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Evaluation of Safe Bearing Capacity by Using Statical Analysis

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ABSTRACT

This paper presents the evaluation of safe bearing capacity by using statistical analysis. Bearing capacity formulae are proposed by various researchers for various conditions. In this study, four researchers namely, Terzaghi, Meyerhof, Hansen and Vesic are selected to use the bearing capacity equations. The required soil data are taken from thirteen soil reports in Chan Aye Thar San Township which includes thirty numbers of boreholes. The bearing capacity of the soil is calculated at the depth of 6ft below ground level and the square footing is considered in this study. The safety factor of 3 is used to obtain the allowable bearing capacity for various equations. To get confidence interval by statistical analysis, the allowable bearing capacity values are divided into three portions. These are the bearing capacity values less than 2 ksf, the bearing capacity values between 2 ksf and 3 ksf, and the bearing capacity values greater than 3 ksf. Confidence interval is taken as 98%. The summary of safe bearing capacity values for different locations is described.

KEYWORDS: *safe bearing capacity, Terzaghi, Meyerhof, Hansen, Vesic, Confidence interval*

I. INTRODUCTION

The lowest part of a structure that transmits its weight to the underlying soil or rock is the foundation. The ultimate strength and longevity of any structure depend on the adequacy of the foundation. The stability of foundation depends on the bearing capacity of the soil and the settlement of soil beneath the foundation.

Bearing capacity generally defined as the safe allowable pressure on the soil. The bearing capacity of the soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil. Soil behaves in a complex manner when loaded, so it is important to know about it's bearing capacity. The bearing capacity of foundations depends on the mechanical properties of the soil (density, shearing strength and deformation characteristics), on the original stresses and the water conditions in the ground, on the physical characteristics of the foundation (size, depth, shape and roughness) and on the way in which the foundation is installed.

II. Bearing Capacity Equations Proposed by Various Authors

Several bearing capacity equations were proposed by various researchers for estimating the ultimate bearing capacity of shallow foundations. In this study, the bearing capacity values are calculated by using the bearing capacity equations of Terzaghi, Meyerhof, Hansen, and Vesic. The bearing capacity values obtain from bearing capacity equations give ultimate bearing capacity values. Allowable bearing capacity is the ultimate bearing capacity divided by a factor of safety.

A. Terzaghi's Bearing Capacity Equation

In 1943, Terzaghi proposed a well-conceived theory to determine the ultimate bearing capacity of a shallow foundation supported by a homogeneous soil layer extending to a great depth.

$$q_u = 1.3cN_c + \bar{q}\,N_q + 0.4\gamma BN_r$$

B. Meyerhof's Bearing Capacity Equation

In 1951, Meyerhof published a bearing capacity equation could be applied to rough shallow foundations

$$q_u = cN_c s_c d_c + \bar{q}\,N_q s_q d_q + 0.5\gamma BN_r s_r d_r$$

C. Hansen's Bearing Capacity Equation

In 1970, Hansen proposed the general bearing capacity equation is shown below:

$$q_u = cN_c s_c d_c i_c g_c b_c + \bar{q}\,N_q s_q d_q i_q g_q b_q + 0.5\gamma BN_r s_r d_r i_r g_r b_r$$

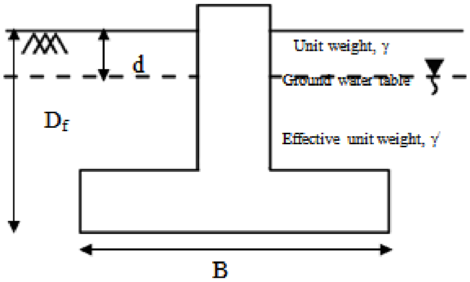
D. Vesic's Bearing Capacity Equation

The equation developed in Vesic (1973, 1975) is based on theoretical and experimental research and numerous methods of analysis. It produces more accurate bearing values and it applies to a much broader range of loading and geometry conditions.

$$q_u = cN_c s_c d_c i_c g_c b_c + \bar{q}\,N_q s_q d_q i_q g_q b_q + 0.5\gamma BN_r s_r d_r i_r g_r b_r$$

E. Effect of Ground Water Table

Groundwater affects many elements of foundation design and construction, so the groundwater table should be established as accurately as possible if it is within the probable construction zone; otherwise, it is only necessary to determine where it is not.



III. Locations of Bore Hole Data for Soil Report

To estimate the allowable bearing capacity of the soil, various bearing capacity equations and methods will be used. To calculate the allowable bearing capacity values, the required soil parameters are taken from soil reports in Chan Aye Thar San Township. There are thirteen locations in this Township for soil reports. It can be seen that there are thirty boreholes for thirteen locations.

