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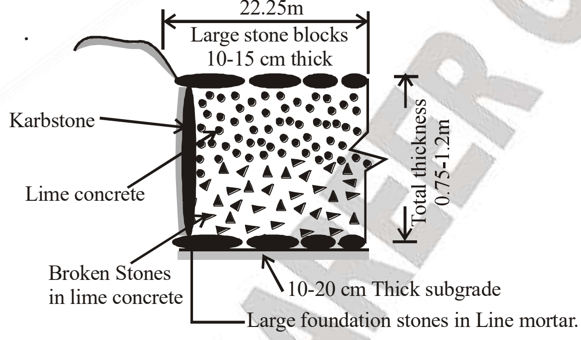
CONTENTS

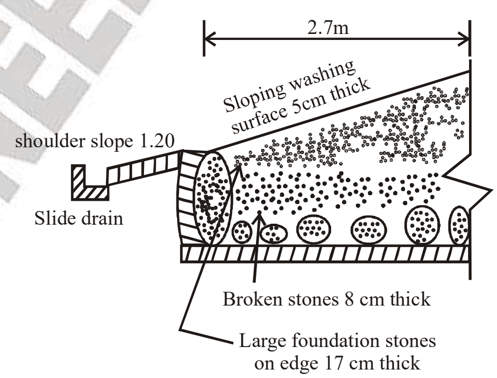
CHAPTER - 1
INTRODUCTION

1.1 DEVELOPMENT OF HIGHWAY
1.1.1 Roman Roads
During this period of Roman civilization many roads were built of stone blocks of considerable thickness. Main features of the Roman roads

1.They were built straight regardless of gradients.
2.They were built after the soft soil was removed and a hard stratum was reached.
3.The total thickness of the construction was *as* high as 0.75 to 1.2 metres at some places even though the magnitude of wheel loads of animal drawn vehicles was very low.
4.The wearing course consisted of dressed large stone-blocks set in lime mortar.

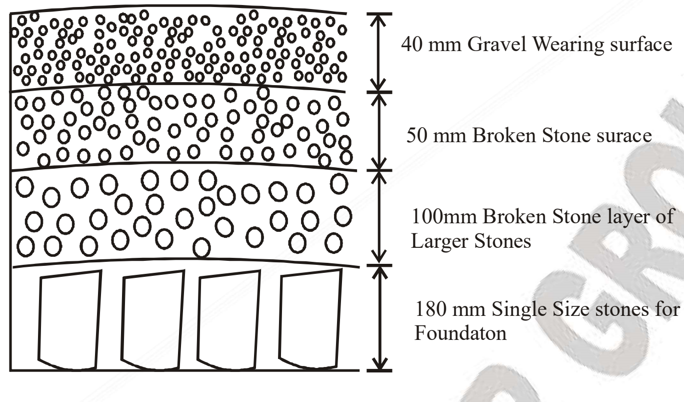


1.1.2 Tresaguet Construction
1. Pierre Tresaguet (1716-1796) developed an improved method of construction in Prance by the year 1764, A.D.
2. The-main-feature of his proposal was that the thickness of construction need to be only in the order of 30 cm.
3. Due consideration was given by him to subgrade moisture condition and drainage of surface water.



1.1.3 Telford Construction
1.Telford provided level subgrade of width 9 meters

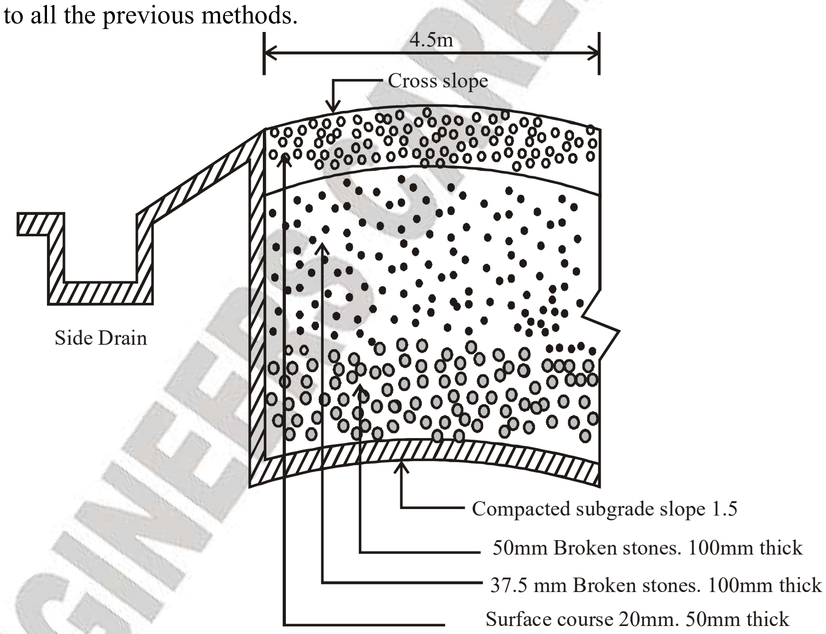
2.A binding layer of wearing course 4 cm thick was provided with cross slope of 1 in 45.
3.Thickness of foundation stone varied from 17 cm at edges to 22 cm at the centre.



Telford's Cross - section of Road

1.1.4 Macadam Construction

1.John Macadam (1756-1836) put forward an entirely-new method of road construction as compared to all the previous methods.



British Roads

2. Macadam was the first person who suggested that heavy foundation stoues are not at all read to be placed at the bottom layer. He provided stones of size less than 5 mm to a uniform thickness of 10 cm. The importance to subgrade drainage and compaction was given so the subgrade was compacted and 'prepared with cross slope of 1 in 36.

3. The size of broken stone for the top layers was decided on the basis of stability under animal drawn vehicles.
4. The pavement surface was also given the cross slope of 1 in 36.
5. Total thickness was kept uniform form edge to centre to a minimum value of 25 cm.

1.2 EARLY DEVELOPMENTS IN HIGHWAY PLANKING IN INDIA

1.2.1 Jayakar Committee

Since 1853, rail transport was mainly used for long distance transportation, and roads acted as a feeder service to the railways. After First World War, as the motor cars came on the roads, the inadequacy of the existing road network came into light.
Hence, in 1927, the government appointed a Road Development Committee headed by. Mr. M.R. Jayakar

1.2.1.1 Recommendations of the Jayakar Committee

1.Committee suggested that Central government should take the proper charge of road considering it as a matter of national interest.
2.They gave more stress on long term planning programme, for a period of 20 years (hence called twenty year plan).
3.They suggested the holding of periodic road conferences to discuss about road construction and development. This paved the way for the establishment of a semi-official, technical body called Indian Road Congress (IRC) in. 1334.
4.They suggested imposition of additional taxation oh motor transport which included duty on motor spirit, vehicle taxation, license fees for vehicles plying for hire. This led to the introduction of a development fund called Central toad fund (CRF) in 1929. Road development in the country was beyond the financial capacity of local governments; and .therefore, the central revenue should support it.
5.They suggested a dedicated research organization to carry out research and development work. This resulted in the formation of Central Road Research Institute (CRRI) in 1950.

1.3 INDIAN ROADS CONGRESS

Indian Roads Congress (IRC) was established in 1934 with the following objectives
1.To promote and encourage the science and practice of road building and maintenance.
2.To provide a forum for expression of collective opinion of its members on matters affecting roads.
3.To promote the use of standard specifications and practices.
4.To advise regarding education, experiment and research connected with roads.
5.To hold periodic meetings to discuss .technical questions regarding roads.
6.To suggest legislation for the development, improvement and protection of roads.
7.To suggest improved -methods of administration, planning, design, operation, use and maintenance of "roads.
8.To establish, furnish and maintain libraries and museums for furthering the science of road making.

1.3.1 The Nagpur Plan (1943-63)

1.Due to the overall economic depression in the country after First World War, the Road Development Fund was not used for development work, but spent in routine maintenance. This caused further deterioration of the roads under the impact of the heavy war time traffic.
2.At this point of time. Conference of Chief Engineers of the Provinces -was convened at Nagpur In 1843.

CHAPTER - 2
GEOMETRIC DESIGN

2.1 INTRODUCTION
1.A highway has many visible dimensions both in the horizontal plane and in the vertical plane. The art of design of the visible dimensions is known as Geometric Design.
2.Proper geometric design will help in the reduction of accidents and their serverity. Therefore, the objective of geometric design, is the provide optimum efficiency in traffic operation and maximum safety at reasonable cost.
3.Highway Geometric Design covers elements such as design vehicle dimensions, user characteristics, terrain, highway classification, design speed, horizontal curves, vertical curves, gradient, sight distances, cross-sectional features, junctions, interchange etc.

2.2 FACTORS CONTROLLING GEOMETRIC DESIGN
Geometric design is influenced by a number of factors such as.
1. Road user characteristics
2. Vehicle characteristics
3. Safety requirements
4. Environmental considerations
5. Economy in construction, maintenance and operation of vehicles
6. Topography
7. Functional classification of roads
8. Traffic volume and composition
9. Design speed
Safety, environmental needs and economy are built into various elements of design. The remaining factors has been discussed as given below.

1. Road User Characteristics
(i)A driver takes a certain amount of time to respond to a particular traffic situation. This can be called as reaction time.
(ii) The action of applying break on seeing a vehicle or obstruction on the road is not an instantaneous phenomenon. But it is a time-consuming phenomenon based on the psychological process involved.
(iii) We can call these processes, as perception, intellection, emotion and volition (PIEV)
(iv) Perception Time is the time required for transmission of the sensations received through eyes, ears and body to the brain and the spinal chord by the nervous system. After perception intellection occurs, that is the formation of new thoughts and ideas. Recalling old memories of similar occasion.
(v) Linked with these two stages is emotion, based on the situation, tike fear or anger. This has vital influence on the final message or decision sent by the brain to the muscle. This actual act of taking a decision to produce action is done through *volition* time.
(vi) The total time required for PIEV. that is, from the instant the object comes in the line of sight of the driver to the instant he arrives at a decision, sav, to slow down or to overtake under normal circumstance is called *reaction time.*
(vii) This could vary from 0.5 second for simple situations to 3 to 4 seconds for complex situation. The reaction time is affected by the condition of the driver fatigue, disease, alcohol consumption

WORKBOOK

Example 1. According to 1981 census, the area of State of Maharashtra was 308, sq. km. The number of town's population above 5,000 was 567. The total number of towns and village was 35,778 Determine the length of various road categories.

Solution.

