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Research Article

Comparison of Subgrade Reaction Coefficient Values Obtained With Different Approaches in Soil Investigations

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Abstract

It is known that the calculation of soil parameters in different ways in geotechnical engineering is important in terms of interpretation and obtaining reliable results. The subgrade reaction coefficient can generally be calculated by field loading tests, laboratory tests and various empirical relations. The subgrade reaction coefficient obtained by using different methods and empirical relations can have very different values. The subgrade reaction coefficient calculations, which are one of the most important parameters used in the interaction of the soil and structure, are mostly not used correctly and the large differences between the results obtained with various approaches affect the determination of the subgrade reaction coefficient in a realistic manner. Subgrade reaction coefficient depends on soil settlement and elastic modulus and therefore on parameters such as Poisson ratio, soil type, unit volume weight values, seismic velocities, safe bearing capacity value. In this study, the previous correlations of various researchers in determining the subgrade reaction coefficient were examined.

In the light of these studies, the subgrade reaction coefficient values calculated from the data obtained from three different locations in Batman city were compared and their compatibility was questioned. It was determined that the subgrade reaction coefficient values obtained from the Standard Penetration Test (SPT) impacts provided higher and different results than the others, and the subgrade reaction coefficient values calculated according to the S wave speed obtained from the safe bearing capacity value, geophysical measurements and soil settlement provided closer results. S wave velocity obtained from seismic methods provides information about the resistance, strength and rigidity of the units on the soil. Therefore, the formulas calculated using S wave velocity is important. Standard Penetration Test (SPT) can yield misleading results when standard and qualified equipment is not used and when it is applied by personnel with insufficient experience. The same impact and power may not be applied to the soil every time during the application phase. This results in misleading and unreliable blow counts. Therefore, calculating the subgrade reaction coefficient, especially in structures with a settlement problem, by considering all of these parameters will give more reliable results.

Keywords: Safe bearing capacity, Settlement, S wave velocity, Subgrade reaction coefficient.

Zemin Araştırmalarında Farklı Yaklaşımlardan Elde Edilen Zemin Yatak Katsayısı Değerlerinin Karşılaştırılması

Öz

Geoteknik mühendisliğinde zemin parametrelerinin farklı şekillerde hesaplanmalarının yorumlama ve güvenilir sonuçlar elde edilmesi açısından önemli olduğu bilinmektedir. Zeminlerin yatak katsayısı genel olarak arazide yükleme deneyleri, laboratuvar deneyleri ve çeşitli ampirik bağıntılarla hesaplanabilmektedir. Farklı yöntemler ve ampirik bağıntılar kullanılarak elde edilen zemin yatak

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katsayıları çok farklı değerler alabilmektedir. Zemin ve yapı birlikteliğinde kullanılan en önemli parametrelerden biri olan yatak katsayısı hesaplamaları çoğunlukla doğru kullanılmamakta ve çeşitli yaklaşımlarla elde edilen sonuçları arasındaki farkların büyük olması yatak katsayısının gerçekçi bir şekilde belirlenmesini etkilemektedir.Zemin yatak katsayısı zeminin oturması ve elastisite modülü dolayısıyla poisson oranı, zemin türü, birim hacim ağırlık değerleri, sismik hızları, zemin emniyet gerilmesi gibi parametrelere bağlıdır. Bu çalışmada zemin yatak katsayısının belirlenmesinde çeşitli araştırmacıların daha önce yaptığı bağıntılar incelenmiştir. Bu çalışmalar ışığında Batman şehrinde üç farklı lokasyonda alınan verilerden hesaplanan zemin yatak katsayısı değerleri karşılaştırılmış ve uyumluluğu sorgulanmıştır. Standart Penetrasyon Deneyleri (SPT) darbe sayılarından elde edilen zemin yatak katsayısı değerlerinin daha yüksek ve diğerlerine göre farklı sonuçlar verdiği, zemin emniyet gerilmesi, zemin oturması ve jeofizik ölçümlerden elde edilen S dalga hızına göre hesaplanan zemin yatak katsayısı değerlerinin birbirlerine daha yakın sonuçlar verdiği tespit edilmiştir. Sismik yöntemlerden elde edilen S dalga hızı zemindeki birimlerin dayanım, mukavemet ve rijitliği ile ilgili bilgi vermektedir. Dolayısıyla S dalga hızı kullanılarak hesaplanan bağıntılar önem taşımaktadır. Standart Penetrasyon Deneyi (SPT) standart ve nitelikli ekipman kullanılmadığında, yeterli deneyimi olmayan personel tarafından uygulandığında yanıltıcı sonuçlar verebilir. Uygulanma aşamasında her seferinde zemine aynı etki ve güç verilemeyebilir. Bu durum da yanıltıcı ve güvenilir olmayan darbe sayıları elde edilmesine yol açar. Dolayısıyla zemin yatak katsayısının, özellikle oturma problemi olan yapılarda bütün bu parametrelerin bir arada düşünülerek hesaplanması daha güvenilir sonuçlar verecektir.

