

STRIP FOOTING SETTLEMENT ON SANDY SOIL DUE TO ECCENTRICITY LOAD

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ABSTRACT: This study investigates the effect of eccentricity load on settlement of shallow foundation rested on sandy soil model. A series of small-scale 1g physical modeling tests was carried out by preparing a model of medium dry sand with 50% of relative density on a rigid testing chamber. A rigid plate was used to replicate a strip footing foundation. Three different locations of loading were created which located at the centre, 0.05 B and 0.1 B from the centre with respect to the width of the footing to investigate the eccentricity effect applied from the footing. Close range photogrammetry and particle image velocimetry (PIV) methods were used to examine the failure mechanisms under the eccentricity design load. In this study, the ultimate, allowable bearing capacity and bearing capacity factor (N_γ) under the eccentricity loading were investigated. It was found that with the increasing of footing eccentricity, the bearing capacity decreased with increasing settlement

Keywords: *Shallow foundation, Settlement, Eccentricity, Particle image velocimetry (PIV).*

1. INTRODUCTION

The function of a shallow foundation is to transmit load from the superstructure to the supporting soils. In some cases, the footing carry eccentric or moment load subjected from the eccentricity of vertical load from the column or by horizontal load acting at some distance above the foundation base. These loads may be permanent (retaining wall) or temporary (wind or seismic load). Many studies have been conducted to investigate the performance of a shallow foundation on sandy soils [1-13].

However, most of the studies were carried out to investigate the geometry shape of shallow foundation rested on a sandy soil. Limited study was conducted to examine the influence of the eccentricity load on this particular soil [12-13]. Although El Sawwaf, [13] performed a study on the effect of eccentricity on the bearing capacity of sandy soil, however he intended to investigate the used of the geogrid layer as an improvement method to enhance the stability of the sandy soil under the eccentricity load. He found that the footing performance could be significantly improved by the used of layers of geogrid leading to an economic design of the footing.

Thus, this study attempts to investigate the effect of eccentricity on settlement of shallow foundation rested on sandy soil. A series of small scale physical modeling was carried out to study settlement behavior. The applied loading on the settlement test was obtained from the ultimate bearing capacity of the sandy soil. The deformation was observed using a close range

photogrammetry and Particle Image Velocimetry techniques [14].

2. EXPERIMENTAL SYSTEM

A rigid aluminum testing chamber with a dimension of 320 mm in height x 150 mm in width x 430 mm in depth was used to construct a 200 mm height of sand model. The front side of the box was fitted with a removable transparent Perspex panel to allow a real time observation on soil movements during the loading test as shown in Fig. 1 [15-16]. Sand model with 50% of relative density index was prepared to represent a medium dense sandy soil by using a light compaction method. A rigid plate of 60 mm in width, B and 150 mm in length, L was used to replicate a strip foundation. 3 holes with a diameter of 3 mm were fabricated at the top of the rigid plate. Each of the holes were located at the centre, 0.05 B and 0.1 B from the centre with respect to the width of the footing. Due to the sand has a uniform white colour, an additive black colour was used to colour the $\frac{1}{4}$ of the total weight of soil by using dyed black solution. The technique was used in order to enhance the difference of brightness intensity during the image analysis using the PIV.

A strain control system with a variable speed AC motor and worm gear configuration was used to provide strain loading system during the bearing capacity testing. The used of the strain loading system is to determine the ultimate bearing capacity of the sandy soil. A dead loading system was used to investigate the settlement of the strip footing by applying an equivalent stress of the ultimate and allowable bearing capacities for both

centric and eccentric cases as shown in Fig.2. The stresses and displacements were recorded using a load cell and Linear Variable Differential Transformer (LVDT) transducers. A digital camera was employed and mounted in front of the Perspex panel to capture the soil movements in continuous shooting mode during the settlement testing. The captured images were analysed using the Particle Image Velocimetry (PIV) so that the failure pattern could be observed with the aid of the Matlab software. A set of target markers was used to calibrate the camera movement during the shooting period. In total, 9 physical modeling tests were conducted to investigate the effect of the eccentricity on the settlement of the strip footing.

