CE 8604 - HIGHWAY ENGINEERING

UNIT - I

HIGHWAY PLANNING AND ALIGNMENT

Significance of highway planning - Modal limitations towards Sustainability - History of Road development in India - factors influencing highway alignment - Soil suitability analysis - Road ecology - Engineering surveys for alignment, objectives, conventional and modern methods - classification of highways - Locations and functions - Typical cross sections of Urban and Rural roads

Significance of Highway Planning

* Transportation contributes to the economic, industrial, social and cultural development of any country.
* It is vital for the economic development of any region.
* Since every community produced whether it is food, clothing, industrial clothing products or medicines need transportation and all stages from production to distribution.
* The adequacy of transportation system of a country indicates its economic and social development.

Highway Planning

* Highway planning is a basic need for highway development.
* Particularly is a basic need for highway planning of great importance when the funds available or limited were as total requirement is much higher.

Significance:

- To provide safe, efficient, economic, comfortable and speedy moment for people & goods.
- To plan for expected features development & Social needs to fix update wise properties for the development of each road link based on utility.
- To optimize the usage of roads with available resources.
- To work out a financing system.
- wide geographical area coverage provided by roads.
- Low capital investment.
- Quick & assured deliveries.
- Employment potential.
- Personalized travel.
- Environmental pollution
- Parking problem
- Long hauls - It has been found that most commodity movements are cheaper by road for short hauls upto 300 - 350 kms. But beyond this range, the cost advantage lie with the railways.
- Road transport consumes greater energy per passenger km & tone km than railways.

Objectives of Highway Planning:

* Planning a highway network for safe, efficient, and fast movement of people and goods.
* Keeping the overall cost of construction & maintenance of the roads in the network to a minimum.
* Planing for future development and anticipated trafic needs for a specific design period.

- Phasing road development programmes from consideration of utility & importance as also of financial resources.
- Evolving a financing system compatible with the cost and benefits.

Model Limitations towards Sustainability

1. Roadways
2. Railways
3. Waterways
4. Airways

The transportation by air is fasted among the four modes. It also provide more comfort apart from saving time.

- Transportation by water is slowest. It needs minimum energy to haul unit load through unit distance. It is possible between parts on sea route or along the rivers or canals wherein land transportation facilities are available.

- Road transport can provide door to door service only. This mode has also the maximum flexibility for travel with reference to route, direction, time & speed of travel.

Scope of Highway Engineering

The road pavements are generally constructed small embankments. Slightly above the general ground level wherever possible inorder to avoid the difficulties in drainage, & maintenance problems.

Scope of Highway Engineering

- **Phases** → **Details**

Development, Planning & Location → Historical background, Basis for planning, Master plan, Engineering Surveys, Highway alignments.

Design, Geometrics & Structures → Road design, Rigid & flexible pavements, Design factors, thickness design, Overlay design, Design of drainage system

Necessity of Highway Planning:

* To plan a road network for efficient & safe traffic operation, but @ minimum cost. The cost of Construction, maintenance and renewal of pavement layers & the Vehicle operation cost are to be given due to consideration.

* To arrive @ the road system and the length of different categories of roads which could provide maximum utility & could be constructed within the available resources during the plan period under consideration.

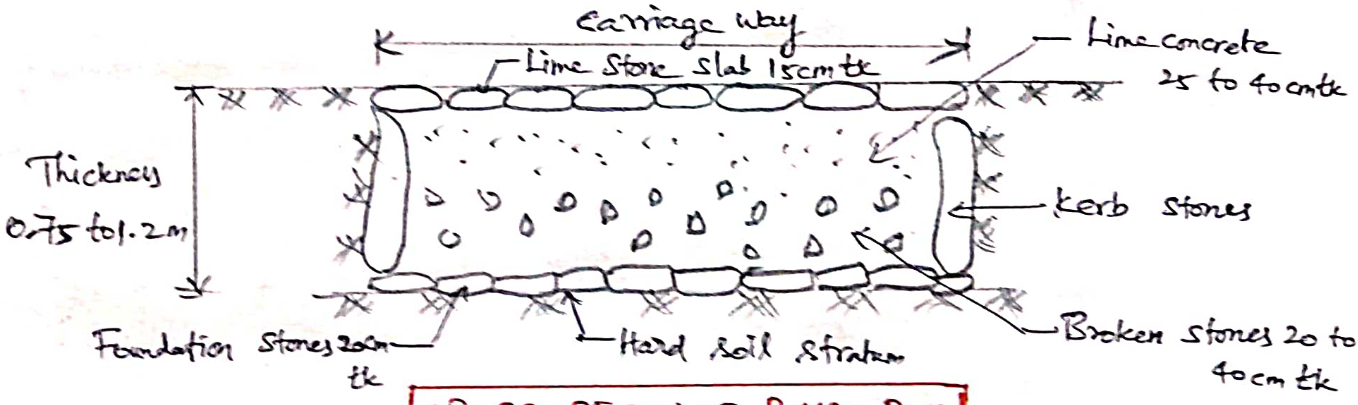
* To fixup datewise priorities for development of road lines based on utility as the main criteria for phases the road development programme.

History of Road Development in India: (Road construction)

- The history of road construction the development of various civilizations.
- The ancient people came to a realization of the importance of improved roads.
- the construction of magnificient roads to move the materials to construct those structures.
- The history of road construction divided by the following four types:

1. Roman Road construction
2. Tresaguets Road construction
3. Telford Road construction
4. Mecadam Road construction

ROMAN ROAD CONSTRUCTION:



CROSS-SECTION OF ROMAN ROAD

The technique of road construction adopted by Romans was found from the following construction of 600km.

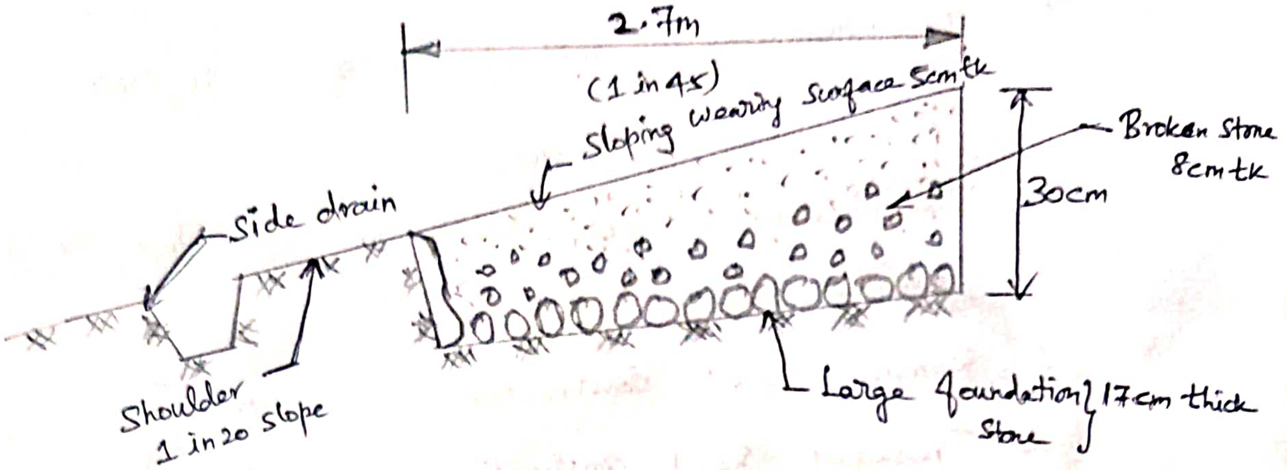
The salient features of Roman roads.

i) straight alignments without gradients.
ii) Soft soils removed till a hard stratum was reached.
iii) The carriage way trench as high as 0.75 to 1.2m
iv) The vertical kerb stones were placed along the edges.

v) The depth of broken stones placed 20 to 45 cm

vi) The wearing course consist of dressed large stone blocks 10 to 15 cm thick.

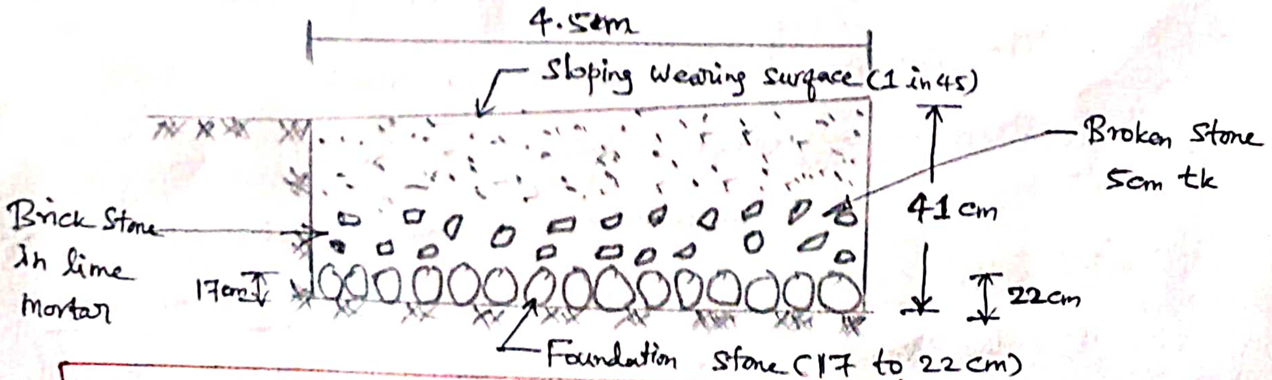
TRESAGUET ROAD CONSTRUCTION:- [1716-1796]



TYPICAL CROSS-SECTION OF TRESAGUET ROAD CONSTRUCTION

* Till a hard stratum was reached and the foundation (subgrade) was prepared well.
* The Large foundation Stones were laid on edge manually.
* The broken stones were packed above the stone layer about 8cm thick.
* The centre of cross slope gradient of 1 in 45 and the shoulder slope 1 in 20.
* The surface drainage provided near by the shoulder.

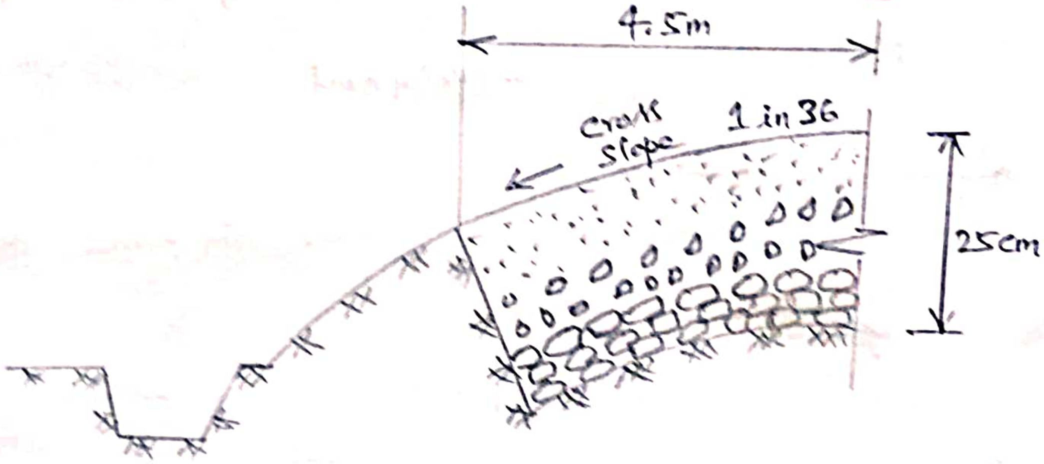
TELFORD ROAD CONSTRUCTION: [1757-1834]



TYPICAL CROSS-SECTION OF TELFORD CONSTRUCTION

* The width of carriage way about 9m was prepared.
* The size of 17 cm laid towards the end of the road.
* It was increased gradually towards the centre of size 22 cm.
* The size of 10 cm angular broken laid over the smaller sized broken stones.
* The wearing course by well compacted gravel with a cross slope of 1 in 45.

MECADAM ROAD CONSTRUCTION :- [1756-1838]



* The importance of subgrade drainage and compaction, the subgrades were prepared with sufficient cross slope '1 in 36'.
* The total thickness of trench as high as 25cm.
* The depth of broken stone 10 cm thick.
* The width of carriage way about 9m wide.

Further Development:

* Mecadam's method has been accepted scientific method.
* The most popular method known as Water Bound Mecadam (WBM).
* In this method, broken stones were used along with stone dust.
* The traffic load increased new methods of road construction such as bituminous road contruction.

HIGHWAY DEVELOPMENT IN INDIA

* Before B.C. → Mohanjadaro and Harappa existed b/w 3500 to 2500 B.C. of broad cities
* Mughal Period
  - ↳ The width of road 6 to 7.5m built by king bimbara 60 B.C.
* British Period → 270 B.C. King Asoka constructed a good network of roads.
* After world wars →
* Jayakar Committee Recommendations and Realisations
* Modern Highway Development

MUGHAL PERIOD

* In this period 24 long roads connected different parts of the country.
* The Road development special attention of Mughal Period.

BRITISH PERIOD:

- A series set back was faced by road construction of british period.
- Britishers few truck roads and bridges constructed.
- In 1853 the Introduction of railways, only a few road construction was carried out.

AFTER WORLD WARS (1939)

- After world wars, Jayakar Committee was formed.
- It was realised that the country must have effective system.
- The chief engineers were held at Nagpur plan in 1943.

Jayakar Committee Recommendations and Realisations

* In the year 1927 the Indian Roads and Transport Development Association (IRTDA) was set up the transport problems and recommend improvements.

In the year 1928 Jayakar committee submitted the following recommendations:

- The road development made by the State government and local bodies were beyond their limit.
- The road development expenses an extra to be levied on Petrol and to be named as CRF. (Central Road Fund)
- The board of road development, Improve the technical supports.
- A research organisation has to be set up national level Research on roads.

Indian Road Congress (IRC) was formed in 1934 and Central Road Research (CRRI) Institute was formed by Jayakar Committee in 1950.

Indian Roads were classified into following five categories. (Nagpur Plan, 1943)

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

MODERN HIGHWAY DEVELOPMENT:

a) Nagpur Plan
b) Bombay Plan
c) Road Development Plan (1981-2001)
d) Road Development Plan (2001-2021)

* The initiation of Nagpur plan which is known as the "First twenty-year plan"

* The National Highway development programmes formed a Golden Quadrilateral comprising a length of 5846 km (connecting Chennai, Mumbai, Delhi, Kolkata)

* North-South and East-West corridors comprising a length of 7300 km (connecting Kashmir to Kanyakumari (4000 k... and Silchar to Porbandar [3300 km]

* In India, is criss-crossed by several rivers of different sizes over the years major bridges were constructed on National Highways and other State Highways.

* Single lane roads have been widened and strengthened.

* In urban areas flyover have been constructed to meet the increasing traffic movement quick and safe.

Institutions for Highway development at National level

i) Indian Roads Congress (IRC)
ii) Highway Research Board (HRB)
iii) National Highway Authority of India (NHAI)
iv) Ministry of Road Transport and Highways (MORTH)
v) Central Road Research Institute (CRRI)

Indian Roads Congress (IRC):

* Indian Road congress was set up in December 1934. It was formally registered as a Society in 1937 (Act of 1860)

1) Role of IRC:

i) To encourage the Science and Practice of construction and maintenance of roads.

ii) To improve the method of administration, planning, design, construction and operation.

iii) To promote the standard specifications and propose specifications.

iv) To advise regarding education, experience and research of roads.

v) To development, Improvement and protection of Roads.

vi) To maintain, libraries and museums for furthering the science of road making.

vii) To publish Journals and other literature for the promotion of the objects of the society.

2. Spectrum and activities:

1) Accepted bridge standard specifications.
2) Codes of Practice
3) Experimental and Testing work carried out.
4) Mechanism results of road research.
5) collective opinion of road Engineers in India.

The Indian Roads Congress involved multi-faceted Activities,

➤ The foundation for the growth and development of road and road transport in India.

a) Nagpur Plan (1941-1961)
b) Bombay Plan (1961-1981)
c) Road Development Plan (1981-2001)
d) Road Development Plan (2001-2021): Vision 2021.

➤ Publication of standards relating to roads.

➤ Publication of Standard Specification and codes of practice of bridge.

➤ Holding National and International seminars and workshops on road transport.

- Interacting with ministries of Road transport develop... Railways, Science and Technology.

Highway Research Board (HRB)

Highway Research Board was set up in 1973. HRB National Centre for road research with the following role to play.

1. Role of HRB:

- To extent of research required.
- To collect research information from various organisation and abroad.
- To sponsor research organisation.
- To collect the disseminate results and research.
- To involve related road research.

National Highway Authority of India (NHAI): [Established in 1988]

- To take responsibility of development and maintenance of all NH's in the country with in a period of 5 years.
- To manage the NH Network and the provides safety and comfort.
- To improve and extend the NH Network.
- To seek visible way to improve the private sector in the provision, operation of roads.
- Improve road safety including road geometrics.
- Provide on-route facilities for road users.

Ministry of Road Transport and Highways (MORTH):

- Headed by Director general, under the central government.
- To formulate plans for development and maintenance of national highway in consultation.
- To examine technically to the protect the roads and bridges.
- To administrate the central road program fund.

- To administrate the central road program.
- To co-ordinate matters pertaining to road research and administer central funds.
- Extent technical and financial support to State governments.
- Evolved Standard specifications for roads and bridges in the Country.
- Serves as a repository of technical knowledge on roads and bridges.
- Preparation and Implementation of Annual Road Safety plan.

Central Road Research Institute (CRRI): [Established in 1948]

- Research and development of roads and runways.
- Traffic and Transportation planning of mega and medium cities.
- Management of roads in different terrains.
- Landslide control and ground improvements.
- Environmental pollution.
- Road traffic Safety analysis and design.
- Performance monitoring / evaluation of roads.
- Technical and Consultancy services to various user organisations.

Requirements of Ideal Alignment:

- ★ Direct → Short and direct possible
- ★ Interference → overhead transmission lines, water supply lines.
- ★ Crossings → Railway crossings
- ★ Environment → Should not disturb landscape, birds
- ★ Existing facilities → Should not disturb historical monuments
- ★ Construction material → Available Construction material
- ★ Road foundation → Should be avoided loose soil, poor drainage
- ★ Grades and Curves → low grades and easy curves
- ★ Earthwork → Possible cutting and embankment.

Factors Controlling Alignment :

i) Traffic
ii) Geometric design
iii) obligatory Factors
iv) Economy
v) other considerations

In hilly areads additional care has to be given for
a) Stability - hill roads slope
b) Drainage - Proper drainage facilities
c) Geometric Standards for hilly region
↳ Gradient curves
d) Resisting length → Ineffective rise & fall

i) Traffic :

- The alignment should suit traffic requirement for the new road.
- Should keep in view the designed lines traffic flow pattern and fume trend.
- origin & destination study should be carried out. in the area and the desire lines be drawn showing the trend of traffic flow.
- New road to be aligned should keep in view the desired lines, traffic flow pattrons & future trends.

