Evaluation of Using Nano Materials in Subgrade Stabilisation Using Finite Element Modeling

Mohammed. S. Ouf and Mokhtar F. Elgendy

ABSTRACT— Nanomaterials (NM) have a wide usage in civil works (soil stabilisation) nowadays. This paper presents a finite element (FE) modeling to evaluate the behavior of stabilised and non-stabilised pavement sections subjected to various values of expected traffic loads (static loading). The materials properties used in (FE) modeling extracted from a previous experimental study carried out on clay specimens stabilised by hydrated lime and Nano slag (NS) with different percentages. The stabiliser used in this study was the combination of hydrated lime (7%) and NS (3%) by dry weight of clay. Pavement responses (total stress and vertical surface displacement) were determined with an incremental loading (300-700) Kpa. The results indicated that increasing the traffic loads, leads to an increase in the total stresses (TS) and vertical displacements (VD). These responses were decreased after stabilised subgrade layer with various thicknesses of stabilisation (20-50) cm. The results also showed that slightly improvement in pavement performance was recorded by exceeding the subgrade stabilised thickness of 30 cm.

Index Terms— Soil stabilisation, Finite element (FE), Plaxis program, Hydrated Lime, Traffic loads, Nano Slag (NS), Strength

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1 INTRODUCTION AND BACKGROUND

Soil stabilisation is an important technique in soil enhancement to make the pavement section able to carry the expected traffic loads (especially illegal traffic loads in Egypt), Mostafa et al. (2016). Several types of additives used in soil stabilisation as lime, silica fume, cement, fly ash, rice hush ash and bitumen. Recently, nanomaterials (NM) as nano silica, cupper, magnesium, slag and clay have been also used in soil stabilisation.

Previous study was carried out on a sample of a clay soil selected from Al-Marg district, Cairo, Egypt to represent a typical Egyptian expansive clayey soil. Unconfined compressive strength (UCS) tests were carried out to evaluate using hydrated lime (L) and nano slag (N.S) as stabilisers on the characteristics of the test soil. The results revealed that UCS of the test soil generally increased with an increase in the total binder (T.B %), and increased with an increase in N.S/T.B ratio up till a specific value and then decreased. The optimum ratio of N.S/T.B which gives the maximum UCS was found to be about 0.30, (Ouf 2016).

The main objective of this paper is using 2D Plaxis Program version (8.20) to evaluate the results of the obtained results by Ouf (2016), for a mix with (TB) of 10% and (NS/TB) ratio is 0.30 comparing with section without stabilised soils and

sections with different thickness of base layers. For details of clay, additives and mix procedures, see Ouf (2016). The finite elements (FE) modeling concept was presented by Turner et al. (1956). 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.

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 the common available FE program, and has been used in the structural analysis of pavement system, Hibbitt et al. (1992). It can be used in simulating both 2D and 3D FE analysis and reduced integration elements 3D to reduce the total computational time, Cho et al. (1996).

Also, one of these programs is ANSYS software. Al-Azzawi A.A., (2012) used the ANSYS software 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 loads.

Mohammed. S. Ouf is currently Associate Professor, Civil Engineering in Helwan University, Cairo, Egypt, and E-mail: drmohamedouf@hotmail.com
Mokhtar F. Elgendy is currently Lecturer, Civil Engineering in Shorouk Academy, Cairo, Egypt, and E-mail: mokhtargendy91@gmail.com

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. It was found that,

the optimum position was decided based upon the predicated tension and compressive stress reduction and deformation rate. The results indicated that, the optimum position of geogrid was between base and subbase layers.

Faheem and Hassan (2014) presented an axisymmetric FE model using Plaxis 2D Program to evaluate 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.

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 stabilised with L mixed with NS for all section types. In this study, the wheel load was simulated as applied pressure acting on a circular area of radius 0.2 m, with values of: 300, 400, 500,600 and 700 Kpa. Linear elastic materials were assigned to the asphalt layer, 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 subgrade and stabilized subgrade based on the outcomes of the physical and engineering tests, Ouf (2016). An axisymmetric model was developed in the analysis using 15-noded structural solid element with fine refinement.

