Evaluation of Stabilized Pavement Sections Using Finite Element Modeling

Mohammed. S. Ouf, Abdelzaher E. A. Mostafa,Mohammed Fathy and Mokhtar F. Elgendy

ABSTRACT— Soil stabilization is a techniques which used in strengthen and stability of subgrade pavement section. Traditional stabilizers as cement, lime, fly ash, rice hush ash and silica fume have been used in this technique. Recently, nanomaterials (NM) have a wide usage in civil works (soil stabilization). This paper presents a finite element (FE) modeling to evaluate the behavior of stabilized and non-stabilized pavement section subjected to various values of expected traffic loads (static loadings). Two types of stabilizers have been evaluated; the first was the combination of lime (L) and silica fume (SF) as traditional stabilizers, while the second was the combination of L and nano silica (NS) as nano material stabilizers. Pavement responses (total stress and vertical surface displacement) were determined for stabilized and non-stabilized pavement sections with an incremental loading (50-700) Kpa. The results indicated that increasing the traffic loads, leads to increase the total stresses and vertical displacements. These responses have been decreased after stabilized subgrade layer with various thicknesses of stabilizations (20-50) cm. The results also showed that slightly improvement in pavement performance was recorded by exceeding the subgrade stabilized thickness of 30 cm.

Index Terms— Soil stabilization, Finite element (FE), Plaxis program, Pavement performance, Traffic loads, Subgrade, Strength

1 INTRODUCTION AND BACKGROUND

Soil stabilization is the treatment of soils to enable their strength and durability to be improved such that they become totally suitable for highways construction, Mostafa et al. (2016). Several types of additives used in soil stabilization as lime, silica fume, cement, fly ash, rice hush ash and bitumen. Recently, nanomaterials (NM) as nano silica, nano cupper, nano magnesium and nano clay have been also used in soil stabilization.

The aim of this paper is evaluating the pavement section performance of stabilized and non-stabilized subgrade layer using finite element (FE) modeling (2D Plaxis Program version (8.20)). In this study, two types of stabilizers have been used, the first was the combination of lime (L) and silica fume (SF) , their percentages were 6%L and 10%SF, while the second was the combination of L and nano silica (NS) with 6%L and 3%NS (by dry weight of soil). The FE modeling concept was presented by Turner et a1. (1956) and Clough (1960). Since its beginning, the literature on FE analysis has grown exponentially and there are many journals and researchers devoted to the theory and applications of the FE such as Zienkiewicz and Taylor (1988) and Reddy (1993).Various empirical methods have been developed for analyzing flexible pavement structures. Due to limitations of analytical tools developed in the 1960's and 1970's, the design of flexible pavements is still largely empirically based. The empirical method limits itself to a certain set of environmental and material conditions, Huang (1993).

FE technique has been successfully used to simulate different pavement problems that could not be simulated using the simpler multi-layer elastic theory, AL-Khateeb (2011).

ABAQUS is a commercially available 3D FE program, and has been used in the structural analysis of pavement system, Hibbitt et al. (1992). It has the ability to accommodate both 2D and 3D FE analysis and reduced integration elements 3D to reduce the total computational time, Cho et al. (1996).

The axisymmetric FE simulations through ANSYS software are carried out by Al-Azzawi A.A., (2012) to evaluate the benefits of using geogrid in flexible pavements. Their study described the behavior of asphalt concrete (AC) pavement under axisymmetric conditions and subjected to static loading. The results of flexible pavements improvement using geogrid are presented and analytical results for four different most possibilities of geogrid reinforcement in the paved road layers have been evaluated. The optimum position was decided based upon the predicated tension and compressive stress reduction and deformation rate. Four types of reinforcing model and one type of unreinforced model of paved road were tried. The results showed that higher tension stress absorption when the geogrid is placed between the base course layer and subbase layer in the selected model.

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Rahman et al. (2011) used a 3D FE application to predict the mechanical behavior and pavement performance subjected to various traffic factors. Different axle configuration, tire imprint areas and inflation pressure are investigated to analyze the considerable impact on pavement damage initiation from fatigue and permanent deformation point of view. Flexible pavement modeling was developed using ABAQUS software in which model dimensions, element types and meshing strategies are taken by successive try and error to achieve desired accuracy and convergence of the study. Thus proper tire imprint area is determined to apply in economical design of pavement for various axle configurations.

