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LONG – TERM SOAKING EFFECT ON STRENGTH AND DEFORMATION CHARACTERISTICS OF A GYPSIFEROUS SUBGRADE SOIL

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ABSTRACT

The behaviour during long-term soaking of the California Bearing Ratio (CBR), the resilient modulus and the deformation of compacted Iraqi gypsiferous soil containing about 34% gypsum was studied. Sixteen (CBR) samples compacted at optimum moisture content and 95% of the maximum dry density of the modified AASHTO compaction test were prepared. Two samples each were soaked for periods of 0,4,7,15,30,60,120 and 180 days with 40 lb (178 N) surcharge load. The tests revealed that the soil swelled initially then it started to settle and the settlement process continued at a slow rate even after 180 days soaking. Directly after soaking and before carrying out the load-penetration test, each sample was subjected to a compressive wave as well as to a shear wave using the ultrasonic pulse velocity technique. The seismic determination of the shear and compression wave velocities allowed a good estimate of the resilient modulus of the gypsiferous soil tested. After the seismic test, the CBR test was completed and the TSS and gypsum content was determined. The tests revealed a marked drop in CBR and to a lesser extent in the resilient modulus M_R with soaking period. The loss in CBR and M_R took place at a high rate within the first week and at a decreased rate thereafter so that the soil strength became almost constant after about six months. The decrease of total soluble salts and gypsum content in soils with a longer soaking period is in full agreement with the loss in CBR and M_R with soaking. The paper reveals that a soaking period of four days can lead to misleading and unsafe results regarding strength, stiffness and deformation of gypsiferous soils.

Keywords: California bearing ratio; deformation; engineering properties; highways; saturation.

I. INTRODUCTION

In the last two decades, there has been a rapidly expanding road construction programs in the Middle East and in many of the world's hot desert regions where evaporation exceeds precipitation. To minimize the construction cost for road projects in such regions, the use of locally available materials will always be a necessary task of highway engineers.

Soil is the foundation material for all highway and airfield pavements .It may be in the from of in – situ subgrade or transported and reworked fill material.

Due to the wide extent of salt – bearing soils in the Middle East (Fookes and French 1977 ; Fookes 1978 ; Fookes et al .1985) , they have been used extensively in road construction both as general embankment material and subbase material (Tomlinson 1978 ; Subhi 1987). Stipho (1986) reported that the successful use of saline soils (Sabkha) for the construction of roads is based on the condition that they are kept free of moisture. Investigations of road constructed on such soils containing excessive amounts of total soluble salt revealed serious pavement cracking and differential settlement (Ahmed 1985; Subhi 1987; Razouki et al.1994).

There are many situations where the ground water table is very high or the subgrade soil is subjected to long-term flood or soaking. In situations where ground water flow is significant, the dissolution of total soluble salt in the subgrade can lead to serious volume changes leading to loss of strength (Razouki and El-Janabi 1998). This can result in severe pavement distress under the common heavy axle loads and their high number of repetitions (Razouki et al. 1982; Pearson-Kirk 1989; Razouki and Razouki 1993).

II. GYPSUM IN SOIL

In most regions of the world, natural soil and aggregates contain varying quantities of soluble salts (Blight 1976). Gypsum is one of these salts, which has a detrimental effect on pavement and earth structures. When the soil is dry, gypsum present in the soil acts as a cementing agent. However, the intrusion of water through rainfall, a rise in the ground water table or leakage through canal linings may result in dissolution of gypsum and softening of gypsiferous soils that can lead to serious damage and even collapse of structures founded on or in such soils (Razouki et al. 1994). Following Subhi (1987), the main composition of soluble salts in Iraqi soils is gypsum with a content varying between (0-80)%. For this reason, there is a great need for studying the strength and deformation characteristics of gypsiferous soil not only in Iraq but also in the whole Middle East.

According to Klein and Hurlbut (1985), gypsum $CaSO_4$.- $2H_2O$ is the most important and abundant hydrous sulphate . As a result of dehydration of gypsum, the first 1.5 molecules of water in gypsum are lost relatively continuously between (0^oC) and ($65\ ^oC$) leading to bassanite $CaSO_4$. ½ H_2O. At about 70 ^oC, the remaining ½ H_2O. molecule in bassanite is still retained relatively strongly but at about ($95\ ^oC$) it is lost and the structure transforms to that of anhydrite $CaSO_4$

Freeze and Cheery (1979) reported that the solubility of gypsum in pure water at ($25\ ^oC$) , a total pressure of 1 bar and at a pH value of 7, is 2.1 kg/m^3. However, James and Kirkpatrick (1980) pointed out that the solubility of gypsum, anhydrite and halite in pure water at ($10\ ^oC$) are 2.5, 2.0 and 360 kg/m^3 respectively.

