SETTLEMENT OF STRIP FOOTING ON SANDY SOIL DUE TO ECCENTRICITY

KREKAR SABER BRAIM

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This thesis is dedicated to my parents.

For their endless love, support, encouragement.

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ABSTRACT

The failure behaviour of the shallow foundation under centric and eccentric loading has been studied extensively. Bearing capacity and settlement are two limits of foundation design. The studies on the effect of eccentricity on bearing capacity are abundant, while the study about the effect of eccentricity on settlement is very rare. The aim of this study is to investigate the effect of eccentricity on settlement of sandy soil. The objectives of this research involve the evaluating the ultimate and allowable bearing capacity and verifying bearing capacity factor (N_γ), determination of settlement of sandy soil under different eccentricity ratio (e/B), analysing the failure mechanism of strip footing on cohesionless soil by close range photogrammetry and particle image velocimetry (PIV) methods, and verifying the laboratory results with theory or analytical analysis for centrally loaded strip footing. This research mainly concentrates on the laboratory tests. Several tests were conducted which consist of physical property tests and small scale physical modelling test. A model of medium sand with 50% relative density was prepared, strip footing was replicated using a rigid plate and loaded with different eccentricity. Moreover, close range photogrammetry and PIV technique were used to observe the failure pattern, contour of displacement, and shear strain under strip footing. It was found that the settlement increases with increasing eccentricity.

ABSTRAK

Tingkah laku kegagalan asas cetek dibawah pemberat *"centric"* dan *"eccentric"* telah dikaji. Keupayaan galas dan enapan adalah dua had kepada rekaan asas. Kajian impak *"eccentricity"* terhadap keupayaan galas telah banyak dilakukan manakala kajian impak *"eccentricity"* terhadap enapan adalah jarang. Tujuan utama kajian ini adalah untuk menyelidik impak *"eccentricity"* kepada enapan tanah berpasir. Objektif kajian ini melibatkan penilaian keupayaan galas muktamad dan dibenarkan dan juga mengesahkan faktor keupayaan galas (N_γ), penentuan enapan tanah berpasir dibawah purata *"eccentricity"* berlainan (e/B), penganalisaan mekanisme kegagalan jalur asas pada tanah jeleket dengan fotogrametri jarak dekat dan kaedah imej partikel velosimetri (PIV) dan mengesahkan keputusan makmal dengan teori dan analisis analitikal untuk beban berpusat jalur asas. Kajian ini memfokuskan kepada ujian makmal. Beberapa ujian telah dijalankan antaranya ujian fizikal properti dan ujian fizikal model berskala kecil. Plat akan digunakan untuk mereplika asas dan dimuatkan dengan *"eccentricity"* berlainan. Selain itu, fotogrametri jarak dekat dan teknik PIV telah digunakan untuk memerhatikan corak kegagalan dan kontour sesaran dibawah jalur asas.Kajian telah menunjukan enapan meningkat dengan peningkatan "*eccentricity*".

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BC	-	Bearing Capacity
BS	-	British Standard
CCD	-	Charge Coupled Device
CPT	-	Static Cone Penetration Test
DMT	-	Flat Dilatometer Testing
FFT	-	Fast Fourier Transform
FS	-	Factor of Safety
LSF	-	Linear Scale Factor
LVDT	-	Linear Variable Differential Transformer Transducer
PIV	-	Particle Image Velocimetry
PLT	-	Plate Load Test
PMT	-	Pressuremeter Test
SPT	-	Standard Penetration Test
SW	-	Well-graded Sand
USCS	-	Unified Soil Classification System

