Focussed on: Fracture and Structural Integrity related Issues

Evaluation of safe bearing capacity of soil foundation by using numerical analysis method

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ABSTRACT. The soil mechanic laboratory results help in accurate soil foundation design and enhancement failure mitigation. The mixing soil design has been used in many geotechnical engineering for soil improvement. In this paper, several types of soil foundations have been made from mixed soil. The bearing capacity of soil foundations by using mixed soil parameters and change footing dimensions have been calculated. 180 footings, placed on 15 soil foundation types have been designed. It is assumed the underground water has not effect to bearing capacity of soil foundation. The results of numerical analysis and mixed soils technique have been combined. The numerical analysis has supported mixed soil design, and introduced an appropriate result for soil foundation design. The effects of mixed soil on depth and width of footing have been compared. The mixed soil design influenced numerical analysis result, and economically, soil foundation design helps to select the appropriate dimensions of footings. The result of numerical analysis supports geotechnical and structural engineering codes, predicts structural stability with different age, natural hazard and prevention as well as it is useful in understanding safe bearing capacity of soil foundation behavior.

KEYWORDS. Mixed soil; Bearing capacity; Failure mitigation; Methodology; Realistic simulation.

INTRODUCTION

The mathematical modeling and numerical simulation have been used to understand tsunami behavior, and a mitigation technique has been proposed, based on bearing capacity of soil concept [1]. Numerically safe bearing capacity of soil foundation is calculated and it is attempted to assess economical dimension of foundation as well as understanding of bearing capacity [2]. The numerical model SSIFiBo has been developed in MATLAB to study soil-structure interaction problems. The model allows computing structural forced-vibrations, as well as seismic responses [3]. There is a numerical analysis and theoretical attempt to evaluate interaction between sandy saturated soil foundation and embankment in presence of confined sandy dense column. In this work some confined sandy dense columns have been considered made up from sand-gravel mixture. The numerically wave theory concept has been applied in analyzing confined sandy dense columns, and the study indicated that the dense zone improves soil foundation bearing capacity [4]. The data relating to the design of foundation for improvement of structure at different layer of subsoil have been collected and, soil mechanical properties have been evaluated. The results of experiments were applied in evaluation of geotechnical characteristics of urban area for the development of a region with high level of structural stability. Ultimately, a new method for calculation of liquefaction force numerically is suggested. It is applicable for improving geotechnical and structure codes and also for the reanalysis of structure and stability of previously constructed buildings [5]. To accurate soil foundation design the numerical computations, using FLAC code, are carried out to evaluate the soil bearing capacity factors. The computational results are presented in the form of tables and graphs, and compared with previous published results available in the literature [6]. The computational results predict the ultimate bearing capacity of shallow foundations on cohesionless soils. The neurofuzzy models combine the transparent, linguistic representation of a fuzzy system with the learning ability of Artificial Neural Networks (ANNs) [7]. The vertical bearing capacity of spudcan foundations in strength anisotropic soils has been investigated numerically by using the MIT-S1 model implemented in the AFENA finite element package. The model in AFENA is validated against existing laboratory test data of normally consolidated soil. The bearing capacities of spudcans in soils with isotropic and anisotropic strengths have been compared [8]. The ZEL method is employed to consider the stress level dependency of soil strength in the bearing capacity computation and load-displacement behavior of foundations, with a computer code was developed in MATLAB to solve ZEL equations [9]. The finite element analyses have been conducted to evaluate the combined horizontal-moment bearing capacities of tripod bucket foundations for offshore wind turbines in undrained clay [10]. To evaluate the safe bearing capacity of soil foundation and select appropriate dimensions of concrete foundation, when soil foundation is constructed from mixed soil, a numerical analysis has been made; ithas been attempted to appropriately improve stability of structures, to optimize application of mixed soil in soil foundation design, and to achieve realistic simulation of soil foundation design.