2 DEVELOPMENT OF FE MODELING

The developed models in this paper are three types of pavement sections named A, B and C. 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 (1). While figures (2) and (3) show the geometry of sections B and C respectively. Sections B and C consist of 15 and 20 cm base layer under AC layer respectively. The geometry of subgrade layer was assumed to be 3m wide and 2m depth. The stabilisation in subgrade layer was varied from 20 to 50cm.
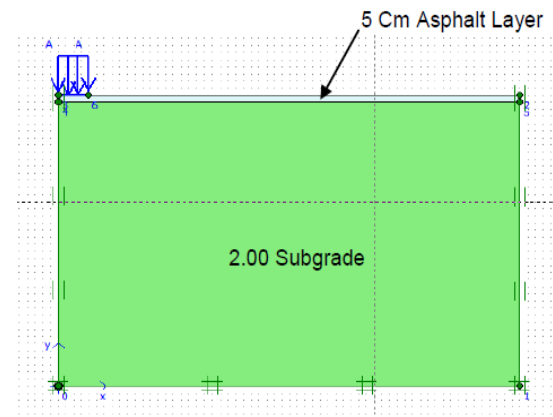

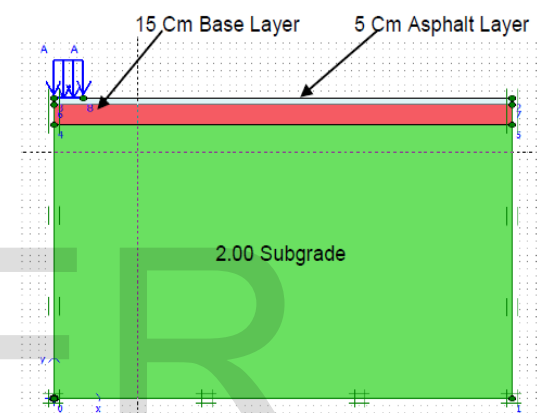Figure (1): Pavement Section Type (A) – No Base Layer

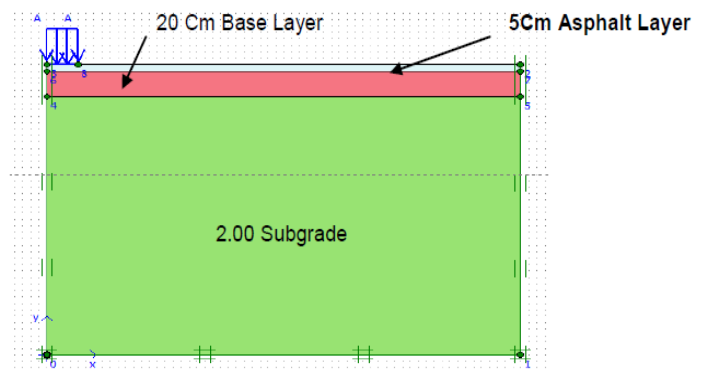Figure (2): Pavement Section Type (B) – 15 Cm Base Layer

Figure (3): Pavement Section Type (C) – 20 Cm Base Layer

Table (1): The properties of Pavement Layers Materials Used in Modeling, (*) Faheem and Hassan (2014), and (**) Ouf (2016)

Material	Asphalt Layer (*)	Base Layer (*)	Subgrade (**)	Stabilised Subgrade (**)
Model in Plaxis	Linear- Elastic	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Thickness (m)	0.05	0.00-0.20	2.00	0.20-0.50
Young's modulus (Kpa)	2100000	100000	6245	17895
Poisson's Ratio	0.45	0.35	0.25	0.25
Dry density (KN/m3)	20.00	20.00	18.20	17.50
Saturated density (KN/m^3)	20.00	22.00	20.30	19.78
Cohesion (KN/m^2)	--	30.0	30.0	30
Friction Angle (degree)	--	43.0	36.97	36.97
Dilatation Angle (degree)	--	13	6.97	6.97

3 RESULTS AND DISCUSSIONS

3.1 INTRODUCTION

About 75 models have been analyzed by Plaxis program to determine the vertical displacement (VD) and the total stress (TS) for the suggested pavement sections. The stabilisation 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. The results indicated that, the surface VD increased with an increase in pressure, and the stabilisation of subgrade layer has been reduced the surface VD.

