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Behavior of Concrete Reinforcement Columns Subjected to Periodic Fire

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Abstract: One of the worst things that can happen to a structure is fire. Nonetheless, reinforced concrete remains one of the most extensively utilized building materials globally due to its high resistance. The skeletal components of reinforced concrete shift when exposed to high temperatures, which frequently results in inclusive cracking. The most crucial structural components in any concrete building are slabs, beams, and columns. In general, structural members are made to meet serviceability and safety limit state standards for a range of environmental circumstances. Structural members are usually designed to satisfy a particular fire resistance rating. Fire resistance depends on a number of factors, including the structure's attributes and the type of occupation. The main objectives of structural fire rating are to allow building occupants to evacuate, to provide firemen enough time to extinguish the fire, and to avoid any possible structural damage. The behavior of several reinforced concrete building structural components under high temperature exposure is summarized in this article. It has been discovered that fire negatively impacts both concrete and reinforcing bars. Additionally, it has been found that when stress or the length of time exposed to fire increases, stiffness and flexibility decrease. Additionally, as the cross-section of the structural element increases, the stiffness and flexibility increase as well; yet, during the fire test, the maximum slab deflection reduces nonlinearly. As temperatures drop, the concrete slabs bottom cools, increasing the bottom reinforcing's yield strength and causing it to shrink with the slabs lower half. As a historical review, this article also provides an analysis of a number of experimental and theoretical findings about the way that beams, slabs, and other structural elements made of reinforced concrete behave thermally under different conditions.

Keywords: behavior، reinforcement، concrete.

1. Introduction

Fire is a common name for the quick chemical reaction that releases energy in the form of heat and light when flammable materials oxidize. The growth, burning, and decay phases are the three primary phases that define a typical fire incident. Even if the growth period is brief and results in low temperatures, it is essential for figuring out how long fire departments can effectively operate in order to intervene and identify fires that cause the least amount of property damage. The burning period begins when a flashover happens and the temperature begins to rise noticeably at an increasing rate until a certain point, after which it decreases until the peak temperature is reached. This occurs after the combustible components burn in an active manner. When the heat produced by the flammable materials equals the heat lost to the environment, the temperature begins to stabilize once more. Following that, there is no need for any additional mitigation throughout the decay period as the temperature progressively drops. The reported temperature is typically interpreted as the average gas temperature within a given volume because the temperature in any enclosed space changes with time and place as well (Lie, 1992). Undoubtedly, reinforced concrete is regarded as one of the most extensively utilized building materials globally. Engineers used this material widely in their designs for larger buildings because of its inherent structural performance and robustness., Better seismic performance, increased durability, and even eco-friendly materials are taken into consideration. Concrete is a non-combustible material with exceptional fire resistance, which means that it does not contribute to fire loads and does not burn at high temperatures, in addition to its advancement in structural applications. Because of its low heat conductivity, it also acts as a fire barrier and an insulator for other building materials like steel and wood. Concrete structures exposed to high temperatures perform well when compared to other building materials, but over time, certain physical and chemical changes in the material result in a major decline in its mechanical qualities and the eventual deterioration of the entire structure.

2. The way reinforced concrete beams behave when exposed to fire

2.1. Isolated Reinforced Concrete Beams

Numerous fire tests on reinforced concrete beams have been conducted over the last three decades by the Portland Cement Association's Fire Research Laboratory, Technology Laboratories, Inc., Skokie, 111. For each of those tests, the fire was used. In order to conduct thermal tests, Ellingwood and Lin [10] assessed six continuous beams in fire trials, including one on reinforced concrete. To find out how concrete coating affected the behavior of the beams, three of them were proposed. Despite having a bigger surface area to assess, the fourth model's four beams were inspected in compliance with ASTM E119 fire exposure. Meanwhile, there was a brief but intense fire in the two remaining beams. According to the investigation, the thickness of the concrete cover had no effect on the beam deflections during the first three hours of the fire (Fig. 1). As early as 90 minutes after the fire started, shear cracks started to show. The flexural cracks, on the other hand, developed after roughly 30 minutes and quickly propagated across all of the beams, preventing them from flexing instead of shearing off. This finding demonstrated that the shear strength of the beams was insignificant at high temperatures, even when nonlinear stress gradients caused extensive internal faulting. El-Hawary and associates [11] built four reinforced concrete beams measuring 200 by 120. Following a day of burning for three identical durations of 30, 60, and 120 minutes in a conventional burning chamber, three of them were put to the test. To give a benchmark for compression resistance, one beam was left unburned. served as the basis for the resistance compression, and the measured responses were connected to fracture patterns, stresses, deformations, deflections, and bending strength. In contrast, as exposure duration grew, fire had a greater impact on concrete than steel reinforcement, increasing compressive strain more than tensile strain instead. Figures 2 to 5. Applying the same standards as, Khan et al. [12] solely examined reinforced concrete beams in the area of tension at the start of the preceding twelve years. They achieved this, as demonstrated, by switching between cooling the beams for 7, 14, 21, and 28 days and burning them at various temperatures (100, 200, and 300 °C). Figure 6. An angled shear crack that developed via the load application point was the primary cause of the beams' largest failure. The initial flexural crackload percentage of beams subjected to 300 °C heat cycles was virtually unaffected by it, but it was greatly impacted and dropped as the number of cycles increased. They found that when heat-treated reinforced concrete beams were heated to peak temperatures of 100 °C and 200 °C, their maximum shear strength rose by 10% as thermal cycles increased., However, at higher thermal cycles, it dropped by 14% for beams heated to peak temperatures of 300 °C. Furthermore, it was observed that when temperatures and thermal cycles increased, the cement paste gradually disintegrated and microcracks appeared as a result of stress in the surrounding concrete. This led to a decrease in shear strength. As a result, it was concluded that the strength further declined due to the stress concentrations close to the important crack edges. Fig. 7.