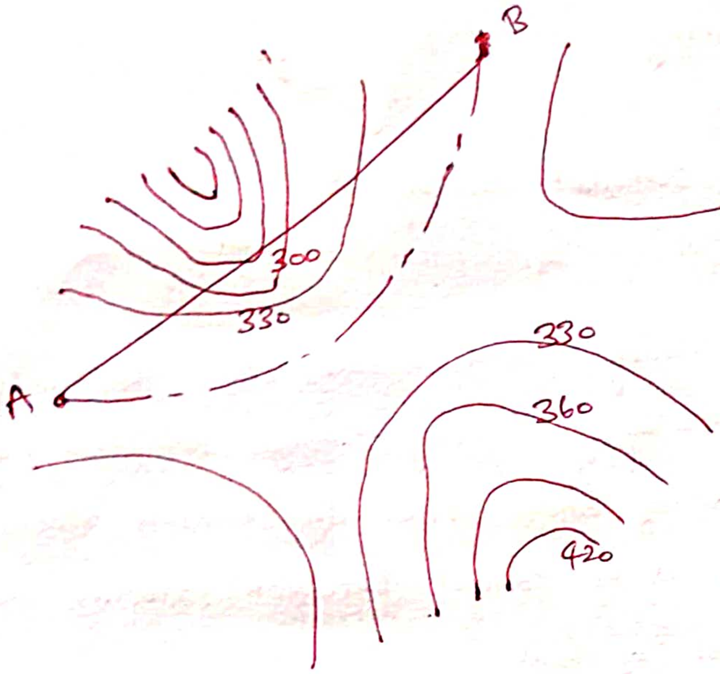
ii) Geometric Design :

- Factors such as gradient, radius of curve & sight distance also would govern the final alignment of highway.
- As far as possible while aligning a new road, the gradient should be flat & less than the ruling (or) Design gradient.
- The absolute minimum sight distance which should invariably be available in every section of the road is to safe stopping distance for the fast moving vehicles.

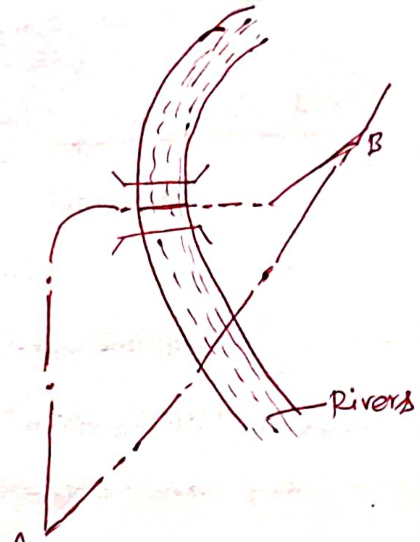
iii) Obligatory points :

- Control points governing the alignment of the highways.
- Divided into two catagories.
- Points through which the alignment to often deviate from the shortest (or) easiest path.
- Various examples are bridge site, intermediate town, a maintain pass.

- when it is necessary to cross hill range, mountains (or) high ridges the various alternatives are to cut a tunnel across (or) to go round the hills (or) to deviate until a suitable hill pass is available.
- The above alternatives are selected based on the topography of the site.



Alignment along a hill side pass



Alignment to suit proper location of bridge

- Obligatory points through which the road should not pass also may make it necessary to deviate from the proposed shortest alignment.
- The obligatory points which should be avoided while aligning a road include religious places, very costly structures, unsuitable land etc...

iv) Economy:

- Alignment finalised based on the above factors should also be economical.
- Initial cost of work.
- cost of maintenance & vehicle operation should be taken into account.

v) Other considerations:

- Drainage considerations
- Hydrological factors
- Political considerations
- Monotony
- Seepage flow & high flood level.

Engineering Survey for alignment, objectives, conventional & modern methods

Stages of Engineering Survey are

1. Map study
2. Reconnaissance Survey
3. Preliminary Survey
4. Final location & Detailed Survey

1. Map Study:

Alignment avoiding valleys, ponds or lakes. when the road has to cross a row of hills. possibility of crossing through mountain pass.

Approximate location of bridge site for crossing rivers, avoid bend of river. when a road is to connect between stations, one on the top and other on foot of hill.

2. Reconnaisance Survey:

* Valleys, Ponds, lakes, marshy lands, hills are avoided along route reconnaissance Survey. Approximate value of grade. No. of drainage system. Maximum flood level & Natural ground water level. Soil type along routes. Sources of construction material.

* Simple survey instruments are used in the reconnaissance procedure.

3. Preliminary Survey:

* To survey alternate alignments. Proposed after the reconnaisance & collect all physical information & details of topography.

* Compare different proposes.

* To estimate quantity of earthwork materials, cost of alternate proposals, sophisticated survey instruments are used. during preliminary Survey. To finalise the best alignment.

Methods of Preliminary Survey

1. Conventional Approach
2. Modern method.

1. Conventional Approach:

- Traverse → run from start to end points, various control points
- Levelling work → Along the centre line (of) proposed road, estimate volume of earthwork
- Topographical features → All geographical & man-made features plotted along the traverse
- Drainage Studies & Hydrological Data → The number of cross drainage structures are estimated.
- Soil Survey → Working out details of earthwork, slope, stability of materials, subsoil & surface.
- Material Survey → Location of construction materials need to be known
- Traffic Survey → Number of lanes, roadway width & pavement design need to be done.
- Determination of final center line → After completion of all the above mention steps.

2. Modern Method:

- Taking aerial photography with required lateral & longitudinal overlaps.
- These are examined under stereoscope and control points are selected for the establishment of traverse.
- The spot lines/levels and contour lines may be obtained from the stereo-pair observations.
- Photo interpretation method is used to grab information on the geological features, soil conditions, drainage requirements.

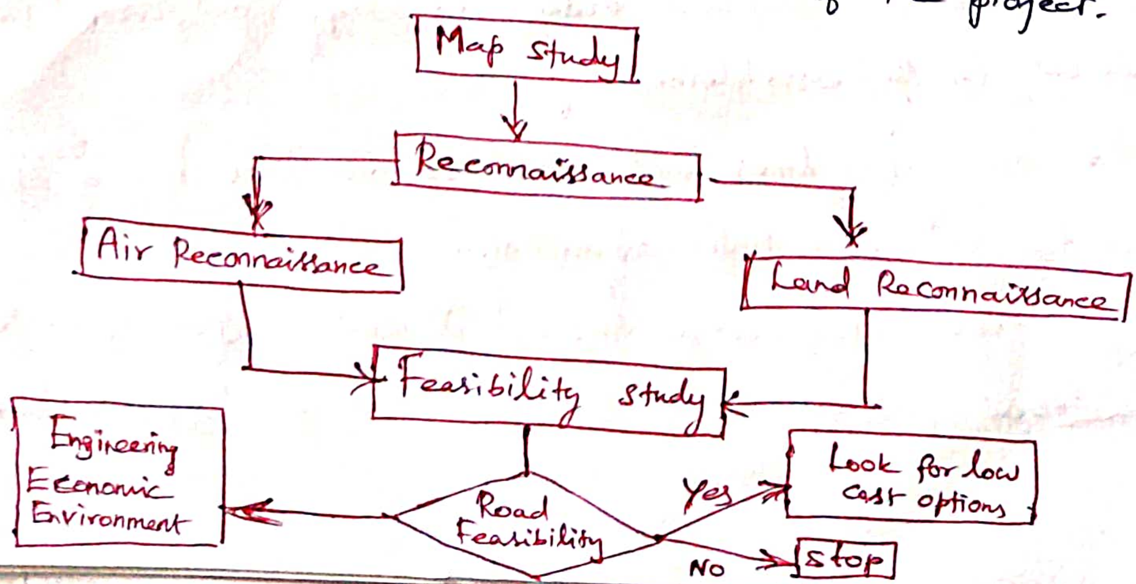
4. Final location and Detailed Survey

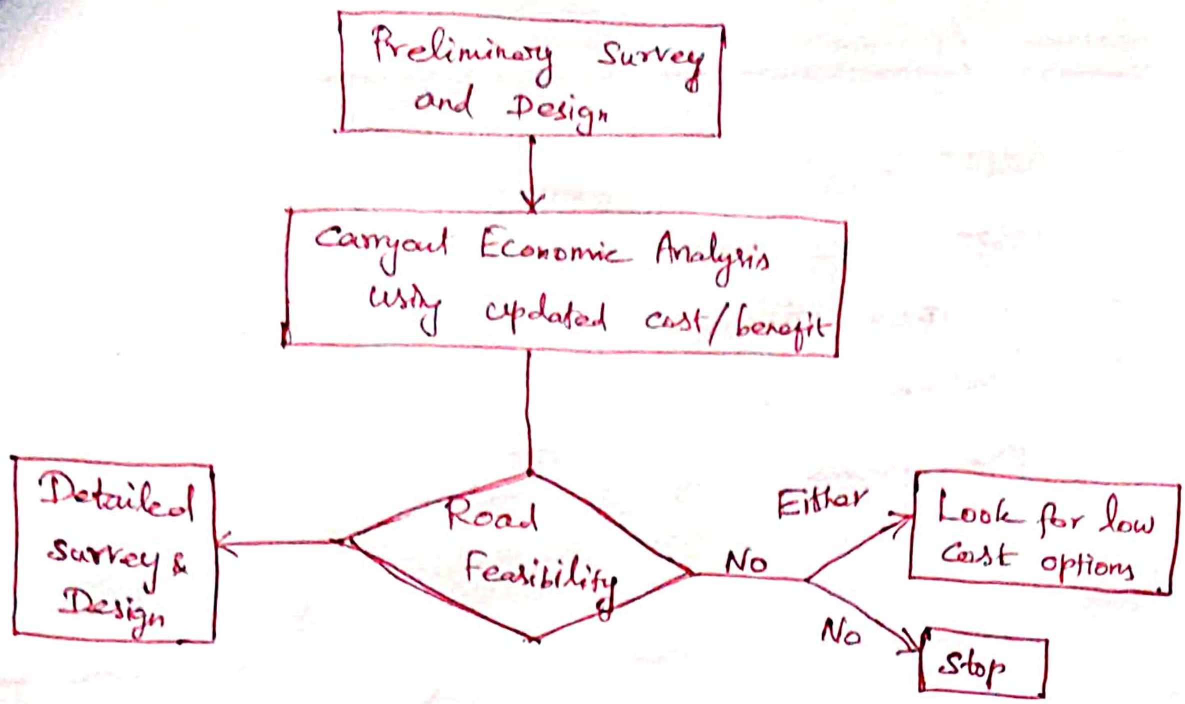
The centre line of the road which is finalised in the prelim. survey is then located in the field. Major & Minor control points are then established on the ground and the central pegs are driven, checking the geometric design criteria. If necessary, the modification of the final location can be altered.

Detailed Survey:

- Temporary Bench marks are fixed at all under pass structures and drainage structures. Levels along the final centre line should be taken with great importance as these data are required for vertical alignment, earth work calculation and drainage details.

- A detailed survey is carried out to enable drawing the soil profile up to the depth of 1.5 to 3 m below the ground line and twice the height of the finished embankment in the case of high embankment. The data during the detailed survey should be elaborated and completed for the preparation of the plans, designing and estimation of the project.





MODERN METHODS OF SURVEY:

- Photogrammetry and Air Survey

Photogrammetry is defined as the Science of obtaining reliable measurements by the use of photographs in order to determine the characteristics such as size, shape, & position of photographed objects.

Techniques:

a) Aerial photogrammetry: Using photographs taken from air or from space with camera usually pointing vertically downwards.

b) Terrestrial Photogrammetry: Using photographs taken on ground with the camera usually pointing in a horizontal direction. A Steno pair of aerial photographs

Photographic Interpolation:

Photographic information is concerned with the examination of photographs in order to identify objects, and is an essential part of air survey.

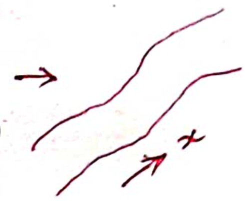
UNIT-II

GEOMETRIC DESIGN OF HIGHWAYS

Cross - Sectional elements - Sight Distances - Horizontal curves, Super elevation, transition curves, widening at curves - Vertical curves - Gradients, special consideration for hill roads - Hairpin bends - Lateral and Vertical clearance at underpasses.

Horizontal Alignment

- Sight distance (Horizontal x axis)



Vertical Alignment - Vertical axis, Rise and fall

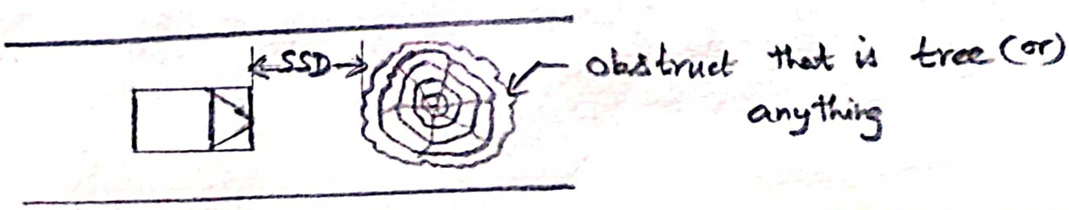
Sight Distance (SD):

* Actual distance along the road surface.
* A driver from a specified height above the carriage way has visibility of stationary (or) moving objects.

Types:

1. Stopping Sight Distance (SSD)
2. Overtaking Sight Distance (OSD)
3. Intermediate Sight Distance (ISD)
4. Safe sight Distance at Intersections.

1. Stopping Sight Distance (SSD)

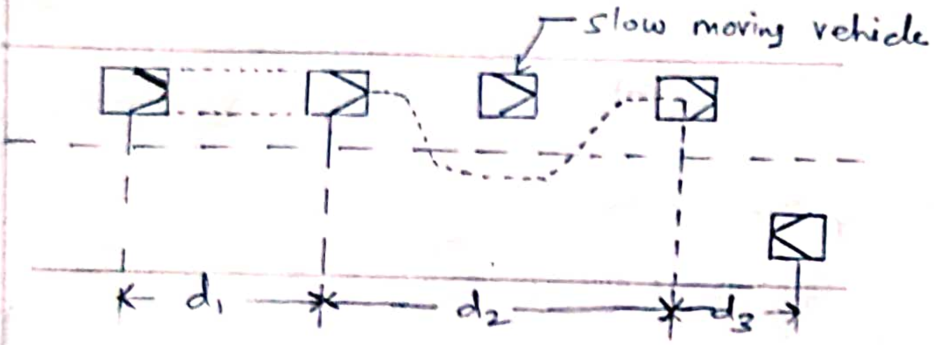


* Distance travelled during reaction time (lag distance)
* Distance required breaking vehicle (breaking distance)

| SSD = Lag Distance + Breaking Distance |

* General equation, | SSD = $V_t + V_{22g}$ ($f_o = o/n$) |
* The sufficient length to enable the driver to stop a vehicle travelling at design speed safety without collision with any other obstruction.

Overtaking Sight Distance (OSD)



* The overtaking sight distance is the vision of the driver of a vehicle intending to overtake the slow vehicle.
* ahead safety against the traffic in opposite direction.
* The driver eye level 1.2m above the road surface.

$$OSD = d_1 + d_2 + d_3$$
$$= V_{bt} + V_{bT} + 2S + VT$$

Where,

V_b = Velocity of slow moving vehicle m/sec2

t = Reaction time

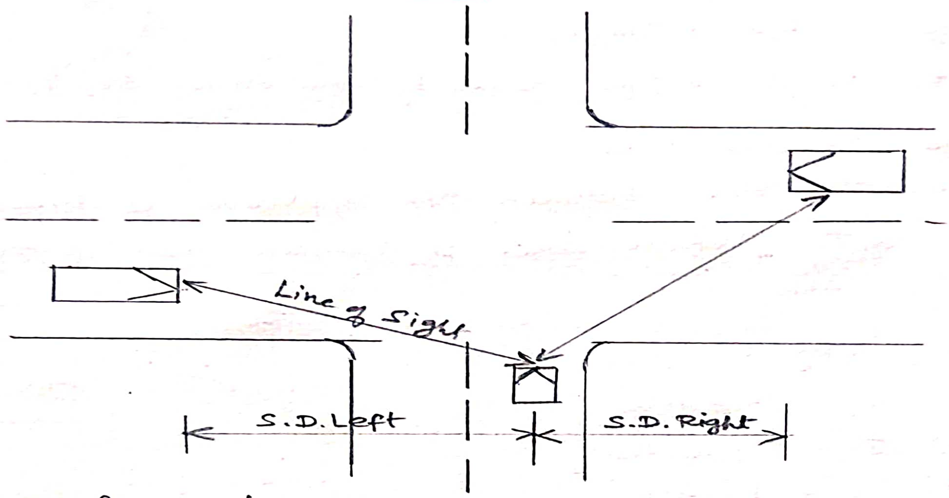
$t = t_1 - t_0$

$T = t_3 - t_1$

Intermediate Sight Distance (ISD):

* It is defined as twice the SSD.
* When overtaking Sight Distance (OSD) cannot be provided to give limited overtaking opportunities to fast moving vehicles.

Sight distance at Intersections:



* Intersections two (or) more roads meet, visibility should be provided.
* SSD - for each road can be computed from design speed.

Conditions:

* Change the speed.
* Vehicle to stop.
* To cross a main road.

Illumination Sight Distance (Head light Sight Distance)

* ISD (or) HLSD is the distance visible to a driver during night driving under the illumination of head light.

Factors affecting SSD:

i) Driver's total Reaction time < Perception Time / Breake Reaction Time

ii) Vehicle Speed.

iii) Breake efficiency

iv) Frictional Resistance

v) Gradient

Perception Time (Think)

* It is the time taken by the driver to perceive the situation.

Breake Reaction Time

* The time between the application of breake. and the moment the Vehicle comes a complete halt is the breake reaction time.

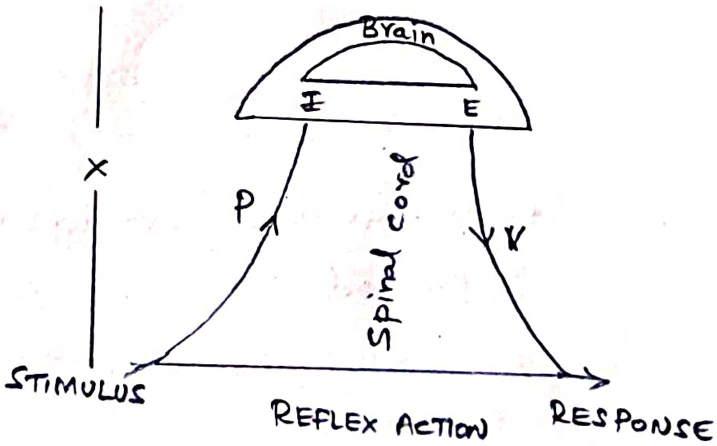
PIEV Theory

i) P - Perception

ii) I - Intellection

iii) E - Emotion

iv) V - Volition



REACTION TIME AND PIEV PROCESS

ANALYSIS OF S.S.D. (Stopping Sight Distance)

S.S.D. = Lag Distance + Breaking distance

Lag Distance

Lag Distance = Speed x Reaction

= V x t

$LD = Vt$

Breaking Distance

Kinetic energy $= \frac{1}{2} m v^2$ | $m = \frac{W}{g}$ → wt. of vehicle; g → gravity due to acceleration

$= \frac{1}{2} \frac{W}{g} v^2 \rightarrow (1)$

Frictional Force $= f.W.L \rightarrow (2)$ | friction force $= F.L$ $= f.W.L$ ↓ ↓ ↓

Equating (1) & (2)

$$\frac{Wv^2}{2g} = f.W.L$$

$$L = \frac{V^2}{2gf}$$

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

$$SSD = 0.278\,Vt + \frac{V^2}{254f}$$

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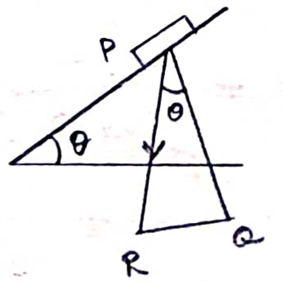
V m/s $= V$ kmph $= \frac{V \times 1000}{60 \times 60}$ hr

$= \frac{(0.278V)^2}{254 \times 9.9 \times f}$

$= 3.9 \times 10^{-3}$

$= \frac{1}{3.9 \times 10^{-3}} \frac{V^2}{f} = \frac{V^2}{254f}$

Derive the expression for S.S.D. distance in plane in gradient



$\sin\theta = \frac{QR}{PR} = \frac{n}{100}$

$\tan\theta = \frac{QR}{PQ}$

When there is an ascending gradient $= +n\%$

$= \frac{n}{100}$

The Component gravity adds to breaking action and breaking distance decreased.

