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Use of Geofoam for Road Construction over Very Soft Clay

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Abstract . Due to scarcity of good land many highways are bound to be constructed on marshy lands consisting of soft to very soft clayey soil. Some ground improvement techniques like sand drain/PVD with preloads are normally being adopted in most of the cases which is usually time consuming process. Use of geofoam minimizes the construction time. Geofoam is expanded polystyrene (EPS) manufactured into large lightweight blocks having density nearly 1% of the density of traditionally used filling soil. The primary function of the geofoam is to provide a lightweight fill in the embankment. Due to a light weight fill material, the dead load of embankment decreases which results into lesser consolidation settlements. Thus the chances of shear failure of soft foundation soil reduces. A laboratory study on scaled model has been conducted to obtain the differences in stresses coming onto the soft foundation soil due to use of geofoam as filling material in place of traditional filling soil used for roadway embankment construction. In this paper, a comparative study between embankments with and without geofoam has also been carried out. It is observed that the stress on foundation soil is much less in case of embankment with geofoam. A numerical model has been made using PLAXIS 3D for parametric studies. Reduction Factors (RF) for stress were introduced. For given undrained shear strength and given thickness of geofoam layer, design charts of Reduction Factors were prepared. Finally it is concluded that geofoam can be suitably used in Indian construction industry.

Keywords: Geofoam; Road Embankment; Soft Clay

1 Introduction

Expanded polystyrene (EPS) geofoam are being vastly used in embankment construction since the last three decades in many countries like USA, Japan, Germany, Norway etc. The light-weight property of geofoam makes it very easy to handle. It requires less skilled labourers. Major engineering properties of EPS geofoam such as Young's modulus, Poisson's ratio, comspressive strength, flexural strength, water absorption are dependent upon the density of the geofoam material [1]. Application of geofoam as a filling material for the embankments over soft soils needs lesser construction time than other traditional ground improvement techniques like stone columns, sand drains, PVDs, lime-cement columns and so forth. Case study done by Franswoth et al. [2] suggested that the usage of geofoam in many parts of I-15 highway construction in Utha, USA proved to be more economical including construction and maintenance expenses. Mohajerani et al. [3] presented a brief review on the manufacturing, engineering properties and applications of geofoam in embankment construction over soft foundation soil. Newman et al. [4] performed numerical simulation to see the effects of ground motion on geofoam embankments. Umashankar et al. [5] concluded that a minimum of 30 cm of cover soil is required over the geofoam blocks to facilitate proper load dispersion. The authors also studied the effect of load distribution slab on top surface of geofoam layer using finite difference based software FLAC 2D. Sheeley and Negusssey [6] studied the behaviour of geofam material at the interfaces with cast-in-place concrete, HDPE and PVC geomembrane. The surfaces of the geofoam blocks were degraded by wetting as well as UV radiation to obtain the critical values. Barrett and Valsangkar [7] discussed on the effectiveness of connectors on geofoam block construction. The failure trends of geofoam embankments and their possible remedies can be found from Horvath [8]. The studies regarding geofoam material and their applications on embankments as light-weight material are available, but are very limited to provide a globally accepted guidelines. In present study, the analysis of geofoam embankment is done through numerical models prepared using PLAXIS 3D and validated with the laboratory model experiments. An effort has also been made to prepare design charts based on shear strength properties of soft foundation soil and thickness of geofoam layers. The stress reduction factors are obtained from comparison between traditional and geofoam embankments.

2 Experimental study

2.1 Foundation soil preparation

The foundation soil bed for the scaled model of both traditional and geofoam embankments were constructed inside a steel tank having length and width of 1m x 1m and a height of 1m. The soil bed was 0.8m in depth. Soft clayey soil was prepared by mixing dry smashed-soil with water to maintain a water content of 50% (± 1%) so that an undrained cohesion value of 12 kPa was achieved. The wet soil was wrapped in polythene sheets and kept for few days for homogeneous mixture. Thereafter the soil was put inside the tank and compacted in layers of 0.1m with predefined weight-volume relationship and compactive effort obtained from trial experiments so that a uniform unit weight of 17 kN/$m^3$is reached. Fig. 1 shows the clayey foundation soil bed prepared for experimental model testing.

