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Relative Settlement of Strip Footing on Sand Mat overlying Thick Soft Clay

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ABSTRACT: Shallow foundations in plot having soft soils deposit can undergo a compression after consolidation and secondary settlement. For low to medium rise building projects on soft soil condition, a deep foundation may not be feasible for high cost. In such cases an alternative to deep foundations may be shallow strip footings placed on a double layer foundation system in which the untreated or cement treated compacted sand is upper layer to reduce the settlement to a permissible level. This research study deals with the bearing capacity of a rigid plane-strain footing placed on the surface of a soil consisting of a untreated or cement treated sand layer overlying a thicksoft clay. The study considered both the thin or thick sand layer is compared to the footing width. The response of the clay layer is undrained for elasto-plastic loading stages and drained in consolidation stages is considered.

The settlement of the shallow strip foundation resting on mentioned layered soilsystem has been analyzed. Parametric study has been conducted to determine the effect of thickness, density, cementation of sand mat and shear strength of the soft clay layer on the settlement of shallow strip foundation. A better insight of elasto-plastic, consolidation and creep settlements of the footing on sand mat under different footing pressure has been developed. This may be a guidelinefor designing shallow strip footing on sand mat over thick soft clay.

The relative settlement (S/S_o) at the center point of the footing for both untreated or cement treated upper sand mat was calculated, where S_o is the settlement for the case with H_i= 0.25m and S is the settlement for other thickness of upper sand mat. A larger value of relative settlement S/S_o indicates larger difference of settlement between the cases of small and larger thickness of sand layer. From this study it is concluded that the relative settlement S/S_0may be considered as the index of the effectiveness of sand layer.Brittle behavior of cemented sand and fracture or cracks is not considered in this analysis.

Keywords-Ground improvement, PLAXIS 2D, primary and secondary settlement, relative settlement, sand Mat, soft clay.

I INTRODUCTION

The bearing capacity of a shallow footing on a homogeneous soil may be estimated shortly using conventional bearing capacity theory in which appropriate bearing capacity factors are adopted assumption that the soil is rigid-perfectly plastic with the strength characterized by cohesion and angle of friction. This approach cannot, in general, be used for cases where the soil properties arevariable with depth. At first design charts for ultimate bearing capacity for sands overlying clay was developed by [1]. Design guideline for cement treated soil overlying clay was developed by [2].If a foundation is placed on the surface of a layered soil, and if the thickness of the top layer is comparable to the foundation width, then this approach may not be appropriate.

This research attempts to Investigate and quantify the effect of dense sand mat on soft soil on the settlement and deformation pattern or strain field of strip footings on underlying layered soil. The study considered both the cases where the thickness of the sand layer is thin or thick compared to the width of footing.The response of the clay layer is undrained for elasto-plastic loading stages and drained in consolidation stages is considered.

A parametric study has been conducted to determine the effect of thickness, density, cementation of sand mat and shear strength of the soft clay layer on the settlement of shallow strip foundation.An insight is developed to study the effectiveness of sand mat for different material characteristics to avoid punching shear failure and to limit the settlement to apermissible level.

II SELECTION OF SOIL PROPERTIES FOR THIS STUDY

Sub-soil Characteristics in different regions of Bangladesh has been used as obtained from previous literature reviewed by us. Inorganic Soft Clay Soils different parts of Bangladesh and sand of Dhaka and Major River bed of Bangladesh has been reviewedby us[3]-[5]& [8].For inorganic clay of Bangladesh generally the value of Liquid Limit (*LL)*is below exceed 60% and Plasticity Index (*PI)*is below 30%. *LL*=60% and *PI*=30% has been selected for this research[3]& [8].For Normally consolidated clay: $E_u^{50} = \frac{15000\, c_u}{I_p\%}$ [6].According to PLAXIS manual, E_u of soft soilmay be converted into $E'$by: $E' = \frac{2(1+v')}{3} E_u$ where $\nu' \leq 0.35$[6]. From literature presented by [2]&[8] for soft high plastic (CH) clay,c_u = 12kPa, $E_u^{50} = 6000$ kPaand E' =5000 kPahave been used.

Correlation between drained shear strength and plasticity index of NC clay isϕ'_{NC}(deg) = 43–10log *PI* (deg)has been used according to[9]. For *PI*=30% thiscorrelation gives asϕ'_{NC} = 28°. A value of 24° for Bangladeshi soft clay has been used in this analysis[3].As PLAXIS does not allow a zero value of drained cohesion and for that a unit value 1.0 kPa for these parameters have been used instead of zero.

According to data obtained by [3] an average value of Dry Density γ_d=14.70kN/m^3 and the relationship, $\gamma_{sat} = \gamma_d + \gamma_w \frac{e}{1+e}$ an average value of Saturated Unit Weight 20 kN/m^3 was taken for this study. According to [3] & [8] correlation for C_c of Plastic Silt and Clay of different area of Bangladesh is, C_c = 0.0078(*LL*– 14). According to the correlation for *LL*= 60%,$C_c$near to 0.35. However, a zero value of C_s is not allowed by PLAXIS and for this reason a very small value of C_s = 0.001 has been used instead of zero. According to[4] the void ratio for inorganic soft clay of Bangladesh is as large as 1.463.Liquid limit isthe mineralogical properties of a soil while the void ratio is a measure of density and may vary keeping the liquid limit fixed. Four different value of void ratio 1.00, 1.15, 1.30 and 1.45 has been used.

The literature related to properties of cement stabilization of sands has been reviewed and parameters of cement treated sand required for the present analysis have been selected from those found from literature review.For coarse-grained soils,a relationship found between cement content (by weight), *C* and unconfined compressive strength f_c for cement treated soilsobtained by[10]which is f_c = 150*C* for 90 days curing time and 413.64 kPa (60 psi) confining pressure. According to same study cement treatment leads to an increase in effective cohesion and the increase in cohesion is: $c(\text{psi}) = 7.0 + 0.225\sigma_c$, where, σ_c is unconfined compressive strength (psi) and *c* is effective cohesion. In a given range of stresses, shear strength of cemented sands can be represented by straight Mohr-Coulomb envelopes defined by c' as a unique function of cementation, and ϕ', which seems to be not affected by the cement content. Cemented soils show a very stiff behavior before yielding. The brittle behavior changes to a ductile soil response as the stress level changes from low to high. Basically, it comprises an initial stiff behavior followed by increasingly plastic deformation approaching failure.The brittle response of cemented soil increases with increasing cement content and decreases as the initial mean effective stress increases andthe axial strain at failure decreases with increasing cement content and decreasing initial mean effective stresses.

III SUB SOIL SYSTEM AND MATERIAL PROPERTIES DATA

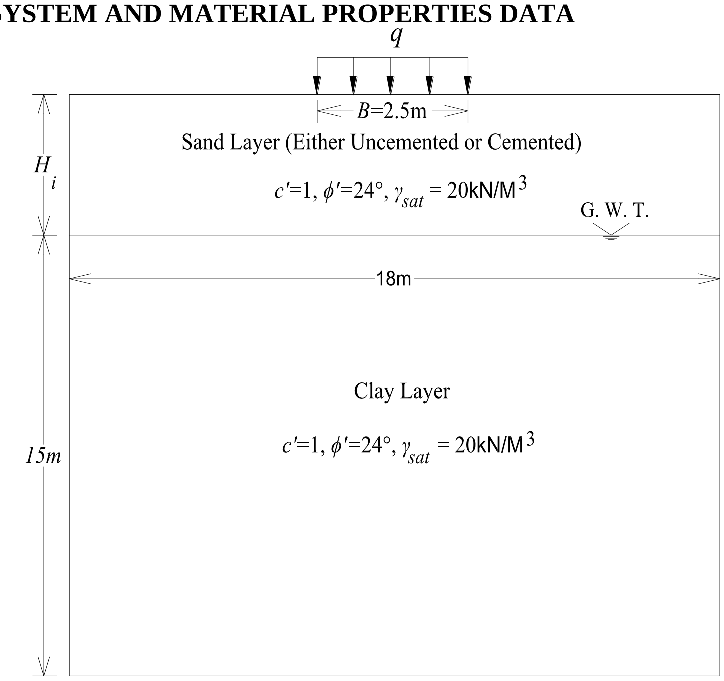

Figure 1.0. Schematic diagram of the problem.

The subsoil and strip footing system has been considered as a two layer system. The top layer is a sand layer of thickness H_i andthe bottom layer is a homogenous soft clay layer with effective shear strength parameters c' and ϕ'. The footing width B=2.5 m and this is placed on the sand layer. The length of the finite element model is 7B, and the depth of clay layer is 6Bhas beentaken as sufficiently large to avoid boundary effect so that there will be no deformation of ground at the model boundary due to footing pressure.

The bearing capacity of soil depends on strength parameters c'_{ref} and φ'. The soils were modeled with three material models-Hardening Soil (HS) Model, Soft Soil (SS) Model and Soft Soil Creep (SSC) Modelaccording to previous literatures [6] & [7]. The HS model is used to simulate the untreated and cement treated sand layer and the SS and SSC model is used to simulate soft clay layer. The input parameters used in different models are represented in Table 1.0 & Table 2.0.

