EVALUATION OF PLATE LOAD TEST RESULTS: A CASE STUDY IN ANKARA/TURKEY

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Abstract

Plate load test is widely used for bearing capacity and settlement calculations of foundations. In this study, 6 plate load tests were carried out to determine the bearing capacity and settlement of the foundation. High-speed railway project will be constructed in related area. The project location is in Ankara/Turkey. Bearing capacity of the station platform building foundation was determined according to plate load test and finite element analysis. Finite element analysis (FEM) software, Plaxis 2D, was used for the understanding of the settlement behaviour of soil. Soil strength and deformation parameters were determined according to plate load test and finite element analysis. Elasticity theory was used for analytical solutions. Field measurements, finite element analysis (FEM) results and analytical solution were compared at final of the study. Finite element analysis (FEM) and elasticity theory settlement calculation results have a strong correlation with field observations.

PLAKA YÜKLEME DENEY SONUÇLARININ DEĞERLENDİRİLMESİ: ANKARA'DA BİR VAKA ANALİZİ

Anahtar Kelimeler
Elastisite Teorisi
Sonlu Elemanlar Metodu
Plaka Yükleme Deneyi
Plaxis 2D
Oturma

Öz

Plaka yükleme deneyi temel taşıma gücü ve oturma hesaplarında yaygın olarak kullanılmaktadır. Bu çalışmada yapılan 6 plaka yükleme deney verisi kullanılarak taşıma gücü ve oturma hesapları yapılmıştır. Deneylerin yapıldığı bölgede yüksek hızlı tren hattı inşa edilecek olup proje lokasyonu Ankara' dır. İstasyon peron yapısı temelleri için sonlu elemanlar yazılımı ve plaka yükleme deney verileri kullanılarak taşıma gücü hesapları yapılmıştır. Zemin oturma davranışı sonlu elemanlar analiz program Plaxis 2D kullanılarak modellenmiştir. Zemin dayanım ve deformasyon parametreleri plaka yükleme deneyi ve sonlu elemanlar yöntemi ile belirlenmiştir. Analitik çözümler için elastisite teorisi kullanılmıştır. Çalışmanın sonunda plaka yükleme deney sonuçları, analitik çözüm ve sonlu elemanlar çözüm sonuçları karşılaştırılmıştır. Sonlu elemanlar ve elastisite teorisi ile hesaplanan oturmaların arazi ölçümleri (plaka yükleme deneyi sonuçları) ile güçlü bir korelasyon oluşturduğu görülmüştür.

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1. Introduction

Soil bearing capacity and settlement are very important for foundation design in geotechnical engineering applications. Ultimate bearing capacity, foundation settlement, elasticity modulus and subgrade modulus can be determined with plate loading test. This test may be carried out on foundation pits or ground surfaces. It is impossible to collect undisturbed samples with this

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test method. Plate load test is carried out for soils, rocks and fills. This test is more suitable for grained soils and stiff fine-grained soils. Plate load tests have been standardized globally, such as ASTM D 1194-94, BS 1377-9: 1990, TS 5744: 1988. In this study, 6 plate load tests were carried out on the construction site. TS 5744: 1988 standard was used in the application. Finite element analysis (FEM) was carried out with Plaxis 2D. The behavior of soil was simulated as a case study.

2. Literature

Detailed literature researched in the scope of the study. Araujo et al. (2017) investigated the footing size effect of shallow foundations in sandy soils. Three plate load tests were carried out with diameters of 0,30, 0,50 and 0,80 m on sand backfill. Obtained stress-strain curves from the plate load test did not show a clear failure pattern, therefore, bearing capacity was determined with conventional failure criteria. In the conventional method, bearing capacity dependent on increasing plate size. For constant applied stress, settlement increases according to plate size increasing. But, obtained results showed that at the same applied stress, the settlement increases, but settlement increases occur nonlinearly.

Ping et al. evaluated the bearing capacity of pavement base and subgrade and embankment soils with a field plate loading test. In the scope of the study, 20 flexible pavement sites were selected in Florida. Bearing capacity, subgrade and embankment layers were determined for each site. Observed elasticity modulus from field plate load test, compared and validated with ELSYM5 software.

