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The Behaviour of Concrete Wall Panel with Opening

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The Behaviour of Reinforced Concrete Wall Panel with Opening

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DECLARATION

I, Chong Fung Yun (12060118) from Faculty of Engineering UNIMAS hereby declare that the work entitled “The Behaviour of Reinforced Concrete Wall Panel with Opening” is my original work. I have not copied from any other students’ work or from any other sources, except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date:

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ABSTRACT

Reinforced concrete wall panels with cut-out opening are the common structural component which are utilised in the construction industry. This research study carries out is aimed at evaluating and determining the structural behaviour of the reinforced concrete wall panels with various cut-out opening sizes, shapes and location. The maximum principal strain and stress, deformation and failure load were used to explain the behaviour of the reinforced concrete wall panels. A parametric study was performed with layered finite element method (LFEM) wall modelling by using the ANSYS software (Version 19.1). In order to evaluate the behaviour of the one-way reinforced concrete wall panels on its opening size, seven different wall types have been modelled, one solid wall and six walls with square opening size ratios, A_o/A between 1% to 20%. The failure loads decrease by around 90% when the opening size ratio increases to 20%. The results shown is in accordance to the hypothesis tested of which the increase in opening size tends to decrease the strength of the reinforced concrete wall panels. In addition, as the 10% of square opening size was taken as the controlled results, the parametric study showed that the investigated shapes of opening gave a reduction in failure load. The effect of the opening shapes which influenced the behaviour of the reinforced concrete wall panels was due to the top or bottom spandrel to the opening and also the areas remained between the left or right piers to the opening sides. To fully understand the behaviour of the reinforced concrete wall panels with opening, the hypothesis design criteria was carried out by manipulating the locations of the opening by shifting it towards the vertical, horizontal and diagonal directions. When the location of the opening is shifted vertically downwards, the failure load has increased. It was mainly due to the increase in the spandrel areas and distance between the top of the opening to the axial loads. Likewise,

when the location of the opening was shifted away from the centre towards the incline directions, it exhibited the same trend of result outcomes with the increase in failure load because the eccentricity has moved away from the centre towards the concentrated areas of which the load acts on the wall panel. For the horizontal allocations of opening, it shows that the further the opening located from the centre, the smaller the failure loads since the eccentricity of the axial loads applied to the opening has been altered and therefore it caused the unbalance distributions of stresses and strains around the areas of the opening and caused the wall panel to deform and decrease in strength. In summary, the variety of the opening sizes, shapes and locations influenced the behaviour of the reinforced concrete wall panels. If the size of opening on the reinforced concrete wall panel is greater, then the strength of the wall panel will be decreased. When the reinforced concrete wall panels are loaded under one-way axial loads, the distributions of the maximum stresses and strains always concentrated around the areas of the opening. The degree of deformations illustrated by the wall panels corresponding to its failure loads of which the wall can be sustained before failure. As this research study is aims to reveal the utilisation of the reinforced concrete wall panel in the construction industry especially the on-site cut off opening due to uncertainty situations on site, therefore, this research contributes valuable knowledge on the effect of opening to the behavior of reinforced concrete wall panels.

Keywords: Reinforced concrete wall panel, opening, maximum principal stress, maximum principal strains, deformations

Sifat bagi Panel Dinding Konkrit Bertetulang dengan Pembukaan Potong di Tapak Pembinaan

