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Capital University of Science and Technology, Islamabad Pakistan

Modern Methods of Residual Strength Assessment of Fire Damaged RC Structure-A Review

[a] Muhammad Sultan Sikandar

a: Civil engineering department, Lahore leads university,sultansikandar618@gmail.com

Abstract- Structures have been severely damaged by fire. As far as fire safety is concerned, it is necessary to build cost-effective but fire-resistant constructions. Reinforced concrete (RC) buildings do not sink during fire exposures, and the building may be able to be used again after the fire. Despite this, fire can cause a permanent loss of concrete strength. Following a fire assessment, many researchers are looking at post-fire assessments; however, they haven't yet looked at recent residual strength evaluation methodologies. The focus of this research is on current methodologies for determining the residual strength of fire-damaged reinforced concrete (RC) structures. As a result of the findings, it has been determined that current methods for determining residual strength are required. The purpose of this research is to determine future directions for investigating new methods of residual strength assessment to improve the utilization of fire-damaged structures.

Keywords- Reinforced concrete (RC) buildings, Residual strength assessment.

1 Introduction

Built infrastructure plays an important role in the socioeconomic development of a country. Many buildings are designed for several decades and provide residential or commercial operations throughout their design life. Buildings are subjected to many hazards i.e. Earthquake etc. and manmade hazards i.e. Fire, explosion etc. These hazards can cause partially or fully damage to buildings. Rapid development across the world make a significant transformation in the form of severity from the fire hazard. The researchers revealed that in the past two decades (1935-2015) a total of 86.4 million fire events have caused greater than one million fire deaths. It is reported that annual loss from the fire hazard about 1 per cent of the world GDP. The researchers revealed that every year in developed and developing countries with an average of 3.8 million fires caused 44,300 fire deaths. Developing countries i.e. India and Pakistan experience the highest number of fire events (10,000-25,000 per year) and fires deaths (100,000-600,000 per year) [1]. The importance of structural fire engineering increased day by day with the increased population.

Pre fire assessment and post-fire assessment are the main concern of structural fire engineering. Pre fire assessment is conducted before a fire event in the buildings and a post-fire assessment is conducted after the fire events in the building. Post-fire assessment is necessary for further use of the fire affected building. There is a need to develop modern methods in the residual strength assessment of fire-damaged reinforced concrete (RC) structure. Because public health and safety is the priority. Modern methods of residual strength assessment of fire-damaged reinforced concrete (RC) structures have recently drawn importance for structural health assessment. The performance of concrete in the fire mainly depends on its ACI design. Normal concrete strength and high concrete strength gives results almost similar at high temperatures while ultra-high-strength concrete behaves differently [2]. The performance of structural members at high temperature could find out by testing [3]. Fire resistance of a reinforced concrete structure could be evaluated under high temperature

by a standard time-temperature curve. Many materials and analytical models have been prepared for finding the residual strength of concrete after fire [4].

Post-fire assessment is carefully considered in damaged reinforced concrete (RC) structure. Keep in mind the exterior condition of the building before entering the building for assessment. If the exterior condition of the building is acceptable damaged then enter into the building for further investigation. On the other side if the exterior condition of the damaged building is not well then use modern techniques for residual strength assessment from the outside. There is a need to develop innovative and cost-effective building models that also take fire safety into account. Many researchers work on the post-fire assessment of fire-damaged buildings because it's important to used already constructed building than newly constructed building from a sustainability point of view. The age of the building must necessary to be considered during the assessment. Chemical changes occurred in the cement and concrete when the temperature is significantly increased. The density decreases as the temperature rises, as shown in Figure 1. So there is a need to develop modern methods for the residual strength assessment of fire-damaged structures.

