ASSESSMENT OF FIRE DAMAGED CONCRETE STRUCTURE

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ABSTRACT

Forensic engineering is the application of science to the investigation of failure or performance problem. This project is about to study the effect and behaviour of concrete structure after exposed to fire and also to study about assessment of fire damaged concrete structure which is under the investigation of forensic engineering structure. This study involved the detail analysis of methodologies on assessment of fire damaged concrete structure which the information is from journal, book and article. Besides that, to know what the current method of assessment of fire damaged concrete structure, collaboration with a forensic engineering company, RNC Technology (M) Sdn. Bhd is conducted. From the collaboration, an interview was held with the experienced engineer and also two projects of fire damaged concrete structure were taken from their previous project to be the case study in this project. This study also discuss about the detail of the assessment including the testing method. The case studies is discuss about the assessment of level of fire damage, whether the damage is slight damage, moderate damage or serious damage and also how the repair technique will be determine from the assessment of the investigation that made. The result shows that the different of case studies in term of different causes of fire and different level of damage of the concrete structure will apply different testing methods used and repair technique that used. Finally, based on the overall result of the case study, a general guideline of methodology's assessment of fire damaged concrete structure in forensic engineering investigation is proposed. This general methodology is applicable for assessment of fire damaged concrete structure.

ABSTRAK

Kejuruteraan forensik adalah aplikasi sains untuk menyiasat kegagalan atau masalah sesuatu struktur. Kajian ini adalah berdasarkan tentang kesan dan keadaan struktur konkrit yang terdedah kepada api dan juga tentang penilaian tentang kerosakan struktur konkrit oleh api yang mana kajian ini adalah penyiasatan di bawah kejuruteraan forensik. Kajian ini adalah berkenaan analisis terperinci tentang kesan api dan keadaan struktur konkrit yang mana sumber yang diperolehi adalah dari jurnal, buku dan artikel. Selain daripada itu, untuk mengetahui cara semasa berkenaan kesan api kepada struktur konkrit, kolaborasi dengan satu syarikat kejuruteraan forensik, RNC Technology (M) Sdn. Bhd telah dibuat. Hasil daripada kolaborasi tersebut, temuduga telah dijalankan dengan jurutera berpengalaman dari syarikat tersebut dan dua projek tentang kerosakan api terhadap struktur konkrit dari syarikat itu telah diambil untuk dijadikan sebagai kajian kes dalam kajian ini. Kajian ini juga membincangkan tentang penilaian yang terperinci termasuklah ujian yang dijalankan. Kajian kes akan membincangkan tentang penilaian mengenai kerosakan struktur konkrit sama ada kerosakan tersebut adalah kerosakan teruk atau kerosakan tak teruk, bagaimana teknik membaiki struktur konkrit akan ditentukan dari penilaian yang dijalankan hasil daripada penyiasatan yang telah dilakukan. Keputusan menunjukkan kajian kes yang berbeza tentang api dan tahap kerosakan struktur konkrit akan membabitkan berbeza ujian yang dijalankan dan juga teknik membaiki. Akhirnya, berdasarkan kepada keseluruhan keputusan daripada kajian kes, satu garis panduan umum tentang methodologi kesan api terhadap struktur konkrit berdasarkan daripada penyiasatan kejuruteraan forensik dicadangkan. Garis panduan umum ini boleh digunakan untuk mana-mana penyiasatan kesan api terhadap struktur konkrit.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Forensic engineering is the application of the engineering sciences to the investigation of failures or performance problems. It is a highly specialized field of engineering practice requiring engineering expertise and knowledge of legal procedures. Forensic structural/civil engineers perform "autopsies" on components or full-sized buildings, bridges, and other engineered constructed facilities/infrastructure in order to determine the causes and the level of damage. A secondary purpose is to determine method of repair, rehabilitation or replacement (Nguee Chin Seng, 2006)

Concrete structure is the most important part or material to build up building or bridges of a construction in civil engineering. Nevertheless, it may be damage of many factors. One of the high risk factor is due to fire damage of concrete structure. The fire damage concrete structure maybe happens to old building or bridges, and it also can damage the concrete structure during the construction when it is exposed to fire.

