RESEARCH ARTICLE OPEN ACCESS

Design of Flexible Pavements by Stabilizing Poor Sub-Grade Soil using Bitumen and Bitumen Epoxy Resin

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ABSTRACT
Stabilization is normally needed when soil strength is poor. Soil stabilization is done to make soil stable in terms of reducing the permeability, compressibility and increasing the shear strength. There are various stabilizers such as lime, cement, bitumen, and fly ash etc., used to stabilize the poor sub-grade soil. The main objective of this research work is to obtain geotechnical and engineering properties of poor sub-grade soils by bitumen of grade 80/100 as a stabilizer along with epoxy resin with varying percentages of bitumen and epoxy resin were added from (2%, 4%, 6% and 8%) by weight of sub-grade soil. Soil properties like soil classification, Atterberg's limits, California bearing ratio (CBR), Maximum dry density (MDD) are evaluated by varying percentages of bitumen and epoxy resin mix and from CBR test results flexible pavement has been designed as per IRC: 37-2001 on poor sub-grade soils.

Keywords – Soil stabilization, California bearing ratio, Maximum dry density and pavement design.

Date of Submission: 26-04-2019 Date of Acceptance: 06-05-2019

I. INTRODUCTION

Bituminous soil stabilization is being used widely as an effective method. Bitumen is non-aqueous system of hydrocarbons which are completely soluble in carbon disulphide. Bituminous material stabilizes the soil either by binding the particles together or protecting the soil from the deleterious effects of water (i.e., waterproofing) or both these effects may occur together. Emulsions and cutbacks, both are used in soil stabilization. Although soil-asphalt has varied applications, it is mostly used in bases for highway and airfield pavements. All inorganic soils with bitumen are either emulsion or cutback can be mixed and stabilized.

The soil sample used for soil stabilization should meet any one of the requirements

Maximum size of the particles is less than the 1/3rd of the compacted thickness of the treated soil layer.

More than 50% of the soil particles are finer than 4.76 mm size.

35% to 100% of soil particles are finer than 1.42 mm size.

Liquid limit of the soil is less than 40%.

Plasticity index of the soil is less than 18%.

An increase in bitumen content gives better results the addition of bitumen does not increase the strength of fine grained soils tremendously but improves the waterproofing parameters of the soil which in turn results in a better stabilized soil. And from the results obtained flexible pavements are designed as per the standards of IRC: 37-2001.

II. MATERIALS USED

The materials used in this research are

- Indian standard bitumen of grade 80/100
- Kerosene
- Cohesive soils
- Polyester epoxy resin with catalyst
- Water

The base binding material is produced by blending 60% bitumen with 40% of domestic kerosene. Drinking water is used for this purpose so as to ensure that there were no deleterious substances.

III. METHODOLOGY:

The following tests were carried out on cohesive soil sample:

- Wet Sieve Analysis
- Atterberg's Limits
- Compaction Test
- California Bearing Ratio Test (CBR)

Wet sieve analysis: The wet sieve analysis is performed as per IS: 2720 (part 4)1985, the soil sample is soaked in 1 gram of sodium hydroxide and one gram of sodium carbonate per liter of water after soaking for 24 hours, the soil sample dried in the sun until it loses its moisture completely and sieve analysis is performed by mechanical sieve shaker.

Atterberg's limit tests: The liquid and plastic limits of soil represents the moisture content at which specific changes in the behavior of soil can be observed physically. From Atterberg's limits engineering properties of cohesive soils are evaluated. The plasticity is the capability of soil to undergo deformation without cracking or crumbling and it also allows a material to go through deformation without noticeable elastic recovery.

Compaction test: Compaction process involves densification of soil by minimizing air voids. The proctor test was adopted this involves compaction of air dried soil sample in a cylindrical mould. The purpose of compaction test is to determine quantity of water properly where the weight of soil in a unit volume is maximum when compacted that amount of water is called optimum moisture content and the obtained density is referred as maximum dry density.