METHODOLOGY AND EXPERIMENT

The footing or concrete foundation tasks are to transfer the structural load to soil foundation. The shallow concrete foundation has ration of $D_f / B \leq 2.5$, where the D_f is the embedment depth and B is the width. The allowable bearing capacity or safe bearing capacity (q_f) is the maximum pressure on soil foundation, and it is margin of safety against the collapse due to shear failure. The 15 types of soil foundation have been produced from mixture of sand, gravel and six types of soils (Table 1). The mechanical properties of mixed soils have been used in numerical analysis. Total 180 types of footing have been designed. The substructure soil interaction behaviors have been depicted in form of graphs and tables. In numerical analysis the Terzaghi method has been adopted. It is well known that the underground water changes safe bearing capacity of soil foundation; due to this reason, to simplify and improve the research output, it is assumed that the underground water has no effect to safe bearing capacity of soil foundation.

Formulas for calculation of safe bearing capacity are the following:

1) $q_f = 1.3C\, N_c + \gamma D N_q + 0.4\, \gamma B N_\gamma$

2) $q_{nf} = q_f - q_{nf} = q_f - \gamma D$

3) $q_s = (q_{nf} / F) + \gamma D$

N_q, N_c and N_γ are the general bearing capacity factors and depend upon 1) depth of footing 2) shape of footing 3) Φ; they have been used from suggestion by the Terzaghi calculation method [11].

Mixed soil Type	% Of Red Soil	% Of Sand	% Of Gravel 4.75 mm	% Of Gravel 2 mm	% Of Black Soil	% Of Green Soil	% Of Dark Brown Soil	% Of Yellow Soil	% Of Light Brown Soil	Optimum Moisture Content (%)	γ (KN/m³)	Φ Degree	C (KN/m²)
1	100	0	0	0	0	0	0	0	0	11.20	21.94	38	21
2	55	45	0	0	0	0	0	0	0	10.61	21.83	39	12
3	55	0	45	0	0	0	0	0	0	10.72	23.46	39	46
4	55	0	0	45	0	0	0	0	0	12.15	23.82	36	28
5	55	0	0	0	45	0	0	0	0	22.39	20.09	32	20
6	55	0	0	0	0	45	0	0	0	18.86	20.95	32	26
7	55	0	0	0	0	0	45	0	0	14.56	23.35	18	44
8	55	0	0	0	0	0	0	45	0	14.23	20.96	30	28
9	55	0	0	0	0	0	0	0	45	14.56	21.61	28	26
10	90	0	0	0	2	2	2	2	2	16.83	21.61	36	22
11	80	0	0	0	4	4	4	4	4	18.27	21.56	15	47
12	70	0	0	0	6	6	6	6	6	16.76	21.07	22	49
13	60	0	0	0	8	8	8	8	8	20.21	21.83	21	33
14	50	0	0	0	10	10	10	10	10	18.68	21.18	27	38
15	55	15	15	15	0	0	0	0	0	9.58	23.02	40	8

Table 1: The mixed soil design and characteristics [12].

RESULTS AND DISCUSSION

Every foundation design requires satisfaction of safe bearing capacity [13]. The safe bearing capacity is governed by shearing strength of the soil and it is estimated by the theories of Terzaghi [14], Meyerhof [15], Vesic [16] and others.

The application of mixed soil in soil foundation design has been using in geotechnical engineering field for several years. The most of works has been performed basing on soil mechanics testing results and satisfying the theories of Terzaghi, Meyerhof, Vesic and others. The application of numerical analysis in soil foundation design from soil mechanics result is a methodology that leads to reduce the gap between theoretical and realistic design. The 180 footings, rested on 15 types of soil foundation have been designed; from the results of these soils foundation designs (Tab. 2-3), 2 major graphs (Fig. 1-2) and 3 minor graphs (Fig. 3-5) have been depicted. The interpretation of result of numerical analysis has been supporting to understand, role of soil morphology and mineralogy on safe bearing capacity of soil foundation and size of concrete foundation. The design of soil foundation and concrete foundation have been attempted to select suitable methodology and analysis, introduce appropriate materials produced from soil mixing technique. The mixed soil design has been responsible for numerical analysis result. In the numerical analysis of soil foundation the depth of footings have 1.00 (m), 1.30 (m), 1.60 (m), 1.90 (m), 2.20 (m) and 2.50 (m) been selected, and width of footings have been selected for 1.00 (m), 1.30 (m), 1.60 (m), 1.90 (m), 2.20 (m), 2.40 (m) and 2.50 (m). The results indicated (Tab. 2-3 and Fig. 1-2) the effect of mixed soil design on width and depth of concrete foundation size. And increase the footing width is economic compared to the increase of depth; it is suggested first to increase the width of concrete foundation for improve soil foundation safe bearing capacity. The increase width of square footing results in a more distributed transferred loads from structure to concrete and soil foundation, and subsequently, the bearing capacity of soil foundation is improved. The founding, from numerical analysis, has good coloration with theoretical concept and experimental results. The observations of mixed soil (in Tab. 2- 3 and Fig. 1-2) have shown that the safe bearing capacity of mixed soil types 10, 11, 12, 13 and 14 have considerable fluctuation while the percentage of basic mixed soil have changed in increment of 2% only. It has been understood the best percentage of any soil in soil mixture depends on soil mineral interaction. Combining mixed soil design with the numerical simulation results, it has been revealed the soil mineralogy effect to the design of concrete footing as well as the right selection type of soil foundation. The mixed soil type 3 with appropriate morphology has best been resulted in numerically design of soil foundation. The mixed soil deign can be introduced as an acceptable mitigation technique if its application has been simulated considering soil mineralogy and morphology. This work clearly shows the effect of soil mineralogy and morphology to select concrete foundation dimensions. The result indicate that failure mitigation of soil foundation is depending on soil mineralogy and morphology. Micro and macro properties of soils have direct influence on footing size, and any modification of soil in soil mixture, reflects to the concrete foundation and soil foundation characteristics.

