Design and Construction of Rigid and Flexible Pavement on the Basis of Laboratory Tests and Analysis

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Abstract

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, who's first and the foremost function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should provide a surface of acceptable riding quality, favorable light reacting characteristics, adequate skid resistance, , and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade. Two types of pavements are flexible and rigid pavements are recognized as the most cost effective and durable in all aspects. This type of research gives an overview of pavement types, layers and their functions, and pavement failures. Improper design of pavements that leads to early failure of pavements acting the riding quality has been taken into consideration for safe and comfortable road construction. Prior to the design of pavement, laboratory tests of soil, aggregate and bitumen were conducted. This followed by preparation of four mould samples of hot mix designs with 4%, 5%, 6% and 7% of bitumen whose grading, bulk density and air voids were calculated.

Keywords: cost analysis, estimation, flexible pavement, rigid pavement.

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INTRODUCTION

An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil, structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed, Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility, Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

Goliya et al. (2013) suggested that flexible pavements are preferred over cement concrete roads as they have a great advantage that these can be strengthened and improved in stages with the growth of traffic and also their surfaces can be milled and recycled for rehabilitation. Bruhaspathi (2012) says that if non-conventional pavement design is adopted in the construction of pavement, there will be improved performance of the pavements thus increasing the life and leading to financial savings. Nantung et al. (2008) suggested that the traffic data includes average annual daily traffic, average monthly and hourly traffic, adjustment factors, axle load spectra, and axle weight and spacing values. The pavement is designed as a flexible method from which each method is designed on the basis of their design thickness from which each method has different cost analysis of a section, from which CBR as per IRC is most appropriate in terms of cost analysis. The pavement is designed as a rigid pavement, the method suggested by IRC is most suitable (Jain et al. 2013).

An area of 600 m is surveyed in the study area (Orissa Engineering College campus). The building of road was initiated so that civil, mechanical and electrical engineering departments can be connected with proper pavement. The project also connects the basic science building to these three departments. The survey began from the basic science building and ends at the auditorium (Figure1).

The total length and breadth of road is 600m and 5.5 m respectively. The cross section of pavement was also surveyed and its details are described below:

[1]. Lower most layer is G.S.B which has a thickness of 250 mm
[2]. The layer above G.S.B is W.M.M. It has a thickness of 150 mm
[3]. Third layer called B.M is 50 mm thick
[4]. And the top layer is S.D.B.C with a thickness of 25 mm

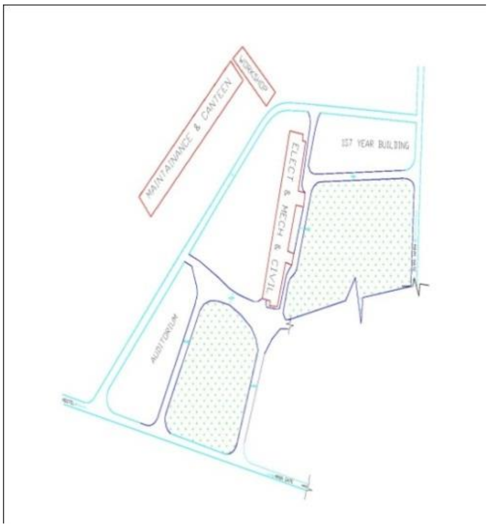

Fig. 1. *Lay Out of the Study Area.*

OBSERVATIONS AND CALCULATIONS

California bearing ratio (CBR) as per IS: 2720 - Part 16 is an empirical test and widely applied in design of flexible pavement over the world (Kumar and Pabithra, 2016). Atterberg limits have been tested for the soil as per IS 2720-Part 5. After laboratory tests being conducted, analysis was done to find the suitability of pavement type for the study area.

Tests on Soil

Standard load results from 3000g to 7800g were used in CBR and the results have been presented in Table 1.

Table 1. *Standard Load Used in CBR Test.*

Penetration of plunger (mm)	Standard load (g)	Penetration of plunger (mm)	Standard load (g)
0.1	3000	2.5	1370
0.2	4500	5.0	2055
0.3	5700	7.5	2630
0.4	6900	10.0	3180
0.5	7800	12.5	3600

Table 2 reflects the liquid limit of the soil and Figure2 records the liquid limit to be 46.4% whereas Figure3 presents the variation of moisture content with dry density of the soil. Table 3 provides the plastic limit (27.2%) of the soil.