The breaking force = W sin θ = W tan θ = W. $\frac{n_1}{100}$

Equating kinetic energy and work done

$$fWL = \frac{WV^2}{2g}$$

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

∴ Breaking distance, $l = \frac{V^2}{2g\left(f + \frac{n}{100}\right)}$

Similarly the B.D. can be derived as descending gradient

$$SSD = Vt + 2g\left[\frac{V^2}{~~2g~~ f \pm 0.01n}\right]$$

$$SSD = 0.278\,Vt + \frac{V^2}{254\,(f \pm 0.01n)}$$

Example 1:

Calculate the S.S.D. required to avoid head on collision of two cars approaching from opposite directions. at 100 km/h and 80 km/h. Make suitable assumptions.

Given Data:

$V_1 = 100$ km/h ; $V_2 = 80$ km/h

Assume, t = 2.5 sec, f = 0.35

Solution:

$$S.S.D._1 = 0.278\,Vt + \frac{V^2}{254f}$$

$$= (0.278 \times 100 \times 2.5) + \frac{100^2}{254 \times 0.35}$$

$$= 69.5 + 112.49$$

$$= \boxed{181.99m}$$

$$S.S.D_2 = (0.278 \times 80 \times 2.5) + \frac{80^2}{254 \times 0.35}$$

$$= 55.60 + 71.99 \Rightarrow \boxed{127.59m}$$

Total SSD = S.S.D_1 + S.S.D_2

= 181.99 + 127.59

= 309.57 m

Result:

Total S.S.D. to avoid head on collision = 310m.

Example-2:

Calculate SSD for a design speed of 80 kmph for a

a) Two-way traffic road and single lane

b) One-way traffic road and one lane (or) single lane

Assume appropriate values for the reaction time of the driver and the co-efficient of friction.

Given - Data:

Design speed, V = 80 km/h

Assume, t = 2.5 sec

f = 0.35

$$S.S.D. = 0.278\,Vt + \frac{V^2}{254f}$$

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

S.S.D = 55.6m (one (or) single way)

S.S.D. for two way = 2 × 55.6

= 111.2m.

RESULT:

S.S.D. for one way Traffic road = 56m

S.S.D. for Two way Traffic road = 112m.

Ex. No: 3:

For a two lane level road following are the particular design speed = 60 kmph, Total reaction time 2.5 sec, co-efficient of friction (f) = 0.36

(i) Calculate Stopping Sight Distance (S.S.D.)

(ii) Calculate SSD for sloping (gradient) roads with ascending gr slopes of 2% and descending slope of 3%.

Given Data:

$V = 60$ kmph

$t = 2.5$ sec

$f = 0.36$

Solution:

(i) $SSD = 0.278\, Vt + \frac{V^2}{254 f}$

$= (0.278 \times 60 \times 2.5) + \frac{60^2}{254 \times 0.36}$

$= 41.7 + 39.37$

$= 81.07$ m.

(ii) Ascending gradient ($n = 2\%$)

$SSD = 0.278\, Vt + \frac{V^2}{254 (f + \frac{n}{100})}$

$= (0.278 \times 60 \times 2.5) + \frac{60^2}{254 (0.35 + \frac{2}{100})}$

$= 41.7 + \frac{3600}{96.52}$

$= 78.99$ m

iii) Descending Gradient (n = 3%)

$$SSD = 0.278\,Vt + \frac{V^2}{254\left(f - \frac{n}{100}\right)}$$

$$= (0.278 \times 60 \times 2.5) + \frac{60^2}{254\left(0.36 - \frac{3}{100}\right)}$$

$$= 41.7 + 42.94$$

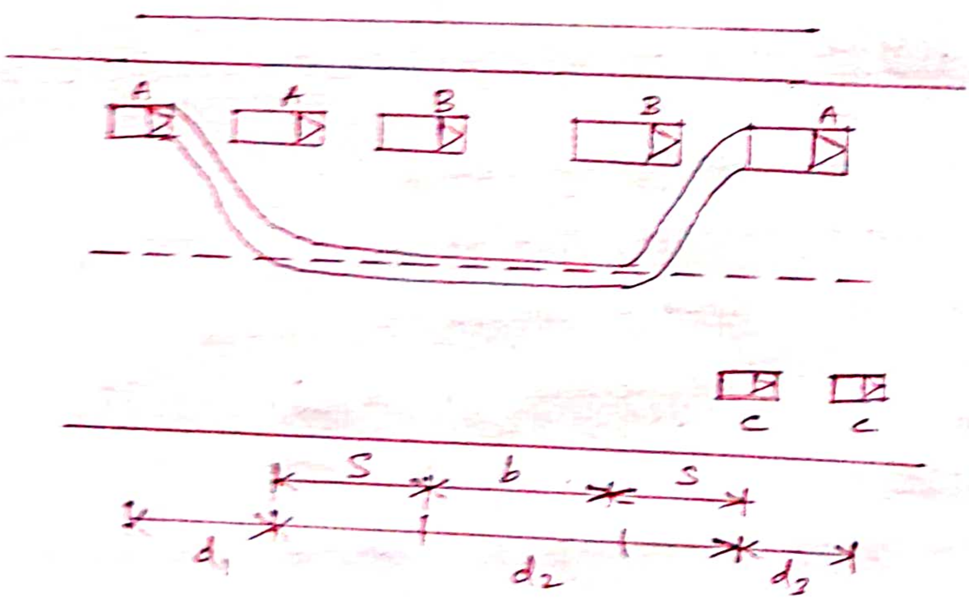
$$= \underline{84.65m}$$

Result:

i) Stopping Sight Distance, S.S.D. = 81.07m.

ii) Hence proved Descending distance is high. Ascending distance is low. (84.65m > 78.99m)

Overtaking Sight Distance:



Overtaking operation

$$OSD = d_1 + d_2 + d_3$$

d_1 = Distance travelled vehicle 'A' (A_1 to A_2)

d_2 = Overtaking operation (A_2 to A_3)

d_3 = Distance travelled coming vehicle (C_1 to C_2)

(i) $d_1 = V_b t$ ('A' is assumed reduce in speed)

(ii) $d_2 = b + 2s$

$= V_b T + 2s$

$$d_2 = V_b T + 2s$$

(iii) $$d_3 = V . T$$

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

$T^2 = \frac{2s}{a}$

$$s = \frac{aT^2}{2}$$

Empirical formula:

$$s = (0.2 V_b + 6) m$$

Overtaking Sight Distance:

$$OSD = d_1 + d_2 + d_3$$

$$= V_b t + V_b T + 2s + VT$$

$$OSD = 0.28 V_b t + 0.28 V_b T + 2s + 0.28 VT$$

where,

A = Fast moving vehicle

t = reaction time in sec

s = spacing between two vehicles

a = acceleration in 'm/sec²'

Example-1:

The speeds of overtaking and overtaken vehicles on a two-way traffic road are 90 km/h and 60 km/h respectively. The acceleration of overtaking vehicle is 0.95 m/sec^2.

a) calculate safe overtaking sight distance

b) Mention the minimum length of overtaking zone.

c) Draw a neat sketch of the overtaking zone and show the position of the sign posts.

Given Data:

$$OSD = d_1 + d_2 + d_3$$

i) OSD

$V = 90$ km/h

$V_b = 60$ km/h

$a = 0.95$ m/sec²

$t = 2$ sec.

$\therefore d_1 = 0.278 V_b t = 0.278 \times 60 \times 2 = 33.36m$

$$d_2 = 0.278 V_b T + 2S$$

$S = 0.2V_b + 6 = (0.2 \times 60) + 6 = 18m$

$T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 18}{0.95}} = 8.71$ sec.

$\therefore d_2 = (0.278 \times 60 \times 8.71) + (2 \times 18) = 181.28m$

$\therefore d_3 = 0.278 \overset{(90)}{V} T = (0.278 \times 90 \times 8.71) = 217.92m$

$\therefore$ Safe O.S.D. $= d_1 + d_2 + d_3$

$= 33.36 + 181.28 + 217.92$

$$\text{Safe OSD} = 433 \text{ m}$$

ii) Minimum length of OSD Zone:

$= 3 \times$ Safe OSD

$= 3 \times 433$

$= 1299m \simeq 1300m.$

Desirable length $= 5 \times$ safe OSD

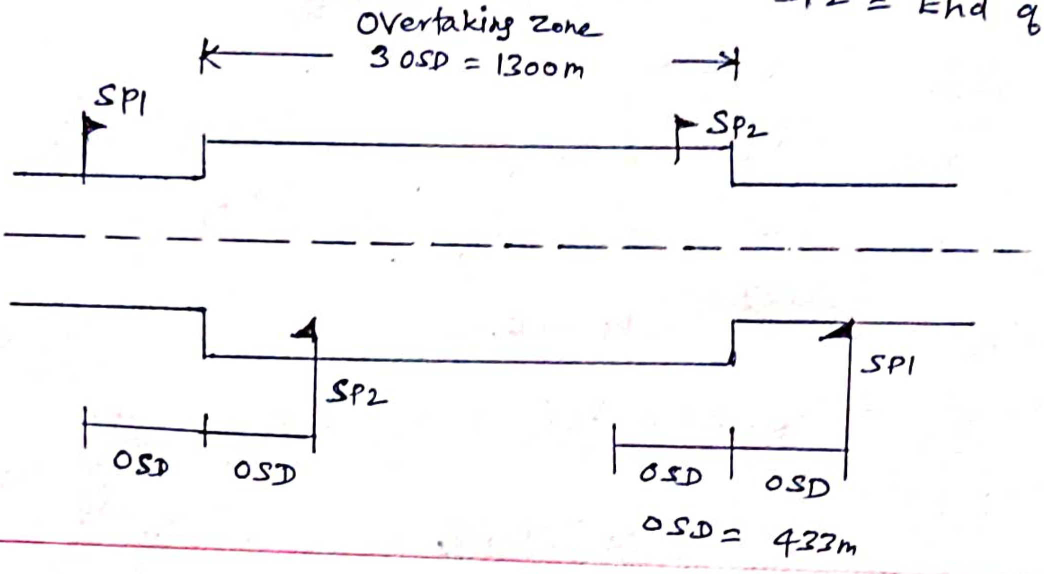
$= 5 \times 433$

$= \underline{2165 m.}$

c) **Sketch of overtaking zone:**

SP1 = overtaking zone

SP2 = End of overtaking zone



Example-2: The speed of overtaking and over taken vehicles are 80 and 50 kmph respectively. On a two-way traffic road. If the acceleration of overtaking vehicle is $0.98 m/sec^2$.

i) Calculate safe overtaking sight Distance

ii) Mention the minimum length of over taking zone.

iii) Show the positions of sight posts.

Solution:

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

$V = 80$ km/h $\quad V_b = 50$ km/h

$d_1 = \underline{27.78 m}.$ $(0.278 \times 50 \times 2)$

$d_2 =$ ~~127.61m~~ . $\underline{144.312m}$. $\quad S = (0.2 \times 50) + 6 = \underline{16 m}.$

$(112.0312 + 32)$ $\quad T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 16}{0.98}} = \underline{8.08}$ Sec.

$d_3 = 179.699 m$.

$\therefore OSD = d_1 + d_2 + d_3$

$= 27.78 + 147.312 + 179.70$

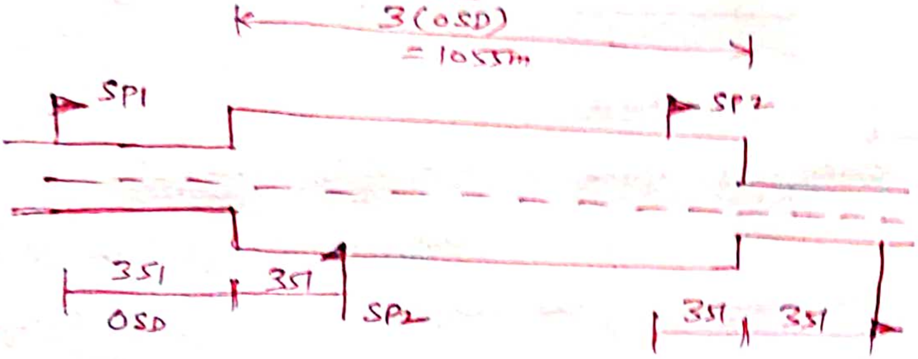
$\boxed{OSD = 351.79m}$

(ii) Minimum length $= 3(OSD)$

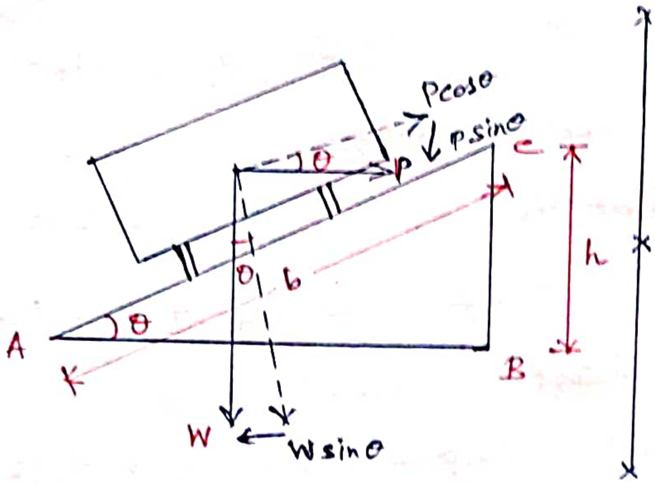
$= 3 \times 351.79$

$= 1055m$

(iii) Position of Sign Posts:



SUPER ELEVATION:



$\tan\theta = e = \frac{BC}{AB}$

'θ' is small

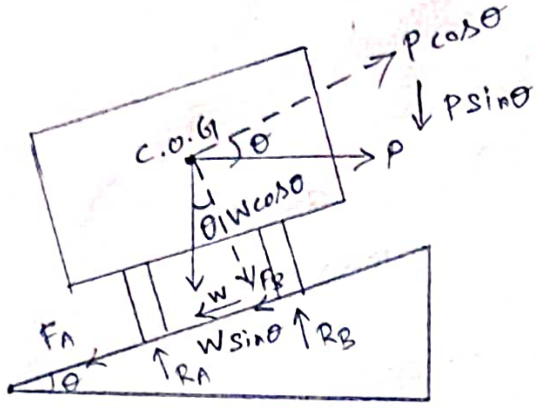
$\tan\theta \simeq \sin\theta = \frac{BC}{AC} = \frac{h}{B}$

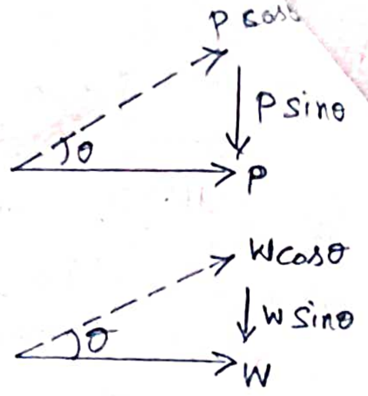
$= \frac{h}{B}$

$\boxed{h = e \times b}$

* When a vehicle moves in a horizontal curve, centrifugal force tends to overthrow the vehicle outwards. The outer edge of the pavement is raised with respect to the inner edge.
* This transverse inclination to the pavement surface is known as super elevation.

Analysis of Super Elevation:





Forces acting on a Vehicle,

(i) P – centrifugal force ($P = \frac{mv^2}{R} = \frac{W}{g}\frac{v^2}{R}$ outwards through the C.O.G.)

(ii) W – The weight of the vehicle (down-wards through the C.O.G.)

(iii) F – Frictional force. $F_A + F_B = f(R_A + R_B)$

Resolving the forces parallel to the surface,

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

$$= W\sin\theta + f(R_A + R_B) \longrightarrow (1)$$

Resolving vertical forces,

$$R_A + R_B = P\sin\theta + W\cos\theta$$

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

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

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

÷ by $W\cos\theta$

$$\frac{P}{W}(1 - f\underbrace{\tan\theta}_{e}) = (\underbrace{\tan\theta}_{e} + f) \quad \text{i.e., } \boxed{\tan\theta = e}$$

$$\frac{P}{W} = \frac{e+f}{1-ef}$$

$$\boxed{\frac{P}{W} = e + f} \qquad 1 - ef \simeq 1$$

$$P = \frac{WV^2}{gR} \qquad \therefore \boxed{\frac{P}{W} = \frac{V^2}{gR}}$$

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

$$e + f = \frac{(0.278V)^2}{9.81R} = \frac{V^2}{127R}$$

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

Factors affecting Super Elevation:

(i) co-efficient of friction (f)
(ii) Velocity of Vehicle (V)
(iii) Radius of curve (R)

Equilibrium Super Elevation:

f = co-efficient of friction value is zero.

If $\boxed{f = 0}$

$$e = \frac{V^2}{127R} - 0 \Rightarrow \boxed{e = \frac{V^2}{127R}}$$

Restriction on speed:

If, $e = 0$

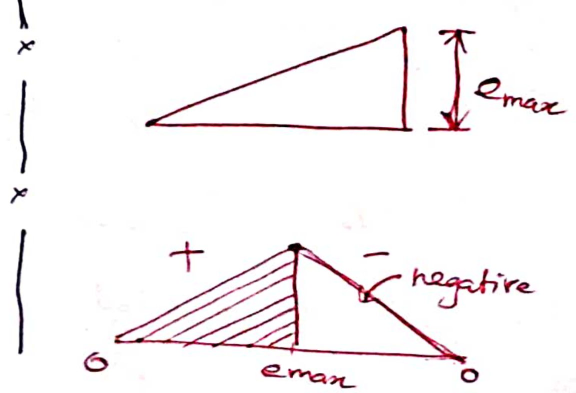
$$f = \frac{V^2}{127R}$$

$$\boxed{V = \sqrt{127Rf}}$$

Values Recommended by IRC

Plain, $e = 0.07$ (max)
Hill, $e = 0.10$
Urban, $e = 0.04$ (min)

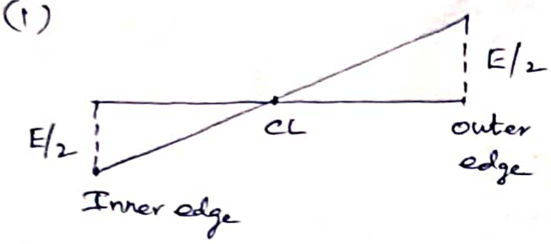
Negative super Elevation



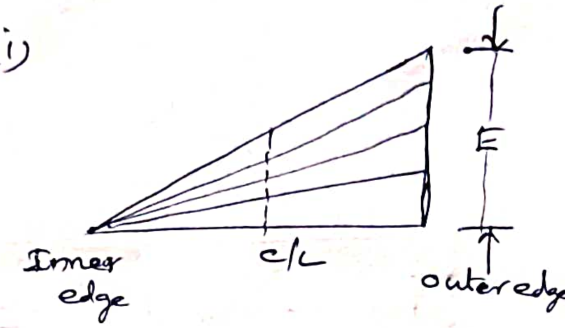
Attainment of Super Elevation (or) Method of Rotating Pavement

1) Rotating pavement about c/L
2) Rotating Pavement about inner edge

(i)



(ii)



⊗ Super Elevation Design:

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

Step-1:

Find 'e' for 75% of design speed $= \frac{(0.75v)^2}{127R} = \frac{v^2}{225R}$ //

Step-2: If $e \leq 0.07$, Take the minimum value as 0.07.

