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A REVIEW ON FIRE DAMAGE ASSESSMENT OF REINFORCED CONCRETE STRUCTURES OF A BUILDING

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Abstract- Event of fire is major hazard that come across in the civil engineering structures. Moreover, a suitable fire safety method is a key constraint in a design of building for guaranteeing the safety to the occupants. Fire is the supreme destructive factor that creates deterioration of reinforced concrete structures (R-C-S). Even that the concrete is a not explosive construction material, when R-C-S are in contact to elevated temperature, their mechanical, chemical and physical properties weaken. The fire damage levels of R-C-S considerably depends upon dimension and fire time period. If the intensity of fire is minor and small, the loss is expected to be lesser in R-C-S elements. Overall aim of this research is to explore the behavior of R-C-S for high rise (H-R) buildings after the sever event of fire, firefighting (F-F) deficiencies and implementation of precautions for recovering the severe effect of damage by fire. The current study is review of previous studies related to fire damage for reinforced concrete structures. Several case studies on deficiencies in firefighting systems have also been reported in this work. After detail literature review, the results shows main sources for damage occur to fire. Further suggestion are given in details for fire related apprehensions of H-R building.

Keywords- Fire, safety; reinforced concrete structures, high rise buildings; damage.

1 Introduction

According to world fire data, around 1 million deaths were caused by fires between 1993 to 2014, and nearly 40% of all fires surrounding the world initiated from structures [1]. In this modern world, the fire hazards are arriving as a threat to reinforced concrete structures (R-C-S) buildings. The main components for fire are oxygen, fuel and heat. The fire calamities happening in the R-C-S building causes damage to the R-C-S elements. The key causes for these threats are explosive materials, electric equipment, human wrongdoings and house hold appliances. These rationales direct them to damage of the R-C-S building. Also this may be affect the life lines of living mortals and treasure damages [2]. Many studies show that the decrease of the strength occurred in concrete of R-C-S at elevated temperatures, be governed by some aspects such as: specimen measurement, loading condition, strength of concrete, temperature stages, cooling method, and heating period [3, 4]. The comparative review of case studies of four fire accidents occurred in the different places were reported. The massive fire adversities arisen in case study, and have discussed almost the planning of the R-C-S building, represents the cause for the happening of the fire event, materials that can be sources for fire to the next phases, occurrence of failure to R-C-S, causes behind the life sufferers and treasure loss and helpful measure taken for each R-C-S building are also estimated. The foremost aspect behind the failure of R-C-S is unsuitable design of the high rise (H-R) buildings; the passive and active remedial measures are recommended to minimize the damage of the structure R-C-S [2]. In Figure 1 various phases during the enlargement of a natural fire are shown.

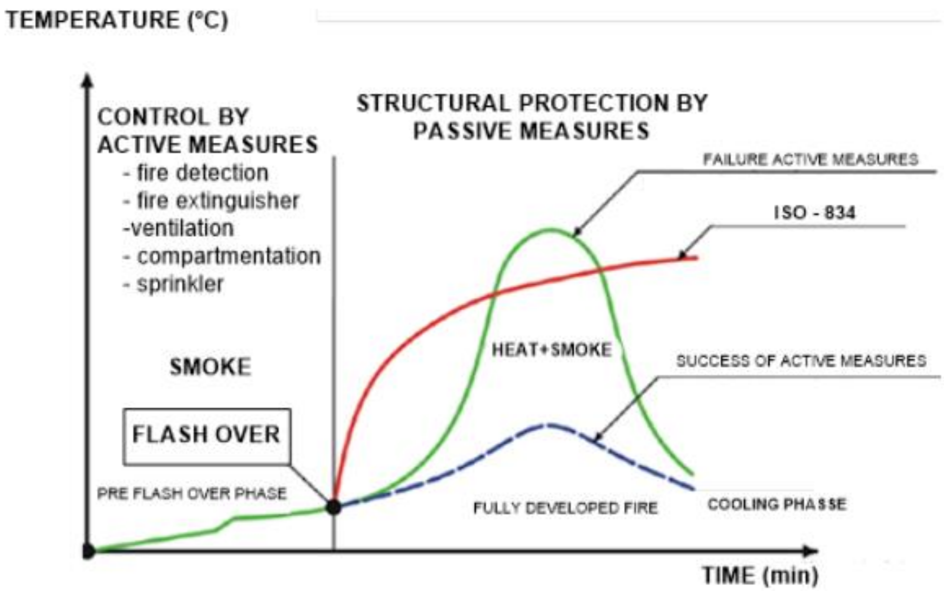

Figure 1. The various phases during the development of a natural fire [5].