Figure (4) shows the recorded VD against load pressure for section type A (no base layer). It was found that, the VD was 17.29 mm at 700 Kpa for control specimen without any additives, while, VD decreased to 14.34 mm, about 17.06% reduction after stabilised of 20 cm. While, VD further reduced to 12.95 mm at the same load pressure, about 25.1% reduction after stabilisation of 30 cm. Slightly decrease in VD was occurred by an increase in stabilised

thickness to 40 and 50 cm as shown in figures (4) to (7). The reduction in VD after stabilisation of subgrade layer, due to the improvement of stabilised layers properties mainly Young's modulus as presented in table (1).

The VD decreased to 12.51 mm (27.65%) at 700 Kpa after increasing the base thickness to 15 cm (section B), as shown in figure (5). VD further reduced to 10.13mm (41.41%) by stabilising of 20 cm of subgrade layer. Also, increasing the stabilised thickness to 30 cm reduced VD to 9.33 mm at the same load pressure with VD reduction percentages of approximately 46.04%. Also, slightly decrease in VD was occurred by an increase in stabilised thickness to 40 and 50 cm as shown in figures (5) and (7).

Figure (6) shows that increasing the base thickness to 20 cm (section C) reduced the VD to 11.06 mm at 700 Kpa (36.03%). The VD decreased to 9.05mm (47.66%) after stabilising of 20 cm of subgrade layer.
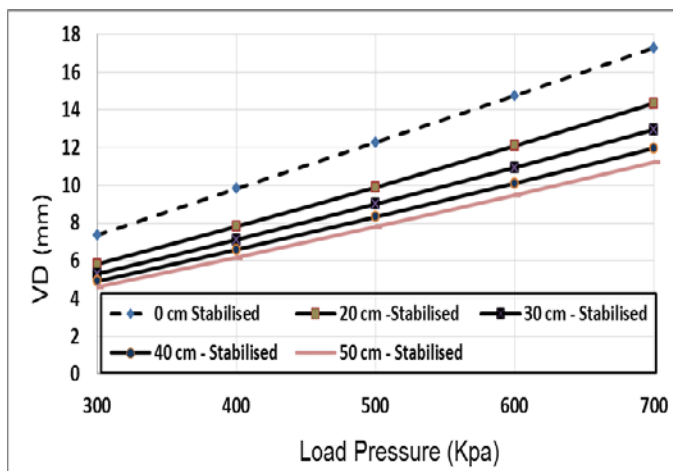
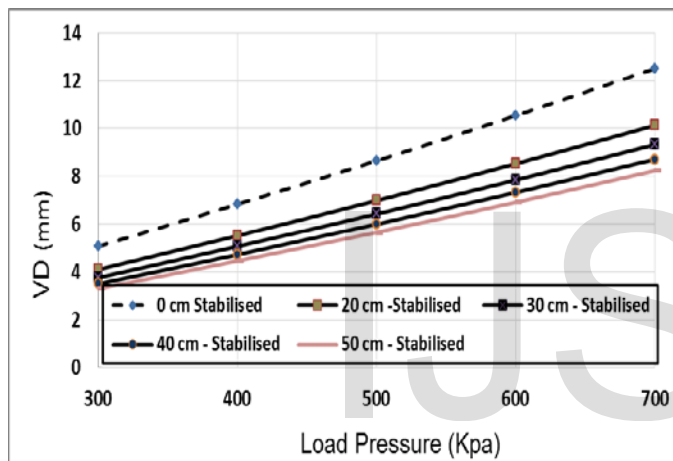Figure (4): Maximum VD versus Applied Pressure for Section (A) – No Base Layer

