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EARTH FILL MODELLING WITH FINITE ELEMENT METHOD

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Abstract- The objective of this study was to examine load-deformation characteristics at different fill layers of a high fill and to determine typical modeling parameters by using plate loading tests in a real construction site. The average value of the modulus of elasticity E_{plaxis} was found to be 53 MN/m^2 and Poisson's ratio was found to be 0.2 for the dense sand soil of the construction site. With proper compaction, load-deformation characteristics were found to be almost identical in different layers of the fill and very close to that of the natural soil.
Keywords: Granular fill, Plate loading test, Plaxis, Elasticity modulus.

1.INTRODUCTION

Compaction is a mechanical process in which soil particles pressed together, reducing pore space and causing the soil to act as a whole. Two important criteria for compaction at highways, railways, canal and dam backfilling are: Reducing the deformation and increasing the strength. By improving the strength as a result of compaction, the bearing capacity of the foundations increases and immediate settlement under load is reduced [1]. Dry unit weight and optimum water content of the material used in backfilling has to be determined and by having necessary precautions, the water content has to be optimized at the site and sufficient ironing is necessary [2]. Otherwise sufficient compaction will not be achieved, or the compaction vehicle will have to use more energy, causing the project costs to rise. Compaction also has an important role in recycling projects. Compaction of waste materials provides additional space and, by decreasing the permeability of the soil, it prevents underground water being polluted by leachate. Thus, soil compaction is used to achieve the intended strength, compatibility and impermeability. In the earth fill works, it is important to find a material with good compaction characteristics that provides a permanent operational solution. In fills under the foundations of structures such as industrial facilities, roads or airports, granular materials are generally preferred and standards are defined for material properties. High earth fills are an economical and optimized solution for some projects. To construct a flat area at the sloping site, an economical solution can be achieved by adjusting the excavating and filling amount. A frequently encountered problem in the field is the use of different filling materials or the inability to provide the same gradation. In this case, the soil's bearing capacity and deformation under loads change. Thus, it is important to predetermine the effects of these changes in soil parameters on filling behavior. The objective of this study is to examine load-deformation characteristics at different fill layers at different heights of a high fill, and to determine typical parameters for modeling this behavior by using plate loading data from a real construction site.

Finite element methods are also applied to ground modeling especially Plaxis finite element modeling program which has been shown in recent studies to provide reliable results in this area. In this study, the effects of different soil parameters on filling material was examined using the Plaxis program,

Plate loading tests were conducted and then modeled in the Plaxis program, using a Mohr-Coulomb model, to examine the soil properties. The reliability of the parameters used in the program was examined, as well as consistency with the test parameters obtained from the field. Yetimoğlu [3] conducted plate loading tests on filling material compacted by vibration in laboratory. The experiment, was modeled on a sand sample compacted layered at 100 cm depth, in a program (DACSAR) that uses finite element analysis. The results indicated that, when using the appropriate model elements and material characteristics, the empirical deformation data was consistent with that predicted by the program. Defossez and Richard [4] examined the compaction effects that occur due to the weight of the construction vehicles used occurs because of the weights of the construction vehicles used in agricultural fields. They compared the results of laboratory and field tests with those obtained using finite element method and concluded that they are consistent. Schweiger and Peschl [5] compared results obtained using the soil parameters chosen in the Plaxis *V8* program with the field test results. They reported that the solutions derived from the chosen model parameters complied with those obtained in practice. Moayed and Janbaz [6] studied foundation size effect on modulus of subgrade reaction in clayey soil using Plaxis program. In the Plaxis program Mohr-Coulomb model is used and the results are calibrated by plate loading tests conducted in the field. Modulus of subgrade reaction calculated by using the program was 33% greater than when using the equation given by Terzaghi in 1955.

