Quantification of Benefits of Soil Stabilized Pavement Layers for Sustainable Road Infrastructure

Dheeraj Bonagiri, Veeraragavan Amirthalingam, and Srinivas Vallabhaneni

Abstract The service life and performance of pavements depend mainly on the quality of the materials used for construction. Naturally available materials such as soil, stone aggregates, sand etc. and some of the processed materials like bitumen are conventionally used for road construction. But they are depleting fast and results in higher procurement and processing cost. Therefore, alternative materials such industrial wastes, chemical products are considered for road construction. If these materials can be suitably utilised in highway construction, the pollution and scarcity of aggregates problems may be partly reduced. In the present study, a soil stabilizer produced by the Stabilroad is investigated for its application in pavement layers. The Stabilroad stabilizer should be used along with cement which can be mixed with the existing soil. This makes the pavement layers to have good compressive strength as well as flexible and waterproof. The StabilRoad allows the agencies to stabilize different soils and build roads using locally available soil without the need to extract new material from the mines. Different dosages of cement and Stabilroad are mixed with the available soil and their geotechnical characteristics are evaluated. The focus was to study the strength characteristics of untreated and stabilized soil samples by Unconfined compressive strength and resilient behaviour under cyclic loading conditions using cyclic triaxial test procedure as per AASHTO T-307 protocol. Typical Red soil was collected for present study investigation. The optimal dosage of cement and stabilizer was determined based on laboratory studies. The strength properties of stabilized soils were determined at optimum dosage. Using the results, alternative pavements were designed according to IRC guidelines and validated using KENLAYER software. The critical strains were found to decrease with stabilized subgrades as compared to natural soil as subgrade. A cost comparison analysis is carried out to assess the financial benefit of using the Stabilroad. The reduction

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in virgin aggregates consumption due to the use of stabilized pavement layer is presented. Typical Red soil was collected for the present investigation.

Keywords Stabilroad stabilized soil · Cement · Unconfined compressive strength · Resilient modulus · Cost analysis · Sustainable pavements

1 Need and Importance

Indian road industry faces several capacity issues and other constraints. The availability of good quality naturally occurring aggregates is considered as one of the major problems faced by the road construction industry now. So due to the scarcity of the naturally occurring good quality materials, removal and replacement of problematic soil become both costly and time consuming. Therefore, it is important to look for innovative pavement design techniques such as stabilization or in situ ground improvement techniques to reduce the thickness of granular pavement layers to achieve reduction in quantity of stone aggregates.

Stabilization is an important technique of improving the soil properties which has been used traditionally from long time. But the type of stabilizer used is changing from period to period considering economy and suitability. Initially stabilization technique was used only for improving the poor soils, but now a days the motto of stabilization is to increase subgrade strength and reduce the usage of virgin aggregates in upper layers. Different waste materials produced from the industry are used as stabilizers for subgrade soils, but their suitability is confined to certain type of soils. So, the corporate sector started research on producing organic materials which can be suitable to all type of soils.

2 Stabilroad

Recently a new stabilizer (manufactured in Germany) is introduced in India called Stabilroad. The stabilizer is a whitish powder made of 100% natural minerals, which should be used along with cement. The stabilizer had been successfully used for nearly 20 years in all climatic zones. The most important feature of this technology is that by using the Stabilroad additive, the construction process can be accelerated (by enhancing cement hydration process), cost of the work can be reduced, and at the same time a very strong, elastic, waterproof and frost-proof surface can be achieved. All these can be achieved by reusing locally available soil.

3 Objective

The research is aimed to investigate the suitability of Stabilroad additive for stabilization of locally available soil and study the effectiveness in terms of improved performance of highway pavement and quantify the benefits of reduced virgin aggregate consumption.

The scope of the work is limited to:

- Stabilization of locally available Red soil with Stabilroad soil stabilizer.
- Evaluation of the strength characteristics of soils by conducting UCS tests and Resilient Modulus tests.
- Pavement design using IRC 37 and analysis by KENPAVE software.
- Assessment of economic and social benefits on the usage of Stabilroad over the traditional materials.

4 Review of Earlier Work

As the stabilizer (Stabilroad) used is a new technology, no earlier work is carried out on it. To investigate it, research related to cement stabilization is studied as the Stabilroad is used along with cement. Work related to optimum dosage of stabilizer, evaluation of cement stabilized layers, pavement design with stabilized layers, cost analysis is studied to carryout current research on Stabilroad additive.

5 Materials

5.1 Soils

For the experimental program of this study two different soil samples were collected from Chennai namely red soil and clay. Particle size distribution of the soils were investigated following the Indian Standard (IS) test method and results are presented in Fig. 1. According to the Unified Soil Classification System (USCS), clay soil was classified as high-plasticity clay (CH) and red soil as clayey sand (SC). Atterberg limits tests were also conducted and found that clay soil has high plasticity index than red soil.

