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STRENGTHENING OF SLAB WITH OPENINGS LOCATED IN THE SHEAR ZONE WITH CFRP SHEETS AND ANCHORS

CHEANG YEE

Thesis submitted in fulfilment of the requirements
for the award of the degree of
B. Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources
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JUNE 2016

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LIST OF SYMBOLS

P_{cr}	Initial cracking load
γ_{cr}	Relative increase against control sample
P_e	Experimental ultimate load
γ_e	Relative increase against control sample
E	Elastic modulus
f_y	Yield stress
μ	Poisson's ratio
f_c	Compressive strength of concrete
Ψ	Dilatation angle
η	Eccentricity

LIST OF ABBREVIATIONS

ACI	American Concrete Institute
BC	Brittle Cracking
CDP	Concrete-damaged Plasticity
CFRP	Carbon Fibre Reinforced Polymer
EB	Externally bonded
FRP	Fibre Reinforced Polymer
GFRP	Glass Fibre Reinforced Polymer
LVDT	Linear-Variable-Displacement-Transducers
NSM	Near-surface Mounted
RC	Reinforced Concrete
SI	Système Internationale

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ABSTRACT

This thesis deals with strengthening of slab with openings located in the shear zone with CFRP sheets and anchors. The objective of this thesis is to determine the behavior of reinforced concrete slab with opening located in the shear zone in terms of load deflection behavior and crack pattern, to evaluate the performances of CFRP sheets and anchors in strengthening of reinforced concrete slabs with openings, and to validate finite element results with experimental results. The thesis uses finite element software, Abaqus version 6.14 from Dassault Systèmes to simulate various configuration of CFRP anchors. The best configuration of CFRP anchors that resulted in highest ultimate load was identified and validation of results was conducted. The material model employed during the finite element analysis was Brittle Cracking model. From the finite element analysis, the highest ultimate load was achieved on slab with opening strengthened with CFRP sheets and anchors. The ultimate load was 58.39 kN, about 202.07 % higher than unstrengthen slab with opening. In experiment, slab with opening strengthened with CFRP sheets had the highest ultimate load among all laboratory specimens. The ultimate load was 15.74 kN, about 10.79 % greater than unstrengthen slab with opening. In terms of crack patterns, for slab without opening, slab with opening and slab with opening strengthened with CFRP had exhibited similar crack pattern, with only a visible vertical crack at the mid-span. Meanwhile, for slab with opening strengthened with CFRP and anchors, two visible cracks were detected at the middle region of the slab. The locations of crack were as predicted in Abaqus, since the stress around these regions was the highest. Finite element and laboratory test results show that both CFRP sheets and CFRP anchors were able to increase the ultimate load of slab with opening. However, in finite element analysis, a combination of CFRP sheets and anchors were found more effective in strengthening than by only using CFRP sheets, however the laboratory test results showed otherwise. This is due to the assumptions of perfect bond between CFRP sheets and concrete surface in Abaqus, and excessive stress inducted to the sample during drilling works.

ABSTRAK

Tesis ini membentangkan penyelidikan pengukuhan papak dengan pembukaan lubang di zon ricih. Objektif tesis ini adalah untuk mengetahui sifat papak dengan pembukaan lubang di zon ricih dalam aspek sifat beban-anjakan serta dengan corak retakan, untuk mengetahui prestasi lampiran *CFRP* dengan *Anchor* pada pengukuhan terhadap papak dengan pembukaan lubang, dan untuk mengesahkan keputusan unsur terhingga dengan keputusan makmal. Tesis ini menggunakan perisian unsur terhingga, *Abaqus* versi 6.14 daripada syarikat *Dassault Systèmes* untuk menjalankan simulasi terhadap konfigurasi *CFRP Anchor* yang berlainan. Konfigurasi *CFRP Anchor* terbaik yang dapat mencapai beban muktamad yang tertinggi akan disahkan dengan keputusan makmal. Model bahan yang digunakan dalam proses penganalisa unsur terhingga adalah model *Brittle Cracking*. Daripada analisa unsur terhingga, papak dengan pembukaan lubang dikukuhkan dengan lampiran *CFRP* berserta *Anchor* mempunyai beban muktamad yang tertinggi. Beban muktamadnya adalah 58.39 kN, lebih kurang 202.07% lebih tinggi daripada papak dengan pembukaan lubang yang tiada pengukuhan. Dalam eksperimen, papak dengan pembukaan lubang dikukuhkan dengan lampiran *CFRP* mempunyai beban muktamad yang tertinggi. Beban muktamadnya adalah 15.74 kN, lebih kurang 10.79% lebih tinggi daripada papak dengan pembukaan lubang yang tiada pengukuhan. Corak retakan untuk papak tiada pembukaan lubang, papak dengan pembukaan lubang, dengan papak dengan pembukaan lubang dikukuhkan dengan lampiran *CFRP* adalah seiras, dengan hanya satu retakan yang boleh dilihat di tengah span. Untuk papak dengan pembukaan lubang dikukuhkan dengan lampiran *CFRP* berserta *Anchor*, terdapat dua retakan di kawasan di tengah-tengah papak. Tempat retakan dilihat adalah sama dengan jangkaan *Abaqus*, kerana tekanan sekitar tempat berkaitan adalah yang tertinggi. Analisa unsur terhingga dan keputusan makmal menunjukkan bahawa lampiran *CFRP* berserta *CFRP Anchor* dapat menambahkan beban muktamad papak dengan pembukaan lubang. Bagaimanapun, dalam analisa unsur terhingga, kombinasi lampiran *CFRP* berserta *CFRP Anchor* adalah lebih berkesan dalam pengukuhan daripada hanya menggunakan sahaja lampiran *CFRP*. Akan tetapi, keputusan makmal menunjukkan yang sebaliknya. Ini adalah disebabkan andaian ikatan mutlak di antara lampiran *CFRP* dengan permukaan konkrit dalam perisian *Abaqus*, serta tekanan berlebihan ke atas spesimen yang disebabkan oleh proses pengerudian.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Slabs are flat plate-shaped load bearing elements, usually in uniform thickness throughout the whole element, designed to carry lateral actions (Yassin & Abdullah, 2015). Sometimes, in order to accommodate several services such as staircases, elevators, escalators, electrical cables, heating and ventilation systems, openings will be entail to slabs (Enochsson, et. al., 2007). These openings leads to deterioration of strength as concrete and reinforcement that are meant to carry the loads are removed. In order to enable these slabs to regain their carrying capabilities, Fiber Reinforced Polymers (FRP) sheets can be used to strengthen them.