Table 2. *Data and Observation Sheet for Liquid Limit.*

Determination no.	**1**	**2**	**3**	**4**
Number of blows	34	23	18	12
Container number	130	123	128	132
Mass of container + wet soil (g)	38.86	46.63	60.36	43.43
Mass of container + dry soil (g)	34.91	39.59	49.02	37.22
Mass of water (g)	3.95	7.04	11.34	6.21
Mass of container (g)	26.08	25.30	26.95	66.06
Mass of oven dry soil (g)	8.83	14.29	22.07	11.16
Water content (%)	44.6	49.4	51.4	55.6

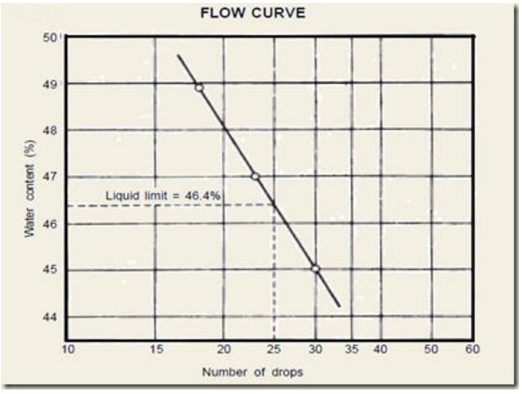

Fig. 2. *Flow Curve of Liquid Limit.*

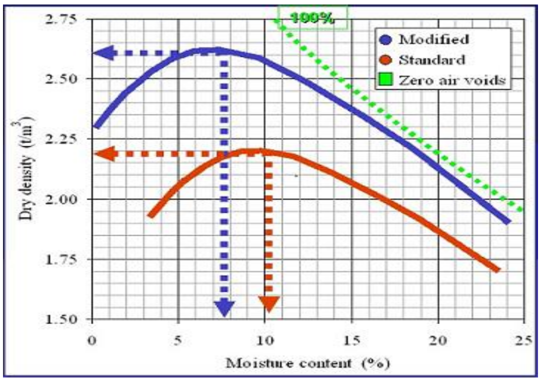

Fig. 3. *Variation of Moisture Content with Dry Density*

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Table 3. *Data and Observation Sheet for Plastic Limit.*

Determination no.	1	2	3
Container No.	33	19	22
Mass of container + wet soil (g)	31.29	30.39	30.87
Mass of container + dry soil (g)	29.75	28.75	29.27
Mass of water (g)	1.54	1.64	1.60
Mass of container (g)	24.01	22.79	23.42
Mass of dry soil (g)	5.74	5.96	5.85
Water content (%)	26.8	27.5	27.3
Plastic limit = 27.2%			

Optimum moisture content (OMC) (IS: 2720-7, 1980)
Mixture with Water:
Weight of empty container = 0.036g m
Weight of container with soil = 0.061g m
Weight of mould along soil = 12.480 kg
Weight of empty mould = 7.945 kg
Volume = (π/4) × 15×15×13 = 2297.28 c.cm
Bulk density = (12480-7945)/2297.28 = 1.97 gm/c.cm
Mixture without Water
Weight of empty container = 0.040 gm

Weight of container with soil = 0.084 gm
Weight of mould along soil = 12.560 kg
Volume = 2297.28 c.cm
Bulk density = (12560–7945)/2297.28 = 2 gm/c.cm
California Bearing Ratio
Soil = 5 kg
Water = 7%
Weight of empty mould = 13.175 kg
2.5 mm penetration =66mm×1.15 = 75.9 kg ≈ 76 kg
5 mm penetration =138 mm×1.15 = 158.4 kg ≈ 158 kg
C.B.R = (Test load/ Standard load) × 100
For 2.5mm penetration C.B.R value = (76/1344) × 100 = 5.58%
For 5mm penetration C.B.R value = (158/2016) × 100 = 7.87%
So the result = 7.87%

Tests on Aggregate (IS: 2386)
Flakiness Index
Weight of passing aggregate = 0.495 kg
Total weight of aggregate = 2.870 kg
% of aggregate = (0.495/2.870)×100 = 17%

