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Swell Control of Expansive Subgrades with Geotextiles and Granular Cushions

C.N.V Satyanarayana Reddy* **and N.V.Rama Moorthy**[†]

Introduction

Expansive soils possess low strength in wet condition and undergo cyclic shrinkage and swelling with moisture variations. So, the flexible pavements over them not only incur high construction costs but also exhibit poor performance. The pavements built over such soil subgrades suffer from the problems of pavement unevenness, longitudinal cracking of pavement along wheel tracks, excessive settlement of the edge region over the central portion and also shear failure of the subgrade with time (Patel and Qureshi, 1979; Katti, 1979; Chen, 1988; Saxena, 1991; Satyanarayana Reddy, 2002). The failures are mainly attributed to the subgrade intrusion into overlying structural layers of pavement and subsequent penetration of sub base material into softened subgrade due to swelling during rainy season. Subgrade softening generally occurs at edge regions of pavements due to ingress of moisture from shoulders during rainy season. Continuous efforts are being made by researchers to evolve a technology for swell control of expansive soil subgrades. The techniques that have been tried for construction of flexible pavements in expansive soil subgrades to improve the performance of pavements are given below.

- Use of blanket courses (sand, moorum and lime stabilised soil cushions) to serve as intrusion barriers and to serve as capillary cut-offs.
- Use of cohesive non-swelling soil cushions to suppress swelling and to support the pavement satisfactorily.

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* Associate Professor, Department of Civil Engineering, Kakatiya Institute of Technology & Science, Warangal - 506015, Andhra Pradesh, India.

† Professor and Head, Department of Civil Engineering, National Institute of Technology, Warangal - 506004, Andhra Pradesh, India.

- Checking entry of moisture into subgrade using moisture barriers.

Indian Roads Congress test track project report rated sand cushions to be more effective as capillary cut-off and lime stabilised and moorum cushions as subsoil intrusion barriers (Natarajan and Shanmukha Rao, 1979; Sen and Chakraborthy, 1977). Lime stabilised expansive soil has been least ranked as capillary cut-off due to its lower value of permeability. As sand cushions cannot totally prevent the subgrade intrusion due to their discrete particulate nature, cohesive non-swelling soil (CNS) cushions of 0.6 to 1 m thickness have been recommended for use over expansive soil subgrades to suppress swelling of the subgrade and to support pavement (Katti, 1979). The method is expensive and moreover, recent studies reported that softening of the CNS cushion material under drying and wetting cycles takes place and thereby becomes less effective with time (Subba Rao, 2000). Polymeric geomembranes have been used as horizontal and vertical moisture barriers by Texas Department of Transportation to check the entry of moisture in to subgrade from shoulder regions (Steinberg, 1992). However the method is expensive and cannot be used in the areas where water table is at shallow depths.

Advent of geosynthetics has attracted the highway engineers to consider polymer-based geogrids and geofabrics to minimise pavement design thickness or to serve as separators (Giroud and Noiray, 1984; Fannin and Sigurdsson, 1996). Limited studies have been also carried out to control swelling in expansive soils by using soil reinforcing technique (Srinivasa Murthy et al., 1987; Sridharan, 1999). The swelling pressure developed in expansive soil serves as normal stress required to mobilize the friction force around the reinforcement. It has been shown that friction force mobilised around reinforcement counteracts the heave in a direction parallel to reinforcement and consequently reduces swell. Horizontal swell pressure is believed to have resisted heave. It is considered that horizontal and vertical swell pressures are same. The improved frictional characteristics of reinforcing rod (Tor steel) has also shown effectiveness in reducing swelling (Sridharan, 1999). Use of geosynthetic reinforcements has been found to reduce swelling of expansive soils (Ramanatha Ayyar et al., 1989). The swell control has been attributed to the friction developed between soil and reinforcement. Based on small-scale tests conducted on expansive soil reinforced with geogrids, geotextiles and geomembranes, considerable reduction in swelling has been also reported (Stalin and Jeyapriya, 2001). Review of literature reveals that there is no established technology for flexible pavement construction that controls swelling of subgrade soil without increasing pavement thickness. Hence, the present study is aimed at exploring the ability of woven and non-woven geotextiles, held in position with granular cushions to control swelling of expansive soil through small and medium scale tests on model pavements.

