27/12/18

Transportation Engineering:

It is application of technology and scientific principles for any mode of transportation in order to provide safe, efficient, economical and environment friendly movement of people, goods and services from one place to another.

Highway Developments in India:

1. Roads in ancient period: The excavations of Mohenjodaro and Harappa has revealed the existence of road in India. In this period roads was considered only for Administrative and military purpose. (Grand trunk road)

* Roads and road's facilities were improved a lot in the Ashoka period.

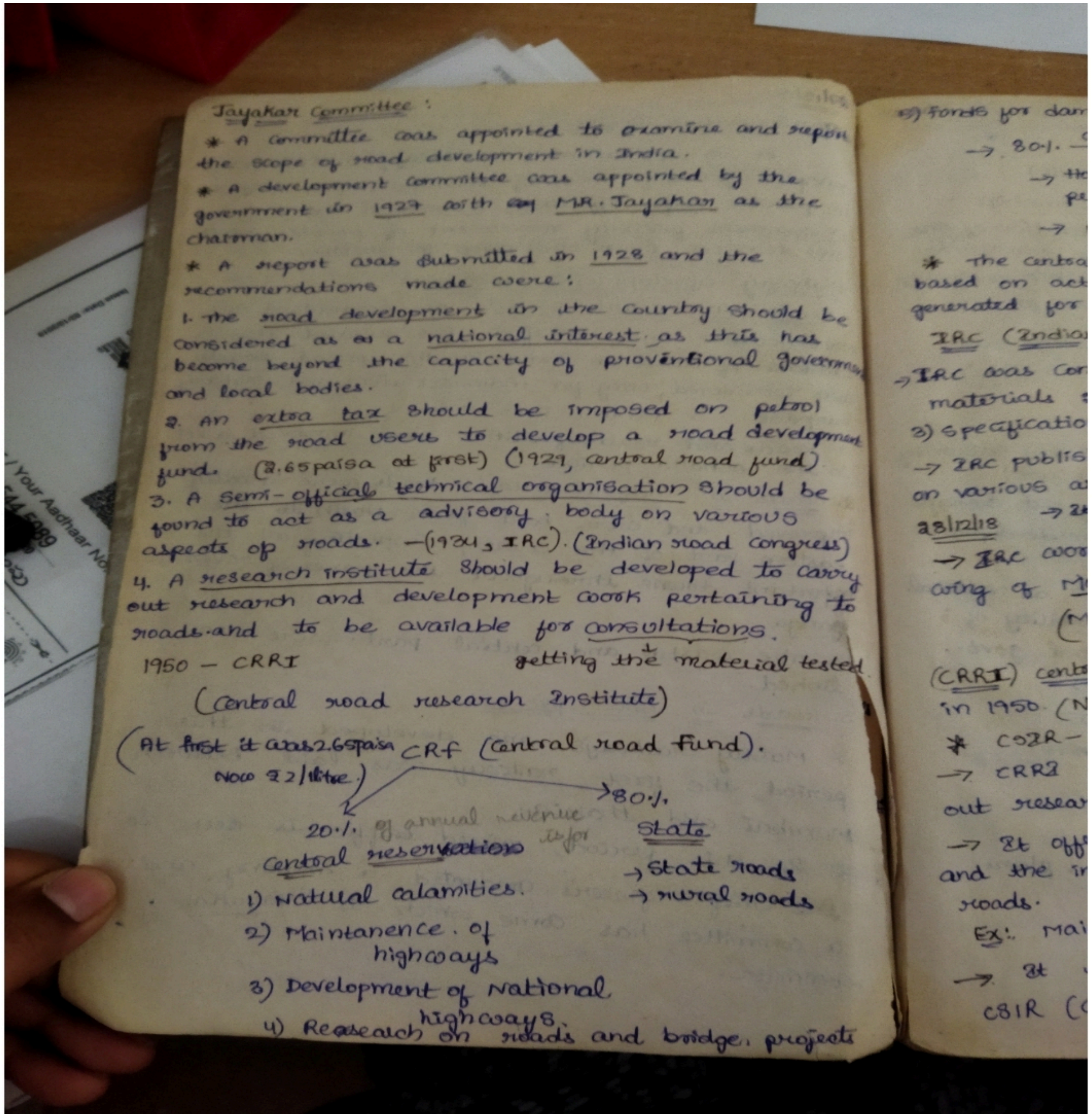
2. Roads in mughal period: Roads were greatly improved and were built from North to the eastern part of the country connecting all the important towns throughout the planes of river ganga.

* The coastal and central part were also linked.

3. Roads in British period:

* Mostly railway's are developed in this period, the first railway was laid between Mumbai and thana.

* In this period, mixed traffic is seen, so the chief engineer's conducted a meeting and a committee has come which is "Jayakar committee".



Jayakar Committee :

* A Committee was appointed to examine and report the scope of road development in India.

* A development committee was appointed by the government in 1927 with MR. Jayakar as the chairman.

* A report was submitted in 1928 and the recommendations made were :

1. The road development in the country should be considered as a national interest as this has become beyond the capacity of provintional governments and local bodies.

2. An extra tax should be imposed on petrol from the road users to develop a road development fund. (2.65 paisa at first) (1929, central road fund)

3. A Semi-official technical organisation should be found to act as a advisory body on various aspects of roads. —(1934, IRC). (Indian road congress)

4. A research institute should be developed to carry out research and development work pertaining to roads and to be available for consultations.
getting the material tested

1950 — CRRI

(Central road research Institute)

(At first it was 2.65 paisa
Now ₹2/litre.)
CRF (Central road fund).

80% of annual revenue is for State
→ State roads
→ rural roads

20%
Central reservation
1) Natural calamities.
2) Maintanence of highways
3) Development of National highways.
4) Reasearch on roads and bridge. projects

5) Funds for damages.

→ 80% — allocated to State government

→ How much revenue is generated from petrol

(or)

→ By. sale of petrol.

* The central government divides the amount based on actual petrol consumption (or) revenue generated for sale of petrol.

IRC (Indian road congress) : (1934).

→ IRC was constituted to prepare 1) standards on materials 2) guidelines on design and construction 3) specifications for roads and bridges

→ IRC publishes Journals, Research publications on various aspects of Highway engineering.

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→ It is one of main recommendations made by Jayakar committee.

→ IRC works in closed colabration with Roads wing of MORT&H (MORTAH) (Ministry of road transport and Highway)

(CRRI) central road research Institute : established in 1950. (New Delhi).

* CSIR – Council for Science & Industrial ~~Institute~~ Research.

→ CRRI was set up in New Delhi for carrying out research ~~perm~~ pertaining to road development.

→ It offers technical advise to the state governments and the industries on various problems related to roads.

Ex: Maintanence, Repair technique etc.

→ It is one of the national laboratories of CSIR (Council for science and Industrial research)

b) Secondary road System: SH
MDR.

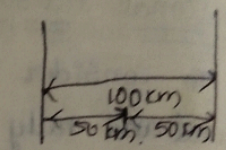
c) Teritiary road System: ODR, VR

② the national highway network should be expanded to form square grids of 100km sides so that no part of the country is more than 50km away from ~~the~~ a national highway.

③ Identification of traffic corridors and Construction of express ways along major traffic corridors.

④ P — greater than 1500 have to be Connected to — MDR

P — 1500-1000 — ODR.



⑤ Roads should be built in less industrialized areas to attract the growth of industries.

* In this square grid pattern is used.

$$\boxed{NH = \frac{A}{L} = \frac{100\times100}{200}} \quad (100+100 = 200)$$

$$= 50.$$

whatever the area the ~~a~~ value must be divided by 50. and that much length of Highway is Constructed.

$$\boxed{SH = \frac{Area}{25}} = \cancel{Area}$$

$$\boxed{MDR = \frac{Area}{12.5}}$$

* Also mostly ~~Concen~~ Concentrated on damages of roads. and rectifying the defects of roads.

Vision - 2021 →

* ~~In~~ ~~0~~ To rea

*① Vision 2021

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Ex:

phase I:

Golden Quadr

② All the isola

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Necessity of

* In developin

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are limited.

objectives:

* To plan a

traffic opera

* To arrive

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maximum

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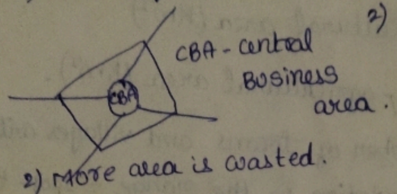
→ In this plan the roads are divided into two categories:

NH, SH, MDR } I   ODR, VR } II   * It ended in 1961.

<u>Star & Grid pattern</u>

1) No traffic.

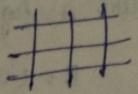


2) More area is wasted.

<u>Grid pattern</u>

1) Traffic is more.

2) Area wastage is less.



→ It is also called as first 20 year road development plan.

→ A conference of cheif engineers from all the States and provisions were conducted in Nagpur.

The total target road length aimed at the end of this plan was 16km/100km² area of the country.

Important features:

Road network in the Country was classified into two categories.

I. { NH - National Highway, SH - State highway, MDR - Major district roads } → These roads must be metal surface

II. { ODR - other district roads, VR - village roads } → These are earth roads and developed into surface.

→ Star and grid pattern of road network was adopted.

9|0[illegible]|19

Formulae's to cover the road length:

The total length of 1st category road's was given by the formula: ~~(NH+SH+~~

$$\boxed{(NH+SH+MDR)_{(Km)} = \left[\frac{A}{8}+\frac{B}{32}+1.6N+8T\right] + D - R.}$$

where A = Agricultural area (Km^2)

B = Non-agricultural area (Km^2).

N = Number of towns and villages with population in the range = 2001-5000

D = Development allowance - 15%.

L = length of railway tracks.

T = Total nomber of towns and villages with population more than 5000

The total length for ~~&~~ 2nd category road's was given by the formula:

$$[ODR+VR]_{(km)} = [0.32V+0.8Q+1.6P+3.2S]+D.$$

where

D = Development (industrial) allowance - 15%.

V = No. of villages with population less than 500

Q = No. of villages with population in range ~~500~~ 501-1000.

P = No. of villages with population in range 1001-2000.

S = No. of villages with population in a range 2001-5000.

Bombay plan: (

* It is initiate

→ Road densit

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6th

→ The focus on

→ Star & Grid

* The length o

as:

NH = [

* NH+SH = [

* NH+SH+MD

* [NH+SH+MD

* [NH+SH+MD

Bombay plan: (2nd 20year plan). 1961-1981

* It is initiated by IRC.

→ Road density — $32 km/100 km^2$.

If we work with this then 10Lakh km is developed.

→ we have 4 five year plans were there.

3rd five plan – 1961-66
4th five plan – 1969-74
> 66-69 (Annual plans)

5th five plan – 1974-78
6th five plan – 1980-85
> 78-80-(Annual plans)

→ The focus on the road development is very less.

→ Star & Grid pattern was used.

* The length of national highway was calculated as: (These lengths are without railway areas)

$$\boxed{NH = \left[\frac{A}{64} + \frac{B}{80} + \frac{C}{96}\right] + [32K + 8M] + D.}$$

* $$\boxed{NH+SH = \left[\frac{A}{20} + \frac{B}{24} + \frac{C}{32}\right] + [48K + 24M + 11.2N + 1.6P]}$$

* $$\boxed{NH+SH+MDR = \left[\frac{A}{8} + \frac{B}{16} + \frac{C}{24}\right] + [48K + 24M + 11.2N + 9.6P + 6.4Q + 2.4R] + D.}$$

* $$\boxed{[NH+SH+MDR+ODR] = \left[\frac{3A}{16} + \frac{3B}{32} + \frac{C}{16}\right] + [48K + 24M + 11.2N + 9.6P + 6.4Q + 2.4R]. + D.}$$

* $$\boxed{[NH+SH+MDR+ODR+VH] = \left[\frac{A}{4} + \frac{B}{8} + \frac{C}{12}\right] + [48K + 24M + 11.2N + 9.6P + 12.8Q + 5.9R + 1.6S + 0.64T + 0.2V] + D.}$$

cohere,

~~A= (A) $\xrightarrow[6.4km]{max}$ surface road~~

~~$\xrightarrow[2.4km]{min}$ Any category / fair weather roads~~

A = developedand agricultural area (km^2)

B = Semi-developed area (km^2)

C = ~~und~~ un-developed area (km^2)

K = number of towns with population over lakh, 1Lakh

M = " " " " " 50,000-1lakh

N = " " " " " 20,000 to 50,000

P = " " " " " 10,000 to 20,000

Q = " " " " " 5,000 to 10,000

R = " " " " " 2,000 to 5,000

S = " " " " " 1,000 to 2,000

T = " " " " 500 to 1,000

V = " " " " Less than 500.

D = Developement allocoance = 5%.

(A) $\xrightarrow[6.4km]{max}$ Surface road.

(A) $\xrightarrow[2.4km]{min}$ Any category load (low cost roads)

(B) $\xrightarrow[12.8km]{max}$ SR

(B) $\xrightarrow[4.8km]{min}$ ACR

* Any developed area away from ~~"~~ max km from S.R and min km away from ACR.

(C) $\xrightarrow[19.2km]{max}$ SR

(C) $\xrightarrow[8km]{min}$ ACR.

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* Express ways
16,000 km of len
Highway resea
National Trans
lucknow Plan

Highway Resear
→ maintanence
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* To consider
rural and hil
in the next
* Strengthen
* Increase the
* To connect
low cost road

Lucknow plan
↓
Road a

* NH — 66,
* SH — 1,4
* Road den

Road wings
① classificati
a) primary

* Express ways were also considered in this plan 16,000 km of length was proposed in this plan.

Highway research Board – 1973: 4/01/19

National Transport policy committee – 1978.

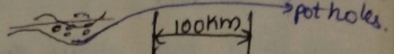
Lucknow Plan – 1985 → NH – 66,000 km
SH – 1,45,000 km.

Highway Research Board – 1973

→ maintanence, development and research schemes were under taken here.

National transport Policy committe : 1978 (NTPC)

* To consider the requirements of roads in rural and hilly areas, so that it ~~can~~ could be included in the next plan.



* Strengthening of national highway systems.
* Increase the funds for maintanence of roads.
* To connect all the villages with all weathered low cost roads in next 20years.

Lucknow plan. – 1985 (3rd 20 year plan).
↓
Road wings (under ministry of Road transport~~ation~~ & highway)

* NH – 66,000 km
* SH – 1,45,000 km.

failures
NH – 57,700 km
SH – 1,24,300 km

* Road density 46 km/100 km² – 1985 (target).
  * But in 2001 – 86 km/100 km² is reached

Road wings:

① classification of roads:–

a) primary road system: Expressways & NH

b) Secondary road System: SH
MDR.

c) Teritiary road System: ODR, VR

② the national highway network should be expanded to form square grids of 100km sides so that no part of the country is more than 50km away from ~~the~~ a national highway.

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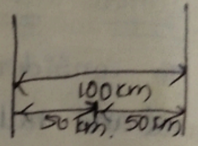

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Vision - 2021 → 21st century plan:

* To rectify the failure of previous plan.

*① Vision 2021 — Important projects were taken up as National highway development projects in different phase I.

Ex:

phase I:

Golden quadrilateral: connecting all metro cities.

② All the isolated areas and north-east region of our country have to be connected.

③ focusing the rural roads in the country were strengthed. under "phradharmantri gram sadhak yojana" (by 2025 all these areas will have good metal roads)

6/1/19

Necessity of highway planning

* In developing country like India planning is quite essential for any new project as the available funds are limited.

objectives:

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

Cost →
- construction cost
- Maintainence cost
- Renewal cost
- vehicle operation cost.

* To arrive at the road system and lengths of different categories of roads which could provide maximum utility, and could be constructed within available resources during the plan period.

$$\frac{\quad}{480} = 0.36$$

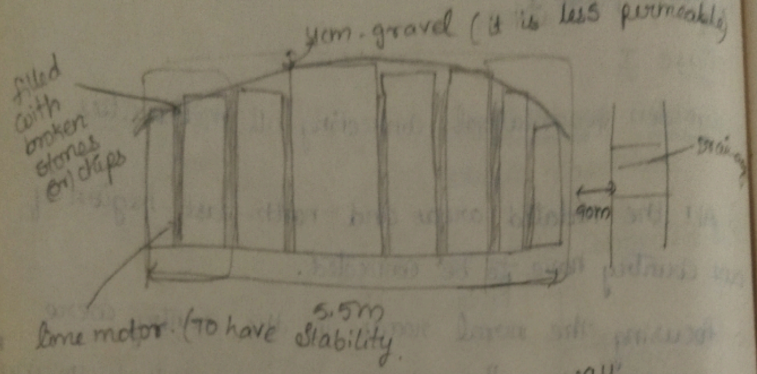
$$\frac{4\times1 + 6\times2 + 1\times3 + 220}{360} = 0.66$$

Sol

* To work out financing system. ~~(future needs)~~.

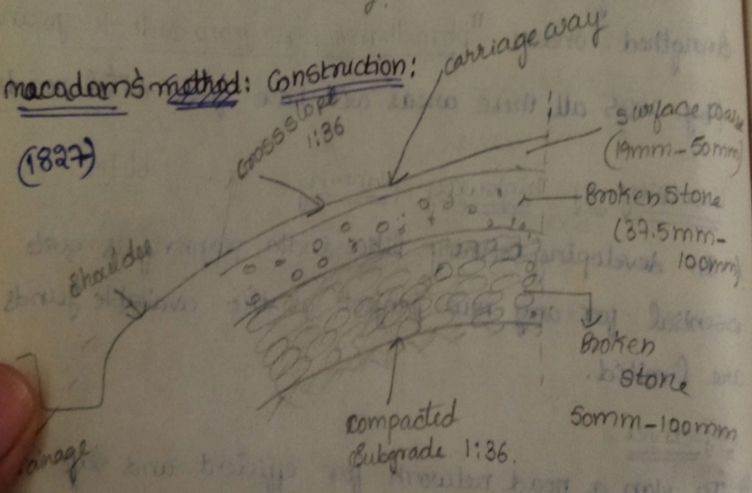
* To plan for future requirement and improvement of roads in view of anticipated developments.

Telford method:



macadam's method: Construction:

(1827)



Slope of 1 in 36

Module - I(B)

Classification of roads

Seasonal use

Surfacin provid

All weather roads (Negotiable during all weather)

(fair weather roads)

traffic may be interrupted during monsoon se

Surface road

Black

classification of w

→ Express ways
→ Arterial roads
→ Sub-arterial r
→ Collector street
→ local streets

Road patterns:

The various r

- Rectangular or
- Radial or St
- Radial or St
- Radial or
- Hexagonal p

Classification of Roads

①

~~class~~
Based on speed & accessibility
- * Freeways (access controlled)
- * Expressways
- * Highways
- * Arterials
- * local streets
- * collector Roads 35-55 km/hr

Based on construction material used
- * Earthen Roads
- * gravel Roads
- * Murram Roads
- * Kankar Roads
- * water Bound Macadam (WBM)
- * Bituminous Roads
- * Cement concrete Roads

Nagpur road classification
- * NH
- * SH
- * DR
- * V or Rural Roads

Based on usage
- * All weather Roads
- * Fair weather Roads

→ Based on carriageway
→ based on Rigidity
→ based on topography
→ based on Economy
→ Based on traffic volume
→ Based on traffic type

Based on carriageways
- * Paved Roads
- * unpaved Roads

based on Rigidity
- * flexible Roads
- * Rigid Roads

Based on topography
- * Hilly Road
- * Plain Area Roads

Based on Economy
- * low cost Roads
- * Medium cost Roads
- * High cost Roads

Based on traffic Volume
- * low traffic Road (400)
- * Medium traffic Road (400-1000)
- * High traffic Roads (1000>)

Based on traffic type
- * cycle tracks
- * Pedestrain tracks
- * Motor ways.

⑩

11:10

Freeway

- access controlled roads
- 4 lanes (or) 2 lanes in each direction
- parking & walking is strictly prohibited
- 45mph to 75mph
  72kmph to 120 kmph

CBP
central business pt

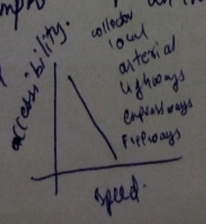
expressways

- * Heavy load Vehicles, Cargo vehicles pedestrians are not allowed.
- * Parking, loading unloading activities

Highway

villages to cities (or) cities to cities (or) state to state (or) road connect the state Capital to National capital

they run through length & breadth of country.



arterial

Free ways

- Freeways are also called as access controlled highways
- Freeways are wide Roads designed for fast moving vehicles to travel long distances with higher speeds.
- These are generally designed in 4 lanes, 2 lanes in each direction.
- Traffic movement on freeways is continous and unhindered because there are no railway (or) road intersections and no signals.
- As mentioned above, access is controlled everywhere in this type of roads the driver never comes in contact with the opposing flow of traffic
- Parking & walking are strictly prohibited on freeways and they don't have foot paths on either sides of roads.
- Min & Max rãge of speed is 72 kmph - 120 kmp.

Highways

- Highways connect villages to cities (or) cities to cities (or) state to state (or) roads connect the state capital to national capital are called highways. Highways are the roads run through the length & breadth of country
- They are generally laid in 2 lanes
- Highways are further classified into NH, SH, Urban Highways & Rural Highways

Arterials

- Arterials are the roads laid inside the city (or) town for the movement high volume of traffic.
- An Arterial road joins the central business point to the outside residential areas

Expressways

- Expressways are one of the superior types of access-controlled roadways where the entry and exit of the expressway are fully controlled by ramps
- As the name itself "express" echoing that these are mint for a free flow of very speed traffic
- Expressways are designed to travel quickly with great comfort & safety by avoiding sharp curves, busy traffic intersections, railway junctions
- Vehicles with high acceleration are only permitted in expressways. Heavy load vehicles cargo vehicles, pedestraians are not allowed
- Parking, loading & unloading are strictly prohibited on expressways

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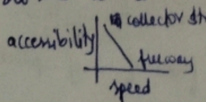
- Arterials provide access to the highways
- Pedestrians are allowed to cross the roads only at intersections or at designated pedestrian crossings.
- The flow of traffic is controlled by a signalling system at intersections
- Parking is not allowed on arterial roads

Local streets

- Local streets don't carry a large volume of traffic like arterials. The speed limit is restricted to 30 km/hr in a local street
- Local streets allow you to properties around it
- In simple the road which you to take to reach the nearest vegetable market is the local street.
- pedestraians can cross the road at any point in local streets.

* Un restricted parking, loading & unloading of vehicles are allowed in local streets.
* They usually don't have any divider with boulders but divided with 1m dotted whitelines (or) straight white lines



Based on Materials used

Earthern Roads

* The roads which are laid with the available soil at the site are called Earthen Roads
* These are the cheapest roads among all the roads
* Earthen roads are designed for very low volume traffic
* Available soil is laid in 2-3 layers & surface of the road is compacted with the rammer to expel the excess voids present in the soil.
* These roads are also called as temporary roads usually laid for moving constructing vehicles while building a structure (or) for moving ~~any~~ army vehicles during war times.
* These roads are not recommended ~~to go~~ in monsoon as the soil may run off during rain.

Gravel roads

* Gravel roads are the second cheapest among all the types of roads & they are also better than Earthen roads
* In this type of roads, the mixture of gravel & Earth is paved on the surface & compacted.
* Gravel roads are also called metal roads.
* These types of roads are easily built & generally laid in villages.

Murram

* Murram is a gravelly lateritic material which is occured during the disintegrated of igneous rocks by weathering agencies.

Collector Roads

* Collector Roads collect & deliver traffic to & from local streets & arterials. The speed limit usually ranges b/w 35 - 55 km/hr
* pedestrians are allowed to cross only at intersections
* parking can be allowed except at peak times.

---

* The roads which are laid using Murram as primary material is called Murram road. The density of murram is higher than the gravel which also provides good surface finish & compaction than above 2 types of roads.

Kankar Roads

* The word kankar is derived from India which means an Impure form of Limestone.
* This type of roads usually recommended at places having a good quantity of lime.
* kankar road is one of the low quality roads but better than Earthen roads & gravel roads.

Waterbound Macadam Roads [WBM]

5cm 3.75cm 1.9cm

* This type of road is also called WBM road. The crushed stone is used as a base course.
* WBM roads are laid as layers
* Aggregates are spread on the surface as a layer having 10cm thickness, water is sprinkled on each layer & then rolled for a better finish
* These Roads are better than Murram, Earthen and kankar roads

Bituminous Roads

* The bituminous is a black viscous & adhesive material occured during the distillation of petrol.
* Bituminous roads are primarily used all over the world which is very easy to lay & provids smooth & good surface finish.
* The thickness of bitumen road depends upon the subgrade soil at the site.
* It is always recommended to lay the bitumen roads in two layers.

concrete roads

* The roads which are laid using the cement concrete material is called concrete roads.
* These are the costlier roads among all types of roads.
* This type of roads are recommended at the places of the high volume of traffic & it takes more time to construct the concrete roads as the concrete ~~road is 40 year~~ requires proper curing.
* The average life of a concrete road is 40 years whereas bituminous road has an average life of 3 years

flexible roads	rigid Roads
surface course	surface course
Base course	Base course
sub base course	sub grade course
sub grade course	

④

What is alignment
→ Horizontal alignment
→ Vertical Highway alignment
→ Importance of Highway alignment
→ Ideal highway alignment criteria
→ factors controlling the HW alignment

→ Highway alignment

~~This covers the~~ The position of central line of highway (or) the layout of planned highway line on the ground is called highway Alignment. Highway alignment is generally phrased as 2 types of Highway plans

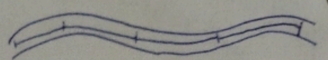
Horizontal Alignment
Vertical alignment.

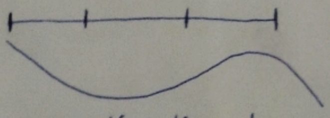
Horizontal Alignment

This covers the horizontal path of the road either it's straight (or) curved (or) both. Top view of road alignment gives horizontal alignment of the road

Vertical Alignment

This deals with the gradients, slopes and levelling of the ground. Perspective view (or) front view (or) side view of the road alignment makes you understand about vertical alignment.


Horizontal


vertical alignment.

Importance of Highway alignment

(1) deciding the highway alignment is most crucial part of road construction.

(2) Road construction involves lot of land acquisition.

(3) Once the alignment is fixed and constructed as per plan it is difficult to transform it because of increment in the cost of adjoining land and development of expensive structures by the side of the road.

(4) A small error in the Highway alignment enchances the cost of construction.

The ideal Highway alignment should meet the following criteria

(1) The alignment should be designed in such a way that the distance b/w the start pt and the end point of the road should be short & straight with fewer curves.

2) The alignment is selected in such a way that it should be very easy to construct & maintain. A good alignment should be linear & have fewer gradients & slopes. To achieve this a small deviation in alignment is permitted.

* The alignment should be considered only when the operation cost, initial cost and maintenance cost is least.

* ~~PKK selected alignment~~.

* The selected alignment should be safe during construction, especially at embankments, slopes, hilly areas and gradients.

Road network Pattern
Engineering survey.
Drawings & Reports
Road Projects initiation
need based planning

Dr. L.R. Kadiyali

17/3/24

III A

1, 2, 3, 5, 7, 8, 9, 10, 11, 12, 14, 16,
17, 18, 19, 20, 21, 22, 23, 24,
25, 26, ㉗, 28, 29, 30, 31, 32,
NSS
33, 35, 36, 37 38, 39, 40,
41, 42, 44; 48, 49, 51,
52, 54, 55, 57, 58, 59, 60.
Li, 3, 4, 5,

Factors controlling Highway alignment

1. Obligatory points: The control points governing highway alignment are called obligatory points. These points decide where the alignment should pass & where the alignments should not pass. ⑤

Alignment should pass:

* Roads are constructed for the development of the areas. A small deviation in alignment can be acceptable if highway passes through the towns, villages cities

* If the alignment passes through the mountain, it is recommended to relook the best alternatives, either to construct the tunnel or go round the hills. The selection of the choice depends on factors like topography, site conditions & construction & operation cost.

Alignment should not pass.

* It is always recommended to avoid the alignment on small lakes & ponds & deviate the alignment up to some extent where required, construction of bridges on these lakes & ponds requires more funds.

* The alignment should not pass through the places which are developed (or) having expensive building (or) high rise buildings acquisition of land at these places incurs huge initial cost and demolishing these structures takes more time.

*So the slight deviation in alignment is acceptable if above these points are in alignment.

* The alignment should not pass through the dense forests & agricultural lands.