2. METHODOLGY

The present study was conducted at an industrial construction site of 46,000 m^2, located in Gebze Industrial zone in Kocaeli, Turkey. There are many important factories in this industrial region. The soil in the region is mostly sand containing, a small amount of silt with high SPT (Standard Penetration Test) values, and usually over 50. The construction site is sloping and it was proposed to locate the planned building on a flat area, after necessary earthworks were completed. To determine the soil characteristics, an initial soil survey was conducted, to obtain soil samples for laboratory analysis and SPT values. Initial test results determined that yellow colored, well graded sand and silty sand soils were present, and that this material was suitable for earth fill works at the site.

This methodology provided an economical solution, taking into consideration the factory's need for the project. In the soil investigations, 12 research pits and 13 drilling holes were opened in the field. Soil mechanics tests were conducted both in situ and in the laboratory. The plate loading tests (*PLT*) for comparison in the field were conducted using German DIN 18134 [7] standards at four different fill layers and natural soil at the same points on a selected part of the field. Stress-deformation graphs were produced from the tests conducted on filling and natural soil, and deformation modules were obtained from test results [8].

The plate loading tests were modeled using the Plaxis finite element program to determine soil parameters for comparison with the actual field data. The Mohr-Coulomb hypothesis was used as the material model in the study. Other important parameters for finite element modeling, such as Poisson's ratio and unit weight of the soil were studied and the results are provided in following sections.

3. MATERIALS

The availability and suitability of the filling material were examined according to Standard and Modified Proctor, sieve analysis, liquid limit, plastic limit and soaked (California Bearing Ratio) CBR tests. Tests were conducted in accordance with ASTM D698, ASTM D1557, ASTM D421&422, ASTM D1883-87 standards [9]. The results are shown in Table 1.

Table 1. Properties of fill material

Soil Classification	
Unified Soil Classification System (USCS)	SW-SM
Atterberg Limits	
PL (%)	N.P
LL (%)	N.L
PI (%)	N.P.
Sieve Analysis - USCS	
Stone (>76.2 mm) (%)	0
Gravel (76.2 mm - 4.76 mm) (%)	4.26-5.50
Sand (4.76mm-0,074) (%)	87.37-89.78
Silt and Clay (<0.074) (%)	5.96-7.13
CBR	
CBR value (%)	80.24
Compaction Parameters	
Max. Dry Unit Weight - Modified Proctor (kN/m^3)	18.64
Optimum Water Content (%) - Modified Proctor	6.6
Max. Dry Unit Weight - Standard Proctor (kN/m^3)	18.03
Optimum Water Content (%) - Standard Proctor	8.4

Sieve analysis showed that the soil comprised of approximately 88% sand and the finer part of the soil is non-plastic. The soaked CBR value was 80.24 at modified Proctor energy level. In the field works, after the weak topsoil was removed from the field, the field was leveled by cutting the soil from high levels and filling the lower sides with compaction controls. The earth fill applications are done with 30 cm thick horizontal layers, controlling the relative compaction values which are greater than 95% relative compaction *(RC)* of modified Proctor energy level by using nuclear methods and sand cone method.

4. RESULTS

4.1. In-situ Plate Loading Tests

The plate loading tests *(PLT)* were conducted with a 30 cm diameter plate at four different fill layers and with natural soil. Tests were performed at the same points on a selected part of the field for comparison. In the tests conducted in filling and natural soil, German DIN 18134 standards were applied, stress-deformation graphs were produced, and deformation modules were obtained from the tests. The results of plate loading tests conducted on the 13, 14, 18 and 19th layers in the field and on natural soil are given in Fig. 1.