Anahtar Kelimeler: Oturma, S dalga hızı, Zemin emniyet gerilmesi, Zemin yatak katsayısı.

1. Introduction

It is the characteristic features of the soil that largely determine the reliability of engineering structures. One of the most important objectives of geotechnical design is the examination of the laboratory and field data by correlating and evaluating and using these data correctly in the project design. The subgrade reaction coefficient calculations, which are one of the most important parameters used in the interaction of the soil and structure, are mostly not used correctly and the large differences between the results obtained with various approaches affect the determination of the subgrade reaction coefficient in a realistic manner. The subgrade reaction coefficient obtained by using different methods and empirical relations can have very different values. Many factors play a role in the soil and structure interaction. It is especially important to evaluate and interpret the subgrade reaction coefficient in a wide range with different approaches by considering the effect of all formations under the construction foundation. Although the subgrade reaction coefficient value is not a soil constant by itself, the value of this parameter is related to many factors such as settlement of soil due to deformation characteristics, foundation and soil stiffness, type of soil, foundation plan dimensions, foundation depth, soil stratification and soil elasticity module. Many researchers have developed various empirical approaches in studying the subgrade reaction coefficient (Biot 1937; Terzaghi, 1955; Vesic 1961; Meyerhof and Baike, 1965; Bowles, 1982; Selvadurai, 1984; Bowles, 1998; Kahraman et al., 2007; Tezcan et al., 2007; Keçeli, 2010). Othman (2005) developed experimental correlations between seismic velocities, rock quality and subgrade reaction coefficient. Moayed and Janbaz (2008) have developed models with the Plaxis program using the field plate loading tests carried out on clayey soil to find the subgrade reaction coefficient in their study.

2. Material and Methods

In this study, the previous correlations of various researchers in determining the subgrade reaction coefficient were examined. The subgrade reaction coefficient values calculated from the data obtained from three different locations in Batman city were compared and their compatibility was questioned. Drilling was done using a hydraulic type rotary drilling machine in the determined locations. Disturbed (SPT) samples were taken to identify the physical and mechanical aspects of the soil layers penetrated while boring a well. Standard Penetration Test (SPT) was performed in order to determine the physical and mechanical properties of the soil layers in the drilled wells. The test consists of driving a split spoon sampler into the soil through a borehole 55 to 100 mm (2 to 4 inch) in diameter at the desired depth. It is done by a hammer weighing 63.5 kg (140 lb) dropping onto a drill rod from a height of 750 mm (30 inch). The number of blows N required to produce a penetration of 300 mm (12 inches) is regarded as the penetration resistance. To avoid seating errors, the blows for the first 150 mm (6 inches) of penetration are not taken into account; those required to increase the penetration from 150 mm to 450 mm constitute the N-value (Coduto, 2000).