Bulk density (γ_b) = $\frac{Wc}{1000}$(gram/cc)

Dry density (γ_d) = $\frac{\gamma_b}{1+\frac{w}{100}}$

California bearing ratio test:

CBR test is one of the most adopted methods for evaluating the strength of sub-grade soil for roads and pavements. It is a measure of resistance of a material to the penetration of standard plunger under controlled density and moisture conditions. From the obtained test results, the empirical curves are used to find the thickness of pavement and its component layers. CBR is calculated as $=\frac{\text{Correctedload}}{\text{standardload}} * 100$

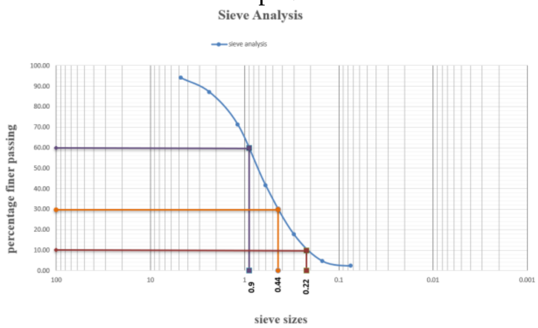
IV. RESULTS AND DISCUSSIONS

Wet sieve analysis as per IS: 2720 (part IV) –1985 is carried out to determine the relative percentages of different sizes of particles in the soil sample. These sizes control the mechanical behaviour of cohesive soil. Dry method of sieving is used for coarser fractions (retained on 4.75 mm sieve) and wet method is used for finer fractions (retained on 75 µm sieve) and pipette method is used for the fractions which are passing through 75 µm sieve. The result of the sieve analysis shows that about 2.24% of the sample passes the sieve number 200 (75 µm sieve) which portrays that the soil has small amount of silt or clay as shown in Table 1. According to Unified soil Classification System (USCS), if $C_U \geq 4$ and C_C lies between 1 and 3 then the soil is classified as well graded soil. In this case, $C_U = 4.09$ and $C_C = 0.97$ and it does not meet Cc. Hence, it is classified as poorly graded soil.

Table 1: Wet sieve analysis of soil specimen

sieve size (mm)	weight retained (grams)	percentage retained	cumulative percentage	Percentage passing (%)
4.75	59	6.02	6.02	93.98
2.36	68	6.94	12.96	87.04
1.18	156	15.92	28.88	71.12
0.6	289	29.49	58.37	41.63
0.3	235	23.98	82.35	17.65
0.15	127	12.96	95.31	4.69
0.075	24	2.45	97.76	2.24
Pan	22	2.24	100	0
	980			

Figure 1: Particle size distribution curve of the soil sample.



Atterberg's Limits:

Table 2: Liquid Limit of soil

Sample No.	Empty weight of container in grams	Weight of wet sample in grams	Weight of dry sample in grams	No of blows	w.c (%) = $\frac{w_2-w_3}{w_3-w_1} * 100$
1	20	24	23	57	33.33
2	24	32	29	32	60
3	21	26	24	12	66.6

Figure 2: Representing liquid Limit of soil specimen as 60%

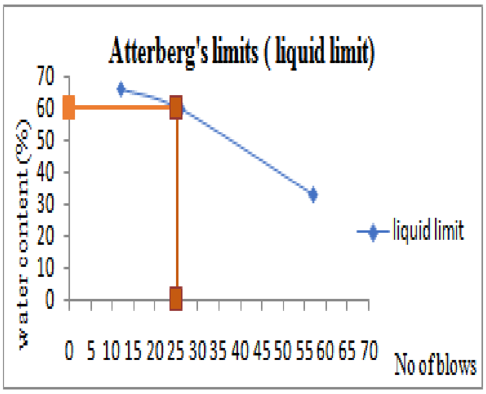


Table 3: Plastic Limit of soil

Sample No.	Empty weight of container in grams	Weight of wet sample in grams	Weight of dry sample in grams	w.c (%) $=\frac{w_2-w_3}{w_3-w_1} * 100$
1	20	26	25	20
2	20	26	24.28	40
3	20	26	15.38	30

