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原著

원유(Crude-Oil)로 오염된 사질토의 공학적 특성

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Geotechnical Characteristics of Crude Oil-Contaminated Sands

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ABSTRACT

The result of an investigation conducted to study the effect of crude oil contamination on the geotechnical properties of sand is presented. The effect of the degree of oil contamination on compaction charateristics, shear strength, and one-dimensional compression charateristics has been investigated. The test results indicate that the compaction charateristics are somewhat influenced by oil contamination The angle friction of sand (based on total stress basis) decreases due to the presence of oil within the pore spaces in sand. The compression charateristics of sand are significantly influenced by oil contamination. The details of the tests conducted and the results are presented in the paper.

key word : Compaction, Crude oil, Contamination, Sand, Shear srength

요 약 문

원유로 오염된 지반의 지반공학적 연구는 환경적인 문제만큼 중요한 사안이나 국내에서는 이와같은 연구가 거의 연구되어지지 않고 있을 뿐만 아니라 심각도 또한 인지하고 있지 못하고 있다. 본 연구는 지반환경학적인 측면에서 원유로 오염된 사질토의 압축강도 특성, 전단강도 및 일축압축강도의 특성을 통하여 원유로 오염된 모래의 물리적 거동을 파악하였다. 실험결과에 의하면 원유로 오염된 모래 지반이 오염되지 않은 지반의 내부마찰각이 간극속에 있는 원유로 인하여 감소하고 있으며 오염도에 따라서 강도정수들 또한 현저한 영향을 보이고 있다. 모래의 압축특성은 오염도에 따라 영향을 받는

다. 각 시험에 관한 자세한 결과치는 본 본문에 소개하였다.

주제어 : 다짐, 오염, 원유, 전단강도, 모래

1. INTRODUCTION

Accidental off-shore oil spills may cause not only environmental and ecological problems. they may also have an adverse effect on the mechanical properties of soils. When the off-shore oil spills reach the shorelines they will contaminate the soil which in turn may change its mechanical properties. This may result in possible slope failure and other disasters. In general, the effect of chemical contamination on the mechanical properties of soil does not seem to have received the attention it deserves, except for the case of chemical soil stabilization using admixtures. Some recent investigation have shown that the mechanical properties of soils are influenced to a considerable extent by chemical contamination. Sherard et al.(1972) have discussed the effect of pore water chemistry on the susceptibility of soil to erosion. Anderson (1982) observed that the permeability of a clay liner in landfills may be altered as a result of prolonged contact with organic liquids. Relatively little attention has however been given to the influence of chemical contaminants on the strength and deformation properties of soils. Lukas et al.(1972) discussed the case of failure of foundation of an industrial complex resulting from the chemical reaction between the subsoil and accidental spillage of chemicals. They also observed considerable reduction in the standard penetration test values in the borings made after the chemical contamination as compared to that before contamination. Shridharan et al. (1981) presented a case history of extensive cracking demage to a light industrial building in a fertilizer complex as a result of chemical contamination of soil. Kumpalrey and Ishola (1985) observed a decrease in shear strength of a clayey soil as a result of chemical contamination from industrial wastes.

In view of the current global emphasis on detailed studies addressing all aspects of disposal of hazardous wastes, and the problem created by accidental oil spills on- shore and off- shore, an ongoing study was initiated at the University of Inchon to investigate the various aspects which addresses the effect of oil contamination on the properties and behavior of cohesionless soils. This paper presents the results obtained from a series of laboratory tests which were conducted as a part of this ongoing study, to determine the effect of *crude oil contamination* on the compaction characteristics shear strength, and one-dimensional compression characteristics of sand.

2. LABORATORY INVESTIGATIONS

The sand used for this present study was river sand. The grain size distribution for this sand is shown in Fig. 1. The sand is uniformly graded and its index properties are as follow:

a. Effective size, D_{10} = 0.150 mm

b. Specific gravity, G_s = 2.67
c. Uniformity coefficient, C_u = 2.07
d. Maximum void ratio, e_{max} = 0.786
e. Minimum void ratio, e_{min} = 0.53
f. Unified soil classification = SP

Crude oil was used as the soil contaminant for this study. The specific gravity of the crude oil as determined in the laboratory was 0.918 at 23℃. The viscosity of the crude oil was observed to be 427 MPa at 23℃. The following laboratory tests were performed as a part of this study:

a. Compaction tests.
b. Direction shear tests and
c. One-dimensional compression tests.

