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# Effect of Base Coarse Layer on Load-Settlement Characteristics of Sandy Subgrade Using Plate Load Test

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***Abstract*****—**The present research has been performed to investigate the effect of base course application on load-settlement characteristics of sandy subgrade using plate load test. The main parameter investigated in this study was the subgrade reaction coefficient. The model tests were conducted in a 1.35 m long, 1 m wide, and 1 m deep steel test box of Imam Khomeini International University (IKIU Calibration Chamber). The base courses used in this research were in three different thicknesses of 15 cm, 20 cm, and 30 cm. The test results indicated that in the case of using base course over loose sandy subgrade, the values of subgrade reaction coefficient can be increased from $7\,\mathrm{N/cm^3}$ to $132\,\mathrm{N/cm^3}$, 224 $\mathrm{N/cm^3}$, and 396 $\mathrm{N/cm^3}$ in presence of 15 cm, 20 cm, and 30 cm base course, respectively.

***Keywords*****—**Base course, calibration chamber, plate load test, loose sand, subgrade reaction coefficient.

## I. Introduction

NOWADAYS, geotechnical engineers are encountered with weak subgrades in many case of construction. Because of high settlement potential, there are many problems in construction of railways, highways and airports on these soils. This issue can cause structural damage and also may reduce the durability of constructions. Application of base course can significantly reduce the settlement and also can increase the bearing capacity of weak subgrades. There are many ways to evaluate the effect of base course application on bearing capacity of weak subgrades. One of them is calculating the subgrade reaction coefficient ($k_{30}$) which is obtained from non-repetitive plate load tests. The other way is calculating the strain modulus ($E_V$) which is obtained from repetitive plate load tests. Due to some differences between the two methods such as the way of evaluating design modulus, number of loading steps, and the testing procedure, the value of these parameters are not equal to each other. Kim and Park studied the relationship between the subgrade reaction coefficient and strain modulus during a series of repetitive and non-repetitive plate load tests to control the compaction quality of subgrade of a high speed railroad in Korea. Their results finally developed an approximate correlation equation between these two parameters ($E_{v2} = 0.36K_{30}$) [1]. Moayed and Alibolandi used back analysis method to estimate the subgrade reaction coefficient using circular plate on clayey soil placed at the bottom of sandy soil layer with different thicknesses. The results showed that the subgrade reaction coefficient increases with sand layer thickness until the value of H/D=2 (H/D=ratio of sand layer thickness to plate diameter) is achieved [2]. Another way to evaluate the efficiency of subgrades is conducting CBR tests in field or laboratory. The obtained values of CBR tests are commonly used in road construction designs because they are valuable indicators of strengths and bearing capacity of subgrades and base course materials. Edincliler and Cagatay studied the effect of adding two different buffing rubbers in improving the CBR value of weak subgrade. Their results indicated that in the case of using fiber with optimum aspect ratio, the CBR value of subgrade increases and also a noticeable reduction in design thickness of pavement occurs [3]. An appropriate way to estimate the effect of base course application in practical stresses on bearing capacity of different soils in laboratory is calculation of subgrade reaction coefficient using static PLT test in calibration chamber.

In the present study, a series of static PLT tests have been conducted in a calibration chamber to investigate the effect of base course application on loose sandy soil as a bearing platform. This effect has been evaluated by calculating the value of subgrade reaction coefficient because it is one of the main criteria in designing the heavy trafficked areas such as airports and container ports.

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## II. Materials

### A. Subgrade

In this study, Firouzkooh #161 crushed silica sand was used as subgrade layer. This soil is defined as fine angular standard sand in Iran and also is classified as SP according to Unified Soil Classification System (USCS). The grain size distribution of this sand is shown in Fig. 1. The sandy subgrade has a mean particle size ($D_{50}$) of 0.27 mm, a uniformity coefficient ($C_u$) of 1.87, and a coefficient of curvature ($C_c$) of 0.88. The magnified picture of this sand is shown in Fig. 2.

To determine the shear strength parameters of weak sandy subgrade, a series of large scale direct shear tests were conducted according to ASTM D3080-11[4]. To obtain the shear strength parameters of sandy subgrade in loose condition, the specimen preparation method used in large scale direct shear box was dry pouring (Fig. 3).

