PREDICTION OF LOAD CARRYING CAPACITY FOR SOIL-CEMENT COLUMN BY QUANTIFICATION METHOD OF MULTIVARIATE ANALYSIS

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INTRODUCTION:

This paper discusses the application of the Quantification Method of Multivariate Analysis as a tool to investigate the correlationship of the load carrying capacity factors (i.e frictional and end bearing) with respect to the soil-cement column head stiffness and the yield load at column head respectively.

METHOD OF ANALYSIS:

The illustrations of the method of analysis are discussed as follows:

(A) Multivariate Analysis (Quantification Type 1):

The Quantification Type 1 Method of Multivariate Analysis is a quantification method of qualitative data for the independent variables by assigned item-category score when an outside variable (i.e dependent variable) is known or measured (i.e qualitative data) and it analyses similarly to the multiple regression analysis which provides the multiple and partial correlation coefficients of the independent variables with respect to the outside variable. Subsequently from the result of analysis, a quantitative formula can be established and this empirical formula is used to predict the outside variable according to the response pattern which is represented by the item-category of the independent variables.
This paper deals only with how to quantified the frictional and end bearing factors as independent variables and the detail explanation of the method had been mentioned by Hayashi.C (1952) and Tanaka.Y et al (1984).

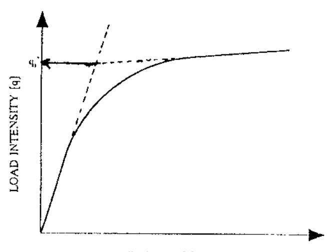

Figure 1: Typical plot of the load intensity versus settlement at column head.

(B) Quantification Of The Frictional Factors:

The plot of the load intensity on the column head [q] versus the settlement at the column head [s] often shows initially a straight line relationship up to some point on the curve as depicted in Figure 1. Therefore it is reasonable to relate the frictional factors as independent variables and the gradient for initial straight line portion (it is defined herein as column head stiffness, q/s) of the q-s plot as outside variable. The frictional factors are classified by seven items in this study. The frictional factors are depended on soil layers and length of the soil-cement column. For soil layers, there are items for clay [f_c], loam [f_l], organic clay [f_o], silt [f_{si}], sand [f_{sd}] and gravel [f_g] have been used in this study. Each of these items is quantified according to its proportional length [L_s/L_c] of the soil-cement column in the particular soil layer i.e $0=L_s/L_c$, $0<L_s/L_c\le0.33$, $0.33<L_s/L_c\le0.67$ and $0.67<L_s/L_c\le1.0$ are categorised as 1 score, 2 scores, 3 scores and 4 scores respectively; where L_s is the partial shaft length and L_c is the full shaft length. However the item for the penetration length of the soil-cement column is quantified based on its length/diameter ratio [l/d] i.e $2\le l/d$, $2<l/d\le4$, $4<l/d\le6$, $6<l/d\le8$, $8<l/d\le10$ and $10<l/d$ are categorised as 1 score, 2 scores, 3 scores, 4 scores, 5 scores and 6 scores respectively.

(C) Quantification Of The End Bearing Factors And The Column Head Stiffness:

In this study, the yield load at column head [q_y^*] is defined by the intersection point of tangent lines drawn through the initial straight portion and the steeper portion of the q-s plot as shown in Figure 1. Thus it is reasonable to relate the column head stiffness factor [q/s] and the end bearing factors as independent variables; and the yield load [q_y^*] as the outside variable. The item for the column head stiffness factor is quantified based on its values [q/s, $tf/m^2/mm$] i.e $q/s\le10$, $10<q/s\le20$, $20<q/s\le30$, $30<q/s\le40$, $40<q/s\le50$, $50<q/s\le60$ and $60<q/s$ are assigned by category score of 1, 2, 3, 4, 5, 6 and 7 respectively. The end bearing factors for this study are represented by four items namely Item L (bearing stratum depth), Item d (diameter of the soil-cement column at the bearing stratum), Item b_f (type of soil at the bearing stratum) and Item N_b (average N-value in the bearing stratum of three times column diameter below the column base). For item L, it is quantified according to the length of column i.e $L\le2m$, $2m<L\le3m$, $3m<L\le4m$, $4m<L\le5m$, $5m<L\le6m$, $6m<L\le7m$ and $7m<L\le8m$ are categorised as 1 score, 2 scores, 3 scores, 4 scores, 5 scores, 6 scores and 7 scores respectively. Item d is quantified based on the column diameter size i.e $d\le600mm$, $600mm<d\le800mm$ and $800mm<d\le1000mm$ are categorised as 1 score, 2 scores and 3 scores respectively. For item b_f, it is quantified according to the soil type i.e clay, loam, silt, sand and gravel are categorised as 1 score, 2 scores, 3 scores, 4 scores and 5 scores respectively. And item N_b is quantified based on the N-value i.e $N\le4$, $4<N\le10$, $10<N\le20$, $20<N\le30$, $30<N\le40$ and $40<N$ are categorised as 1 score, 2 scores, 3 scores, 4 scores, 5 scores and 6 scores respectively.