The plastic limit of the soil =(20+40+30)/3 = 30%

Calculation of Plasticity index = Liquid Limit – Plastic Limit = 60% -30%= 30%. From the Unified soil classification system the A line of value is = 0.73(liquid limit -20) =0.73(60% -20%) = 29.2%. Here Plasticity index of soil is 30% > 29.2%. The soil specimen is identified as clay of high compressibility (CH)

Compaction Test

The moisture contents and dry densities of soil specimens are tabulated in Table 4 and 5 the relationship between water content and maximum dry density (MDD) of soil are graphically represented. When soil is stabilised with varying percentages of bitumen (2%, 4%, 6%, 8%), it was observed that the soil has achieved its Maximum dry density at 4% bitumen with Optimum Moisture Content at 16.07% when compared to other percentages of bitumen. When the soil is stabilised with varying percentages of bitumen epoxy resin (2%, 4%, 6%, 8%), it was observed that the soil has achieved its Maximum dry density at 6% bitumen epoxy resin and Optimum Moisture Content at 13.2% when compared to other percentages of bitumen epoxy resins mix.

Table 4: Calculation of optimum moisture content and maximum dry density of soil with varying percentages of bitumen

Soil samples	S.No.	Determination	Sample 1	Sample 2	Sample 3
Natural soil sample	1	Weight of mould + compacted soil	5280	5550	5400
	2	Weight of compacted soil (Wt)	1680	1910	1800
	3	Wet density, Vt=Wt/V	1.68	1.91	1.8
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	41.5	41	37
	6	Weight of container + weight of dry soil (grams)	39	38	34
	7	Weight of water (ml)	450	525	600
	8	Weight of container (grams)	21.5	21.5	22
	9	Weight of dry soil (grams)	17.5	16.5	12
	10	Water content (%)	14.28	18.18	25
	11	Weight of wet soil (grams)	20	19.5	15
	12	Dry density (gm/cc)	1.46	1.62	1.44

2% of bitumen	1	Weight of mould + compacted soil	5280	5500	5400
	2	Weight of compacted soil (Wt)	1680	1875	1775
	3	Wet density, Vt=Wt/V	1.68	1.875	1.775
	4	Container number	1	1	2
	5	Weight of container + weight of wet soil (grams)	41.5	41	37
	6	Weight of container + weight of dry soil (grams)	39	38	34
	7	Weight of water (ml)	450	450	525
	8	Weight of container (grams)	21.5	21.5	22
	9	Weight of dry soil (grams)	17.5	16.5	12
	10	Water content (%)	14.28	18.18	25
	11	Weight of wet soil (grams)	20	19.5	15
	12	Dry density (gm/cc)	1.46	1.58	1.42
4% of bitumen	1	Weight of mould + compacted soil	5350	5550	5450
	2	Weight of compacted soil (Wt)	1725	1925	1825
	3	Wet density, Vt=Wt/V	1.725	1.925	1.825
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	29	34.5	41
	6	Weight of container + weight of dry soil (grams)	28.03	32.7	38
	7	Weight of water (ml)	300	375	450
	8	Weight of container (grams)	20	21.5	23
	9	Weight of dry soil (grams)	8.03	11.2	15
	10	Water content	12	16.07	20

		(%)			
	11	Weight of wet soil (grams)	9	13	18
	12	Dry density (gm/cc)	1.54	1.66	1.51
6% of bitumen	1	Weight of mould + compacted soil	5550	5600	5370
	2	Weight of compacted soil (Wt)	1925	1975	1745
	3	Wet density, Vt=Wt/V	1.925	1.975	1.745
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	30.5	31	38
	6	Weight of container + weight of dry soil (grams)	29	29.4	35.4
	7	Weight of water (ml)	375	450	525
	8	Weight of container (grams)	20	20.5	23
	9	Weight of dry	9	8.9	12.4

		soil (grams)			
	10	Water content (%)	16.67	17.9	21
	11	Weight of wet soil (grams)	10.5	10.5	15
	12	Dry density (gm/cc)	1.6	1.63	1.44
8% of bitumen	1	Weight of mould + compacted soil	5335	5405	5375
	2	Weight of compacted soil (Wt)	1710	1780	1750
	3	Wet density, Vt=Wt/V	1.71	1.78	1.75
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	34.5	41	38
	6	Weight of container + weight of dry soil (grams)	32.6	37.6	34.8
	7	Weight of water (ml)	450	525	600
	8	Weight of	23	22	21.5

		container (grams)			
	9	Weight of dry soil (grams)	9.6	15.6	13.3
	10	Water content (%)	18.75	21.1	24.1
	11	Weight of wet soil (grams)	11.5	19	16.5
	12	Dry density (gm/cc)	1.44	1.47	1.41