Elongation Index
Weight of passing aggregate = 0.122 kg
Total weight of aggregate = 2.870 kg
% of aggregate = (0.122/2.870)×100=4.25%

Abrasion Test
Original weight of aggregate = 5 kg
After passing 20mm sieve and retained 12.5mm sieve = 4.5 kg
12.5mm passing 10mm retained = 500 gms
Mixture of 5kg aggregate put in Los-Angeles Apparatus and after test the net weight of aggregate = 4.907 kg
Percentage = {(5000–4907)/5000} ×100 = 1.86%

Impact Test
Weight of empty mould = 123gms
Passing 12.5mm and retained 10 mm = 200gms
Weight of aggregate = 200gms
Mass of mould with aggregate = 407gms
Aggregate after impact = 216gms
Total weight after impact with mould = 339gms
Amount of passing = (407–339) = 68gms
Mass of net aggregate = (407–123) = 284gms
% of passing = (68/284) ×100 =23.94% < 30%

Crushing Test
Mass of aggregate with mould = 4.668 kgs
Mass of mould = 1.937 kgs

Mass of aggregate = 4.668-1.937 = 2.731 kgs
Mass of aggregate after sieving = 2 kgs
Crushing percentage = {(2.731-2.000)/2.731}×100 = 26.76% < 30%

Tests on Bitumen (ASTM, USA)
Softening Point
The softening point of bitumen =45°celcius≈50°celcius
Ductility Test
Elongation =100 cm
Penetration Test
Bitumen = Low quality; Grade = 8200; Time = 5 sec; Division = 110 mm
Specific Gravity Test
Empty container (a) = 0.581kg
Empty container+ Full of water (b) = 1.607 kg
Bitumen with container (c) = 0.904 kg
Bitumen+ Water container (d) = 1.630 kg
Specific gravity = (weight of bituminous material/weight of equal volume of water at 27°c)
= (c-a) / {(b-a) - (d-c)} = (0.904-0.581) / {(1.607-0.581)-(1.630-0.904)} = 1.076 kgs

HOT MIX DESIGN (The Asphalt Institute, USA)
According to grading, the samples taken are: -
Specific gravity of coarse aggregate = 2.65 (G1)
Specific gravity of fine aggregate = 2.60 (G2)
Specific gravity of filler = 2.50 (G3)
Specific gravity of bitumen = 1.05 (G4)

First Sample (4% of Bitumen)
Mould diameter = 10cm; Mould height = 6.5 cm
Volume of specimen = $(\pi/4)$ d^2h = $(3.14/4)\times10^2\times6.5$ = 510cc
Weight of specimen = 1199 gm
Stability test result = 750.2 kg
Flow=9.8u nit

Grading
Coarse aggregate = 20%; Fine aggregate = 60%; Filler =20%
Hence, coarse aggregate = 1200× (20/100) = 240 gm (w1)
Fine aggregate = 1200 × (60/100) = 720 gm (w2)
Filler = 1200 × (20/100) = 240 gm (w3)
Bitumen =1200 × (4/100) = 48 gm (w4)
Theoretical specific gravity of mix

$$G_t = \frac{W1+W2+W3+W4}{\left(\frac{W1}{G1}\right)+\left(\frac{W2}{G2}\right)+\left(\frac{W3}{G3}\right)+\left(\frac{W4}{G4}\right)} = \frac{240+720+240+48}{\left(\frac{240}{2.65}\right)+\left(\frac{720}{2.6}\right)+\left(\frac{240}{2.5}\right)+\left(\frac{48}{1.05}\right)} = \frac{1248}{509.63} = 2.44$$

Bulk density

$G_m = \frac{Wm}{Wm-Ww}$; W_m = weight of mix in air; W_w = weight of mix in water

$$G_m = \frac{1199}{510} = 2.35$$

Air Voids (V_v):

$$V_v = \left[\frac{-Gm}{}\right]\times 100 = \left[\frac{2.44-2.35}{2.44}\right]\times100 = 3.68\%$$

Percentage of volume of bitumen (V_b)

$V_b = \frac{\left(\frac{W4}{G4}\right)}{(W1+W2+W3+W4)/Gm} \times 100 = \frac{\left(\frac{48}{1.05}\right)}{(240+720+240+48)/2.35} \times 100 = 8.608\%$

