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Full Length Research Paper

An experimental study for settlement of strip foundation on Geogrid-Reinforced sand

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In this study, design factors affecting the settlement of strip foundation on geogrid-reinforced sand were investigated experimentally. The experiments were carried out according to Taguchi's 5 parameter, 4 level, and standard L16 orthogonal arrays. Signal-to-noise (S/N) and variance analysis are used to determine the levels of the factors affecting the bearing capacity. It was determined that the most effective parameters on settlement value are foundation width (with 52% influence ratio) and foundation depth (with 30% influence ratio). While the foundation width and depth increased, the settlement value increased also.

Key words: Reinforced sand, Taguchi method, Geogrid, foundation settlement, sandy soils.

INTRODUCTION

Geosynthetic materials based on polymers have been recently at the top of the most commonly used; the most rapidly developed and varied material in geotechnic engineering. The polymeric materials which are produced under factory conditions are used with the soil and play an important role in actualizing the geotechnic projects. In addition to this, aesthetic and economical solutions are obtained by them since they increase the performance of the medium as well as decrease the costs. In 1960s, many researches were carried out in French way research laboratory in order to evaluate the beneficial effects of reinforced sand usage and a comprehensive evaluation was performed via Vidal (1968) by taking the results of previous studies into consideration.

Geogrid having high tensile strength, modulus of elasticity and peel resistance is a type of geosynthetic material on which there are homogenously distributed eclipses, rectangular and square gaps and which are especially used for soil improvement. Geogrids are separated into two groups such as one-axis and two-axis. The main principle in strengthening with geogrids is to form high tensile strength against low deformation in the structure of the soil. This only occurs by coupling between foundation soil and geogrid. Various scientific researches have been performed on geogrid reinforced sand until now and a few of them are summarized. Yetimoglu et al. (1994) searched the carrying capacity of rectangular foundations which settle on one-axis geogrid reinforced sand foundation. As a result of the study, it was determined that the settlements during collapse were more in the experiments performed with reinforced soil and the final carrying power of reinforced sand was 4 fold more than that of unreinforced soil. In multi-layer reinforced sand soils, it was indicated that the depth of first reinforcement layer had its maximum carrying capacity when the value was u = 0.3B, the vertical range between reinforcements varied in z = 0.20B~0.40B and BCR value was constant if reinforcement length exceeds 4.5 B.

Adams and Collin (1997) investigated the effects of reinforcement parameters of square single foundations on carrying power and settlement which settled on reinforced sand soil in model experiments under specified loadings until collapse formation. Reinforcement parameters such as vertical space between reinforcements, dimension of reinforcement layer, number of reinforcement layers and degree of compactness were selected. When number of reinforcement was N = 3, maximum carrying capacity was obtained and it was determined that soil improvement was not only dependent on number of layers but also varied with total reinforcement depth and vertical space between reinforcements.

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In a study carried out by Shin and Das (2000), the carrying capacity of strip foundation on sand which was strengthened with geogrids was investigated. BCR values of strip foundation settled on sand which was intermediately compacted and was multi-layer geogrid reinforced were searched under different depths and surface soil conditions. Depth of foundation was kept smaller than width of foundation. As a result of the experiment, it was indicated that maximum carrying capacity was obtained when the depth of first reinforcement layer was u = 0.3B.

Alawaji (2001) searched the carrying capacity of circular foundation settled on sandy and soft soil (D=100 mm). The experiments were performed in a 450 mm-diameter and 350 mm-height circular steel tank with 80% soft and 20% sandy soil together with TENSAR SS2 geogrid reinforcement material. In the study, the amount of settlement, modulus of elasticity and carrying capacity were investigated by varying the depth and width of geogrid layer.

Atalar et al. (2002) carried out loading experiments on the area gained from an ocean (Inchon International Airport Construction in South Korae) in order to measure the strength transmitted with regular loaded circular plaques placed on geogrid reinforced separate-grained soil. In the study, strength distribution, the size of load on the foundation, number of geogrid reinforced plates used for reinforcement and the thickness of geogrid reinforced soil were investigated.

