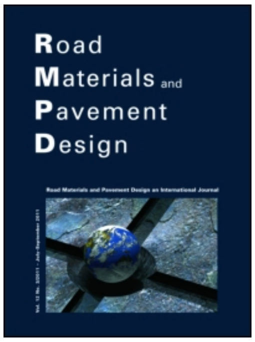

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Strength Behaviour of Geogrid Reinforced Shedi Soil Subgrade and Aggregate System

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ABSTRACT. *Shedi soil (Lithomargic clay), a yellowish-white silty soil underlying lateritic soil, is densely deposited along Konkan belt of India. The strength behaviour of Shedi soil under varying moisture content is major problem for road construction projects in this region. In the present investigation, the subgrade is stabilized with geogrid, keeping the geogrid at different positions from top of subgrade, to locate its optimum position. The plate load tests were also conducted at soaked and unsoaked conditions for unreinforeced, reinforced (with Geogrid) subgrade with aggregate base course. An equation has been established based on load-deflection values recorded for subgrade of un-reinforced and reinforced with geogrid at different levels. The deflection values obtained from equation and from the laboratory investigation were compared. In the case of reinforced subgrade with aggregate base course, the theoretical deflection values were computed based on Burmister's theory and compared with laboratory deflection values.*

KEYWORDS: *Shedi Soil, Geogrid, Load Test, Deflection, Elastic Modulus, Subgrade Reaction.*

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1. Introduction

India is presently engaged in executing multitude road construction projects at various levels starting from rural (Village) roads and to the National Highways, Expressways etc. Huge need for quality construction materials for these massive road infrastructure development activities has created perilous threat to her landscape. In the Present context, an effective solution is needed to maintain the balance between pace of infrastructure development and ecology of the country. Effective utilization of locally available material with minimum modification definitely relieves the thrust for requirement of quality aggregate materials. Research activities, with this objective are greatly encouraged by the National Rural Road Development Authority and Ministry Road Transport & Highways, India.

Use of Geosynthetics has played a significant role as one of the best ground improvement techniques. Studies carried out both in India and abroad encourage the use of Geogrids for ground improvements in weak soils. Main function of geogrid in roadway application is a separation between subgrade and aggregate matrix. On the other hand it may also fulfill secondary functions of reinforcement, filtration and / or drainage. Number of research papers provides information on the various types of investigations carried out using the geogrids as one of the reinforcing material. The information is based on the laboratory investigation, field studies, computational analysis, theoretical analysis, or combinations of thereof.

Laboratory model studies depicted the mechanism by which inclusion of geogrid can improve performance of unpaved roads (Milligan and Love, 1984). Inclusion of three layers of geogrid in highway embankment of lithomargic clay fill resulted in its improved drainage characteristics (Setty *et al.*, 1995). Use of Tensar SS-2 geogrid has significantly improved the bearing capacity of weak subgrade like, peat (Jarret, 1985). Zha *et al.* (1997) were carried out studies on stabilization of a weak subgrade using multilayered geogrid. Studies were concentrated on the field performance of the weak subgrade over which 0.6 m thick highly plastic clay with geogrid reinforcements at different depth was provided. Authors concluded that multiple geogrid reinforcement system in 0.6 m thick clay liner has eliminated the need of a 0.3 m crushed stone layer. In some other laboratory model studies, reduction in settlement by 50 per cent was observed in case of geogrid reinforced model pavement when compared to that of un-reinforced model pavement (Mehenidratta *et al.*, 1991). Laboratory studies indicated an improvement in plate load carrying capacity at relatively low displacement levels for sand layers reinforced with Geogrids (Gabr and Hart, 2000).

The short-and long-term deformations and pavement surface conditions were recorded during the full-scale field tests carried out on a geosynthetic reinforced unpaved roads on a soft subgrade (Huffenus *et al.*, 2006). The considerable reduction in the rut-depth along the geotextile reinforced section was attributed to the improved bearing capacity and higher level compactability of particular weak subgrade soil. Findings also impart on the stiffness of geosysthetic, as a criteria in its selection for different soils. The reduction in deformation of base layer is mainly because of the confinement and interlocking of material with geogrid, and reduction in subgrade deformation is due to improved load distribution on the subgrade layer (Nejad and Small, 1996).

Merchant *et al.* (2002) based on their laboratory plate load tests on geogrid-reinforced expanded shale light weight aggregate, suggested that the use of a stiffer geogrid is of less beneficial compared to flexible geogrid, provided displacement is less than 6 mm. It was also recommended to provide geogrid reinforcement for a width equal to 4 times the width/diameter of the footing and located not below the critical depth. The reinforcement in base layer resulted in reduction in rutting and deflection at asphalt concrete surface by reducing the vertical strains and subsequent plastic settlement of subgrade (Caroll and Hass, 1987). Providing Geogrid in asphalt concrete and granular base resulted in retardation of reflection cracks in overlays, improved bond strength at interface (Rao *et al.*, 1991). Geogrid reinforced beam studies showed higher bending resistance and higher modulus of deformation (Bose *et al.*, 1995).