Table 1.0. Material set input parameters for the lower clay layer

Parameter	**Material Set**					**Unit**
	Clay			**Sand**		
	Elastoplastic Stage	**Consolidation Stage**	**Creep Stage**	**Untreated sand)**	**Cement Treated**	
Materialmodel	HS	SS	SSC	HS	HS	-
Drainage Condition	U	U	U	D	U	-
Poisson's Ratio,v'	0.2	0.15	0.15	0.2	0.2	-
Saturated Unit Weight (below phreatic level),γ_{sat}	20	20	20	20	20	kN/m^3
Unsaturated Unit Weight (above phreatic level),γ_{unsat}	15	15	15	18	18	kN/m^3
Drained Cohesion, c'_{ref}	1	1	1	1	300	kN/m^2
Drained Friction Angle,ϕ'	24	24	24	38	38	degree
Dilatancy Angle,ψ	0	0	0	8	8	degree
Initial Stress, K_0=1-sinϕ'	0.593	0.593	0.593	0.384	0.384	-
OCR	1	1	1	-	-	1
Interface Reduction Factor, R_{inter}	1	1	1	1	1	-
Horizontal Permeability, k_x	1.0E-4	1.0E-4	1.0E-4	1	1.0E-5	m/day
Vertical Permeability, k_y	1.0E-4	1.0E-4	1.0E-4	1	1.0E-5	m/day
Triaxial Stiffness, E_{50}^{ref}	5000	-	-	5.0E+4	6.0E+5	kN/m^2
Oedometer Stiffness, E_{oed}^{ref}	4750	-	-	4.75E+4	5.7E+5	kN/m^2
Unloading/Reloading Stiffness, E_{ur}^{ref}	15000	-	-	1.5E+5	1.8E+6	kN/m^2
Power, m (Required for HS Model)	1.00	-	-	0.5	0.5	-
Compression Index, C_c	-	0.36	0.36	-	-	-
Swelling Index, C_s	-	0.001	0.001	-	-	-
Creep Index, C_α	-	-	0.018	-	-	-
Natural Void Ratio, e_{init}	1.00,1.15,1.30,1.45			0.5	0.5	-
U -Undrained and D -Drained						

Table 2.0. Material parameters for the Concrete Strip Footing

Input Parameter	Parameter Value	Unit
Material Type	Plate	-
Material Model	Elastic	-
Drainage Condition	Undrained	-
Normal Stiffness, EA	4.5E+07	kN/m

Input Parameter	Parameter Value	Unit
Flexural Rigidity, EI	1.35E+06	kNm^2/m
Equivalent Thickness, d	0.60	m
Poisson's Ratio, v'	0	-
Weight, w	0	kN/m/m

IV NUMERICAL ANALYSIS IN PLAXIS

While a three-dimensional finite element analysis is frequently used in structural or mechanical applications, it is rarely used in geotechnical problems. A plane strain finite element model has been used to carry out current two-dimensional finite element analyses. Elongated shallow footing which support load bearing walls

or a single row of columns are generally referred to a strip footing. The characteristic feature of a Plane Strain 2D Analysis is the dimension along the z-axis is considerably very large compared with the other two dimensions. Loads and boundary conditions are independent of the largest dimension and the strains in the direction of z-axis are considered to be zero. Finite Element Analysisof the strip footing on double layered soil using PLAXIS 2D is done including general settings of model geometry, standard fixities and15-node triangular element having 12 stress points i.e. gaussian integration points is used in current analysis.The type of element for structural and interfaces elements is automatically taken to be compatible with the selected type of element for adjacent soil.The 15-node triangle is a very accurate element that has produced high quality stress results for complex problems.
The plate elements are composed of beam elements having three degrees of freedom per node. A plate element has five nodes if used with 15 noded soil elements. The plate element has been selected “elastic” for all the cases to simplify the calculations and is in accordance with the reality, since strip footings are designed to have an elastic response. Interface elements are used to simulate the interaction between two materials. The boundary type restricts both horizontal and vertical displacements to zero at the bottom boundary and horizontal displacements to zero at the side boundaries.An unstructured mesh with elements and the initial water pressure is generated from the phreatic level. In the consolidation analysis, closed consolidation boundary has been used at the left and right side of the geometry andthe bottom horizontal boundary is automatically closed consolidation boundary with the top of the geometry is kept open for consolidation.

When the material is granular and the pore pressures dissipate quickly relative to the speed of loading, the added load is carried by the soil skeleton and not pore pressures. This situation is drained and effective stresses has been used in the analysis. On the other hand during loading a saturated material that allowing noporewater to dissipate quickly compared to the speed of loading, the load will be carried by the pore pressures rather than the soil skeleton and the situation is undrained analysis. Material data set has been reassigned to soil clusters to simulate its appropriate condition in different phases during various constructionstages. Automatic load stepping and load advancement was allowed and additional load step was needed.

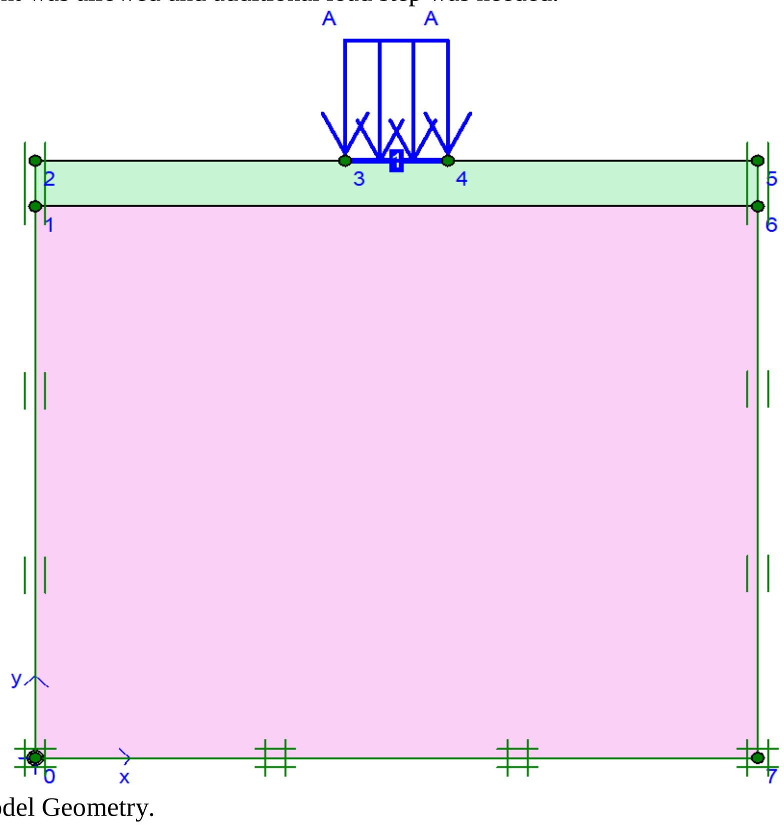

Fig.2.0 PLAXIS Model Geometry.

V 2D MODELING OF STRIP FOOTING ON SAND LAYER OVER CLAY DEPOSIT

During the modeling in PLAXIS 2D, a natural clay deposit of 15m thickness and 18m width has been used. A untreated or cement treated dense sand layer of varying thickness is considered over the natural clay deposit.

A 2.5m wide concrete strip footing is installed at the center of top surface of the sand layer (Figure 2.0). Ground water level is at top level of clay deposit that make this fully saturated. Uniformly distributed vertical load of varying value is applied to the strip footing and lots of analysis of this soil and foundation system has been carried out using PLAXIS 8.0 for the primary and secondary settlement.

Distributed load has been applied only in *y*-direction. Loads were activated firstly in the second plastic calculations phase and secondly in the creep calculations phase. Only the effective soil parameters are used in both types of material drained or undrained. A Poisson's coefficient (ν) of 0.3 has been used, which is suitable for drained conditions and alternative stiffness parameters are automatically calculated from the Young modulus and the Poisson's ratio.

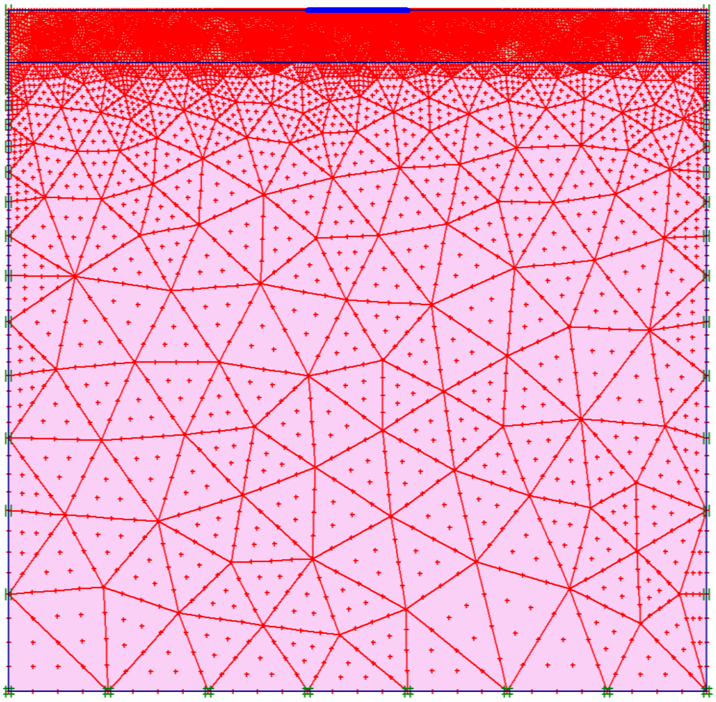

Fig.3.0 Finite element mesh for the geometry model.

