Analysis of Geogrid Reinforced Sub-Base Under Grade Slab for Different Material Stacking Condition by Numerical Modelling

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Abstract : The increased value of land has augmented the use of material stacking by various methods in the Industrial world. This material storage is done by pallet racking systems which generates point loads or by block stacking (storage of material over one another) creating huge distributed loads. Grade slab subjected to these loads normally gets cracked because of poor prediction of support provided by sub-base. This study aims to analyze the sub-base characteristics and improvement of the same by providing geogrid within it to control the settlement induced by these loads. In this specific investigation, numerical modelling (FEM) of concrete grade slab, square in shape (12.3m x 12.3m) having a thickness of 150mm on sub-base of compacted sand underlain by stratified soil profile with top layer of soft soil (clayey type) is done using PLAXIS3d. To investigate the impact, a parametric study of each factor is considered by forming different cases for variant sub-base stiffness (E), sub-base thickness (t), tensile stiffness of geogrid (EA), and also a varied depth of geogrid (d); for different loading condition i.e., block-stacking and static rack loading with the moving loads of material handling equipment (MHE). The economic viability of geogrid reinforced subbase for particular soil and loading condition is also swotted. Overall scenario concludes that the competence of geogrid reinforced subbase in reduction of the differential settlement of industrial grade-slab is greatly influenced by subbase stiffness and thickness. By the use of numerical analysis, behaviour and effectiveness of geogrid reinforced subbase for grade slab subjected to different loading conditions are easily understood.

Index Terms - **Geogrid, Subbase, Industrial Racking, Numerical Modelling, PLAXIS.**

1 INTRODUCTION

The term "grade slab" is used to describe a system consisting of a concrete slab, reinforced or unreinforced, resting on a continuous subgrade. The most common applications of concrete slabs on grade are industrial floorings such as warehouses, process units and pavement systems. The thickness of the slab can vary depending on the type and magnitude of loading on the floor, as well as the characteristics of the supporting subgrade. One of the major problems for material storage system in a warehouse is the differential settlement of grade slab, which leads to cracking of grade-slab. This generally occurs because of poor prediction of support provided by sub-soil, excessive loading or weak sub-soil conditions such as soft clay.

The case study of an industrial slab for a production hall underlain by soft soil, done by D. Marian et al [1] clearly define the need for proper evaluation of ground conditions to predict the behaviour of grade slab. J. Kawalec and J. Sękowski [2] has stated that industrial floors, high-bay warehouses, open storage yards with loading 30 kN/m2 or more requires a greater depth (at least to the depth equivalent to the replacement height of an earth embankment) of investigation to avoid cracking and differential settlement problems. Even though soil or subbase characteristics and ground conditions play an important role in the behaviour of grade slabs, traditional methods for designing grade slabs do not account for the effect of soil properly. A study by O. A. Sall et al [3] shows the impact of soil characteristics on the deformation of grade slab compare to characteristics of concrete. J. Irving [4] claims that slab on ground is more resistant when the subgrade stiffness is more, or first cracking load increase if subgrade is stiffer. In contrast, E. P. Kearsly and W. Elsaigh [5] claims that more ductile slab is better when the subgrade is not very tough. D. Tomasovicovaa and N. Jendzelovskya [6] has carried out a numerical study considering 4 thickness of subbase and 12 subbase stiffness to examine the behaviour of grade slab under a set of applied point load.

Characteristics of sub-base soil can be improved by various ground improvement methods. However, from all the methods use of geosynthetics (geogrids) as reinforcement under grade-slab is more practical because it is very easily available and easy to install at most locations. Geogrids generally mobilize high soil-reinforcement bond stress, provide high tensile strength and good axial stiffness, which leads to better load-settlement characteristics and saving in construction costs. (M. Laman and A. Yildiz [7]). Also, geogrid as reinforcement can be used instead of compaction of the soil, thus reducing labour and equipment requirements considerably. Geogrids are strong in tension, which allows them to transfer forces to a larger area of soil leads to beneficiary use over soft soils. Reinforcement provided in soil develops a bond by frictional contact between the surface area of reinforcement and the soil particles. Deformation induced in the soil reasons a tensile or compressive force to develop in the reinforcement, depending on whether the reinforcement is inclined in a direction of tensile or compressive strain in the soil. (R. Jewell [8]) R. Rowe and K. Soderman [9] examined the probable effects of geotextile reinforcement on the stability of embankments constructed on peat (organic soil) underlain by a soft clayey layer. R. Unnam et al [10] carried out a study to investigate the performance of subgrade soil using geogrids on two different subgrades with different geosynthetic reinforcement by analyzing the CBR parameter. Large scale testing was done on slab on grade strips resting on a uniformly graded lightweight aggregate reinforced with geogrids is done by O. Hernandez et al [11]. The study had concluded that the subgrade with unreinforced soil had a lower modulus of subgrade than a reinforced soil. A. Demir et al [12] carried out a study on 8 field tests using circular footing with a diameter of 0.30 m, rigid in behaviour resting over compacted granular fill underlain by soft soil. Results from the study conclude that significant improvement in load-settlement characteristics can be obtained by placing a compacted subbase layer of limited thickness over a soft clay subsoil. And further improvement in load-settlement characteristics can be achieved by placing geogrid reinforcement layers within compacted subbase layer.

