REHABILITATION OF FIRE DAMAGED REINFORCED CONCRETE COLUMNS USING ULTRA HIGH PERFORMANCE FIBRE REINFORCED CONCRETE

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by

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LIST OF SYMBOLS

A	Cross Sectional Area of Column
A_g	Gross Area of Column Cross-Section
A_{sc}	Area of Longitudinal Reinforcement for Column
D	Maximum Size of Aggregate
e_M	Maximum Paste Thickness (MPT)
E_{hc}	Hardening Modulus
f_{cd}	Design Compressive Strength of Concrete
f_{ck}	Characteristic Compressive Strength of Concrete
f_I	Increment Factor
f_l	Confining Pressure
$f_{o\mathrm{t}}$	Tensile Strength of SIFCON
$f_{y,T}$	Reduced Yield Strength of the Compression Reinforcement
g^*	Packing Density of the Aggregates
g	Actual Volume of Aggregate in the Mix
g	Energy Absorption
$\mathrm{g}_{\mathrm{f,a}}$	Energy per unit volume
$\mathrm{G}_{\mathrm{f,b}}$	Dissipated Energy per Cracked Surface Area
i	Radius of Gyration
I	Second Moment of Inertia
k	Secant Stiffness
N_{ED}	Design Ultimate Axial Load in the Column

P_p	Peak Compressive Load
P_u	Axial Load on the Column
R	Radius of Concrete Column
t	Time in Minutes
u	Ductility
V_f	Volume of Steel Fibre
Δ_p	Displacement at Peak Compressive Load
Δ_u	Displacement at Ultimate Load
Δ_y	Displacement at Yield
ε_{cc}	Strain at first crack
ε_{pc}	Strain at Peak
ε_{res}	Residual Strain
λ	Slanderness Ratio
λ_{lim}	Upper Limit of Slanderness Ratio
l_o	Effective Length of Column
σ_{cc}	Tensile Stress at first crack
σ_{pc}	Tensile Strength
θ_g	Furnace Temperature

LIST OF ABBREVIATIONS

CPT	Cone Penetration Test
C-S-H	Calcium Silicate Hydrate
FRP	Fibre Reinforced Polymer
L/D	Length-diameter Ratio (Aspect Ratio)
MIP	Matrix Initial Porosity
MPT	Maximum Paste Thickness
OPC	Ordinary Portland Cement
RPC	Reactive Powder Concrete
R-UHPFRC	Reinforced Ultra High Performance Fibre Reinforced Concrete
SFCBC	Steel Fibre Concrete Brass Coated
SIFCON	Slurry-Infiltrated-Fibre Reinforced Concrete
UHPC	Ultra High Performance Concrete
UHPFRC	Ultra High Performance Fibre Reinforced Concrete
UHSC	Ultra High Strength Concrete
UTM	Universal Testing Machine
W/C	Water-Cement Ratio

PEMULIHARAAN KECACATAN TIANG KONKRIT BERTETULANG DISEBABKAN KEBAKARAN MENGGUNAKAN KONKRIT BERPRESTASI ULTRA BERTETULANG SERAT

ABSTRAK

Tujuan kajian ini adalah untuk menyiasat potensi penggunaan konkrit berprestasi ultra bertetulang serat (KBUBS) sebagai bahan untuk membaiki tiang pendek konkrit yang cacat disebabkan kebakaran. Sebelum ini, pengkaji menggunakan Polimer Bertetulang Serat (PBS) untuk membaiki tiang konkrit yang rosak disebabkan kebakaran, tetapi mereka mendapati ia tidak dapat menggembalikan keupayaan menanggung beban tiang konkrit segi empat yang terlibat. Tambahan lagi, PBS juga tidak dapat meningkatkan kekukuhan tiang bulat dan segi empat yang cacat disebabkan kebakaran. KBUBS menunjukkan kekuatan ikatan yang cemerlang dengan konkrit yang cacat kerana kebakaran dan kemampuannya untuk memulihkan keupayaan galas beban tiang konkrit tersebut. Namun, tiada bukti kajian makmal menunjukkan kesan lapisan KBUBS dalam meningkatkan sifat mekanikal tiang konkrit bertetulang yang cacat kerana kebakaran. Dalam kajian ini, empat puluh empat (44) spesimen tiang konkrit bertetulang telah dipanaskan pada suhu 600^{o}C selama dua jam dan diuji dibawah beban mampatan. Semua spesimen tiang telah diuji dibawah beban mampatan ekapaksi. Tegasan dan terikan telah diukur dan direkodkan menggunakan LVDT dan tolok terikan pada titik yang kritikal. Tiga pembolehubah yang dipertimbangkan ialah geometri tiang, (keratan rentas segiempat sama dan bulat), ketebalan bahan baik pulih dan amaun serat di dalam KBUBS. Didapati bahawa peningkatan ketebalan jaket KBUBS dan kandungan serat keluli telah meningkatkan kapasiti galas beban, kekukuhan dan kemuluran tiang konkrit bulat dan empat segi sama. Kajian ini mencadangkan untuk menggunakan jaket KBUBS dengan ketebalan 20 mm dan 2% kandungan serat keluli untuk membaiki tiang konkrit yang rosak disebabkan kebakaran. Kesimpulannya, penggunaan KBUBS sebagai bahan baik pulih di dalam kaedah jaket adalah satu kaedah yang effektif untuk membaik pulih tiang pendek bertetulang yang rosak disebabkan kebakaran.