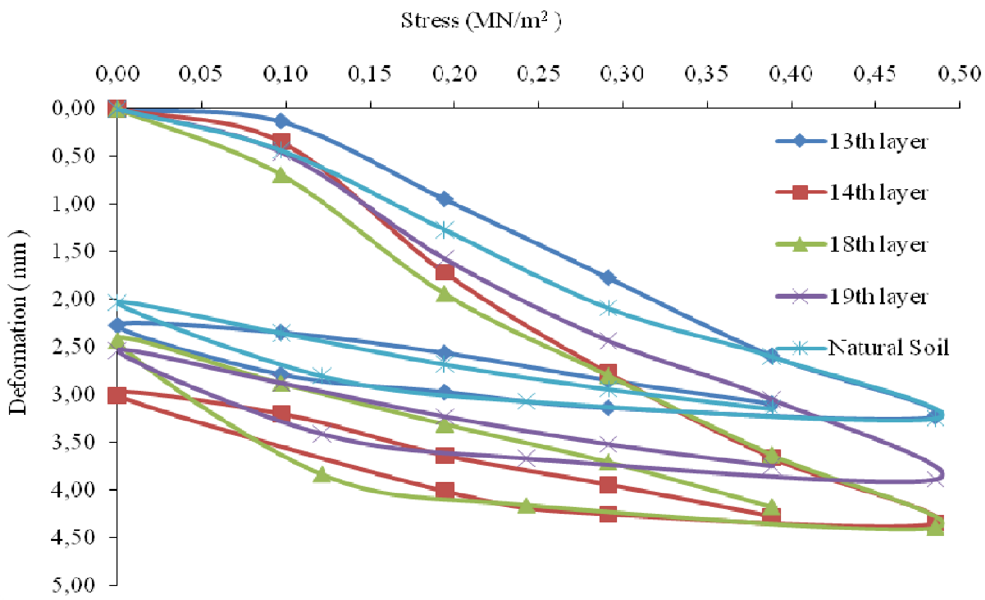

Figure 1. Plate loading test results for various fill layers and natural soil

The strain modulus for design calculations in road construction was determined according to DIN 18134 standards. The test procedure specifies that a 300 mm loading plate shall be used and the load increased until a settlement of 5 mm or a normal stress below the plate of 0.5 MN/m^2 is reached. If the required settlement is reached first, the normal stress measured at this stage shall be taken as maximum stress. In the study, since the soil was very dense, all the deformations were below 5 mm, so the loading was applied until 0.5 MN/m^2.

The maximum deformations *(s_{max})* that occurred under the maximum stress were between 4.39 mm and 3.23 mm. The permanent deformations at the same stresses were found to be between 2.03 mm and 3.01 mm. It is seen in Fig. 1 that the minimum deformation value was obtained at the 13th layer, and the maximum deformation values occurred in 14th and 18th layers. In the 19th layer, which is the top layer, 3.89 mm deformation was obtained. In the plate-loading test conducted on natural soil, 3.25 mm deformation was obtained. This value is 0.02 mm greater than the deformation value obtained in the 13th filling layer, but is less than that recorded in all the other filling layers.

The maximum permanent deformation *(s_{perm})* value recorded was 3.01 mm, obtained from the test conducted at layer 14. The minimum permanent deformation value recorded was 2.03 mm, obtained from the test conducted on natural soil.

Modulus of subgrade reaction *($k_s=\sigma_0/s$)* values were calculated for the tests defined above, conducted on filling layers and natural soil at 1.25 mm settlement. At each layer of the fill, 95% minimum relative compaction of modified Proctor and also water content of between ±2% of optimum moisture content was achieved (See Table 2). As shown in Table 2, the modulus of subgrade reaction values were between 112 and 176 MN/m^2.

Table 2. Summary of plate loading tests and density measurements in-situ

Soil	Layer	k_s(MN/m^2)	s_{max}.(mm)	$s_{perm.}$(mm)	RC (%)	w (%)
Fill	1st	-	-	-	98.0	5.12
Fill	13th	176	3.23	2.71	97.5	5.39
Fill	14th	128	4.35	3.01	97.5	5.27
Fill	18th	112	4.39	2.43	99.0	4.10
Fill	19th	136	3.84	2.54	97.0	5.50
Natural	-	152	3.25	2.03	-	5.03

According to these results, the Modulus of subgrade reaction value, which shows differences between layers, is not directly proportional to filling height. As expected, the permanent deformation results of plate loading tests obtained in natural soil produced the lowest values in comparison with others.