In this research work, a detailed literature review is discussed related to fire damages to reinforced concrete structures, firefighting deficiencies for high rise buildings, and remedial measure adopted for fire prevention in reinforced concrete structures of high rise buildings. Some of case studies also investigated for effect of intensity of fire on structural elements of buildings. Factors effecting stability of concrete and steel structures in sever event of fire are also identified.

2 Evaluation of reinforced concrete structure of high rise buildings in term of fire intensity

One of the greatest severe probable hazards for R-C-S building is fire, and because of this international codes provide specific guiding principle to taking into account fire in R-C-S design. In many kingdoms (i.e. Greece, Spain, Turkey, Portugal in the Mediterranean area and Italy), where seismic activity is an event with extraordinary danger for physical grievance and harm to items and assets, national codes are leading more guideline for the risk of fire, by considering that human activities are in constant development and evolution and can be more dangerous than natural events. Amongst the building materials, the concrete is commonly considered by adequate performance for fire. Concrete exposed to long duration of elevated temperature, mechanical loss due to the transformations of microstructure in cement paste and aggregates occurring and changes in volume persuaded by thermal stresses [6]. Fire exposures resulting an earthquake may be noteworthy because of improved possibility ignition of fires, firefighting resources demand increased, and probable barriers to suitable reaction. Ignitions increment and extensive flame duration have substantial structural effects on R-C-S which are generally considered to have advanced performance in events of fire [7]. The Grenfell Tower fire occurred on 14 June 2017, killing 72 people. The pattern and speed of vertical and horizontal fire spread characterize this catastrophic event. After the façade ignited at the fourth floor, vertical propagation over time is linear, with a vertical fire spread rate of around 3.5 m/min until the fire reached the sixth floor. Then fire propagation decelerated [8]. Hotel Aseman Fire, Iran Building features: 22-storey Concrete building Fire occurred on Aug. 3, 2019 No deaths significant structural damage to slabs & shear walls need repair and retrofitting Fire cause occurred during renovation work [9]. Figure 2 shows the damaged reinforced concrete structural elements expose to fire.

Figure 2. Destruction in slab soffit: a. Slab#1, b. Slab#2 and (c) Slab#3 [10].

Exposure to fire can cause R-C-S deterioration, even lead to the collapse of building. Depends upon the fire period and on the structural details i.e. concrete cover, R-C-S elements to be able to bear the effect of fire and stay stable afterward cool down. In the latter case, a structure cannot be bent during a fire, it can still undergo from weakening of the steel and concrete because of higher temperatures. Structural property of reinforced concrete is the flexural ductility i.e. ratio between deformations at state of ultimate and at tension steel yield [11]. Minimum duration to resist the fire in R-C-S shown in Table 1.

Table 1. Minimum fire resistance time period of building in minutes [12]

Category		**Fire resistance time period of building in minutes**			
		Height of building			
		Up to 5m	**Up to 18m**	**Up to 30m**	**Above 30m**
		Minutes	**Minutes**	**Minutes**	**Minutes**
Residential flats	Non- Sprinkler	30	60	90	120
Offices	Non- Sprinkler	30	60	90	Not permitted
	Sprinkler	30	30	60	120
Commercial	Non- Sprinkler	60	60	90	Not permitted
	sprinkler	30	60	60	120
Industrial	Non- Sprinkler	60	60	120	Not permitted
	Sprinkler	30	90	90	120

2.1 Effect of fire damage on strength of reinforced concrete structures

Fire event exposed to a particular raised temperature, concrete is usually lesser defenseless to fire as compare to steel [13]. Most of the fires in R-C-S, structural destruction was detected due to the deterioration of the materials i.e. as concrete and reinforcement of steel. Furthermore guidelines of design R-C-S cannot provide any of reliable estimation of structural performance afterward event of fire, so as a result the level of fire safety against the risk of structural collapse is just unknown [14]. On the behalf of researchers studies concluded that high temperature effect on R-C-S indicate that the calculation of fire resistance is basically depends on tabularized data having the dimensions of R-C-S elements cross-sections and cover of concrete. Buckling mode is noticed at a temperature of 500°C and a crushing failure mode is at lesser temperatures [15]. In addition the creation of non-uniform thermal strain and pore pressure cause in concrete spalling and thermal stresses [16]. Damaged reinforced concrete due to fire with variation of temperature is shown in Table 2.