According to James and Lupton (1978), the solution rate of gypsum depends on the concentration of salts in solution, flow rate and temperature. This rate increases linearly as the flow velocity increases and as the concentration of sodium chloride increases.

III. PROPERTIES OF GYPSIFEROUS SOIL TESTED

The gypsiferous soil of this work was obtained from a region near Baghdad. To arrive at the chemical properties of this soil, the total soluble salt (TSS) was determined on samples at various dilution ratios. It was found that a dilution ratio of 1:250 was sufficient for complete dissolution of (TSS) present in the soil which was about 36%. The sulphate content of the soil was determined in accordance with BS 1377 (1990). The sulphate content as SO_3 was 15.78 % and hence by calculation, the gypsum content was estimated as 33.92% of the dry weight of soil. Accordingly, the gypsum content was about 94.3% of TSS indicating that nearly all of the total soluble salt in the soil tested is gypsum.

To arrive at the physical properties of the soil tested, various standard tests were carried out to determine the particle size distribution, plasticity, specific gravity and compaction characteristics of the soil. Figure 1 shows the particle size distribution, plasticity i.e. liquid limit (LL) and plasticity index (PI), specific gravity and compaction characterstics of the soil.

According to the British soil classification system for engineering purposes (B.S 5930 :1981), the soil tested is a well graded silty sand SWM. Using the unified soil classification system (ASTM D2487-85), the soil is well-graded sand with silt (SW-SM). Note that according to the AASHTO soil classification system (M 145-82), the soil is A-2-4 (O).

Figure 2 shows the compaction characteristics of the soil tested. It is quite obvious from this figure that the maximum modified AASHTO dry density (equivalent to that of the B.S. heavy compaction test) of 18.2 kN/m^3 took place at an optimum moisture content of 12%.

IV. SUBGRADE SOIL STRENGTH

The strength of subgrade soils for highways and airports is usually expressed in terms of the California bearing ratio (CBR) or the resilient modulus (dynamic elastic modulus M_R). Hight and Stevens (1982) pointed out that the CBR is an index of the strength and stiffness of a subgrade soil.