Volume of mineral aggregate (VMA)

VMA = $V_v + V_b$ = 3.68+8.608 = 12.68%

Voids filled with bitumen (VFB)

VFB = (Vb/VMA) × 100 = (8.608/12.28) × 100 = 70.03%

Second Sample (5% of Bitumen)

Mould diameter = 10 cm; Mould height = 6.5 cm

Volume of specimen = $(\pi/4)$ d²h = (3.14/4) × 10^2 × 6.5 = 510 cc

Weight of specimen = 1200 gm

Stability test = 812 kg

Flow = 12.5 unit

Grading

Coarse aggregate = 20%; Fine aggregate = 60%; Filler = 20%

Hence, coarse aggregate = 1200 × (20/100) = 240gm (w1)

Fine aggregate = 1200 × (60/100) = 720gm (w2)

Filler = 1200 × (20/100) = 240gm (w3)

Bitumen = 1200 × (5/100) = 60gm (w4)

Theoretical specific gravity of mix

$Gt = \frac{W1+W2+W3+W4}{\left(\frac{W1}{G1}\right)+\left(\frac{W2}{G2}\right)+\left(\frac{W3}{G3}\right)+\left(\frac{W4}{G4}\right)} = \frac{240+720+240+60}{\left(\frac{240}{2.65}\right)+\left(\frac{720}{2.6}\right)+\left(\frac{240}{2.5}\right)+\left(\frac{60}{1.05}\right)} = \frac{1248}{521.17} = 2.41$

Bulk density

$G_m = \frac{Wm}{Wm-Ww}$; W_m= weight of mix in air; W_w = weight of mix in water

$G_m = \frac{1200}{510} = 2.35$

Air Voids (Vv):

$V_v = \left[\frac{-Gm}{}\right] \times 100 = \left[\frac{2.41-2.35}{2.41}\right] \times 100 = 2.48\%$

Percentage of volume of bitumen (V_b)

$V_b = \frac{\left(\frac{W4}{G4}\right)}{(W1+W2+W3+W4)/Gm} \times 100 = \frac{\left(\frac{60}{1.05}\right)}{(240+720+240+60)/2.35} \times 100 = 10.65\%$

Volume of mineral aggregate (VMA)

VMA = $V_v + V_b$ = 2.48+10.65 =13.13

Voids filled with bitumen (VFB)

VFB = (V_b/VMA) × 100 = (10.65/13.13) × 100 = 81.11%

Third Sample (6% of Bitumen)

Mould diameter = 10cm; Mould height = 6.5cm

Volume of specimen = $(\pi/4)$ d²h = (3.14/4) × 10^2 × 6.5 = 510cc

Weight of specimen = 1198gm

Stability test = 768.6kg

Flow = 14.7unit

Grading

Coarse aggregate = 20%; Fine aggregate = 60%; Filler = 20%

So Coarse aggregate = 1200 × (20/100) = 240gm (w1)

Fine aggregate = 1200 × (60/100) = 720gm (w2)
Filler = 1200 × (20/100) = 240gm (w3)
Bitumen = 1200 × (6/100) = 72gm (w4)
Theoretical specific gravity of mix

$$Gt = \frac{W1+W2+W3+W4}{\left(\frac{W1}{G1}\right)+\left(\frac{W2}{G2}\right)+\left(\frac{W3}{G3}\right)+\left(\frac{W4}{G4}\right)} = \frac{240+720+240+72}{\left(\frac{240}{2.65}\right)+\left(\frac{720}{2.6}\right)+\left(\frac{240}{2.5}\right)+\left(\frac{72}{1.05}\right)} = \frac{1248}{532} = 2.39$$

Bulk density

$Gm = \frac{Wm}{Wm-Ww}$; Wm = weight of mix in air; Ww = weight of mix in water

$Gm = \frac{1198}{510} = 2.34$

Air Voids (Vv)

$$V_v = \left[\frac{-Gm}{}\right] \times 100 = \left[\frac{2.39-2.34}{2.39}\right] \times 100 = 2.09\%$$

