CORRELATION BETWEEN UNIAXIAL COMPRESSIVE STRENGTH AND MODULUS OF SUBGRADE REACTION FOR COMPACTED CLAY

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1. *Synopsis*

Uniaxial strength predictive equation was developed based on modulus of subgrade reaction for compacted clay in the soil mechanics laboratory. The results of a large number of compacted clay samples with different densities and moisture contents were carried out by the authors. The results were estimated using the linear regression analysis. Approximately 300 experiments were carried out in order to find the correlation between compressive stress and modulus of subgrade reaction. It was found that for compacted clay, the relationship between the uniaxial strength and the modulus of subgrade reaction for both 3 cm diameter footing and 5 cm diameter footing was highly correlated. The Oedometer tests yield valuable results for the prediction and calculation of the modulus of subgrade reaction. It was also found that, the relationship between the modulus of subgrade reaction for both 3 cm diameter footing and 5 cm diameter footing was strongly correlated. Formulas related to the uniaxial strength and the modulus of subgrade reaction were predicted. These formulas were compared to similar formulas published in other literature. Corresponding graphs to explain all results were plotted.

2. *Introduction*

The term modulus of subgrade reaction (K_s) indicates a relation between the pressure (P) on the surface of content between a loaded footing and the subgrade on which it rests, and the corresponding settlement (S), where:

$$K_s = \frac{P}{S} \qquad (1)$$

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The value of (K_s) depends on the elastic properties of the subgrade and on the dimensions of the area acted upon by the subgrade reaction. In comman practice (K_s) is determined by the plate load test. Terzaghi (1967) stated that the influence of the dimensions of the area acted by the subgrade reaction on the value of modulus of subgrade reaction varied widely and in many instances and the exsistance of this influence had been ignored. Therefore the errors involved in the application of the theory of subgrade reaction to the solution of engineering problems had often been very great.

Several researchers pointed out that (K_s) should be considered variable, depending on stress level e.g. Bowels (1988). Dembicki (1981) mentioned that the relative spacing of foundations influenced the modulus of subgrade reaction. The smaller the relative spacing the higher was bearing capacity of the soil carrying surface foundation.

Behooper (1989) showed that for clayey and silty clay soils the Standard Penetration Test yiels important conclusions for estimating the modulus of subgrade reaction and strength. It was also concluded that the general pessimistic view of applicability of STP to cohesive soil is not warranted. For clayey and silty clay soils tested, the modulus of subgrade reaction and strength were highly correlated with Standard Penetration Tests.

Correlation between strength and modulus of subgrade reaction was considered by Hanthequeste (1989), Harvath (1984), Martak (1981) and Stroud and Butler (1975). Slight differences between these correlations resulted from the fact that different footing diameters and different soil densities were adopted. Carrying out more tests are preferred in order to enhance the predicted equations for correlating the uniaxial strength and the modulus of subgrade reaction. Consequently these equations should become more accurate.

For footings resting on clay, the modulus of subgrade reaction can be evaluated from the relation:

$$K_s = K_1 \, . \, B \qquad (2)$$

where:

K_s = Modulus of subgrade reaction for footing with width B.

K_1 = Modulus of subgrade reaction from a 30 x 30 cm square plate load test.

The values in equation (2) are valid for contact pressure which are smaller than one-half of the ultimate unite bearing capacity of the clay. For normally consolidated clays, the values of modulus of subgrade reaction are so small that the bending moments in loaded foundations should be computed on the assumption that the load supporting structure is rigid.

Recent researchs in the field of soil-structure interaction using computers involve incorporation of the modulus of subgrade reaction, whether in a simple constant form, or stress dependent variable form. For expansive clays, the challenge of solving foundations resting directly on these clays is under taken by several researchers e.g. Mansour (1990). Making reasonable estimation for the modulus of subgrade reaction is a traditional goal. Formulas has been developed for such estimates based on other soil properties.