Length of National Highway = $\frac{\text{Area}}{50} = \frac{308,000}{50} = 6,160\,\text{km}$

Length of State Highway = $\frac{\text{Area}}{25} = \frac{308,000}{25} = 12,320\text{km}$

Or = 62.5 × No. of towns above = 500 population – $\frac{\text{Area}}{50}$

= 62.5 × 567 – 6,160 = 35,438 – 6,160 = 29.278 km

Length of Major District Roads Length = $\frac{\text{Area}}{12.5} = \frac{308,000}{12.5} = 24,640\text{km}$

Length = 90 × Number of towns and villages with population above = 5000

= 90 × 567 = 51,030 km

Length of Total road = 4.74 × Number of towns and villages

= 4.74 × 35,778 = 1,69,587 km

Length of Rural Road = 1,69,587 – (6,160 + 12,320 + 24,640)

= 1,69,587 – 43,120 = 1,26,467 km

Example 2. Determine the (1) Length of National Highways, State Highways and Major District Roads and (2) Length of other District Roads and village Roads for a state with the following details as per the Nagpur plan

1. Agricultural- Area in sq km = *40,000*
2. Non-agricultural area in sq km = 20,000
3. Number of towns and village

Population over 5000 ------------ 50
Population 200 -5000 ------------75
Population 100 - 2000 -----------120
Population 501 – 1000 ----------- 2000
Population less than 500 --------- 1000

4. Length of Railways = 1500 km

Solution.

Length of NH, SH. MDR

$= \frac{A}{5} + \frac{B}{20} + N + 5T + D - R$

The above formula is in FPS system. The length in km is given by suitably changing the formula as under .

Length (km) = $\frac{A \times 1.6}{(1.6 \times 1.6)5} + \frac{B \times 1.6}{(1.6 \times 1.6)20}$

$+1.6N + 5 \times 1.6T + D - R$

where A and B are .in sq. km.

Substituting the given values,

Length of HN, SH and MDR = $\frac{40,000 \times 1.6}{1.6 \times 1.6 \times 5} + \frac{20,000 \times 1.6}{1.6 \times 1.6 \times 20}$

$+1.6N + 5 \times 1.6T + D - R$

= 5000+ 625+ 120 + 400 + D + R

Assume D = 15%

Length = 6145 + 922 – R = (7067 – R) km

= 7067 – 1500 = 5567 km

Length of ODR and VR = $\frac{V}{5} + \frac{Q}{2} + R + 2S + D$

This formula gives length in miles. The length in km is given by

$= 1.6\left(\frac{V}{5} + \frac{Q}{2} + R + 2S\right) + D$

$= 1.6\left(\frac{1000}{5} + \frac{2000}{2} + 120 + 2 \times 75\right) + D$

= 3200 + 1600 + 192′ + 240 + D = 5232 + D

Taking D = allowance for future development as 15%

Length of ODR and VR = 5232 + 785 = 6017 km

CHAPTER - 3
TRAFFIC ENGINEERING

3.1 INTRODUCTION
The basic objective of traffic engineering is to achieve free & rapid flow of traffic with least no. of accidents. For this various studies are carried out. These studies are divided into
1. Traffic characteristics
2. Traffic studies and analysis
3. Traffic control regulation
Based on these studies traffic planning & geometrical design will be done.

3.1.1 Traffic Characteristics
Study of traffic characteristics is the most important, for any improvement of traffic facilities.
In traffic characteristics, we generally study
1. Road user characteristic
2. Vehicular characteristic
3. Breaking characteristic

1. Road User Characteristics
It is important to study the characteristics and limitations of road users because the physical mental and emotional characteristics of human beings affect their ability.
Factors affecting road user characteristics are
(i)Physical. Vision, hearing, strength and General reaction to traffic situations.
(ii)Mental. Knowledge, skill, intelligence, experience and literacy.
(iii)Psychological. Attentiveness, fear, anger, superstition, impatience, general attitude towards traffic and regulations and maturity.
(iv)Environmental. Facilities to the traffic, atmospheric condition and locality.

2. Vehicular Characteristics
The study of vehicular characteristics affects the design and traffic performance.
(*i*) *Vehicle dimensions*
(a) Vehicle dimensions mainly considered are the overall width, height, and length of different vehicles, particularly of the largest ones.
(b) The width of the vehicle affects the width of the traffic lanes, shoulders and parking facilities.
(c) Height of the vehicle affects the clearance to be provided under structures such as overbridges underbridges, electric and other service lines.
(d) Length of the vehicle is an important factor in the design of horizontal alignment as it effects the extra width of pavement and minimum turning radius. Length affects the safe overtaking distance, capacity of a road and parking facilities.
(ii) Weight of Loaded Vehicle
The maximum weight of loaded vehicle affects the design of pavement thickness and gradients. In fact the limiting gradients are governed by both the weight and power of the heavy vehicles.

GATE QUESTIONS

1. A priority intersection has a single-lane one-way traffic road crossing an undivided two-lane two-way traffic road. The traffic stream speed on the single-lane road is 20 kmph and the speed on the two-lane road is 50 kmph. The perception-reaction time is 2.5 s, coefficient of longitudinal friction is 0.38 and acceleration due to gravity is 9.81 m/s^2. A clear sight triangle has to be ensured at this intersection. The minimum lengths of the sides of the sight triangle along the two-lane road and the single-lane road, respectively will be

[GATE - 2018]

(a) 50 m and 20 m (b) 61 m and 18 m
(c) 111 m and 15 m (d) 122 m and 36 m

2. A 7.5 m wide two-lane road on a plain terrain is to be held along a horizontal curve of radius 510 m. For a design speed of 100 kmph, super-elevation is provided as per IRC : 73-1980. Consider acceleration due to gravity as 9.1 m/s^2. The level difference between the inner and outer edges of the road (in m, up to three decimal places) is _________.

[GATE - 2018]

3. A car follows a slow moving truck (travelling at a speed of 10 m/s) on a two-lane two-way highway. The car reduces its speed to 10 m/s and follows the truck maintaining a distance of 16 m from the truck. On finding a clear gap in the opposing traffic stream, the car accelerates at an average rate of 4 m/s^2, overtakes the truck and returns to its original lane. When it returns to its original lane, the distance between the car and the truck is 16 m. The total distance covered by the car during this period (from the time it leaves its lane and subsequently returns to its lane after overtaking) is

[GATE - 2018]

(a) 64 m (b) 72 m
(c) 128 m (d) 144 m

4. While aligning a hill road with a ruling gradient of 6%, a horizontal curve of radius 50m is encountered. The grade compensation (in percentage, up to two decimal places) to be provided for this case would be ____.

[GATE - 2017]

5. The radius of a horizontal circular curve on a highway is 120m. The design speed is 60km/hour, and the design coefficient of lateral friction between the tyre and the road surface is 0.15. The estimated value of superelevation required (if full lateral friction is assumed to develop), and the value of coefficient of friction needed (if no superelevation is provided) will, respectively, be

[GATE - 2017]

(a) $\frac{1}{11.6}$ and 0.10 (b) $\frac{1}{10.5}$ and 0.37
(c) $\frac{1}{11.6}$ and 0.24 (d) $\frac{1}{12.9}$ and 0.24

6. A motorist traveling at 100 km/h on a highway needs to take the next exit, which has a speed limit of 50 km/h. The section of the roadway before the ramp entry has a downgrade of 3% and coefficient of friction (f) is 0.35. In order to enter the ramp at the maximum allowable speed limit the braking distance (expressed in m) from the exit ramp is________.

[GATE - 2016]

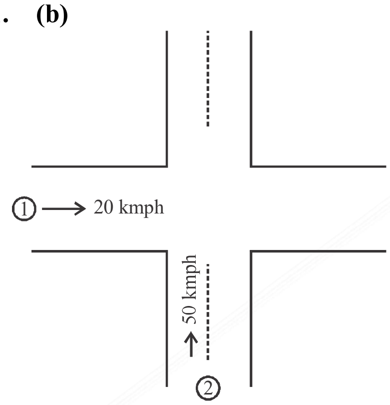
7. A superspeedway in New Delhi has among the highest super-elevation rates of any track on the Indian Grand Prix circuit. The track requires drivers to negotiate turns with a radius of 335 m and 33° banking. Given this information, the coefficient of side friction required in order to allow a vehicle to travel at 320 km/h along the curve is

[GATE - 2015]

(a) 1.761 (b) 0.176
(c) 0.253 (d) 2.530

SOLUTIONS

Sol. 1. (b)

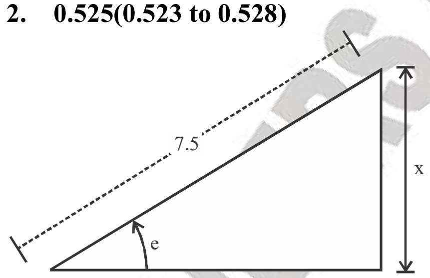


$$SSD_2 = 0.278 \times Vt_R + \frac{V^2}{254f}$$

$$= 0.278 \times 50 \times 2.5 + \frac{50^2}{254 \times 0.38} \simeq 61\,m$$

$$SSD_1 = 0.278 \times 20 \times 2.5 + \frac{20^2}{254 \times 0.38} \simeq 18\,m$$

Sol. 2. 0.525(0.523 to 0.528)



$$e = \frac{V^2}{225R} = \frac{100^2}{225 \times 510} = 0.0871 \not> 0.07 = \tan\theta$$

$\sin\theta \simeq 0.07$

$x = 7.5 \times \sin\theta = 0.525$ m

Sol. 3. (b)

Overtaking time, $T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 16}{4}} = 4$ sec.

S = Space heady way = 16 m

a = acceleration = 4 m/s^2

Distance travelled by vehicle = S_2

$$S_2 = uT + \frac{1}{2}aT^2 = 10 \times 4 + \frac{1}{2} \times 4 \times 4^2 = 72\,m$$

Sol. 4. (1.5)

Ruling gradient, G = 6% (> 4% grade compensation is allowed as per 1Rc)

Radius Of curve, R = 50m

Grade compensation, $GC = \frac{30+R}{R}$

$= \frac{30+50}{50} = 1.6\%$

$= = \frac{75}{R} = \frac{75}{50} = 1.5$

$\therefore$ Use min value of GC = 1.5%

Sol. 5. (c)

Design speed, R = 120m

Design speed, V = 60 km/hr (16.67 m/s)

Coefficient of lateral friction, f = 0.15

(i) Superelevation for the development of full friction

$$e + f = \frac{V^2}{gR} \rightarrow e + 0.15 = \frac{16.67^2}{9.87 \times 120}$$

$$e = 0.086 = \frac{1}{11.63} \simeq \frac{1}{11.6}$$

(ii) For no superelevation coefficient of friction required is $e + f = \frac{v^2}{gR}$

$$0 + f = \frac{16.67^2}{9.81 \times 120}$$

F = 0.236 = 0.24

Sol. 6. (92.14)

Downward gradient, N = - 3%

f = 0.35

$$S_b = \frac{(v_i)^2 - (v_f)^2}{2g(f - N)}$$

ESE OBJ QUESTIONS

1. The rate of equilibrium superelevation on a road is
(1) Directly proportional to the square of vehicle velocity
(2) Inversely proportional to the radius of the horizontal curve
(3) Directly proportional to the square of the radius of the horizontal curve
Which of the above statements are correct?

[ESE - 2018]

(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

2. The following purposes served by a trasnistion curve in a highway alignment include.
1.Gradual introduction of the centrifugal force on moving vehicles from zero on the straight alignment to aconstant final value on the circular curve.
2.Enabling the gradual introduction of superelevation on the roadway.
Select the correct answer using the codes givehn below.