Table 2. Composition of concrete damage with varying temperatures [17].

Temperature	Damage Level	Grade
~300 ◦C	No damage	I
	Finishing material damage (soot, surface exfoliation)	II
300~600 ◦C	Concrete damage without steel damage (small cracks in concrete or spalling)	III
600~950 ◦C	Bond damage of steel bars (large cracks in concrete or exposure of steel bars)	IV
950~1200 ◦C	Damage or buckling of steel bars (large damage or deformation of structural members, heavy exposure of steel bars in a wide area)	V
~1200 ◦C	Concrete melting	

Thus the residual capacity of R-C-S members is lesser as per original residual capacity, so that for which these were designed and constructed. The feature exposed to fire were inspected by numerous researchers, assessment of the residual-bearing-capacity of R-C-S next to the event of fire. [13, 18]. Consequently, the importance of variance between the change in properties of materials against pre-fire and post-fire event, reduced the load-bearing capacity, however after the event of post fire reduced capacity because of the concrete deterioration [19]. Reinforcement of steel, the property i.e. residual once, depending upon type of steel, yield strength, young modulus of cold-worked rebar's that are subject to high temperatures ~300oC reduced significantly, for hot-rolled rebar's decrease capacity starts after exposure to ~500oC [20]. So review revealed that steel and residual properties of concrete materials are severely damaged by contact up to~200 temperature, although temperatures cooling ranges from 400oC to 800oC, goes to reduction of residual compressive strength of concrete of with comparison to original strength [21, 22]. It was concluded that the reliability reduced non-linearly with time, whereas the most effective factors influencing the dependability of R-C-S elements were cover of reinforcement, load ratio, exposure of fire and boundary conditions [23].

3 Imperfections in firefighting systems of reinforced concrete structures

In 2009-2013, U.S. fire departments responded to an average of 14,500 R-C-S on fires per year in H-R buildings. These fires initiated yearly usually of: 40 civilian fire deaths, 520 civilian fire harms, and $154 million in direct property destruction. 5 property use groups responsible for just about 3 quarters (73%) of H-R fires: Multi-family housing/Apartments i.e. 62% of all H-R fires, Hotels i.e. 4% of H-R fires, Dormitories i.e. 4% of H-R fires, Offices i.e. 2% of H-R fires, Conveniences that attention for the sickening i.e. 2% of H-R fires [24, 25]. The Shanghai Tower is a mega-tall skyscraper in Lujiazui, Shanghai. The Tower consists minimum of 3 hours fire resistance withstand fire persuaded advanced failure. The R-C-S elements have minor residual displacements reference with steel elements. It is recommended that, reinforced concrete and related structures design, that effective for protection of fire, should be provided for the outrigger trusses to assurance the assembly between the central and mega columns [26]. The World Trade Center (WTC) New York, the United States in 2001, which murdered 2,451 persons, and destruction amount is 33.4 $ billion. It is defined that the separation of the building into fire sections in the vertical for the case was purely nominal [27-29]. Pictorial view of R-C-S of H-R buildings are shown in Figure 3.