The first theoretical study was carried out by Winkler (1867) on subgrade reaction coefficient. According to Winkler (1867), this theory is based on the foundation that the soil is in an elastic environment and consists of an infinite number of independent arcs adjacent to each other. The arcs provide the relation between basic soil pressure and soil deformation, and the subgrade reaction coefficient approach is considered as a mathematical model established for the soil, which is a constant environment. Subgrade reaction coefficient (ks) accepts the floor as an elastic environment and expresses the flexibility of the arcs representing this environment. It is defined, as given in the Equation (1), as the ratio between the pressure (qa) at one point on the soil and the settlement of the same point (ΔH) (Uzuner, 2000; Kanıt, 2003).

$$\mathbf{k_s} = \frac{q_a}{\Delta H} \qquad (1)$$

The subgrade reaction coefficient can be calculated by making use of the number of subgrade reaction coefficient (ks) defined according to the soil type. Table 1 shows the subgrade reaction coefficient value ranges in various soil types provided by Bowles (1996). The subgrade reaction value can be calculated according to the type of soil using different empirical relations, the Standard Penetration Test (SPT), the safe bearing capacity value, the soil settlement, and the seismic S wave velocity obtained from geophysical measurements.

Table 1. Subgrade reaction coefficient (ks), kN/m 3 (Bowles, 1996)

Soil Type	Subgrade reaction coefficient (ks), kN/m^3
Loose Sand	4.800- 16.000
Medium Sand	9.600- 80.000
Dense Sand	64.000- 128.000
Silty Medium Sand	24.000-48.000
Clayey Soil (qu<0.2 Mpa)	12.000-24.000
Clayey Soil (qu= 0.2-0.4 Mpa)	24.000-48.000
Clayey Soil (qu> 0.8 Mpa)	>48.000

2.1. Calculation of Subgrade Reaction Coefficient with Standard Penetration Test (SPT) (Scott, 1981)

It can be calculated according to the Equation (2) proposed by (Scott, 1981) in accordance with the blow counts in the Standard Penetration Test (SPT).

$$\mathbf{k_S = 1800 * N_{30} = kN/m^3 = 180 * N_{30} = t/m^3} \quad (2)$$

2.2. Calculation of Subgrade Reaction Coefficient According to the Approach with Safe Bearing Capacity Value (Bowles, 1988)

Bowles proposed Equation (3) in the calculation of the subgrade reaction coefficient according to the safe bearing capacity value of the soil, since the foundation structure is 10 times more rigid than the soil.

$$k_s = 40\, q_{sınır} = 40\,(G_k) q_a \quad kN/m^3 \quad (3)$$

In Equation (3), q_a ; represents safe bearing capacity value (kN/m^2), G_s; represents safety coefficient.

2.3. Calculation of Subgrade reaction coefficient According to Settlement (Bowles, 1988) Approach

It can be calculated by using the Equation (4) proposed by (Bowles, 1988) using the settlement value of the soil.

$$\mathbf{k_S = q_{net}/(S/1000)\ (kN/m^3)} \quad (4)$$

In Equation (4), q_{net}; represents net soil pressure (kN/m^2), and S; settlement (mm).

2.4. Subgrade Reaction Coefficient Estimation According to Geophysical S Wave Velocity (Vs) Measurements (Tezcan et al., 2010)

The seismic horizontal (shear) wave is directly related to determining the mechanical properties and shear strength of the soil. Therefore, determination of S-velocity changes of undersoil layers is crucial in geotechnical engineering investigations. Physical properties of undersoil layers such as modulus of elasticity can be obtained much more accurately and quickly with seismic velocities obtained from seismic methods. Since the soil does not always have elastic behavior, it is important to know the modulus of elasticity in approximate calculations. The modulus of elasticity defined by seismic velocities is shown in Equation (5) (Keçeli, 2010).

$$E = \left(\rho V_S^2\right) \frac{3V_P^2 - 4V_S^2}{V_P^2 - V_S^2} \quad (5)$$

In Equation (5); represents density (gr/cm^3), V_P; P wave velocity (m/sn), and V_S; S wave velocity (m/sn).