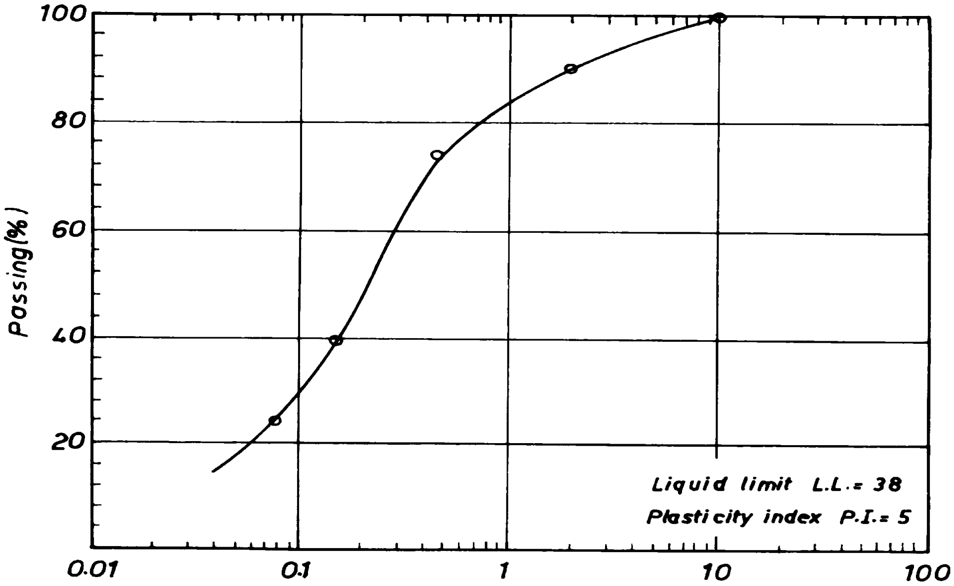

Fig. (1) Particle size distribution of gypsiferous soil tested

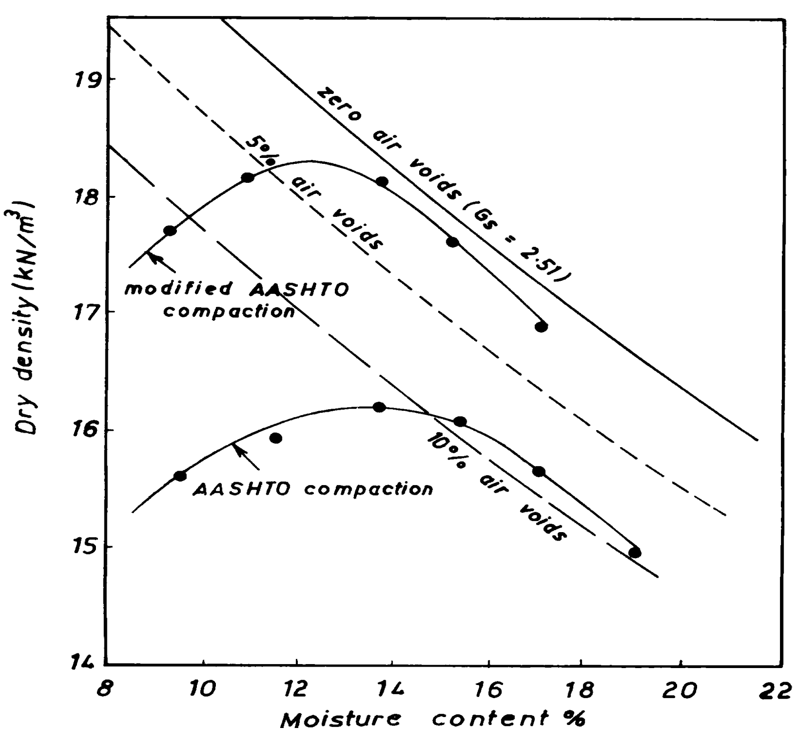

Fig. (2) Compaction curves of gypsiferous soil tested

The resilient modulus is a measure of the elastic property of soil that recognizes certain nonlinear characteristics. The test is conducted in a triaxial device equipped for repetitive load conditions as described in AASHTO test method T 274. However, the laboratory equipment for this test is both expensive and complex and many agencies do not have resilient modulus equipment (AASHTO Guide 1986, The Asphalt Institute 1981). Due to this fact, the resilient modulus is estimated from either correlation between M_R and CBR or non-destructive tests (Heukelom and Klomp 1962; Kirwan et al. 1982; Brown et.al 1982 ; Powell et al. 1984; AASHTO Guide 1986).

In this work, the ultrasonic pluse velocity technique is used to estimate the resilient modulus of the gypsiferous soil before and after soaking. The new Sonicviewer (Model – 5217 A) testing instrument used in this work consisted of the main device with a CRT display and two pairs of ultrasonic probes (transducers), one pair for P-waves and the other for S-waves (Das 1983).

According to Das (1983), the longitudinal wave velocity of a soil sample confined in a mould is related to its elastic parameters as follows:-

$$V_C = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}} \qquad (1)$$

where :

V_c = compression wave velocity.
E = Young's modulus of elasticity.
ρ = mass density .
μ = Poisson's ratio.

The Poisson's ratio is related to the ratio of compression wave velocity to shear wave velocity as follows (Das 1983).

$$\mu = \frac{1-0.5\left(\frac{V_C}{V_S}\right)^2}{1-\left(\frac{V_C}{V_S}\right)^2} \qquad (2)$$

where :

V_s = shear wave velocity.

Thus both the compression and shear wave velocities are first required. They can be calculated from the corresponding measured times as follows :-

$$V_c = L / t_c \quad , \qquad V_s = L / t_s \qquad (3)$$

where :

L = length of soil sample
t_c ,t_s = transmission time of the pulses through soil sample for compression wave and shear wave respectively.

Once V_c and V_s are known, Poisson's ratio can be obtained from equation (2) and the modulus of elasticity E representing an estimate for the resilient modulus can then be calculated from equation (1).

V. THE CALIFORNIA BEARING RATIO TEST RESULTS

The AASHTO T-193-81 (1986) specification requires usually four days soaking for CBR samples, while soaking is not compulsory in the B.S. 1377 (1990) and ASTM (D 1883 – 87).The soaking test is rather necessary where the subgrade soil will be saturated for at least some of the time.