Step-3:

Find, f_1,

$$e + f = \frac{V_a^2}{127R} \quad (e = 0.07)$$

$$f = \frac{V_a^2}{127R} - 0.07$$

~~$f_2 < 0.0$~~ $f < 0.15$ Safe.

Step-4:

Find Va, $e = 0.07$, $f = 0.15$

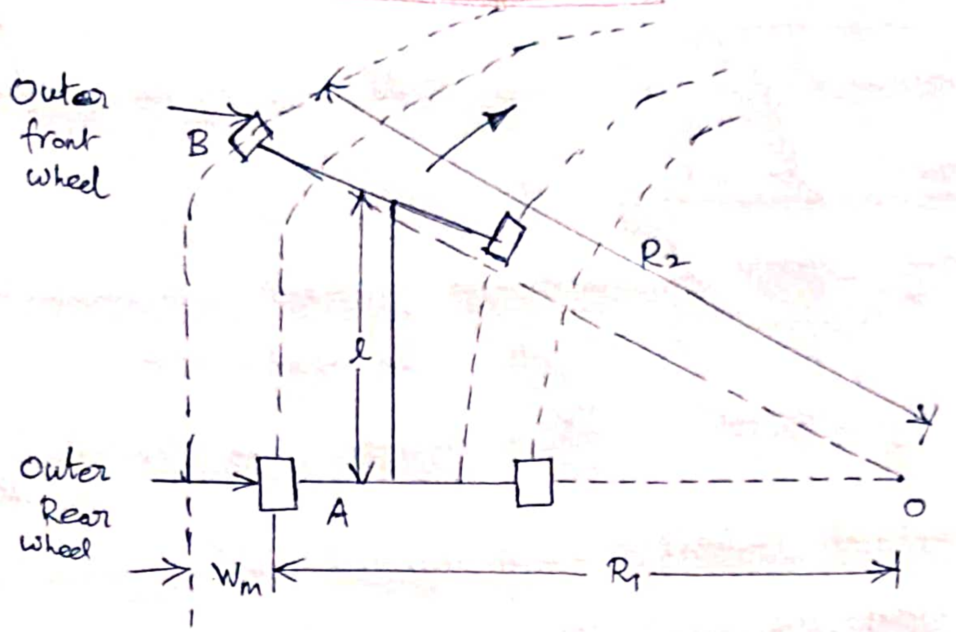
$$0.07 + 0.15 = \frac{V_a^2}{127R}$$

$$V_a = \sqrt{0.22 * 127R} = \sqrt{27.94R} \text{ km/h.}$$

'Va' is less than the design speed, otherwise speed limit has to be erected.

x———x ———x———x

Widening of Pavement on curves:



$R_1 \to$ Radius of outer rear wheel | l = length of wheel base

$R_2 \to$ Radius of outer front wheel | W_m = Mechanical widening

Off tracking:

$$\boxed{W_m = R_2 - R_1}$$

The Phenomenon of the rear wheels not following the front wheels is known as off tracking.

Analysis of Extra widening

(i) Mechanical widening

(ii) Psychological widening

(i) Mechanical widening:

In ΔOAB $\quad OB^2 = OA^2 + AB^2$

$$R_2^2 = R_1^2 + l^2 \Rightarrow R_1^2 = R_2^2 - l^2$$

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

$$R_2^2 + W_m^2 - 2R_2W_m = R_2^2 + l^2 = 0$$

$$l^2 = 2R_2W_m - W_m^2$$

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

$W_m = R_2 - R_1$

$-R_1 = W_m - R_2$

$\times(-)$

$\boxed{R_1 = R_2 - W_m}$

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

$[\because W_m \text{ small}]$

$$\boxed{W_m = \frac{l^2}{2R_2}}$$ for one lane

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

Vertical Alignment:

Vertical alignment is the side view of the centre line of the road

Categories of gradient

* Ruling gradient : Maximum gradient with which the vertical profile of the road. ex: (1 in 30)
* Limiting gradient : It is steeper than the ruling gradient (1 in 20)
* Exceptional gradient : It is provided in an exceptional (1 in 15)
* Minimum gradient : It may be possible to lay roads with zero gradient.

Gradient:

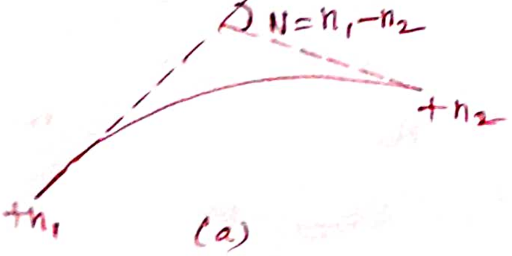
Gradient is the rise or fall with respect to longitudinal direction.

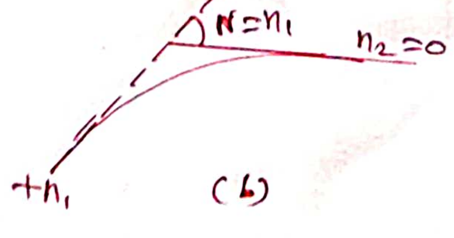
Summit curve:

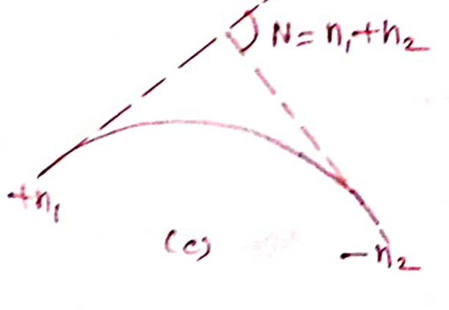
Summit curve are vertical curves with gradient upwards.

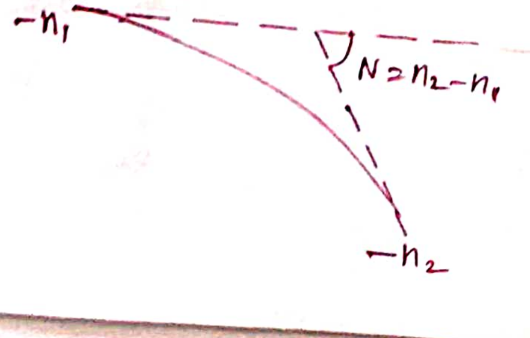
- When a positive gradient meets another positive gradient.
- When positive gradient meets a flat gradient.
- When an ascending gradient meets a descending gradient.
- When a descending gradient meets another descending gradient.

$$N = n_1 - n_2$$









Example-1:

Ruling design speed and minimum design speed of a National Highway is 100 km/h and 80 km/h respectively. Calculate the ruling and absolute minimum radius of curvature at a horizontal curve of the N.H. in plain terrain.

Given Data:

* Ruling speed, $V_1 = 100$ km/h.
* Minimum speed, $V_2 = 80$ km/h.
* Assumption, $e = 0.07$, $f = 0.15$ (plain Terrain)

To find

* Design Ruling speed curvature
* Minimum radius

Solution:

$$R_{ruling} = \frac{V^2}{127(e+f)} = \frac{100^2}{127(0.07+0.15)} = 360m.$$

$$R_{min} = \frac{V^2}{127(e+f)} = \frac{80^2}{127(0.07+0.15} = 230m.$$

Result:

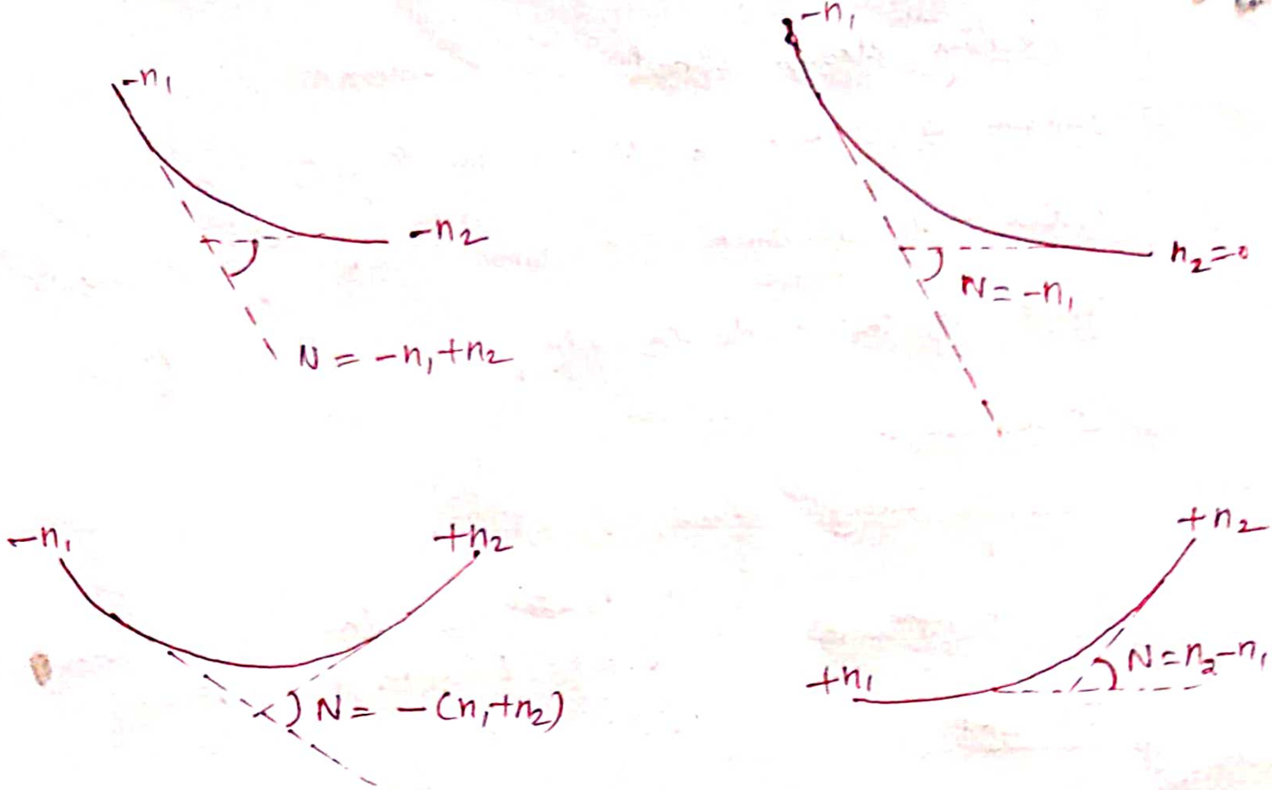
Rulling radius of curvature = 360m.

Minimum radius of curvature = 230m.

Valley curve

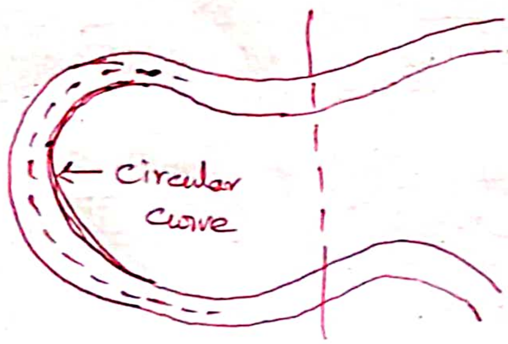
Valley curves are Vertical curves with gradient downwards.

- When a descending gradient meets another descending gradient.
- When descending gradient meets a flat gradient.
- When descending gradient meets an ascending gradient.
- When an ascending gradient meets another ascending gradient.



Geometric Design of Hill roads

Hair-pin bends



* A bend may be for reversing road direction on same face of hill slope.

Geometric Design:

1. Design speed (IRC Recommendations) — Min 50; Max 60 NH
2. Formation width (IRC – 7m NH)
3. Sight Distance (SSD – $0.278\, V_t + \frac{V^2}{254 f}$)
4. Radius of horizontal curve
5. Super elevation ($e = \frac{V^2}{225 R}$)
6. Length of Transition curve
7. Gradient
8. Camber
9. Set back Distance
10. Widening of curve
11. Hair-pin bends
12. Slope of hill cuttings

UNIT-III

FLEXIBLE AND RIGID PAVEMENTS

Pavement components and their role - Design principles - Design practice for flexible and rigid pavements (IRC methods only) - Embankments - Problems in flexible pavement design

Pavement:

* The term pavement means a covered surface however in highway design.
* It is refers to few layers of hard level surface constructed over the prepared soil.

Need for Highway Pavements:

* The surface of the road should be stable and non-yielding to allow the heavy wheel loads.
* The pavements carries the wheel load and transfer the load to subgrade.
* The fast moving vehicle to move safely & comfortably.
* The roadways is provided with a suitable designed and constructed pavement structure.

Requirements of a quality pavement:

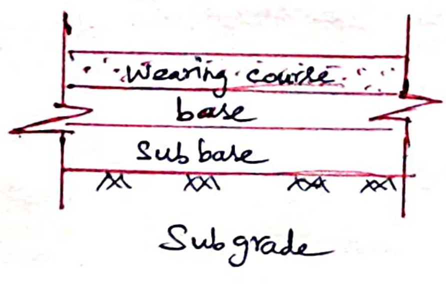
1. Perfect compaction
2. Optimum moisture content
3. Maximum dry density

Types of Highway Pavement

1. Flexible pavement
2. Rigid Pavement
3. Semi-rigid pavement

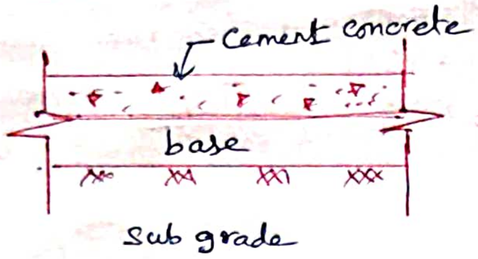
Flexible Pavement:

CROSS-SECTION OF FLEXIBLE PAVEMENT



• Flexible pavement have low (or) negligible flexural stre...
(Ex. bituminous concr... materi...

Rigid Pavements:



CROSS-SECTION OF RIGID PAVEMENT

* Rigid Pavement possess very high flextural Rigidity. (Ex: Portland cement concrete)

Semi-Rigid Pavements:

* The flextural strength of semi rigid pavement lies between the other two types.

Components of Pavements:

Flexible	Rigid
1) Sub-grade	1) Sub-grade
2) Sub-base	2) base
3) base	3) Cement concrete [CC]
4) Wearing coarse	

Functions of Subgrade:

- The subgrade is generally the in-situ soil over which a highway is constructed.
- It provides support to pavement.
- Poor soil subgrade may result in formation of many defects in the pavement.
- Improves the load supporting capacity by distributing load through finite thickness.
- Prevents pumping (or) Ejection of soil is slurry through joints and cracks.

Materials

Base course material:

1. Bound aggregates (or)
2. Un bound aggregates (or)
3. Broken Stones

Sub-base course material:

1. Stabilized soil
2. Selected granular material.
3. Boldad Stones
4. Broken Stone

Functions of wearing course:

* Provides Smooth riding surface.
* Resist pressure erected by the tyres.
* Take up wear & Tear.
* Prevents infiltration of rain water in to the pavement and subgrade.

Difference between flexible and rigid Pavement

Features	Flexible	Rigid
1. Flexural Strength	Low	High
2. Design Principle	Layer concept	slab action
3. Stress	Compressive stress	Tensile & temperature Stresses
4. Transfer of Stress	Layer to layer	Deformation not reflected in bottom layer
5. Material	Granular Material	Portland cement
6. Design Practice	Empirical charts and equations	Elastic Theory

Design Principles of Pavements:

Flexible	Rigid
* Load is dissipated through granular material. * Intensity of load reduces in geometric proportion * strength, over pressure reduces with increased depth	Design load is based on flexural strength of slab. Distributed load over large area due to rigidity and modulus of Elasticity of pavement material.

Design Factors

- Mix design
- Thickness of Component layers

Factors for design
- Design wheel load
- Subgrade soil
- climate factors
- Pavement materials
- Environmental factors
- Special factors
  - Cross-Sectional Elements
  - Traffic characteristics
  - Special information

(i) Design wheel load:

* Thickness of pavement depends upon the design wheel load.
* Higher the wheel load, higher will be thickness provided.

Elements of design wheel load:

- Static load on each wheel / dual / dual tandem wheel.
- Contact Pressure.
- Load repetition and dynamic effect.

2. Subgrade soil:

- Decides thickness requirement of the pavement.
- Variations of moisture content affect the stability.

3. Climate factor:

- Rainfall affects moisture content in turn the stability of the subgrade.
- Variation in temperature.
- Freezing temperature results in frost action in the subgrade

4. Pavement Materials:

- Durability and stress distribution of pavements depends upon the materials.

5. Environmental factors:

- Height of embankment
- Depth of cutting
- Foundation details
- Depth of sub-surface water table
- Land use.

6. Special Factors:

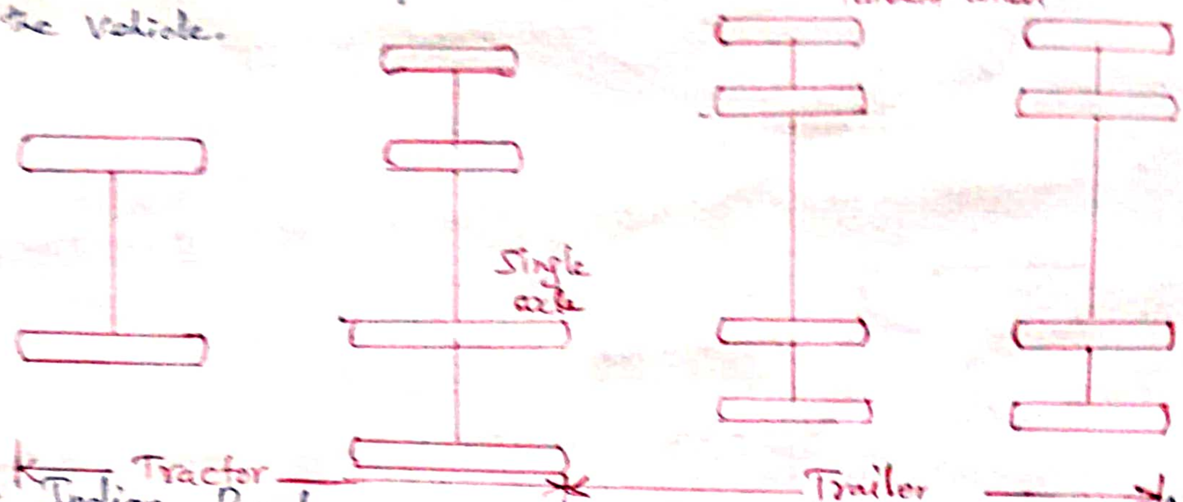
1. Cross-Sectional elements: Ex: right of way, carriage way
2. Traffic characteristics: Ex: Physical, static and dynamic characteristics speed, acceleration.
3. Special factors: Ex: Shrinkage cracks, fatigue behaviour.

Design wheel load: The design wheel load depends on the

(i) Maximum wheel load
(ii) Contact pressure
(iii) Equivalent single wheel load
(iv) Repetition of loads

1. Maximum Wheel load:

* The pavement surface depends on the wheel configuration of the vehicle.



* Indian Road congress has specified the maximum legal load as 8170 kg and maximum single wheel load as 4085 kg.