Moreover, compaction properties of the soils were determined and are presented in Table 1. The geotechnical properties of soil (such as compressive strength, CBR, permeability, and compressibility etc.) are dependent on the moisture and density at which the soil is compacted. Higher level of compaction enhances the geotechnical parameters of the soil; therefore, achieving desired degree of relative compaction is necessary to meet desired strength of the soil.

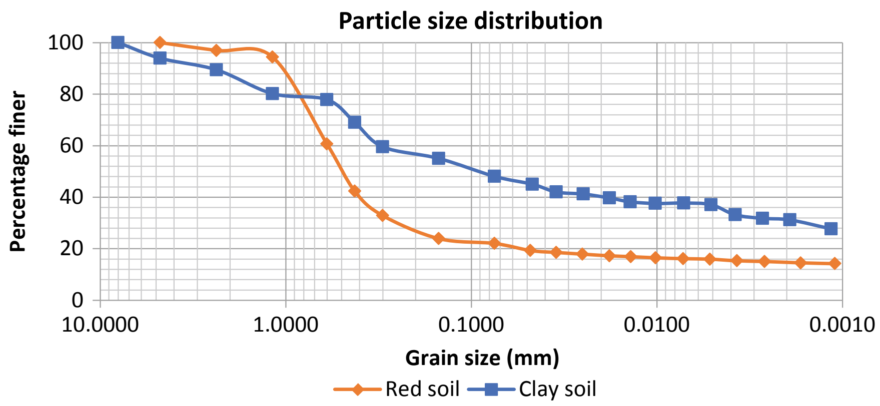

Fig. 1 Particle size distribution of red and clay soils

Table 1 Basic properties of clay and red soil

Soil property	Clay	Red soil
Liquid limit (LL)	86%	27.40%
Plastic Limit (PL)	17.90%	12.80%
Plasticity index (PI)	68.10%	14.60%
Shrinkage limit (SL)	10.20%	11.70%
Specific gravity (G_s)	2.682	2.647
Gravel	6%	3%
Sand	42%	78%
Silt	19%	5%
Clay	33%	14%
Soil Classification (According to USCS)	Highly compressible clay (CH)	Clayey sand (SC)
Swelling index	130%	12%
Optimum moisture content (OMC)	17.60%	8.80%
Maximum dry density, kN/m^3	16.9	19.8
CBR	–	8%

5.2 *Stabilizer*

The stabilizers used for the present study are Ordinary Portland Cement (OPC) and Stabilroad (Whitish powder). Different dosages of cement and Stabilroad were mixed with soil and the respective tests were carried out to characterize the properties of stabilized soil.

5.3 Experimental Investigation

Laboratory testing was conducted to characterize the soils. The testing program was conducted at the Geotechnical Laboratory at IIT Madras. Soil samples with and without the stabilizer were subjected to different tests to determine their physical properties, compaction characteristics, unconfined compressive strength, CBR and resilient modulus.

As the clay soil property (High plasticity) is not suitable for cement stabilization. Red soil only is considered for stabilroad stabilization.

6 Stabilization of Soil

6.1 Tests on Soil with Cement

Red soil is considered for stabilization with cement as its properties are suitable for it i.e. less plasticity index value. Two different dosages of cement 10% and 12% are added to soil and the samples were prepared with optimum moisture content for testing. The samples were wrapped, and the unconfined compressive strength is determined at different time periods as the strength varies with curing time. Variation of UCS with cement dosage and curing time is shown in Fig. 2 which shows increase in strength with dosage. 12% cement dosage was chosen as optimum dosage as 7 day UCS value of it lies within the range given by Indian Road Congress IRC-37 i.e. 28–35 kg/cm^2

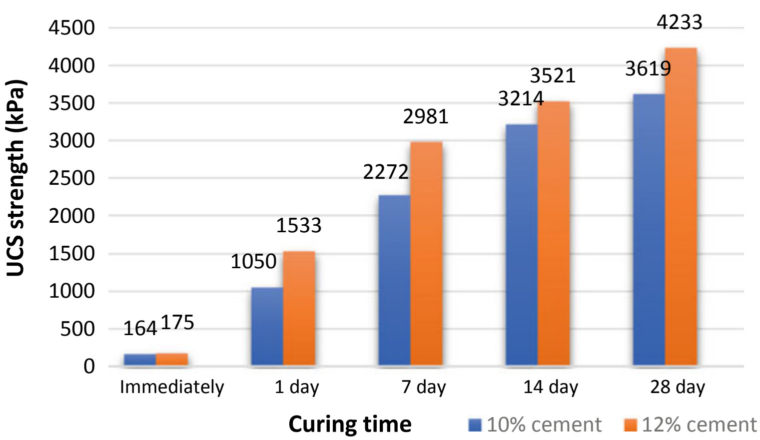

Fig. 2 Variation in UCS with curing time

6.2 Tests on Soil with StabilRoad Additive

The Stabilroad stabilizer is added to soil in addition to the cement to increase the strength of the soil further. The dosages of the stabilizer considered are 1, 2, 3% of cement content as suggested by the supplier.

