# EFFECTS OF CFRP ON REINFORCED CONVENTIONAL CONCRETE AND ULTRA HIGH PERFORMANCE CONCRETE FRAMES

**By**

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**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,in Fulfilment of the Requirement for the Degree of Master of Science**

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**Chair: Farzad Hejazi, PhD**
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In this era, mankind faces lots of threats and misfortunes, one of the biggest threats is earthquake, which destroy building and leave thousands of people dead and homeless, during earthquake load, the first part that lead to buildings failure are the joints. Many researches have been conducted to investigate the effect of the external use and rehabilitee of old structures with Carbon Fiber Reinforced Polymer (CFRP). However, very few researches have been carried out investigating the internal use of the CFRP in the structures. The main objective of this study is, to reinforce the frame beam-column joint with CFRP in order to sustain the seismic load. CFRP bars were implemented into two frames, conventional reinforced concrete (RC) frame and ultra-high performance concrete (UHPC) frame, to investigate the effect of embedded CFRP. Experimental test was conducted on the frames with embedded CFRP, to assess the seismic performance, functionality of the frames subjected to cyclic load, the experimental test showed that the ductility behaviour, overall stiffness and failure mechanism, enhanced in both the RC frame with embedded CFRP and the UHPC with embedded CFRP, where the load capacity increased 26%, 11% respectively, compared with the bare frame. Numerical analysis were also used alongside the experimental test, to evaluate the seismic behaviour of the embedded CFRP in joints. Numerical analysis result showed that, the ultimate load capacity increased in the frames with embedded CFRP in the RC frame and UHPC frame, 23%, 52% respectively. Moreover, a good agreement observed between the experimental test and the numerical analysis. Furthermore, finite element model developed for the RC frame with embedded CFRP in the special finite element program code, static nonlinear and nonlinear dynamic analysis were conducted .The static nonlinear result showed that the capacity of the frame with CFRP increased 66% compared to the bare frame and Nonlinear dynamic analysis showed that the maximum displacement for the frame with CFRP diminished 66% compared to bare frame. The efficiency and capability of embedded CFRP in RC frame and UHPC is proved.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**KESAN CFRP PADA KONKRIT KONVENSIONAL BERTETULANG DAN BINGKAI KONKRIT PRESTASI ULTRA TINGGI**

Oleh

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**Ogos 2017**

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Pada zaman ini, manusia menghadapi pelbagai ancaman dan musibah, salah satu ancaman yang terbesar adalah gempa bumi, yang memusnahkan bangunan dan menyebabkan kematian beribu-ribu orang dan kehilangan tempat tinggal, semasa kejadian gempa bumi, bahagian pertama yang membawa kepada kegagalan bangunan adalah rusuk. Pelbagai kajian telah dijalankan untuk mengkaji kesan penggunaan luaran dan rehabilitee struktur lama terhadap Carbon Fiber Reinforced Polymer (CFRP). Namun, sangat sedikit kajian yang telah dijalankan menyiasat penggunaan dalaman CFRP di dalam struktur. Objektif utama kajian ini adalah untuk mengukuhkan kerangka rasuk-tiang bersama dengan CFRP untuk mengekalkan beban seismik. Bar CFRP telah dilaksanakan kepada dua bingkai, bingkai “conventional reinforced concrete” (RC) dan bingkai “ultra-high performance concrete” (UHPC), untuk menilai kesan penanaman CFRP. Penyelidikan telah dijalankan ke atas bingkai yang dimasukkan CFRP, untuk menilai prestasi seismik, kefungsian bingkai tertakluk kepada beban kitaran, hasil kajian menunjukkan bahawa mekanisme tingkah laku kemuluran, kekakuan keseluruhan dan kegagalan, dipertingkatkan dalam kedua-dua bingkai RC dengan unsur CFRP dan UHPC dengan unsur CFRP, di mana kapasiti beban meningkat 26%, masing-masing 11%, berbanding dengan bingkai yang terdedah. Analisis “numerical” juga telah dijalankan bersama-sama ujian eksperimen, untuk menilai tingkah laku seismic CFRP yang dimasukkan di dalam sendi. Hasil “numerical” analsis menunjukkan bahawa, kapasiti beban muktamad meningkat dalam bingkai dengan CFRP yang dimasukkan di dalam bingkai RC dan bingkai UHPC, masing-masing 23% dan 52%. Selain itu, persamaan di lihat di antara ujian eksperimen dan analisis “numerical”. Tambahan pula, model unsur “finite” dibangunkan untuk rangka RC dengan kemasukan CFRP di dalam elemen “finite” kod program khas, statik tak linear dan analisis dinamik tak linear telah dijalankan .Hasil tak linear statik menunjukkan bahawa kapasiti bingkai dengan CFRP meningkat 66% berbanding dengan bingkai yang terdedah dan analisis dinamik tak linear menunjukkan bahawa anjakan maksimum untuk bingkai dengan CFRP.