2. Contact Pressure:

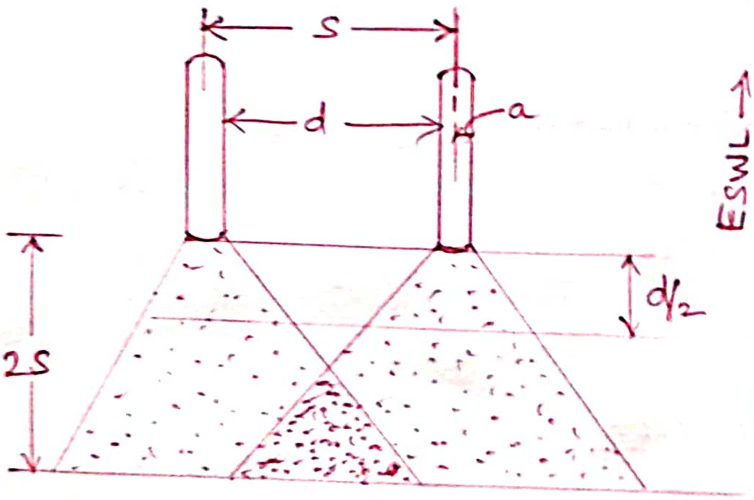
Contact pressure, $P = \frac{L}{A}$

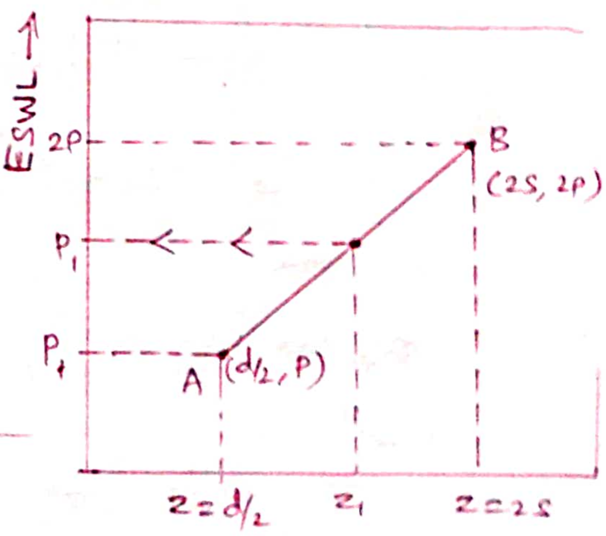
* Contact pressure is given by the relationship.

Where, P = Contact Pressure ; L = Load on wheel.

A = Contact Area

3. Equivalent Single wheel load (ESWL):





GRAPHICAL REPRESENTATION OF ESWL

Let,

d = clear gap between two wheels

S = Spacing between the centres of wheels.

P = Wheel load

a = Radius of the circular Contact area.

* A straight line relationship is assumed between ESWL and depth on log-log Scale.
* Points A & B are plotted on a log-log graph with Co-ordinates of "A". (d/2, P), B (2S, 2P).
* Line AB is a plot which is the points where any single wheel load.
* It is equivalent to a certain set off dual wheels.
* To calculate the ESWL for dual wheel assembly. It is essential to estimate a design thickness of pavement.
* If the design thickness show obtained is equal to estimated thickness then 'ESWL' calculations are correct.
* If not trials are to be made calculations are to be repeated.

(4) Repetition of Loads:

* The load is repeatedly applied. un covered deformation increases.
* This may even result in the failure of the pavement.
* Equivalent wheel load is a single load equivalent to the repeated applications of any particular wheel load on a pavement.
* Which requires the same thickness and strength of pavements.

The approach converts wheel loads of various magnitudes they are,

* climate
* Sub-grade soil
* Traffic

Climate:

* Cement concrete pavement due to daily variation in temperature and consequent warping of the pavement.

* Bituminous pavement becomes soft in hot weather and brittle in very cold weather.

Sub-grade Soil:

* High moisture variation could be controlled by providing suitable surface.

Traffic:

* Computation of traffic for use of pavement thickness design chart

$$N = \frac{365A\left[(1+r)^n - 1\right]}{r} \times D \times F$$

Where,

N = No. of standard axles.
D = Distribution factor.
A = Number of commercial vehicle per day
F = Vehicle damage factor
n = Design life in years
r = Annual growth of commercial vehicles.

Design Practice for flexible pavement: CBR & IRC method

C.B.R. Method (California Bearing Ratio) - 1970

* CBR is a property of subgrade soil. It is measured by an empirical test devised by California State Highways department of the USA.

* CBR is the ratio of force per unit area required to penetrate a soil mass with a circular plunger of 50mm ϕ at the rate of 1.25mm/min to that corresponding penetration of a standard material.

* The department devised design curves for,

Wheel load	Traffic
3175 kg	light
4082 kg	Medium
5443 kg	Heavy

Recommended method of design (IRC 37-2001):

(i) content
(ii) Design approach criteria
(iii) Estimation of design traffic
(iv) Design life
(v) Vehicle damage factor (VDF)
(vi) Distribution of Commercial traffic
(vii) Computation of design Traffic.
(viii) Sub-grade
(ix) Pavement thickness and composition
(x) Methodology for the design.

(i) Context:

* National highways and Arterial roads carry loads far greater than 30 msa. – (million standard Axle)
* Therefore, the revised guidelines, (IRC:37-2001) reanalysed the existing designs for "design traffic" upto 150 msa.

(ii) Design approach criteria:

* Vertical compressive strain at the top of the sub-grade which leads to permanent deformation at the pavement.
* Horizontal tensile strain at the bottom of the bituminous layer which the causes fracture at the bituminous layer.

(iii) **Estimation of "Design Traffic":**

* The design life of standard axles. (8160 kg)
* Commercial vehicles of gross vehicle weight of three tonnes or more and their axle loading only is considered for the purpose of structural design.
* **CVPD** (No. of commercial vehicle per day)

(IV) **Design life:**

IRC Recommendations on design life

No.	Type of Road	Design life
1.	NH/SH	15 years
2.	Express way and urban Roads	20 years
3.	Others	10-15 years

(V) **Vehicle damage factor (VDF):**

* The VDF is defined as equivalent number of standard axles per commercial vehicles.
* The VDF values indicated by IRC.

No.	Range of Commercial Vehicle	Terrain	
		Rolling/Plain	Hilly
1.	0 - 150	1.5	0.5
2.	150 - 1500	3.5	1.5
3.	More than 1500	4.5	2.5

(vi) Distribution of Commercial Traffic:

No.	No. of lanes of Carriage Way	Basis of design
1.	Single lane	Commercial Vehicle in both directions
2.	Two lanes Single Carriage Way	75% Commercial vehicle in both directions
3.	Four lanes Single carriage way	40% of Commercial vehicle in both directions
4.	Dual Carriage roads	
	• Two lanes	75% of C.V. in each direction
	• Three lanes	60% of C.V in each direction
	• Four lanes	45% of C.V. in each direction

(vii) Computation of Design Traffic:

$$N = \frac{365 \cdot A \left[(1+r)^{n} - 1 \right]}{r} \cdot D.F$$

(viii) Sub-grade:

No.	Type of Road	compaction
1.	Express way	97% dry density with heavy Compaction materials used.
2.	NH, SH, MDR	

(ix) Pavement Thickness and composition:

* The Pavement thickness is related to CBR value and design traffic.
* The pavement consist of granular Sub-base, granular base and bituminous Surface.

No.	Minimum CBR Value	Traffic	Thickness
1.	2%	< 10 msa	150mm
2.	less than 2%	≥ 10 msa	200mm

(X) Methodology for the design:

* The IRC has given two design charts under these guide lines.
* The traffic range 1 to 10 msa — chart ①
* The traffic range 10 to 150 msa — chart ②

Chart - 1

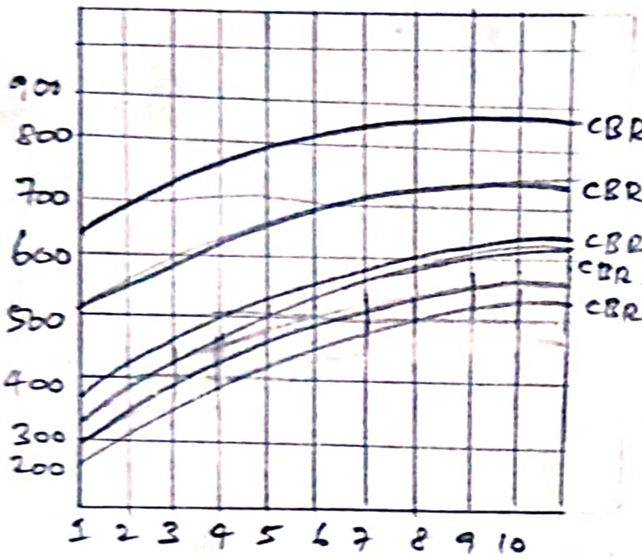
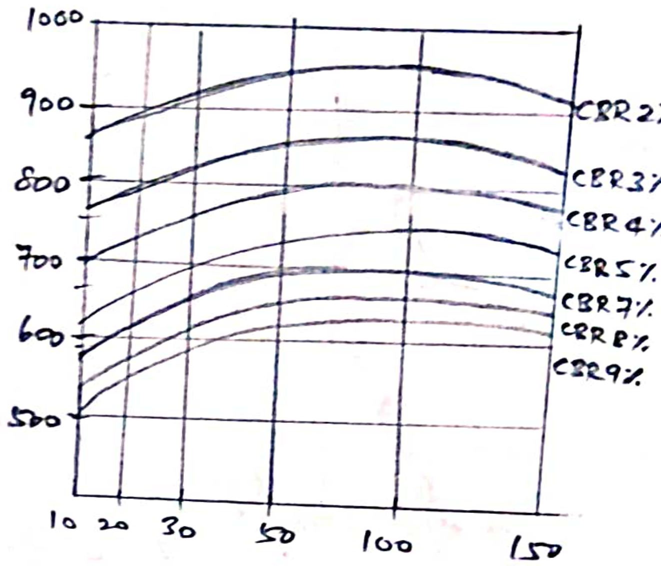


Chart - 2



Problem 1:

Design the flexible pavement for construction of new highway with the following Data:

Number of commercial vehicles as per ~~last~~ last count = 1000 c.v.
Period of Construction = 3 years
Annual traffic growth rate = 8%.
Design CBR of Subgrade soil = 10%
Catagory of road = National highways, Two lanes Single carriage way.
Design life = 10 years

Given Data:

$n = 3$ years

$P = 1000$

$r = \frac{8}{100} = 0.08$

$F = 3.5$

$\therefore D = 0.75$ (two lane single carriage way)

$n = 15$ (for N.H.)

$$N = 365 \left[\frac{(1+r)^n - 1}{r} \right] \times A \times D \times F$$

To find Design the flexible pavement

Solution:

Initial Traffic, $A = P(1+r)^n$

$= 1000(1+0.08)^3$

$= 1259.7$ say 1260 nos.

$\therefore N = 365\left[\frac{(1+0.08)^{15}-1}{0.08}\right] \times 1259.7 \times 0.75 \times 3.5$

$= 32771245.6$

$N = 32.77$ msa.

Refer chart 3.8 (i) for → CBR value ⇒ 10%

Pavement thickness required is

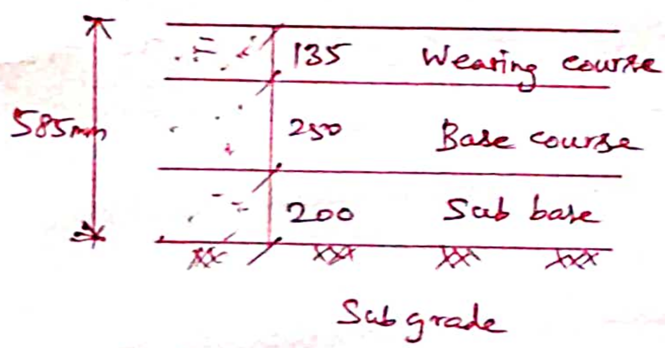
580mm → 30msa
600mm → 50 msa → 32.77 msa

$t = 580 + \frac{(600-580)}{(50-30)} \times (32.77-30)$

$= 580 + \frac{20}{20} \times 2.77$

$t = 582.77$ mm say 585mm

Result:



Design Practice for rigid Pavement : [IRC Recommendation]

(i) Design Parameters of wheel loads
(ii) Calculation of stresses
(iii) Design steps for slab thickness
(iv) Spacing of Joints
(v) Design of dowel bars
(vi) Design of tie bars
(vii) Design of reinforcement
(viii) Design period.

(i) **Design of wheel loads:**

Axle	Tonne
Single	10.2
Tandem	19.07
Tridem	24.07

(ii) **Calculation of stresses:**

* The wheel load stress at edge region is calculated for the designed slab.
* Temperature stresses at edge region is calculated.

(iii) **Design steps for slab thickness:**

* The width of the slab is decided based on the joint spacing.
* The load stress in edge region is found using stress chart.
* The design thickness is adjusted for the traffic intensity.

(iv) **Spacing of Joints:**

* The maximum spacing recommended for 25mm wide expansion joint is 140m.
* When the foundation is Smooth spacing 90m for slab thickness up to 20cm, and spacing at 120m for slab thickness of 25cm.

* The maximum spacing may be kept as 4.5m in un reinforced slab.

(V) Design of dowel bars:

* The minimum dowel length as [Ld + d (deflection)] the value of Ld is determined.

* The load capacity of the dowel system is assumed to be 40% of the design wheel load.

(Vi) Design of tie bars:

* Permissible bond stress is deformed is 24.6 kg/cm².

(Vii) Design of reinforcement:

* The area of longitudinal and transverse steel required per meter width, $A = \frac{Lfs}{2S}$

Where,

A = area of steel required per meter width.
L = Distance between free transverse joint.
f = Co-efficient of friction
S = spacing of main reinforcement.

CONSTRUCTION PROCEDURE FOR WATER BOUND MACADEM ROAD (WBM)

1. Preparation of foundation for receiving the WBM course
2. Provision of Lateral continment meant
3. Spreading of course aggregate
4. Rolling
5. Application of Screens
6. Sprinkling & shouting
7. Application of binding material
8. Setting & drying

1. Preparation of foundation for receiving the WBM Course

a) Required grade & camber

b) Dust & loose material cleared

c) Depression & pot holes are filled and corrugation removed.

2. Provision of lateral continent meat

a) Before starting WBM construction

b) By construct shoulder in advance

c) Thickness = height of shoulder

3. Spreading of course materials

a) Course aggregate are spread uniformly to proper practice.

4. Rolling

a) After spreading coarse aggregate compaction is done by a 3 wheeled power roller of 6 to 10 tonnes.

b) Rolling is factored from edge to centre, rolling being done forward & backward.

5. Application of screens

a) After compaction, the dry screening are applied gradually over the surface fill the intersticas in 3 (or) more application.

6. Sprinkling & shouting:

a) After the screening, the surface is sprinkled with water the rolled.

7. Application of blinding material

a) After the screening, rolling the binding material is applied at a uniform and slow rate at 2 (or) more successive thin layers.

b) After the each application of binding material the surface is copiously sprinkled with water and wet slurry.

c) Water is applied to wheel to wash down the binding material that sticks to the rolling.

8. Setting and drying

a) WBM course is allowed to set over night on the next day.

b) The Screening (or) binder material lightly mixed with water if necessary rolled.

MERITS:

* It provide base course for top surface.
* It can be used with little care.
* It is a cheap method.
* It introduce the concept of subbase drainage.

DEMERITS:

* It dettoriated very easily.
* It cannot be used without surface covering.
* It aggregates get loose when water lose from them.

UNIT-IV

HIGHWAY CONSTRUCTION MATERIALS AND PRACTICE

Highway Construction materials, properties, testing methods, – CBR Test for Subgrade – tests on aggregate & bitumen – Test on Bituminous mixes – Construction practice including modern materials and methods, Bituminous and concrete road Construction, Polymer modified bitumen, Recycling, Different materials - Glass, Fiber, Plastic, Geo-textiles, Geo-membrane (problem not included) – Quality Control measures – Highway drainage – Construction machineries.

CONSTRUCTION PROCEDURE FOR RIGID (or) CEMENT CONCRETE PAVEMENT

1. **Materials:**
   - a. Cement
   - b. Coarse aggregates
   - c. Fine aggregates
   - d. Water
   - e. Mild steel bars
   - f. Joint Filler
   - g. Joint filler Compound
2. Admixtures
3. Proportioning of Concrete
4. Cement Content
5. Side forms and guide mixes
6. Construction
7. Equipment
8. Placing of Concrete
9. curing

a) Cement

The following types of Cement divided strength may be used.

Ordinary Portland cement (OPC)	33 grade	IS:269
	43 grade	IS:8112
	53 grade	

b) Coarse aggregates

Aggregate	size ≯ 25mm
Aggregate	Water absorption ≯ 2%

c) Fine aggregates

This shall consist of

1. Clean
2. Natural sand (or) sand (or)
3. Combination of the above two.

d) Water

This shall consist of

1. clean
2. Free from oil
3. salt
4. Acid
5. Vegitable matter

e) Mild steel bars

* Dowel bars shall conform to Grade 8240 and tie bars grade 8415 respectively.

f) Joint Filler

* Joint filler board for expansion proposed for use at bridges and Converts shall be 20-25mm thickness.

g) Joint Sealing Compound

i) Hot poured electrometric type
ii) cold applied Poly sulphide type.

2. Admixtures

* There shall be permitted to improve the feasibility of Concrete.

3. Proportioning of Concrete

* Concrete design mix shall be prepared.
* Compressive strength of Concrete shall be established on the basis of atleast thirty tests on samples.

4. Cement Content

* The cement content shall not be more than ~~200~~ 350 kg/cu.m. of Concrete and shall not exceed 425 kg./cu.m. of Concrete.

5. Side forms and guide mixes

* All side forms shall be of mild steel of depth equal to the thickness of pavement.

6. Construction

* Batching and mixing of the concrete shall be done of Central batching and mixing plant.

7. Equipment

* Paving equipment is used to spread, Consolidate, float, and finish the mix.
* Vibratory Compaction is used to throughly Correct the layer.

8. Curing

* The Slab shall be cured by the resin based aluminated reflective curing compound.

9. Placing

* Concrete mixed in Central mixing plant shall be transported immediately to the site.
* Generally tipper can be used to transport the mix.

Desirable Properties of Soil

* Stability
* Incompressibility
* Permanancy of Strength
* Minimum Variation in Volume
* Good drainage
* Ease of compaction

Stability

1. The soil with high stability provides excellent sub grade.
2. It should be able to regain its original position after the movement of wheel load.
3. The main function of the subgrade is to give adequate support to the pavement.

Incompressibility

1. It is the property to avoid differential settlement of soil.
2. The subgrade may fail due to differential settlement.

Permanancy of Strength

1. The subgrade soil should possess resistance to weathering.
2. It should be able to retain its characters under adverse rain, temporature and frost action.

Minimum change in Volume

1. Bulding and shrinking under adverse weather conditions should be minimum.
2. This property will help the soil to retain its property.

Good drainage

1. It is essential to avoid excessive moisture retension and reduce potential frost action.
2. It also improves the stability of the soil.

Ease of Compaction

1. This ensure higher dry density and strength under particular type and amount of compaction.

Aggregates

* Aggregates are used in rigid and flexible pavements.
* In rigid pavement, they are used in cement concrete.
* In flexible pavement, they are used in bituminous concrete.

Desirable Properties:

i) Strength
ii) Hardness
iii) Toughness
iv) Durability
v) Shape of aggregates
vi) Adhesion with bitumen

Strength:

* The aggregates should be stronger enough to withstand the stresses due to wheel load.
* The aggregates used in the wearing course must the wear and tear and resist curing.

Hardness:

* It is subjected to abrasion and attrition.
* Abrasion is rubbing of wheels with aggregates.
* Attrition is rubbing between aggregates movement.
* Wheels of moving vehicles rub the surface course.
* Abrasive action may be increased due to presence of abrasive materials sand.

Toughness:

* Toughness is the resistance to hammering action by moving wheelloads.
* Jumping of moving wheels from one stone aggregate to another at different levels, cause severe impact on aggregates.
* There are for resistance to hammering such impacts is a a desirable property of aggregates.

Durability:

* It is the property of resistance for disintegration due to the action of weather. (wind, rain, sun).
* The stone aggregates used in road construction should have property of durability.

Shape:

* Aggregates are generally selected by size not by shape.