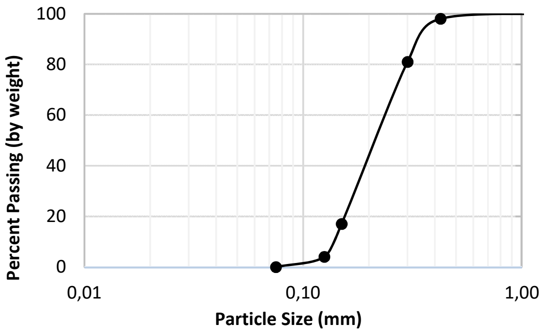


Fig. 1 Grain size distribution of silica sand

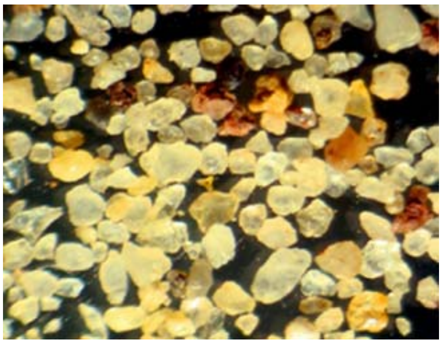

Fig. 2 Magnified picture of silica sand grains

Fig. 3 Large scale direct shear tests on sandy soil in loose condition

The samples were sheared at a constant rate of 1mm/min, which was included in the proposed range by ASTM D3080-11. Tests were done under three various normal stresses of 50 kPa, 100 kPa, and 200 kPa. Fig. 4 shows the results of the tests in different normal stresses. The peak shear strengths of sandy subgrade in different normal stresses are also shown in Fig. 5. Based on the obtained results, the internal friction angle (ϕ) of loose sandy subgrade was about 31.7°.

As can be seen from Fig. 6, to evaluate the bearing capacity of sandy subgrade in loose condition, some CBR tests were conducted according to ASTM D1883-16 [5]. Results of the tests indicated that the CBR value of Firouzkooh #161 loose laid sand was about 1.5%.