Percentage of volume of bitumen (V_b)

$$V_b = \frac{\left(\frac{W4}{G4}\right)}{(W1+W2+W3+W4)/Gm} \times 100 = \frac{\left(\frac{72}{1.05}\right)}{(240+720+240+72)/2.35} \times 100 = 12.61\%$$

Volume of mineral aggregate (VMA)
VMA = Vv+Vb = 2.09 + 12.61 = 14.7%
Voids filled with bitumen (VFB)
VFB = (Vb/VMA) × 100 = (12.61/14.7) × 100 = 85.78%

Fourth Sample (7% of Bitumen)
Mould diameter = 10cm; Mould height = 6.5cm
Volume of specimen = $(\pi/4)\ d^2h = (3.14/4) \times 10^2 \times 6.67 = 520$cc
Weight of specimen = 1198gm
Stability test = 670.8kg
Flow = 17.91unit

Grading

Coarse aggregate = 20%; Fine aggregate = 60%; Filler =20%
Hence, coarse aggregate = 1200 × (20/100) = 240gm (w1)
Fine aggregate = 1200 × (60/100) = 720gm (w2)
Filler = 1200 × (20/100) = 240gm (w3)
Bitumen = 1200 × (7/100) = 84gm (w4)
Theoretical specific gravity of mix

$$Gt = \frac{W1+W2+W3+W4}{\left(\frac{W1}{G1}\right)+\left(\frac{W2}{G2}\right)+\left(\frac{W3}{G3}\right)+\left(\frac{W4}{G4}\right)} = \frac{240+720+240+84}{\left(\frac{240}{2.65}\right)+\left(\frac{720}{2.6}\right)+\left(\frac{240}{2.5}\right)+\left(\frac{84}{1.05}\right)} = \frac{1248}{543.48} = 2.36$$

Bulk density

$Gm = \frac{Wm}{Wm-Ww}$; Wm = weight of mix in air; Ww = weight of mix in water

$Gm = \frac{1199}{520} = 2.30$

Air Voids (Vv)

$$Vv = \left[\frac{-Gm}{}\right] \times 100 = \left[\frac{2.36-2.30}{2.36}\right] \times 100 = 2.54\%$$

Percentage of volume of bitumen (Vb)

$$Vb = \frac{\left(\frac{W4}{G4}\right)}{(W1+W2+W3+W4)/Gm} \times 100 = \frac{\left(\frac{84}{1.05}\right)}{(240+720+240+84)/2.35} \times 100 = 14.3\%$$

Volume of mineral aggregate (VMA)
VMA = Vv+Vb = 2.54 + 14.3 = 16.87%
Voids filled with bitumen (VFB)

VFB = (Vb/VMA) × 100 = (14.3/16.87) × 100 = 84.76%

Table 6. *Variation of Stability with % of Bitumen.*

Sl. no	**Bitumen content**	**Stability (kg)**	**Flow (unit)**	**Vv in (%)**	**VFB in (%)**	**Gm (gm/cm^3)**
01	4%	750.2	9.8	3.68	70.03	2.35
02	5%	812	12.5	2.48	81.10	2.35
03	6%	768.6	14.7	2.09	85.78	2.34
04	7%	670.8	17.9	2.54	84.76	2.30