Shape	Used
Rounded	Cement Concrete
Angular	WBM Road
Flaky & Elongated	Not used for roads

Adhesion with Bitumen:

* The adhesion affinity of aggregates should be more towards bituminous materials than to water.

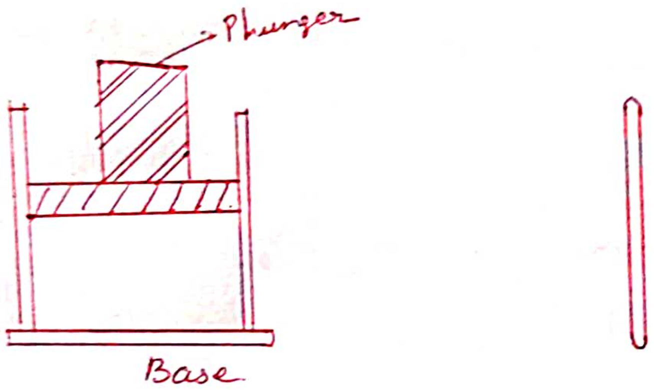
Tests on soil:

1. California Bearing Ratio Test (CBR Test)
2. Field Density Test (core-cutter test)

Test for aggregates

1) Crushing Test
2) Abrasion Test
3) Impact Test
4) Water absorption Test
5) Flakiness and Elongation Test
6) Stone polishing value Test

Crushing Test



* The aggregates crushing value provides a relative measure of resistance to crushing under gradually applied crushing load.
* The test consist of subjecting the specimen of aggregates in std mould to a compression test under standarad load conditions.
* Dry aggregates passing through 12.5 mm sieves and retained 10mm sieves are called in a cylinderical measure of 11.5 mm diameter and 18 cm height in three layers.
* Each layer is tampered 25 times with at standard tamping rod.

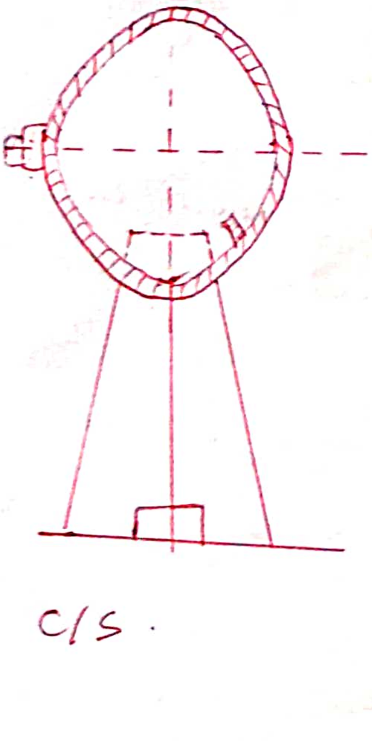
* The test sample is weighed and placed in the test cylinder in three layers each layer being tampered again.

* The specimen is subjected to a compressive load of 40 tonnes gradually applied at the rate of 4 tons per minute.

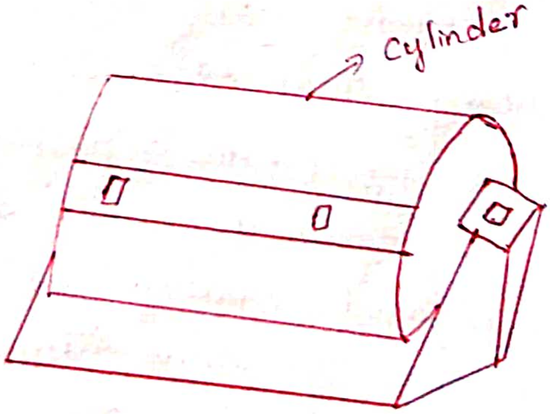
* Then crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material (We) is expressed as % of the weight of the total sample (W_1)

* Aggregate crushing value Aggregates crushing value $= (W_1/W_2)\ 100$

* A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates.



C/S.



Los ongels machine

significance :

This test is more reliable than other abrasion tests because the rubbing and powdering action in this test simulate the field conditions better.

Objective :

To determine the abrasion value of coarse aggregates.

Apparatus :

Los angels machine.

Abrasion charge :

The abrasive charge shall consists of cast iron sphere or steels spheres approximately 48 mm dia. Each sphere weighs between 390 g and 445 grams.

Test sample :

The machine is rotated at a speed of 33 revolutions / minute. Depending upon the graduations of the aggregates. On completion of the test, the materials is discharged from the machine and is sieved on a 1.70 mm IS sieve.

$$\text{Abrasion value} = \frac{W_1 - W_2}{W_1} \times 100$$

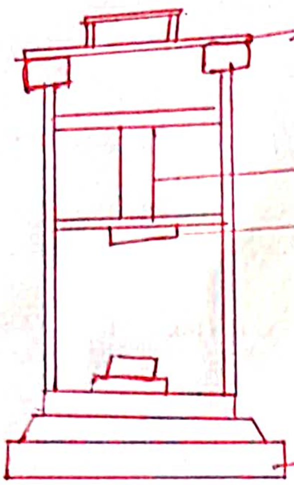
Where, $W_1 \rightarrow$ Original wt. of the test sample.
$W_2 \rightarrow$ wt of material retained on 1.7mm sieve.

Abrasion value :

CC, Bituminous concrete $< 30\%$.
Base course like WBM $\leq 40\%$.

Flaki

Impact test :



* The aggregate impact test is carried out to evaluate the resistance to impact of aggregates.

* Aggregates passing 12.5 mm sieve and retained on 10mm sieve is called in a cylinderical steel cup of internal dia 10.2 mm & depth 5 cm.

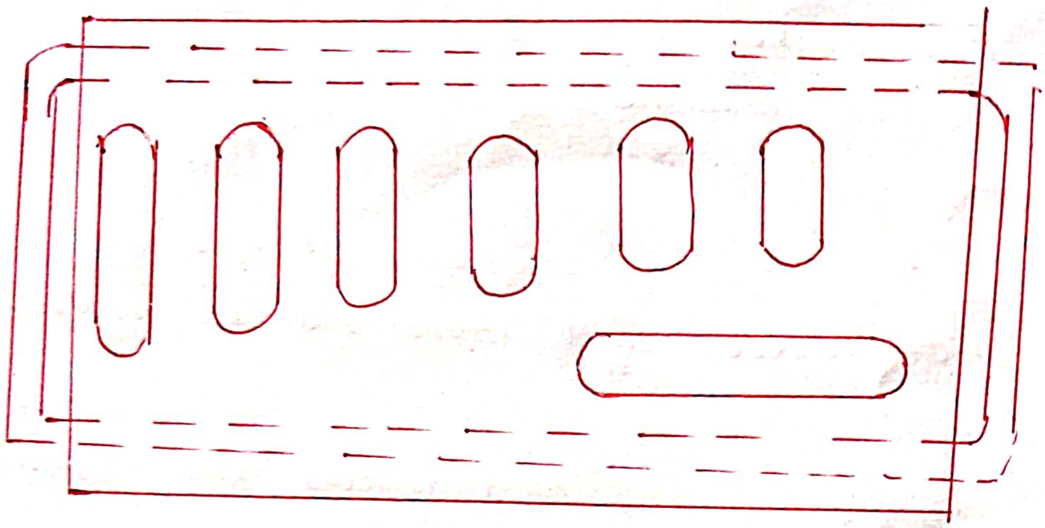
* The material is called in 3 layers where each layer is tamped for 25 no. of blows.

* Metal hammer of weight 13.5 to 14 kg is arranged to drop with a free fall of 38 cm by vertical guides and the test specimen is subjected to 15 no of blows.

* The crushed aggregate is allowed to pass through 2.36 mm IS sieve. And the impact value is measured as % of aggregates passing sieves (w_2) to the total wt of sample (W_1)

* Aggregates to be used for wearing course, the impact value should not exceed 30%.

Flakiness and Elongation Test



* The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it.

* Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes.

* The flakiness index is defined as the % by weight of aggregate particles whose least dimension is less than 0.6 times their mean size.

* The elongation index of an aggregate is defined as the % by weight of particles whose greatest dimension is 1.8 times their mean dimension.

* This test is applicable to aggregates longer than 6.3mm.

Tes

Water absorption test :

Apparatus :

(i) Wire basket

(ii) Weighing machine

Procedure :

* About 2 kg of dry aggregate sample is placed in a wire basket and immersed in water for 24 hrs.

* The sample is weighed under this condition which gives the buoyant weight.

* The aggregates are then dried out and weighed after drying the surface.

* Then the aggregates are dried in an oven for 24 hrs at a temp 100-110°C and then the dry weight is determined.

* The water absorption is expressed as the % water absorbed in terms of oven dried wt of the aggregates :

$$\text{Water absorption} = \frac{\text{Mass of water absorbed}}{\text{Dry mass of the aggregate}} \times 100$$

Limitations.

* Higher value of water absorption is accepted for aggregates used in bituminous pavement construction.

* Rock samples having more than 0.6% water absorption are unsatisfactory.

Test on Bitumen

1. Penetration Test
2. Ductility Test
3. Viscosity Test
4. Binder content
5. Softening point test.

1. Penetration Test :

* It measures the hardness or softness of bitumen by measuring the depth in tenths of a mm to which a std. loaded needle will penetrate vertically in 5 sec.
* BIS had standardized the equipment and test procedure. The penetrometer consists of a needle assembly with a total wt of 100g and a device for releasing and locking in any position.
* The bitumen is softened to a pouring consistency, stirred thoroughly + poured into containers at a depth at least 15mm in excess of the expected penetration.
* A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at std Test conditions.

Ducti

Stone polishing value test.

(i) Curved - mould
(ii) Rotating pneumatic wheel
(iii) Portable Tester for getting the degree of polishing.

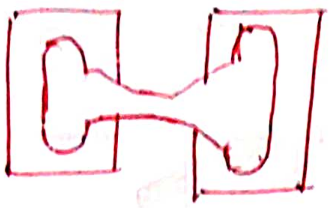
The old procedure adopted for testing the polishing characteristics is to embed the stones in a curved mould in cement / sand mortar and subject the sample to accelerated polishing brought by a rotating pneumatic wheel.

* The size of each specimen is 45 mm x 90.5 mm
* The rubber wheel is 20 cm φ and 5 cm broad, loaded with 40 kg load at a tyre pressure of 3.15 kg/cm^2
* The specimen is then fixed and rotated at a speed of 320 to 325 rpm for 3 hrs + 15 mins
* Sand and water are fed to the machine.
* Specimens are tested for their polishing value on a portable tester.
* The slider of the machine is released which brushes past the specimen and comes to a halt.

Limitations :

Type	PSV	Quality.
Lime stone	35 to 40	Poor
Granite	40 to 48	Fair
Sand stone	>55	Good.

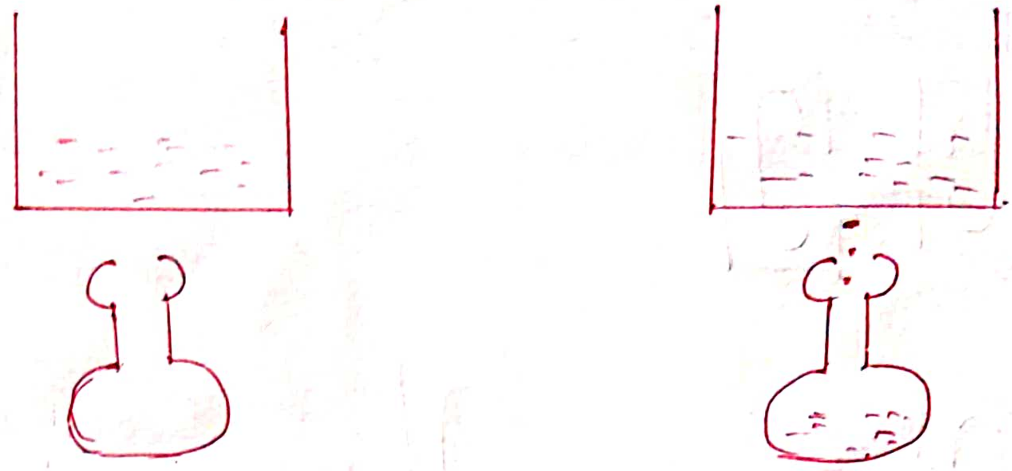
Ductility Test.



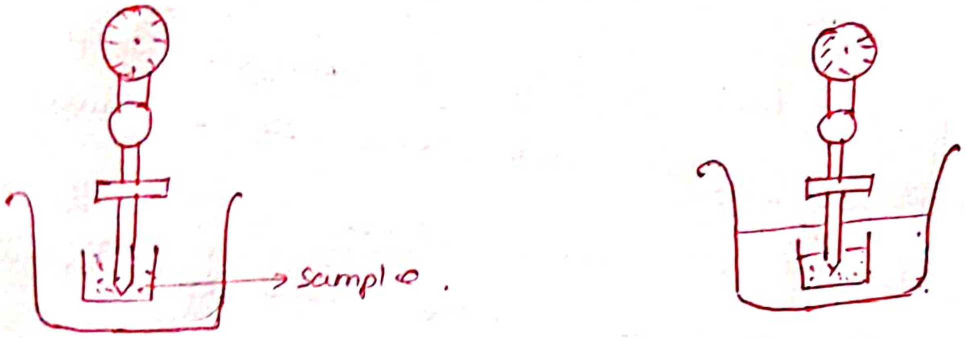
Start.

End.

* Ductility is the property of bitumen that permits
it to undergo great deformation or elongation
* It is defined as the distance in cm, to which
a std sample of the material will be elongated
without breaking.
* Dimension of the sample thus formed is exactly
1 cm square the bitumen sample is heated and
poured in the mould assembly placed on a plate.
* Thus sample with moulds are cooled in the
air and then in water bath at 27°C temp.
The excess bitumen is cut and the surface is levelled
using a hot knife.
* The mould with assembly containing sample is
kept in water bath of the ductility machine for
about 90 min.
* The distance upto the point of breaking of thread
is the ductility value which is reported in cm.



Start END.



1) The cut back bitumen in viscous form is placed in the viscometer

2) The timer is started and flow of the liquid allowed which fails drop by drop in the std 50cc spherical glass bulb.

3) The time taken in sec to fill the specific mark in the bulb is noted and expressed as the viscosity.

4) High viscosity resists the compaction effort.

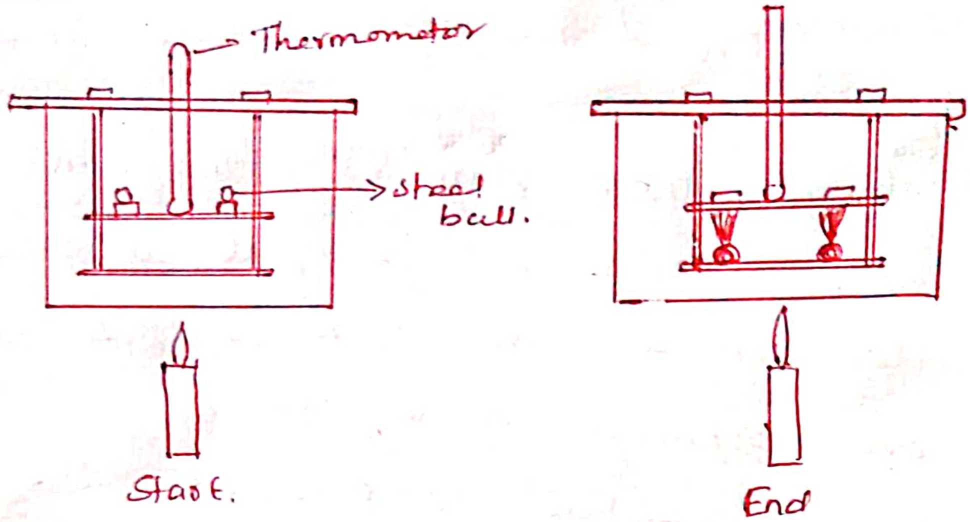
5) Low viscosity the bituminous binder simply lubricants the aggregates particles unstead of forming and uniform film for binding action.

Binder content :

* The durability of the pavement is mainly governed by the binder content. In general, higher the binder content, more durable is the mix.
* Binder content should be adequate to give the max stability for a given mix grading & there is an optimum binder content.
* In order to facilitate the placement, the binder content should be such as to provide workability.

Traffic	Climate.			
	Hot	Hot Humid	moderate	cold.
A. Main Highways				
(i) Heavy & very heavy traffic	30/40 60/70	60/70	80/100	80/100
(ii) Medium & light traffic	80/100	80/100	80/100	120/150
B. Common roads				
i) Heavy & Very heavy	30/40 60/70	60/70	80/100	80/100.

Softening point test :



Procedure

* The given bitumen sample is taken in the brass ring
* The brass ring along with the bitumen sample is suspended in water at a particular temp.
* A steel ball is placed upon the bitumen and the water is then heated at a rate at 5° C / min
* The bitumen will starting melting and start flowing down.
* The temp noted is the softening point of the bitumen.

Limitations :

* Hard grade bitumen possesses higher softening point than soft grade bitumen.
* Bitumen used in paving job should have softening point varying b/w 35 to 70°c

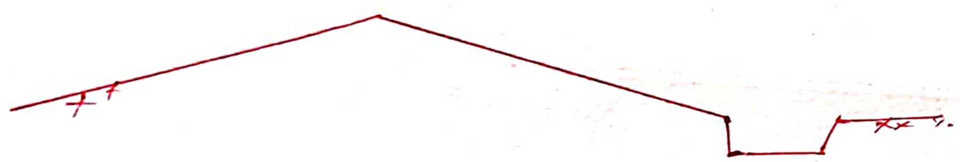
Highway Drainage :

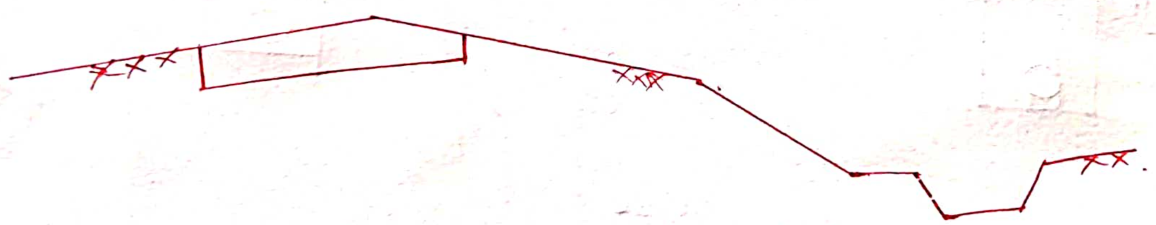
It is the process of removing and controlling excess surface and sub surface water with in the right of way.

Surface drainage :

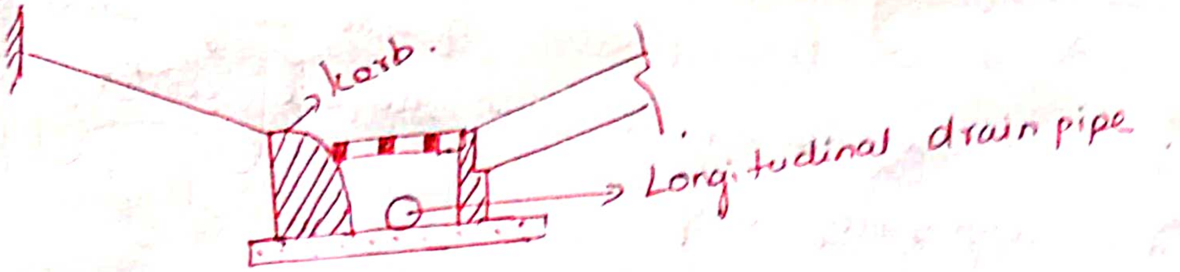
(i) Collection of surface water.