[ESE - 2017]

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) neither 1 nor 2

3. The radius of a horizontal circular curve is 480 m and design speed therein 70 kmph. What will be the equilibrium super elevation for the pressure on the inner and the outer wheels to be equal?

[ESE - 2015]

(a) 5% (b) 6%
(c) 7% (d) 8%

4. Which one of the following items of hill road construction does not help in the prevention of landslides during the monsoon season?

[ESE - 2015]

(a) Breast walls
(b) Hair-pin
(c) Catch-water drains
(d) Retaining walls

5. What will be the non-passing sight distance on a highway for a design speed of 100 kmph when its ascending gradient is 2%? Assuming coefficient of friction as 0.7 and brake efficiency as 50%.

[ESE - 2015]

(a) 176 m (b) 200 m
(c) 150 m (d) 185 m

6. A descending gradient of 4% meets an ascending grade of 1 in 40 where a valley curve of length 200 m is to be formed. What will be the distance of the lowest point on the valley curve from its first tangent point?

[ESE - 2015]

(a) 100 m (b) 111 m
(c) 125 m (d) 118 m

7. In an area of heavy rainfall, a State Highway of (14.0 m wide) is to be constructed. What will be the height of the crown of the road relative to the edges for a composite camber (i.e. middle half as parabolic and the rest as straight lines)?

[ESE - 2015]

(a) 14 cm (b) 21 cm
(c) 28 cm (d) 7 cm

8. A four-lane divided highway, with each carriageway being 7.0 m wide, is to constructed in a zone of longitudinal slope of 3% and is provided a camber of 2%. What is the hydraulic gradient on this highway in this stretch?

[ESE - 2015]

(a) 4.0% (b) 3.6%
(c) 4.5% (d) 3.0%

9. The maximum super elevation t0 be provided on a road curve is 1 in 15. If the rate of change of super elevation is specified as 1 in 120 and the road width is 10 m, then the minimum length of the transition curve on each end will be

[ESE - 2015]

SOLUTIONS

Sol. 1. (a)
Correct option is (a)
Rate of equilibrium superelevation.

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

Thus, statement (3) is incorrect

Sol. 2. (c)
Transition curve in a highway alignment is provided to include
1.Gradual introduction of the centrifugal force between the tangent point on straight curve zero to max on circular curve.
2.To enable the driver turn the steering gradiually for has own comfort and security.
3.To provide gradual introduction of super elevation.
4.To provide gradual introduction of extrawidening.
5.To enhance the aesthetic appearance of the road.

Sol. 3. (d)
Equilibrium super elevation

$$e = \frac{V^2}{127\,R} = \frac{70^2}{127 \times 480} = 0.08 \text{ i.e. } 8\%$$

Sol. 4. (b)

Sol. 5. (a)

$$\text{SSD} = 0.278\ Vt + \frac{V^2}{254(kf + S\%)}$$

$$= 0.278 \times 100 \times 2.5 + \frac{100^2}{254(0.5 \times 0.7 + 0.02)}$$

= 175.9 m

Sol. 6. (b)

$$x = L\left(\frac{n_1}{2N}\right)^{1/2}$$

x = Horizontal distance from end of first tangent point to the lowest point in meters.
n_1 = Natural tangent of first tangent.
$N = n_1 + n_2$

$$= \left|-\frac{4}{10} - \frac{1}{40}\right| = 0.065$$

$$x = 200\left(\frac{0.04}{2 \times 0.065}\right)^{1/2} = 110.94 \simeq 111 \text{ m}$$

Sol. 7. (a)
Camber to be provided for state highway is 1 in 50.
$\therefore$ Height of the crown

$$= \left(\frac{14}{2}\right) \times \frac{1}{50} \times 100 \text{ cm} = 14\,\text{cm}$$

Sol. 8. (a)
Hydraulic gradient is twice of camber.
Given, camber = 2%
$\therefore$ Gradient = 2 × 2% = 4%

Sol. 9. (c)
Length of transition curve based on rate of change of super elevation is,
L = eNw

$$L = \frac{1}{15} \times 120 \times 10 = 80 \text{ m}$$

Sol. 10. (c)
Data given
V = 60 kmph
R = 800 m

$$e = \frac{V^2}{127\,R} = \frac{(60)^2}{127 \times 800}$$

= 0.03543

and $e = \tan\theta = \frac{y}{x}$

$\therefore \frac{y}{x} = e = 0.3543$

CHAPTER - 4
HIGHWAY MATERIALS

4.1 INTRODUCTION
1.CBR test, an empirical test, has been used to determine the material properties for pavement design.
2.Empirical tests measure the strength of the material and are not a true representation of the resilient modules.
3.It is a penetration test wherein a standard piston, having an area of 19.62 cm^2 (or 50 mm dia.) is used to penetrate the soil at a std. rate of 1.25 mm/min. The pressure up to a penetration of 12.5 mm and its ratio to the bearing value of a std. crushed rock is termed as the CBR.
4.In most cases, CBR decreases as the penetration increases.
5.The ratio at 2.5 mm penetration is used as the CBR.
6.In some case, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm should be used if confirmed by repeating the test.
7.The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture condition. The test may be conducted in re – moulded or undisturbed specimen in laboratory. It is extensively used for filed correlation of flexible pavement thickness requirements.

4.2 TEST PROCEDURE
1.The laboratory CBR apparatus consists of a mould 150 mm dia with a base plate and a collar, a loading frame & dial gauges for measuring the penetration values and the expansion on soaking.
2.The specimen in the mould is soaked in water for four days and the swelling and water absorption values are noted.
3.Load is applied on the sample by a standard plunger with dia of 50 mm at the rate of 1.25 mm/min. A load penetration curve is drawn.
4.The load values on standard crushed stones are 1370 kg (70 kg/cm^2) and 2055 kg (105 kg/cm^2) at 2.5 mm and 5.0 mm penetrations respectively.
5.CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above. Therefore,

$$CBR = \frac{\text{load carried by specimen}}{\text{load caried by standard specimen}} \times 100$$

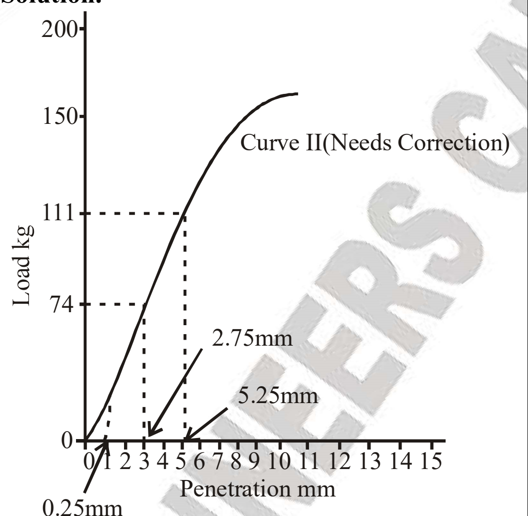
6.Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted.
7.If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking.
8.If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value.
9.The average CBR value of three test specimens is reported as the CBR value of the sample.

WORKBOOK

Example 1. Load and penetration values from a CBR test are given below. Calculate the CBR value.

Penetration	Load (kg)
0	0
0.5	7
1.0	24
1.5	41
2.0	59
2.5	70
3	81
4	98
5	110
7.5	129
10	143
12.5	150

Solution.



The load penetration curve is plotted in figure (Curve II). The observation need correction. The tangent to the curve meets the x – axis at the value of 0.25 mm. The origin needs shifting by this amount. Thus, the loads at 2.5 mm and 5.00 mm penetration are 74 and 111 kg respectively.

CBR value from 2.5 mm penetration = $\frac{74}{1370} \times 100 = 5.4$

CBR value from 5.00 mm penetration $= \frac{111}{2055} \times 10 = 5.4$

The CBR value is 5.4 percent.

Example 2. Plate bearing tests conducted on a 30 cm dia plate yielded the following observations.

Load	Settlement (mm)
270	0.25
580	0.50
770	0.75
1010	1.00
1260	1.25
1480	1.50
1690	1.75

Determine the k value corresponding to a plate of 75 cm diameter.

Solution.

At a settlement of 1.25 mm, load = 1260 kg

Loading stress, $p = \frac{1260}{0.7854 \times 30^2} \times \frac{9.81}{10^6}$

$= 0.175 \text{MN/m}^2\text{/m}$

$k = \frac{P}{1.25} \times 1000 \text{MN/m}^2\text{/m} = 140 \text{MN/m}^2\text{/m}$

$k_{75} = 0.4\ k_{30} = 0.4 \times 140 = 56\ \text{MN/m}^2\text{/m}$.

Example 3. The specific gravities and weight proportion for aggregate and bitumen are as under for the preparation of Marshall mix design. The volume and weight of one Marshall specimen was found to be 475 cc and 1100 gm. Assuming absorption of bitumen in aggregate is zero. Find V_a, V_b

Item	CA1	CA2	FA	Filler	Bitumen
Wt(gm)	825	1200	325	150	100
Sp. Gr	2.63	2.51	2.46	2.43	1.05

CHAPTER - 5
PAVEMENT DESIGN

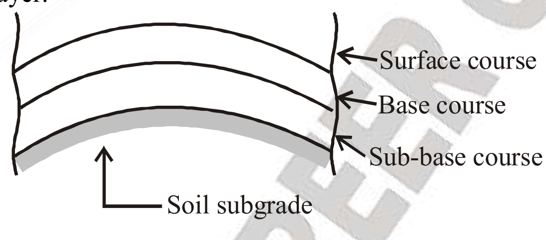
5.1 TYPES OF PAVEMENT

A pavement is the load bearing and load-distributing component of a road. Pavements can be classified as.

1. Flexible
2. Rigid
3. Semi-rigid
4. Composite

5.1.1 Flexible Pavement

1.A flexible pavement is one that is made up of one or more layers of materials, the highest quality material forming the top layer.



Flexible Pavement

2.Loads are transmitted through the layers, care being taken to ensure that the stresses in each layer are within the permissible values and the stress on the sub-grade is within its bearing power.
3.The load carrying capacity of the flexible pavement is derived from the load-distribution property and not from its flexural or bending strength.
4.The flexible pavement layers reflect, the deformation of the lower layer, Thus if the lower layer of the pavement of soil subgrade is undulated, the flexible pavement surface also gets undulated.
5.A typical flexible pavement consists of four components
(i) Soil subgrade
(ii) Sub base-course
(iii) Base course
(iv) surface course

(i) Soil Subgrade

It is a layer of natural soil prepared to receive stress from layers above. It is normally the top natural soil.

(ii) Sub Base Course

It is provided beneath base course. Primary function is to provide structural support, improve drainage and reduce intrusion of fines from subgrade in the pavement structure. A pavement constructed over a high quality stiff subgrade does not require subgrade.

(iii) Base Course.