Fig. 1. Foundation soil bed made of soft clay

2.2 Traditional embankment model

After the foundation soil bed was constructed, the pressure transducer was placed at the middle of the soft soil surfacefollowed by construction of scaled traditional embankment (Fig. 2). The objective of instrumentation with the pressure transducer was to measure the stresses generated due to surcharge loading as well as self-weight of the embankment. The model of traditional embankment had a top width of 15 cm, side slope of 1V: 1H and height of 7.5 cm. A$c - \phi$ soil was used for embankment. To prepare embankment, dry soil was mixed with water to achieve a water content of 14% and unit weight of 16.5 kN/m^3.As the foundation soil below the model embankment was to remain in soft condition, lesser compactive effort was applied during the preparation of the model embankment. Hence, lesser density than the MDD (Maximum Dry Density) was achieved. This wet soil was placed in a single layer over the soft soil with the help of a wooden plank to give it the appropriate size, shape and dimensions of the embankment. After the model of traditional embankment was constructed, a wooden box having the bottom dimensions same as the top surface of the embankment was used to apply a gradual static loading as the surcharge on top of the embankment. The wooden box was placed on the top of the embankment and dry sand was filled up to a predetermined height to reach a total surcharge loading of 10 kPa (including self-weight of the box), which is generally taken as traffic load [9]. The experimental model of the traditional embankment is shown in Fig. 3. The properties of soft foundation soil and embankment soil are provided in Table. 1.

Fig. 2. Pressure transducer below the traditional embankment model

Fig. 3. Experimental model of traditional embankment

2.3 Geofoam embankment model

After the experiment on the model of traditional embankment was completed, same experiment was done on geofoam embankment. The only difference between those two experiments was that a major portion of the embankment filling soil was replaced by geofoam block. The geofoam block had a length of 1 m, width of 0.18 m and height of 0.05 m. Same dimension of the embankment was maintained in this experiment. A schematic diagram of the geofoam embankment is shown in Fig. 4. All the other conditions were kept same as the previous model experiment. The wooden box was used in similar fashion for applying surcharge load of 10 kPa on the top of geofoam embankment. The properties of EPS geofoam block that is used for this experiment are provided in Table 1.

Table 1. Material properties for experimental study

Material	Parameter	Value	Unit
Foundation soil(Soft clay)	Specific gravity	2.61	-
	Liquid limit	65	%
	Plastic limit	32.5	%
	OMC	25	%
	MDD	1.6	g/cc
	Clay	73.2	%
	Silt	26.8	%
	Compression index	0.36	-
	Coefficient of consolidation	0.152	cm^2/s
Geofoam	Density	10.8	kg/m^3
	Elastic modulus	1431	kN/m^2
	Poison’s ratio	0.11	-
Embankment soil (c - ϕ soil)	Specific gravity	2.6	-
	OMC	14	%
	MDD	1.93	g/cc
	Cohesion	33	kN/m^2
	Sand	50.3	%
	Gravel	0.54	%
	Silt	19.15	%
	Clay	30.01	%
	Angle of internal friction	25	Degrees(°)

3 Numerical modelling

The numerical modelling was done using PLAXIS 3D software. At first, the numerical models of geofoam embankment and traditional embankment were prepared as per the laboratory conditions so that it can be validated with the help of the data obtained from experimental studies. The dimensions and shapes of the numerical models on PLAXIS 3D were kept exactly same as the experimental models. Material properties were provided as per Table. 1. The soils were simulated by Mohr-Coulomb model. Side boundaries of the foundation soil were kept fixed in the direction perpendicular to the planes. Bottom boundary was kept fully fixed and top was kept free. Medium mesh size was selected for all the numerical analysis from mesh convergence study for good results within lesser time. Fig. 5 shows the model of geofoam embankment made on PLAXIS 3D.

The stresses generated at the bottom of the embankments for both traditional and geofoam embankment models due to gradual static loading on the top surface of embankment were observed. Consolidation analysis was simulated only in the vertical direction for both the models and the surcharge was applied in the form of surface load on top surface of the embankments.

