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Bearing Capacity of a Strip Footing Adjacent to a Sand Slope with Soft Pocket

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ABSTRACT

Underground voids located in the failure zone of the footing can cause serious engineering problem leading to instability of the foundation and severe damage to the superstructure. This paper presents the results of laboratory model tests of the behavior of a strip footing placed adjacent to a sand slope with soft pocket. A comparison between the stress and settlement in the different cases was made to study the most efficient case. The parameters were varied in the study that include the setback distance of the slope crest and the depth of the soft pocket below the footing. Initially the bearing capacity of horizontal cases were determined and then compared with those of footing on sand slopes. The results were then analyzed to study the effect of each parameters. The test results indicated that the existence of such soft pocket within the subgrade layer below the footing has a great effect on the bearing capacity and settlement of strip footing. Also, changing the depth of the soft pocket below the footing was an effect on the stress values. It has been found that the ultimate bearing capacity and the settlement of horizontal ground decreased about 39.8% and 49.1% respectively, compared with the sand slope (b/B =1.0) at Y/B =1.5.

Keywords: *Sand slope crest, Strip footing, Laboratory test, Soft pocket.*

INTRODUCTION

There are many situations where footings are constructed on sloping surfaces or adjacent to a slope crest such as footings for bridge abutments on sloping embankments. When a footing is located on a sloping ground, the bearing capacity of the footing may be significantly reduced, depending on the location of the footing with respect to the slope [1]. In addition to, in engineering practice, the existence of underground soft pocket or soft pockets under rigid surface structures (e.g., pavements, pipelines and footings) requires special attention because soft pocket can influence the integrity of structures. Soft pocket in ground are known to form for many reasons, some of which are the thawing of subsurface ice lenses [2], the dynamic loadings induced by mining and tunneling activities [3], the dissolution of soluble materials such as salt, gypsum, limestone and dolomite [4], the dissociation of methane hydrate [5], and the presence of leaking CO_2 storage reservoirs [6]. The performance of footings underlain by subsurface soft pocket has been investigated by several researchers. Baus and Wang [7] studied experimentally and numerically the bearing capacity behavior of strip footings on silty clay with single continuous soft pocket, and showed that for a given soft pocket size, the bearing capacity decreases as the distance between the footing and soft pocket reduces. Wang and his colleagues [8] continuously explored the effects of soft pocket location, size, shape, and orientation with respect to the footing axis on the stability of square footings with different sizes, shapes and embedment depths. The soft pocket can be also found in the form of soft clay or peat layer as stated.

Based on the paper in literature it can be seen that all investigation were carried out to investigate the effect of existence such soft pocket on the bearing capacity on the flatted ground without slopes. Therefore this paper presents the experimental tests for the determination of the bearing capacity of surface strip footings on sand slope with soft pocket (void). The main objective of this study is to investigate the behavior of sand slopes of a strip footing loaded with installed on soft pocket .The effect of the location of soft pocket on the B.C. and settlement is also submitted. Moreover the effect of the distance between strip footing and slope crest in the existence of such pocket is analyzed.

MODEL BOX AND FOOTING

The experimental work aimed to study the effects of non-stabilizing an earth slope on the bearing capacity of a strip footing on sand slope with soft pocket. A plane strain footing was used in the study while a fiber was used to as a soft pocket (void) as showing in fig. 1.a. The main elements of the used apparatus are a tank and a horizontal steel beam over the tank. The test box, having inside dimensions of 0.90 m * 0.40 m in plan and 0.50 m in depth is made from steel with the front wall made of 20 mm thickness glass and is supported directly on two steel columns as shown in fig. 1.b. The glass side allows the sample to be seen during preparation and sand particle deformations to be observed during testing. The tank box was built sufficiently rigid to maintain plane strain conditions by minimizing the out of plane displacement. To ensure the rigidity of the tank, the back wall of the tank was braced on the outer surface with two steel beams fitted horizontally at equal spacing. The inside walls of the tank are polished smooth to reduce friction with the sand as much as possible by attaching fiber glass onto the inside walls.

(a) **(b)**

Fig. 1: The experimental apparatus.

