Strong Correlation between the Bearing Capacity and CBR of a Gypsiferous Subgrade Soil Subjected to Long-Term Soaking

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ABSTRACT: Presented in this paper is a correlation between the bearing capacity of a gypsiferous subgrade soil with the corresponding CBR value. The geotechnical tests carried out on this soil indicate that the soil is sandy lean clay of CL group according to the USCS and A-6 (6) group according to AASHTO Soil Classification System. The soil contains about 33% gypsum content. For this purpose, thirty six CBR samples were prepared at optimum moisture content (of the modified AASHTO compaction test) namely 11.5% at compactive efforts of 1, 2 and 4.56 times that of the Proctor compaction (standard AASHTO). These samples were soaked for 0, 4, 7, 15, 30, and 120 days under the effect of 40 lbs (178 N) surcharge load. For each soaking period, three pairs of CBR soil samples were prepared, one for each compactive effort. The first CBR sample from each pair was used to determine the CBR value while the second CBR sample was used to obtain triaxial soil samples for unconsolidated undrained tests to arrive at the corresponding shear strength parameters. The present paper reveals that for each soaking period, there is a linear increase of the ultimate bearing capacity with increasing compactive effort, while a significant drop in the ultimate bearing capacity of the tested soil took place with increasing soaking period. The paper reveals also that there is a strong linear correlation between the estimated ultimate bearing capacity and the corresponding CBR value indicating that the Rosenak's equation correlating the bearing capacity with CBR value is very conservative.

KEY WORDS: Bearing capacity, California bearing ratio, compaction, gypsiferous soil, soaking.

1 INTRODUCTION

The subgrade of a road pavement, like any foundation, must be capable of supporting the imposed loading without shear failure or excessive deformation (Hight & Stevens, 1982).

A major input to all methods of design of pavements is a measure of the strength of the soil, i.e. its ability to resist the stress imposed by traffic loading. This input is required for the design of new roads and for the design of the total or partial reconstruction of damaged existing roads (Black, 1979).

The strength of subgrade soil for highways and airports is usually expressed in terms of the California Bearing Ratio (CBR).

In foundation design, the bearing capacity of the soil is usually of great concern.

Due to the wide spread of gypsiferous soils in the Middle East (Fookes 1976, 1978; Fookes and French, 1977; Tomlinson, 1979; Razouki and El-Janabi, 1999) the present paper is devoted to such soils.

2 SOIL PROPERTIES

To have complete information about the properties of the gypsiferous soil under study, chemical and physical tests are carried out on it. They indicate that the soil is sandy lean clay of CL group according to the Unified Soil Classification System. The soil contains about 35% total soluble salts (TSS) and about 33% gypsum content.

To arrive at the type and amount of each clayey mineral present in soil tested, a quantitative X-ray diffraction analysis (Mitchell, 1976) was carried out on the clayey fraction of the soil sample. The test results reveal that the tested soil consists of 6% montmorillonite, 7% kaolinite, 17% palygorskite and illite and 2% mixed layer.

In order to obtain the moisture-density relations for the modified Proctor compaction tests according to ASTM D 1557 (1989), a mold of 6″ (152.4-mm) internal diameter and 4.584″ (116.43-mm) height is used. The test indicates a maximum dry unit weight of 18.18 kN/m^3 taking place at the optimum moisture content of 11.5%. More details about the mineralogical, physical and chemical properties of the soil are described in Table 1.