The aim of this research is to investigate how the modulus of subgrade reaction can be estimated for compacted swelling clay. Two model footing with different dimensions are tested as plate load tests. The relationship between the uniaxial compressive strength and the modulus of subgrade reaction for both 3 cm diameter footing and the 5 cm diameter footing is obtained using the regression analysis.

3. Experimental Work

The tests were performed in the Soil Mechanics Laboratory, Faculty of Engineering and Technology at Matareia, University of Helwan.

3.1 Material Characteristics

The samples used in this research are yellow-green clay from Elmokatam, Cairo.
Their principal characteristics are summarized as below:

Sand	0%
Silt	76%
Clay	24%
Type of soil according Unified Classification	CH
Liquid limit	64%
Plastic limit	33%
Plasticity Index	31%
Specific gravity	2.74
Natural water content	6.50%

3.2 Modulus of Subgrade Reaction Tests

The tested soil samples were compacted in steel ring 14 cm diameter and 5 cm high. The ring with the soil was placed on a base, then loaded in the consolidation loading frame. Samples were prepared at different water contents of 5%, 10%, 15% and 20% and at different densities equal to 1.5 t/m^3, 1.6 t/m^3, 1.8 t/m^3 and 2.0 t/m^3. All samples were loaded by model footings and the contact pressures used were 2 kg/cm^2, 5 kg/cm^2, 10 kg/cm^2 15 kg/cm^2 and 20 kg/cm^2. The footing diameters used in this research were equal to 3 cm and 5 cm. The resulting settlement was measured and the modulus of subgrade reaction was calculated.

3.3. Uniaxial Strength Tests

Uniaxial strength tests were run on 6 cm diameter and 12 cm high specimens of the soil samples. These samples were compacted at the different densities and different water content as given above. All tests were run with the same loading rate of 1 mm/min. The load at failure was registered and the area at failure was calculated. The uniaxial compressive strength was determined.

4. *Analysis of Test Results and Discussion*

From the loading tests, diagrams showing the relationship between the average contact stress and settlement were plotted for different densities and water contents for both 3 cm and 5 cm diameter footings. This is shown in figures (1) and (2). From these figures it was noticed that the minimum settlement occurred at maximum density equal to 2/tm^3, minimum water content of 5% for the 5 cm diameter footing.

Figures (3) and (4) show the relationship between the modulus of subgrade reaction (K_s) and average contact stress at different water contents, different densities and different footing diameters. From these figures it is shown that the modulus of subgrade reaction increases with increasing the contact average stress. The maximum modulus of subgrade reaction occurred at maximum density and minimum water content. Increasing footing dimensions led to increase of the modulus of subgrade reaction.

Figure (5) shows the relation between uniaxial compressive stength and density at different water contents. The uniaxial compressive strength increases with increasing the density and decreasing the water content.

Figure (6) shows the relation between the modulus of subgrade reaction for 5 cm and 3 cm footing diameters for the soil samples at different densities, water contents and average contact stress. Linear regression lines relating the variables, lines enclosing 95% of data points and number of data points are shown. The correlation shown in this figure indicates that the correlation factor is about 88%.

Using the results shown in figure (6), the relation between (K_s) values for the tested plates 5 and 3 cm diameters is:

$$(K_s)_5 = 1.377 \quad (K_s)_3 \tag{3}$$

where:

$(K_s)_5$ = modulus of subgrade reaction for 5 cm footing diameter.

$(K_s)_3$ = modulus of subgrade reaction for 3 cm footing diameter.

The obtained factor 1.377 is slightly different from that which is directly obtained from equation (2) which yields 1.67.