The loading system consists of a hand operated hydraulic jack and pre-calibrated load cell. A strip model footing made of steel with a hole at its top center to accommodate bearing ball was used. The footing is 398 mm in length, 100 mm in width (B) and 20 mm in thickness. The footing was positioned on the sand bed with the length of the footing running the full width of the tank. The length of the footing was made almost equal to the width of the tank in order to prevail plane strain conditions within the test set-up. The two ends of the footing plate were polished smooth to minimize the end friction effects. The load is transferred to the footing through a bearing ball. Such an arrangement produced a hinge, which allowed the footing to rotate freely as it approached failure and eliminated any potential moment transfer from the loading fixture.

TEST MATERIAL

The sand used in this research is medium to coarse sand, washed, dried and sorted by particle size. According to grain size analysis it has been found that the coefficient of uniformity 4.26 and the coefficient of curvature (Cc) 0.792 ,It is composed of rounded to subrounded particles. The specific gravity of the soil particles was (Gs) 2.632 determined by the gas jar method. Three tests were carried out and the average value was obtained. The maximum and the minimum dry densities of the sand were 1.894 and 1.44 (kN/m^3) measured and the corresponding values of the minimum and the maximum void ratios were 0.3896 and 0.5069 respectively. The relative density achieved during the tests was monitored by collecting samples in small cans of known volume placed at different locations in the test tank. In this study provided a uniform relative density of approximately (Dr) 55% with a unit weight of 16.6 kN/m^3. The estimated internal friction angle at the same Dr used the model tests was 32^o.

Preparation of soft pocket

The model of soft pocket (void) made of fiber that was placed below the centre of the footing as a layer at studied depth such that the length of the void was parallel with the width of the tank. The dimensions of fiber is 398 mm in length and 200 (2B) mm in width (w). The fiber is 20 mm in thickness. All the tests were performed with fiber installed horizontal during preparing sand samples.

TESTING PROCEDURE

The model soil was constructed with the bed level observed through the front glass wall. Then the sand slope was set up to form a slope of 3 (H): 2 (V). During constructed the model slope, a soft pocket was driven horizontally at the design place and spacing considering the different depths. Great care was given to level the top surface of the sand and the slope face using special rulers so that the relative density of the top layer was not affected. The footing was placed on position and the load was applied incrementally by the hydraulic jack until reaching failure. Each load increment was maintained constant till the footing settlement had stabilized. This settlement was measured using two 0.001 mm accuracy dial gauges, placed on opposite sides across the center of the footing. To ensure an accurate reading, all of devices are calibrated prior to each test. The general view of the testing tank and all relevant attachments at the beginning of a test are shown in Fig. 2.
A total of 16 tests were carried out in laboratory. Initially, the response of the model footing supported on the horizontal ground was determined (3 tests with soft pocket in different depths below the footing and one test without soft pocket). Then, 3 series of tests (12 tests) were performed to study the effect of the different parameters of soft pocket on the footing behavior as shown in Fig. 2. The parameters were varied which include the setback distance between the slope crest and the strip footing b/B = 0, 1.0 and 2.0 also the depth of soft pocket below the footing Y/B = 1, 1.5 and 2.0. Several tests were repeated at least twice to verify the repeatability and the consistency of the test data.

Fig. 2: The experimental setup.

RESULTS AND DISCUSSION

In this section, the tests results of the laboratory model are presented with a discussion highlighting the effects of the different parameters. The value of stress of the footing on sand slope and on soft pocket under vertical load , also the settlement of the footing under the combinations of static load has been obtained as described. The failure load can be defined as a peak failure in all the different models.

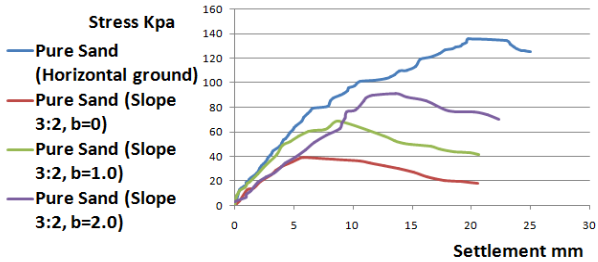

Fig. 3: Variation of stress with settlement for footing on sand without soft pocket for horizontal ground and sand slope 3:2 at b/B =0, 1.0 and 2.0, respectively.