Omar (2017) investigated the strengthening of geogrid reinforcement of foundations on weak soils. Test pits were excavated 2 m x 2 m x 1,3 m, the diameter of plate is 0,45 m and thickness of the plate is 25 mm. The plate load test was carried out to understand the effect of geogrid layers on bearing capacity of soil. Earth pressure cells were used to measure horizontal and vertical stress in soil mass at different depths. With using of geogrid reinforcement, loads are transferred to soil as uniform and settlements values decrease.

Sultana et al. (2018) used the plate load test to estimate of ultimate bearing capacity of footings on soft clayey soil. According to using experimental results from the plate load test, author carried out sensitivity analysis. The author used hyperbolic model for the ultimate bearing capacity of footings. Confidence interval was determined as %95. This value shows that hyperbolic model is useful for footing design on soft clayey soils.

Boyle (1992) gave information about determining in situ deformability of rock using the plate load test according to The International Society for Rock Mechanics (ISRM). Author simulated the plate load test with finite element software SPECTROM-31. Material models were selected as intact rock, jointed rock and partially excavated rock. Alternative method developed by author and discussed advantages and disadvantages.

Agharazi et al. (2014) evaluated the plate load test to determine the rock mass deformability at large dam sites. Numerical modeling was used to interpret for plate load test at the Bakhtiary Dam site. Jointed rock model was used for back analyses. The equivalent continuum deformation modulus was determined numerically.

3. Testing Procedure

In this test 10-25 mm thickness plate is used. Plate load test is carried out following stages. The testing procedure and typical load settlement graphic are shown in Figure 1.

- A hole is excavated with a minimum diameter of 4B (B is the diameter of the test plate) to a depth of Df, the depth of the proposed foundation.
- The plate is placed at the center of the hole.
- Load is applied stage by stage.
- Plate settlements are measured and plotted the load-settlement curve. The measurement device must have an accuracy of 0,02 mm. The limit of settlement for ultimate bearing capacity is considered as 25 mm.

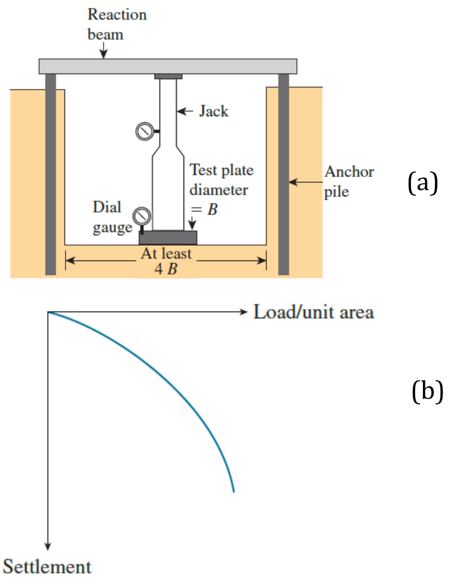

Figure 1. (a) Testing Procedure (b) Load-Settlement Curve (Das, 2019)

4. Theoretical Background of Plate Load Test

Stress and settlement determination is the base of the plate load test. When stress increases, plate settlement will increase. This relationship is represented by the Winkler method. Winkler (1867) was investigated the stress-settlement relationship. This relationship is defined as a subgrade reaction in equation (1). Subgrade reaction is dependent on applied stress (q) and foundation settlement (Δ). Winkler's theory is illustrated by Das (2019) in Figure 2.

$$k = \frac{q}{\Delta} \tag{1}$$

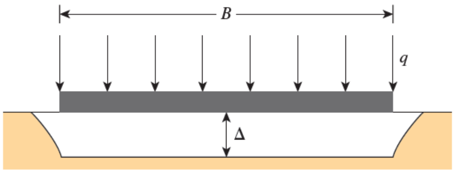

Figure 2. Winkler Theory (Das, 2019)