Table 5: calculation of optimum moisture content and maximum dry density of soil with varying percentages of bitumen with epoxy resin

Soil samples	S. No.	Determination	Sample 1	Sample 2	Sample 3
2% of bitumen epoxy resin	1	Weight of mould + compacted soil	5400	5600	5550
	2	Weight of compacted soil (W_t)	1775	1975	1875
	3	Wet density, V_t=W_t/V	1.775	1.975	1.875
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	32.15	41	33.5
	6	Weight of container + weight of dry soil (grams)	31.16	38.45	31.5
	7	Weight of water (ml)	300	375	450
	8	Weight of container (grams)	20	21.5	21
	9	Weight of dry soil (grams)	11.16	16.95	10.5
	10	Water content (%)	12	15.04	19.04
	11	Weight of wet soil (grams)	12.15	19.5	12.5
	12	Dry density (gm/cc)	1.58	1.72	1.57
4% of bitumen epoxy resin	1	Weight of mould + compacted soil	5529	5650	5600
	2	Weight of compacted soil (W_t)	1904	2025	1975
	3	Wet density, V_t=W_t/V	1.904	2.025	1.975
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	29.5	31	32
	6	Weight of container + weight of dry soil (grams)	28.75	29.89	30.9
	7	Weight of water (ml)	300	375	450
	8	Weight of container (grams)	22.5	22.5	20
	9	Weight of	6.25	7.3	9.89

		dry soil (grams)		9	
	10	Water content (%)	12	15.02	18
	11	Weight of wet soil (grams)	7	8.5	12
	12	Dry density (gm/cc)	1.7	1.76	1.67
6% of bitumen epoxy resin	1	Weight of mould + compacted soil	5550	5650	5550
	2	Weight of compacted soil (W_t)	1925	2025	1925
	3	Wet density, $V_t=W_t/V$	1.925	2.025	1.925
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	36	32	39
	6	Weight of container + weight of dry soil (grams)	34.72	30.6	36.5
	7	Weight of water (ml)	250	300	375
	8	Weight of container (grams)	22	20	21.5
	9	Weight of dry soil (grams)	12.72	10.6	15
	10	Water content (%)	10	13.2	16.6

	11	Weight of wet soil (grams)	14	12	17.5
	12	Dry density (gm/cc)	1.75	1.78	1.65
8% of bitumen epoxy resin	1	Weight of mould + compacted soil	5345	5450	5500
	2	Weight of compacted soil (W_t)	1720	1825	1875
	3	Wet density, $V_t=W_t/V$	1.72	1.825	1.875
	4	Container number	1	2	3
	5	Weight of container + weight of wet soil (grams)	29	49.79	49.5
	6	Weight of container + weight of dry soil (grams)	28.50	46.8	45.5
	7	Weight of water (ml)	225	300	375
	8	Weight of container (grams)	23	21.92	22.81
	9	Weight of dry soil (grams)	5.5	24.88	22.69
	10	Water content (%)	9	12.01	17.62
	11	Weight of wet soil (grams)	6	27.87	26.69
	12	Dry density	1.57	1.63	1.59

		(gm/cc)			

Figure 3: Representing Optimum moisture content and Maximum dry density of Natural Soil Sample

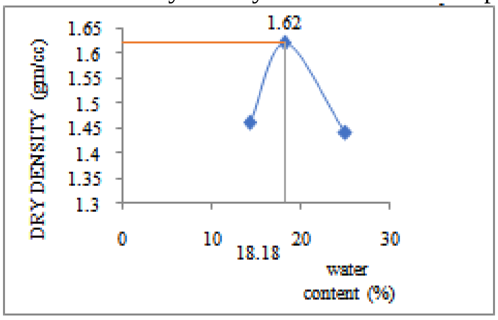


Figure 4: Representing Optimum moisture content and Maximum dry density of Natural Soil Sample with 2% bitumen mix