4.2 Plate Loading Test Modeling in Plaxis Program

The plate loading tests were modeled using the Plaxis finite element program to determine soil parameters, which were then compared with the data obtained at the test site. Mohr-Coulomb hypothesis was used as the material model in the program. In the study, five soil parameters given below have to be defined in the program. In cohesive soil, parameters can be more easily obtained by laboratory tests conducted with undisturbed samples taken from field, but because of the difficulty of taking undisturbed samples from granular soil, soil parameters must be calculated from empirical formulas given for other tests (Sieve Analysis, *CBR*, Modified Proctor, Plate Loading Test etc.) or with various methods described in the literature. The program uses elastic modulus, Poisson's ratio, internal friction angle, dilatancy angle, cohesion and unit weight of the soil as data, which are defined below.

i) Elastic modulus *(E)* is obtained by the calibration that is done with the plate loading tests.

ii) The Poisson's ratio *(v)* for sand filling material is accepted as 0.2. In their studies on sand, Laman and Keskin [10] used 0.2 as the value for Poisson's ratio.

iii) Internal friction angle *(Ψ)* for the soil is taken as 45° based on the researches defined in US Army Corps of Engineers manual [11]. The existing soil and compacted fill layer consist of very dense sand with *SPT* blow counts as high as 50. Reference data for internal friction angle is shown in Table 3.

Table 3. Internal friction angle for granular soils [10]

Soil Type	Standard Penetration Resistance N_{60} (Terzaghi and Peck 1967)	Internal Friction Angle Ψ, deg		
		Meyerhof (1974)	Peck, Hanson and Thornburn (1974)	Meyerhof (1974)
Very Loose	< 4	< 30	< 29	< 30
Loose	4 - 10	30 - 35	29 - 30	30 - 35
Medium	10 - 30	35 - 38	30 - 36	35 - 40
Dense	30 - 50	38 - 41	36 - 41	40 - 45
Very Dense	> 50	41 - 44	> 41	> 45

iv) Dilatancy angle *(Φ)* = 15° (In Plaxis user guide, *Φ* = *Ψ* – 30 correlation is recommended for dilatancy angle)
v) Cohesion *(c)* was taken as 0.5 kN/m^2. From the plastic limit and liquid limit tests conducted in the laboratory, it was clear that the filling material did not show any plastic and liquid behavior. However, the Plaxis user guide program user guide recommends using a very low value instead of taking it as 0, so the cohesion value was taken as 0.5.
vi) Unit weight of the soil was taken as 19 kN/m^3 using the modified Proctor test results

Plate loading tests were modeled two-dimensionally in Plaxis *V9* program. The plate used in the plate loading test is circular so the model in the computer program is formed as axially symmetrical. In the model in the program, the soil is modeled as 90 cm*90 cm (30 cm. filling layer thickness' are also modeled). The plate loading test model and finite element mesh are shown in Fig. 2 below.