Materials

Expansive Soil

The expansive soil used in the investigations has been procured from a site near National Institute of Technology, Warangal. Laboratory investigations have been carried out to determine the engineering properties of the soil. It is not preferable to compact expansive soils under heavy compaction conditions as it results in higher swelling. So, compaction characteristics of the soil have been evaluated from IS light compaction tests (IS 2720 – Part VII and VIII, 1983). Swell pressure has been determined from swell under load method (IS 2720 – Part XLI, 1977). Percent swell has been determined as the ratio of swell under a surcharge load of 49 N to that of initial thickness of expansive soil. It has been determined from the soaked specimens of expansive soil prepared in C.B.R mould at O.M.C and corresponding maximum dry unit weight obtained in I.S light compaction

TABLE 1 : Index and Engineering Properties of Expansive Soil and Moorum

Property	Expansive soil	Moorum
Specific Gravity	2.59	2.67
Grain Size Analysis		
a) Gravel (%)	2.0	26.4
b) Sand (%)	18.6	53.4
c) Fines (%)	79.4	20.2
Atterberg Limits		
a) Liquid limit (%)	82.5	24.8
b) plastic limit (%)	30.2	19.2
c) Shrinkage limit (%)	9.8	19.8
Compaction Characteristics		
a) Optimum moisture content (%)	19.3	7.6
b) Maximum dry unit weight (kN/m^3)	15.5	20.1
Shear Parameters (from consolidated undrained tests)		
a) Cohesion (kN/m^2)	34	12
b) Angle of internal friction	50	420
Swell Characteristics		
a) Free swell index (%)	120	---
b) Swell pressure (kN/m^2)	95	---
c) Percent swell (%)	11.2	---

condition. Free swell index has been determined as the ratio of difference of volumes of soil in distilled water and kerosene to volume of soil in kerosene, expressed as a percentage. The index and engineering properties of the expansive soil determined from laboratory tests are presented in Table 1.

Cushion Materials

Two types of granular materials namely moorum and rock flour have been used as cushions in the studies. The details of cushion materials used are given below.

Moorum

The moorum has been procured from a local quarry near Parkal, Warangal district. The properties of moorum obtained from laboratory investigations are presented in Table 1.

Rock Flour

Rock flour, also called stone dust, is generated during processing of coarse aggregate from rocks at rock crushing plants and is available as waste material. The rock flour is a granular material like sand with more number of angular particles. Rock flour has been collected from a granite crushing plant located in Hunter Road, Hanamkonda. The index and engineering properties of rock flour obtained from the laboratory investigations are presented in Table 2. Maximum dry unit weight values of rock flour have been determined under IS light and heavy compaction conditions as well as by vibrating technique in dry state, as it is granular in nature. The shear parameters in dry and wet states have been determined from direct shear tests.

Aggregate

The aggregate used in the medium scale swell studies was procured from a granite crushing plant, located in Hunter Road, Hanamkonda. The gradation characteristics and engineering properties of aggregate (Grade-III) used in the study are given in Tables 3a and 3b.

Reinforcing Materials

Two woven and two Non-woven geotextile fabrics manufactured from polypropylene have been used as reinforcing materials in the swell control studies. Woven and non-woven geotextiles have been procured from Garware - Wall Ropes Limited, Pune and Tenax Geosynthetics Limited, New Delhi respectively. The properties of geotextiles are presented in Table 4. The

TABLE 2 : Index and Engineering Properties of Rock Flour

S. No	Property	Value
1.	Specific gravity	2.62
2.	Grain size analysis	
	a) Gravel size (%)	01
	b) Sand size (%)	90
	c) Fines (%)	09
	d) Coefficient of uniformity	8.6
	e) Coefficient of curvature	2.2
3.	Maximum dry unit weight (kN/m^3)	
	a) Light compaction	17.2
	b) Heavy compaction	18.6
	c) Under vibrations	18.8
4.	Shear strength parameters	
	a) Cohesion (kN/m^2)	0.00
	b) Angle of internal friction	
	I.S Light compaction	
	i) Dry condition	39°
	ii) Wet condition	36°
	I.S Heavy compaction	
	i) Dry condition	47°
	ii) Wet condition	45°

TABLE 3a : Gradation of Grade–III Aggregate

Sieve Size (mm)	Percent Passing by Weight
90	100
63	100
53	60
45	5
22.4	0

TABLE 3b : Engineering Properties of Aggregate

S. No.	Property	Value
1.	Specific Gravity	2.82
2.	Crushing Value (%)	20.2
3.	Impact Value (%)	21.7
4.	Abrasion Value (%)	22.5

TABLE 4 : Properties of Woven and Non-Woven Geotextiles

Property	Woven Geotextile		Non-woven Geotextile	
	WG 1	WG 2	NWG 1	NWG 2
Density of Material (g/m^2)	217	158	330	220
Average Thickness (mm)	0.46	0.29	3.4	2.58
Tensile Strength (kN/m)	56	27	17.5	22.5
Corresponding Strain (%)	21	22	25	25

tensile strengths of the geotextiles at different strains as obtained from wide width strip tension tests (ASTM D 4595 – 86, 1994) are presented in Figs.1 and 2.

Swell Control Studies

Preliminary investigations have been carried out on specimens prepared in CBR moulds to assess the potential of moorum and rock flour cushions to control/absorb swelling of expansive soil. The benefit of using reinforcing material in the form of woven and non-woven geotextiles at the interface of expansive soil and cushion materials has also been evaluated.