ABSTRAK

Panel dinding konkrit bertetulang dengan pembukaan potong di tapak pembinaan adalah komponen struktur biasa yang digunakan dalam industri pembinaan. Kajian penyelidikan yang dijalankan ini bertujuan untuk menilai dan menentukan tingkah laku struktur panel dinding konkrit bertetulang dengan pelbagai pembukaan yang beza dalam ukuran, bentuk dan lokasi. Tegasan maksimum, ubah bentuk dan beban kegagalan digunakan untuk menjelaskan kelakuan panel dinding konkrit bertetulang dengan pembukaan potong di tapak pembinaan. Kajian parametrik dilakukan dengan pemodelan dinding kaedah linear (LFEM) dengan menggunakan perisian ANSYS (Versi 19.1). Untuk menilai tingkah laku panel dinding konkrit bertetulang sehala pada ukuran pembukaannya, tujuh jenis dinding yang berbeza telah dimodelkan, satu dinding padat dan enam dinding dengan nisbah ukuran pembukaan persegi, Ao / A antara 1% hingga 20%. Beban kegagalan menurun sekitar 90% apabila nisbah ukuran bukaan meningkat sehingga 20%. Hasil yang ditunjukkan adalah sesuai dengan hipotesis yang diuji dimana peningkatan ukuran pembukaan cenderung menurunkan kekuatan panel dinding konkrit bertetulang. Di samping itu, saiz 10% pembukaan persegi diambil sebagai hasil yang dikawal, kajian diteruskan dengan mengkaji kesan pembukaan dengan bentuk yang berlainan. Kajian parametrik menunjukkan bahawa bentuk pembukaan yang disiasat memberikan pengurangan beban kegagalan. Kesan bentuk pembukaan yang mempengaruhi kelancaran panel dinding konkrit bertetulang adalah disebabkan oleh luas permukaan dinding di keliling pembukaan. Untuk memahami sepenuhnya tingkah laku panel dinding konkrit bertetulang dengan bukaan, kriteria reka bentuk hipotesis dilakukan dengan memanipulasi lokasi bukaan dengan mengalihkannya ke

arah menegak, mendatar dan pepenjuru. Apabila lokasi pembukaan dialihkan secara menegak ke bawah, beban kegagalan meningkat. Ini terutama disebabkan oleh peningkatan kawasan spandel dan jarak antara bahagian atas pembukaan ke paksi beban. Begitu juga, ketika lokasi pembukaan dipindahkan dari pusat ke arah lereng, ia menunjukkan arah aliran hasil yang sama dengan peningkatan beban kegagalan kerana eksentrisitas telah bergerak jauh dari pusat ke arah kawasan pekat yang bebannya bertindak pada panel dinding. Untuk peruntukan bukaan mendatar, ini menunjukkan bahawa semakin jauh pembukaan yang terletak dari tengah, semakin kecil beban kegagalan kerana eksentrisitas beban paksi yang dikenakan pada pembukaan telah diubah. Oleh itu ia menyebabkan pembahagian tekanan dan ketegangan yang tidak seimbang kawasan pembukaan dan menyebabkan ketidak sempurnaan panel dinding dan penurunan kekuatan. Ringkasnya, pelbagai ukuran, bentuk dan lokasi pembukaan mempengaruhi tingkah laku panel dinding konkrit bertetulang. Sekiranya ukuran bukaan pada panel dinding konkrit bertetulang lebih besar, maka kekuatan panel dinding akan berkurang. Apabila panel dinding konkrit bertetulang dimuat di bawah beban paksi sehala, pengedaran tegasan dan regangan maksimum selalu tertumpu di sekitar kawasan bukaan. Tahap ubah bentuk yang digambarkan oleh panel dinding sesuai dengan beban kegagalannya yang mana dinding dapat ditahan sebelum kegagalan. Oleh kerana kajian penyelidikan ini bertujuan untuk mendedahkan penggunaan panel dinding konkrit bertetulang dalam industri pembinaan terutamanya pembukaan terputus di lokasi kerana keadaan tidak menentu di lokasi, oleh itu, penyelidikan ini menyumbang pengetahuan berharga mengenai kesan pembukaan terhadap tingkah laku panel dinding konkrit bertetulang.