2. Horizontal curve & gradient

* The Horizontal curve must be as flat as possible. The gradient should be kept as flat as possible to avoid the the excessive rise & fall of the highway alignment

3. The volume of traffic

The volume of traffic & an increase in the traffic volume per year and peak traffic is analyzed & alignment is finalized by considering all previous data of traffic respectively.

4. Type of traffic

If the traffic is of vehicular type & for fast moving vehicles, it is advised to keep the alignment as straight as possible with fewer curves. seperate lanes for faste moving vehicles are recommended.

5. Earthwork and back filling

Earthwork & backfilling to level the land constitutes huge costs after the land acquisition. The alignment has deviated wherever required to avoid the excessive cutting of earthwo & backfilling.

6. Railway crossing

Road alignment should cross a rail lane ideally at 90 Degrees.

For fast moving lanes (or) national highways or expressways, it is advisable to construct the bridge over rail lane to avoid the traffic jams.

7. Radius of the Horizontal curve

Large curves on highways are not desirable. To maintain the comfortable and constant speed on Highways, The radius of the horizontal curve should be less than 230m. To achieve this, the alignment can be changed

8. Bridges

selection of bridge site involves many factors and is finalized where the river path is the same throughout the year. The road alignment should cut the river at 90° same as Railway lane.

9. Sight Distance:

To avoid accidents, mininum sight distance should always be available for the drivers. The alignment should not obstruct the visibility of drivers, especially during nights.

10. Proper Drainage

Proper water drainage is provided at the edges of the alignment to avoid water logging during monsoon.

11. Stability of slopes

Special care is to be taken for road alignment in hilly areas, the problem with the hilly areas is landslides. The road should be aligned to the side of the hill which is stable. Excessive earthwork cutting & backfilling affect stability.

12. Monotony:

Straight and even road alignment are possible for flat terrain but it monotonous for driving which may lead to accidents for a sudden curve.

It is recommended to keep the slight bend for every few miles to alert the driver.

13. Economy:

The initial cost, operating cost & maintenance cost should be minimum for the finalized alignment. Avoid High embankments & deep cutting to reduce the cost of cons[illegible]

14. Formation bed:

The alignment should go through the good soil having enough strength, to achieve this a slight change in alignment is acceptable

~~cost should be minimum for the finalized alignment. Avoid High embankments & deep cut~~

Engineering survey &

(1) Map study
(2) Reconnaissance
(3) Preliminary survey
(4) Final location & detailed survey.

Types of survey & Investigations

Transport planning survey

alignment & route location survey

1. desk study
2. Reconnaissance survey
3. Preliminary survey
4. Final location survey.

desk study ~~includes~~ for highway of an area includes. Maps, Aerial photographs, Charts (or) graphes to obtains engineering data environmental data, social data, economic data.

Survey for Road project

(1) Desk Study

- → Reading Topographical map
- → obtaining information about contours, drainage features, existing roads, rivers, Ponds etc.
- → Geological features like faults, ground water table etc.
- → Rainfall intensity map
- → Possible Routes are decided.

(2) Reconnaissance survey

- → Determine any necessary deviation in the basic geometry to be provided in road
- → Aerial Reconnaissance | ground Reconnaissance.
- → Most feasible route to be choosen
- → Alignment, gradient, curves etc
- → Plan to be prepared of general profile, cost estimate & Material availability.

(3) Preliminary survey.

- → (~~Technical~~ survey of ~~most feasible route~~)
- → Sub soil information for foundation
- → conducting open traverse survey on the selected route.

(4) Location Survey

- ~~→ To fix the centre-line of the proposed route on the ground.~~
- ~~→ To collect data necessary for the aquisition of Right of way.~~
- ~~→ To determine the cost of Road Project.~~

Reconnaissance Survey

The engineer visits the site to examine general charateristics of the area with a view to select possible alternate alignment.

* Some details to be collected during reconnaisance are

- → obstructions like lakes, marshy land etc along the route which are not available in the map.
- → soil type, observation of geologica features.

Preliminary Survey:

- * To finalise the best alignment from all considerations
- * To estimate the quantity of earth work material
- * decide feasibility of proposed alignment.

In this stage all the physical information ~~read~~ required to finaliz alignment is collected method to carry out preliminary survey:

(a) Conventional approach - primary traverse (theodolite)

- Topographical features.
- levelling work
- Drainage studies & hydrological data
- Soil survey
- Material survey.
- traffic studies.

(b) Rapid approach:- Aerial survey & modern techniques using GPS

- Suitable for vast area & terrain is difficult

(d) Final Location & Detailed Survey:

→ The alignment finalised at the design office after the preliminary survey is located on the field by establishing the centre line.

→ Levelling work is carried out for vertical alignment, Earthworks calculations & drainage details.

→ All topographical details are noted down & also plotted using conventional signs

- A detailed soil survey is carried out to enable drawing of the soil profile.

→ Soil sampling is done 1.5 to 3m below Ground level (or) grade level which ever is lower.

- For high embankments depth of Sampling is up to twice the height of the finished embankment.

ⓐ

Drawings & Report

(a) Drawings

(i) Key Map: shows the proposed and existing Roads and important places to be connected (22x20cm).

(ii) Index Map: shows general topography of area (32x20cm)

(iii) Preliminary survey plans: (10cm = 1km) (25cm-1km)

(iv) Detailed logitudinal & detailed C/S.

(v) Land acquistion plans.

(vi) Drawings of c/s cross drainge

(vii) Drawings of Road intersection

(viii) Land plans for quarries.

(b) Report:

- Feasibility Report: Prepared after completing the preliminary surveys.
- DPR - Prepared at the project and includes Reports, drawing estimates.

Module - 2

①①

GEOMETRIC DESIGN

Importance of Geometric Design

def:- The geometric design of Roads is the branch of highway engineering concerned with the positioning of the physical elements of the roadway according to standards.

Importance of geometric design.

* The geometrics of highway should be designed to provide efficiency in traffic operations with maximum safety at reasonable cost.

* The designer may be exposed to either planning of new highway network (or) improvement of existing highways to meet the requirements of the existing & the anticipated traffic.

Geometric design of Highways deals with following elements.

(1) Cross. section elements
(2) Sight distance considerations
(3) Horizontal alignment details
(4) Vertical alignment details
(5) Intersection elements.

crossection elements

→ width of pavement, formation and land, surface characteristics & cross slope of pavement.

* Sight distance (or) clear distance

Visibility ahead of a driver at horizontal & vertical curves and at intersections govern safe movement of vehicles.

{ Horizontal curves

change in the ~~de~~ road direction are made possible by introducing horizontal curves.

* Super elevation is provided by raising the outer edge of pavement with respect to the inner edge to counteract part of the centifugal force developed on a vehicle traversing a horizontal curve.
* Extra width of the pavement is also provided on horizontal curves.
* In order to introduce the centrifugal force & the superelevation gradually
* transition curves are introduced b/w the straight & circular curves.

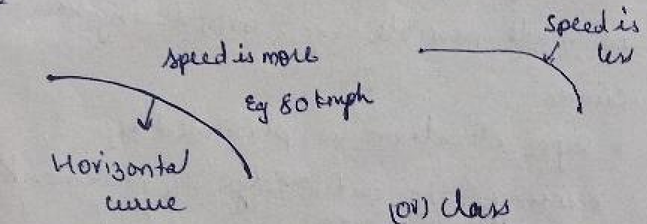
Factors affecting geometric design

(a) Design speed
(b) Topography (or) terrain
(c) Traffic factors
(d) Design hourly volume & capacity
(e) Environmental & other factors

Design speed

* This design speed is the most important factor controlling the geometric design elements of highways.

*



* depending on the classification (or) class of roads speed is designed.

* further design speed is modified depending on terrain (or) topography.

* pavement surface characteristics, c/s elements of road such as width clearance requirements, sight distance etc are designed according to speed considerations.

* horizontal alignments elements such as radius of curve, superelevations, transition curve length.

* Vertical alignment elements such as gradient, length of summit and vally curves also depend on speed considerations.

Topography

* terrain are classified based on general slope of the country across the alignment.
  - plain terrain
  - rolling terrain
  - mountainous
  - Steep terrains.

speed	slope	terrain
100 kmph	<10%	plain terrain
80 kmph	10 - 25%	Rolling
50 kmph	25 - 60%	Mountaineous
	>60%	Hilly terrain.

In hilly terrain it is necessary ~~for~~ to allow for steeper gradients and sharper horizontal curves due to construction problems.

Traffic factors

* factors associated with traffic that effect geometric design of roads are vehicular characteristics & human characteristics of road users.

* users — physical, mental, psychological charateristics of drivers.

design hourly volume capacity

* The traffic flow (or) volume keeps fluctuating with time
  low at off peakhours
  high at peakhours.

* It becomes uneconomical to design the pavement for peak hour traffic

* So, resonable Value of traffic volume is decided for the design & This is called "design hourly volume"

* Ratio of $\frac{\text{volume of traffic}}{\text{capacity of pavement}}$

  $= LOS.$

Environmental & other factors

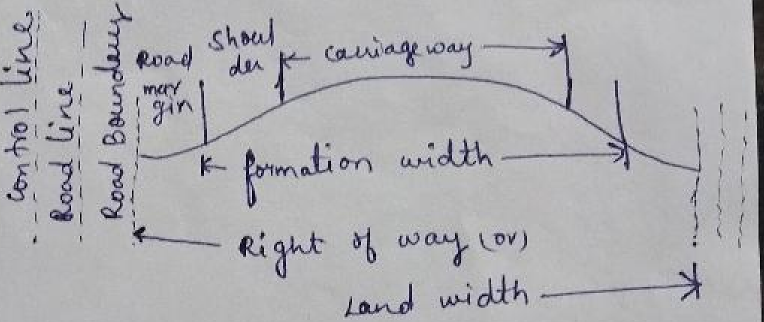
* Environmental factors such as asthetics, landscaping, air pollution, noise pollution & other local conditions

* Some arterial high speed highways and express ways are designed for higher speed standards & unintenapted flow of vehicles by providing controlled access.

Highway Cross-section Elements ② ②

→ Pavement surface charateristics

(a) friction
(b) uneveness
(c) Light reflecting charateristics
(d) Drainage of surface water



(a) Friction

* Friction (or) Skid resistance b/w vehicle type and pavement surface is one of the factors determining the operating speed & the minimum distance required for stopping the vehicles.

* when a vehicle negotiates a horizontal curve the lateral friction developed counter acts the centrifugal force & governs the safe operating speed.

* It is very important factor in acceleraton & retardationabilities of vehicles.

* The maximum coefficient of friction comes in to play only when the braking

efficiency is high enough to partially arrest the rotation of the wheels on application of brakes, at low speeds.

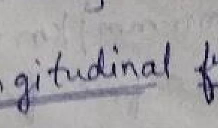
Skid occurs when the wheels slide with out revolving (or) rotating (or) when the wheels partially revolve i.e when the path travelled along the road surface is more than the circumferential movements of the wheels due to their rotation.

✓ when the brakes are applied, the wheels are locked partially (or) fully and if the vehicle moves forward, the longitudinal Skidding takes place which may vary from 0 to 100 %.

✓ while a vehicle negotiates a horizontal curve, if the centrifugal force is greater than the counteracting forces. lateral skidding takes place.

Longitudinal friction: when we apply break, friction develops b/w tyres & break. This friction is opposite direction

(μ= 0.35 to 0.4) for safe stopping distance



Lateral friction: friction which is perpendicular to the vehicle axes. ③ ③ occurs when vehicle negotiates a curve it tends to move out wards due to centrifugal force which is counteracted by lateral friction.

(μ= 1.5) → for safe stopping distance

Slip: occurs when a wheel revolves more than the corresponding longitudinal movement along the roads.

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

Factors affecting friction (or) skid resistance

(a) Type of pavement
(b) condition of pavement (wet (or) dry)
(c) Type and condition of tyre (ie) new with good treads
(d) Speed of vehicle
(e) Extent of brake application (or) brake efficiency
(f) Load & tyre pressure
(g) temp of tire & pavement
(h) Type of skid

coefficient of friction reduces partially when pavement is smooth & wed increases when increase in temp tyre pressure and load.

→ Smooth & worn out tyres offer higher friction factors on dry pavements than new tyres with treads because of larger area of contact.

* but on wet pavements, new tyres with good treads give higher friction factors than worn out tyres. This is because the lubricating effect of water on the wet pavement is reduced as the water entrapped b/w tyre & pavement escapes into the treads of the tyre.

* There fore new tyres are more dependable than old in adverse surface & other conditions prone to skidding, suchas wet pavements.

Pavement unevenness

The longitudinal profile of the road pavement has to be "even" in order to provide good riding comfort to fast moving vehicles and to minimise the vehicle operation cost.

* Presence of undulations on the pavement surface is called pavement unevenness. which results in

→(i) Increase in discomfort & fatigue to road users

(ii) increase in fuel consumption & tyre wear.

(iii) increase in vehicle maintenance cost

(iv) reduction in vehicle operating speed

(v) increase in accident rate.

* loose road surface increases the resistance to traction & causes increase in fuel consumption.

* Unevenness of pavement surface is commonly measured by using a simple equipment called "Bump Integrator" (BI) interms of "unevenness index", which is cumulative measure of vertical undulations of the pavement surface recorded per unit length of the road.

* unevenness index should be kept low preferrably less than 1500 mm/km for good pavement surface for high speed highways

* A value of 2500mm/km is considered just satisfactory up to a speed of about 100 kmph.

* unsatisfactory value exceeds 3500mm/km

for 50 kmph speed. $BI = 630(IRI)^{1.12}$
IRI → International Roughness index m/km

* Causes of unevenness

(i) inadequate (or) improper compaction of either the fill, subgrade (or) pavement layers (or) combination of these

(ii) use of improper construction machinery

(iii) use of inferior pavement materials

(iv) improper surface & subsurface drainage

(v) unscientific construction practices including the use of boulder stones & bricks as "soling course" over loose (or) weak subgrade soil.

(vi) poor maintenance practices &

(vii) localized failures due to combination of causes.

Light reflecting characteristics

* Night visibility depends upon the colour and light reflecting characteristics of the pavement surface.

* The glare caused by the reflection of head lights is considerably high on wet pavements surface than on the dry pavement

* Light coloured (or) white pavement surface give good visibility at night particularly during rains, however white (or) light colour of pavement surface may produces glare & eye strain during bright sunlight.

* Black top pavement surface on the other hand provides very poor visibility at nights, especially when the surface is wet.

Cross - Slope (or) CAMBER

Cross slope (or) camber is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface.

(i) To prevent the entry of surface water into the pavement layers

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

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

skidresistance of pavement decreases considerably when the pavement is wet

type of Road surface	Range of camber in areas of	
	Heavy rainfall	low rainfall
cement concrete & high type Bituminous surface	1in50 (or) 2%	1in60 (or) 1.7%
Thin bituminous surface	1in 40 (or) 2.5%	1in 50 (or) 2%
water bound macadam & gravel pavement	1in33 (or) 3%	1 in 40 (or) 2.5%
Earthroad	1in 25(or) 4%	1in33 (or) 3%

Types of Camber

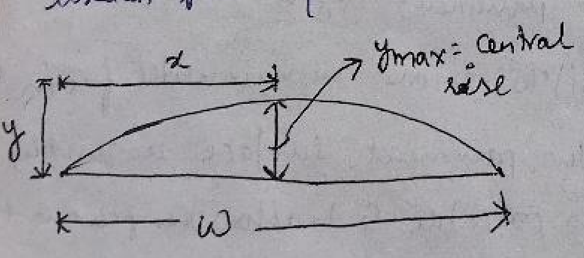
(1) parabolic camber

(2) Straight camber

(3) combination camber

(1) PARABOLIC CAMBER

used in flexible pavements.



B.T, W.B.M, Stone/gravel, Earth

W = width of carriage way.

equation to be adopted $y = \frac{x^2}{a}$

$$y_{max} = \frac{2x^2}{NW} \; ; \; x = W/2$$

if camber given 3% then

$$\Rightarrow \frac{3}{100} \Rightarrow 1/(100/3)$$

$$1 \text{ in } 30 \Rightarrow \frac{1}{30} = \frac{1}{N}$$

1 in N

$$\boxed{N = 30}$$

Eg:- BT road in High rainfall area width of road W = 3.75m central rise w.r to edges

Sol: W = 3.75m

$$x = \frac{W}{2} = \frac{3.75}{2}$$

$$= 1.875 \text{ m}$$

for Highrainfall; BT road = 1 in40 (from table)

N = 40.

$$y_{max} = \frac{2x^2}{NW} = \frac{2 \times (1.875)^2}{40 \times 3.75}$$

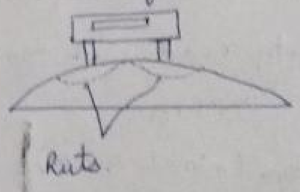
$$= 0.0468 \text{ m}.$$

find the central rise of WBM road in low rainfall area with width = 3.75m

Drawbacks of Parabolic camber

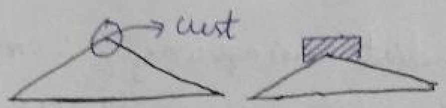
→ High central Rise

→ Rut formation occurs



(2) Straight Camber

used in C.C road | RCC Roads.



Drawbacks

* sharp crest causes discomfort while shifting lanes.

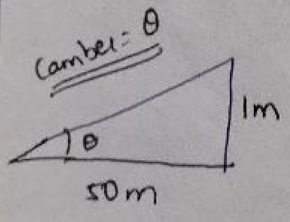
* crest is concealed by median (divider) in multilane roads.

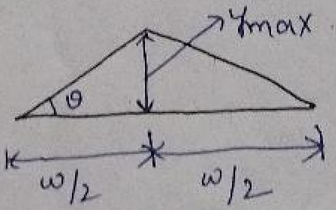
eg: C.C Road in High rainfall area width of road, $W = 3.75m$; find the central rise w.r.to edges.

So) As per IRC

camber for CC Roads with High rainfall = 1 in ⑤⓪

N





$$\tan\theta = \frac{Y_{max}}{\left(\frac{w}{2}\right)} = \frac{Y_{max}}{\frac{3.75}{2}}$$

$$\tan\theta = \frac{opp}{adj} = \frac{1}{50}$$ ⑤ ⑤

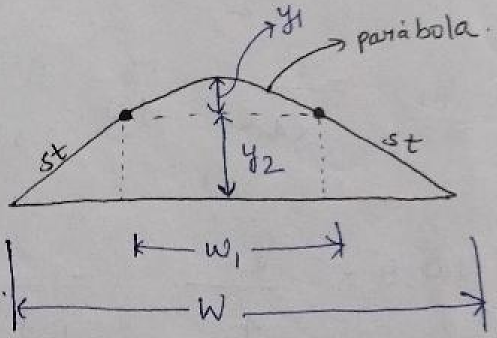
$$\frac{1}{50} = \frac{Y_{max}}{\frac{3.75}{2}}$$

$$\boxed{Y_{max} = 0.0375\,m \text{ (or) } 37.5\,mm}$$

(3) Combination Camber

→ used on multilane Roads.

→ parabolic equation is valid for central parabolic zone



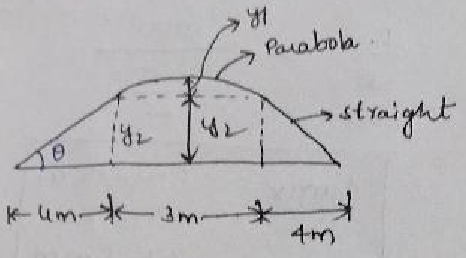
$$\boxed{y_1 = \frac{2x^2}{NW_1}}$$

y_2 is Based on Similar Δles for straight zone

advantages

* decrease in central rise.

Eg: Camber 1 in 40, combination camber is used.



$$y_1 = \frac{2x^2}{Nw_1}$$

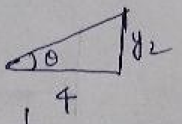
$$y_1 = \frac{2\times\left(\frac{\cancel{w_1}^2}{2}\right)}{N\cancel{w_1}}$$

$$y_1 = \frac{\cancel{2}\times w_1}{\cancel{4}_2\times N} = \frac{w_1}{2N}$$

$$y_1 = \frac{3}{2\times40} = \frac{3}{80} = 0.0375m$$

$$= 37.5mm$$

$$\tan\theta = \frac{y_2}{4}$$



$\downarrow$

$$\tan\theta = \frac{1}{40}.$$

$$\frac{1}{\cancel{40}_{10}} = \frac{y_2}{\cancel{4}}$$

$$y_2 = 0.1m$$

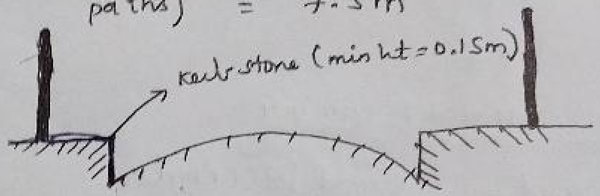
$$y_{max} = y_1 + y_2$$

$$= 0.0375 + 0.1m$$

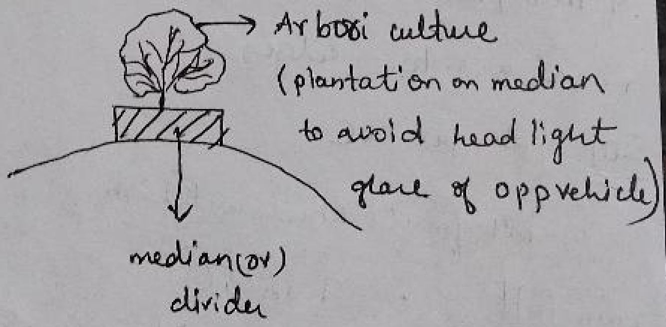
$$= 0.1375m$$

$$\boxed{y_{max} = 137.5mm}$$

- * width of single lane Road = 3.75m
- * Multi lane road width = n(3.5)
- * 2 lane with raised kerbs (available on bridge / city roads with foot paths) = 7.5m



- * Intermediate carriage way = 5.5m (in the middle of single & double lane)
- * Min width of shoulder = 2.44m (or) 2.5m
- * Max width of vehicle = 2.44m
- * Median (if space is available) width = 5m



Find the central rise of WBM Road in low rainfall area with width = 3.75m

Sol $W = 3.75m$ from IRC table

$\boxed{1 : N = 1 : 40}$:- $N = 40$

$$y_{max} = \frac{2x^2}{NW}$$

$$= \frac{2 \times \cancel{x}^2}{NW} = \frac{2\times\left(\frac{W}{2}\right)^{\cancel{2}}}{NW}$$

$$= \frac{\cancel{2}^{1} \times W}{\cancel{4}_{2} \times N} = \frac{3.75}{2\times40}$$

$$= 0.0468m$$

for WBM roads we use parabolic camber ∴ parabolic eq is used.

GRADIENT: [slope along the length of Road]

- To take the road along the existing topography gradient is required.

Types of gradient

(1) Ruling gradient (2) Limiting gradient
(3) Exceptional gradient (4) Minimum gradient.

(1) Ruling gradient: (design gradient)

→ Max allowable gradient to achieve maximum speed.

→ while moving on this gradient vehicle can move on top gear.

(2) Limiting gradient:

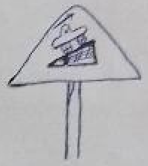
→ gradient more than ruling gradient

→ on this gradient min design speed is achieved

→ Vehicle can move with top gear.

(3) Exceptional gradient

- gradient more than limiting gradient
- speed on this gradient less than minimum design speeds.
- Vehicle can move with lower gear only.
- should be indicated by warning sign.
- As per IRC length of exceptional gradient should notbe more than 60m in 1km road.



(4) Minimum Gradient

- For proper drainage along the side of a road.

RELATION B/T GRADIENT & CAMBER:

$$\boxed{G = 2C}$$

Eg:- $G = 1$ in 100 ; $C = ?$

$$G = 2C$$

$$\frac{1}{100} = 2C$$

$$C = \frac{1}{200}$$

$$\boxed{C = 1 \text{ in } 200}$$

Eg: $C = 1 : 60$; $G = ?$

$$G = 2\left(\frac{1}{60}\right)$$

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

$$\boxed{G = 1 : 30}$$

GRADE COMPENSATION: (GC) (Imp)

Gradient is accompanied by Horizontal curve

→ Grade compensation is required if the horizontal curve is accompanied by gradient.

→ Def:- The grade compensation is the reduction given to the gradient if it is accompanied by horizontal curve

Emperical formula given by IRC

$$\underbrace{\% \, G.C = \frac{30+R}{R} = \frac{75}{R}}_{\text{Result directly comes in percentage}} \left.\right\} \text{use minimum of 2}$$

where R = Radius of curve in "m"

GC comes in % directly.

→ Compensated gradient = gradient to be provided on the road after grade compensation.

$$\boxed{\text{Actual gradient} - \text{Grade Compensation}}$$

↓

≮ 4% as per IRC

* For gradients flater than 4% grade compensation is not required.

* The grade compensation is allowed till the compensated gradient becomes up to 4%. (≮ 4% is not allowed)

Eg:-① gradient = 4.8%

Radius = 155m

grade compensation = ?

compensated gradient = ?

$$G.C = \frac{30+155}{155} = 1.19\%$$

$$= \frac{75}{R} = \frac{75}{155} = 0.48\%$$

use min of above 2 results = 0.48%.

Compensated gradient = 4.8 − 0.48

= 4.3%.

(>4% hence ok).

Eg:-② gradient = 4.2%

Radius = 120m

grade compensation = ?

Compensated gradient = ?

Sol: $$G.C = \underbrace{\frac{30+R}{R} = \frac{30+120}{120} = 1.25\% \;\Big|\; \frac{75}{R} = \frac{75}{120} = 0.625\%}_{\text{Consider minimum}}$$

~~grade compensation~~ compensated gradient = 4.2 − 0.625

= 3.575

(< 4% not ok ∴ not allowed).

use compensated gradient is to be

taken = 4%. ⇒ ∴ consider 4% = compensated gradient;

∴ grade compensation = 0.2%. ⇒ grade compensation = Actual gradient − compensated gradient

$= 4.2 - 4$

grade compensation = 0.2%.

eg ③ gradient = 1/20; Radius = 300m

grade compensation = ?

Compensated gradient = ?

Sol G.C (%) = $\frac{30+R}{R}$ | $\frac{75}{R}$

$= \frac{30+300}{300}$ | $\frac{75}{300}$

$= 1.1\%$ | 0.25%

min % taken = 0.25%.

compensated gradient = Actual gradient − Grade compention

$= 5\% - 0.25\%$

$= 4.75\%$

{ >4 Hence ok }

$\frac{1}{20}$ should be converted to %.

$\frac{1}{2\cancel{0}} \times 10\cancel{0}^{5} = 5\%$

SIGHT DISTANCES :-

* The minimum clear distance available for the driver for various operations on the road is called sight distance

(i) Stopping sight distances

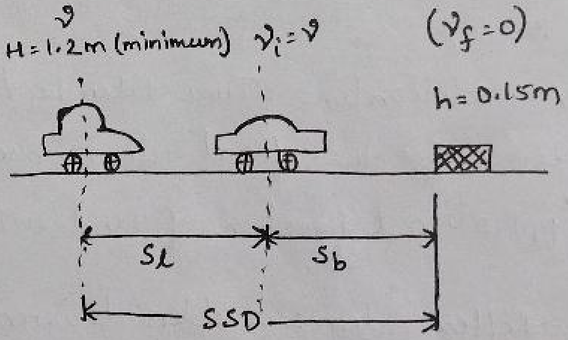
(ii) Intermediate SD

(iii) Over taking Sight distances (OSD)

(iv) Head light Sight distances (HSD)

STOPPING SIGHT DISTANCE (SSD)

The minimum visible clear distance ahead of driver to observe the obstruction & to stop the vehicle before the obstruction.



S_l = lag distance

S_b = breaking distance

(distance moved after the application of breaks)

Lag distance (distance moved with uniform design speed, during reaction time of avg driver)

$$\boxed{S_l = v \times t}$$

v = velocity of vehicle

t = reaction time of avg driver

(2.5 Sec as per IRC maximum)

t is generally based on PIEV Theory

(a) PIEV Theory

P = Perception time : Time required to perceive on boy object ~~as~~ situation. (function of eyes, Ears)

I = Intellection time : Time required for understanding the situation (function of Brain)

E = Emotion : Time elasped during which Emotional ~~and~~ like fear, anger etc comes in to the picture & decision wheather to stop (or) not (function of Brain)

V = Volitiontime : Time taken by the driver for the final action. brake application (function of Hands (or) legs)

→ Reflex Action : sudden decision to stop (or) turn.

(b) speed of vehicle : Higher speed requires higher SSD.