Sl. No	γ (kN/m³)	Φ Degree	C (kN/m²)	d=1.00 (m)	d=1.30 (m)	d=1.60 (m)	d=1.90 (m)	d=2.20 (m)	d=2.5 (m)
1	21.94	38	21	1577.81	1708.04	1838.28	1968.51	2098.75	2228.98
2	21.83	39	12	1470.57	1617.58	1764.58	1911.58	2058.59	2205.59
3	23.46	39	46	2735.73	2893.71	3051.69	3209.67	3367.65	3525.63
4	23.82	36	28	1382.55	1485.93	1589.31	1692.69	1796.07	1899.45
5	20.09	32	20	700.81	757.06	813.31	869.56	925.82	982.07
6	20.95	32	26	822.31	880.97	939.63	998.29	1056.95	1115.61
7	23.35	18	44	368.96	386.70	404.45	422.20	439.94	457.69
8	20.96	30	28	703.14	750.38	797.62	844.87	892.11	939.36
9	21.61	28	26	570.13	610.37	650.61	690.84	731.08	771.32
10	21.61	36	22	1169.07	1262.86	1356.64	1450.43	1544.22	1638.00
11	21.56	15	47	308.93	322.00	335.06	348.13	361.19	374.26
12	21.07	22	49	522.43	544.47	566.51	588.55	610.59	632.63
13	21.83	21	33	357.89	378.41	398.93	419.45	439.97	460.495
14	21.18	27	38	653.38	688.67	723.95	759.24	794.52	829.81
15	23.02	40	8	1564.83	1738.21	1911.60	2084.99	2258.37	2431.76

Table 2: Safe bearing capacity of soil foundation (kN/m²) when width of square footing is 2.5 m.

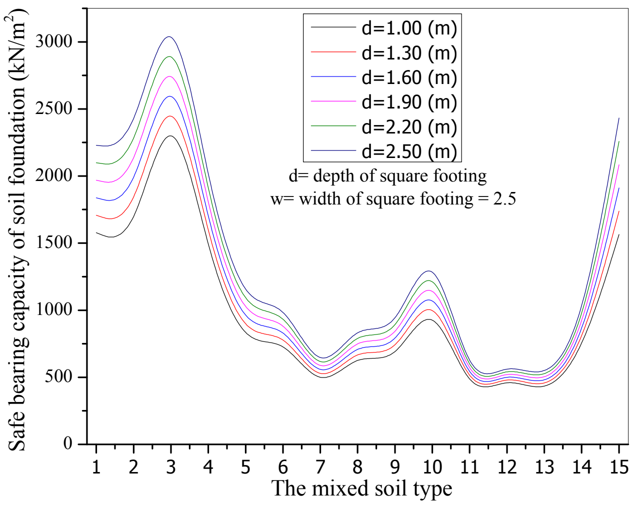

Figure 1: Safe bearing capacity of soil foundation (kN/m²) Vs the mixed soil type.