Plate properties parameters have been given in Table 2.0. For thin and flexible structures a Poisson's coefficient (ν) of value of zero and strip footing has been modeled through the plate element. Then generated Fine mesh has been provided by refinement at surrounding location of footing plate for better accuracy of results and the coarseness has been increased gradually at distant location (Figure 3.0).The initial stress-state was calculated with the K_0-procedure (Jaky's formula, K_0 = 1- sin$\phi$and proper *OCR*)and the initial water condition was calculated by the direct method, using the phreatic level. The calculation was performed as a plastic and consolidation calculation and the 'Updated mesh analysis' has been chosen for all phases, as large deformations were expected. 'Updated water pressure analysis' has been used for lowering of water head. Period of secondary compression is 10-30 years. 'Ignore undrained behavior' has not been selected with K0 -procedure. PLAXIS distinguishes between drained and undrained soils to model permeable sands as well as almost impermeable clays. Excess pore pressures are computed during plastic calculations when undrained soil layers are subjected to loads.

Each calculation is carried out with an initial phase and three subsequent phases which are described below:

Phase 1: Strip foundation on a sand mat underlain by natural clay deposit. In this phase the lower layer is 'Undrained Clay' (SS Model) and the upper layer is Drained Sand or Undrained Cemented Sand (HS Model). Strip footing plate and load is activated in this phase. Elastoplastic deformation of the problem geometry under assigned load is calculated in this phase.

Phase 2: The lower layer is 'Undrained Clay' (SS Model) and the upper layer is 'Drained Sand' or 'Undrained Cemented Sand' (HS Model). No additional load is activated in this phase. Deformation of the problem geometry due to consolidation under the load applied at 'Phase 1' is calculated in this phase. The consolidation settlement occurred in this phase through dissipation of pore water pressure up to a very small value which is 1.0kN/m2.

Phase 3: The lower layer is 'Undrained Clay' (SSC Model) and the upper layer is same as 'Phase 2'. No additional load is activated in this phase. After about full dissipation of pore water pressure inter particle rearrangement or creep is occurred without application of any additional load. Creep deformation of the problem geometry under load applied at 'Phase 2' is calculated in this phase.

VI PARAMETRIC STUDY

The load that causes bearing capacity failure (soil body collapse) of surface footing is less than that for footing embedded into ground. Consolidation settlement of surface footing is more than that of embedded footing under the same load. Elasto-plastic Settlement obtained from PLAXIS analysis is 61-87% of calculated values of these from classical settlement theory. Consolidation Settlement obtained from PLAXIS analysis is 64-66% of calculated values of these from classical consolidation theory.

From each analysis total vertical settlement at footing center and deformation of the subsoil was obtained from 2D PLAXIS analyses. Footing*width*, B is kept constant for all the analysis done in this study.The dimensionless forms for a wide range of values are used to generalize their effect. Here, H_i/B is the non-dimensional layer thickness,$q/\gamma_{sat}B$ is the non-dimensional loads on strip footings.c and ϕ of soft clay and ϕ of sand mat are also kept constant for all the analysis done in this study and the value of$q$and$H_i$was varied.

Analysis was done for different footing pressure q, vertical settlement S and void ratio e_{init} for different thickness of upper sand mat layer, H_i. The values of e_{init} are 1.0, 1.15, 1.3, 1.45, values of H_i (m) are 0.75, 1.0, 1.25, 1.5, 1.75, 2.0 and q (kN/m^2) are 50, 75, 100, 125, 150, 175, 200 used in analysis which are similar to foundation pressure of three to eight storied residential or commercial buildings. The values of relative depth H_i/B used are 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 and normalizes footing pressure $q/\gamma_{sat}B$used are 1, 1.5, 5, 2.5, 3, 3.5 and 4. Settlement (downward vertical displacement) of footing center (midpoint of footing plate) is denoted as S when H_i (m)=0.75, 1.0, 1.25, 1.5, 1.75 and 2.0m. Analyses were conducted by changes of the thickness of upper sand layer from 0.25 to 2.00m.

Settlement at midpoint of footing plate when H_i=0.25m is S_0. It was tried to analyze the current problem without any sand mat and in this case bearing capacity failure occurred before completion of application of total load. Hence, a small thickness of upper sand layer equal to 0.25m has been used which is the minimum thickness to avoid soil body collapses during application of total amount of load in a PLAXIS analysis and to get the total settlement due to that load. Sand layer thickness, H_i=0.75m or more has been used for improvement purpose of the ground. It may be noted that both S_o and S changes when footing pressure changes. Settlement of the footing on improved ground is S and this is always less than $S_{0.}$ So that, $S/S_0<1.0$.This is the definition and significance of the term relative settlement, S/S_0 introduced by this research.

VII RESULTS FOR UNTREATED SAND AS UPPER LAYER

Variations of S/S_0 with $q/\gamma_{sat}B$ for different $e_{init}$is presented in Fig. 4 as plots of S/S_0 (the relative settlement) against $q/\gamma_{sat}B$, e_{init} and H_i. Effect of initial void ratio on the relative settlement is not significant. The difference of relative settlement for different normalized footing pressure remains more or less same for different value of relative thickness of upper sand mat at right zone.For a given H_i/B, with a given increase in S_o is higher compared to the increase in S. As a result S/S_o $_{is}$ decreased.Stated in a different way, a larger relative settlement means that the sand mat is more effective in controlling the settlement.For a given thickness of sand mat and clay layer, the effectiveness of the sand mat reduces with increase of footing pressure and after a certain value of footing pressure the sand mat appears to be no longer effective. For a given $H_i$as $q/\gamma_{sat}B$ is increased up to a value of 2.5 the relative settlement decreases indicating the effectiveness of the sand layer in settlement reduction. S/S_omay be considered as the index for the effectiveness of the sand layer.Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ presented in figures 5.1 to 5.4.

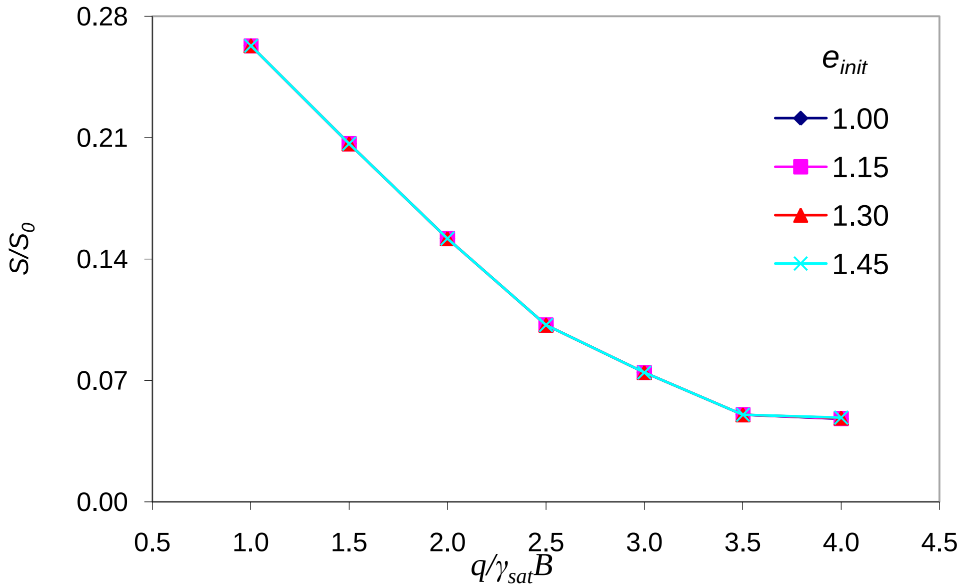

Fig. 4 Variation of S/S_0 with $q/\gamma_{sat}B$ for different e_{init} at H_i/B=0.60