Table 1: Classification and properties of tested soils

Soil Classification	Soil Properties	Specifications
Classifications	CL	ASTM D 2487-93
	A-6 (6)	AASHTO T 88-93
<u>Particle size distribution</u> Silt and Clay Fine Sand Coarse Sand	 67.66% 23.66% 8.68%	A ASHTO M 145-86
<u>Consistency limits</u> Liquid Limit Plastic Limit Plasticity Index	 29% 17% 12%	AASHTO T 89-95(a) AASHTO T 90-95(b)
Specific gravity	2.47	B.S. 1377-1990, Test 6 (B) with white spirit instead of water
Modified AASHTO Compaction $\gamma_{d\,max}$ OMC	 18.18 (k N/m^3) 11.5%	AASHTO T 180-95(c)
<u>Chemical Tests</u> Initial T.S.S. Initial Gypsum Content	 35.1% 33%	U.S. Earth Manual (1980) at dilution of 1:200 From Sulphate (SO_3)
<u>X-ray analysis</u> Montmorillonite Kaolinite Illite & Palygorskite	 6% 7% 17%	X-ray diffraction analysis with 2 °/min scan speed

3 SAMPLE PREPARATION AND TESTING PROGRAM

Due to the fact that the bearing capacity of the soil as well as the CBR depend on relative compaction of the soil, three compactive efforts were chosen by changing the number of blows per layer of the soil sample compacted in 5 layers in the CBR mould by 10 lbs (4.54 kg) hammer falling from 18" (45.7 cm) height. The number of blows adopted in this study and the corresponding compactive efforts are shown in Table 2, where

$$CE = \frac{W \times H \times N_b \times N_l}{V} \tag{1}$$

where:

CE= Compactive effort, $CE_{Proctor}$= Proctor compactive effort, W = Weight of hammer,
H = Height of drop of hammer, N_b = Number of blows per layer, N_l = Number of layers,
V = Volume of compacted soil.

The smallest compactive effort corresponding to 12 blows per layer used in this study represents almost the compactive effort corresponding to standard AASHTO compaction (standard Proctor).

The compactive effort corresponding to 56 blows per layer represents the modified AASHTO compaction.

Table 2: Chosen compactive efforts

No. of blows/ layer	Compactive effort, CE (kN. m / m^3)	CE /$CE_{Proctor}$
12	586	$0.98 \approx 1$
25	1221	2
56	2735	4.56

For the purpose of this work, it was decided to use a surcharge load of 40 lbs (178 N) in CBR test that represents an average flexible highway pavement thickness of 50 cm. The effect of surcharge load on the CBR can be taken into consideration using Razouki and Al-Shefi (2002) approach.

Due to the fact that gypsiferous soils can be subjected to infiltration of rain water or tap water from irrigation or leaky water pipes, it is necessary to simulate this in the laboratory.

In the CBR test, long-term soaking of samples can take care of this fact.

To avoid full saturation of water in soaking tanks with gypsum, it is necessary to change their water continuously. Day (1992) reported that the amount of swell of soil samples could be affected by the type of water the soil is submerged in. According to Ismael and Mollah (1998) tap water is more convenient to use in leaching of gypsiferous soil samples and it is similar to ground water in the field. Therefore, tap water is used in soaking of CBR soil samples used in this study.

Thirty six CBR samples were prepared at optimum moisture content of the modified AASHTO compaction test namely 11.5% at compactive efforts of 1, 2 and 4.56 times that of the Proctor compaction. These samples were soaked for 0, 4, 7, 15, 30, and 120 days under the effect of 40 lbs (178 N) surcharge load. Note that for each soaking period, 8 CBR soil samples were prepared two for each compactive effort (one of these two CBR samples was used to determine the CBR value and the other one to extrude UU triaxial soil samples for the determination of the corresponding values of cohesion and angle of internal friction).

4 ULTIMATE BEARING CAPACITY

The bearing capacity of a soil is a direct measure of the resistance of the soil to lateral displacement, and since the CBR test was designed to measure this property, some degree of correlation would be expected (Black, 1962).

The Terzaghi's bearing capacity equation for circular foundation under centric loading, as given by Bowles (1988) is

$$q_u = 1.3\ c\ N_C + p_o\ N_q + 0.3\ \gamma\ B\ N_\gamma \quad (2)$$

where:

q_u = Terzaghi's ultimate bearing capacity, c= Soil cohesion, γ= Unit weight of soil (when the water table is above the underside of the footing the submerged unit weight γ' has to be used instead of γ), p_o= Overburden pressure at the base of the footing, B= Diameter of the footing, N_c, N_q and N_γ= Terzaghi bearing capacity factors.