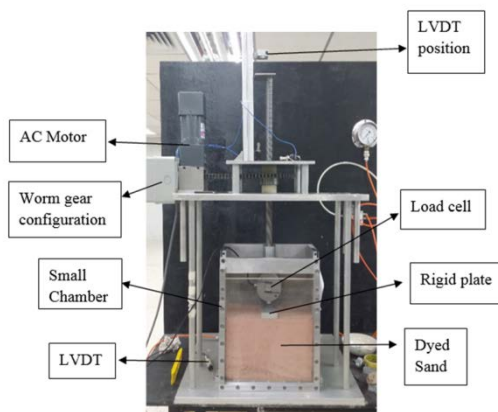


Fig. 1: Experimental setup using a strain control system

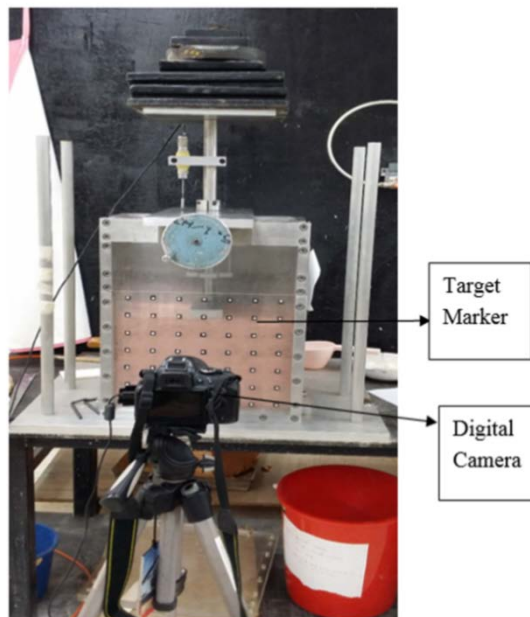


Fig. 2: Dead loading system

3. TESTING MATERIAL

Several soil basic properties tests were conducted to determine the soil properties of the sandy soil according to British Standard Institution (BS) [17-18]. Sieve analysis test was used to determine the sandy soil particle size distribution. The soil then is classified from the obtained result from the sieve test by using the value from coefficients of uniformity and gradation [17]. The specific gravity of the sand was determined from the small pyknometer test. In order to obtain the 50% of relative index, I_D that was used to represent an intermediate dense of soil, a relative density test was carried out to determine the maximum dry density ($\gamma_{d_{max}}$) and minimum dry density ($\gamma_{d_{min}}$) of the sandy soil. Direct shear test was used to determine the internal friction angle, ϕ of the sandy soil of 50% relative density. The ϕ value is used to determine the bearing capacity factor of the sandy soil model using the Meyerhof [1] formula.

4. RESULTS AND DISCUSSIONS

4.1. Soil Properties

The result of physical property of sand is listed in Table 1. The particle size distribution test result was shown in Fig. 3. The result from the sieve test shows that the particle distribution curve is well graded sand (SW) which means that the particle size is distributed in a wide range. The grade is determined from the value of coefficient of uniformity and gradation obtained from the curve where the results are 6.55 and 1.01 respectively. It has been recorded that the minimum and maximum dry unit weight ranges from 15.01 kN/mm³ to 18.39 kN/mm³. Therefore, the 50% of relative density is 16.53 kN/mm³. Fig. 4 shows the result of normal stress-ultimate shear stress obtained from direct shear test. It was found that the ϕ value of sandy soil is 35.9°.

Table 1: Physical property of sandy soil

Property	Value
Specific gravity, G_s	2.65
Maximum dry unit weight, $\gamma_{dry (max)}$, kN/m ³	18.39
Minimum dry unit weight, $\gamma_{dry (min)}$, kN/m ³	15.01
Relative Index, I_D	50%
Effective size, D_{10} (mm)	0.22
D_{30} (mm)	0.57
D_{60} (mm)	1.45
Coefficient of uniformity, C_u	6.55
Coefficient of gradation or curvature, C_c or C_r	1.01
Angle of Internal friction, $\phi_{direct\ shear}$ (degree)	35.89
Modulus of elasticity, E (kPa)	2887.9