Whereas, Raymond and Ismail (2003) worked on simulation of behavior of geogrid reinforced foundation systems using two-dimensional FEM analysis, and compared with deformation behavior under laboratory static and repeated load tests. Ling and Liu (2003) analyzed the geogrid-reinforced pavement system using the two-dimensional finite element methods and further, it was validated with several well-controlled laboratory loading-tests and for series of parametric studies. Giroud and Han (2004) developed theoretical design method for geogrid-reinforced unpaved roads, by considering the various input factors viz., stress distribution, strength of base course, interlayer interlock, stiffness of geogrid, traffic volume, wheel loads, tire pressure, subgrade strength, etc.

2. Objectives and scope

Shedi soil has good strength in dry condition, but its strength drastically reduces with increase in moisture content. This typical behaviour is of serious concern for the road projects in this area and any method of ground improvement proves to be economical. Present investigation is aimed at achieving the following objectives:

– to study load-deflection behaviour shedi soil with and without geogrid at soaked (S) and unsoaked (US) conditions;

– to find the optimum position of geogrid in the subgrade;

– to study strength behaviour of geogrid reinforced shedi soil and aggregate system.

In the first stage, studies were conducted to evaluate strength behaviour of shedi soil with and without geogrid subjected to un-soaked and soaked conditions. Model subgrade was constructed in a ferro-cement tank of dimension 1m x 1m x 1m, with loading frame of 200 kN capacity and hydraulic jack of 100 kN capacity. The diameter (a) of loading plate used was 156 mm. Geogrid was placed in shedi soil subgrade with height-plate diameter ratio or spacing ratio (h/a) of 1.5, 0.75, and 0.5, and corresponding load-deflection behaviour was observed for unsoaked condition. In soaked condition, load-deflection behaviour of single layer of geogrid placed at 0.5a, and two-layer reinforcement at spacing of 0.5a and 0.75a were recorded. In the second stage, load-deflection behaviour of aggregate layer compacted over shedi soil subgrade with and without geogrid, for both soaked and un-soaked test conditions were observed.

3. Experimental studies

The studies include characterization of test soil and aggregates, tests on tensile strength property of geogrid, and load-deflection behaviour of model pavements. All the tests have been carried out incompliance with the relevant specifications of Indian Standards (BIS, 1989).

3.1. *Characterisisation of test materials*

Shedi soil was procured from the road construction site at Surathkal, Mangalore, India. Physical and strength properties of soil are shown in Table 1.

Crushed granite stone aggregates were used as base course material. The Physical properties of coarse aggregates viz., abrasion value, aggregate impact value, and crushing strength, were 20%, 25%, and 28% respectively. Gradation of aggregates considered for the study was based on the specifications suggested by Ministry of Road Transport and Highways (MORT&H) and the details are shown in Table 2.

High Density Polyethylene (HDPE) geogrid was used for the study. Stress-strain characteristics and failure load of geogrid were obtained by conducting tensile strength tests (ASTM, 2003) using sophisticated Universal Testing Machine (UTM) and properties of geogrid are shown in Table 3.

Table 1. *Basic properties of the shedi soil*

Sl. No.	Particulars	Test Method	Test Results
1	Specific Gravity	IS : 2720 (P-3)	2.60
2	Grain size Distribution	IS : 2720 (P-4)	
	Fractions > 4.75 mm, %		1
	4.75 mm to 0.075 mm, %		45

	0.075 mm to 0.002 mm, %		41
	< 0.002, %		13
3	Consistency limits		
	- Liquid limit, %	IS : 2720 (P-5)	47
	- Plastic limit, %	IS : 2720 (P-5)	37
	- Shrinkage limit, %	IS : 2720 (P-6)	20
	- Plasticity index	IS : 2720 (P-5)	10
4	Classification	IS : 1498	SM-MH
5	I S Light compaction	IS : 2720 (P-7)	
	- Optimum moisture content, %		20.0
	- Maximum dry density, kN/m^3		16.2
6	CBR Values	IS : 2720 (P-16)	
	- Un-soaked (OMC) Condition		18
	- Soaked Condition		04
7	Shear Parameters	IS : 2720 (P-39)	
	- Angle of internal friction, ϕ		19
	- Cohesion (C), kN/m^2		80.0