(c) Efficiency of brakes : Braking efficiency is said to be 100%. If the wheels are fully locked preventing them from rotating on the application of the brakes
↳ may lead to skidding.

To avoid skid, braking forces should not exceed the frictional force b/w the wheels and tyres.

(d) frictional Resistance b/w Road & tyres.

skid resistance (or) friction coefficient "f" = 0.35 to 0.40

Analysis of SSD

$$SSD = S_l + S_b$$

= lagdistance + Braking distance

~~lagdistance~~:

Braking distance : distance travelled by the vehicle after the application of brakes, until the vehicle comes to a dead stop.

Applying work energy principle

work done = change in K.E

(forces along the displacement) $= \frac{1}{2}m(v_f^2 - v_i^2)$

$$\{-F\}\{S_b\} = \frac{1}{2}\frac{W}{g}(0^2 - v^2)$$

$$-F \times S_b = \frac{-Wv^2}{2g}$$

$$\boxed{F = fN}$$

$$-fN \times S_b = \frac{-Wv^2}{2g}$$

$$+f\cancel{W}S_b = \frac{+\cancel{W}v^2}{2g}$$

$$\boxed{S_b = \frac{v^2}{2gf}}$$

SSD = $S_l + S_b$

$$\boxed{SSD = \vartheta t + \frac{\vartheta^2}{2gf}}$$

f = coefficient of longitudinal friction
(0.35 - 0.4)

Factors effecting SSD:

1) lag distance depends only on driver characteristics not related to type of vehicle

Braking distance mainly depends on which in turn depends on braking efficiency & gradient.

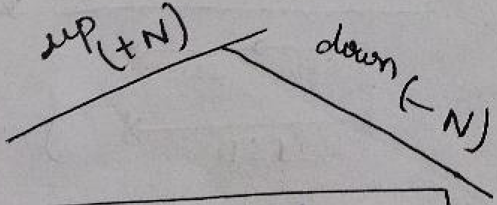
2) Breaking efficiency

if loss @in Braking = 20%.

∴ efficiency of Braking $\eta = 0.8$

$$\boxed{SSD = \vartheta t + \frac{\vartheta^2}{2g(\eta f)}}$$

3) Gradient (N):



$$\boxed{SSD = \vartheta t + \frac{\vartheta^2}{2g(f \pm N)}}$$

N = gradient (must be substituted as a Ratio.

SSD with Gradient + Brake efficiency

$$\boxed{SSD = \vartheta t + \frac{\vartheta^2}{2g(\eta f \pm N)}}$$

Eg:- The design speed on a highway 80 kmph; Reaction tym of driver 2.3Se coefficient of longitudinal friction. determine SSD

(i) level ground

(ii) upward gradient of 2%.

(iii) level ground with 25% of loss at brakes.

(iv) 2% downward gradient & breaking efficiency 0.85.

Sol Given: ϑ = 80 kmph

$= \frac{80}{3.6} = 22.22$ mps

converting 80 kmph to mps

$$= 80 \times \frac{10\cancel{0}\cancel{0}}{6\cancel{0} \times 6\cancel{0}} = \frac{80}{3.6}$$

1km = 1000mts

1 hr = (60×60) secs

f = 0.35 - 0.4 (any value b/w this range can be considered)

Let us consider f = 0.37

t = 2.3 S

(i) Ground level (level ground)

$$S_b = \frac{v^2}{2gf} = \frac{22.22^2}{2\times 9.8\times 0.37} = 68.081m$$

$$S_l = vt = 22.22\times 2.3 = 51.106m$$

$$SSD = S_b + S_l$$

$$= 68.081 + 51.106$$

$$= 119.187\ m$$

(ii) Up ward gradient of 2%.

$$\text{upward gradient} = +\frac{2}{100}.$$

N has to be substituted in Ratio

$$SSD = vt + \frac{v^2}{2g(f+N)}$$

$$= (22.22\times 2.3) + \frac{22.22^2}{2\times 9.8\left(0.37+\frac{2}{100}\right)}$$

$$= 115.696m.$$

(iii) level ground with 25% of loss of brakes. → $\eta = 0.75$

$$SSD = vt + \frac{v^2}{2g(\eta f)}$$

$$= (22.22\times 2.3) + \frac{22.22^2}{2\times 9.8(0.75\times 0.37)}$$

$$= 141.88m.$$

(iv) 2% downward gradient, Brake efficiency = 0.85

$$SSD = vt + \frac{v^2}{2g(\eta f - N)}$$

$$= (22.22\times 2.3) + \frac{22.22^2}{2\times 9.8\left(0.85\times 0.37 - \frac{2}{100}\right)}$$

$$= 136.51m.$$

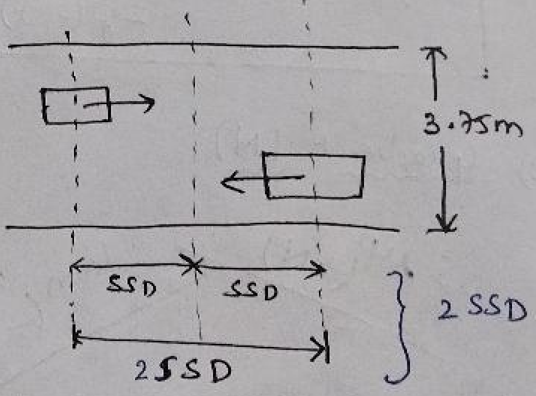
→ SAFE S.S.D (Absolute min sight distance)

* Depends on (1) No of lanes

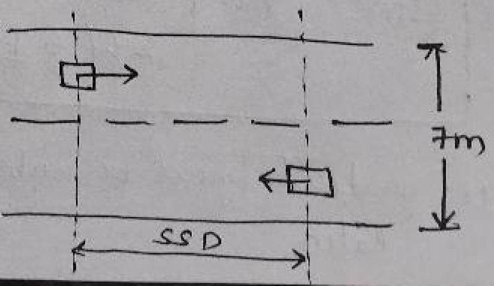
(2) Direction of traffic

(i) Single Lane (one-way)

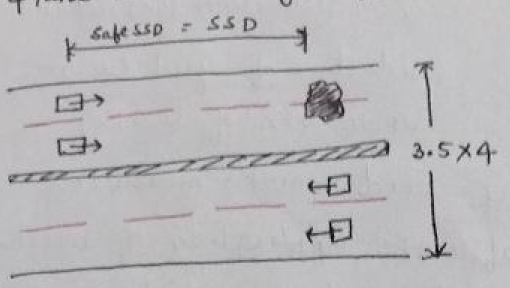
(ii) single lane (two way traffic)



(iii) Two lane (Two way)



(iv) 4 lane divided (Highway)



Eg: Design speed, 40 kmph, reaction time of driver = 2.3s; longitudinal friction coefficient = 0.35

(i) Safe SSD in single lane one way

(ii) safe SSD in single lane 2 way

(iii) safe SSD in 6 lane divided highway.

Sol Given: $\vartheta = 40$ kmph

$= \frac{40}{3.6}$ mps

$= 11.11$ mps

$t = 2.3s$; $f = 0.35$

(i) Safe SSD in single lane one way.

$$SSD = \vartheta t + \frac{\vartheta^2}{2gf}$$

$$= (11.11)(2.3) + \frac{(11.11)^2}{2\times9.8\times0.35}$$

$$= 43.52m.$$

(ii) safe SSD in single lane 2way.

Safe SSD = 2 × SSD

= 2×43.52

= 87.05m

(iii) Safe SSD in 6 lane divided highway

Safe SSD = 1 SSD = 43.52m

SKID: The linear distance moved by the tyre is more than rotational distance of tyre.

due to: sudden application of breake, Improper friction b/w road & tyre.

SLIP: The rotational distance moved by tyre is more than linear distance moved.

If vehicle skids → SSD eqn cannot be used

→ linear motion equation

$$\left.\begin{array}{l} V = u + at \\ v^2 - u^2 = 2as \\ S = ut + \frac{1}{2}at^2 \end{array}\right\}$$ are to be used when vehicle skids.

Eg:- A vehicle travelling on a road skids for 16m before haulting in 2 secs of time the coefficient of linear friction is 0.3 determine initial speed of vehicle

Sol: Given: $S = 16m$

$t = 2$

$f = 0.3$

$\vartheta_i = ?$

$-fg = -a$

$a = fg$

$a = 0.3 \times 9.81 = 2.94 \text{ m/s}$

$S = ut + \frac{1}{2} a t^2$

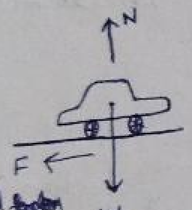
$16 = u(2) + \frac{1}{2}(2.94)(2)^2$

$u = 10.94 \text{ m/s}.$

$u = 10.94 \times \frac{18}{5}$

$u = 39.384$ kmph.

Relation b/w f & deceleration (a)
↳ in direction of motion



frictional ~~factor~~ force
↑

$F = fN = fW$

$-F = ma$

$-fW = ma$

$-fW = \frac{W}{g} a$

$-fg = a$

D alemberts principle

$\Sigma F_x = m . a_x$

$-F = ma$

$-fw = \frac{w}{g} a$

$$\boxed{-fg = -a}$$

$-a$ = deceleration (or) retardation (reduction of speed due to application of breaks)

Eg:- Skid marks measuring 20m. after the application of breaks the initial speed of vehicle is 40 kmph Determine the coefficient of friction developed b/w the road and tyre.

Sol: Given:- $u = 40$ kmph
$V = 0$ kmph

$u = 40 \text{ kmph} = \frac{40}{3.6} = 11.1 \text{ m/s}$

$S = 20\text{m}$

$v^2 - u^2 = 2aS$

$-(11.11)^2 = 2(a)(20)$

$a = \frac{-11.11^2}{2 \times 20}$

$a = -3.08 \text{ m/s}$

$-a = fg$

$f = \frac{-a}{g} = \frac{3.08}{9.81} = 0.314$

Eg:- while driving at a speed of 40 kmph down the gradient the driver requires twice the breaking distance while moving up the same gradient. $f = 0.35$ calculate the gradient.

Sol: $\mu = 40 \text{ Kmph} = \frac{40}{3.6} = 11.11 \text{ m/s}$

$f = 0.35$

$2\ S_b\ (\uparrow) = (\downarrow)\ Sb$

$$2\left[\frac{v^2}{2g(f+N)}\right] = \left[\frac{v^2}{2g(f-N)}\right]$$

$$2\left[\frac{v^2}{2g(0.35+N)}\right] = \left[\frac{v^2}{2g(0.35-N)}\right]$$

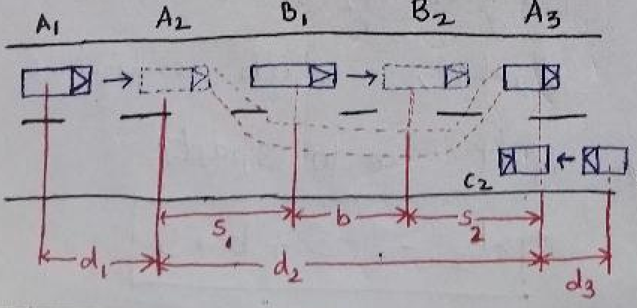
$$\frac{2(0.35-N)}{0.35+N} = 1$$

$$3N = 0.35 + 2(0.35)$$

$$N = 0.116 = 11.6\%$$

OVER TAKING SIGHT DISTANCE:

- * Over taking is not allowed on single lane roads. (a min of 2 lane road is required)
- * If all the vehicles are going with design speed then over taking is not allowed.
- * The minimum visible distance required in front of the driver for safe over taking process is OSD



Overtaking may be split up into 3 operations, thus dividing the overtaking sight distance, OSD into 3 parts d_1, d_2 & d_3.

1) d_1 is the distance (m) travelled by the overtaking vehicle "A" during the reaction time t (secs) of the driver, from position A_1 to A_2 before starting to overtake the slow vehicle "B"

2) d_2 is the distance (m) travelled by the vehicle "A" during the actual overtaking operation during T (secs) from position "A_2 to A_3"

3) d_3 is the distance (m) travelled by on coming vehicle "C" during the actual overtaking operation of "A" during T (secs) from position "C_1 to C_2"

Thus on a 2 lane road with 2 way traffic the overtaking sight distance,

$$\boxed{OSD = d_1 + d_2 + d_3\ (m)}$$

Assumptions made in the analysis

(1) The overtaking vehicle A is forced to reduce its speed from

the design speed V (m/sec) to V_b (m/sec) of the slow vehicle B & move behind it, allowing a space S (m), till there is an opportunity for safe overtaking operation.

* when the driver of vehicle A finds sufficient clear gap ahead decides with in a reaction time t (sec) to accelerate and overtake the vehicle B, during which the vehicle A moves at speed V_b (m/sec) through a distance d_1, from position A_1 to A_2

* The vehicle A accelerates & overtakes the slow vehicle B with in a distance d_2 during the overtaking time T (sec) between the position A_2 to A_3

* The distance d_2 is split up into 3 parts

(i) spacing S (m) between A_2 & B_1

(ii) distance b (m) travelled by the slow vehicle B between B_1 & B_2 during the overtaking of A &

(iii) spacing S (m) b/w B_2 & A_3

during this over taking time T (sec) the vehicle C coming from opposite direction travels through a distance d_3 from position C_1 to C_3

Determining OSD:

* from position A_1 to A_2; distance travelled by the overtaking vehicle A is d_1; travelling with a reduced speed of V_b (m/sec) during the reaction time t (sec) as per IRC the reaction time of driver is taken as 2 secs as an average value.

$$\therefore d_1 = V \times t$$

$$\boxed{d_1 = v_b \times 2 \text{ (m)}}$$

* from position A_2, the vehicle A starts accelerating, shifts to the adjoining lane, overtakes the vehicle B and shifts back to its original lane ahead of B in position A_3 during the overtaking time, T (secs). The Straight distance b/w position A_2 & A_3 is taken as d_2 (m), which is further split in to 3 parts

$$\boxed{d_2 = S + b + S}$$

* The minimum distance b/w position A_2 & B_1 may be taken as the minimum spacings (m) b/w 2 vehicles while moving with the speed V_b (m/sec). The min spacing b/w vehicles depends on their speed & given by empirical formula

$$\boxed{s = (0.7V_b + 6) \ (m)}$$

* The min distance b/w B_2 & A_3 may also be assumed equal to s (m). (using above empirical formula). If the overtaking time by vehicle A for the overtaking operation from position A_2 to A_3 is T (sec)

The distance covered by the slow vehicle B travelling at a speed of $V_b T$ (m).

$$\boxed{d_2 = (b + 2s) \ (m)}$$

* The time T depends on speed of overtaken vehicle B & the average acceleration "a" (m/sec²) of overtaking vehicle A. The overtaking time T (sec) may be calulated by equatiing the distance d_2 to $(V_bT + \frac{1}{2}aT^2)$, using the general formula for the distance travelled by an uniformly accelerating body with initial speed V_b m/s & "a" is the avg acceleration during overtaking in m/sec²

$$\boxed{d_2 = (b + 2s) = V_bT + \frac{aT^2}{2}}$$

↳ (i)

$$b = V_bT \quad \therefore \quad 2s = \frac{aT^2}{2}$$

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

$$s = (0.7V_b + 6)$$

$$QSD = d_1 + d_2 + d_3$$

~~$= 2V_b + b + 2s +$~~

From Linear motion eq

$$s = ut + \frac{1}{2}at^2$$

$$d_2 = V_B(T) + \frac{1}{2}aT^2$$

↳ (ii)

~~equating eq (i) & (ii)~~

~~$b+2s = V_B T + \frac{1}{2} a T^2$~~

Calculating d_2 distance

$$d_2 = S_1 + b + S_2$$

$$d_2 = S_1 + V_b T + S_2 \rightarrow ①$$

b = distance travelled by vehicle A (straight path) during overtaking

$b = V_b T$

from Linear motion eq

$$S = ut + \frac{1}{2} a t^2$$

$$d_2 = V_b T + \frac{1}{2} a T^2 \rightarrow ②$$

equating ① & ②

$$S_1 + \cancel{V_b T} + S_2 = \cancel{V_b T} + \frac{1}{2} a T^2$$

$$S_1 + S_2 = \frac{1}{2} a T^2$$

$$\frac{2(S_1+S_2)}{a} = T^2$$

$$\boxed{T = \sqrt{\frac{2(S_1+S_2)}{a}}}$$

$d_3 =$ ~~ϑT~~

* distance travelled by vehicle C moving at design speed ϑ (m/s) during the overtaking operation of vehicle A i.e during time T (sec) is the distance d_2 (m) between positions C_1 to C_2

$$\boxed{d_3 = \vartheta T \text{ (m)}}$$

$$OSD = d_1 + d_2 + d_3$$

$$\boxed{OSD = 2V_b + S_1 + V_b T + S_2 + \vartheta T}$$

V_b = initial speed of ~~slow moving~~ vehicle, kmph → slow moving
ϑ = speed of ~~overtaking~~ vehicle "C"

* If V_b is not given V_b

$$\boxed{\begin{aligned} V_b &= V - 16 \quad \text{kmph} \\ \vartheta_b &= \vartheta - 4.5 \quad \text{m/s} \end{aligned}}$$

V_b = initial speed of overtaking vehicle kmph

V = deigh speed in Kmph

ϑ_b = initial speed of overtaking vehicle m/sec

ϑ = design speed in m/sec

* if $\boxed{S_1 = S_2 = 0.7 V_B + l}$

l = length of rigid wheel base / length of vehicle = 6.1m as per IRC

* Effect of OSD on.

(i) Break efficiency

→ OSD has no effect

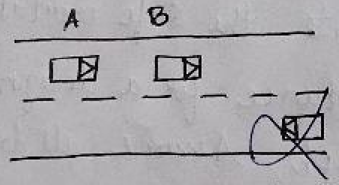
(ii) Gradient

→ OSD has no effect

SAFE OSD

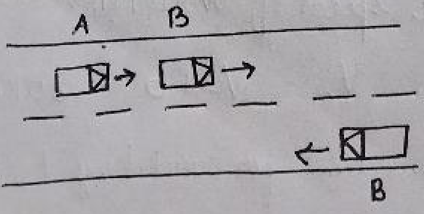
depends on
- No of lanes
- Direction of traffic

(i) Two lane one way



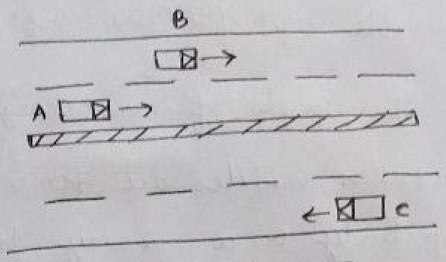
$\boxed{\text{Safe OSD} = d_1 + d_2}$

(ii) Two lane (2 way traffic)



$\boxed{\text{Safe OSD} = d_1 + d_2 + d_3}$

(iii) 4 lane (2 way lane)



$\boxed{\text{Safe OSD} = d_1 + d_2}$

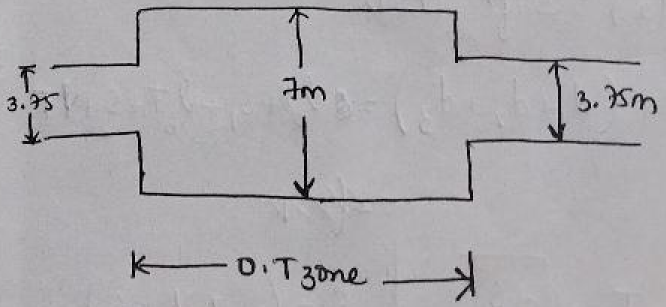
→ Only in case of 2 lane 2 way traffic "d_3" must be considered in all other roads safe OSD is taken as $d_1 + d_2$

$\boxed{\text{Safe OSD} = d_1 + d_2 + d_3 \rightarrow \text{2 lane 2 way traffic}}$

$\boxed{\text{Safe OSD} = d_1 + d_2 \rightarrow \text{all other roads}}$

OVER TAKING ZONES:

Overtaking zone are provided ~~from~~ for O.T purpose



at frequent intervals overtaking zones are provided.

min length of O.T zone = 3 (Safe OSD)

desirable length of O.T zone = 5 (Safe OSD)

Eg:- The speeds of overtaking & overtaken vehicles are 70 & 40 kmph respectively on a 2 way traffic road. The average acceleration during overtaking may be assumed as 0.99 m/sec^2

(a) Cal Safe overtaking sight distance

(b) what is min length of overtaking zone

Sol:- Given: $V_b = 40$ Kmph

$v_b = \frac{40}{3.6} = 11.1$ m/s

$V = 70$ kmph

$v = \frac{70}{3.6} = 19.4$ m/s

$a = 0.99$ m/sec^2

(a) Safe OSD

$$(d_1+d_2+d_3) = v_b t + S_1 + v_b T + S_2 + vT$$

~~$= 2(11.1$~~

$$T = \sqrt{\frac{4S}{a}}$$

$S = (0.7 V_b + 6)$

$= (0.7(11.1)+6)$

$= 13.8$m

$$T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4(13.8)}{0.99}}$$

$= 7.47$ sec

assuming reaction tym $t = 2$ sec

$$OSD = v_b t + S_1 + v_b T + S_2 + vT$$

$$= \underbrace{2(11.1)}_{d_1} + \underbrace{13.8 + (11.1)(7.47)}_{} + \underbrace{13.8}_{d_2} + \underbrace{(19.4)(7.47)}_{d_3}$$

$= 277.6$ m

$\simeq 278$ m.

(b) Min length of overtaking zone

$= 3(OSD) = 3(278) = 834$m

desirable length of overtaking zone

$= 5(OSD) = 5(278) = 1390$m

Eg:- Calculate the safe overtaking sight distance for a design speed of 96 kmph. Assume all data suitably.

Sol: Given design speed, $V = 96$kmph

Assume speed of overtaken vehicle

$V_b = V - 16 = 80$kmph

reaction time for overtaking $t = 2$sec

Acceleration; $A = 2.5$ kmph/sec

(from table 4.8)

$$d_1 = v_b t = \frac{80}{3.6} \times 2 = 44.44m$$

$$d_2 = 2S + V_bT = [2(21.554)] + [(22.22) \times 11.3]$$

$$= 297m.$$

$$S = (0.7 V_b + 6) = 0.7 \times (22.22) + 6$$

$$= 21.554m$$

$$T = \sqrt{\frac{4S}{a}} = \cancel{\sqrt{\frac{4(21.554)}{2.5}}}$$

$$= \sqrt{\frac{4 \times 3.6S}{A}} = \sqrt{\frac{14.4S}{A}} = \sqrt{\frac{14.4 \times 21.5}{2.5}}$$

$$= 11.3sec$$

$$d_3 = VT = \frac{96}{3.6} \times 11.3 = 301.33m$$

$$OSD = d_1 + d_2 + d_3$$

$$= 44.44 + 297 + 301.33$$

$$= 642.77m \simeq \underline{\underline{643 m}}$$

HORIZONTAL CURVES:

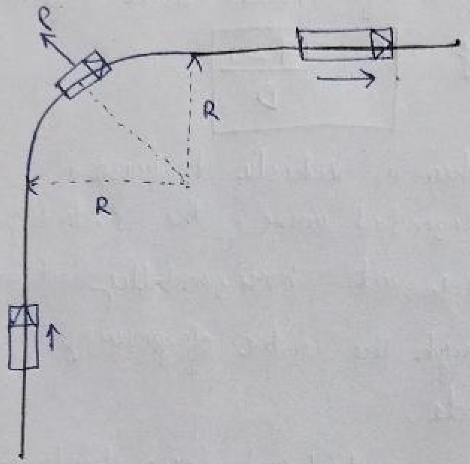
A horizontal highway curve is a curve in plan to provide change in direction to the centre line of a Road. A simple circular curve may be designated by either the radius, R of the curve in metres (or) the degree, D of the curve. The degree of the curve (D°) is the central angle subtended by an arc of length 30m & given by the relation $\frac{RD\pi}{180} = 30.$

∴ The Relation b/w radius & degree of circular curve is given by $\boxed{R = \frac{1720}{D}}$.

* when a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle.
* The centrifugal force developed depends on the radius of the horizontal curve & the speed of the vehicle negotiating the curve.
* This centrifugal force is counteracted by the traverse frictional resistance developed b/w the tyres & pavement which enables the vehicle to change the direction along the curve & to maintain the stability of the vehicle. Centrifugal force P is given by equation

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

P = Centrifugal force, kg
W = weight of vehicle, kg
R = Radius of the circular curve, m
v = speed of vehicle, m/s
g = acceleration due to gravity $= 9.8\ m/s^2$



The ratio of the centrifugal force to the weight of vehicle, P/W is known as "centrifugal ratio" (or) "Impact factor".

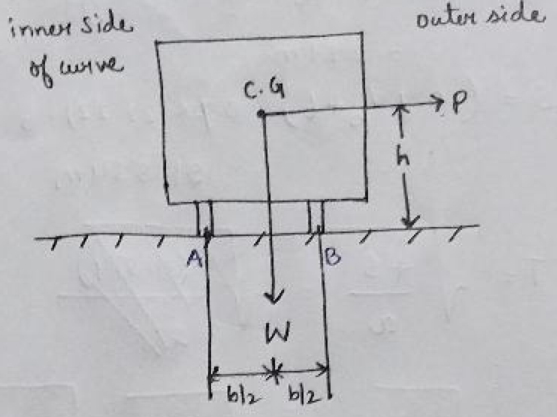
$$\boxed{\text{centrifugal Ratio} \left(\frac{P}{W}\right) = \frac{v^2}{gR}}$$

* The Centrifugal force acting on a vehicle negotiating a horizontal curve has the following 2 effects

(i) Tendency to overturn the vehicle outwards about the outer wheels

(ii) Tendency to skid the vehicle laterally outwards.

(i) Over turning effect:



* The centrifugal force that tends the vehicle to overturn about the outer wheels B on horizontal curve without superelevation.

h = ht of centre of gravity of vehicle above the road surface
b = width of the wheel base

Overturning moment due to centrifugal force (P) = P.h

This is resisted by the restoring moment due to weight of the vehicle W.

$$\text{Restoring moment} = W \times \frac{b}{2}$$

$$\text{At equilibrium} \quad Ph = W\frac{b}{2}$$

∴ There is a danger of overturning when the centrifugal ratio

$$\frac{P}{W} \text{ (or) } \frac{v^2}{gR} = \frac{b}{2h}$$

* At the verge of overturning the contact b/w the road & the inner tyre will be lost.

∴ Normal Reaction passes through outer tyre only.

taking movement about outertyre

$$W \times \frac{b}{2} - P \times h = 0.$$

$$\frac{Wb}{2} = Ph$$

$$\frac{P}{W} = \underbrace{\boxed{\frac{b}{2h}}}\rightarrow \text{Resistance against overturning}$$

$\frac{P}{W} < \frac{b}{2h}$ → no overturning

$\frac{P}{W} > \frac{b}{2h}$ → overturning occurs.

↑b ; ↑ stability (but max width 2.44m as per IRC)

↓h ; ↑ stability

(iii) Lateral skid (outwards)

$$\Sigma F_x = 0$$

$$P = F$$

$$P = fW$$

$$\boxed{\frac{P}{W} = f}$$

$$\boxed{\begin{matrix} F = fN \\ F = fW \end{matrix}}$$

where f = lateral friction / Skid Resistance

$\frac{P}{W} < f$ → No skid

$\frac{P}{W} > f$ → skid occur

(i) $\left.\begin{matrix} \frac{P}{W} \ngtr \frac{b}{2h} \\ \frac{P}{W} \ngtr f \end{matrix}\right\}$ No overturning, No lateral skid

(ii) $\left.\begin{matrix} \frac{P}{W} > \frac{b}{2h} \\ \frac{P}{W} \ngtr f \end{matrix}\right\} \rightarrow$ overturning occurs

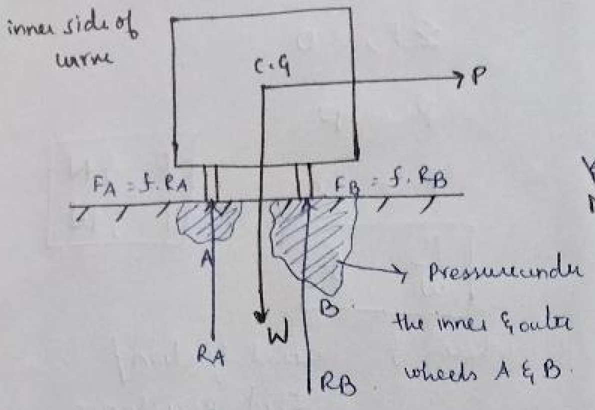
(iii) $\left.\begin{matrix} \frac{P}{W} \ngtr \frac{b}{2h} \\ > f \end{matrix}\right\}$ Skid occurs

(iv) $\left.\begin{matrix} \frac{P}{W} > \frac{b}{2h} \\ \frac{P}{W} > f. \end{matrix}\right\}$

(a) $\frac{b}{2h} > f$ → lateral skid & overturning occurs

(b) $\frac{b}{2h} < f$ → overturning occurs

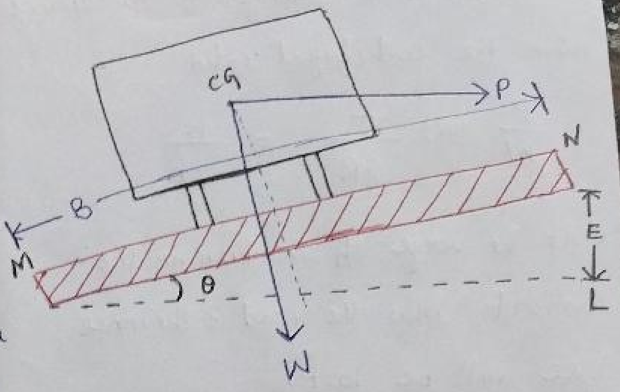
(c) $\frac{b}{2h} = f$ → overturning occurs



To avoid Overturning Super Elevation (or) Cant (or) angle of banking is provided

In order to counteract the effect of centrifugal force & to reduce the tendency of the vehicle to overturn (or) skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as "superelevation" (or) cant (or) banking.