Patra et al. (2005) investigated the carrying capacity of the soil by taking into consideration the situation of eccentric loaded strip foundation on multi-layer geogrid reinforced and intermediately compacted sandy soil under different depths and surface foundation conditions. In the experiments, natural soil with 42° angle of internal friction and 71% relative compactness together with unidirectional TENSAR BX1100 geogrid reinforcement were used. Dimensionless parameters were accepted as u/B = 0.35 h/B = 0.25, b/B = 5 and e/B = 0.1 throughout all experiments performed on reinforced soil.

In a study performed by Yıldız et al. (2006), the carrying capacity of circular foundations settled on geogrid reinforced sand was investigated by using finite element analysis and PLAXIS computer programme. In the analysis, the parameters for reinforcement configuration (u, h, N and BR) were selected and the increases occurred in carrying capacity due to reinforcement were defined with BCR term which was the rate of carrying capacity.

When the first reinforcement layer was selected as 0.30D, the vertical distance between reinforcement layers as 0.20D-0.30D, the number of reinforcement layers as N=4 and the length of reinforcement as BR = 3B, it was determined that BCR value increased 3.5 folds in reinforced soil. In the study of Kumar et al. (2007), final carrying capacity of strip foundations constructed on (reinforced/unreinforced) foundation soil was investigated which was formed with strong sand layer on sand fill having low carrying capacity.

In this present study, the required amount of settlement was investigated empirically in order to obtain limit capacity of foundation in central loaded strip foundations settled on geogrid reinforced sand by taking 5 factors (width of foundation, depth of foundation, length of reinforcement, number of reinforcement layers and distance between reinforcements) into consideration. The experiments were performed according to Taguchi method with 5 parameters and 4 level standard L16 orthogonal sequence table. Degree of influence and reliability of factors were determined by S/N and variance analysis. The details of the study were given in our previous study (Demiröz, 2008).

TAGUCHI METHOD

The effect of parameters on the results can be searched with Taguchi method by performing less number of experiments and by the most suitable orthogonal sequence selected via using factors that can be effective and controlled for the result of experimental study.

Orthogonal sequence (L16) with 5 parameters and 4 levels selected for this study is given in Table 1. In Table 1, T1, T2, T3, T4 and T5 show selected parameters in the study and the numbers in each row of experiment number show the level of parameter that the experiment will be carried out. This orthogonal sequence table prepared according to Taguchi Method is shown with L16 symbol. Every row shows the experiment programme that will be carried out by using factor levels in each row.

The analysis in Taguchi Method is performed by using S/N (signal to noise) rates (gradient index). The reason for using S/N gradient index is to see the effect of outer conditions or uncontrolled variables on the results while repeating the experiments. The rate of S/N is determined by the following equation:

$$S / N = -10\log_{10}\left(MSD\right) \qquad (1)$$

Here, MSD is defined as the mean of squares of deviation around target values. MSD value is determined by the following equations in case of target value is maximum and minimum.

For the target value to be maximum:

$$MSD = \left(\frac{1}{Y_1^2} + \frac{1}{Y_2^2} + ... + \frac{1}{Y_n^2}\right) / n \qquad (2)$$

For the target value to be minimum:

$$MSD = \frac{Y_1^2 + Y_2^2 + ... + Y_n^2}{n} \qquad (3)$$

Where Y1, Y2, ...Yn: are results of experiments, n: is the number of repetition in an experiment, Yo: is the known specific target value. In the design of an experiment according to this method, expected target values under optimum experimental conditions together with expected values (Yexp) when no experiments are performed can be predicted. This value is determined by taking the average S/N

Table 1. Orthogonal sequence L16 (45).

Experiment No.	Parameters and the levels of parameters in the experiments				
	T1	T2	T3	T4	T5
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	2	1	2	3	4
6	2	2	1	4	3
7	2	3	4	1	2
8	2	4	3	2	1
9	3	1	3	4	2
10	3	2	4	3	1
11	3	3	1	2	4
12	3	4	2	1	3
13	4	1	4	2	3
14	4	2	3	1	4
15	4	3	2	4	1
16	4	4	1	3	2

Table 2. Properties of test sand.