5. Settlement Based on Elasticity Theory (Analytical Method)

All structural materials possess to a certain extent the property of elasticity, producing deformation of a structure, do not exceed a certain limit, the deformation disappears with the removal of the forces (Timoshenko et al., 1951). Elasticity theory is a useful method for a lot of geotechnical engineering problems. There are several assumptions for settlement calculations. The soil is treated as an elastic continuum. The settlement occurs uniform for rigid foundations and nonuniform for flexible foundations. A plate of the plate load test is considered a rigid foundation. The settlement equation is given in equation (2). Settlement is dependent on applied stress (q_0), foundation width (B), soil elasticity modulus (E_s), Poisson ratio (μ_s) and influence factor (I). For circular foundations influence factor becomes I=1 for the center of the foundation and I= $2/\pi$ for the perimeter of the foundation.

$$S_e = \frac{q_0 B}{E_s}\,(1-\mu_s^2)I \tag{2}$$

6. Parameters From Plate Load Test

Mainly two parameters are determined from the plate load test. These parameters are elasticity modulus and subgrade modulus. Elasticity modulus is a very important parameter for the deformation behaviour of soil and foundation. A lot of correlations were developed by researchers for various soils and rocks. Elasticity modulus (E_s) derived from equation (2) and expression with equation (3).

$$E_s = \frac{q_0 B}{S_e}\,(1-\mu_s^2)I \tag{3}$$

Subgrade modulus is derived from Equation (1). The value of the coefficient of subgrade modulus is not a constant for a given soil. Subgrade modulus is also given by Bowles (1997) in Table 1.

Table 1

Subgrade Modulus Ranges (Bowles, 1997, Table 9.1)

Soil Type	**k_s, kN/m^3**
Loose sand	4800-16000
Medium dense sand	9600-80000
Dense sand	64000-128000
Clayey medium dense sand	32000-80000
Silty medium dense sand	24000-48000
Clayey soil;	
$q_a \leq 200$ kPa	12000-24000
$200 < q_a \leq 800$ kPa	24000-48000
$q_a > 800$ kPa	> 48000

7. Experimental Study

The construction site is in Ankara/TURKEY. 6 plate load tests were carried out on the construction site. Subgrade soil contains dense gravel. Clayey soil stratum is beneath the subgrade soil. Test locations are shown in Figure 3. The plate width is 450 mm. Loads increased by 6 stages as 50, 130, 220, 330, 450, 550 kPa. Plate thickness is 25 mm. Plate load test was simulated in finite element analysis (FEM) software Plaxis 2D. Plaxis 2D is a two-dimensional finite element modeling software for solving geotechnical problems. Mohr-Coulomb material model is selected for subgrade soil. This is well-known linear elastic perfectly-plastic model is used as a first approximation of soil behaviour in general. It is recommended to use this model for a first analysis of the problem considered. A constant average stiffness is estimated for the soil layer. Due to this contact stiffness, computations tend to be relatively fast and a first estimate of deformations can be obtained (Plaxis 2D Reference-Manual). Plaxis 2D model is given in Figure 4. Axisymmetry property is used for geometrical modeling. Subgrade modulus thickness is 2 m. All load stages were defined in the analysis. Settlements are read at every load stage. Test results are given in Figure 5. Ultimate bearing capacity was calculated as 550 kPa according to the plate load test. Subgrade material soil properties is given in Table 2. Field photo during plate load testing is shown in Figure 6.