* The ~~ratio~~ rate of super elevation, "e" is expressed as the ratio of the height of outer edge w.r.t horizontal width.



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

$\therefore \frac{E}{B}$ which is measured as the ratio of the relative elevation of the outer edge "E" and width of pavement "B".

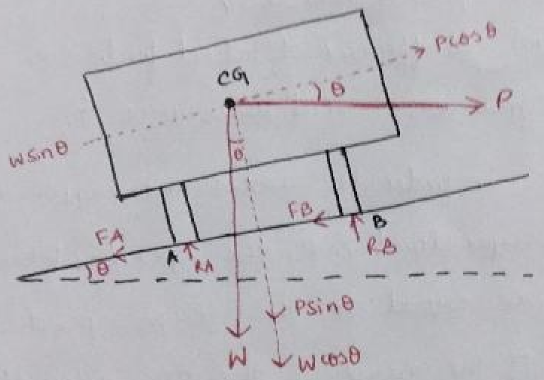
Analysis of Super elevation:

The forces acting on the vehicle while moving on a circular curve of Radius R metres at speed of v m/s These forces are

(a) The centrifugal force $P = \frac{Wv^2}{gR}$ acting horizontally outwards through the centre of gravity, CG

(b) The weight W of the vehicle acting vertically downwards through CG

(c) The frictional force developed b/w the wheels & the pavement counteracting transversely along the pavement surface towards the centre of the curve.



The Centrifugal force developed is thus opposed by corresponding value of

(i) the friction developed b/w tyres & pavement surface

(ii) a component of the force of gravity due to the superelevation provided.

Considering the equilibrium of components of forces acting parallel to the plane, the component of Centrifugal force, (Pcosθ) is opposed by the component of gravity (wsinθ) and Frictional forces FA & FB

for equilibrium condition

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

The full (maximum) values of Frictional forces F_A & F_B are fR_A and fR_B respectively

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

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

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

Dividing by $W\cos\theta$

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

the centrifugal ratio $\frac{P}{W} = \frac{\tan\theta + f}{1 - f\tan\theta}$

The value of coefficient of lateral friction "f" is taken as 0.15 for design of horizontal curves.

Value of $\tan\theta$ exceeds 0.07 (or) $\frac{1}{15}$

$\therefore f\tan\theta$ is $= 0.01$

& $1 - f\tan\theta = 0.99$ can be considered equal to 1.0

$$\therefore \frac{P}{W} \simeq \tan\theta + f = e + f \rightarrow (i)$$

$$\boxed{\tan\theta = e}$$

$$\frac{P}{W} = \frac{v^2}{gR} \rightarrow (ii)$$

∴ equating 2 eq for design of super elevation

$$\boxed{e + f = \frac{v^2}{gR}}$$

where

e = rate of super elevation = tan θ

f = design value of lateral friction coefficient = 0.15

v = speed of vehicle, m/sec

R = Radius of horizontal curve m

g = acceleration due to gravity = 9.8 m/s²

If the speed of vehicle is given as V V kmph then the above eq can be written as

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

where

V = speed (kmph)

R = radius of horizontal curve, m.

The maximum value of ~~sp~~ super elevation is limited to 7% (or) 0.07 & the min value of lateral friction coefficient, f taken for design of highways (except expressways) = 0.15

The superelevation "e" required on a horizontal curve depends on 3 factors

(i) Radius of the curve R

(ii) Speed of vehicle V

(iii) coefficient of lateral friction (or) transverse skid resistance f.

∴ In order to assess the required superelevation e, the speed is taken as equal to the design speed of the road & the min value of transverse skid resistance, f for design purpose is taken as 0.15.

Eg: 1 The design speed of a highway is 80 kmph over a horizontal curve of 300m radius, the coefficient of lateral friction b/w the road & tyre is 0.13 determine super elevation required with friction also determine rise of outer edge w.r.t Inner edge. If B width of road is 7m

Sol: Given $V = 80\,kmph = \frac{80}{3.6} = 22.22\ m/s$

f = 0.13

R = 300m

B = 7m

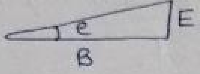
E = ?

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

$$e + 0.13 = \frac{22.22^2}{9.81 \times 300}$$

$$e = 0.037$$

$$e = 3.7\ \%$$



$$e = \frac{E}{B}$$

$$\Rightarrow E = e \times B$$

$$= 0.037 \times 7$$

$$= 0.26m$$

$$\boxed{E = 260mm}$$

Eg: The Radius of horizontal curve is 100m. The design speed is 50kmph & design coefficient of lateral friction is 0.15

(a) cal the superelevation required if full lateral friction is assumed to develop

(b) cal the coefficient of friction needed if no superelevation is provided.

Sol Given $V = 50kmph = \frac{50}{3.6} = 13.88m/s$

$f = 0.15$

$R = 100m.$

(a)

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

$$e + 0.15 = \frac{13.88^2}{9.8 \times 100}$$

$$e = 0.047$$

∴ superelevation rate when full lateral friction is developed is 0.047 (or) 1 in 21.2

(b) If no superelevation is provided $e = 0$; & friction factor developed

$$f = \frac{v^2}{127R} = \frac{50^2}{127 \times 100}$$

$$= 0.19.$$

IRC has fixed the maximum limit of superelevation in plain & rolling terrains & in snow bound areas as 7.0% (or) 0.07 taking such mixed traffic into consideration.

* For hilly roads not bound by snow a maximum superelevation upto 10% has been recommended.

* On urban road stretches with frequent intersections, it may be necessary to limit the max superelevation to 4.0 percent, keeping in view the convenience in construction & that of turning movements of vehicles.

Equilibrium super elevation (Balanced super elevation)

The superelevation required to balance centrifugal force without taking the help of coefficient of lateral friction

$$e_{EQ} + \cancel{f}^{0} = \frac{v^2}{gR} \qquad \boxed{e_{EQ} = \frac{v^2}{gR}}$$

Design of superelevation

Step: 1 The superelevation is calculated for 75% of design speed (i.e 0.75v m/s (or) 0.75 V kmph); neglecting friction.

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

$$e + \cancel{f}^{0} = \frac{(0.75v)^2}{gR}$$

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

v = velocity m/s

V = velocity kmph

$e_{DGN} \not> e_{max}$ given by IRC

Type of terrain	e_{max} as per IRC
plain / Rolling terrain	7%
Hilly (or) mountaneous	10%
Snow bound Hilly (or) mountaneous (North India)	7% (To avoid skid inwards) due to snow on road overturn of vehicles (of Snow vehicles reduced to 7%)

If $e_{DGN} \not> e_{max}$ (Then provide e_{DGN} on road)

— END

If $e_{DGN} > e_{max}$ (Then provide e_{max} on road then go to step2)

Step: 2: Fix $e = e_{max}$ use full speed and calculate lateral friction required to balance the speed

$$e_{max} + f = \frac{v^2}{gR}$$

$$\boxed{f = \frac{v^2}{gR} - (0.07)}$$

$$\boxed{f \not> 0.15 \text{ as per IRC}}$$

* If $f \leq 0.15$, the friction is resisting the speed on road, provide $e = e_{max}$ — END.

* If $f > 0.15$, then not safe, go to step- 3 & reduce the design speed (on the curved part only)

Step: 3 $e = e_{max}$; $f = 0.15$, then reduce design speed.

$$e_{max} + f = \frac{v^2}{gR}$$

$$\boxed{e_{max} + 0.15 = \frac{v^2}{gR}}$$

v = ? speed limit on road

Round it to lower whole number.

Eg:- Design speed is 100kmph, R= 600m plain terrain (i) design super elevation (ii) allowable speed on road.

Sol Given $V = 100\text{kmph}$

$$= \frac{100}{3.6} = 27.77\,\text{m/s}.$$

$R = 600\text{m}$

plain terrain from table $e_{max} = 7\%$.

Step: 1

$$e + \cancel{f}^{\nearrow 0} = \frac{(0.75v)^2}{gR}$$

$$\cancel{e_1 = \frac{(27.77)^2}{9.81 \times 600} =}$$

$$e = \frac{(0.75 \times 27.77)^2}{9.81 \times 600}$$

$e = 7.37\% > e_{max}$ i.e 7%. on plain terrain.

use $e = e_{max} = 7\%$. ~~proceed to~~ speed ~~step-2~~

design super elevation = 7%.

~~step: 2~~

(ii) allowable speed on Road.

$$e_{max} + f = \frac{v^2}{gR}$$

$$f = \frac{(27.77)^2}{9.81 \times 600} - 0.07$$

$$f = 0.060 < 0.15$$

∴ super elevation on Road = 7%.

allowable speed on road = 100 kmph.

Eg:- design speed = 80 kmph Radius of curve - 150m, plain terrain

(i) design super elevation

(ii) allowable speed on Road.

Sol: Given $V = 80\text{kmph}$

$$= \frac{80}{3.6} = 22.22\,\text{m/s}.$$

$R = 150\text{m}$; plain terrain $e_{max} = 7\%$.

(i)
$$e + \cancel{f}^{\nearrow 0} = \frac{(0.75v)^2}{gR}$$

$$e = \frac{(0.75 \times 22.22)^2}{9.81 \times 150}$$

$$e = 0.18 > 7\%.$$

$e = e_{max} = 0.07$; design superelevation $= 7\%$.

(ii) allowable speed on Road

$$e_{max} + f = \frac{v^2}{gR}$$

$$f = \frac{(22.22)^2}{9.81 \times 150} - 0.07$$

$$f = 0.26 > 0.15$$

(Not safe)

Consider $f = 0.15$

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

$$0.07 + 0.15 = \frac{v^2}{9.8 \times 150}$$

$$v = 17.99\,\text{m/s}$$

$V = 64.76$ kmph

$V \simeq 60$ Kmph

Ruling Radius on the curve:

This is the minimum radius required to balance a vehicle moving on a curve with ruling design speed (or) design speed with coefficient of lateral friction.

$$e + f = \frac{\vartheta^2_{Ruling}}{gR}$$

$$\boxed{R_{Ruling} = \frac{\vartheta^2_{Ruling}}{(e+f)\,g}}$$

R = Ruling Radius

ϑ = Ruling design speed | max design speed.

- Minimum Radius on the curve

$$\boxed{e + f = \frac{\vartheta^2_{min\,speed}}{gR}}$$

R = minimum most Radius.

The min most possible radius on a curved road while the vehicle is moving with minimum design speed with friction

$$\boxed{R_{min} = \frac{\vartheta^2_{min}}{(e+f)\,g}}$$

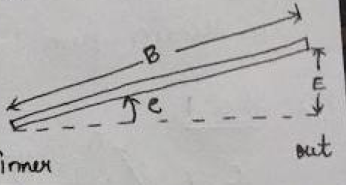
Note: On imp Highways & expressways the min radius should be ruling radius only so that the vehicle can safely move on the curved Road with ruling design speed.

ATTAINMENT OF SUPER ELEVATION:

(1) Rotation about inner edge

$$\sin\theta = \theta = e = \frac{E}{B}$$

$$E = eB$$



E = ↑ increase of outer edge with respect to inner edge (or) ground level.

B = width of road on curve.

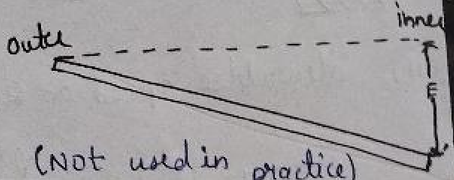
Advantages

- No drainage problem

disadvantages

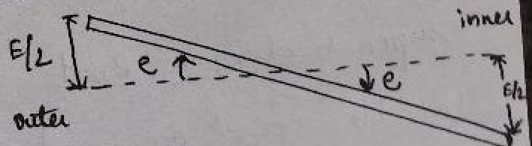
- filling is required
- central line is to be shifted up.

(2) Rotation of pavement w.r.t outer edge



disadvantages (Not used in practice)

- drainage problem
- cutting is required
- central line is shifted to down

(3) Rotation about central line

$$\boxed{\frac{E}{2} = \frac{eB}{2}}$$

Advantages (used on bridges)

(1) filling cutting

(2) No need to shift central line

(3) used over bridges (best suited)

disadvantages

* drainage problem.

Eg:- design speed 80kmph, Radius of Horizontal curve 550m, fatual friction 0.15, find super elevation with friction; width of pavement = 7m. Rise of outer edge w.r.t ground level.

(i) Rotation about inner edge

(ii) Rotation about central line

Sol: Super elevation

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

$$e + 0.15 = \frac{(22.22)^2}{9.18 \times 550}$$

$$e = -0.058$$

-ve e says no need of superelevation (even if their is no superelevation the vehicle is safe)

No need of rising inner (or) outer edge

Eg:- Radius of Horizontal curve 150m; velocity (or) designed speed 80 kmph, width of pavement = 7m

find super elevation

(i) Rotation about inner edge

(ii) Rotation about • central line.

Sol: Given $V = 80\text{kmph}$

$$= \frac{80}{3.6} = 22.22 \text{ m/s}$$

$$R = 150\text{m}; \quad B = 7\text{m}$$

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

$$e + 0.15 = \frac{(22.22)^2}{9.81 \times 150}$$

$$e = +0.18$$

only in super elevation e should be compared with e_{max}.

(i) $E = eB$

$$E = 0.18 \times 7$$

$$E = 1.29\text{m}$$

(ii) Rotating about central line

$$\frac{E}{2} = \frac{eB}{2}$$

$$\frac{E}{2} = \frac{0.18 \times 7}{2}$$

$$E = 0.64\text{m}$$

Eg:- super elevation = 3% ; lateral friction = 0.13, Ruling design speed = 80 kmph ; Min design speed = 60 kmph

Cal (i) Ruling radius

(ii) Absolute Min Radius.

Sol: (i) Ruling Radius

$$R_{ruling} = \frac{v^2_{max / Ruling\ design\ speed}}{(e+f)g}$$

$$R = \frac{(22.22)^2}{(0.03+0.13)9.81}$$

V = 80 kmph

$v = \frac{80}{3.6} = 22.22$

$R_{ruling} = 314.55m$ (Round to upper whole number)

(ii) Absolute Min Radius.

$$R_{min} = \frac{v^2_{min}}{(e+f)g}$$

$$\boxed{\begin{array}{l} V_{min} = 60kmph \\ v_{min} = \frac{60}{3.6} = 16.66 m/s \end{array}}$$

$$R_{min} = \frac{(16.66)^2}{(0.03+0.13) \times 9.81}$$

$R_{min} = 176.83m$

provide 314.55 = R in important Road

176.83 = R in hilly terrain, non imp roads.

Eg:- design speed 60 kmph, Radius of curve = 178m ;

(i) Equilibrium super elevation (Pressure on outerwheel = inner wheel)

(ii) Design super elevation on hilly terrain

(iii) Super elevation with a lateral friction of 0.14

Sol: Given V = 60 kmph

$v = \frac{60}{3.6} = 16.67 m/s$

R = 178 m

(i) Equilibrium super elevation

@ equilibrium f = 0.

$$e + \cancel{f}^{\,0} = \frac{v^2}{gR}$$

$$e_{EQ} = \frac{v^2}{gR}$$

$$e_{EQ} = \frac{16.67^2}{9.81 \times 178}$$

$e_{EQ} = 0.159 = 15.9\%$

(ii) Mixed Roads.

$$e + \cancel{f}^{\,0} = \frac{(0.75 v)^2}{gR}$$

$$e = \frac{(0.75 \times 16.66)^2}{9.81 \times 178}$$

$e = 0.089 < 10\%$. hilly terrain

(iii) super elevation with a lateral friction of 0.14

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

$$e = \frac{(16.66)^2}{9.81 \times 178} - 0.14$$

$$e = 0.019$$

WIDENING OF PAVEMENT ON HORIZONTAL CURVES

* An automobile such as, Car, bus (or) truck has a rigid wheel base & only front wheels can be turned. when the vehicle takes a turn to negotiate a horizontal curve, the rear wheel donot follow the same path as that of the front wheels. This phenomenon is called "off tracking."

* OFF tracking depends on
  (i) the length of the wheel base of the vehicle
  (ii) the turning angle or the radius of the horizontal curve negotiate.

* At speeds higher than the design speeds when the superelevation & lateral friction developed are not fully able to counteract the outwards thrust due to the centrifugal force, Some transverse skidding may occur & rear wheels may take paths on the outerside of those traced by the front wheels on the horizontal curves. However these occurs only at excessively high speeds.

* while 2 vehicles cross (or) overtake at horizontal curve there is a psychological tendency to maintain a greater clearance b/w the vehicles than on straights for increase safety.

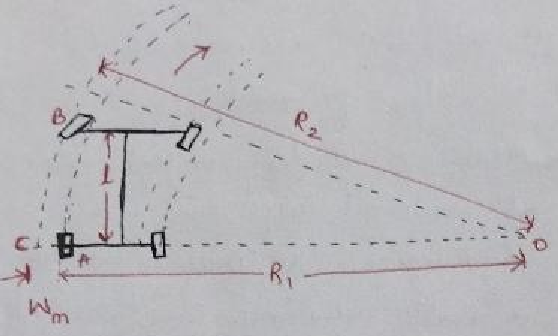
* Inorder to take curved path with larger radius & to have greater visibility at curve, the drivers have tendency not to follow the central path of the lane, but to use the outer side at the beginning of a curve.

* The path traced by the wheels of a trailer in the case of trailer units, is also likely to be on either side of the central path of the towing vehicle, depending on the speed, rigidity of the universal joints & pavement roughness.

→ The extra widening of pavement on horizontal curves is divided into 2 parts

(i) Mechanical

(ii) psychological widening.



Mechanical widening:

The widening required to account for the off tracking due to the rigidity of wheel base is called "mechanical widening" (Wm)

OA = R_1 = radius of the path transversed by the outer rear wheel, m

OB = R_2 = radius of the path traverse by the outer front wheel, m

R = mean radius of the horizontal curve m

W_m = mechanical widening due to off tracking, m

l = length of wheel base, m

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

From $\Delta OAB, OA^2 = OB^2 - BA^2$

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

$$R_1 = R_2 - W_m$$

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

$$R_2^2 - 2W_mR_2 + W_m^2 = R_2^2 - l^2$$

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

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

$$w_m = \frac{l^2}{2R}$$

W_m = mechanical widening

R = radius of curve

n = no of lanes

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

Psychological widening

At horizontal curves drivers ~~have~~ have a tendency to maintain a greater clearance b/w the vehicles than on straight stretches of road. ∴ An extra width of pavement is provided for psychological reasons for greater manoeuvrability of steering at higher speeds & to allow for the extra space requirements for the over hangs of vehicles.

Empirical formula recommended by IRC

$$W_{ps} = \frac{V}{9.5\sqrt{R}}$$

w_{ps} : psychological widening

V = design speed

R = Radium curve

Total widening

$$W_e = W_m + W_{ps}$$

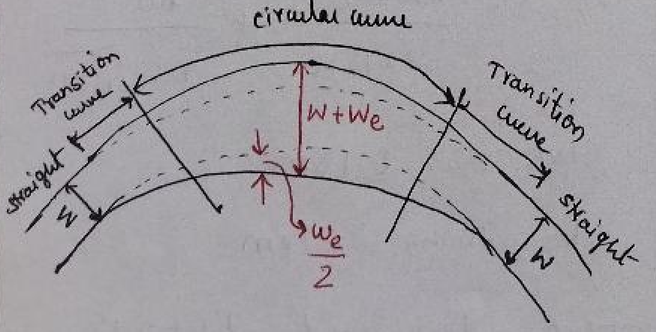
$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

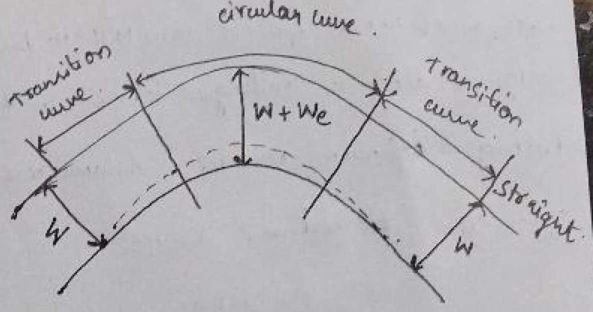
n = number of traffic lanes

l = length of wheel base of longest vehicle, m. The value of l may normally taken 6.1m (or) 6.0m for commercial vehicles

V = design speed, kmph

R = Radius of horizontal curve, m.





widening of pavement onsharp curve.

Eg:- Calulate the extra widening required for a pavement of width 7.0 m on a horizontal curve of radius 200m if the longest wheel base of vehicle expected on the road is 6.5m Design speed is 65 kmph.

Sol:- Given width of pavement = 7m.

R = 200m ; n=2

l = 6.5m

V = 65 kmph

$\cancel{v} = \frac{\cancel{65}}{\cancel{3.6}}$

$$W_e = W_m + W_{ps}$$

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

$$= \frac{2 \times 6.5^2}{2 \times 200} + \frac{65}{9.5\sqrt{200}}$$

$$= 0.21 + 0.48$$

$$W_e = 0.69m.$$

Eg: Find total width of a pavement on a horizontal curve for a new NH to be aligned along a rolling terrain with a Ruling minimum radius. Assume necessary

Sol: ~~Give conditions~~ Assuming.

$V = 80$ kmph

$W = 7$m

$n = 2$.

$l = 6$m

$e = 0.07$, $f = 0.15$

$$R_{ruling} = \frac{V^2}{127(e+f)} = \frac{80^2}{127(0.07+0.15)}$$

$$= 229\text{m}$$

$$= 230\text{m}$$

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

$$= \frac{2\times6^2}{2\times230} + \frac{80}{9.5\sqrt{230}}$$

$$= 0.157 + 0.555$$

$$= 0.712\text{m}$$

Total pavement width on curve $= W + W_e$

$$= 7 + 0.71$$

$$= 7.71\text{m}.$$

OFF tracking considered for single vehicle $= \frac{l^2}{2R}$.

Mechanical widening for complete traffic $= \frac{nl^2}{2R}$

Eg: off tracking of a test vehicle = 0.012m, rigid wheel base = 6.1m design speed 60kmph, width of road = 7m (2 lanes)

Find total width of road on horizontal curve & extra widening

Sol Given off tracking = 0.012 m

& $l = 6.1$m, $V = 60$kmph

$w = 7$m.

$$\text{off tracking} = \frac{l^2}{2R}$$

$$0.012 = \frac{l^2}{2R}$$

$$0.012 = \frac{6.1^2}{2\times R}$$

$$R = 1550.41\text{m}.$$

$$W_e = W_m + W_{ps}$$

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

$$= \frac{2\times 6.1^2}{2\times1550} + \frac{60}{9.5\sqrt{1550}}$$

$$W_e = 0.18\text{m}$$

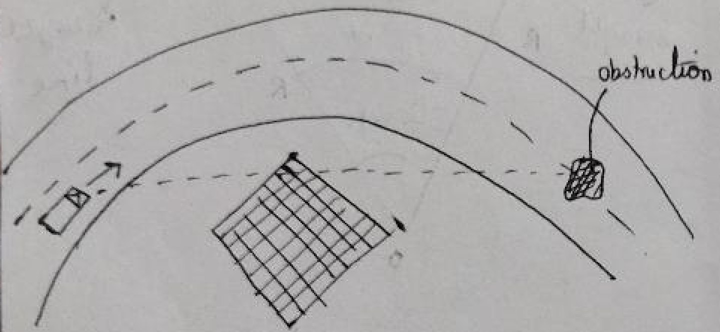
extra widening = 0.18m

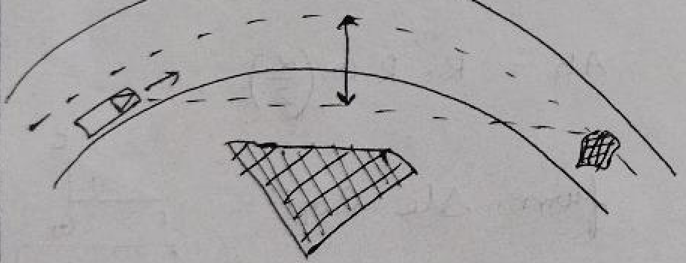
Total width of road = 7.0 + 0.18

= 7.18m

SET BACK DISTANCE :

The distance from centre line of entire road to the inner side obstruction so that their should be required site distance for the driver at all the positions on the curve.



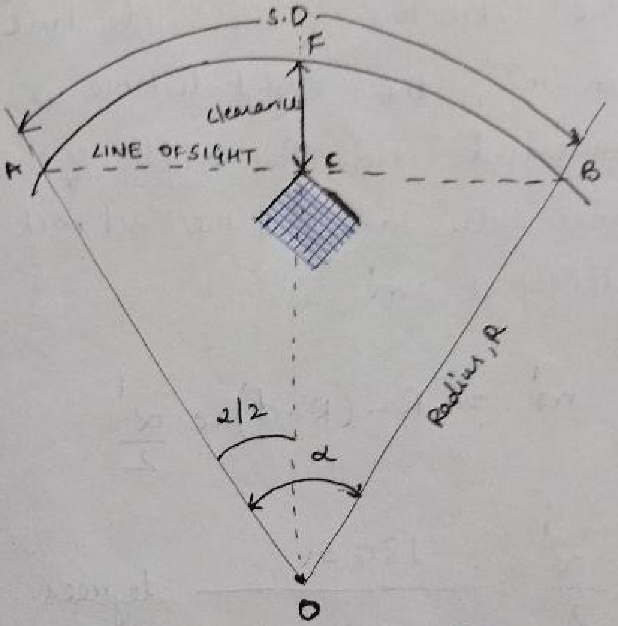


(i) When : $L_c > S$

when the length of curve L_c is greater than the sight distance S, let the angle subtended by the arc length S at the centre be α. On narrow roads such as single lane roads, the sight distance is measured long the centre line of the road & the angle subtended at the centre, α is equal to S/R radians. ∴ half central angle is given by

$$\frac{\alpha}{2} = \frac{S}{2R} \text{ Radians}$$

$$= \frac{180 \times S}{2\pi R} \text{ degrees}$$



C = the obstruction to vision on the inner side of a horizontal highway curve of radius R,

ACB the line of sight & arc /

AFB be the sight distance S.