In the case of highly gypsiferous soils, duration of soaking is of great significance as the dissolution of gypsum is increased the longer the soaking period (Razouki and El-Janabi 1999). To determine the effect of soaking on the strength and deformation characterstics (swelling/ settlement behaviour), sixteen CBR samples were prepared in accordance with ASTM (D-1883 – 87). The samples were compacted to 95% of the maximum modified AASHTO dry density at the optimum moisture content (of 12%) of the modified AASHTO compaction test (modified Proctor or B.S heavy compaction test).

To have a reference CBR, two CBR samples were tested unsoaked under the effect of 40 lb (70 N) surcharge load. The test revealed a relatively high CBR of 56% as the gypsum acts as a good cementing agent under dry conditions.

To determine the effect of long-term soaking on the strength and swelling/settlement characteristics of the gypsiferous soil, it is necessary to avoid full saturation of the water in soaking tank with gypsum. If the concentration of gypsum is allowed to approach the saturated concentration, no further dissolution of gypsum will take place leading to misleading results .

For this reason, the water in soaking tank of this work was changed continuously at a certain rate depending on the volume of water in soaking tank, soaking period and number of samples in the tank (Al-Azawi 1998).

To determine the effect of long-term soaking, seven soaking periods were chosen namely 4,7,15,30,60,120 and 180 days. For each soaking period, a set of two CBR samples was prepared using 40 lb (78 N) surcharge load. Figure 3 shows the decrease in CBR with increasing soaking period. It is quite obvious from this figure that the soaking period has a significant effect on the CBR indicating that the four days soaking period for gypsiferous soil can lead to a serious overestimation of soil strength. The drop in CBR is very sharp initially, after about two weeks becoming less pronounced. The residual CBR values after 30,60 and 180 days soaking period were 39,36 and 32 respectively. Compared to the unsoaked CBR of 56, the soaked strength at 30, 60 and 180 days makes about 70% , 64% and 57% of the unsoaked strength respectively indicating the serious effect of long-term soaking on soil strength. The significant drop in CBR due to long –term soaking is associated with the dissolution of gypsum in water . After the CBR test was finished, each CBR sample was tested for TSS and gypsum content. Figure 4 shows the variation of TSS and gypsum content with soaking period for the top 1 inch (25.4)m. and for the bottom 1 inch (25.4 mm) of the CBR sample. It is quite obvious from this figure that there is a continuous dissolution of soluble salt (mainly gypsum) of the sample in the fresh water in soaking tank. This dissolution and leaching of gypsum s initially rapid and dies out gradually and the gypsum content curve becomes almost coincident with that for TSS after about four months soaking period.

It should be noted that no changes were observed in TSS and gypsum contents in samples taken from middepth of the CBR samples even after a soaking period of 180 days. This may be attributed to the slowness of diffusion of water to the core of the samples because of the high degree of compaction (modified AASHTO compaction) used in preparing the samples.

To support this fact, the moisture content was measured for samples from the middepth of the CBR samples and compared with the molding moisture content. It was found that the moisture content at middepth of the sample, even after 180 days soaking period, remained almost unchanged.

VI. RESILIENT MODULUS TEST RESULTS

As mentioned previously, the ultrasonic pulse velocity technique was used in this work to estimate the resilient modulus of the soil. Each CBR sample was subjected before soaking and directly after soaking (but before performing the CBR load penetration test) first to P-wave then to S-wave. The time of transmission of each wave was measured and the wave velocities were then calculated. The Poisson’s ratio was then obtained from equation (2) and the modulus of elasticity (resilient modulus) was then determined using equation (1). Table 1 shows that the compression wave velocity increased while the shear wave velocity decreased due to 4 days soaking.