Table 2. *Gradation of aggregate for base layer*

Sieve Size, mm	63	53	45	22.4	11.2
Per cent passing	100	95	40	10	5
Specified limits as per MORT&H (2001)	100	90-100	25-75	0-15	0-5

Table 3. *Results of tensile strength test on Geogrid*

Sl. No.	**Particulars**	**Test method**	**Machine direction**	**Cross-machine direction**
1	Gauge length, mm	ASTM D 6637 -01	50.0	50.0
2	Tensile Strength at maximum load, kN/m		7.84	6.34
3	Elongation at maximum load, %		42.4	34.0
4	Load at 10% extension, kN/m		4.70	4.40

3.2. *Construction and testing of model subgrade*

Plate load tests were conducted in a ferro-cement tank of dimension 1m x 1m x 1m, and metallic subgrade box was designed to avoid the end effects of loading. The walls of the subgrade box were made with mild steel sheet and provided with perforations of size 10 mm diameter spaced at 90mm c/c. To avoid the lateral bulging of the steel walls during loading, mild steel angles of standard size were provided to act as a stiffener. For saturating the subgrade the ferro-cement tank was filled with water. Due to capillary action and entry of water through perforations the soil got completely soaked.

Loading frame had a capacity of 200 kN with a hydraulic jack of capacity 100 kN. Mild steel loading plates of 156 mm diameter a) were used to conduct the test on subgrade; square plate of 200 mm width b) was used for the model pavement. Tank was positioned concentrically below the hydraulic jack fixed to loading frame; typical test setup is shown in Figure 1.

Studies were carried out in two stages; i) to evaluate the load deflection behaviour of shedi soil subgrade with geogrid, and ii) reinforced shedi soil subgrade with aggregate system.

3.2.1. *Shedi soil subgrade with geogrid*

Shedi soil subgrade of 600 mm thick was constructed with 100 mm lift thickness. The soil was compacted at a predetermined optimum moisture content and maximum dry density. Plate was firmly seated on a thin layer of sand spread over subgrade and a minimum seating pressure of 7 kPa was applied and released before starting the load test. Average surface deflection (d) was determined based on deflections recorded by four dial gauges fixed on independent datum frame. Deflections were observed for each increment of load, and continued up to the failure.

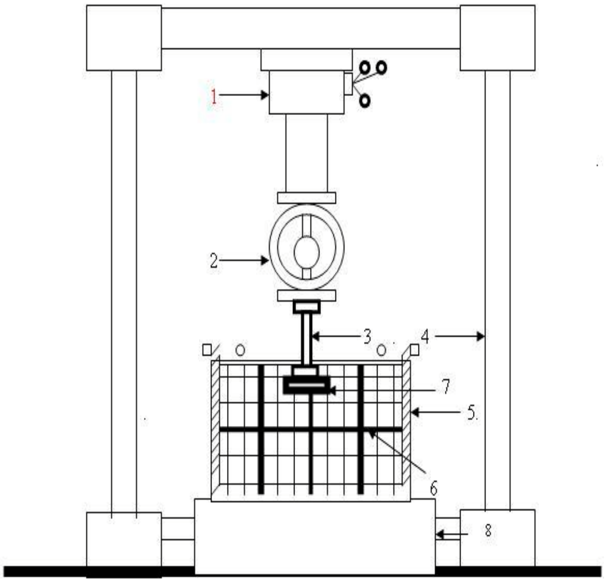
Load-deflection pattern for the un-reinforced subgrade under un-soaked (UR-US) and soaked conditions (UR-S) were recorded.

Similar studies on load-deflection pattern were carried out for shedi soil subgrade by introducing a geogrid mat at different spacing (h) under un-soaked and soaked conditions.

The load-deflection values were recorded for the following cases:

- Unsoaked condition
  - Geogrid at a depth of 1.5a. (1.5a-US)
  - Geogrid at a depth of 0.75a. (0.75a-US)
  - Geogrid at a depth of 0.5a. (0.5a-US)
- Soaked condition
  - Geogrid at a depth of 0.5a. (0.5a-S)

- Geogrids each at a spacing of 0.5a and 0.75a. (0.5a + 0.75a-S)



1. Vertical jack
2. Proving ring
3. Packing
4. Loading frame
5. Adjustable testing box
6. Stiffeners
7. Circular Plate
8. Pedestal

Figure 1. *Experimental set-up of the laboratory plate load test*

3.2.2. *Reinforced shedi soil subgrade with aggregates layer*

Shedi soil subgrade was constructed to a thickness of 400 mm. The soil was compacted for a predetermined optimum moisture content and maximum dry density, and with a lift thickness of 100 mm. Crushed stone aggregates were laid and compacted on the prepared subgrade for a thickness of 225 mm in three lifts. The thickness of aggregate layer was arrived at based on the soil properties. Load-deflection patterns were recorded for the following cases:

– un-reinforced shedi soil subgrade and aggregate layer in un-soaked condition. (UR-US-AL);

– un-reinforced shedi soil subgrade and aggregate layer in soaked condition. (UR-S-AL);

– reinforced shedi soil subgrade and aggregate layer in un-soaked condition. (R-US-AL);

– reinforced shedi soil subgrade and aggregate layer in un-soaked condition. (R-S-AL).