The length of curve , = L_c

the set back distance (or) clearance

$m = CF = OF - OC$

OF = Radius ; R of horizontal curve

$OC = R \cos \alpha/2$

∴ Set back distance, m required from the central line on narrow roads is given by.

$$m = R - R\cos\left(\frac{\alpha}{2}\right)$$

in the case of wide roads with 2(or) more lanes ; if "d" is the distance b/w the central line of the road & the centre line of the inside lane in 'm', the sight distance is measured along the middle of the inner side lane & the set back distance, m' is

$$m' = R - (R-d)\cos\frac{\alpha'}{2}$$

$$\frac{\alpha'}{2} = \frac{180S}{2\pi(R-d)} \text{ degrees.}$$

---

considering $m = R - R\cos\left(\frac{\alpha}{2}\right)$

~~from Δle~~ [illegible]

$$S = R\alpha$$

$$\alpha = \frac{S}{R}$$

from Δle OAC

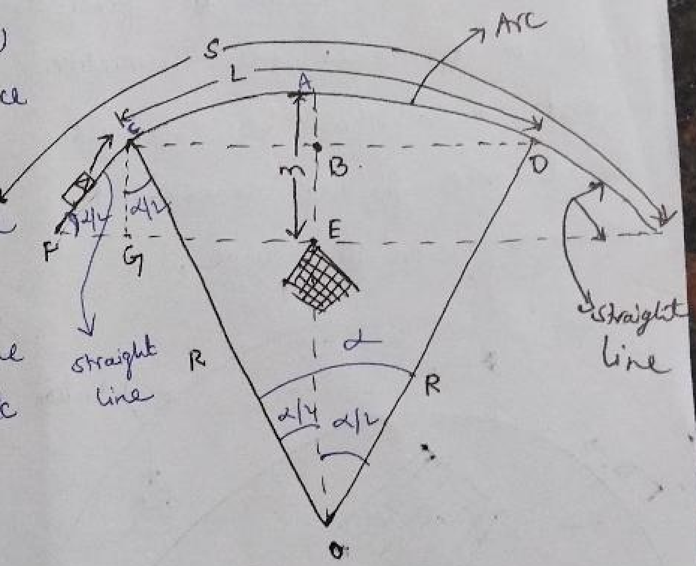
$$\cos\left(\frac{\alpha}{2}\right) = \frac{OC}{OA}$$

$$\cos\left(\frac{\alpha}{2}\right) = \frac{OC}{OA}$$

$$OC = OA\cos\left(\frac{\alpha}{2}\right)$$

$$= R\cos\frac{\alpha}{2}$$

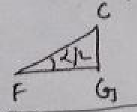
Case-2 L < S.



S = given sight distance

m = set back = AB + BE

$$AB = R - R\cos\left(\frac{\alpha}{2}\right)$$



$$\boxed{CF = \frac{S-L}{2}}$$

from Δle OGE

$$\sin\left(\frac{\alpha}{2}\right) = \frac{CG}{FC}$$

$$\sin\left(\frac{\alpha}{2}\right) = \frac{CG}{\left(\frac{S-L}{2}\right)}$$

$$CG = \left(\frac{S-L}{2}\right)\sin\frac{\alpha}{2}$$

$$CG = BE = \left(\frac{S-L}{2}\right)\sin\frac{\alpha}{2}$$

$$m = R - R\cos\frac{\alpha}{2} + \left(\frac{S-L}{2}\right)\sin\frac{\alpha}{2}$$

$$\boxed{m = R\left(1 - \cos\frac{\alpha}{2}\right) + \left(\frac{S-L}{2}\right)\sin\left(\frac{\alpha}{2}\right)}$$

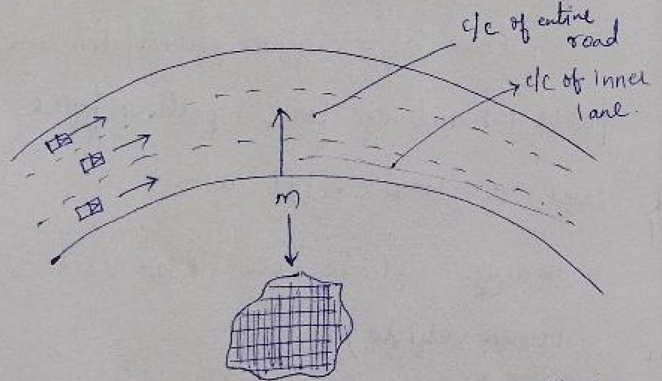
$$L = R\alpha$$

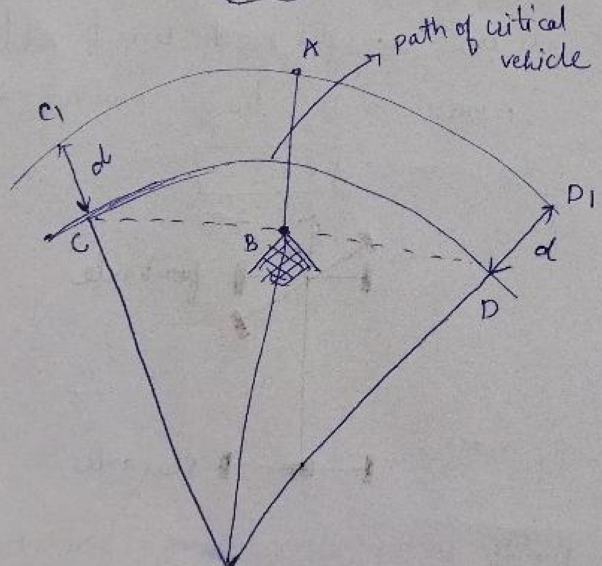
$$\alpha = \frac{L}{R}$$

$$\boxed{\text{radian} = \frac{L}{R} \times \frac{180}{\pi}}$$

For multi lane

In multi lane roads the critical vehicle is moving on centre line of inner lane however the set back distance should be measured from the centre line of entire road to the inner side obstructions.





$$m = AB$$

$$m = OA - OB$$

$$m = R - (R-d)\cos\frac{\alpha}{2}$$

$$\boxed{m = R\left(1 - \cos\frac{\alpha}{2}\right) + d\cos\frac{\alpha}{2}}$$

↳ $\boxed{L > S}$

$$OC_1 = R$$

$$OC = (R-d)$$

from △le OCB.

$$\cos \alpha/2 = \frac{OB}{OC}$$

$$OB = (R-d)\cos\frac{\alpha}{2}$$

$$S = (R-d)\alpha$$

$$\boxed{\alpha = \frac{S}{R-d} \times \frac{180}{\pi} \text{ degrees}}$$

Check:

* for single lane road $(d=0)$

set back ; $m = R - R\cos\left(\frac{\alpha}{2}\right)$

also $\alpha = \frac{S}{R} \times \frac{180}{\pi}$ degrees

Case-2 $\boxed{L < S}$

$$\boxed{m = R - (R-d)\cos\left(\frac{\alpha}{2}\right) + \left(\frac{S-L}{2}\right)\sin\frac{\alpha}{2}}$$

$$\alpha = \frac{L}{R-d} \times \frac{180}{\pi} \text{ degree}$$

d = the distance b/w the central line of the road and the centre line of the inner lane in meters.

eg:- 4 lane road, length of curve = 300m

Radius of curve = 580m, cal the set back.

dist if (i) S = SSD = 180m

(ii) S = OSD = 420m

sol Given n = 4

R = 580m

L = 300m

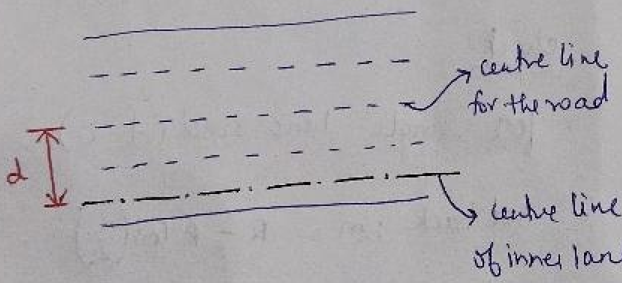
(i) given S = 180m.

$L > S$ condition to be used.

width of road d = 4 × 3.5 → width of each lane

= 14 m.

d = distance b/w the centr line of the road and the centre line of the inner lane.



$$d = (3.5+3.5) - \frac{3.5}{2}$$

d = 5.25 m.

$$m = R - (R-d)\cos\frac{\alpha}{2}$$

m = 12.27m

m is from centre line of entire road to nearest inner side obstruction

$$\alpha = \frac{S}{(R-d)} \frac{180}{\pi}$$

$$= \frac{180}{(580-5.25)} \times \frac{180}{\pi}$$

$$\alpha = 17.94^{\circ}.$$

(ii) Given S = OSD = 420m

$\boxed{L < S}$ condition to be used

$$\alpha = \frac{L}{R-d} \times \frac{180}{\pi} = 29.9^{0}$$

$$m = R-(R-d)\cos\left(\frac{\alpha}{2}\right) + \frac{(S-L)}{2}\sin\left(\frac{\alpha}{2}\right)$$

m = 40.18m.

Case (i)

Dist from centre lane of inner lane to nearest inside obstruction = m − d

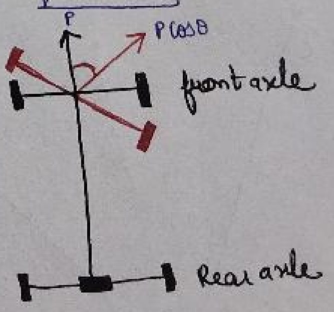
= 12.27 − 5.2

= 7.02m

CURVE RESISTANCE

Loss of engine power / tractive force / hauling force / pulling force over a horizontal curve

- Heavy vehicles are (Rear wheel driven vehicle)
- on straight road Direction of power & Direction of motion are the same $\boxed{CR = 0}$



Power in the direction of motion = Pcos θ

Loss of engine power in direction of

P = actual power of engine

$CR = P - P\cos\theta$

$CR = P(1-\cancel{P}\cos\theta)$

$\boxed{CR = P(1-\cos\theta)}$

Eg(1) St road, $\theta = 0$, CR = ?

$CR = P(1-\cos\theta) = P(1-\cos 0)$

$CR = 0$

Eg:2 $\theta = 30^\circ$

curve resistance; $CR = P(1-\cos 30^\circ)$

$= 0.134P$

13.4% of power (engine power) is lost

Eg:3 $\theta = 90^\circ$

curve resistance $= P(1-\cos 90)$

$= P$

complete engine power is lost

∴ vehicle stops.

→ car front wheel driven vehicle (engine is connected to fron axle)

→ Power of engine will be in direction of motion.

∴ No loss of power for any angle θ

$\boxed{CR = 0}$

SUV : sports utility vehicle

(All terrain vehicle like jeeps, Army trucks

4 wheel driven vehicles engine connected to all axles

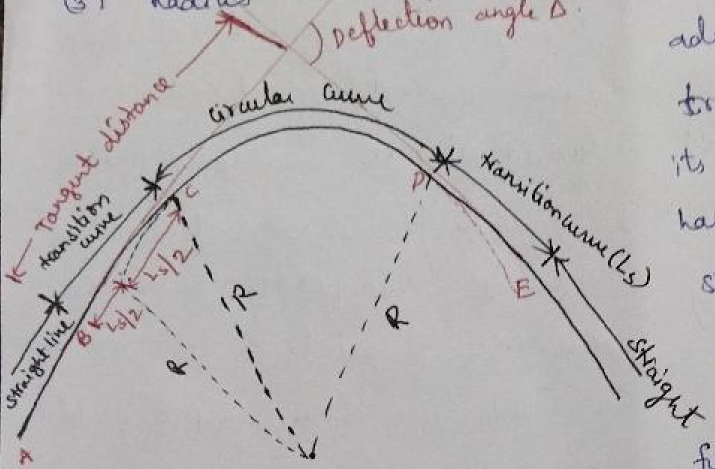
→ But in the vehicles with front driving wheels (like modern cars) this problem does not exist. Most of the heavy commercial vehicles have rear driving wheels & hence on sharp curves the additional curve resistance should also be considered while designing the geometric features of highways. This problem of curve resistance is acute on hill roads as the curves are often sharp & in addition the roads have steep gradients.

HORIZONTAL TRANSITION CURVES

A transition has a radius which decreases from infinity at the tangent point to a designed radius of the circular curve. When a transition curve is introduced b/w a straight & circular curve, the radius of the transition curve decreases & becomes minimum at the beginning of the circular curve. The rate of change of radius of the transition curve will depend on the shape of the curve adopted & the equation of the curve.

The curve used to change (or) induce (or) introduce

(1) superelevation
(2) centrifugal force
(3) Radius.



Why it is important to provide transition curve.

* Suppose a curve of radius R takes off from straight road, & a vehicle travels on this road, then due to the centrifugal force which suddenly acts on the vehicle just after the tangent pt, a sudden jerk is felt on the vehicle.

* This not only causes discomfort to the passengers, but also makes it diffiult to steer the vehicle safely.

* If a transition curve BC of length L_s is introduced b/w the straight line AB & curve CD of radius R, the centrifugal force will also be introduced gradually as the radius of the transition curve decreases gradually from infinity.

* The rate at which this force is introduced can be controlled by adopting suitable shape of the transition curve & by designing its length, so, that the vehicle can have smooth entry from the straight to the circular curve at design speed.

functions of transition curve

(a) To introduce gradually the centrifugal force b/w the tangent point & the beginning of circular curve, avoiding a sudden jerk on the vehicle

(b) to enable the driver turn the steering gradually for his own comfort & Safety.

(c) to enable gradual introduction of designed superelevation & extra widening of pavement at the start of the circular curve

(d) to improve the aesthetic appearance of road.

The radius is first designed and suitable shape of the transition curve is selected and its length is designed.

* The ideal shape of a transition curve should be such that the rate of introduction of centrifugal force or the rate of change of centrifugal acceleration should be consistent.

* This means that the radius of the transition curve should consistently decrease from infinity at the tangent point B to the radius R of the curve at pt C, the end of the transition curve of length L_s.

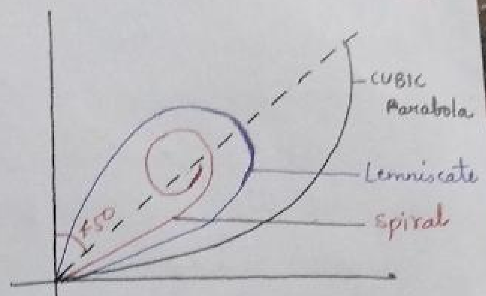
* In an ideal transition curve the length L_s should be inversely proportional to the radius R

i.e $L_s \propto \frac{1}{R}$ (or) $L_s R = \text{constant}$.

* The ideal form of transition curve is "Spiral transition curve".

Different types of transition curves.

(a) Spiral
(b) Lemniscate
(c) cubic parabola



* In all these curves, radius decreases as the length increases. But the rate of change of radius & hence the rate of change of centrifugal acceleration is not constant in the case of lemniscate & cubic parabola, especially at deflection angles higher than 4°

* In spiral curve the radius is inversely proportional to the length & the rate of change of centrifugal acceleration is uniform throughout the length of the curve.

* ∴ ideal transition curve is Spiral curve.

IRC recommends to use spiral as transition curve in horizontal alignment of highways because

(i) The spiral curve satisfies the requirements of an ideal transition, as the rate of change of centrifugal acceleration is uniform throughout the length.

(ii) The geometric property of spiral is such that the calculations & setting out the curve on the field is simple & easy.

equation of spiral can be written as

$$LR = L_S R_C = \text{constant}$$

$$L = m\sqrt{\theta}$$

m = constant = $\sqrt{2RL_S}$

θ = tangent deflection angle in radius

Calulation of length of transition curve

design criteria for a transition curve

(1) Centrifugal force | Comfort Criteria

$$\text{Rate of change of centrifugal acceleration} \Big\} = \frac{\text{acceleration}}{\text{time}}$$

$$\boxed{C = \frac{80}{75+V}} \rightarrow (i)$$

↳ IRC recommended

$$\boxed{0.5 < C < 0.8}$$

$$C = \frac{v^2}{Rt} = \frac{(v^2/RL_s)}{v}$$

$$= \frac{v^3}{L_s R} \quad (m/sec^3)$$

L_s = length of transition curve (m)

t = time taken in seconds to traverse this transition curve

V = design speed (m/sec)

$$t = \frac{L_s}{V}$$

max centrifugal acceleration = $\frac{v^2}{R}$

∴ rate of change of centrifugal acceleration $C = \frac{v^2}{Rt}$

As per IRC recommedation to find C eq ① is to be used

V = design speed in Kmph

C = Rate of change of centrifugal /radial acceleration (m/s³)

If the calulated 'C' value is less than 0.5 take it as 0.5, If "C" value is more than 0.8 reduce it to 0.8 m/s³

$$\boxed{L_s = \frac{v^3}{CR}}$$

spiral eqn

v = speed m/sec

if the equation of spiral curve is given in kmph then eq becomes.

$$L_s = \frac{v^3}{CR}$$

$$L_s = \frac{\left(\frac{V}{3.6}\right)^3}{CR}$$

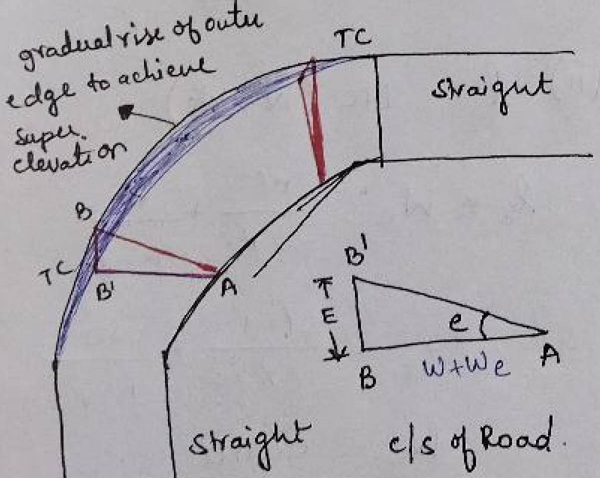
$$\boxed{L_s = \frac{0.0215V^3}{CR}}$$

V = design speed in kmph

C = rate of change of centrifugal acceleration (0.5 to 0.8 m/sec³)

R = radius of circular curve (m).

(2) Introduction of Superelevation.



$$\boxed{BB' = E}$$

The rate of introduction of super elevation 1 in N

for a distance of "N" on transition curve the rise of edge is 1

$$\sin\theta = e = \frac{E}{W+W_e}$$

W_e: extra widening

E = rise of outer edge

$$E = e(W+W_e)$$

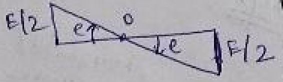
$$\begin{array}{c|c} \mu & V \\ \hline N & 1 \\ l_s & E \end{array}$$

$$l_s = N \cdot E$$

$$l_s = N(e(W+W_e))$$

$$\boxed{l_s = Ne(W+W_e)}$$

→ for rotation about inner edge



$$\boxed{l_s = \frac{Ne(W+W_e)}{2}}$$

→ for rotation about central line

For plain (or) Rolling terrain

1 in N ⇒ 1 in 150

For hilly terrain

1 in N ⇒ 1 in 60

as per IRC

$$W_e = \text{extra widening} = \frac{V}{9.5\sqrt{R}} + \frac{nl^2}{2R}$$

e = given super elevation (or) use design super elevation as per mix traffic condition.

③ Emperical eqn given by IRC

For Plain | Rolling terrain

$$\boxed{l_s = \frac{2.7V^2}{R}}$$

for hilly terrain

$$\boxed{l_s = \frac{V^2}{R}}$$

Imp

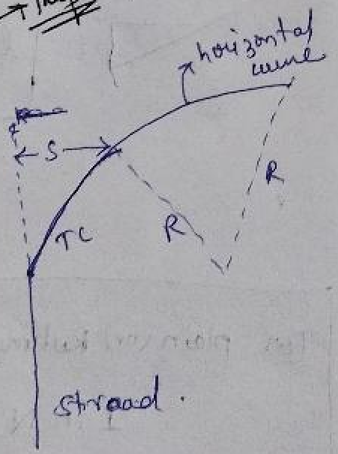
V = Kmph

In design use Max length of above 3 cases.

SHIFT

$$\boxed{S = \frac{l_s^2}{24R}}$$

Imp



s = shift

Eg:- design speed = 80 kmph
Radius of curve = 300m
plain terrain, pavement rotated about inner edge, width of road = 7m
Rate of super elevation = 1in150
what is min length of transition curve & shift?

Sol:- Given V = 80 kmph
R = 300 m
W = 7m

(i) $C = \frac{80}{75+V}$

$= \frac{80}{75+80} = 0.516$

hence C is between the limits 0.5 to 0.8.

$l_s = \frac{v^3}{CR}$

$l_s = \frac{\left(\frac{80}{3.6}\right)^3}{0.516 \times 300}$

$l_s = 70.86m$.

(ii) $l_s = Ne\,(W + We)$

~~l_s~~ $We = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

$= \frac{2(6.1)^2}{2 \times 300} + \frac{80}{9.5\sqrt{300}}$

$We = 0.610$

$W + We = 7 + 0.610 = 7.610$ m

~~l_s~~ =

use design super elevation for Mixed traffic criteria for mixed traffic condition $f = 0$.

$$e_{dgn} + \cancel{f}^{0} = \frac{v^2}{gR}$$

$$e_{dgn} = \frac{(0.75V)^2}{gR}$$

$$e_{dgn} = \frac{(0.75 \times 22.22)^2}{9.81 \times 300}$$

$$e_{dgn} = 0.09 \simeq 9\% > 7\%$$

$\therefore$ provide $e_{max} = 0.07$.

(iii) $$l_s = \frac{2.7V^2}{R}$$

$$= \frac{2.7 \times 80^2}{300}$$

$$= 57.6m$$

$\therefore$ Min length of transition curve to be used on the road (by satisfying all the criteria) is the maximum of all the 3 cases i.e 79.89m.

$$\text{Shift} = \frac{l_s^2}{24R} = \frac{79.89^2}{24 \times 300} = 0.886m$$

Eg: Design min length of transition curve in hilly terrain design speed = 60 kmph, 2 lane road, Radius of curve = 500m, pavement rotated curve abt centreline Length of vehicle = 5m.

Sol: given : $V = 60kmph$, $R = 500m$

$n = 2$, $l = 5m$.

(i) comfort criteria

$$C = \frac{80}{75+V}$$

$$C = \frac{80}{75+60} = 0.592$$ within the limits.

$$l_s = \frac{V^3}{CR} = \frac{(16.66)^3}{0.59 \times 500}$$

$$= 15.65m$$

(ii) super elevation criteria.

$$e + \cancel{f}^{0} = \frac{(0.75V)^2}{gR}$$

$$e = \frac{(0.75 \times 16.66)^2}{9.81 \times 500}$$

$$e = 0.0318$$

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

$$= \frac{2 \times 5^2}{2 \times 500} + \frac{60}{9.5\sqrt{500}}$$

$$= 0.332$$

$$l_s = \frac{Ve(W + W_e)}{2}$$

$$= \frac{60 \times 0.31(7 + 0.332)}{2}$$

$$l_s = 6.81m.$$

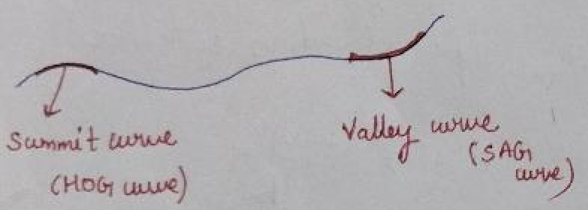
(iii) Empirical formula

for hilly terrain ← $\boxed{l_s = \frac{v^2}{R}} = \frac{60^2}{500} = 7.2\text{m}$

Min length of transition curve is max of 3 criteria i.e 15.65m.

$$\text{shift} = \frac{l_s^2}{24R} = \frac{15.65^2}{24 \times 500} = 0.02\text{m}$$

VERTICAL CURVES:



The vertical alignment of a highway influences
(i) Vehicle speed
(ii) acceleration & deceleration
(iii) stopping distance
(iv) sight distance
(v) comfort while travelling at high speeds
(vi) Vehicle operation cost.

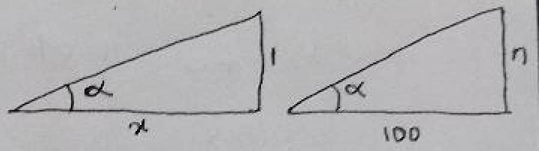
GRADIENT:

Longitudinal gradient (or) Slopes on roads

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 (1 vertical unit to x horizontal units).

* The gradient is also expressed as a percentage, such as n%, the slope being n vertical units to 100 horizontal units.



(a) Gradient = 1 in x
$= \tan\alpha$
$= \frac{100}{x}\%$

(b) gradient = n in 100
$= n\%$

Types of gradient

Gradients are divided into four categories
(i) Ruling gradient
(ii) Limiting gradient.
(iii) Exceptional gradient.
(iv) Minimum gradient.

(i) Ruling gradient.

Ruling gradient is the maximum gradient with in which the designer attempts to design the vertical profile of a road.

The IRC Recommended ruling gradient
(a) 1 in 30 on plain and rolling terrain
(b) 1 in 20 on mountainous terrain
(c) 1 in 16.7 on steep terrain.

LIMITING GRADIENT:

where topography of place compels adopting steeper gradient than the ruling gradient, 'limiting gradient' is used is used in view of enormous increase in cost in constructing roads with gentler gradients.

* However the length of continous grade line steeper than ruling gradient should be limited.

EXCEPTIONAL GRADIENT:

In some extra ordinary situations it may be unavoidable to provide still steeper gradients than limiting gradient at least for short stretches & in such cases the steeper gradient up to exceptional "gradient" may be provided.

* However the exceptional gradient should be strictly limited only for short strectches not enceeding about 100m at a stretch.

Gradients for roads in different terrains

type of terrain	Ruling gradient	Limiting gradient	Exceptional gradient
Plain (or) Rolling	3.3% (1 in 30)	5% (1 in 20)	6.7% (1 in 15)
Mountainous terrain & steep terrain having elevation more than 3000m above the mean sea level	5% (1 in 20)	6% (1 in 16.7)	7% (1 in 14.3)
steep terrain up to 3000m ht	6% (1 in 16.7)	7% (1 in 14.3)	8% (1 in 12.5)

MINIMUM GRADIENT:

The road can be level with little (or) no gradient. In such cases there will be problems of drainage.

* Though the suface can be drained off to the side drains by providing proper camber on the pavement suface and cross.

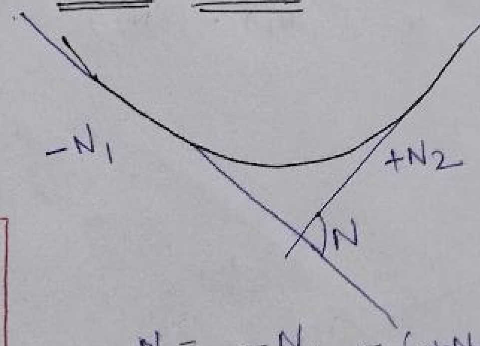
GRADE COMPENSATION:

Grade Compensation, % = $\frac{30+R}{R}$

The maximum value of grade compensation is limited to = $\frac{75}{R}$

The compensated gradient = ruling gradient − grade compensation

VALLEY CURVES



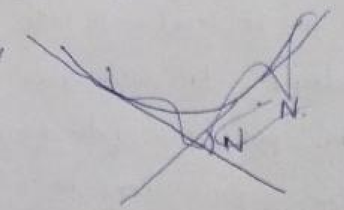
$$N = -N_1 - (+N_2)$$

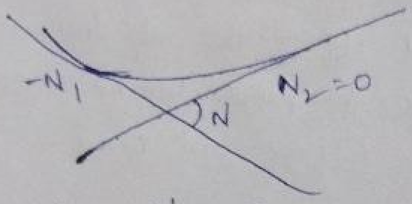
$$N = -(N_1+N_2)$$

deflection angle is −ve for Valley curves.

Other forms of valley curves

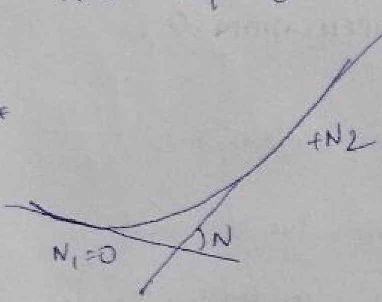
*





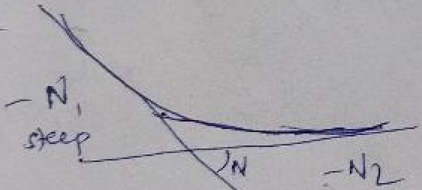
$N = -N_1 - 0$

*

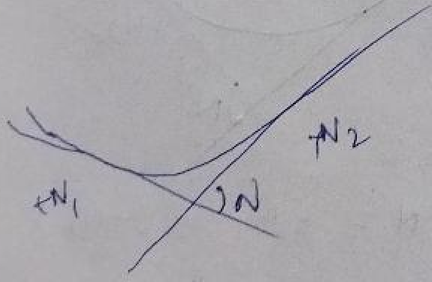


$N = 0 - (+N_2)$

*



$N = (-N_1) - (-N_2)$



$N = N_1 - N_2$

Ideal form of valley curve

3° parabola

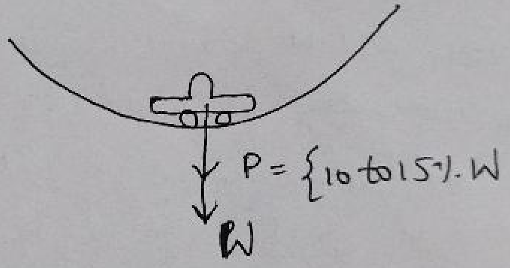
Cubic parabola

Design criteria:

(1) Centrifugal criteria / comfortcriteria

Over valley curve centrifugal force creates a problem.