Subgrade reaction coefficient is generally shown in Equation (6) according to the Hooke's law.

$$k_s = \frac{q}{\delta} = \frac{q\,(kN/m^2)}{\delta\,(m)} \quad kN/m^3 \quad (6)$$

In this study, S Wave Velocity measurements and the determination of subgrade reaction coefficient/settlement estimation can be calculated according to (Tezcan et al., 2010). The relationship between the elastic modulus of the soil (E), settlement value (d) and the subgrade reaction coefficient (ks) was examined by using S wave velocity according to (Tezcan et al., 2010). According to (Tezcan et al., 2010) (Figure 1) settlement of a soil column with vertical load (P), cross-sectional area (A) and height (H) is shown in equation (7) when the column is under axial P - load or safe bearing capacity stress.

$$d = PH/AE = qf = H/E \quad (7)$$

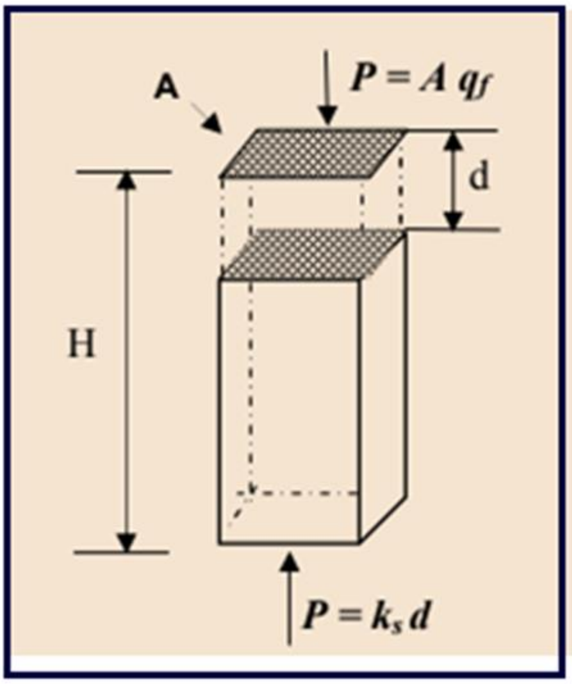

Figure 1. Settlement, d, subgrade reaction coefficient, ks (Tezcan et al., 2010)

The subgrade reaction coefficient (ks) is the soil stress required to make unit settlement on a soil column in a unit cross-section area. When the settlement amount is d, the vertical stress acting on the soil column in the unit cross-section area is given in (8) (Tezcan et al., 2010).

$$qf = k_s\, d \qquad (kN/m^2) \qquad (8)$$

With the help of Equation (8), the vertical stress of the soil is shown in Formula (9).

$$qf = Ed/H \qquad (9)$$

If the equation is equalized with (8) and (9), the modulus of elasticity is obtained as in equation (10).

$$E = H\, k_s \qquad (kN/m^2) \qquad (10)$$

The relationship between the bearing power of the soils qf and the subgrade reaction coefficient ks is shown in Bowles (1982) Equation (11).

$$k_s = 40\, qf \qquad (kN/m^3) \qquad (11)$$

According to (Tezcan et al., 2010), bearing capacity of the soil is shown in Formula (12).

$$qf = n\ \ qa = 0.1\, \gamma\, V_s \qquad (kN/m^2) \qquad (12)$$

In Equation (12); qf; represents the bearing capacity of soil, n; safety factor, qa; safe bearing capacity value (kN/m^2), γ; soil unit weight (kN/m^3) and V_s; shear wave velocity (m/sn). Equation (14) is achieved for elastic settlements when qf expression provided with Equation (12) is placed in Equation (13).