The site locations of number (4) and number (12) have 3 bore holes for each. There are four bore holes in the site location of 80 street between 30& 31 streets, location 9. The remaining site locations have two boreholes. The water table was not found in six boreholes. The values of soil parameters are described in Table 1 for each location.

Table1. Soil Report of Thirty Bore Holes

Location	Bore Hole	Water Table Depth (ft)	Unit Weight of Soil (lb/cu-ft)		Shear Characteristics	
			Wet	Dry	c ib/ft²	φ
1	1	0.5	106.6	81.3	550	2° 30′
	2	0.5	110.75	85.3	875	4°
2	1	0.5	117.3	91.5	500	3°
	2	0.5	116.5	90.6	490	2° 45′
3	1	1	104.6	81.5	745	2° 30′
	2	1	104.5	81.3	660	2° 30′
4	1	1	104.3	81.2	660	2° 30′
	2	1	104.2	81	655	2° 30′
	3	1	102.5	78.7	580	2°
5	1	1	104.3	81.2	665	2° 30′
	2	1	104.2	81	660	2° 30′
6	1	2	104.2	81	660	2° 30′
	2	2	104.3	81.2	665	2° 30′
7	1	2	104.3	81.2	665	2° 30′
	2	2	104.2	81	660	2° 30′
8	1	2	104.3	81.2	660	2° 30′
	2	2	102.5	78.7	580	2°
9	1	3	118.1	95.3	970	4°
	2	3	118.8	96.3	980	4°
	3	3	118	95.2	965	4°
	4	3	118.1	95.1	960	4°
10	1	3	102.6	76.9	550	2° 15′
	2	8	102.5	76.8	331	2°
11	1	3	104.2	81	660	2° 30′
	2	-	104.3	81.2	665	2° 30′
12	1	-	114	91.1	765	3°7′30″
	2	-	113.4	90.4	712.5	2°52′30″
	3	-	113.6	90.5	762.5	3°
13	1	-	118.8	99.3	955	6°
	2	-	118.8	99	950	6°

IV. Calculation of Allowable Bearing Capacity Values

To calculate the allowable bearing capacity values, the necessary data are taken from soil reports in Table 1. In this paper, thirteen soil reports (thirty boreholes) in Chan Aye Thar San Township are used for evaluation. The types of footing are square footings at depth 6 ft below ground level for all boreholes. The size of the footing is 4 ft x 4 ft. If the foundation is located below the groundwater table, the effect of the ground water table is considered in the calculation of bearing capacity. Water table occurs mostly at shallow depth. But, water table occurs at depth 8 ft below ground level in borehole number 2 of location 10. By using the bearing capacity equations of Terzaghi, Meyerhof, Hansen, and Vesic are obtained the ultimate bearing capacity values. To get the allowable bearing capacity values, the factor of safety, 3 is used. The allowable bearing capacity values obtained from bearing capacity equations proposed by Terzaghi, Meyerhof, Hansen, Vesic are described in Table 2.

Table2. Allowable Bearing Capacity Values with Four Formulae

Location	Bore hole	Terzaghi	Meyerhof	Hansen	Vesic
		q_{all} (ksf)	q_{all} (ksf)	q_{all} (ksf)	q_{all} (ksf)
1	1	1.689	1.878	1.956	1.96
	2	2.824	3.158	3.302	3.309
2	1	1.599	1.787	1.856	1.862
	2	1.548	1.727	1.795	1.799
3	1	2.246	2.492	2.604	2.609
	2	2.007	2.228	2.325	2.33
4	1	2.006	2.227	2.324	2.328
	2	1.991	2.211	2.308	2.312
	3	1.73	1.917	1.998	2.001
5	1	2.02	2.242	2.34	2.345
	2	2.005	2.226	2.324	2.328
6	1	2.016	2.239	2.335	2.339
	2	2.03	2.255	2.352	2.356
7	1	2.03	2.255	2.352	2.356
	2	2.016	2.239	2.335	2.339
8	1	2.016	2.24	2.336	2.34
	2	1.74	1.929	2.008	2.011
9	1	3.165	3.543	3.7	3.707
	2	3.196	3.578	3.736	3.743
	3	3.148	3.524	3.68	3.687
	4	3.133	3.508	3.663	3.67
10	1	1.686	1.874	1.949	1.952
	2	1.092	1.225	1.253	1.257
11	1	2.026	2.252	2.347	2.351
	2	2.072	2.308	2.398	2.404
12	1	2.462	2.75	2.86	2.868
	2	2.276	2.541	2.638	2.646
	3	2.435	2.719	2.826	2.834
13	1	3.569	4.061	4.227	4.246
	2	3.551	4.041	4.206	4.224