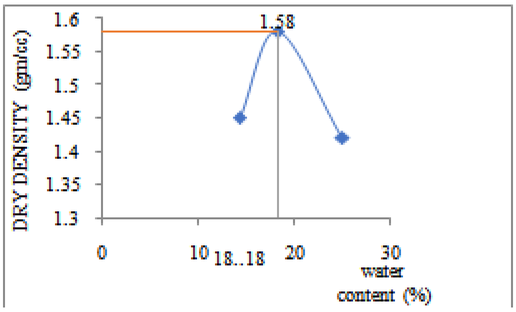


Figure 5: Representing Optimum moisture content and Maximum dry density of Natural Soil Sample with 4% Bitumen mix

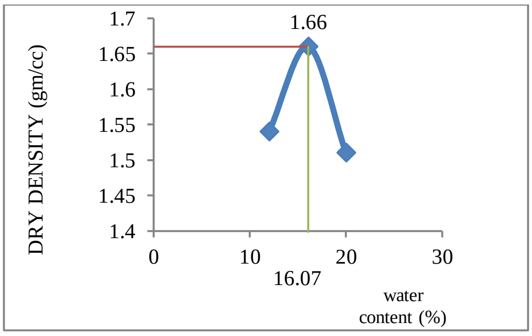


Figure 6: Representing Optimum moisture content and Maximum dry density of Natural Soil Sample with 6% bitumen mix

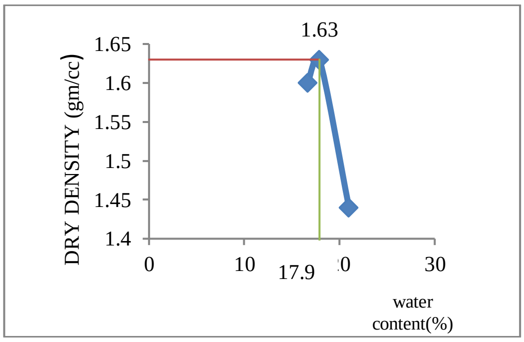


Figure 7: Representing Optimum moisture content and Maximum dry density of Natural Soil Sample with 8% bitumen mix

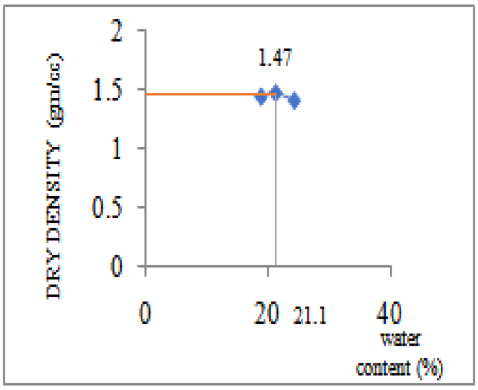


Figure 8: Representing Optimum moisture content and Maximum dry density of Soil Sample with 2% Bitumen Epoxy Resin

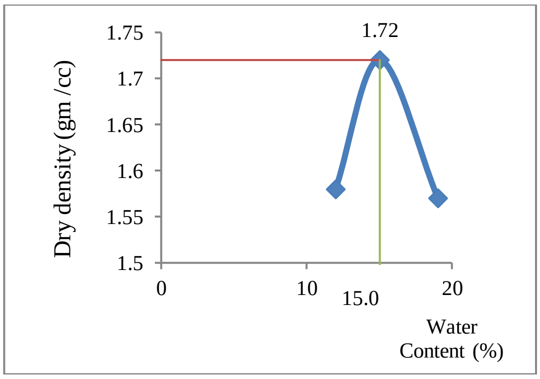


Figure 9: Representing Optimum moisture content and Maximum dry density of Soil Sample with 4% Bitumen Epoxy Resin mix