Two approaches were developed over a time span to simplify the problem of soil-structure interaction which were mechanical approach and elastic continuum. Over time numerical methods are developed to solve the differential equations generated from these approaches in computer easily and swiftly, which leads to a numerical approach to solve the complex soil-related problems. This study aims to examine the sub-base characteristics and improvement of the same by providing geogrid within it to control the settlement induced by different loading schemes. In this specific investigation, numerical modelling of concrete grade slab, on sub-base of compacted sand underlain by soft soil (clayey type) is done using Plaxis3D. The main objective of the study is to examine the behaviour of grade slab for different subbase stiffness and subbase thickness under different loading conditions i.e., Static rack loading and Block-stacking for both unreinforced (URSB) and geogrid reinforced (GRSB) subbase. The economic viability of geogrid reinforced subbase for a reduction in thickness of subbase under industrial loading is also swotted. In addition to this, the influence of geogrid parameters such as strength and location of geogrid is also considered in this study.

2 Numerical Modelling and Materials

In this study, behaviour of the grade slab having a size of 12.3m x 12.3m is subjected to both loading conditions is studied by series of three-dimensional numerical analyses (FEM modelling). This grade slab has the properties of M25 grade concrete and a thickness of 150 mm. As shown in fig 1, block-stacking conditions were considered which ranges from 50 to 190 kN/m2 depending on the density of the material to be stored and 7 stage racking system as shown in fig. 2 is considered for a static rack case. Generally, loading in static rack case varies from 80 to 200 kN.

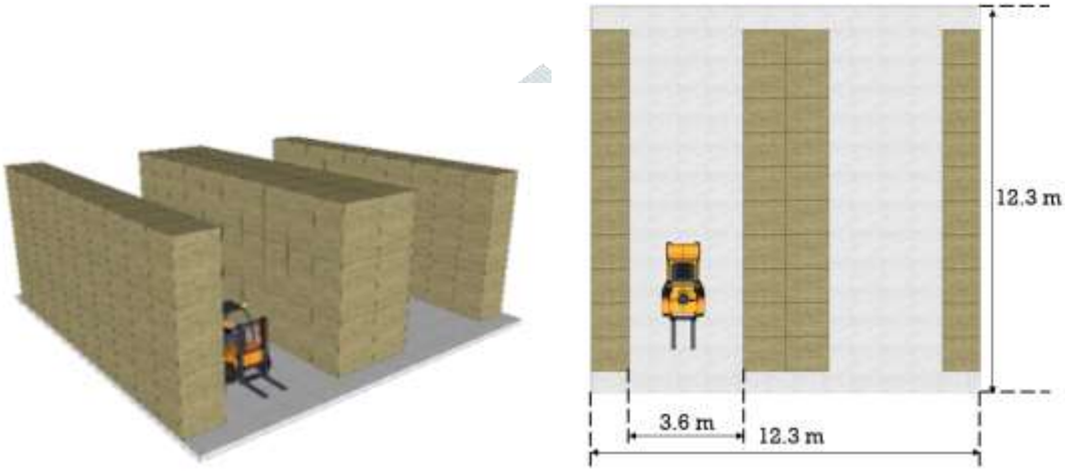

Fig. 1 Block stacking considered for study (a) 3D visualization (b) Plan

Loads are selected for this study in such a manner that total load intensity per m^2 acting on grade slab is same for both the case. For both the case, aisle width is 3.6 m as shown in fig. 1 and fig. 2. Also, a load of material handling Unit (MHE) is same for both the case. The characteristics of MHE (here, forklift) are length of 2500 mm, width is 900 mm and load capacity of 2270 kg. To investigate the impact of every factor, a parametric study of each factor is considered by forming different cases for variant sub-base stiffness (E), sub-base thickness (t), axial stiffness of geogrid (EA), and also a varied depth of geogrid (d) is carried out. Variables considered for this study are shown in table 1.