Sl. No	γ (kN/m³)	Φ Degree	C (kN/m²)	w=1.00 (m)	w=1.30 (m)	w=1.60 (m)	w=1.90 (m)	w=2.20 (m)	w=2.50 (m)
1	21.94	38	21	1289.96	1347.53	1405.10	1462.67	1520.24	1577.81
2	21.83	39	12	1133.52	1200.93	1268.34	1335.76	1403.17	1470.58
3	23.46	39	46	2373.51	2445.96	2518.40	2590.84	2663.29	2735.73
4	23.82	36	28	1180.57	1220.96	1261.36	1301.76	1342.16	1382.56
5	20.09	32	20	606.29	625.19	644.10	663.00	681.91	700.81
6	20.95	32	26	723.74	743.46	763.17	782.89	802.60	822.31
7	23.35	18	44	352.62	355.89	359.16	362.43	365.69	368.96
8	20.96	30	28	628.94	643.78	658.62	673.46	688.30	703.14
9	21.61	28	26	510.92	522.77	534.61	546.45	558.29	570.14
10	21.61	36	22	985.82	1022.47	1059.12	1095.77	1132.42	1169.07
11	21.56	15	47	299.28	301.21	303.14	305.07	307.01	308.94
12	21.07	22	49	497.41	502.41	507.42	512.43	517.43	522.44
13	21.83	21	33	336.06	340.43	344.80	349.16	353.53	357.89
14	21.18	27	38	603.82	613.74	623.65	633.56	643.47	653.38
15	23.02	40	8	1155.99	1237.76	1319.53	1401.30	1483.06	1564.83

Table 3: Safe bearing capacity of soil foundation (kN/m²) when depth of square footings is 1.00 m.

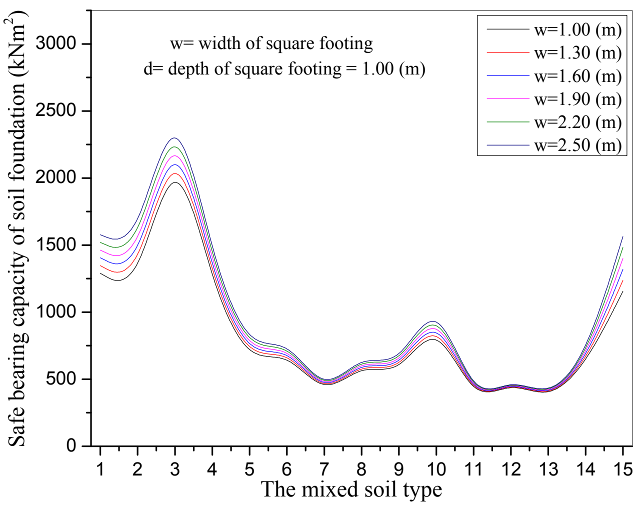

Figure 2: Safe bearing capacity of soil foundation (kN/m²) Vs the mixed soil type.

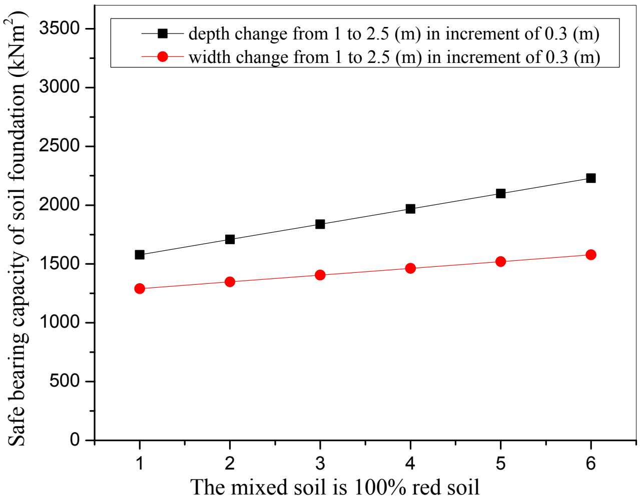

Figure 3: Fluctuation of safe bearing capacity of soil foundation (kN/m²) Vs the mixed soil type.