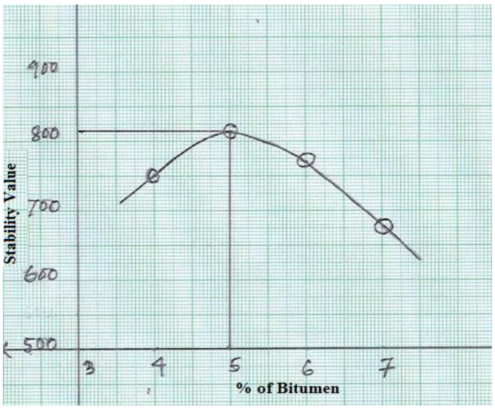

Fig. 4. *Variation of Stability with % of Bitumen.*

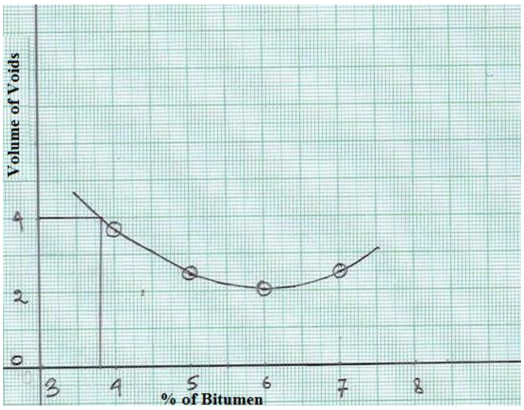

Fig. 5. *Variation of Volume of Air Voids with % of Bitumen.*

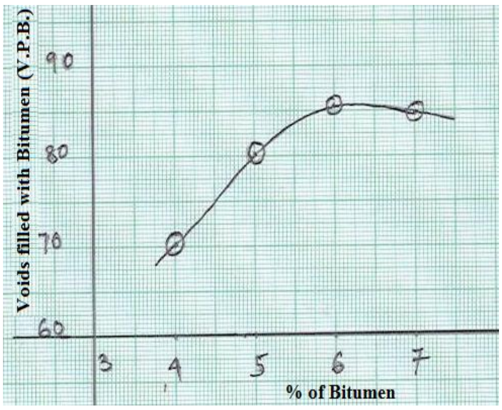

Fig. 6. *Variation of V.F.B with % of Bitumen.*

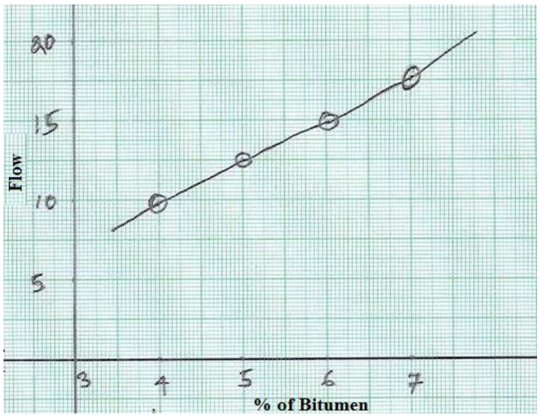

Fig. 7. *Variation of flow with % of Bitumen.*

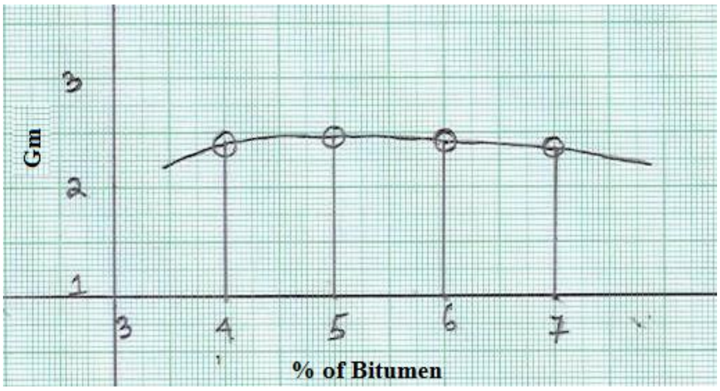

Fig. 8. *Variation of Bulk Density with % of Bitumen.*

From Figure 4 to Figure8 the following details are established.
Maximum stability = 5% bitumen
Maximum Bulk density = 5% bitumen
Maximum air voids from graph = 3.8%
So optimum bitumen content is the average of three $\frac{5+5+3.8}{3}$= 4.6
Finally, from the observation we got optimum bitumen content as 4.6%.

CONCLUSION

The pavement is designed as a flexible pavement upon a black cotton soil sub grade, the CBR method as per IRC 37-2001 is most appropriate method than available methods. The pavement is designed as a flexible method from which each method is designed on the basis of their design thickness from which each method has different cost analysis of a section, from which CBR as per IRC is most appropriate in terms of cost analysis.
The pavement is designed as a rigid pavement, the method suggested by IRC is most suitable. It is observed that flexible pavements are more economical for lesser volume of traffic. The life of flexible pavement is nearly 15 years whose initial cost is low but needs a periodic maintenance after a certain period of time and maintenance costs too high.
The life of rigid pavement is much more than the flexible pavement of about 40 years approx. 2.5 times life of flexible pavement whose initial cost is much more than the flexible pavement but maintenance cost is very less.

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