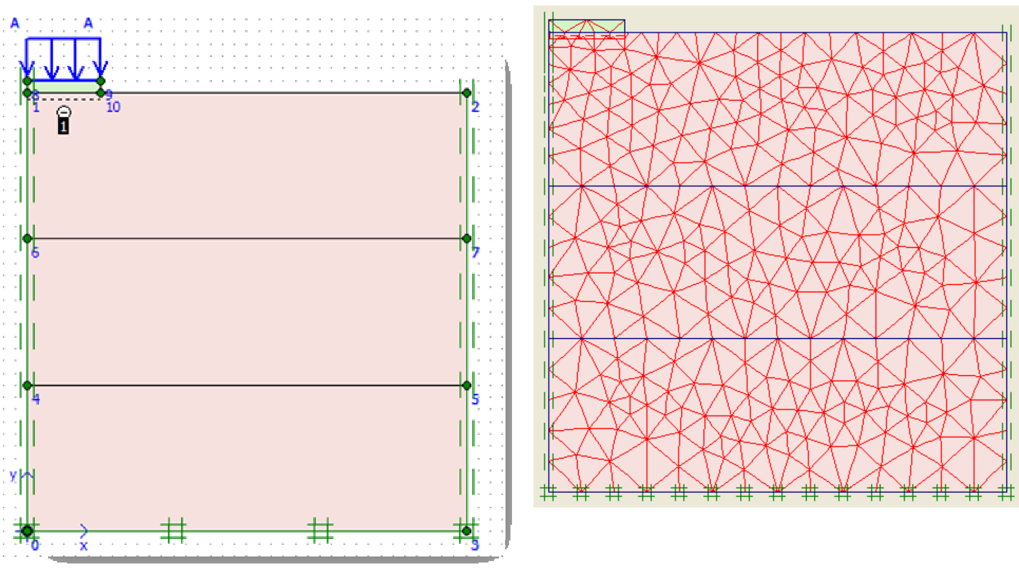

Figure 2. Plate loading test Plaxis model and finite element mesh

The results of the *PLT* model produced in Plaxis program were compared with the *PLT* results obtained from the field. To determine the elastic modulus that will be used in the Plaxis program, an elastic module that gives the same deformation in the field test was chosen, after many runs of the program, and also its correlation with the first and the second strain modules that are obtained by the plate loading tests was examined. The strain modulus is a parameter expressing the deformation characteristics of a soil, and can be calculated taking values from the stress-settlement curve obtained from the first loading cycle, from the gradient of the secant between points $0{,}3\sigma_{max}$ and $0{,}7\sigma_{max}$ (DIN 18134).

Strain modulus Ev_1 and Ev_2 are defined in the DIN 18134 standard as from 1st and 2nd loading, using the following equation *(1):*

$$Ev = 1{,}5x\ r\ x\ (\Delta P/\Delta S) \quad (1)$$

Fig.3 shows the 18th layer *PLT* test and final Plaxis graph, modeled using the data in Table 4.

Table 4. Chosen Plaxis parameters (19th layer)

E(Elastic Modulus) [kN/m²] =	53000
υ (Poisson's ratio) [-] =	0.2
Ψ(Internal Friction angle) [°] =	45
Φ(Dilatancy angle) [°] =	15
c(Cohesion) [°] =	0.5
γ (Soil unit weight) [kN/m³] =	19

The Plaxis program was run many times using different elasticity values found between Ev_1 and Ev_2 strain modules and, finally, the two graphs for the actual *PLT* and Plaxis *PLT* graphs matched at 53 MN/m². The final case is given in Fig. 3. below.

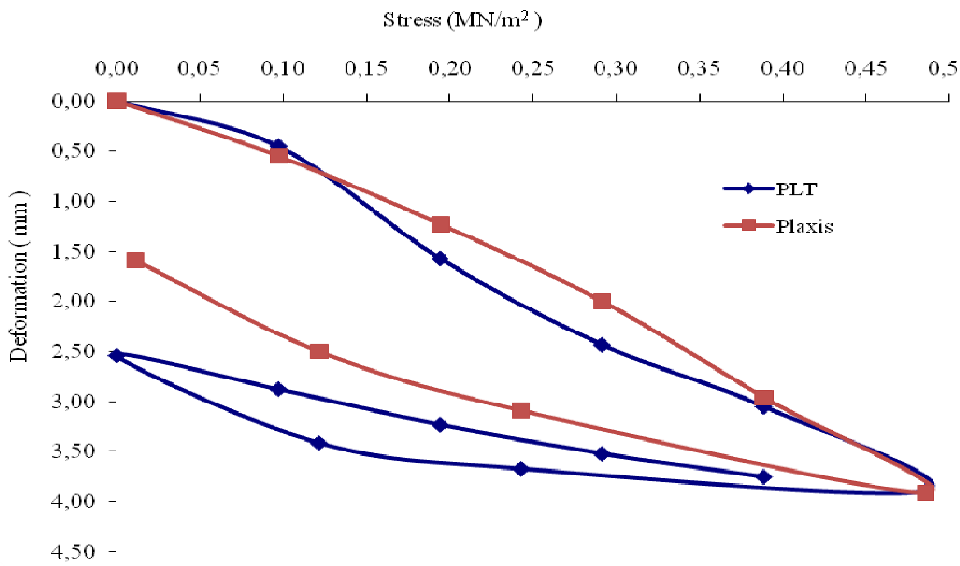

Figure 3. Comparison between plate loading test and Plaxis results (19th layer)