The correlations between modulus of subgrade reaction and uniaxial compressive strength are present in figures (7) and (8). On each figure a linear regression line and a line enclosing 95% of data points are plotted. From these figures it is seen that the correlation between uniaxial compressive strength and modulus of subgrade reaction depends on the diameter of footing. The following relations are obtained:

$$(K_s)_5 = 40\ q_{un} \tag{4}$$

$$(K_s)_3 = 28.6\ q_{un} \tag{5}$$

The ratio $(K_s)_5$ / $(K_s)_3$ is 1.39 . This is slightly different from that indicated by equation (2). Therefore, $(K_s)_{30}$, the conventional modulus of subgrade reaction obtained for plate 30 cm diameter, which is used in structural analyses after correction for footing size can be estimated as follows:

$$(K_s)_{30} = 240\ q_{un}, \text{ or}$$
$$(K_s)_{30} = 286\ q_{un}$$

It is suggested to used an average correlation coefficient of 260 to obtain $(K_s)_{30}$ from the uniaxial strength of compated expansive clay.

5. *Conclusions*

This research shows that uniaxial compressive strength can be used to estimate the modulus of subgrade reaction for compacted expansive clay. The modulus of subgrade reaction for 3 and 5 cm footing diameters were highly correlated. The correlations between uniaxial compressive strength and modulus of subgrade reaction are presented for these plates from which a correlation factor to obtained the modulus of subgrade reaction for the conventional 30 cm diameter plate from uniaxial strength tests is obtained.

6. *References*

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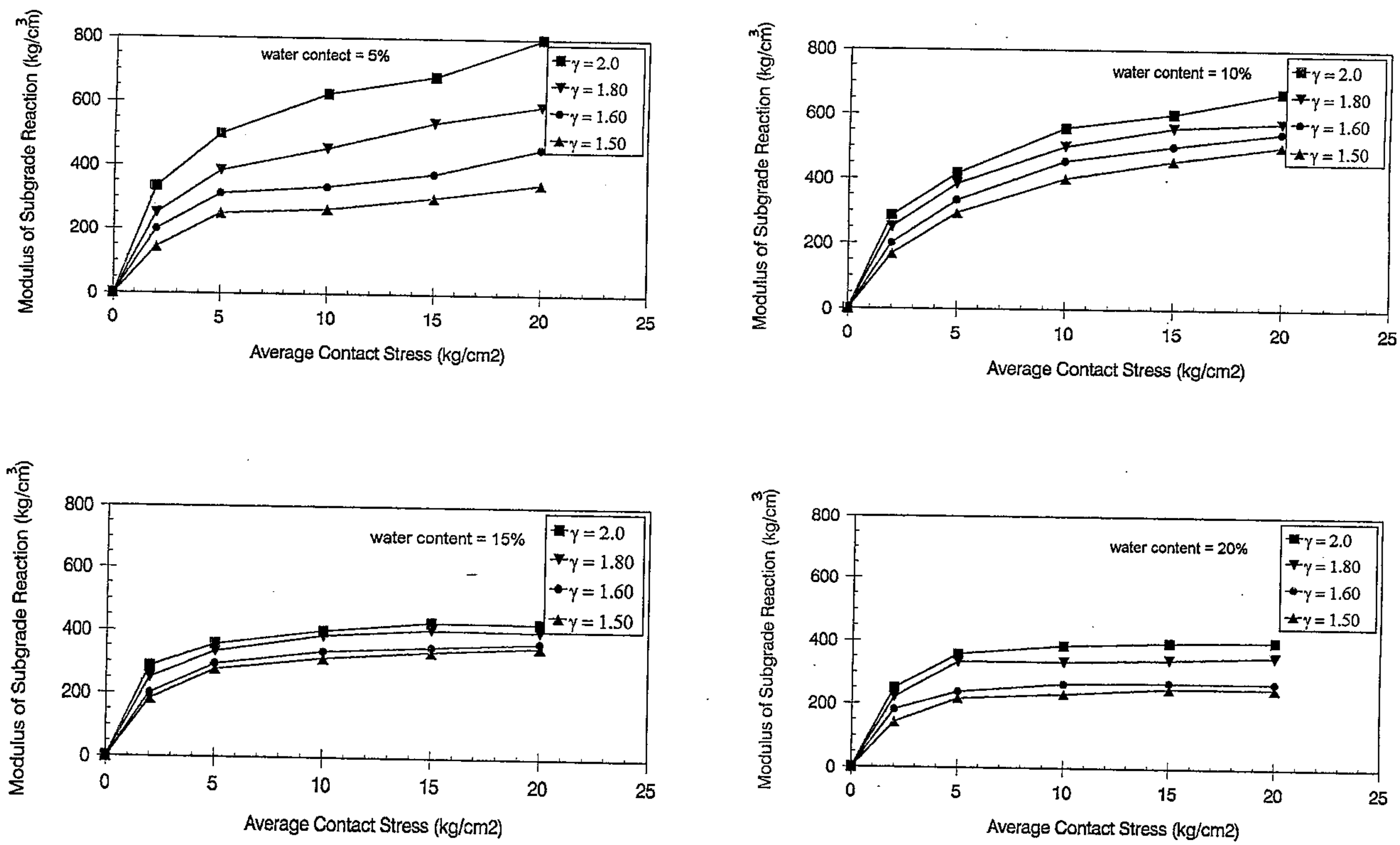

