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THE IMPORTANCE OF AMOUNT OF SETTLEMENT IN DETERMINING THE BEARING CAPACITY OF SOILS

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ABSTRACT

In this study, it is aimed to determine safe bearing capacity of soils, which are out cropped around Tamzi and Akcakale villages located in Gumushane, providing allowable settlement conditions for an optimum foundation design. To define the geotechnical properties of soils, three trenches were dug and two seismic refraction with two Multichannel Spectral Analysis of Surface Waves (MASW) were carried out in each research area. Sieve analyses, shear box tests, triaxial compression tests were carried out on disturbed and undisturbed samples taken from the trenches. Seismic velocities of the soils are determined by seismic refraction and MASW methods. While determining the safe bearing capacity; the equations proposed by Terzaghi, Meyerhof, Kurtuluş, Tezcan and Özdemir, Türker, Keçeli were used and the obtained safe bearing capacity values were compared to each other. After, the soils were modeled numerically by using finite elements method and safe bearing capacities providing allowable settlement conditions were determined. According to the results, safe bearing capacity values obtained from empirical equations are not satisfactory to have an optimum foundation design. For the optimum foundation design, safe bearing capacity should be accepted as 190 kN/m^2 for clayey soil (CL) and 485 kN/m^2 for the clayey sand (SC).

1. Introduction

For engineering studies to be reliably and economically designed the use of different methods to determine design parameters and comparison of results obtained from these methods is a basic principle of engineering studies. The most important of these engineering parameters is soil bearing capacity and is very important in terms of structural statics. To date researchers (Terzaghi, 1943; Meyerhof, 1963; Keçeli, 1990; Richards et al., 1993; Keçeli, 2000; Kurtuluş, 2000; Türker, 2004; Çinicioğlu, 2005; Keçeli, 2010; Tezcan et al., 2010; Uzuner et al., 2000; Tezcan and Özdemir, 2011) have recommended many empirical equations to determine soil bearing capacity. When these empirical equations are investigated, they appear to use different engineering properties of soils. Some researchers (Terzaghi, 1943; Skempton, 1951; Meyerhof, 1963) have noted basic dimensions of the physical and mechanical properties of soils, while other researchers (Keçeli, 1990; Richards et al., 1993; Keçeli, 2000; Kurtuluş, 2000; Türker, 2004; Çinicioğlu, 2005; Önalp and Sert, 2006; Keçeli, 2010; Tezcan et al., 2010; Uzuner et al., 2000; Tezcan and Özdemir, 2011) have used dynamic property parameters of soils. These empirical equations are commonly chosen by researchers and engineers to determine bearing capacity of soils (Alemdağ and Gürocak, 2006; Alemdağ et al., 2008; Kayabaşı and Gökçeoğlu, 2012; Uyanık and Gördesli, 2013; Alemdağ, 2015). However, for the design to be sound, the equation to be used should be chosen well and it is important that the design is made by comparing the results of different equations. Additionally, checking the results of the empirical equations with numerical analyses is necessary for comparison of results and the structure design.

Another important situation to be considered during determination of bearing capacity of soils after the design is completed by noting the bearing capacity value determined empirically is that the settling and compression amount that will occur in the soil as a result of stress transmitted to the ground by the structure foundations should be within acceptable limits. This situation is ignored the majority of the time and it is assumed the settling amount is within acceptable limits. However, a significant amount of

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settling and compression will occur in soils with high compressability and these settling and compression values exceeding acceptable limits may cause severe damage to the structure. As a result, the bearing capacity values obtained from empirical equations become important for determination of the amounts of settling and compression caused in soils.

This study determined the bearing capacity of soils comprising disintegration products from Gümüşhane granitoid complex and the Şenköy formation in Akçakale and Tamzı villages (Figure 1) in Gümüşhane province using empirical equations recommended by different researchers. The amount of settlement and compression caused in soils with these bearing strength values were determined by numerical analysis and an attempt was made to determine the empirical equations producing results appropriate for design.

2. Field and Laboratory Studies

To determine the bearing capacity of soils comprising the disintegration products of the Early Carboniferous-age Gümüşhane granitoid complex (Topuz et al., 2010; Dokuz, 2011; Kaygusuz et al., 2012; Karslı et al., 2017) outcropping in Akçakale village and the Early Jurassic-age Şenköy formation (Kandemir and Yılmaz, 2009) outcropping in Tamzı village, both field and laboratory studies were completed. Field studies include two line studies in each area (Figure 2) using seismic refraction and multi-channel analysis of surface wave (MASW) measurements to determine the V_p and V_s wave velocities of soil layers (Table 1). This study obtained the V_p wave velocity from the seismic refraction method and the V_s wave velocity from the MASW method. Additionally, three trial pits were dug in each study area and disturbed and undisturbed samples were taken for laboratory experiments.

To determine the dynamic parameters of soils in the study areas, seismic refraction and MASW methods were used to obtain V_p and V_s velocities, and the elasticity module, slip module and Poisson ratio were determined using the empirical equations of Bowles (1988) with density determined according to the equation by Keçeli (2012) (Table 2).

$$\varrho = 0.44V_s^{0,25} \quad (1)$$

$$\upsilon = (V_p^2 - 2V_S^2) / 2(V_p^2 - V_S^2) \quad (2)$$

$$\mu = \varrho\, V_S^2/100 \quad (3)$$

$$E = \mu\,(3V_p^2 - 4V_S^2) / (V_p^2 - V_S^2) \quad (4)$$

In these equations, V_p: compressional wave velocity (m/s), V_s: shear wave velocity (m/s), ϱ: density (gr/cm^3), υ: Poisson ratio, μ: shear modulus (kg/cm^2), and E_m is the elasticity modulus (kg/cm^2).