Table 2

Subgrade Material Soil Properties

γ (kN/m^3)	c (kPa)	ϕ (°)	E (MPa)
23	10	42	149

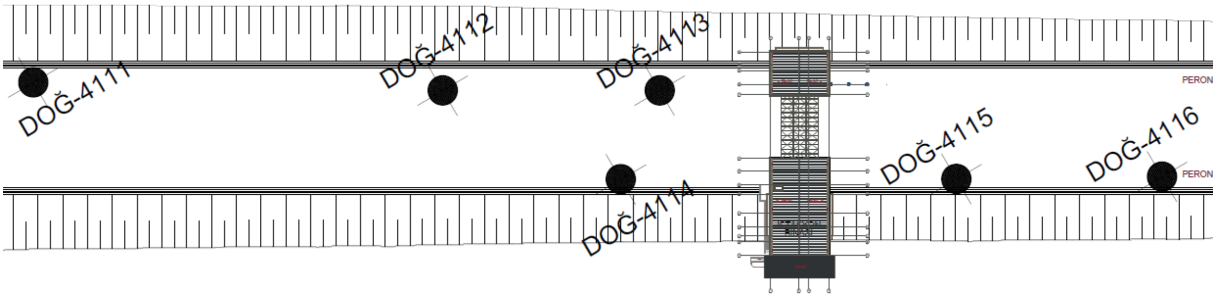

Figure 3. Plate Load Test Locations

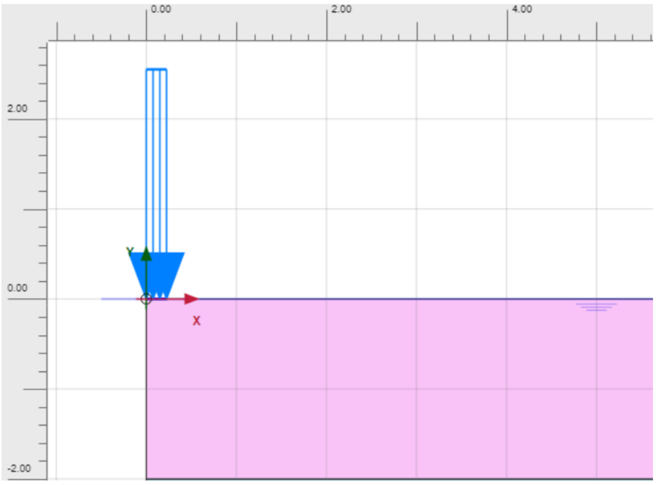

Figure 4. Plaxis 2D Model

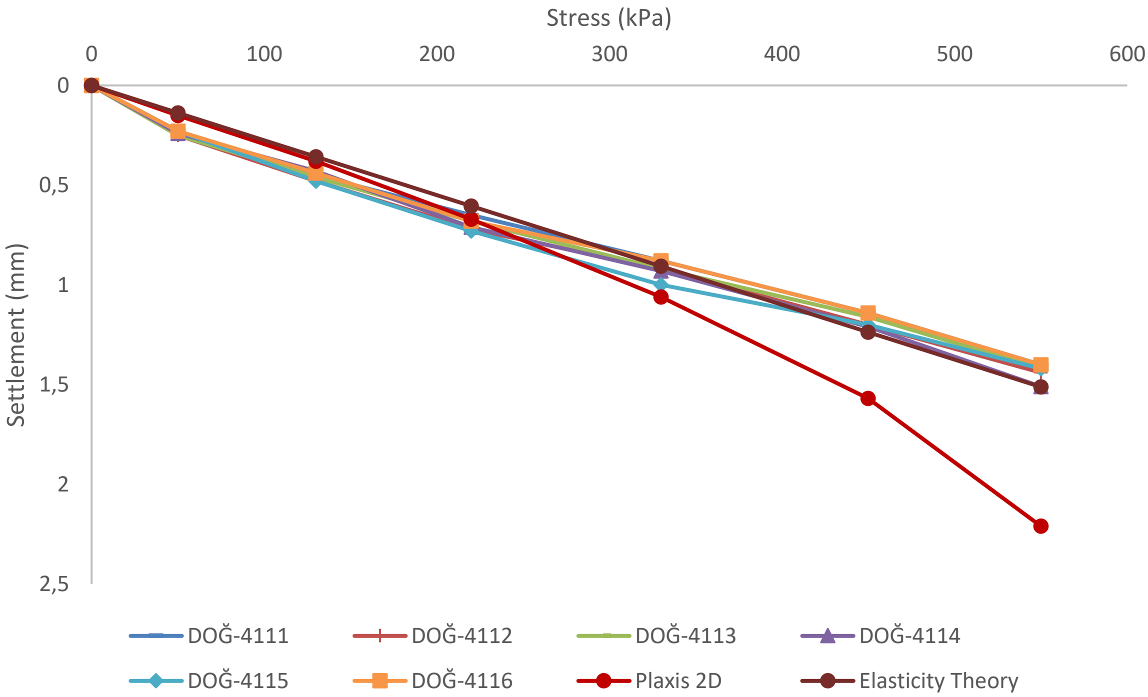

Figure 5. Load-Settlement Curve

Figure 6. During Plate Load Testing- Field Photo

8. Conclusion

Three different calculations were performed in this study. At the construction site a plate load test was carried out. Finite element analysis (FEM) was carried out with Plaxis 2D. Settlements were also calculated based on elasticity theory. A comparison of results is shown in Figure 7. Plate load test experiments and elasticity theory results are so close to each other. Finite element analysis settlement results are a little bit bigger. The maximum settlement from finite element analysis is 2,21 mm. The results of finite element analysis (FEM) are more conservative from plate