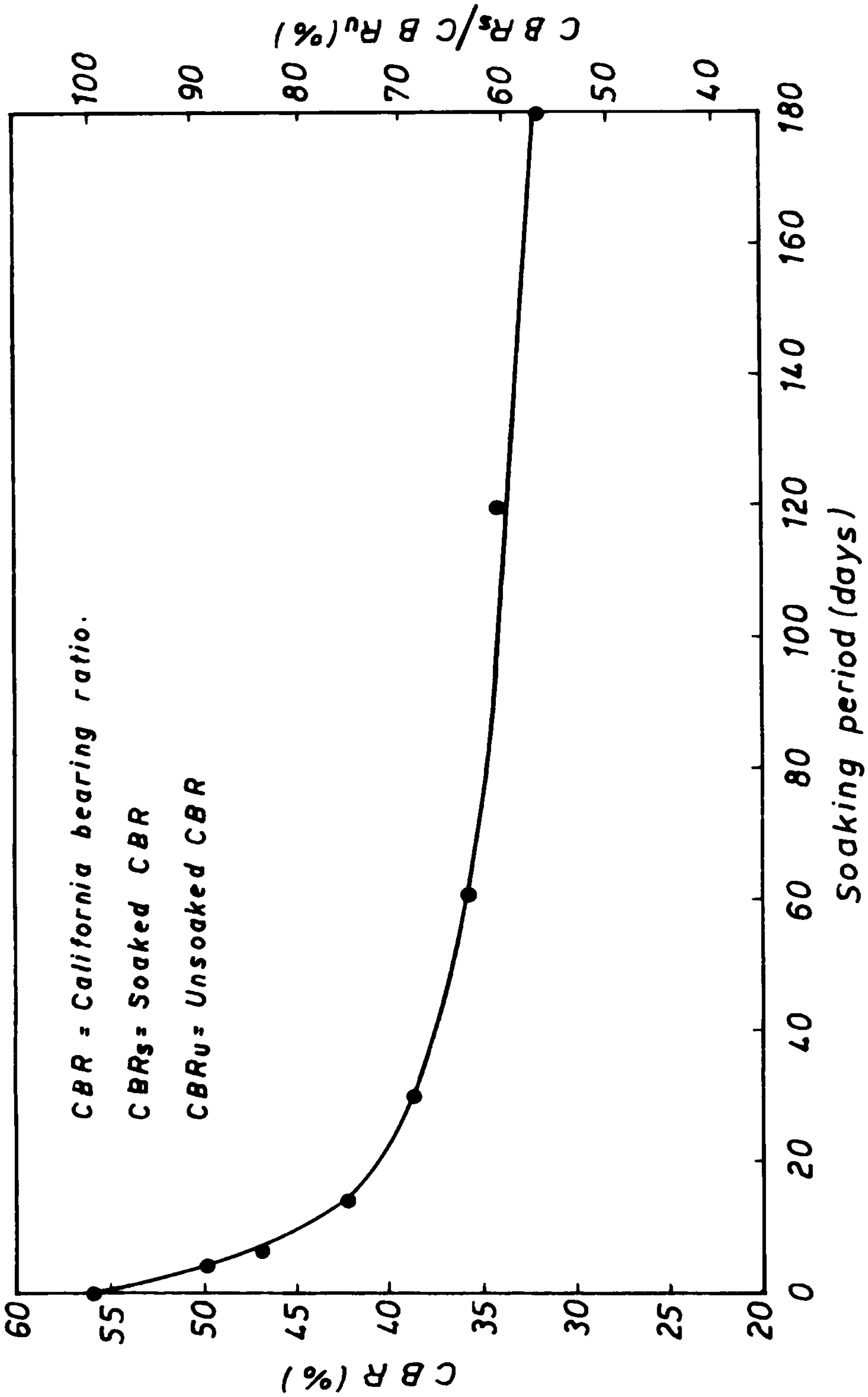

Fig. (3) Effect of soaking period on CBR of gypsiferous soil tested

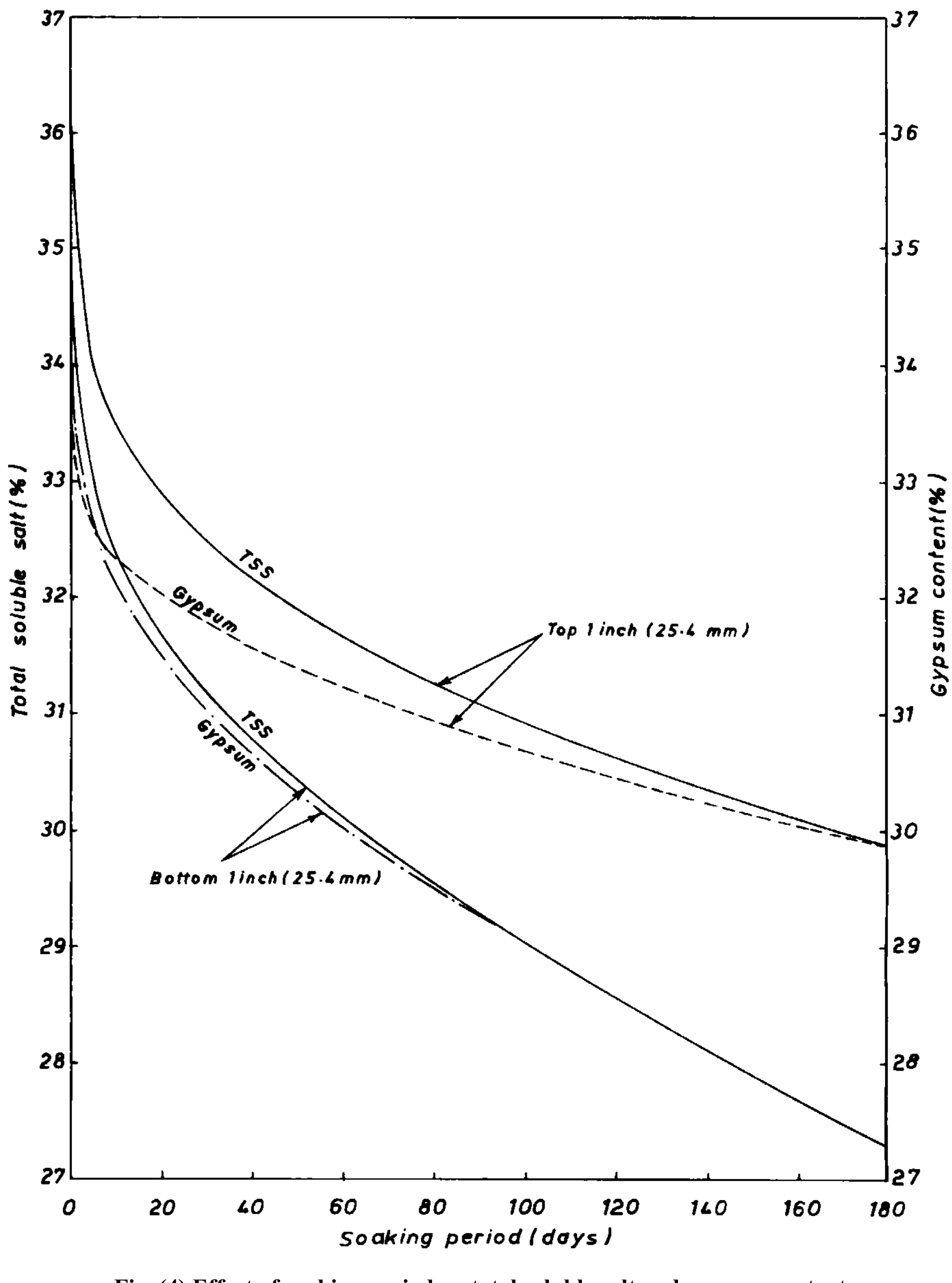

Fig. (4) Effect of soaking period on total soluble salt and gypsum content of gypsiferous soil tested

Table (1) : Resilient modulus before and after soaking

Condition of CBR sample	Before soaking	After 4 days soaking
Compressive wave velocity V_c (m/sec)	399.14	428.38
Shear wave velocity V_s (m/sec)	188.13	176.26
Poisson's ratio	0.366	0.3981
Resilient modulus M_R (MPa)	179.76	174.95

The Poisson's ratio increased due to soaking as the soil is becoming closer to full saturation, while the resilient modulus decreased due to the dissolution of gypsum. Figure 5 shows the decrease in the resilient modulus with increasing soaking period, which is in full agreement with that for the CBR.