Sieve analysis experiements in laboratory studies of the disturbed samples taken from the trial pits were completed according to ASTM D 422-63 (2003) standards. For undisturbed samples, shear box tests (ASTM, 2011) and triaxial compression tests (ASTM D 4767-95, 2003) were completed to determine soil resistence parameters with the aid of shear stress-normal stress graphs (Figure 3). Combined soil classification of samples from the Akçakale area was clayey sand (SC) while soils in Tamzı village had low plasticity clay (CL) properties. The results for the engineering properties of the investigated soils are given in table 3.

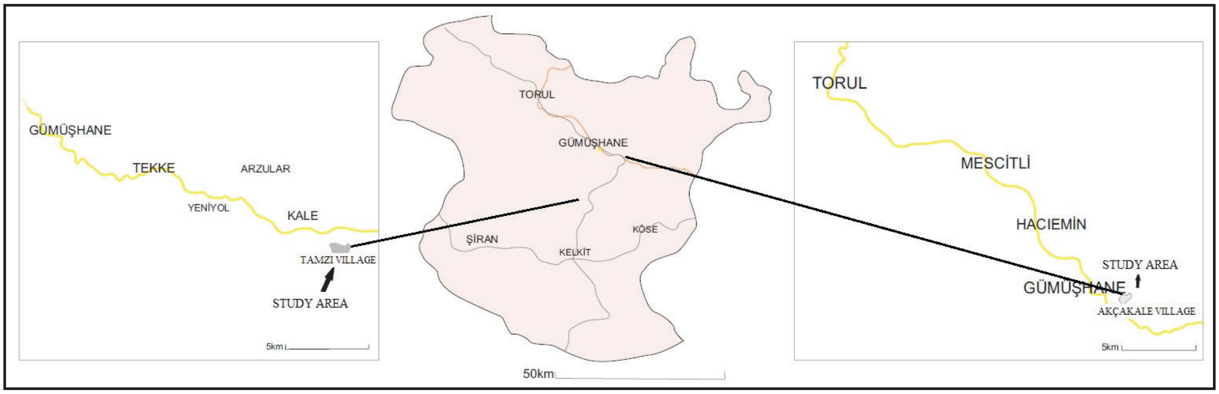

Figure 1- Location map of the study area.

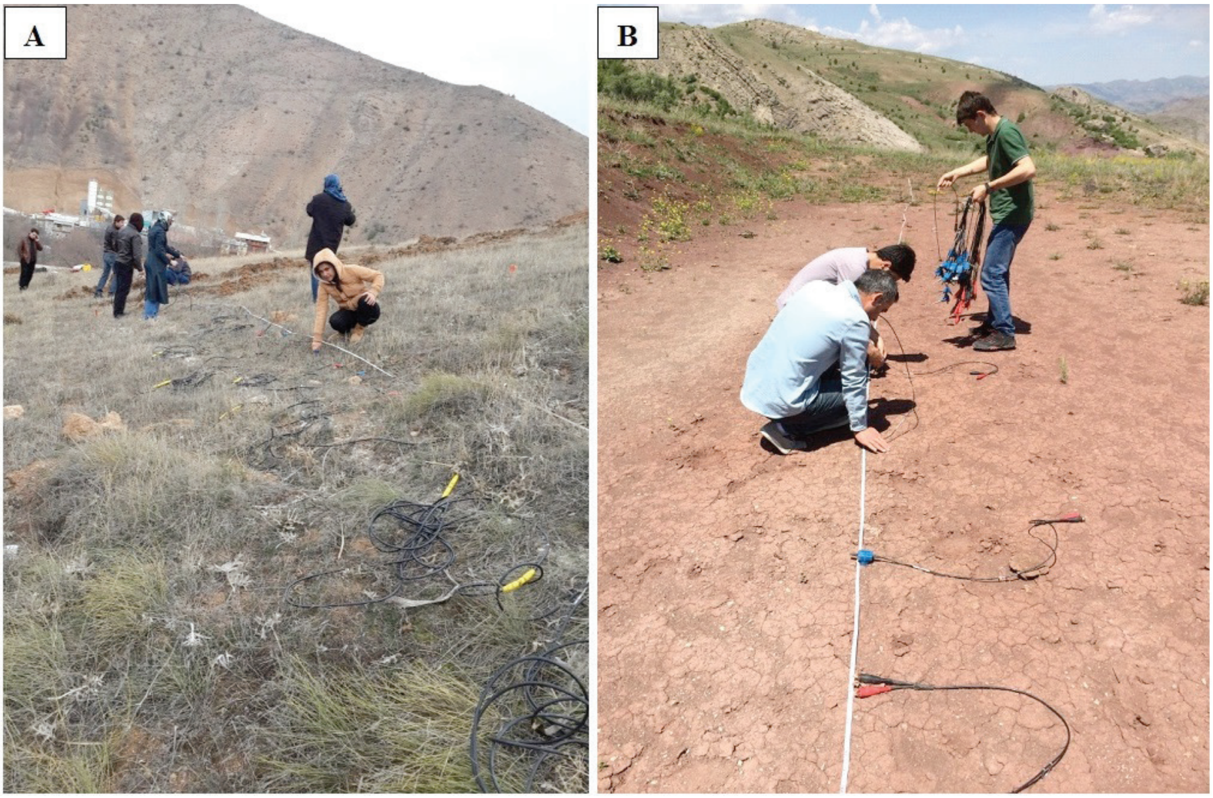

Figure 2- Geophysical studies in Akçakale (A) and Tamzı (B) villages.