load testing and elasticity theory. Calculated and observed settlement values are shown in Figure 7. Finite element analysis (FEM) result was correlated y= 0,7329x and the confidence interval was determined as %97. Elasticity theory calculation results were very close as mentioned before. Calculation result was correlated y= 0,9845x and the confidence interval was determined as %99. In these correlations, "y" axis represents observed settlement and "x" axis represents calculated settlements according to finite element analysis (FEM) or elasticity theory. This study showed that, finite element analysis (FEM) and elasticity theory are strong methods to predict and calculate foundation settlements.

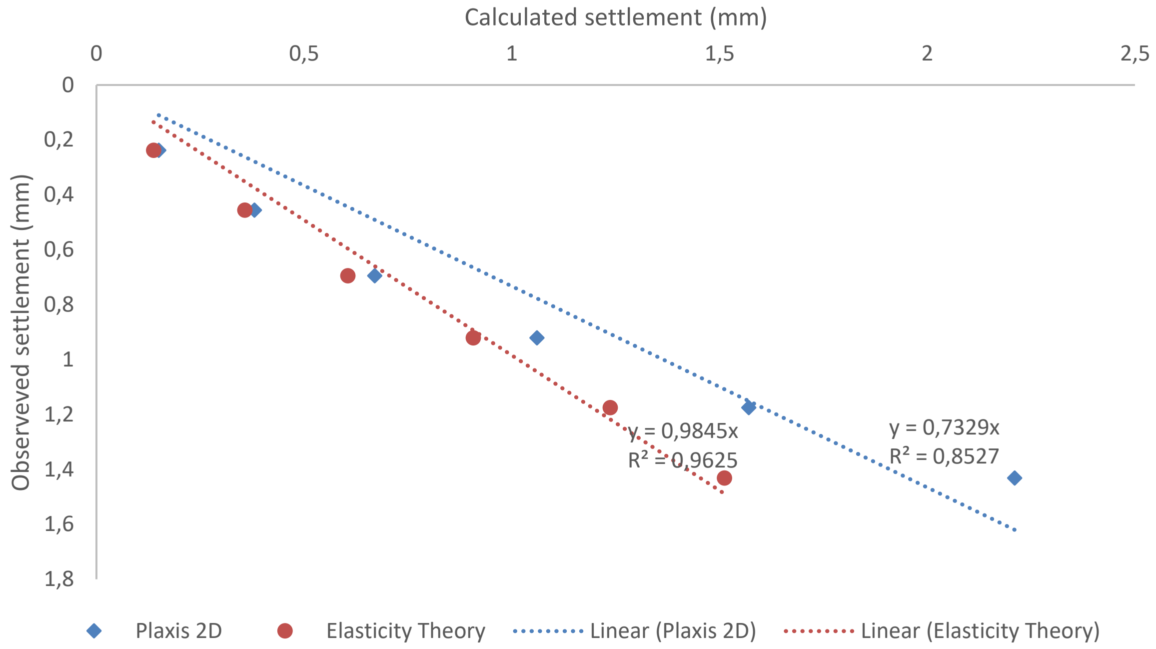

Figure 7. Comparison of Results

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Conflict of Interest

No conflict of interest was declared by the author.

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