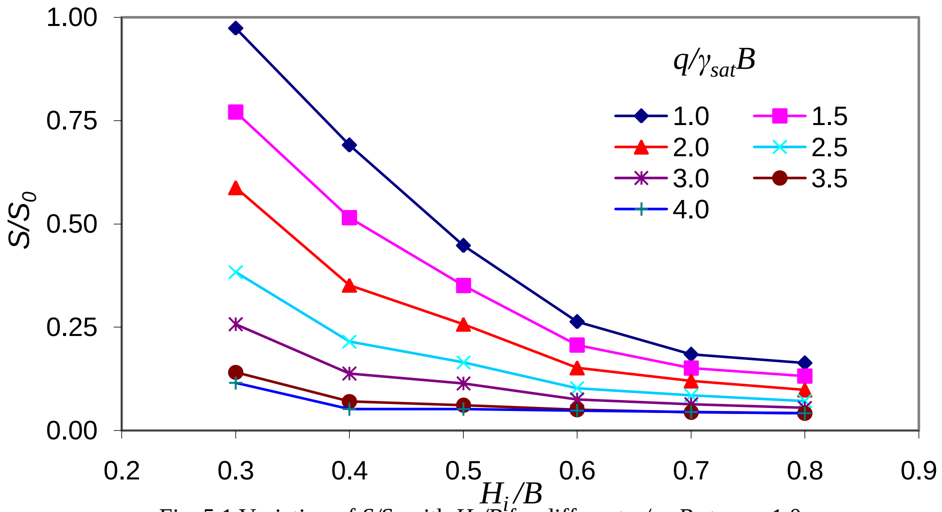

Fig. 5.1 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init} =1.0

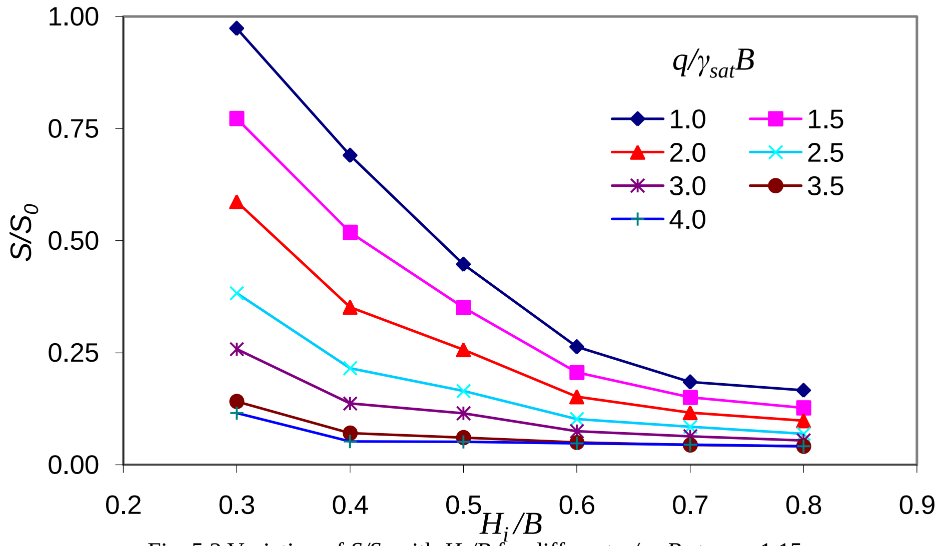

Fig. 5.2 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init} =1.15

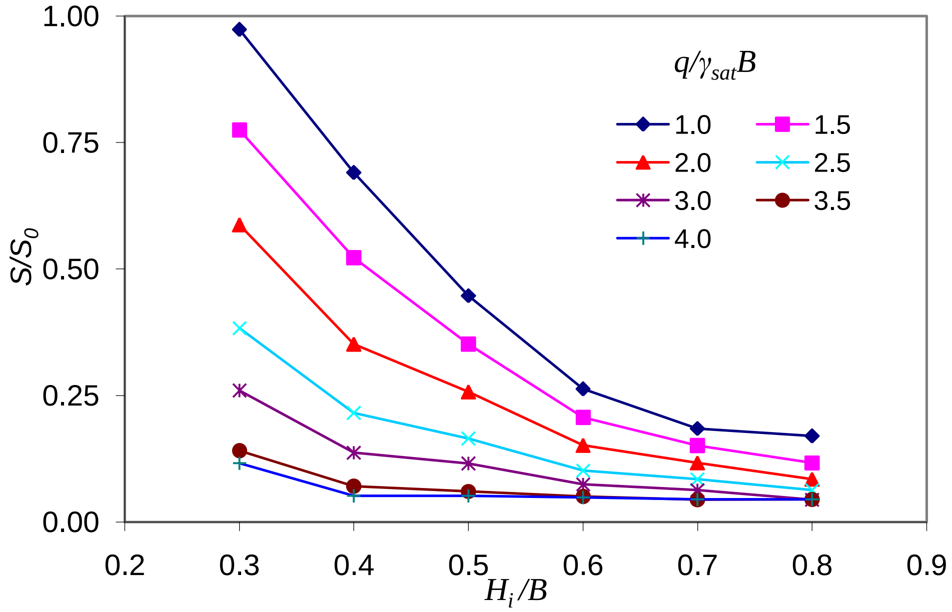

Fig. 5.3 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init} =1.3

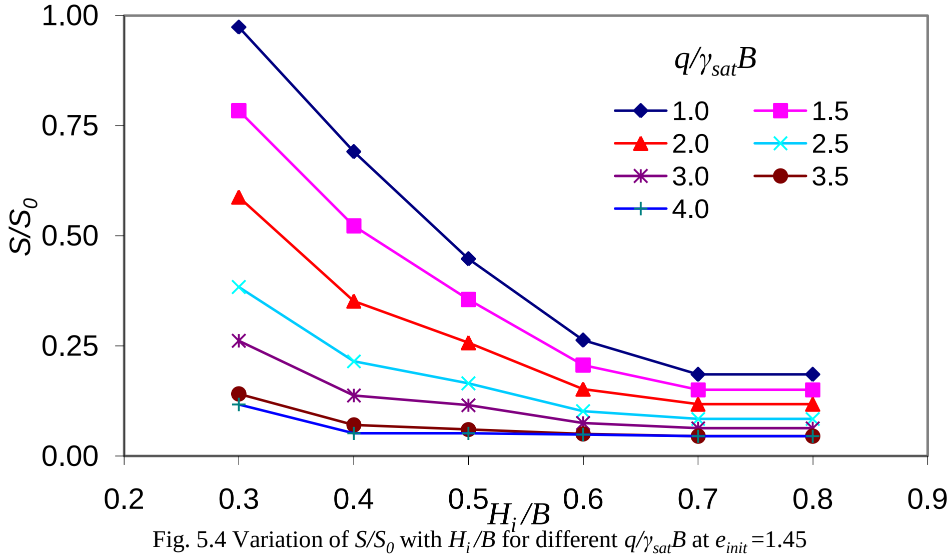

Fig. 5.4 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init}=1.45

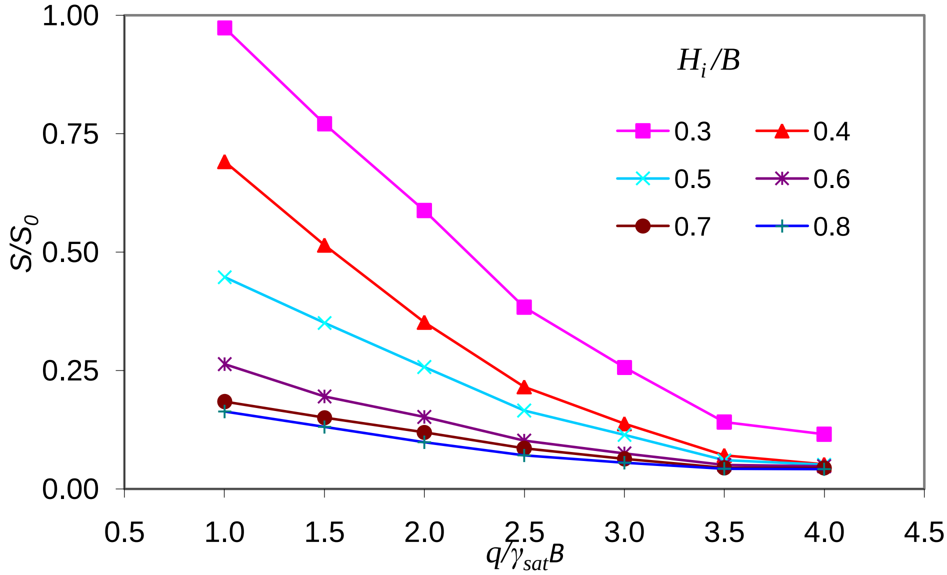

Fig. 6.1 Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at e_{init}=1.0

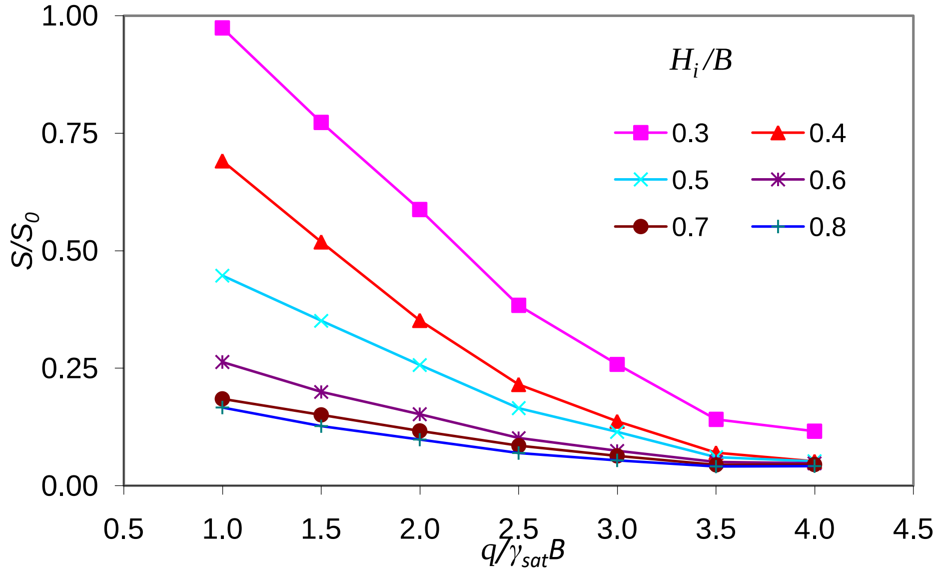

Fig. 6.2 Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at e_{init}=1.15

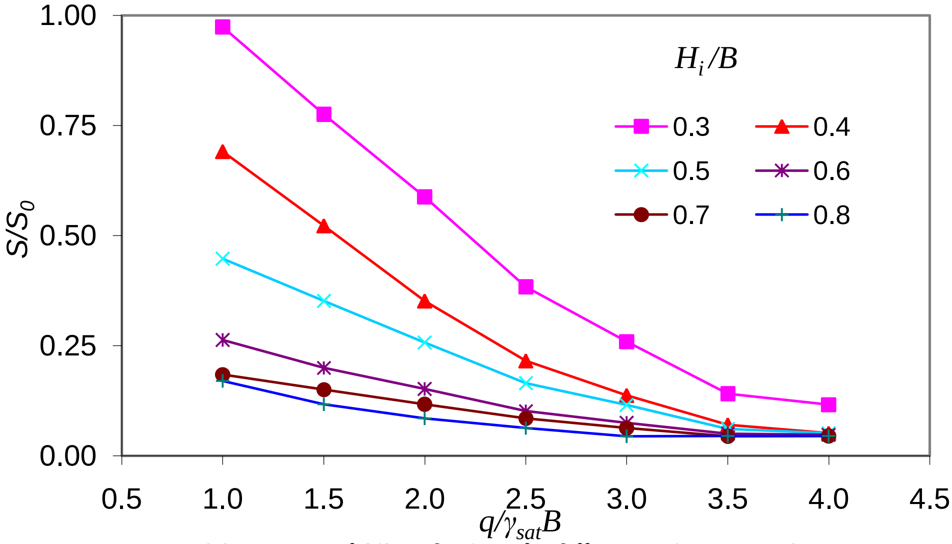

Fig. 6.3 Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at e_{init} =1.3

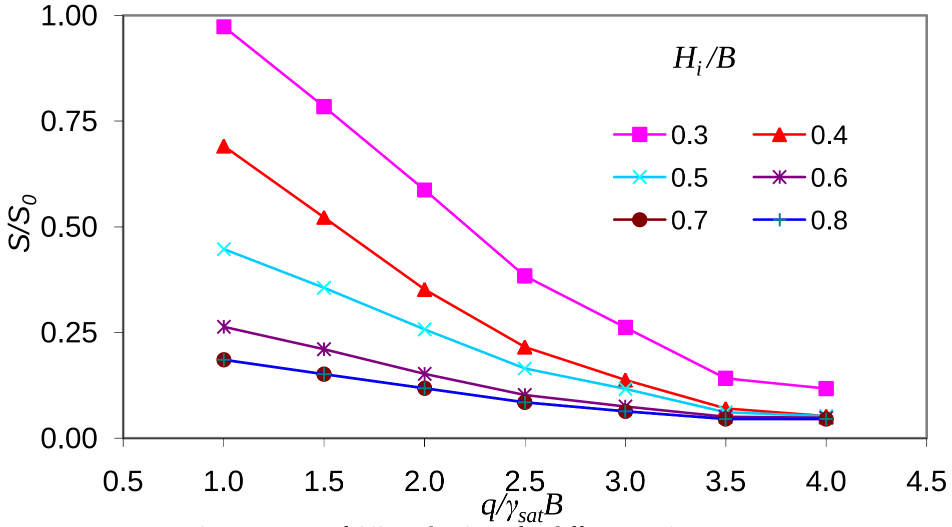

Fig. 6.4 Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at e_{init} =1.45

For a particular value of normalized footing pressure, $q/\gamma_{sat}B$, S_0 is same and therefore decrease of S/S_0 implies decrease of settlement, *S*. Thus, reduction in S/S_0 with increase in H_i/B for a given $q/\gamma_{sat}B$ indicates better settlement control (reduction) by the sand mat. It can be observed that for all value of e_{init}, S/S_0 decreases with increase of normalized value of thickness of upper sand layer *i. e.* H_i/B for a particular $q/\gamma_{sat}B$. For a value of $H_i/B \leq$ 0.6, increase of S/S_0 with $q/\gamma_{sat}B$ is more significant for values of $q/\gamma_{sat}B$ equal to 2.5 and above. On the other hand for H_i/B> 0.6, there is little change of S/S_0 with $q/\gamma_{sat}B$. For values of $q/\gamma_{sat}B$< 2.5, changes in S/S_0 for different $q/\gamma_{sat}B$ are small for any H_i/B.

Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at a given void ratio e_{init} is presented inFig. 6.1 through 6.4. It is observed that, for all value of e_{init}, S/S_0 decreases with increase of different $q/\gamma_{sat}B$ for normalized value of thickness of upper sand layer H_i/B. The relative settlement decreases at a high rate with the increase of thickness of upper sand layer H_i/B upto $q/\gamma_{sat}B$=2.5. After this particular value of footing pressure, this rate of decrease of relative settlement is smaller. For a particular value of H_i/B, decrease of S/S_0 with $q/\gamma_{sat}B$ is more significant for value of $q/\gamma_{sat}B$<2.5. For values of $q/\gamma_{sat}B$>2.5, S/S_0 at different $q/\gamma_{sat}B$ are quite closer.

IX RESULTS FOR CEMENT TREATED SAND AS UPPER LAYER