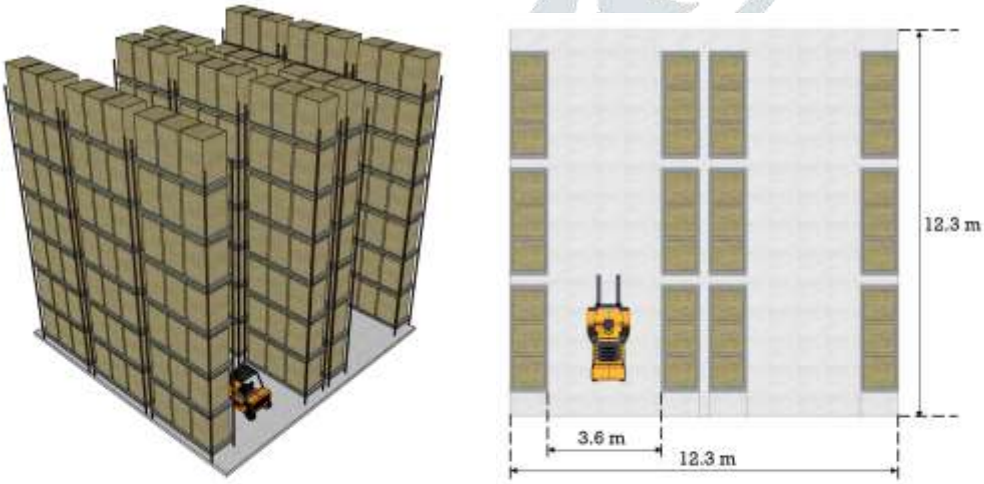

Fig. 2 Static rack loading considered for study (a) 3D visualization (b) Plan

Table 1 Parameters considered for the study

Parameters used in this study		
Load Type	Point load (kN)	200, 160
	UDL (kN/m^2)	185, 150
Subbase Characteristic	Stiffness (kN/m^2)	20, 22.5, 25, 35, 45, 55, 65
	Thickness (mm)	950, 1050, 1150, 1250
Geogrid characteristics	Elevation from G.L. (mm)	500, 1050
	EA=Axial Stiffness (kN/m)	1000, 1500, 2500

In this study borehole of 30 m is modelled in Plaxis3D, which has different layers of soft soil – classified as CH, Intermediate plastic clay – CI, and clayey sand – SC. The soil profile considered for this study is shown in table 2. The water table is assumed at 3.0 m below ground level.

CI and SC soils are modelled as Hardening soil model and CH soil is modelled with soft soil in Plaxis3D. In Hardening soil model, the strains (elastic and plastic) are calculated based on the hardness of the surface tension and this hardness is different for the initial loading and unloading/loading. (R. Obrzud [13]) In this model, the behaviour of the material is nonlinear before the break, and after defeating, behaviour is determined based on Mohr-Coulomb strength parameters (cohesion and angle of internal friction). The hardening Soil model is quite suitable for soft soils. Indeed, most soft soil problems can be analyzed using this model, but the Hardening Soil model is not suitable while considering very soft soils with high compressibility, i.e., $E_{oedref}/E_{50ref} < 0.5$. For such soils, the Soft Soil model may be used. So, for CH soil soft soil model is utilized. The parameters of soils considered in the study are shown in table 3.

Table 2 Soil profile

Nos.	Soil	Top (m)	Bottom (m)
1	Subbase – Moorum sand	0.00	-1.05
2	Soft soil - CH	-1.05	-10.30
3	Clay - CI	-10.30	-13.50
4	Clayey sand - SC	-13.50	-19.00
5	Soft soil - CH	-19.00	-25.00
6	Clayey sand - SC	-25.00	-28.00
7	Soft soil - CH	-28.00	-30.00

Table 3 Soil properties

Parameter	Name	Compacted Sand	CI	SC	Soft soil	Unit
Dry unit weight	γ_{unsat}	17	16.5	16.6	15	kN/m^3
saturated unit weight	γ_{sat}	20	19	20	18	kN/m^3
Modified compression index	λ^*	-	-	-	0.05	-
Modified swelling index	κ^*	-	-	-	0.01	-
Secant stiffness in standard drained triaxial test	E_{50ref}	$25 \cdot 10^3$	$9.6 \cdot 10^3$	$35 \cdot 10^3$	-	kN/m^2
Tangent stiffness for primary oedometer loading	E_{oedref}	$25 \cdot 10^3$	$10.5 \cdot 10^3$	$35 \cdot 10^3$	-	kN/m^2
Cohesion	$c_{ref'}$	1	0	5	2	kN/m^2
Friction angle	φ'	33	28	30	15	°
Dilatancy angle	ψ	3	0	0	0	°