* It is increasing with wt of passengers causing discomfort & also increasing compression the spring.



Rate of change of centrifugal radial acceleration for valley curves $\boxed{C = 0.61\ m/sec^3}$

A fixed value

* As centrifugal force is a design criteria it should be induced gradually in the design.

∴ cubic parabola which is a form of transition curve is recommended by IRC

$$\boxed{L = 2l_s = 2\left[\frac{N\vartheta^3}{C}\right]^{1/2}}$$

L= total length of valley curve = $2l_s$

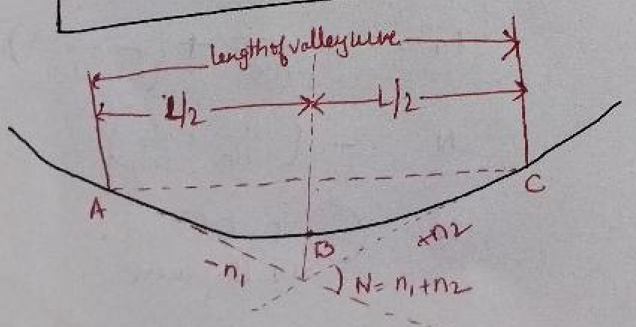
N= deviation angle in radians (or) the algebraic difference in 2 gradients.

ϑ = design speed m/sec

C = The allowable rate of change of centrifugal ~~force~~ acceleration the value of C is taken as 0.6 m/sec³.

If the above equation is expressed in kmph then the modified formula

$$\boxed{L = 2l_s = 0.38(NV^3)^{1/2}}$$



(2) Sight distance criteria

* SSD during day is not a problem

* OSD during day time is not a problem

* ISD is not a problem during day

* SSD during night is a problem
HSD = SSD = is a problem

* In the design care must be taken so that the head light focus should reach a min of SSD over valley curve.

* OSD during night is not a problem

* ISD is also not a problem during night.

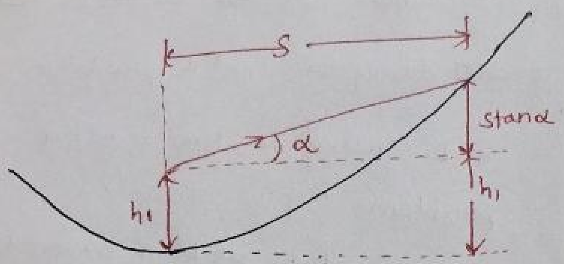
NOTE: SSD during nyt tym is a problem on valley curves all other sight distances are not creating problem over valley curves.

consider

S= HSD = SSD

Case 1 $\boxed{L \geq S = HSD}$

$$\boxed{L = \frac{NS^2}{2h_1 + 2S\tan\alpha}}$$



$\boxed{L > SSD}$

L = total length of valley curve, m ($L > S$)

S = SSD, m

N = deviation angle ($n_1 + n_2$) with slopes $-n_1$ & $+n_2$

h_1 = height of the head light. (0.75m)

Beam angle, α can be taken as 1°.

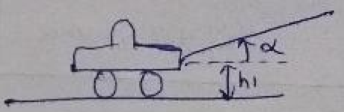
Case = 2. $\boxed{L < SSD}$

$$L = 2S - \frac{(2h_1 + 2S\tan\alpha)}{N}$$

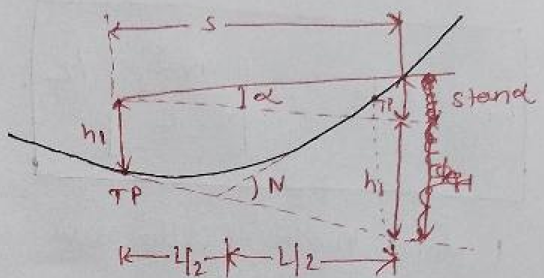
h_1 = ht of head light over road surface

min h_1 = 0.75 m (as per IRC 2½ ft)

α = angle of head light beam. with horizontal ($\alpha = 1^{\circ}$ upward)



Minimum length of the valley curve is that maximum of above 2 conditions (2 criteria).



$\boxed{L < S}$

Eg:- A valley curve is formed by a downward gradient of 2% meeting with upward 3%. The design speed is 65 kmph, the rate of change of centrifugal acceleration is 0.61 m/s³ The HSD is 200m determine min length of valley curve & also the position of lowest pt from the first tangent pt.

Sol Given V = 65

$$v = \frac{65}{3.6} = 18.05 \text{ m/s}$$

$$N = -\frac{2}{100} + \left(-\frac{3}{100}\right)$$

$$N = -\left(\frac{2}{100} + \frac{3}{100}\right)$$

$$N = \textcircled{-}\ 0.05$$

→ valley curve.

$C = 0.61\ m/s^3$

$S = HSD = 200m$.

(1) Centrifugal criteria

$$L = 2\left[\frac{N.\ v^3}{C}\right]^{1/2}$$

$$L = 2\left[\frac{0.05 \times (18.05)^3}{0.61}\right]^{1/2}$$

$L = 43.91 \rightarrow$ ①.

(2) HSD = SSD during night

assume $L \geq S = HSD$.

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha} = \frac{\left(\frac{5}{100}\right)(200)^2}{2(0.75 + 200\tan 1^\circ)}$$

$= 235.79m \rightarrow$ ②

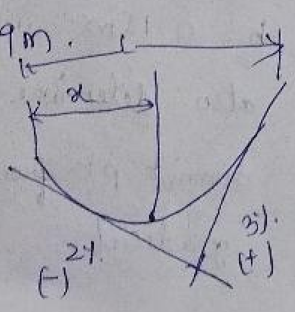
$235.79 > 200$.

$L > S$ ✓

assumption is correct

Min length of Valley curve to be provided is the maximum value of ① & ②.

$L = 235.79m$.



$$x = L\left(\frac{N_1}{N}\right)$$

$$= 235.79\left(\frac{2}{5}\right)$$

$x = 94.31\ m$

DESIGN OF SUMMIT CURVES

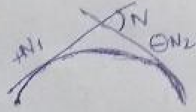
㉙

summit curves. (HOG curve).

N = algebraic diff of gradient up the

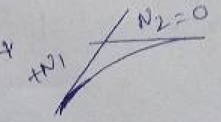
$= (+N_1) - (-N_2)$

$= N_1 + N_2$



OTHER FORMS OF SUMMIT CURVES

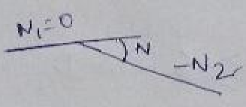
*



$N = N_1 - 0$

$\boxed{N = N_1}$

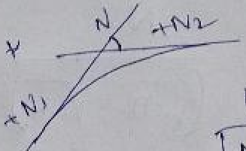
*



$N = 0 - (-N_2)$.

$\boxed{N = N_2}$

*

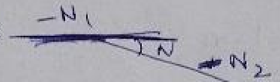


$N = +N_1 - (N_2)$

$\boxed{N = N_1 - N_2}$

$N_1 > N_2$

*



$N = -(N_1) - (-N_2)$

$\boxed{N = -N_1 + N_2}$

for summit curves deflection angle is always "+ve"

Ideal summit curve (as per IRC)

Parabola

2° parabola curve

Sq parabola curve

design of summit curve

(1) sight distance (S)

(a) S = SSD is imp on single lane roads with one way.

(b) S = 2 SSD = ISD is required on a single lane 2 way road

(c) S = OSD: multi lane road with one way (or) 2way traffic.

$$\boxed{SSD = S}$$

case -1 $L \geqslant S = SSD$.

$$\boxed{\text{Length of summit curve } L = \frac{NS^2}{(\sqrt{2H}+\sqrt{2h})^2}}$$

where $H = 1.2m$

$h = 0.15m$.

Case -2 $L < S = SSD$

$$\boxed{L = 2S - \frac{(\sqrt{2H}+\sqrt{2h})^2}{N}}$$

$$\boxed{S = OSD \,|\, ISD}$$

case -1 $L \geqslant S$.

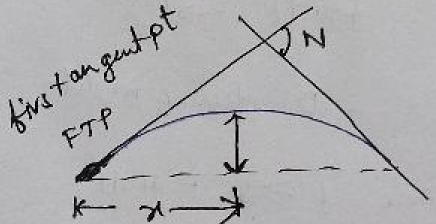
$$\boxed{\left.\begin{matrix}\text{length of}\\ \text{summit curve}\end{matrix}\right\} L = \frac{NS^2}{(\sqrt{2H}+\sqrt{2H})^2}} = \frac{NS^2}{8H}$$

Case -2 $L < S$

$$\boxed{L = 2S - \frac{(\sqrt{2H}+\sqrt{2H})^2}{N}}$$

$$= 2S - \frac{8H}{N}$$

Distance of Peak Point (summit point



$N \longrightarrow L$

$N_1 \longrightarrow x = L\left(\frac{N_1}{N}\right)$

$$\boxed{x = L\left(\frac{N_1}{N}\right)}$$

(Q) on a highway a summit curve is formed by an ascending gradient of 1 in 50 meeting at decending gradient of 1 in 60. determine length of summit curve using H = 1.2m h = 0.15m with a SSD = 120m also determine the distance of the summit pt from the starting of steep gradient.

Sol Given $S = SSD = 120m$

$N_1 = 50.$

$N_2 = 60.$

deviation angle / deflection

$$N = \left(\frac{1}{50}\right) - \left(-\frac{1}{60}\right)$$

$N = 0.036.$

$S = SSD = 120m$ given

(i) assuming first condition

$L > S$

$$L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2} = \frac{0.036 \times 120^2}{(\sqrt{2 \times 1.2} + \sqrt{2 \times 0.15})^2}$$

$$= 117.89m$$

But $\underset{SSD}{117.89 < 120}$

∴ our assumption is wrong then consider 2nd condition $L < S$ and find L

$L < S$

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

$$L = 2(120) - \frac{(\sqrt{2 \times 1.2} + \sqrt{2 \times 0.15})^2}{0.036}$$

$L = 117.85m < S$

use 117.85m as length of summit curve.

$$x = L\left(\frac{N_1}{N}\right)$$

$$x = 117.85\left(\frac{\frac{1}{50}}{0.036}\right)$$

$x = 65.47m.$

distance of peak (or) summit pt for steep (1 in 50) gradient 65.47m.

Assignment Questions for 1st Mid Exam

Module – 1

1. Explain briefly outline the important features of the Nagpur Road plan and Recommendations of Jayakar committee.

2. Explain with neat sketch various road patterns

Module - 2

1. The speed of overtaking & overtaken vehicle are 80 & 50 kmph respectively on a two lane traffic road. If the acceleration of overtaking vehicle is 0.99 m/s^2. Solve for overtaking sight distance. Minimum length of overtaking zone. Draw a neat sketch of overtaking zone & show the positions of the sign posts.

2. ~~The~~ ~~design~~ Explain the important pavement surface characteristics with respect to highway geometric design.

Module - 3

1. Marshall test specimen is prepared for bituminous material with a bitumen content of 5% by the weight of total mix. Theoretical and the measured unit weight of the mix are 2.442 g/cc & 2.345 g/cc. Bitumen has a specific gravity of 1.02. Calculate the % voids in mineral aggregate filled (VFB)

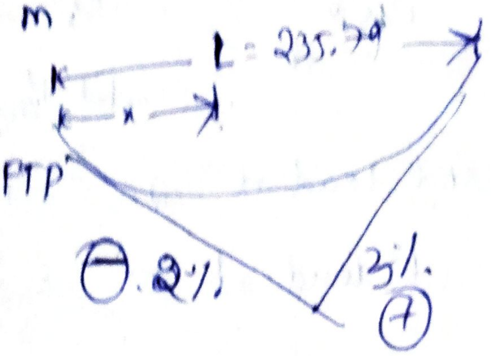
1. Explain desirable properties of bitumen. Compare tar with bitumen.

lowermost pt

min valley curve length

$L =$ max of ① & ②

$L = 235.79$ m



$x = L\left(\frac{N_1}{N}\right)$

$= 235.79\left(\frac{2}{5\%}\right)$

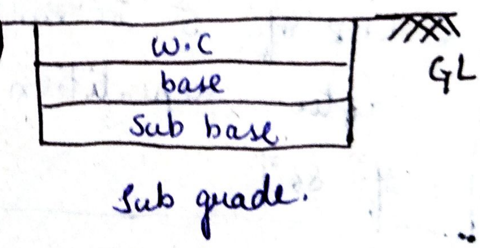
$x = 94.31$ m

HIGHWAY MATERIAL & TESTING

Subgrade: lowermost layer of a pavement with locally available strata

w.C = wearing course

Properties of Subgrade required:



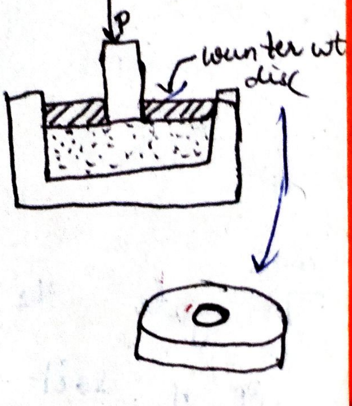
(1) CBR = (california bearing ratio)
lab test

CBR is a parameter representing strength of Sub grade soil.

(2) Modulus of sub-grade reaction (k).

"k" is a parameter representing stiffness of subgrade soil.

CBR TEST IN LAB:

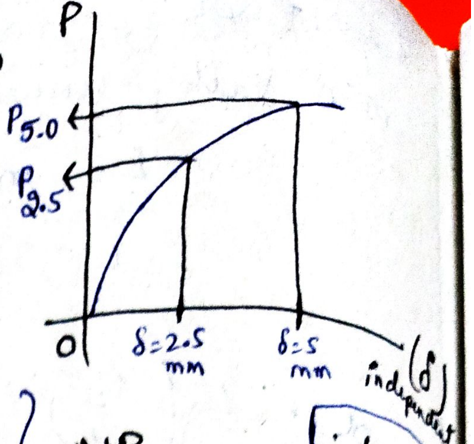


P = load

δ = deflection / settlement.

To avoid heaving (lifting) up of the soil counter weight is used

Then $CBR_{2.5} = \frac{P_{2.5}}{std\ P_{2.5}} \times 100$



$CBR_5 = \frac{P_{5.0}}{Std\ P_{5.0}} \times 100$

independent - X axis
dependent - Y axis

* std load at 2.5 = 1370 kg.
* std load at 5 = 2055 kg } IMP

The std loads are given by the California university. by conducting CBR test on locally available crushed aggregate.

CBl

* In general CBR of 2.5 is the higher value then CBR of soil is CBR of 2.5

* CBR of 5 is more then repeat the experiment, after repeatition the higher value will be CBR of soil

Eg: load at $P_{2.5} = 80$ kg ; $P_5 = 98$ kg.

$$CBR\ of\ soil = \frac{80}{1370} \times 100$$

$CBR_{2.5} = 5.839$ %.

$$CBR_5 = \frac{98}{\cancel{1370}\ 2055} \times 100 = 4.7\%.$$

∴ The CBR of soil = $\underline{5.84}$ %.

<u>NOTE</u>

In gate the max value of CBR 2.5 & CBR of 5 is CBR of soil

↑ CBR value : ↑ strength of soil

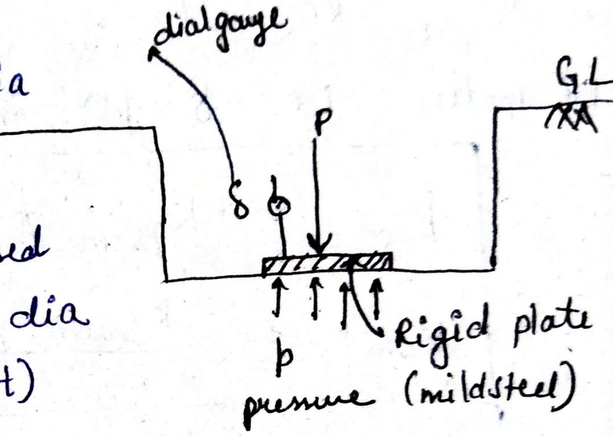
NOTE:- CBR value is a relative strength parameter compared to crushed aggregate in california.

PLATE BEARING TEST - field test

* **AIM** :- 1. Bearing capacity of soil
  2. Modulus of sub grade reaction (K)
  3. Modulus of elasticity (young's modulus) E

→ std size of plate = 75cm dia (2½ ft).
(dia of plate)

→ alternate & commonly used dia of plate = 30cm dia (1ft)



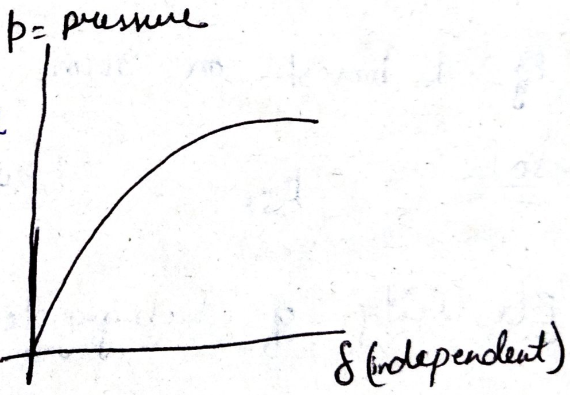
Modulus of sub grade reaction (K).

pressure required to cause unit settlement in soil

$$K = \frac{p}{\delta}$$

units of K = $\frac{N/mm^2}{mm}$

= N/mm^3 (or) kg/cm^3.



↑ K : ↓ settlement : ↑ stiffness.

Method - 1 Fix $\delta = 1.25mm$

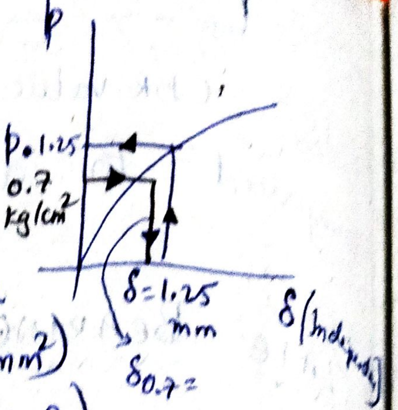
$$\boxed{K = \frac{p_{1.25}}{(1.25\,mm)}}$$

Method : 2 Fix $p = 0.7\ kg/cm^2$

$= 0.07\ MPa$

$(\because 1MPa = 1N/mm^2$

$= 10\ kg/cm^2)$



$$\boxed{K = \frac{0.7\ kg/cm^2}{\delta_{0.7}}}$$

As per IRC it is recommended to fix independent parameter i.e $\delta = 1.25\ mm$.

$$\boxed{\begin{aligned} K_{soil} &= K_{75cm}\ \phi\ plate \\ K_{soil} &= \frac{K_{30cm}\ \phi\ plate}{2} \end{aligned}}$$ } IMP

Eg: K based on 30cm dia plate = 200 kg/cm³.

Sol $K_{soil} = \frac{K_{30cm}\ \phi\ plate}{2} = \frac{200}{2} = 100\,kg/cm^3$

Elasticity of Subgrade Soil: ISRO 2017

(Boussinesq's ~~Eqn~~ Emperical eqn are used)

**(I) Rigid (Mild steel) plate

$$\boxed{E_s = \frac{1.18\,pa}{\delta}}$$

p = pressure
a = radius plate
δ = deflection

(ii) Rubber (flexible) plate.

$$\boxed{E_s = \frac{1.5\,Pa}{\delta}}$$

In practice the load transfer on to the soil is by inflated rubber tyres (blowen with air)

p = pressure on soil

a = radius of plate

δ = settlement

Eg: In a plate load test on 30cm dia plate a pressure of 20kg/cm² is applied. The corresponding settlement of the plate is 2.3cm. determine modulus of elasticity of soil considering Boussinesq empirical equation.

Sol) $a = \frac{30}{2}$cm, p = 20 kg/cm², δ = 2.3cm

$$E_s = \frac{1.18 \times Pa}{\delta} = \frac{1.18 \times 20 \times (30/2)}{2.3}$$

$$= 153.91 \text{ kg/cm}^2$$

$\frac{kg}{cm^2} \times cm$

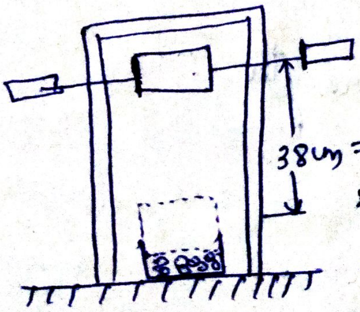
PROPERTIES OF Coarse Aggregates:

(HBG = Hard Blasted Granite chips are used)

1) Toughness :- Resistance to the impact (load suddenly by moving wheels.

Procedure:

* Aggregate impact test is used.



* hammer wt = 13.5 kg - 14 kg

*15 blows

Impact energy in each blow = W.h = m.g.h

imp = 14kg (9.81) (38)

= 5218.92 N-cm

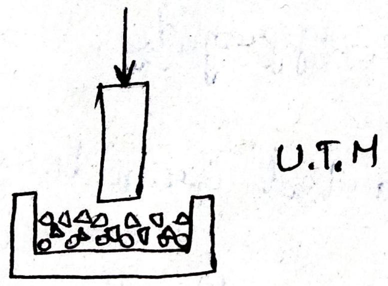
after 15 blows take out & sieve on 2.36 mm IS sieve

Aggregate Impact Value = AIV = $\frac{\text{wt of aggregate passing through 2.36 mm sieve}}{\text{Total weight}} \times 100$

↑ aggregate value ↓ Impact strength

② Aggregate crushing value Test

- to determine strength of road aggregate
- strength : resistance against gradual load
- Based on Aggregate Crushing value test (ACV)



- After failure of aggregate. Sieve it on 2.36 mm sieve

Aggregate crushing value (ACV) = $\frac{\text{wt of aggregate passing through 2.36 mm sieve}}{\text{Total weight}}$

↑ A.C.V : ↓ strength.

③ Soundness Test

* Sound : Good (aggregate).

* soundness is resistance to weathering action.

* Create artificial weathering: by dipping into salt solutions

(1) sodium sulphate (2) magnesium sulphate.

* soundness is estimated based on % loss of wt.

↑ % loss of wt : ↓ sound Aggregate.

(4) SHAPE ~~&~~ TEST :

* recommended shape of aggregate : Angular (for good interlocking)

* Flaky aggregates : too thin aggregate [Not stronger fails easily]

* Thickness ~~of~~ (least dimension) < 0.6 (avg size) ⇒ flaky aggregate

Don't use it in construction.

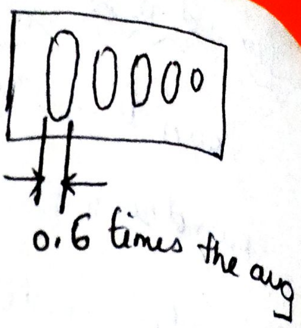
* Elongated (too long) : Too long Aggregates [not stronger aggregate fail easily]

length (max dimension) > 3 × 0.6 (avg size). } not used in road construction
> 1.8 (avg size) }

* Slot tests are used

for flaky aggregate : thickness gauge is used.

Flakness Index $\Big\}$ $FI = \dfrac{\text{wt of flaky aggregates}}{\text{Total wt of sample}} \times 100$



$\boxed{\uparrow FI \;:\; \downarrow \text{Strength}}$

For elongated aggregates length gauge is used

$$\text{Elongation Index} = \frac{\text{wt of elongated aggregates}}{\text{wt of Non flaky aggregates.}} \times 100$$

Non flaky aggregates = total wt of sample − wt of flaky aggregates

$\boxed{\uparrow EI \;:\; \downarrow \text{Strength}}$

In shape testing firstly flakiness index should be determined & then on non flaky aggregates, Elongation is determined.

Eg In the shape test total wt of aggregate taken is 1000 g in that wt of flaky aggregate = 320 g wt of Elongated aggregate is 148 g determine FI, EI

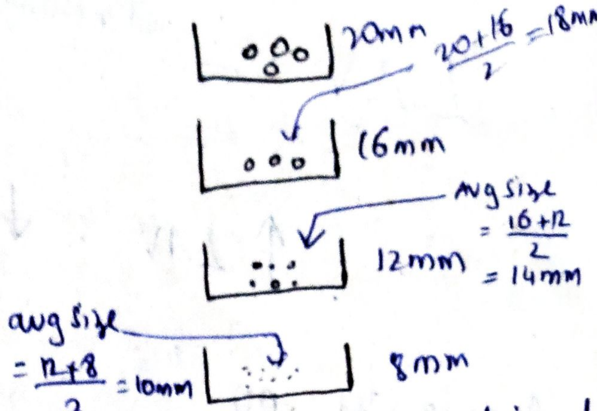
Sol

$$FI = \frac{320}{10\cancel{0}\cancel{0}} \times 1\cancel{0}\cancel{0} = 32\%$$

$$EI = \frac{148}{1000-320} \times 100 = \frac{148}{680} \times 100 = 21.7\%$$

To determine Avg. Size of aggregate

∴ Conduct Sieve Analysis 10 - 15 min



Eg: Aggregate passing through 12mm Sieve & retained on 8mm Sieve.

Size of thickness gauge for flakyness index } = 0.6 (avg size)

$= 0.6 \left(\frac{12+8}{2}\right)$

= 6mm

Size of length gauge for elongation Index } = 3 x 0.6 (avg).

1.8(10) = 18mm.

Hardness : resistance against $\boxed{\text{abrasion}}$

↑ rubbing action b/w particles of diff nature.

Attrition : rubbing action b/w particles of same nature.

Test:-

(1) los angeles test → commonly used (Impact + abrasion) effect.

(2) Deval Abrasion test

(3) Dorry test.

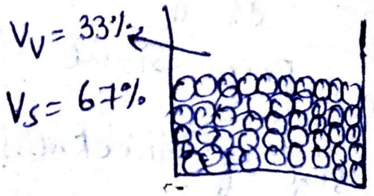
* After specified no of rotations of drum remove th aggregate & Sieve it on 1.7mm IS Sieve.

$$L.A.V = \frac{\text{wt passing through 1.7mm sieve}}{\text{total wt}} \times 100$$

↑ LAV : ↓ Hardness (or) soft aggregate.

Angularity no

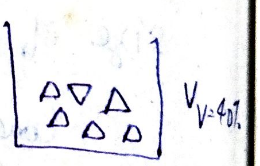
⇒ voids in excess of 33 %.



perfectly rounded aggregates.

AN = voids in excess of 33%.

$\boxed{AN = 7}$



Eg : $V_V = 27$
$AN = 0$

less than 33%. never cound angularity no

Eg : $V_V = 33$
$AN = 0$.

↑ AN : ↑ Interlocking : ↑ voids.

Recommended angularity no as per IRC $\boxed{0 \text{ to } 11}$

11:30 - 1pm test.
G.D.

2:830
TE
$\boxed{308}$

* **Specific Gravity of Road Aggregates**

(2.6 - 2.9)

Water absorption ≯ 0.6% by wt

↑ water absorption : ↑ voids & ↑ cracks ↓ strengt

* **Bitumen Adhesion Test:**

→ static immersion test:

- complete surface of aggregate should get attached with bitumen.
- Smooth surface & surface with moisture is not getting proper adherance

TEST ON BITUMEN

Bitumen

↓

Fractional distillation of crude oil

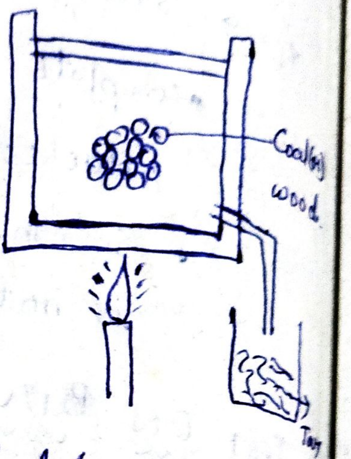
- Gasolene — purest
- Naptha
- Petrol
- diesel
- ⋮
- Bitumen — impure

Stabilised bitumen — Asphalt (Bitumen + stabilizer)

Asphalt will be under solid condition at all temperatures . ∴ It is suitable for surface treatments.

TAR

- Coal based product
- always available in liquid form.
- obtained by distructive distillation of wood (or) Coal.



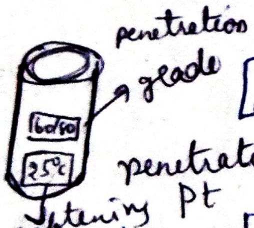
Tests on Bitumen

(1) Penetration test :

- To determine the Softness (or) hardness of bitumen.
- Penetrometer apparatus

Imp - grade of bitumen is also decided based on penetration value.