It is provided immediately below the surface course, provides load distribution & contributes to sub-surface drainage. It is composed of crushed stones.

(iv) Surface Course

CHAPTER - 6
HIGHWAY MAINTENANCE

6.1 INTRODUCTION
By early detection-& repair of defects at initial stages the rapid deterioration of the pavement can be prevented. Such surveys & evaluations should be carried out periodically so as to plan necessary preventive maintenance measures.

6.2 MAINTENANCE OF HIGHWAY

6.2.1 Various Maintenance Operation are
1. Routine Maintenance
These includes filling up of pot holes and patch repairs, maintenance of shoulders and the cross slope and repairing of cracks which are required to be carried out by the maintenance staff almost round the year.
2.Periodic Maintenance
These include renewals of wearing course of pavement surface and maintenance of various items.
3.Special Repairs
The include major restoration or upgrading of the pavement through reconstruction or application of overlays to rectify structural deficiencies.

6.2.2 Symptoms, Causes, And Treatment of Defects
The types of defects in bituminous surfacing are grouped under four categories.
1.Surface Defects
which include fatty surfaces, smooth surfaces, streaking, and hungry surfaces.

2.Cracks
Under which hair-line cracks, alligator cracks, longitudinal cracks, edge cracks. shrinkage cracks, and reflection cracks are dealt with.

3.Deformation
Under this are grouped slippage, rutting, corrugations, shoving, shallow depressions, and settlements and upheavals; and

4. Disintegration
Covering stripping, loss of aggregates, ravelling, pot-holes, and edge breaking.
(i) We will 1st of all describes the symptoms and causes of these defects and indicates the possible types of treatment,
(ii) In each case of pavement distress, the cause or causes of the distress should first be determined. It will be possible to provide suitable maintenance measures which will not only correct the damage but also prevent or delay its recurrence.
(iii) In many situations, lack of proper drainage is the principal cause for stripping loss of materials from the pavement and shoulder, weakening of the pavement layers and siibgrade, resulting in the failure of the pavement.
(iv) In such situations the cause should be completely elimmated before takimgany maintenance measure.

GATE QUESTIONS

1. A bitumen sample has been graded as VG30 as per IS : 73-2013. The '30' in the grade means that

[GATE - 2018]

(a) Penetration of bitumen at 25°C is between 20 to 40
(b) Viscosity of bitumen at 60°C is between 2400 and 3600 Poise
(c) Ductility of bitumen at 27°C is more than 30 cm
(d) Elastic recovery of bitumen at 15°C is more than 30%

2. The initial concavity in the Load-penetration curve of a CBR test is NOT due to

[GATE - 2018]

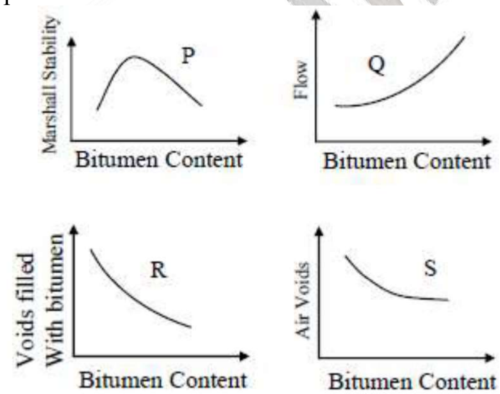
(a) Uneven top surface
(b) High impact at start of loading
(c) Inclined penetration plunger
(d) Soft top layer of soaked soil

3. The following observations are made while testing aggregate for its suitablility in pavement construction
(i)Mass of oven dry aggregate in air = 1000g
(ii)Mass of saturated surface-dry aggregate in air = 1025 g
(iii)Mass of saturated surface-dry aggregate under water = 625 g
Based on the above observations, the correct statement is

[GATE - 2017]

(a)Bulk specific gravity of aggregate = 2.5 and water absorption = 2.5%
(b)Bulk specific gravity of aggregate = 2.5 and water absorption = 2.4%
(c)Apparent specific gravity of aggregate = 2.5 and water absorption = 2.5%
(d)Apparent specific gravity of aggregate = 2.5 and water absorption = 2.4%

4. During a forensic investigation of pavement failure, an engineer reconstructed the graphs P, Q, R and S, using partial and damaged old reports.



Theoretically plausible correct graphs according to the 'Marshall mixture design output' are

[GATE - 2016]

(a) P, Q, R (b) P, Q, S
(c) Q, R, S (d) R, S, P

5. Match the information related to test on aggregates given in List-I with that in List-II.

List-I
A.Resistance to impact
B.Resistance to wear
C.Resistance to weathering action
D.Resistance to crushing

List-II
(i)Hardness
(ii)Strength
(iii)Toughness
(iv)Soundness

[GATE - 2015]

Codes:
(a) A-i, B-iii, C-iv, D-ii
(b) A-iii, B-i, C-iv, D-ii
(c) A-iv, B-i, C-iii, D-ii
(d) A-iii, B-iv, C-ii, D-i

6. In Marshall method of mix design, the coarse aggregate, fine aggregate, fines and bitumen having respective values of specific gravity 2.60, 2.70, 2.65 and 1.01, are mixed in the

SOLUTIONS

Sol 1. (b)

Sol 2. (b)
Initial concavity in CBR test due to
(i) Improper compaction
(ii) Soft top layer
(iii) Inclined plunger

Sol 3. (a)
Bulk specific gravity; G

$$G = \frac{\text{oven dry weight}}{\text{Saturated surface dry weight} - \text{weight in water}}$$

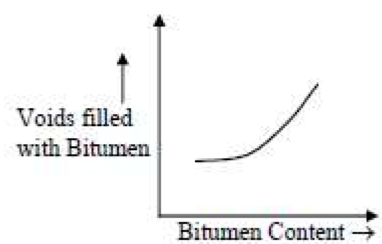
$$= \frac{1000}{1025-625} = 2.5$$

Water absorption; w

$$w = \frac{\text{saturated surface dry weight} - \text{oven dry weight}}{\text{oven dry weight} \times 100}$$

$$= \frac{1025-1000}{1000} \times 100 = 2.5\% \text{ g}$$

Sol 4. (b)
The graph wrong among the given is 'R'
The correct graph should be



Sol 5. (b)

Sol 6. (a)
Theoretical specific gravity

$$G_t = \frac{W_1 + W_2 + W_3 + W_4}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_3}{G_3} + \frac{W_4}{G_b}}$$

$$= \frac{55+35.8+3.7+5.5}{\frac{55}{2.6} + \frac{35.8}{2.7} + \frac{3.7}{2.65} + \frac{5.5}{1.01}} = 2.42$$

Effective specific gravity of aggregates (coarse + fine) is given by

$$G' = \frac{(55\times 2.6)+(35.8\times 2.7)}{55+35.8}$$

= 2.639 = 2.64

Sol 7. (8)
Relationship between penetration and temperature is given by
$P=AT+K$
Where P is penetration
A is temperature susceptibility
K is Constant
With increase in temperature, penetration increases. Hence, we will simply take

Sol 8. (68.79%)

$$V_v = \frac{G_t - G_m}{G_t} \times 100 = \frac{2.441-2.324}{2.441} \times 100$$

= 4.79%
Void filled with bitumen

$$V_b = G_m \times \frac{W_b(\%)}{G_b} = 2.324 \times \frac{5}{1.1}$$

= 10.56%
VMA = V_v + V_b = 4.79 + 10.56 = 15.35%

$$\therefore \text{ VFB} = \frac{V_b(\%)}{\text{VMA}} \times 100 = \frac{10.56}{15.35} \times 100$$

= 68.79%

Sol 9. (d)

$$\text{VFB} = \frac{V_B}{V_V} = \left(\frac{15-4.5}{15}\right) \times 100\% = 70\%$$

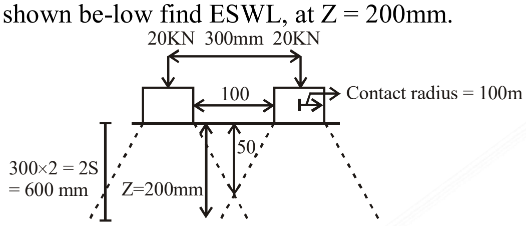
Sol 10. (c)
Since softening point for Y is higher than X.
$\therefore$ Viscosity of Y is high as compared to X and penetration will be more in X, because it will offer less resistance to penetrate.
$\therefore$ Both statement I & II are false.

Sol 11. (c)

Sol 12. (d)

WORKBOOK

Example 1. For the multi-wheel condi-tion shown be-low find ESWL, at Z = 200mm.



Solution.

$$\log\left(\text{ESQL}\right)=\log 20+\frac{\log 40}{\log 600-\log 50}$$

$$\left[\log\left(200\right)-\log\frac{50}{2}\right]$$

$$\log g\left(\text{ESWL}\right)=1.46734$$

ESWL = $10^{1.46734}$ = 29.44kN.

Example 2. The result of 1 day axle load survey of trucks on a road is tabulated as below. Find the no. of repetitions of a standard 80KN axle in a year.

Wt in KN	Frequency (n)	Mid Point (x)	$\text{EALF}=\left(\frac{x}{80}\right)^4$	n_1EALF
0-40	50	20	$\frac{1}{256}$	$\frac{50}{256}$
40-80	250	60	$\frac{81}{256}$	$\frac{(250\times81)}{256}$
80-120	400	100	$\frac{625}{256}$	$\frac{(400\times625)}{256}$
120-160	25	140	$\frac{2401}{256}$	$\frac{(250\times2401}{256}$
				Σ = 3400

No. of repetition of standard axles in one year will be 3400 × 365 = 1.241 MSA

Example 3. If in the previous example, 950 no. no. of axles were surveyed and the no. of vehicles were 400, find the vehicle damage factor.

Solution.

400 vehicle is equivalent to 3400 nos. standard axle.

1 vehicle is equivalent to $\frac{3400}{400}$ = 8.5 st. axle

$\Rightarrow$ 1 commercial vehicle = 8.5 no. of standards axles.

Thus vehicle damage factor = 8.5

VDF for a road traffic is calculated using axle load survey

Example 4. T he no. commercial vehicle per day at present count is 6000. Design life is 15 yrs. Traffic growth rate is 8% VDF is 4.5 lateral distribution factor for 6 lane divided highway = 0.6.

Calculate the no. of standards axles in the design life if the construction period is 2yrs.

Solution.

P = 6000 vehicle/day

Traffic after two year = $P(1 + r)^x$

(A) = $6000\ (1 + 0.08)^2$

= $6000(1.08)^2$ =6998veh./day

$\Rightarrow$ No. of commercial vehicles after the end of construction period is 6998 veh./day.

No. of commercial vehicle in design life

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

$$=\frac{365\times6998\left[\left(1.08\right)^{15}-1\right]}{0.08}$$

N = 69.35×10^6 vch.