In the present study, for all the cases grade slab of M25 Grade and 150 mm thickness is considered as an elastic plate, such that the grade slab behaves like a flexible foundation. From another study, it is observed that by increasing the thickness of the grade slab the behaviour becomes more rigid and deformation among grade slabs will be more uniform. To design the grade slab structurally, the minimum thickness should be adopted to counter the forces and moments induced in the grade slab. Geogrids are modelled as linear elastic tension member with varied axial stiffness of 1000, 1500 and 2500 kN/m. In Plaxis3D, any surface can be modelled as a tension member by selecting it as a “geogrid” element as shown in fig. 3. It will take only axial forces, and no bending moments or shear forces will be induced in this element. To consider the membrane effect in geogrids “updated mesh” is to be selected. In the normal small deformation’s theory (without update mesh), it is not possible to model second-order effects: axial strains develop due to the differential lateral displacements of the geogrid (not in the geogrid's axial direction). However, with an updated mesh, this will work because the nodes of the finite element mesh will be updated at each step. Also, Geogrids are modelled with an offset of 1 m outside the grade slab to provide end anchorage. If geogrids were cut off at the edge of the grade slab, then tension force developed in geogrid at the edge will not be transferred to soil properly.

To reduce the run time and achieve sufficient accuracy, the global mesh size is selected as medium with a maximum size of element as 3.84 m. However, for grade slab and geogrid, a coarseness factor of 0.5 is used to get the finer mesh. For point loads and moving loads coarseness factor of 0.25 is used. Loading was applied in 3 stages for both the cases i.e., unreinforced subbase (URSB) and geogrid reinforced subbase (GRSB). 1st stage includes installation of grade slab, 2nd stage includes static loads from racking posts or block stacking. These two stages were analysed by plastic calculation. In the 3rd stage moving-load of MHE is applied as a moving point load with constant velocity along the line. This stage is analysed by dynamic calculations.

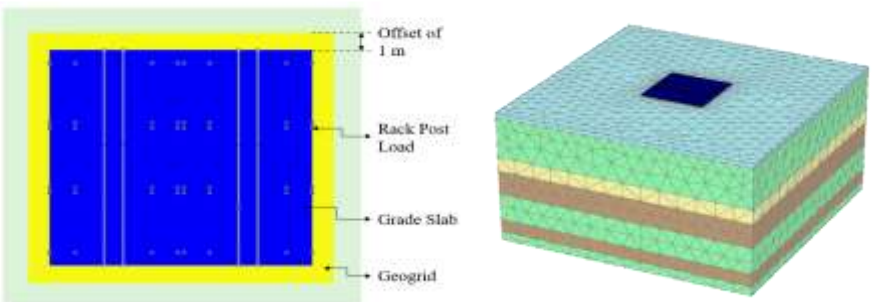

Fig. 3 (a) Geogrid layout (b) Meshed Model

3 Results and Discussion

Differential settlement is one of the major criteria while designing the grade slab for different material stacking. As differential settlement cause rotation to grade slab leads to instability of racking systems. Also, utilization of material handling equipment is affected due to it. Hence all the comparison for different factors is based on improvement in reduction of differential settlements. Critical sections for different loading schemes at which settlement profile is taken corresponding to maximum settlement for follower results were shown in fig. 4. Differential settlement is considered as the maximum settlement difference between points 1 & 2 or 2 & 3 as shown in fig. 4.

3.1 Effect of different loading schemes

The basic difference between the two loading schemes is that in the case of static rack system, loads of palette are transferred to rack posts which creates point loads, and in case of block stacking material or palette are stored directly on grade slab which generates distributed loads. The settlement profile of grade slabs for both the loading schemes was shown in fig. 5 (E=25 MPa, 1050 mm). In the case of static rack case the settlement profile of grade slab with respect to minor loading axis is shallow W-shaped with maximum settlements under rack posts, but in the case of block stacking settlement profile is U-shaped with the most settlement at the centre.

