
TRANSPORTATION
ENGINEERING

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CE 15, 1500045

"Whoever travels a path in search of knowledge, Allah makes easy for him a path to Paradise" (Sahih Muslim)

Special THANKS to-

My friend

SAYEM AHAMEED

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CE 3205: Transportation Engineering

Traffic: means movement of persons (people) and vehicles on road.
Transport: means movement of persons (people) and goods from one place to another place.
Transportation: means the entire activity involving traffic and transport.
Transportation engineering deals with the transhipment of persons and goods by any sorts of vehicle.

The Transportation System

Definition and Scope: A transportation system may be defined as consisting of the *fixed facilities*, the *flow entities* and the *control system* that permit *people and goods* to move from one place to another place *efficiently* in order to *participate* in a *timely* manner in some *desired activity*.

Fixed facilities: are the network of links (e.g., roadway segments, railway track and pipe) and nodes (e.g., intersections, interchanges, transit terminals, harbors and airports) of the transportation system.
Flow entities: are the vehicles (from bicycles to large tractor-trailer), container units, railroad cars, etc.
Control system: consists of vehicular control and flow control for efficient & smooth operation of vehicles.

Transportation Demand: Transportation systems are built to serve people in undertaking their economic, social and cultural activities. People do not normally travel or move their possessions for the sake of movement but to fulfill certain needs, such as going to school, to work, to shop, or to visit with friends. Transportation engineers accommodate these social activities by providing efficient ways to satisfy the population's needs for mobility. Transportation engineers often cooperate with other professionals (including economists, planners and social scientists) for efficient ways from the consideration of safety, speed, convenience, economic, protection of environmental quality and protection of individual rights.

Transportation System Classification: Transportation system can be categorized according to the types of technology they employ, type of service they provide, who is responsible for their operation and so forth. The transportation system is further categorized into four major subsystems according to the medium on which the flow elements are supported and commonly referred to as **modes**.
Modes of transportation are:
1. Highways 2. Railways 3. Waterways 4. Airways 5. Beltways, Pipelines.

Importance: As blood transportation through body arteries is essential for well being of the human being, similarly a good transportation system is essential for well being of a nation. A good transportation system comprises of good network of highways, railways, well-developed waterways and airways.

For rapid economical, industrial, social and cultural development of any country, a good system of transportation is very essential.

Some of the important roles played by transportation are: EID QGP TSP

1. It gives "place utility" to goods.
2. It gives "time utility" to goods and people.
3. It bridges the space gap between the consumer and the producer.
4. It gives facilities for the exploitation of natural resources.
5. It gives facilities for the international trade and commerce.
6. It is important for the defense of a country.
7. It determines the pattern of growth of towns and cities.
8. It is a promoter of tourism.

Transportation system in Bangladesh: Transportation system in Bangladesh is good because it comprises a good network of highways, railways, well-developed waterways and airways.
Highways: It included the National highways, Regional highways, Feeder roads, Rural roads and Village roads. Road transport has been growing very fast and many advantages offered by the road transport.
Railways: It included the Broad Gauge line in the west zone and Meter Gauge line in the east zone. From the safety point of view and other facilities, publics are attracted to railway transport now a days.
Waterways: Bangladesh has a long coast-line and hence the potentially for coastal shipping in enormous. The total length of navigable inland waterway is notable. 50% of river waterways are suitable engine launch.
Airways: Bangladesh has two levels of air-lines: (i) International Carrier, Bangladesh Biman (ii) Domestic Trunk Route Carrier, Bangladesh Biman and some private airlines.

Transportation Planning Process

Introduction: Advancement in all spheres of life has been to a large extent influenced by transportation. Any change in the transportation system is reflected in number of impacts. Motor vehicles brought comfort, pleasure and convenience but created problems of congestion, lake of safety and degeneration of environment. To under stand the nature of these problems and formulate proposals for the safe and efficient movement from one place to another is the subject of transportation planning. The output of the planning function should be in terms of (i) what needs to be done (ii) what alternative approaches can be used (iii) how well these alternatives match the community desires and (iv) what steps ultimately need to be taken to implement plans.

Both land use and transportation are part of a dynamic system that constantly evolving ( ) due to changes in policy, technology, economics, and even culture/values among others. As a result, the interactions between land use and transportation are the outcome of the many decisions made by residents, businesses and governments. The cycle interaction of transportation facilities and land use is shown in Fig.1. The most significant components of urban dynamics are:
(i) Land use (ii) Transport network (iii) Movements (iv) Employment & workplace (v) Population & housing

The major components of the **spatial imprint** ( ) of urban transportation are:
Pedestrian areas: Refer to the amount of space devoted to walking. This space is 10% to 20% of right of way.
Roads and parking areas: On average 30% is devoted to roads while another 20% is required for off-street parking.
Cycling areas: Reserved lanes and parking facilities should be required for bicycles in urban areas.
Transit systems: It share road space with automobiles, which often impairs (deteriorate) their respective efficiency.
Transport terminals: The amount of urban space required to support terminal facilities (ports, stations, yards etc.).

The interaction between land use and transportation
The distribution of **land use** (residential, industrial or commercial) determines the locations of human **activities** (living, working, shopping, education or leisure). The 'land use and transport feedback cycle' is shown in Fig.2.
The distribution of human **activities** requires trips in the **transport system** to overcome the distance.
Distribution of infrastructure in the **transport system** create opportunities that can be measured as **accessibility**.
Distribution of **accessibility** co-determines location decisions and so results in changes of the **land-use** system.

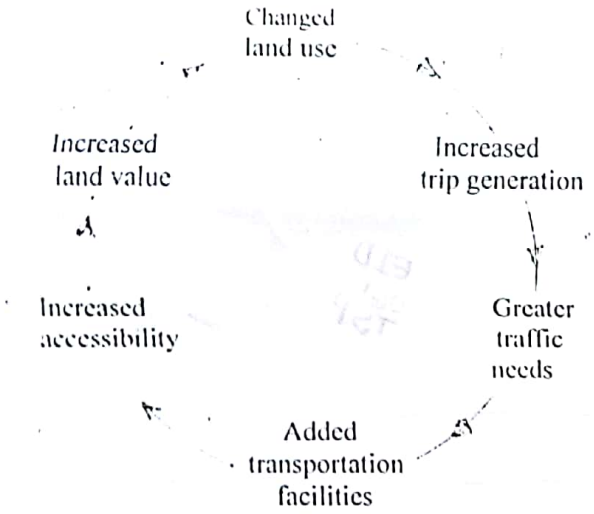


Fig.1 The land use transportation cycle

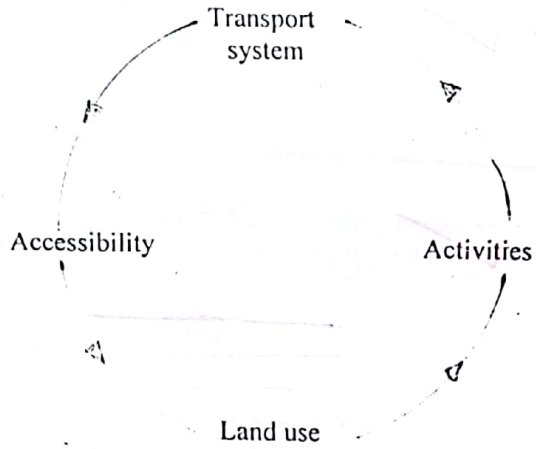


Fig.2 The 'land use and transport feedback cycle'

Stages in Transportation planning: Transportation planning process divided into five important stages:
1. Survey: Information on the origins and destination of the journeys should be collect within study area.
2. Analysis and model building: Data analysis is necessary to design existing facilities. Model building is important for forecast future travel demands. The transport model is divided into four stages. These are:
(a) Trip generation or the decision to make a journey (b) Trip distribution or the selection of a suitable destination.
(c) Trip assignment or the actual journey undertaken in a route (d) Model split or the method of travel used for the trip.

3. Forecasting: Forecasts are required regarding planning parameters, population, employment, & income distribution.
4. Evaluation: Numerical evaluation, accuracy of the resultant forecast, operational evaluation are necessary.
5. Programme adoption: The best alternative emerging from the evaluation study is selected for implementation.

Traffic Engineering

General: Traffic engineering is that phase of engineering which deals with the study of traffic, the determination of its characteristics and the application of the knowledge so gained to achieve safe, convenient, rapid and economic transportation of persons and goods.
Traffic engineering techniques are used to ensure that new traffic facilities operate efficiently and safely for all the traffic, including pedestrians, using them. Also it used to improve the operation of existing facilities.

The Traffic Problem: The behaviour of road traffic is now a complex interaction between four components – the road user, the vehicle, the road and the environment. The degree of complexity of traffic behaiour depends on the variability and interaction between these four components. Variables are discussed below.

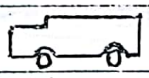
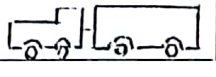
Application of Traffic Data: The information obtained from traffic studies are used (1) to test and improve the efficiency of existing road systems (2) to determine the need for new traffic facilities and (3) to design and locate traffic control devices.

TRAFFIC CHARACTERISTICS

1. Road user characteristics: Road user is human element includes the driver, pedestrian, cyclist, motor cyclist, bullock cart driver, etc. The factors or characteristics of road users that influence the road safety are:
(i) Physical characteristics: Vision, hearing power, strength, general reaction to traffic situations (PIEV), Temporary physical characteristics like: Fatigue, alcohol, drugs, illness, etc.
(ii) Mental characteristics: Skill, Intelligence, experience, knowledge, literacy, etc.
(iii) Psychological factors: Impatience, attentiveness, Fear (ভয়), anger, maturity, home worries mind, etc.

2. Vehicular characteristics: A vehicle that represents the design standards is termed as **design vehicle.**
The factors or characteristics of vehicle that influence the road safety are:
(i) Dimensions:
(a) Width – affects the lane width, width of shoulders, width of parking lots and road capacity.
(b) Length – affects the design of horizontal elements, passing S.D, road capacity and parking facilities.
(c) Height – affects the clearance provided under structures like bridge, tunnel, electric service lines, etc.
(ii) Weight: affects the design of pavement thickness, design of bridges, ruling and limiting gradient etc.

Vehicle Dimensions (Recommended by IRC)

Dimensions	Particulars	Max. dimensions (m)
Width	All vehicles	2.50
Height	(a) Single-decked vehicle	3.80
	(b) Double-decked vehicle	4.75
Length	(a) Single-unit truck with two or more axles (SU) 	11.00
	(b) Single-unit bus with two or more axles (BUS) do	12.00
	(c) Semi-trailer tractor combinations (WB-40) 	16.00
	(d) Tractor and trailer combinations (WB-50) 	18.00

(iii) Speed: affects the design of curves, design of intersection, super-elevation, skid resistance, S.D, etc.
(iv) Power: affects the total resistance to traction consisting of inertia, rolling and grade resistance.
(v) Braking system: affects the stopping sight distance, overtaking sight distance and traffic capacity.
(vi) Lighting system: affects the safe turning, effective night operation, number of accidents at night.

3. Road characteristics: The factors or characteristics of road surface that influence the road safety are:
(i) Friction: affects the safe speed, distance (stopping, starting & turning), super-elevation, skid resistance.
(ii) Light reflection characteristics: affects the night visibility of road. Dark surfaces give poor visibility.
(iii) Unevenness: affects the cost of vehicle operation, comfort of driver & passengers and driver's safety.
(iv) Surface slope: The camber required would depend on the ability of the surface to drain off water.
Skid: When longitudinal movement of wheel is greater than circumferential movement of wheel and the reverse is **Slip.** Three types skid are (i) Straight skidding (ii) Impending skidding and (iii) Sideway skidding.

4. Environmental factors: The factors that influence the road safety are:
(i) Atmospheric condition (weather and visibility) (ii) Land, its use and activities (iii) Fixed facilities for traffic (divider, flyover, terminals) and (v) Traffic streams and its characteristics e.g. mixed traffic flow.

TRAFFIC SURVEYS

Systematic traffic studies and scientific analysis are essential to reduce the problem of congestion, delay and accident. Traffic surveys are carried out relating to (i) road users (ii) vehicles (iii) roads (iv) accidents and (v) environment. The data obtained from the above surveys help in (1) pavement design (2) planning of road network (3) geometric design (4) traffic regulation and control and (5) design the drainage system & bridges.

1. Traffic volume study

Traffic volume is the number of vehicles that pass a given line of road per unit time at any selected period. It is express in vehicles per hour or vehicles per day. For mixed traffic, it is the normal practice to convert the flow into equivalent passenger car unit (PCU).

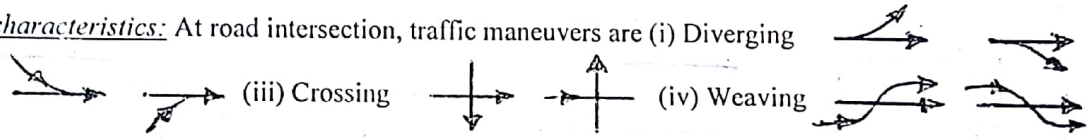
PCU: Mixed traffic flow characteristics are much complex when compared with flow of passenger cars only. Estimation of traffic volume is difficult unless the interaction of mixed traffic bring to a common unit. Passenger car is considered as a standard common unit called PCU. The PCU factors based on their relative interference & space requirements value are given in table below. It is not an absolute but relative value.

Vehicles	Bicycle	M. cycle, Scooter	Car, Tempo, Pickup	Light commercial vehicles, Tractors	Rickshaw, Van, Auto	Bus, Minibus, Truck, Handcart	Tractor-trailers	Tonga	Bullock cart
PCU	0.5	0.75	1.0	1.5	2.0	3.0	4.5	4.0	6.0

Time headway: is the time interval between the passes of successive vehicles moving in one way stream and measured from head to head as they pass a point on the road.

Space headway: is the distance between successive vehicles moving in one way stream and measured from head at any instance. Maximum flow is attained at the speed when the time headway is the minimum.

Traffic flow characteristics: At road intersection, traffic maneuvers are (i) Diverging (ii) Merging (iii) Crossing (iv) Weaving



Traffic flow study is essential at large intersection for (i) the proper geometric design (ii) the decision of traffic regulatory measures (iii) the design of traffic control system and (iv) identification of conflict points.

Purposes of traffic volume study:

(i) To establish relative importance of any road (ii) Helps in designing new routes and new facilities. (iii) For the planning, designing and regulation phase of traffic engineering. (iv) Helps in design of road pavements, bridges and culverts.(v) Used for studying economic use of roads and tax collection levy (ফলদায়ক (লাভ)).

Volume counting methods: (i) Manual counts (ii) Moving car method and (iii) Automatic counter.

Traffic volume gives the following information:

(i) Hourly, daily, yearly and seasonal traffic volume variations (ii) Volume and direction of traffic (ii)Variation of flow on different parts of a road system (iv) Proportion of cars, heavy and slow vehicles etc.

Presentation of traffic volume data:

(1) Average daily traffic (ADT): is the average flow of traffic only for a few days like 7 days, 15 days etc.

(2)Annual average daily traffic (AADT): the average flow of traffic for one year e.i 1/365 of annual flow.

(3) Peak hourly volume: is the maximum number of vehicles moving at particular period of time.

(4) Design hourly volume (DHV): is the 30th height hourly volume that will exceed only 29 hrs. out of 8760 hrs. in a year (Fig. 3) and all others hourly volume will be less than this value when only motor traffic is involved. Road facilities provided considering peak hourly volume will be uneconomical and those are considering AADT will be inadequate for most of the time in the year but those are considering DHV is found to be satisfactory for both economic and adequacy points of view. This volume on a percentage basis varies very little from year to year. Traffic congestion on such road is expected for 29 hours out of 8760 hrs.

Traffic projection factor (TPF): is the factor that gives the ultimate volume at the end of design period in terms of current traffic. For the projection of traffic to some future years the following elements are considered: (i) Normal traffic growth – due to general increase of vehicles (ii) Generated traffic – due to construction of new facilities (iii) Development traffic – due to improvements in the adjacent area and (iv) Current traffic – that would immediately use a new road, when opened to traffic. Equation for calculation of TFP is: $A = P(1 + r)^{n+x}$; Where A = Number of vehicles/day for design, P = Number of vehicles/day at last census, r = Annual rate of increase in traffic, n = Construction period in years and x = Design period in years.

2. Speed study

Speed is the rate of movement of traffic. In planning a road system, it is essential to know the distribution and performance of the traffic on existing road. The main object of speed studies is to determine/carry out: (i) Speed trends (ii) Capacity & economy studies (iii) Planning traffic control & regulation measures (iv) Accident studies (v) Comparison among drivers & vehicles under specified conditions (vi)Geometric design.

Design speed is the maximum speed maintainable throughout the journey compatible with safety and comfort when weather and traffic conditions are favourable & the geometric features are controlling factors.

Spot speed is the instantaneous speed of a vehicle at a specified location.

Average speed is the average spot speed of all vehicles passing through a particular section or spot.

(1) Time mean speed is the average of a number of spot speed (Radar speed meter) e.i; $V_t = [\sum_{i=1}^{n} V_i] \div n$.

(2) SMS is the average of spot speeds measured over a space (Time-lapse camera) e.i; $V_s = nd \div [\sum_{i=1}^{n} t_i]$. $= \frac{n}{\sum 1/v_i}$

Prob. Five spot speeds 10, 12, 15, 18 and 20 m/s recorded within section of 80 m. Calculate TMS and SMS.

TMS, $v_t = \sum v \div n = 75 \div 5 = 15$ m/s and SMS, $v_s = nd \div \sum t = nd \div \sum d/v = n \div \sum 1/v = 5 \div 0.3555 = 14.1$ m/s.

Running speed is the average speed over a given route while in motion = Length of course ÷ Running time.

Travel speed is the effective speed with which a vehicle traverses = Distance ÷ Total time (including all delays).

Speed depends upon (i) Geometric features (ii) Traffic characteristics & conditions (iii) Time, location and weather.

95th percentile speed: The speed below which 95% of all the vehicle travel, used as a design speed in geometric design.

15th percentile speed: Speed below which 15% of all the vehicle travel, is used to as the lower speed limit on highway.

Example: Following data was collected while counting spot speed studies at certain stretch of a road. Determine (i) Upper and lower values of speed limits for regulation of mixed traffic and
(ii) The design speed for checking the geometric design elements of the road.

Table: Frequency distribution of spot speed data

Speed class limit, kph	26-30	30-34	34-38	38-42	42-46	46-50	50-54	54-58	58-62	62-64
Mid-point speed, kph	28	32	36	40	44	48	52	56	60	64
Number of vehicles	9	74	79	75	66	33	17	6	1	3
Frequency, %	2.5	20.4	21.7	20.7	18.2	9.1	4.7	1.6	0.3	0.8
Cumulat Frequency, %	2.5	22.9	44.6	65.3	83.5	92.6	97.3	98.9	99.2	100.0

85th percentile speed: The speed below which 85% of all the vehicles travel or 15% of the vehicles exceed this speed at the spot. These 15% drivers are considered to be driving faster than the safe speed under existing conditions. This speed is used for determining the speed limits for traffic regulation.

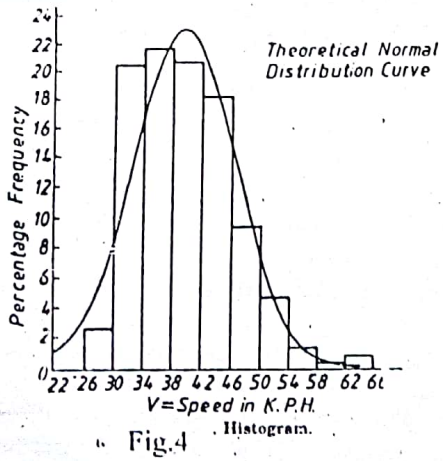


Fig.4 Histogram.

Frequency distribution curve of spot speed

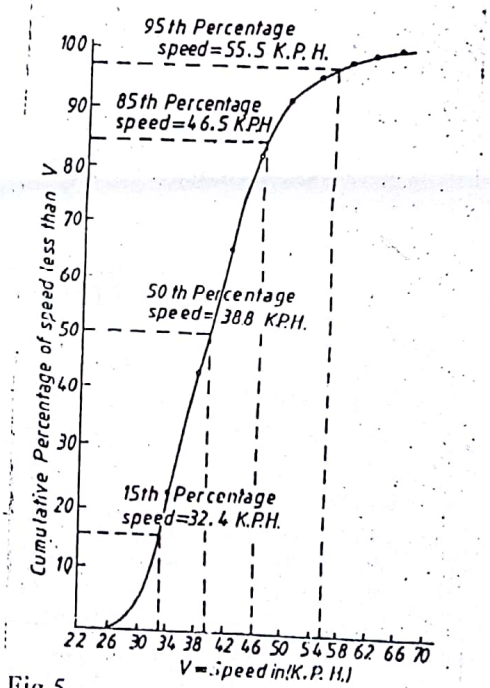


Fig.5 Histogram and cumulative frequency curve.

Cumulative distribution curve of spot speed

Modal speed is the speed at which maximum percent of the vehicles travel through the particular road section. It is the peak value of the frequency distribution curve.

1. Upper speed limit for regulation = 85th percentile speed of 46.5 K.P.H.
2. Lower speed limit for regulation = 15th percentile speed of 32.4 K.P.H.
3. Speed to check the geometric design elements = 95 th percentile speed of 55.5 K.P.H.

Fig.4 Fig.5

Travel Time and Delay Study:

Purpose: (1) To evaluate the quality of traffic movement along a route and determine the locations, types and extend of traffic delays by using a moving test vehicle. (2) To compare operational conditions before and after roadway or intersection improvements have been made. (3) To monitor level of service for local government comprehensive plans. (4) To develop recommendations for improvements such as traffic signal retiming, safety improvements, turn lane additions and channelization enhancements. (5) To find amount, locations, duration, frequency and causes of delay in the traffic stream, as well as the amount of time spent in actual motion from point to point along a given route.
Fixed delays: Traffic is held up due to some obstruction like traffic signals, stop signs and level crossings.
Operational delays: Due to congestion, turning, crossing, merging, pedestrians, double parking, accidents.

This study is carried out to analyses the following:
(i) Congestion (ii) Congestion indices (iii) Efficiency of road (iv) New facilities and (v) Economic studies.
On the basis of this study, spots of traffic congestion, their causes and remedies can be easily suggested.
Applications: (1) Enables the traffic engineer to define problem locations where design and operational improvements may be essential to increase operational efficiency and safety. (2) Enables the traffic analyst to monitor the roadway's level of service for local government comprehensive plans.

3. Traffic capacity study

Traffic capacity of a lane is the ability of the lane to accommodate traffic (maximum hourly rate) during a given time period under operating conditions (prevailing roadway and traffic conditions). Unit is vehicles/hr.
Traffic density is the number of vehicles occupying a unit length of lane at a given instant. Unit is Vehicle/km.

Importance of traffic capacity study:
(i) It governs the number of lanes, width of lanes, intersections and weaving sections.
(ii) It assessed the adequacy or deficiency of a highway networks by comparing with the present volume.
(iii) It helps to make plan for improvements in the geometric features, junctions, control devices and TMM.

Basic capacity is the maximum number of passenger cars that can pass a point on a lane during one hour under the most ideal roadway and traffic conditions. (Uninterrupted flow, passenger cars only, clear S.D, wide lane).
Possible capacity is the maximum number of vehicles that can pass a point on a lane during one hour under prevailing roadway and traffic conditions. (Disregard the effect in delaying and restriction of movement of driver).
Practical capacity or Design capacity is the maximum number of vehicles that can pass a point on a lane during one hour under the prevailing roadway and traffic conditions, without unreasonable delay or hazard.

Capacity on the basis of theoretical formula:
Basic capacity / hr./ lane; $C = 1000\ V/S$, where V→ Speed, in KPH, S → Average spacing in metres of moving vehicles. e.i, $S = (S.D.+ L) = [(0.278Vt + 0.01V^2) + 5]$ where L = Average length of vehicle = 5 m.