Evaluation of Cushion Materials

Expansive soil was compacted in CBR mould up to different heights (0.5H, 0.6H, 0.67H, 0.75H and 0.8H) at its optimum moisture content and corresponding dry unit weight. The remaining volume is filled with the

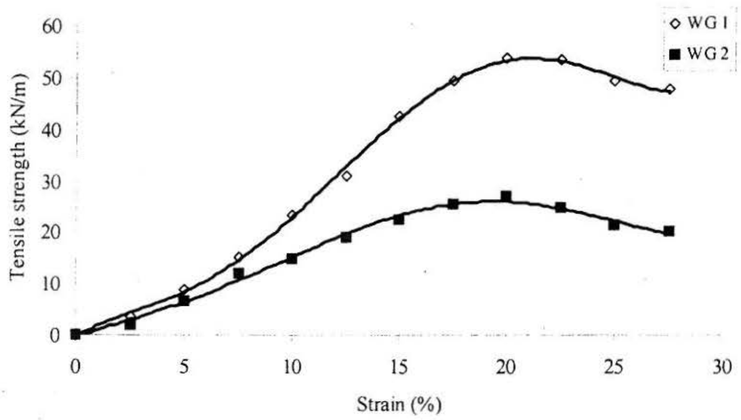

FIGURE 1 : Tension Test Results of Woven Geotectiles

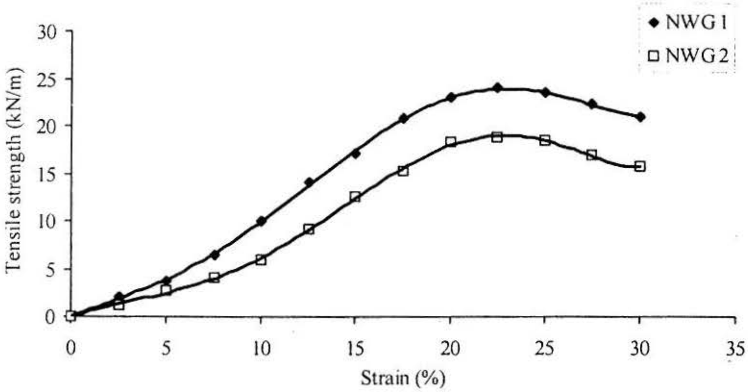

FIGURE 2 : Tension Test Results of Non-Woven Geotextiles

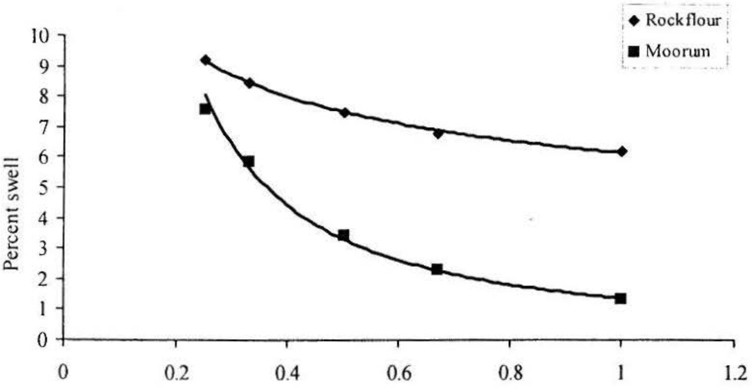

FIGURE 3 : Effect of Cusions on Swelling of Fxpansive Soil

cushion material. Moorum was compacted under heavy compaction condition at water content of 7.6% and a dry unit weight of 20.1 kN/m^3 whereas rock flour was compacted in dry condition at its dry unit weight corresponding to I.S light Compaction condition. The specimens were subjected to a surcharge of 49 N and were soaked in water for a period of 96 hours and the swell is recorded. The values of the percent swell have been calculated as the ratio of swell observed at the surface of specimens to the thickness of expansive soil. The percent swell values of expansive soil with cushion materials have been presented in Fig.3.

Referring to Fig.3, it may be seen that the swell decreases with increase in cushion thickness. Further, it may be observed that the moorum cushions control swelling of expansive soil in a better manner in comparison to rock

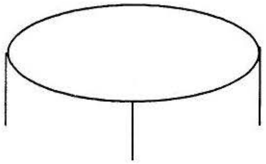

FIGURE 4 : Circular Ring used to hold Fabrics in Position at Expansive Soil Interface

flour cushions. It may be also noticed that percentage reduction in percent swell has been significant at lower cushion to expansive soil thickness ratios. The better cushioning effect of moorum can be attributed to cohesion present in it, in addition to frictional characteristics and dense packing of particles.

Effect of Reinforcing Fabrics on Swell Control

Laboratory investigations have been carried out to study the swell control of expansive soil by placing the fabric at the interface of expansive soil and the cushion material. The effects of simple placement and fabric held in position in controlling swell have been assessed. Pre-fabricated circular rings made from 4 mm diameter mild steel bars with three legs as shown in Fig.4 have been used to hold the fabric in position. The reinforcing fabric has been tightly folded around the fabricated rings and tied to its circumference using a binding wire. The rings have been fabricated to have different lengths of legs to suit placement over expansive soil of varying thickness in the CBR moulds. Woven as well as non-woven geotextiles have been used in the laboratory investigations.