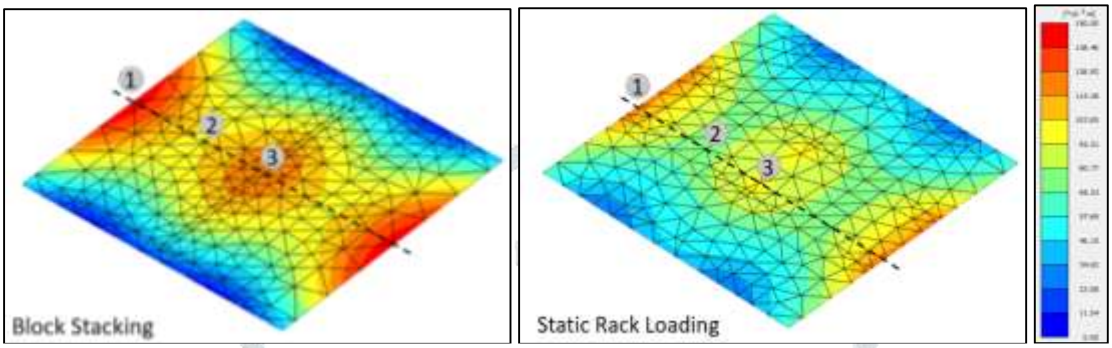

Fig. 4 Displacement contour for grade slab (a) Block stacking (b) Static rack loading

From the study, it is known that settlements induced in static rack loading are 20 % less than the block-stacking case for the same loading intensities as shown in fig 4. in form of colour contour. In the case of static rack case soil between two rack posts creates local support and reduces the overall settlements. However, if loading intensities decrease change of settlements between two loading schemes is also decrease.

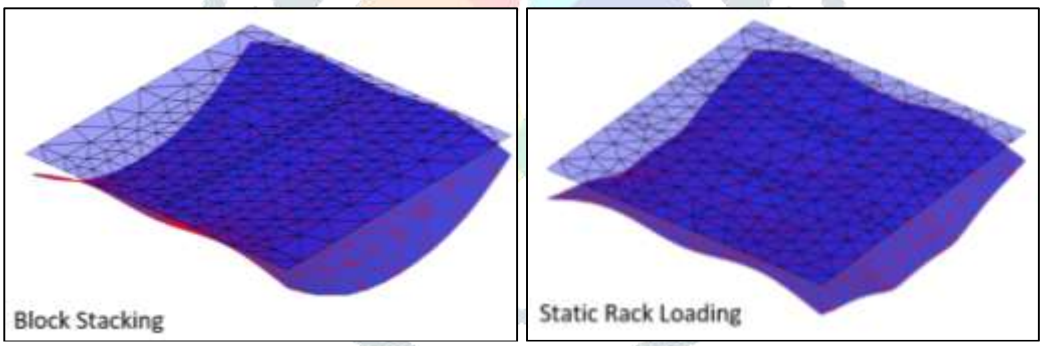

Fig. 5 Deformation pattern for grade slab (a) Block stacking (b) Static rack loading

3.2 Effect of subbase stiffness

To study the stiffness of subbase, 7 different stiffness from 20 MPa to 65 MPa with the same strength characteristics, Eoedref/E50ref, and 1050 mm subbase thickness was chosen. However, strength characteristics for any soil do not remain constant for this wide range of E50 (20 MPa to 65 MPa). But here, this extensive range is considered hypothetically to check the impact of stiffness on subbase settlements. Settlements induced in the soil at a critical location for block stacking case is shown in fig. 6 (1050 mm, geogrid at the interface of soft soil and subbase). Geogrid reinforced subbase (GRSB) with E = 20 MPa and Unreinforced subbase (URSB) with E = 55 MPa shows almost same settlements with variation of ± 3 % for block stacking. It leads to an important conclusion that lesser compacting effort is required in the case of the geogrid reinforced subbase.

As subbase stiffness increases, the soil becomes more supportive which reduces the overall settlements induced in the soil and also reduce the efficiency of geogrid reinforcements. For lesser load intensities, geogrid reinforcements don't help much in percentage reduction of maximum settlements with respect to different stiffness values as, for block stacking case it is average 10% (77.91mm-URSB to 69.16mm-GRSB, for E=25 MPa) compare to 24% (140.54mm-URSB to 106.72mm-GRSB, for E=25 MPa) for higher loading intensities. Similarly for static rack loading and lower intensities improvement is about 7% (69.88mm-URSB to 64.33mm-GRSB, for E=25 MPa) compare to 16% (114.11mm-URSB to 94.08mm-GRSB, for E=25 MPa) for higher loading intensities.