Level of service (LOS): denote the level of facility one can derive from a road under different operating characteristics and traffic volumes. Factors considered in evaluating the level of service are --
(a) Speed & travel time (b) Traffic interruptions (c) Freedom to maneuver (d) Driver comfort (e) Economy

Operating conditions for the six levels of service selected by the Highway Capacity Manual (. Fig.6 .) are:
A: Free flow, with low volumes and high speeds. Driver can maintain their desired speeds with little or no delay. Operating speed is ≥100 KPH for rural highways and overall travel speed is ≥80 KPH for urban streets.
B: Zone of stable flow. Drivers still have reasonable freedom to select their speeds and lane of operation. Operating speed about 90 KPH for rural highways and the overall travel speed is ≥80 KPH for urban streets.
C: Still in the zone of stable flow but speeds & maneuverability are more closely controlled by higher volumes. Operating speed is75 KPH for rural highways and overall travel speed is ≥30 KPH for urban streets.
D: Approaches unstable flow, with tolerable operating speeds. Drivers have little freedom to maneuver. Operating speed is 60 KPH for rural highways and average overall travel speed is 25 KPH for urban streets.
E: Operating speed lower than in level D. Flow is unstable & there may be stoppages of momentary duration Operating speed is50 KPH for rural highways and average overall travel speed is 25 KPH for urban streets.
F: Forced flow, operations at low speed. Stoppages occur for short or long periods of time due to congestion. Operating speed is < 50 KPH for rural highways and overall travel speed is below 15 KPH for urban streets.

Factors affecting capacity and level of service:
(1) Lane width, (2) Lateral clearance, (3) Shoulders, (4) Surface condition, (5) Alignment, (6) Grade etc.

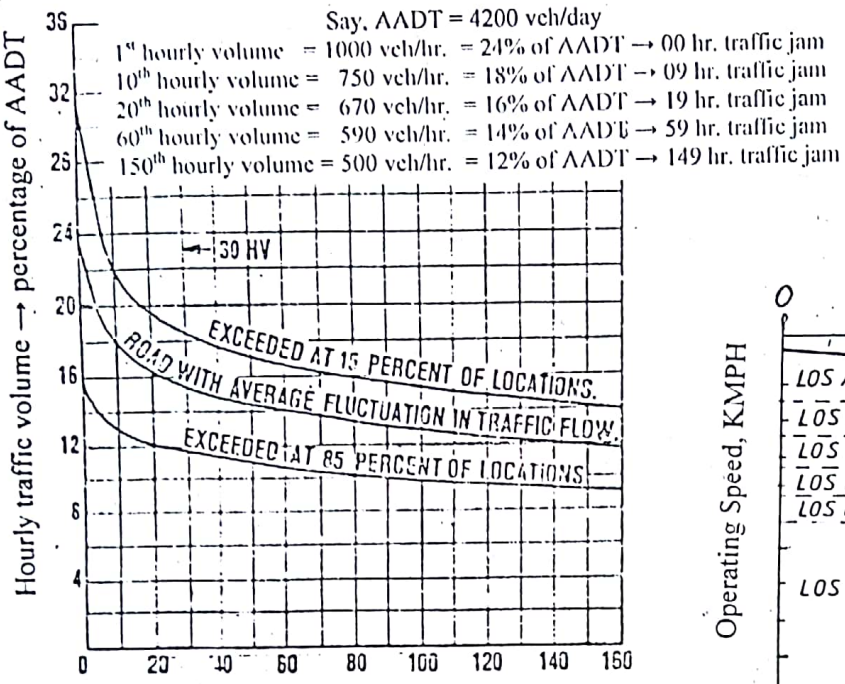


Fig.3 Relation between peak hour flows and AADT on rural highways.

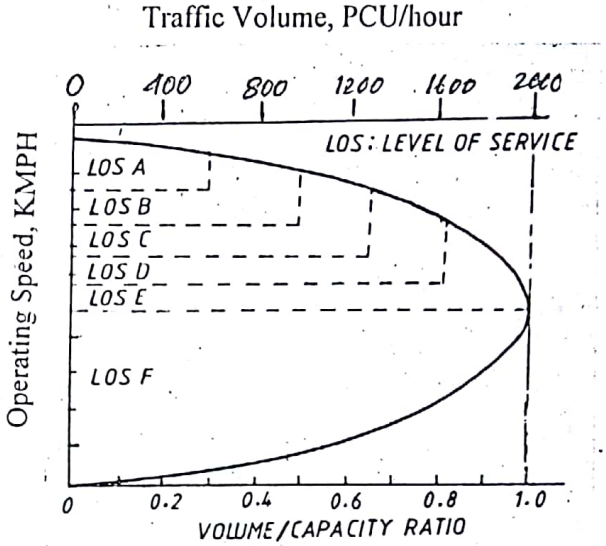


Fig.6 HCM Classification of Level of Service

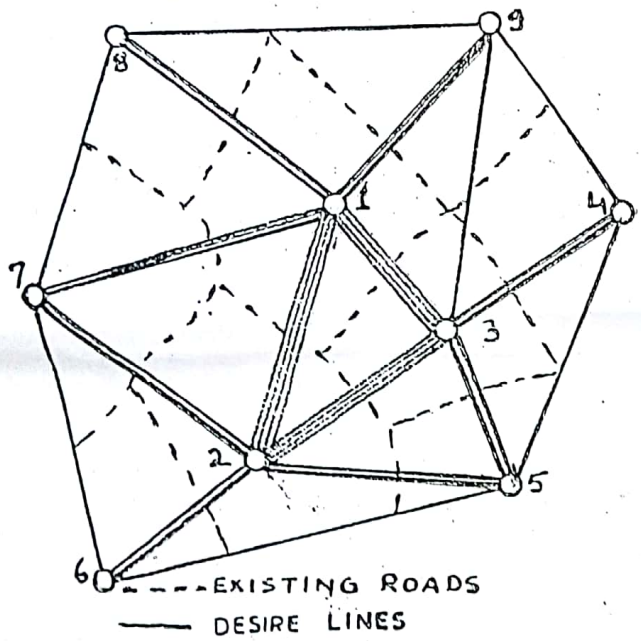


Fig.7 . Desire lines chart.

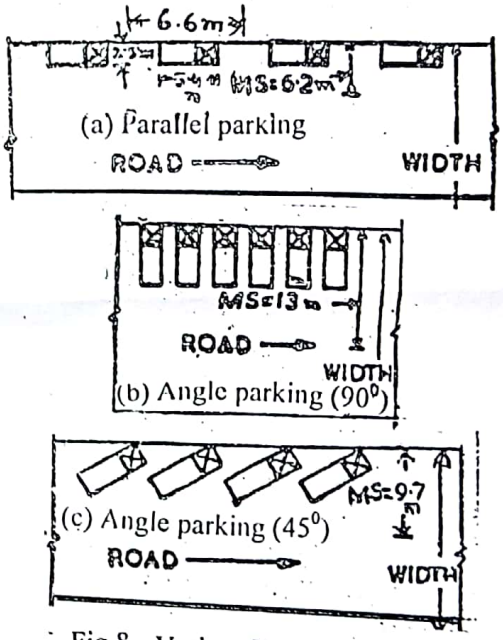


Fig.8 Various Types of Parking

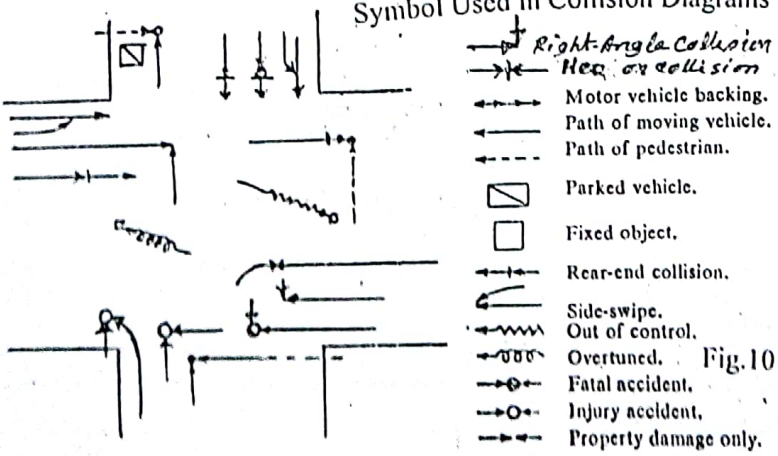


Fig.9 Collision Diagrams

Fig.10

4. Origin and Destination (O&D) study

Origin is defined as the place where the trip begins and **destination** is defined as the place where the trip ends. It is not only necessary to know how many trips are made, but also group these trips with reference to the zones of their origin and destination. Other information yielded by the O&D study are (i) land-use of the zones of origin and destination (ii) household characteristics of the trip-making family (iii) time of the day when the journeys are made (iv) trip purpose and mode of travel.

The specific uses or purposes of this study:
(i) To determine the No. of by-passable traffic that enters in a town and thus establish the need for a bypass.
(ii) To determine the extent to which the present highway system is adequate and to plan for new facilities.
(iii) To plan public transportation system in the cities.
(iv) To establish over or under bridge sights according to the traffic demand.
(v) To provide wide roads along the maximum desire lines of travel.

Methods used for collecting O&D data:
(i) Drivers-interview (ii) License plate method (iii) Return post card method
(iv) Home interviews (v) Tag on car method (vi) Distributing cards in schools and college.

This study is carried on to get the answer of the following questions:
(i) Why people travel – (purpose of trip) (ii) When people travel – (time and duration)
(iii) How the people travel – (mode of travel) (iv) Where the people want to go – (origin and destination)
(v) Where and why people stop – (to determine concentration of vehicles that needs of parking facilities).

Data collected by O&D study can be presented in the following forms:
(i) Graphical form by desire lines (shown in Fig.7) (ii) Tabular form and (iii) In the form of Pie chart.

5. Parking study

Out of 8760 hours in a year, the car runs on an average for only 400 hours, remaining 8360 hours when it is parked. As the city grows, the use of land increases considerably creating problem for space for parking purposes. The demand of parking space is one of the major problems in big cities. Vehicles if improperly parked cause lot of problems like – traffic congestions, accidents, obstruction to fire-fighting operation, environment pollution etc. Certain terms associated with parking are:

Parking Accumulation: is the total number of vehicles which are parked in an area at a specified moment (hrs. /day).
Parking Volume: is the number of vehicles parking in an area for a unit time and measured as vehicles/day.
Parking Load: is the total sum of vehicle hrs of parking and represents as vehicle-hour for 2, 4 or 6 hrs. AM/PM
Parking Duration: is the length of time a vehicle remain in parked position
Parking Index: is the ratio of number of bays occupied to the theoretical number of bays available.
Parking Turn-over: is the ratio of number of vehicles parked during a period to the actual number of parking spaces.

Following aspects should be investigated during parking studies:
(1) Parking demand: The parking demand is estimated and recording the peak demand for parking facilities.
(2) Parking space inventory: Existing parking facilities and open spaces for adopting as parking places are recorded.
(3) Parking practices: Study to know, how many people would like to bring their cars if parking facility is provided.
(4) Parking characteristics: (i) present practice of parking (ii) parking pattern (iii) accidents involved during parking

Parking systems

(1) On-street (curb) parking: Parked along the curb which is very convenient for peoples but causes of traffic jams. Common methods of on-street parking are (i) Parallel parking (ii) Angle parking & (iii) Right angle parking (Fig.8) .

To ensure safety and convenience, it is desiravle to prohibit parking at following locations:
(i) Near intersections (ii) Near level crossings (iii) Near pedestrian crossings (iv) Narrow streets (v) Near structures, etc.

(2) Off-street parking: When parking places are provided away from the road curb. *Methods of on-street parking:*
(i) Surface car parks (ii) Multi-storey car parks (iii) Roof parks (iv) Mechanical car parks (v) Underground car parks.

(3) Peripheral parking schemes: Parking facilities are provided at the periphery of the town. They are:
(i) Park and walk (ii) Park and ride and (iii) Good-bye (kiss) and ride.

6. Road Accident

Road accident is an accident which occurred or originated on a road open to public traffic resulting in either injury or loss of life, or damage to property, in which at least one moving vehicle was involved.
The primary objective of traffic engineering is to provide accident free, safe and quick traffic movements on the road. The accident problem is of very complex nature as so many factors are involved in its occurrence. The increase in road traffic has been followed by a steep increase in the road accident. Every day as many as 140,000 people are injured on the world's roads. More than 3000 die and some 15000 are disabled for life. Nearly 12,000 people are killed (02.10.2010) on the roads every year in Bangladesh. Age of 80% of these killed are 5 to 45 years. Families struggle with poverty when they lose a bread-winner.

Causes of Road Accidents: The causes of road accidents are many and varied. They can be grouped as:

(1) Road Factors and its effect on road accidents
(i) Design speed (ii) Control of access (iii) Pavement width (iv) Pavement surface (v) Shoulders (vi) Horizontal curve (vii) Vertical alignment (viii) Median width (ix) Sight distance (x) Intersections, etc.

(2) Vehicle Factors and its effect on road accidents
It is said that vehicles are the biggest culprits that cause serious accidents. The vehicle factors that influence the road safety are: (i) Vehicle body and its features (ii) Tyers (iii) Braking system (iv) Lighting system (v) Steering system (vi) Vehicle inspection and maintenance (vii) Mixed traffic (viii) Overloading.

(3) Road Users and its effect on road accidents

*Driver (4 wheel vehicles): The driver is the key factor in most of the accidents. He is the human element in charge of the machine. He drives it, steers it, accelerates it, decelerates it, and stops it. The driver characteristics that influence the road safety are: (i) Driver judgment, skill and emotional make-up (ii) Age of drivers (iii) Gender (sex) of the drivers (iv) Marital status (v) Training of drivers (vi) Fatigue (vii) Alcohol & drugs and the driver (viii) Use of crash helmets (ix) Use of safety belts, etc.

*Motor-cycle and Scooter Riders: The rider of a motor cycle or a scooter is very much vulnerable to accidents because he is totally unprotected. Compulsory regulatory measures for safety to these riders are:
(i) Provision of rear view mirrors (ii) Provision to cover the rear wheel (iii) Driver and one pillion rider (iv) No pillion rider during learning (v) Proper foot rest for the pillion (vi) Rider must wearing the crash helmet (vii) Stoppage or standing at the extreme left of the carriageway (viii) Carefully merging, diverging and crossing (ix) No competition with car or other motor-cycle (x) No talk with pillion rider.

*Cyclists: Cycles are a major mode of traffic in cities, towns and even in the rural areas. Cycles become popular in recent times, mostly because of (a) consumes no energy (b) occupies less space (c) free of noise and pollutants. But a large number of accidents are associated with it. Usual causes for cycle accidents are:
(1) Improper turns (2) Violation of traffic laws (3) Double riding (4) More than two cycles remain abreast (5) Towed by other vehicles (6) Defective brakes (7) Lake of night lamps or reflector (8) Avoid foot-ways

*Passengers: Bad characteristics of passenger are – (i) Alighting from or getting into moving vehicles (ii) Mounting on roof and hanging at side of the vehicle (iii) Pushing or walking on roof (5) Keeping hand and head outside (6) Talking with driver (7) Excited the driver mentally and disturb the drivers attention.

*Pedestrians: A large number of road accidents involve pedestrians. In Bangladesh, the pedestrians constitute 45% of the fatalities from road accidents. This figure indicate that the seriousness of the pedestrian safety problem. Factors that affect the pedestrian safety are:

Personal factors: Carelessness, illiteracy, violation of rules and regulations, play on road, etc.
Road factors: Geometric features, intersections, crossing facilities, footways facilities, road light, etc.
Time factors: Dark period and day in a week when traffic is heavy, special rush days in a year, etc.
Other factors: Age, gender, social conditions, drunken pedestrian, familiarity with the locality, etc.

(4) Environmental Factors: Elements of weather that involved in road accidents are -
(i) Factors that make the roads slippery like – Snow, ice, rain water, etc.
(ii) Factors that restrict the normal visibility of road users like – Fog, smoke, heavy rainfall, etc.

(5) Other Factors: Ribbon development, advertisement boards, trees, attractive views, material on road, etc.

Accident Studies: The various steps involved in the traffic accident studies are as follows:

(1) Collection of accident data: (a) General (date, time, persons involved in the accident) (b) Location of accident (c) Details of vehicles involved (d) Nature of accident (e) Road and traffic conditions (f) Primary causes of accident (g) Accident costs (h) Driver conditions.

(2) Accident report: The accidents should be reported to police authorities who would take legal actions especially in more serious accidents involving injuries or damage to properties.

(3) Accident records: The accident records are maintained giving all particulars of the accidents, location and other details by means of (a) Location file, (b) Spot maps and (c) Collision diagrams (Fig. 9, and Fig.10).

Accident Investigations: Following investigations may be carried out to analysis the accident properly:

(1) Recording general observations: Skid length of pavement, relative position of vehicles & objects.
(2) Driver tests: Analysis of breath and spinal fluid for alcohol content, tests on driver characteristics.
(3) Vehicle tests: Test on the (a) condition of brakes & steering (b) essential accessories (c) details of dents.
(4) Probable causes of the accident: Accident types, site conditions, position of vehicles & objects involved.
(5) Cost analysis: Injuries and fatalities of persons involved, damage of vehicles & properties, traffic delay.

Measures for the Reduction in Accident Rates: The measures to decrease the accident rates are:

Engineering Measures:
(a) Road design (b) Preventive maintenance of vehicles (c) Accident records "before and after" the introduction of preventive measures to study the efficiency (d) Road lighting at intersections.

Enforcement Measures:
(a) Speed control (b) Traffic control devices (c) Training and supervision (d) Medical check (e) Special precautions for commercial vehicles (f) Observance of law and regulation.

Educational Measures:
(a) Education of road users: The passengers and pedestrians should be taught the rules of the road, correct manner of crossing etc. by introducing necessary instruction in the schools
(b) Propaganda and Exhortation: By Proper adult education and training, Related advice by religious leader, teachers and society leaders. Related programs in the electronic media, news paper and magazine. Make poster of the serious accidents and use of imaginative and catching slogans.
(c) Safety drive: Imposing traffic safety week, special provisions should be made for giving knowledge of traffic rules to the common man by the help of traffic police.

Driving and driver related laws may be like this:

* Minimum age of professional driver must be at least 20 years.* If a driver is a criminal or drinker or violets the rules, his driving license must be withdrawn.* The conductor and the helper must have license for their job.* The driver must not exceed the speed limit and must park their vehicle in definite area. * Eye-sights of drivers should be re-examined at interval of one year.* Drivers and helpers should wear uniform, so that they can easily be identified.* If faulty vehicles running on road with valid fitness, licensing authority personnel should be punished.

Following improvement of infrastructure of communication is required:

* There should be divider on every highway.* More fly-over and underpass should be established quickly. * Parking-bay should be made in multiple place of the city.* Road intersection should be reduced as minimum as possible.* Shops on the footpath and markets, kacha bazaar beside the highway should be removed.* There should be no right turn on main road from any sub lane and some road may be one way. * Buses in the main road should be encouraged rather than small vehicles.* Every roadside shopping mall should have their own basement-parking place.* Every pedestrian should use the foot over-bridge. * Free footpath should be ensured for the pedestrian.* Carriageway at major intersections should be widening.

"ধৈর্য্যের সাথে সচেতন হয়ে রাস্তায় চলি
সকলে মিলে নিরাপদ সড়ক গড়ে তুলি"

TRAFFIC OPERATIONS

For the safe traffic operation on highways, it is essential to impose adequate traffic regulations and traffic control devices. The public should be assured that these regulations and controls are for their interest.

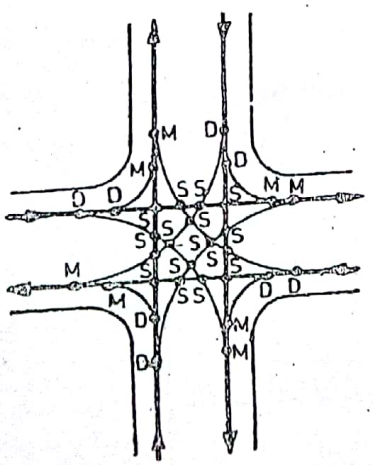
1. Traffic Regulations

Need: The motor vehicle is a machine in charge of a human being. It is necessary to formulate the suitable regulations for safe and efficient movement of traffic and pedestrians. Most of the countries have uniform traffic laws operating in all parts of the country so that the laws are understood everywhere and are obeyed.

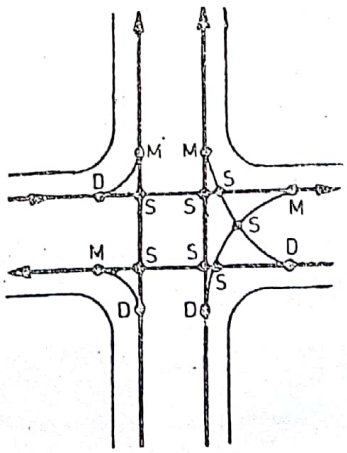
(i) Regulation of Speed: High speeds are always associated with accidents. Speed limits selected should be 'realistic' e.i. should be appropriate to the conditions at site so that they are not disregarded by the drivers. In Bangladesh, the traffic is mixed in character. In many towns, streets are narrow and pedestrian traffic is heavy. Speed limits in urban areas are 25 to 30 km/hr. (heavy to medium vehicles). Speed limits in rural areas are 50 km/hr. for vehicles with one trailer & 60 km/hr. for heavy vehicles (Bus/Truck) without trailer. Before selecting any particular speed limit, the following factors should be considered: (a) Speed of traffic, (b) Road conditions, (c) Environment of the road (d) Traffic and (e)Traffic accident rates,
For success of speed regulation measures, strict enforcement of law is needed. Motorists who violate the speed limit must be arrested and penalties must be imposed. A distinctive coloured motor cycle with speedometer used to follow the violator for detecting the speed violation.

(ii) Regulation of Vehicles: The regulation of vehicles broadly covers the aspects are -
(a) Vehicle Registration (b) Construction and equipment of vehicles (c) Size, weight and loads of vehicles (d) Lighting of vehicles (e) Inspection of vehicles (f) Insurance.
(iii) Regulations Concerning the Driver: cover the following aspects - (a) Licensing of the driver (b) Age of drivers (c) Requirements of physical fitness of drivers (d) Disqualification and endorsement of licenses.
(iv) Regulations Concerning Traffic: Any city will have to develop a system of rules and enforce them strictly to regulate mixed traffic: Cycles, Motor cycles, Scooters, Rickshaws, Animal vehicles, Pedestrians.
(v) General Rules Concerning Traffic: (a)"Keep to the left" rule (b) Overtaking rules (c) Priority rules at intersection (d) Turning rules (e) Hand signals (f) Rules intended to promote pedestrian movement on footway.
(vi) Parking Regulations: It is said that proper parking policy is the key to the traffic problems of a town.
(a) Space controls (b) Time controls (d) Restrictions on loading and unloading (e) Curb space for bus stops (f) Exclusive parking spaces for taxis (g) Peak hour parking prohibitions (h) Parking control by fees.
(vi) Enforcement of Regulations: (a) Traffic police forces have a vital role to play in traffic law enforcement (b) The courts have the final say in the matter of punishing the offenders by interpreting the law.
(vii) Regulations Concerning Traffic Flow: Traffic movements at junctions involve a number of points of conflict. These generate delay, congestion and accident hazards. One-way road system can overcome these problems.

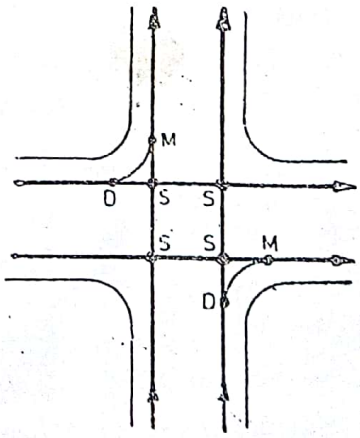
S → Cross conflict point M → Merging conflict point D → Diverging maneuvering point



32 conflicts with Two-way traffic



15 conflicts with One-way Regulation on One Road



8 conflicts with One-way Regulation on Both Roads

2. Traffic Controls

The various aids and devices used to control, regulate and guide the traffic are called traffic control devices. Requirements of traffic control devices are: attention, meaning, time for response and respect to road users.

In order to facilitate people traveling from one country by road in another country where the language may be different, standardization of traffic signs assumes considerable importance. Realizing the need for such standardization, the U.N (1949) has evolved a code of system for signs, signals and markings to convey messages, rather than lettered messages. The most common of these devices are:

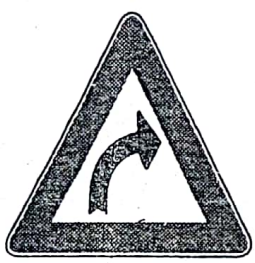
(i) Traffic Signs: Traffic sign is a device mounted on a fixed or portable support to convey a specific information by means of words or symbols. The signs should be placed such that they could be seen and recognized by the road users easily and in time.