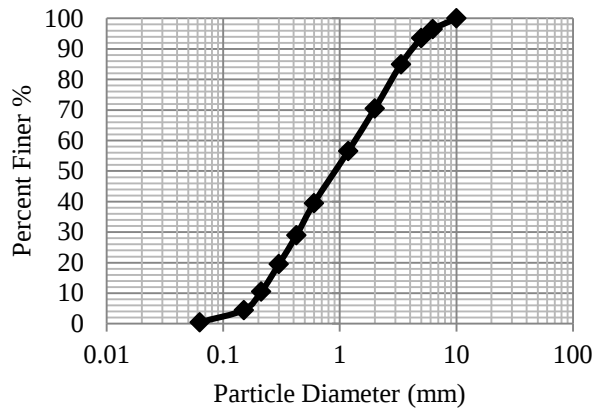


Fig. 3: Particle size distribution of sand

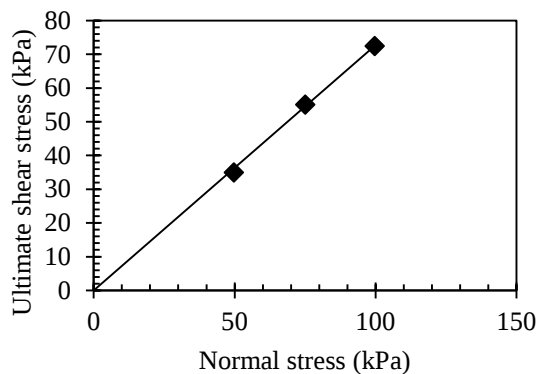


Fig. 4: Direct shear box test result

4.2 Bearing Capacity and Bearing Capacity Factor N_γ

Three different tests were conducted for centrically and eccentrically loaded of strip footing with 0.0B, 0.05B, and 0.1B eccentricities for Tests 1, 2, and 3 respectively. For each test, the rigid plate which represents strip footing was loaded until reach 20 mm penetration to meet the failure state. Fig.5 shows the stress- displacement/ footing width curve. It was found that the ultimate bearing capacity values, q_{ult} for Tests 1, 2, and 3 are 43.66 kPa, 35.38 kPa, and 29.85 kPa respectively. It can be seen that the value of q_{ult} decreases when the eccentricity is increases.

Equation 1 was used to calculate the bearing capacity factor, N_γ for each test based on the q_{ult} results [1]. The values of N_γ were found as 104.81, 102.89, and 107.85 for Tests 1, 2, and 3 respectively. The angle of internal friction of sand model was determined as 43.56 based on the N_γ results. It was noticed that the discrepancies between the angle of internal friction of sand obtained from the small scale physical model and shear box test was approximately 17.6%. The difference between the theoretical and physical modeling test which might be contributed from the wall friction between the testing chamber wall, the roughness of the footing interface and

non-homogeneity of the soil bed during the loading.

$$q_{ult} = \frac{1}{2} \gamma (B - 2e) N_\gamma s_\gamma d_\gamma i_\gamma \quad (1)$$

where, γ is the unit weight of soil, s_γ , d_γ and i_γ are the shape, depth and inclination factors respectively.

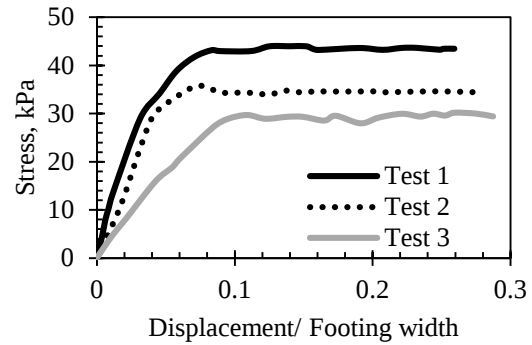


Fig. 5: Stress- Displacement/footing width curve

4.3 Settlement Measurement

Six tests were conducted under 3 differences load locations to determine the settlement as presented in Table 3. Each case consists of two tests under fully and two third of ultimate bearing capacities. It can be observed that by increasing the eccentricity values, the settlement for each test was increases. Fig. 6 shows the effect of eccentricity on footing settlement. The results show that the settlement increases with the increasing of the eccentricity. The settlement over footing width ratio (S/B) and the applied stress was plotted as shown in Fig. 7. It can be seen that when the applied stress decreased due to increasing of eccentricity, the settlement is increased.

Table 3: Settlement test results

Tests	Stress condition	q (kPa)	S (mm)
1	e=0.0B	2/3 q_{ult}	29.11
2		q_{ult}	43.66
3	e=0.05B	2/3 q_{ult}	23.59
4		q_{ult}	35.38
5	e=0.1B	2/3 q_{ult}	19.2
6		q_{ult}	29.85

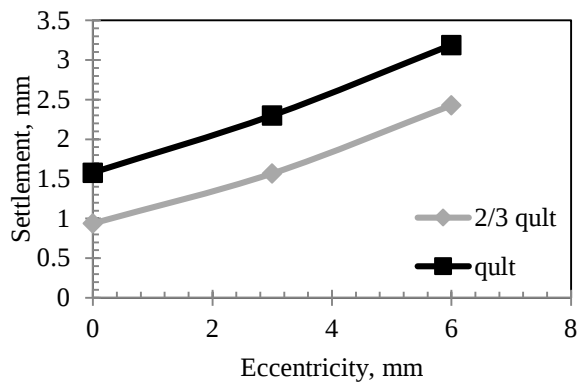


Fig. 6: Effect of eccentricity on the soil settlement

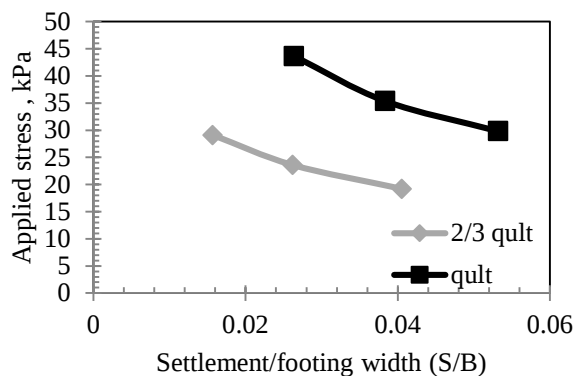


Fig. 7: Relationship between settlement/footing width and applied stress

The main parameters of footing settlement due to eccentricity load which may act on the sand parameters are those due to footing width, eccentricity, dry unit weight, γ and applied stress, q . Based on the Buckingham π theory [19], two dimensionless equation were chosen to investigate the effect of the those parameters. The proposed dimensionless equations are $\gamma e/q$ and S/B . Fig. 8 shows the plot of $\gamma e/q$ and S/B . It was found that the normalized settlement increased with the increasing of $\gamma e/q$ value.