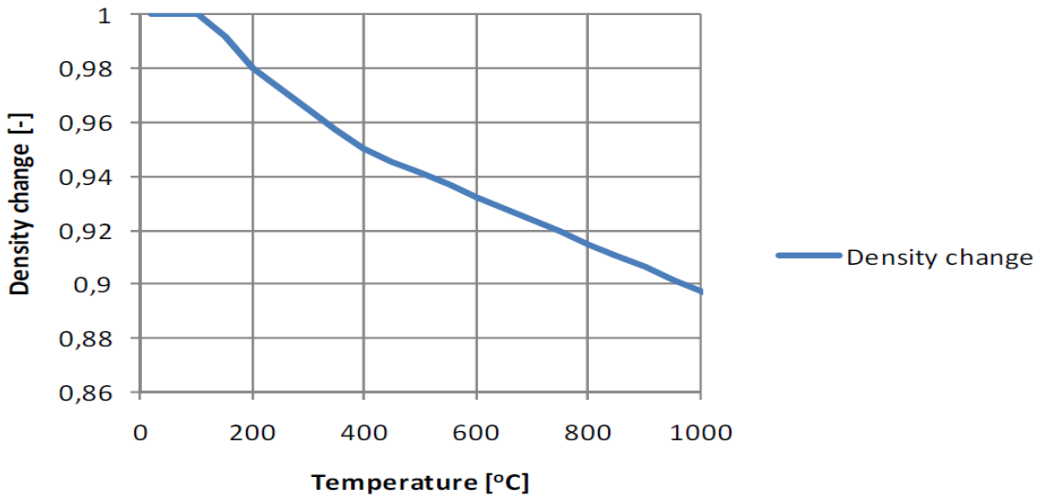

Figure 1: Reduction in density with temperature [5]

2 FIRE RISKS IN RC STRUCTURE

A structural fire is a fire that requires the structural components of many types of residential, commercial or industrial buildings [5]. There is always risks of fire in the reinforced concrete (RC) structure. It is impossible that there are no risks of fire in the reinforced concrete (RC) structure. Always deal to reduce the risks in the reinforced concrete (RC) structure. Fire is the most important potential risks for the buildings and reinforced concrete (RC) structures [6]. And for this reason during the design of a building fire safety codes must be considered. Buildings have many sources to start a fire. Active fire protection system i.e. heat and smoke detectors etc. And passive fire protection system i.e. Structural and nonstructural components of the buildings are capable to resist fire. When fire exposed at a high temperature for a longer duration then changes occurred in cement, sand and aggregate and due to these changes mechanical deformation occurred in the concrete [6]. When fire breaks out in reinforced concrete (RC) structure the structural members i.e. Columns starts to rise because of their lower thermal conductivity and high specific heat of concrete [7].

At the initial stages of fire outer faces of concrete is much hotter than internal concrete. When the fire continued for a certain time then internal concrete also starts to heat up. The increase in temperature disturbs the strength and modulus properties of steel and concrete. Fire causes a severe hazard in developing and developed countries all over the world [7]. And it disturbs the structure and environment. In the buildings, there are many reasons to start a fire. A massive fire erupted in Pakistan (Lahore) Hafeez plaza on 18-10-20 morning. The fire started from the second floor in the building but gradually travelled to the fourth floor. The reason for the fire is a short circuit. When a detailed study conducted on Hafeez centre there are no safety rules to be followed in the building. Figure 2 shows the methods to reduce fire risks.

Fire protection features, regulation and enforcement, common or civic sense and technology and firefighting resources are shown in Figure 2.

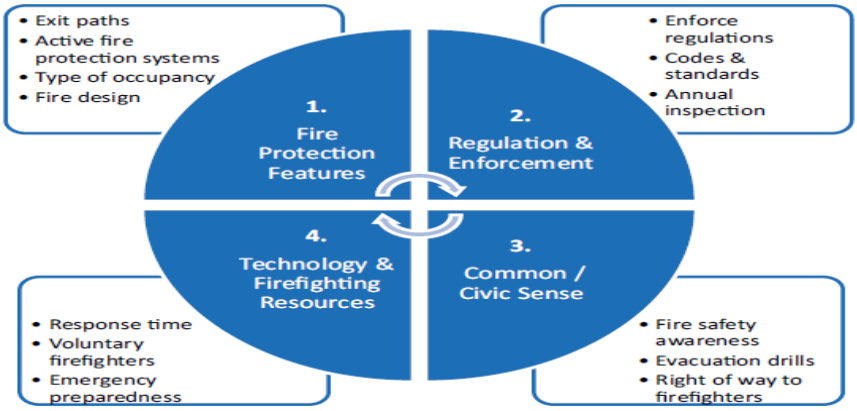

Figure 2: Methods to reduce Fire Risks [1]