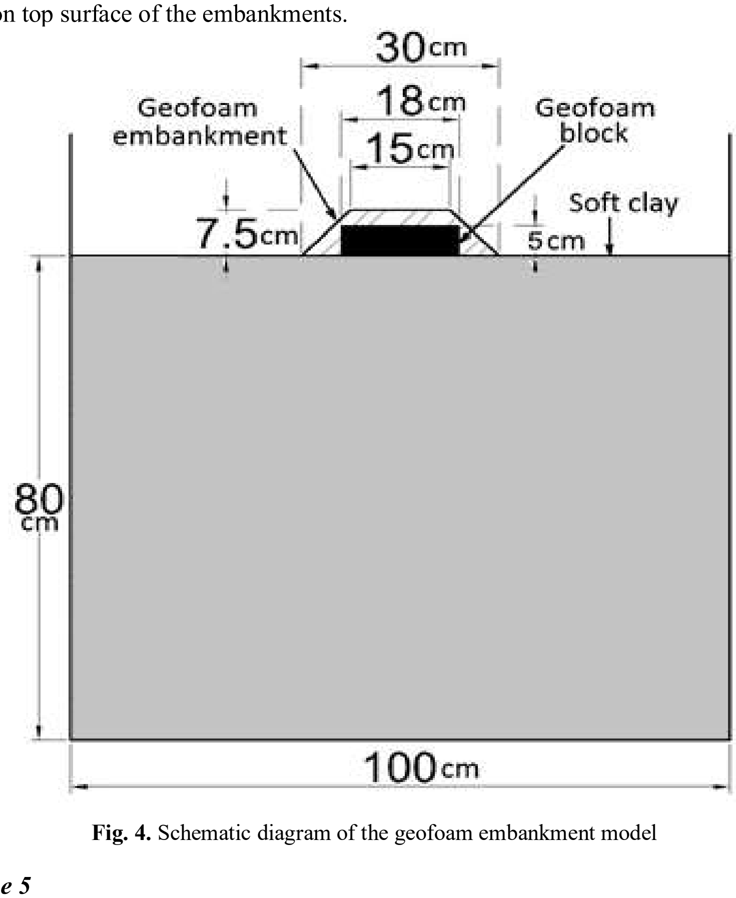

Fig. 4. Schematic diagram of the geofoam embankment model

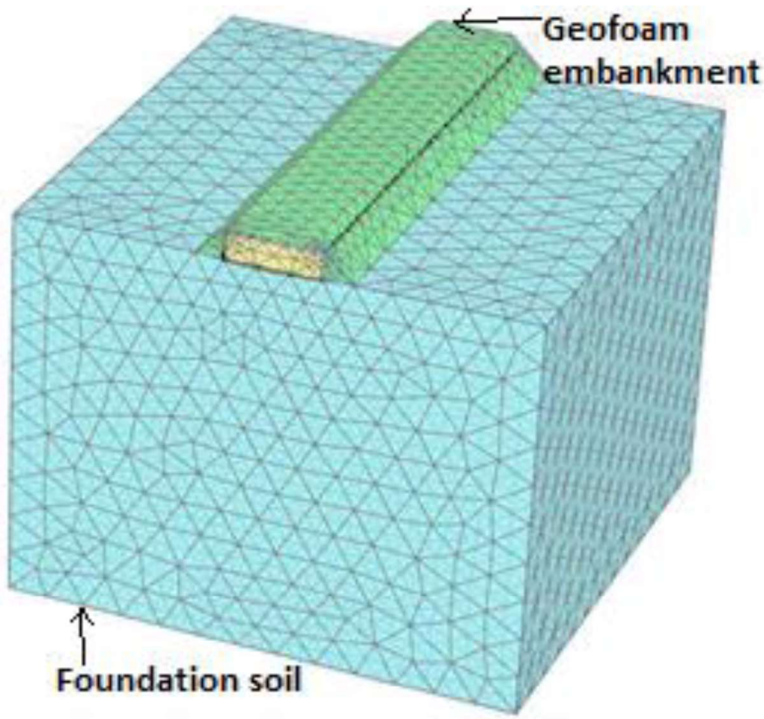

Fig. 5. Numerical model of geofoam embankment on Plaxis 3D

4 Results and discussions

4.1 Validation

The data obtained from the numerical study was compared with the data obtained from experimental study. The variation of stress coming at the bottom of the traditional embankment due to application of surcharge is shown in Fig. 6. Similarly, Fig. 7 represents how the stress at the bottom of the geofoam embankment changes with the change in surcharge pressure at top. Both the numerical models of geofoam as well as traditional embankments tend to follow similar nature of curve and shows good agreement with the curves obtained from experimental studies.