2.1 Compaction Tests

These tests were performed to determine the effect of crude oil on the compaction characteristics of sand. Standard Proctor compaction tests were performed for this purpose following the procedure recommended in ASTM Test Designation D-698. The tests were also repeated using water as the pore fluid to provide a basis for assessing the effect of crude oil contamination on the compaction characteristics.

3.2 Direct Shear Tests

The shear strength parameters of crude oil contaminated sand were determined from direct shear tests on specimens measuring 62.5 mm × 62.5 mm × 25 mm (height). The adverse effects of the presence of oil in the pore spaces on the strength-deformation behavior, and the angle of friction were investigated. The shear strength tests were conducted on dry sand and also by preparing specimens of sand at various degrees of oil saturation. The degree of oil saturation S_o is defined as

$$S_o = (V_o/V_v) \times 100\% \qquad (1)$$

where V_o = volume of oil occupying the void space, and V_v = volume of void space in the soil mass.

The test parameters for the direct shear tests are given in Table 1. All tests were performed in an undrained condition at a constant rate of horizontal displacement of 0.25 mm/minute.

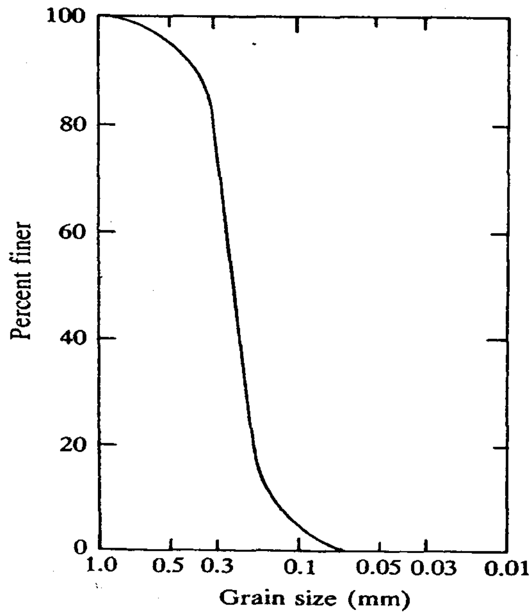

Fig. 1. Grain-size distribution of River sand

Table 1. Test Parameters Used For Direct Shear Tests

Initial relative density, D_r (%)	40, 60, 85
Degree of oil saturation, S_o (%)	0~28.5
Total normal pressure (kN/m²)	34.5~172.5

2.3 One-Dimensional Compression Test

These tests were conducted to determine the effect of oil contamination on the load-deformation characteristics and deformation modulus of sand. These tests were conducted in a hollow cylindrical steel mold having an internal diameter of 135 mm and a height of 290 mm, with a steel plate bellow the base. The test samples were prepared in the mold at desired relative densities and degree of crude oil saturation. A loading plate 133.0 mm in diameter was placed at the top. The mold assembly was placed in a triaxial device and was loaded from the top using a constant rate of axial strain of 0.25 mm/min. The applied load and the corresponding vertical deformation of the sand specimen were measured. The magnitudes of the relative densities, and the degree of oil saturation used for these tests were the same as used for the direct shear tests (Table 1). The tests were conducted under undrained conditions only.

3. TEST RESULTS AND DISCUSSION

3.1 Compaction Characteristics

The results of the present compaction tests are plotted in the form of dry unit weight versus the degree of oil saturation in Fig. 2. It can be seen from Fig. 2 that a maximum dry unit weight of about 17.4 kN/m^3 is achieved when the degree of oil saturation is about 63%. The corresponding value of the oil content is about 12%. Oil content may be defined as:

$$w_o = (W_o/W_s) \times 100\% \quad (2)$$

where w_o = oil content, W_o = weight of oil in the soil specimen, and W_s = weight of dry soil.

The compaction behavior with water as the pore fluid is also shown in Fig. 2. The maximum dry unit weight achieved with water as the pore fluid is about 16.45 kN/m^3 when the degree of saturation is about 62% (water content = 13.45 %). As expected, the maximum dry unit weight obtained under the same compactive effort is about 6% higher when crude oil is used for compaction as compared to water. This is due probably to the fact that oil is more effective in reducing the friction between the sand grains thus helping them to occupy closer configuration resulting in higher dry unit weight.