If lateral destribuiton of traffic is accounted for then

GATE QUESTIONS

1. Given the following data : design life n = 15 years, lane distribution factor D = 0.75, annual rate of growth of commercial vehicles r = 6%, vehicle damage factor F = 4 and initial traffic in the year of completion of construction = 3000 Commercial Vehicles Per Day (CVPD). As per IRC : 37-2012, the design traffic in terms of cumulative number of standard axles (in million standard axles, up to two decimal places) is ___________.

[GATE - 2018]

2. The radii of relative stiffness of the rigid pavement P and Q are denoted by ℓ_P and ℓ_Q . respectively.The geometric and material properties of the concrete slab and underlying soil are given below.

Pavement	Concrete					Soil
	Length of slab	Breadth of slab	Tickenss of slab	Modulus of Elasticity	Poisson's Ratio	Subgrade Reaction modulus
P	L	B	H	E	μ	K
Q	L	B	0.5h	E	μ	2K

The ratio (up to one decimal place) of $\frac{\ell_p}{\ell_Q}$ is

[GATE - 2017]

3. In the context of the IRC 58-2011 guidelines for rigid pavement design, consider the following pair of statements.

I. Radius of relative stiffness is directly related to modulus of elasticity of concrete and inversely related to Poisson's ratio

II. Radius of relative stiffness is directly related to thickness of slab and modulus of subgrade reaction.

Which one of the following combinations is correct?

[GATE - 2016]

(a) I-True; II-True (b) I-False; II-False
(c) I-True; II-False (d) I-False; II-True

4. A traffic survey conducted on a road yields an average daily traffic count of 5000 vehicles. The axle load distribution on the same road is given in the following table.

Axle load (tonnes)	Frequency of traffic (%)
18	10
14	20
10	35
8	15
6	20

The design period of the road is 15 years, the yearly traffic growth rate is 7.5% and the load safety factor (LSF) is 1.3. If the vehicle damage factor (VDF) is calculated from the above data, the design traffic (in million standard axle load, MSA) is ______.

[GATE - 2014]

5. A pavement designer has arrived at a design traffic of 100 million standard axles for a newly developing national highway as per IRC.37 guidelines using the following data. life = 15 years, commercial vehicle count before pavement construction = 4500 vehicles/day, annual traffic growth rate = 8%. The vehicle damage factor used in the calculation was

[GATE - 2012]

(a) 1.53 (b) 2.24
(c) 3.66 (d) 4.14

6. It is proposed to widen and strengthen an existing 2-lane NH section as a divided highway. The existing traffic in one direction is 2500 commercial vehicles (CV) per day. The construction will take 1 year. The design CBR of soil subgrade is found to be 5 per cent. Given. traffic growth rate for CV = 8 per cent,

SOLUTIONS

Sol 1. 76.45(76.43 to 76.48)

$$N_S = \frac{365A\left[\left(1+\frac{r}{100}\right)^n - 1\right]\times VDF \times LDF}{\frac{r}{100}}$$

$$= \frac{365\times 3000[1.06^{15}-1]\times 4\times 0.75}{0.06}\times 10^{-6}$$

= 76.45 msa

Sol 2. (2)

Westergaard defined the term radius of relative stiffness, ℓ which is expressed as

$$\ell = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$$

$$\ell_P = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$$

$$\ell_Q = \left[\frac{E(0.5h)^3}{12(2k)(1-\mu^2)}\right]^{1/4}$$

$$= \left[\frac{(0.5)^3}{2}\times\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$$

$$\left(\frac{(0.5)^3}{2}\right)^{1/4}\left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$$

$$\frac{\ell_P}{\ell_Q} = \frac{\left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}}{\left(\frac{(0.5)^3}{2}\right)^{1/4}\left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}}$$

$$= \left(\frac{2}{(0.5)^3}\right)^{1/4} = \frac{\ell_P}{\ell_Q} = 2$$

Sol 3. (b)

Radius of relative stiffness, $l = \left[\frac{Eh^3}{12k(1\text{-}\mu^2)}\right]^{1/4}$

Statement -1. False

Directly proportional to modulus of elasticity and also μ

($\therefore$ As μ increases l decreases)

Statement-2. False

Sol 4. (309.08msa)

Vehicle damage factor

$$= 0.1\left[\frac{18}{8.2}\right]^4 + 0.2\left[\frac{14}{8.2}\right]^4 + 0.35\left[\frac{10}{8.2}\right]^4$$

$$+0.15\left[\frac{8}{8.2}\right]^4 + 0.20\left[\frac{6}{8.2}\right]^4$$

$$N_s = \frac{365A\left((1+r)^n - 1\right)DF}{r}.$$

$$= \frac{365\times 5000\left((1.075)^{15}-1\right)\times 1.3\times 4.988}{0.075}$$

N_S = 309.08 msa

Sol 5. (b)

Number of commercial vehicles per day,

A = 4500

Annual traffic growth rate, r = 8%

Design life, n =15 years

The cumulative standard axles,

$N_s = 100 \times 10^6$

Vehicle damage factor used,

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

$$= \frac{100\times 10^6 \times 0.08}{365\times 4500\times\left[(1+0.08)^{15}-1\right]} = 2.24$$

Sol 6. (b)

Number of commercial vehicles per day,

A = existing traffic × traffic distribution factor

= 2500 × (1.08) × 0.75 = 2025

Annual growth rate of commercial vehicles = 8%

Vehicle damage factor, F = 3.5

Design life, n = 10 years

ESE OBJ QUESTIONS

1. As per IRC 37 : 2012, the fatigue life of a flexible pavement consisting of granular base and sub-base depends upon
1. Resilient Modulus of bituminous layers
2. horizontal tensile strain at the bottom ofbituminous layer
3. Mix design of birumen
4. Vertical subgrade strain
Which of the above statements are correct?
[ESE - 2018]
(a) 1, 2 and 4 only (b) 1, 3 and 4 only
(c) 1, 2 and 3 only (d) 2, 3 and 4 only

2. In revised CBR design method recommended by the IRC for the design of flexible pavement, the total thickness depends upon
[ESE - 2017]
(a)Only the CBR value of the soil
(b)The CBR value of the soil and the magnitude of wheel load
(c)The CBR value of the soil cumulative standard axle loads
(d)The CBR value of the soil and number of commercial vehicles passing per day

3. Consdier the following statements regarding pavements.
1.Rigid pavements are more suitable than flexible pavements for stage construction.
2.Rigid pavements are more affected by temperature variations than flexible pavements.
3.In a flexible pavement, any deformation in the top layers is transferred to underlaid layers; but in rigid pavements, there is slab or beam action due to which any deformation is only in the top layer of the concrete slab.
Which of the above statemnts are correct?
[ESE - 2017]
(a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

4. Bankleman beam deflection method is used for design of
[ESE - 2014]
(a) Rigid overlays on rigid pavements
(b) Rigid overlays on flexible pavements
(c) Flexible overlays on flexible pavements
(d) Flexible overlays on rigid pavements

5. In a flexible pavement
[ESE - 2014]
(a)Vertical compressive stresses decrease with depth of the layer
(b)The vertical compressive stress is the maximum at the lowest layer
(c)Tensile stresses get developed
(d)Maximum stress induced by a given traffic load is dependent on the location of the load on the pavement surface.

6. What is the deflection at the surface of a flexible pavement due to a wheel load of 40 kN and a tyre pressure of 0.5 MPa? The value of E for pavement and subgrade is 20 MPa.
[ESE - 2014]
(a) 15 mm (b) 11 mm
(c) 9 mm (d) 6 mm

7. The corrected modulus of sub-grade reaction for standard diameter plate is 6.0 kg/cm^3. What would be the modulus of sub-grade reaction of the soil when tested with a 30 cm diameter pates?
[ESE - 2013]
(a) 15 kg/cm^3 (b) 25 kg/cm^3
(c) 30 kg/cm^3 (d) 60 kg/cm^3

8. Which of the following correspond to the recommendations of IRC for pavement thickness determination by CBR method?
1.CBR tests are to be conducted in situ
2.Static compression is best adopted
3.The top 50 cm of subgrade should be compacted to as near the proctor density as possible
[ESE - 2011]
(a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

SOLUTIONS

Sol. 1. (c)
Does not depend on vertical subgrade strain

Sol. 2. (c)
In revised CBR design method recommended by the IRC. For the design of flexible pavement IRC. For the design of flexible pavement IRC has provided charts for different CBR in which relation between pavement thickness and cumulative traffic axle is given.

Sol. 3. (d)
1.Rigid pavements are more suitable than flexible pavements for stage construction.
2.Rigid pavements have more temperature venations.
3.Flexible pavements transfer the load by grain to grain contact which rigid pavements resist the deflection through flexural action.

Sol. 4. (c)

Sol. 5. (a)

Sol. 6. (d)

Deflection, $\Delta = \dfrac{1.5\ P.a}{E_s}$ (For flexible plate)

Where, P is Contact pressure due to wheel load = 0.5 MPa
a is Radius of contact area
Now,

$$\text{Contact area} = \frac{\text{Wheel load}}{\text{Tyre pressure}}$$

$$= \frac{40\times10^3\ N}{0.5\,N/mm^2} = 80 \times 10^3\ mm^2$$

and, area, $\pi \times a^2 = 80 \times 10^3$

$$a = \sqrt{\frac{80\times10^3}{\pi}} = 159.615\ mm$$

$E_s = 250$ MPa

$$\text{So, } \Delta = \frac{1.5\times0.5\times159.617}{20} = 6\ mm$$

Sol. 7. (a)
$k = 6$ kg/cm^3
When, a = 75 cm

$$k_1 = \frac{6(75)}{30} = 15\ kg/cm^3$$

Sol. 8. (c)
Some of the important points recommended by the IRC for the CBR method of design (IRC. 37-1970) are.
(a) The CBR tests should be performed on remoulded soils in the laboratory. In-situ test are not recommended for design purposes. The specimens should be prepared by static compaction wherever possible and otherwise by dynamic compaction. The standard test procedure should be strictly adhered to.
(b) For the design of new roads, the subgrade soil sample should be compacted at OMC to proctor density whenever suitable compaction equipment is available to achieve this density in the field. In the case of existing roads, the sample should be field density of subgrade soil (at OMC or at a field moisture content).
(c) In new constructions the CBR test samples may be soaked in water for four days period before testing.
(d) Atleast three samples should be tested on each type of soil at the same density and moisture content. The specified limits of maximum variation in CBR are 3% for CBR values upto 10% 5% for values 10 to 30 and 10% for values 30 to 60%.
(e) The top 50 cm of subgrade should be compacted atleast upto 95 to 100 percent of Proctor density.

Sol. 9. (b)
(i) During Summer. Critical combination of stresses = load stress + warping stress – frictional stress, at edges region.
(ii) During winter. The critical stress combination = load stress + warping stress + frictional stress, at edges region.
(iii) At corner region. The critical stress combination = load stress + warping stress, at corner regions

ESE OBJ QUESTIONS

1. Hot bitumen is sprayed over freshly constructed bituminous surface followed by spreading of 6.3 mm coarse aggregates and rolled. Which one of the following is indicated by this type of construction?