Type of soil (USCS)	SP
Effective particle diameter D10 (mm)	0.35
D30 (mm)	0.48
D60 (mm)	0.55
Coefficient of uniformity Cu	1.4
Coefficient of Gradation Cc	1.05
Specific Gravity Gs	2.68

values of factor levels under optimum conditions and the average S/N value of all design into consideration.

$$Y_{exp} = \sqrt{\frac{1}{MSD}} \quad (5)$$

Various statistical analysis are performed in order to determine the reliability of experimental results and the degree of influence of parameters on the results. For this, standard statistical technique which is known as variance analysis (ANOVA) is used. The reliability levels of the results are measured by variance. The effect of each parameter in orthogonal sequence is evaluated by ANOVA analysis. The detailed information about this method can be found in Taguchi (1987).

MATERIALS AND METHODS

Materials

The materials and experimental set-up used in the experiments of model carrying power settled on unreinforced and reinforced sandy soil (Dr= 85%) are explained as follows:

Test sand

In the experiments, natural sand which is graded as bad in the range of 0.4 and 2 mm was used. The index properties of sand are given in Table 2.

Geogrid

The properties of unidirectional geogrid (UR55) used in the experiments are given in Table 3.

Experimental set-up

The experiments for carrying power of model foundations were carried out in a tank with 39 cm width, 112.50 cm length and 80 cm height (Figure 1). The front and back surfaces of the tank are made of thick tempered glass plaques while side surfaces are made of steel sheet with 3 mm wall thickness. Side surfaces of the tank are supported with horizontal and vertical profiles in order to prevent deformations during experiments.

Experimental tank is installed in loading frame. Loading frame is manufactured from different steel profiles and designed as vertical load can be applied from its upper floor level. The values obtained during experiments are transferred to the computer by data collecting system and recorded.

Experimental programme

The parameters used in the experiments and the levels of these parameters are given in Table 4 while schematic drawing of them is given in Figure 1. The experiments were carried out according to L16 design given in Table 1 and the results were evaluated.

Table 3. Physical and mechanical properties of Geogrid (URL-1, 2008).

Type of reinforcement	**GEOGRID UR55**					
Unit weight (g/m^2)	500					
Raw material	PP					
Roller sizes (m)	Length			Width		
	60			1		
Tensile strength (kN/m)	Longitudinal			Latitudinal		
	55			12		
Strain failure (%)	Longitudinal			Latitudinal		
	11			13		
Dimensions (mm)	A	B	c	d	t1	t2
	80	14	5	10	2.50	0.95