Generally, most of concrete structures exposed to fire could be retrieved and returned to service even after severe fires. In this process the damaged structural members must reach to a minimum strength, ductility and stiffness which they have possessed before the fire. After heating concrete to the high temperatures, a series of physical and chemical reactions lead it to exhibit changes such as loss of moisture, decomposition of aggregate particles and dehydration of cement paste. These

changes could strongly affect the structure of concrete members by reducing mechanical properties of concrete, namely the decrease in both strength and stiffness of the concrete. Also variation of brittleness of the softening behaviour is going to show more ductility with raising the temperature. To investigate and rehabilitate the mentioned structural members this point is crucial to have a good estimation on the effects of temperature on mechanical properties of concrete.

Heating of concrete, due to fire or otherwise, may result in a variety of structural changes like cracking, spalling, debonding of aggregate and rebar, expansion, and chemical changes such as discoloration, dehydration, dissociation. When a concrete structure is exposed to fire, differential expansion and contraction of various components and constituents within the concrete take place.

Fires has been cause of devastating structural collapses throughout history, most prominently in our mind is the failure of the World Trade Center Towers 1 and 2 in New York City on September 11, 2001. As a result of earlier catastrophic failures, building materials, such as steel, are typically insulted to protect from exposure to elevated temperatures, but concrete is commonly designed and built with no fireproofing (Buchanan, 2002)

Once the concrete structure is exposing to fire, the insurer or owner may commission an investigation of the damage. These parties will often have a major interest in finding the most cost-effective solution for repairing the structure. In the most concise terms, the assessment, design and repair of fire-damaged structures consist of the following stages:

i) Preliminary inspection
ii) Assessment of damage
iii) Testing and detailed assessment
iv) Design of repairs to structural elements
v) Implementation of structural repairs

1.2 RESEARCH SIGNIFICANT

The effect of fire on the behaviour of concrete subjected to elevated temperatures has been widely research. This assessment on fire damage concrete structure is to determine and investigate the causes and effect of fire damage to concrete structure that exposed to fire burning or hot temperature that come from the expanding of material under the higher temperature of fire. The fire can rapidly damage the structure of the concrete when the material used is not durable to cover the concrete structure at high temperatures of fire. After a fire, the damage portions of buildings should be examined quickly and thoroughly. Once the degree of damage has been determined, damage should be assessed accurately so that rational restoration measures can be undertaken.

1.3 PROBLEM STATEMENT

Concrete does not necessary perform as we would like. Even though concrete is one of the best fire-resistant and high strength products found in the construction of buildings and flatwork, once the concrete were exposed to high temperature or fire burning, the concrete structure will damage. Nevertheless, intensive heat not only affects concrete, it can weaken it to the point where the only solution without demolished or reconstruction is repair. The structure concrete will not strong which is it strength and not durable enough to stand and for the best solution is need further investigation and treatment. Assessment on the condition of the structure that damage is needed to determine whether the strength of the structure is remain the same or the strength of the structure is become weaker. The damage preliminary inspection and immediate measures is needed to determine the damage for securing public safety. Testing of the concrete structure is the method to determine the level damage of concrete structure whether the structure is extensive damage, slight damage or no damage.

1.4 OBJECTIVES

The objectives of this study are:

i) To study the effect of fire and behaviour of concrete after exposed to the fire.

ii) To study the current method of assessment for fire damage to concrete structure.

1.5 SCOPE OF STUDY

The main focus on this study is about the investigation of structural effect of fire damage concrete structure and also about determination of the behaviour of concrete structure after it is exposed to fire. In order to carry out the work, methods of assessment need to be establish.