Faheem and Hassan (2014) presented an axisymmetric FE model using Plaxis 2D Program (see figure (1)) to analyze the behavior of unreinforced and geogrid reinforced bituminous pavement subjected to static and dynamic loadings. The model was loaded with an incremental loading and the critical pavement responses such as effective stress and vertical surface deflection were determined for unreinforced and geogrid reinforced flexible pavement. The results indicated that during static loading, a moderate effect on the pavement behavior was observed due to the reinforcing geogrid layer. This effect was not noted in case of dynamic loading. The effect of dynamic loading frequency on pavement settlement was significant especially for high loading amplitudes. The results also showed no significant improvement in pavement system behavior was obtained by adding another layer of geogrid reinforcement.

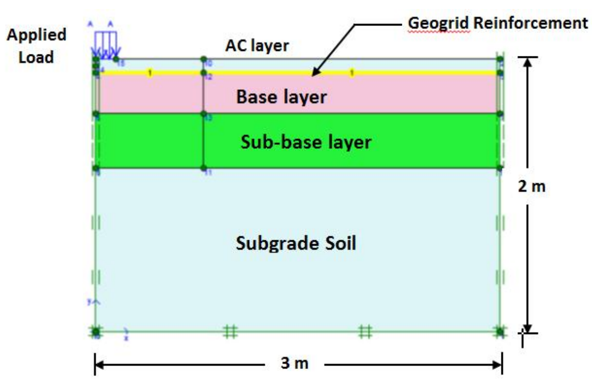

Figure (1): Pavement FE Modeling by 2D Plaxis program, Faheem H.and Hassan M.A., (2014).

2 Development of FE Modeling

The developed models in this paper (compatible with the Egyptian code for highway engineering) named A, B; C and D. The structure of all models consists of 5 cm asphalt concrete (AC) layer. In section A, the AC layer rest directly on subgrade layer as shown in figure (2). While figure (3) shows the geometry of sections B and figure (4) shows the geometry of section C, while the geometry of section D is shown in figure (5). Sections B, C and D consist of 10, 15 and 20cm base layer under AC layer respectively. The geometry of subgrade layer was assumed to be 3m wide and 2m depth. The stabilization in subgrade layer was varied from 20 to 50cm.

The purpose of development of FE modeling is to determine the vertical displacement (VD) and total stress (TS) observed under expected traffic loads on pavement surface, if 20, 30, 40 and 50 cm of subgrade layer have been stabilized with L mixed with SF and NS for all section types. In modeling, the non-stabilized subgrade layer is SG, while SG1and SG2 are the stabilized subgrade layers by combination of (L and SF) and (L and NS) respectively. In this study the wheel load was simulated as applied pressure acting on a circular area of radius 0.2 m with values: 50, 100, 200, 300, 400, 500,600 and 700 Kpa. Linear elastic materials were assigned to the AC, while the base and subgrade layers were modeled using Mohr-coulomb model. It should be noted that, the properties of asphalt and base layer have been assumed as presented by Faheem and Hassan (2014), and their properties are constant for all models. Also, the Poisson ratio for subgrade layers have been assumed as showed in table (1). Also, table (1) shows the properties of SG, SG1 and SG2 based on the outcomes of the physical and engineering tests, Mostafa et al. (2016).

An axisymmetric model was developed in the analysis using 15-noded structural solid element with fine refinement.