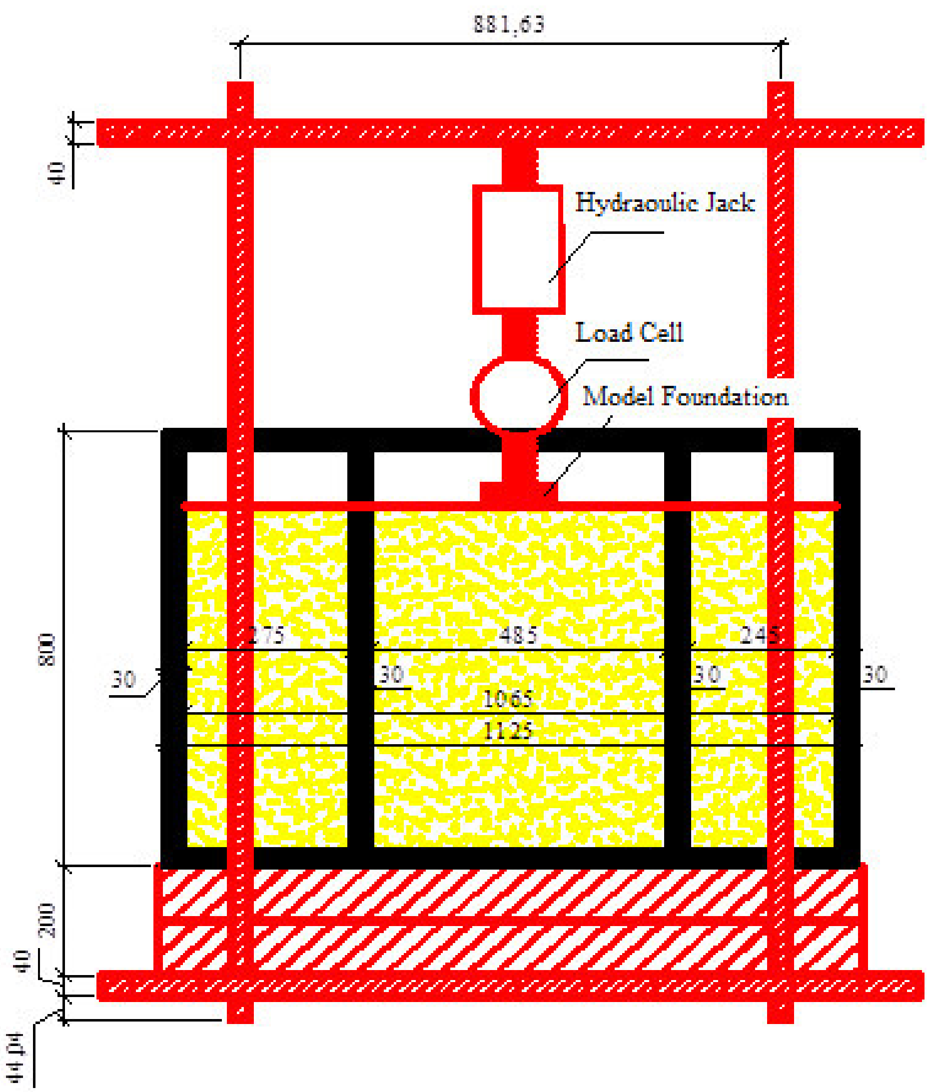

Figure 1. Experimental set-up.

Table 4. Selected parameters and their levels.

Level	Parameter				
	Width B (cm)	Number of reinforcements, N	Rate of reinforcement depth, U	Length of reinforcement, LG	Depth of foundation, Df
1	B1=4	N1=1	U1=0.25B	LG1=4B	Df1=0
2	B2=6	N2=2	U2=0.50B	LG2=6B	Df2=0.5B
3	B3=8	N3=3	U3=0.75B	LG3=8B	Df3=1.0B
4	B4=10	N4=4	U4=1.0B	LG4=10B	Df4=1.5B

Table 5. S/N rates for amounts of settlements.

Experiment No.	1	2	3	4	5	6	7	8	
Average settlement (mm)	0.6	5.9	3.85	4.5	13	12.3	3.7	2.0	Average S/N rate
S/N rate	42.5	54.6	54.7	54.4	54.9	57,6	52.3	50.0	
Experiment No.	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	
Average settlement (mm)	10.2	4.4	29.5	13.4	18.3	18.6	17.0	40.4	55, 70
S/N rate	54.2	50.4	63.5	60.1	57.0	58.7	60.7	65.7	

Table 6. Average S/N values of parameter levels.

Parameter	S/N Rates			
	1st level	2nd level	3rd level	4th level
Width of foundation (B)	29.0	35.4	41.0	46.6
Number of reinforcements (N)	35.6	38.7	39.4	38.4
Rate of reinforcement depth(U)	39.7	41.2	35.9	35.2
Length of reinforcement (LG)	33.7	38.8	39.6	39.9
Depth of foundation (Df)	29.6	39.7	40.2	42.6
Average S/N	38.0			

RESULTS AND DISCUSSION

S/N and variance analysis

S/N values calculated by using amounts of settlement which were measured for 16 different experiments are given in Table 5 while average S/N values belonging to levels of parameters are given in Table 6. Variation figures drawn by using average S/N values indicated in Table 6 are shown in Figures 2 - 6.