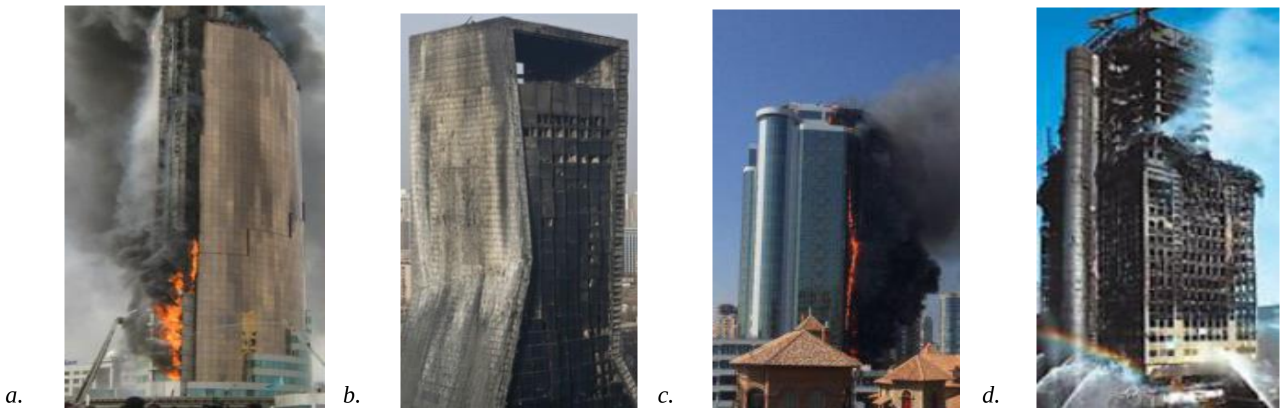

Figure 3. Pictorial view of fire on:: a. Skyscraper Transport-Tower, Astana; b. Hotel Mandarin Oriental, Beijing; c. Building in Odessa; d. Madrid building [30].

3.1 Case studies on deficiencies in firefighting systems

Bashundhara City, Dhaka the first biggest commercial complex in Bangladesh. A fire starting through short circuit broke out on 18th floor of the office tower. In addition, the fire-plug could not be used because it was installed inside of an office. The building was not equipped with a sprinkler system but have fire alarms and smoke detectors. The fire hose was installed only in an office area on the standard floor, not compartmented by fire rated walls [31]. Odessa in 2015, paneling on the top floors of the incomplete buildings of the complex Arcadia. The fire was extinguished by two tall ladders 30m and 50 m. However the issue was that the sleeves not have sufficient pressure, and not provide interior fire extinguishing system in building. In 2005 event of fire occur in 106m and 32-storey Vidzor building of office, firefighters reached just over two hours. The building was combination of central reinforced concrete core and outer frame is steel, as an outcome the fire come into contact with 6 upper floors. A fire event occurred in government 32-storey skyscraper Transport Tower in the Kazakh capital Astana in 2006. The fire was convoyed by the scattering to glass-façade shards. In event of fire happened in Mandarin Oriental hotel building, Beijing 2009, fire quickly blow down to the front. Continuation of fire almost to five hours [30]. In Los Angeles 1988, a fire arisen in 62-storey building, although the point is that effectively the whole H-R building area was sprinkler system equipped. Simply through the optimal fire defense of load-bearing components, construction of skyscraper of steel with stood three hours contact with fire intensity. [32].

4 Prevention of fire damage to reinforced concrete structures of high rise buildings

Subsequently the tragedy of WTC, New York, United States in 2001, several criterions have been revised on the behalf of fire event occurrence information manual. As earlier happened fires in H-R buildings cannot lead to whole damage of R-C-S buildings, more or less, the guidelines in many kingdoms permit the evacuation plan by just the fire floor and adjacent floors below and above [33]. Modern H-R policies within the UK requires a minutest fire safety standard as prescribed in the current building regulations "Part B" which can be accomplished through passive and active performance based fire protection methodologies [34]. The remedy for issues in the design of new and renovated H-R structures applied through following procedures: actions for well-timed evacuation and safety contrary to smoky; alarm devices for fire and management evacuation; procedures to protect lives and bound the risk of fire to the materials, buildings and structures. Active Protection System for H-R structures to prevent fire damage: alarm devices for fire and F-F; strong-hold of the fire; Central remote control device systems for fire defense of H-R buildings [30]. In Figure 4 shown some of the F-F equipment's for R-C-S of H-R buildings.

Figure 4. Pictorial view of: a. Fire detection and alarm systems; b. Internal and external (above ground) hydrants; c. Sprinkler head [35].

The American National Fire Protection Association (NFPA, 2003) has developed a framework for evaluating fire safety, so called Fire Safety Concepts Tree [36]. The leading cause of serious fatalities in fires event is smoke suffocation i.e. the number of smoke casualties ranges 80% to 90%, whereas a considerably fewer people die due to collapse of building [37]. On the contrary, all buildings must be designed in such a way as to maintain their structural integrity during the fire and thus enable safe evacuation of people and provide a certain level of protection for firefighters. Time duration before the structural collapse should be minimal of 15 minutes, for lightweight wooden/steel structures, including roofs, 1 hour for: small buildings and 3 hours: for H-R buildings [38].