For the case of CBR test, B= diameter of the plunger = 1.954"=4.963 cm, p_o= overburden pressure due to surcharge load.

Equation (2) was used to estimate the ultimate bearing capacity of the tested soil when compacted at OMC of 11.5% under the effect of 56, 25 and 12 blows/layer and soaked for 0, 4, 7, 15, 30 and 120 days.

Table 3 shows a sample of calculation of the ultimate bearing capacity making use of the values of ø and c determined from UU triaxial tests together with the corresponding values of the unit weight and Terzaghi bearing capacity factors as given by Terzaghi & Peck (1967). The effect of compactive effort on the ultimate bearing capacity of the tested soil compacted at the OMC is shown in Figure (1).

Table 3: Terzaghi ultimate bearing capacity for unsoaked soil samples compacted at OMC

Compactive effort (blows/layer)	Ø * (degrees)	c * (kPa)	N_c	N_q	N_γ	q_u ** (kPa)
56	27	150	29.32	15.94	15	5894.07
25	25	135	25.20	12.75	10	4563.76
12	22	90	20.32	9.21	6	2478.96

** Determined from UU (Unconsolidated Undrained) triaxial tests on samples extruded from CBR soil samples soaked for different soaking periods under the effect of 40 lbs (178 N) surcharge load.

* See eq. (2)