6.3 Methods

To evaluate the effects of different dosages of stabilizers, strength properties of the stabilized soils were determined for varied amount of stabilizer (i.e. 1%, 2%, 3% of Stabilroad)

6.4 Unconfined Compressive Strength (UCS)

IS 2720-10 (Standard test method for unconfined compressive strength of cohesive soil) was followed to conduct UCS tests on each specimen. The loading rate was 0.625 mm/min. Material proportions were measured gravimetrically and mixed thoroughly, and then compacted such that height to diameter ratio is 2 at optimum moisture content. The UCS tests on untreated soil specimens were conducted immediately after compaction, whereas the treated/stabilized soil specimens were cured in a humid room for 7 days or 28 days prior to testing. Unconfined compressive strength determined for different dosages of stabilizer was shown in Fig. 3.

6.5 Repeated Loaded Triaxial Testing (RLT)

In order to characterize the resilient and permanent deformation behaviour of the treated/stabilized subgrade soils, RLT tests were performed to determine the resilient modulus (Mr) according to AASTHO T307 (Standard method for determining the resilient modulus of subgrade soils). The RLT tests were conducted by applying a repeated axial cyclic stress of a fixed magnitude, load duration, and cycle duration to a cylindrical test specimen for a certain number of cycles. The cyclic loading consists of haversine shaped load pulse. The resilient modulus is found to increase with stabilization, variation can be clearly seen in Table 2.

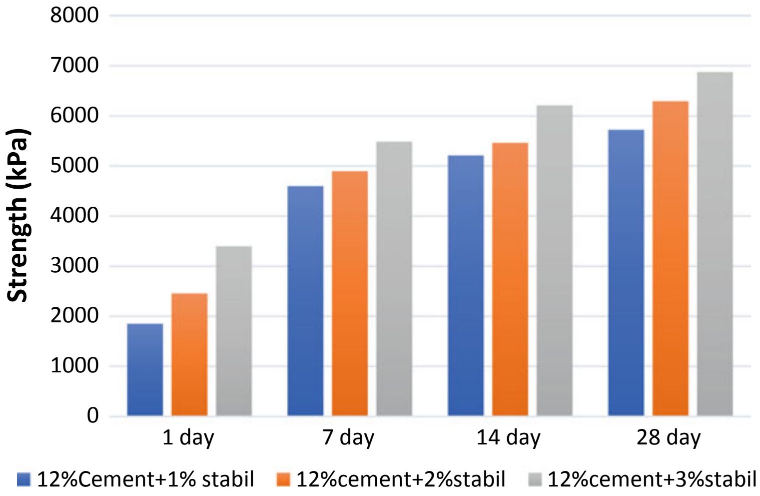

Fig. 3 Variation in UCS with time with Stabilroad

Table 2 Resilient modulus values for different cycles

Sequence	Confining Pressure(kPa)	Maximum Stress (kPa)	Resilient modulus (MPa)		
			Natural red soil	With 12% Cement	With 12% Cement + 3% Stabilroad
0	41.4	27.6	105.33	263.69	133.37
1	41.4	13.8	121.25	151.67	92.94
2	41.4	27.6	84.56	210.71	130.18
3	41.4	41.4	104.49	275.95	222.31
4	41.4	55.2	111.65	297.7	339.55
5	*41.4*	*68.9*	*121.13*	*256.52*	*370.98*
6	27.6	13.8	78.41	202.88	201.63
7	27.6	27.6	101.05	288.11	225.01
8	27.6	41.4	108.06	329.2	285.07
9	27.6	55.2	119.08	353.01	355.85
10	27.6	68.9	123.07	345.99	362.64
11	13.8	13.8	79.46	233.24	213.31
12	13.8	27.6	102.55	266.29	234.25
13	13.8	41.4	106.26	277.78	257.54
14	13.8	55.2	108.1	305.56	288.68
15	13.8	68.9	108.54	305.66	452.74

Table 3 Thickness of pavement alternatives

Layer	Thickness (mm)	Mr (MPa)	Damage ratio
Untreated soil			
BC	150	3000	0.92
GSB	450	208	n/a
Subgrade	500	66.7	0.015
Cement treated soil			
BC	100	3000	0.98
AIL	100	450	n/a
CTB	300	250	0.42
Subgrade	500	67	0.015
Stabilroad treated soil			
BC	90	3000	0.911
AIL	100	450	n/a
STB	280	350	0.61
Subgrade	500	67	0.006

6.6 Pavement Design

Using the results of Unconfined compressive strength and resilient modulus from experimental investigation, alternate pavement was designed (considering traffic of 30 msa) as per the guidelines of IRC 37. KENLAYER analysis was carried out to validate the design. The final designed thickness is given in Table 3. In present study three alternatives were considered. They are untreated red soil, cement treated (12% cement) and Stabilroad treated (12% cement + 3% stabilroad additive).

