

Evaluation of Engineering Properties of a Rigid Pavement Using Plaxis Software

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ABSTRACT: The construction of foundations of most engineering structures requires adequate information about the engineering properties of the soil and sub-soil condition of the area this is more important especially in the design and construction of highways. Usually the subgrade strength of the soil is mostly expressed in terms of CBR (California Bearing Ratio). Weaker subgrade essentially requires thicker layers whereas the stronger subgrade works well with thinner pavement layers. The pavement and the subgrade mutually must withstand the traffic volume. The present paper focuses at investigating and establishing the sub-soil types and profile to determine the engineering characteristics of the underlying soils. Representative soil samples are collected and analyzed in the laboratory for geotechnical engineering standards. The laboratory investigations have been carried out on a number of soil samples procured from different roadwork sites of proposed site. The site characterized by low volume rural roads where the sustainable load is limited to 3tonns. The total length of road is 3350 meters passing through two villages. The load bearing capacity of the pavement is analyzed using the Plaxis software and concluded regarding the stability and deformation characteristics of the road.

KEYWORDS: subgrade strength, design and construction, bearing capacity, stress and strain deformation Plaxis software

I. INTRODUCTION

The main characteristics of low volume rural roads that set them apart from more conventional highways are: Rural Road Connectivity is important key component of Rural Development by Promoting access to economic and social services and thereby generating increased agricultural incomes and productive employment opportunities in India. The development of the rural road has a high potential to influence economic development through supply side effects. For example improved accessibility may lead to changes in crop types -from subsistence crops to cash crops – or to improvements in health and education leading to more productive days work per year and a better skilled workforce. The paper attempts to understand and investigate the variations in sub-soil type and profile to determine the geotechnical and engineering characteristics of the underlying soils by CBR test with moisture contents. Thus, various soil samples with different densities and moisture content are to be calculated. A detailed analysis of results has to be carried out to get this inference. Subgrade soil is the integral part of the road pavement structure which provides support to the pavement. The subgrade and its different properties are very much important in the pavement design structure. The major function of the subgrade is to provide the support to the pavement against traffic loading and for this the subgrade should possess sufficient stability under adverse climate and heavy loading conditions.

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II. MATERIALS USED AND EXPERIMENTAL PROCEDURE

1. Sieve Analysis: A sample of approximately 1000grams was used for the test after washing and oven-dried. The sieving was done by mechanical method using automatic shakers and a set of sieves.
2. Liquid Limit Determination: A liquid limit the sample isdetermined by using Casagrande apparatus
3. Aggregate Crushing Value: Two test were conducted aggregates crushing value is determinedby passing the sample through 12.5mm and retained on 10mm IS Sieve are oven-dried at a temperature of 100 to 110°C for 4hrs and cooled. Aggregatecrushingvalue = $\left(\frac{B}{A}\right) \times 100$
4. Aggregate impact value test: The mean of two observations, rounded to nearest whole number is reported as the aggregate impact value. The specimen is passed through 12.5mm and retained on 10mm IS Sieve are oven-dried at a temperature of 100 to 110°C for 4hrs and cooled. Aggregate impact value = $\left(\frac{B}{A}\right) * 100\%$

III. LITERATURE REVIEW

Wang et.al (1972) made his study on the response of rigid pavements subjected to wheel loads. His theory was based on krichoff's plate theory. The stresses and deflections in the slab are computed by finite element model

Huang (1983) prolonged his study to the multiple slabs and different load transfer devices similar to ILLI-SLAB model which is earlier developed by Tabatbaie and Barenberg in year (1980) the subgrade was considered as an elastic half space and the contact between subgrade and slab was also considered

Tayabji et.al (1986)analyzedpavement resting on winkler foundation by using JSLAB which is similar to ILLI-SLAB. He utilized plate elements to represents slab and a bounded or unbounded base

Helwany et.al (1998)identified the importance of finite element method in the analysis of three layer pavement system subjected to various typeof loadings at different pressures this method is very much useful for observing responses of pavements subjected to axle loads with different tyre pressures.

Hadi and Arfiadi (2001)according to them the design of rigid pavements based upon the two assumptions1) flexural fatigue of the concrete base 2) erosion of subgradeby considering these two factors the most safe and economical designs were achieved .

Long and Shatnawi(2011) studied on performance of rigid pavements and resolvedthe thick slab and lean concrete layers beneath the pavement the deflection response and the formation of voids under the slab has no significant effect on subgrade reaction

Jain (2013) he identified the suitability and need of flexible and rigid pavements to the various situations and he also analysed the cost involved in the construction of rigid and flexible pavements he concluded the life span of rigid pavement is much more than the flexible pavement.