Figure (5): Maximum VD versus Applied Pressure for Section (B) – 15 Cm Base Layer
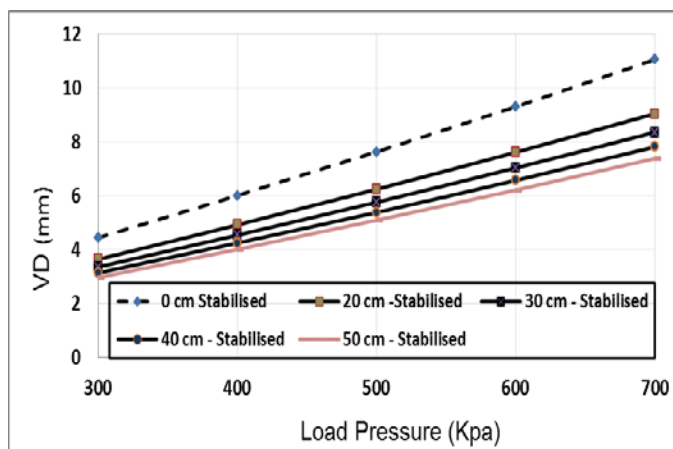

Figure (6): Maximum VD versus Applied Pressure for Section (C) – 20 Cm Base Layer

While increasing the stabilised thickness to 30 cm, reduced the VD to 8.36 mm (51.65%), at the same load pressure. Also, slightly decrease in VD was observed with an increase in stabilised thickness to 40 and 50 cm as shown in figures (6) and (7). The reduction in VD after stabilisation of subgrade layer due to the same reasons explained above, and the increase in base layer thickness from 15 to 20 cm increased the rigidity of the pavement section. Figures (8) and (9) show the VD shape and distribution in Plaxis.
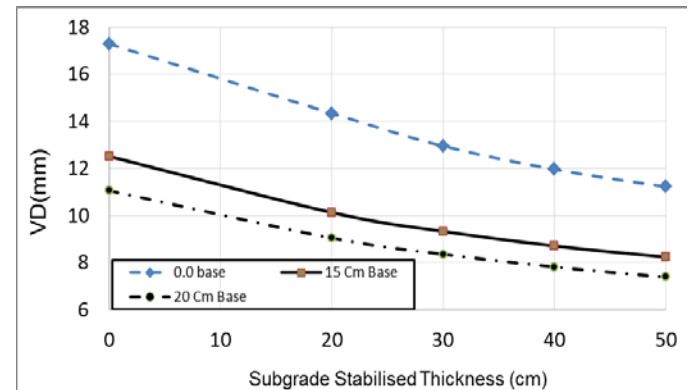

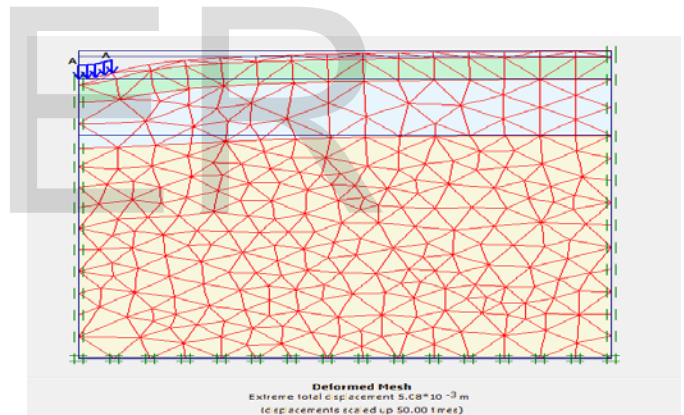Figure (7): Maximum VD versus Subgrade Stabilised Thickness – 700 Kpa.
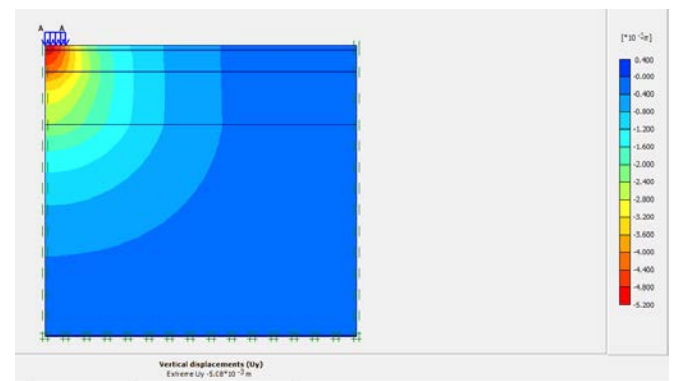