Importance of Traffic Signs:

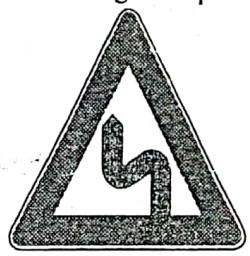
(i) They give timely warning of hazardous situations where they are not self evident.
(ii) They help in regulating traffic by imparting massages to the drivers about the need to stop or give-way.
(iii) They give information as to highway routes, directions and points of interest.

Types of Traffic Signs: Traffic signs have been divided into three categories according to **Motor Vehicle Act.**

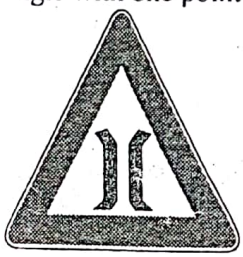
(a) Warning Signs(Danger signs): These signs convey to the drivers, the conditions ahead where some cautions is required. The shape of the sign is equilateral triangle with one point upward as shown below.



RIGHT HAND CURVE



ZIG-ZAG ROAD

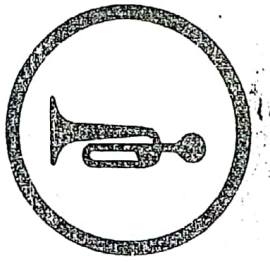


NARROW BRIDGE

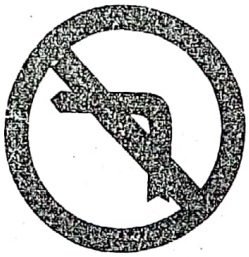
SCHOOL

(b) Regulatory Signs (Mandatory signs): These signs are used to inform the drivers of certain laws, regulations and prohibitions. Violation of signs is a legal offence. Shape of sign is circular as shown below.

DIRECTION SIGN



SOUND HORN

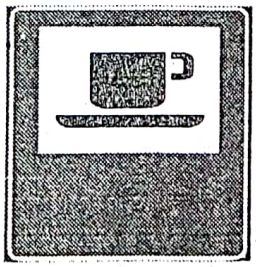


LEFT TURN PROHIBITED

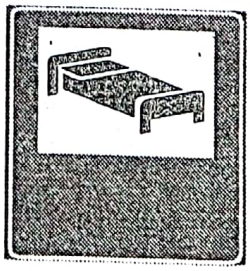
HORN PROHIBITED

(c) Informatory Signs: These signs are used to guide the drivers with information to make travel easier, safe and pleasant. These signs are displayed on rectangular boards of specific size as shown below.

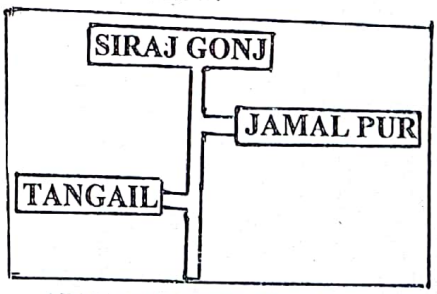
EATING PLACE



LIGHT REFRESHMENT



REST HOUSE



ADVANCE DIRECTION SIGN

(ii) Traffic Signals: Traffic signals are such control devices which can alternately direct the traffic to stop and proceed at level intersections (place of accidents & congestion) using red and green traffic light signals. Yellow period is a transition interval between red to green & green to red. The main requirements of traffic signals are to draw attention, provide meaning and time to respond and to have minimum waste of time.

The cycle length is the time required for one complete sequence of signal indications as shown figure.
Phase is a part of the cycle length allocated for specific traffic movement.
Interval is the time for which any division of the signal cycle continues to reflect the same coloured light.

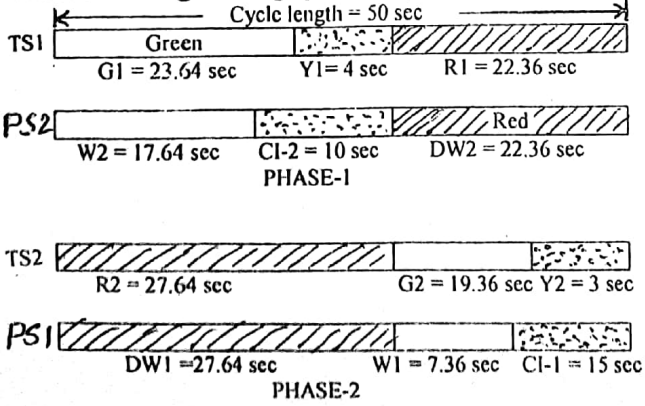
1. Traffic control signals
(a) Manually operated signals: A police man from his cabin gives red & green lights to the traffic as needs.
(b) Fixed-time signals: are set to repeat regularly a cycle of red, amber and green lights. Phase time is fixed.
(c) Traffic actuated signals: Timings of the phase and cycle can be changed according to the traffic needs.

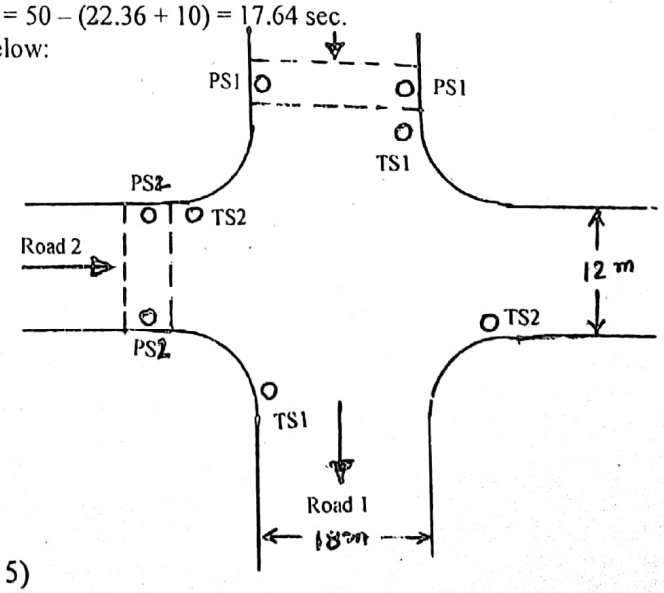
2. Pedestrian Signals: They are meant to give right of way to the pedestrians to cross a road during the walk period when the vehicles shall be stopped by red signal. The green walking man represents cross indication.

Example: An isolated signal with pedestrian indications is to be installed at right-angled intersection with Road 1of 18 m wide and Road 2 of 12 m wide. The peak volume (V) per hour for each lane of Road 1 and Road 2 are 275 PCU and 225 PCU respectively. The approach speeds are 55 kmph and 40 kmph, for Road 1 and Road 2 respectively. Design the timings of traffic and pedestrian signals on the basis of pedestrian crossing time.
Solution:

Design of traffic signals
(i) Based on the approach speed; yellow periods:
For Road 1 with 55 kmph, yellow period Y1 = 4 sec For Road 2 with 40 kmph, yellow period Y2 = 3 sec.
(ii) Based on the pedestrian walking speed of 1.2 m/sec, the pedestrian clearance time is calculated:
Pedestrian clearance time (interval) for Road 1 = width of road/walking speed = 18/1.2 =15 sec and pedestrian clearance time for Road 2 = width of road/walking speed = 12/1.2 =10 sec.
(iii) Adding 7 sec for initial walk-period, minimum red time for Road 1 = (15+7) sec and that for Road 2 = (10+7) sec.
(iv) Minimum green times based on pedestrian criterion: Road 1 = (10+7) – 4 =13 sec & Road 2 = (15+7) – 3 =19 sec
(v) Based on approach volume, the green time (G) calculated is increased for Road 1 with higher volume as: G1/G2 = V1/V2 , here green time for vehicles on Road 2 = G2 = 19 sec, therefore, G1 = (275/225) x 19 = 23.2 sec
(vi) Total cycle length = G1+Y1+R1 = G1+Y1+G2+Y2 = 23.2 + 4 + 19 + 3 = 49.2 sec. Signal cycle time should be multiples of 5 sec and so the cycle time (length) = 50 sec. The extra (50 – 49.2) = 0.8 sec distributed proportionally as:
Corrected green time G1 = 23.2 + (275 ÷ 500) x 0.8 = 23.64 sec & corrected G2 = 19 + (225 ÷ 500) x 0.8 = 19.36 sec
Red time for Road 1, R1 = G2 + Y2 = 19.36 + 3 = 22.36 sec & that for Road 2, R2 = G1 + Y1 = 23.64 + 4 = 27.64 sec

Design of pedestrian signals
Do not walk (DW) period of pedestrian signal at Road 1 (PS1) is red period of traffic signal at Road 2.
For PS1, DW1 = R2 = 27.64 sec and for PS2, DW2 = R1 = 22.36 sec.
Pedestrian clearance intervals (CI) are of 15 and 10 sec respectively for Road 1 & Road 2 for crossing from (ii) above.
The walk time (W) is calculated from total cycle length.
For PS1, W1 = 50 – (27.64 + 15) = 7.36 sec and for PS2, W2 = 50 – (22.36 + 10) = 17.64 sec.
Details of design timings phase diagram is shown in figure below:





Example: At right angled intersection of two roads, Road 1 has four lanes with a total width of 12.0 m and Road 2 has two lanes with a total width of 6.6 m. The volume of traffic approaching the intersection during design hour are 900 and 743 PCU/hour on the two approaches of Road 1 and 278 and 180 PCU/hour on the two approaches of Road 2. Design the signal timings as per IRC guidelines.

Solution:
Design traffic on Road 1 = higher of the two approach volume per lane = 900/2 = 450 PCU/hour
Design traffic on Road 2 = higher of the two approach volume per lane = 278/1 = 278 PCU/hour
=728 PCU/hour

(i) Pedestrian green time for Road 1 = width of road/walking speed + initial walking time =12/**1.2** + **7** =17 sec/person
Pedestrian green time for Road 2 =width of road/walking speed + initial walking time= 6.6/**1.2** + **7**=12.5 sec/person

(ii) Green time for vehicles on Road 2, G_2 =.17 seconds i.e. pedestrian green time for Road 1.
Green time for vehicles on Road 1, G_1 = 17 x 450/278 = 27.5 seconds.

(iii) Total cycle time required for each phase = (amber + G_2 + inter-green period) + (amber + G_1 + inter-green period)
= **(2** +17 + **2)** + **(2** + 27.5 + **2)** = 52.5 sec. Signal cycle time should be multiples of **5 sec** & so cycle time = 55 sec
The extra 2.5 sec (55 – 52.5) per cycle apportioned to the green time for vehicles of Road 1 and 2, as 1.5 and 1.0 sec and so corrected G_1 = 27.5 + (450/728) x 2.5 = 29.0 sec and corrected G_2 = 17.0 + (278/728) x 2.5 = 18.0 seconds.

(iv) Vehicle arrivals per lane per cycle on Road 1 = 450/55 = 8.2 PCU
Minimum green time for clearing vehicles on Road 1 = **6** + (8.2 – 1.0)**2** = 20.4 sec < green time G_1 = 29.0 sec. OK.
Vehicle arrivals per lane per cycle on Road 2 = 278/55 = 5.1 PCU
Minimum green time for clearing vehicles on Road 2 = **6** + (5.1 – 1.0)**2** = 14.2 sec < green time G_2 = 18.0 sec. OK.

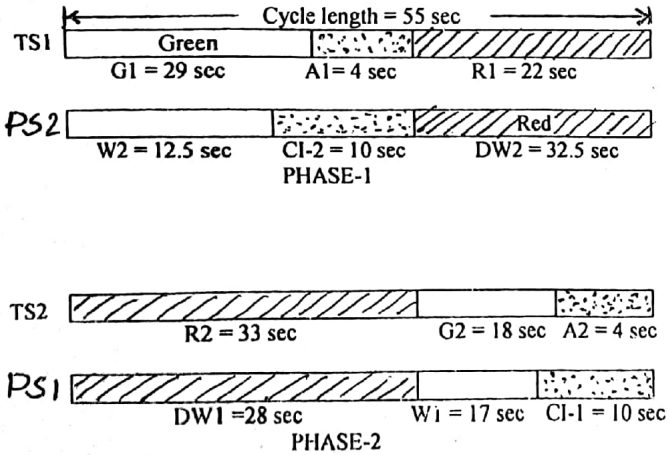
Optimum cycle time, C_o = (1.5 L + 5)/(1 – Y) where L = Lost time per cycle and Y = y_1 + y_2.

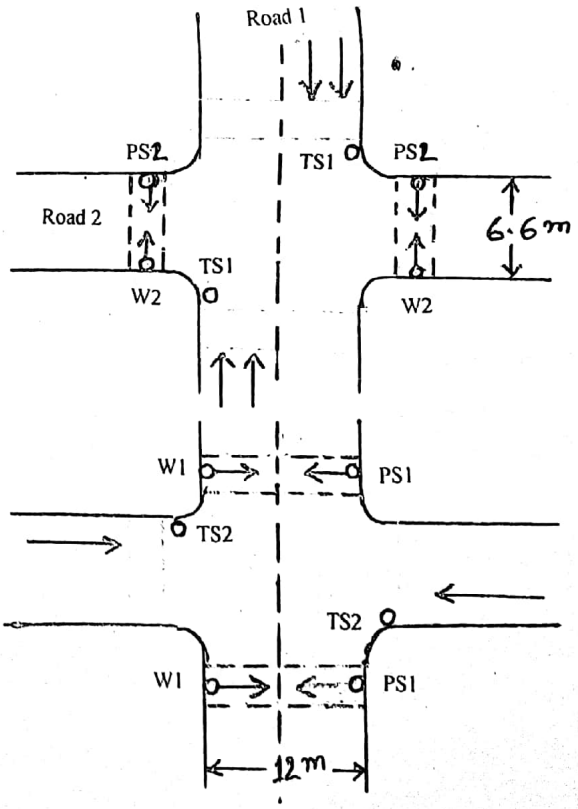
Approach road width (Curb to median or centre line), m	3.0	3.5	4.0	4.5	5.0	5.5	> 5.5
Saturation flow values, PCU/hr. per meter width	1850	1890	1950	2250	2550	2990	525

L = Amber time + inter-green time + time lost for initial delay of first vehicle = [2 + 2 + (6 – 2)] 2 = 16 sec
Saturation flow S_1 for Road 1 = 525x 6 = 3150 PCU/hr. Saturation flow S_2 for Road 2 = 1850 + 40 (0.3/0.5) = 1874 PCU/hr.

For Road 1, y_1 = Normal flow/Saturated flow =900/3150 = 0.286 & for Road 2, y_2 = 278/1874 = 0.148, then Y = 0.434
C_o = (1.5 L + 5)/(1 – Y) = (1.5 x 16 + 5)/(1 – 0.434) = 51.2 sec. Therefore the designed cycle time 55 sec is acceptable

The details of the signal timings are given below: Pedestrian clearance intervals (CI) =10 sec from (i) e.i 12/1.2 = 10.





(iii) Road Marking

Road or traffic markings are made of lines, patterns, words, symbols or reflectors on the pavement, kerb, sides of islands or on the fixed objects within or near the roadway. This special signs are used to control, warn, guide or regulate the traffic. The markings are made using paints in contrast with colour and brightness of the pavement or other back ground.

(a) Colour of Road Markings (given in Table 14.1)

(b) Types of Road Markings

1. Pavement or Carriageway Markings: Some common types of pavement markings are:

(i) Centre Lines:- These broken line are meant to separate the opposing streams of traffic on undivided two-way roads. On rural highway, line width 0.1 m, segment length 4.5 m & gaps 7.5 m. These lengths reduced to 3m and 6 m at horizontal curves and approaches to intersections. On urban roads, line width 0.10 m to 0.15 m, segment length 3 m and gap 4.5 m. On undivided roads with at least two traffic lanes for each direction of traffic flow, the centre line marking shall consist of two solid continuous lines (Fig. 14.1).

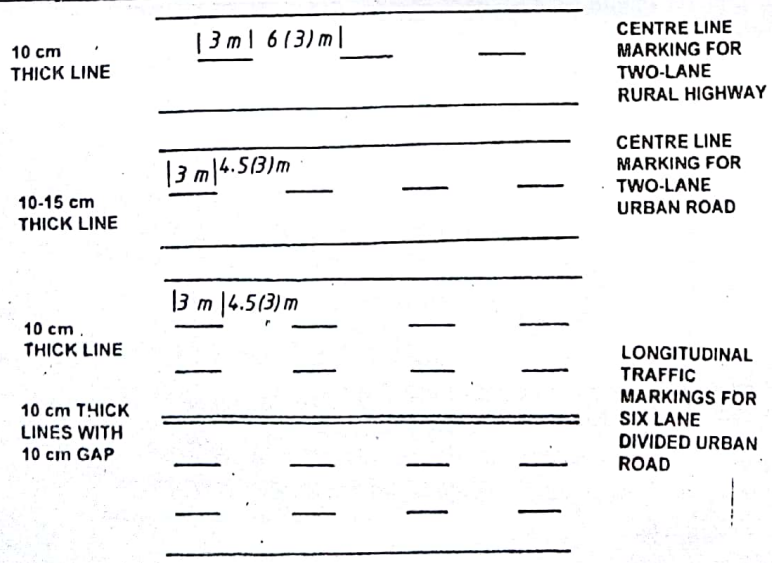
(ii) Lane Lines:- These broken line are drawn to designate traffic lanes. These are used to guide the traffic and to properly utilize the carriage way. It is offence to cross such a line (Fig. 14.1).

(iii) Route Direction Arrows:- are used to guide effectively the traffic in the correct direction and lanes. Arrows must be elongated in the direction of traffic to be properly legible (Fig. 14.11)

(iv) Stop Lines:- are solid white lines provided transversely to the carriageway and used to indicate the point behind which vehicles are required to stop in compliance with a STOP sign as shown in Fig. 14.7.

Table 14.1
Colour of Roads Markings as per Indian Practice

Colour	*Uses*
White	All carriageway markings except those intended for parking restrictions.
Yellow	(*i*) Markings intended for parking restrictions (*ii*) Continuous centre and barrier line markings.
Alternate bands of white and black.	Kerb and object markings.



NOTE : FIGURES IN BRACKETS TO BE USED ON CURVES AND APPROACHES TO INTERSECTIONS

Fig. 14·1. Centre line and lane markings.

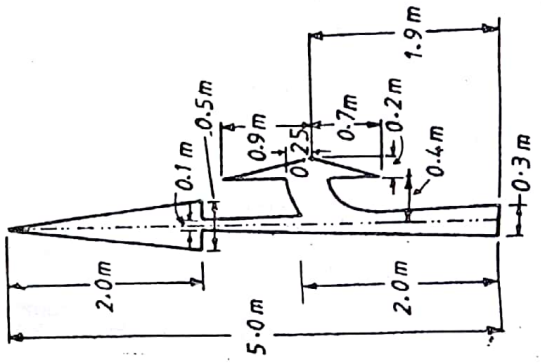


Fig. 14·11. designs for route direction arrows.

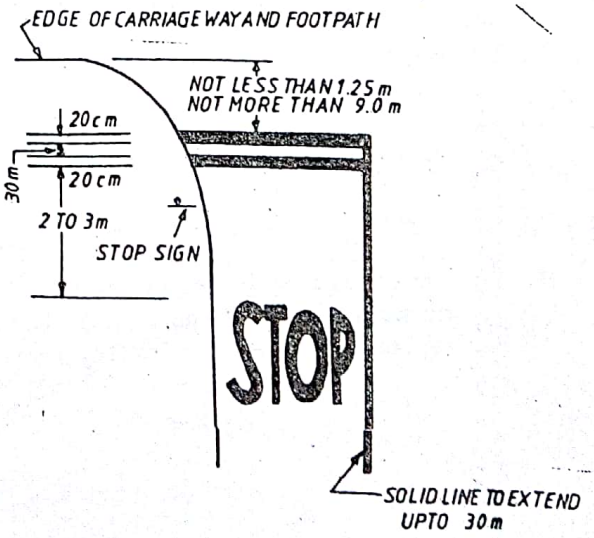


Fig. 14·7. Details of a stop line.

(v) Cross Walk Lines:- Pedestrian crossings (2m wide) are very important for their safety as shown in Fig. 14.9

(vi) Parking Space Limits:- For proper utilization of parking facility, markings are made.

(vii) Bus Stops:- Kerb length reserved for buses to stop are marked by continuous yellow line on kerb indicating ' parking prohibited' or marked by the word 'BUS'.

2. Kerb Markings: These may indicate certain regulations like parking regulations. Also the markings on the kerb and edges of islands with alternate black and white line increase the visibility from a long distance. During night time they prove very helpful.

3. Object Markings: Hazardous obstructions near the road, like supports for signs & signals, level crossing gates, traffic islands, narrow bridges culvert head walls, trees etc.

4. Reflector Unit Markings: Hazardous obstructions are indicated by fixing reflector units reflecting yellow light at night. Reflector unit should be visible from 150 m distance

(iv) Traffic Islands

Traffic islands are raised areas constructed within the roadway to establish physical channels through which the vehicular traffic may be guided to travel and avoid conflict. Based on the function, islands are classify as :

1 Divisional Islands:- are provided to separated opposing flow of traffic in a road having four or more lanes. It reduces the possibilities of head on collision and other accidents. The width should be large to reduce the head light glare during night driving.

2 Channelizing Islands:- are normally of triangular shape and used to guide the motorists at turning points. Channelizing islands are very useful as a traffic control device, particularly, at intersections having large areas. Minimum area desirable size of this island should be 5 sqm in area and preferable length of one side of triangle should be 4 m. The various uses of properly designed channelizing islands are listed below :
(i) The area of possible conflicts between traffic stream is reduced.
(ii) They establish the desired angles of crossing and merging of traffic streams.
(iii) They are useful when the direction of the flow is to be changed.
(iv) They serve as refuge islands for pedestrians.

3 Central Island or Traffic Rotary:- Rotary (Central) island is an enlarged highway intersection where all the approaching vehicles from all the converging roads are forced to move around a large centrally situated island* before they weave out into the desired radiating road. It is usually circular in shape but can be elliptical or any other shape.

* in clockwise direction

Functions : (i) They segregate vehicular traffic from pedestrian traffic.(ii) They segregate traffic into specified paths. (iii) They reduce the conflict area (iv)They increase the traffic capacity of the road and (v) They increase traffic safety.

(v) Highway Lighting

To promote the safe and efficient movement of vehicular and pedestrian traffic along the roadway proper lighting is essential. The rate of highway accidents and fatalities that occur during night travel is many times higher than that during day time travel. One of the many reasons of increased accident rate during night may be due to the poor visibility at night. Highway lighting is more important at intersection, bridge site & level crossings.

During night driving, the visibility of objects on road varies with the absolute level of brightness of the object and the relative brightness of the road surface and the object. During night objects are discerned (রাত্রিকালীন দৃশ্যমানতা বিভিন্ন ভাবে) by three ways:

Silhouette (সিলুয়েট) :- When the brightness of the object is less than that of the background.
Reverse Silhouette:- When the brightness of object is more than that of the background.
Surface Detail:- When the variations in brightness and colour of the object surface without regard to its background.

The various factors that influence the night visibility are:

1. Size of the object 2. Brightness of the object 3. Brightness of the background
4. Reflecting characteristics of the pavement surface 5. Glare on the eyes of the driver
6. Time available to see the object 7. Amount and distribution of light flux from the lamp.

Design factors of highway lighting

1. Lamps:- Road lighting lamps may be as follows :

Tungsten filament lamps: It is the cheapest lamp but have low light producing efficiency.

Fluorescent lamps: Long life, good visibility, least dazzling but low output per lamp.

Sodium vapour lamps: Yellow coloru, costly but these are preferred at large intersections

Mercury vapour lamps: Bluish white colour, costly but more pleasing to the eye.

2. Luminaire distribution of light:- should be downward so that higher percentage of lamp light is utilized and should cover the pavement between the kerbs and the adjacent area. The unit of illumination in the metric system is **lux** or lumen per square metre. It is suggested the average level of illumination on road side should be 20 to 30 lux on urban roads carrying fast traffic, about 15 lux for mixed traffic and 4 to 8 lux on secondary road

3. Spacing of lighting units:- The spacing of lighting units is influenced by the electric distribution poles, road layout and type of side features. Spacing should be 3 to 5 times the mounting height on straight roads and less than this on sharp curves. From economy point of view, large lamps with high mounting and greater spacing should be used.