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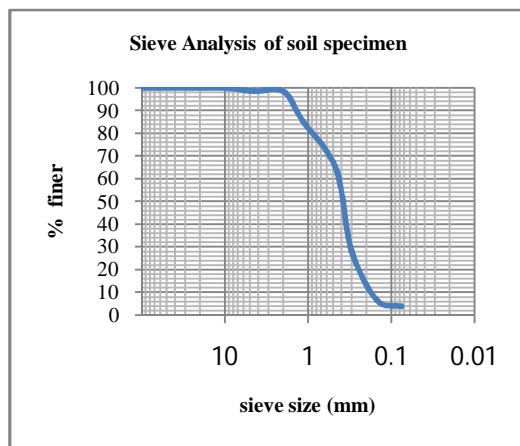
IV. EXPERIMENTAL RESULTS AND ANALYSIS

The following experiments were conducted for the evaluation of subgrade strength and also for the analysis of soil properties, aggregate properties as follows

Grain size analysis of soil specimen

Sample Depth:	36-51 inches		Test Number:	1		
USCS Soil Classification:	SP					
AASHTO Soil Classification:	A-3					
S.no.	IS sieve	Particle size D(mm)	weight retained (grams)	% retained	cumulative % retained	% finer N
1	100	100	0	0	0	100
2	63	63	0	0	0	100
3	20	20	0	0	0	100
4	10	10	0	0	0	100
5	4.75	4.75	14	1.4	1.4	98.6
6	2	2	0	0	1.4	98.6
7	1.18	1.18	128	12.8	14.2	85.8
8	0.6	0.6	136	13.6	27.8	72.2
9	0.425	0.425	118	11.8	39.6	60.4
10	0.3	0.3	322	32.2	71.8	28.2
11	0.15	0.15	216	21.6	93.4	6.6
12	0.075	0.075	28	2.8	96.2	3.8
	Pan					

Table.1 Representing the details of sieves having larger opening sizes are placed above the ones having smaller opening sizes. This sieves are sived by motorized sieve shaker to gain the distribution of soil in each sieve



Graph.1 Represents grading curve. Corresponding to 10% 30% and 60% fines. From this graph we can consider the geotechnical parameters such as coefficient of curvature and coefficient of uniformity.

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Grain Size Distribution Curve Results:					
% Gravel:	98.6	D ₁₀ :	0.15	C _u :	2.83
% Sand:	351.8	D ₃₀ :	0.3	C _c :	1.41
% Fines:	3.8	D ₆₀ :	0.425		

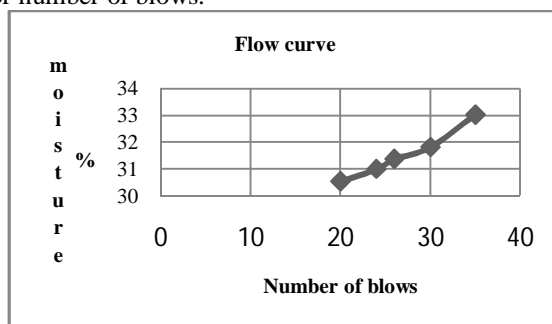
Table.2 Represents diameter of particle size, coefficient of uniformity and coefficient of curvature of the specimen.

$D_{10} = 0.15$, $D_{30} = 0.30$, $D_{60} = 0.425$, Coefficient of curvature $C_c = \frac{(D_{30})^2}{(D_{10} \cdot D_{60})} = \left(\frac{(0.3)^2}{0.15 \cdot 0.425}\right) C_c = 1.411$, Coefficient of uniformity $C_u = \frac{D_{60}}{D_{10}} = 2.83$. According to the USCS Soil Classification system, the sample was poorly graded sand, gravelly sand, with little or no fines. According to the AASTHO Soil Classification system the sample belongs to A-3 group with fine sand. The soil sample shows a Coefficient of curvature of 1.411, Coefficient of uniformity of 2.83 so it is fine sand

Calculations of Liquid Limit Test

S.NO	Determination	Sample1	Sample2	Sample3	Sample4	Sample5
1	Weight of container + wet soil(gm)	47.76	49.13	47.53	47.77	48.14
2	Weight of container + dry soil(gm)	37.23	38.18	37.19	37.78	38.18
3	Loss of moisture	10.53	10.95	10.34	9.99	9.96
4	Weight of container (gm)	14.893	14.727	14.587	15.55	15.531
5	Weight of dry soil (gm)	22.337	23.453	22.603	22.230	22.649
6	Moisture content	33.03	31.82	31.38	31.00	30.54
7	Number of blows	35	30	26	24	20

Table.3 Representing the details on calculations of liquid limit test for five soil samples from this we can gain the percentage of moisture content for number of blows.



