*v*) 2000 km expressways have been considered in this plan along major traffic corridors to provide fast travels.

(a) Primary Road System

This includes expressways of total 2000 km and NH based on the concept of 100 km square grids. 100 + 100 = 200 km of NH length are 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.

(b) Secondary Road System

This includes:

(*i*) Total length of road = 4.74 × [No. of towns and villages] or Road density × Area

(*ii*) National Highway and State Highway

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

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

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

(*iii*) Major District Road:

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

EXAMPLE - 1.1

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*) $$\text{Length of NH} = \frac{13400}{50} = 268 \text{ km}$$

(*ii*) Length of SH:

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

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

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

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

(a) By area, $MDR = \frac{13400}{12.5} = 1072$ 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.

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

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

(c) Tertiary Road System

It includes other district roads and village road. On the basis of weather, roads are classified into two categories:

(i) All Weather Roads: An all weather roads is a road that is trafficable in all weather conditions. Typically, this means a road that is constructed in such a way that excessive rain does not cause it to be flooded or sudden to such an extent that vehicles travelling over it are likely become bogged.

(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: If they are provided with a hard pavement course which should be atleast a water bound macadam layer.

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

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

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

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

1.13 ROAD PATTERNS

The various road patterns may be classified as follows:

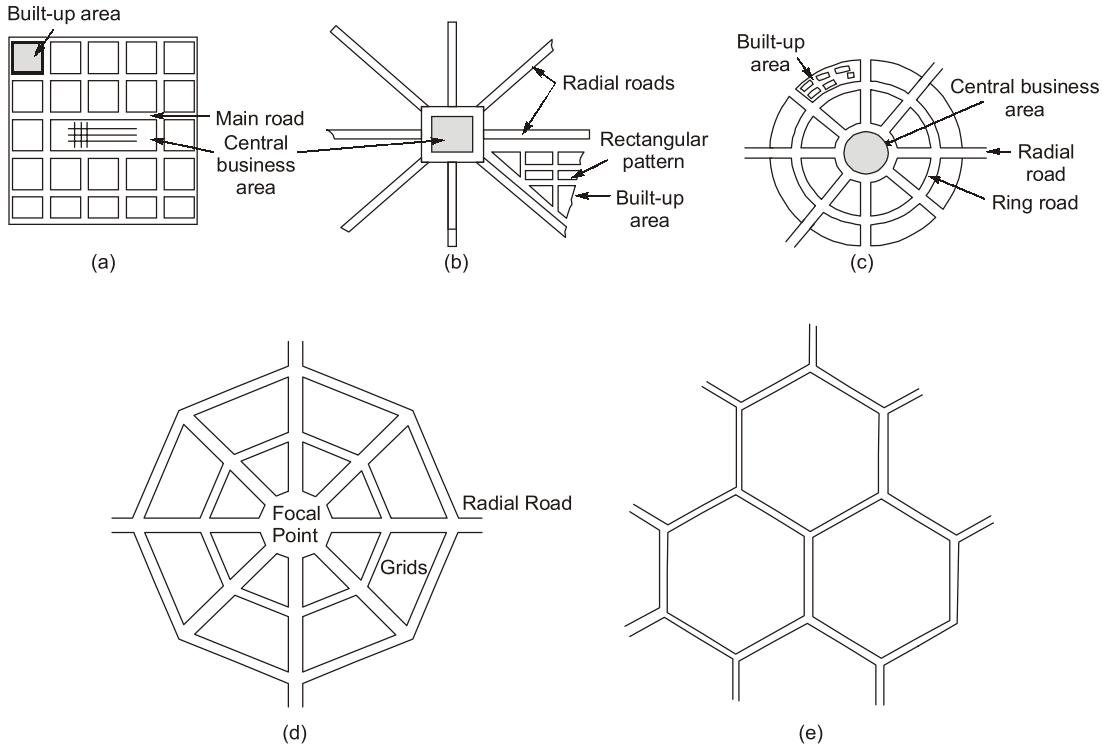


Fig. Road Pattern : *(a) Rectangular or Block pattern (b) Radial or Star and Block pattern (c) Radial or Star and Circular pattern (d) Radial or star and Grid pattern and (e) Hexagonal pattern*

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

1.14 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

1.14.1 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 the permissible gradient.

