THE ASSESSMENT OF REINFORCED CONCRETE SOLID FLOOR SLABS SUBJECTED TO COMBINED ACTIONS OF VERTICAL AND LATERAL LOAD

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ABSTRACT

Reinforced concrete floor slabs carry gravity load and behave as rigid floor diaphragms to provide stability and lateral resistance to wind actions, earthquakes and lateral soil loads. Floor slabs are often analyzed and designed as uniform plate elements which only possess out-of plane stiffness to carry forces acting normal to the plane. However, an important issue which is often overlooked by the design engineers is that in order for a slab to provide ideal diaphragm actions, the slabs must possess adequate thickness. When slabs are subjected to out-of-plane bending moment due to gravity load and significant compressive forces, they would behave like a slender columns or walls. As consequences of additional deflection and secondary stresses on slabs, particularly at basement floor where lateral forces due to earth and water pressure are significant, the concrete slabs might crack. The project studied the assessment of strength and behaviour of conventional basement floor solid slabs that are subjected to combined actions of vertical and lateral forces. A typical conventional basement floor was proposed and analysed. The solid slabs panels were analysed and designed according to equation and coefficient in code of practice BS8110. Besides, first order and second order analysis using finite element method were carried on the proposed model subjected to gravity force and combined gravity and lateral forces. The results indicate that non-linear analysis could significantly increase the vertical deflection slabs upto 12.29%, bending moment upto 8.45% and shear forces upto 5.86% in minor or major axis of the slabs spanning. Possible visible cracking would occur near to the column support area and soffit of corner slab panels.

ABSTRAK

Papak lantai konkrit bertetulang menampung beban graviti dan berkelakuan sebagai medan lantai yang tegar untuk menyediakan kestabilan dan rintangan sisi kepada tindakan angin, gempa bumi dan beban tanah sisi. Papak lantai sering dianalisis dan direka bentuk sebagai unsur-unsur plat seragam yang hanya mempunyai sifat kekukuhan "luar-satah" untuk menampung daya yang bertindak secara normal kepada satah. Walau bagaimanapun, isu penting yang sering diabaikan oleh jurutera reka bentuk adalah bahawa dalam syarat bagi papak untuk menyediakan tindakan diafragma yang ideal, papak mestilah mempunyai ketebalan yang sepatutnya. Apabila papak adalah tertakluk kepada daya lentur luar-satah akibat beban graviti dan daya mampatan yang ketara, kelakuannya berubah menjadi seperti tiang-tiang atau dinding langsing. Pesongan tambahan dan tegasan sampingan pada papak, terutamanya di tingkat bawah tanah di mana daya sisi disebabkan oleh bumi dan tekanan air yang ketara menyebabkan papak konkrit mungkin mengalami keretakan. Projek ini mengkaji dan menilai kekuatan dan kelakuan papak lantai konvensional bawah tanah yang tertakluk kepada tindakan gabungan daya-daya menegak dan sisi. Satu tingkat besmen tipikal yang konvensional telah dicadangkan dan dianalisis. Panel papak lantai telah dianalisis dan direka mengikut persamaan dan pekali dalam kod amalan BS8110. Selain itu, analisis peringkat pertama dan peringkat kedua menggunakan kaedah elemen terhingga telah dilaksanakan ke atas model tersebut semasa ditindakan dengan daya graviti serta gabungan daya graviti dan daya sisi. Keputusan menunjukkan bahawa analisis tidak-linear akan meningkatkan pesongan tegak sebanyak 12.29%, lentur momen sebanyak 8.45% dan daya ricih sebanyak 5.86% dalam paksi minor atau major rentangan papak lantai. Analysis juga mendapati bahawa keretakan mungkin berlaku di kawasan berhampiran dengan sokongan dan permukaan bawah panel papak sudut.

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3D	–	Three dimensional
DL	–	Dead /permanent load
FE	–	Finite element
FH	–	Basement floor to floor height
r.c.	–	Reinforced concrete
LL	–	Live /imposed load
LEL	–	Lateral earth load
M&E	–	Mechanical and electrical
Mid	–	Middle
SDL	–	Superimposed dead load
Supp	–	Support

LIST OF SYMBOLS

a_u – Calculated additional deflection for member subjected to axial load

a_v – Distance of a concrete section from support face

A_c – Net cross section area of concrete

A_s – Area of tension reinforcement

A_s’ – Area of compressive reinforcement

A_{sc} – Area of reinforcement

A_{sv}/s_v – Area of shear link reinforcement to link spacing

b – Slab / beam design width

B1 – Resultant lateral earth force on basement 1 floor

B2 – Resultant lateral earth force on basement 2 floor

B3 – Resultant lateral earth force on basement 3 floor

c – Concrete cover

d – Effective depth of tension reinforcement

d' – Depth of compressive reinforcement

Dx – Horizontal deflection in the X-axis direction of analysis model

Dy – Horizontal deflection in the Y-axis direction of analysis model

Dz – Vertical deflection in the Z-axis direction of analysis model

E – Modulus of elasticity.