When the strain modules in Fig. 3. where the same vertical deformation was obtained as a result of Plaxis and field tests (19th layer), are compared, it was determined that the E_{plaxis} value obtained from the Plaxis program trials remained within the range of strain modules of the first and second loading Ev_1 and Ev_2.

All the conducted *PLT* tests were used for modeling. The final E_{plaxis} values after the modeling is given in Table 5, with comparisons of strain modules Ev_1 and Ev_2.

Table 5. Plate loading tests and Plaxis elasticity results summary

	Ev_1 (MN/m^2)		Ev_2 (MN/m^2)				
Layer	ΔP (MN/m^2)	Δs(mm)	ΔP (MN/m^2)	Δs (mm)	Ev_1	Ev_2	E_{plx}
13th	0.20	1.68	0.18	0.47	26.8	86.2	64.0
14th	0.20	2.09	0.18	0.71	21.5	57.0	47.0
18th	0.20	1.75	0.18	0.74	25.7	54.7	47.0
19th	0.20	1.64	0.18	0.61	27.5	66.4	53.0
Natural	0.20	1.51	0.18	0.42	29.8	96.4	63.0

Table 5 clearly shows that all the Plaxis values were found between Ev_1 and Ev_2. Elasticity values and Poisson's ratio values are very important for finite element modeling. In the study, the analyses were conducted to find the best elasticity modulus which was the closest to the values found in plate loading tests in the field. According to the results shown above, the E_{plx} was found using between the strain modulus of Ev_1 and Ev_2 and the average E_{plx} value of fill layers was found as 53 MN/m^3. The E_{plx} was also found to be proportional to the two elastic moduli and the value using average for fill layers was found to be $Eavg=1.15(Ev_1+Ev_2)/2$. This average value, with a multiple of 1.15, covers the elasticity value found by the Plaxis program, and is within ±2% for the fill layers used in the study.

4.3. The Effect of Poisson's Ratio on Modeling with Plaxis

The Poisson' ratio value is an important parameter for modeling. It is very difficult to determine, but significantly affects the modeling results, and so should be accurately defined. In the study the Poisson's ratio was studied after fixing the elasticity modulus. A typical fill layer (13th layer) was chosen to determine the exact value of the Poisson's ratio. The data in Table 6 was used for modeling and the final stress-deformation graphs are given in Fig. 4.

Table 6. Chosen Plaxis parameters for different Poisson's ratio values

E(Elastic modulus) [kN/m^2] =	64000
υ (Poisson's ratio) [-] =	0.19/0.2/0.21/0.22/0.23/0.47
Ψ(Internal Friction angle) [°] =	45
Φ(Dilatancy angle) [°] =	15
c(Cohesion) [°] =	0.5
γ (Soil unit weight) [kN/m^3] =	19

In the model of the plate-loading test, only the Poisson's ratio is changed. The Poisson's ratio values used in the model were 0.19, 0.20, 0.21, 0.22, 0.23, 0.49 and the 13th fill layer.