1.6 EXPECTED OUTCOME

Assessment is the detail investigation from analysis that made up for some cases. A good assessment is shown the best result of analysis from the investigation. The general of investigation of fire damaged concrete structure will carry out from this study included the testing that can be used in determining the condition of the damaged concrete structure. Assessment of fire damage concrete structure is analyse to determine the type of damage and level of damage, so that the solution for the damage can be solve by the suitable repair technique for further work. A good and accurate assessment method will give an idea on what is the best repair technique to be used.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete today is widely used in construction work such as for road pavements, bridges and high-rise building structures. From the previous research, there are many investigators proved that the strength and durability of concrete will not remain the same when there are causes of fire damage to concrete structures. Many investigations have shown that concrete does not perform as well as it expected due to the effect of many factors which contribute to or cause the damage of concrete structures. The causes of fire damage and repair techniques are described and brief in this section.

2.2 DEFINITION OF FIRE DAMAGE

Fire damage is refers to the damage or destruction goods and property cause by fire. In civil engineering, especially in construction work, fire damage will affect the structure of building, bridge, dam, or others. Fires occur in structures with a wide range of different types or combinations of materials for their structural members. Hence, the forensic investigator must understand the effect that heating has on a variety of different construction materials. (Jeremy Ingham, 2009)

2.3 GENERAL ASSESSMENT PROCESS

Concrete structure that exposed to fire need to verify first whether the structure is safe to enter or not. There are several processes that consist in the determining of the structure safe or not. Those steps are representing in **Figure 2.1**:

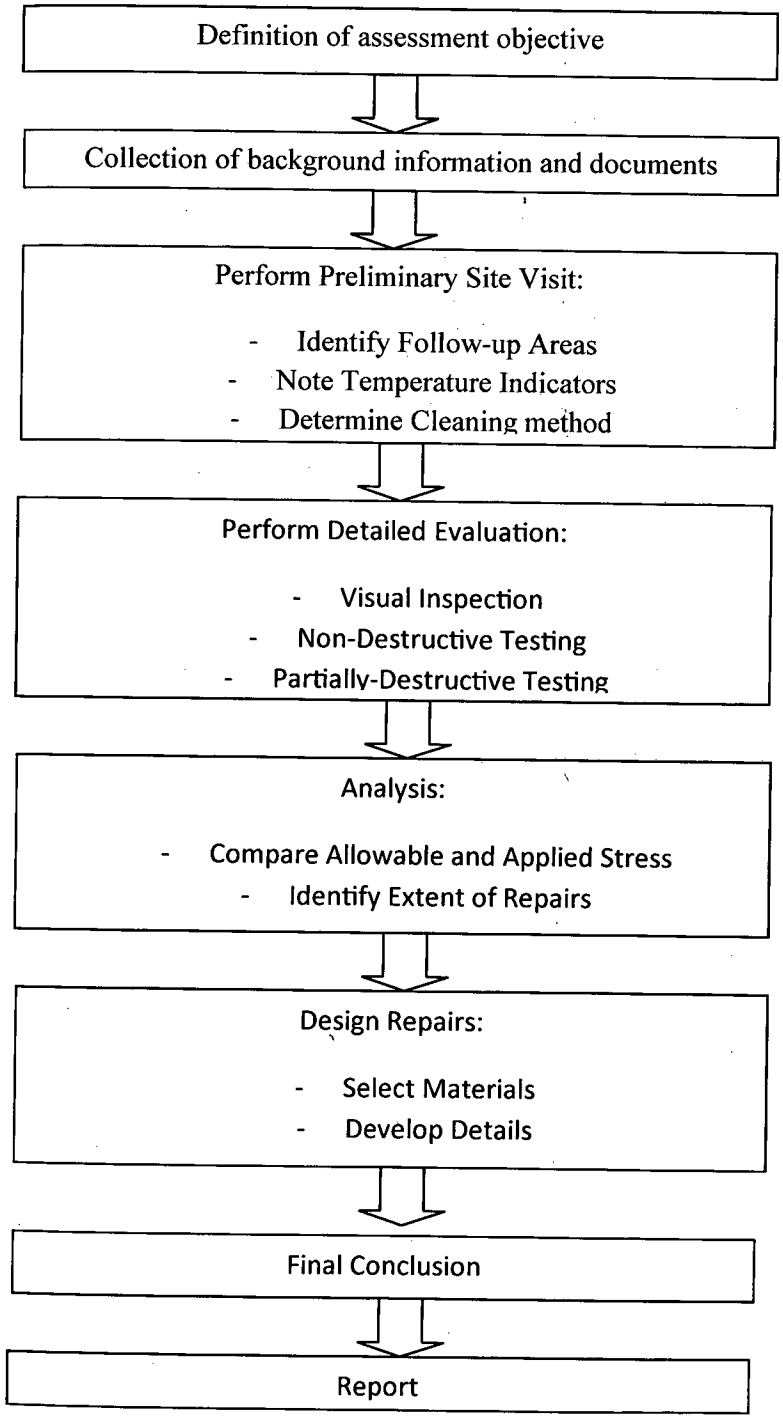

Figure 2.1: Process Flow Chart

2.4 ASSESSMENT OF FIRE DAMAGED

The aim of assessment of a fire damaged structure is to propose appropriate repair methods or to decide whether demolition of elements or the whole structure is more appropriate.

2.5 SITE VISIT

The preliminary stage of assessment of fire damaged concrete structure is by visit the site which is exposed to fire damaged. During the site visit, investigation may involve in making observations and measurements on several sources, documenting existing conditions and interviewing eyewitnesses.

2.6 VISUAL INSPECTION

The primary on site investigation technique is visual inspection, which records such features of collapse, distortion, deflections, degree of damage to materials and smoke damage. On site investigation of fire damaged concrete structures typically starts with visual inspection and hammer tapping, which identifies collapse, deflections, spalling, cracking, surface crazing and smoke damage. An example of a damage classification scheme suitable for fire damaged concrete structures is shown in **Table 2.1**.

Table 2.1: Simplified visual concrete fire damage classification (Jeremy Ingman, 2009)

Class of damage	Features observed					
	Finishes	Colour	Crazing	Spalling	Reinforce-ment	Cracks/ deflection
0 (Decoration required)	Uneffected	Normal	None	None	None exposed	None
1 (Superficial repair required)	Some peeling	Normal	Slight	Minor	None exposed	None
2 (General repair required)	Substantial loss	Pink/ red	Moderate	Localised	Up to 25% exposed	None
3 (Principal repair required)	Total loss	Pink/red Whitish grey	Extensive	Consider able	Up to 50% exposed	Minor/ None
4 (Major repair required)	Destroyed	Whitish grey	Surface lost	Almost total	Up to 50% exposed	Major/ distorted

2.7 EFFECT OF FIRE ON CONCRETE

Concrete structure is the highest priority that will damage because concrete act as cover to protect steel from any other damage. Heating of a concrete in a fire causes a progressive series of mineralogical and strength changes that are summarised in **Table 2.2**.

Table 2.2: Summary of mineralogical and strength changes to concrete caused by heating (Jeremy Ingham, 2009)

Heating temperature (°C)	Changes cause by heating	
	Mineralogical changes	Strength changes
70-80	Dissociation of ettringite	Minor loss of strength possible (<10%)
105	Loss of physically bound water in aggregate and cement matrix commences, increasing capillary porosity	
120-163	Decomposition of gypsum	
250-350	Oxidation of iron compounds causing pink/red discolouration of aggregate. Loss of bound water in cement matrix and associated degradation becomes more prominent	Significant loss of strength commences at 300°C
450-500	Dehydroxylation of portlandite. Aggregate calcines and will eventually change colour to white/grey	
573	5% increase in volume of quartz(to-quartz-transition) causing radial cracking around the quartz grains in the aggregate	Concrete not structurally useful after heating in temperatures in excess of 500-600°C
600-800	Release of carbon dioxide from carbonates may cause a considerable contraction of the concrete (with severe micro-cracking of the element matrix)	
800-1200	Dissociation and extreme thermal stress cause complete disintegration of calcareous constituents, resulting in whitish-grey concrete colour and severe micro-cracking	
1200	Concrete starts to melt	
1300-1400	Concrete melted	