E_{LT} – Long Term Modulus of elasticity

E_{ST} – Short Term Modulus of elasticity

f_{cu} – Concrete grade /compressive strength.

f_y – Strength of flexural reinforcement

f_{yv} – Strength of shear reinforcement

F – Ultimate vertical design load

GL – Resultant lateral earth force on ground floor

h – Slab thickness

h_1 – Ground water level below ground

h_2 – Height of ground water constituting water pressure

H – Storey floor height

I – Area moment of inertia

K – Column effective length factor / Strength reduction factor for concrete section subjected to axial load

K_o – Coefficient of at-rest lateral earth pressure

KL – Effective length of column

L – Span of member or length of cantilever/ unsupported length of column

L_e – Effective member span length

L_o – Clear member span length

L_{fac} – Modification factor for span length in deflection checking

M – Design bending moment

M_1, M_2 – Initial moment

M_{add} – Additional moment due to additional deflection

M_{ft} – Modification factor for tension reinforcement in deflection checking

M_{fc} – Modification factor for compressive reinforcement in deflection checking

M_{mid} – Moment at mid-span

M_{supp} – Moment at support

Mx(B) – Bottom surface local X-axis moment / flexural reinforcement / crack width

Mx(T) – Top surface local X-axis moment/ flexural reinforcement / crack width

My(B) – Bottom surface local Y-axis moment/ flexural reinforcement / crack width

My(T) Top surface local Y-axis moment/ flexural reinforcement / crack width

N – Design ultimate axial load

N_{uz} – Design ultimate axial capacity

N_{bal} – Design axial capacity of balanced section

P_{cr} – Maximum or critical force for buckling

$P–\delta$ – Member curvature effects

$P–\Delta$ – Member side sway effects

q – Surcharge load on ground

Sx – Local X-axis shear force

Sy – Local Y-axis shear force

T – Design torsional force

V – Design shear force

v_c – Concrete section shear capacity

$V_{c,av}$ – Enhanced Shear Strength at distance 'a_v' from support face

V_{supp} – Design shear force at support

v_t – Torsional shear stress

$v_{t,min}$	–	Minimum torsional shear stress, which reinforcement is required
v_{tu}	–	Maximum combined shear stress (shear plus torsion)
W_1, W_2, W_3	–	Calculated lateral earth pressure
W_{beam}	–	Supporting beam width
z	–	Lever arm of the design concrete section
λ	–	Slenderness of member
β	–	Coefficient value for effective span length
β_a	–	Coefficient value for calculated additional deflection for concrete section subjected to axial load
Ǿ	–	30 Years Creep Coefficient
γ	–	Soil bulk density
γ_{sat}	–	Saturated soil density
γ_w	–	Water density

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CHAPTER 1

INTRODUCTION

1.1 General

Slabs are the flooring systems of most structures including office, commercial and residential buildings, bridges, sports stadiums and other facilities building. The main functions of slabs are generally to carry gravity forces, such as loads from human weight, goods and furniture, vehicles and so on. In modern structure design particularly for high rise buildings and basement structures, slabs as floor diaphragms help in resisting external lateral actions such as wind, earthquake and lateral earth load.

Depending on the structure framing configuration, architectural requirement, analysis and design methods selected by the engineer, slabs can be uniform thickness or ribbed spanning in one way or two ways between beams and/or walls. These flooring systems can be cast-in-situ reinforced concrete, metal deck with in-situ concrete, precast concrete or prestressed concrete. Concrete slabs which are resting on support columns only either with or without column heads and drop panels are defined as flat slabs.

1.2 Background

In general, reinforced concrete floor slabs are often analyzed and designed as uniform plate elements which only possess out-of plane stiffness to carry loads acting normal to the plane of the slab. In other words, slabs are designed to resist only the bending moment in two orthogonal directions as well as twisting moments .

Besides that, slabs also contribute to the lateral load resistance and stability by transmitting the forces to main framing systems, that are, the floor beams, columns, shear walls or core walls. This is based on the assumption that in-plane stiffness of slabs is so great that it act as a rigid diaphragm. Three common types of lateral actions on a structure are the lateral earth pressures, wind forces and seismic loads.