3 POST-FIRE ASSESSMENT

Reinforced concrete (RC) structure inherent Fire can nevertheless result in a permanent loss of concrete strength. The post-fire assessment is necessary for deciding to further use the affected building or not. Post-fire assessment of reinforced concrete (RC) structure describes what is the current condition of the affected building after the fire. At high temperatures, the micro-structural properties of concrete are exposed [8]. Concrete is mostly used construction material worldwide. The performance of concrete in fire event is better than other kinds of construction materials [9]. At high temperature, the mechanical and physical properties of concrete changed [9]. Reinforced concrete (RC) structure shows better performance under fire exposures [10]. When the temperature of concrete is increased then the water vapour pressure in the concrete also increased and creates cracks and spalling in the concrete [10]. The results of high temperature are mostly deformation, disintegration and fracturing [11]. The concept of fire resistance applied to the structural elements not on the materials but the properties of the material affect the structural performance. After fire exposures, there is a need to check the technical condition of the reinforced concrete structure [12]. First of all, inspect the affected building from the outside that is the right way to enter the damaged building for the assessment or not.

Check the affected area concrete strength and unaffected area concrete strength. If the damages are too high in the building then detail specialized analysis are to be performed. If building design live load of 100 Psi and residual strength of concrete remain 60 psi. Then there is another method to deal residual strength for use of the damaged building to reduce the live load i.e.60 Psi. For further use the affected building according to concrete strength. The aim of the post-fire assessment is to repairing a structure after a fire and restore it to condition before the fire. During assessment collect valuable information regarding fire and its temperature on particular places of structure. Classify the damages and their impact on the safety level of the building. Find out mechanical properties of material i.e. concrete and steel by adopting destructive or nondestructive testing. Check there is a need to strengthening of structure or retrofitting of structure. Moderate cracks are (> 0.5 mm) and the concrete chippings are greater than 10mm in size. If the 25% exposed reinforcing bars the surface colour is pink-red. If the reinforcing bars are exposed to greater than 50% then the pink surface is converted to red or whitish-grey [11].

For this checking, there is a need to select the damaged and undamaged parts of the structure. Concrete at the temperature of 500-600 °C is not suitable for further use in the structure [12]. At higher temperatures, the loss of strength is more severe; for example, at 650 °C, just 20% of the original strength remains. Cold drawn bars, wires, and strands are more vulnerable to high temperatures than hot-rolled bars. At 400 degrees Celsius, the strength is reduced by half, and at 650 degrees Celsius, just 10% of the original strength remains. The initial yield strength of cold wrought steel will be regained after cooling if the temperature is less than 450 °C. 650 °C is the corresponding temperature for hot-rolled

steels. The residual yield and fire load are not possible [13]. The study revealed that post-fire tests on material show degrading of mechanical properties of concrete [14]. Fire damages decrease the load-bearing capacity of the reinforced concrete structure [14]. After being d strength will diminish as the temperature rises over these levels. The researchers revealed that the effect of dynamic loading subjected to fire, the shear capacity and stiffness of the RC beams both decreased [15]. The researchers studied that fire exposure reduced the lateral/seismic load capacity and ductility of the two reinforced concrete column specimens significantly [16]. Table 1 shows that some research on post-fire curing.

Table 1- Some studies on the post-fire curing [9]

Authors	Year	Materials	Exposed temperature (C°)
Crook and Murray	1970	Concrete	620
Lin et al.	1996	Concrete	900
Poon et al.	2001	Concrete	600, 800
Henry et al.	2013	Paste & Concrete	600
Henry et al.	2014	Concrete	600