Variation of S/S_0 with $q/\gamma_{sat}B$for different $e_{init}$is presented inFig. 7 shows that for a single thickness of upper sand layer, S/S_0 decreases with increase of $q/\gamma_{sat}B$for different value of e_{init}. This decreasing rate (slope) is not constant for all $q/\gamma_{sat}B$. It is observed for Fig. 7 that the relative settlement decreases at a high rate with the increase of normalized footing pressure upto a certain value of normalized footing pressure. After this particular value of normalized footing pressure, this rate of decrease of relative settlement is smaller. In general three distinct zones can be identified in the relationship of S/S_o vs$q/\gamma_{sat}B$for different e_{init}. At left zone up to $q/\gamma_{sat}B$=2.5 the S/S_o decreases rapidly and at middle zone from $q/\gamma_{sat}B$=2.5–3.5,S/S_o rate of decrease of S/S_o is low and at right zone for

$q/\gamma_{sat}B$>3.5 there is no decrease of S/S_o.Thus for $q/\gamma_{sat}B$>3.5, sand mat is no longer effective to reduce settlement. The difference of relative settlement for different normalized footing pressure remains more or less same for different value of relative thickness of upper sand mat at right zone. A higher value of S/S_o implies smaller difference between S and S_o.

For a given thickness of sand mat and clay layer, the effectiveness of the sand mat reduces with increase of footing pressure and after a certain value of normalized footing pressure 3.5 the sand mat appears to be no longer effective. Similar observation can be made for all other thickness (0.75m–2.0m) of sand layer.
For a given $H_i$if the $q/\gamma_{sat}B$ is increased up to a value of 2.5 the relative settlementS/S_o decreases indicates increasing effectiveness of the sand layer in reducing the settlement. However, beyond the value of $q/\gamma_{sat}B$=2.5, there is little reduction in relative settlement.

Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ *and* for different void ratiosis presented in figures 8.1 to 8.4. For a particular normalized footing pressure, $q/\gamma_{sat}B$, S_0 is same and therefore decrease of relative settlement, S/S_0 implies decrease of settlement, S. Reduction in S/S_0 with increase in H_i/B for a given $q/\gamma_{sat}B$ indicates better settlement control (reduction) by the sand mat. It can be observed from these graphs that for all value of e_{init}, S/S_0 decreases with increase of normalized value of thickness of upper sand layer *i. e.* H_i/B for a particular $q/\gamma_{sat}B$. For a value of $H_i/B \leq 0.6$, increase of S/S_0 with $q/\gamma_{sat}B$ is more significant for values of $q/\gamma_{sat}B$ equal to 2.5 and above. On the other hand for H_i/B> 0.6, there is little change of S/S_0 with $q/\gamma_{sat}B$. For values of $q/\gamma_{sat}B$< 2.5, changes in S/S_0 for different $q/\gamma_{sat}B$ are small for any H_i/B.