Fig. 3 presents the stress-settlement behavior of both horizontal ground and sand slope without soft pocket at different setback distance from the footing. The results indicated that the stress decreased as expected with an sand slope. In sand slope the ultimate B.C. and the settlement were decreased about 71%, 58% and 32.9% and 70.32%, 55.2% and 31.2% at b/B=0, b/B=1.0 and b/B = 2.0 respectively, compared to the horizontal ground.

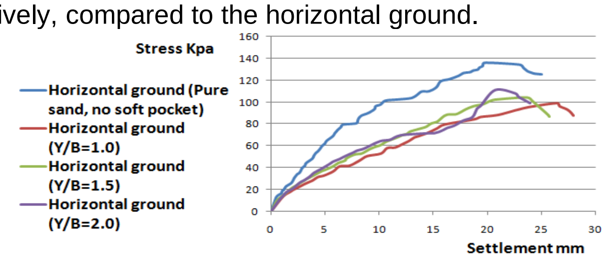

Fig. 4: Variation of stress with settlement for footing on horizontal ground with and without soft pocket.

In Fig. 4 shows the stress-settlement behavior of the horizontal ground with and without soft pocket. The results indicate significantly that the stress decreased in horizontal ground with soft pocket compared to the stress of horizontal ground without void. The ultimate B.C. decreased about 71% at Y/B=1.0, 23.4% at Y/B=1.5 and 18.4% at Y/B=2.0, respectively compared to the ultimate B.C. of the horizontal ground without soft pocket. But the settlement of footing in the same case increased to 34.3%, 20.13% and 5.37% respectively.

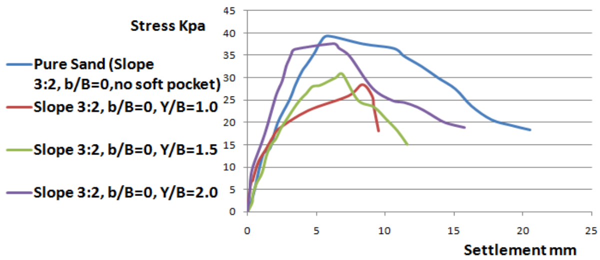

Fig. 5: Variation of stress with settlement for footing on sand slope with and without soft pocket at b/B = 0.

Fig. 5 presents the stress-settlement behavior of the sand slope with and without soft pocket at setback distance of the slope crest equal 0. The results indicate that the ultimate B.C. decreases as expected with an sand slope with soft pocket about 27.57%, 21.78% and 4.4%, respectively at the different depths of the soft pocket below the strip footing (Y/B) 1.0, 1.5, and 2.0, while the settlement of footing in this case increased to 42.2%, 17.8% and 6.6% respectively, compared to the sand slope without soft pocket at the same setback distance of the slope crest (b/B).

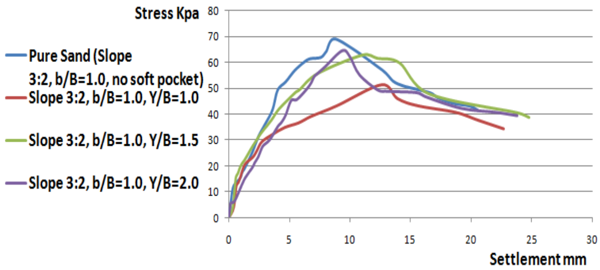

Fig. 6: Variation of stress with settlement for footing on sand slope with and without soft pocket b/B = 1.0.

In Fig. 6 shows the stress-settlement behavior of the sand slope with and without soft pocket at setback distance of the slope crest equal 1.0. The results indicate that the ultimate B.C. decreases with an sand slope with soft pocket about 25.68%, 9.2% and 6.6%, respectively at the different depths of the soft pocket below the strip footing (Y/B) 1.0, 1.5, and 2.0, respectively compared to the sand slope without soft pocket at the same setback distance of the slope crest (b/B). While the settlement of footing in this case increased to 42.65%, 24.8% and 5.82% respectively.