The pavement thickness was found to be reduced due to the stabilization of subgrade, especially the thickness of bituminous layer was reduced which helps in saving natural resources (bitumen and aggregates).

6.7 Cost Analysis

Cost analysis is a process of evaluating the total economic worth of the project, which can be adopted to decide the best alternative.

The cost analysis was carried out for one-km of a four lane divided highway with 3.5 m lane width (Table 4). The rate analysis for the different layers were considered based on the Schedule of Rates, 2019, followed by the road agencies.

Table 4 Cost analysis of alternative pavements

1. Conventional natural soil (CBR = 8%) subgrade			
Pavement layer type	Optimized thickness (mm)	Unit cost (Rs/m^3)	Cost/layer/m^2
BC + DBM	150	8859	1329
GSB	450	1647	742
SUBGRADE	500	100	50
Total cost (Rs/m^2) 2120			
Total cost for 4-lane divided highway will be Rs.2.97 crores/km			
2. Cement stabilized layers			
Pavement layer type	Optimized thickness (mm)	Unit cost (Rs/m^3)	Cost/layer/m^2
BC + DBM	100	8859	322
AIL	100	2423	219
CTB	300	1301	390
SUBGRADE	500	100	50
Total cost (Rs/m^2) 1569			
Total cost for 4-lane divided highway will be Rs. 2.2 crores/km			
3. Stabilroad stabilized layers			
Pavement layer type	Optimized thickness (mm)	Unit cost (Rs/m^3)	Cost/layer/m^2
BC + DBM	90	8859	797
AIL	100	2423	242
STB	280	1523	426
SUBGRADE	500	100	50
Total cost (Rs/m^2) 1515			
Total cost for 4-lane divided highway will be Rs. 2.1 crores/km			

6.8 Aggregate Consumption

The aggregate requirement for the three alternative pavements are shown in Table 4. The data on aggregate requirement for different types of pavement layers are worked out. The aggregate requirements for StabilRoad pavement is nearly one third of the requirements of conventional pavements. The use of StabilRoad will result in sustainable pavements.

7 Conclusions

- Unconfined compressive strength of cement stabilized soil (7-day curing) is found to be 15 times higher than the natural soil, whereas StabilRoad stabilized soil's strength is found to be 34 times higher.

Table 5 Aggregate consumption calculation per km (4-lane)

Pavement alternative	Layer	Thickness	Quantity to be executed/cum	Aggregate in MT per cum	Aggregates required in MT
Conventional pavement	BC	150	21,000	2.3	48,300
	GSB	450	63,000	1.62	102,060
	SUBGRADE	500	70,000	0	0
					150,360
Cement Stabilized soil	BC	100	14,000	2.3	32,200
	AIL	100	14,000	2.11	29,540
	CTB	300	42,000	0	0
					61,740
Stabilroad stabilized soil	BC	90	12,600	2.3	28,980
	AIL	100	14,000	2.11	29,540
	STB	280	39,200	0	0
					58,520

(BC—Bituminous Concrete, GSB—Granular subbase AIL—Aggregate Interlayer, CTB—Cement treated soil, STB—Stabilroad treated base)

- Resilient modulus of stabilized soil is found to increase significantly with curing time when treated with stabilizer.
- The thickness of conventional pavement is 600 mm; the thickness of the pavement with cement stabilized pavement layers is 500 mm and with Stabilroad stabilized layer is 470 mm.
- The construction cost of traditional pavement is Rs.2.97 Cr (0.421 US$ million)/km, cement stabilized soil is Rs.2.2 Cr (0.321 US$ million)/km and Stabilroad stabilized soil is Rs.2.1 Cr (0.297 US$ million)/km which concludes that using the stabilized layers in pavement construction, the cost can be reduced. The use of stabilized pavement layers reduces the transportation of aggregates over long distances.
- The aggregate consumption for stabilized layer pavement is three times lesser than conventional pavement. Thus, use of Stabilroad stabilizer ensures sustainable pavements and the pavement can be constructed saving natural resources, significantly.

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