4. Plate-load test results and discussion

4.1. *Shedi soil subgrade with Geogrid reinforcement*

4.1.1. *Failure strength*

The load-deflection behaviour as shown in Figure 2 indicates the variation in failure load for subgrade soil under different conditions. The significant influence of position of geogrid layer on failure strength of subgrade has been noticed. Failure strength increases by a factor of 1.7, 2.0 and 2.2 for geogrid placed at 1.5a, 0.75a, and 0.5a respectively when compared to the failure strength of un-reinforced subgrade in un-soaked condition.

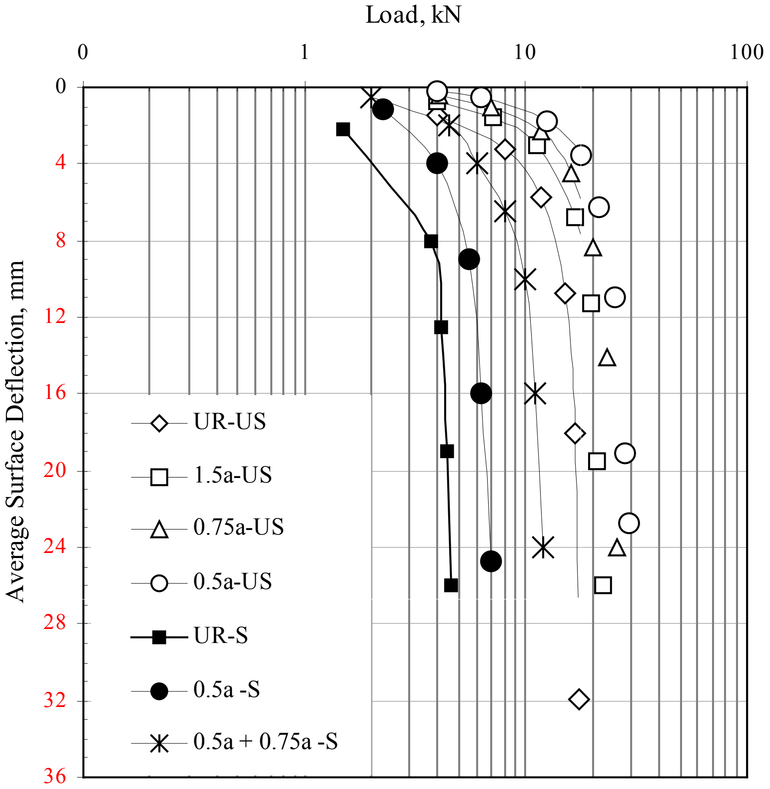


Figure 2. *Load-deflection behaviour of subgrade*

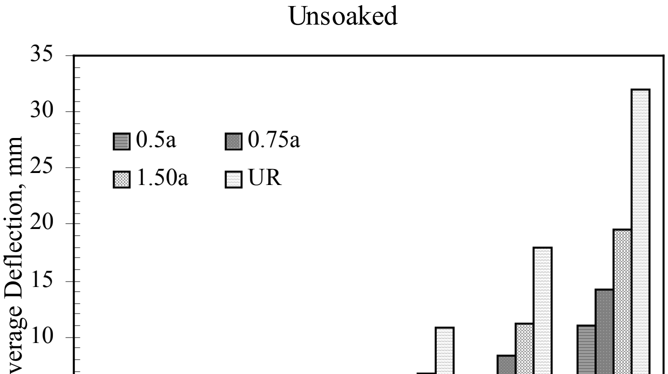
In soaked condition failure strength of un-reinforced subgrade was 33% of the failure load of un-reinforced un-soaked condition. Strength increase in soaked condition was by a factor of 1.4 for geogrid placed at a depth of 0.5a. Failure load was improved by a factor of 2.6 when subgrade reinforced with two layers of geogrid placed at 0.5a and 0.75a spacing. Resistance to failure in case of geogrid at lower depth was because of increase in shear strength induced due to *pseudo-cohesion* by the interlocking of soil particles, where soil struck through the apertures of grid forming a stiff dense matrix, which created a firm bond between geogrid and soil particle.