Kata kunci: *Panel dinding konkrit bertetulang, pembukaan, tegasan pokok maksimum, regangan utama maksimum, ubah bentuk*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
A_g	Gross cross-sectional area of wall in plane
A_0	Area of opening
A_{sv}	Area of vertical steel in wall
AS	Australian Standard
BS	British Standard
f_v	Yield strength of steel
H	Height of wall panel
H_0	Height of opening
IBS	Industrialised Building System
L	Length of wall panel
LFEM	Linear Finite Element Analysis
L_0	Length of opening
N_u	Ultimate load for solid wall
N_{uo}	Ultimate load for wall with openings
s_x	Opening spacing parameter for walls with two openings located side by side
t_w	Thickness of concrete wall panel
x	Opening geometry parameter
x_x	Opening parameter with respect to the influence of opening size and location in the horizontal direction
x_y	Opening parameter with respect to the influence of opening size and location in the vertical direction

x_{xy}	Opening parameter defined by the opening size and location in both horizontal and vertical directions and the spacing between opening
α	Dimensionless parameter accounting for the opening width
$\propto_{xy}$	Dimensionless parameter accounting for the opening width and opening height
β	Effective height factor
η_x	Distance between centre of gravity of solid wall and the centre of gravity of wall with opening in x direction
$\tilde{\eta}_x$	Distance from the left vertical edge to the center of gravity of the cross-section of the panel with openings
η_y	Distance between centre of gravity of solid wall and the centre of gravity
$\tilde{\eta}_y$	Distance from the top vertical edge to the center of gravity of the cross-section of the panel with openings

CHAPTER 1

INTRODUCTION

1.1 General

Industrialised building system (IBS) is a term used in Malaysia for a technique of construction where-by components are produced in a controlled environment, either at site or off site, placed and assembled during construction works. Over the years, precast reinforced concrete wall panels are widely use in the construction industry. The demand for precast product particularly on precast concrete wall panels is continuously increasing in IBS. Precast reinforced concrete wall panels are usually used as load-bearing structural elements because these concrete products are able to resist high compressive stresses. Therefore, a precast reinforced concrete wall panel is acceptable as an important structural element apart from slabs, beams and columns. This acceptance is due to the increase in research undertaken by the researchers on the behaviour of concrete wall panels to improve and uplift their performance in construction industry.

Eurocode 2 (2014) defines a wall as reinforced concrete wall panel with a length to-thickness ratio of 4 or more, in which the reinforcement is taken into account in the strength analysis. IBS has categorised the reinforced concrete wall panel as in the form of precast concrete wall panel. Reinforced concrete wall panels have several advantages when they are used in IBS. By using this type of walls, some structural components such as beams and columns can be eliminated. Consequently, it may help to reduce the dead loads on the building which in turn reduce the cost of footings and foundations. Reinforced concrete wall panels are easy to design and use in fast track project. The reduction in time of construction will save the cost of construction at the same time.

In order to satisfy the demand in construction, functional modifications need to be made on the reinforced concrete wall panels. These modifications refer to the door and window openings, and also openings for ventilation system, electricity and water pipe. Figure 1.1 shows a cut-out opening for a window on the reinforced concrete wall. Therefore, modification on reinforced concrete wall panels is a necessity. It is more beneficial both environmental and economic to make these modifications of existing building than demolishing them and build up a new building. Therefore, the reinforced concrete wall panels with opening have become important structural elements in construction works. The opening in the reinforced concrete wall causes local cracking around the opening which leads to decrease in load carrying capacity (Mohammed et al., 2012).