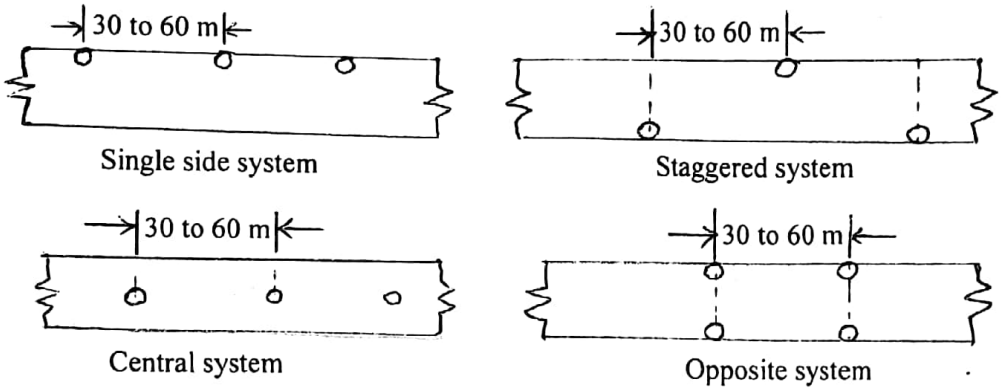
4. Height and over hang of mounting:- The mounting height of lamp governs the distribution of light, shadow and the glare effect. Usually the mounting height varies from 6m to 10m. Over hangs (≤ 2 m) would keep the poles away from the road edges.

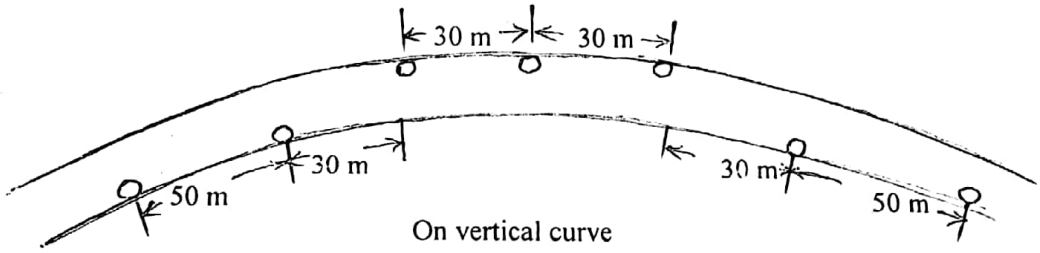
5. Lateral placement:- If poles are too close to the carriageway, free movement of traffic is obstructed, decreasing the capacity of the road. The horizontal clearance required for lighting poles are given below:

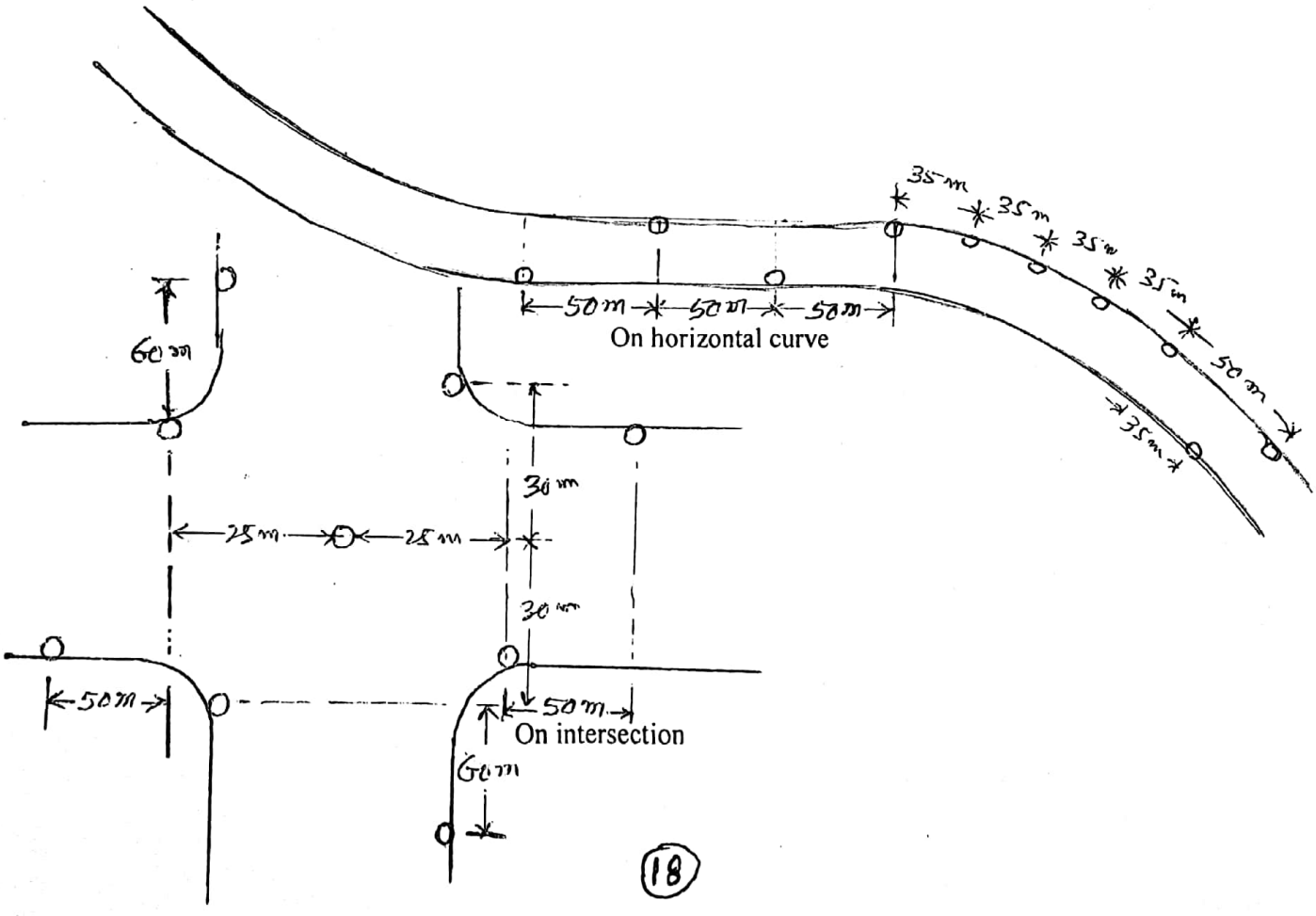
(a) For roads with raised kerbs (as in urban roads) > Minimum 0.3 m and desirable 0.6 m from the edge of raised kerb.

(b)) For roads without raised Kerb (as in rural roads) > Minimum 1.5 m from the edge of carriageway. or minimum 5.0 m from the centre line of carriageway.

6. Lighting layout:- On straight roads the lighting layout may be of the following types:



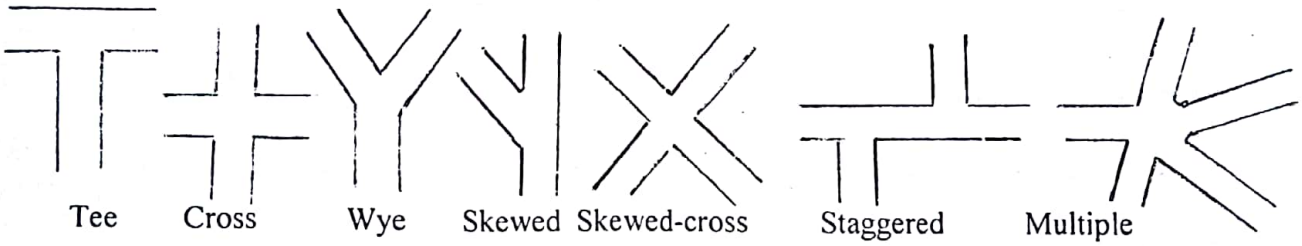




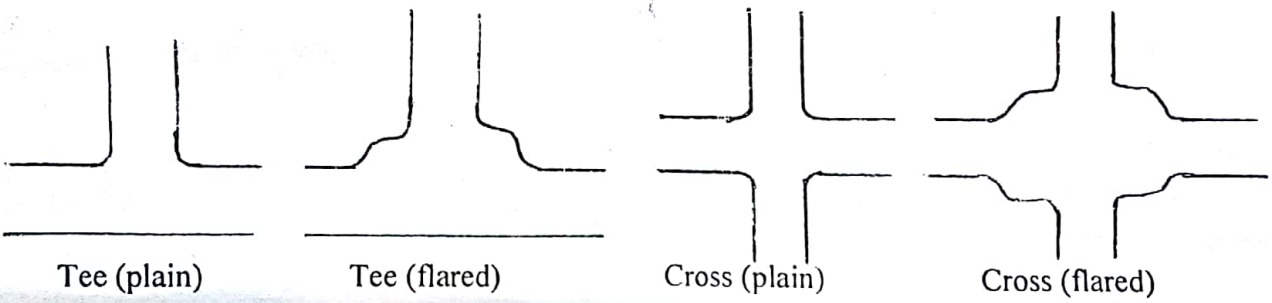
1.5 Road Intersections

Road Junctions or Road Intersections are the places where two or more roads cross each other at different angles. Different types of movements (through, turning and crossing) are involved at road intersections. There is no problem in traffic movements on straight roads. But intersections are points of traffic hazards which affect safety, speed, efficiency, capacity and cost of operation of the whole road. Pedestrian movements at intersection produce increased potential hazards and delays.

1.5.1 Intersection at grade or level: These include all roads which meet at more or less the same level. The traffic manoeuvres like merging, diverging & crossing are involved here.
Types of level intersection according to the system of intersecting roads at intersection are:

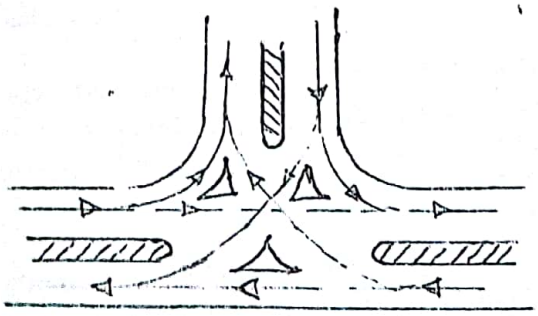


1.5.2 Unchannelized Intersection:- There is no provision of any direction island or central island. To avoid frequent accidents, heavy traffic at such intersections can be controlled by installing traffic signals or with the help of traffic police. No additional pavement width for turning is called plain intersection and with additional pavement width is called flared intersection.

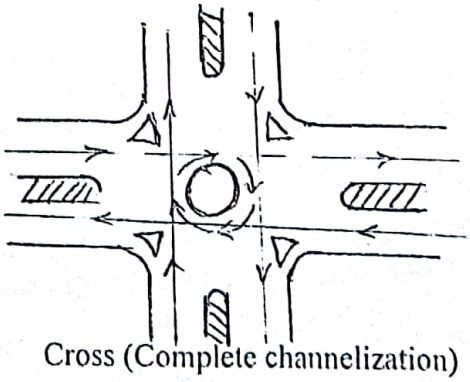


1.5.3 Channelized Intersection:- is achieved by introducing islands into the intersectional area, thus reducing the total conflict area available in the unchannelized intersection. Channelization may be either partial or complete with *divisional* and *directional* island and medians. The advantages of channelized intersection are as follows:

(i) Vehicles can be confined to definite paths. (ii) Points of conflicts can be separated.
(iii) Refuse islands can be provided for pedestrians. (iv) Angle of merging kept minimum.

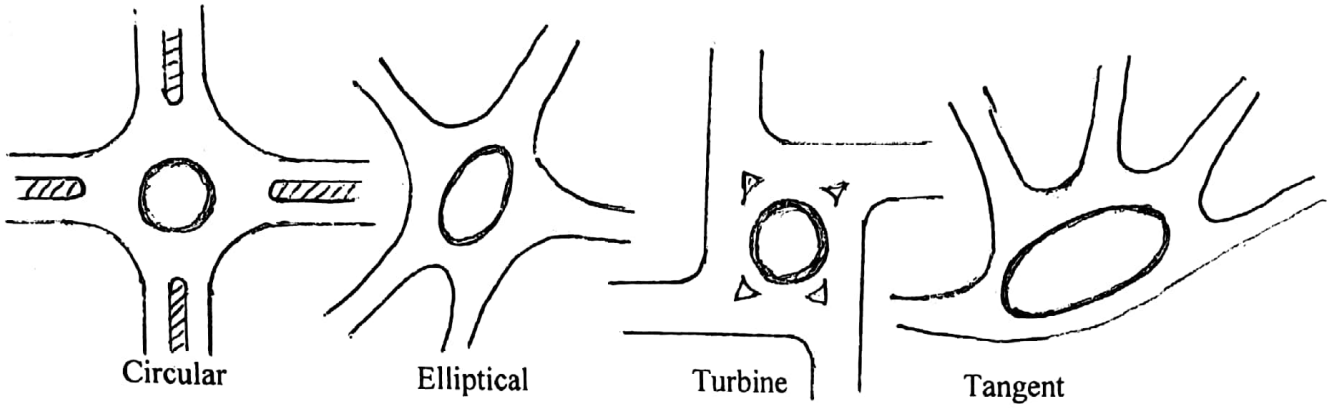


Tee (Complete channelization)



Cross (Complete channelization)

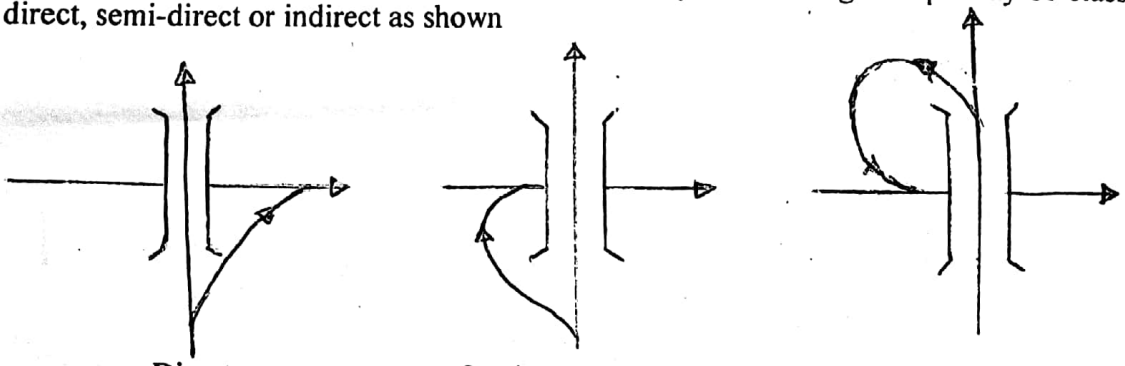
1.5.4 Rotary Intersection:- By provision of rotary, necessity of stopping at road intersection is eliminated. Traffic from all the converging roads keeps on moving round the central island in clock wise direction and adopts its road of desire to move out of rotary without stopping any where. On rotary, crossing conflicts are completely eliminated.



Advantages: (i) Traffic handling capacity is the highest (ii) It is more safe (iii) All vehicle get equal preference (iv) Operational cost of vehicle is less (v) There is no need of traffic police or signal (vi) Number of accidents are low.

Disadvantages: (i) Requires a large area of land and hence it is costly in built up area. (ii) If the vehicular traffic have to stop to allow pedestrian to cross, the main purpose of rotary if defeated. (iii) If large number of pedestrians and cyclists are involved, design and operation of rotary becomes very complicated. (iv) When there are more than seven intersecting roads, rotaries are unsuitable and unjustified for very low traffic volume.

1.5.5 Grade separated intersection:- The intersecting roads are separated by passing one road over or below the other and thus eliminating the crossing manoeuvres. This intersection causes least delay and hazard to the crossing traffic and much superior to intersections at grade from the point of view of traffic safety and efficient operation. Transfer of route at the grade separation is provided by interchange facilities consisting of ramps. Interchange ramps may be classified as direct, semi-direct or indirect as shown



Advantages : (i) Maximum facility is given to the crossing traffic. (ii) There is increased safety for turning traffic. (iii) They provide comfort and convenience to the driver and saving the travel time & operation cost. (iv) It is essential part of controlled access highway like expressway and freeway. (v) It can be designed for any angle of intersection

Disadvantages : (i) It involves very large areas. (ii) It involves lot of expenditure in providing bridges under passes and interchange ramps. (iii) Unnecessary rising grades and sags are introduced in vertical alignment.

1.5.6 Over-pass:- When the major highway is taken above by raising its profile above the general ground level by embankment and an over-bridge across another highway.

Advantages: (i) Drainage problem may be reduced (ii) Cost of bridge structure is less for small span of cross road. (iii) There is aesthetic preference and less feeling of restriction (iv) Future expansion or construction of separate bridge structure is possible.

Disadvantages: (i) In rolling terrain, the vertical profile of major road will also have rolling grade line. (ii) Embankment with steep gradient increase the grade resistance (iii) Long vertical curve required for clear sight distance.

1.5.6 Under-pass:- When the highway is taken by depressing it below the ground level to cross another road by means of an under-bridge.

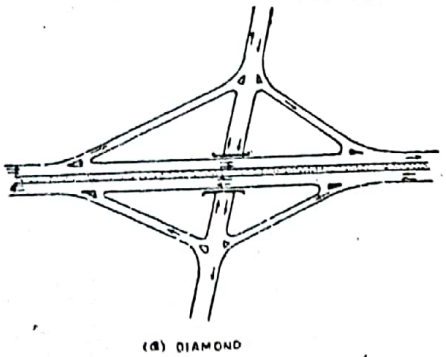
Advantages: (i) If main road is retained at ground level and cross road is depressed, under pass proves advantageous. (ii) If main road is depressed, below cross road, traffic from cross road will reach main road with increased acceleration and traffic from main road will reach cross road with retardation.

Disadvantages: (i) Drainage problem is very troublesome. (ii) Rise of underground water table during monsoons may further complicate the drainage problem. (iii) There is a feeling of restriction to traffic at the sides. (iv) The over head structure may restrict the vertical sight distance. (v) There is no possibility of stage construction for the bridge.

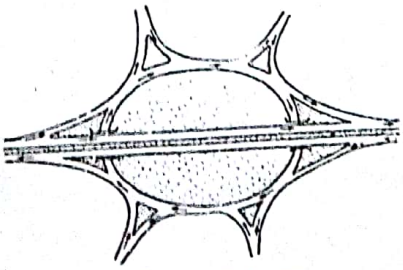
1.5.7 By-pass:- is an arrangement for diverting a traffic flow to avoid unnecessary hazards.

1.5.8 Fly-over:- is a bridge over a large road intersection for safe traffic flow avoiding conflict.

1.5.9 Interchanges:- Grade separated intersection with complete interchange facilities is essential to develop a highway with full control of access. Some of the types of interchanges are shown in Figure 5.39. Of all these complete *full clover leaf* fulfils all the requirements of turning traffic involving the simplest traffic manoeuvers, viz; diverging to the left and merging from the left by providing four indirect ramps.

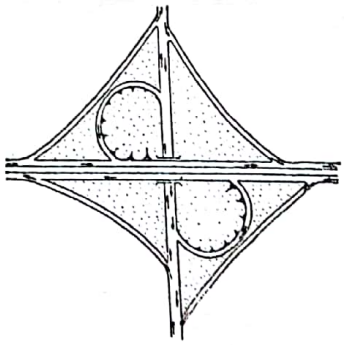


(a) DIAMOND

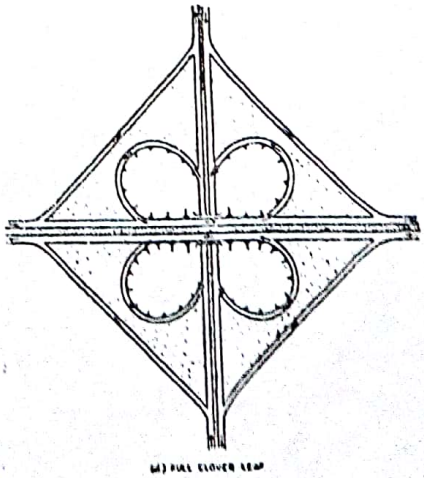


(b) Rotary Interchanges

Figure 5.39 (a) & (b) Types of Interchanges



(c) PARTIAL CLOVER LEAF



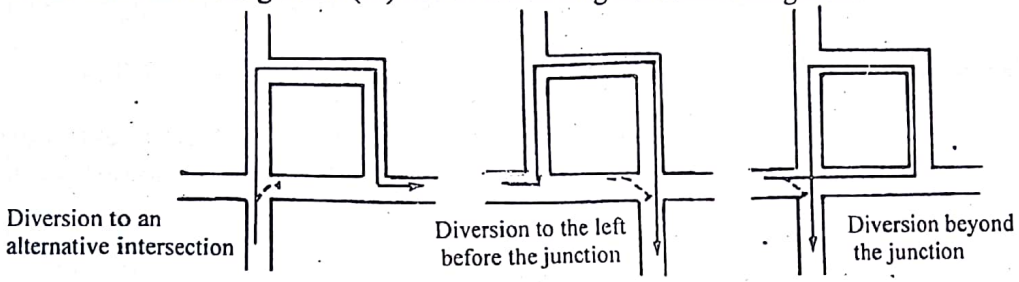
(d) FULL CLOVER LEAF

Figure 5.39 (c) & (d) Types of Interchanges

Transportation System Management (TSM)

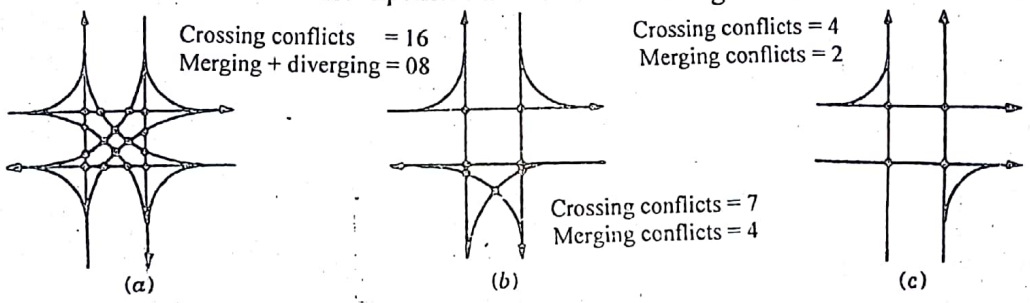
As the traffic on the existing road system in the cities grows, congestion becomes a serious problem. Medium and long term solution like widening of roads, providing flyovers and constructing by-passes and urban expressways are costly. Simple and inexpensive solutions can tide over (সাময়িকভাবে সমাধান করে) the crisis for some times. TSM is a package of short term measures to make the most productive and cost-effective use of existing transportation facilities. Some of the well-known traffic management measures are:

(1) Restrictions on right-turning movements: Right –turning traffic can cause serious loss of capacity. Heavy right-turning traffic can control by (i) to incorporate a separate right-turning phase (ii) to introduce an early cut-off or late start arrangement (iii) to ban the turning movement altogether.



Prohibited right turning schemes.

(2) One-way streets: These streets are those where traffic movement is permitted in only one direction. They afford the most immediate and the least expensive method of alleviating the traffic conditions in a busy area.



Vehicular points of conflict with 2-way streets and one-way streets.

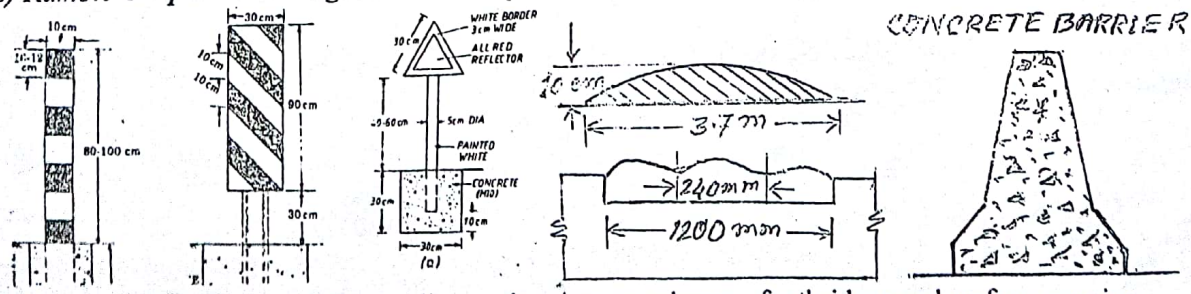
(3) Tidal-flow operation: Method is to allot more than half the lanes for one direction during the peak hours.