4.1.2. *Yield load*

The yield load corresponds to the maximum load beyond which leads to plastic yield (Permanent settlement). The yield load for the un-reinforced subgrade system was found to be 12.8 kN and 3.8 kN in unsoaked and soaked test condition respectively. In case of reinforced subgrade systems *i.e.* reinforcement at 1.5a, 0.75a, and 0.5a, the yield loads for unsoaked test condition was found to be 19.2 kN, 22.6 kN, and 23.5 kN respectively. Where as, in soaked condition these were found to 3.8 kN, 5.5 kN, and 10.0 kN with respective to their reinforcement positions.

4.1.3. *Surface deflection*

Figure 3 gives an explanatory comparison between deflections under a particular load for different subgrade conditions (un-soaked and soaked).



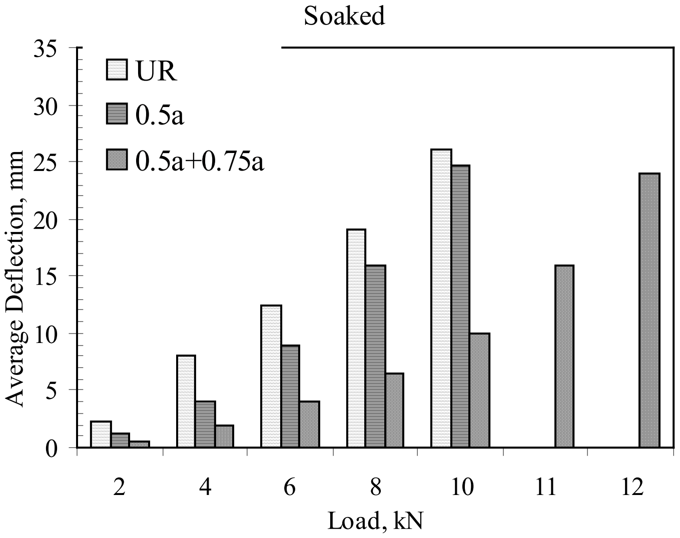


Figure 3. *Load-deflection histogram*

Here, the surface deflection is referred to the average value of settlements recorded using three dial gauges for each increment of load. In un-soaked condition, deflection corresponding to 26 kN load was 32 mm for un-reinforced subgrade which is nearly three times higher when compared to subgrade reinforced with geogrid at a depth of 0.5a. A maximum deflection of 19.5 mm was recorded for reinforced subgrade system for the reinforcement placed at 1.5a depth. In soaked condition, deflection corresponding to 2 kN load was above 2 mm for un-reinforced subgrade system and less than 1 mm for reinforced system. Subgrade with two-layers of geogrid reinforcement sustained a maximum load of 12 kN with a deflection of 24 mm in soaked condition.

4.1.4. *Elastic modulus and modulus of subgrade-reaction of subgrade*

Elastic modulus (E) of subgrade was determined based on Burmister's Equation. Load intensity sustained for a deflection of 5 mm was considered for computing Elastic modulus of the model subgrade system. Table 4 gives the elastic modulus and modulus of subgrade reaction (K) values computed by considering the suitable correction factors. The position of geogrid has significantly influenced on elastic modulus and modulus of subgrade reaction values of subgrade. In un-soaked condition, gain in the E-value was in the range 1.42 to 1.64 times when compared to un-reinforced subgrade. Gain in the K-value was in the range of 1.7 to 2.12.

In soaked test condition, the reduction in E and K values for un-reinforced subgrade was 3.3 and 2.43 times respectively when compare to values in un-soaked condition. With inclusion of geogrid, reduction in E-value was in the range of 2.5 to 1.57 and K-value to the range of 1.7 to 1.13 depending upon the position of Geogrids. The deflection values have been considerably reduced when geogrid was placed in two layers. Relationship between spacing ratio and E & K values are shown in Figure 4.

Table 4. *Modulus of elasticity and modulus of subgrade reaction*

Particulars	Un-soaked Test Condition		Soaked Test Condition	
	E, MPa	**K, kN/m^2/m**	**E, MPa**	**K, kN/m^2/m**
Un-reinforced subgrade				
Un-reinforced	10.584	142.24 x 10^3	3.178	58.59 x 10^3
Geogrid reinforced subgrade				
Spaced at 1.5d	15.024	242.72 x 10^3	-------	-------
Spaced at 0.75d	16.180	343.20 x 10^3	-------	-------
Spaced at 0.5d	17.335	418.56 x 10^3	4.237	83.70 x 10^3
Spaced at 0.5d & 0.75d	-------	-------	6.741	125.56 x 10^3