(ii) Disposal of collected surface water.





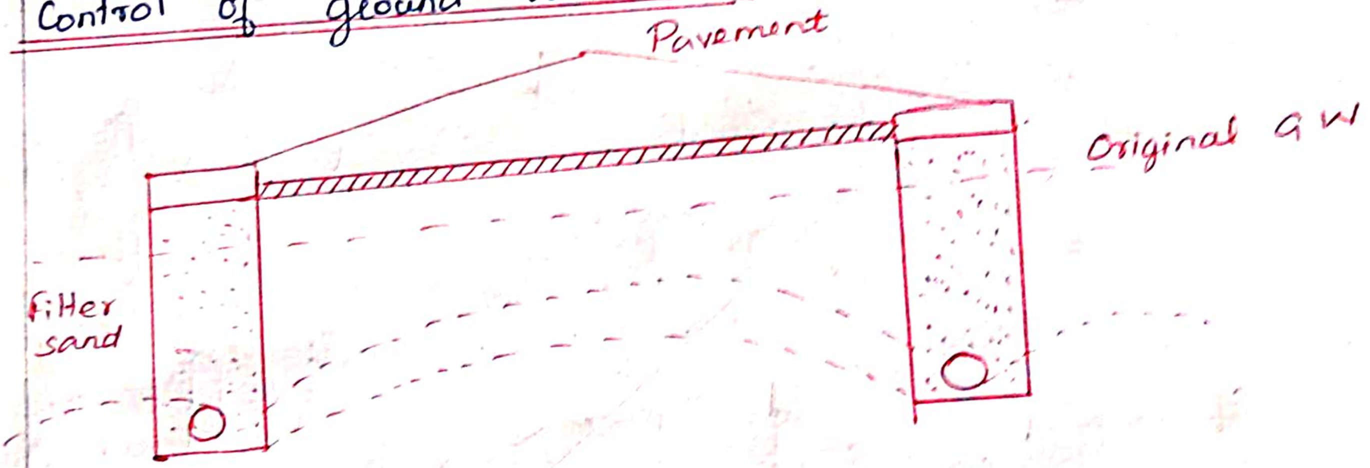
Surface drainage in urban roads:



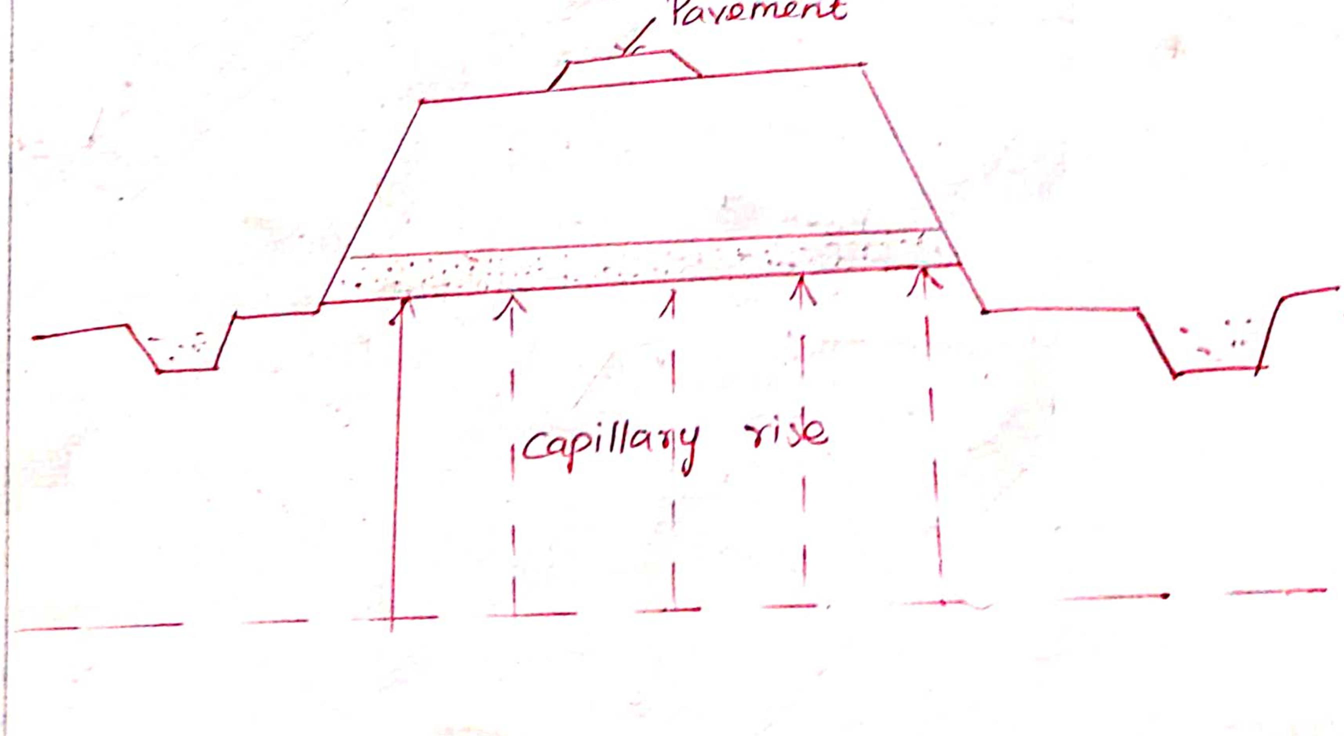
Sub-surface drainage

1) Control of Ground water table
2) Control of seepage flow.
3) Control of capillary Rise.

Control of ground water table.



Control of capillary Rise.



Survey Applications of photogrammetry:

Unit-V

1. Topographical Mapping
2. Large Scale plans
3. Cadastral Plans
4. Land use maps
5. Hydrographic Maps & charts

EDM:

Electronic Distance measuring instruments have been used recently. Measurement of Distance → Replacing chain, tape, Sunlight or artificially generated electromagnetic wave → use different wavelength of such as microwave, infrared waves, visible light waves are useful for distance measurement.

These waves are reflected at point upto which distance is to be measured from instrument station and again received by instrument. Time taken by the wave to travel distance may be measured by knowing the velocity of wave.

Time too short by measuring time taken is difficult one.

Uses: Phase difference method in which no. of completed wave, incompleted wave is measured.

Types of EDM:

1. Microwave instruments

- Range of instrument up to 100km.
- Two identical units → Master unit & Remote unit.

- Master unit → Pressing button master unit convert remote unit & Remote unit to master unit.

2. Infrared wave instruments

- Range of distance upto 3 km.
- Are light & economical.

3. Light wave instruments

- Named as Geodimeter
- Range of distance 2 to 5 km.
- Accuracy of 0.5 to 5mm / km distance.

Advantages → Speed & accurate.

TOTAL STATION:

Various applications distance measurement, slopes and angle measurements. Combination of EDM & electronic theodolite.

Advantages:

- Field work is carried out very fast.
- Accuracy is high.
- Manual errors involved in reading & recording is eliminated
- Calculation of co-ordinates is very fast & accurate.
- Computers can be employed for map making & plotting contour and cross-sections.

GIS: Geographic Information System:

A geographic information system is a system designed to capture, store, manipulate, analyse, manage, and present all types of spatial (or) geographic data.

GIS Functions:

[Capture] → GPS satellites
↓
[Store] → Stores in Vector (or) Raster format Spatial & attribute data.
↓

Query → Identifying specific features, identifying features on conditions.

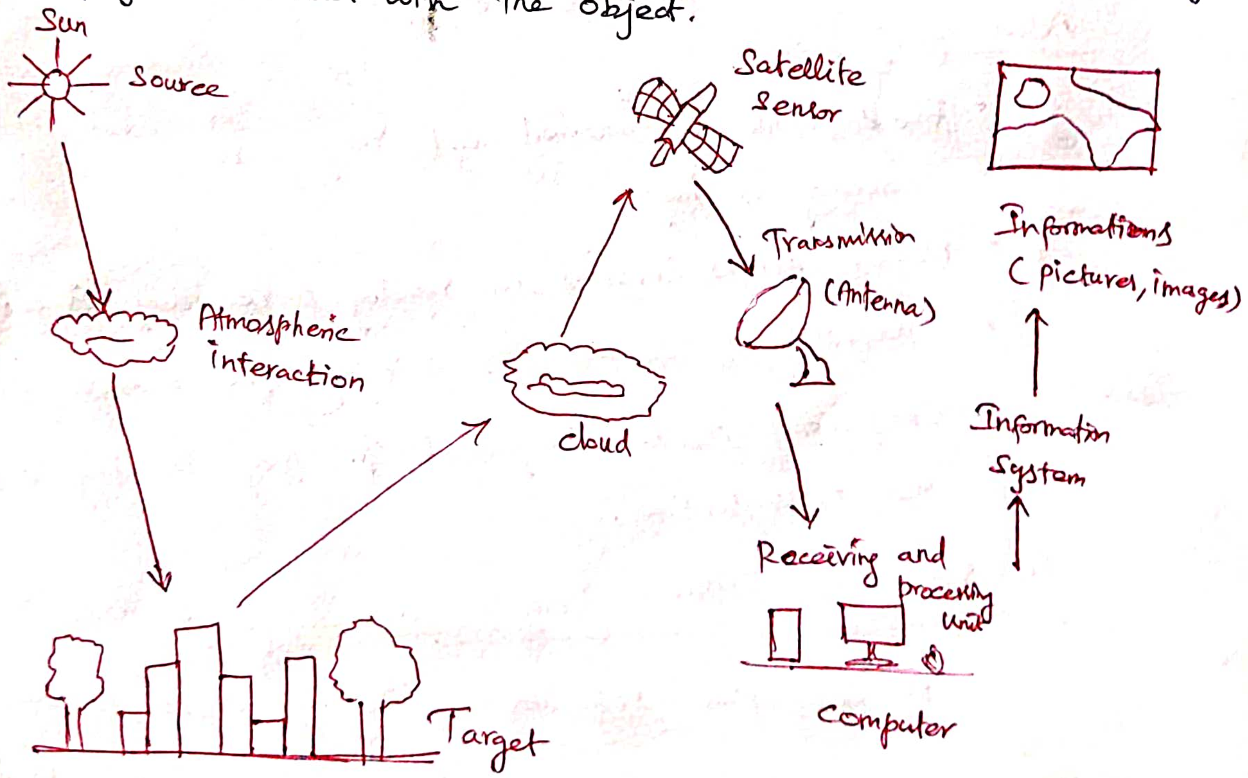
Analysis → Proximity analysis
Overlay analysis → overlap 2 layers
Network analysis → Linear features.

Display → Visualized as a maps
Reports, 3D views, photographs.

Output → Paper map, document, image

Remote Sensing:

* It is the collection of information about an object without being in direct physical contact with the object.



Types of Remote sensing:

- Passive Sensing → Measures energy naturally available (ex: sun energy)
- Active Sensing → sensor emits radiation directed toward the target (ASTER)

ASTER → Advanced Spaceborne Thermal Emission and Reflection Radiometer.
↳ The radiation reflected from the target is detected and measured by the sensor.

GPS - Global Positioning System:

It is radio navigation System that allows land, sea and airborne users to determine their exact location (latitude, longitude), time, velocity in all weather conditions.

Soil Suitability Analysis:

American Association of State Highway and Transportation officials (AASHTO) is used as a guide for the classification of soils and soil aggregate mixures for highway construction purpose.

A-1 → Well graded, essentially non-plastic

A-1-a → more gravelly (storey) with or without fine particles.

A-1-b → More Sandy with or without fine particle.

A-3 → Uniformly graded sand.

A-2 → Granular material not being a A_1 or A_3 material; a distinction is made between grade.

A-2-4, A-2-5, A-2-6, A-2-7 → Relatively coarse grained mixtures with Substanial amount of fine particles.

A-4 → Loam soil (It is composed mostly of sand and silt, and smaller amount of clay) (40-40-20 % Concentration)

A-5 → Loam soil containing mica's: this causes a rather elastic behaviour of soil that makes the soil difficult to compact.

A-6 → clay.

A-7 → clay a further distinction made between a A-7-5 & A-7-6 clay.

General classification	General Material [35% or less passing 0.075mm Sieve]			Silt clay materials [>35% passing the 0.0[illegible] Sieve]			
Group classification	A1	A3	A2	A4	A5	A6	A7
	A-1-a, A-1-b	A-2-4, A-2-5	A-2-6, A-2-7				A-7-5, A-7-6
Used types of sig. constituent materials	Stone Fragments Sand	Fine Sand	silty or clayey gravel or Sand	Silty Sand		clayey Soil	
	Excellent to good			Fair to Poor.			

Shrinkage and Swell of Soil:

Shrinkage and Swell of Soils Containing large clay fraction ($< 2\mu m$) Can lead to Severe damage on road pavements.

Swell results in Serious cracking and unevenness of the pavement. shrinkage may cause loss of support resulting in greater Stresses in pavement Structure due to traffic loading and thus Shorter pavement life.

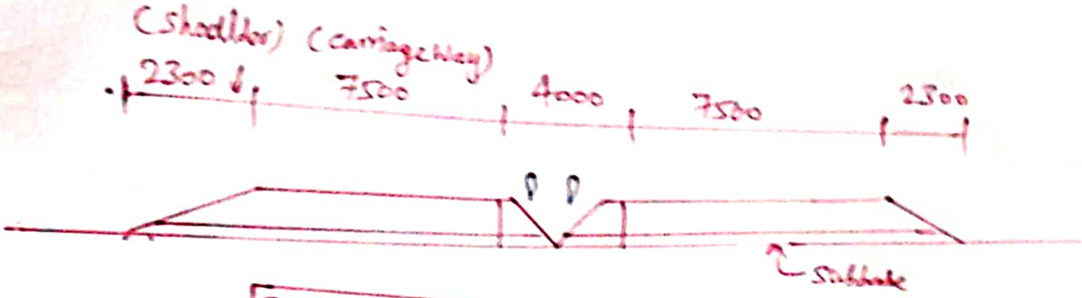
These problems can be solved through Stabilisation of Soil. The application of layers impermeable for water can also provide a Solution.

Classification of Rural Roads

Based on location and Functions

1. Express way
2. National Highway (NH)
3. State Highway (SH)
4. Major District Roads (MDR)
5. Other District Roads (ODR)
6. Village Roads (VR)

-xpress way:



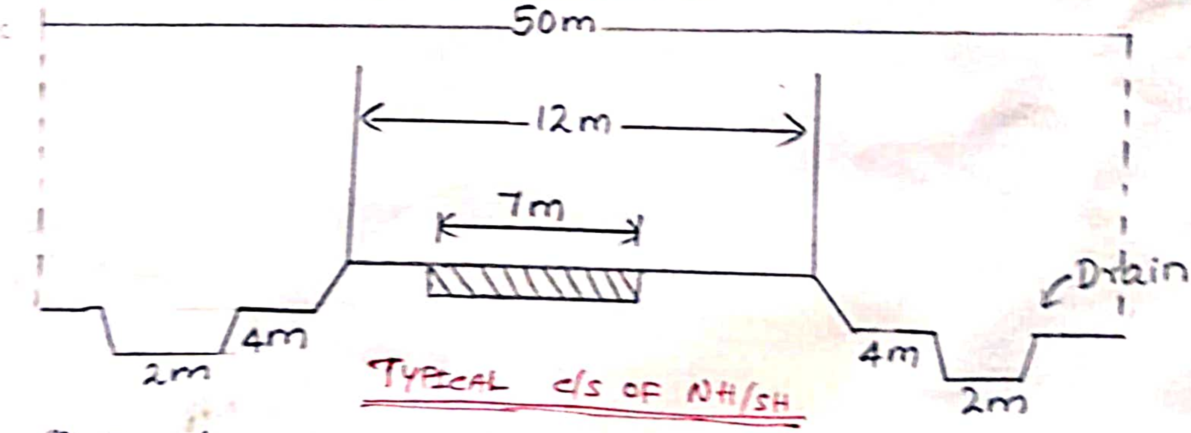
Cross-section of expressway

* They are superior type of highways and are designed for high speeds 120 km/hr.

* They are generally provided with grade separations at Intersections.

* Parking, loading and unloading of goods and pedestrian traffic is not allowed.

2) National Highway & State Highways:



TYPICAL c/s OF NH/SH

* Connect capitals of large States.
* Link the National highway of adjacent States.
* Connect District Headquarters Towns.

Immediate settlement:

The reduction in volume of soil (or) the settlement of soil occur just after the application of load is known as immediate settlement (or) Initial consolidation.

For partially saturated soil – Decrease in volume due to expulsion and compression of air in the voids.

For saturated soils due to compression of solid particles.

Primary consolidation settlement:

After initial consolidation, further reduction in volume occurs due to expulsion of water from voids.

In fine grained soils → Primary consolidation occurs over a time.
In coarse grained soils → Primary consolidation occurs rather quickly due to high permeability.

Secondary consolidation settlement:

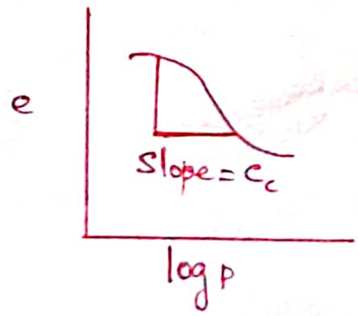
The reduction in volume continues at a very slow rate even after the water is fully dissipated and primary consolidation is complete. It is may be due to readjustment of solid particles. In most of the cases, the secondary consolidation is ignored, its having less magnitude. The settlement means that indicates the primary consolidation.

DETERMINATION OF SETTLEMENT:

1) $$\Delta H = \left[\frac{\Delta e}{1+e_0}\right] H \rightarrow (A)$$

where, ΔH = settlement ; Δe = change in void ratio ; e_0 = initial void ratio.
H = Thickness of soil layer.

2) From e-log p curve



slope of e-log p curve gives C_c.

C_c = Compression index

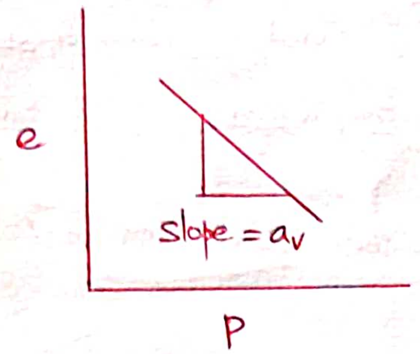
$$C_c = \frac{\Delta e}{\Delta \log p} \rightarrow (B)$$

$$\Delta e = C_c \, \Delta \log p$$

Sub. in equation (A),

$$\Delta H = \left[\frac{C_c \log P}{1+e_0}\right] H$$

3) From e-p curve:



Slope of e-p curve gives a_v

$$a_v = \frac{\Delta e}{\Delta p} \rightarrow (C)$$

$a_v \rightarrow$ coefficient of compressibility

from (B), $\Delta e = a_v \cdot \Delta p$

Substitute in (A)

$$\therefore \Delta H = \left(\frac{a_v \cdot \Delta p}{1+e_0}\right) H$$

m_v = co-efficient of volume compressibility $= \frac{a_v}{1+e_0}$

$C_c = 0.007 (W_L - 10) \rightarrow$ disturbed soil

$C_c = 0.009 (W_L - 10) \rightarrow$ undisturbed soil, W_L = liquid limit (%)

TERZAGHI'S ONE DIMENSIONAL CONSOLIDATION THEORY – GOVERNING DIFFERENTIAL EQUATION:

Consolidation:

A consolidation is a gradual process of reduction of volume under static loading, reduction in volume of a soil due to squeezing out of water from soil.