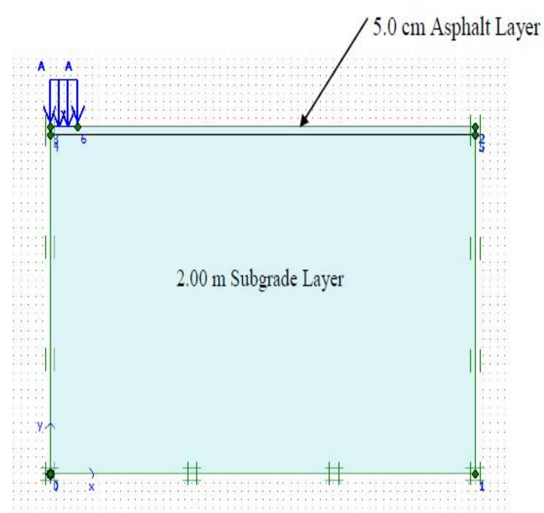

Figure (2): Pavement section type (A) – No base layer

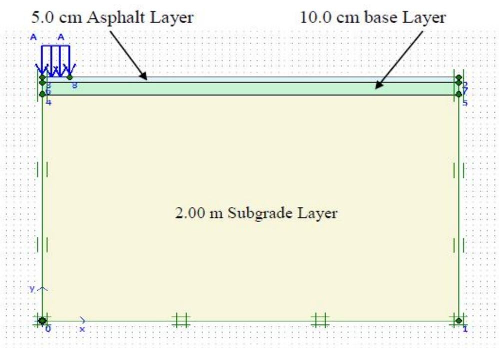

Figure (3): Pavement section type (B) – 10cm base layer

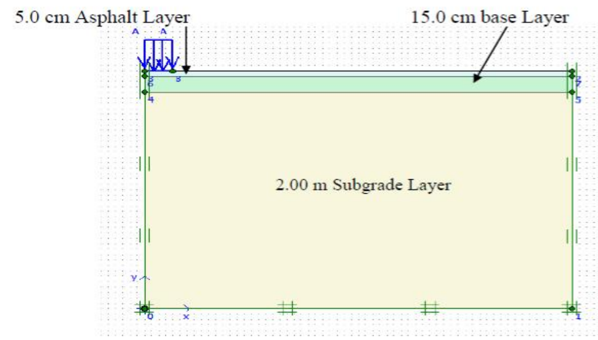

Figure (4): Pavement section type (C) – 15cm base layer

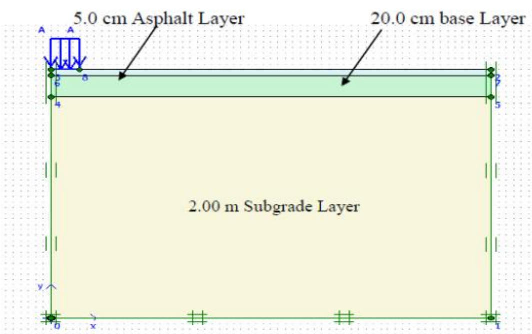

Figure (5): Pavement section type (D) – 20cm base layer

Table (1): The properties of pavement layers materials Used in Modeling, Faheem H.and Hassan M.A., (2014) and Mostafa et al. (2016)

Material	AC	Base Layer	SG	SG1	SG2
Model	Linear- Elastic	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Thickness (m)	0.05	0.00-0.20	2.00	0.20-0.50	0.20-0.50
Young's modulus (Kpa)	2100000	100000	11900	26900	27904
Poisson Ratio	0.45	0.35	0.25	0.25	0.25
Dry density (KN/m3)	20.00	20.00	20.25	19.13	19.41
Saturated density (KN/m3)	20.00	22.00	22.72	22.07	22.17
Cohesion (KN/m2)	--	30.0	30.0	130	60
Friction Angle (degree)	--	43.0	36.97	52	40.6
Dilatation Angle (degree)	--	13	6.97	22	10.60

3 Results and Discussions

3.1 Introduction

About 300 models have been developed by Plaxis program to determine the VD and the TS for the suggested pavement sections. The stabilization of subgrade layer has been improved the performance of pavement sections, and the following paragraphs will present the results and discussions in details.

3. 2 Vertical Displacement

The relationships between the applied pressure and the VD are shown in figures below, while Figures (10) and (11) illustrate the typical deformed shape and VD distribution, respectively. The results indicated that by increasing pressure load, the surface VD was increased, and the stabilization of subgrade layer has been reduced the surface VD.

Figure (6) shows the recorded VD against load pressure for section type A (no base layer). It was found that without subgrade stabilization, the VD was 10.86 mm at 700kpa (for example), while after stabilizing 20 cm of subgrade layer by SG1 and SG2, VD decreased to 8.67and 8.61mm respectively. That means, the VD reduction percentages were 20.16%, 20.72% respectively, and it can be noted that no significant difference between SG1 and SG2. Also, after increasing the stabilized thickness to 30 cm, the recorded VD was 7.98 and 7.91 mm for SG1 and SG2 at the same load pressure with VD reduction percentages 26.52% and 27.16% respectively. Slightly decrease in VD has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (6). The reduction in VD after stabilization of subgrade layer, due to the improvement of stabilized layers properties (Young's modulus, Cohesion and internal friction angle) as presented in table (1).