Figure (8): Typical VD Shape in Plaxis

Figure (9): Typical VD Distribution in Plaxis

3. 2 TOTAL STRESS

The following paragraphs explain the importance of subgrade stabilisation and the presence of base layer in pavement section on TS which occurred under applied pressure. Figure (8) shows the recorded TS versus load pressure for section type A (no base layer). It was found that without subgrade stabilisation, the TS was 11800 Kpa at 700kpa, while after stabilising of 20 cm of subgrade layer, TS decreased by 11.53% and reached to 10440 Kpa. After increasing the stabilised thickness to 30 cm, the recorded TS was 9570 Kpa at the same load pressure with TS reduction percentages of 18.90%. Slightly decrease in TS was observed with an increase in stabilised thickness of 40 and 50 cm as shown in figures (10) and (13).
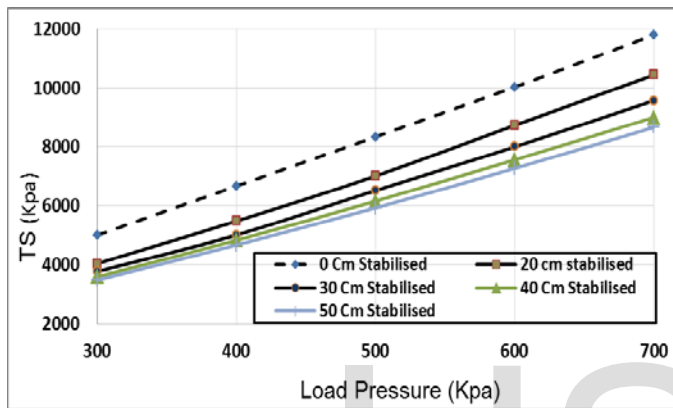

Figure (11): Maximum TS versus applied pressure for section (B) – 15 Cm Base layer

Figure (10): Maximum TS versus applied pressure for section (A) – No Base layer
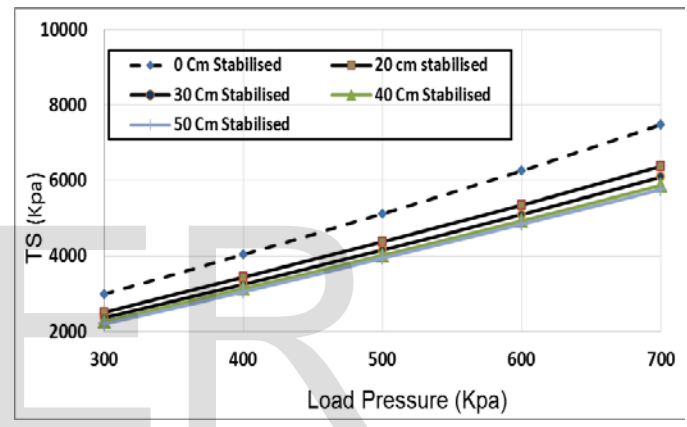
Figure (12): Maximum TS versus applied pressure for section (C) – 20 Cm Base layer

Increasing the base layer thickness to 15 cm (section B), reduced the recorded TS to 8860 Kpa at 700kpa, about 24.92% reduction, as shown in figure (11). Stabilizing of 20 cm of subgrade layer decreased the TS to 7500kpa, about 36.44% reduction. Also, increasing the stabilised thickness to 30 cm reduced the recorded TS to 7110 Kpa, about 39.75% reduction, at the same load pressure. Also, slightly decrease in TS was observed by an increase in stabilised thickness to 40 and 50 cm as shown in figures (11) to (13). The reduction in TS after stabilisation of subgrade layer due to the same reasons explained above.