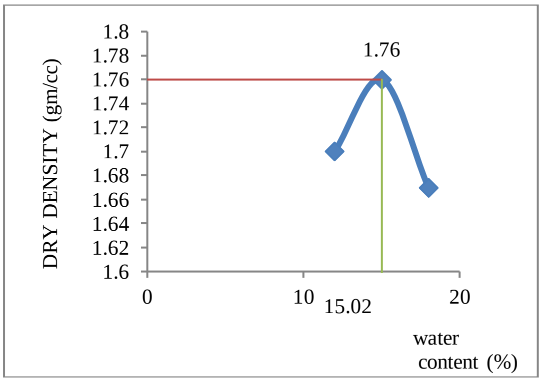


Figure 10: Representing Optimum moisture content and Maximum dry density of Soil Sample with 6% Bitumen Epoxy Resin mix

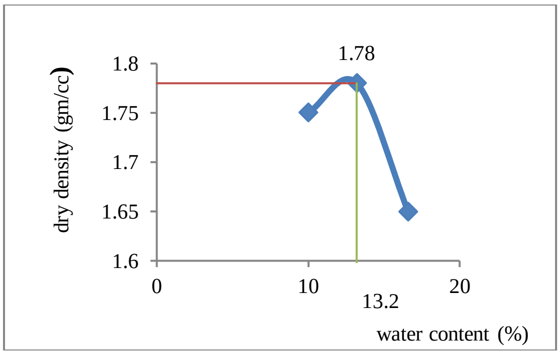
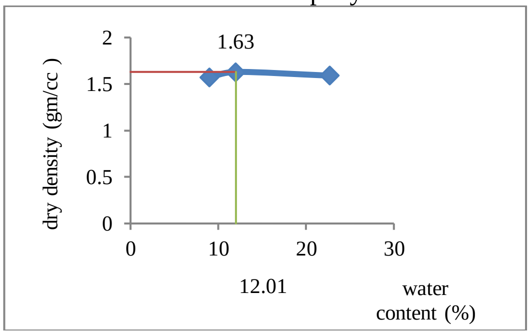


Figure 11: Representing Optimum moisture content and Maximum dry density of Soil Sample with 8% Bitumen Epoxy Resin



California Bearing Ration test:

From the compaction test results it was noticed Maximum Dry Density (MDD) for less water contents achieved at 4% of bitumen mixed with soil. Therefore, the CBR of this soil is 5.4% ≅ 5% and it was also noticed Maximum Dry Density (MDD) for less water content is achieved at 6% bitumen epoxy resin mixed with soil. Therefore, the CBR of this soil sample 5.9% ≅ 6%.

Table 6: California Bearing Ration test results of natural soil sample

Penetration (in mm)	Proving ring reading No. of divisions			Corrected load			Standard load (in kg)	Percentage of CBR (%)			Average CBR
0.5	1.3	1.4	1.4								
1	3.8	6.6	6.7								
1.5	10.9	8.9	8.8								
2	11.1	11.1	11.1								
2.5	15.8	18.5	18.4	32.4	37.8	37.53	1350	2.4	2.8	2.78	2.66
4	21.3	21.6	19.5								
5	22.35	23.3	20.3	45.6	47.5	41.4	2055	2.21	2.31	2.01	2.18
7.5	34	32.3	32.2								
10	51	48	45								
12.5	63	62.5	63								

Table 7: California Bearing Ration test results of soil sample stabilized with 4% Bitumen

Penetration (in mm)	Proving ring reading No. of divisions			Corrected load			Standard load (in kg)	Percentage of CBR (%)			Average CBR
0.5	1.5	2	1.5								
1	8.5	9.5	8								
1.5	18	17	19								
2	23	27	24								
2.5	35	35.5	37	71.4	72.4	75.5	1350	5.28	5.36	5.58	5.4
4	49.7	44	46								
5	54	51	53	110	104	108	2055	5.06	5.25	5.35	5.22
7.5	97	105	98.5								
10	105	111	119								
12.5	138	144	126								

Table 8: California Bearing Ration test results of soil sample stabilized with 6% Bitumen Epoxy Resin

Penetration (in mm)	Proving ring reading No. of divisions			Corrected load			Standard load (in kg)	Percentage of CBR (%)			Average CBR
0.5	21	20	23								
1	25	26	27								
1.5	31	32	33								
2	36.5	37	34								
2.5	38.5	39	40	78.5	79.65	80.86	1350	5.81	5.9	5.99	5.9
4	52.5	51	52								
5	53.9	52.39	54	109.9	106.86	110.1	2055	5.34	5.2	5.36	5.3
7.5	69.5	68	67								
10	83	81	85								
12.5	98	97	94								

Table 9: Traffic volume studies for two days.