Figure (4) Relation Between Average Contact Stress and Modulus of Subgrade Reaction for (D = 5cm)

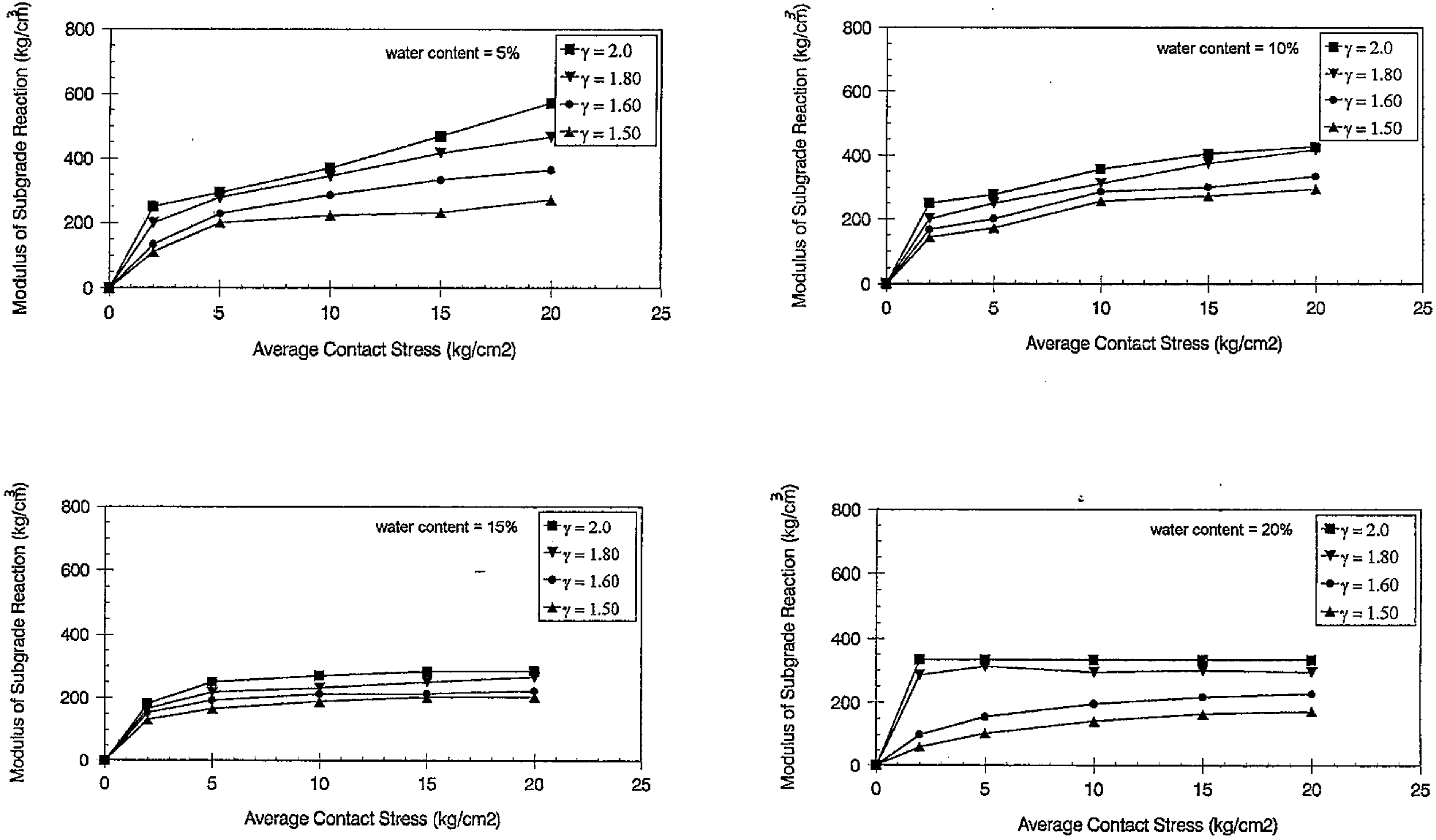

Figure (3) Relation Between Average Contact Stress and Modulus of Subgrade Reaction for (D = 3cm)