[ESE - 2009]

(a) Surface dressing
(b) Gravel-bitumen mix
(c) Liquid seal coat
(d) Seal coat

2. Assertion (A): In water-bound macadam construction, grade I has better load dispersion characteristics as compared to grade III aggregates.
Reason (R): The plasticity index of the binding material should be less than 6%.

[ESE - 2009]

(a)Both A and R are true and R is the correct explanation of A
(b)Both A and R are true but R is not a correct explanation of A
(c)A is true but R is false
(d)A is false but R is true

3. Consider the following statements with reference to Water Bound Macadam (WBM) and Wet Mix Macadam (WMM).
1. WBM is a road mix and WMM is a plant mix.
2. WBM usually has plastic filler, while WMM has non–plastic filler.
3. WBM is modern road mix and WMM is a traditional road mix.
Which of these statements is/are correct?

[ESE - 2008]

(a) 1 and 2 (b) 2 and 3
(c) 1 only (d) 2 only

4. Consider the following bituminous surfacing.
1. SDBM 2. PMC
3. AC 4. SD
5. Mastic Asphalt (MA)
Which one of the following is the correct sequence in increasing order with respect to their performance and wearing qualities?

[ESE - 2008]

(a) 4, 1, 2, 3, 5 (b) 2, 4, 1, 5, 3
(c) 4, 2, 1, 3, 5 (d) 1, 4, 3, 2, 5

5. Match List-I (Type of wall) with List-II (feature) and select the correct answer using the code given below the lists.
List-I
A. Parapet wall
B. Check wall
C. Breast wall
D. Gabion wall
List-II
(i)Constructed with dry stone encased in wire mesh.
(ii)To add the overall stability to the hill face.
(iii)To buttress the uphill slopes of the road cross-section
(iv)To give protection to the motorists.

[ESE - 2007]

Codes:
(a) A-ii, B-iv, C-i, D-iii
(b) A-iv, B-ii, C-i, D-iii
(c) A-iv, B-ii, C-iii, D-i
(d) A-ii, B-iv, C-iii, D-i

6. A road surface is corrected by spreading a layer of dry sand in a thickness varying from 5 mm to 10 mm and rolling the surface by heavy rollers. Which one of the following maintenance works does it apply to?

[ESE - 2007]

(a) Repair of ruts and patches
(b) Repairing of blow ups
(c) Repair of bleeding surface
(d) Sealing of joints and cracks

7. Based on Fuller's maximum density criterion, for 4 mm maximum size of soil particles what is the percentage of particles between 4 mm and 2 mm by weight?

[ESE - 2007]

SOLUTIONS

Sol. 1. (a)

Sol. 2. (d)

Sol. 3. (a)
WBM is a traditional road mix and WMM is a modern road mix.

Sol. 4. (c)

Sol. 5. (c)

Sol. 6. (b)

Sol. 7. (c)
According to Fuller's maximum density criterion the gradation is given by

$$p = 100\left(\frac{d}{D}\right)^n$$

where,
p is per cent finer than diameter 'd' (mm) in the material
D is diameter of largest particle, mm
n is gradation index (taken as 0.5 by Fuller)

$$\therefore \quad p = 100\left(\frac{2}{4}\right)^{0.5}$$

$\Rightarrow$ p = 70.71
Thus, the percentage of particles between 4 mm and 2 mm will be by
100 – 70.71 = 29.29 ≃ 30%

Sol. 8. (c)
The vertical sand drains increase the effective permeability of excess pore pressure in high embankment in soft soils.
Fir urban road surface drainage surface consists of inlets and gratings. The limitation of land width and presence of foot paths, dividing islands and other road facilities necessitates underground longitudinal drains.
In order to intercept and divert water from the hill slope, catch water are provided, running parallel to the roadways. Water from catch water drains is diverted by slopping drain and carried across the road by means of causeways and culverts.
Beside catch water drains, road side drains on one side of hill road are provided. They are angle, saucer, and kerb and channel drain types.
In hill roads where rainfall is heavy, the culverts are needed at 60 to 90 m to facilities drainage of water across the roads. This may be quite costly. Hence often 8 to 10 scuppers (cross-drainage structures) are provided in addition to the bridges and regular culverts.

Sol. 9. (a)
Bituminous premixed carpet is a surfacing course.

Sol. 10. (b)
According to MORST specification bitumen content are as follows.
(i) Bituminous mastic, 14-17%
(ii) Dense bituminous macadam for nominal aggregate size 40 mm minimum 4% and for nominal aggregate size 25 mm minimum 4.5%.
(iii) Bituminous macadam for nominal aggregate size 40 mm, 3.1-3.4% and for nominal aggregate size 19 mm, 3.3-3.5%
(iv) Bituminous concrete for nominal aggregate size 19 mm, 5-6% and for nominal aggregate size 13 mm, 5-7%.

Sol. 11. (a)

Sol. 12. (b)

Sol. 13. (c)
Usually MC (medium curing) or SC (slow curing) cutbacks of suitable grade or viscosity is chosen depending upon the porosity of the surface to be treated.

Sol. 14. (d)

Sol. 15. (d)

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CONTENTS

CHAPTER - 1
FUNDAMENTALS OF SURVEYING

1.1 INTRODUCTION

1. Surveying may be defined as the method of making measurements of the relative positions of, natural and man-made features on earth’s surface and the presentation of this information either graphically or numerically.
2. The commonest methods of presentation are by means of a Plan or Map.
3. Both Plans and Maps are the graphical representation of the features on a horizontal plane.
4. Plan is a large scale representation whereas Map is a small scale representation.
5. Height information can be added either as spot heights, which are individual heights of points, or as contours which give a less detailed but better visual representation of the area.

1.2 PLANE AND GEODETIC SURVEYING

1. Surveying is divided primarily into Geodetic surveying & Plane surveying.
2. In Geodetic surveying, large areas of earth's surface are involved and the curvature of earth is taken into account.
3. In Plane surveying, relatively small areas are under consideration, and it is assumed that the earth's surface is flat.
4. In Plane surveying, measurements plotted will represent the projection on the horizontal plane of the actual field measurements.

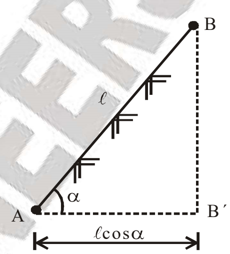
Example. AB is plotted as AB

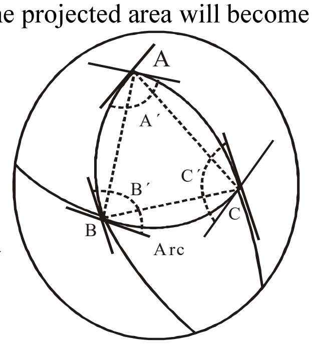
(i) A horizontal plane is normal to the direction of gravity (as defined by a **Plumb bob** at that point).

(ii) However, such a plane will infect be tangential to the earth's surface at that point.

Thus, if a large area is considered, the deseripency will become apparent between the area of the horizontal plane and the actual curved area of the earth's surface.

(iii) In the above figure if actual area is ABC, the projected area will become A’B’C’.

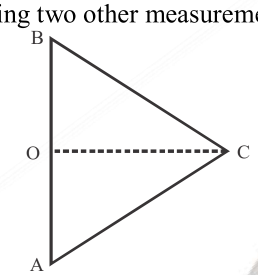




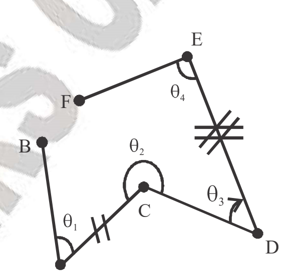
That Arc AC will be projected as Chord A’C’ represented by dotted line. If Arc AB = 18.5 km then Chord A’B’ will be 1.52 cm shorter than Arc Ab.

CHAPTER - 2
COMPASS SURVEYING

2.1 INTRODUCTION
From the fundamental principle of surveying we know that on any area of land to he surveyed, it is always possible to choose two points and to measure distance between them. Other points can be located relative to the 1st line by taking two other measurements.



1. The line AB is called **base line** and all measurements are taken from this line.
2. In chain surveying point 'C' was located by taking only distance measurements.
3. However in compass surveying point 'C' is located by taking measurement of angle between BA and AC and measurement of length AC or angle-between AB & BC, BA & AC.
4. When the whole area to be surveyed cannot be seen from this one line, additional lines have to be defined relative to the 1st, using again two measurements. The points of the junctions of these lines are called **Control Points**, and together with the lines they constitute a framework or control. This method of establishing the control points is called control surveying.
5. In chain surveying the control network consisted of series of triangles of survey lines.
6. In compass surveying points C, D, E, F are established by measuring lengths AC, CD, DE, EF etc & angles θ_1, θ_2, θ_3, θ_4 etc.



7. This method of establishing points C, D, E, F etc successively by taking linear & angular measurements is called traversing.
8. Where lines AB, BC, CD, DE. EF etc are called traverse lines.
9. In traverse surveying the frame work consists of a series of connected lines forming an open or closed polygon. Accordingly, the traverse is called open traverse or closed traverse.

2.1.1 Closed Traverse
1. A closed traverse starts from a station and closes either on the same station or another station whose location is already known.
2. As shown below figure (a), the traverse starts from the station A and closes on the same station. It forms a closed polygon. This type of closed traverse is called as a loop traverse.

CHAPTER - 3
THEODOLITE

3.1 INTRODUCTION
1. A theodolite is an important instrument used for measuring horizontal and vertical angles in surveying.
2. It can also be used for a number of surveying operations, such as prolonging a line, measuring distances indirectly and levelling.

3.2 CLASSIFICATION
Theodolites can be classified into transit and non-transit theodolites.

3.2.1 Transit Theodolite
A theodolite is said to be a transit one when its telescope can he rotated through $1SO^{Q}$ in a vertical plane about its horizontal axis. Thus, directing the telescope in exactly opposite direction.

3.2.2 Non-Transit Theodolite
A theodolite is said to be a non-transit one when its telescope cannot be rotated through 180° in a vertical plane about its horizontal axis. Such theodolites are obsolete nowadays

3.3 TYPES OF THEODOLITE
Theodolites can also be classified into two types as follows:

1. Vernier Theodolites

In vernier theodolites, verniers are used for taking the readings. These theodolites are most commonly used in general work. Most of the vernier theodolites can read angles up to 20". (i.e., the least count of theodolite is 20")

2. Precise Optical Theodolites

Precise optical theodolite is fitted with an optical system which is used to read both horizontal and vertical angles precisely. These Theodolites are having a micrometer for taking readings and are also called as Microptic Theodolites.

These theodolites are used for precise work. Most of these theodolites can read angles up to 1 or less. The size of a theodolite is defined by the size its lower graduated circle. For example a 20 cm theodolite means the diameter of the graduated circle of the lower plate is 2(1 cm. Generally the size of the theodolites varies from 8 to 25 cm.