Duration of traffic volume count at peak hours		Two wheelers	Four wheelers	Buses	Tractors	Bicycles	Total
Day1	9 A.M. to 10 A.M.	164	48	55	9	12	288
	4 P.M. to 5 P.M.	173	64	53	53	11	324
Day 2	9 A.M. to 10 A.M.	160	52	55	10	19	296
	4 P.M. to 5 P.M.	180	51	52	11	20	314

Average number of vehicles = (288+324+296+314)/4 = 305.5

From the above data of traffic volume, the average traffic volume taken as 305.5 CVPD

Design of Flexible pavement for stabilized soil with 4 % bitumen mix as per IRC: 37-2001

The California bearing ratio of soil sample when stabilized by 4% bitumen = 5.4 % ≅ 5 %

Cumulative number of standard axle loads N=(365[(1+r)^n-1])/rx A x D x F

Where, Average number of vehicles A = 305.5 CVPD

Lane distribution factor for 2 lane road D= 75% = 0.75

Vehicle damage factor F = 4.5

Annual growth rate of commercial vehicles r = 7.5 % = 0.075

design life in years n = 15 years

N=(365[(1+0.075)^15-1])/0.075x 305.5 x 0.75 x 4.5 = 9.82 msa≅ 10 msa.

The designed thickness of flexible pavement with 4% bitumen stabilized soil.

Total pavement thickness for 5% California Bearing ratio and 10 msa design traffic is 660 mm.

- Granular sub base = 300 mm
- Granular base course =250 mm
- Dense bituminous concrete =70 mm
- Bituminous concrete = 40 mm

Design of Flexible pavement for stabilized soil with 6 % bitumen epoxy resin as per IRC: 37-2001

The California bearing ratio of soil sample when stabilized by 6% bitumen epoxy resin = 5.9 % ≅ 6 %

Cumulative number of standard axle loads N=(365[(1+r)^n-1])/rx A x D x F

Where, Average number of vehicles A = 305.5 CVPD

Lane distribution factor for 2 lane road D= 75% = 0.75

Vehicle damage factor F = 4.5

Annual growth rate of commercial vehicles r = 7.5 % = 0.075

Design life in years n = 15 years

N=(365[(1+0.075)^15-1])/0.075x 305.5 x 0.75 x 4.5 = 9.82 msa≅ 10 msa.

The designed thickness of flexible pavement with 6% bitumen epoxy resin stabilized soil

Total pavement thickness for 6% California Bearing ratio and 10 msa design traffic is 615 mm.

- Granular sub base = 260 mm
- Granular base course =250 mm
- Dense bituminous concrete =65 mm
- Bituminous concrete = 40 mm

V. CONCLUSION:

The compaction and strength properties of cohesive soil stabilized with bitumen and bitumen epoxy resin were investigated. The results showed that the properties were improved with the addition of bitumen and bitumen epoxy resin. The maximum dry density (MDD) and the California bearing ratio (CBR) increased when 4% bitumen and 6% bitumen epoxy resin were used. It was found that excess bitumen and bitumen epoxy resin caused reduction in the MDD and CBR of the stabilized soil. This indicates that a low but optimum binder is needed for a mixture with better load bearing capacity and resistance to deformation. Excess bitumen and bitumen epoxy resin in stabilized soil will reduce the voids. Therefore, it can carry more load than it can sustain. From the pavement design catalogues the total pavement thickness for 5% California Bearing ratio and 10 msa design traffic is 660 mm, similarly for total pavement thickness for 6% California Bearing ratio and 10 msa design traffic is 615 mm.

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