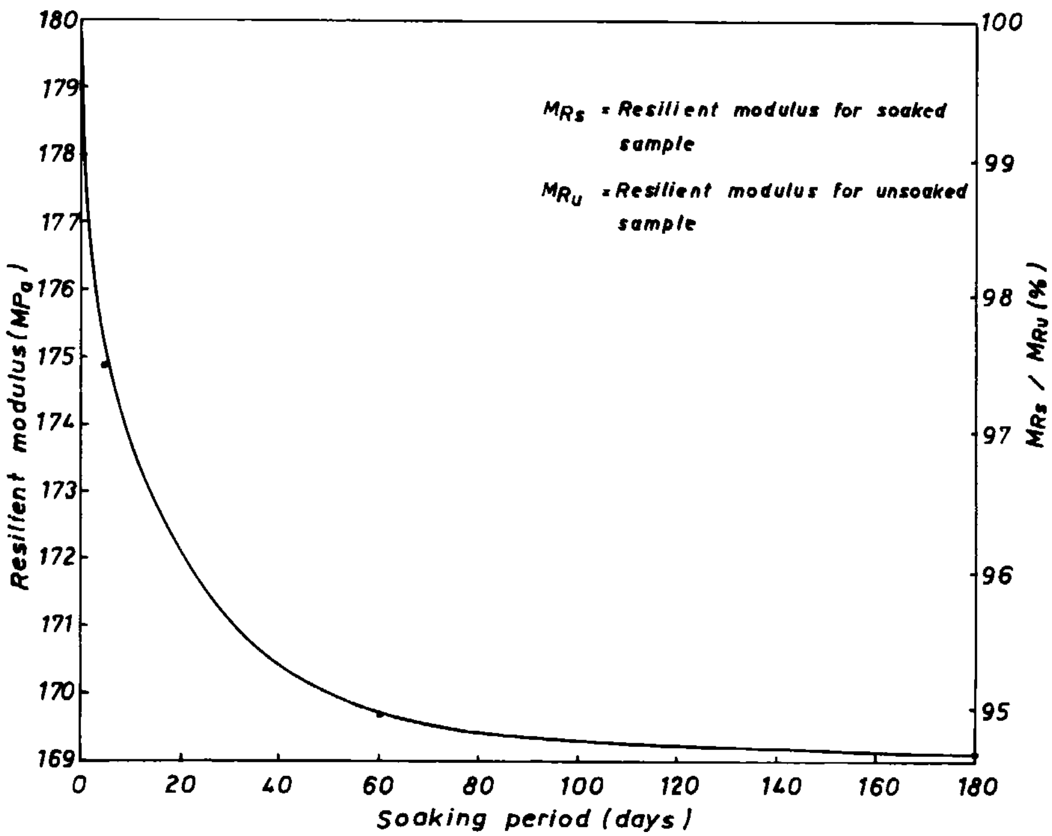

Fig. (5) Effect of long term soaking on resilient modulus of gypsiferous soil tested

However, the resilient modulus appears to be less sensitive to the soaking period than the CBR. The CBR is greatly affected by the softened soil at the top of sample during soaking, while the resilient modulus reflects the effect of the whole sample length. The core of the CBR sample is much less affected by the water than the top and bottom of the sample due to the low permeability of the soil and relatively long path for the water to reach the core of the sample.

Note that the resilient modulus at the end of 180 days soaking period was about 94.1 % of that under unsoaked conditions indicating the effect of sample size on the overall soil behavior.

VII. SWELLING-SETTLEMENT CHARACTERSTICS

During soaking in CBR test, measurement of vertical movemen (swelling or settlement) was carried out by means of an 0.02 mm dial gauge attached to the stem of the swelling plate. Figure 6 shows the variation of vertical movement during the soaking period of 180 days under the effect of 40 lb (178 N) surcharge load .

Initially, the soil is partially saturated having negative pore water pressure or suction (Rosenak 1968). This suction causes water to enter the soil from its top and bottom until it becomes fully saturated. Therefore, the soil swells initially. The swelling becomes maximum at about 20 days soaking period then decreases gradually indicating that settlement takes place at an increasing rate. The settlement eliminates the swelling after about 45 days then the settlement continues to increase at a relatively constant rate until a soaking period of 120 days in reached. Thereafter, the settlement rate decreases but the settlement continues to increase so that even at 180 days the settlement did not stop indicating the significant effect of the soaking period on the deformation behavior of gypsiferous soils.