The fabricated ring with tied reinforcing fabric has been placed over the compacted expansive soil in the lower half of the mould and then its legs are gently pressed into the compacted expansive soil until the fabric is seated over the expansive soil. Above the fabric, the cushion material has been compacted in a manner similar to the case of preparation of specimens in unreinforced case. The swell values have been recorded by monitoring the dial gauge readings placed at top of the specimen, after a soaking period of 96 hours. The specimens have been subjected to a surcharge of 49 N. Based on the observed values of swell, the values of percent swell and hence percentage reductions in percent swell of expansive soil with cushion materials using woven and non-woven geotextile fabrics have been determined. The swell characteristics data generated from the tests using cushions with woven geotextile WG 1 is given in Table 5. Similar data has been obtained for other types of geotextiles under study namely, woven geotextile WG 2, non-woven geotextiles NWG 1 and NWG 2. From the results of tests presented in Table 5, it can be seen that simple placement of geotextile does not help in controlling the swelling of expansive soil. It

TABLE 5 : Swell Characteristics of Expansive Soil with Cushions and Woven Geotextile 1 (WG 1)

S. No.	Specimen Description	Ratio of cushion to expansive soil thickness	(Rock flour cushion)			(Moorum cushion)		
			Swell (mm)	Percent Swell	% reduction of swell	Swell (mm)	Percent Swell	% reduction of swell
1.	Expansive soil	-	14.2	11.2	-	14.2	11.2	-
2.	Expansive soil + cushion material	1.0	3.94	6.20	44.6	0.84	1.32	88.2
	a) Reinforcement just placed	1.0	3.98	6.25	44.2	0.93	1.46	87.0
	b) Reinforcement held in position	1.0	0.28	0.44	96.1	0.12	0.20	98.2
3.	Expansive soil + Cushion material	0.67	5.2	6.80	39.3	1.76	2.30	79.5
	a) Reinforcement just placed	0.67	5.1	6.67	40.4	1.74	2.28	79.6
	b) Reinforcement held in position	0.67	0.41	0.53	95.3	0.11	0.15	98.6
4	Expansive soil + cushion material	0.5	6.41	7.52	33.0	2.95	3.46	69.0
	a) Reinforcement just placed	0.5	6.42	7.53	33.4	2.87	3.37	69.9
	b) Reinforcement held in position	0.5	0.65	0.76	93.2	0.28	0.33	97.1
5.	Expansive Soil + cushion material	0.33	8.08	8.46	24.5	5.60	5.88	47.5
	a) Reinforcement just placed	0.33	8.06	8.44	24.6	5.58	5.84	47.9
	b) Reinforcement held in position	0.33	1.28	1.34	88.0	0.72	0.75	94.3
6.	Expansive soil + cushion material	0.25	9.33	9.20	18.2	7.74	7.60	32.1
	a) Reinforcement just placed	0.25	9.32	9.49	15.3	7.72	7.58	32.3
	b) Reinforcement held in position	0.25	2.72	2.67	76.2	1.89	1.86	83.4

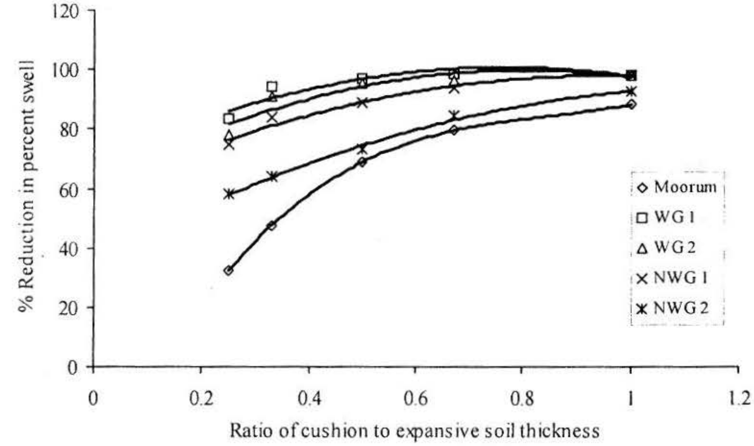

FIGURE 5 : Reduction of Swelling of Expansive Soil with Moorum Cushions with Geotextiles held in Position at Interface

infers that it can not perform its reinforcing function since it is not held in position and that it simply serves as a separator. It can be observed from the results presented that the reinforcing fabrics held in position could suppress swelling of expansive soil due to their restraining ability. The reinforced moorum cushions have shown better swell control than rock flour cushions. The rate of reduction in the percentage swell of expansive soil with moorum cushions using geotextiles as reinforcing material has been presented in Fig.5. The reduction in percent swell values of expansive soil with rock flour cushions and geotextile reinforcements is presented in Fig.6.