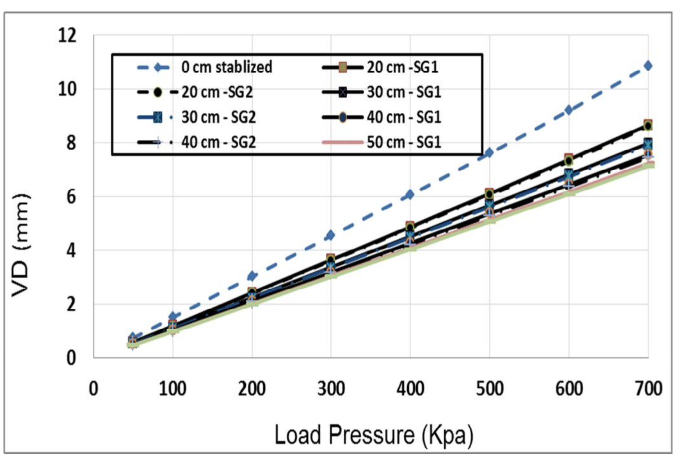

Figure (6): Maximum VD versus applied pressure for section (A) – No base layer

Also, the slightly decrease in VD of 40 and 50 cm of stabilized layer may be due to the distribution of load pressure at depth more than 20 and 30 cm.

Figure (7) shows the recorded VD against load pressure for section type B (10cm base layer). It was found that due to the presence of 10cm base, the VD was 8.92 mm at 700kpa, with VD reduction percentage of 17.86%. After stabilization of 20 cm of subgrade layer, the VD has been reduced to 7.07 (SG1) and 7.01 (SG2) mm, with VD reduction percentages of 34.89%, 35.45% respectively. Also, after increasing the stabilized thickness to 30 cm, the recorded VD were 6.61 and 6.55 mm for SG1 and SG2 at the same load pressure with VD reduction percentages of 39.13% and 39.69% respectively. Also, slightly decrease in VD has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (7). The reduction in VD after stabilization of subgrade layer, due to the improvement of stabilized layers and the presence of base layer, increased the stiffness of pavement section.

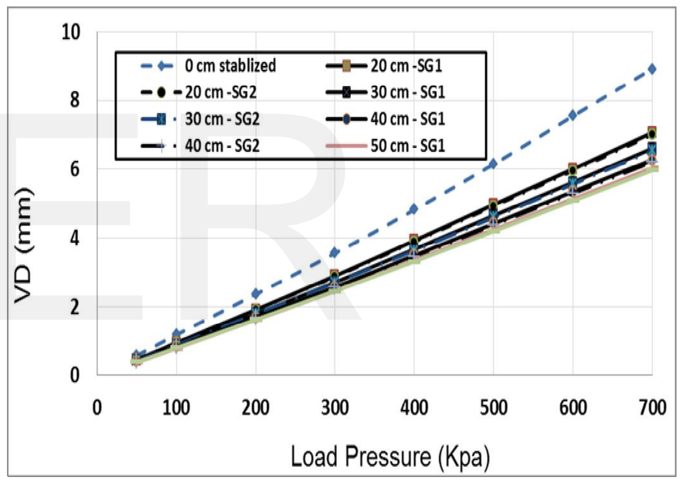

Figure (7): Maximum VD versus applied pressure for section (B) – 10cm base layer

Increasing the base layer thickness to 15 cm (section C), the recorded VD was 7.90 mm at 700kpa; It reduced the VD by 27.26% as shown in Figure (8). By stabilizing 20 cm of subgrade layer, the VD was 6.43mm (SG1) and 6.39mm (SG2) with VD reduction percentages of 40.79% and 41.16% respectively. Also, by increasing the stabilized thickness to 30 cm, the recorded VD were 6.05 and 5.99 mm for SG1 and SG2 at the same load pressure with VD reduction percentages of 44.29% and 44.84% respectively. Also, slightly decrease in VD has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (8). The reduction in VD after stabilization of subgrade layer due to the same reasons explained above, in addition, increasing base layer thickness from 10 to 15 cm increased the rigidity of the pavement section.