Graph.2 Represents a flow curve corresponding to 25 blows using casagrande apparatus from this graph we can gain the optimum water content in the specimen

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Calculations of Plastic Limit Test

S.NO	Determination	Sample1	Sample2	Sample3
1	Weight of container + weight of wet soil (gm)	41.00	38.007	37.925
2	Weight of container + weight of dry soil (gm)	34.34	33.387	33.585
3	Loss of moisture (gm)	6.66	4.62	4.340
4	Weight of container (gm)	15.773	14.156	16.580
5	Weight of dry soil (gm)	18.567	19.231	17.005
6	Weight of wet soil (gm)	25.227	23.851	21.345
7	Moisture content %	26.400	19.370	20.332

Table.4 Representing the details on calculations of plastic limit test for three soil samples from this we can gain the percentage of moisture content.

Result of plastic limit test

Compute the average of the moisture contents to determine the plastic limit, PL

$$\text{Plastic limit} = \frac{26.400 + 19.370 + 20.332}{3} = 22.034\%$$

Plastic limit of the soil sample was 22.034%

$$\text{Plasticity index} = \text{liquid limit} - \text{plastic limit} = 31.38 - 22.034 = 9.346 < 10$$

Engineering Properties of Soils based on laboratory testing have been correlated to the liquid limit and plastic limits test and these soil atterberg limits are used to classify a fine-grained soil according to the Unified Soil Classification system and AASHTO system.

Here plasticity index (PI) = 9.346 and liquid limit (LL) = 31.38

so the soil is CL-ML (ML-Inorganic silt and CL-Inorganic clay)

Calculations of California bearing ratio test for dynamic compaction

S NO	Determination	Sample 1	Sample 2	Sample3
1	Weight of mould + compacted soil	4912	4307	4149
2	Weight of compacted soil (W_t)	2015	1828	1737
3	Wet density $\gamma_t = W_t/V$	2.015	1.828	1.737
4	Container number	1	2	3
5	Weight of container + weight of wet soil (gm)	81.48	88.65	82.78
6	Weight of container weight of dry soil(gm)	75.84	80.06	73.680
7	Weight of water(gm)	5.64	8.59	4.10
8	Weight of container(gm)	15.108	11.280	13.940
9	Weight of dry soil(gm)	60.732	68.780	59.740
10	Water content (%)	8.497	11.102	13.219
11	Weight of wet soil (gm)	66.372	77.37	68.84
12	Dry density(gm/cc)	1.857	1.645	1.534

Table.5 Representing the Calculations for California bearing ratio test values for the three samples from this we can gain the dry density of the soil specimen.

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California Bearing Ratio Test											
Penetration in mm	Proving ring reading NO. Division			Corrected load			standard load (Kg)	% of CBR			Average CBR
0											
0.5	4	5	4								
1	6	7	6								
1.5	8	7	9								
2	10	10	9								
2.5	14	13	13	35	32.5	32.5	1370	2.5 5	2.3 7	2.3 7	2.43%
3	15	13	14								
4	15	13	14								
5	16	16	15	80	80	75	2055	3.8 9	3.8 9	3.6 4	3.80%
7.5	19	20	23								
10	24	23	25								
12.5	28	27	28								

Table.6 Representing the detail Calculations for California bearing ratio test the penetration generally calculated for 2.5mm and 5mm penetration.

Percentage of California bearing ratio for sample 1 at 5 mm penetration = $\frac{80}{2055} \times 100 = 3.89$

Percentage of California bearing ratio for sample 1 at 5 mm penetration = $\frac{80}{2055} \times 100 = 3.89$

Percentage of California bearing ratio for sample 1 at 5 mm penetration = $\frac{78}{2055} \times 100 = 3.64$

Finally the average California bearing ratio test value at 5 mm penetration is calculated by taking the mean of three samples and placed in (column 6)

Average California bearing ratio test value at 5 mm = $\frac{3.89+3.89+3.64}{3} = 3.80\%$

Result of California bearing ratio test

If the California bearing ratio value for 5 mm penetration exceeds that of 2.5mm, the test should be repeated if identical results follow the California bearing ratio corresponding to 5 mm penetration should be taken for design so the California bearing ratio test value of 5mm i.e.; **3.80%** is considered for designing of pavement.