$$k_s = 40\, qf = 40(0.1)\gamma V_s = 4\gamma\, V_s\ \ (k/m^3) \qquad (13)$$

$$d = qf / ks = 0.1\gamma\ Vs / 4\gamma\ Vs = 0.025\ m \qquad (14)$$

In Equality (12), Tezcan et al. (2010) proposed Formula (15) for subgrade reaction coefficient depending on shear wave velocity by using the Equation (13) provided by Bowles (1982) in which qf;bearing capacity at the time of failure,H; layer thickness for elastic modulus, qa;safe bearing capacity value, γ; unit volume weight and n; safety factor (n=4) were experientially provided.

$$k_s = 4\, \gamma\, V_s \qquad (kN/m^3) \qquad (15)$$

The safe bearing capacity value formula determined based on the shear wave velocity is always in the order of d = 0.025 m (Terzaghi and Peck, 1967).

3. Results and Discussion

In this study, the subgrade reaction coefficient values calculated from the data obtained from three different locations in Batman city were compared and their compatibility was questioned.

Field features-1

In the study area, foundation depth is 6, foundation width is 24 and foundation length is 20.5 meters. In the drillings, vegetal soil is found between 0,30 m, silty clays between 0,30-6,00 m, silty sands between 6,50-7,50 m, gravel, sandy and silty clays between 7,50-9,00 m, silty sands between 9.00- 10.50, gravel, sandy and silty clays between 10.50-14.00 m, gravel, sandy and silty clays with high plasticity between 14.00-20.00 m. The SPT values were found as SPTN30 = 19 due to the fact that the test was carried out under the soil water level, the soil type consisting of thin sand or silty sand and carrying out silty sand correction due to N > 15 blow / 30 cm value. Unit volume weight of the soil was found as γ: 19.0 kN/m^3. According to seismic measurements, the first layer was located to a depth of 1.63 meters, P wave velocity was calculated as Vp = 323 m / sec and S wave velocity as Vs = 211 m / sec. The next layer was located up to a depth of 6.56 and had medium dense soil properties according to the calculated S wave velocity value and field works conducted and in this layer, medium dense clayey units with P wave velocity Vp = 908 m / sec and S wave velocity Vs = 230 m / sec were found. The seismic velocity of the second layer was taken since the foundation depth was 6 meters. The parameters used in the bearing capacity and safe bearing capacity were found as cohesion (c) 38 kg/cm^2, shear strength angle $(\emptyset^0)$ 5^0. According to Terzaghi and Pack (1967), bearing capacity was found as 555.6341 kN/m^2 and safe bearing capacity was found as 147.2114 kN/m^2 (1.50 kg/cm^2) when net load was 441.6341 kN/m^2. The average pressure increase in the soil layer was found as (Δq) 0.46 kgf / cm^2, the compressible soil layer thickness (H) as 20 meters, and volumetric compression coefficient (M_v) as 0.00291 cm^2 / kgf. The consolidation settlement calculated according to Bowles (1988) was found as 26 mm by using these values.

For this field sample, subgrade reaction coefficient values (Figure 2) were calculated as 34200 kN / m^3 according to Scott, 1981; safe bearing capacity value was calculated as 17640 kN / m^3 according to Bowles, 1988; soil settlement value was calculated as 16962 kN / m^3 according to Bowles, 1988 and seismic S wave velocity was calculated as 17480 kN / m^3 according to Tezcan et al., 2010. Scott's (1981) formula provided the highest subgrade reaction coefficient value. This value was found higher compared to other methods. Therefore, it can be stated that the results of SPT will not be very healthy considering that this formula only uses blow count for the calculation of subgrade reaction coefficient affected by many parameters and the disadvantages of this test. Closer values were found in results obtained with other methods. The formula of Bowles, 1988 calculated in accordance with settlement provided the lowest subgrade reaction coefficient. It is thought that the safety factor value used in the safe bearing capacity formula of Terzaghi and Peck (1967) had an effect on the result calculated in accordance with the safe bearing capacity stress formula of Bowles, 1988.