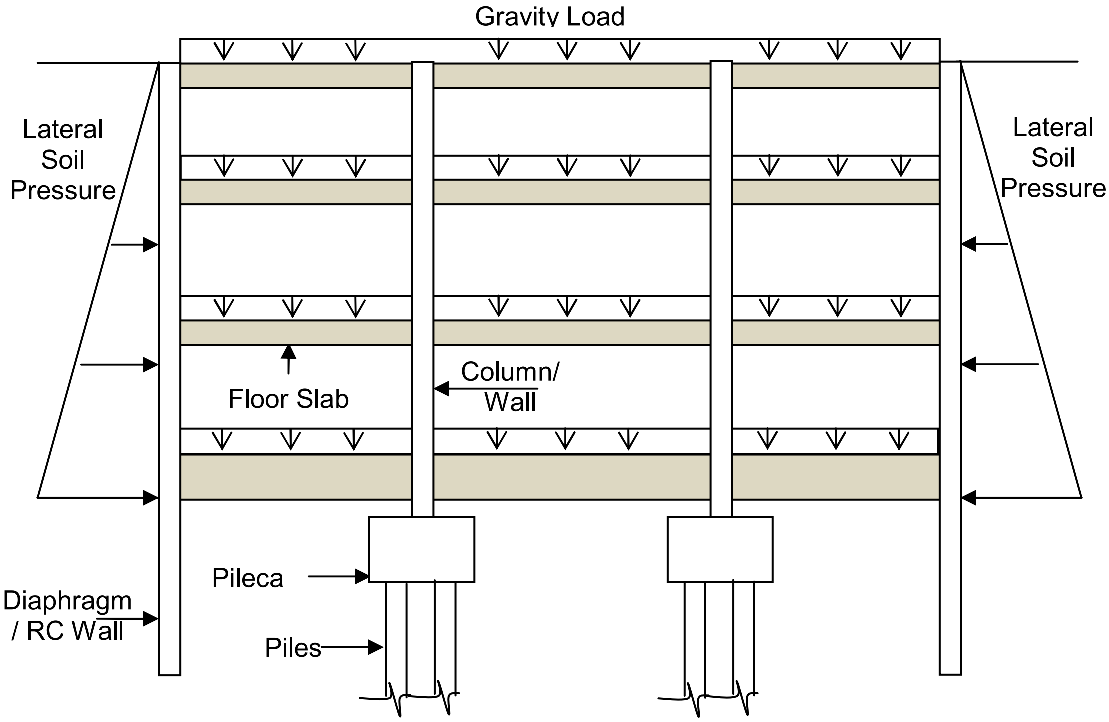

Figure 1.1: A Typical Basement Floor Structure

However, an important issue which is often overlooked by the design engineers is that in order for a slab to provide ideal diaphragm actions, the slabs must possess adequate thickness [1]. The diaphragm stresses in slab due to in-plane forces, might have exceeded the concrete resistance capacity and often slabs are not checked regarding this matter. The cast-in-situ reinforced concrete connection between slabs and beams or between slabs and columns or walls is another important feature that is often not carefully reviewed and detailed by the end of design stage to tally with the preceding analysis assumption.

In addition, when slabs are subjected to out-of-pane bending moment due to gravity load and significant compressive forces due to lateral forces simultaneously, they would behave like uniaxial bending slender columns. There might be significant secondary moment and shear forces due to axial forces acting on the deflected slab. This is difficult to identify based on the first order linear elastic analysis that are usually adopted for slab design.

The additional deflection and stresses due to additional lateral forces, improper connection detailing and secondary effect of combined actions, may cause slabs to crack or even fail, should these are not taken into consideration of analysis and design. Once the slabs start to crack, the stiffness would be reduced affecting the performance of the floor system as well as the diaphragm effect on structural stability. For example, cracks are often observed at basement floor slabs where the structure may be subjected to both lateral load and gravity load simultaneously. Figure 1.1 illustrate a typical basement floor structure subjected both gravity loads and lateral soil loads.

1.3 Objectives

The main objectives of this project are as below:

i. To study the behaviour of reinforced concrete solid slabs at basement floor subjected to combined actions of gravity loading and lateral earth loading and investigate the possibility of cracking,

ii. To investigate the impact of second order analysis on slender solid floor slabs, considering nature of geometrical non-linear, concrete short term and long term modulus of elasticity.

iii. To propose recommendation for design and detailing requirement of reinforced concrete solid floor slabs, depending local floor stresses, framing configuration and support systems.

1.4 Scope of Study

In this study, only numerical analysis has been carried out and there is no experimental work or laboratory test. The structural analysis is based on static analysis of combined gravity loads and lateral forces on slabs. The study focuses on a proposed conventional type of car park floor model with typical design superimposed load of 0.5kN/m^2 and imposed load of 2.5kN/m^2. Besides carrying gravity load, the basement slabs also act as a strut system to a series of diaphragm walls or reinforced concrete walls that retains the surrounding earth. As the loads acting on the structures are stationery or very slowly over time, the dynamic effect is assumed insignificant and not considered in the analysis.

Prior to the analysis, suitable thickness for the slab models is determined using the simple calculation span-to-effective-depth ratio method as recommended by the code of practice The critical force is later compared with some calculated lateral soil loads, assuming the slabs to be constructed at basement floor with both functions of flooring and strutting system to earth retaining wall.

Then, first order linear and second order elastic analysis using finite element method is carried on the proposed slab models which are applied with gravity force and followed by combined gravity and lateral forces. The results of internal forces, displacements, bending moments and shear forces for both types of analysis are observed and discussed. Possible cracks in slabs due to the stresses and strains are checked and identified by comparing with the typical design provision and detailing.

Based on the analysis results, some designs and detailing requirements of reinforced concrete basement slabs are proposed to optimize the design and to avoid slab cracking and failure.