1.14.2 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. So, it should be collected at site 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.

1.14.3 Preliminary Survey

The main objective of the preliminary survey are:

(*i*) To survey the various alternate alignments proposed after the reconnaissance and the 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.

1.14.4 Final Location and Detailed Survey

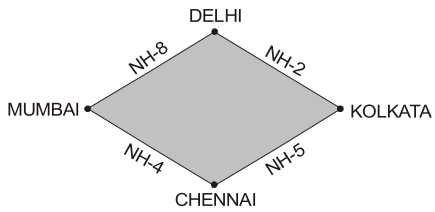
The alignment finalized at the design office after the preliminary survey is to be first located on the field by establishing the centre line. The centre line of the road finalized is translated on the ground during location survey. Detailed survey is done to fix temporary bench mark and levelling work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

1.15 NATIONAL HIGHWAY DEVELOPMENT PROGRAM (NHDP)

It consists the following program:

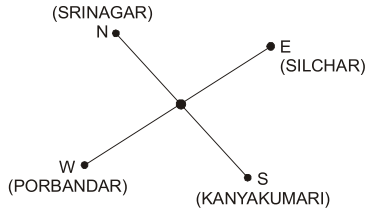
(i) Golden Quadrilateral: Delhi-Mumbai-Chennai-Kolkata

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



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

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



PRACTICE QUESTIONS

Question : 1

What are the varies studies and data compiled before of new road scheme?

Solution:

For a new road scheme or a new highway planning; field surveys are to be carried out to collect the data required for determining the length of the road system. And finally; preparation of master plan showing phasing of plan in annual or five year plans is to be completed. Field surveys or planning survey consist of the following studies;

(a) Economic studies: In these studies; various details useful in estimating the economics involved in highway development programme such as;

(i) Population; its distribution and classification
(ii) Trend of population growth
(iii) Listing of agricultural and industrial products development and future trends.
(iv) Existing facilities with regard to communication, recreation and education etc.
(v) Per capita income, banking, post office etc.

(b) Financial studies: To study the various financial aspects such as:

(i) Sources of income and estimated revenue from taxation on road transport.
(ii) Living standards
(iii) Resources at local level, toll taxes vehicle, registration and fines.
(iv) Future trends in financial aspects.

(c) Traffic or road use studies: Traffic surveys should be carried out in whole area and on selected routes and locations in order to collect the following particulars:

(i) Traffic volume in vehicles per day, peak and design hourly traffic volume.
(ii) Origin and destination studies, traffic flow pattern.
(iii) Accidents, their cost analysis and causes.
(iv) Future trend and growth in traffic volume and trend in choice of modes.

(d) Engineering studies: These studies include:

(i) Topographic survey, soil survey
(ii) Location and classification of existing roads.
(iii) Road life studies.
(iv) Estimation of possible developments in all aspects.
(v) Special problem in drainage, construction and maintenance of roads.

Preparation of Plans:

The above details collected are tabulated and plotted on the maps of area under planning. Usually four drawings are prepared showing the various details of area as under:

Plan I General area plan showing almost all existing details such as topography, existing road network drainage structure, rivers, canals, towns and villages with population, commercial, industrial and agricultural activities.

Plan II Distribution of population groups in accordance with the categories.

Plan III Location of places with their respective quantities of productivity.

Plan IV Existing roads network with traffic flows and desire lines obtained from *O* and *D* studies.

Preparation of Master Plan and its phasing:

- Master plan is the final road development plan. Based on above plans, different possible network of new roads are proposed. In each proposal; the population and productivity of each locality, traffic flow, topography and other details both existing and possible changes in future are kept in view.
- The next step is to compare the various alternate proposals of road system and to select most optimum network under plan period.
- After deciding the optimum road length for a plan period, the final step is the phasing of road development plan by fixing up the priorities for construction of different road links. The priority for each road link may be fixed scientifically based on maximum utility per unit length of road based on population and productivity for each road.