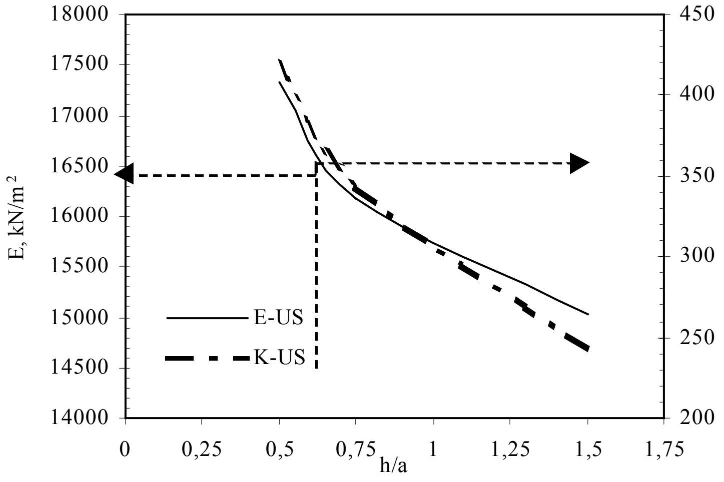


Figure 4. *E and K-values vs. Geogrid spacing*

4.1.5. *Model for load-deflection spectrum*

Load-deflection patterns were found similar for the entire test conditions, where pressure-deflection ratio (p/d) decreases with increase in settlement ratio (d/a). An attempt has been made to establishing a relationship between "p/d" and "d/a", as given in Equation [1].

$$(p/d) = N \times (d/a)^{-m} \tag{1}$$

where:

N = component of pressure-deflection ratio, N/mm^2/mm,

m = reduction factor, dimensionless,

In order to obtain the pressure-deflection spectrum for reinforced system, modifications for N and m were made:

$$N = N_i \left[2.6394 \times \left(\frac{E_r}{E_{ur}} \right) - 2.4108 \right] \tag{2}$$

$$m = m_i \left[0.1223 \times \left(\frac{E_r}{E_{ur}} \right) + 0.8266 \right] \tag{3}$$

where:

N_i and m_i are pressure-deflection component and reduction factor of un-reinforced soil system respectively.

E_r = modulus of elasticity of reinforced soil system, N/mm^2

E_{ur} = modulus of elasticity of un-reinforced soil system, N/mm^2

Elastic-modulus of reinforced soil system depends on spacing of the geogrid. Relationship between elastic-modulus and spacing of geogrid is shown in Equation [4].

$$\frac{E_r}{E_{ur}} = 1.4829 \times \left(\frac{h}{a} \right)^{-0.1277} \tag{4}$$

Comparison between laboratory load-deflections and theoretical deflections (corresponds to Equation [2] values) were made, and shown in Figure 5. Normalisation of settlement ratio (d/a) starts in the range of 0.01 to 0.03 for both laboratory and theoretical deflection pattern. Load-deflection values were not significantly varied both in pre-normalisation and post-normalisation. Similar normalisation range was observed for geogrid reinforced sand layers, *i.e.* 0.015 to 0.03 (Gabr and Hart, 2000).