Table 1- V_p and V_s wave velocities obtained with seismic refraction and MASW methods.

AKÇAKALE VILLAGE					TAMZI VILLAGE		
Measurement No	Layer No	Depth (m)	V_p Wave Velocity (m/s)	V_s Wave Velocity (m/s)	Depth (m)	V_p Wave Velocity (m/s)	V_s Wave Velocity (m/s)
Line 1	1	7.5	452.4	184	7.5	516.9	213
	2	13.5	763.0	224	13.5	883.7	349
	3	-	2510.3	288	21	2423	394
Line 2	1	7.5	320.8	143	7.5	585.6	235
	2	13.5	800.5	215	13.5	996.9	391.5
	3	21	2506.2	304	21	2058.5	573.7

Table 2- Dynamic parameters of soils.

Study Line No	USC	ρ (gr/cm³)	V_p (m/s)	V_s (m/s)	μ (kg/cm²)	Poisson Ratio	E_m (kg/cm²)
Tamzı Village							
1	CL	1.68	516.9	213	762.62	0.39	2131.9
2	CL	1.72	585.6	235	951.38	0.40	2671.5
Akçakale Village							
1	SC	1.62	452.4	184	548.65	0.40	1537.2
2	SC	1.52	320.8	143	311.14	0.38	856.3

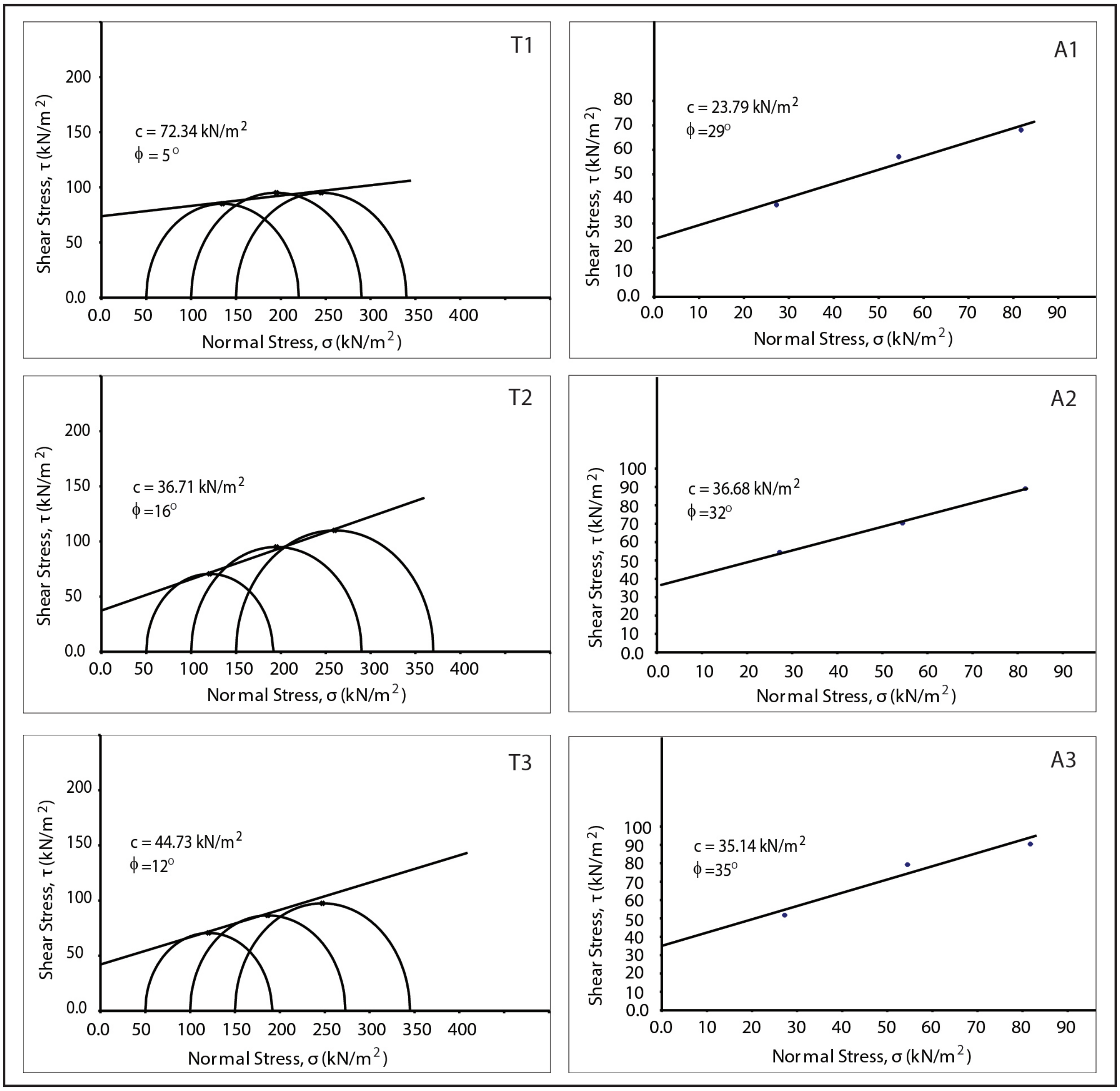

Figure 3- Shear stress (t)-normal stress (s) graphs for the soils.