LIST OF SYMBOLS

B	-	Footing Width
B'	-	Effective Width
B_R		Reference footing width
C_c or C_r	-	Coefficient of Gradation
C_u	-	Coefficient of Uniformity
c_c	-	Compression Index
C_W	-	Water Correction Factor
C_D	-	Embedment Correction Factor
c'		Effective Cohesion
D'	-	Depth of Failure Surface
D_f	-	Footing Embedment Depth
D_{10}		Particle Effective Size Correspond to 10% Finer
D_{30}		Particle Size Correspond to 30% Finer
D_{60}		Particle Size Correspond to 60% Finer
e	-	Eccentricity
e_o	-	In Situ Void ratio
E_s		Modulus of Elasticity
G_s	-	Specific Gravity
I_D or D_r	-	Relative Index or Relative Density
I_s	-	Strain Influence Factor
K_E	-	Dimensionless Modulus Number

L	-	Footing Length
M	-	Moment
N	-	Blow count
N_{60}	-	Uncorrected Blow Count
$(N_1)_{60}$	-	Corrected Blow Count
p'	-	Effective Overburden Stress at Mid-Depth
p_a	-	Atmospheric Pressure
q	-	Net Footing Stress
q_{min}	-	Minimum Footing Base Pressure
q_{max}	-	Maximum Footing Base Pressure
q_c	-	Cone Penetration Resistance
q_{ult}	-	Ultimate Bearing Capacity
q_{allow}	-	Allowable Bearing Capacity
Q_{uc}	-	Ultimate Load Capacity of Centrally loaded Footing
Q_{ue}	-	Ultimate Load Capacity of Eccentrically Loaded Footing
R_k	-	Bearing Capacity Reduction Factor
$R_{(s)}$	-	Cross Correlation Estimator
$R_{n(s)}$	-	Normalized Cross Correlation Estimator
$N_{c,}\ N_{q,}N_{\gamma}$	-	Bearing Capacity Factors
$s_{c,}\ s_{q,}s_{\gamma}$	-	Footing Shape Factors
$d_{c,}\ d_{q,}d_{\gamma}$	-	Footing Depth Factors
$I_{c,}\ I_{q,}I_{\gamma}$	-	Load Inclination Factors
N_{γ}^{*}	-	Modified Bearing Capacity Factors
$\emptyset_{sb}$	-	Angle of Internal Friction from Shear Box Test
$\emptyset_{tr}$	-	Angle of Internal Friction from Triaxial Test

$\emptyset_{pl}$	-	Angle of Internal Friction from Plane Strain Condition
$\emptyset'$	-	Effective Angle of Internal Friction
$\emptyset^{*}$	-	Modified Angle of Internal Friction
γ	-	Unit weight
γ_{dry}	-	Dry Unit Weight
$\gamma_{dry(min)}$	-	Minimum Dry Unit Weight
$\gamma_{dry(max)}$	-	Maximum Dry Unit Weight
σ_o	-	Total Overburden Pressure
σ_o'	-	Effective Overburden Pressure
$\Delta\sigma'$	-	Net Effective Stress
μ_s	-	Poissons' Ratio
ψ	-	Angle of Dilation
s_e	-	Elastic or Immediate Settlement
S	-	Patch Displacement
U	-	Patch Location

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CHAPTER 1

INTRODUCTION

1.1 Background of research

Structures have often been supported by footings in a soil which is adequately strong to serve as bearing layer (Junhwan and Rodrigo, 2002). Settlements above tolerable limit under working loads generally impair serviceability and function of both foundation and the superstructure which ultimately leads to failure of infrastructures (Junhwan and Rodrigo, 2002). Thus, structures need to be supported by foundation such that settlement at the footing is kept within bearable limits. Therefore, it is imperative to estimate potential settlement to critically assess soil bearing capacity during the design of foundation such that settlement under working load is within the tolerable range. Basically settlement of foundation consists of two components which are the elastic and consolidation settlements (Braja et al, 2009). Thus, elastic settlement is common is sandy soil material. And is estimated based on linear elastic approach. However, foundation induced stress-strain in the soil is usually in the form of elasto-plastic range (Lee and Selgado, 2002). Granular soil material has been modeled by number of researchers in which deformations of sandy soil and bearing capacity factors under different loading situations such as centrally inclined, eccentrically inclined, eccentrically vertical, centrally vertical (Meyerhof, 1953; Meyerhof, 1963; Loukidis et al, 2008).