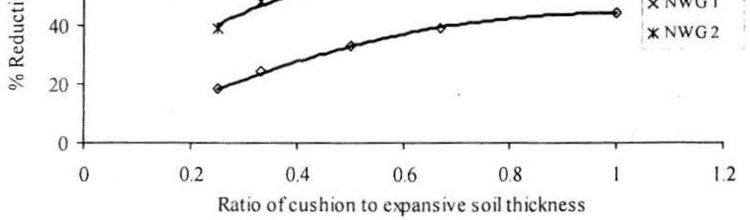

FIGURE 6 : Reduction of Swelling of Expansive Soil with Rockflour Cushions with Geotextiles held in Position at Interface

Figures 5 and 6 impress that the percent swell values of expansive soil have decreased significantly with usage of reinforcing fabric held in position in association with cushion materials. Woven geotextiles have shown better swell control than non-woven geotextiles due to their higher stiffness. From Fig.5, it can be noted that the usage of reinforcing fabric with moorum cushion having cushion to expansive soil thickness ratios of 0.25 to 0.40 can reduce swell by as high as 80 percent. Figure 6 indicates that geotextiles can also control swelling of expansive soil when used with rock flour cushions. However, rock flour cushion efficiency is less in comparison to moorum cushion.

Observations from Small Scale Studies

The following observations are made from the results of small-scale tests conducted.

1) Moorum cushions are effective than rock flour cushions in counteracting the swelling of expansive soil.

2) The swell control increases with increase of cushion thickness. The increased swell control with increased cushion thickness is more pronounced with moorum cushions.

3) A moorum thickness of 0.25 to 0.3 m can control swell of expansive subgrade by about 30 to 40 percent, considering active expansive soil layer of 1 m thickness.

4) Simple placement of reinforcing fabric does not control swelling, except acting as a separator.

5) Swelling of expansive soil using woven geotextiles WG 1 and WG 2 under study with moorum cushion decreases by 83.4% and 78.2% respectively at a cushion to expansive soil thickness ratio of 0.25.

6) For non-woven geotextiles, swell reduction is only 58.1% for NWG 2 and 74.6% for NWG 1 with moorum cushions at a cushion thickness ratio of 0.25.

However restraining effect provided by geotextiles in small-scale experiments does not exactly reflect that attainable in the field. So, to simulate actual field condition, swell tests on model pavement layers with anchored geotextiles have been carried out.

Swell Studies on Model Pavement Systems

As the results from small scale testing gave interesting information on swell control of expansive soil, model pavement layers with use of geotextile fabric at interface of subgrade and sub base have been proposed for assessment of swell control. As geotextiles can control swelling of underlying expansive soil only when they are held in position, in the laboratory model tests, geotextile fabrics have been planned to have side anchorage into expansive soil near the edges. In the field, the geotextile fabrics are proposed for anchorage by burial into longitudinal trenches made in shoulder regions of pavement. Moorum is considered as backfill material in anchorage trenches because of its high strength, good frictional characteristics and volume stability.

As the swelling of expansive soil is controlled, it exerts normal pressure on controlling media. The pressure exerted depends on amount of swelling prevented. If the total swelling is prevented, the expansive soil exerts a pressure equal to swell pressure. It is considered that the lateral swell pressure is equal to vertical swell pressure. The vertical residual swell pressure exerted on the geotextile fabrics causes tension in the fabric and tend to pull out the fabric from the anchored portions. In the swell studies on reinforced model pavements, it is considered that the horizontal swell pressure exerted by the expansive soil on the fabric in anchored zones is useful in mobilising the necessary pull out resisting force to withstand the tension developed in the fabric due to vertical pressure exerted on fabric at subgrade level and thereby the swelling is prevented due to restrainment. The following experimental program has been carried out to investigate into the swell control mechanism of anchored geotextiles.

Reinforced model flexible pavement systems were prepared in a mild steel tank of size 1.0 m × 0.8 m × 0.8 m. Expansive soil was compacted up to a thickness of 300 mm at its optimum moisture content and maximum dry unit weight corresponding to light compaction condition. Two longitudinal trenches of width (b) 120 mm have been excavated to a depth (d) of 200 mm at a clear spacing (l) of 400 mm. The reinforcing fabric is spread over the expansive soil (including into trenches) and then moorum is backfilled in the trench portions by compacting at its O.M.C and respective maximum dry unit weight corresponding to IS heavy compaction condition. Half portion (by length) is filled with rock flour and remaining with moorum to a thickness of 75 mm, to serve as sub base layers and also as cushions. The rock flour has been compacted at its maximum dry unit weight corresponding to light compaction condition whereas the moorum has been compacted at its heavy compaction condition and over that a water bound macadam layer of 75 mm thick has been prepared. In water bound macadam layer, stone aggregate volume is taken as 10 percent of surface area and moorum is used