CHAPTER - 4
TRAVERSING

4.1 INTRODUCTION

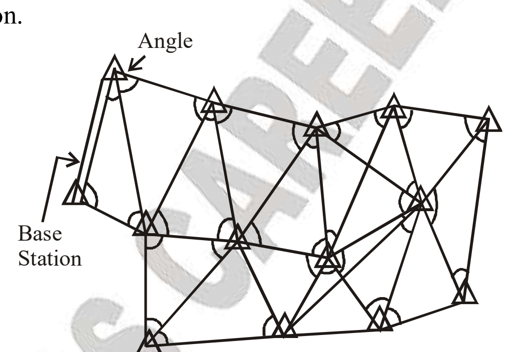
A traverse is a series of connected lines whose length and direction are measured in field. The field work in a theodolite traverse consists of

1. Reconnaissance,
2. Selection and marking of stations
3. Measurement of traverse lines
4. Angular measurements
5. Picking up the details

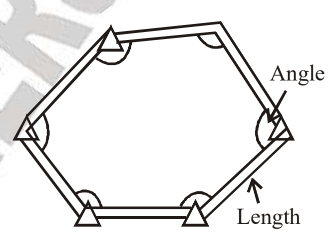
(i)A theodolite traverse is commonly used for providing a horizontal control system to determine the relative positions of the various points on the surface of the earth.

(ii)Earlier when sophisticated distance measurement instruments were not available, we relied on triangulation. (A method where one base line was measured and all angles-are measured to find out lengths of other lines).

(iii)However with the advent of Electronic Distance Measurement Instruments (EDMI), traversing is fast replacing triangulation.



Triangulation



Traversing

Traverses are classified as

(a) Closed traverse

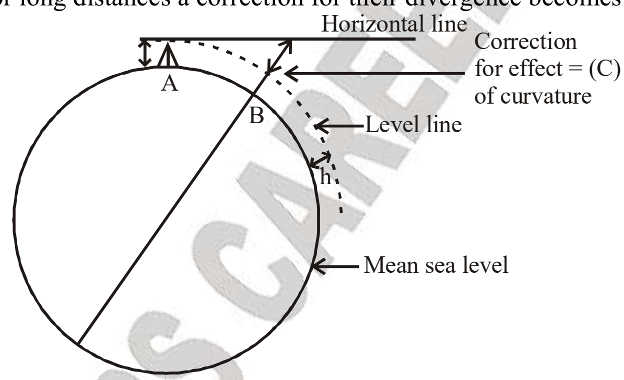
(b) Opened traverse

(Already discussed in chapter of compass surveying)

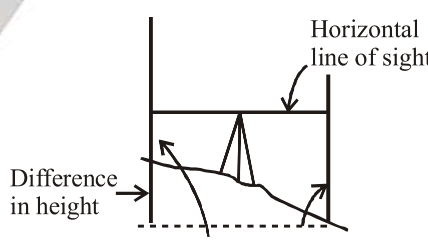
CHAPTER - 5
LEVELLING

5.1 INTRODUCTION

1. Levelling is the operation required in the determination or, more strictly, the comparison of heights of points on the surface of the earth.
2. If a whole series of heights is given relative to a plane, this plane is called a datum, and in topographical work the datum used is the mean level of the sea, because it makes international comparison of heights possible.
3. The value for mean sea level (m.s.l.) as datum is obtained by averaging the elevations of high and low tides, at several points, for a long period of time, about 19 years.
4. The vertical heights of points above or below a datum are referred to as levels.
5. A level line is one that is at a constant height relative to mean sea level, and because it follows the mean surface of the earth it must be a curved line.
6. A horizontal line is tangential to the level line at any particular point, because it is perpendicular to the direction of gravity at that point. For short distances these two hues considered to coincide with each other; but for long distances a correction for their divergence becomes necessary.



7. Thus although point A & B are both at mean sea level in the previous figure due to curvature of level line (curvature of earth), it will be misconstruced that point B is below mean sea level. Thus it is clear that why correction is required for the effect of curvature.
8. The difference in the readings on the vertically held graduated staff where it is intersected by the horizontal line of sight is a direct measure of the difference in height between the two staff stations.



9. **Elevation:** It is the vertical distance of the point above or below the datum surface. It should be noted that the vertical distances are measured along the direction of gravity.

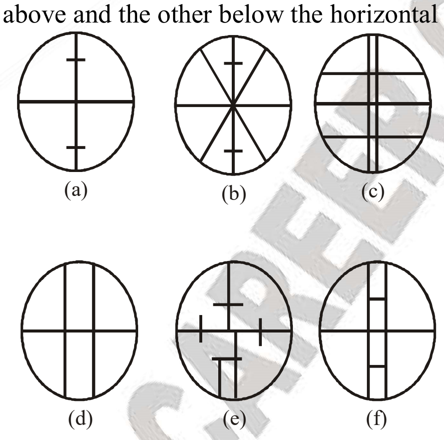
CHAPTER - 6
TACHEOMETRY

6.1 INTRODUCTION

1. Tacheometry is defined as an optical distance measurement method. The other names given to Tacheometry are Tachymetry of Telemetry.
2. As compared to chaining on flat grounds, the accuracy of tacheometric distance is low, but on rough and steep grounds the accuracy is more.

6.2 TACHEOMETER

It is a transit theodolite fitted with stadia diaphragm. The stadia diaphragm consists of two stadia hairs at equal distances, one above and the other below the horizontal hair of the cross.



Stadia diaphragms

6.2.1 Important Characteristics of Tacheometer

1. Value of the multiplying constant, k = 100.
2. Value of the additive constant, C = 0.
3. Telescope should be fitted with an anallactic lens.
4. Magnification power of the eyepiece is kept high.

6.2.2 Stadia Rod

1. It is also called as vertical slave.
2. It is a 5-15 m long rod, graduated in decimals of metre.
3. For small distances up to 100 m. an ordinary leveling staff may be used but beyond this a stadia rod is used, since the graduations of an ordinary levelling staff become indistinct.
4. The staff can be held either vertical or normal to the

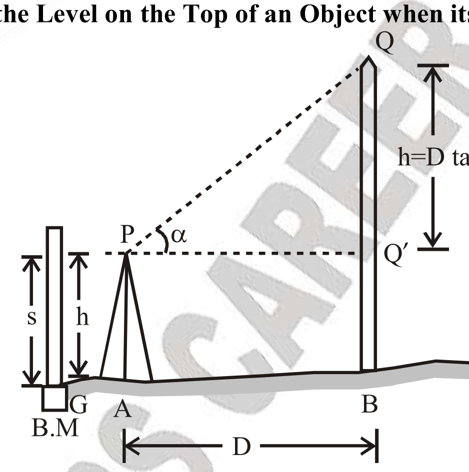
The staff is held normal to the line of sight can be judged when staff in intercept is minimum.

CHAPTER - 7
TRIGONOMETRIC LEVELLING

7.1 INTRODUCTION

1. Trigonometric levelling is m indirect method of levelling in which the relative elevations of various points are determined from the vertical angles and horizontal distances measured with a thedolite and a tape respectively.
2. The height of a point above the plane of collimation is determined from the horizontal distance of the point from the instrument station and the vertical angle.
3. Trigonometric levelling is not as accurate as direct levelling. It is generally used in topographic work and in areas where direct levelling is difficult. The use of tacheometers has made trigonometric levelling easy, as the horizontal distances are also calculated indirectly from the observations made, and, therefore, these need not be measured in the field.

7.1.1 Determination of the Level on the Top of an Object when its Base is accessible



1.Let the base B of the chimney is accessible, and the horizontal distance D between the instrument station A and the base B can be measured using a tape. Let Q be the top of chimney whose elevation is to be calculated. Let G be the bench mark (B.M.)
2.Set up the theodolite over A. Take a backsight on the B.M. and determine the height of instrument
3.R.L. of the line of collimation R.L. of B.M. + s where s is the reading on the staff.
4.If the line of collimation intersects the chimney at Q′, the distance PQ' is same as the horizontal distance D.
5.Sight the top Q of the chimney, and measure the angle of elevation α. In the triangle PQQ′,
$QQ' = D \tan\alpha$
$\therefore$ R.L. of the top of the chimney = R.L. of B.M. + s + D $\tan\alpha$

CHAPTER - 8
PHOTOGRAMMETRY

8.1 INTRODUCTION

1. Photogrammetry is the science of obtaining information about physical objects through process of recording, measuring and interpreting of photographs of the area.
2. Aerial photogrammetry is the branch of photogrammetry in which photographs of the area are taken with a camera mounted on an aircraft.
3. Terrestrial photogrammetry is the branch of the photogrammetry in which photographs are taken with a camera fixed on or near the ground. It is also called as Ground Photogrammetry.
4. In Terrestrial photogrammetry the instrument used is a photo-theodolite, a combination of a photographic camera fitted on a tripod with its axis horizontal and a theodolite.
5. Use of terrestrial photogrammetry is limited to the plotting of special features eg. vertical cliff, mountaineous terrain etc. However, aerial photograph is used for topographical surveys, preliminary route surveys, i.e. highways, railways pipelines, etc., forest and agricultural surveys.
6. The main advantages of aerial photogrammetry are the speed with which an area is covered, the ease with which topography of inaccessible areas can be detailed, there is no possibility of omitting any field data, and the tremendous amount of details shown.

8.2 TYPES OF PHOTOGRAPHS

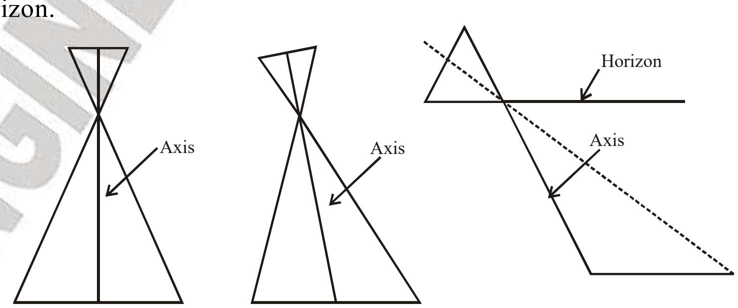
Aerial photographs are classified into two types:
1. Vertical photographs
2. Oblique photographs

8.2.1 Vertical Photographs

1. Vertical photographs are taken when the camera axis is vertical i.e. it coincides with line of the gravity of camera.
2. When the camera axis is perfectly vertical, the photo plane is parallel to the datum plane and the resulting photograph is truly vertical photograph. When the camera axis is tilted slightly from vertical, the resulting photograph is known as tilted photograph. The tilt is generally less than 1^o and rarely exceeds 3^o. This tilt is unintentional.

8.2.2 Oblique Aerial Photographs

1. Oblique aerial photographs are taken with a camera axis considerably inclined to the vertical. The camera axis is intentionally kept oblique from the vertical.
2. A low oblique photographs does not include the horizon. Whereas a high oblique photograph includes the horizon.