(4) Closing Side-streets: It may be possible to close some of these side-streets without affecting the traffic.

(5) Exclusive Bus-lanes: A lane can be reserve exclusively for bus where the carriageway is adequate width.

(6) Traffic aids:

(a) Roadway Delineators: are intended at turning point to provide visual aids to drivers at night.
(b) Hazard Markers: are intended to define obstructions like guardrails and abutments at road sides.
(c) Object Markers: are used to indicate hazards and obstructions within channelising islands.
(d) Speed Breakers: humps painted with white paint are used to control speed near crowded area.
(e) Rumble Strips: are corrugated surfaces producing noise and a physical sensation on the steering.



(f) Guard-Rails: are needed for guiding pedestrians to subways, footbridges and surface crossing.
(g) Safety Barriers: are intended to prevent vehicles that accidentally leaving the highway.
(h) Barricades: are required for controlling and diverting traffic on construction zones.
(i) Traffic Attenuators: are required to absorb the impact energy of vehicles that go out of control.

Hierarchy of Roads

Road: is a convenient way for communication from one place to another and may be bituminous or concrete.
Street: is a road within the town, which has defined by buildings constructed along one or both of its sides.
Highway: is a roadway of standard width, meant for all sorts of traffic & include all public roads and streets.
Bypass road: is an arrangement for diverting a traffic flow to avoid congested areas of towns or cities.
Boulevard (Avenue): is a very wide road in a city with trees on either side and used as processional roads.

Needs of highway classification: (i) For a designer, it enables him to relate the geometric and structural design standards. (ii) For a planner, this provides a basis for long-term planning. (iii) Also it serves various administrative needs. Based on location and function, two broad categories of road are: (i) Urban – falling within the municipalities and (ii) Non-urban (Rural) – located in areas other than urban.

Urban roads are classified as under:

Expressways: A divided arterial highways for heavy volume of motor traffic at high speeds, with full control of access and provided with grade separation at intersections. Parking & pedestrian are not permitted.

Arterial Streets: A divided highways for through traffic with fully or partially controlled access. Parking, loading and unloading activities are usually restricted. Pedestrians are allowed to cross only at intersections.

Sub-arterial Streets: A street with lower level of mobility & access to adjoining areas is more than arterial streets. Parking, loading-unloading are restricted & regulated. Pedestrians are allowed to cross at intersection

Collector Streets: A collector street provided for collecting and distributing the traffic to and from local streets. Full access is allowed from abutting properties. A few parking restrictions except during peak hours.

Local Streets: A local street provided for access to residence, business or other abutting property. A local street may be residential, commercial or industrial. It allows unrestricted parking and pedestrian movements.

Rural roads are classified as under:

National Highways: are the main highways running through the length and breadth of the country connecting ports, foreign highways, capitals of States large towns and industrial areas and roads for strategic value.

State Highways: are the other main trunk or arterial roads of a State, connecting up with the National highways or highways of adjacent State and linking the district headquarters and important cities within the State.

District Roads: are roads traversing each district, serving areas of production & markets & connecting these with each other or with NH/SH. M.D.R. is for higher order of traffic and O.D.R. is for lower order of traffic.

Village Roads: are roads connecting villages or groups of villages with each other and to the nearest district road, NH or SH or Railway or navigational routes. They are in essence road from the village to a market.

Based on construction materials, classifications of road are:

(1) Earth road (2) Gravel road (3) Brick road (4) Soil stabilized road (5) Water Bound Macadam (WBM) road (6) Bituminous road (7) Cement concrete road.

THE ROAD IN BANGLADESH

S	Category	Length	Definition
1	National Highway (NH)	3163 Km	Connecting capital city with district headquarters, ports & international highways
2	Regional Highway (RH)	2911 Km	Connecting different regions with each other which are not connected by the NH
3	Feeder Road Type-A (FRA)	9996 Km	Connecting Thana headquarters to the arterial network ( )
4	Feeder Road Type-B (FRB)	17058 Km	Connecting growth centers to the RHD network or to the Thana headquarters
5	Rural Road Category-1 (R_1)	56136 Km	Connecting Union headquarters/local markets with the Thana headquarters
6	Rural Road Category-2 (R_2)	48874 Km	Connecting villages and farms to local markets/Union headquarters
7	Rural Road Category-3 (R_3)	61286 Km	Roads within villages

Traffic and the Environment

The automobile is the outstanding (prominent) inventions of man. Problems of traffic have a direct impact on the environment in which we live. The traffic engineer has a great responsibility in ensuring that the road traffic does not spoil this environment. The **environmental area** is an area having no extraneous (অপ্রাসঙ্গিক) traffic, and within which considerations of environment predominate over the use of vehicles. The areas should be safe, reasonably free from noise and generally agreeable.

The **detrimental effects of traffic** on our surroundings are discussed below:

(i) Road safety: Everybody wants a road safety i.e, movement on roads should be free from accidents. Safety of road users has been seriously endangered by the motor vehicle and because of its great importance this subject is discussed in separate chapter as *Road Safety.*

Factors involved in road accidents are (1) Road Factors (2) Vehicle Factors (3) Road Users (driver, scooter and motor-cycle riders, cyclists, passengers, pedestrians etc.). (4) Environmental Factors (5) Other Factors.

(ii) Noise: Noise is unwanted sound intruding (অনাধিকার প্রবেশ) upon the quiet life and privacy of the urban dwellers. The detrimental effects of traffic noise can be considered under the following major groups:

(a) Subjective effects: Such as annoyance (discomfort), dissatisfaction, disturbance, bother and noisiness.

(b) Behavioural effects: Such as interference in speech, T.V. programs, studies, student mind in class room.

(c) Physiological effects: The startle (হঠাৎ চমকানো) phenomena that can results in harmful effects on body.

The generation of noise by traffic (1) Noise generated by various parts of the vehicle; (2) Noise contributed by the interaction between vehicles and road surfaces (3) Noise dependent on speed, flow & traffic density. Motor cycles and scooters are noisier than car; commercial trucks & old vehicles are a main source of noise Sound level is recorded by the sound level meter and expressed as the decibel (dB). In order to account for the ear's response at low and high frequencies, different weighing filters, A, B and C are used. Normally, noise having a level of not more than 60 dB (A) will be rated by many as quiet. Noise level of 90 dB (A) and above will be rated by many as extremely noisy. Acceptable noise levels inside the building in suburban and busy urban areas are 45 dB(A) & 50 dB(A) for day time and 35 dB(A) for night respectively.

Control of Traffic Noise: (i) Changes in design of vehicles and tyres (ii) Elimination of noisier vehicles, etc.

(iii) Air Pollution: Pollution of the atmosphere by fumes and smell emitted by the motor vehicles makes the urban streets extremely unpleasant. The source of the pollutant: (1) The major source is the exhaust gas emitted by the internal combustion engine (2) Evaporative losses from the fuel tank & the carburetor and (3) losses from the crank case.

Small doses of carbon monoxide, oxides of nitrogen and lead compounds does not appear to be a danger to health but the increase in the concentration may ultimately affect the well-being of the residents. Smog is a result of the combination of smoke and fog and can cause hazards to driving and irritation to the eyes.

Measures for Controlling Air Pollution:

(1) Reducing the pollutants at the source by improving the vehicle design and maintenance.
(2) Use of small cars instead of bigger ones and patronage of public transport system (tubes and railways).
(3) Use of alternative fuels, bypasses and ring roads (4) Staggering work hours, to reduce peak hour traffic.

(iv) Vibration: A vehicle moving on road surface induces following types of vibration in the surroundings:
(1) Vibrations generated in the contained air between the buildings may be annoying to the people.
(2) Surface vibrations set up on the superstructures (3) Underground vibrations set up in the substructures.
(4) Vibration due to irregular road surface causes of cracking of plaster, rattling of doors, windows & glass.

Vibrations with 10-15 mm/sec (peak particle velocity in the vertical direction) (i) considered unpleasant by people & unacceptable to some people walking on bridges (ii) cause architectural damage and possible minor structural damage.

Ameliorative (উন্নতি সাধক) Measures: (1) Improvement of road surface (2) Reducing the number of heavily loaded vehicles (3) Enforcing a minimum space between adjacent buildings (4) Provision of wider roads.

(v) Visual Intrusion and Degrading the Aesthetics: Buildings seem to be rise from a plinth of cars.. Service stations, garages and petrol filling stations have sprung up along the road and added their mite to the degradation of the general scene.

(vi) Severance (বিচ্ছেদন): is the psychological, cultural and physical disturbance caused by a traffic facility on the neighborhoods, the land, the society and its life style. Land crisis is problem of rehabilitation.

HIGHWAY MATERIALS

Highway materials are the engineering materials used for the construction of highway pavement. Materials generally used for road construction are soil, aggregates and binders.

Soil: In a broad sense, soils include all earth materials, organic and inorganic, occurring in the zone overlying the rock crust of the earth.

Sub-grade soil: is the natural soil used for the preparation of foundation layer of road to receive the other layers of the road. Therefore this soil should possess sufficient strength and stability under adverse climatic and loading conditions. Pavement defects such as the formation of waves, corrugations, rutting, shoving, etc. in flexible pavements and mud pumping, cracking, etc. in cement concrete pavements are developed due to poor sub-grade.

The desirable properties of soil as a highway material are :

(1) Stability (2) Incompressibility (3) Permanency of strength
(4) Minimum volume change (5) Good drainage and (6) Ease of compaction.

Aggregate: is an inert material which forms a substantial part of concrete. Different type of aggregates are khoa, stone chips, gravel, cinder, slag, sand, etc.

Aggregates form the major portion of pavement structure and they form the prime materials used in pavement construction. Aggregates have to bear stresses occurring due to the wheel loads on the pavement and on the surface course they also have to resist wear due to abrasive action of traffic. Therefore the properties of aggregates are of considerable significance to the highway engineers.

The desirable properties of aggregate as a highway material are :

1. Strength. The aggregate to be used for roads should be sufficiently strong to withstand the stresses due to traffic wheel loads. The strength of coarse aggregate is determined by Aggregate Crushing Value (ACV) test.

2. Hardness. The aggregates used in the surface courses are subjected to constant abrasion due to moving vehicles. The mutual rubbing (Attrition) of stones also causes wear in the aggregates. The hardness of aggregates is tested by Los Angeles Abrasion Value (LAV) test.

3. Toughness. Aggregates in pavements are also subjected to impact due to moving wheel loads. The toughness of aggregates is determined by Aggregate Impact Value (AIV) test.

4. Durability. Aggregates used in pavements have to withstand the adverse action of weather such as physical and chemical actions of rain and ground water and effects of atmosphere etc. The durability of aggregates is determined by soundness test.

5. Shape. Aggregate particles may have rounded, cubical, angular, flaky or elongated shapes. Too flaky and too elongated aggregates should be avoided as far as possible due to their less strength. Angular or rough textured aggregates should be preferred due to their more interlocking capacity. Shape of the particles are evaluated with reference to Flakiness Index, Elongation Index and Angularity Number.

6. Adhesoin with bitumen. Aggregates used in bituminous pavements should have more affinity with bituminous material than water, otherwise bituminous coating on aggregates will be stripped off in the presence of water. The static immersion test is very commonly used to determine the adhesion of bituminous binder to an aggregate in the presence of water.

BITUMINOUS MATERIALS : As per ASTM, "Bituminous materials are the mixture of hydrocarbon of natural or hydrogenous origin or a combination of both, found in gaseous, liquid, semi-solid or solid form and completely soluble in carbon disulphide".

Bituminous binder used in road construction works are bitumen and tar.

BITUMEN: As per ISI, Bitumen may be define as "a non crystalline solid or viscous material having adhesive properties derived from petroleum, either by natural or refinery process and completely soluble in carbon disulphide."

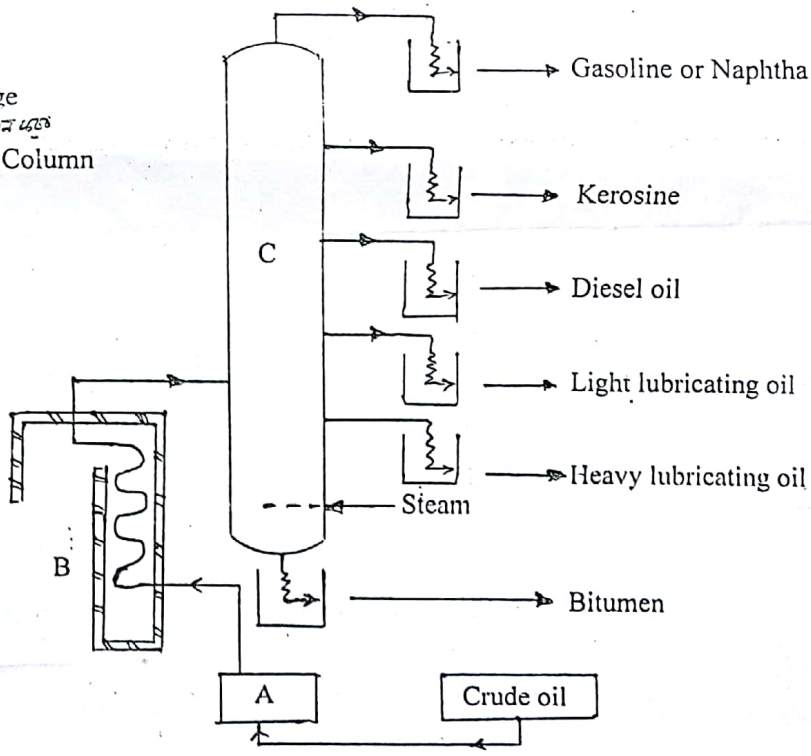
In British terminology, **Bitumen** is define as a pure bitumen i.e there is no inert materials Bitumen obtained by refinery processes from petroleum is called *Petroleum Bitumen* and bitumen found as a natural deposit is called *Natural Bitumen.* **Asphalt** is a natural or mechanical mixture in which bitumen is associated with a substantial proportion of inert matter. If found in lakes, it is known as *Lake Asphalt*. If found as a naturally occurring calcareous rock, it is known as *Rock Asphalt*.

In American terminology, the materials coming under the two British terms 'Bitumen' and 'Asphalt' are commonly known as "**Asphalt**".

Manufacture of Bitumen : Bituminous materials are a component of petroleum crude. They are obtained as end-product in fractional distillation of crude petroleum. For bitumen refining, two different processes are used (i) Steam and vacuum distillation method and (ii) Solvent extraction method.

From crude petroleum, the volatiles are separated in a fractionating column (Fig. below).

A – Heat Exchange
B – Tube Still
C – Fractionating Column



Straight run bitumen: Bitumen which has been produced by distillation process to a definite viscosity or penetration without further treatment. This bitumen mostly used for road construction and before use its viscosity has been reduced by heating.

Penetration grade bitumen: is a bitumen whose degree of hardness can be measured by the standard penetration test.

Air-Blown-bitumen: is a bitumen obtained by further treatment of straight run bitumen by running it, while hot, into a vertical column and blowing air through it. It is a very useful element in roofing materials, battery boxes, water proofing paints and joint filler.

Cutback Bitumen: is defined as the bitumen, the viscosity of which has been reduced by a volatile diluents. For use in surface dressings, bituminous macadam and soil-bitumen stabilization, it is necessary to have a fluid binder which can be mixed relatively at low temperatures. Hence to increase fluidity of the bituminous binder at low temperatures, the binder is blended with a volatile solvent. After the cutback mix is used in construction work, the volatile gets evaporated and the cutback develops the binding properties (called curing). Depending upon the diluents used, there are three types of cut-backs : (i) Rapid Curing (RC) are manufactured by blending bitumen with highly volatile solvent like gasoline or naphtha (ii) Medium Curing (MC) are made by fluxing bitumen with some what less volatile solvent like kerosene and (iii) Slow Curing (SC) are manufactured when bitumen is blended with a high boiling point light oil which contains little or no volatile constituent.

Bitumen Emulsion: is a combination of bitumen (30% to 60%), an emulsifying agent (0.5% to 1%) and water (remaining portion). When heated bitumen and water are mixed together and agitated, the bitumen disperses in water in the form of spherical globules of about 2 micron diameter. To prevent bitumen spheres from coalescing, an emulsifying agent is added in the emulsion which remains dissolved in water. Emulsifying agents usually adopted are soaps, surface active agents and colloidal powders. Depending upon the stability of the protective coating of emulsifying agent the emulsion may be classified as Rapid Setting (RS), Medium Setting (MS) and Slow Setting (SS).

When road aggregate mixed with emulsion is applied on the road, it starts breaking. The first sign of emulsion break is reflected when its colour changes from chocolate brown to black. As the emulsion starts breaking it starts binding the aggregates. When full water gets evaporated, it develops its full binding power.

Emulsions are used in bituminous road constructions, especially in maintenance and patch repair works. The main advantage of emulsion is that it can be used in wet weather even when it is raining. Also emulsion have been used in soil stabilization.

Tar: is the viscous liquid obtained when natural organic materials such as wood and coal are carbonized or destructively distilled in the absence of air. Based on the material from which tar is derived, it is referred to as wood tar or coal tar ; the latter is more widely used for road work because it is superior. Composition of tar can be diagrammated as:

Tar ——— Light Liquid oil + Middle oil + Heavy oil + Pitch

Light road tar ——— Middle oil + Heavy oil + Pitch

Heavy road tar ——— Heavy oil + Pitch

Pitch ——— Pitch

Based on their viscosity and other properties, road tars are classified in five grades:

RT – 1 is used for surface dressing under exceptionally cold weather.
RT – 2 is used for surface dressing under normal climatic conditions.
RT – 3 is used for surface dressing, renewal coats, premixing chippings and light carpet
RT – 4 is used for premixing tar macadam in base course.
RT – 5 is used for grouting purposes.

Comparison between Bitumen and Tar:

Bitumen	Tar
1. Dark brown to black colour	1. Dark brown to black colour
2. Produced from crude petroleum	2. Produced by distillation of wood or coal
3. Free carbon content is less	3. Free carbon content is more
4. Bitumen does not have any toxicity	4. Tar possesses phenol which is toxic
5. Setting time is less than tar	5. Setting time is more than bitumen
6. Useful for road construction	6. Useful for roofing materials & joint filler
7. Hardens very slowly	7. Hardens at much faster rate than bitumen
8. Soluble in carbon disulphide CS_2	8. Soluble in carbon disulphide.
9. Costlier than tar	9. Cheaper than bitumen.

Introduction

 # Transportation: Transportation is the system by which humans and goods can be shifted from one place to another by means of any kind of vehicle.

 # Transportation Engineering: Transportation engineering is the application of technology and scientific principles to the planning, functional design, operation and management of facilities for any mode of transportation in order to provide safe, efficient, rapid, comfortable, convenient, economical and environmentally compatible movement of peoples and goods.

 # Roles of Transportation: 16, 09

1. Transportation contributes to the economic, industrial, social and cultural development of any country.
2. Transportation is vital for the economic development of any region.
3. Every commodity (produced whether it is food, industrial products, clothing or medicine) needs transport at all stages from production to distribution.
4. In production stage, transportation is required for carrying raw materials like seeds, manure, coal, steel etc.
5. In distribution stage, transportation is required from the production center viz.: farms and factories to the marketing centers and later to the retailers and customers for distribution.
6. The inadequate transportation facilities retard the process of

socio-economic development of the country.

7. The adequacy of transportation system of a country indicates its economic and social development.

Role of Transportation in Rural Development: 17, 15, 14, 13, 11

1. With over 75 percent of the population of the country living in the villages, the development in urban centers alone do not indicate the overall development of the country.

2. Only with improvement in transportation facilities in rural areas, there could be faster development of the rural centers.

3. The fertilizers and other inputs for agriculture and cottage industries could reach the rural population easily.

4. Similarly, products can be sold at the nearest marketing centers for more remunerative price, resulting in faster economic growth and decrease wastage.

5. With improved facilities for education, health care and other social needs in the villages, the urge for the migration to urban centers decreases, thus helping in balance development of the country as a whole.

Different modes of Transportation: 08, 09, 10

Three basic modes of transport are:

1. Land : Land has given scope for development of road and rail transport.
2. Water: Water has developed waterways.
3. Air: Air has developed Airways.

Apart from these major transportion, other modes include:

i. pipelines,

ii. elevators,

iii. belt conveyors,

iv. cable cars,

v. aerial rope ways, and

vi. monorails.

So, The four major modes of transportation are:

1. Roadways or Highways.
2. Railways.
3. Water ways.
4. Air ways.

Advantages and Disadvantages of Different modes of Transport:

Road Transport: 16

Advantages:

1. It has less capital outlay.
2. It provides door to door service.
3. It gives service in Rural areas.
4. It is a flexible service.
5. It is suitable for short distance.
6. It has lesser risk of damage in transit.
7. It saves packing cost.
8. Less cost.
9. Rapid speed.
10. Private owned vehicles.

Disadvantages:

1. seasonal.
2. Accidents and Breakdowns.
3. unsuitable for long distance.
4. Bulky Traffic.
5. Lack of organization.

Railway Transport:

Advantages:

1. Dependable.
2. Better organized.
3. High speed over long distance.
4. Cheaper transport.
5. More safety.
6. larger capacity.
7. suitable for bulky and heavy goods.
8. public welfare.
9. Administrative facilities of goverment.
10. Employment opportunities.

Disadvantages:

1. Huge capital outlay.
2. Lack of flexibility.
3. Lack of door to door service.
4. Monopoly.
5. unsuitable for short distance.
6. booking formalities.
7. No rural service.
8. under utilized capacity.
9. Centralized administration.

Air Transport:

Advantages:

1. High speed.
2. comfortable and quick service.
3. No investment in construction of track
4. Easy access.
5. Emergency service.
6. quick clearences.
7. National Defence.
8. Space exploration.
9. Most suitable for carrying light goods of high value.
10. No physical barriers.

Disadvantages:

1. very costly.
2. small carrying capacity.
3. uncertain and unreliable.
4. Large investment.
5. Breakdowns and Accidents.
6. Specialized skill.
7. unsuitable for cheap and bulky goods.
8. Legal restrictions.

#Characterestics of Road Transportation: 17, 15, 14, 13, 11, 10, 09, 07, 06, 05

The characterestics of road transport are:

(i) Roads are used by various types of vehicles like passenger cars, buses, trucks, pedal cycles and animal drawn vehicles etc.

(ii) Road transport requires a relatively small investment for the goverment.

(iii) construction and maintenance cost of roads is cheaper than that of railway tracks, docks and airports.

(iv) Road transport offers a complete freedom to road users to transfer vehicle from one lane to another and from one road to another according to the need and convenience.

(v) In particular, for short distance travel, road transport saves time.

(vi) Road transport is subjected to a high degree of accidents due to flexibility of movement offered to the road users.

(vii) Road transport is the only means of transport that offers itself to the whole community alike.

Elements of Transport: 17, 16

Movement of goods or passengers traffic, through rail, sea, air or road transport requires adequate infrastructure facilities for free flow from place of origin to place of destination.

Irrespective of modes, every transport system has some common elements:

(i) Vehicle: Vehicle or carrier is to carry passenger or goods. Dimension of vehicle, its capacity and type are some of factors, which influence selection of a transport system for movement of goods from one place to another.

(ii) Route: Route or Path is for movement of carriers from one place to another. This route may be surface ways, airways, water ways. Hence Route plays an important role. Route should be well designed and well planned. It is very important and effective because initial cost, maintainance cost, vehicle operation cost should be economical.

(iii) Terminal facilities: objectives of transportation can not be fulfilled if there is no proper facilities for loading and unloading of goods and passengers from carriers.

(iv) Prime Mover: Power or fuel is used for moving of vehicles for transportation.

(v) Transit time and cost: Transportation involves time and cost. Time element is a valid factor for determining effectiveness of a particular mode of transport.

(vi) Cargo: Nature and size of cargo depends on the types of goods. It also influences the effectiveness of modes of transport.

Economic Activity and Transport:

The economic activities are the processes by means of which the products are utilized to satisfy human wants. Two important factors well known in economic activity are:

(i) Production or supply.