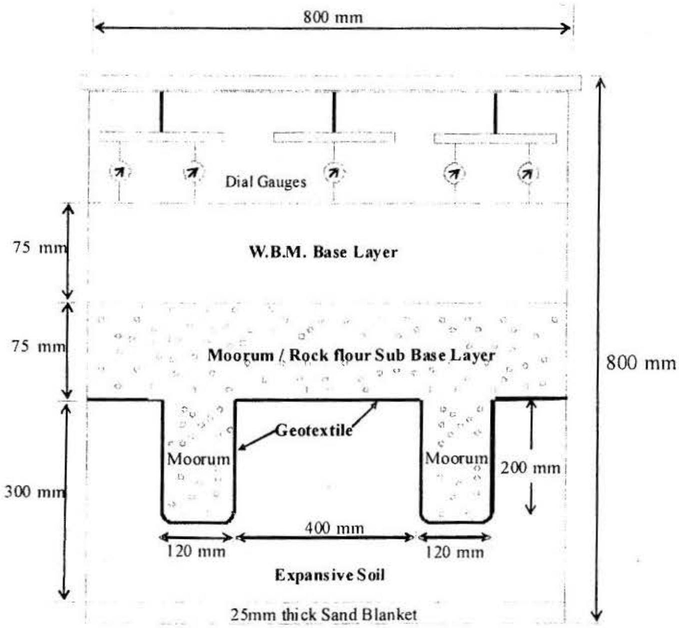

FIGURE 7 : Cross-Section of Model Reinforced Flexible Pavement System used in the Studies

as screening material as per the M.O.S.T specifications (MOST, 2001). Cross section of model reinforced flexible pavement system used in swell studies is shown in Fig.7.

The prepared model pavement system is connected to water supply tank and allowed to soak for one month. The swell measurements are noted at several positions using dial gauges. The testing is repeated for the two woven and two non-woven geotextile fabrics under study. The results of the tests conducted are presented in Table 6. The results impress that the swelling of expansive soil may be controlled by about 50-70 percent using geotextiles with cushion material of different tensile strengths and stiffnesses when used in association with moorum cushion. Moorum cushion is more effective in suppressing swelling than rock flour cushion. The side anchorage of geotextile in shoulder region in actual pavements not only checks swelling but also provides strength to shoulder portion and avoids shear failure of subgrade during offtracking of vehicles in rainy season.

Swell Control Mechanism – Interpretation from Model Tests

The results of swell studies presented in Table 6 indicate that the anchorage of geotextile fabrics at sides into the expansive subgrade with

TABLE 6 : Swell Characteristics of Model Reinforced Pavement Systems

S. No.	Location	Sub base layer material	NWG1			NWG2			WG1			WG 2		
			Swell (mm)	Per cent well	% reduction in swell	Swell (mm)	Per cent swell	% reduction in swell	Swell (mm)	Per cent swell	% reduction in swell	Swell (mm)	Per cent of swell	% reduction in swell
1.	Centrally above expansive soil at top of W.B.M Layer	Moorum	14.1	4.7	58.0	17.6	5.87	47.6	10.5	3.5	68.8	11.7	3.9	65.2
		Rock flour	18.4	6.13	45.3	20.2	6.73	39.9	14.9	4.97	55.6	17.2	5.73	48.8
2.	Above anchored region at top of WBM layer	Moorum	3.0	2.0	80.1	3.8	2.50	77.7	2.4	1.6	85.7	2.8	1.87	91.0
		Rock Flour	5.0	3.33	67.4	5.5	3.67	67.2	3.6	2.4	78.6	4.2	2.8	75.0
3.	Edge region at top of W.B.M.	Moorum	21.5	7.30	34.8	21.6	7.2	35.7	21.4	7.13	36.3	21.7	7.23	35.4
		Rock Flour	26.0	8.72	22.1	26.3	8.76	21.6	26.5	8.83	21.1	26.8	8.93	20.3

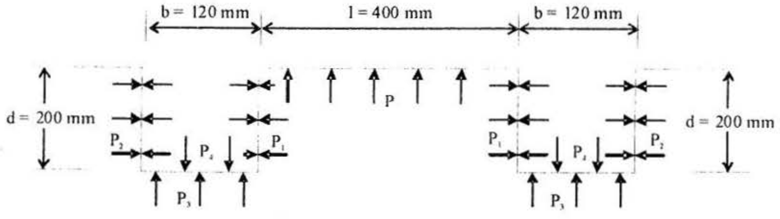

FIGURE 8 : Normal Pressures Exerted by Expansive Soil on the Fabric

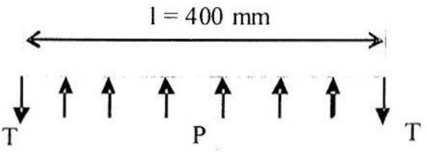

FIGURE 9 : Free Body Diagram of Fabric Restraining Swelling of Expansive Soil

cushion material has resulted in decreased values of swelling. This infers that the frictional resistance mobilised at the anchored fabric surface is sufficient to withstand the pull out of the fabric due to tension developed in it due to residual vertical swell pressure. Considering normal pressures acting on geotextile fabric surfaces in anchored portion shown in Fig.8 and the free body diagram of fabric at expansive soil subgrade restraining swell in model pavement shown in Fig.9, the restraining mechanism of fabrics is explained below.