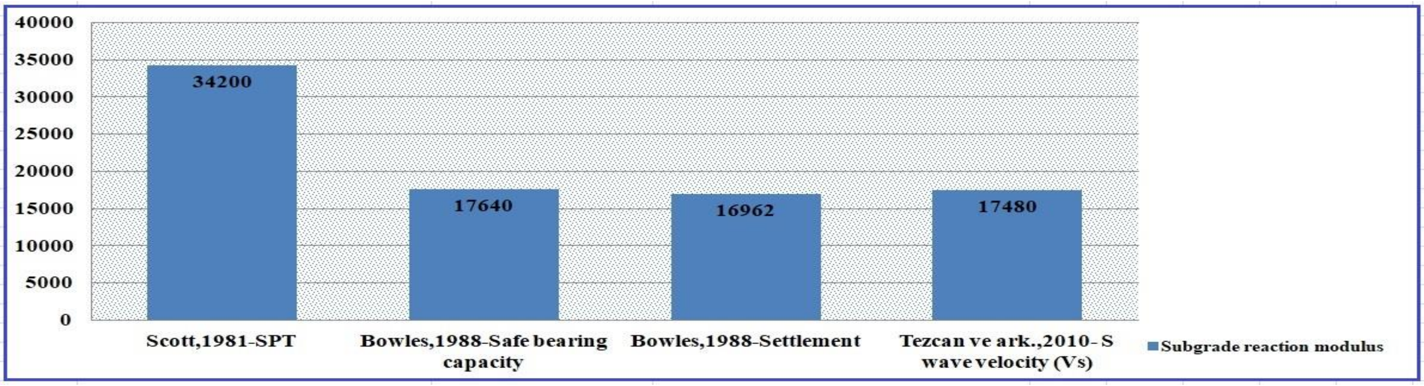

Figure 2. Subgrade reaction coefficient values calculated for Field-1

Field features-2

In the study area, foundation depth is 3, foundation width is 17 and foundation length is 24 meters. In the drillings, filling was observed between 0.5 meters, silty hard clay between 0.50-3.80 meters, and clayey, silty gravel unit between 3.80-20.00 meters. Silty sand correction was carried out for SPT values and SPTN30= 20 were achieved. Unit volume weight of the soil was found as γ: 18 kN/m^3. According to seismic measurements, the first layer went up to 4.49 m of depth with medium dense clayey units and P wave velocity was calculated as Vp = 374 m / sec and S wave velocity as Vs = 235 m / sec. Then, medium dense clayey units were observed up to 11.50 m of depth and P wave velocity was calculated as Vp = 761 m / sec and S wave velocity as Vs = 353 m / sec. The seismic velocity of the first layer was taken since the foundation depth was 3 meters. The parameters used in the bearing capacity and safe bearing capacity were found as cohesion (c) 38 kg/cm^2, shear strength angle ($\emptyset^0$) 5^0 According to Terzaghi and Pack (1967), bearing capacity was found as 628.4821 kN/m^2 and safe bearing capacity was found as 190.694 kN/m^2 (1.94 kg/cm^2) when net load was 572.0821 kN/m^2. The average pressure increase (Δq) in the soil layer was found as 1.4 kgf/cm², the compressible soil layer thickness (H) as 10 meters, and volumetric compression coefficient (M_v) as 0.0025 cm²/kgf. The consolidation settlement calculated according to Bowles (1988) was found as 35 mm by using these values.

For this field sample, subgrade reaction coefficient values (Figure 3) were calculated as 36000 kN / m^3 according to Scott, 1981; safe bearing capacity value was calculated as 22800 kN / m^3 according to Bowles, 1988; soil settlement value was calculated as 16343 kN / m^3 according to Bowles, 1988 and seismic S wave velocity was calculated as 16920 kN / m^3 according to Tezcan et al., 2007. Scott's (1981) formula provided the highest subgrade reaction coefficient value. This value was found higher compared to other methods. It is seen that subgrade reaction coefficient values calculated in accordance with the Bowles, 1988-soil settlement and Tezcan et al., 2010-seismic S wave velocity provided similar results.