Question : 2

Calculate the SSD for design speed for SH at rolling terrain for

(i) Two way traffic on two lane road.

(ii) Two way traffic on one lane road.

Solution:

Design speed for national and state highway in rolling terrain is 80 kmph.

Note : For assuming longitudinal friction coefficient, use following guidelines:

Speed, kmph	20 to 30	40	50	60	65	80	100
Coefficient	0.40	0.38	0	0	0.36	0.35	0.35

$\therefore$ f = 0.35 and reaction time of driver = 2.5 sec

SSD = Lag distance + Braking distance

$$= Vt_R + \frac{V^2}{2gf}$$

$$V = V \times 0.277 = 80 \times 0.277 = 22.216 \text{ m/s}$$

$$\text{SSD} = (22.216 \times 2.5) + \frac{22.216^2}{2 \times 9.81 \times 0.35} = 127.41 \text{ m}$$

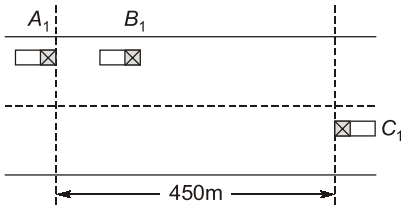
(i) SSD, when there are 2 lanes = SSD × 1 = 127.41 m

(ii) SSD, when there is 1 lane = SSD × 2 = 254.82 m

Question : 3

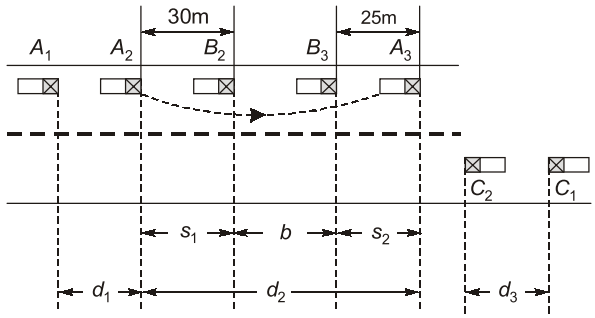
On a two lane two -way highway, a car A was following a truck B and both were travelling at a speed of 40 kmph. While looking for an opportunity to overtake the truck, the driver of car A saw another car C coming from the opposite direction. At that moment, the distance between A and C was 450 m. After an initial hesitation period of 2 seconds, the driver of car A started the overtaking operation. The distance between A and B at that instant rate of 1.20 ms^{-2}. When the overtaking operation was completed, there was a distance of 25 m between B and A. Determine the distance between different vehicles given as measured from the front bumber of the one vehicle to front bumber of another vehicle design speed of the highway is 80 kmph.

Solution:



Assume: Length of vehicle = 6 m

Now, we see the situation in given problem in following diagram.



Overtaking operation

Total distance by A = $d_1 + d_2$

d_1 = Distance travelled in reaction time

d_2 = Distance travelled in overtaking

Now, Reaction time, t_R = 2 sec

$$d_1 = V_A \times t_R = \left(40 \times \frac{5}{18}\right) \times 2 = 22.22 \text{ m}$$

Time taken during overtaking operation:

$$\Rightarrow \quad T = \sqrt{\frac{2(s_1 + s_2)}{a}} = \sqrt{\frac{2(30+25)}{1.2}} = 9.5743 \text{ sec}$$

Now, $d_2 = s_1 + b + s_2 = 30 + V_B \times T + 25$

$$= 30 + \left(40 \times \frac{5}{18}\right) \times 9.5743 + 25 = 161.38 \text{ m}$$

$D_A = d_1 + d_2 = 22.22 + 161.38$

Thus, D_A = 183.6 m

During overtaking distance travelled by vehicle C:

$$d_3 = V_C (t_R + T)$$

$$= \left(80 \times \frac{5}{18}\right) \times (2 + 9.5743) = 257.2 \text{ m}$$

Hence remaining distance between front bumbers of vehicles A and C

$= 450 - (d_1 + d_2 + d_3)$

$= 450 - (183.6 + 257.2)$

$= 9.2$ m

and remaining distance between front bumber at vehicles B and C:

$= s_2 + 9.2 = 25 + 9.2 = 34.2$ m