(ii) consumption for human wants or demand.

The importance of transportation in economic activity is to be found in its effects on both human wants for goods and satisfaction

through production and distribution. The increased productivity and its transportion can lower the cost of products. The transportation cost is always an influencing factor on consumer price of commodities.

Advantages of Transportation:

1. Transportation is for advancement of community.
2. Transportation is essential for the economic prosperity and general development of country.
3. Transportation is essential for strategic movement in emergency for defence of the country and to maintain better law and order.

Scope of Highway Engineering:

Highway Engineering deal with various phase, such as

(i) Development, planning and alignment of roads.
(ii) Highway design, geometrics and structures.
(iii) Highway Traffic operation and its control.
(iv) Materials, construction and maintenance.
(v) Economic considerations, finance and administrations.

Major decipline of Transport:

Transportation engineering consists of four major decipline:

(i) Transportation planning.
(ii) Geometric design.
(iii) Pavement design.
(iv) Traffic engineering.

Highway Development And Planning

07,08,09,10,11,13,14,15,16,17

Necessity of Highway Planning:

⇒ In the present era, planning is considered as a pre-requisite before attempting any development programme.

⇒ This is particularly true for any engineering work, as planning is the basic requirement for any new project.

⇒ Thus, Highway planning is also a basic need for highway development.

⇒ Particularly, planning is of great importance when the funds avaiable are limited, where as the total requirement is much higher.

⇒ Planning helps best utilization of avaiable funds has to be made in a systematic and planned way.

07,08,09,10,11,13,14,15

Objectives of highway planning:

1. To plan a road network for efficient and safe traffic operation, but at minimum cost.

2. To arrive at the road system and the lengths of different categories of roads which could provide maximum utility and could be constructed with in the avaiable resources during the plan period under consideration.

3. To fix up date wise priorities for development of each road link based on utility as the main criterion for phasing the road development programme.

4. To plan for future requirements and improvements of roads in view of anticipated developments.

5. To workout financing system.

Road Patterns: 2016,17

The various road patterns may be classified as follows:

1. Rectangular or block pattern.
2. Radial or star and block pattern.
3. Radial or star and circular pattern.
4. Radial or star and grid pattern.
5. Hexagonal pattern.
6. Minimum travel pattern.

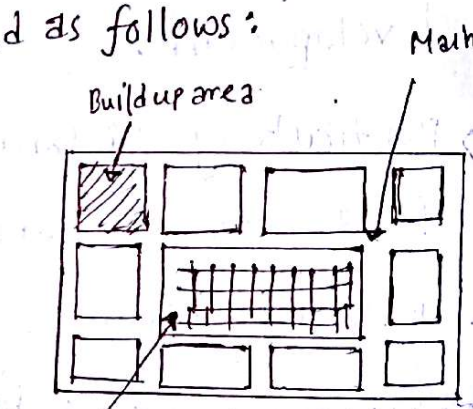


Fig. Rectangular pattern

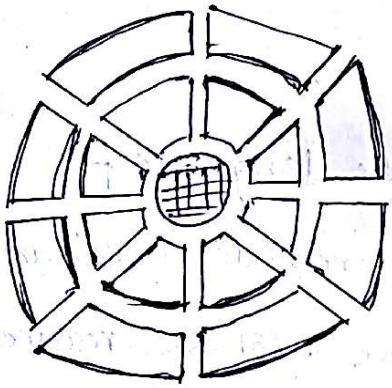


Fig. Radial or star and circular pattern

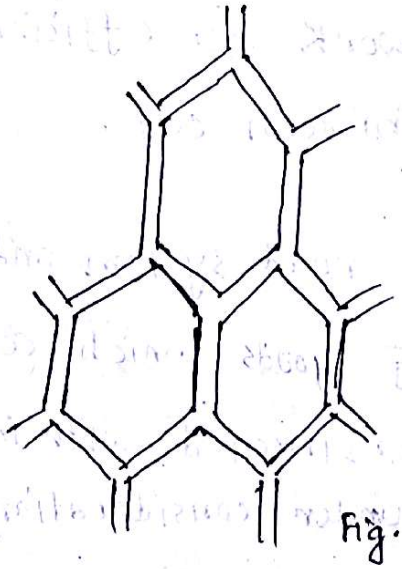


Fig. Hexagonal pattern

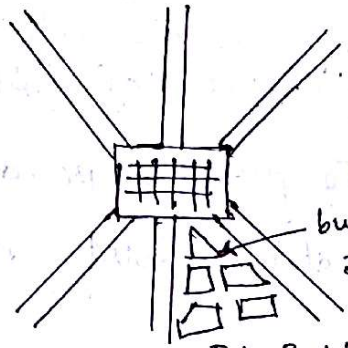


Fig. Radial or star and block patter

[See Figure in Books Page-25 (Khanna)]

17, 16

Rectangular or block pattern: In this pattern, the whole area is divided into rectangular blocks of plots, with streets intersecting at right angle. The main road which passes through the centre of the area should be sufficiently wide and other branch roads may be comparatively narrow.

Advantages:

1. The rectangular plots can be further divided into small rectangular blocks for construction of buildings and having road in front of them.
2. The construction and maintenance is comperatively easier.

Limitations/ Disadvantages:

1. This pattern is not very much convenient from traffic point of view,
2. At intersection, vehicles face each other causing collisions and congestion.

Radial or star and block pattern: In this pattern, Entire area is divided into a network of roads radiating from business area outwardly. In between radiating main roads, the built-up area may be planned with rectangular blocks.

Advantages:

1. Reduces the primary level of congestion at bottleneck location.
2. prevents traffic from accessing local flow routes

Disadvantages:

1. safety appurtenances have not been designed to provide adequate protection from the opposite direction of travel.

2015

Classification of roads based on location & Function:

Based on location and function Roads are classified in to following categories:

1. Express ways
2. National Highways
3. State Highways
4. Major district roads
5. other district roads
6. Village roads

6. Village roads: These are roads connecting villages with each other to the nearest road of a higher category.

1. Express ways: This is a seperate class of highway with superior facilities, design standards and high speeds.

2. National highways: These are main highways running through the length and breadth of a country, connecting major ports, foreign highways, capital of large states including roads required for strategic movement.

3. State Highways: These are arterial roads of a state, connecting up with the national highways of adjacent state.

4. Major district roads: These are important roads with in a district serving areas of production and markets and connecting those with each other.

5. other district roads: These are roads serving rural areas of production and providing them with outlet to market centers.

Planning surveys

Highway planning phase includes:

- Assesment of road length reaviirement fore an area (dist/state/country)
- prep of master plan showing phasing. in annual or 5year plans.

planning surveys consist of studies:-

→ economic studies

population and its dist. in each locality with area classified in groups.

→ trend of population growth
→ Agri. and indus. products and their listing in classified groups, area wise.
→ Indus. and agri. dev. and future trends.
→ existin facilities with regard to comm., recreation, edu, meds, etc.
→ Per capita income

→ Engineering study

→ Topographic survey
→ soil survey
→ location and clanification of existing roads.
→ estimation of possible development in all aspects due to proposed highway development
→ road life studies.
→ traffic studies. origin and destination studies.
→ special problems. (drainage, construction, maintenance)

→ hourly traffic volume
→ origin and destination studies.
→ traffic flow pattern.
→ mass transportation facilities
→ Accidents their cost analysis and causes.
→ future trend and growth in traffic vol. goods traffic, pattern.
→ growth of passenger trips and trends in choice of modes.

Highway Alignment and Surveys

09, 11, 15, 16

Basic requirements of ideal alignment:

The basics requirements of an ideal alignment between two terminal stations are that it should be:

(a) Short
(b) Easy
(c) safe
(d) Economical

Short: It is desirable to have a short alignment between two terminal stations. A straight alignment would be the shortest, though there may be several practical considerations which would cause deviations from the shortest path.

Easy: The alignment should be easy to construct and maintain. It should also be easy for the operation of vehicles with easy gradients and curves.

Safe: The alignment should be safe enough for construction and maintenance from the view point of stability of natural hill slopes, embankment and cut slopes.
It should also be safe for traffic operation with safe geometric features.

Economical: The alignment should be economical. The alignment could be considered economical only if the total cost, initial cost, Maintenance cost and vehicle operation cost is lowest.

Factors affecting Alignment: 2017, 14, 12, 11, 09

The various factors which control the high way alignment in general may be listed as:

(a) Obligatory points

(b) Traffic

(c) Geometric Design

(d) Economics

(e) Other considerations

In hilly roads additional care has to be given for:

(i) Stability

(ii) Drainage

(iii) Geometric standards of hilly roads

(iv) Resisting length.

Obligatory Points: 13, 11

There are control points governing the alignment of highways. These control points may be divided into two categories:

(i) points through which alignment is to pass

(ii) point through which the alignment should not pass.

(i) points through which road alignment has to pass may cause the alignment to often deviate from the shortest path

Example: Bridge site, intermediate town, a mountain pass or a quarry.

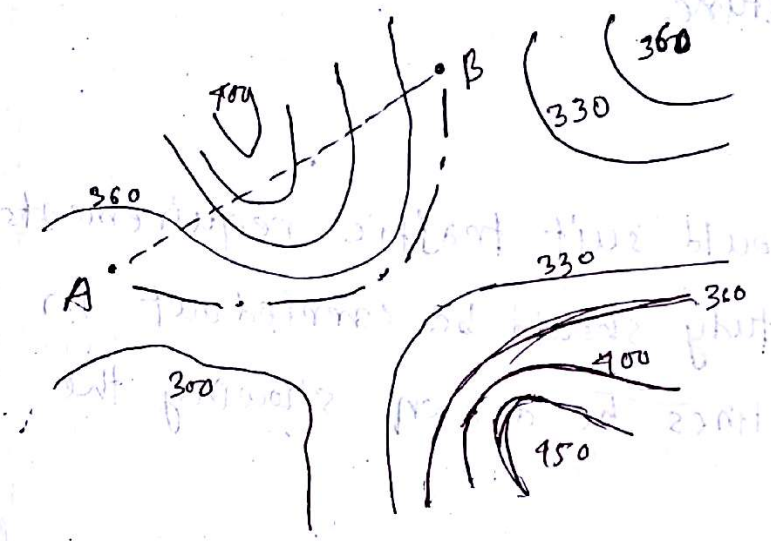


Fig. Alignment along hill side pass

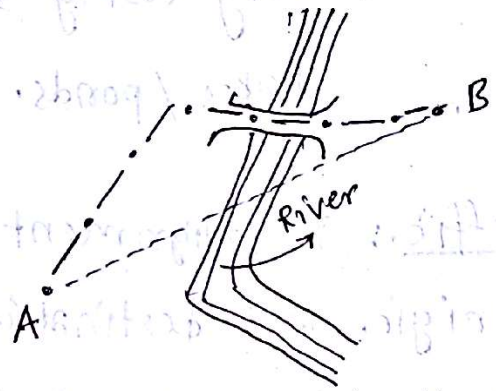
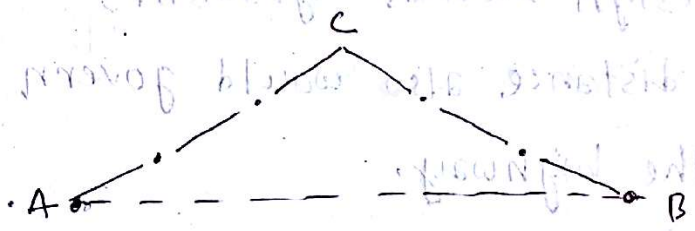
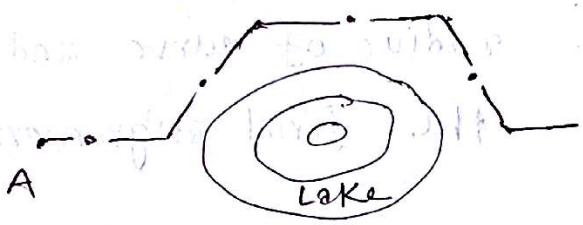


Fig. Alignment to suit proper location of bridge





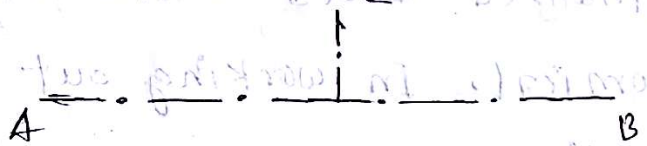


Fig. Alignment to connect intermediate town.

Fig. Alignment avoiding an intermediate area.

(iii) Obligatory points through which the road should not pass also may make it necessary to deviate from the proposed shortest alignment.

Example: Religious places like temple, mosques, church, grave etc.
very costly structure
Lakes / ponds.

Traffic: The alignment should suit traffic requirements. Origin and destination study should be carried out in the area and the desire lines be drawn showing the trend of traffic flow.

Geometric design: Geometric design such as gradient, radius of curve and sight distance also would govern the final alignment of the highway.

Economy: The alignment finalised based on the above factors should also be economical. In working out the economics, the initial cost, cost of maintenance and vehicle operation should be taken in to account.

Other considerations: Drainage consideration, hydrological factors, political considerations etc. may govern the alignment.

2008, 11, 13

Engineering surveys for highway locations:

The stages of engineering surveys are:

(i) Map study

(ii) Reconnaissance

(iii) Preliminary surveys

(iv) Final location and detailed surveys.

(i) Map study: The probable alignment can not be located on the map from the following details available on the map:

(a) Alignment avoiding valleys, ponds or lakes

(b) When the road has to across a row of hills, possibility of crossing through a mountain pass.

(c) Approximate location of bridge site for crossing rivers, avoiding bend of the river, if any.

(ii) Reconnaissance: some of details to be collected during reconnaissance are given below:

(a) valleys, ponds, lakes, hills and other obstructions along the route which are not in the map.

(b) Approximate values of gradient, length of gradient and radius of curves of alternate alignment.

(c) Number and type of cross drainage structures

(d) soil type along the routes.

(iii) Preliminary survey: The main objectives of preliminary survey are:

(a) To survey various alternate alignments proposed after reconnaissance

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

(c) To estimate quantity of earth work materials

(d) To finalise the best alignment from all considerations.

(iv) Final location and detailed survey: In this survey two operation are involved:

(a) To layout the final center line of the by means of continuous transit survey.

(b) Detailed levelling.

16 What do you mean by 'Highway Alignment'.

The position or the layout of the centerline of highway on the ground is called Alignment of Highway.

Horizontal alignment includes the straight path, horizontal deviations and curves.

changes in gradient and vertical curves are covered under vertical alignment.

Highway Geometric Design

Geometric Design of Highway: 2016

Geometric Design of Highway is the branch of highway engineering which deals with the dimensions and layout of visible features of the highway such as alignment, sight distances and intersections.

Importance of geometric design: 2016, 2013

1. The geometric design of highway deals with the dimension and layout of visible features of the highway.
2. Proper Geometric design will help in reduction of accidents and their severity.
3. Geometric Design provides optimum efficiency in traffic operation and maximum safety at reasonable cost.
4. Planning can not be done stage wise like that of a pavement, but has to be done in advance.
5. Geometric Design helps to reach destination in shortest possible time.
6. To achieve maximum speed with safety, it has great importance.

Elements of Geometric Design: 2016, 2013

Geometric design of highways deals with following elements:

(i) cross section elements – It includes cross slope, various width of roads and features in road margin.

(ii) sight distance considerations – The sight distance visible ahead of a driver at horizontal and vertical curves and at interseections govern the safe movement of vehicles.

(iii) Horizontal alignment details – It includes features like superelevation, transition curve, extra widening and set back distance.

(iv) vertical alignment details – It includes gradients, sight distance and design of length of curves.

(v) Intersection features – It includes layout, capacity etc.

Factors affecting geometric design: 2014, 2011

The factors which control geometric design requirements are:

(i) Design speed: Design speed is maximum speed maintainable through out the journey compatible with safety and comfort when weather and traffic conditions are favourable & the geometric features are controlling factors.
Speed is the most important governing factor of geometric design elements.

(ii) Topography: The topography or terrain conditions influence the geometric design of highway significantly. The terrains are classified based on the general slope of the country across the alignment.
The design standards specified for different classes of roads are different depending on the terrain classification.

(iii) Traffic factors: The factors associated with the traffic that affect geometric design of roads are vehicular characteristics and human characteristics of road users.
It is difficult to decide the design vehicle under mixed traffic flow condition

(iv) Design hourly volume and capacity: It will be uneconomical to design the roadway facilities for peak traffic flow. Therefore a reasonable value of traffic volume is decided for design and this is called design hourly volume.
The ratio of volume to capacity affects the level of service of the road.

(v) Environmental factors: The environmental factors such as aesthetics, landscaping, air pollution, noise pollution etc. should be given due to consideration in the design of road geometries.

(vi) Economy: Design adopted should be economical as far as possible. It should match with funds allotted for capital cost and maintenance cost.

(vii) Other factors: Geometric design should be such that aesthetics of region is not affected.

Pavement Surface Characteristics:

Friction: The friction between vehicle tyre and pavement surface is one of the important factors determining the operating speed and distance requirements in stopping and accelerating the vehicles.

2007
Skid: When the path travelled along the road surface is more than the circumferential movements of the wheels due to their rotation, it is called skid.

There are two types of skid.

(i) Longitudinal skid

(ii) Lateral skid.

Longitudinal skid: It occurs when the slide without revolving or when the wheels partially revolve.

When the brakes are applied, the wheels are locked partially

or fully, and if the vehicle moves forward, the longitudinal skidding takes place.
It varies from 0 to 100 percent.

Lateral skid: While a vehicle negotiates a horizontal curve, if the centrifugal force is greater than counteracting forces, Lateral skidding occurs.
It is considered dangerous as the vehicle goes out of control leading to an accident.

Factors affecting friction or skid resistance:
The maximum friction offered by pavement surface or the skid resistance depends upon following factors:

(i) Type of pavement surface namely bituminous, earth surface
(ii) Macro-texture of the pavement surface
(iii) condition of pavement namely wet or dry, smooth or rough
(iv) Type and condition of tyre
(v) Speed of vehicle
(vi) Brake efficiency
(vii) Load and Tyre pressure
(viii) Temperature of tyre and pavement
(ix) Type of skid, if any.

2010, 2011, 2013

Slip: When a vehicle revolves more than the corresponding longitudinal movement along roads, It is called slip.

It usually occurs in the driving wheel of a vehicle when the vehicle rapidly accelerates from the stationary position or from slow speed on pavement surface which is either slippery and wet or when the road surface is loose with mud.

Pavement unevenness: Higher operating speeds are possible on even pavement surface than on uneven or poor surfaces. Hence pavement surface should be maintained with minimum possible unevenness, so that the design speed can be maintained in conformity with other geometric standards.

Pavement unevenness also affect vehicle operation cost, comfort and safety.

2007, 08

Unevenness index: unevenness index is a measure of unevenness which is cumulative measure of vertical undulation of pavement surface recorded per unit horizontal length of road.

An unevenness index value less than 1500 mm/km is considered as good. A value less than 2500 mm/km is satisfactory up to the speed of 100 km/hr.

Camber or Cross slope: 2014, 2013, 11, 07

Camber or cross slope is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface.

Why camber is provided:

Drainage and quick disposal of water from pavement surface by providing cross slope is considered important because of these reasons:

(i) To prevent the entry of surface water into subgrade soil through pavement. The stability, surface condition and the life of pavement get adversely affected if the water enters in the subgrade soil and the soil gets soaked.

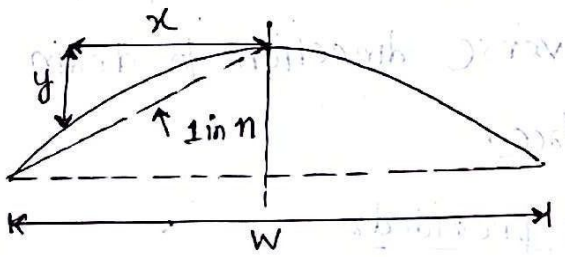
(ii) To prevent the entry of water into the bituminous pavement layers, as continued contact with water causes stripping of bitumen from the aggregates and results in deterioration of the pavement layer.

(iii) To remove the rain water from pavement surface as quickly as possible and to allow the pavement to get dry soon after the rain.

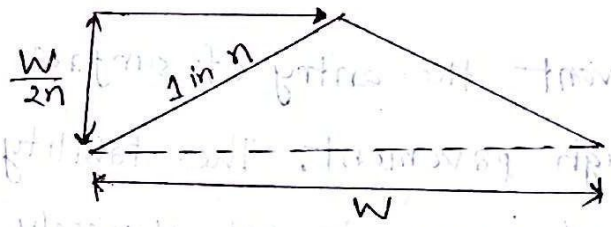
Type of camber: There are three types of camber:

(i) Parabolic shape

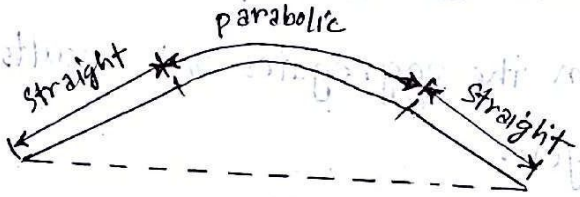
$$\left[y = \frac{2x^2}{nW}\right]$$



(ii) Straight line camber



(iii) combination of straight and parabolic shape



04, 07, 08, 15

Carrage way: The metalled portion of road which indended for movement of the traffic is called Carrage way.

It depends on the width of traffic lane and number of traffic lane.

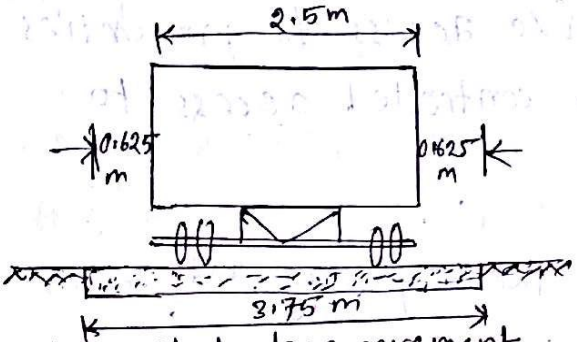


Fig. Single lane pavement

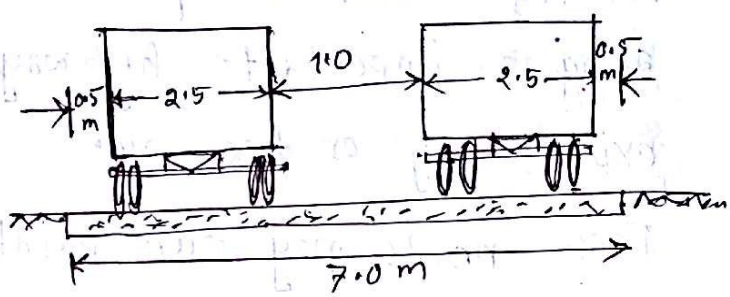


Fig. Two lane pavement

The maximum width of vehicle as per IRC specification is 2.44 m.

2014, 2017

Kerb:

The boundary between the pavement and shoulder or sometimes islands or foot path or kerb parking space is called kerb.

It is desirable to provide kerbs on urban roads.

Kerb may be divided into three groups:

(i) Low or mountable type kerbs.

(ii) Semi barrier type kerb.

(iii) Barrier type kerb.

Traffic separators of medians:

The main function of traffic separator is to prevent head-on collision between vehicles moving in opposite directions on adjacent lanes. The separator may also help to -

(i) channelize traffic into stream at intersections

(ii) shadow the crossing and turing traffic.

(iii) segregate slow traffic and to protect pedestrians.

2017, 2016, 2014, 13, 11, 15

Frontage Road:

Frontage roads are provided to give access to properties along an important highway with controlled access to express way or free way.

These roads may run parallel to the highway and are isolated by a seperator, with approaches to the through facility only at selected points, preferably with grade separations

2017, 16, 15, 14, 11

Right of way:

Right of way is the area of land acquired for the road, along its alignment. The width of this aquired land is known as land width.

It depends on the importance of the road and possible future development. To prevent ribbon developments along highway, control lines and building lines may be provided.

* Factors affecting Right of way:

(i) width of road way and road margins,

(ii) Height of embankment or depth of cutting

(iii) side slopes of embankment or cutting.

(iv) Drainage system and their size.

(v) sight distance consideration on horizontal curve

(vi) Reserved land for future widening.