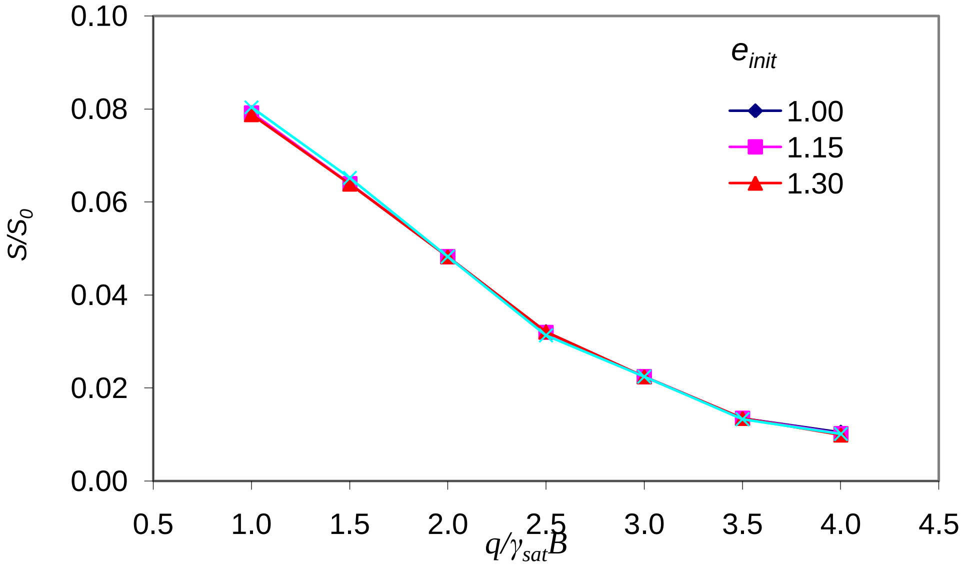

Fig. 7 Variation of S/S_0 with $q/\gamma_{sat}B$ for different e_{init} at H_i/B=0.40

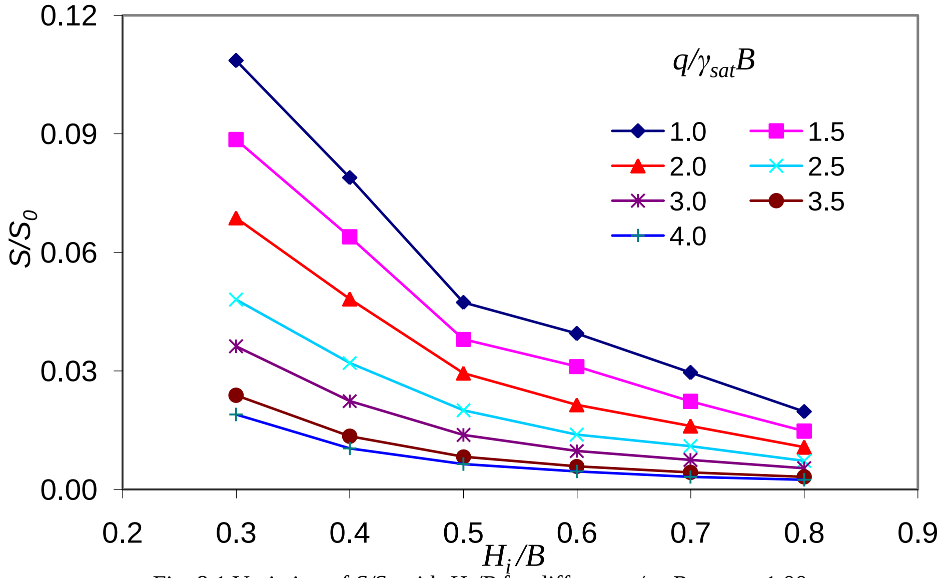

Fig. 8.1 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init} =1.00

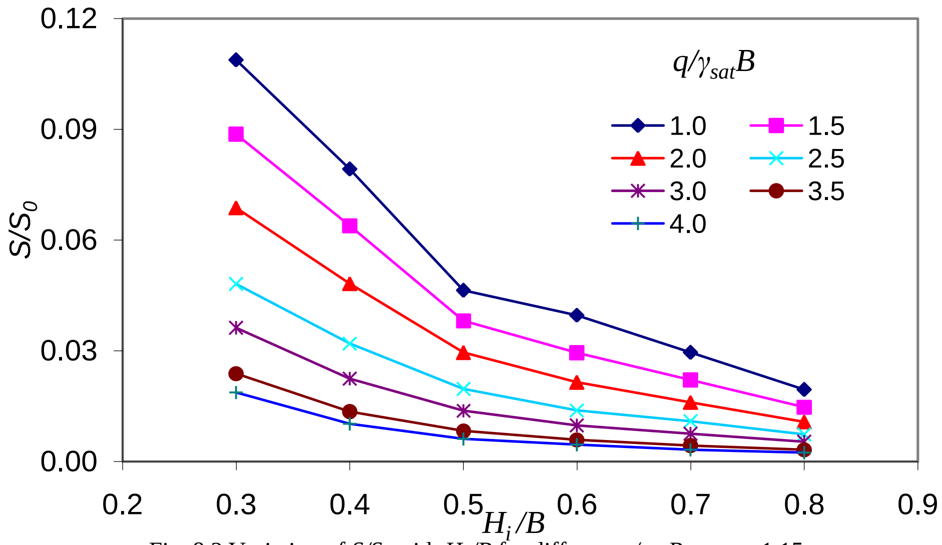

Fig. 8.2 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init}=1.15

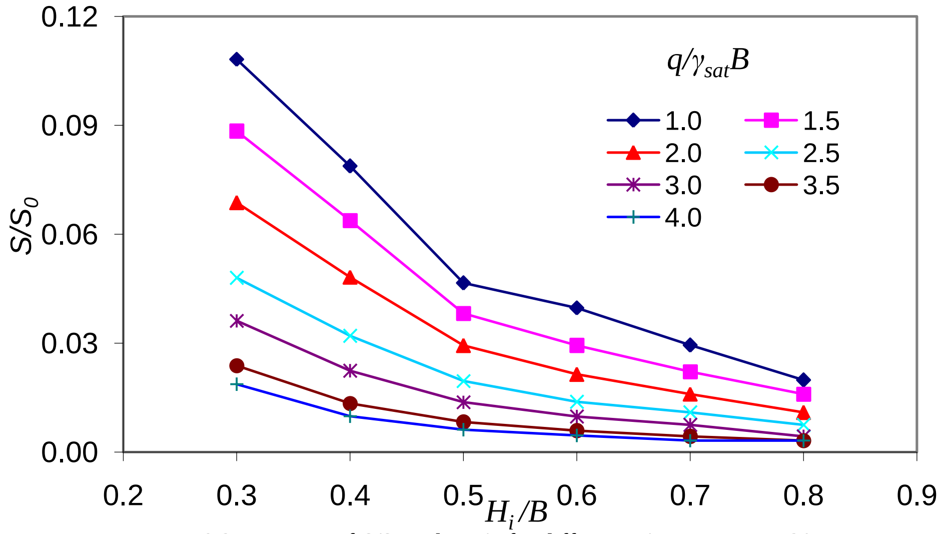

Fig. 8.3 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init}=1.30

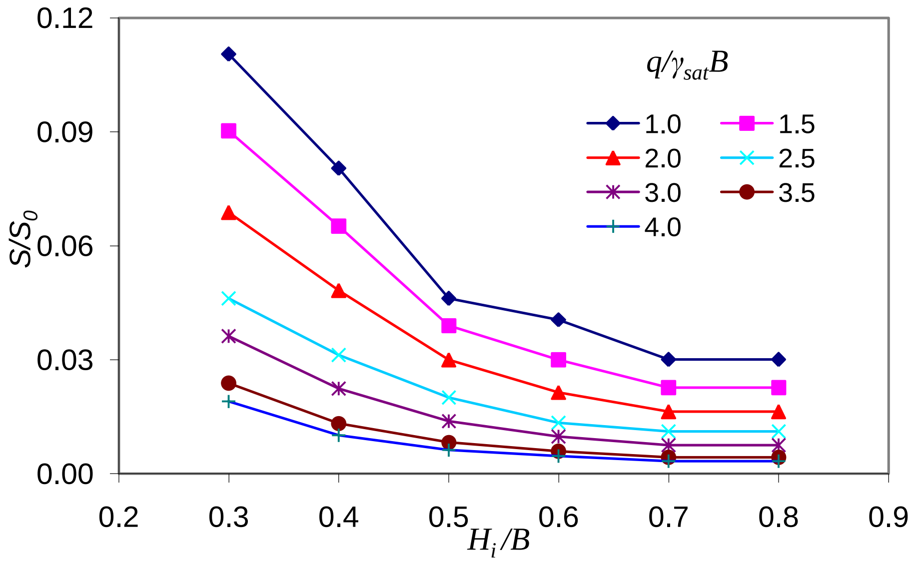

Fig. 8.4 Variation of S/S_0 with H_i/B for different $q/\gamma_{sat}B$ at e_{init}=1.45

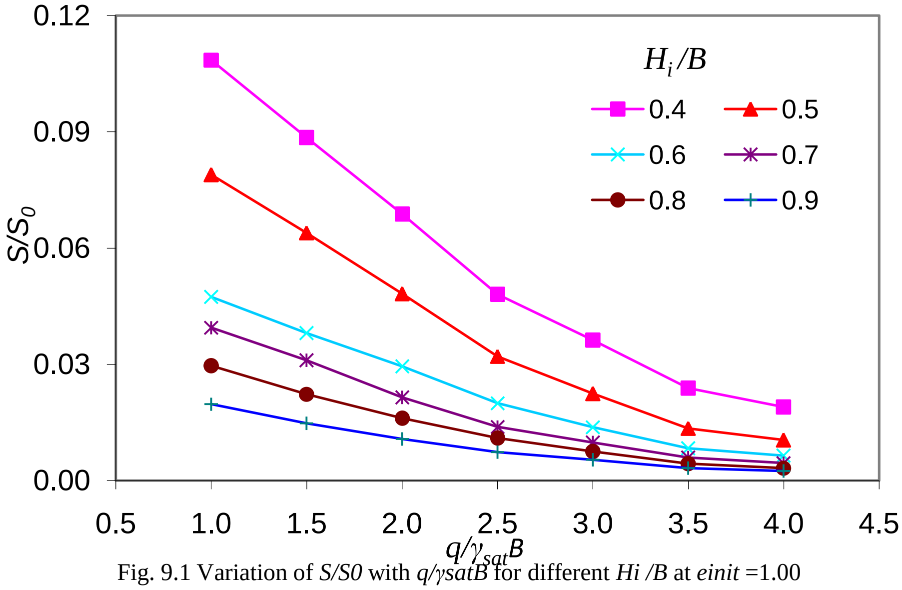

Fig. 9.1 Variation of *S/S0* with *q/γsatB* for different *Hi /B* at *einit* =1.00