As the width of foundation increases in the strip foundation on geogrid reinforced soil, the amount of settlement at the time of obtaining limit carrying power linearly increases (Figure 2). When the variation graph of reinforcement number with S/N rate (Figure 3) is examined, it can be seen that settlement generally increases until the number of reinforcement is N = 3. The amount of settlement increases until 2nd level of reinforcement depth rate (u = 0.5B) and it decreases after this level (Figure 4). Settlement slowly increases until the length of reinforcement is LG = 10B (4th level) and then the rate of increase decreases especially after the 2nd level (Figure 5). The value of settlement rapidly increases as the depth of foundation increases until the value of Df = 0.5B and after this value, on the other hand, a little increase is observed until the value of Df = 1.5B (Figure 6).

Multi-variable variance analysis (ANOVA) was carried out in order to determine the effects and effect of influence of parameters for strip foundations settled on geogrid reinforced sand and its results are given in Table 7. As can be seen from the results of variance analysis carried out for settlement, the most effective parameter is the width of foundation (B) with 51.90% rate whereas the second most effective parameter is the depth of foundation (Df) with 30.30% rate. The effect of reinforcement depth rate is determined as 7.7% while that of reinforcement number as 2.5% and the degree of effect of

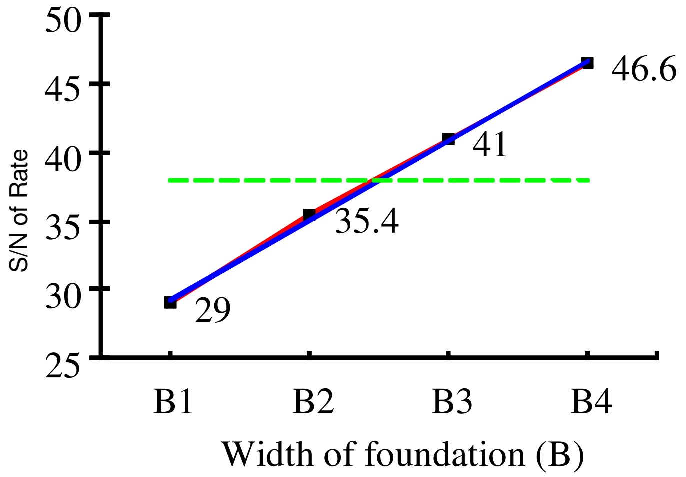

Figure 2. Variation of foundation width with S/N rates.

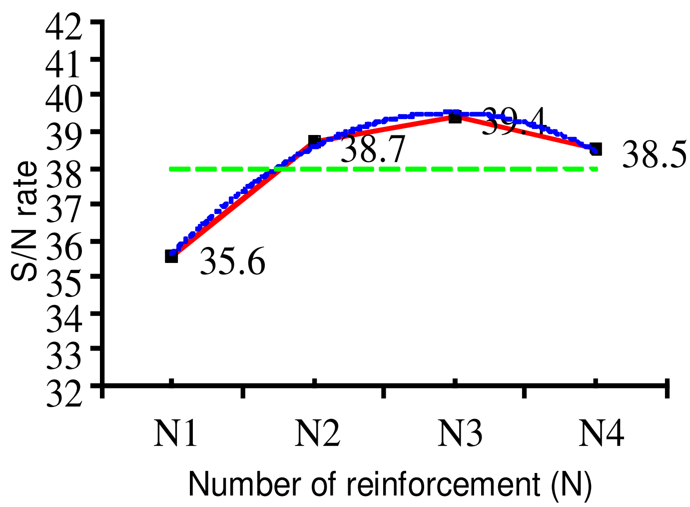

Figure 3. Variation of reinforcement numbers with S/N rates.