2016

Sight Distance:

Sight distance available from a point is the actual distance along the road surface which a driver from a specified height above the carriage way has visibility of stationary or moving objects.

Three sight distance situations are considered:

(i) stopping sight distance

(ii) safe overtaking sight distance

(iii) Safe sight distance for entering into un controlled intersections.

* **Intermediate sight distance**: This is defined as twice the stopping sight distance. When overtaking sight distance can not be provided, Intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles.

* **Head light sight distance**: This is the distance visible to a driver during night driving under the illumination of the vehicle head lights.

Stopping sight distance:

The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle travelling at design speed, safely without collision with any other obstruction, is called stopping sight distance.

Total Reaction time: 2013, 2012

Reaction time of the driver is the time taken from the instant the object is visible to the driver to the instant the brakes are effectively applied.

The total reaction time may be split into two parts.

(i) perception time

(ii) Brake reaction time

perception time: The perception time is the time required for a driver to realise that brakes must be applied. It is the time from the instant the object comes on the line of sight of the driver to the instant he realises that the vehicle needs to be stopped.

The perception time depends on several factor:
- speed of the vehicle
- distance of object
- Enviromental conditions

Brake reaction time: It depends on several factors including the skill of the driver, the type of problem and various environmental factors.

Factors that SSD depends upon:

(i) Total reaction time of the driver.

(ii) Speed of vehicle.

(iii) Efficiency of brakes.

(iv) Frictional resistance between the road and the tyre

(v) Gradient of the road, if any

PIEV Theory: 2013, 2012

According to this theory the total reaction time of the driver is split into four parts viz. time taken by the driver for

(i) P-Perception

(ii) I-Intellection

(iii) E-Emotion and

(iv) V-Volition

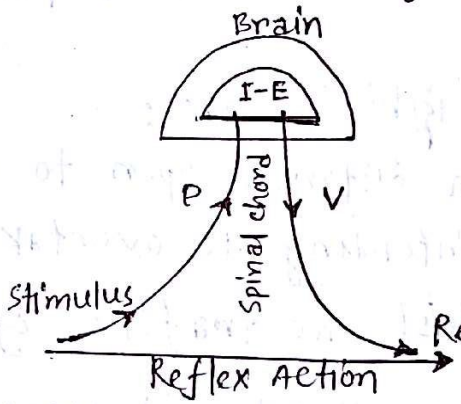


Fig. PIEV process

Perception time: It is the time required for the sensations received by the eyes or ears to be transmitted to the brain through the nervous system and spinal chord.
In other words, it is the time required to perceive an object or situation.

Intellection time: It is the time required for understanding the situation. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.

Emotion time: It is the time elasped during emotional sensations and disturbance such as fear, anger or any other emotional feelings with reference to the situations.

Volition time: It is the time taken for the final action.

* The PIEV time of a driver depends on several factors, such as:

(i) physical and psychological characteristics of the driver.

(ii) Type of the problem involved.

(iii) Environmental condition.

(iv) Temporary facors (e.g. motive of the trip, travel speed, fatigue consumption of alcohol etc.)

Overtaking sight distance:

The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as overtaking sight distance.

* Factors on which OSD depends:

(1) speed of (i) overtaking vehicle (ii) overtaken vehicle (iii) the vehicle coming from opposite direction.

(2) Distance between the overtaking and overtaken vehicle

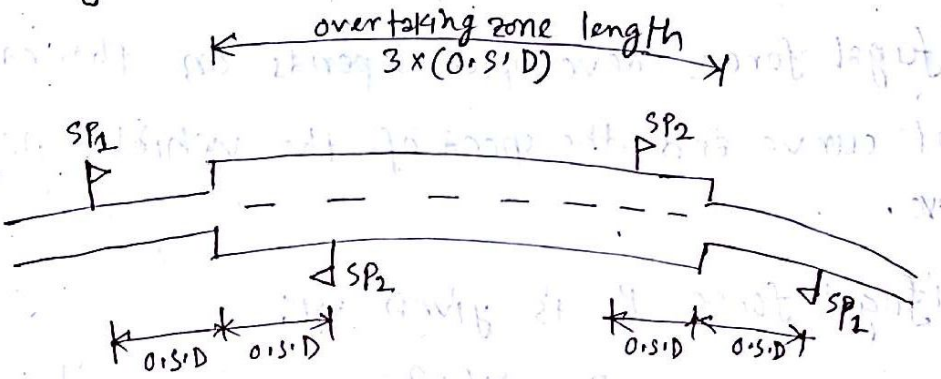
(3) Skill and reaction time of driver.

(4) Rate of acceleration of overtaking vehicles.

(5) Gradient of the road, if any.

Overtaking zones:

Overtaking opportunity for vehicles at design speed should be given at frequent intervals. These zones which are meant for overtaking are called overtaking zones.



Sight distance at Intersection: The sight line is obstructed by structures or other objects at the corners of the intersections. The design of sight distance at intersections may be based on three possible conditions:

(i) Enabling the approaching vehicle to change speed.

(ii) Enabling the approaching vehicle to stop.

(iii) Enabling stopped vehicle to cross a main road.

Horizontal Curve:

A horizontal highway curve is a curve in plan to provide change in direction to the central line of a road.

The centrifugal force developed depends on the radius of horizontal curve and the speed of the vehicle negotiating the curve.

Centrifugal force, P is given by:

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

Here,

W = weight of the vehicle

R = Radius of the circular curve

v = speed of the vehicle

g = acceleration due to gravity.

* **centrifugal ratio:** The ratio of the centrifugal force to the weight of the vehicle, $\left(\frac{P}{W}\right)$ is known as the centrifugal ratio or Impact factor.

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

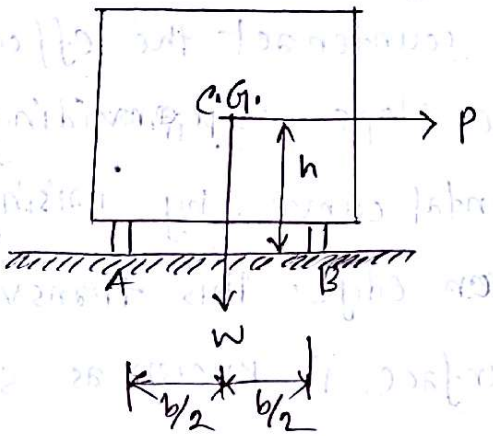
* The centrifugal force acting on a vehicle negotiating a horizontal curve has two effects:

(i) overturning effect

(ii) Transverse skidding effect

(i) Overning effect:

Taking moment of force with respect to outer wheel when vehicle is just about to over ride,



$$Ph = W \times \frac{b}{2}$$

At equilibrium, overturning is possible when,

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

For safety following condition must be satisfied,

$$\frac{b}{2h} > \frac{v^2}{gR}$$

(ii) Transverse skidding effect:

If the centrifugal force P developed exceeds the maximum possible transverse skid resistance due to friction, the vehicle will start skidding in the transverse direction.

The equilibrium condition for the transverse skid resistance -

$$P = F_A + F_B = f(R_A + R_B) = fW$$

Where, 'F_A' & 'F_B' are frictional force at tyre A and B respectively. 'f' is the lateral co-efficient of friction.

R_A & R_B are the normal Reactions at wheel A and B.

For safety following condition must be satisfied,

$$f > \frac{v^2}{gR}$$

2014, 2015

Super elevation:

In order to counteract the effect of centrifugal force, A transverse slope is providing throughout the length of the horizontal curve, by raising the outer edge with respect to inner edge. This transverse inclination to the pavement surface is known as super elevation or cant or banking. Superelevation is expressed as

$$e = \frac{NL}{ML} = \tan\theta \simeq \sin\theta = \frac{E}{B}$$

2014, 16, 17

Steps for practical design of super elevation:

Step (i): The super elevation 'e' for 75 percent of design speed is calculated neglecting the friction

$$e = \frac{(0.75V)^2}{gR} \quad \text{or} \quad \frac{(0.75V)^2}{127R}$$

Step (ii): If the calculated value of $e \leq 7\%$ or 0.07 then,

$e = e_1 = \frac{(0.75V)^2}{gR}$ else if $e_1 > 0.07$, then go to Step (iii)

step (iii): Find f_1 for design speed and max. e i.e.

$$f_1 = \frac{V^2}{gR} - e = \frac{V^2}{gR} - 0.07$$

If $f_1 < 0.15$, then max. $e = 0.07$ is safe for design speed else if go to step (iv)

Step(iv): Find allowable speed V_a for maximum $e = 0.07$ and $f = 0.15$, $V_a = \sqrt{0.22gR}$

If $V_a > V$, then design is adequate. Otherwise use speed adopt control measures or look for speed control measures.

Attainment of superelevation:

The attainment of superelevation may be split up in to two parts:

(i) Eliminating of crown of cambered section

(ii) Rotation of pavement to attain full superelevation

Eliminating of crown of the cambered section: 2015,13,11

This may be done by two method.

In first method, The outer half of the cross slope is rotated about the crown at desired rate, such that the surface falls on the same plane as the inner half and the elevation of the center line is not altered.

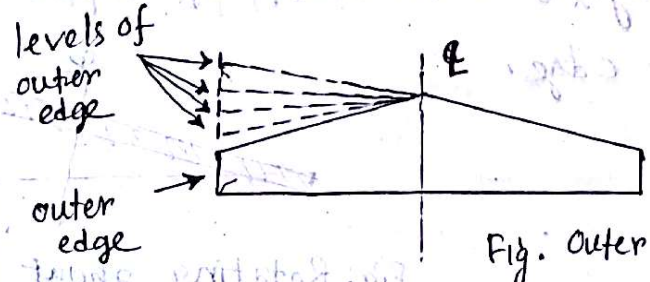


Fig: Outer edge rotated about the crown

In the second method of eleminating the crown, known as diagonal crown method is progressively shifted outwards, thus increasing the width of the inner half of cross section progressively.

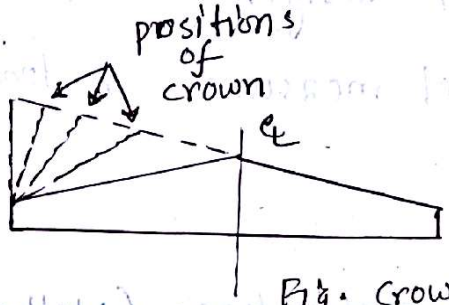


Fig. Crown shifted outward

Rotation of pavement to attain full superelevation: is done by two method.

In first method, The pavement cross section is rotated about the center line, depressing the inner edge and rising the outer edge each by half the total amount of super elevation i.e. by $\frac{E}{2}$ with respect to center.

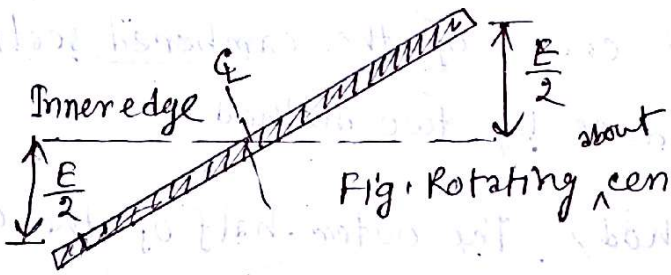


Fig. Rotating about centerline.

In second method, The pavement cross section is rotated about the inner edge of the pavement section, rising both the center as well as the outer edge such that outer edge is raised by the full amount of super elevation E with respect to inner edge.

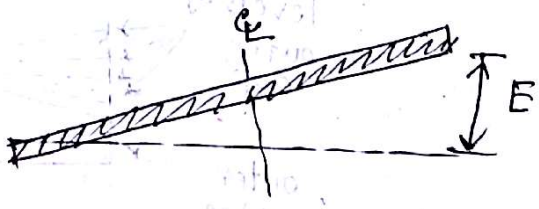


Fig. Rotating about the inner edge.

Object of providing extra widening of pavement on horizontal curve.

Extra widening refers to additional width of carriage way that is required on a curved section of a road over and above that required on a straight alignment.

The object of providing extra widening of pavement are:

2017, 2012

1. Off tracking. (The rare wheel does not follow the same path as that of the front wheels, is called off tracking)
2. Traverse skidding due to excessive speed.
3. Towing of vehicle.
4. Tendency of driver to follow outer edge of curve.
5. Greater clearence between crossing or overtaking vehicle.

Factors that extra-widening depends on:

1. Length of wheel base of the vehicle
2. Radius of curve negotiated
3. Psychological factors (function of speed and radius)

Horizontal Transition curve:

A transition curve has a radius which decreases from infinity at the tangent point a designed radius of the circular curve.

The rate of radius of the transition curve will depend on the equation of the curve or its shape.

2015

* Functions of Transition curve:

1. To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding a sudden jerk on the vehicle.

2. To enable the driver turn the steering gradually for his own comfort and security.

3. To enable gradual introduction of the designed super elevation and extra widening of pavement at the start of the circular curve.

4. To improve the aesthetic appearance of the road.

Gradient:

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x.

Gradients are divided in to following category:

(i) Ruling gradient
(ii) Limiting gradient
(iii) Exceptional gradient
(iv) Minimum gradient

Vertical Curve:

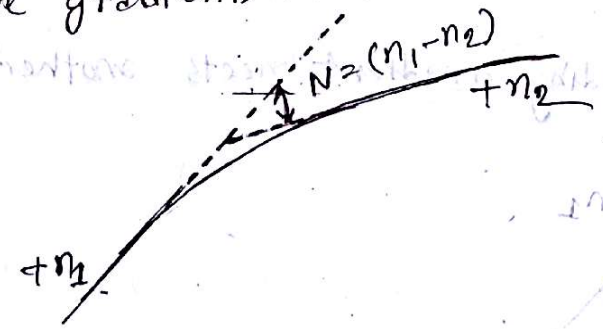
Due to change in grade in the vertical alignment of highway, vertical curves are provided at the intersections of different grades.

The vertical curves may be classified in to two categories;

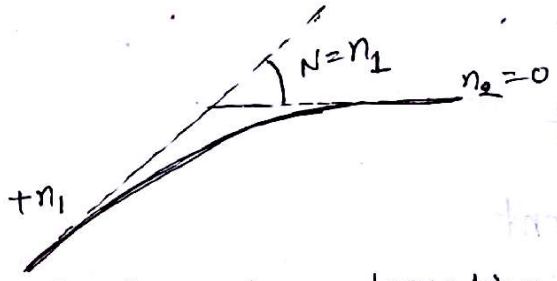
(i) summit curve. (crest curve)
(ii) valley curve (sag curve)

Summit curve: Summit curve are vertical curves with gradients upward. They are formed in four ways:

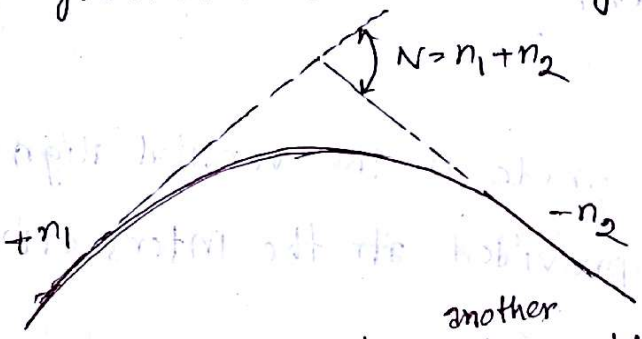
(i) when a positive gradients meets another positive gradient



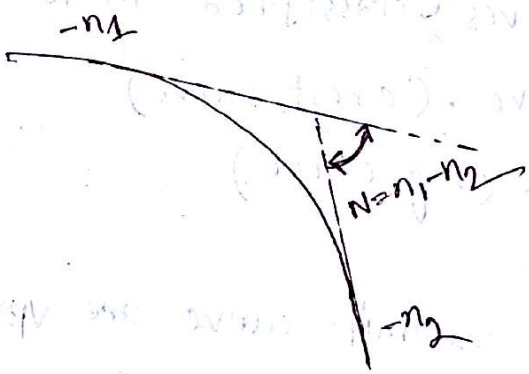
(ii) When a positive gradient meets a flat gradients.



(iii) When ascending gradient meets a decending gradients



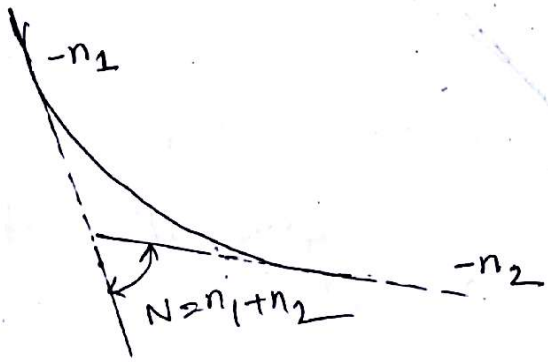
(iv) When a descending gradient meet another descending gradients.



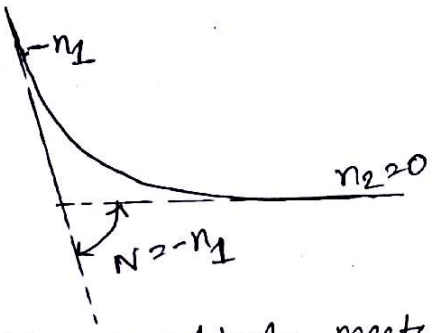
Valley curve:

Valley curves or sag curves are vertical curves with convexity downwards. They are formed in four ways:

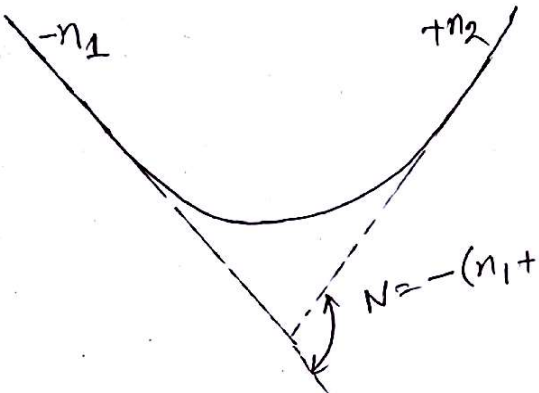
(a) When a decending gradient meets another decending gradient



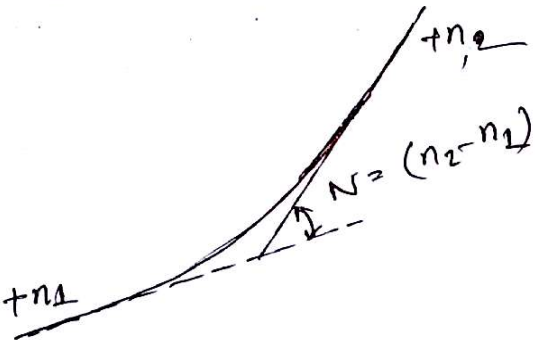
(b) When a descending gradient meets a flat gradient —



(c) When a decending gradient meets another ascending gradient



(d) When an ascending gradient meets another ascending gradient



Traffic Signal

Problem: No of vehicles per unit lane for 15 minutes,

traffic count on Road-1 = 150 pcu

Road-2 = 120 pcu

Design the signal timings by **trial cycle** method

Given, Average time head-way = 2.5 sec.

Solution:

Assume,

Amber colour for Road-1 $Y_1 = 4$ sec.

" " " Road-2 $Y_2 = 3$ sec.

Let, one cycle time = 50 sec.

No. of cycle in 15 minutes $= \frac{15 \times 60}{50} = 18$ cycle.

Total green time for Road 1 $= (150 \times 2.5) = 375$ sec.

$\therefore$ green time per cycle $G_1 = \frac{375}{18} = 20.83$ sec.

Similarly, green time per cycle on Road-2, $G_2 = \left(\frac{150 \times 2.5}{18}\right)$ sec.

$= 16.67$ sec.

$\therefore$ Total cycle, $C = G_1 + Y_1 + R_1$

$= G_1 + Y_1 + G_2 + Y_2$

$= (20.83 + 4 + 16.67 + 3)$

$= 44.5$ sec.

(not OK)

Trial-1: Let $C = 40$ sec.

$$\text{No. of cycle} = \frac{15 \times 60}{40} = 22.5 \text{ cycle}$$

$$G_1 = \frac{375}{22.5} = 16.67$$

$$G_2 = \frac{120 \times 2.5}{22.5} = 13.33$$

$$\therefore C = G_1 + Y_1 + G_2 + Y_2$$

$$= 16.67 + 4 + 13.33 + 3$$

$$= 37 \text{ sec.}$$ (not OK)

Trial-2: Let $C = 30$ sec.

$$\text{No. of cycle} = \frac{15 \times 60}{30} = 30 \text{ cycle}$$

$$G_1 = \frac{375}{30} = 12.5$$

$$G_2 = \frac{300}{30} = 10$$

$$\therefore C = G_1 + Y_1 + G_2 + Y_2$$

$$= 12.5 + 4 + 10 + 3$$

$$C = 29.5 \text{ sec.} \sim 30 \text{ sec}$$ (OK)

$\therefore$ Actual $G_1 = 12.5 + (30 - 29.5) = 13$ sec.

Road-1

13	4	13
G_1	Y_1	R_1

Road-2

10	3	17
G_2	Y_2	R_2

Highway Lighting

2017

Problem: Find the spacing between lighting units from the data:

(i) Width of road = 15 m (ii) Mounting height = 6 m

(iii) Lamp size = 600 lumens (iv) Average lux = 5

(v)

Ratio	1.5	2.0	2.5	3.0	3.5
co-efficient of utilization	0.35	0.40	0.45	0.48	0.50

Solution: $\text{Ratio} = \frac{\text{width of road}}{\text{Mounting height}} = \frac{15}{6} = 2.5 \quad \therefore C = 0.45$

$$\text{Spacing between lighting units} = \frac{\text{lamp size} \times \text{co-efficient of utilization} \times \text{Maintenance factor}}{\text{Average lux} \times \text{width of the road.}}$$

$$= \frac{600 \times 0.45 \times 0.75}{5 \times 15}$$

$$= 2.7$$

(Ans).

Speed Study

2017

Problem: Five spoot speeds 10, 12, 15, 18 and 20 m/s recorded with in section 80 m. Calculate TMS and SMS.

Solution:

We know, $TMS = \frac{\Sigma V}{n} = \frac{10+12+15+18+20}{5} = \frac{75}{5} = 15$ m/s

again, $SMS = \frac{n}{\Sigma \frac{1}{V}} = \frac{5}{\left(\frac{1}{10}+\frac{1}{12}+\frac{1}{15}+\frac{1}{18}+\frac{1}{20}\right)} = \frac{5}{16/45}$

$\therefore$ SMS = 14.0625 m/s. (Ans)

Derivation of SSD at level and grades: 2017

Let, a vehicle moves in design speed V m/sec.

Reaction time of the driver = t sec.

∴ Lag distance = $V \times t$

if Maximum frictional force developed in stopping = F

braking distance = l (m)

Then, The work against friction forces in stopping vehicle is,

$Fl = (f W l$ where, W = total weight of vehicle

Again,

The kinetic energy at design speed,

$$K.E = \frac{1}{2} mv^2 = \frac{1}{2} \times \frac{W}{g} \times V^2$$

Now,

$$f W l = \frac{1}{2} \frac{W V^2}{g}$$

$$\Rightarrow f l = \frac{V^2}{2g}$$

$$\Rightarrow l = \frac{V^2}{2gf}$$

∴ stopping distance = lag distance + braking distance

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

if design speed, V is in kmph, $S.D = .278 Vt + \frac{V^2}{254f}$

SD at slopes:

Let, ascending gradient $= +n\%$.

The componet of gravity adds to the braking action and hence breaking distance is decreased.

$$W\sin\alpha = W\tan\alpha = \frac{Wn}{100}$$

Equating kinetic energy and work done.

$$\left(fW + \frac{Wn}{100}\right) l = \frac{1}{2}\frac{Wv^2}{g}$$

$$\Rightarrow l = \frac{v^2}{2g\left(f + \frac{n}{100}\right)}$$

for decending gradient $= -n\%$.

The component of gravity opposites to braking action. and hence breaking distance is increased.

$$\therefore \left(fW - \frac{Wn}{100}\right) l = \frac{1}{2}\frac{Wv^2}{g}$$

$$\Rightarrow l = \frac{v^2}{2g\left(f - \frac{n}{100}\right)}$$

Example: 4.2 (Page-92) Khanna.