The upward pressure (p′) exerted by expansive soil on geotextile fabric can be calculated as, p′ = percent reduction in swell by geotextile x swell pressure (p_s)

Tension developed in fabric due to upward pressure is,

$$T = \frac{p' \times l}{2} = 0.5 p' l$$

where l = clear distance between anchorage trenches (length of geotextile fabric between anchorage trenches

The resisting force to pull out of the fabric from anchorage portion can be calculated as given below.

$$F = d\begin{bmatrix} \left\{C_{a_e} + p_1 \tan\phi_{\mu_e}\right\} + \left\{C_{a_m} + p_1 \tan\phi_{\mu_m}\right\} \\ + \left\{C_{a_e} + p_2 \tan\phi_{\mu_e}\right\} + \left\{C_{a_m} + p_2 \tan\phi_{\mu_m}\right\} \end{bmatrix}$$

$$+ b\left[\left\{C_{a_e} + p_3 \tan\phi_{\mu_e}\right\} + \left\{C_{a_m} + p_4 \tan\phi_{\mu_m}\right\}\right]$$

where p_1 = percentage swell controlled in central portion x swell pressure (p_s)

p_2 = percentage swell controlled in edge region x p_s

p_3 = percentage swell controlled in anchored portion x p_s

p_4 = effective overburden pressure at geotextile fabric in anchored trench

b = width of trench for anchoring geotextile fabrics

d = depth of trench for anchoring geotextile fabrics

C_{a_e} = adhesion of expansive soil with geotextile fabric

ϕ_{μ_e} = interfacial friction angle of expansive soil with geotextile fabric

C_{a_m} = adhesion of moorum with geotextile fabric

ϕ_{μ_m} = interfacial friction angle of moorum with geotextile fabric

In the analysis, moorum in anchored trenches has been considered to mobilise reactive pressures balancing the lateral swell pressures exerted by neighbouring expansive soil. The values of p′, p_1, p_2 and p_3 calculated for woven and non-woven geotextile fabrics with moorum and rock flour cushions in the model pavement studies are tabulated in Table 7. If the

TABLE 7 : Normal Pressures (kN/m^2) Exerted by Expansive Soil on Geotextile Fabrics

Normal pressure on fabric	WG 1		WG 2		NWG 1		NWG 2	
	Moorum	Rock Flour	Moorum	Rock Flour	Moorum	Rock Flour	Mooru m	Rock Flour
P′	34.87	35.6	26.51	29.3	25.7	18.72	10.55	20.6
P_1	65.4	52.8	61.9	46.4	55.1	43.0	45.2	37.9
P_2	34.5	20.5	33.6	19.3	33.1	21.0	33.9	20.5
P_3	81.4	74.7	86.5	71.3	76.1	64.0	73.8	63.8

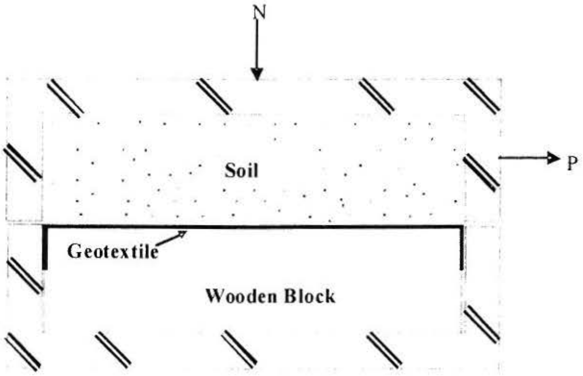

FIGURE 10 : Schematic Diagram of Modified Direct Shear Test Setup

frictional resistance developed (F) due to horizontal swell pressure is greater than the tension developed in the fabric due to residual vertical swell pressure, the fabric will be able to restrain the expansive soil and controls swell. For calculation of the frictional force mobilised at the interfaces of geotextile in anchored portion, the adhesion and angle of interfacial friction angle of reinforcing materials with expansive soil and cushion materials have been determined as explained below.

Frictional Characteristics of Geotextiles with Subgrade Soil and Cushion Material

The frictional characteristics of woven and non-woven geotextiles under study with subgrade soil and cushion materials have been determined from modified box shear tests (Hussaini and Perry, 1978). In the shear box, the geotextile layer was placed over a wooden block in lower half such that it is flush with edges and the expansive soil / cushion material was filled in the upper half at respective optimum moisture contents and maximum dry unit weights, as shown in Fig.10. The test specimens were sheared at different normal pressures under undrained condition to get the corresponding shear strengths. The values of adhesion and angles of interfacial friction (ϕ_μ) have been obtained by plotting the strength envelopes. While preparing the test specimens, expansive soil and rock flour were compacted at maximum dry unit weights corresponding to light compaction conditions and moorum was compacted at its maximum dry unit weight corresponding to heavy compaction conditions. The shear parameters of synthetic geotextile fabrics with subgrade soil and cushion material obtained from the laboratory investigations have been presented in Table 8.