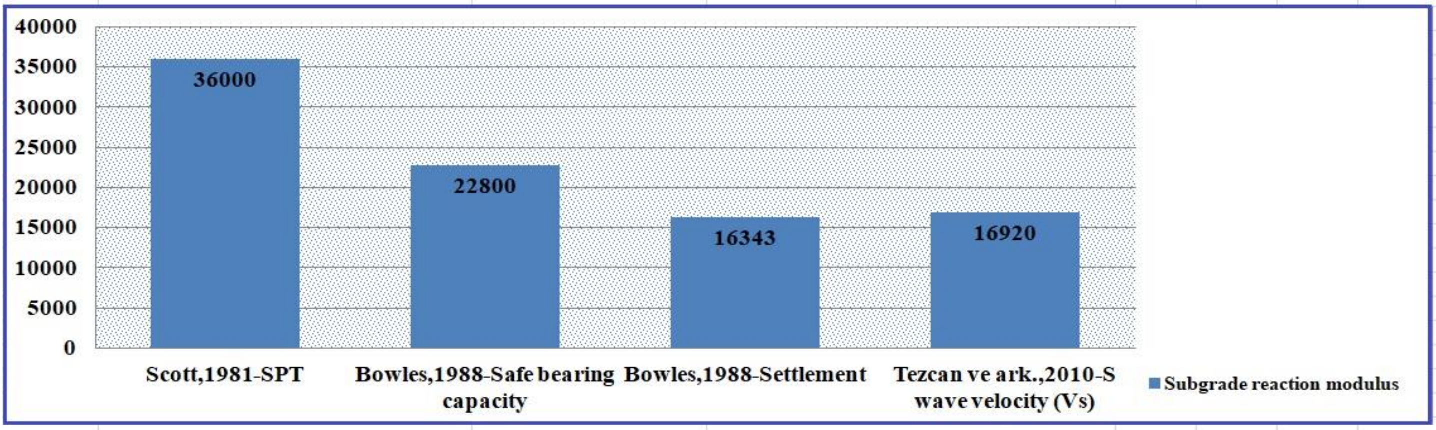

Figure 3. Subgrade reaction coefficient values calculated for Field-2

Field features-3

In the study area, foundation depth is 3, foundation width is 16 and foundation length is 19 meters. In the drillings carried out, low silty clay was observed up to 20.00 m of depth after passing the initial 0.5 meters of vegetal soil. The SPT values were found as SPTN30 = 18 due to the fact that the test was carried out under the soil water level, the soil type consisting of thin sand or silty sand and carrying out silty sand correction due to N > 15 blow / 30 cm value. Unit volume weight of the soil was found as γ: 19 kN/m^3. According to seismic measurements, the first layer was observed up to 3.51 m of depth and its P wave velocity was calculated as Vp = 350 m / sec and S wave velocity as Vs = 220 m / sec. Then, medium dense clay units were observed up to 7.58 of depth and P wave velocity of this unit was calculated as Vp = 915 m / sec and S wave velocity as Vs = 270 m / sec. The seismic velocity of the first layer was taken since the foundation depth was 3 meters. The parameters used in the bearing capacity and safe bearing capacity were found as cohesion (c) 38 kg/cm^2, shear strength angle as $(\emptyset^0)$ 5^0. According to Terzaghi and Pack (1967), bearing capacity was found as 558.4065 kN/m^2 and safe bearing capacity was found as 167.03 kN/m^2 (1.50 kg/cm^2) when net load was 505.1065 kN/m^2.The average pressure increase (Δq) in the soil layer was found as 0.4 kgf/cm², the compressible soil layer thickness (H) as 20 meters, and volumetric compression coefficient (M_v) as 0.0037 cm² / kgf. The consolidation settlement calculated according to Bowles (1988) was found as 31 mm by using these values.