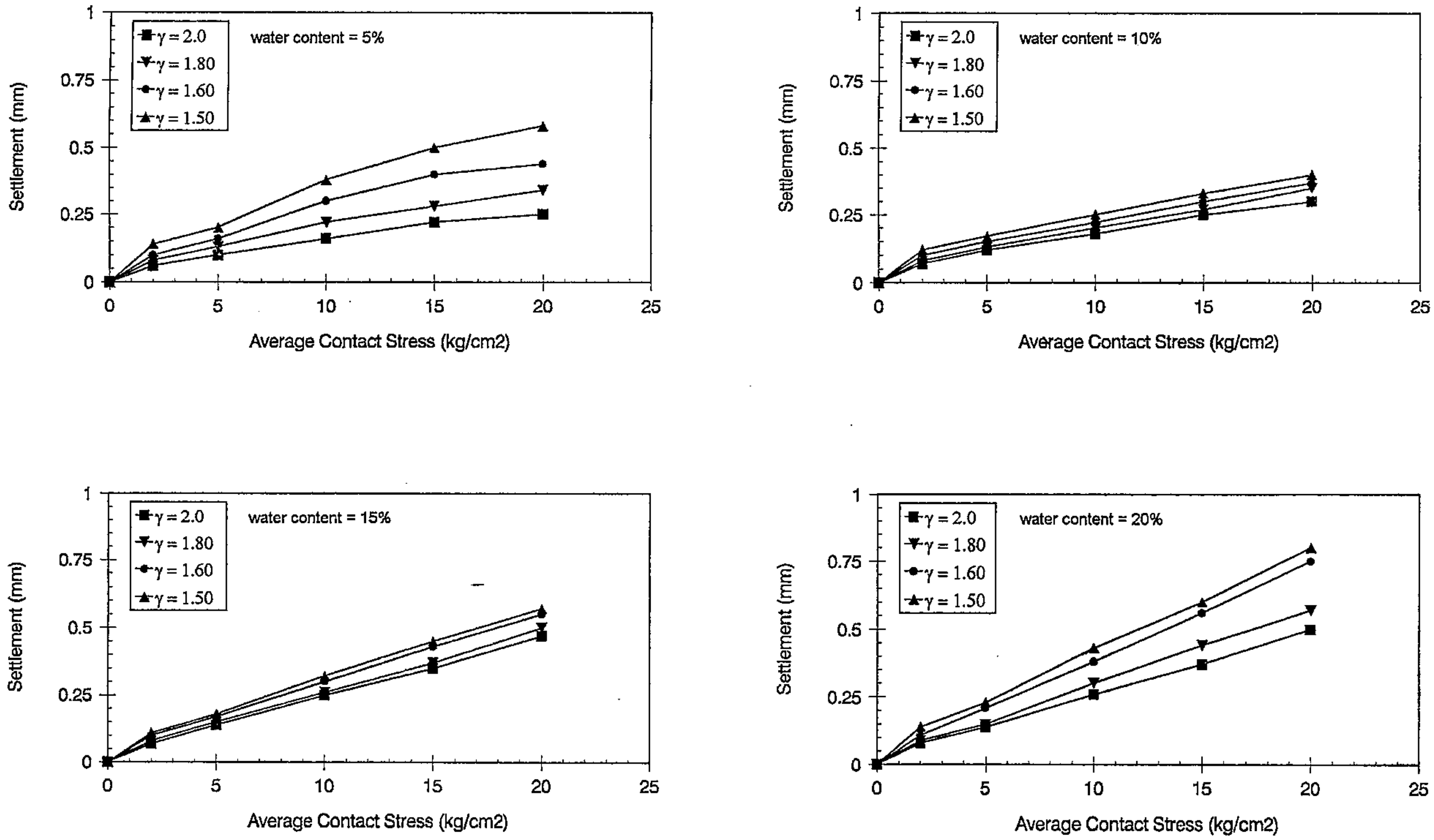

Figure (2) Relation Between Average Contact Stress and Settlement for (D = 5 cm)