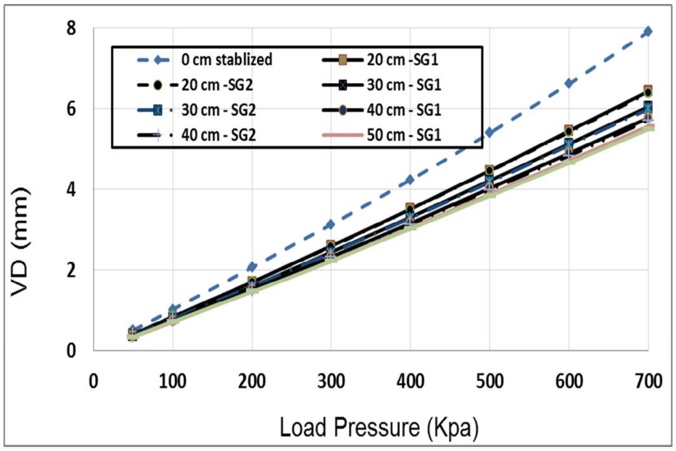

Figure (8): Maximum VD versus applied pressure for section (C) – 15cm base layer

The recorded VD was 7.00 mm at 700kpa; by increasing the base layer thickness to 20 cm (section D) as shown in Figure (9).It reduced the VD by 35.54%. By stabilizing 20 cm of subgrade layer, the VD was 5.87mm (SG1) and 5.85mm (SG2) with VD reduction percentages of 45.95% and 46.13% respectively. Also, after increasing the stabilized thickness to 30 cm, the recorded VD were 5.61 and 5.58 mm for SG1 and SG2 at the same load pressure with VD reduction percentages of 48.34% and 48.62% respectively. Also, slightly decrease in VD has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (9). The reduction in VD after stabilization of subgrade layer due to the same reasons explained above, in addition of increasing base layer thickness from 15 to 20 cm increased the rigidity of the pavement section.