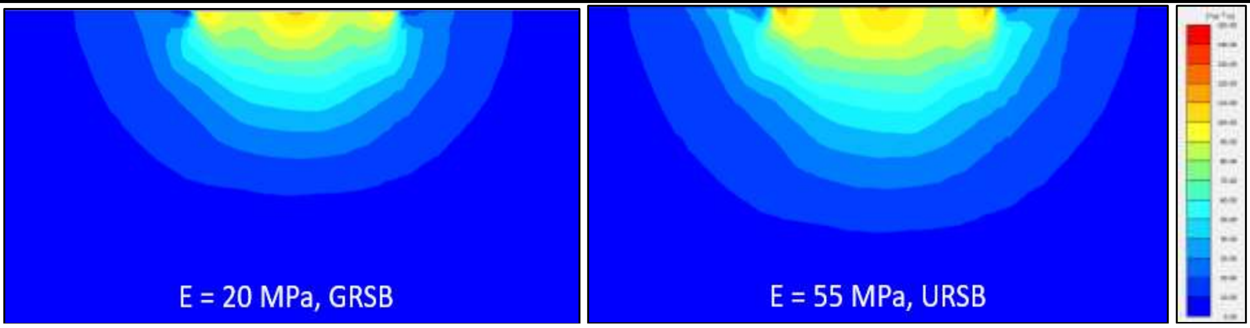

Fig. 6 Settlement induced in soil for static rack case (a) E = 20 MPa - GRSB (b) E = 55 MPa – URSB

The benefit of geogrid reinforcements in differential settlements for both loading schemes were shown in table 4. From the results, it is known that percentage reduction in differential settlement for block stacking condition changes rapidly with the change in stiffness value of subbase, but in static rack case change in percentage reduction in differential settlement is less with change in stiffness of subbase.

Table 4 Percentage reduction in differential settlement for various E of subbase

E (MPa)	Differential Settlement (mm)							
	Block Stacking - 185 kN/m^2				Static Rack Loading - 200 kN			
	URSB	GRSB	Reduction (mm)	Reduction (%)	URSB	GRSB	Reduction (mm)	Reduction (%)
20	45.56	26.59	18.969	*41.63%*	47.07	31.42	15.657	*33.26%*
22.5	44.00	26.67	17.335	*39.39%*	44.95	29.88	15.074	*33.53%*
25	40.92	26.20	14.722	*35.98%*	43.00	28.59	14.403	*33.49%*
35	36.30	26.66	9.648	*26.57%*	37.66	24.92	12.740	*33.82%*
45	32.98	26.58	6.401	*19.41%*	34.37	23.84	10.532	*30.63%*
55	30.41	26.54	3.873	*12.74%*	31.94	23.74	8.203	*25.68%*
65	28.32	26.47	1.851	*6.54%*	29.94	23.64	6.298	*21.03%*

3.3 Effect of subbase thickness

Subbase thickness plays an important role in the behaviour of the grade slab. As subbase thickness increases, load dispersion on the soft soil layer is more uniform leads to lesser settlements. For different subbase thickness settlement profiles at critical locations for URSB and GRSB for block stacking is shown in fig 7. (E = 25 MPa, geogrid at interface of soft soil and subbase). The effect of subbase thickness on differential settlements for E = 25 MPa is mentioned in tabular form in table 5. This research also includes the study of subbase thickness for E = 20 & 22.5 MPa, which shows that in the case of block stacking, for 950 mm subbase thickness percentage reduction in the differential settlement is almost constant with change in stiffness of subbase. But for 1250 mm thickness, percentage reduction in differential settlement changes rapidly with the change in E of the subbase. From the same study, an important conclusion is found out that by reinforcing the subbase with geogrid, subbase thickness can be reduced up to 16% for particular loading conditions and soil characteristics. The settlement induced in grade slab for the same were shown in fig. 8. (EA = 1500, geogrid at interface of soft soil and subbase). Economic considerations for the same are shown in table 6 for the 30m x 30m grade slab.