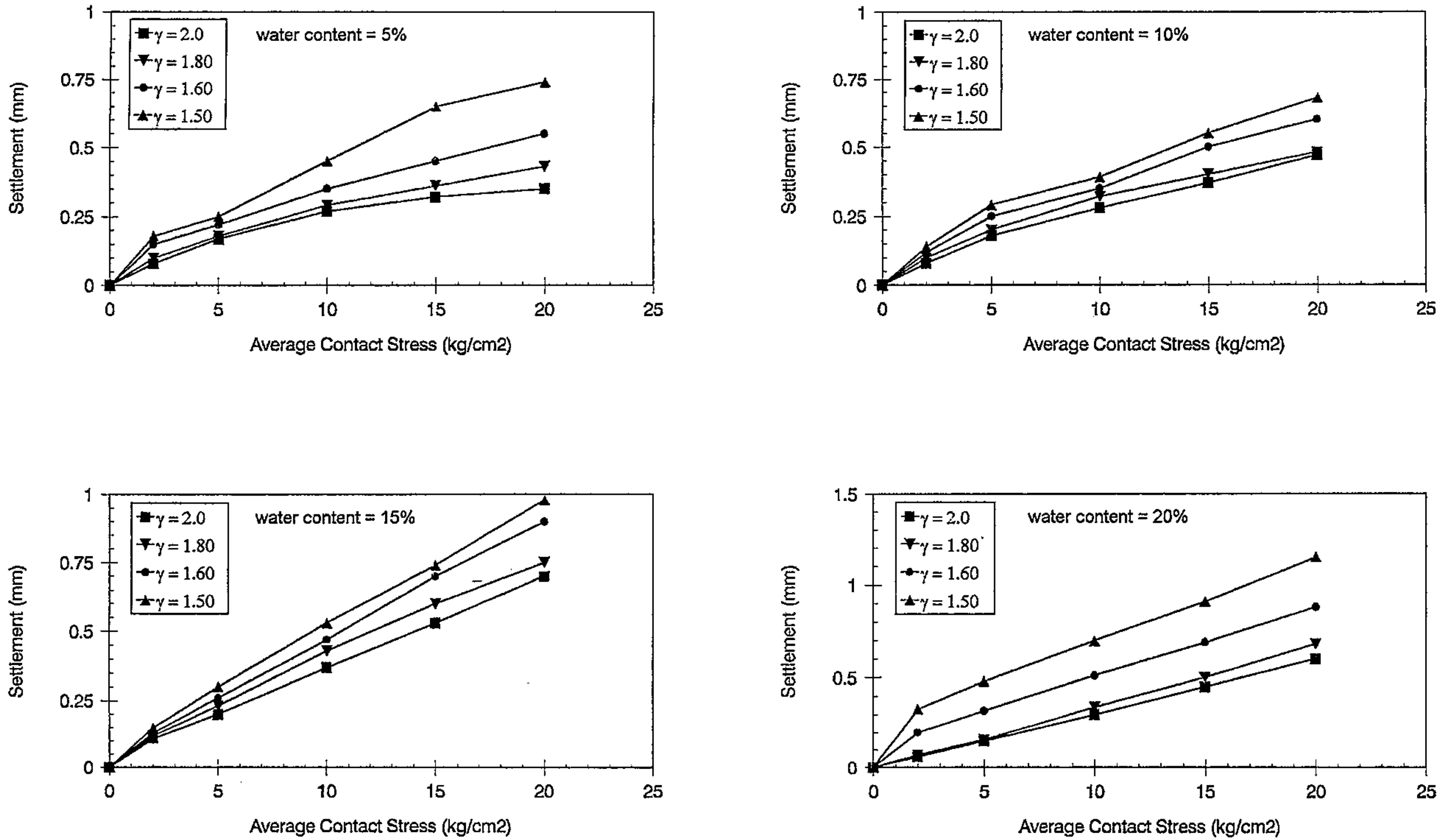

Figure (1) Relation Between Average Contact Stress and Settlement for (D = 3 cm)