Table 3- Resistance parameters and classification of soils in the study area.

Research Trench	Retained in 4 No. sieve (%)	Passing 200 No. Sieve (%)	LL (%)	PL (%)	PI (%)	c (kN/m²)	ϕ (°)	g_n (kN/m³)	USC
T1	12	90.55	42	17	25	72.34	5	18.96	CL
T2	10.65	76.50	38	20	18	36.71	16	18.44	CL
T3	8.23	71.20	26	15	11	44.73	12	19.22	CL
A1	10.05	18	22	12	10	23.79	29	19.81	SC
A2	8.50	15.6	28	10	18	36.68	32	19.62	SC
A3	11.30	13	26	14	12	35.14	35	18.53	SC

T 1-2-3: Tamzı Village
A 1-2-3: Akçakale Village
c: Cohesion; ϕ: Internal Friction Angle; g_n: Unit Volume Weight

3. Determination of Bearing Capacity with Empirical Equations

The results of the seismic studies and laboratory experiments on soils outcropping in Tamzı and Akçakale villages were used in the empirical equations recommended by Terzaghi (1943), Meyerhof (1963), Kurtuluş (2000), Türker (2004), Keçeli (2010) and Tezcan and Özdemir (2011) and bearing capacity for strip footing was determined.

3.1. Bearing Capacity According to Terzaghi's (1943) Equation

The bearing capacity equation recommended by Terzaghi (1943) is one of the equations commmonly used for geotechnical studies in many fields today. This equation is recommended for different foundation types with strip footing assessed in this study.

$$q_u = K_1\, c\, N_c + \gamma\, D_f\, N_q + K_2\, \gamma\, B\, N_\gamma \qquad (5)$$

$$q_{net} = q_u - \gamma D_f \qquad (6)$$

$$q_{em} = q_{net}/G_s + \gamma D_f \qquad (7)$$

In these equations; q_u: final bearing capacity, q_{net}: net bearing capacity, q_{em}: safe bearing capacity, K_1, K_2: coefficients linked to the foundation type, c: cohesion, D_f: foundation depth (3m), G_s: reliability number (3), B: foundation width (2 m), γ: unit volume weight, and N_c, N_q, N_γ: bearing strength factors, calculated from the following equations.

$$N_q = e^{(p\tan\phi)} \tan^2 [45+(\phi/2)] \qquad (8)$$

$$N_c = (N_q-1) \cot\phi \qquad (9)$$

$$N\gamma = 1.8\,(N_q-1) \tan\phi \qquad (10)$$

According to equation 7 above, the safe bearing capacity values for soils in the study area are given in table 4.

3.2. Bearing Capacity According to Meyerhof's (1963) Equation

The bearing capacity equation produced by Meyerhof (1963) includes the parameters depth (d) and shape (s) different from Terzaghi (1943). Here a rectangular foundation type was used.

$$q_u = cN_c s_c d_c + \gamma D_f N_q s_q d_q + 0.5\gamma B N_g s_g d_\gamma \qquad (11)$$

In this equation; B=2, L=4, D_f=3, and G_s=3 were used.

$$K_p = \tan^2(45+\phi/2) \qquad (12)$$

$$s_c = 1+0.2K_p(B/L) \qquad (13)$$

$$d_c = 1+0.2K_p^{0.5}\,(Df/B) \qquad (14)$$

$$s_q = s_\gamma = 1+0.1K_p(B/L) \qquad (15)$$

$$d_q = d_\gamma = 1+0.1K_p^{0.5}(D_f/B) \qquad (16)$$

$$N_q = e^{\pi\tan\phi} \tan^2 (45+\phi/2) \qquad (17)$$

$$N_c = (N_q-1) \cot \phi \qquad (18)$$

$$N_\gamma = (N_q-1) \tan(1.4\phi) \qquad (19)$$

The safe bearing capacity values for soils in the study area according to Meyerhof's (1963) bearing capacity equation are given in table 5.

Table 4- Bearing capacity of soils according to Terzaghi's (1943) equation.

Parameters	Trial Pits					
	T1	T2	T3	A1	A2	A3
c (kN/m^2)	72.3	36.7	44.7	23.8	36.7	35.1
ϕ (°)	5	16	12	29	32	35
g_n (kN/m^3)	18.96	18.44	19.22	19.81	19.62	18.53
N_c	6.5	11.6	9.28	27.8	35.4	46.1
N_q	1.57	4.33	2.97	16.4	23.2	33.3
N_γ	0.09	1.72	0.75	15.4	24.9	40.6
K_1	1	1	1	1	1	1
K_2	0.5	0.5	0.5	0.5	0.5	0.5
q_u (kN/m^2)	561	693	604	1943	3151	4220
q_{net} (kN/m^2)	504	637	547	1884	3093	4165
q_{em} (kN/m^2)	225	267	240	687	1090	1444
USC	CL	CL	CL	SC	SC	SC

Table 5- Bearing capacity of soils according to Meyerhof's (1963) equation.