From the above table, it can be found that the allowable bearing capacity values by using Terzaghi's equation are less than that of Meyerhof, Hansen and Vesic equations. The allowable bearing capacity values of Vesic's equation are the largest values in four equations. Shape factors, depth factors and inclination factors are not included in Terzaghi's bearing capacity equation. In the bearing capacity equations of Meyerhof, Hansen and Vesic, shape factors and depth factors are considered. Therefore, the allowable bearing capacity values by using the equations of Meyerhof, Hansen and Vesic are large values. The greater the factors included in equations, the larger the bearing capacity values.

V. Evaluation of Safe Bearing Capacity by Using Statistical Analysis

The allowable bearing capacity values are obtained by calculation of Terzaghi, Meyerhof, Hansen and Vesic equations. The allowable bearing capacity values are diffusely between one and five. Therefore, the available data were analyzed into three portions arranged in descending order. These three portions are bearing capacity values less than 2 ksf, bearing capacity values between 2 ksf and 3 ksf, and bearing capacity values greater than 3 ksf. And then, variation and confidence interval will be calculated by statistical analysis. The confidence level is taken as 98%. Each portion calculated by statistical analysis is described as a table. So, it can be easily seen the confidence interval of resultant data by using table form.

A. Determination of Safe Bearing Capacity Values less than 2 ksf

In one hundred and twenty boreholes, the allowable bearing capacity values less than 2 ksf are twenty-six boreholes by using four equations. These are eight boreholes in Terzaghi's equation, seven boreholes in Meyerhof's equation, six boreholes in Hansen's equation and five boreholes in Vesic's equation. To get the safe bearing capacity of the soil, a 98% confidence interval is used by a statistical approach. The calculation procedure for safe bearing capacity values less than 2 ksf is described in Table 3.

Table3. Calculation Procedure for Safe Bearing Capacity Values less than 2 ksf

Location	D_f (ft)	Bore hole	Terzaghi q_{all} (ksf)	Meyerhof q_{all} (ksf)	Hansen q_{all} (ksf)	Vesic q_{all} (ksf)
10	6	2	1.092	1.225	1.253	1.257
2	6	2	1.548	1.727	1.795	1.799
2	6	1	1.599	1.787	1.856	1.862
10	6	1	1.686	1.874	1.949	1.952
1	6	1	1.689	1.878	1.956	1.96
4	6	3	1.73	1.917	1.998	
8	6	2	1.74	1.929		
4	6	2	1.991			
Minimum Value	Q0	min	1.092	1.225	1.253	1.257
First Quatile	Q1	25%	1.574	1.742	1.735	1.664
Second Quatile	Q2	50%	1.688	1.874	1.903	1.862
Third Quatile	Q3	75%	1.735	1.907	1.96	1.954
Maximum Value	Q4	max	1.991	1.929	1.998	1.96
Percentile		80%	1.763	1.916	1.969	1.956
Range (max - min)			0.899	0.704	0.745	0.703
Inter Quatile Range (Q3-Q1)			0.162	0.165	0.226	0.291
Average Value	$\vec{x}$		1.634	1.762	1.801	1.766
Varience	s^2		0.061	0.057	0.071	0.077
Standard Deviation	s		0.247	0.239	0.266	0.277
Coefficient of Variation	V(%)		15.112	13.533	14.794	15.675
Maximum error of Estimate	E	98%	0.262	0.283	0.366	0.464
Confidence interval		min	1.373	1.479	1.435	1.302
		max	1.896	2.046	2.167	2.23

Based on the calculation of allowable bearing capacity values by four equation, a 98% confidence interval is obtained by statistical analysis. To get 98% of safety, maximum error values of 0.262 ksf at Terzaghi, 0.283 ksf at Meyerhof, 0.366 ksf at Hansen and 0.464 ksf at Vesic are allowed. Confidence interval are from 1.373 to 1.896 ksf of allowable bearing capacity values at Terzaghi's equation, 1.479 to 2.046 ksf at Meyerhof equation, 1.435 to 2.167 ksf at Hansen equation and 1.302 to 2.23 ksf at Vesic equation. From the above calculation results, the safe bearing capacity values should be used from 1.3 to 2 ksf.