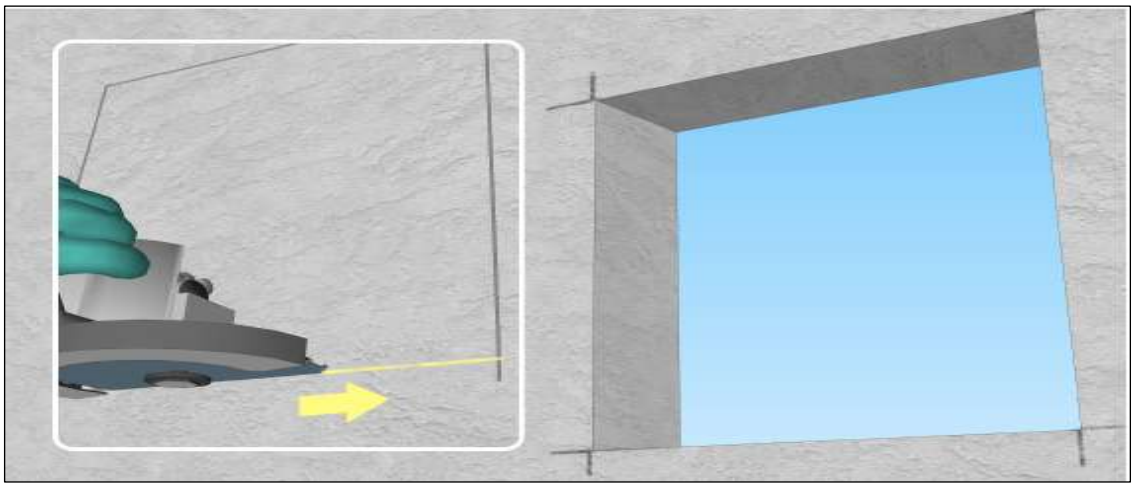

Figure 1.1: Cut out opening for a window opening, WikiHow (2018)

Generally, there are three types of openings in walls, which are, existing openings, enlarged existing openings and newly created openings (Popescu et al., 2015b). Existing opening is an opening that has been deliberately created in the factory. Once the location of the opening has been identified, the reinforcement can be placed around the opening according to the design method. An enlarged existing opening is the opening that cut the

surrounding wall to enlarge the opening. Newly created opening is an opening that is modified or created in an existing reinforced concrete wall. A cut-out opening has no design method. The opening is cut-out from an existing reinforced concrete wall panel. Previous researchers have studied on the behaviour of reinforced concrete wall panel with openings with different boundary condition, aspect ratio, size and position of opening and loading conditions (Saheb & Desayi, 1990a; Lee, 2008; Doh et al., 2010; Guan et al., 2010; & Fragomeni et al., 2015). However, the study on cut-out opening on reinforced concrete wall is less explored and the research on the subject is very limited. The cut-out opening on the concrete wall affects the structural capacity and stress distribution of the concrete wall panel due to the cut-off and reduction of reinforcement. Popescu et al. (2015a) studied the behaviour of cut-out opening on concrete wall panel and found that fibre-reinforced polymer can increase the strength of the wall panel as externally bonded reinforcement. The change in behaviour of the reinforced concrete wall panel with opening influenced the load carrying capacity of wall panels, but none came to conclude regarding the ideal behaviour and the optimal size of existing opening of reinforced concrete wall panels. Recently, Jaseela and Pillai (2017) found the optimum shape of cut-out opening on concrete structural wall panel. Majority of the previous researchers studied the effect of boundary conditions in one-way and two-way wall but the study on the effect of load eccentricity and reinforcement ratio are less pronounced.

1.2 Problem Statement

The modification of opening on reinforced concrete wall panels is a necessity for door and window openings, and also openings for ventilation system, electricity and water pipe. Moreover, most Malaysians prefer to improve their house by doing renovation and

extension (star online, 2015). However, Malaysians have limited knowledge about reinforced concrete wall panel with opening. The opening created on the wall panel will reduce the load bearing capacity and lead to crack.