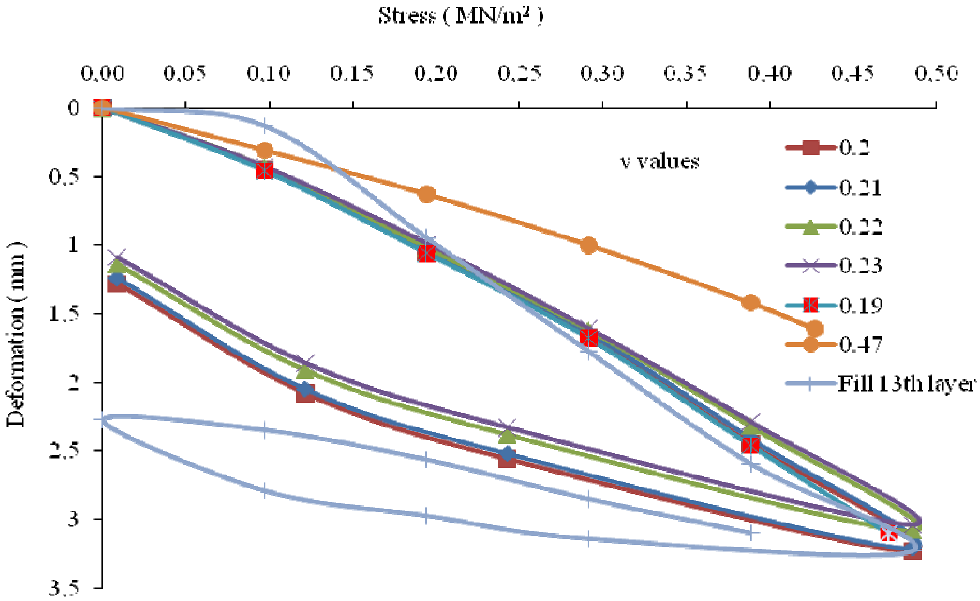

Figure 4. Plaxis results for different Poisson's ratio values and Plate loading test result

As seen in Fig.4., for the Poisson's ratio of 0.2, a deformation of 3.23 mm was obtained. When the Poisson's ratio was 0.23, deformation was 3.04 mm. According to these results, it is possible to estimate the potential variation in deformation and changes in load-bearing capacity for the different filling materials that may be used in the field. The Poisson's ratio was changed from 0.19 to 0.47 in the model, to find the value closest to the actual *PLT* results. The Plaxis results matched the actual *PLT* data at a Poisson's ratio of 0.2.

At Poisson's ratio values greater than 0.24, the model predictions diverge from the real data and show failure in the soil at a value of 0.47. The results of the present study related to Poisson's ratio support those reported for a model developed by Laman and Keskin [9].

4.4. The Effect of Unit Weight of Soil on the Modeling with Plaxis

Filling materials of different unit weights were modeled using the Plaxis program, to examine the effect on the plate loading table (See Table 7).

A typical fill layer (13th layer) was chosen to determine the exact unit weight of the soil. The data in Table 7 was used for modeling and the final stress-deformation curves are given in Fig. 5.

Table 7. Chosen Plaxis parameters for different soil unit weights of soil

E(Elastic modulus) [kN/m^2] =	64000
υ (Poisson's ratio) [-] =	0.2
Ψ(Internal Friction angle) [°] =	45
Φ(Dilatancy angle) [°] =	15
c(Cohesion) [°] =	0.5
γ (Soil unit weight) [kN/m^3] =	19/20/21

In the plate loading test model produced using the data in Table 7, only the unit weight of the filling material changed. The soil unit weights used in the model were 19 kN/m^2, 20 kN/m^2 and 21 kN/m^2.