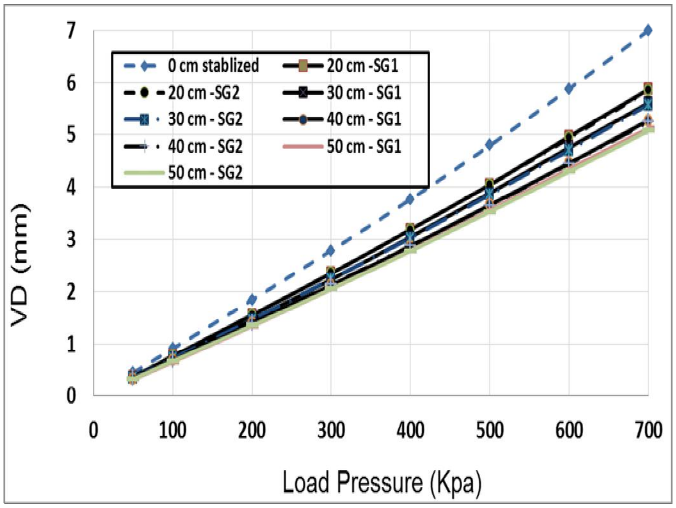

Figure (9): Maximum VD versus applied pressure for section (D) – 20cm base layer

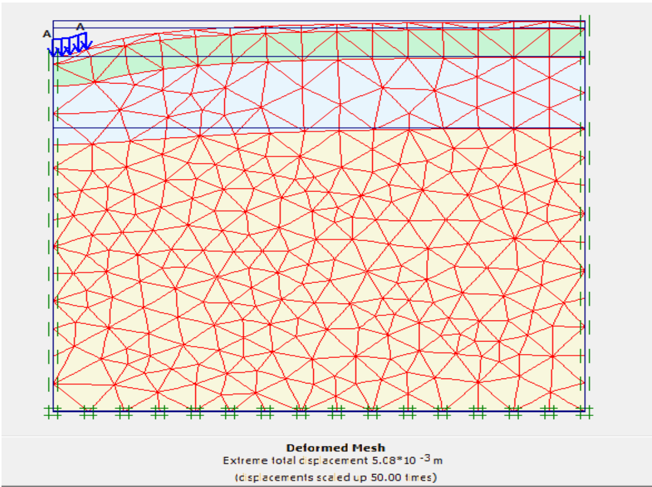

Figure (10): Typical VD shape in Plaxis

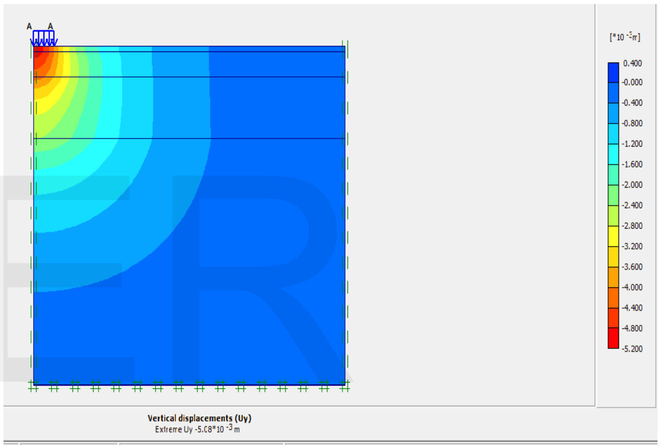

Figure (11): Typical VD distribution in Plaxis

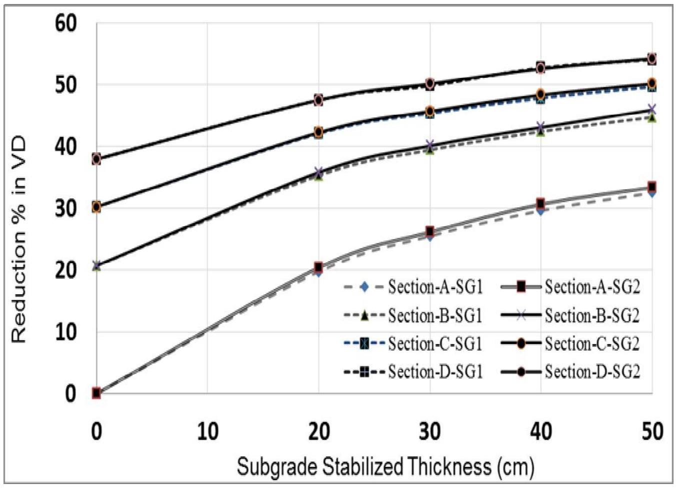

Figure (12): Reduction% in VD versus subgrade stabilized thickness at 400Kpa for S.G1and S.G2

Figure (12) shows the summary of relationship between the reduction percentages of VD versus the stabilized subgrade thickness at 400kpa (as the mid value of pressure group). It can be concluded that, the significant change in VD reduction has been occurred at 20 and 30cm subgrade stabilization for all pavement sections. After stabilizing of 40 and 50 cm of subgrade, the VD reduction slightly decreased as shown in figure (12). Also, the importance of presence of base layer in pavement section has been observed. Also, give several techniques of increasing the pavement section rigidity by subgrade stabilization, the presence of base layer or both.

3. 2TOTAL STRESS

The following paragraphs will explain the importance of subgrade stabilization and the presence of base layer in pavement section on TS which occurred under applied pressure. Figure (13) illustrates the typical stress distribution under applied pressure in Plaxis models.

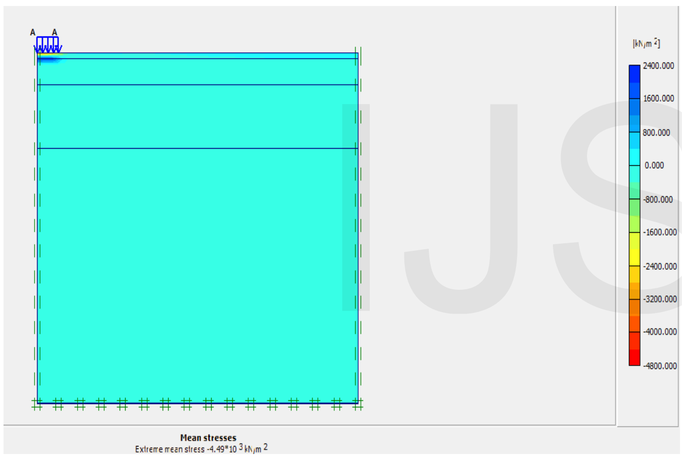

Figure (13): Typical TS distribution in Plaxis

Figure (14) shows the recorded TS versus load pressure for section type A (no base layer). It was found that without subgrade stabilization, the TS was 9280 Kpa at 700kpa, while after stabilizing 20 cm of subgrade layer by SG1 and SG2, TS decreased to 7360and 7330kpa respectively. That means, the TS reduction percentages were 20.69%, 21.01% respectively, and it was observed that no significant difference between SG1 and SG2. Also, after increasing the stabilized thickness to 30 cm, the recorded TS was 6840 and 6760 Kpa for SG1 and SG2 at the same load pressure with TS reduction percentages 26.29% and 27.16% respectively. Slightly decrease in TS has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (14). The reduction in VD after stabilization of subgrade layer may be due to the improvement of stabilized layers properties (Young's modulus, Cohesion and internal friction angle) as presented in table (1).