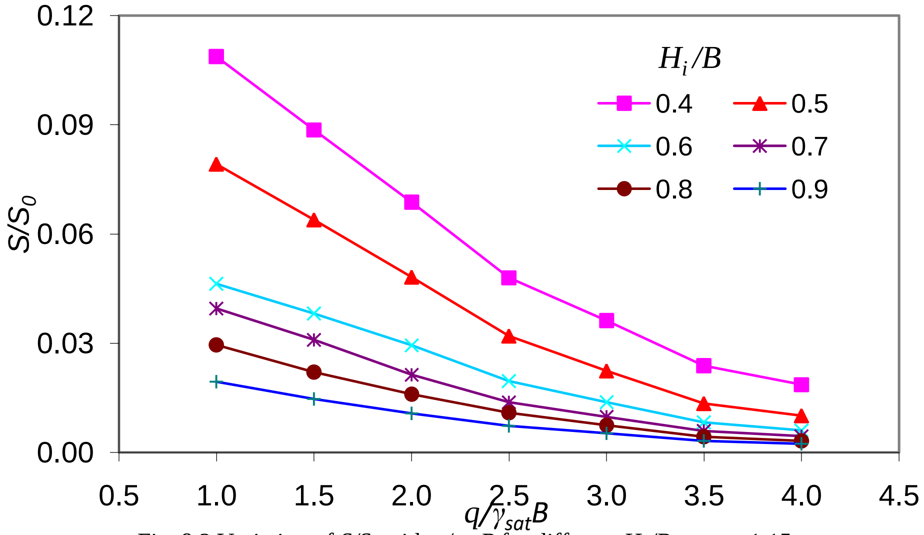

Fig. 9.2 Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at e_{init} =1.15

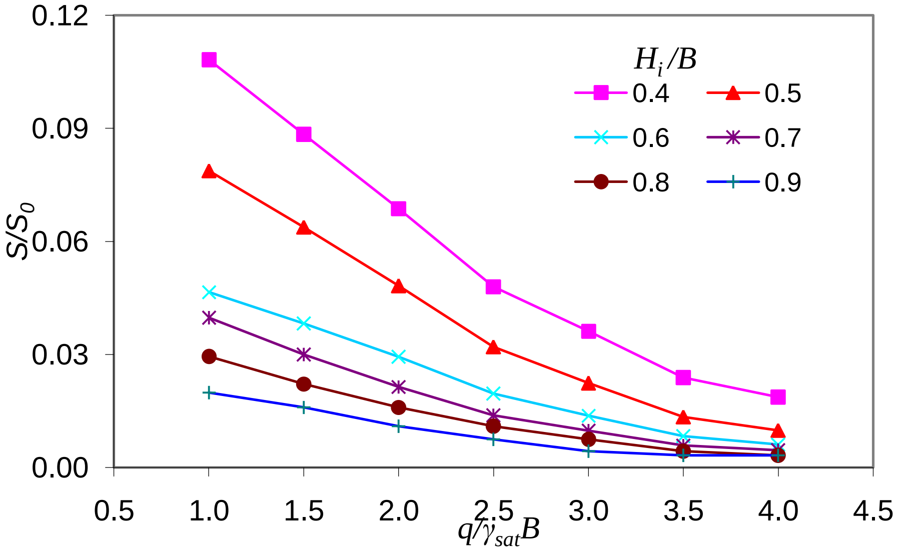

Fig. 9.3 Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at e_{init} =1.30

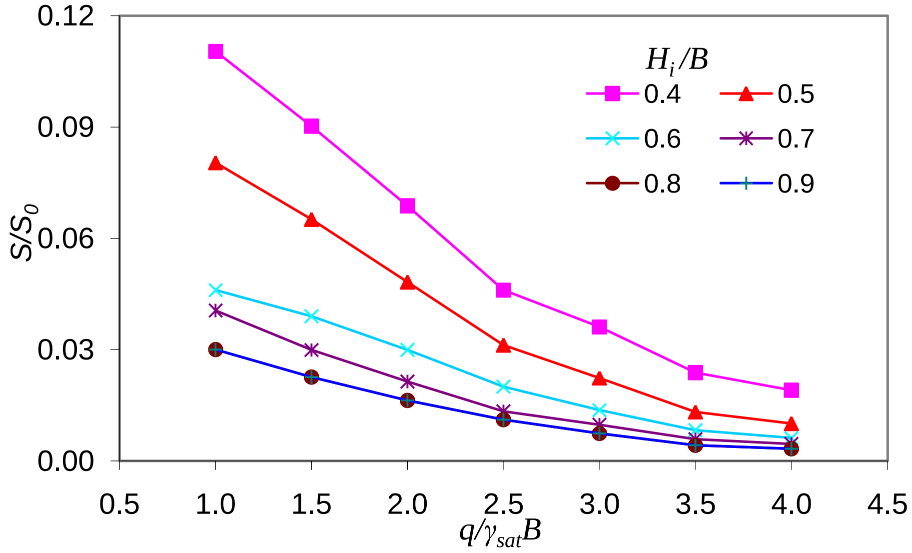

Fig. 9.4 Variation of S/S_0 with $q/\gamma_{sat}B$ for different H_i/B at e_{init}=1.45

Variation of S/S_0 with $q/\gamma_{sat,1}B$ for different H_i/B is presented in Fig. 9.1 through 9.4 presents the effect of $q/\gamma_{sat}B$ on S/S_0 for various H_i/B and at a given e_{init}. It is observed that for all value of e_{init}, S/S_0 decreases with increase of different $q/\gamma_{sat}B$ for normalized value of thickness of upper sand layer H_i/B. It is observed that the S/S_0 decreases at a high rate with the increase of thickness of upper sand layer H_i/B =2.5. After this particular value of footing pressure, this rate of decrease of S/S_0 is smaller. For a particular value of H_i/B, decrease of S/S_0 with $q/\gamma_{sat}B$ is more significant for value of $q/\gamma_{sat}B$<2.5. For values of $q/\gamma_{sat}B$>2.5, S/S_0 at different $q/\gamma_{sat}B$ are quite closer.

X COMPARISON BETWEEN EFFECTIVENESS OF UNTREATED AND CEMENT TREATED SAND LAYER

The effectiveness of Untreated and Cement Treated Sand upper layer is compared in this section.For e_{init}=1.0 the effectiveness of untreated upper sand layer and cement treated upper sand layer is presented in Fig. 10.1 and Fig. 10.2 as variation of S/S_0 with $q/\gamma_{sat}B$for different Sand Type at different H_i/B.
From Fig. 9.1 through 9.4 it is observed that for $q/\gamma_{sat}B$< 2.5 the cement treated upper sand layer is more effective than untreated upper sand layer in reducing S/S_0 and for $q/\gamma_{sat}B$> 2.5 the effectiveness of untreated upper sand layer and cement treated upper sand layer is about similar in reducing relative settlement S/S_0.

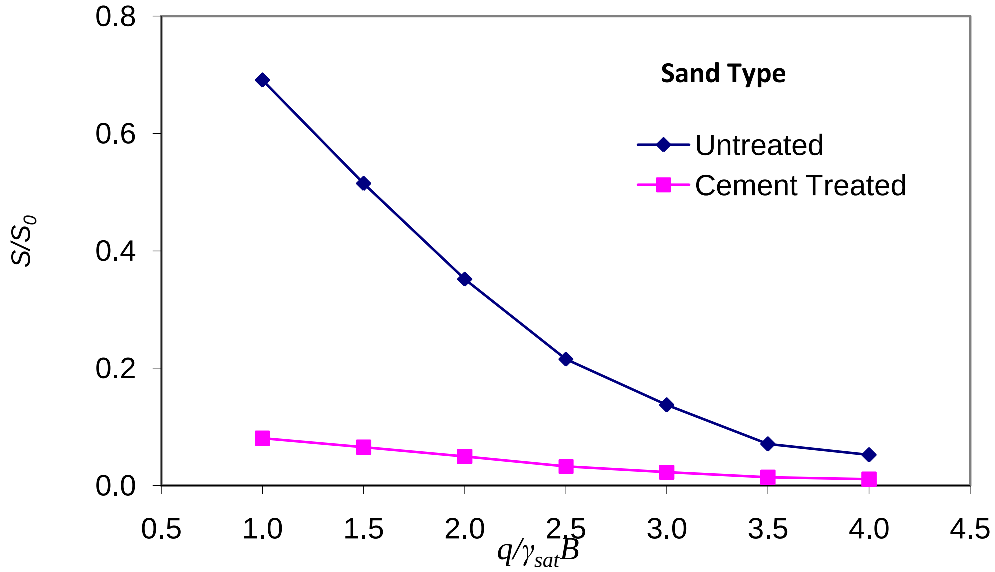

Fig. 10.1 Variation of S/S_0 with $q/\gamma_{sat}B$ for different Sand Type at H_i/B=0.4