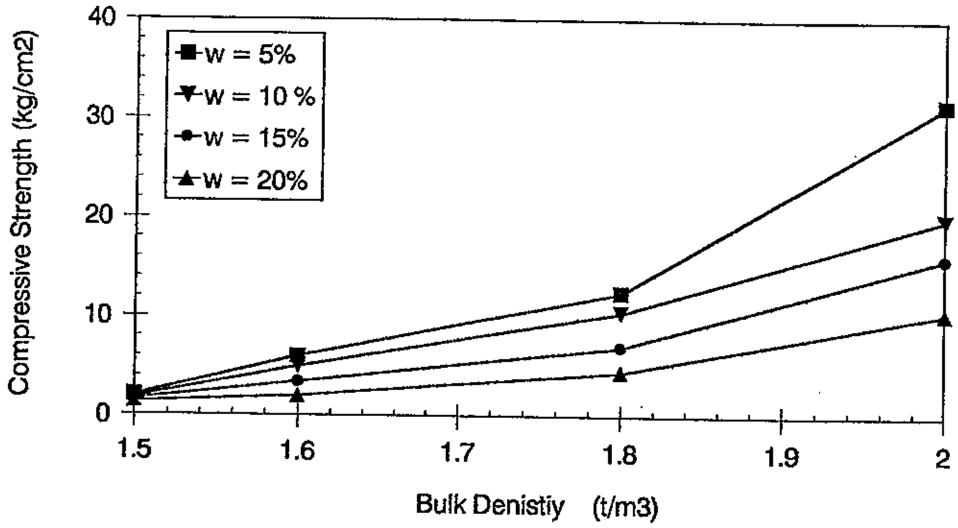

Figure (5) Relation Between Unaxial Compressive Strength and Density

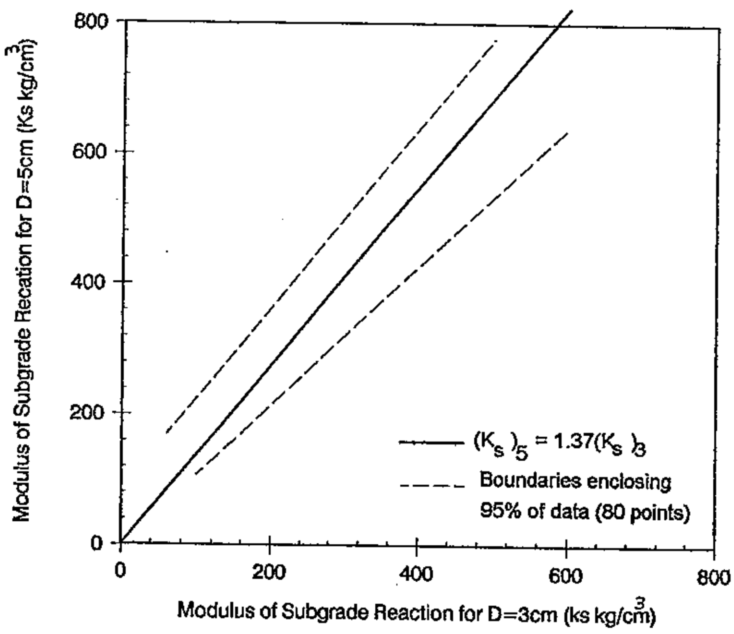

Figure (6) Correlation of Modulus of Subgrade Reaction
for D = 3 cm and D = 5 cm

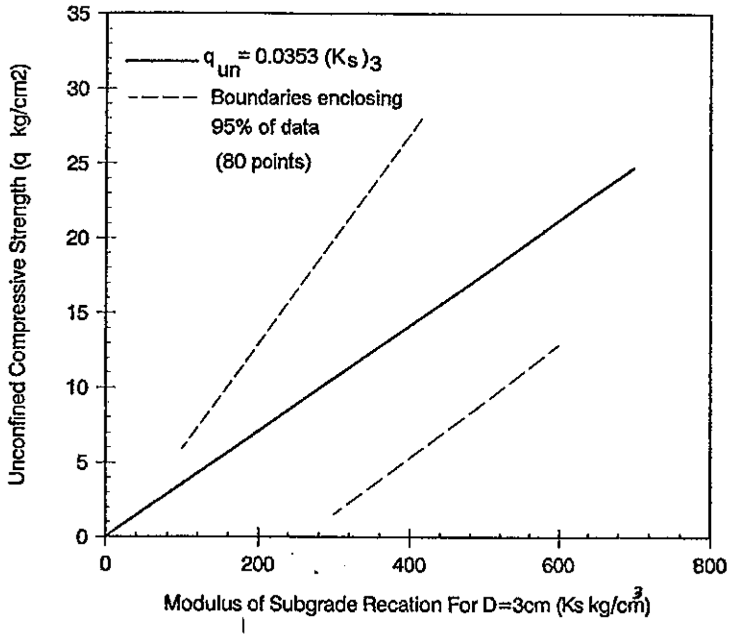