Given, $V = 50$ kmph

Assume, $f = 0.37$ (0.35 ~ 0.37) and $t = 2.5$ sec.

∴ Stopping distance = ~~[illegible]~~

$$= 0.278 V t + \frac{V^2}{254 f}$$

$$= 0.278 \times 50 \times 2.5 + \frac{(50)^2}{254 \times 0.37}$$

$$SD = 61.35 \text{ m}$$

(a) SSD when two way two lane = SD = 61.35 m

(b) SSD when two way single lane = 2SD = (2 × 61.35) m

= 122.7 m

(Ans)

Example: 4.3 (Page-93) Khanna

Given, $V_1 = 90$ kmph

$V_2 = 60$ kmph

$t = 2.5$

$f = 0.7$

brake efficiency = 50%.

∴ friction developed = (.5 × 0.7) = 0.35

$SD_1 = 0.278 \times 90 \times 2.5 + \frac{90^2}{254 \times .35} = 153.66\ m$

$SD_2 = 0.278 \times 60 \times 2.5 + \frac{60^2}{254 \times .35} = 82.2\ m$

$\therefore$ SD to avoid collision $= SD_1 + SD_2 = (153.66 + 82.2)\ m$

$= 235.8\ m.$

Example: 4.4 Page-(94) - Khanna

Given $V = 80$ Kmph Assume, $f = .35$

$n = -2\% = -\frac{2}{100}$

$\therefore SSD = .278 \times V t + \frac{V^2}{254\left(f - \frac{n}{100}\right)}$

$= .278 \times 80 \times 2.5 + \frac{(80)^2}{254 \times \left(.35 - \frac{2}{100}\right)}$

$= 131.95\ m$

$\therefore SSD \simeq 132\ m$

(Ans.)

Example: 4.5 - Page (95) - Khanna.

Given $V = 65$ Kmph

$f = 0.36$

$t = 2.5$ sec.

$\therefore SD = .278 \times 65 \times 2.5 + \frac{65^2}{254 \times .36}$

$= 91.4\ m$

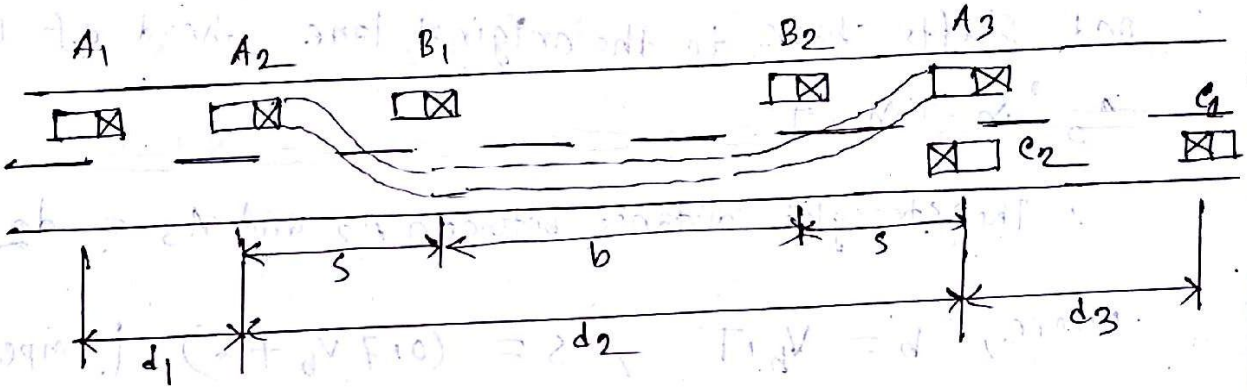
(a) Head light sight distance $= SD = 91.4\ m$

(b) Intermediate " " $= 2SD = (2 \times 91.4)\ m$

$= 182.8\ m$

(Ans.)

Derivation of over taking distance:



Let, The above figure single lane two way where,

A = overtaking vehicle running at design speed V_a in m/sec. as A_1, A_2, A_3

B = Slow moving vehicle in speed V_b in m/sec. as B_1, B_2

C = opposite directional vehicle as C_1, C_2 at design speed V in (m/sec)

The overtaking maneuver may be split into three operations,

Thus, O.S.D $= d_1 + d_2 + d_3$

(1) It may be assumed that vehicle 'A' is forced to reduce its speed V_b of the slow vehicle B and moves behind it an allowing space S.

The distance travelled by vehicle A during reaction time t,

$d_1 = V_b \times t$ between A_1 and A_2

(ii) From the position A_2, vehicle A starts accelerating, shifts to the adjoining lane, overtakes the vehicle 'B' and shifts back to the original lane ahead of B in position A_3 in Time T.

∴ The straight distance between A_2 and $A_3 = d_2 = (b + 2s)$
$= (V_b T + \frac{aT^2}{2})$

where, $b = V_b \cdot T$, $s = (0.7 V_b + 6)$: [emperical formula]

and, $2s = \frac{1}{2} a \cdot T^2$

Therefore, $T = \sqrt{\frac{4s}{a}}$

(iii) The distance travelled by vehicle C at design speed V (m/sec) during time T,

$$d_3 = V \times T$$

Thus, the over taking distance, $O.S.D = (d_1 + d_2 + d_3)$

$$\therefore O.S.D = (V_b t + V_b T + 2s + VT)$$

if V is Kmph,

Then, $O.S.D = 0.28 V_b t + 0.28 V_b T + 2s + 0.28 V.T$

2017, 16, 13,

Example-4.6 (Page-100)-Khanna

Given,

$V = 70$ Kmph $= \frac{70}{3.6} = 19.44$ m/sec.

$V_b = 40$ Kmph $= \frac{40}{3.6} = 11.11$ m/sec.

$a = 0.99$ m/sec^2, Assume, $t = 2$ sec.

$d_1 = V_b t = (11.11 \times 2) = 22.22$ m

$d_2 = V_b \cdot T + 2s$

Here, $s = (0.7 V_b + 6) = (0.7 \times 11.11 + 6) = 13.78$ m

$\therefore T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 13.78}{0.99}} = 7.46$ sec.

$\therefore d_2 = (11.11 \times 7.46 + 2 \times 13.78) = 110.44$ m

$d_3 = VT = (19.44 \times 7.46) = 145$ m

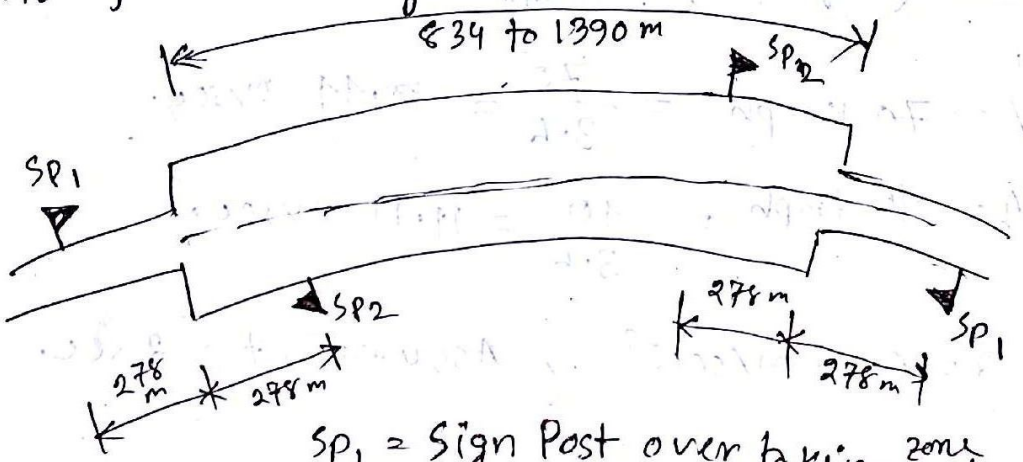
$\therefore$ OSD $= d_1 + d_2 + d_3$

OSD $= (22.22 + 110.44 + 145) = 277.66$ m $\simeq 278$ m

Minimum length of overtaking zone $= 3$ (OSD) $= (3 \times 278)$ m $= 834$ m

Desirable length of overtaking zone $= 5$ (OSD) $= (5 \times 278) = 1390$ m

(c) Details of overtaking zone.



SP_1 = Sign Post over taking zone ahead

SP_2 = Sign Post End of over taking zone

(Page-101) Khanna.

Example: 4.7 Given, V = 96

$\therefore V_b = V - 16 = (96-16) = 80$ Kmph

Assume, A = 2.5 Kmph/sec.

t = 2

$d_1 = 0.28\, V_b t = (0.28 \times 80 \times 2) = 44.8$

$d_2 = 0.28\, V_b T + 2S$

$S = (0.2\, V_b + 6) = (0.2 \times 80 + 6) = 22$ m

$T = \sqrt{\frac{4S}{A}} = \sqrt{\frac{4 \times 22}{2.5}} = 11.3$ sec.

$\therefore d_2 = 0.28 \times 80 \times 11.3 + 2 \times 20 = 297$ m

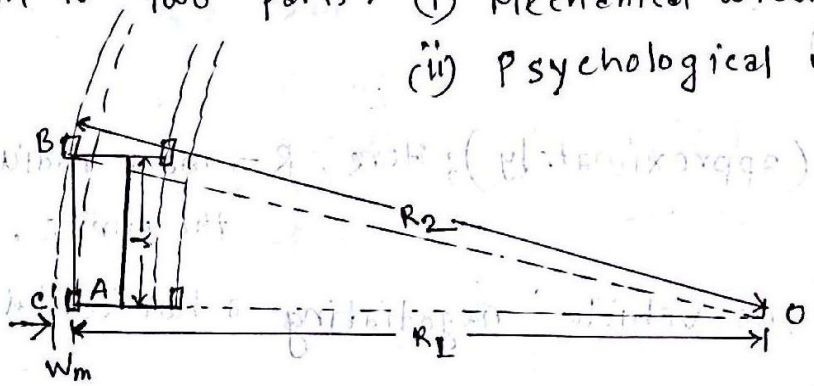
$\therefore d_3 = .28\, VT = (.28 \times 96 \times 11.3) = 303.7$ m.

O.S.D on one way traffic road = $d_1 + d_2 = 341.8$ m $\simeq 342$ m

O.S.D on two way traffic road = $d_1 + d_2 + d_3 = d_1 + d_2 + d_3 = 645.5$ m $\simeq 646$ m

Derivation for finding extra widening required on horizontal curve. 2016, 2014, 2012

The extra widening of pavement on horizontal curve is divided in to two parts. (i) Mechanical widening
(ii) Psychological widening.



(i) Mechanical widening: The widening required to account for the off tracking due to rigidity of the wheel base, is called Mechanical widening (W_m). It is calculated as given below:

Let,
R_1 = radius of the path traversed by the outer rear wheel, (m)
R_2 = " " " " " outer front wheel, (m)
W_m = off tracking or mechanical widening, (m)
l = length of the wheel base, m

$$W_m = OC - OA = OB - OA = R_2 - R_1$$

From $\triangle OAB$, $OA^2 = OB^2 - BC^2$

$$R_1^2 = R_2^2 - l^2$$

But, $R_1 = R_2 - W_m$

Hence, $(R_2 - W_m)^2 = R_2^2 - l^2$

$$\Rightarrow R_2^2 - 2R_2 W_m + W_m^2 = R_2^2 - l^2$$

$$\Rightarrow l^2 = W_m(2R_2 - W_m)$$

$$\Rightarrow W_m = \frac{l^2}{(2R_2 - W_m)}$$

$$\therefore W_m \simeq \frac{l^2}{2R} \quad \text{(approximately)}$$; Here, R = mean radius of the curve.

It is required for one vehicle negotiating a horizontal curve along one traffic lane.

Hence, in road having 'n' traffic lane, as 'n' vehicles can travel simultaneously.

The total mechanical widening is given by,

$$W_m = \frac{nl^2}{2R}$$

(ii) Psychological widening: Extra width of pavement is also provided for psychological reasons such as to provide greater clearance for crossing and overtaking vehicles on the curve.

An emperical formula has been recommended by IRC,

$$W_{PS} = \frac{V}{9.5\sqrt{R}}$$ where, V in (Kmph) = design speed

Hence, The total widening, $W_e = W_m + W_{PS}$

$$\therefore W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

2017, 2014

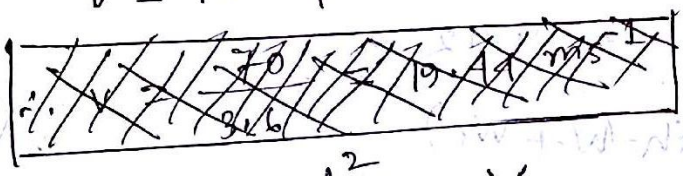
Example 4.14 : (Khanna – Page 123)

Given data, $n = \frac{7}{3.5} = 2$

$l = 7\,m$ (if not given, Assume $l = 6\,m$)

$R = 250\,m$

$V = 70\,Kmph$



Now, $We = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

$= \frac{2 \times 7^2}{2 \times 250} + \frac{70}{9.5 \times \sqrt{250}}$

$\therefore We = (0.196 + 0.466) = 0.662\,m$ (Ans.)

Example 4.15 :

Assume, $V = 80\,Kmph$

Pavement width, $W = 7\,m$

$\therefore n = \frac{7}{3.5} = 2$

wheel base, $l = 6\,m$

Now, $R_{ruling} = \frac{V^2}{127(e+f)}$

Assume, f (skid resistance) $= 0.15$ and

e (Max. super elevation) $= 0.07$

$\therefore R = \frac{80^2}{127(0.07+0.15)} = 229\,m \simeq 230\,m$

∴ Extra widening, $W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

$= \frac{2 \times 6^2}{2 \times 230} + \frac{80}{9.5\sqrt{250}}$

$= (0.157 + 0.555)$

$= 0.712$

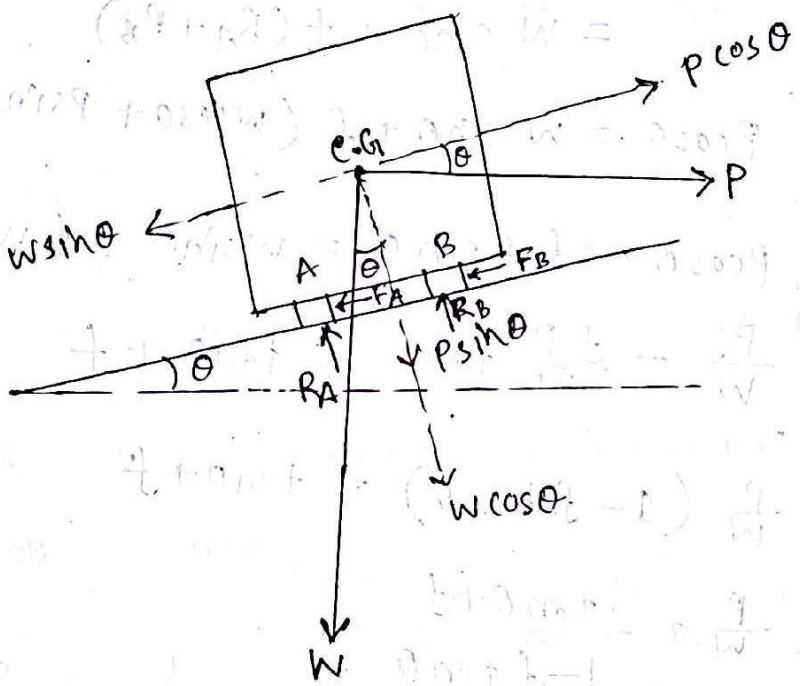
∴ Total pavement width $= (W + We)$

$= (7 + 0.712)$

$= 7.712\ m$

(Ans.)

Derivation for super elevation with design frictional co-efficient 'f' 2011



The force acting on the vehicle while moving on a circular curve of radius R m at speed of V m/sec.

(i) The centrifugal force, $P = \frac{WV^2}{gR}$ acting horizontally through the C.G.

(ii) The weight of the vehicle W acting vertically through the C.G.

(iii) The frictional force F developed between the wheels of the vehicle and pavement counter action transversly along the pavement surface towards the center of the curve.

For equilibrium condition,

$$P\cos\theta = W\sin\theta + F_A + F_B$$

$$= W\sin\theta + fR_A + fR_B$$

$$= W\sin\theta + f(R_A + R_B)$$

$$\Rightarrow P\cos\theta = W\sin\theta + f(W\cos\theta + P\sin\theta)$$

$$\Rightarrow P\cos\theta - fP\sin\theta = W\sin\theta + fW\cos\theta$$

$$\Rightarrow \frac{P}{W} - \frac{fP}{W}\tan\theta = \tan\theta + f$$

$$\Rightarrow \frac{P}{W}(1 - f\tan\theta) = \tan\theta + f$$

$$\Rightarrow \frac{P}{W} = \frac{\tan\theta + f}{1 - f\tan\theta}$$

But we know, $P = \frac{Wv^2}{gR} \Rightarrow \frac{P}{W} = \frac{v^2}{gR}$

Hence, $\frac{v^2}{gR} = \frac{\tan\theta + f}{1 - f\tan\theta}$

for design purposes, $f = 0.15$ and $\theta < 1°$,

so, $(1 - f\tan\theta) \simeq 1$ $\quad \sin\theta \simeq \tan\theta \simeq e$

Now, $\frac{v^2}{gR} = e + f$ where, e = rate of superelevation

v = design speed (m/sec)

if v in Kmph,

$$e + f = \frac{V^2}{127R} \quad (V \text{ in Kmph})$$

Here, three specific case may arise.

case-1: if there is no friction due to some practical reasons, then.

$$e = \frac{v^2}{gR} \quad (v \text{ m/sec})$$

$$= \frac{v^2}{127R} \quad (v \text{ kmph})$$

In this case, pressure on inner and outer wheel will be same, but will require very high super elevation (e)

case-2: If no super elevation is provided due to some practical reasons, then,

$$f = \frac{v^2}{gR} \quad (v \text{ m/sec})$$

$$= \frac{v^2}{127R} \quad (v \text{ kmph})$$

In this case, friction has to fully counter act the centrifugal ratio.

case-3: if $e=0$, $f=0.15$

When it is not possible to provide super elevation, allowable speed of vehicle negotiating a turn should be restricted to the condition,

$$f = \frac{v^2}{gR}$$

$$\therefore v = \sqrt{fgR}$$

if v is kmph $V = \sqrt{127fR}$

Example-4.8 (Khanna - Page - 109)

Given, $R = 100\ m$

$V = 50$ Kmph

$f = 0.15$

(a) if full lateral friction is assumed to develop,

$$e + f = \frac{V^2}{127R}$$

$$e + 0.15 = \frac{(50)^2}{127 \times 100}$$

$$\therefore e = (0.197 - 0.15) = 0.047$$

$\therefore$ super elevation rate is 1 in 21.3

(b) if no super elevation is provided, $e = 0$

$$0 + f = \frac{V^2}{127R} = \frac{50^2}{127 \times 100}$$

$$\therefore f = 0.197$$

(c) For the pressure on inner and outer wheels to be equal,

$f = 0$

$$\therefore e + 0 = \frac{V^2}{127R} = \frac{50^2}{127 \times 100} = 0.197$$

$$\therefore e = 0.197$$

(Ans)

Design rate of Super elevation

Example – 4.9 (Khanna – Page 112)

Given, $V = 80$ Kmph

$R = 480$ m

Step 1: $e = \frac{V^2}{225R} = \frac{80^2}{225 \times 480} = 0.059 < 0.07$ (OK)

Hence, the super elevation of 0.059 may be adopted.

Raising of outer edge with respect to center,

$E = \frac{B.e}{2} = \frac{7.5 \times 0.059}{2} = 0.22$ m (Ans.)

2015

Example – 4.10 (Khanna – Page 113)

Given, $R = 500$ m

$V = 100$ Kmph

Step 1: $e = \frac{V^2}{225R} = \frac{100^2}{225 \times 500} = 0.089 > 0.07$ (not OK)

Hence, actual super elevation to be provided is restricted to 0.07

Step 2: (check for friction) $f = \frac{V^2}{127R} - 0.07$

$= \frac{100^2}{127 \times 500} - 0.07$

$\therefore f = 0.087 < 0.15$ (OK)

Hence, design is safe with a super elevation 0.07

Example: 4.1 (Page - 113) - Khanna

Given, $R = 200$ m

$V = 80$ Kmph

Step 1: $e = \frac{V^2}{225R} = \frac{80^2}{225 \times 200} = 0.142 > 0.07$

The actual superelevation to be provided is restricted to 0.07

step 2: (check for friction)

$$f = \frac{V^2}{225R} - 0.07$$

$$= \frac{80^2}{225 \times 200} - 0.07$$

$$\therefore f = 0.18 > 0.15$$

Step 3: Hence, The speed has to be restricted,

$$V_2 = \sqrt{27.94R} = \sqrt{27.94 \times 200} = 74.75 \text{ Kmph}$$

∴ The speed may be restricted to less than 74.75 Kmph on that curve.

(Ans)

SUMMIT CURVE

When, $L > S.S.D$, $L = \frac{NS^2}{4.4}$ Here, $N = n_1 - n_2$

$S = S.S.D$

$L < S.S.D$, $L = 2S - \frac{4.4}{N}$

When, $L > O.S.D$, $L = \frac{NS^2}{9.6}$ Here, $N = n_1 - n_2$

$S = OSD$

$L < OSD$, $L = 2S - \frac{9.6}{N}$

Example - 4.22 (Page - 151) -- Khanna

Given, $n_1 = 3\%$

$n_2 = -5\%$

$\therefore$ Deviation angle, $N = n_1 - n_2 = \{3 - (-5)\} = 8\% = 0.08$

$SSD = 0.278 Vt + \frac{V^2}{254 f}$ Assume, $t = 2.5$; $f = 0.35$

$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.35}$

$\therefore SSD = 127.6 m \simeq 128 m$

Let $L > SSD$, $\therefore L = \frac{NS^2}{4.4} = \frac{0.08 \times (128)^2}{4.4} = 297.9 m$ ($L = 128 m$)

$\therefore L = 298 m$

2017, 2016

Example: 4.23

Given, $n_1 = \frac{1}{100}$, O.S.D = S = 470 m

$n_2 = -\frac{1}{120}$

$\therefore$ Deviation angle $= \frac{1}{100} - \left(\frac{-1}{120}\right) = \frac{11}{600}$

if L > OSD,

$$L = \frac{NS^2}{9.6} = \frac{11/600 \times 470^2}{9.6} = 422\text{ m} < L$$

Hence, for L < OSD,

$$L = 2S - \frac{9.6}{N}$$

$$= 2 \times 470 - \frac{9.6}{11/600} = 416.4\text{ m}$$

$\therefore L = 417\text{ m} < 470\text{ m}$

$\therefore$ The length of summit curve = 417 m.

VALLEY CURVE

For comfort condition,

$$L = 2\left[\frac{Nv^3}{c}\right]^{\frac{1}{2}}$$ where, v in m/sec.

For Head light sight distance condition,

when $L > S.S.D$, $L = \frac{NS^2}{1.5 + 0.035S}$ when, $S = S.S.D.$

$L < S.S.D$, $L = 2S - \frac{1.5 + 0.0355}{N}$

Example:-4.25

Given, $n_1 = \frac{-1}{25}$, $c = 0.6\ m/sec^3$

$n_2 = \frac{1}{30}$

Deviation angle, $N = -\frac{1}{25} - \frac{1}{30} = -\frac{11}{150}$

~~Given~~ $V = 80\ Kmph = \frac{80}{3.6} = 22.2\ m/sec.$

(i) comfort condition,

$$L = 2 \times \left[\frac{Nv^3}{c}\right]^{\frac{1}{2}} = 2 \times \left[\frac{11}{150} \times \frac{22.2^3}{0.6}\right]$$

$\therefore L = 73.1\ m$

(ii) Head Light sight distance condition.

$$S.S.D = vt + \frac{v^2}{2gf} \qquad \text{Assume } f = 0.35$$

$$= 22.2 \times 2.5 + \frac{22.2^2}{2 \times 9.8 \times 0.35}$$

$$\therefore S.S.D = 127.3\ m$$

If $L > S.S.D$

$$L = \frac{NS^2}{1.5 + 0.035S}$$

$$= \frac{\frac{11}{150} \times 127.3^2}{1.5 + 0.035 \times 127.3}$$

$$= 199.5\ m > 127.3\ m$$

$\therefore$ The design length of valley curve $199.5\ m \simeq^{(OK)} 200\ m$

(Ans)