Though rock flour has higher friction angle with the geotextiles, it was not used for backfilling as being a granular material, can not generate reactive

TABLE 8 : Interfacial Shear Parameters of Geotextiles with Expansive Soil and Cushion Materials

Material	Geotextile	Shear Parameters	
		Adhesion (kN/m^2)	Interfacial Friction Angle
Expansive Soil	WG 1	22.4	8°
	WG 2	23.2	7°
	NWG 1	24.3	4°
	NWG 2	24.5	5°
Moorum	WG 1	8.3	20°
	WG 2	7.8	19°
	NWG 1	9.1	21°
	NWG 2	8.7	20°
Rock flour	WG 1	0.0	28°
	WG 2	0.0	26°
	NWG 1	0.0	32°
	NWG 2	0.0	30°

force onto neighboring expansive soil exerting lateral swelling pressure. So in the model tests carried out, only moorum has been used as backfill material in the anchored portions. The values of mobilised frictional resistance at the fabric interfaces with expansive soil and moorum backfill in the anchored portion and the tensions developed in the fabric due to vertical swell pressure exerted by expansive soil with moorum and rock flour cushions, obtained from the analysis are summarized in Table 9. The mobilised values of pull out resisting force are calculated against a factor of safety of 2.0.

TABLE 9 : Tensions and Pull out Resisting Forces Developed due to Swell Control of Expansive Soil Subgrade

Model Pavement System	Moorum Sub base / Cushion				Rock flour Sub base / Cushion			
	WG1	WG2	NWG1	NWG2	WG1	WG2	NWG1	NWG2
Tension (kN/m)	6.97	6.3	4.93	2.95	7.1	5.8	5.15	4.12
Mobilised Pull out Resisting Force F_m (kN/m)	14.3	14.8	13.02	12.5	12.8	11.9	12.1	11.4

TABLE 10 : Comparison of Tensions and Strains developed in Geotextile Fabrics based on Swell Control data with Strength Properties

Sub Base / Cushion Material	Geotextile Fabric	Experimental Data		Strength Properties	
		Tension (kN/m)	Strain (%)	Tension (kN/m)	Strain (%)
Moorum	WG 1	7.0	5.3	8.8	5.0
	WG 2	6.3	5.9	7.5	6.0
	NWG 1	4.9	7.0	5.8	7.0
	NWG 2	3.0	8.8	5.0	9.0
Rock Flour	WG 1	7.1	7.5	15.0	7.5
	WG 2	5.8	8.6	12.5	8.5
	NWG 1	5.2	9.2	8.5	9.0
	NWG 2	4.1	10.1	6.5	10.0

From the data presented in Table 9, it can be noticed that pull out resisting forces (mobilised frictional forces) from anchorage portions are greater than tensions (pullout forces) induced due to vertical swell pressure exerted by subgrade soil and hence, it can be concluded that the fabrics are able to restrain expansive soil and could control swell. Based on the observed values of swell at center portion of expansive soil, the values of strains developed in the fabric have been worked out by considering the swell to be uniform. The values of strains along with the tensions developable in the fabrics for reinforced model pavement systems under study have been presented in Table 10. The data has been compared with strength characteristics of the fabrics.

From Table 10, it can be seen that the stiffness data of reinforcing fabrics pertaining to reinforced flexible pavement layers with moorum cushions from the analysis is nearly matching with the stiffness of the fabrics. Hence, it can be concluded that geotextiles can restrain the expansive soil if it is anchored through burial into expansive soil, provided some swell is prevented initially by the cushion material. The swell control depends on the stiffness of the fabric and its frictional characteristics with expansive soil and backfill material used in the anchored portion. Further, it can be observed that the estimated values of induced tensions in the fabrics based on swell control by rock flour cushioning action are low for associated higher strain values calculated based on observed swell. This depicts that initially fabrics are strained due to high swell pressure exerted by expansive soil than that estimated in analysis by considering suppress of swell by rock flour, which infers that rock flour cushions do not suppress swelling, but rather absorb.

So moorum cushions are to be preferred for field applications to suppress swelling and additional swell control can be achieved with usage of anchored geotextiles.

Conclusions

Moorum cushions are effective over Rock flour cushions in suppressing swelling of expansive soils due to existence of cohesion and better packing of the particles. A moorum cushion of 25 to 30 percent the thickness of active expansive soil layer can control swell by about 30 to 40 percent. Further swell control can be achieved through holding geotextiles in position at expansive soil subgrade by anchorage into longitudinal trenches using moorum backfill. If reinforcing fabric is not held in position through anchorage at sides, it can not control swell and serve as reinforcing element.

Rock flour absorbs swelling of expansive soils rather than suppressing and so it cannot be advantageously used as a cushion to suppress swelling of expansive soils. Hence it is not recommended for use in sub base courses of reinforced flexible pavements over expansive soils. However, it may be used as a blanket course over clayey subgrades to serve as capillary cut-off. It may be also used as a fill material with synthetic reinforcements in construction of reinforced soil structures due to its good frictional characteristics.

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