Figure (7) Correlation Between Unaxial Compressive Strength and Modulus of Subgrade Reaction for D = 3 cm

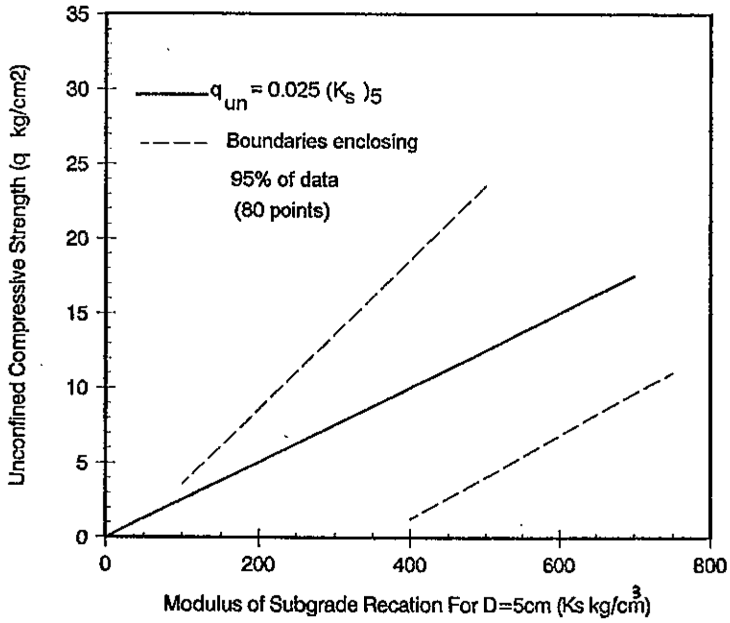

Figure (8) Correlation Between Unaxial Compressive Strength and Modulus of Subgrade Reaction for D = 5 cm