Parameters	Trial Pits					
	T1	T2	T3	A1	A2	A3
c (kPa)	72.34	36.71	44.73	23.79	36.68	35.14
ϕ (°)	5	16	12	29	32	35
g_n (kN/m³)	18.96	18.44	19.22	19.81	19.62	18.53
N_c	6.5	11.6	9.3	27.8	35.4	46.1
N_q	1.6	4.3	3.0	16.4	23.1	33.3
N_γ	0.1	1.4	0.6	13.2	22.0	37.1
q_u (kN/m²)	810.7	1039.3	894.3	3064.5	5306.5	7362.1
q_{net} (kN/m²)	754	984	837	3005	5248	7307
q_{em} (kN/m²)	308	383	337	1061	1808	2491
USC	CL	CL	CL	SC	SC	SC

3.3. Bearing Capacity According Kurtuluş's (2000) Equation

The shear and compression wave velocities obtained for the zone forming the foundation level (first layer) near the surface as a result of seismic refraction and MASW tests from study lines in the study areas were used in the final bearing capacity equation of Kurtuluş (2000) to determine the soil bearing capacity of soils in Akçakale and Tamzı villages (Table 6). In the equation recommended by Kurtuluş, the wave velocities of soil, are used together with a unitless P constant, foundation width (B) and foundation depth (D) parameters to determine safe bearing capacity of soils. Additionally to determine the safe bearing capacity the reliability coefficient was taken as the velocity ratio ($F_s = V_p/V_s$).

$$q_u = (PV_s)/200 \text{ (kg/cm}^2\text{)} \quad (20)$$

$$q_{em} = q_u/F_s \quad (21)$$

$$P = 1+0.33 \, D/B \quad (22)$$

$$\rho = 0.31 \, V_p^{0.25} \text{ (gr/cm}^3\text{)} \quad (23)$$

3.4. Bearing Capacity according to Türker's (2004) Equation

Türker accepted the dominant soil vibration period (T) as 0.33 seconds and recommended the following equation for final bearing capacity. For safe bearing capacity, the reliability coefficient (G_s) was taken as 3.

$$q_u = (V_s g T)/40) + (\gamma D_f)/10 \text{ (kg/cm}^2\text{)} \quad (24)$$

$$q_{em} = q_u/G_s \quad (25)$$

$$\rho = 0.31 \, V_p^{0.25} \text{ (gr/cm}^3\text{) (Kurtuluş, 2000)} \quad (26)$$

Using the velocities obtained from seismic measurements of soils in the study areas, the safe bearing capacity values are given in table 7.

Table 6- Soil bearing capacity according to Kurtuluş's (2000) equation.

Study Line No	B (m)	D_f (m)	ρ (gr/cm³)	V_p (m/s)	V_s (m/s)	P	F_s (Vp/Vs)	q_u (kN/m²)	q_{em} (kN/m²)	USC
Tamzı Village										
1	2	3	1.48	516.9	213	1.495	2.43	156.13	64.25	CL
2	2	3	1.52	585.6	235	1.495	2.49	172.25	69.18	CL
Akçakale Village										
3	2	3	1.43	452.4	184	1.495	2.46	134.87	54.83	SC
4	2	3	1.31	320.8	143	1.495	2.24	104.82	46.79	SC

Table 7- Soil bearing capacity according to Türker's (2004) equation.

Study Line No	D_f (m)	γ (gr/cm^3)	V_p (m/s)	V_s (m/s)	q_u (kN/m^2)	q_{em} (kN/m^2)	USC
Tamzı Village							
1	3	1.48	516.9	213	298.19	99.40	CL
2	3	1.52	585.6	235	334.78	111.59	CL
Akçakale Village							
3	3	1.43	452.4	184	254.88	84.96	SC
4	3	1.31	320.8	143	190.37	63.46	SC

3.5. Bearing Capacity According to Keçeli's (2010) Equation

The bearing capacity equation recommended by Keçeli only used the wave velocities, and appears not to consider the dimensions of the foundation. The safe bearing capacity of soils in the study areas were determined by using the following equations, with results given in table 8.

$$q_u = rV_s/100 \text{ (kg/cm}^2\text{)} \quad (27)$$

$$q_{em} = (rVs^2/Vp)/100 \text{ (kg/cm}^2\text{)} \quad (28)$$

$$\rho = 0.44\, V_s^{0.25} \text{ (gr/cm}^3\text{)} \quad (29)$$

3.6. Bearing Capacity According to Tezcan and Özdemir's (2011) Equation

In addition to the wave velocities, to determine safe bearing capacity of soils Tezcan and Özdemir developed a α coefficient representing foundation width. In this study the foundation width was taken as B=2 m and the following equations were used.

On condition that $1.2 \leq B \leq 3.0$m;

$$\alpha = 1.13 - 0.11B \quad (30)$$

$$\gamma = 4.3\, V_s^{0.25} \text{ (kN/m}^3\text{)} \quad (31)$$

$$q_u = 0.1gV_s\alpha \text{ (kN/m}^2\text{)} \quad (32)$$

With the condition $Vs \leq 750$ as n=4 is accepted as, n (reliability coefficient)

$$q_{em} = 0.025gV_s\alpha \text{ (kN/m}^2\text{)} \quad (33)$$

Using the bearing capacity equation of Tezcan and Özdemir, the soil bearing capacities of soils in Tamzı and Akçakale villages were determined (table 9).