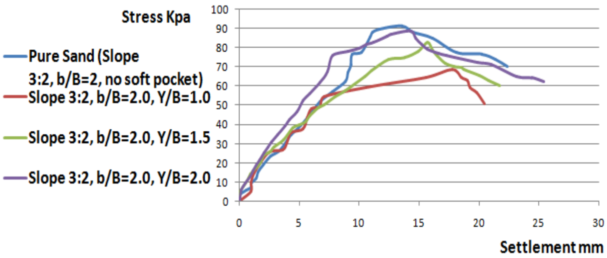

Fig. 7: Variation of stress with settlement for footing on sand slope with and without soft pocket at b/B = 2.0.

While in Fig. 7 shows the stress-settlement behavior of the sand slope with and without soft pocket at setback distance of the slope crest equal 2.0. The results indicate that the ultimate B.C. decreased with an sand slope with soft pocket about 24.96%, 9.43% and 2.77%, respectively at the different depths of the soft pocket below the strip footing (Y/B) 1.0, 1.5, and 2.0, respectively compared to the sand slope without soft pocket at the same setback distance of the slope crest (b/B). While the settlement of footing in the same case was increased to 30.87%, 15.69% and 5.45% respectively.

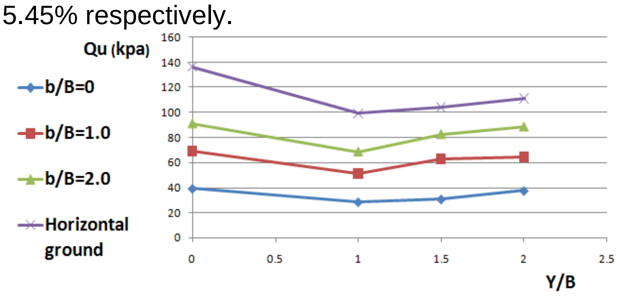

Fig. 8: Variation of Qu with Y/B for footing on sand slope and horizontal ground with and without soft pocket at the different both of the setback distance of the slope crest and the depth of the soft pocket.

Fig. 8 presents the Qu with Y/B for footing on sand slope and horizontal ground with and without soft pocket at the different both of the setback distance of the slope crest b/B = 0, 1.0 and 2.0 and the depth of the soft pocket Y/B = 1.0, 1.5 and 2.0, respectively. The results indicate that the ultimate B.C. Qu decreased with an sand slope without soft pocket about 71%, 58% and 32.9% at b/B = 0, 1.0 and 2.0, respectively compared to the horizontal ground also without soft pocket. However the results indicate that the ultimate B.C. Qu decreased with an sand slope with soft pocket about 71.32%, 48.39% and 31.1% at b/B = 0, 1.0 and 2.0 and Y/B = 1.0, respectively compared to the horizontal ground also with void at Y/B = 1.0. Beside that the results indicate that the ultimate B.C. Qu decreased with an sand slope with soft pocket about 70.45%, 39.84% and 20.65% at b/B = 0, 1.0 and 2.0 and Y/B = 1.5, respectively compared to the horizontal ground also with soft pocket at Y/B = 1.5. Also the ultimate B.C. Qu decreased with an sand slope with soft pocket about 66.12%, 41.95% and 20.1% at b/B = 0, 1.0 and 2.0 and Y/B = 2.0, respectively compared to the horizontal ground also with soft pocket at Y/B = 2.0. It can be concluded that the critical depth of existence of soft pocket location Y/B is found to be at Y/B = 1.

CONCLUSION

Based on the experimental analysis, the following conclusions can be drawn:

1. The ultimate B.C of footing near slopes at b/B = 0, 1.0 and 2.0 without soft pocket decreased to 21.85%, 9.17%, and 9.43% and the settlement of footing increased to 17.76%, 24.83% and 15.696% respectively, compared to the same case with soft pocket at Y/B =1.5.
2. Increased the depth of the soft pocket below footing Y the ultimate B.C was increased, the ultimate B.C of horizontal ground with soft pocket at depth Y/B =2.0 decreased to 11.72% compared to the same case with soft pocket at depth Y/B =1.0 but the settlement of footing in the same case increased to 27.5%. Finally, It noticed that over the range of Y/B > 1 the bearing capacity is relatively increased compared with other location.

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