This has been confirmed by other researchers (Erol et al, 2009). It has been established that lateral forces due to water, earthquake and wind can subject foundations to moments. Eccentricity in strip footing is defined as the ratio of moment (M) to vertical load (Q). As the eccentricity increases, ultimate load decreases usually. This leads to the formation of failure surface of eccentric footing largely at one side of the footing, as against nearly symmetrical failure surface for centric footing. (Meyerhof, 1953; Prakash and Saran, 1971; Uzuner, 1975; Moroglu et al, 2005) have all observed this type of failure mechanism for eccentric footing. Accordingly, it causes less failure compared to the same centric footing

Meyerhof (1953) effective width concept and conventional methods were used for calculating the ultimate load (Q_u) of the eccentrically loaded foundation. Meyerhof (1953) considered the ultimate load of eccentrically loaded strip footing equal to that of centrally loaded strip footing but with a reduced footing width, B. Linear stress distribution, vertical equilibrium for all forces, moment equilibrium were the assumptions made in the determination of normal base pressure distribution under an eccentrically loaded foundation using customary analysis. These assumptions were further confirmed (Uzuner, 1975).

The amount of settlement superstructure can tolerate and determines the design of foundation on sandy soil (Nova and Montrasio, 1991). Hadi and Ali (2010) have confirmed that excessive settlement causes structural damages due to loss of bearing capacity of the underlying soil. Thus, Shahriar (2012) suggested that foundations on cohesionless soil should be designed such that settlement is within tolerable limits. Otherwise, excessive vertical deformation will occur (Díaz and Tomas, 2014). Other effects of settlements were the distortion of structural geometry due to tilting and angular distortion of superstructure (Saurabh et al, 2014). This further leads to cracks due to induced tensile stresses more that of the carrying capacity of the structure. Structural instability can also be generated due to formation of sudden joint as a results of large size cracks.

1.2 Problem Statement

It has been established that settlement of foundation beyond tolerable limits impairs the functionality and serviceability of superstructure. Thus, excessive settlement is caused by loss of soil bearing capacity underneath the footings. Consequently, leads to structural damages. Also settlements were known to cause the distortion of structural geometry due to tilting and angular distortion of superstructure. Eccentric loading, however, subjects the foundation to moments. Thus, leads to the formation of failure surface largely to one side of the footing. Therefore, this study will give an insight on the effects of eccentric loading induced settlement.

1.3 Aim and Objectives

The aim of this study is to observe the settlement behaviour of eccentrically loaded surface strip footing on a sandy soil.

The objectives of the study are as follows:

1. To evaluate the ultimate and allowable bearing capacity and verifying bearing capacity factor N_γ of sand under different eccentricity.
2. To determine the settlement of sandy soil under strip footing with different eccentricity ratio (e/B).
3. To analyse the failure mechanism of strip footing on cohesionless soil by Close Range Photogrammetry and Particle Image Velocimetry (PIV) methods.
4. To verify the laboratory results with theory/analytical analysis for centrally loaded strip footing.

1.4 Scope and limitation of the research

In this research, physical properties tests and major physical chamber test were be conducted. Physical properties tests include sieve analysis, specific gravity, relative index, and Shear Box tests. Shear Box Test was used to obtain angle of internal friction of the soil. The material used in this research is sand with 50% relative density (medium packed sand). Then, from main chamber physical test, a strain controller was used to carry out the Bearing capacity test and determine the Bearing capacity factor $N\gamma$ and dead load system was used to measure settlement of strip footing on a sandy soil with both centric and eccentric loading conditions respectively. Linear vertical displacement transducer (LVDT) and load cell were used to record displacements and stresses during loading. Close Range Photogrammetry and Particle image velocimetry (PIV) were utilized to reveal the failure surface pattern under strip footing.

1.5 Significance of research

The significance of this study is to investigate the behavior of granular soil, to observe the failure pattern and determination of bearing capacity factor under different eccentricity. The failure pattern under strip footing was revealed by particle image velocimetry.

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