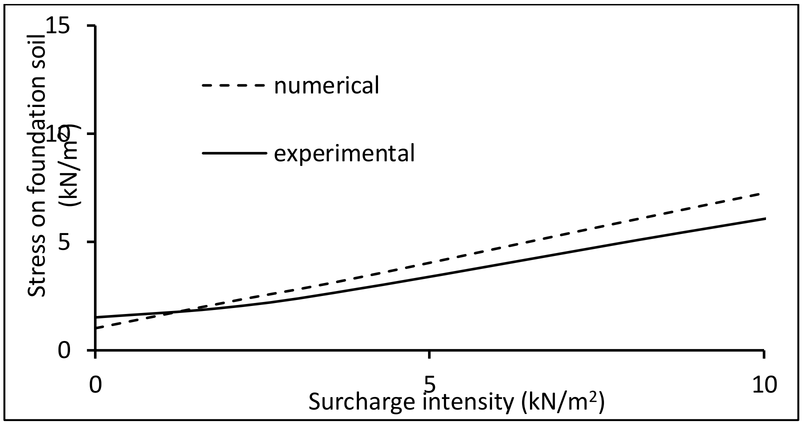

Fig. 6. Effect of surcharge intensity on vertical stress at the bottom of traditional embankment

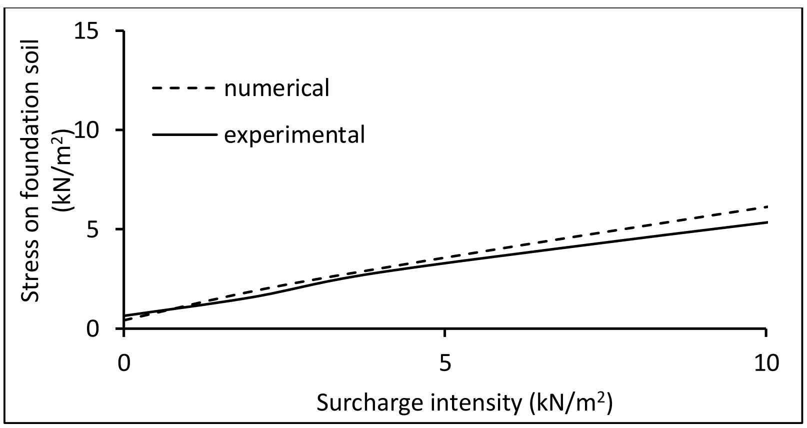

Fig. 7. Effect of surcharge intensity on vertical stress at the bottom of geofoam embankment

4.2 Parametric studies

Further parametric studies were performed on numerical models of prototype geofoam and traditional embankment. The prototype embankments had a height of 3m, bottom width of 21 m and side-slope of 1V: 1.5H (Fig. 8). The properties of foundation soil was taken from tutorial number 3 (clay soil) of global material properties of PLAXIS 3D 2018 tutorial manual [10]. The co-efficient of permeability of the soft foundation soil was assigned to 0.04752 m/day in all the three directions (x, y and z) and the interface behavior was changed to rigid. Surcharge loading was applied up to 25 kPa which satisfies the loading criteria on geofoam embankments mentioned by Stark et al. [11]. For the embankment soil properties, global material properties of tutorial number 4 (embankment soil) of PLAXIS 3D tutorial manual is referred [12]. For the EPS geofoam properties, ASTM 6817-06 [13] was referred and EPS22 was selected for this particular study as it stands fairly at the middle of the range of grade of geofoams available in market. The EPS22 geofoam blocks were taken as 2 m in length, 1m in width and 0.9 m in height, which satisfies standard geofoam block dimensions. Three layers of geofoam blocks of thickness 0.9 m each are used for constructing the geofoam embankment and a layer of cover soil of 0.3 m thickness is laid over it [5]. Thereafter, the stresses on the foundation soil along the cross-section of the embankment were measured before and after the total surcharge was applied. Fig. 9 showsthe variation of vertical effective stress on foundation soil along the cross-section of the embankment due to onlythe self-weight of the embankment. As geofoam is a very light-weight substance compared to soil, the self-weight of the embankment reduces significantly in case of geofoam embankments compared to traditional embankments and thus the vertical stresses are seen to be reducing even before the surcharge application.