B. Determination of Safe Bearing Capacity Values between 2 ksf and 3 ksf

In one-hundred and twenty boreholes, the allowable bearing capacity values between 2 ksf and 3 ksf are sixty-seven boreholes by using four equations. These are sixteen boreholes in Terzaghi's equation and Meyerhof's equation, seventeen boreholes in Hansen's equation and eighteen boreholes in Vesic's equation. To get the safe bearing capacity of the soil, 98% confidence interval is used by statistical analysis. The calculation procedure for safe bearing capacity values between 2 ksf and 3 ksf is described in Table 4.

Table4. Calculation Procedure for Safe Bearing Capacity Values between 2 ksf and 3 ksf

Location	D_f (ft)	Bore hole	Terzaghi q_{all} (ksf)	Meyerhof q_{all} (ksf)	Hansen q_{all} (ksf)	Vesic q_{all} (ksf)
4	6	3				2.001
8	6	2			2.008	2.011
4	6	2		2.211	2.308	2.312
5	6	2	2.005	2.226	2.324	2.328
4	6	1	2.006	2.227	2.324	2.328
3	6	2	2.007	2.228	2.325	2.33
6	6	1	2.016	2.239	2.335	2.339
7	6	2	2.016	2.239	2.335	2.339
8	6	1	2.016	2.24	2.336	2.34

5	6	1	2.02	2.242	2.34	2.345
11	6	1	2.026	2.252	2.347	2.351
6	6	2	2.03	2.255	2.352	2.356
7	6	1	2.03	2.255	2.352	2.356
11	6	2	2.072	2.308	2.398	2.404
3	6	1	2.246	2.492	2.604	2.609
12	6	2	2.276	2.541	2.638	2.646
12	6	3	2.435	2.719	2.826	2.834
12	6	1	2.462	2.75	2.86	2.868
1	6	2	2.824			
Minimum Value	Q0	min	2.005	2.211	2.008	2.001
First Quatile	Q1	25%	2.016	2.234	2.325	2.328
Second Quatile	Q2	50%	2.028	2.247	2.34	2.343
Third Quatile	Q3	75%	2.261	2.4	2.45	2.424
Maximum Value	Q4	max	2.824	2.75	2.86	2.868
Percentile		80%	2.324	2.507	2.59	2.572
Range (max - min)			0.819	0.539	0.852	0.867
Inter Quatile Range (Q3-Q1)			0.245	0.167	0.125	0.095
Average Value	$\vec{x}$		2.155	2.339	2.412	2.394
Varience	s^2		0.054	0.032	0.042	0.049
Standard Deviation	s		0.233	0.178	0.205	0.222
Coefficient of Variation	V(%)		10.809	7.631	8.489	9.288
Maximum error of Estimate	E	98%	0.152	0.116	0.128	0.135
Confidence interval		min	2.004	2.223	2.284	2.26
		max	2.307	2.455	2.541	2.529

Based on the calculation of allowable bearing capacity values by four equation, a 98% confidence interval is obtained by statistical analysis. To get 98% of safety, maximum error values of 0.152 ksf at Terzaghi, 0.116 ksf at Meyerhof, 0.128 ksf at Hansen and 0.135 ksf at Vesic are allowed. The confidence interval is from 2.004 to 2.307 ksf of allowable bearing capacity values at Terzaghi's equation, 2.223 to 2.455 ksf at Meyerhof's equation, 2.284 to 2.541 ksf at Hansen's equation and 2.26 to 2.529 ksf at Vesic's equation. From the above calculation results, the safe bearing capacity values should be used from 2 to 2.5 ksf.

C. Determination of Safe Bearing Capacity Values greater than 3 ksf

In one-hundred and twenty boreholes, the allowable bearing capacity values greater than 3 ksf are twenty-seven boreholes by using four equations. These are six boreholes in Terzaghi's equation, seven boreholes in Meyerhof's equation, Hansen's equation and Vesic's equation. To get the safe bearing capacity of the soil, 98% confidence interval is used by statistical analysis. The calculation procedure for safe bearing capacity values greater than 3 ksf is described in Table 5.

Table 5. Calculation Procedure for Safe Bearing Capacity Values greater than 3 ksf