4 MODERN METHODS OF RESIDUAL STRENGTH ASSESSMENT

Repairing is restoring structural components that have damaged to an honest condition for further use. Repairs are performed to regain the strength of structural members after a fire disaster. Modern methods of residual strength assessment increase the efficiency of the affected buildings. Root cause analysis is conducted for now the defects in design, material or construction. Destructive testing and nondestructive testing are known for modern methods. Within the destructive testing, the material is broken and can't be further used. Nondestructive testing is a technique for determining material qualities without causing harm. [17].Detecting delamination in concrete by ultrasonic pulse ECHO, Infrared thermal imaging and Eddy current. Find out concrete strength or quality by rebound hammer (with calibration) (ASTMC805), ultra-sonic pulse velocity (UPV) (ASTM597), Windsor probe test and Impact Echo. To estimate thickness cover and rebar spacing use GPR scanning (ASTM 6432) and impact echo (ASTM C1383).For evaluating corrosion use half-cell potential and resistivity [18]. These all are included within the nondestructive testing. According to the ACI 562-16, section 6.4.3.2 non-destructive strength testing to judge in situ strength of concrete shall be permitted if a legitimate correlation is established with core sample compressive strength test results and nondestructive test results. Quantifications of concrete compressive strength by nondestructive testing alone shall not be permitted as a substitute for core sampling and testing.

Within the concrete destructive testing concrete core and pull out the test (ASTM C 900) are used for compressive strength. Rebar sample extraction is additionally destructive testing. Load test is nondestructive testing but it can destructive testing if it ends up in failure. Strengthening of structure and retrofitting are known for the trendy methods of residual strength assessment. Strengthening of structure applied individual members i.e. slabs, columns by using different techniques i.e. jacketing, replacement of spalled concrete. Retrofitting technique is employed for damaged areas to create more proof to loads. The rebound hammer, ultrasonic pulse measurements, and microscope procedures are among the traditional assessment methods included in the experimental section of the report. These are compared to full-field optical strain measurements on drilled cores during a compressive load cycle, i.e. the new approach proposed to quantify the degree of damage in a fire-exposed cross-section. The first step is to conduct an inspection to identify the fire's progression, size, and spread pattern (if possible). A visual mapping of damage, such as spalling, cracking, delamination, deformations, and other physical effects from the fire, should also be included. It's helpful to have a hammer and a chisel on hand for your initial inquiry so you can identify very valuable items.

Ultrasonic pulse measurements on different depths from the fire exposed side of the core can be done on-site immediately after drilling to gain a basic picture of the depth of damage. On the drilled cores, optical full-field strain measurements

during a compressive load cycle can be done to get a direct linkage to mechanical properties. The true mechanical response of the material in the cross-section may be estimated, and the most damaged regions would deform more under load due to reduced stiffness. Different microscopy approaches can be used in the lab to study the cores. For estimating acceptable concrete strength of recent structures use the ACI 318 code and for estimating the concrete strength of existing structures use ACI 562 or ACI 214 code. In keeping with ACI 562 section 6.4.2.1, it shall be permitted to see the compressive strength of sound concrete by taking cores from the members being evaluated. Located steel reinforcement before locating the cores to be extracted [19]. The cores shall be selected, tested and removed under ASTM C42 and ASTM 823. Predetecting fire temperatures by visual inspection i.e. if windows aluminium are melted it means temperature exceeds 450-500 ºC. It's also done by petrographic analysis and using standard curves. Concrete cores are used for testing of actual properties of concrete in existing structures like strength, permeability, chemical analysis, carbonation etc. [20].

5 Conclusion

This work sought to introduce post-fire assessment of fire-damaged reinforced concrete structures as well as new methodologies for determining the residual strength of fire-damaged reinforced concrete (RC) structures. The following conclusions are derived based on the literature.

- The buildings have suffered extensive damage as a result of the fire. There is a need to develop techniques for making buildings safer from a fire standpoint.
- When designing reinforced concrete structures, adhere to the building code.
- There is a need to introduce modern methods of residual strength assessment of fire-damaged reinforced concrete (RC) structure.
- There is a need for individuals to be more conscious of fire safety.
- The government makes the policies and strategies regarding fire safety and such policies are strictly followed by everyone.
- A current approach of determining residual strength aids in the reuse of a damaged structure.

The above conclusion demonstrates the importance of fire safety during the design process. Furthermore, contemporary methods of residual strength assessment aid in the reuse of afflicted structures as well as the creation of long-term sustainability.

6 Future Recommendations

- Investigating new approaches for post-fire evaluation to repurpose fire-damaged structures.
- To assess the concrete/reinforcement strength, consider using a visual scanning method in the future.

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