4.2. *Aggregate base course over Geogrid reinforced Shedi soil subgrade*

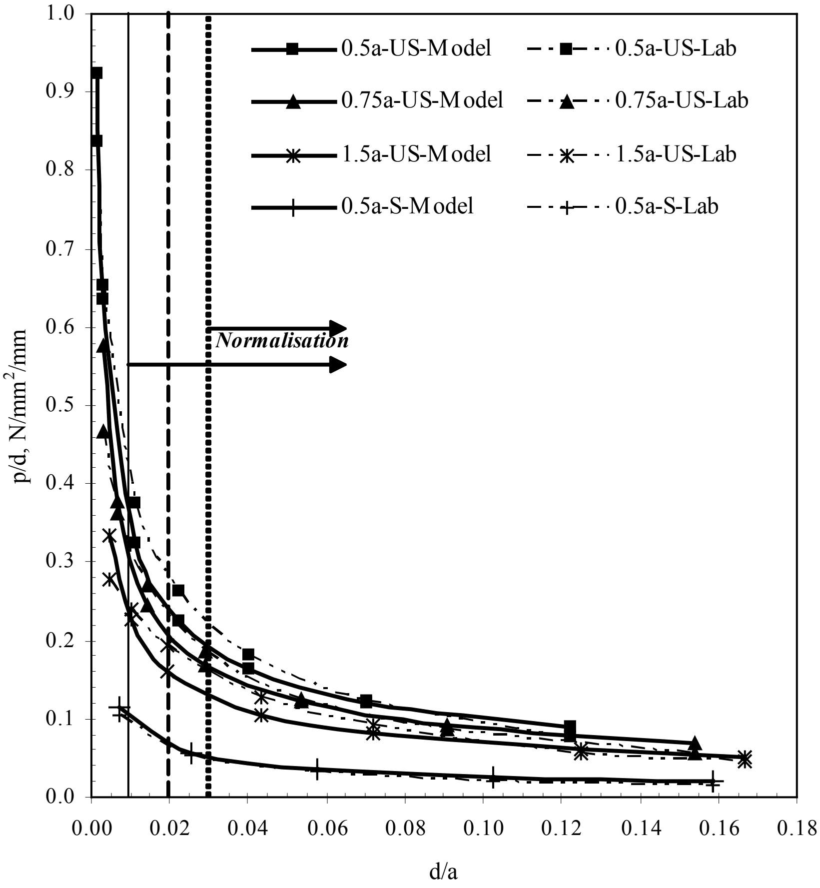


Figure 5. *Load intensity-deflection spectrum by Laboratory and model values*

In this stage of investigation, plate load tests have been carried out over aggregate base layer laid on 400 mm thick Shedi soil subgrade with and without geogrid. Subgrade was reinforced with Geogrid mat, placed at 0.5b (b is the width of square plate; 200 mm) from the surface of subgrade. Load-deflection patterns were observed for un-soaked and soaked condition for both un-reinforced and reinforced model pavements.

4.2.1. *Yield load and surface deflection*

Reinforcing the subgrade with geogrid has shown its influence on improving yield load. The load-deflection behaviour of model pavement with aggregate base course laid over shedi soil subgrade, for different test conditions are shown in Figure 6. Yield load recorded for reinforced model pavement in un-soaked condition was 1.27 times higher than the un-reinforced system, and it is 0.96 times in soaked condition.

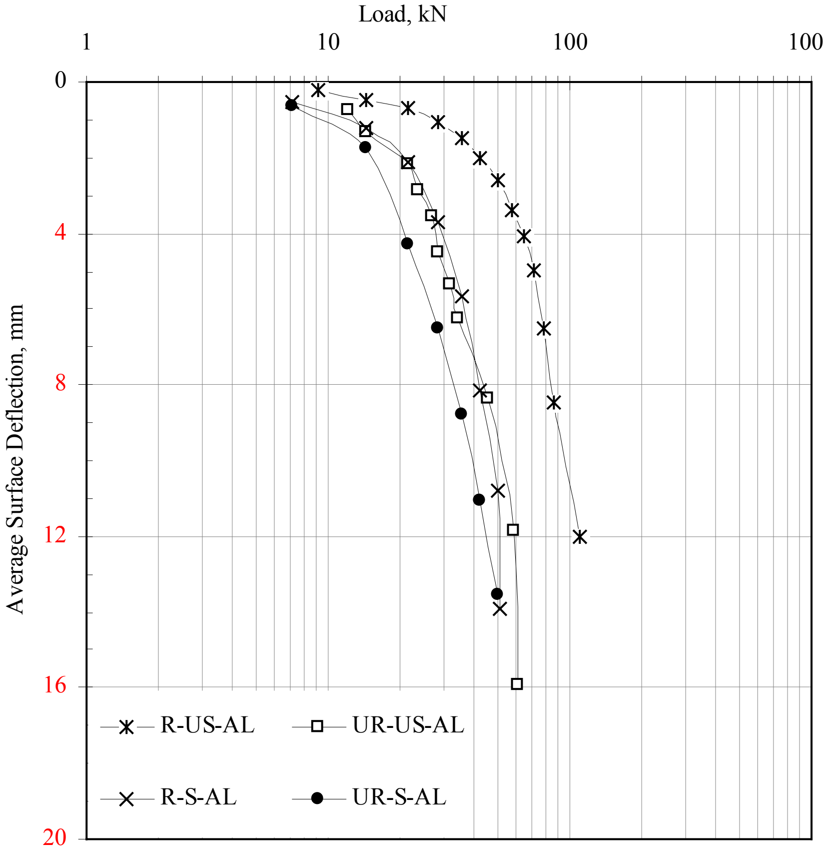


Figure 6. *Load-deflection behaviour of aggregate base course and subgrade*

Least ultimate surface deflection of 12 mm was recorded for reinforced pavement system under un-soaked condition with the highest ultimate load sustained as 110 kN. In un-soaked condition, reduction rate of surface deflection has followed a negative path *i.e.* amount of reduction was higher for initial load compare to next increments. In the case of soaked condition the trend was reverse, up to certain load, rate of reduction increased and then it reduced. Reduction in surface deflection due to reinforcement was in the range of 45 to 71 per cent for un-soaked condition, and for soaked condition it was 20 to 51 per cent. The reduction in surface deflection was due to firm bond between the soil particles and the geogrid mat by which densification of soil took place. Beyond failure load, deflection rate has followed a normal path and it represented a plastic failure.