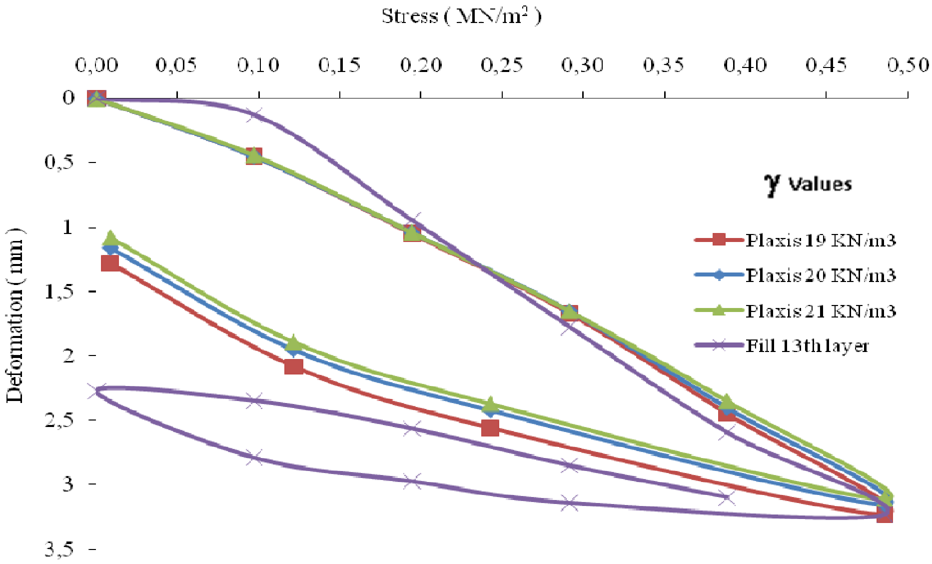

Figure 5. Plaxis model results for different soil unit weights with site plate loading test result

As seen in Fig. 5, the use of different soil unit weights in the Plaxis program caused different deformations under the same stresses. As shown in the graph, the higher soil unit weight produced greater deformation (3.11 mm) than the lower soil unit weight (3.23 mm). The exact value found using a modified Proctor test was the same, which supports the validity of the other parameters used in the Plaxis finite element model.

5. SUMMARY AND CONCLUSIONS

This research was done in the field, using the data obtained from an actual filling study. According to the field tests and modeling results, E_{plx} was between the elasticity modulus of Ev_1 and Ev_2 and the average E_{plx} value of fill layers was 53 MN/m^3. The E_{plx} was also found to be proportional to two elastic modulus and the average value, with a multiple of 1.15, found for fill layers was $E_{avg}=1.15(Ev_1+Ev_2)/2$. This average value covers the elasticity value produced by the Plaxis program and was within ±2% for the fill layers. In a forthcoming study, deformation module values for the dense sand above values can be used as the elastic modulus of the soil for the initial assumption.

For the analysis performed using the Plaxis program, in the fine sand filling material, only Poisson's ratio was changed, while keeping other parameters constant for this material. The range for Poisson ratio values, within which the soil would not collapse under the 0.5 MN/m^2 stress was found to be between 0.19 and 0.47. In this study, the Poisson's ratio for sand filling material was accepted as 0.2 and this value was found to represent the soil very well.

Plaxis was also used to examine deformations under the same load but with a different unit weight for the filling material. Soil unit weights used in the model were 19 kN/m^2, 20 kN/m^2 and 21 kN/m^2, which are the probable unit weights of sand type soils.

As expected, different soil unit weights used in Plaxis program produced different deformations under the same loads. The Plaxis results matched actual PLT data at 19 kN/m^3 unit weight of soil. The exact unit weight value found using a modified Proctor test was the same, which supports the validity of the other parameters used in the Plaxis finite element model.

Modulus of subgrade reaction values were calculated for plate loading tests that are conducted on filling layers and natural soil. According to these results, the Modulus of subgrade reaction value, which shows differences between layers was not directly proportional to filling height. As expected, the permanent deformation results of plate loading tests obtained in natural soil produced the lowest values in comparison with others. The maximum deformations using PLT tests found for the fill layers were between 3.23 and 4.39 which are very small therefore the bearing capacity does not change considerably at different fill layers. This findings suggests that filling height does not have a particularly strong effect on load bearing capacity but that, when the filling height is increased, the soil's bearing capacity at the base of the filling and especially slope stability (if the earth fill is on a sloped area) must be examined.

Comparison of the Plaxis modeling with the plate loading tests conducted in the field suggests that granular soil (especially dense silty and well graded sand, as used in the present study) can be modeled very well using the Plaxis finite element program to determine the stress-deformation behavior of the soil.

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