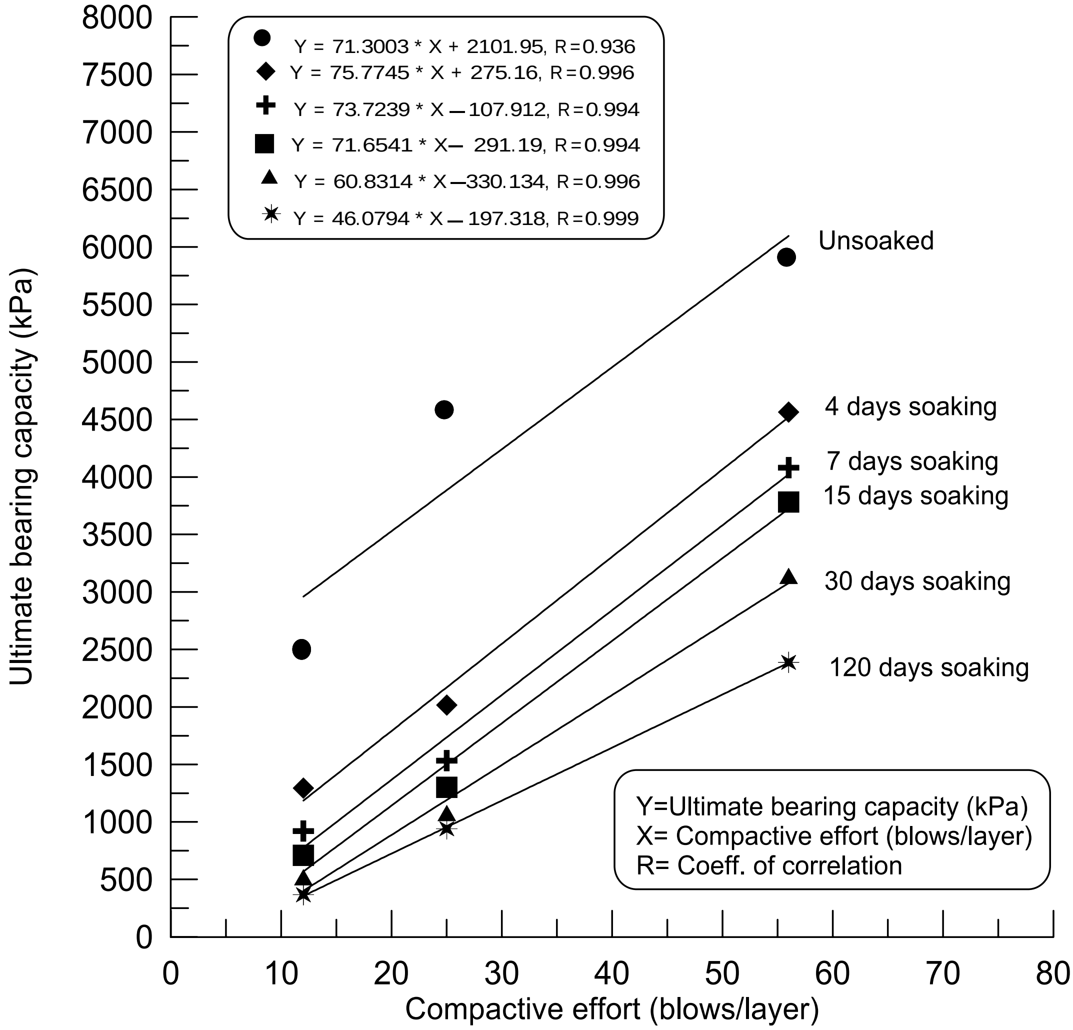

Figure 1: Effect of compactive effort on the ultimate bearing capacity of soil samples compacted at OMC for different soaking periods

It is apparent from this figure that the ultimate bearing capacity of the tested soil increases with increasing compactive effort and decreases with increasing soaking period.

Figure 1 reveals also that for the unsoaked conditions, the increase in the compactive effort from 12 blows/layer to 56 blows/layer causes a significant increase in the ultimate bearing capacity from 2478.96 kPa to 5894.07 kPa (about 2.4 fold increase). For 120 days soaking, the ultimate bearing capacity increased from 365.63 kPa to 2387.32 kPa (about 6.5 fold increase) when increasing the compactive effort from 12 to 56 blows/layer. This means that the effect of compactive effort becomes more pronounced as the soaking period increases.

Figures 2 shows the effect of soaking period on the ultimate bearing capacity for samples compacted at OMC. It is apparent from this figure that the ultimate bearing capacity of the tested soil at 120 days soaking is 28.3%, 46.6% and 52% relative to that for 4 days soaking for the compactive efforts of 12, 25 and 56 blows/layer respectively, indicating a significant decrease in strength with soaking time which is in full agreement with Razouki and El-Janabi (1999) and Razouki and Kuttah (2004). Accordingly, the use of the common 4 days soaking is not recommended for gypsiferous soils as it leads to serious overestimation of soil strength.