- Depth of penetration of std. needle in 5s of time should be noted.



[Unit of penetration = $\frac{1}{10}$mm]

penetration value = 6mm to 8mm.

grade $\boxed{80/100}$

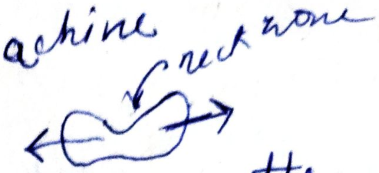
penetration value = 8mm to 10mm.

Ductility test:-

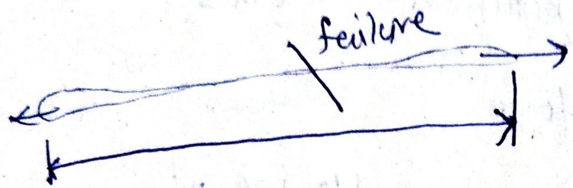
* The property by which the material can be made in to thin wires.

* ductile material are generally elastic can deform easily with out cracking & failure.

Apparatus: Ductility testing machine



Briquette
(Dumbell shape specimen).



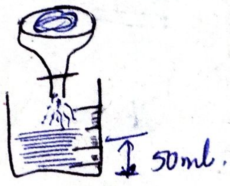
* elongation of specimen @ failure is a measure of ductility.

1 unit = 1cm.

(3) Viscosity test:-

* resistance to flow.
* Orifice type Viscometer.
  (used for bitumen in Liquid form)

The time in seconds for the bitument to pass through standard orifice & to collect 50 ml of bitumen is a measure of viscosity

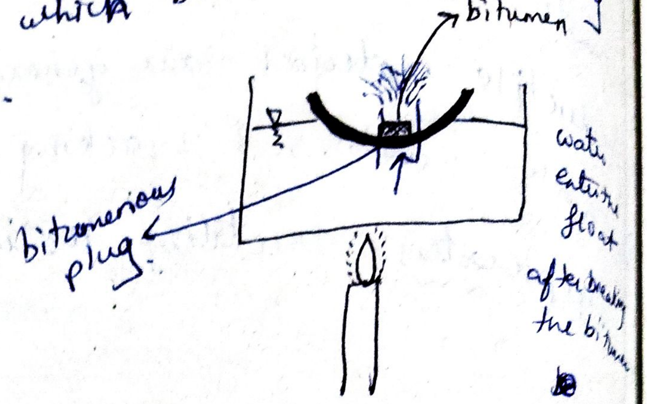


↓time in sec ; ↓ viscosity
↑fluidity.

(4) FLOAT TEST :-

* used for bitumen in solid form.

* The time • in (sec) @ which bitumenous ~~blocks~~ plug gives a way to water.

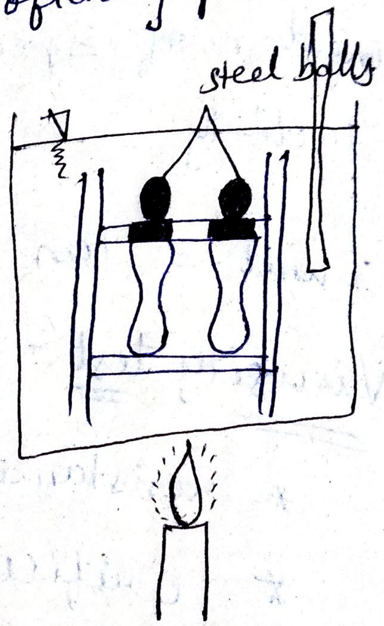


Softening pt test

* The temp @ which bitumen becomes soft & looses its form. (& starts flowing) is softening pt

* Ring & ball test.

The temp at which bitumenous plug touches lower horizontal bar is softening point.



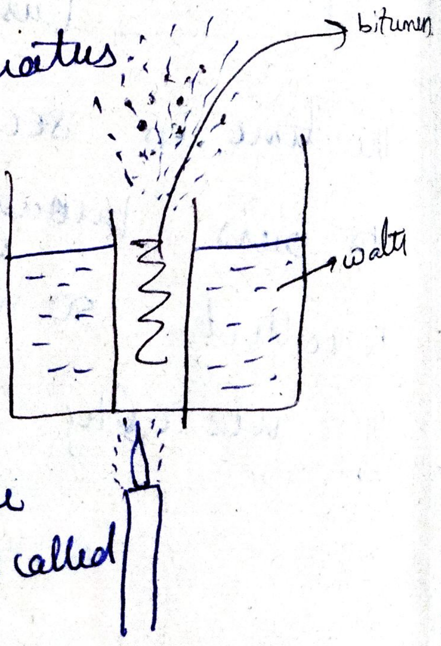
Flash & fire pt Test

* Pensky – Marten's apparatus

* flash pt $\boxed{175^\circ C}$ for Indian bitumen

* sparks.

* The temp at which sparks come out of bitumenous vapour is called flash pt temp



- The temp at which entire bitumen catches to fire is fire pt temp.

Soluability test :-

- Bitumen dissolves completely in all higher order material.

  like gasoline, ...

  In Lab : Bitumen : Benzene

- Tar complete dissolves in Vola, Toluene

- Sp. gravity of Bitumen approx = 0.97 - 1.02

- Sp gravity of Tar = 1.1 to 1.25.

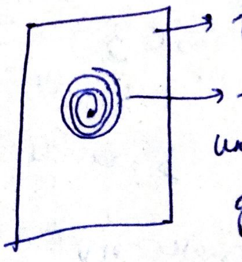
  Tar is heavier than bitumen.

SPOT TEST

- Used to determine over heated (or) cracked bitumen.

- Bitumen which is over heated cracks are formed.

- Cracked bitumen is brittle & has lesser life



Water Content

≯ 0.2% by wt loss on heating

>1% (heated @ 163 °C for 5 hrs.)

Cut back

* Bitumen + dilutant

Bitumen with reduced viscosity

types

* Rapid curing (RC) — Bitumen + Gasolene /Naptha/ petrol
* medium curing (MC) — Bitumen + (medium type of volatile) i.e diesel (or) kerosene
* slow curing (S.C) — Bitumen + (high boiling pt oils)

RC0, RC01, RC2, RC3 ------ RC5
MC0, MC1 ------------ MC5 } grades
SC0, SC1 ------------ SC5

More no more viscosity. after mixing with dilutant before placing on road

Eg:- RC1, MC.4 which is more viscous

Sol MC4

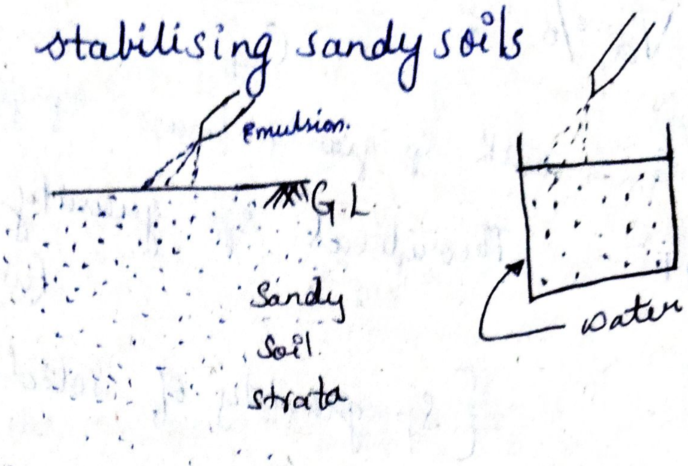
Eg RC3, SC3 which is more viscous.

Sol Same viscosity

same no. But RC_3 becomes harder after placing on road.

Emulsion

- * Bitumen + Aquaceous medium + emulsifier
- * used for stabilising sandy soils



Bitumenous Concrete

Bitumen : Binder

CA : strength

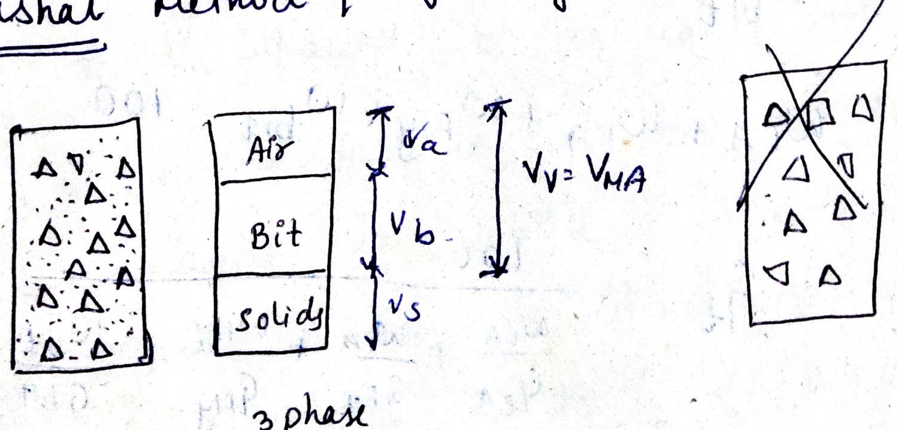
FA : Void filler

fly ash: void filler

Bitumenous concrete mix is adopted for **Hot mixes**

* **Marshal** method / of design is used in IRC

[MP 2m]



Bitumenous concrete

3 phase diagram

% Air voids.

$$V_a\,\% = \frac{G_t - G_m}{G_t} \times 100.$$

(practical sp. gravity) G_m : bulk sp. gravity / mass sp gravity (with air)

G_t : Theoritical sp. gravity of bit. concrete (with out air)

{Sp. gravity of solids}

can be calculated by a weighted avg

$$\frac{100}{G_t} = \frac{W_{CA}}{G_{CA}} + \frac{W_{FA}}{G_{FA}} + \frac{W_{FLY}}{G_{fly}} + \frac{W_{bit}}{G_{bit}}$$

W_{CA} = % wt of C.A

W_{FA} = % wt of F.A

W_{Fly} = % wt of fly ash

W_{bit} = % wt of bitumen

$$W_{CA} + W_{FA} + W_{Fly} + W_{bit} = 100.$$

$$G_t = \frac{100}{\frac{W_{CA}}{G_{CA}} + \frac{W_{FA}}{G_{FA}} + \frac{W_{FLY}}{G_{Fly}} + \frac{W_{bit}}{G_{bit}}}$$

$$G_m = \frac{\gamma_m}{\gamma_w} =$$

γ_w = 1 gm/cc

γ_m = wt density of material. (bit concrete)

$$\gamma_m = \frac{\text{wt of bit concrete sample}}{\text{volume of bit concrete sample}}$$

$\therefore$ % Volume of bitumen $\Big\}$ $V_b = G_m \left[\frac{W_{bit}}{G_{bit}}\right]$

$W_{bit} =$ % wt of bit.

Voids in the mineral Aggregate

* (VMA) : Voids available b/w mineral aggregates (i.e CA, FA & Fly ash)

$$VMA \text{ (in \%)} = V_a + V_b$$

Road Roughness

Bump indicator

* **Voids filled by bitumen**

$$\boxed{VFB = \frac{V_b}{VMA} \times 100}$$

In good Bitumenous concrete mix V_b should be higher & V_a should be as less as possible

Eg 1: In a bitumenous concrete mix avg sp gravity of the material is 2.632 & Theoritical Specific gravity is 2.848. The density of bitumen used is 1gm/cc with 4.23 % of bitumen by wt. determine VMA & V_{FB}

$V_a = 7.58$

$V_b = 11.10$

Sol

$G_m = 2.632$, $G_t = 2.848$, $\gamma_b = 1g/cc$

V_{MA} $V_a + V_b$

$$* V_a = \frac{G_t - G_m}{G_m} \times 100$$

$$= \frac{2.848 - 2.632}{2.632} \times 100$$

$$= 0.082 \% \times 100$$

$$= 8.2 \%$$

$$* G_b = \frac{\gamma_b}{\gamma_w} = \frac{1}{1} = 1$$

$$* V_b = G_M \left[\frac{W_{bit}}{G_{bit}} \right]$$

$$= 2.632 \left[\frac{4.23\%}{1} \right]$$

$$= 11.13\%$$

$$* VMA = V_a + V_b$$

$$V_{MA} = 8.2 + 11.13$$

$$VMA = 19.33$$

$$* V_{FB} = \frac{V_b}{VMA} \times 100$$

$$V_{FB} = \frac{11.13}{19.33} \times 100 = 57.57 \%$$

Q) The sp gravities & weights are given % in the following table for the preparation of Marshal cylindrical mould. The wt of Marshel specimen is 1150 gm, Volume is 500 cc determine

(i) V_a

(ii) V_{mA}

(iii) V_{FB}.

Specimen	A_1	A_2	A_3	A_4	Bit
weights (g)	625	478	486	232	125
Sp gravity (G)	2.63	2.73	2.57	2.36	1.06

Sol $G_t = ?$

Total wt = 1946

A% = 32.11%

B% = 24.56%

C% = 24.97%

D% = 11.92%

E% = 6.4%

$$G_t = \frac{100}{\frac{32.11}{2.63} + \frac{24.56}{2.73} + \frac{24.97}{2.51} + \frac{11.92}{2.36} + \boxed{\frac{6.4}{1.06}}}$$

$\frac{W_b}{G_b}$

$G_t = 2.367$

G_{mm} = ~~Bulk density~~ $\gamma_m = \frac{w}{V} = \frac{1150}{500} = 2.3\ g/cc$

~~Va~~ $G_m = \frac{\gamma_m}{\gamma_w} = \frac{2.5}{1} = 2.5$

$V_a = \frac{2.36 - 2.3}{2.3} \times 100 = 2.60$

$V_b = G_M \left[\frac{W_{bit}}{G_{bit}}\right] = 2.5 \left[\frac{6.4}{1.06}\right]$

$= 13.93\%$

$V_{ma} = 16.53$

$V_{FB} = \frac{13.93}{16.53} \times 100$

$= 84.27$

Q) In a bituminous

5 % Asphalt (Bitumen), the Sp gravities are 2.7 for coarse aggregate 2.63 for fine aggregate, 1.02 for Asphalt. determine unit weight of mix with 6.5% air voids.

Sol $V_a = 6.5\%$.

$$G_t = \frac{100}{\frac{65}{2.7} + \frac{30}{2.63} + \frac{5}{1.02}} = 2.476.$$

$$V_b = G_m\left[\frac{W_b}{G_b}\right] = \frac{\gamma_m}{\gamma_w}\left[\frac{W_b}{G_b}\right]$$

$$V_a = \frac{G_t - G_m}{G_m} \times 100$$

$$\frac{6.5}{100} = \frac{2.476 - G_m}{G_m}.$$

$$6.5 G_m = 247.6 - 100 G_m.$$

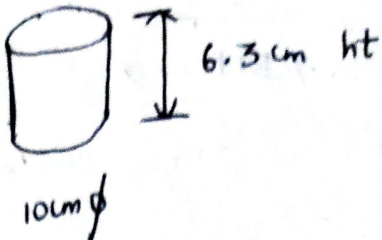
$$106.5 G_m = 247.6$$

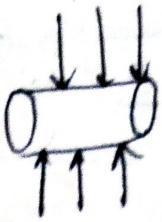
$$G_m = 2.32.$$

$$V_b = 2.32\left[\frac{5}{1.02}\right] = 11.396.$$

Marshal Testing

Marshal cylindrical specimen :





Marshal testing machine is used. @ failure Note

→ load @ failure (in kg).

→ deformation @ failure (in $\frac{1}{4}$ mm units).

* Marshal stability value (M_S)

→ load (in kg) @ failure

↑ M_S : ↑ strength.

* Marshal flow value (M_F)

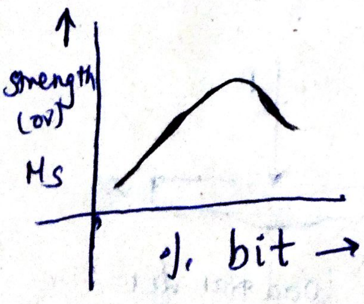
→ Deformation @ failure

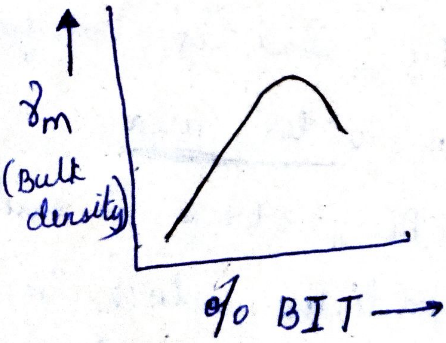
1unit : $\frac{1}{4}$ mm

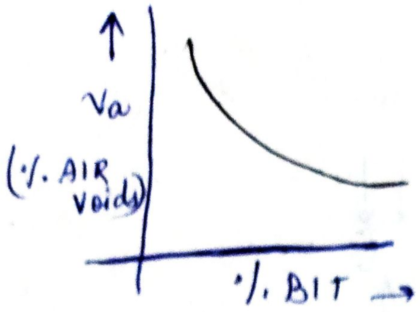
↑ M_F : ↑ Flowability : ↓ stiffness.

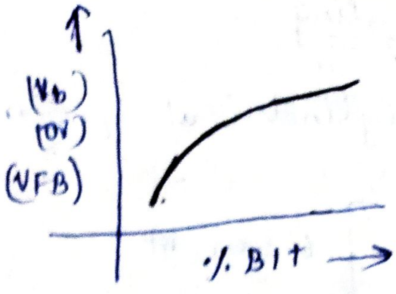
Imp

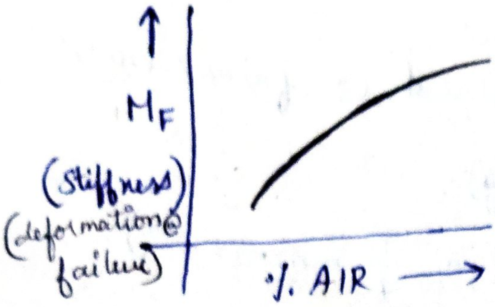
* Marshal graphs









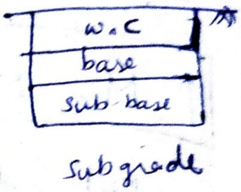


PAVEMENT DESIGN: 2 (or) 3 marks

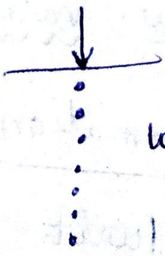
TYPES

1. Flexible pavements.

Eg: BT, WBM, Gravel, Earth



* grain to grain transfer

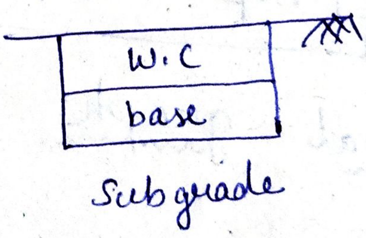


load transfer: Grain to Grain

* (IRC: 37 – 2012)

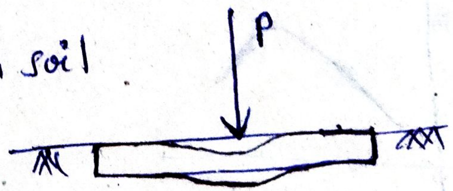
2. Rigid Pavement : (IRC - 58 - 2011)

Eg: C.C & RCC



* The load is transfered on a wider area

∴ The stress intensity on soil particles reduce in rigid pavement.



load transfer

flexural (or) Bending action (or) Slab action.

TRAFFIC ENGG

abst.

Q) In green bergs logarithmic model free mean speed is 80 kmph. The jam density is 200 vehicles in 1km length road determine capacity of traffic flow.

Sol) $V = 80$ kmph

$k_m = 200$ veh/km

for Green berg's model

$$\boxed{q_m = \frac{k_m \cdot V_m}{e}} = \frac{200 \times 80}{e^1} = 5886.1$$

ORIGIN - DESTINATION STUDIES: (imp).

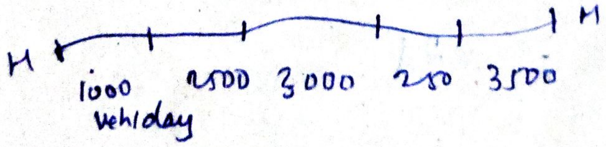
METHOD OF O.D. STUDIES:

(1) Road side interview method

(2) Post card method

(3) Stickers on vehicle

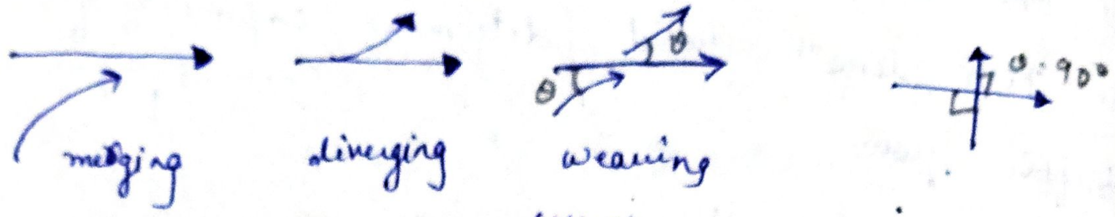
Desire line – St. line joining origin & Destination whose thickness indicates traffic on road. (according to traffic).



desire line

Traffic flow charateristics.

Traffic volume: Flow: No vehicle crossing Section per unit time



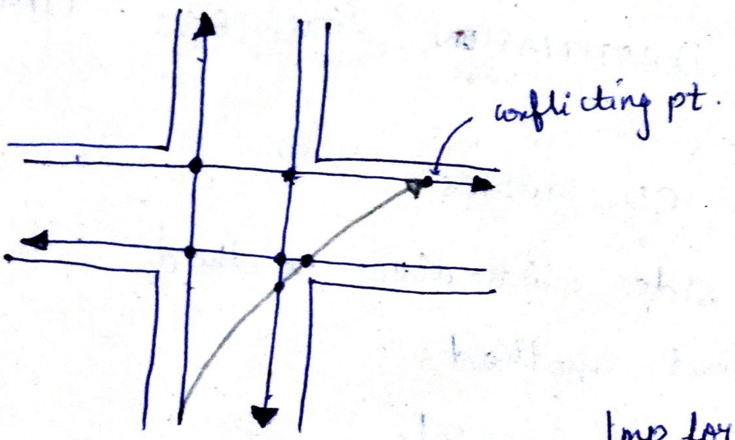
(merging + diverging)

θ = weavingangle

weaving at 90 is crossing

POINT OF CONFLICTS: (POC)

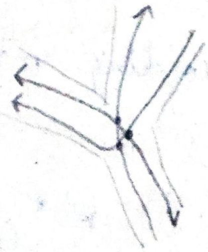
Accident zone @ a crossing

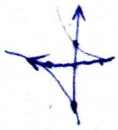


Imp for 1mark.

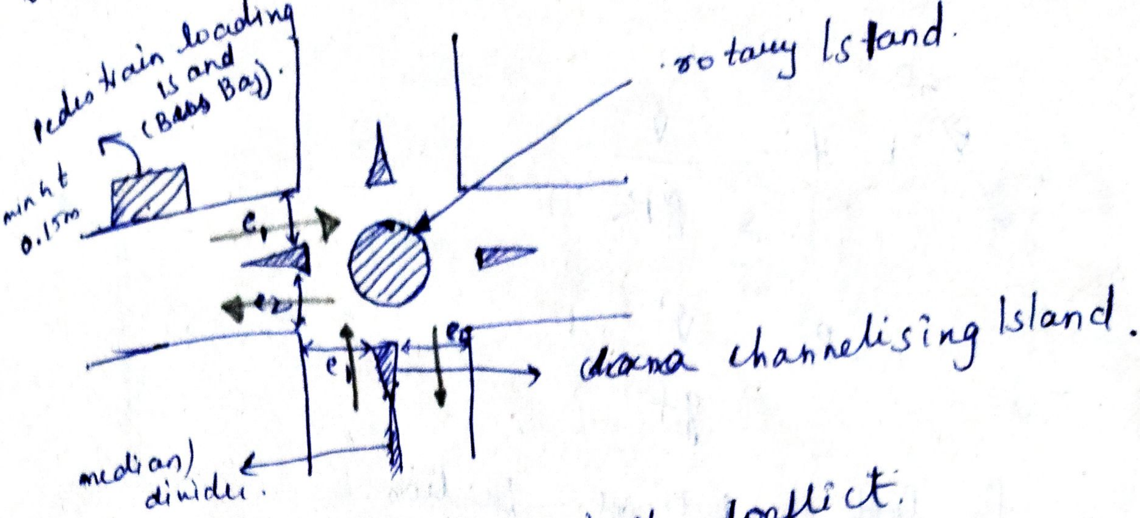
Type of roads meeting	No of POC
* both one way	6.
* one road: one way & the other 2way	12 -1 = 11
* both 2way	24

Dia - Text





TRAFFIC ISLANDS-



* Purpose : To minimise pts of conflict.

→ Design of Rotary Island

design speed :

rural area : 40 kmph.

urban area : 30 kmph.

[very much less than dgn speed of road).

Super elevation

* entry & exit is difficult

∴ No super elevation is provided on rotary road.

* Lateral friction manages centrifugal force

Radius of Rotary road

$$\cancel{e}^{0} + f = \frac{v^2}{gR}$$

$$\boxed{R = \frac{v^2}{gf}}$$

f= Coff of lateral friction

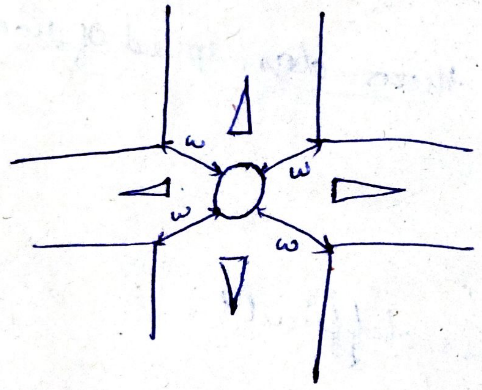
v = Dgn speed of rotary in (m/s).

e_1 = entry width

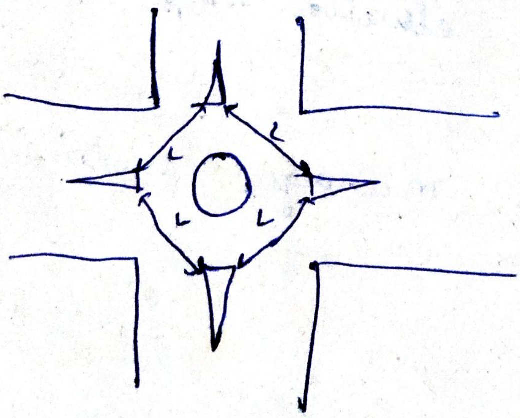
e_2 = exit width.

usually $e_2 > e_1$

if not specified use $e_1 = e_2$.



w = width of rotary road.
[width of road b/w 2 channelising Islands]



L= weaving length
dist b/w 2 adjacent channelising Islands
(In this length the weaving operation can be done)

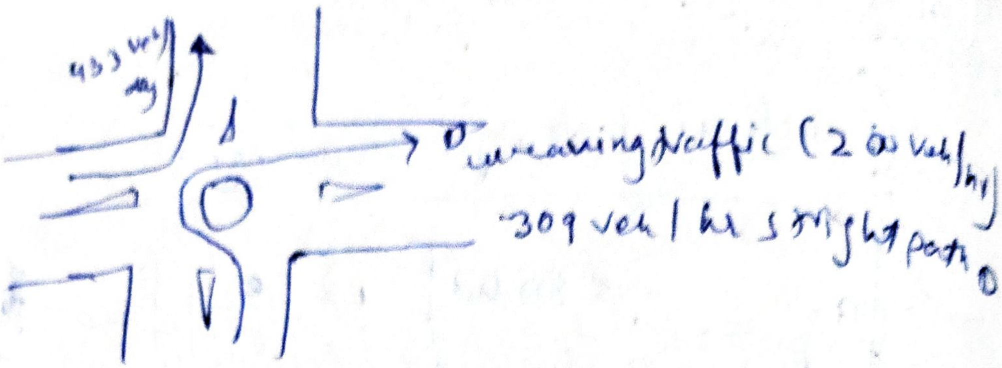
CAPACITY OF ROTARY ROAD

(Practical / design capacity)

$$Q_p = \frac{280w\left[1+\frac{e}{w}\right]\left[1-\frac{p}{3}\right]}{\left[1+\frac{w}{l}\right]}$$

empirical formula [illegible]

- $e = \frac{e_1+e_2}{2}$
  (avg of entry lanes)
- if not given
  $w = \left(\frac{e_1+e_2}{2}\right) + (3.5\ m)$ ← (width of exit lane excluding lane itself)
- l = length of weaving section
- p = proportion of weaving traffic to the total traffic
- $= \frac{\text{weaving traffic}}{\text{total traffic}}$



$$P = \frac{\text{weaving traffic}}{\text{Total traffic}}$$

$$P = \frac{330+200}{330+200+433+309}$$

$$P \sim 0.42$$

* More weaving traffic the capacity reduces

$\boxed{\uparrow P \quad \downarrow Q_P}$ Q_P = practical capacity

* If the weaving traffic is very high to improve the traffic at the rotary it is better to provide a fly over

Q) A round about is provided with avg entry & exit width as 6 m. width of weaving section is 12 m.. The length of weaving section b/w adjacent channelizing islands is 25 m. The crossing traffic

& total traffic on the weaving section are 1,500 & 2300, pcu per hr. resp the capacity of rotary is pcu/hr

Sol)

$$q_p = \frac{280w\left(1+\frac{e}{w}\right)\left(1-\frac{p}{3}\right)}{\left(1+\frac{w}{l}\right)}$$

$$q_p = \frac{280\times12\left(1+\frac{6}{12}\right)\left(1-\frac{1500}{2300\times3}\right)}{\left(1+\frac{12}{125}\right)}$$

$$q_p = 2665.1 \text{ pcu/hr}$$

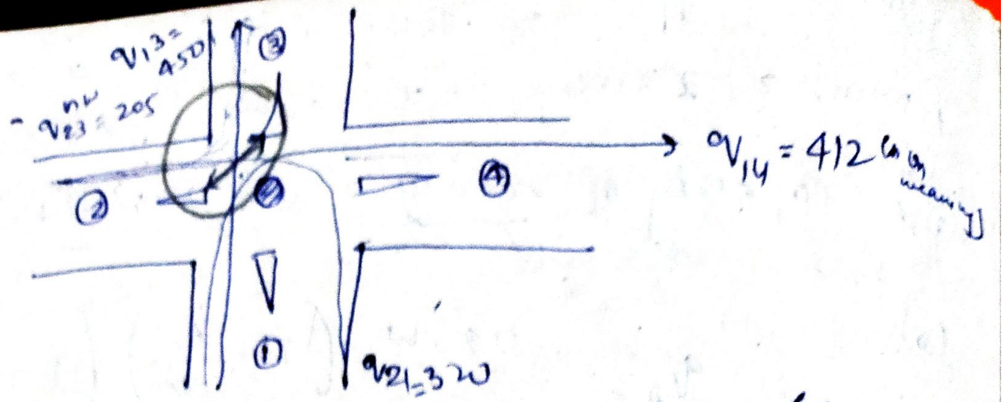
$$q_p \simeq 2665 \text{ (lower value)}$$

Q) The traffic flow on 4 legs of rotary intersection are given below, Determine proportion of weaving traffic b/w the legs 2 & 3.