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Calculation for Aggregate Crushing Value

Test Number:		1			
weight of sample		1000 grams			
S.NO	sieve sizes of Aggregate passing through	Net weight of aggregate in the measure in grams (A)	The fraction passing through 2.36mm IS sieve in grams (B)	The fraction retained 2.36mm IS sieve in grams	Aggregate crushing value (B/A*100)
1	12.5mm-10mm	284	79	205	27.81
2	12.5mm-10mm	269	63	206	23.42
Average Value					25.615

Table.7 Representing the I.S. sieve sizes for aggregates in mm the net weight of aggregates passing through 12.5 mm I.S. sieve and retaining on 10 mm I.S. sieve is taken and crushing test is found for two samples

The mean of the crushing value obtained in the two tests is reported as the aggregate crushing value

Aggregate crushing value of the two samples obtained = $\frac{27.81+23.42}{2} = 25.615\%$

The aggregate crushing value for cement concrete pavement shall not exceed 30% and the aggregate crushing value for wearing surfaces shall not exceed 45%

Calculation For Aggregate Impact Value

Test Number:		1			
weight of sample		500 grams			
S.NO	sieve sizes of Aggregate passing through	Net weight of aggregate in the measure in grams (A)	The fraction passing through 2.36mm IS sieve in grams (B)	The fraction retained 2.36mm IS sieve in grams	Aggregate impact value (B/A*100)
1	12.5 mm-10 mm	354	44	310	12.42
2	12.5 mm-10 mm	368	56	312	15.21
Average Value					13.815%

Table.8 Representing the I.S. sieve sizes for aggregates, the net weight of aggregates passing through 12.5 mm I.S. sieve and retaining in 10 mm I.S. sieve is taken and impact test is conducted on two specimens

The mean of the aggregate impact value obtained in the two tests is reported as the aggregate impact test value

Aggregate impact value of the two samples are obtained = $\frac{12.42+15.21}{2} = 13.815\%$

The aggregate impact value for cement concrete pavement shall not exceed 30% and the aggregate impact value for wearing surfaces shall not exceed 45% The Average Calculated for Aggregate Impact Value was 13.815%.

The minimum wheel load for design of rural roads is considered to be 30KN or 3 tons and minimum tyre pressure 0.5MPa and maximum wheel load if any possibility of traffic consisting of mini-trucks and buses a design wheel load of 50KN or 5.20 tons with minimum tyre pressure of 0.7MPa should be considered. As per IRC: SP: 62-2004. The values of elastic modulus of concrete to be taken 3×10^4 MPa, coefficient of thermal expansion of concrete is 10×10^{-6} per

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ν and Poisson's ratio of cement concrete is 0.15. As a research a test load of 100 Kilonewtons or 10 tons was applied on rigid pavements

Total thickness of rigid pavement is 400 mm

Thickness of improved sub grade thickness 100mm (layer 1)

Thickness of Granular sub-base and compacted base of gravel 100mm thick (layer 2 and 3)

Thickness of Proposed CC PAVEMENT is 200mm thick (layer 4)

This road surface is designed to carry the design speed of 50 KMPH. The roadway width of 7.50 meters and carriage way width of 3.75 meters Vertical curves are not required as the road is having plain embankment along the entire length. Maximum Height of embankment of 0.50 meters PLAXIS is a finite element package that has been developed specifically for the analysis of deformation and stability in geotechnical engineering projects. The simple graphical input procedures enable a quick generation of complex finite element models and the enhanced output facilities provides a detail presentation of computational results. The calculation itself is fully automated and based on robust numerical procedures. The minimum clearance between the road face of the kerb and the outer edge of the wheel should be 1.2 m and width of the wheel is as 0.86 m the figure the plates represented on the top layer of the pavement it representing the

Plaxis analysis on the rigid pavement Assigning the rigid pavement layers with all material properties and a test load of 10 tons and the details of Rigid pavement layers are as follow thickness of improved sub grade thickness 100mm (layer 1) thickness of Granular sub-base and compacted base of gravel 100mm thick (layer 2 and 3) and thickness of Proposed CC PAVEMENT 200mm thick (layer 4) the rigid pavement.