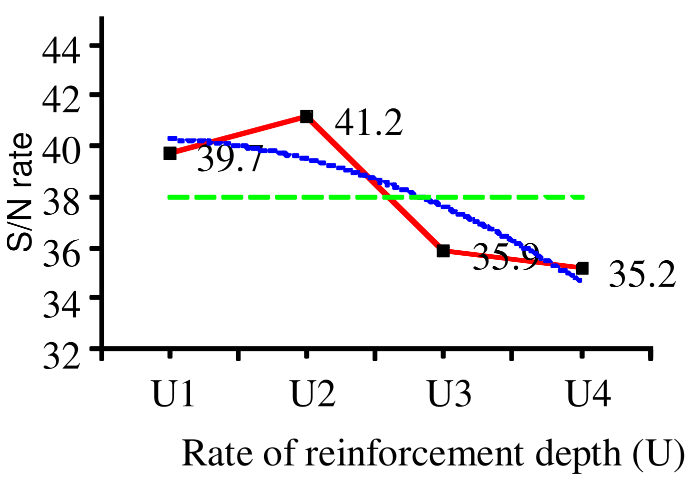

Figure 4. Variation of reinforcement depth rate with S/N rate.

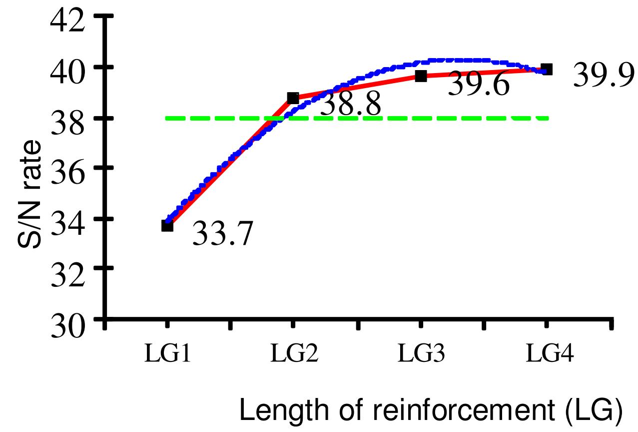

Figure 5. Variation of reinforcement length with S/N rates.

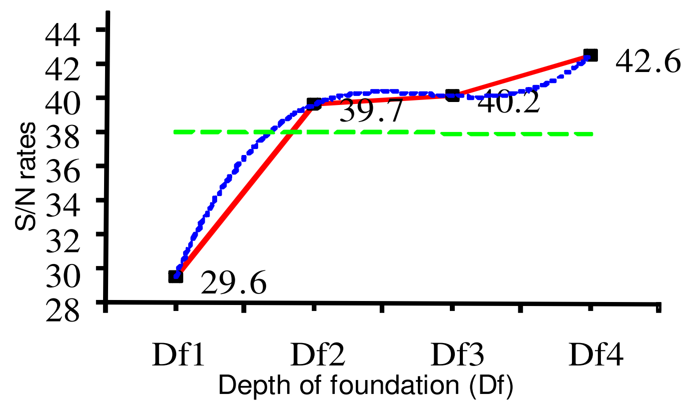

Figure 6. Variation of foundation depth with S/N rates.

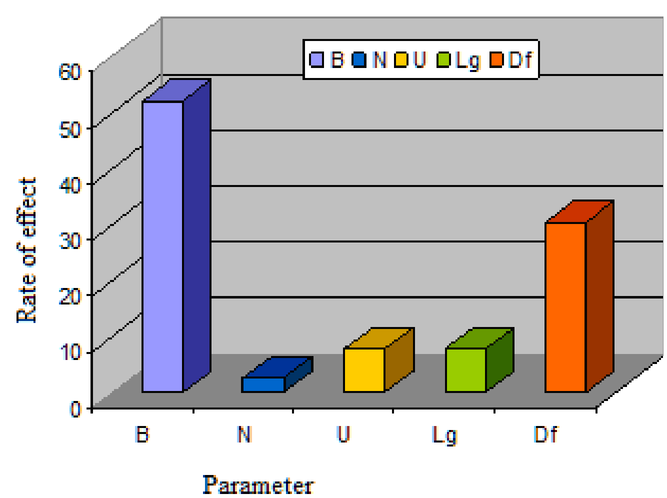

Figure 7. The effect rates of parameters for settlement.

reinforcement length as 7.6%. The degree of influence of parameters is shown in Figure 7 as graphs.

Table 7. Results of variance analysis.