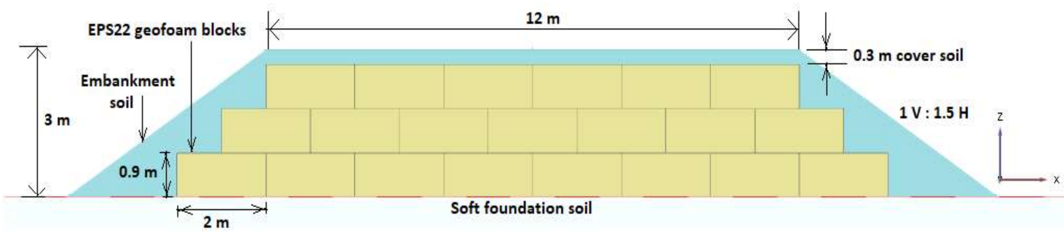

Fig. 8. Prototype geofoam embankment made on PLAXIS 3D

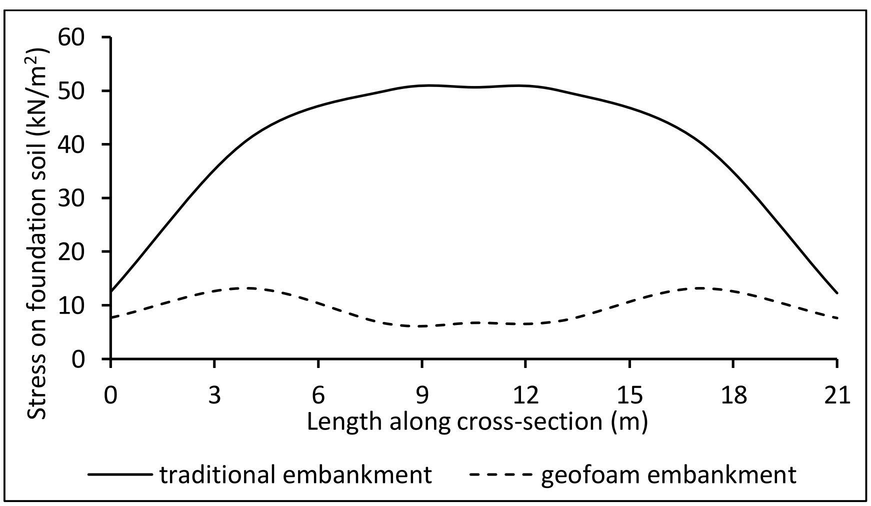

Fig. 9. Vertical effective stress on foundation soil before applying surcharge

Similarly, Fig. 10 shows the vertical effective stress coming on the foundation soil after applying total surcharge of 25 kPafor both traditional and geofoam embankments.

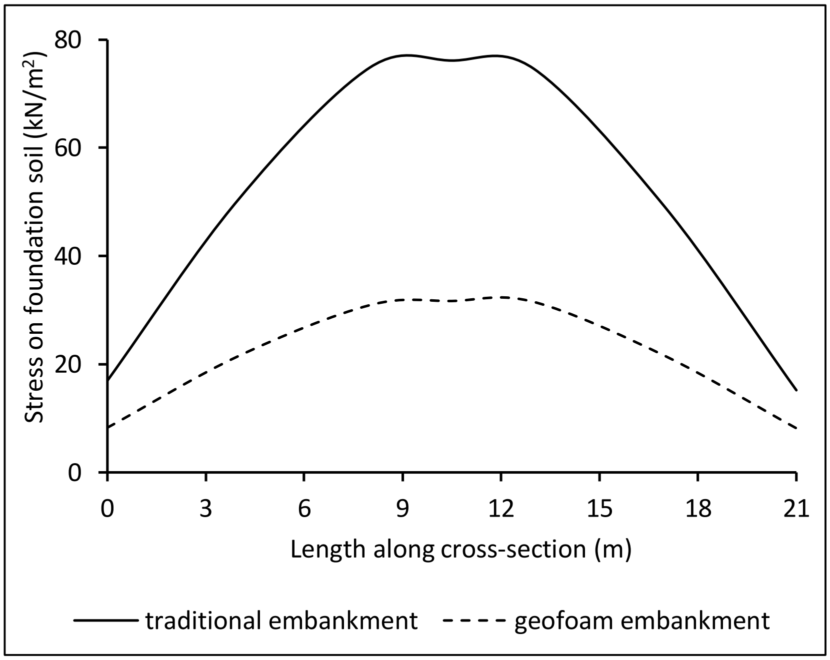

Fig. 10. Vertical effective stress on foundation soil after 25 kPa surcharge application

Reduction factors (RF) for stresses were introduced as the ratio of difference between the output values for traditional embankment and geofoam embankment to the output value of traditional embankment.

$$RF\ for\ stress = \frac{\begin{pmatrix} Stress\ for \\ traditional\ embankment \end{pmatrix} - \begin{pmatrix} Stress\ for \\ geofoam\ embankment \end{pmatrix}}{Stress\ for\ traditional\ embankment}$$

Fig. 11 shows the comparison of stress RFs along the cross-section of the embankment when no surcharge is applied and when 25 kPa surcharge is applied.