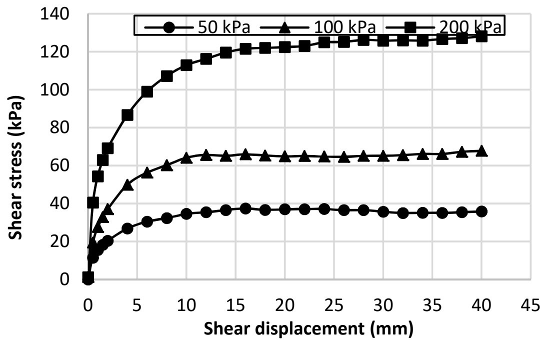


Fig. 4 Stress-strain behavior of sandy subgrade under different normal stresses

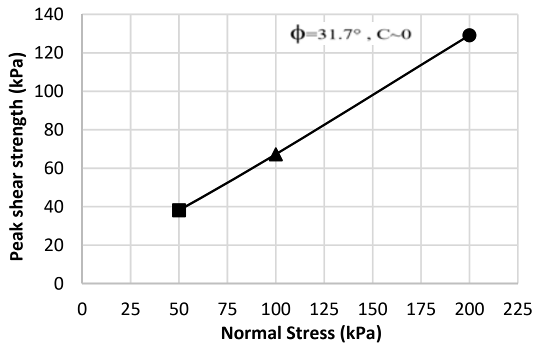


Fig. 5 Peak shear strength versus normal stress for sandy subgrade

Fig. 6 CBR tests on sandy subgrade in loose condition

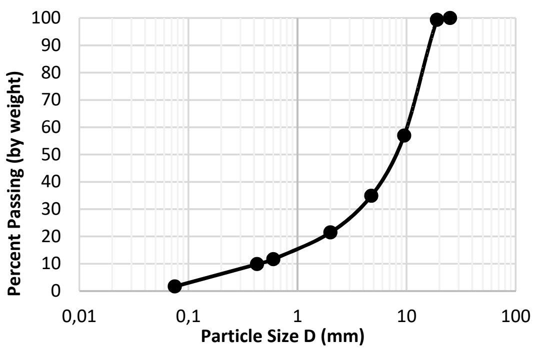


Fig. 7 Grain size distribution of base course material

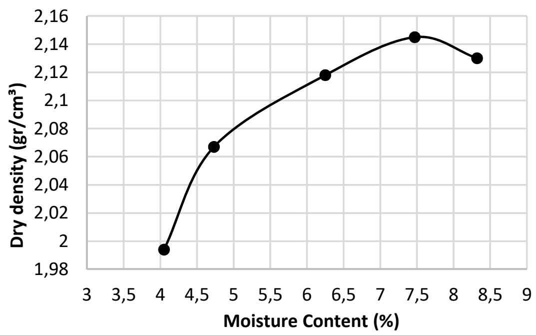


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Fig. 8 Compaction curve of base course material

TABLE I
GRADING REQUIREMENT FOR SOIL-AGGREGATE MATERIALS (ASTM D1241)

| | Mass Percent Passing Square Mesh Sieves | | | |
|---|---|---|---|---|
| **Sieve Size** | **Gradation A** | **Gradation B** | **Gradation C** | **Gradation D** |
| **2-in** | 100 | 100 | … | … |
| **1-in** | … | 75 to 95 | 100 | 100 |
| **3/8-in** | 30 to 65 | 40 to 75 | 50 to 85 | 60 to 100 |
| **No. 4** | 25 to 55 | 30 to 60 | 35 to 65 | 50 to 85 |
| **No. 10** | 15 to 40 | 20 to 45 | 20 to 50 | 40 to 70 |
| **No. 40** | 8 to 20 | 15 to 30 | 15 to 30 | 25 to 45 |
| **No. 200** | 2 to 8 | 5 to 15 | 5 to 15 | 8 to 15 |

*B. Base Layer Material*

The base layer material used for all test sections was prepared based on the grading requirements for soil-aggregate material according to ASTM D1241-15 [6]. These features are presented in Table I. Grain size distribution of base material is also shown in Fig. 7. The base material had an effective particle size ($D_{10}$) of 0.43 mm, a mean particle size ($D_{50}$) of 8 mm, a uniformity coefficient ($C_u$) of 23.25, and a coefficient of curvature ($C_c$) of 3.18. The results of grading analysis indicated that the base material used in this study is in "A" gradation of ASTM D1241-15. The maximum dry density and the optimum moisture content of the base material were determined by the modified proctor test according to ASTM D1557-12 [7]. Based on the results, the maximum dry density of base material was obtained 2.08 gr/cm$^3$ at optimum moisture content of 7.5%. This material is classified as GW and A-1-a according to Unified Soil Classification System (USCS) and the American Association of State Highway & Transportation Officials (AASHTO) classification system, respectively. Fig. 8 shows the modified compaction curve of the base course material.

## III. EXPERIMENTAL PROGRAM

*A. Test Apparatus*

A large scale steel test box (IKIU calibration chamber) with dimension of 1.35 m long, 1.0 m wide, and 1.0 m deep was constructed to simulate the soil sections similar to field conditions. A schematic of this apparatus is shown in Fig. 9. The calibration chamber was made sufficiently rigid to prevent any lateral deformation during loading procedure. A hydraulic jack, which had a force rating of 50 kN was used to apply the load to the surface of soil section.