Parameter	Degree of freedom (DOF)	Sum of squares (Ss)	Variance	Rate of effect (P) (%)
Width of foundation (B)	3	658.7	228.6	51.9
Number of reinforcement (N)	3	33.1	11.0	2.5
Rate of reinforcement depth (u)	3	101.2	33.7	7.7
Length of reinforcement (Lg)	3	99.7	33.2	7.6
Depth of foundation (Df)	3	400.1	133.4	30.3
Total	15	1319.9		100

Conclusıons

In this study, the amounts of settlement were investigated at the time of obtaining limit carrying power in strip foundations settled on geogrid reinforced sand empirically and the experiments were carried out according to Taguchi method by selecting standard L16 orthogonal sequence table with 5 parameters and 4 levels. The results belonging to the evaluation of experimental and statistical studies are given as follows:

1. The most effective parameter on the amount of settlement necessary to obtain limit carrying power is the width of foundation with 52% rate and as the width of foundation increases, the amount of settlement also increases almost linearly.
2. The second most effective parameter is the depth of foundation with 30% rate and as the depth of foundation increases, the amount of settlement also increases.
3. As the number of reinforcement and the length of reinforcement increase, the amount of settlement necessary to obtain limit carrying power also increases.
4. The reliability of these results is very important in terms of applying Taguchi method in such experimental researches in Geotechnical Engineering and in developing mathematical models.

More general results can be obtained for applications by performing more comprehensive experiments with the parameters such as different soils (type of soil, compactness, hardness), foundations (square, rectangular, raft and circular) and reinforcements (geogrid, geotextile).

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REFERENCES

Adams MT, Collin JG (1997). Large Model Spread Footing Load Tests on Geosynthetic Reinforced Soil Foundation, J. Geotech. Geoenviron. Eng., 123(1): 66-72.

Alawaji HA (2001). Settlement and Bearing Capacity of Geogrid-Reinforced Sand over Collapsibe Soil, Geotextiles Geomembranes, 19: 75-88.

Atalar C, Das MB, Omar MT, ve Shin EC (2002). Stress Distribution Under a Geogrid-Reinforced Soil Pad", Ninth Turkish Congress on Soil and Foundation Engineering, University of Anadolu, Eskisehir, 2: 509-518. (In Turkish).

Demiröz A (2008). Experimental Investigation of Design Factors Affecting the Bearing Capacity of Strip Foundation on Geogrid-Reinforced Sand", PhD Thesis, University of Selcuk, Graduate School of Natural and Applied Sciences, Konya, p. 247. (in Turkish).

Kumar A, Ohri LM, Bansal KR (2007). Bearing Capacity Tests of Strip Footings on Reinforced Layered Soils, Geotech. Geol. Eng., 25: 139-150.

Patra CR, Das MB, Shin EC (2005). Ultimate Bearing Capacity of Eccentrically Loaded Strip Foundations on Sand Reinforced With Geogrids, Paper Presented in International Symposium on Tsunami Reconstruction with Geosynthetics, Bangkok, pp. 335-344.

Shin EC, Das MB (2000). Experimental Study of Bearing Capacity of a Strip Foundation on Geogrid-Reinforced Sand, Geosynthetics Int., 7(1): 59-71.

Taguchi G (1987). System of Experimental Design, ASI, Dearborn.

Vidal MH (1968). La Terre Arme, AnnAnneles de L'Intitut Technique du Batiment et des Travoux Publics, pp. 888-938. (as referred by Das MB,1990).

Yetimoglu T, Wu J, Sağlamer A (1994). Bearing Capacity of Rectangular Footing on Geogrids-Reinforced Sand, J. Geotech. Eng. ASCE, 120(12): 2083-2099.

Yıldız AA, Laman M, Örnek M, Demir A (2006). Numerical an Analysis Circular Foundations Supported by Sand Reinforced with Geogrid", Second National Conference on Geosynthetics, University of Boğaziçi, İstanbul, pp. 75-84. (in Turkish)

URL -1 (2008). http://www.cevreplastik.com.tr.