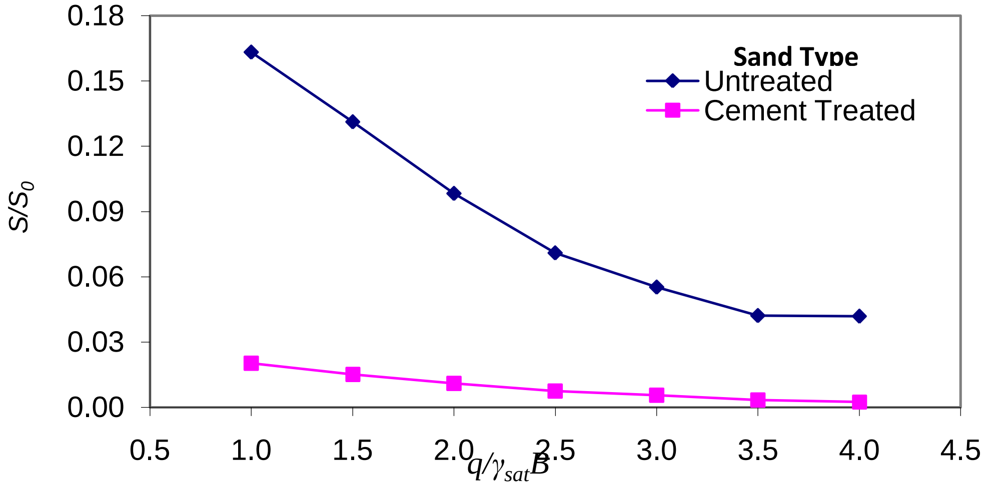

Fig. 10.2 Variation of S_R/S_{0R} with $q/\gamma_{sat}B$ for different Sand Type at H_i/B=0.8

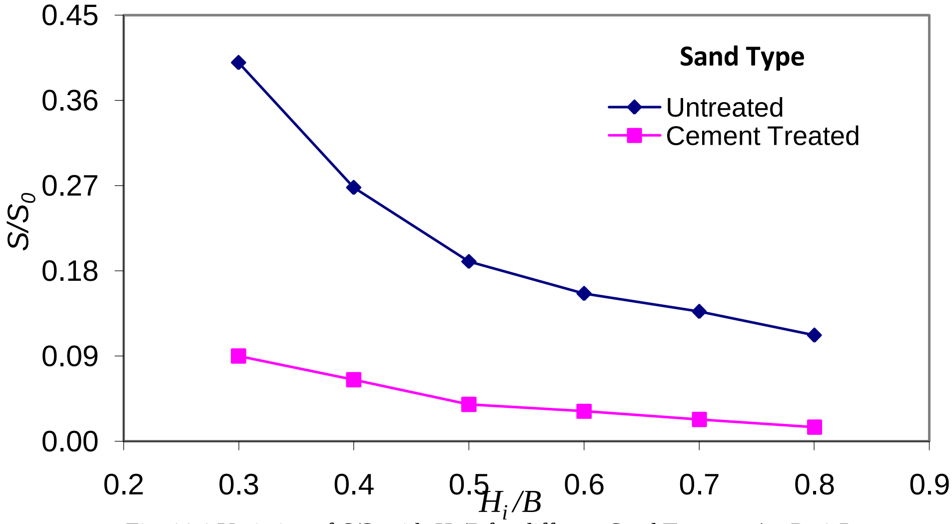

Fig. 11.1 Variation of S/S_0 with H_i/B for different Sand Type at $q/\gamma_{sat}B$=1.5

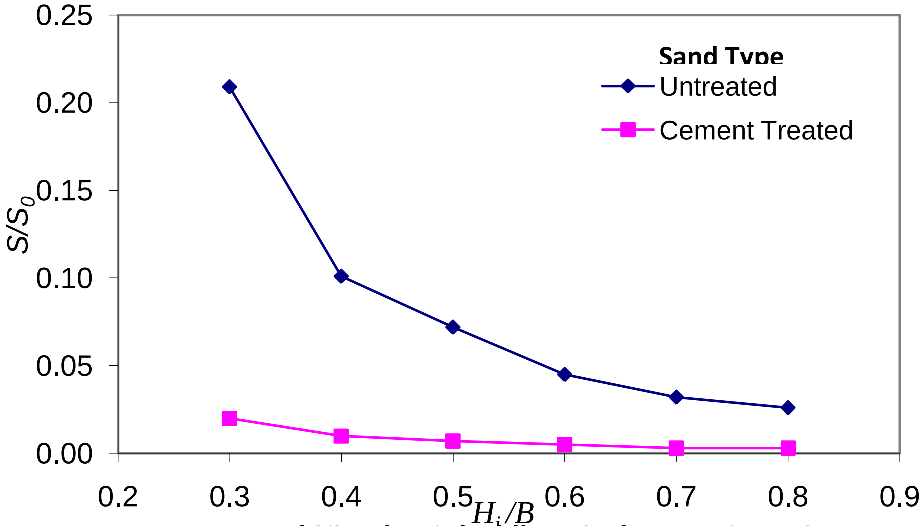

Fig. 11.2 Variation of S/S_0 with H_i/B for different Sand Type at $q/\gamma_{sat,1}B$=3.5

For e_{init}=1.0 the effectiveness of untreated upper sand layer and cement treated upper sand layer is presented in Fig. 11.1 and 11.2 as variation of S/S_0 with H_i/B for different Sand Type at different $q/\gamma_{sat,1}B$. It is observed that for H_i/B<0.5 the cement treated upper sand layer is more effective than untreated upper sand layer in reducing relative settlement S/S_0 and for H_i/B>0.5 the effectiveness of untreated upper sand layer and cement treated upper sand layer is about similar in reducing relative settlement S/S_0.

XI SIGNIFICANCE OF RELATIVE SETTLEMENT S/S_0

Thus a higher value of S/S_o implies larger difference between S and S_o. Stated in a different way a larger relative settlement means that the sand mat is more effective in controlling the settlement. For a given thickness of sand mat and clay layer, the effectiveness of the sand mat reduces with increase of footing pressure and after a certain value of footing pressure the sand mat appears to be no longer effective. Similar observation can be made for both untreated or cement treated upper sand layer.

The relative settlement decreases at a high rate with the increase of normalized footing pressure upto a certain value of normalized footing pressure for both untreated or cement treated upper sand layer. In general three distinct zones can be identified in the relationship of S/S_o vs$q/\gamma_{sat}B$for different e_{init}. At left zone up to $q/\gamma_{sat}B$=2.5 the S/S_o decreases rapidly and at middle zone from $q/\gamma_{sat}B$=2.5 to 3.5 the S/S_o decreasing rate of S/S_o is low and at right zone for $q/\gamma_{sat}B$>3.5 there is no decrease of S/S_o. That is sand mat is no longer effective to reduce settlement at $q/\gamma_{sat}B$>3.5. The difference of relative settlement for different normalized footing pressure remains more or less same for different value of relative thickness of upper sand mat at right zone. The relative settlement decreases for a given $H_i$if the $q/\gamma_{sat}B$ is increased up to a certain value of 2.5 means the effectiveness of the sand layer in controlling settlement reduces for both untreated or cement treated upper sand layer. S/S_omay be considered as the index of the effectiveness of sand layer.The relative settlement decreases with increase of normalized value of thickness of upper sand layer *i. e.* H_i/B for particular $q/\gamma_{sat}B$for all value of e_{init}. The relative settlement decreases at the same rate with the increase of thickness of upper sand layer H_i/B. For a particular value of H_i/B increase of S/S_0 with $q/\gamma_{sat}B$ is more significant for values of $q/\gamma_{sat}B$> 2.5. For $q/\gamma_{sat}B$<2.5,S/S_0 at different $q/\gamma_{sat}B$ are closer.For all value of e_{init}, S/S_0 decreases with increase of different $q/\gamma_{sat}B$ for normalized value of thickness of upper sand layer H_i/B. The relative settlement decreases at a high rate with the increase of thickness of upper sand layer H_i/Bupto a certain value of normalized footing pressure which is 2.5. After this particular value of footing pressure, this rate of decrease of relative settlement is smaller. For a particular value of H_i/B increase of S/S_0 with $q/\gamma_{sat}B$ is more significant for $q/\gamma_{sat}B$>2.5. For $q/\gamma_{sat}B$<2.5 S/S_0 at different $q/\gamma_{sat}B$ are closer.

The cement treated upper sand layer is more effective than untreated upper sand layer in reducing relative settlement S/S_0,for $q/\gamma_{sat}B$<2.5 and for $q/\gamma_{sat}B$>2.5, the effectiveness of untreated upper sand layer and cement treated upper sand layer is about similar in reducing relative settlement. For H_i/B<0.5 the cement treated upper sand layer is more effective than untreated upper sand layer in reducing relative settlement S/S_0 and for H_i/B>0.5 the effectiveness of untreated upper sand layer and cement treated upper sand layer is about similar in reducing relative settlement.

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