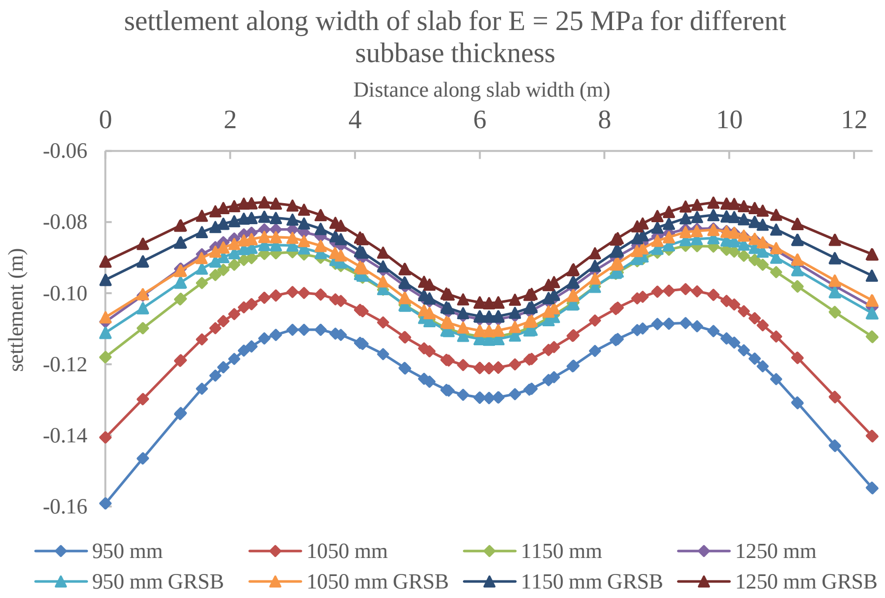

Fig. 7 Settlement along width of slab for different subbase thickness, E = 25 MPa & Block Stacking – URSB & GRSB

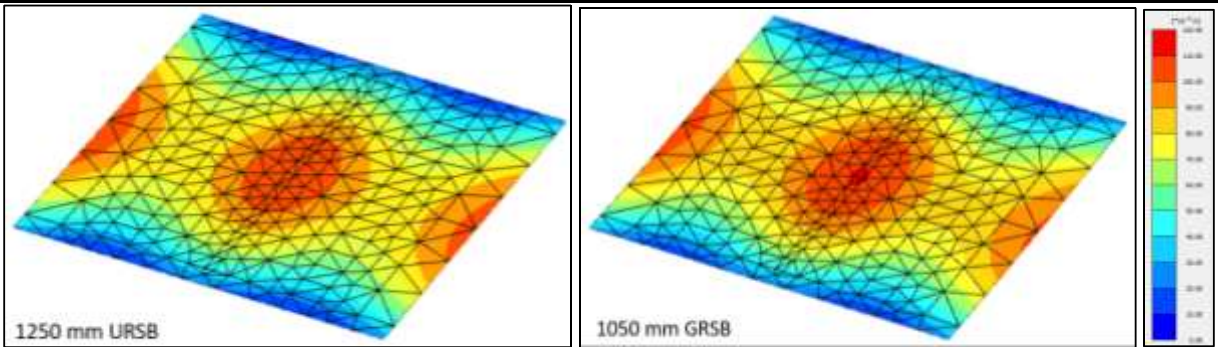

Fig.8 Settlement contour (1) 1250 mm - URSB (2) 1050 mm – GRSB

Table 5 Percentage Reduction in differential settlement for various subbase thickness

	Differential Settlement (mm)							
	Block Stacking - 185 kN/m^2				Static Rack Loading - 200 kN			
Thickness (mm)	**URSB**	**GRSB**	**Reduction (mm)**	**Reduction (%)**	**URSB**	**GRSB**	**Reduction (mm)**	**Reduction (%)**
950	48.8	26.4	22.35	45.77%	57.3	32.9	24.43	42.58%
1050	40.9	26.2	14.72	35.98%	43	28.6	14.4	33.49%
1150	29.5	27.2	2.22	7.52%	35.5	25.4	10.11	28.44%
1250	26	27.4	-1.42	-5.45%	31.5	25.2	6.36	20.13%

Table 6 Cost consideration for 30 m x 30 m grade slab for initial costing

URSB		GRSB		saving
rate of excavation	₹ 67,500	rate of excavation	₹ 64,512	₹ 13,868
rate of sand filling	₹ 9,00,000	rate of sand filling	₹ 7,56,000	
rate for geogrid	₹ 0	rate for geogrid	₹ 1,33,120	
total cost	₹ 9,67,500	total cost	₹ 9,53,632	

3.4 Effect of geogrid axial stiffness (EA)

Geogrid axial stiffness (EA) is decided on the basis of availability of product and design recommendation. However, a study for this particular loading condition and soil characteristics shows that by varying the EA of geogrid from 1000 to 2500 reduction in the settlement is not significant. Percentage reduction at different points within the critical section is shown in table 7. With an increase in EA of percentage reduction in overall settlement increases but percentage reduction in differential settlement decreases for block stacking case. But in the case of static rack loading with an increase in axial stiffness of percentage, the percentage reduction in the differential settlement also increases as shown in table 7. The data presented in table 7. is for E = 25 MPa and geogrid at the interface of subbase and soft soil. However, with an increase in stiffness of subbase, this phenomenon affects more. For different E values and axial stiffness of geogrid percentage reduction in differential settlement is mentioned in table 8.