In the precast construction project, precast reinforced concrete wall panel is not the preferred material chosen by the client or architect for construct a building. This is because the opening of the reinforced concrete wall panel is usually modified in the factory. It need specialist to construct the opening design consideration. The cut-out opening in the wall panel changes the structural behaviour of the reinforced wall panel (EssayUK, 2008). Hence, reinforced concrete wall panel that can accommodate cut-out opening is desired in the market. The size and location of the opening affects the stress distribution and structural capacity of reinforced concrete wall panel (Lee at al., 2008, Guan et al., 2010). However, no design method for cut-out openings in reinforced concrete wall panel exist in current design codes especially for the cut-out opening on reinforced concrete wall panel at site (Eurocode 2 (2008), AS 3600 (2009), ACI (2011)). Eurocode 2 (2008) and AS 3600 (2009) provide limits for when an opening can be neglected and designed as a solid reinforced concrete wall panel, however, there are no agreed limits between large and small opening (Popescu et al., 2016). Most of the reinforced concrete wall panels were created at factory with existing mould and design that have been consult with specialist to save on production cost. This make difficulty for either contractor to create an opening during construction process or owner to make any renovation changing after the building was fully completely built.

The hypothesis tested analysis in this research include the significance difference between the strength of the concrete wall panel and the size of the opening. There are several factors which has significance impact on strength of the wall panel which included the size of the opening, shape of opening and location of the opening.

1.3 Research Aim and Objectives

The aim of this study is to determine the effect of opening shape ratio and location in reinforced concrete wall panel in order to evaluate the failure load, stress, strain and deformation of wall panel with cut-out opening on site. As this research study is aims to reveal the utilisation of the reinforced concrete wall panel in the construction industry especially the on-site cut off opening due to uncertainty situations on site, therefore, this research provides valuable knowledge on the effect of opening to the behavior of reinforced concrete wall panels.

The objectives of this study are focus on:

i. To investigate the relationship between the failure load, stress and strain distribution to reinforced concrete wall panel with cut-out opening on site.
ii. To evaluate the structural behaviour of reinforced concrete wall panel with cut-out opening on site with two-layer of reinforcement.
iii. To relate the effect of the configuration of opening in shape and location in reinforced concrete wall panel towards the cut-out opening on site.

1.4 Scope of the Study

This research focuses on the effect of cut-out opening on reinforced concrete wall panel's strength. In order to obtain a more comprehensive evaluation on the behaviours of reinforced concrete wall panel with opening, several parametric manipulations have been included in this research study. These parametric studies included the opening with different shape, size and location.

In this research study, all the reinforced concrete wall panels with 150 mm thick and double-layered reinforcement are modelled using the ANSYS software and are subjected to

one-way axial loads. One-way axial loads is preferable to the two-way loads since it can provide more direct comparison on the effect of the opening since it is only limited to one-way deflection, therefore, the deflection and deformation patterns can be obtained clearly.

To investigate the structural behaviour of the reinforced concrete wall panel with various opening, the results for the maximum failure load retained by the wall panels, stress and strain distribution displayed by each of the wall modelling are determined. Meanwhile, the opening with size ratio of 10% in square shape is selected as the controlled sample in this study since square shape represented the most widely practiced cut-out shape in the construction industry. At the meantime, opening with size ratio of 10% is the limit of the opening size ratio in the wall panel since the opening with size ratio of 10% or less can be regarded as a solid wall. Previous studies showed that it did not raised significance cut-off effect on the wall. Therefore, 10% of opening size ratio is selected in order to extend previous studies and to reveal the effects of the 10% cut-out opening size towards the structural behaviour of the reinforced concrete wall panel.

To relate the effect of the configuration of opening in shape and location in precast concrete wall panel towards the cut-out opening on site, the opening has been manipulated into square shape with opening size ratio ranges from 0% to 20%. Apart from that, the shape of the opening is manipulated into square, fillet square, slit rectangular, wide rectangular and circle. The location of the opening is configured to shift vertically upwards and downwards, horizontally to the left and diagonally to the south-west and north-west directions. By the end of this research study, the configuration on the opening which raised the optimum performances in all the aspects of retained failure loads, maximum stress and strain distributions are determined.