RESULTS OF THE ANALYSIS:

(A) The Frictional Factors And The Column Head Stiffness:

From the result of analysis, where the qualitative values of the column head stiffness [i.e q/s] as outside variable, the empirical equation (1) is established and the numerical values of items according to the item–category score for the frictional factors are obtained as depicted in Table 1.

$q/s=(X_{fc}+X_{fl}+X_{fo}+X_{fsi}+X_{fsd}+X_{fg}+X_{L/d}+5.6)^2$ tf/m^2/mm(1)

where; X_{fc}, X_{fl}, X_{fo}, X_{fsi}, X_{fsd}, X_{fg} and $X_{L/d}$ are the numerical values of items for the equation based on the item–category score for the soil type i.e clay, loam, organic clay, silt, sand and gravel; and the penetration length respectively.

Table 1: Numerical values of items for the frictional factors.

CATEGORY SCORE	X_{fc}	X_{fl}	X_{fo}	X_{fsi}	X_{fsd}	X_{fg}	$X_{L/d}$
1	2.4	1.0	0.3	2.6	2.5	-0.01	0.3
2	2.8	0.9	3.4	0.3	5.4	2.7	0.1
3	-3.1	-11.5	-8.1	-2.4	-1.4	-2.5	-1.0
4	-7.8	-11.0	-6.3	-9.5	-5.3		1.1
5							-0.3
6							0.5
R_p	0.91	0.92	0.88	0.90	0.89	0.76	0.76

For n=37 (R=0.94)

$$q/s = (X_{fc} + X_{fl} + X_{fo} + X_{fsi} + X_{fsd} + X_{fg} + X_{L/d} + 5.6)^2 \quad tf/m^2/mm \qquad (1)$$

Notes:
1. n = number of the field static load test data being used for the analysis.
2. R = multiple correlation coefficient.
3. R_p= partial correlation coefficient.

Table 2: Numerical values of items for the end bearing factors and the column head stiffness.

CATEGORY SCORE	X_L	X_d	X_{bf}	X_{Nb}	$X_{q/s}$
1	-0.2	0.3	1.8	-1.1	-1.7
2	-0.7	2.2	-0.6	-0.4	-0.6
3	0.1	-0.9	-0.1	0.2	0.3
4	0.4		-0.2	0.5	-0.01
5	0.9		-0.1	2.6	0.8
6	-1.1			1.0	0.9
7	1.2				-2.8
R_p	0.57	0.72	0.48	0.67	0.64

For n=37 (R=0.82)

$$q_y^* = (X_L + X_d + X_{bf} + X_{Nb} + X_{q/s} + 9.4)^2 \quad tf/m^2 \qquad (2)$$

Notes:
1. n = number of the field static load test data being used for the analysis.
2. R = multiple correlation coefficient.
3. R_p= partial correlation coefficient.

(B) The End Bearing Factors, The Column Head Stiffness And The Yield Load:

The empirical equation (2) is established from the result of analysis where the qualitative values of the yield load at column head [q_y^*] as outside variable. The numerical values of items based on the item–category score for the independent variables of the end bearing factors and the column head stiffness are obtained as depicted in Table 2.

$q_y^* = (X_L+X_d+X_{bf}+X_{Nb}+X_{q/s}+9.4)^2$ tf/m^2/mm (2)

where; X_L, X_d, X_{bf}, X_{Nb} and $X_{q/s}$ are the numerical values of items for the equation based on the item–category score for the end bearing factors (i.e bearing stratum depth, column diameter at the bearing stratum, soil type at the bearing stratum and average N–value in the bearing stratum below the column base) and the column head stiffness respectively.

DISCUSSION AND CONCLUDING REMARKS:

Figures 2 and 3 depict the predicted versus observed values for the column head stiffness (q/s, tf/m^2/mm) and the yield load at column head (q_y^*, tf/m^2) respectively. Both figures show the predicted values are closely distributed over or under or even on the equal line, these indicate the reliability of the predictions by the two empirical equations. The predicted/observed ratio of q/s and q_y^* are within the region of 0.65 to 1.5 for the available 37 load–settlement data in this study. Therefore it is useful for preliminary estimation of the load carrying capacity of different dimensions of the soil–cement column range from 400 to 1000 mm in diameter and 1.5 to 8 m long in various geotechnical conditions.

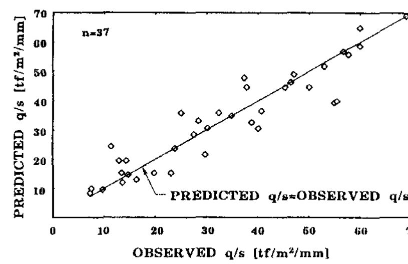

Figure 2: Predicted versus observed values of the column head stiffness [q/s].

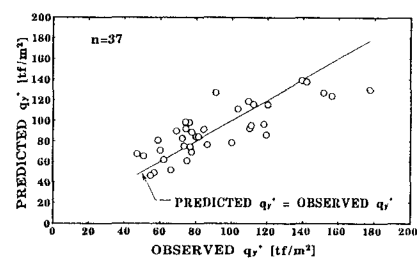

Figure 3: Predicted versus observed values of the yield load at column head [q_y^*].

ACKNOWLEDGEMENT:

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