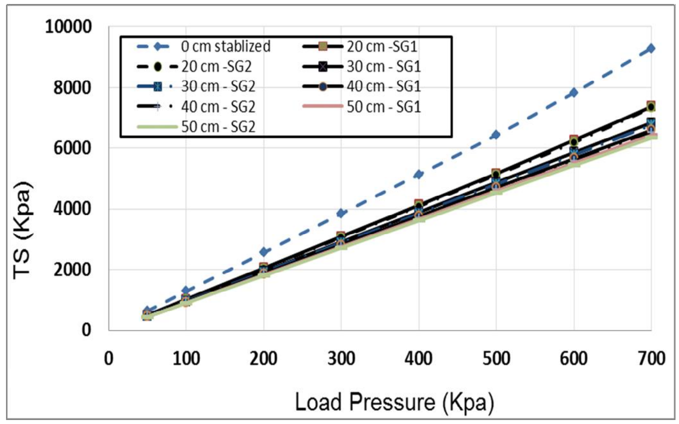

Figure (14): Maximum TS versus applied pressure for section (A) – No base layer

Figure (15) shows the recorded TS against load pressure for section type B (10cm base layer). It was found that at the presence of 10cm base, the TS decreased to 8010 Kpa at 700kpa, with TS reduction percentage of 13.68%. After stabilizing 20 cm of subgrade layer, the TS decreased to 5980 (SG1) and 5910 (SG2) Kpa, with TS reduction percentages of 35.56%, 36.31% respectively. Also, after increasing the stabilized thickness to 30 cm, the recorded TS were 5610 and 5520 Kpa for SG1 and SG2 at the same load pressure with TS reduction percentages of 39.55% and 40.52% respectively. Also, slightly decrease in TS has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (15). The reduction in TS after stabilization of subgrade layer, due to the improvement of stabilized layers properties and the presence of base layer, increased the stiffness of pavement section.

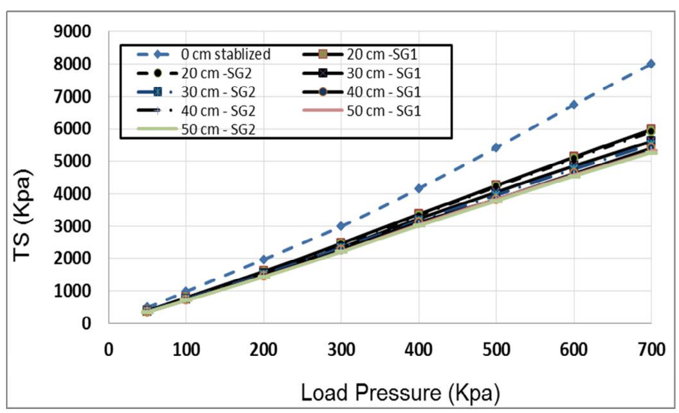

Figure (15): Maximum TS versus applied pressure for section (B) – 10 cm base layer

By increasing the base layer thickness to 15 cm (section C), the recorded TS was 7100 Kpa at 700kpa, It reduced the TS by 23.49% as shown in Figure (16). By stabilizing 20 cm of subgrade layer, the TS decreased to 5510kpa (SG1) and 5450 Kpa (SG2) with TS reduction percentages of 40.63% and 41.27% respectively. Also, after increasing the stabilized thickness to 30 cm, the recorded TS were 5090 and 5030 Kpa for SG1 and SG2 at the same load pressure with TS reduction percentages of 45.15% and 45.79% respectively. Also, slightly decrease in TS has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (16). The reduction in TS after stabilization of subgrade layer due to the same reasons explained above, in addition of increasing base layer thickness from 10 to 15 cm leads to forming high stiffness pavement section.

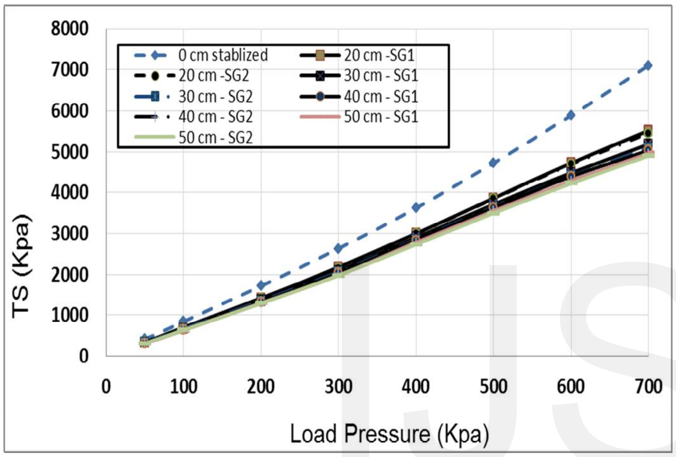

Figure (16): Maximum TS versus applied pressure for section (C) – 15 cm base layer