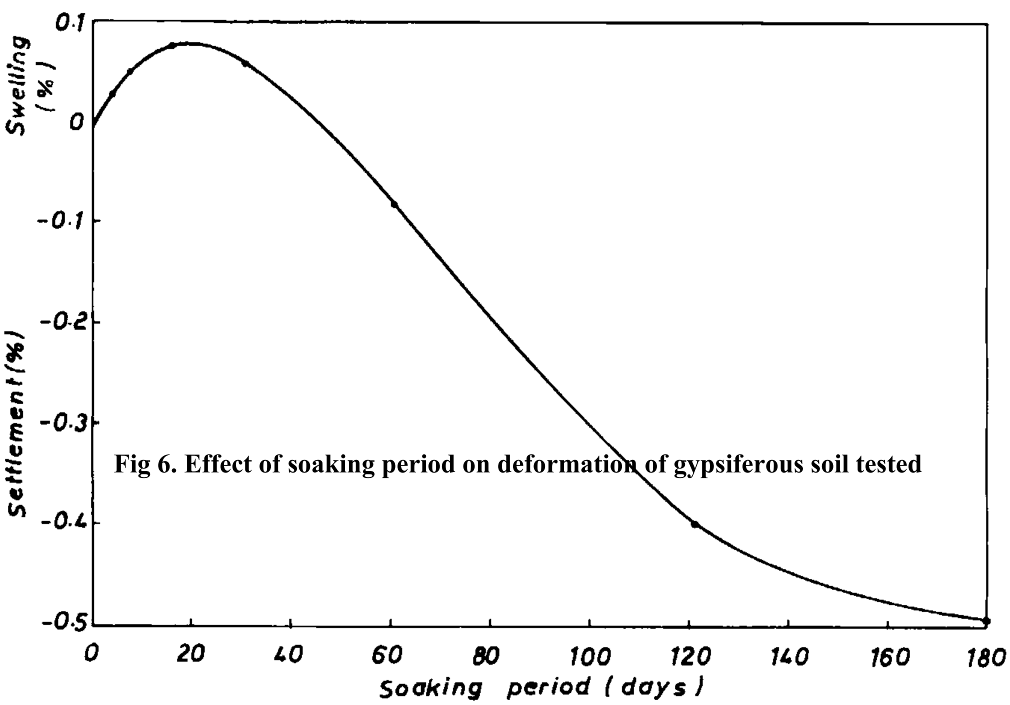

Fig 6. Effect of soaking period on deformation of gypsiferous soil tested

Fig. (6) Effect of soaking period on deformation of gypsiferous soil tested

According to Fig, 6, it is obvious that wrong conclusions can be drawn from the common four days soaking period as the soil can show swelling at the end of four days soaking but settlement after longer period of soaking. Such type of movement can result into uneven pavement deformation that can cause rapid reduction in pavement serviceability (Yoder and Witczak 1975) requiring major pavement maintenance or complete rebuilding.

VIII. EFFECT OF SURCHARGE LOAD

As mentioned previously, a surcharge load of 40 lb (178 N) was used throughout this work. According to Terzaghi and Peck (1967), an increase in surcharge load causes an increase in the bearing capacity of the soil and hence in its CBR value.

At the same time, the increase in surcharge load will decrease the suction in the dry soil samples. A decrease in soil suction will lessen the absorption of water during soaking.

This in turn will affect the dissolution of gypsum as well as the swelling/settlement behavior of the soil. This fact may explain some of the differences between he results of this work and those reported by Razouki and El-Janabi (1999) as they used 20 lb (89 N) surcharge load compared with 40 lb (178 N) of this work. However, the effect of surcharge load can be of great significance when considering the strength and deformation characteristics of gypsiferous subgrade soils for flexible pavements of taxiways and airport runways (Yoder and Witczak 1975, Horonjeff and McKelvey 1994; Al-Azawi 1998).

CONCLUSION / SUMMARY

1. The gypsiferous soil studied, containing 34% of gypsum, was obtained from Iraq near Baghdad. The soil is silty sand belonging to A-2-4 (0) AASHTO soil group and SW-SM group after the unified soil classification system.
2. The chemical analysis of the soil revealed a total soluble salt (TSS) of 36%. The gypsum made 94% of TSS so that a dilution ratio of 1:250 was required for determining the TSS.
3. Soil samples compacted at the optimum moisture content and at 95% of the maximum modified AASHTO dry density revealed an unsoaked CBR of 56% and a corresponding resilient modulus of 179,76 MPa under the effect of 40 lb (178 N) surcharge load.
4. Significant decrease in CBR value took place during soaking . The decrease was very rapid initially, became progressively slower so that after 180 days soaking in fresh water, the CBR value was 32%..
5. The decrease in the resilient modulus with soaking period is similar to but much lower than that for the CBR so that after 180 days soaking in fresh water the resilient modulus was 169.15 MPa.
6. A corresponding decrease in the TSS and the gypsum content of the top 1 inch (25.4 mm) and bottom 1 inch (25.4mm) of the CBR soil sample occurred with soaking period. After about four months of soaking, the gypsum content curve was almost identical to that of TSS.
7. The soaking period has a significant effect on the deformation characteristics of gypsiferous soils. Under the effect of 40 lb (178 N) surcharge load, the soil initially showed swelling that became maximum at about 20 days soaking, followed by settlement taking place at increasing rate. After 120 days soaking, the settlement rate decreased but the settlement continued to increase and did not stop even at 180 days soaking.
8. Use of the four days soaking period is completely misleading for highly gypsiferous soils and can lead to a serious overestimation of soil strength and stiffness. Instead a soaking period not less than 120 days is recommended to be able to predict more accurately the ultimate soil strength, soil stiffness and soil deformation.

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