4.1 *Standards of fire safety measures for reinforced concrete structures*

Fire detectors and alarm systems are the basic fire protection components of each building whose installation and use can considerably decrease the losses of human lives and property after fire. The types of detectors almost usually used in H-R buildings, particularly when human lives are exposed, are heat and smoke detectors, and detectors of other fire phenomena, as well as combined detectors. Control of smoke is compulsory because of difficulties produced by the toxic matters existent in it as well as due to the widespread disorientation effect, due to decreased visibility. [35]. F-F evacuation directions for reinforced concrete structures of H-R building are shown in Figure 5.

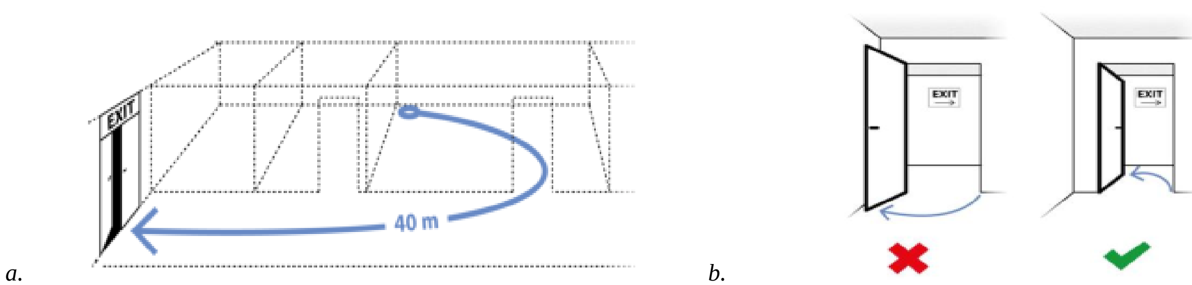

Figure 5. Pictorial view of: a. Maximum travel distance; b. Exits opening direction [35].

There are obvious negative significances of interaction between ventilation devices and sprinkler systems. The issues recognized are produced by effect of the water cooling the smoke, which prevents its upward buoyance [39]. A number of tests 34 have been conducted in connection with this phenomenon and design guidelines have been published [40]. Evacuation is one of the most essential problems in fire, and each building must be designed so that occupants can escape on their own or with the help of rescuers/other persons. In all rooms where more than 20 occupants can be accommodated, the exit door must be provided and must be opened in the direction of the exit path. All the width of the stair-way and the corridors must be suitable for the estimated number of people. This also applies to external access to the balcony when people are used primarily for way out. Buildings must be equipped with a backup light with a standby battery to confirm safe evacuation in situation of power failure [35].

5 Conclusion and suggestions

Numerous important information for structural assessment of a fire damaged building are important to be considered. These factors are categories of building elements and materials, fire initiated point, exposure condition, necessary data required, expected temperature of fire and time period of fire. Fire ignition can take its peak level because of the limited numbers of fire prevention equipment's and other parameters. The study further shown the requirement to advancement on fire safety actions carry out for the owner of property and designers. The review results show the popularity of survey and case study in fire damage related to reinforced concrete structures. It was found that major corporate source of fire occurrence is faults in electric system, fire detection system not in active condition and lack of firefighting equipment's and barriers in emergencies exits way. Following are some suggestion for R-C-S of H-R buildings to fight with fire disasters and all of these must be in operational condition:

- Educate all workers and other staff regarding to save their life from fire disaster. Install fire hydrants that in the surrounding of high rise building. Increase the access to fire control room and assembly area. Emergency stairs are need to be opened all time, tag instruction poster and hang key near the stairs exit door.
- Increase the numbers of smoke detectors, fire extinguishers, automatic fire alarms, and fire proof electric circuit boxes.
- Posters of emergency phone numbers (i.e. help from inside and outside sources), emergency response guidelines (i.e. personal injury response and fire), first aid kit, evacuation plan and fire exits must be placed on walls at different locations of each floor of reinforced concrete structure buildings. Make sure the availability of stock of full face masks on every floor to avoid the effects of fire and smoke in an emergency condition.

Further study should be carried out in detail for automatic controlling of the fire ignition and fire related concerns of high rise building in terms of applicability of above suggestions.

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