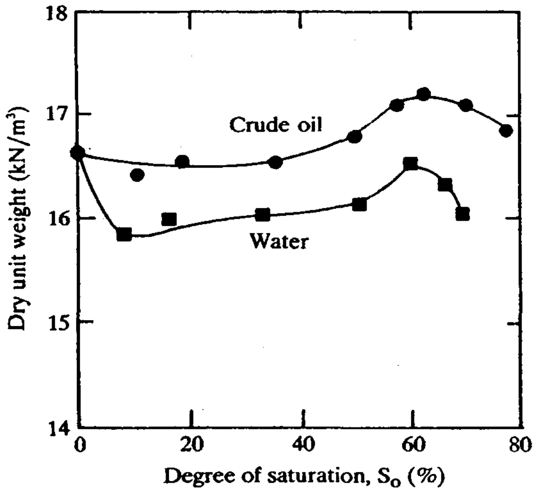

Fig. 2. Plot of dry unit weight versus degree of saturation

3.1 Shear Strength

The data from the direct shear tests conducted in the laboratory was used to obtain shear stress versus horizontal displacement plots for the specimens of dry sand, and also for crude oil contaminated sand specimens.

Figure 3 shows typical shear stress versus horizontal displacement plot for the sand at an intial relative density of 65% and at a total normal stress of 103.5 kN/m^2. It may be observed from this figure that the peak shear strength for dry sand is about 92 kN/m^2. When the degree of oil saturation is 9.5%, the peak shear stress decreases to 74 kN/m^2. In general, the peak shear stress decreases as the degree of oil saturation increases. The peak shear stress is only about 63 kN/m^2 when the degree of oil saturation becomes 28.5%. Another interesting fact may also be observed from Fig. 3 is that the magnitude of horizontal displacement required to mobilize peak shear stress increases sharply with the increase of the degree of oil saturation. The peak shear stress for the case of dry sand (Fig. 3) is mobilized at a horizontal displacement of about 1.2 mm. It is observed from the same figure that the amount of horizontal displacement for mobilizing peak shear stress is of the order of 3 mm when the degree of oil saturation is 9.5%, and increases to 5 mm as the degree of oil saturation increases to 28.5%. The order of horizontal displacement for mobilizing peak shear stress in oil contaminated sand is thus 3~5 times the value obtained for the case of dry sand.

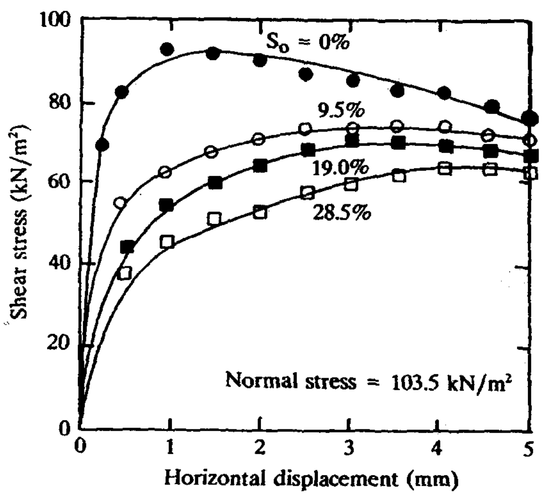

Fig. 3. Typical plots of shear stress versus horizontal displacement (D_r = 65%)

The angle of internal friction ψ(based on total stress) also decreases due to the presence of oil in the pore spaces. The soil friction angle is influenced by the amount of clay particles, viscosity of pore fluid, angularity of soil skeleton, density of soil, and etc. The variation of the angle of friction (total stress) with degree of oil saturation is shown in Fig. 4. For tests at a relative density (Dr) of 85%, the angle of friction is about 41° for dry sand and its value decreases to about 30° when the degree of oil saturation increases to about 19. 5%. For tests at a relative density of 40%, the angle of friction decreased from 35° for dry sand to about 29° as the degree of oil saturation increased to about 19.5%. The reduction of soil friction angle is greatly decreased the bearing capacity of foundation soil because the bearing capacity factors, Nc, Nr, Nq in Terzaghi's equation are function of ψ. The decrease in the angle of friction is observed to be a function of the initial relative density of sand and the degree of crude oil saturation. Within the range of parameters studied, the percentage of decrease in the value of angle of friction ranged from 17.6% to 25% as compared to its values at the same relative density in the dry state. For a given degree of oil saturation the decrease in angle of friction is more for sand at a higher relative density.