The recorded TS was 6020 Kpa at 700kpa; by increasing the base layer thickness to 20 cm (section D) as shown in Figure (17).It reduced the TS by 35.13%. By stabilizing 20 cm of subgrade layer, the TS decreased to 4950 Kpa (SG1) and 4880 Kpa (SG2) with TS reduction percentages of 46.66% and 47.41% respectively. Also, after increasing the stabilized thickness to 30 cm, the recorded TS were 4820 and 4780 Kpa for SG1 and SG2 at the same load pressure with TS reduction percentages of 48.06% and 48.49% respectively. Also, slightly decrease in TS has been occurred by an increase in stabilized thickness of 40 and 50 cm as shown in figure (17). The reduction in TS after stabilization of subgrade layer as the same reasons explained above, in addition of increasing base layer thickness from 15 to 20 cm makes the pavement section more stiffness and resists the applied load on pavement surface.

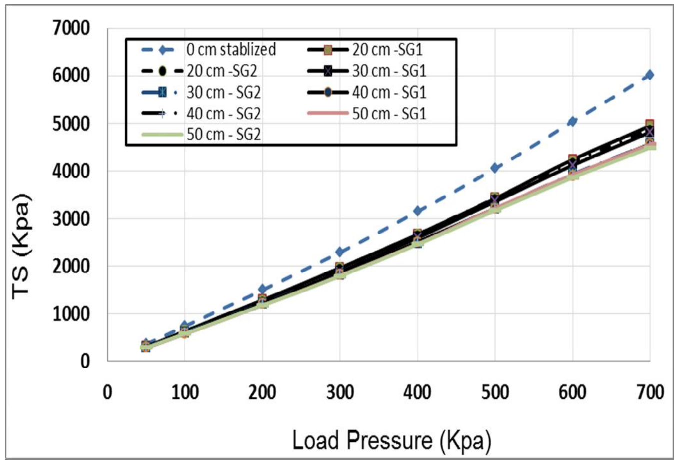

Figure (17): Maximum TS versus applied pressure for section (D) – 20 cm base layer

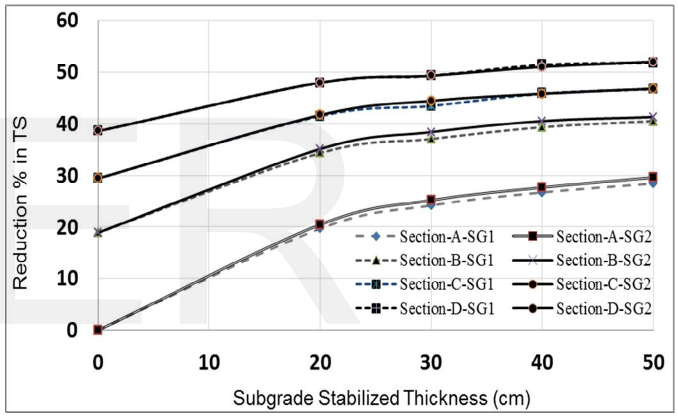

Figure (18): Reduction% in TS versus subgrade stabilized thickness at 400Kpa for S.G1 and S.G2

Figure (18) shows the summary of relationship between the reductions percentages of TS versus the stabilized subgrade thickness at 400kpa. It can be concluded that, the significant change in TS reduction has been occurred at 20 and 30cm subgrade stabilization for all pavement sections. After stabilizing 40 and 50 cm of subgrade, the TS reduction slightly decreased as shown in figure (18). Also, the importance of presence of base layer in pavement section has been occurred, and can be comparing between various thicknesses of base layer. Also, gives more alternatives of increasing the rigidity of pavement section by subgrade stabilization and base thickness increasing.

4 Conclusions

1- The VD and TS increased with an Increase in load pressure. The significant reduction in VD and TS occurred after stabilizing 20 and 30 cm of subgrade layer. After that, slightly decrease has been recorded for all pavement sections.
2- The presence of 10 and 15 cm base layer, leads to significant reduction in the VD and TS, after that, slightly decrease has been observed for all pavement sections.
3- The subgrade stabilization provides a significant improvement in pavement section performance in case of no base layer more than the case of the presence of base layer.
4- The difference between the stabilization of subgrade layer by SG1 and SG2 can be neglected.
5- Improvement in subgrade properties (young's modulus, density, cohesion and internal friction angle) leads to enhancement of the pavement section performance.

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