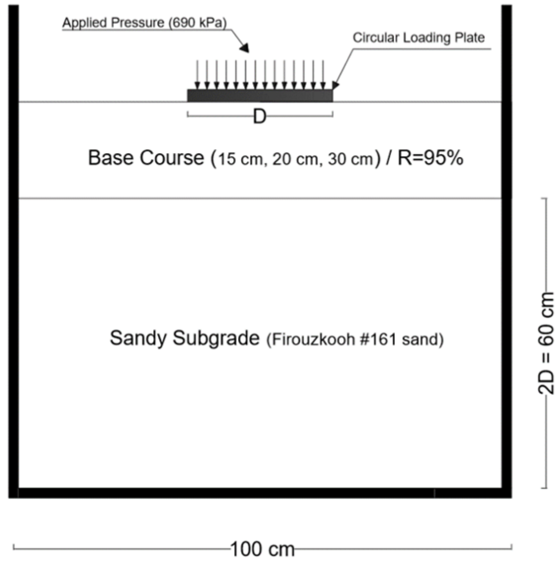


Fig. 9 Schematic representation of testing apparatus

*B. Test Procedure*

In the present study, in order to evaluate the load-settlement properties of sandy subgrade with and without base course application, some static plate load tests were conducted according to ASTM D1196-12 [8], where the load increments were applied until the rate of settlement was less than 0.03 mm/min for three minutes consecutively. The loading plate used in tests was a 25.4-mm thick circular steel plate, 300 mm in diameter. In these tests, the load and corresponding loading plate settlement were measured by a digital load cell and three linear variable displacement transducers (LVDT), respectively.

To investigate the bearing capacity of specimens, the subgrade reaction coefficient ($k_{30}$) was measured by a 30-cm diameter circular plate in the stress corresponding to 1.25 mm settlement. The maximum applied load was 50 kN, which resulted in a loading pressure of 690 kPa and it was applied to soil surface in 10 equal steps.

Ziaie Moayed et al. investigated the effect of boundary condition during some PLT tests in a 1 m×1 m×1 m calibration chamber using FDM method. Their results indicated that stress values in the chamber walls do not exceed 12% of applied stress to soil surface while using loose or dense sands [9]. Fig. 10 presents the stress distribution due to uniform normal stress ($\Delta q_s$) acting over a circular area of radius R on a soil profile. X and Z are the distances from center of loading plate and depth from ground surface, respectively [10]. In order to minimize the boundary condition effect caused by bottom of calibration chamber on soil specimens during loading procedure, the thickness of sandy subgrade was chosen 2 times the diameter of loading plate (60 cm). In this condition, the ratio of Z/R=4 and just less than 10 percent of vertical stress is distributed in the soil according to

Fig. 10.

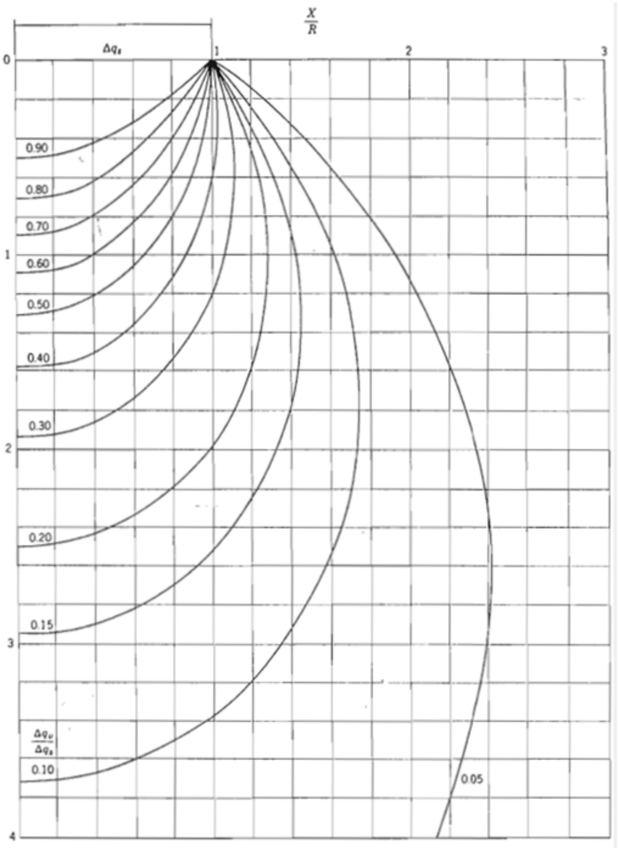

Fig. 10 Vertical stress induced by uniform load on circular area

## IV. Results and Discussion

Subgrade layer preparation was done by dry pouring method to obtain the loosest condition. A plate load test was first conducted on weak sandy subgrade without base course application to calculate the subgrade reaction coefficient ($k_{30}$). Due to loose condition, the loading procedure was strain-controlled in this test. Stress-settlement curve of the test is shown in Fig. 11. The results illustrate that the subgrade reaction coefficient ($k_{30}$) of sandy subgrade is about 7 $N/cm^3$ in loose condition.