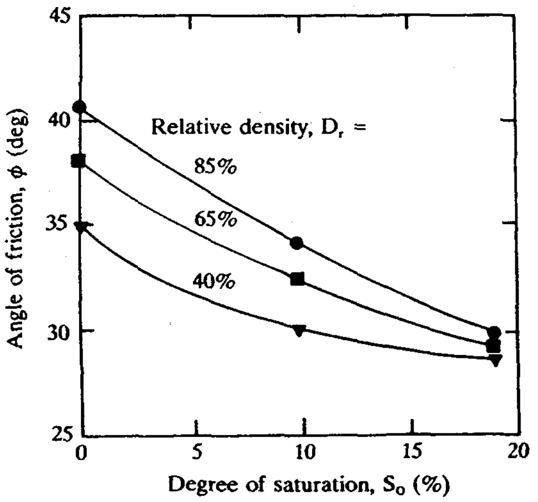

Fig. 4. Variation of angle of friction versus degree of saturation

3.3 One-Dimensional Compression Tests

Typical results from one-dimensional compression tests for specimens at an initial relative density of 60% for the dry as well as oil contaminated sand are shown in Fig. 5. The presence of oil in the soil mass had an adverse effect on the one-dimensional compression was observed to be greater for soil with oil in the pores

compared to the case of dry soil. It should be mentioned here that these were constrained one-dimensional compression tests on partially saturated sand under undrained conditions. This trend of results was observed for all tests conducted as part of this study. Figure 6 shows the variation of constrained modulus E_c with a degree of oil saturation for any given strain level. The value of E_c decrease with an increase in degree of oil saturation for all strain levels used in the tests. The test results reflect the behavior of oil contaminated sand when the applied loads are small. Also the loads were applied only for small duration of time. The decrease in constrained modulus clearly indicates that the settlement of an existing structure will increase as a result of contamination of soil with crude oil.

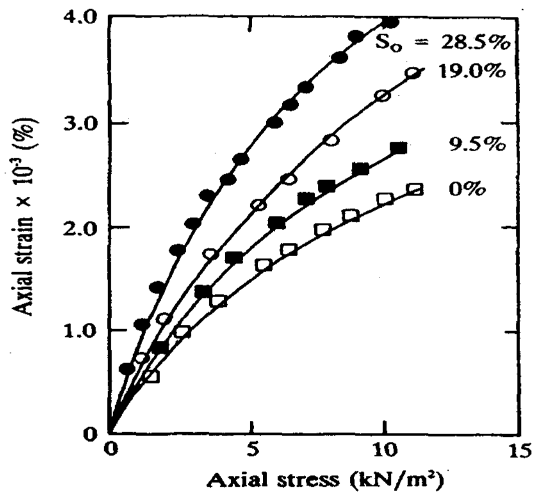

Fig. 5. Plot of axial stress versus strain confined compression tests (D_r = 60%)

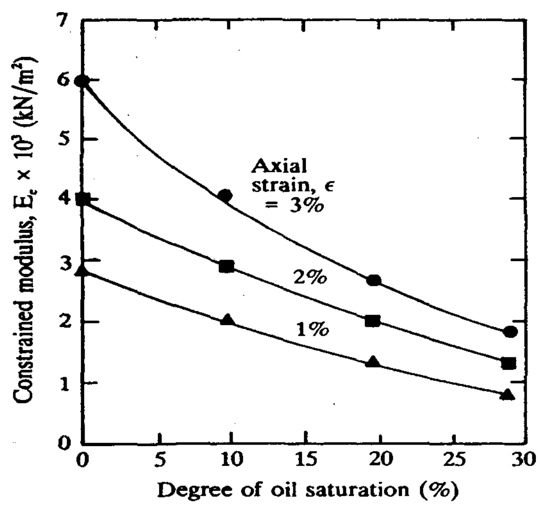

Fig. 6. Constrained modulus versus degree or oil saturation

4. CONCLUSIONS

An ongoing research investigation was recently initiated at the University of Inchon to investigate geotechnical and environmental aspect of crude oil-contaminated soils. The results reported in this paper are based on some preliminary experimental work conducted as a part of this research program. The conclusions given below are based on the limited amount of data available so far.

1. Compaction characteristics of the test sand with oil as the pore fluid are generally similar to the compaction characteristics with water as the pore fluid. The maximum dry unit weight for a given compactive effort occurred at approximately the same degree of saturation both for the case of oil or water used as the pore fluid.
2. The shear strength parameters of sand are adversely affected by oil contamination. A reduction of 17.6 ~ 25% in the value of the angle of friction compared to its value for dry sand was observed in this study.
3. For low axial loads and undrained conditions, the constrained modulus decreases with the presence of crude oil in the soil mass.
4. The angle of soil friction can be influenced by the amount of clay particles, angularity of soil skeleton, viscosity of pore fluid in the soil void spaces, applied state of stress on the soil specimen, and other reasons.

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