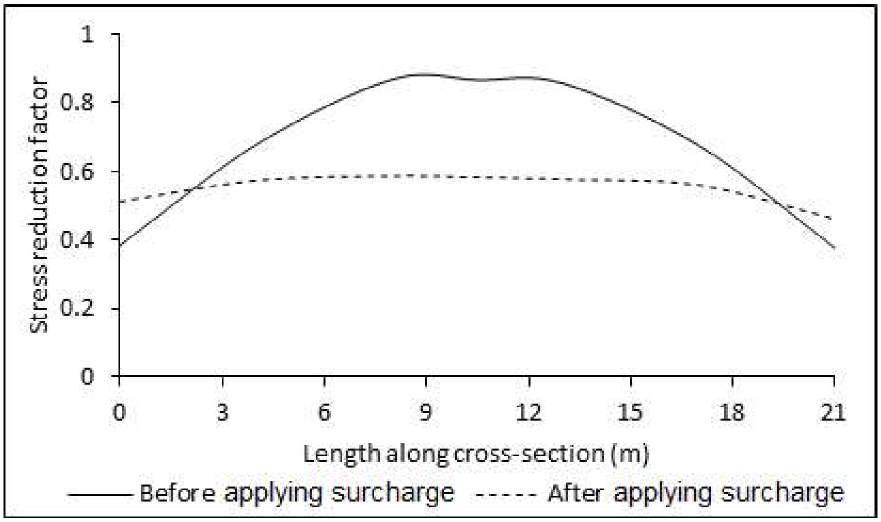

Fig. 11. Comparison of stress RF along cross-section before and after loading

Further studies were carried out considering the maximum values of stresses which were generally found to be occurring at the middle of the cross-section of the embankment. As the middle of the embankment (in cross sectional view) is more vulnerable due to maximum amount of stresses occurring there, the stress RFs for the middle are taken into consideration and studied.Design charts for stress RFs were prepared by varying the undrained cohesion value of foundation soil and the thickness of geofoam provided in the embankment. The Young's modulus values were also changed with respect to undrained cohesion values [14]. Table 2 and Table 3 show the charts of RFs for maximum vertical effective stresses on foundation soil before and after loading respectively.

Table 2. Chart of RFs for maximum vertical effective stress on foundation before loading

Undrained cohesion value (c_u)	Thickness of geofoam 2.7 m	Thickness of geofoam 1.8 m	Thickness of geofoam 0.9 m
10	0.860	0.579	0.288
20	0.829	0.575	0.283
30	0.829	0.574	0.283
40	0.828	0.574	0.283
50	0.827	0.574	0.282

Table 3. Chart of RFs for maximum vertical effective stress on foundation after loading

Undrained cohesion value (c_u)	Thickness of geofoam 2.7 m	Thickness of geofoam 1.8 m	Thickness of geofoam 0.9 m
10	0.583	0.393	0.204
20	0.574	0.384	0.190
30	0.571	0.381	0.186
40	0.570	0.379	0.185
50	0.569	0.378	0.184

5 Conclusions

Present study demonstrates advantages of geofoam as substitute material to embankment soil. It is evident that geofoam embankment provides a good alternative to ground improvement for embankment construction over soft soil. The major findings of the present study are summarized as follows:

1. The maximum vertical effective stresses on foundation soil due to surcharge and self-weight of embankment tend to occur towards the middle of the cross-section of the embankment which makes this portion more vulnerable.
2. The RF for stress generally tend to decrease significantly after the surcharge loading is completely applied.It is seen to drop from 0.867 to 0.583 at the middle of embankment cross-section.
3. The RF for stress tends to increase towards the middle portion of the embankment cross-section. Before application of surcharge, at the edge of embankment it is 0.385 whereas at the middle it is 0.867. Similarly, after the whole surcharge is applied, the stress RF at the edge is 0.512 but at te middle of embankment cross-section it increases and becomes 0.583.
4. The design charts can be used for primary prediction of efficiency of EPS geofoam embankment constructed on soft foundation soil and also to evaluate the stresses that can be generated from the application of dead load and surcharge load.

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