To determine the effect of base course application on bearing capacity of sandy subgrade, three base course with different thicknesses of 15 cm, 20 cm, and 30 cm which were placed at the top of weak sandy subgrade were used as bearing platform. In order to compare the results at the same condition and due to practical considerations, soil specimens were all compacted at 95% of maximum dry density (R=95%) with 7.5% moisture content. The base courses were compacted using a 450 mm×450 mm plate compactor in two equal layers. To control the field unit weight of compaction, sand cone method according to ASTM D1556-15 [11] was used after each test. Fig. 12 presents the load-settlement curve for tests in which base courses were used as bearing platform. The results indicated that subgrade reaction coefficient ($k_{30}$) in the stress corresponding to 1.25 mm of settlement will increase to 132 $N/cm^3$, 224 $N/cm^3$, and 396 $N/cm^3$ in presence of 15 cm, 20 cm, and 30 cm base course, respectively. The $k_{30}$ values in different base course thickness are shown in Fig. 13.

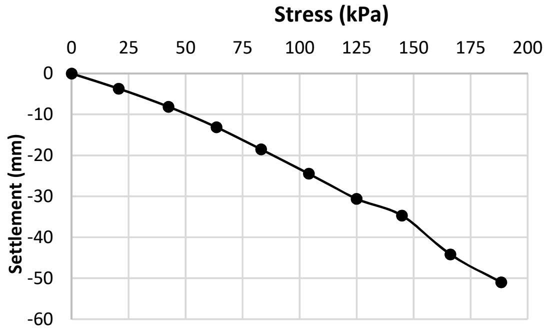


Fig. 11 Stress-settlement curve of sandy subgrade in loose condition

The settlement corresponding to stress of 190 kPa was about 50 mm in weak subgrade without base application. In the presence of base course with different thickness of 15 cm, 20 cm, and 30cm, the settlement in the mentioned stress decreased to 1.5 mm, 0.65 mm, and 0.3 mm, respectively.

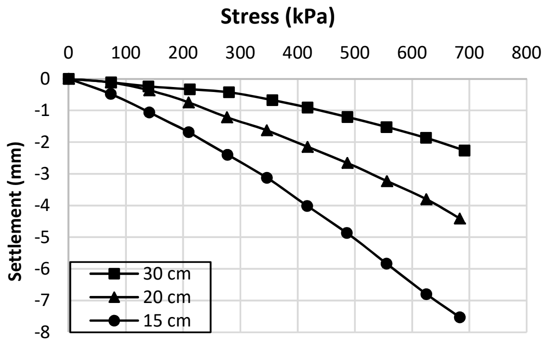


Fig. 12 Stress-settlement curves in application of base course in different thicknesses

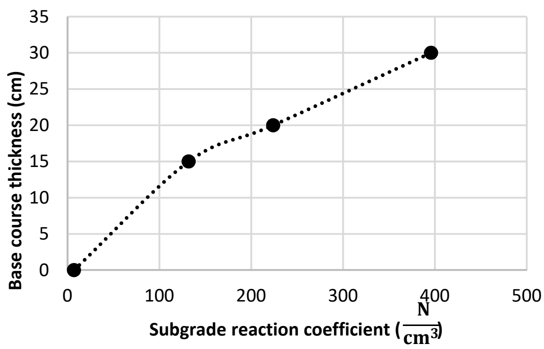


Fig. 13 Subgrade reaction coefficient in different base course thickness

## V. Conclusions

The results of the four large scale tests to examine the improvement of subgrade reaction coefficient ($k_{30}$) and also the load-settlement characteristics of loose sandy subgrade due to application of base course material have been reported. The results illustrate that when base course material with relative density of 95% is used on the top of loose sandy subgrade, the subgrade reaction coefficient ($k_{30}$) can be improved up to 56 times of the initial value of $k_{30}$ and the settlement can be reduced up to 16 times of the initial settlement, depending on base course thickness from 15 cm to 30 cm.

## ACKNOWLEDGMENT

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