Table 7 Percentage reduction in settlement for different axial stiffness (EA) (a) Block stacking (b) Static rack loading

Percentage reduction in settlements by use of GRSB, E = 25MPa						
EA	Block Stacking			Static Rack Loading		
	at edge	**at center**	**Differential**	**at edge**	**at center**	**Differential**
1000	22.23%	7.79%	36.38%	14.72%	1.13%	28.29%
1500	24.06%	8.64%	35.98%	17.56%	1.56%	33.49%
2500	29.08%	10.4%	33.49%	19.1%	1.88%	35.81%

Table 8 Effect of axial stiffness of geogrid on differential settlement for different E value and block stacking

Differential Settlement (mm) - Block Stacking						
EA	E = 20 MPa			E = 25 MPa		
	Diff. settlement (mm)	**reduction (mm)**	**reduction (%)**	**Diff. settlement (mm)**	**reduction (mm)**	**reduction (%)**
URSB	45.566			40.923		
1000	26.480	19.085	41.89%	26.033	14.890	36.38%
1500	26.597	18.969	41.63%	26.201	14.722	35.98%
2500	27.180	18.386	40.35%	27.216	13.707	33.49%

3.5 Effect of geogrid location

From the study, it is known that geogrid provided at the interface of subbase and soft soil is the optimum location to attain the maximum benefit of geogrid reinforcement. Percentage reduction in settlement by reinforcing geogrid at 500 mm below G.L. & at the interface of subbase and soft soil is shown in table 9 (E = 25 MPa, thickness = 1050 mm). In this study well-compacted subbase underlaid by soft soil is utilized, however, if the subbase is not properly compacted then geogrid at a mid-depth of subbase and at the interface will lead to better results.

Table 9 Percentage reduction in settlement for locations of geogrid (1) Block stacking (2) Static rack loading

Percentage reduction in settlements by use of GRSB, E = 25MPa						
Location	**Block Stacking**			**Static Rack Loading**		
	at edge	**at center**	**Differential**	**at edge**	**at center**	**Differential**
500 mm below G.L.	20.65%	8.34%	34.25%	19.95%	3.13%	31.32%
1050 mm below G.L. (At interface of soft soil and subbase)	27.14%	9.74%	43.09%	27.99%	3.92%	45.85%

4 CONCLUSIONS

The main objective of the study is to explore the use of geogrid reinforcement particularly for grade slabs of industrial warehouses. The results from numerical modelling in Plaxis3D conclude that geogrid reinforcement impacts more on the reduction of differential settlements of grade slabs, rather than overall settlements. Some of the important conclusions made from the study are mentioned below.

- Overall settlements in block-stacking case are about 15-20% more than static rack case. The behaviour of grade slab in case of block stacking is like one way slab, but in case of static rack case due to local support of soil between two-point loads behaviour is more like continuous slab. However, when loading intensity decrease, change in settlement in both the loading is also decreases.
- Study shows that subbase stiffness and subbase thickness play a vital role in the behaviour of normal as well as geogrid reinforced subbase. When the stiffness of soil increases, the soil became more supportive. From this study, it is known that Geogrid reinforcement can be used to reduce the required compaction effort of the subbase, thus reducing labour and equipment requirements considerably. Also, Geogrids help while compacting the soil resting on soft soils because of the separation function.
- When the thickness of the subbase increases the load dispersion on soft soil is more uniform, results in lesser overall settlements. However, to control the differential settlements adequate subbase thickness and geogrid reinforcement should be provided based on subsoil conditions & loading characteristics. It is observed from the study that by use of geogrid as reinforcement, the thickness of the subbase can be reduced by 200 mm (16 % of subbase thickness) with the same results as shown in the graph for both the loading cases, which leads to reduction of initial cost of about 13500 ₹ for 30m x 30m grade-slab. Geogrid reinforcing in the subbase contributes to almost 30 % reduction in differential settlements.
- The Geogrid axial stiffness does not affect much on settlement reduction. From the study, it is known that geogrid provided at the interface of subbase and soft soil is the optimum location to attain the maximum benefit of geogrid reinforcement.

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