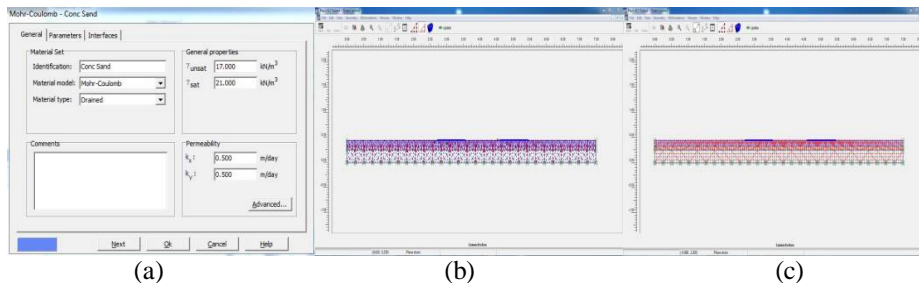


Fig 1(a) assigning input parameters of geotechnical properties using plaxis software (b) assigning pavement layers and generation of mesh for the designed values of pavement(c) assigning test plates and stress points beneath the pavement layers to view the deformation ,stress, strain after the test

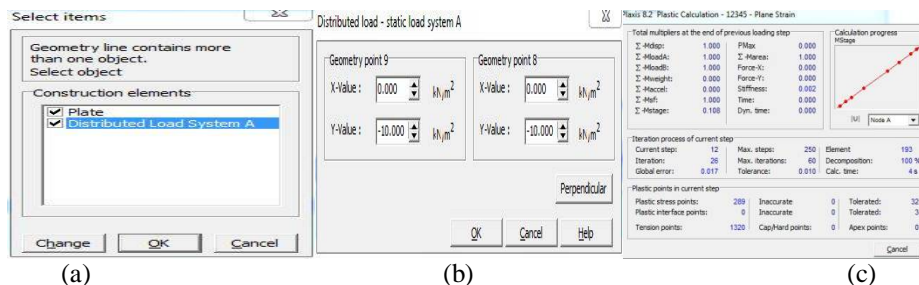


Fig 2 (a)Two plates were selected and a uniform distributed load of -10KN is applied on the testplates (b) assignimgthe test load of -10KN to see the pavement properties (c) Represents the evaluation process of pavement properties using Plaxis software

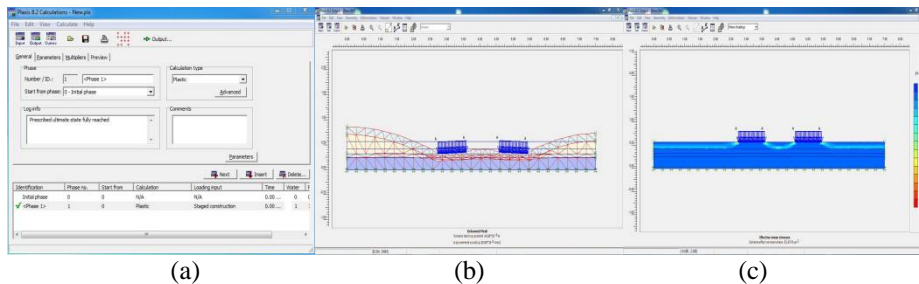


Fig 3 (a) Represents ultimate satisfactory result of the rigid pavement after the evaluation process (b) Represents minute deformation below the pavement layers due to the applied load of -10KN.(c) Represents satisfactory results in stress and strain parameters of the pavement.

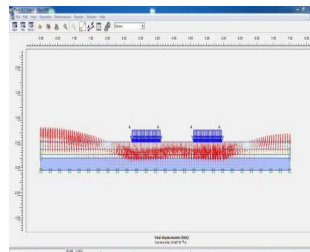


Fig 4 (a) Representing the minor displacement of pavement layers due to the applied load of -10KN.

V. CONCLUSION

From the results and discussions of several tests conducted on the disturbed subsoil samples the California bearing ratio test was recorded as 3.80%. Hence subgrade strength is poor according to the pavement design chart of IRC: SP: 72-2007. The minimum wheel load for design of rural roads is considered as 30KN or 3 tons and the maximum wheel load if any possibility of traffic consisting of mini-trucks and buses a design wheel load of 50KN or 5.20 tons to be considered but as a research the test load of 100 Kilo Newton or 10 tons was applied on the rigid pavements using the application of plaxis

The simple graphical input procedures enable a quick generation of complex finite element models and the enhanced output facilities provides a detail presentation of computational results. The calculation itself is fully automated and based on robust numerical procedures it is concluded that the Rigid pavement is away from zone of failure

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