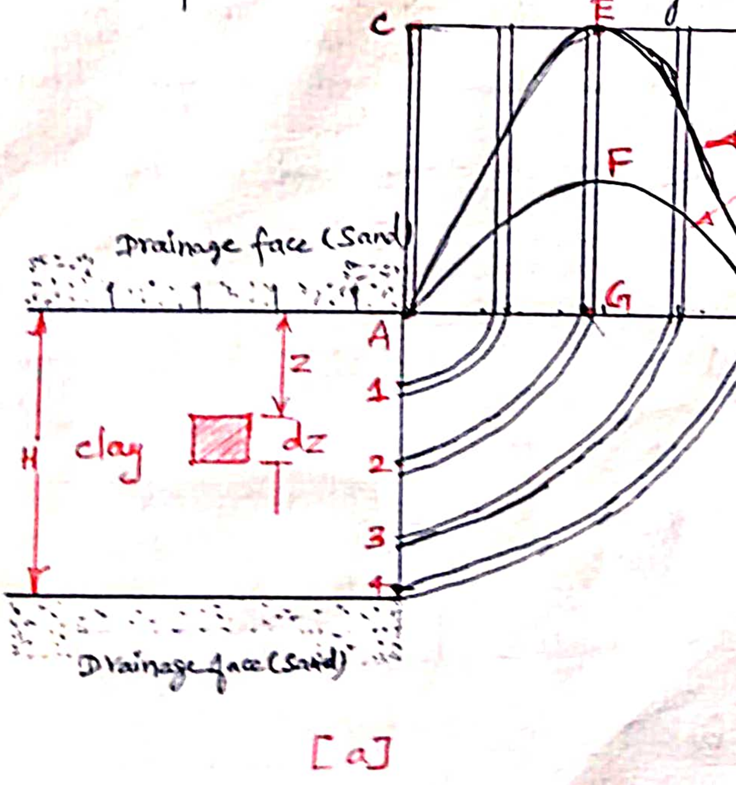
It is a process which occurs in nature when the saturated soil deposits are subjected to static loading caused by the weight of the building and other structures.

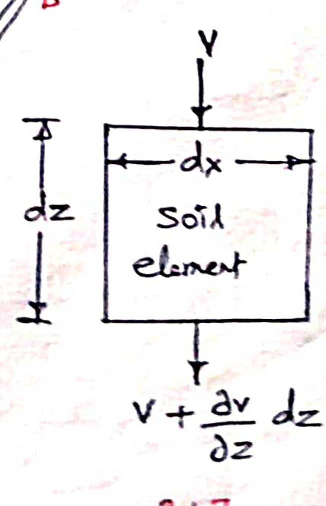
The theoritical concepts of the consolidation process was developed by Terzaghi. (1923).

TERZAGHI'S THEORY OF ONE-DIMENSIONAL CONSOLIDATION

The theoritical concept of the consolidation process was developed by Terzaghi (1923). The following assumptions are made:

1) The soil is homogeneous and fully saturated.
2) Soil particles and water are incompressible. (γ & γ_w are constant)
3) The compression (load) and deformation (flow) are one-dimensional (vertical).
4) Strains are small.
5) Darcy's law is valid at all hydraulic gradients.
6) The co-efficient of permeability 'k' and the co-efficient of volume compressibility 'm_v'. remains constant throughout the process.
7) There is a unique relationship, independent of time, between 'e' and 'σ'' (effective stress).
8) The time taken for consolidation is entirely depends upon the permeability of soil.
9) Excess pore water drains out only in the vertical direction.





ONE-DIMENSIONAL CONSOLIDATION

Let, a saturated clay layer of thickness 'H' lies between two layers of sand which serve as two drainage faces.

When the clay layer is subjected to a pressure increment $\Delta\sigma$, it is first borne by pore water so that at initial time 't_0' the excess pore pressure, $\boxed{\bar{u} = \Delta\sigma}$ at all points along the depth of clay layer and it is plotted as line 'CD' in fig. (a).

Drainage of pore water into the sand layers starts and excess pore pressure at top and bottom boundaries of clay layer drops down to zero and remains so at all times, during the consolidation process.

At the end of process, say at $\boxed{t = t_f}$ the excess pore pressure will have been completely dissipated, so that $\boxed{\bar{u} = 0}$ at all points and is represented by the line 'AB' in fig. (a).

At any intermediate time t, between 't_0 and t_f', part of consolidation pressure '$\Delta\sigma$' is transferred to soil particles so that $\boxed{\Delta\sigma = \Delta\sigma' + u}$

The distribution of excess pore pressure '$\bar{u}$' at any intermediate time 't' is represented by a curve such as AFB in fig. (a).

A number of such curves representing excess pore pressure distribution along the depth of clay layer at different instants of time $t = t_1, t_2 \ldots$ can be drawn and they are known as Isochrones.

The slope of an isochrone at any point at a given time gives the rate of change of '$\bar{u}$' with depth.

At any time t, the hydraulic head 'h' corresponding to the excess pore pressure $\bar{u}$ is given by,

$$h = \frac{\bar{u}}{\gamma_w} \qquad [\because \bar{u} = h \cdot \gamma_w]$$

The hydraulic gradient 'i' is given by,

$$i = \frac{\partial(h)}{\partial z} = \frac{1}{\gamma_w}\frac{\partial \bar{u}}{\partial z}$$

Applying Darcy's law, the velocity of flow of pore water due to this hydraulic gradient is given by,

$$V = Ki = \frac{K}{\gamma_w} \cdot \frac{\partial \bar{u}}{\partial z}$$

The rate of change of velocity along the depth of the layer is given by

$$\boxed{\frac{\partial v}{\partial z} = \frac{k}{\gamma_w} \cdot \frac{\partial^2 \bar{u}}{\partial z^2}} \rightarrow (A)$$

Let us consider a soil element, of size dx, dz and of width 'dy' perpendicular to the plane of figure. If,

V → velocity of water at entry

Velocity of water at exit $= \left(V + \frac{\partial v}{\partial z} \cdot dz\right)$ as indicated in fig (b)

The quantity of water entering the soil element in unit time

$= V \cdot dx \cdot dy$. (velocity × Area = Q)

The quantity of water leaving the soil element in unit time

$= \left(V \cdot \frac{\partial v}{\partial z} \cdot dz\right) \cdot dx \cdot dy$ ($\because Q = AV$)

Hence, the net quantity of water squeezed out of the soil element in unit time is given by,

$$\Delta q = \left(V + \frac{\partial v}{\partial z} \cdot dz\right) dx\, dy - V\, dx\, dy$$

$$\therefore \Delta q = V\, dx\, dy + \frac{\partial v}{\partial z} dx\, dy\, dz - V\, dx\, dy$$

$$\boxed{\Delta q = \frac{\partial v}{\partial z} dx\, dy\, dz} \rightarrow (1)$$

The decrease in the volume of soil element is equal to the volume of water squeezed out.

Also, we have, $\Delta V = -m_v V_0 \Delta \sigma'$

V_0 = volume of soil element at time 't₀' = dx dy dz

∴ change in volume per unit time is given by,

$$\frac{\partial}{\partial t}(\Delta V) = -m_v\,(dx\,dy\,dz)\,\frac{\partial(\Delta\sigma')}{\partial t} \rightarrow (2)$$

Comparing (1) & (2)

$$(dx\,dy\,dz)\frac{\partial v}{\partial z} = -m_v\,\frac{\partial(\Delta\sigma')}{\partial t}\,(dx\,dy\,dz)$$

$$\boxed{\frac{\partial v}{\partial z} = -m_v\,\frac{\partial(\Delta\sigma')}{\partial t}} \rightarrow (3)$$

Now,

$$\Delta\sigma = \Delta\sigma' + \bar{u}$$

(or)

$$\boxed{\Delta\sigma' = \Delta\sigma - \bar{u}}$$ where, '$\Delta\sigma$' is constant.

$$\therefore \frac{\partial(\Delta\sigma')}{\partial t} = -\frac{\partial\bar{u}}{\partial t}$$

Substituting in Equation (3),

$$\boxed{\frac{\partial v}{\partial z} = +m_v\,\frac{\partial\bar{u}}{\partial t}} \rightarrow (B)$$

Now, Comparing equations (A) & (B), we get,

$$\frac{k}{\gamma_w}\,\frac{\partial^2\bar{u}}{\partial z^2} = m_v\,\frac{\partial\bar{u}}{\partial t}$$

$$\frac{\partial\bar{u}}{\partial t} = \frac{k}{m_v\cdot\gamma_w}\,\frac{\partial^2\bar{u}}{\partial z^2}$$

(or)

$$\boxed{\frac{\partial\bar{u}}{\partial t} = c_v\,\frac{\partial^2\bar{u}}{\partial z^2}}$$ where, $c_v = \frac{k}{m_v\cdot\gamma_w}$

$c_v \rightarrow$ co-efficient of consolidation.

The above equation is the basic differential equation of consolidation which relates the rate of dissipation of excess pore pressure with the rate of expulsion of pore water from a unit volume of soil.

We know that, $c_v = \frac{(T_v)_{90} d^2}{t_{90}}$

for 90% consolidation,

$$T_v = 1.7813 - 0.9332 \log_{10}(100 - U\%)$$

($U\%$ = 90)

$$\boxed{T_v = 0.848}$$

$$\therefore \boxed{c_v = \frac{0.848 d^2}{t_{90}}}$$

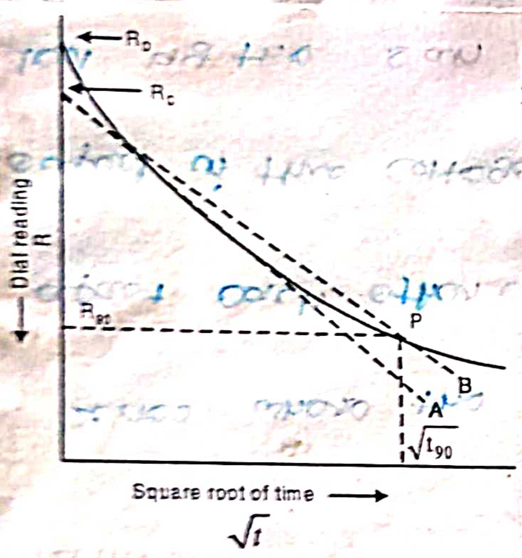


Fig. 11.9. R versus $\sqrt{t}$ (from laboratory data)

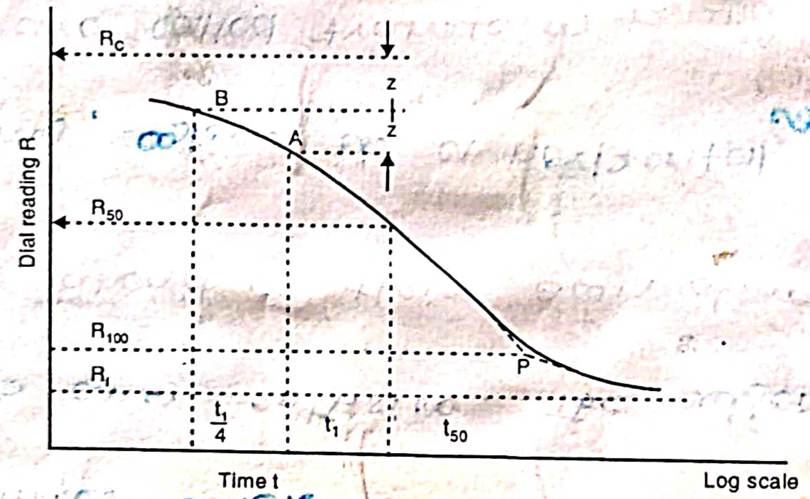


Fig. 11.11. R versus log t (from laboratory data)

3) Logarithm of time fitting method (or) log t method (or) Casagrande's method:

- The curve is drawn between log t and dial reading 'R'. Select any point on the initial portion of the same curve (A) extend that point along y-axis on x-axis find time t_1.
- Then 't_1' is multiplied by '4' as '$4t_1$' measured along ~~y~~-axis. Extend that point on the curve in vertical direction (B).
- Measure the distance between 'A' & 'B' as 'z'. Mark this distance from first selected point (A) from the initial portion in vertical direction, to get initial dial reading R_0.
- Draw the tangent from middle portion and bottom portion of the curve, these two meets at a particular point note it as 'P'.
- Extend this point parallel to x-axis, it meets on y-axis, that point is R_{100}.

Co-efficient of volume change:

1) Change in void ratio method:

In this method, the coefficient of volume change (m_v) is computed using the following equation.

$$m_v = \frac{\Delta e}{1+e_0} \cdot \frac{1}{\Delta \sigma'}$$

2) Change in thickness method:

In this method, the co-efficient of volume change is calculated using the following equation.

$$m_v = -\frac{\Delta H}{H_0} \cdot \frac{1}{\Delta \sigma'}$$

Determination of co-efficient of consolidation:

The co-efficient of consolidation (C_v) is determined by methods based on the comparison between

i) The characteristics of the theoretical relation b/w "T_v" and 'U'

ii) Relation b/w the elapsed time 't' and 'U'

— obtained for soil specimen in laboratory test.

Two commonly used methods are,

i) Square root of time fitting method

ii) Logorithm of time fitting method.

1) Square root of time fitting method (or) $\sqrt{t}$ method (or) Taylors method

* Draw the curve between '$\sqrt{t}$' as x-axis, and the dial reading 'R' in y-axis. The initial dial reading 'R_0' corresponds to time $t=0$ and $u=0$.

* The starting portion (line A) is produced back to meet y-axis at reading 'R_c'. From "R_c" another line 'B' is drawn that its magnitude is 1.15 times that of 'line A'.

* The intersection of 'line B' with the consolidation curve gives a point 'P' corresponding to 90% consolidation, whose dial reading and time may be designated as 'R_{90}' & '$\sqrt{t_{90}}$' respectively.

- Find the mid point between R_0 and R_{100} to get R_{50}. Mark it, find the corresponding t_{50}.

$$\therefore \boxed{C_v = \frac{(T_v)_{50}\, d^2}{t_{50}}}$$

for 50% consolidation:

$$T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$$

$$= \frac{\pi}{4}\left(\frac{50}{100}\right)^2$$

$$\boxed{T_v = 0.197}$$

now, $\therefore \boxed{C_v = \frac{0.197\, d^2}{t_{50}}}$

3) Determination of Co-efficient of Permeability: (k)

The co-efficient of permeability (k) is calculated by using the following relation, $\boxed{k = C_v . m_v . \gamma_w}$; $\boxed{m_v = \frac{a_v}{1+e_0}}$

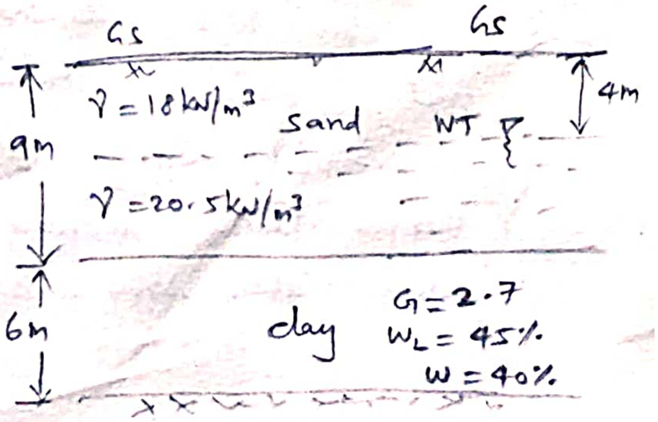
Knowing C_v & m_v, 'k' can be obtained.

PROBLEMS ON SETTLEMENTS.

1) A 6m thick bed of clay is overlain by 9m thick layer of sand with water table at 4m below ground surface. For the clay layer specific gravity of soil particles is 2.7, average liquid limit 45%, and natural water content 40%. For the sand layer the bulk unit weights above and below water table are 18 kN/m³ and 20.5 kN/m³ respectively. Calculate the settlement of a building constructed on sand layer if it causes an increase in effective vertical stress of 100 kN/m² at the middle of clay layer.

Given Data:

Increase in effective pressure, $\Delta\sigma' = 100\, kN/m^2$.



Solution:

sand layer : γ above W.T. = 18 kN/m³

γ below W.T. = 20.5 kN/m³.

$\therefore \gamma' = \gamma_{sat} - \gamma_w = 20.5 - 9.81$

$\gamma' = 10.69$ kN/m³.

for clay layer $e_o = w_{sat} G.$ [$\because S = 1$]

$= 0.4 \times 2.7$

$e_o = 1.08$

$$\gamma' = \frac{(G-1)\gamma_w}{1+e} = \frac{(2.7-1)\,9.81}{1+1.08} = 8.02 \text{ kN/m}^3.$$

At middle of clay layer,

Initial effective pressure } $\sigma_o' = 4 \times 18 + 5 \times 10.69 + 3 \times 8.02$

$\sigma_o' = 149.51$ kN/m².

for clay layer, C_c = Compression index $= 0.009\,[W_L - 10]$

$= 0.009\,[45-10]$

$C_c = 0.315$.

$\therefore$ Settlement at bottom of clay layer } $$S = \frac{C_c H}{1+e_o} \log_{10} \frac{\sigma_o' + \Delta\sigma'}{\sigma_o'}$$ (H → depth of clay layer)

$$= \frac{0.315 \times 6}{1+1.08} \log_{10} \frac{149.51+100}{149.51}$$

$= 0.2021$ m

$$\boxed{S = 202.1 \text{ mm}}$$

2) A 5m thick saturated soil stratum has a compression index of 0.25 and co-efficient of permeability 3.2×10^{-3} mm/sec. If the void ratio is 1.9 at vertical stress of 0.15 N/mm², compute the void ratio when the vertical stress is increased to 0.2 N/mm². Also calculate the settlement due to above stress increase and time required for 50% consolidation.

Given Datas:

$C_c = 0.25$; $H = 5m$

$K = 3.2 \times 10^{-3}$ mm/sec.

$e = 1.9$; $\sigma_0 = 0.15 N/mm^2$.

$\sigma_1 = 0.2 N/mm^2$, $e_1 = ?$.

Solution:

We know,

$$\text{Compression index, } C_c = \frac{\Delta e}{\Delta \log \sigma} = \frac{e_0 - e_1}{\log \sigma_1 - \log \sigma_0}$$

$$e_0 - e_1 = C_c \log \frac{\sigma_1}{\sigma_0} \Rightarrow 0.25 \log \frac{0.2}{0.15} \Rightarrow 0.0312$$

Void ratio ; $e_1 = 1.9 + 0.0312 = \underline{1.869}$.

ii) Settlement:

$$\Delta H = \frac{C_c H_0}{1+e_0} \log \frac{\sigma_1}{\sigma_0}$$

$$= \frac{0.25 \times 5000}{1+1.9} \log \frac{0.2}{0.15}$$

$$\Delta H = 53.8 mm.$$

iii) Time required: (t):

For $U = 50\%$, $T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2 = \frac{\pi}{4}\left(\frac{50}{100}\right)^2 = 0.196$

Co-efficient of volume change } $m_v = \frac{\Delta V}{V_0} \times \frac{1}{\Delta \sigma} \Rightarrow \frac{\Delta e}{1+e_0} \cdot \frac{1}{\Delta \sigma}$

$$= \frac{1.9 - 1.869}{1+1.9} \times \frac{1}{(0.2-0.15)}$$

$$m_v = 0.214 mm^2/N.$$

Coefficient of Consolidation } $C_v = \frac{k}{m_v \gamma_w} \Rightarrow \frac{3.2 \times 10^{-3}}{0.214 \times 9.81 \times 10^{-6}} \Rightarrow 1524 mm^2/sec.$

Also, T_v = Time factor = $\frac{C_v t}{d^2}$ and $d = H$ for single drainage.

$$\therefore t = \frac{T_v d^2}{C_v} \Rightarrow \frac{(0.196) \times (5000)^2}{1524} = 3215.2 \text{ sec.}$$

$t = 53.58$ minutes Time required for 50% Consolidation.