berkurangan 66% berbanding dengan tempoh yang terdedah. Kecekapan dan keupayaan CFRP tertanam dalam bingkai RC di antra UHPC terbukti.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Earthquakes and tsunami are threats that destroy building and leave thousands of people dead and homeless, during earthquake load the first part that lead to buildings failure are joints. And strengthening the joint could minimize the damage. There are different ways to strengthen structures. One way is by using composites, as humans since ancient times were using composite, by mixing mud and straw to make bricks to give it more strength. The merge of Fiber Reinforced Polymer (FRP) into the commercial world is much less than hundred years. FRP composite materials date back to the early 1940s in the defence industry, especially for use in aerospace and naval features. The FRP is high strength weight ratio and strong resistance to the corrosive effects of weather, salt air, and the ocean. FRP composites were initially introduced to reinforce concrete structures fifty years ago and since then Composites have been upgraded starting with temporary buildings and rehabilitation of historic buildings and structural enforcement. A big growth of FRP in civil engineering is the use of externally bonded FRP for rehabilitation, strengthening of RC structures (Busel et al. 2007).

Recently, FRP reinforcements have been utilized broadly as an alternative reinforcement material to steel for new development and also to strengthen and repair of existing structures. Bonded FRP sheets and strips are presently the most used techniques for flexural and shear enforcement of concrete beams and slabs. A few researchers detailed that the failure of members reinforced with bonded FRP sheets and strips externally can be brittle due to de-bonding, exfoliation of the FRP sheets and strips, especially in areas with high flexural and shear stresses (Ei-hacha & Rizkalla, 2005). Another way to strengthen structures is by using the Ultra- High Performance Concrete (UHPC), as in structural field cement is one of the principle materials that is utilized as a part of development. UHPC is formulated by means of Portland cement and silica fume, quartz flour, fine sand, excessive variety water reducer, water, steel or fibres. UHPC is the most encouraging cementitious materials created to date it has the possibility of being a reasonable answer for enhancing the flexibility and maintainability of the structures due to its high strength, sturdiness. Research UHPC illustrated a fantastic impact resistance, yet there may be no any statistics about its dynamic behaviour.

## 1.2 Problem Statement

The brief literature review above highlight the following problems:

1. The experience of the recent earthquake indicated that the joints are the most critical to the initial damage under dynamic load.
2. In the areas of high humidity, after few small cracks in the concrete led to corrosion in the steel reinforcements, which reduce the strength of the structure.
3. Little information is observed on the application of the embedded CFRP as most of the research available in the literature regarding of retrofitting and strengthening are focused on the externally use of CFRP.
4. The application of CFRP rod in RC frame is not investigated well.
5. There is no study for application of CFRP in UHPC frames.

## 1.3 Objectives

The objectives of this study are:

1. To propose new design for beam-column connection with embedded CFRP bar in RC frame and UHPC frame to increase the capacity and flexibility of the frame against dynamic load.
2. To evaluate dynamic behaviour of the RC frame and UHPC frame strengthened by embedded CFRP bars in beam column joint through experimental test using dynamic actuator and verify with finite element analysis.
3. To develop finite element model and evaluate the effect of CFRP bar in RC frame subjected to dynamic load.

## 1.4 Research questions

Bases on the review of literature, the following questions were concluded:

1. What are the effects of embedded CFRP in conventional reinforced concrete frame?
2. What are the effects of embedded CFRP in ultra-high performance concrete frame?
3. How can CFRP improve the seismic performance of the RC and UHPC frames?
4. How is the performance of UHPC frame against lateral dynamic load?

Therefore, to address these questions. The aim of this research is to reinforce the frame beam-column joints with embedded CFRP in both RC and UHPC frames. And then investigate and assess the seismic performance of embedded CFRP subjected to dynamic load.

## 1.5 Scope of study

The following sequences are conducted to achieve the objectives:

1. Design the frames with embedded CFRP bars in both the conventional RC frame and UHPC.

2. Conducting cyclic test using dynamic actuator in the laboratory to evaluate the performances of the embedded CFRP in frame joints.
3. Carry out Finite element analysis using (ABAQUS) to evaluate the seismic behaviour of the embedded CFRP in joints.
4. A parametric study is conducted on different arrangements and geometry of the embedded CFRP in joints.
5. Developing finite element model with (ARCS3D) and preform nonlinear static (pushover) and dynamic (time history analysis).

## 1.6 Limitation of study

The limitations of this study are:

1. CFRP only embedded in the joints of the frames, and not the whole frame.
2. Only experimental done for one story frames, due to limitation of testing facility.

## 1.7 Organization of the thesis

The thesis is divided into 5 chapters and a brief description about each chapter is presented below:

Chapter 2, covers the review of works related to the application CFRP in structures. And the seismicity in Malaysia, finite element analysis for FRP, and ductility, stiffness requirements of the structure.

Chapter 3, presents the research methodology of this study, including the proposed new design joints, the prototype fabrication. Experimental test procedure, finite element analysis procedure using ABAQUS, and the development of finite element model using ARCS3D.

Chapter 4, illustrate the seismic performance of the RC and UHPC frame with the embedded CFRP in joints. Through experimental testing and numerical analysis. Finally the verification between the experiential test and numerical test is presented chapter.

Chapter 5, summarize and conclude the present study its general and specific conclusions. And recommendation of future works are also discussed.

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