The safe bearing capacity values calculated using empirical equations for soils outcropping in Tamzı and Akçakale villages are given in table 10.

Table 8- Soil bearing capacity according to Keçeli's (2010) equation.

Study Line No	ρ (gr/cm^3)	V_p (m/s)	V_s (m/s)	q_u (kN/m^2)	q_{em} (kN/m^2)	USC
Tamzı Village						
1	1.68	516.9	213	351.09	144.67	CL
2	1.72	585.6	235	396.99	159.31	CL
Akçakale Village						
3	1.62	452.4	184	292.39	118.92	SC
4	1.52	320.8	143	213.36	95.11	SC

Table 9- Soil bearing capacity according to Tezcan and Özdemir's (2011) equation.

Study Line No	B (m)	ρ (kN/m^3)	V_p (m/s)	V_s (m/s)	a	n	q_u (kN/m^2)	q_{em} (kN/m^2)	USC
Tamzı Village									
1	2	16.43	516.9	213	0.91	4	318.41	79.60	CL
2	2	16.84	585.6	235	0.91	4	360.03	90.01	CL
Akçakale Village									
3	2	15.84	452.4	184	0.91	4	265.17	66.29	SC
4	2	14.87	320.8	143	0.91	4	193.50	48.37	SC

Table 10- Safe bearing capacity values for soils.

Researcher	Tamzı (CL) q_{em} (kN/m^2)	Akçakale (SC) q_{em} (kN/m^2)
Terzaghi (1943)	225	687
	267	1090
	240	1444
Meyerhof (1963)	308	1061
	383	1808
	337	2491
Kurtuluş (2000)	64.25	54.83
	69.18	46.79
Türker (2004)	99.40	84.96
	111.59	63.46
Keçeli (2010)	144.67	118.92
	159.31	95.11
Tezcan and Özdemir (2011)	79.60	66.29
	90.01	48.37
CL: Low Plasticity Clay, **SC:** Clayey Sand		

When the safe bearing capacity results in Table 10 are assessed, the clays (CL) outcropping in Tamzı village have carrying capacity according to Terzaghi (1943) equation varying from 225-267 kN/m^2, while the clayey sand (SC) outcropping in Akçakale village varies from 687-1444 kN/m^2. According to Meyerhof's (1963) equation, the clays (CL) have bearing capacity of 308-383 kN/m^2, while the clayey sand (SC) have bearing capacity of 1061-2491 kN/m^2.

When the safe bearing capacity results obtained from geophysical methods are investigated, the bearing capacity of clays (CL) in Tamzı village are from 64-159 kN/m^2, while the clayey sand (SC) in Akçakale village have bearing capacities varying from 47-119 kN/m^2.

3.7. Determination of Settlement Amounts with Numerical Analysis

Acceptable settlement values for soils are predicted as ≤7.5 cm for clayey soils and ≤5 cm for sandy soils. The stress values which provide these settlement amounts are defined as the maximum vertical stress that can be applied to the soils. As a result using the bearing capacity values obtained from empirical equations is important to determine whether the settlement values for the soils are within acceptable limits.

To determine which vertical stress values provide acceptable amounts of settling in the clay (CL) and clayey sand (SC) soils investigated in this study, numerical analysis was completed with the finite element method (FEM). Noting the condition of two-dimensional plane deformation, the strain-deformation behavior of the material was modeled with a finite element network showing linear behavior. The modeling used the Phase^2 v6.0 (Rocscience, 2006) finite element-based computer program and under Mohr Coulomb failure conditions, settling that will occur in a vertical direction was determined. The values of parameters used in the numerical analysis of clay and clayey sand soils are given in table 11.

Table 11- Values of parameters used in numerical analysis.

USC	γ (kN/m^3)	ϕ (°)	c (kN/m^2)	Poisson Ratio (ν)	E_m (MN/m^2)	P (kN/m^2)
CL	18.87	11	51.26	0.39	213	190
SC	19.32	32	31.87	0.38	85.6	485
P: Uniform stress applied to soil						

Taking note of the acceptable vertical settling for construction foundations in clay (CL) and clayey sand (SC) soils in the model sections (clay soils ≤7.5 cm, sands ≤5cm) and the safe bearing capacity for strip footing geometry obtained from empirical equations (3 m foundation depth, 2 m foundation width), each soil was separatedly evaluated under uniform load.

According to the numerical analysis results, uniform vertical strains causing acceptable settling conditions were determined as 190 kN/m^2 for clay soils (CL) and 485 kN/m^2 for clayey sand (SC) (Figures 4-5). Under this uniform vertical strain the amount of vertical settling in clay soils is 6.40-7.20 cm (Figure 4). When clayey sand is assessed in this situation, the vertical settling amount varies from 3.75-4.75 cm under 485 kN/m^2 uniform vertical stress (Figure 5).

When the uniform vertical stress values ensuring acceptable settling conditions obtained from numerical analysis are compared with the bearing capacity values obtained from empirical equations, it is possible to see that the safe bearing capacity values obtained from the empirical equations recommended by Terzaghi (1943) and Meyerhof (1963) for clay (CL) and clayey sand (SC) soils are higher that the values obtained from the numerical analysis.