4.2.2. *Comparison of experimental and theoretical results*

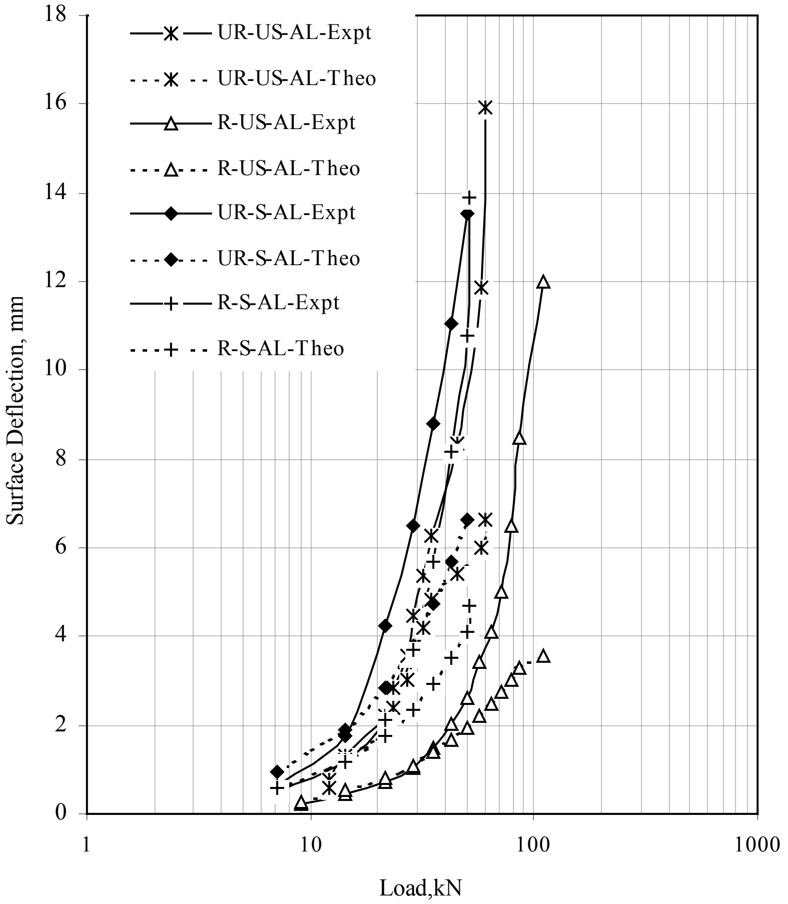


Figure 7. *Comparison of theoretical and experimental surface deflections*

Experimental surface deflection (d_E) were compared with theoretical surface deflection (d_T), where latter was computed based on Burmister's two layer theory. Figure 7 shows the theoretical and experimental surface deflection pattern under different pavement conditions. It could be noticed that, the difference between theoretical and experimental deflections were not significant up to 2 mm surface deflection.

Surface deflections were recorded up to 40 kN in un-soaked condition, and up to 15 kN in soaked condition and were reasonably comparable with the theoretical deflections. Beyond these loads, the differences in deflection values were significantly higher, *i.e.* more than 50 per cent and the difference increased with th increase in Plate load. This indeed indicated the plastic deformation, where the Burmister's elastic theory is not valid. From all the above cases it was observed that, the elastic state exists for loading in the range of 30 to 40 per cent of respective ultimate load.

5. Conclusions

Studies confirmed the atypical strength behaviour of shedi soil under soaked condition. Reduction of elastic modulus for soaked subgrade was by 70 per cent when compare to that of un-soaked condition. Reduction in modulus of subgrade reaction due to soaking was by 72 per cent. Inclusion of a single layer of geogrid at a depth of 0.5a reduced above values to 60 and 40 per cent (for elastic modulus and modulus of subgrade reaction) respectively. But, these values reduced to 36 and 12 per cent (for elastic modulus and modulus of subgrade reaction) respectively when two layers of geogrid were placed in the subgrade at a spacing of 0.5a and 0.75a.

Equations 1 to 4 developed for load-deflection spectrum for un-soaked condition with varied geogrid positions gives a reasonable deflection values both in elastic and plastic state. There is a need for further studies, regarding justifying the model in other test conditions.

In subgrade-aggregate system deflections can be reduced by placing geogrid in the subgrade at a spacing of 0.5b. The reduction was in the range of 45 to 71 per cent for un-soaked condition, and it was 20 to 51 per cent for soaked condition.

Based on the above investigation, reinforcement can be recommended for weak subgrade where availability of materials is scarce. Other stabilization methods like, chemical stabilization requires minimum seven days of curing to get the required strength. In most of the cases, in rural areas the existing link is the only connectivity. Therefore diverting the traffic on alternative route is ruled out and in such cases the weak subgrades can be stabilized by using Geosythetics.

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