For this field sample, subgrade reaction coefficient values (Figure 2) were calculated as 34200 kN / m^3 according to Scott, 1981; safe bearing capacity value was calculated as 20040 kN / m^3 according to Bowles (1988); soil settlement value was calculated as 16290 kN / m^3 according to Bowles, 1988 and seismic S wave velocity was calculated as 16720 kN / m^3 according to Tezcan et al. (2007). Scott's (1981) formula provided the highest subgrade reaction coefficient value. This value was found higher compared to other methods. It is seen that subgrade reaction coefficient values calculated in accordance with the Bowles, 1988-soil settlement and Tezcan et al., 2010-seismic S wave velocity provided similar results.

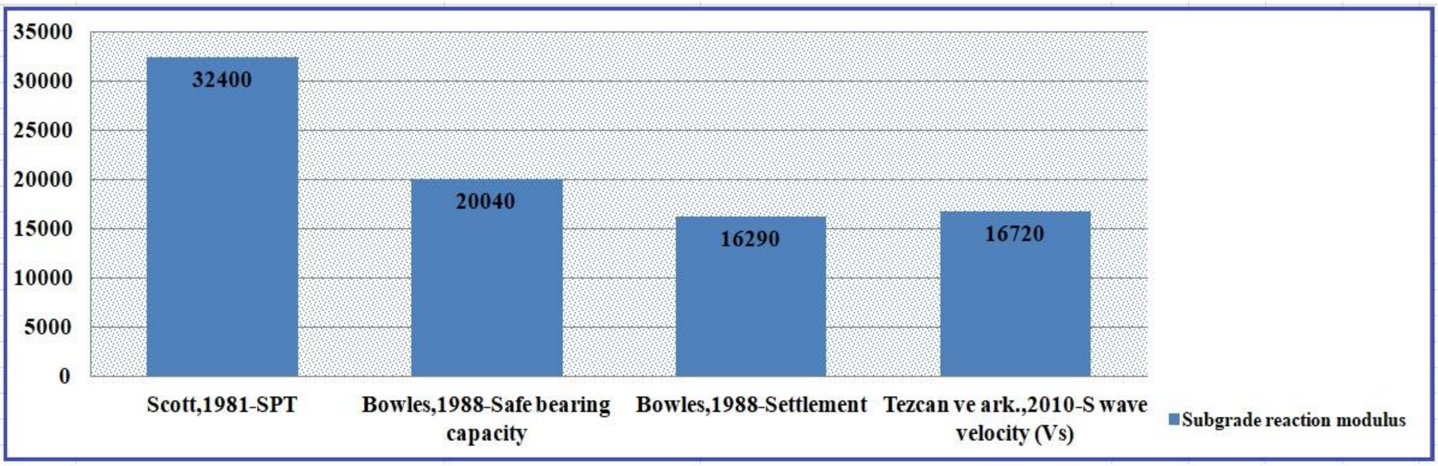

Figure 4. Subgrade reaction coefficient values calculated for Field-3

4. Conclusions

In this study, the subgrade reaction coefficient was calculated by using different methods and its results were interpreted. In three separate field investigations taken as study areas, it was observed that the subgrade reaction coefficient values and S wave velocity obtained from the calculations made according to the safe bearing capacity value and settlement were compatible. Furthermore, it was observed that the subgrade reaction coefficient values obtained with the blow counts of Standard Penetration Tests provided higher and different results than the others. Standard Penetration Test (SPT) can yield misleading results when standard and qualified equipment is not used and when it is applied by personnel with insufficient experience. The same impact and power may not be applied to the soil every time during the application phase. Therefore, this results in misleading and unreliable blow counts. S wave velocity obtained from seismic methods provides information about the resistance, strength and rigidity of the units on the soil. Therefore, the formulas calculated using S wave velocity is important. In calculations of the subgrade reaction coefficient using the S wave velocity, it was observed that the results were similar to other methods. Subgrade reaction coefficient depends on soil settlement and elastic modulus and therefore on parameters such as Poisson ratio, soil type, unit volume weight values, seismic velocities, safe bearing capacity value. Therefore, calculating the subgrade reaction coefficient, especially in structures with a settlement problem, by considering all of these parameters will give more reliable results.

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