2.7.1 Colour

Colour of concrete will change after it is exposed to fire. Changes of colour concrete are different due to the level temperature of the fire. For temperature above 300°C the colour of siliceous aggregate normally change to pink or red especially temperature of fire in range 300 - 600°C. For the fire temperature in range 600-900°C, the colour of siliceous aggregate will turn to whitish grey and temperature of fire in range 900-1000°C will change to buff. The pink or red discolouration results from the presence of iron compounds, in fine or coarse aggregate, which is dehydrate or oxidise in the range of the temperature. (N.R Short, J.A. Purkiss& S.E. Guise, 2001)

According to colour image analysis made by Omer Arioz, intensity of the yellow colour increased with increase in temperature and red colour appeared when the temperature increased to 800 °C. Therefore, it seemed that the results of colour image analysis may also be used to assess the level of temperature to which the concrete subjected.

2.7.2 Spalling

Spalling is the loss of larger pieces or flakes of concrete. Concrete spalling is caused by the exposure of the concrete to high temperatures. Spalling itself is actually the deterioration of the concrete causing chunks of the concrete to separate from the concrete structure. The most common concrete spalling is cause by fire.

Spalling of the surface layers is a common effect of fires and may be grouped into two or more types. Explosive spalling is erratic and generally occurs in the first 30 minutes of the fire. A slower spalling, referred to as 'sloughing off', occurs as cracks form parallel to the fire-affected surfaces leading to a gradual separation of concrete layers and detachment of a section of concrete along some plane of weakness, such as a layer of reinforcement. The thermal incompatibility of aggregates and cement paste causes stresses which frequently lead to cracks, particularly in the form of surface crazing. Thermal shock caused by rapid cooling from fire-fighting water may also cause cracking. (Jeremy Ingman, 2009)

Spalling may be difficult to observe during the test but may be audible to the technician. If spalling occurs the following parameters must be reported:

- Time when spalling occurs (if detectable)
- Size of the spalled particles
- Area of spalling and maximum depth of spalling
- Amount of spalled material

Layers of material which are loosened during the test are assessed and reported. For example, if steel fibres are used, some of the spalled particles are still connected by one fibre to the concrete. It is also possible that a protection system has loosened from the construction. But for some reasons which depend on the construction of the sample or test furnace this layer is still in place.

Figure 2.2: Spalling occur at surface of concrete structure

2.7.3 Crack

All concrete structures crack. Cracks in concrete have many causes. Crack in concrete that cause by fire is different at different temperature of the fire. The seriousness of the cracks is determined by difference level of temperature. Higher temperature will cause the bigger crack of the structure. Especially when the samples have a high bending rate, horizontal and vertical cracks may occur. If this can be

observed during the test, the time when it occurs should be noted. The location, number, width and spacing distance of these cracks shall be reported.

Other than crack width, depth and spacing, crack density is an important parameter in determining the seriousness of deterioration. Crack with provide a valuable information in forensic investigations cracks less than about 0.1 mm (0.004 in) are difficult to see and are not normally a cause for concern. Cracks width above 0.5 mm (0.02 in) was clearly visible and many indicate serious problem (M. Yacub & Q.Z Khan, 2006).