Location	D_f (ft)	Bore hole	Terzaghi q_{all} (ksf)	Meyerhof q_{all} (ksf)	Hansen q_{all} (ksf)	Vesic q_{all} (ksf)
1	6	2		3.158	3.302	3.309
9	6	4	3.133	3.508	3.663	3.67
9	6	3	3.148	3.524	3.68	3.687
9	6	1	3.165	3.543	3.7	3.707
9	6	2	3.196	3.578	3.736	3.743
13	6	2	3.551	4.041	4.206	4.224
13	6	1	3.569	4.061	4.227	4.246
Minimum Value	Q0	min	3.133	3.158	3.302	3.309
First Quatile	Q1	25%	3.148	3.512	3.667	3.674
Second Quatile	Q2	50%	3.181	3.543	3.7	3.707
Third Quatile	Q3	75%	3.509	3.925	4.089	4.104
Maximum Value	Q4	max	3.569	4.061	4.227	4.246
Percentile	80	%	3.556	3.999	4.163	4.18
Range (max-min)			0.436	0.903	0.925	0.937
Inter Quatile Range (Q3-Q1)			0.361	0.413	0.421	0.43
Average Value		$\vec{x}$	3.294	3.63	3.788	3.798
Varience		s^2	0.039	0.095	0.099	0.102
Standard Deviation		s	0.198	0.308	0.315	0.32
Coefficient of Variation		V(%)	6.024	8.484	8.312	8.417
Maximum error of Estimate	E	98%	0.273	0.366	0.374	0.38
Confidence interval		min	3.021	3.265	3.414	3.418
		max	3.566	3.996	4.162	4.178

Based on the calculation of allowable bearing capacity values by four equation, a 98% confidence interval is obtained by statistical analysis. For 98% of safety, allowable maximum values are 0.273 ksf at Terzaghi, 0.366 ksf at Meyerhof, 0.374 ksf at Hansen and 0.380 ksf at Vesic. Confidence interval from 3.021 to 3.566 ksf of allowable bearing capacity values at Terzaghi's equation, 3.265 to 3.996 ksf at Meyerhof equation, 3.414 to 4.162 ksf at Hansen equation and 3.418 to 4.178 ksf at Vesic equation. From the above calculation results, the safe bearing capacity values should be used from 3 to 4 ksf.

VI. Summary of Safe Bearing Capacity Values for Different Locations

By using statistical analysis, maximum error and 98% confidence interval of safe bearing capacity are obtained. The bearing capacity values less than 2 ksf have confidence interval ranging from 1.3 to 2 ksf. The values between 2 ksf and 3 ksf are ranging confidence interval 2 to 2.5 ksf. The bearing capacity values larger than 3 ksf are between 3 and 4 ksf of the confidence interval. The bearing capacity values between this confidence interval are considered to be safe. Therefore, the summary of safe bearing capacity values according to locations in Chan Aye Thar San Township is described in Table 6.

Table6. Summary of the Safe Bearing Capacity Values for Different Locations

<table>
<tr><th rowspan="2">Location</th><th colspan="3">Usable Bearing Capacity</th></tr>
<tr><th>Bearing Capacity Values <2 ksf</th><th>2ksf< Bearing Capacity Values <3 ksf</th><th>Bearing Capacity Values >3 ksf</th></tr>
<tr><td>Seiktara Mahi Quarter</td><td>1.3-2</td><td>2-2.5</td><td>3-4</td></tr>
<tr><td>Pyi Kyi Myat Hman Quarter</td><td rowspan="2">1.3-2</td><td rowspan="2">2-2.5</td><td rowspan="2"></td></tr>
<tr><td>Pyi Kyi MyatShin Quater</td></tr>
<tr><td>Hay Mar Za La Quarter</td><td rowspan="2">1.3-2</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Pat Kone Pyaw Pwel Quarter</td></tr>
<tr><td>Pat Kone Win Kyin Quarter</td><td rowspan="3"></td><td rowspan="3">2-2.5</td><td rowspan="3"></td></tr>
<tr><td>Yan Myo Lone Quarter</td></tr>
<tr><td>Kan Kout Quarter</td></tr>
<tr><td>Maw Ya Zi War Quarter</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">3-4</td></tr>
<tr><td>Aung Nan Yate Thar Quarter</td></tr>
</table>

VII. Conclusions

The loads from superstructure are transmitted to the foundation materials. To distribute the load to the foundation material, the bearing capacity of the foundation material is required to know. In this study, four researchers, namely, Terzaghi, Meyerhof, Hansen and Vesic are used to calculate the bearing capacity. The resulted values are evaluated by statistical analysis to know the confidence interval. The required parameters for bearing capacity calculation are taken from thirteen soil reports (thirty boreholes) in Chan Aye Thar San Township. Three portions are considered such as bearing capacity values less than 2 ksf, between 2 ksf and 3 ksf, and greater than 3 ksf. After analyzing these data, the resulted values are calculated to obtain their variation and confidence interval by using statistical analysis. It is required to have a 98% confidence interval. To get 98% of safety, maximum errors are calculated by statistical analysis. And then, the confidence interval is obtained. All bearing capacity values are influenced according to the number of parameters. In conclusion, the greater the number of factors considered in the Equation, the larger the accuracy of bearing capacity values.

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