The empirical equation recommended by Keçeli (2010) calculated a safe bearing capacity value that ensured acceptable settling values only for clay soils (CL). The values obtained from equations recommended by Kurtuluş (2000), Türker (2004), and Tezcan and Özdemir (2011) were determined to cause much less settling compared to the acceptable settlement conditions.

4. Results and Discussion

This study calculated the safe bearing capacity of clay and clayey sand soils in Tamzı and Akçakale villages in Gümüşhane using bearing capacity equations recommended by several researchers and attempted to determine which values obtained from these empirical equations ensured acceptable settlement conditions for the soils. With this aim

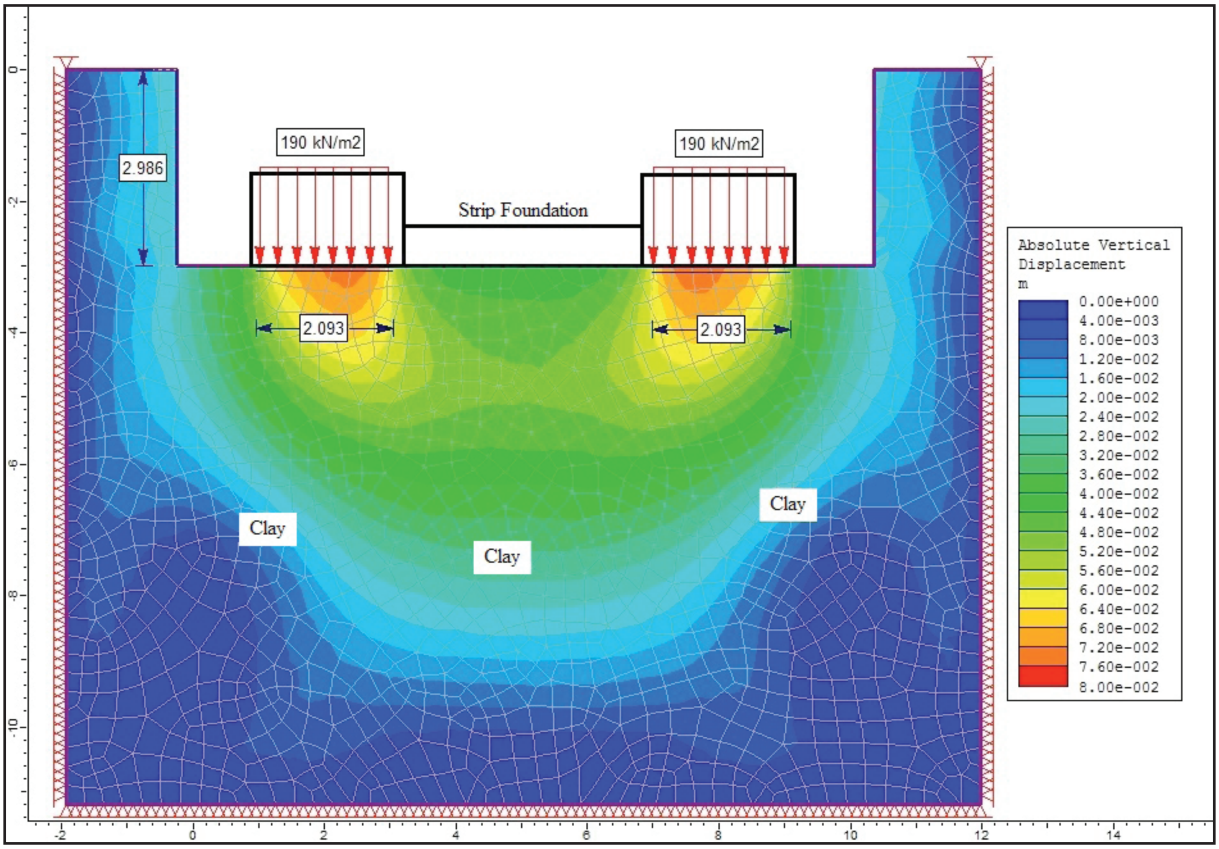

Figure 4- Numerical analysis model of vertical settling of clays (CL) under uniform stress.