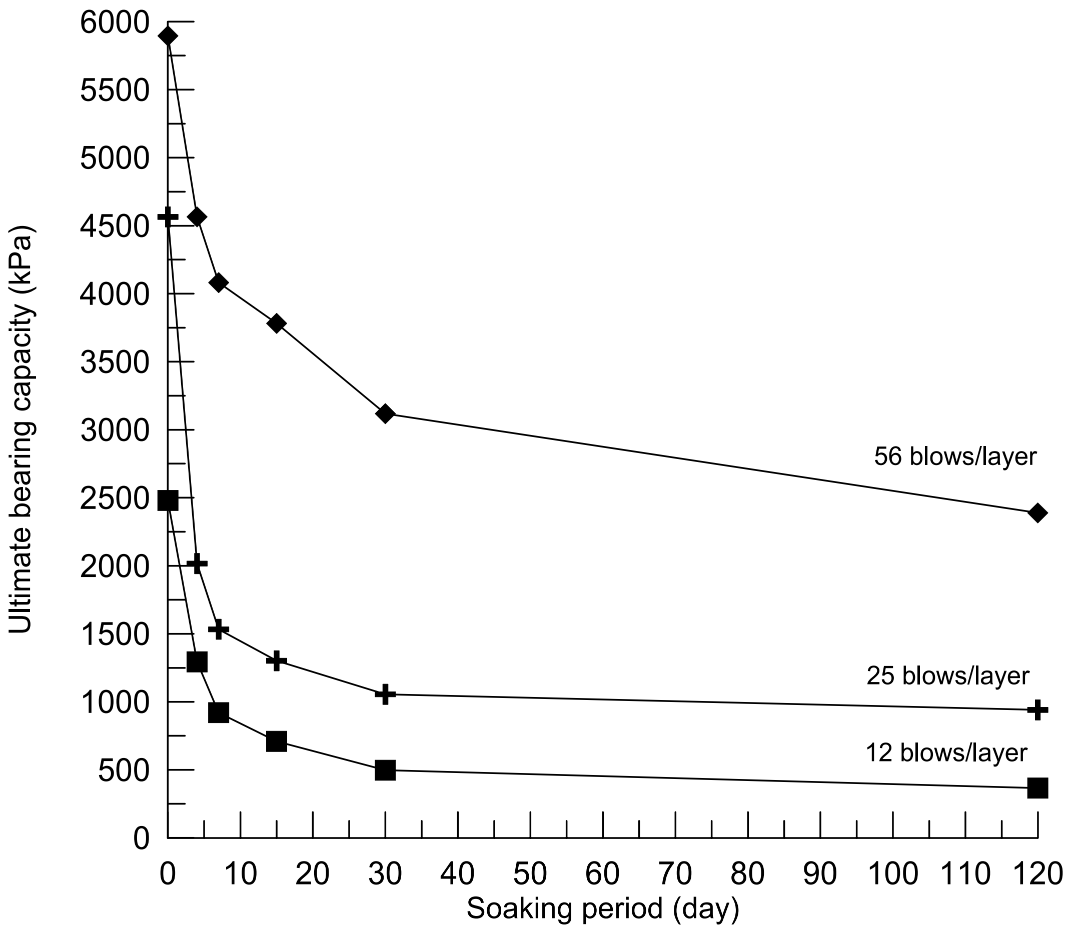

Figure 2: Effect of soaking period on the ultimate bearing capacity of soil samples compacted at the OMC for different compactive efforts

5 CORRELATION BETWEEN CBR AND ULTIMATE BEARING CAPACITY

To enable the engineer to estimate the ultimate bearing capacity of soils (similar to that tested) from the CBR (California Bearing Ratio) value for design purposes, a relationship between the ultimate bearing capacity and CBR is required. Figure 3 shows the correlation between the ultimate bearing capacity of the tested soil versus the CBR for soil samples compacted at OMC of 11.5%.

The use of linear regression analysis yields the following regression equation correlating the ultimate bearing capacity of the tested soil with the CBR:

$$q_u = 172.6\,(CBR) - 601 \qquad \text{for } CBR > 5\% \qquad (3)$$

where:

qu = Ultimate bearing capacity in (kPa)
CBR= California bearing ratio in (%)

Equation 3 represents strong correlation after Anderson and Sclove (1978) due to the high correlation coefficient of R=0.944.

Rosenak (1968) assumed that the bearing capacity is in direct correlation with the CBR of the soil as shown below:

$$q_u \text{ (psi)} = 10 \text{ CBR} \tag{4 a}$$

$$q_u \text{ (kPa)} = 68.89 \text{ CBR} \tag{4 b}$$

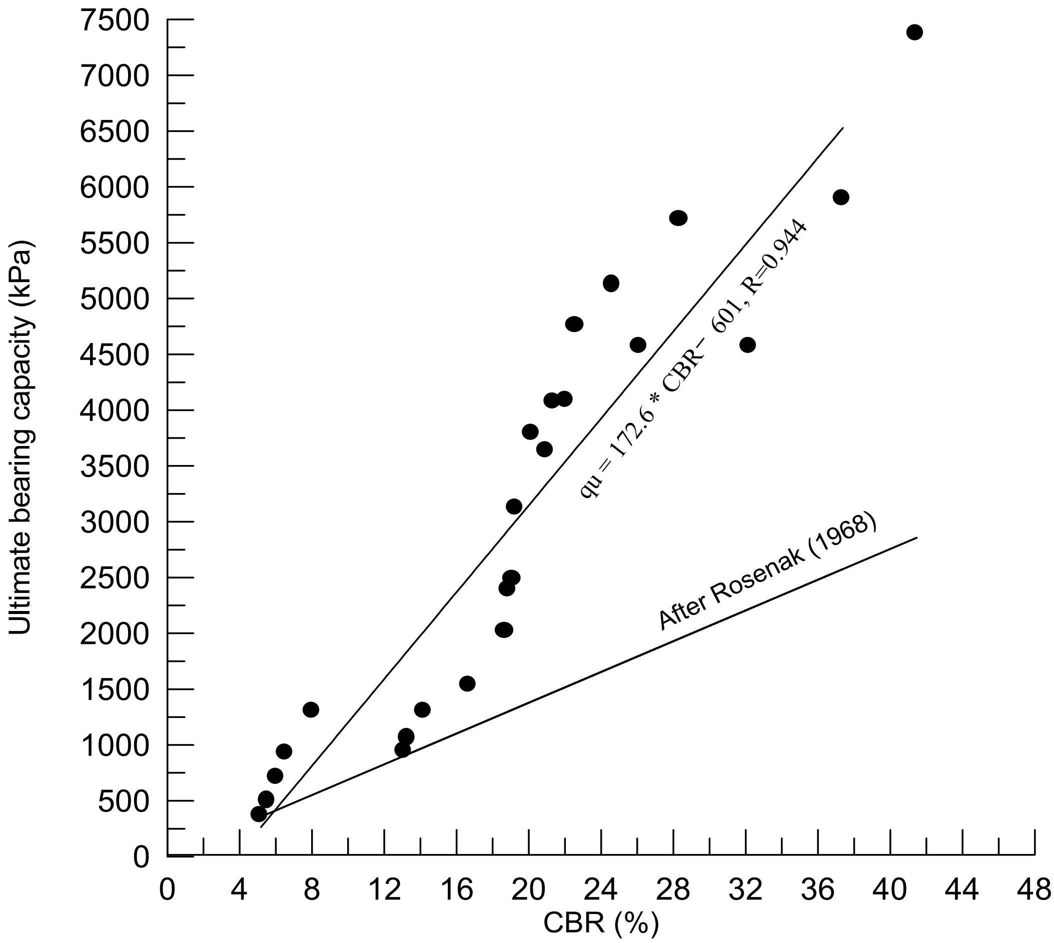

Figure 3: Correlation between the ultimate bearing capacity and CBR of soil samples compacted at the OMC

Figure (3) shows a comparison of the relationship obtained in the work between the Ultimate bearing capacity and the CBR of the tested soil with that of Rosenak (1968). It is obvious from this figure that the equation suggested by Rosenak (1968) underestimates significantly the ultimate bearing capacity especially for the higher CBR values.

6 CONCLUSIONS

Based on this study carried out on an A-6 (6) gypsiferous soil after the AASHTO soil classification system and sandy lean clay after the Unified Soil Classification system with 33% gypsum content, the following conclusions can be obtained:

- Upon soaking, a linear increase of the ultimate bearing capacity with increasing compactive effort took place.
- Increasing the compactive effort from 12 to 56 blows/layer causes an increase of 2.3 fold and 6.5 fold in the estimated ultimate bearing capacity for the unsoaked and soaked samples for 120 days respectively, indicating that the effect of compactive effort becomes more pronounced as the soaking period increases.
- There is a significant drop in the ultimate bearing capacity of the tested soil with increasing soaking period. The ultimate bearing capacity of the tested soil at 120 days soaking is 28.3%, 46.6% and 52% relative to that for 4 days soaking for the compactive efforts of 12, 25 and 56 blows/layer respectively
- There is a strong linear correlation between the estimated ultimate bearing capacity and the corresponding CBR value.
- Rosenak (1968) equation underestimates significantly the ultimate bearing capacity especially for the higher CBR values.

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