REHABILITATION OF FIRE DAMAGED REINFORCED CONCRETE COLUMNS USING ULTRA HIGH PERFORMANCE FIBRE REINFORCED CONCRETE

ABSTRACT

The aim of this study is to investigate the potential use of UHPFRC as a repair material for fire damaged reinforced concrete (RC) short columns. Previously researchers used Fibre Reinforced Polymer (FRP) to repair fire damaged RC columns but they found that it cannot reinstate the original load carrying capacity of the affected square columns. Moreover, FRP also failed to improve the stiffness of fire damaged square and circular RC columns. UHPFRC has shown an excellent bond strength with fire damaged concrete and its ability to recover the load bearing capacity of the fire damaged RC columns. However, there is no experimental evidence on the effect of UHPFRC layer in enhancing mechanical properties of fire damaged RC column. In this current study, forty four (44) specimens RC short columns were heated at 600^{o}C for two hours and tested under compression load. All the RC short column specimens were tested under uniaxial compression load. Stress and strain were measured and recorded using LVDTs and strain gauges at the critical points. Three variables were considered namely geometry of column (square and circular cross section), thickness of repair material and the amount of fibre in UHPFRC. It was found that the increase of UHPFRC jacket thickness and steel fibre content have significantly improved the load bearing capacity, stiffness and ductility of fire damaged RC square and circular columns. This study proposes to use 20 mm thick UHPFRC jacket with 2% steel fibre to repair fire

damaged RC columns. In conclusion, the use of UHPFRC as repair material in jacketing technique is one of effective repair material to retrofit fire damaged RC short columns.

CHAPTER 1

INTRODUCTION

1.1 Background

In general, concrete structures have good performance during fire events due to its low thermal conductivity properties that protect the steel reinforcement which has higher thermal conductivity inside the concrete. According to BS EN1994-1-2 and BS EN1993-1-2, concrete exhibits lower heat conductivity of about 1.6 W/mK than that of steel (45 W/mK). Therefore, the properly designed concrete structures with sufficient concrete cover able to minimize the damage to the reinforcement and concrete core due to fire and successfully safeguard the integrity of the concrete structure during fire event.

However, after exposure to high temperature for long duration, the mechanical properties of concrete and steel reinforcement may significantly degrade and cause the deformation to happen. The compressive strength of concrete, tensile strength of steel reinforcement as well as the stress strain behaviour of the reinforced concrete structural member definitely will be different in comparison with pre fire events, even though, there is no damage encountered at the surface of concrete structure. According to BS EN1992-1-2, the conductivity of concrete degrades with the rise of surrounding temperature. Many previous studies have proved that prolonged exposure to high temperatures negatively affects the strength of concrete and the steel reinforcement bar inside it. Chan et al. (1999) reported that the residual compressive strength of concrete is only 50% after heated to 600^{o}C. Moreover, it becomes 20% after exposure to 800^{o}C. Furthermore, normal strength concrete experiences a severer loss in indirect tensile strength compared with compressive strength at 600°C. The porosity of concrete also affected by fires which lead to pore structure coarsening and consequently increases its permeability but reduces durability of the concrete. After exposure to 600°C, the cumulative pore volume in normal-strength concrete increases twice. At temperatures higher than 600°C, extreme C-S-H gel dehydration and pore structure coarsening negatively affect the durability and mechanical properties of concrete (Chan et al., 1999).

Concrete structures affected by fires or high temperature rarely experience serious global structural damage and fortunately, in many cases the fire affected concrete structures can be rehabilitated and reoccupied. It can be seen from the fire event experienced by Winsor Tower on 14 February 2005. After about two hours of fire event, the concrete structure still standing as shown in Figure 1.1 (Denoel, 2007).

Therefore, it is more economical to repair and reuse the affected concrete structures instead of demolish and build new one (Yaqub and Bailey, 2011a). Even though sometimes the cost for repair works is higher than new construction, in case of partially affected buildings, the buildings still can be used during repair works. Repairing or strengthening fire damaged concrete structure is the best choice provided the proper and thorough assessment campaign has been carried out. Detail and thorough assessments is mandatory prior to the design and commencement of repair works. Then, based on assessment findings, the suitable repair material and appropriate repair technique can be identified.