(a) Vertical Photograph **(b) Low Oblique Photograph** **(c) High Oblique Photograph**

CHAPTER - 9
CURVES

9.1 INTRODUCTION

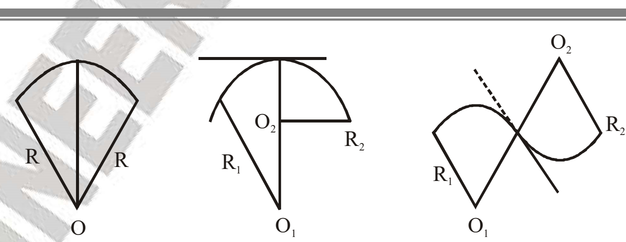
1. The initial design of the curved (i.e. a route) is generally based on a series of connected straight lines. In the final design, a curve is provided at the intersection of the straight lines to provide a gradual change in the direction.
2. A horizontal curve is provided at the point where the two straight lines intersect, in the horizontal plane. Generally the horizontal curves provided are circular in nature.
3. A vertical curve is provided at the point where the two straight lines at different gradients intersect in the vertical plane. The vertical curve provides a smooth change in the gradients. Generally the vertical curves provided are generally parabolic in nature.

9.1.1 Types of Horizontal Curves

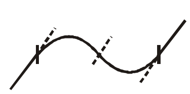
Horizontal Curves are of three types:
1. Simple circular curve
2. Compound curve
3. Reverse curve

1. Simple Circular Curve: It consists of a arc of the-circle. This curve is tangential to two straight lines of the route.
2.Compound Curve: It consists of two circular arcs of different radii with their centres of curvature on the same side of the common tangent.
3.Reverse Curve: It consists of two circular arcs (either of same or different radii) with their centre's of curvature on the opposite side of the common tangent.
(a) Reverse curve are provided on the routes when the two straight lines are parallel or when angle between them is very small, for example hilly roads.

Compound and reverse curves are provide for low speed, roods and railways.



Simple circular curve (Plan) | Compound curve (Plan) | Reverse Curve (Plan)



CHAPTER - 10
CONTOURING

10.1 INTRODUCTION

The relative position of points in a plane is represented by a map. The value of the map is even more if the relief (variation in the elevation of earth's surface) is also included along with their relative positions.

There are two methods by which the conformation of the ground may be presented on a map.

1. By delineating the surface slopes by shading, intended to given an impression of relative relief. The relative elevations of the points are not indicated in this case.
2. By plotting the contour lines (imaginary line passing through points of equal elevations) on maps. These lines are arranged such that the form of the earth's surface can be portrayed with greater accuracy and thoroughness, and can be readily be interpreted.

Contours are used by engineers in a many ways.

10.2 USE OF CONTOURS

1. Proper and precise location of engineering works such as roads, canals, etc.
2. In location of water supply, water distribution and to solve the problems of steam pollution.
3. In planning and designing of dams, reservoirs, aqueducts, transmission lines, etc.
4. In selection of sites for new industrial plants.
5. Determining the intervisibility of stations.
6. Determining the profile of the country along any direction.
7. To estimate the quantity of cutting, filling, and the capacity of reservoirs.

10.3 DEFINITION OF CONTOUR

A contour may be defined as an imaginary line passing through points of equal elevation on the earth surface.

A contour line may also be defined as the intersection of a level surface with the surface of the earth.

Contour lines on a plan illustrate the topography of the ground.

When the contours are drawn underwater, they are termed as submarine contours, fathoms. Or bathymetric curves.

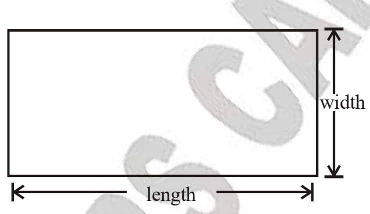
CHAPTER - 11
AREA AND VOLUME

11.1 INTRODUCTION
One of the objectives of many of the survey is to obtain quantities such as areas and volumes.

11.1.1 Measurement of Area
The method selected for computation of area depends upon the shape of the tract and the accuracy desired. Foremost reasons for making land surveys for the determination of area.
Prevalent methods of measurement of area are:
1. By Field Measurements
2. By Plan Measurements
(i) If the plan is enclosed by straight lines, it can be divided into geometrical figures e.g. Triangle, Rectangle, Square etc. The area of these figures can be determined by using appropriate formulas.
(ii) But, if the boundaries are irregular, then approximate methods are being used.

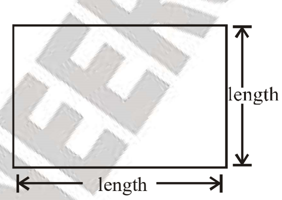
> Plainmeter is used to determine area of irregular shape.

11.1.2 Computation of Area of Geometrical Figures
1. Rectangle



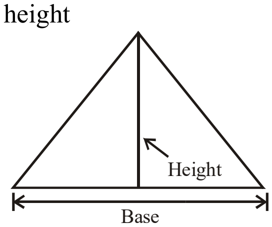
A = length × width

2. Square



A = length × length

3. Triangle
A = base × half of the perpendicular height



4. Parallelogram

CHAPTER - 12
THEORY OF ERROR

12.1 INTRODUCTION
1.Measurements of angles and distances are made in various surveying operations.
2.It is impossible to determine the true values of these quantities because some type of errors always creep in every measurement.
3.The errors occur due to imperfection in instruments, due to human limitations, due to environmental changes or due to carelessness
4.As a quality surveyor our aim should be to minimize these errors while taking observation.
5.Still the errors which creep in should be eliminated or their effects should be corrected.

12.2 TYPES OF ERRORS
The errors can be classified into three types:
1. Gross errors or mistakes
2. Systematic or cumulative errors
3. Accidental or random errors

1. Gross Errors (Mistakes)
Mistakes occur due to inexperience or carelessness of the surveyor. Mistakes are quite random both is occurrence and magnitude but by careful work and by adopting standard procedures and methods, these mistakes can be avoided.

2. Systematic Errors
The systematic errors always follow some pattern which may be some mathematical or physical law.
(i)The systematic errors are of same magnitude and nature in the identical conditions.
(ii)The systematic errors can be computed and suitable corrections applied.
(iii)For example, the error in the length of the steel tape due to change in temperature is a systematic error.
(iv)Surveying instruments should be so designed and used that, systematic errors are automatically eliminated.
(v)For example, most of the systematic errors in measurement of angles with a thodolite can be eliminated by taking both the face readings.
(vi)The systematic errors which cannot be eliminated must be evaluated and a suitable correction should be applied, as in the case of the error due to temperature changes in the measurement of a distance with a steel tape.
(vii)Systematic errors are also called as cumulative errors.

3. Accidental (or Random) Errors
(i) Accidental errors occur due to lack of perfection in human eye.
(ii) For example, while measuring a distance with a steel tape marked in centimeters, if one has to estimate the distance in millimeters, he might estimate a distance of 5 mm as 6 mm or 4 mm because the eye cannot judge the exact division.
(iii)The accidental errors tend to cancel out each other when a large number of such measurements are made because there is as much change of their being positive as being negative.

CHAPTER - 13
PLANE TABLE

13.1 INTRODUCTION

1.The plane table is an instrument used for surveying by a graphical method in which the field work and plotting are done simultaneously.
2.The main feature of plane tabling is that the topographic features to be mapped are in full view. Hence no chance of missing of any important detail.
3.It is suitable for small and medium scale- mapping (1 : 10,000 to 1: 2, 50,000). Where the great accuracy is not required. It is also used for plotting the topographical maps in the field.
4.Before commencing a plane table survey, the instrument stations are fixed to cover the entire area.
5.These stations may be fixed by surveying a trigonometrical framework, establishing a network of control points on a pattern to suit the scale at which plane tabling is carried out.
6.The elevations of these points are determined with the help of leveling.
7.A surveyor starts filling in details from any of these control points, one by one, and traverses all the control points.
8.The finished maps so produced are known as topographic maps.
9.This graphical method of producing topographic maps is known as cartographic surveying.
10.It should be noted that all the measurements made are plotted directly on the drawing sheet instead of recording in the field book.
11.The principle used in plane table surveying is that an unknown point of interest can be established by measuring its directions from known points.

13.1.1 Advantages

1. The sighting and plotting are done simultaneously. Therefore, there is no risk of omitting necessary details.
2. The error and mistakes in plotting can be checked by drawing the check lines.
3. Irregular objects can also be plotted accurately as the lay of land is in view.
4. It is most rapid and useful for filling in details.
5. No great skill is required.
6. It is very advantageous in areas, where compass survey is not reliable e.g. area affected by magnetic fields.

13.1.2 Disadvantages

1. It is not suitable for, work in a wet climate and in a densely wooded country.
2. The absence of measurements (field notes) causes inconvenience, if the survey is to be replotted to some different scale.
3. Plane table is heavy and akward to carry and the accessories are likely to be lost.
4. It does not give very accurate results.

13.2 ALIDADE

An alidade is a straight-edge ruler having some sighting device, it is used for sighting the objects and drawing the lines.
Plain Alidade it is a straight-edge ruler about 450 mm long, made of a metal or wood. One of the edges is beveled and graduated. The alidade is provided with a sight vane at each end. The sight vanes have hinges at the lower end so that they can be folded down on the ruler when not in use.

CHAPTER - 14

ENGINEERING INSTRUMENTS

14.1 HAND LEVEL

1.A hand level is a small leveling instrument which is held in hand while leveling.
2.It is used for approximate determination of elevations in reconnaissance, preliminary, surveying for locating contours on the ground, and for taking short cross-sections in profile levelling.

14.2 ABNEY LEVEL

1. An Abney level is an improved version of the hand level. It can be used as a hand level for levelling, and as a clinometers for measuring slopes. It is a quite light and compact instrument.
2. The vertical scale is extended type

14.3 INDIAN PATTERN CLINOMETER

1. The Indian Pattern Clinometer, also called the tangent clinometers, is a simple instrument used for determining the difference of elevations of the two points by measuring the inclination of the line of sight.
2. It is specially useful for plane tabling.

14.4 CEYLON GHAT TRACER

1. The Ceylon ghat tracer is a simple instrument used for measuring the slopes.
2. It is specially useful for setting out a grade contour on a given gradient in the preliminary survey of a road in a hilly area.

14.5 SEXTANT

1. A sextant is an instrument used for measurement of the horizontal and vertical angles.
2. The distinguishing feature of a sextant is the arrangement of two mirrors which enables the observer to sight two different objects simultaneously.

There are two types of sextants
1. Nautical sextant and
2. Box sextant

14.5.1 Nautical Sextant

It has two glasses called Index glass and Horizon glass. If the angle of inclination between Index glass and Horizon glass is angle θ then angle between two sides objects in the ground will be 2θ.

14.5.1.1 Used of Nautical Sextant

1.The nautical sextant measures angle in the plane of the two objects and the telescope. It is unlike a theodolite (or a compass) which measures the angle in a horizontal plane. Therefore, the nautical sextant is a more versatile instrument.
2. An angle can be measured while the observer is on a ship or a boat.
3. It is specially useful for navigation and astronomical purposes.
4. The angle measured between the two objects at different elevations can be reduced to the horizontal angle, if required.