Figures (12 and 13) show that the recorded TS is 7480 Kpa at 700kpa for section (A), while increasing the base layer thickness to 20 cm (section C) reduced the TS by 36.61%. Stabilising 20 cm of subgrade layer decreased the TS to 6380 Kpa, about 45.93% reduction. Increasing the stabilised thickness to 30 cm reduced the recorded TS to 6090 Kpa at the same load pressure with TS reduction percentages of 48.38%. Also, slightly decrease in TS was observed with an increase in stabilised thickness of 40 and 50 cm see figures (12) and (13). Also, figure (14) shows TS distribution in Plaxis.
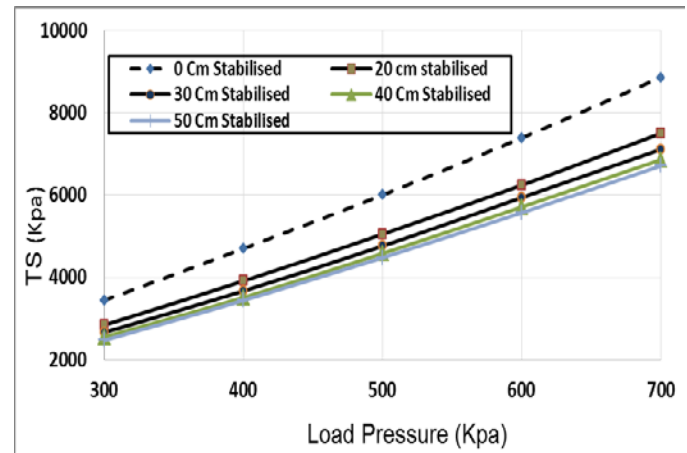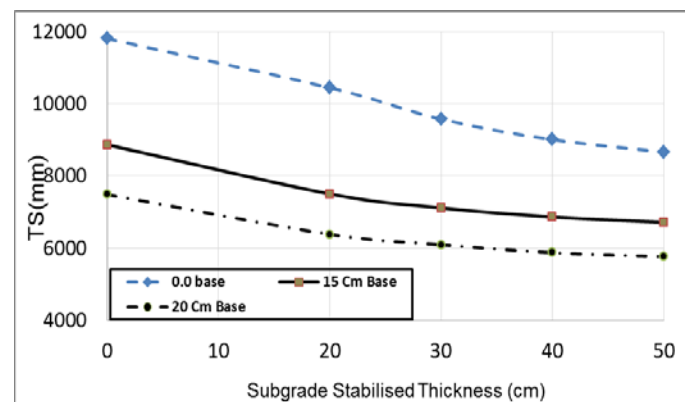

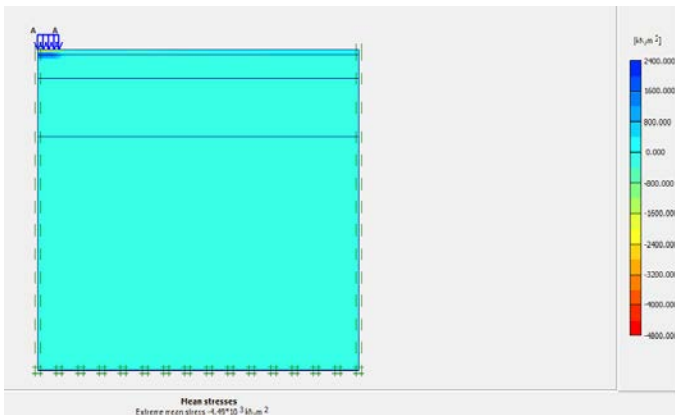Figure (13): Maximum TS versus Subgrade Stabilised Thickness – 700 Kpa.

Figure (14): Typical TS Distribution in Plaxis

The reductions in VD and TS with an increase in stabilised layer thickness are results from the reaction of NS and lime with the clay portion of the test soil and the formation of new cementitious materials. In addition, this improvement is due to the change in soil gradation due to the presence L and NS. Similar behavior was found when adding normal slag activated by lime to clay by Higgins et al., (1998).

In a study carried out on clay- slag- lime system, when slag is mixed with water a Si-Al-O layer forms on the slag particle surfaces and this layer absorbs H+ from mixing water, resulting in increase in OH- concentration and then the pH of the solution increases to the pH of a saturated lime solution (Caijun and Day, 1993, Ouf 2016). At these values of pH, Si-O and Al-O bonds are broken and then semi-crystalline C-A-S-H and C-A-H are formed. In clay–lime– NS system, due to the finer grading size, it is expected to form C-A-S-H gel with high Al/Si ratio.

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 was recorded in all pavement sections.
2- The presence of 15 and 20 cm base layer, leads to significant reduction in the VD and TS.
3- 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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