Sol)

q_{12}	150	q_{21}	320	q_{31}	660	q_{41}	250
q_{13}	450	q_{23}	205	q_{32}	520	q_{42}	120
q_{14}	412	q_{24}	900	q_{34}	420	q_{43}	140

Sol



consider traffic b/w 2 & 3 only (traffic going through the circular zone should be considered)

The traffic crossing the red line joining adjacent channelising islands is weaving traffic other will non weaving.

$$P_{2-3} = \frac{\text{weaving}}{\text{weaving + non weaving}}$$

$$= \frac{(450 + 320 + 900 + [illegible] + 140)}{(450 + 320 + 900 + [illegible] + 140) + (412 + 205 + [illegible])}$$

$$= 0.745.$$

cal P_{3-4} = ?

P_{4-1} = ?

P_{1-2} = ?

In the design max of P_{1-2}, P_{2-3}, P_{3-4}, P_{4-1} should be considered.

|3|16

ROAD INTERSECTIONS:

* Road crossings

Types

① At grade intersection

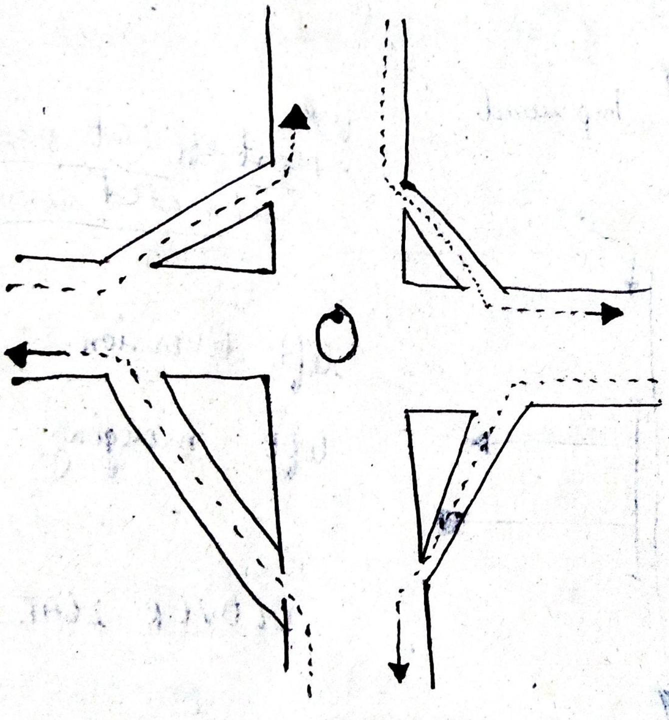
roads crossing @ the same grade | Same elevation

② Grade seperated intersection

roads crossing @ diffrent gradients | elevations.

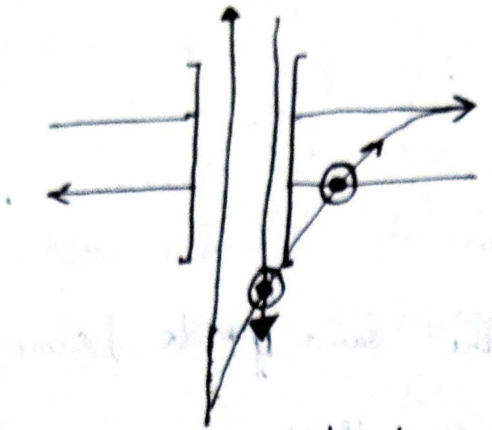
Eg: fly overs.

IMP Diamond intersection most effecient @ grade intersection



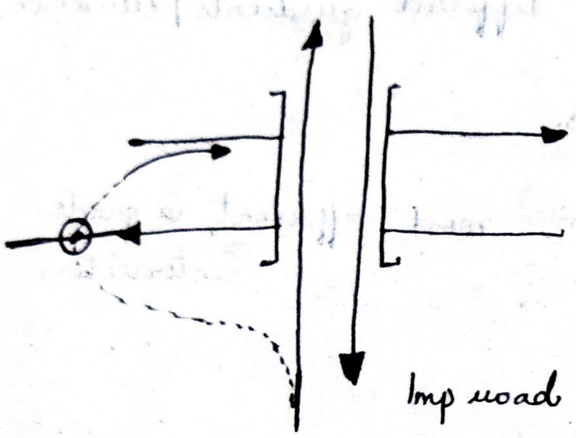
Grade separated

(1) Directed interchange



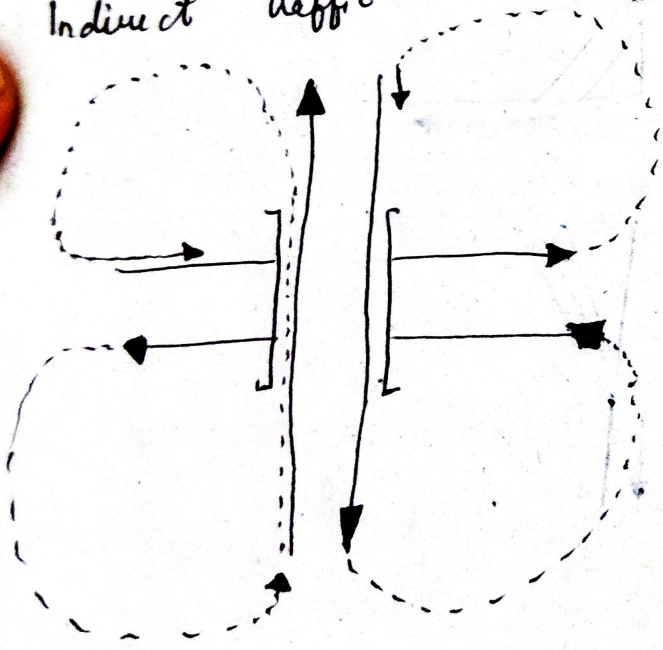
Right diversion &
Right merging

(2) Semi direct interchange



not so Imp.

) Indirect traffic

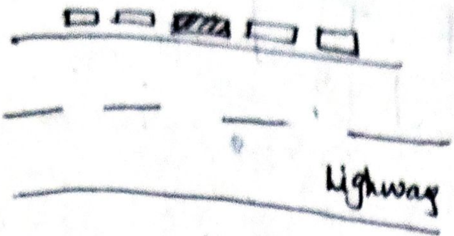


imp
Most efficient grade separated interchange

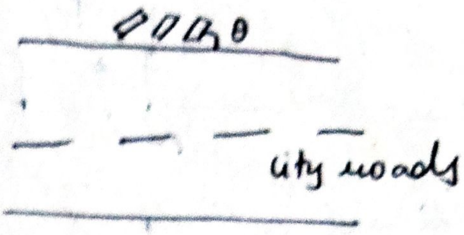
left diversion &
left merging.

CLOVER LEAF

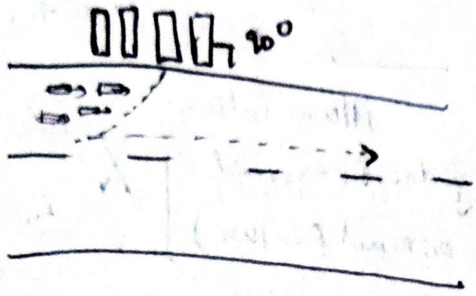
(1) way side / road side parking.



parallel parking.



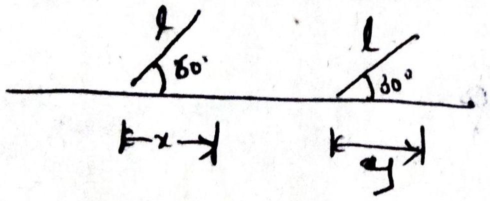
(2)



Space effective.

Eg Space required for 30° parking to 60° parking.

Sol



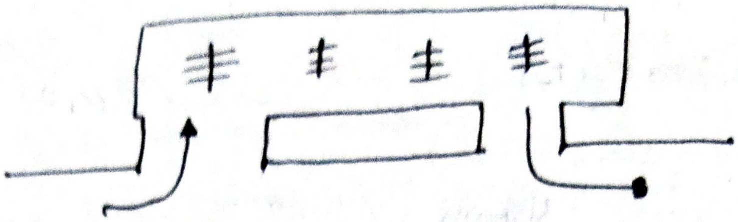
$$\cos 60^\circ = \frac{x}{l} \; ; \qquad \cos 30^\circ = \frac{y}{l}.$$

$$x = l\cos 60^\circ \; ; \qquad y = l\cos 30^\circ$$

$$\frac{y}{x} = \frac{\cancel{l}\cos 30^\circ}{\cancel{l}\cos 60^\circ} = \frac{1.73}{1}$$

(2) off street parking

* less disturbance for traffic.



HIGHWAY LIGHTING: (Im)

$$\text{Spacing of Lamps} = \frac{\text{lamp capacity (in lumens)} \times \text{coeffici utilizat} \times \text{maintance factor}}{\text{illumination} \left[\text{brigntness required on road (in lux)}\right] \times \text{width road}}$$

TRAFFIC CONTROLLING DEVICES

(1) Signals — 2m. V imp

(2) police

(3) Signs — Im Imp.

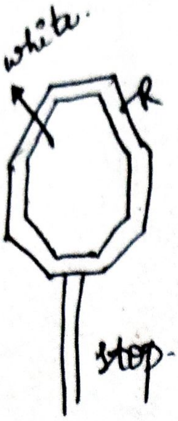
(4) medians, Rotary

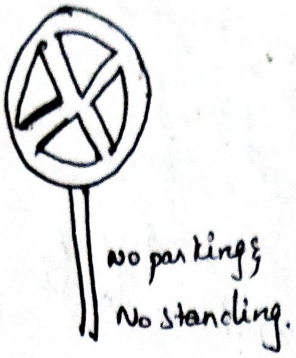
(5) road markings. (Imp)

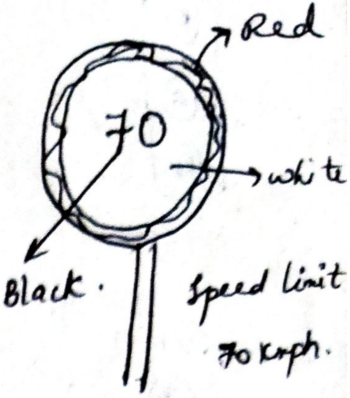
Traffic Signs

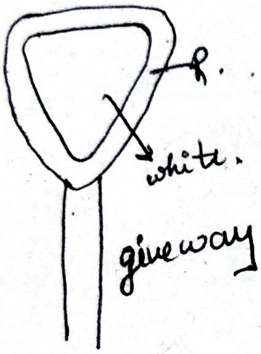
(1) Mandatory / regulatory / compulsory (VVIMP)

if not followed fine.





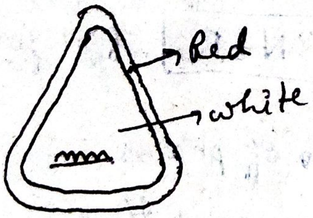




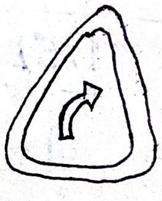
IRC mandatory sign Imp

(2) Warning / cautionary signs.

Not following fine is not charged.

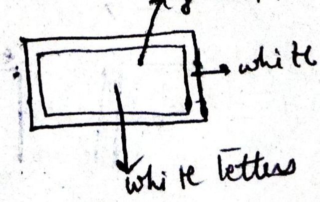


- level crossing.
- men at work.
- Speed breaker
- turn.

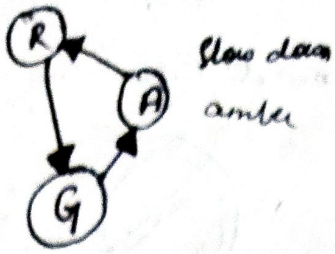


(3) INFORMATORY SIGNS

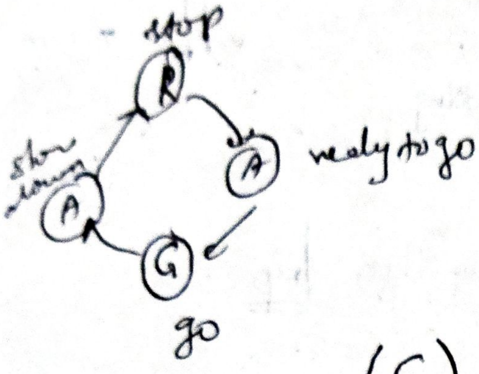
- petrol bunk ahead
- metro construction ahead etc
- Mile Stone



TRAFFIC SIGNALS:



new system



→ not in India.

Cycle time (C_0)

$$C_0 = R + G + A$$

Webster's Method (as per IRC) (IMP) V)

(Emperical formula)

$$\boxed{C_0 = \frac{1.5L+5}{1-Y}}$$

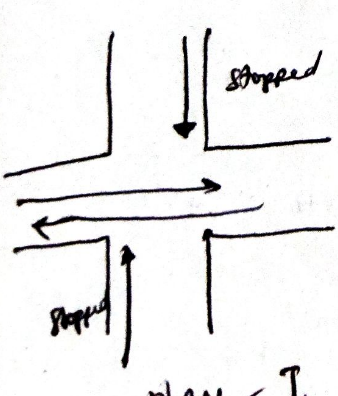
$Y = Y_1 + Y_2 + Y_3 + Y_4 + \cdots$

L = lost time per cycle (in sec)

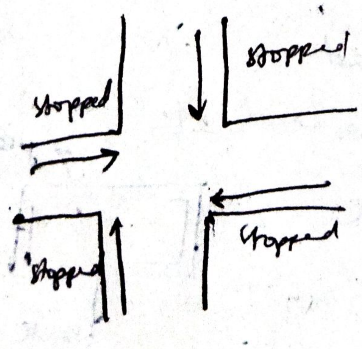
$\boxed{L = 2N + R}$ if n't given.

N = no of phases

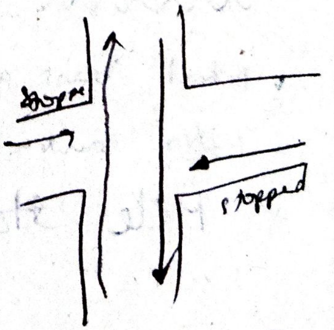
R = all red time



phase - I



All red time

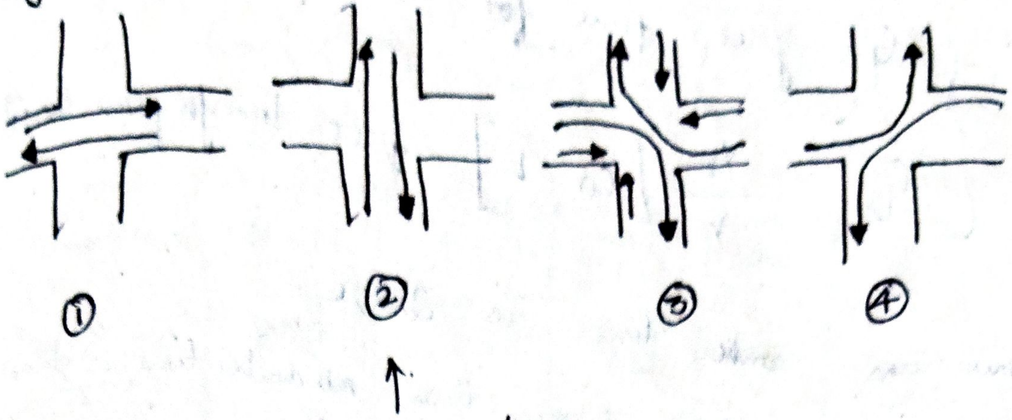


phase - 2

* All red time is based on observation till the rotary is cleared.

*

Right turning traffic is allowed



4 phase road

$$Y_1 = \frac{\text{normal flow on road}}{\text{saturated flow on road}} = \frac{q_1}{s_1}$$

$$Y_2 = \frac{q_2}{s_2}.$$

q_1, q_2, q_3 → normal flows / volume

s_1, s_2, s_3 → saturated flows / volume

Saturated flow

No of vehicles crossing a section, if completely green is given in unit time.

* Normal flow is the no of vehicles crossing a section of road (or) the junction in unit time with red & green ~~ga~~ signals going on.

* Saturated flow ; the no of vehicles crossing a section of road at a junction in unit time with green signal going on.

observation.

$G_1 = \frac{y_1}{y}[C_0 - L)$

where G_1: green time for phase -1

$G_2 = \frac{y_2}{y}[C_0 - L]$ green time for phase ~~2~~ 2

* minimum amber time is 2 sec.

* from the obtained green time ~~as~~ amber time is given.

~~lex~~

Q) The critical flow ratios for 3 phase signals are found to be 0.3, 0.25 & 0.25. The total time lost in the cycle is 10sec. The pedestrians crossing at the junction are not significant. The respective green times expressed in secs & rounded to nearest integer ~~(s)~~ are ______

Sol ~~1.252.~~

$$C_0 = \frac{1.5(10)+5}{1-(0.3+0.25+0.25)}$$

$C_0 =$ ~~[illegible]~~ 100s

$G_1 = \frac{0.3}{0.8}[100s - 10] = 34s$

$G_2 = \frac{0.25}{0.8}(100 - 10) = 28s$

$G_3 = \frac{0.25}{0.8}(100 - 10) = 28s.$

$$\boxed{\text{Check} = G_1 + G_2 + G_3 = (C_0 - L)}$$

Q) A

12 sec. Th

are ment

(i) cycle

(ii) green t

Parameters
q(PCU/hr)
S(PCU/hr)

Sol C

Y =

Y =

Co

C

$G_{N\to}$

$G_{E\to}$

1) A 2 phase signal the lost time per cycle 12 sec. The normal & saturated flows in diff directions are mentioned in the table. determine.

i) cycle time.

(ii) green times on north south & east west roads.

Parameters	N	S	E	W
q (PCU/hr)	800	600	650	770.
s (PCU/hr)	1500	1500	2000	2000.

Sol

$$C_0 = \frac{1.5L+5}{1-Y}$$

PCU = passenger car units. per hr.

$$Y = \frac{800}{1500} + \frac{770}{2000}$$

$q_{N\to S} = 800$

$q_{EW} = 770$

$Y = 0.9.$

$S_{N\to S} = 1500$

$S_{E\to W} = 2000$

$$C_0 = \frac{(1.5 \times 12)+5}{1-0.9}$$

$Y_1 = 0.53$

$Y_2 = 0.385$

$C_0 = 230\,s$

$$G_{N\to S} = \frac{0.53}{0.9}\left[230-12\right] = 129\,s$$

$$G_{E\to W} = \frac{0.39}{0.9}(230-12) = 96\,s.$$

Check: $\boxed{G_{NS} + G_{EW} = (C_0-L)}$

Capacity of EW road

* capacity = max traffic volume which can be accomed

$q_0 \rightarrow q_{NS}$

$C_0 \rightarrow g_{EW}$

$G_{EW} \rightarrow C_{EW} = ?$ (capacity)

$230 \rightarrow 2000$

$96 \rightarrow C_{EW} = 834$ p

∴

Capacity of NS road.

$230 \rightarrow 1000$

$122 \rightarrow C_{NS} =$ 796 sec

In N→S roads the critical capacity of the road is 796 PCU per hr (upto 796 pcu/h the signals in N → S direction can opperate smothly with given green time of 122 s). In presen condition the critical traffic in N→S direction is 800 pcu/hr which is more than 796.

∴ Adjust the green time N→S direction to accomedate 800 pcu/hr

* take $C_{NS} = 800$

$x \rightarrow 1000$

$122 \rightarrow 800$

$= \cdot C_0 \approx 229s$

$\simeq 230s$

Webster's Delay

green

Average delay per cycle (in sec) $\Big\}$ $$d_i = \frac{\frac{C_o}{2}\left[1-\boxed{\frac{G_i}{C_o}}\right]^2}{\left[1-\frac{q_i}{S_i}\right]}$$

If data is not given avg delay on a road $= \frac{\text{Red time}}{2}.$

(Q) The cycle time on a signalised junction is 90sec. The effective green ratio is 0.55. The normal flow on the road is 1000 V/hr, saturated flow is 2500 V/hr. determine avg delay. also determine the critical capacity of the road.

$$\text{Green ratio} = \frac{\text{green time of a road}}{\text{cycle time}}.$$

$$d_i = \frac{\frac{90}{2}\left[1-0.55\right]^2}{\left(1-\frac{1000}{2500}\right)} = 15.18\text{ s}$$

per cycle (avg delay)

Critical capacity of Road

$Co \rightarrow S_i$

$G_i \rightarrow C_i = ?$

$Co \rightarrow 2500$

$G_i \rightarrow C_i = ?$

$$C_i = 2500\left(\frac{G_i}{Co}\right)$$

$= 2500(0.55)$

$C_i = 1375$ v/hr

Effective green time

The green time which can be utilized by the vehicles.

Effective green time (Imp) = Actual green + Amber ⊖ delays.

Types of delay → start up delay.
→ clearance delay.

Eg Actual green time = 98 sec
Amber time = 2 sec
start up lost time : 5 s.
clearance lost time = 3 s.
effective green time = 98 + 2 − 8
= 92 sec

Q) The cycle time of an intersection is 60s the green time for the phase is 27 sec. Yellow (Amber) time 4s start up lost time 5 sec clearance lost time is 2 sec. Saturation head way is 2.4 s / vehicle determine critical capacity of the lane.

L=

Sol

Satu

Satu

effective

criti

Pede

$L = 60S.$

Sol

saturation head way = 2.4 s/veh.

saturated traffic flow $\Big\} S_i = \frac{1}{2.4} \cdot \frac{veh}{sec}$

$= \frac{60 \times 60}{2.4} \frac{veh}{hr}$

$= 1500$ veh/hr.

effective green time = $27 + 4 - 5 - 2$

$= 24$ sec

critical capacity of lane = $C_0 \rightarrow S_i$

$g_i \rightarrow C_i = ?$

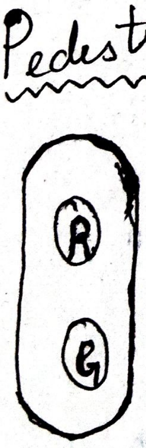
$60 \longrightarrow 1500$ veh/hr

$24s \longrightarrow C_i = ?$

$C_i = \frac{24 \times 1500}{60} = 600$ veh/hr

Pedestrain Green time:

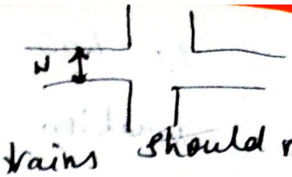
$G_p = t_s + \frac{W}{V_s}$ ∤ Red time on road.



t_s = Start up delay (Pedestrains = 2.4S) as per IRC

V_s = Speed of pedestrain (1.2 m/s as per IRC)

$V = \frac{dis}{t} = \frac{w}{2.4}$



The green time for pedestrains should nt be less than red time of road. Otherwise the all red time is increased for the same & crossing of pedestrains.

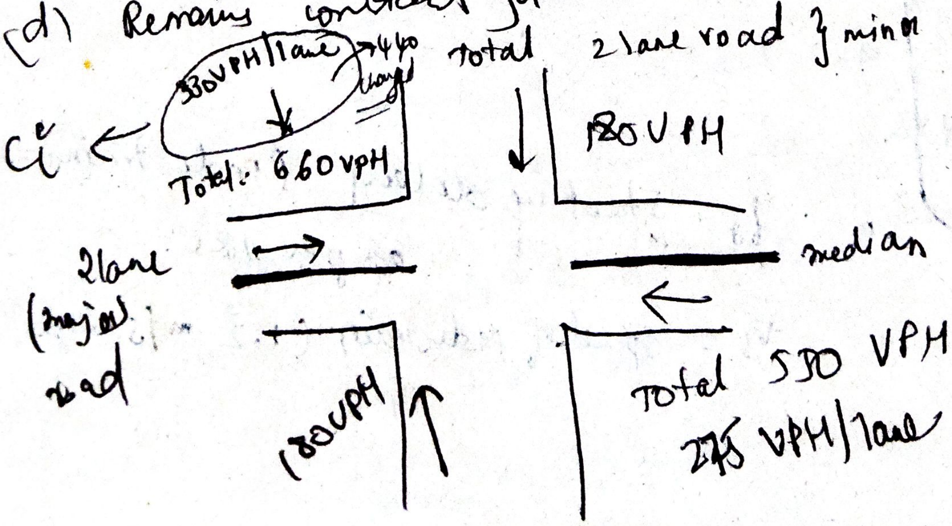
Q) In the signalised intersection the green time for major & minor roads respectively (or) 34 sec & 18 sec respectively. The criticallane volume on major road. is changed to 440 vehicles/hr per lane. which of the following statements is true

~~(a)~~ ↑ increase green tym for major road & same for minor

(b). ↑ green time for minor road & same for major

(c) ↑ same for both

(d) Remains constant for both



Sol (a)

Q) In a signa

which of the

nt possible

~~(a)~~ 2-4; 4

(b) 1-4; 3-

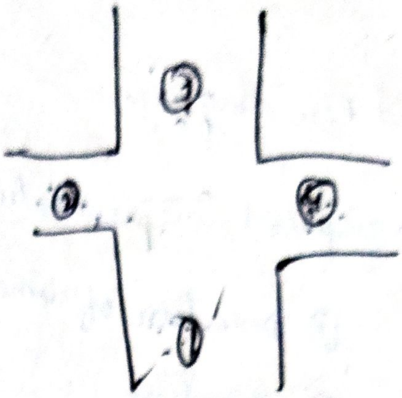
~~(c)~~ 2-4; 2-

~~(d)~~ 3-4; 4

Sol (a), 4 d

(a)

) In a signalised junction showed in fig which of the following traffic flows are nt possible at a time



(a) 2-4; 4-2; 3-1; 1-3

(b) 1-4; 3-2; 3-3; 1-1

(c) 2-4, 2-1, 3-1, 3-3.

(d) 3-4; 4-3; 1-2; 1-4

Ans (a), c d are nt possible

8 - 1 red
-(311)
2-8-(304)