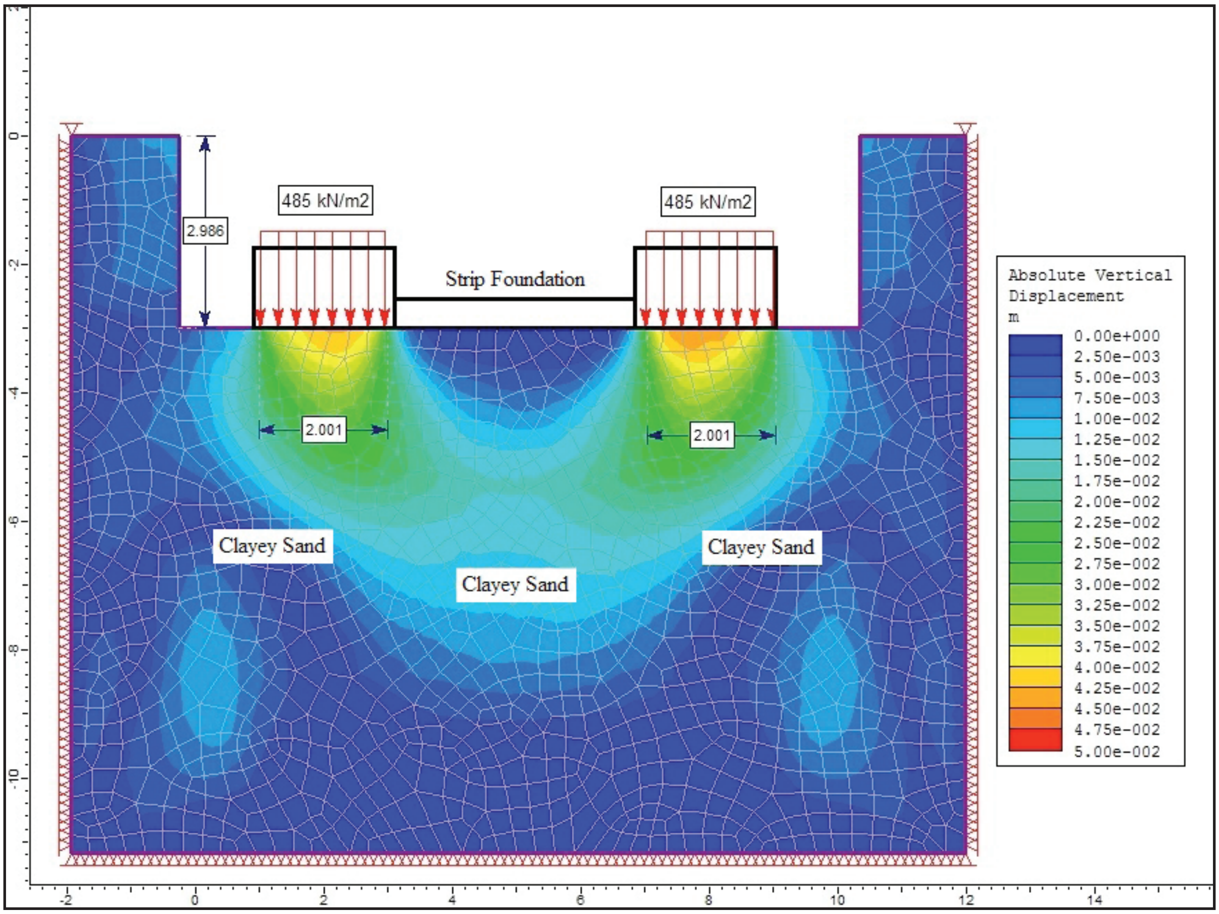

Figure 5- Numerical analysis model of vertical settling of clayey sand (SC) under uniform stress.

values obtained from field and laboratory studies were used to complete numerical analysis. The results obtained from the study are summarized below.

1. The safe bearing capacity values calculated from empirical equations based on geophysical methods showed great differences both compared with each other and with the safe bearing capacity values obtained from laboratory experiments. Using geophysical methods, the safe bearing capacity was 64.25-159.31 kN/m^2 for clay soil (CL) and 46.79-118.92 kN/m^2 for clayey sand (SC). Bearing capacity values calculated from empirical equations based on laboratory data varied from 225-383 kN/m^2 for clay soil (CL) and from 687-2491 kN/m^2 for clayey sand (SC).

2. When parameters obtained from laboratory tests are noted and the bearing capacity equations of Terzaghi (1943) and Meyerhof (1963) are used, there were significant differences in the values obtained from these two equations. According to the equation recommended by Meyerhof (1963), bearing capacity for both clays (CL) and clayey sand (SC) had higher values. Similarly, when geophysical data are used the safe bearing capacity values obtained using the empirical equations recommended by Kurtuluş (2000), Türker (2004), Keçeli (2010) and Tezcan and Özdemir (2011) presented very different values.

3. When the numerical analysis of soils are assessed, the uniform vertical strain value ensuring acceptable settlement conditions was determined as 190 kN/m^2 for clay (CL) and 485 kN/m^2 for clayey sand (SC). These values are the optimum safe bearing capacity values for the soils and if more stress is applied to these soils, the settlement values in the soils will exceed acceptable limits. If less stress is applied than these values, there will be less than the necessary stress applied and optimum design will not ensue.

4. When the safe bearing capacity values calculated with the aid of different empirical equations for clay (CL) and clayey sand (SC) soils are compared with the uniform vertical stress obtained from numerical analysis and ensuring acceptable settlement conditions, the values obtained from the empirical equations recommended by Terzaghi (1943) and Meyerhof (1963) provide higher settling above the limits of acceptable settlement in both soil types (clay soils ≤7.5 cm, sands ≤5cm). The values obtained from the empirical equations of Kurtuluş (2000), Türker (2004), Keçeli (2010) and Tezcan and Özdemir (2011) cause much less settling. These results show that the safe bearing capacity values obtained from all empirical equations are not appropriate for optimum design. As a result, to complete optimal foundation design, the safe bearing capacity values should be taken as 190 kN/m^2 for clay soil (CL) and 485 kN/m^2 for clayey sand (SC),
5. The study shows that determination of whether empirical calculation of safe bearing capacity of soils ensures acceptable settlement conditions is very important for optimum design. Thus, it is fundamental to apply the maximum stress that the soil can bear in foundation design while keeping the settlement amount caused by this stress within acceptable limits. As a result, during foundation design, it is necessary to note not only the soil safe bearing capacity but also the settling amount that will occur in soils.

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