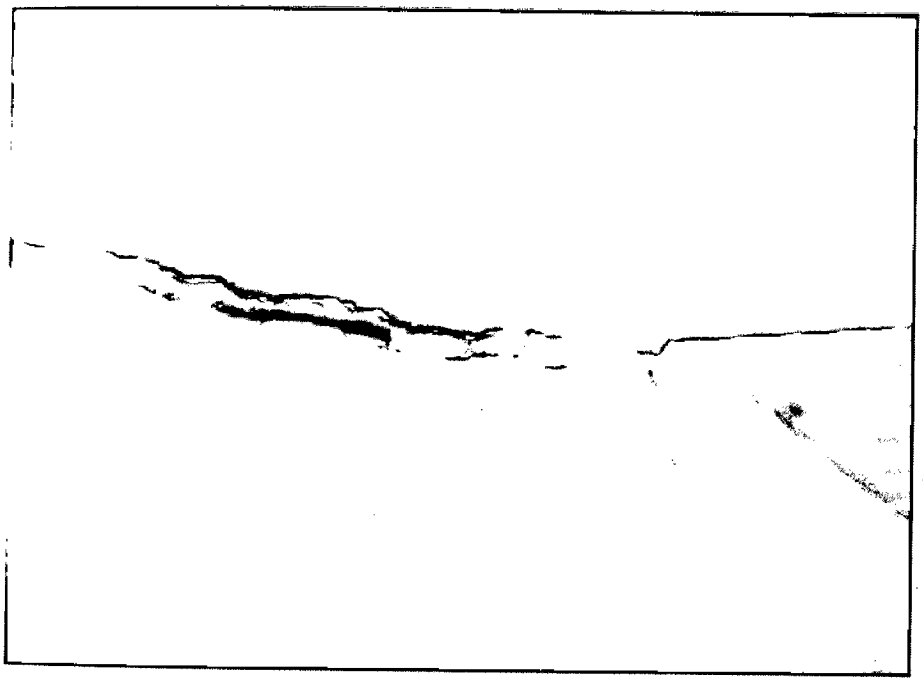

Figure 2.3: Crack occur

2.7.4 Deformation

Deformation of structural members and associated materials can provide valuable information to develop a heat intensity map.

Table 2.3: Typical Grading Scheme for Damage Classification (Mr. Parnam Singh)

Member	Location	Severity of Damage	Description
Beams, Columns, Floor, etc	Location of grid	1	Local surface spalling surface grey or sooty, spalled patches, brown or sooty, no cracks, no steel exposed.
		2	Surface spalling in localised areas, surface, grey or sooty-slightly pink at edges, certain areas sound hollow, minor cracks, no steel exposed.
		3	Extensive spalling, surface grey, slightly pink or slightly sooty, major vertical cracks, vertical strips sound hollow, only links exposed.
		4	Spalling over 50% of surface, some spalling due to sudden cooling by water, surface grey, slightly pink, slightly sooty, spalled areas grey, slightly sooty-pink edges, major vertical cracks, extensive areas sound hollow, main steel exposed, no buckling in steel.

2.7.5 Material

2.7.5.1 Steel Work and Steel Reinforcement

Steel is use as reinforcement in concrete to make the structure become stronger. Its strength will decrease when the steel were exposed to fire. However,

recovery of yield strength after cooling is generally complete for temperatures up to 450°C for cold-worked steel and 600°C for hot-rolled steel. Above these temperatures, there will be a loss in yield strength after cooling. (Jeremy Ingman, 2009)

The effect of fire to steel work and steel reinforcement consist of reduction in physical properties distortion, axial shortening of columns, and buckling. This is all because of the heating of concrete structure that cause by fire.

To assess fire damage of steel reinforcement in concrete, the visual assessment is usually backed up by taking samples and doing laboratory testing. This typically comprises testing for yield, elongation and tensile strength with the results being compared with the relevant standard for the grade of steel concerned.
(Jeremy Ingman, 2009)

2.7.5.2 Stone and Brick Masonry

Damage of fire to stone and brick masonry is depending on the type of the brick. Clay bricks can withstand in fire of temperature around 1000°C. Other type of brick usually will damage at temperature of fire 250-300°C and the damage of the brick usually can be observe by the colour change of the brick. (Jeremy Ingman, 2009)

2.7.5.3 Aggregate

Types of aggregate will influence the level of damage of concrete structure that exposed to fire. Different aggregate compositions will make concrete behave differently at different temperature of fire. This is because most of aggregate expand at high temperatures.