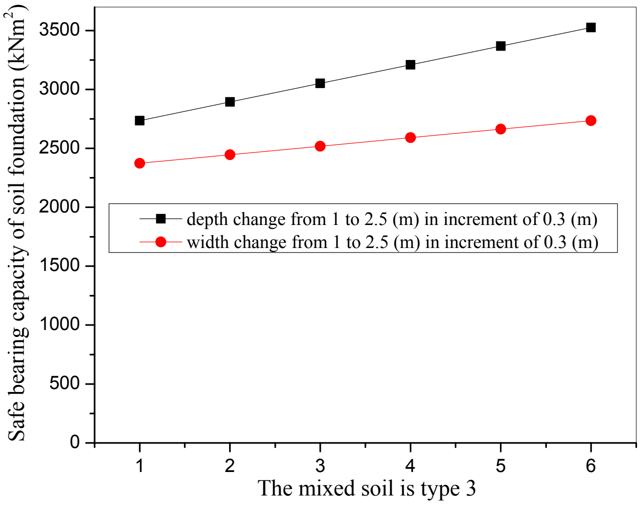

Figure 4: Fluctuation of safe bearing capacity of soil foundation (kN/m²) Vs the mixed soil type.

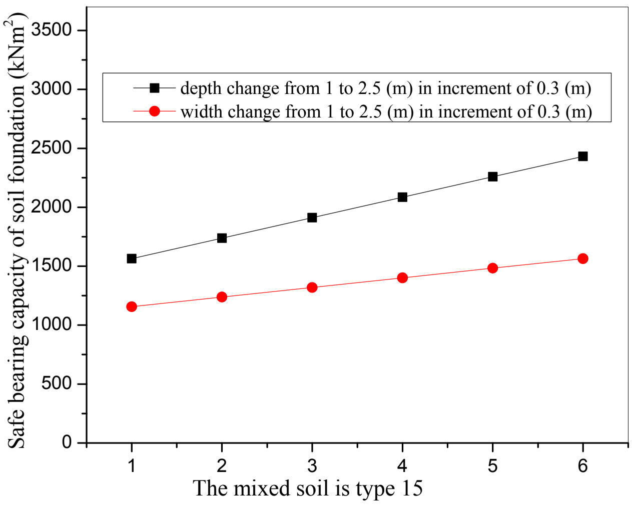

Figure 5: Fluctuation of safe bearing capacity of soil foundation (kN/m²) Vs the mixed soil type.

Fig. 3-5 shows the fluctuation of safe bearing capacity of soil foundation versus the mixed soil type. It has been reported higher safe bearing capacity with increasing depth, and in comparison of concrete used in construction of footing, the increase width is cost effective method. This research work is applicable in design of soil foundation and to minimize soil foundation failure. The result and interpretation of numerical analysis support the foundation design, it can be used to enhance structure stability, to improve geotechnical and structural engineering codes, to predict structural stability with different age and estimate structures stability while changing mechanical properties of soil foundation. One of the important factor that changes soil mechanical properties is the fluctuation of groundwater level; it occurs in many part of the world, due to many reasons like flood and etc. The numerical analysis helps in evaluation and application of geotechnical engineering map in construction industry, natural hazard prediction and prevention as well as soil foundation behavior. The founding may be required to be considered in data collection of site for understanding behavior of soil and concrete foundations.

There is an experimental analysis. The shaking table has been used to generate dynamic force on embankment and embankment soil foundation. To improve system dynamic stability, dense zones have been installed in subsoil [17]. The seismic mechanical properties of soil mechanics are required in seismic numerical analysis, and seismic soil foundation design. It is important to use accurate data in seismic numerical analysis of soil foundation considering the changes of the soil characteristics.

CONCLUSION

To accurate understanding failure mitigation of soil foundation, the numerical analyses of several soil foundations and results of mixed soil technique have been employed. 180 footings have been designed placing them on 15 soils foundation types. It has been observed that the mixed soil technique has the ability to predict soil foundation behavior. The results show soil parameters control footing dimensions. The effect of mixed soil on footing depth and width have been compared. The soil mineralogy and morphology govern safe bearing capacity of soil foundation and size of concrete foundation. The result of numerical analysis supports geotechnical and structural engineering codes, natural hazard prediction, prevention and understanding soil foundation behavior, predicts structural stability with different age.,. The methodology in this research work supports the application of mixed soil in designing soil foundation. To extent this research work , the role of mixed soil design in stress path can be investigated.

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