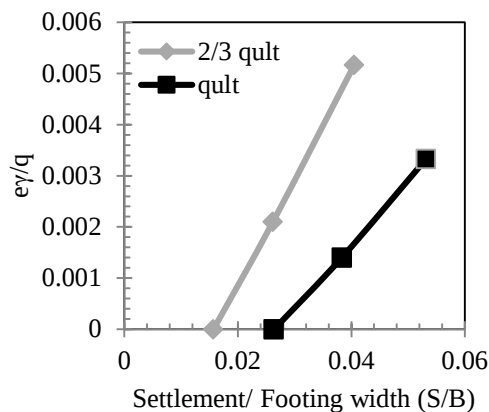


Fig.8: Relationship between $\gamma e/q$ and S/B

4.4 Soil Deformation

The images taken during the ultimate bearing capacity tests were analyzed using the Particle Image Velocimetry analyses. Figs. 9 to 11 show the soil deformation obtained from the PIV analyses for Tests 2, 4 and 6. Fig. 8 shows a clear Prandtl failure mechanism with the soil beneath and adjacent the footing deformed approximately the same size of the footing width. Based on the Figs. 10 to 11, a clear soil movement toward the right side of the footing was observed due to the footing eccentricity. The footing experienced a larger rotation on the eccentricity side when the eccentricity was increased as shown in Fig. 10.

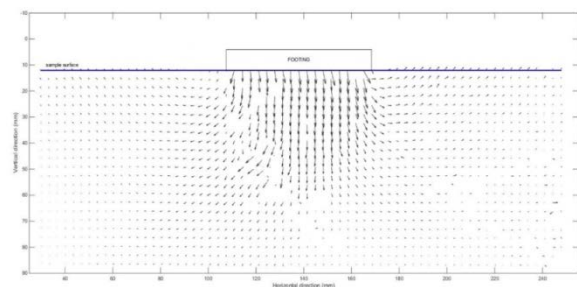


Fig. 9: Vector of soil deformation for Test 2

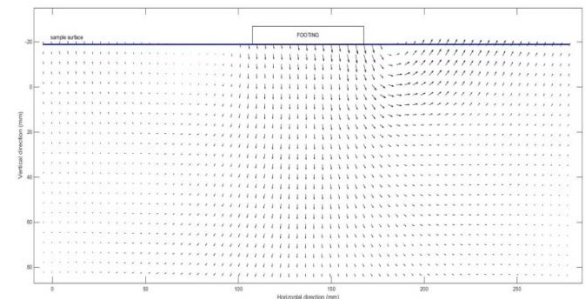


Fig. 10: Vector of soil deformation for Test 4

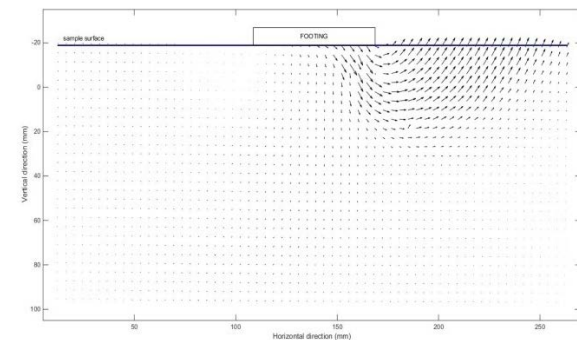


Fig. 11: Vector of soil deformation for Test 6

5. CONCLUSION

The bearing capacity factor, settlement, and ground deformation of sand was investigated based on small physical modelling and PIV method. The conclusions that can be made from this research are listed as follows:

1. The bearing capacity decreased while the settlement increased with the increasing of eccentricity to footing width ratio.
2. The discrepancies between the angle of internal friction of sand back-calculated from the small scale physical model and shear box test was approximately 17.6%. The difference between the theoretical and physical modeling test which might be contributed from the wall friction between the testing chamber wall, the roughness of the footing interface and non-homogeneity of the soil bed during the loading.
3. A clear soil movement toward the right side of the footing was observed due to the footing eccentricity with the largest rotation happened on the largest eccentricity side as shown in Figure 11.

6. ACKNOWLEDGEMENTS

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