Depending on the material, Carbon Fiber Reinforced Polymers (CFRP) or Glass Fiber Reinforced Polymers (GFRP) is a sheet-like material typically used for rehabilitation and strengthening works of reinforced concrete structure. FRP is light in terms of weight, easy to use and apply and gives significant increase in strength. These characteristics makes FRP an ideal material for rehabilitation and strengthening works. Usually, epoxy resin was used to bond FRP sheets to the surface of concrete, and loads applied on concrete will be transferred to FRP sheet. Unfortunately, bonded FRP sheets tends to suffers from debonding, whereby the FRP sheets detached from the concrete surface together with concrete substrates under loading before reaching the rupture strain of CFRP laminates. Debonding of CFRP sheets from concrete surface occurs as the strength of concrete substrate is lower than the bonding strength of epoxy to concrete surface and CFRP sheet. Anchors can be used to prevent debonding from occurring as

these anchors functions as an alternate force transfer mechanism for CFRP sheets to reach carrying capacity before debonding happens (Sun & Ghannoum, 2015).

Previously, some researchers showed that the strength and carrying capacity of reinforced concrete structures can be enhanced by using a combination of FRP sheets together with anchors (Koutas & Triantafillou, 2013; Smith, et al., 2011). Besides, finite element analysis on strengthening effect of FRP sheets on slabs with openings has been carried out by Enochsson, et al. (2007) and shows satisfactory results. However, not much finite element analysis was conducted on strengthening effect of CFRP sheets with CFRP anchors, especially on slabs with openings.

1.2 PROBLEM STATEMENT

A concrete slab with an opening usually will have decreased the strength and thus lower the load capacity than a same-sized slab without opening, whereby the larger the opening is, the larger the decrease in load capacity of the slab. Besides, the corners and edges of opening may act as crack initiators, making them more susceptible to cracking when loaded. Thus, slabs with openings need certain strengthening mechanism to enable the slab to carry the design load. Fiber Reinforced Polymer (FRP) laminates are commonly used for strengthening works of reinforced concrete structural member. FRP sheets is bonded to the concrete surface by using epoxy specified by the sheet's respective manufacturer and anchor is installed to prevent debonding of sheets. As the strengthening effect of CFRP is better than GFRP (Zhang, et. al., 2012), hence this study uses CFRP as the material for strengthening. The target of this study is to identify the strengthening effect of CFRP sheets together with anchors on slab with opening at shear zone.

1.3 OBJECTIVES OF THE STUDY

The objectives of the study are as follows:

i) To determine the behavior of reinforced concrete slabs with opening located in the shear zone in terms of load deflection behavior and crack pattern.

ii) To evaluate the performance of CFRP sheets and anchors in the strengthening of reinforced concrete slabs with openings.

iii) To validate the finite element results with the experimental results.

1.4 SCOPE OF THE STUDY

The scope of the research is to carry out analysis using commercially available finite element analysis program and later to verify these results by experimental works. The finite element analysis of the slabs were conducted by using Abaqus version 6.14 with slab specimen of dimension 500 mm x 120 mm x 1500 mm with opening of size 200 mm x 200 mm at the shear zone of the slab. The CFRP sheet used is *SikaWrap@-231 C* and the epoxy used is *Sikadur@-330 Epoxy Adhesive*. Since the effect of the design of anchor on arresting debonding of CFRP sheets is not a part of the studies, the design of anchor will not be consider in this research. Previously, Zhang, et. al., (2012) experimented with several design of anchors on arresting debonding of CFRP sheets and had proposed an optimum design of anchor on arresting debonding of CFRP sheets. Hence, the design of anchor adopted the optimum design as researched by Zhang, et al. (2012), which is flexible anchor made from 200 mm wide fiber sheet. The research examines the effect of arrangement of anchors on increment of the strength of slab. Laboratory test were conducted on the optimum arrangement of anchors which gives the highest increment of strength at University Malaysia Pahang Concrete Lab. The result considered in this study were the load-deflection curve/behavior, the debonding behavior of CFRP sheets from the slab and the crack pattern of slab.

1.5 RESEARCH SIGNIFICANCE

This research will provide a suggested arrangement of anchors to prevent or delay debonding of CFRP sheets from occurring when reinforced concrete structural members is strengthen by CFRP sheets, especially on slab members with openings. By preventing debonding of CFRP sheets from the surface of reinforced concrete structural members, the maximum rupture strains of CFRP sheet can be achieve before they detach from the surface and thus increase the strength of the aforesaid reinforced concrete structural members. Besides, this research may also provide a suitable location of anchors to prevent the installation of anchors to become crack initiators, especially when the anchors is installed nearby openings.