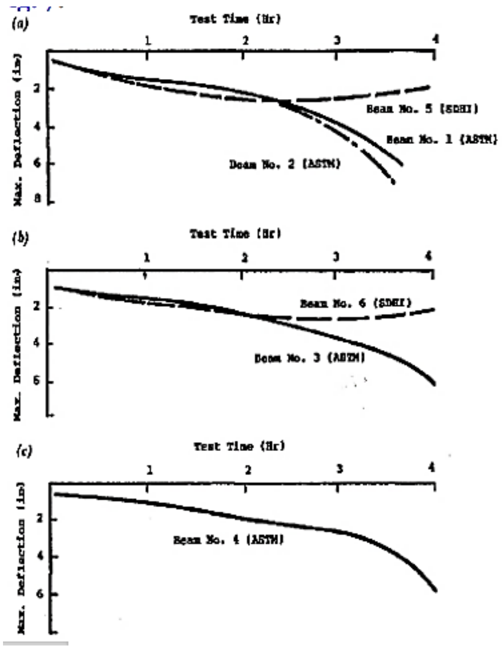

Fig. 1 Fire Test Measured Maximum Deflections [10].

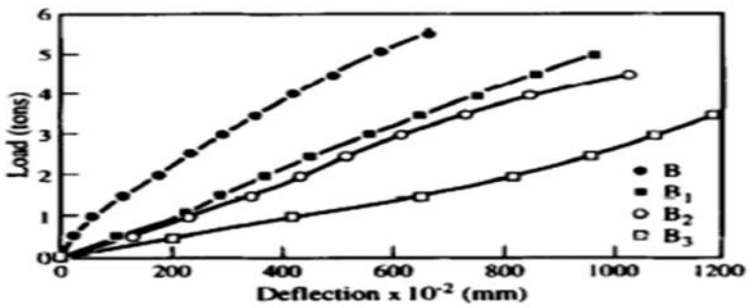

Fig. 2 Maximum Deflection by Load [11].

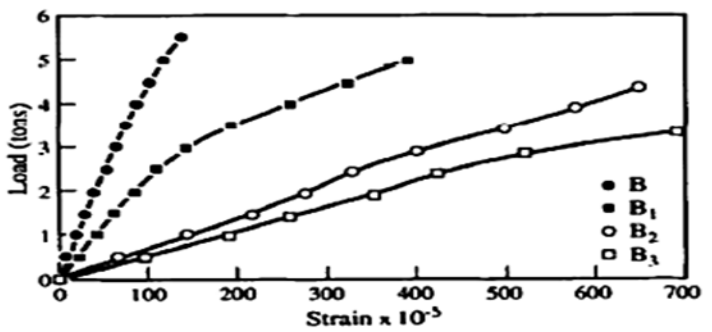

Fig. 3 Maximum Compressive Strains at Load [11].

Strains [11].

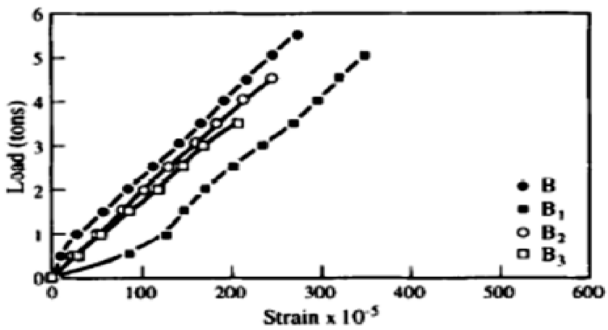

Fig. 4 Maximum Tensile Strains under Load [11]

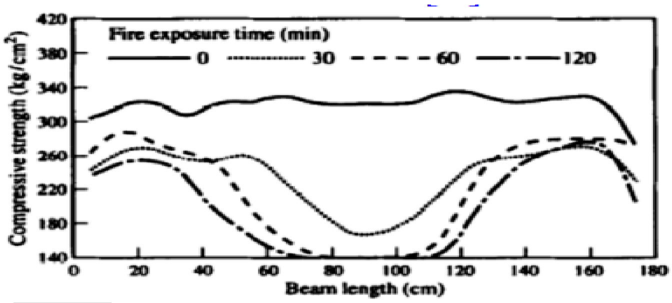

Fig. 5 Compressive strength throughout the middle zone's fire-exposed beams [11].

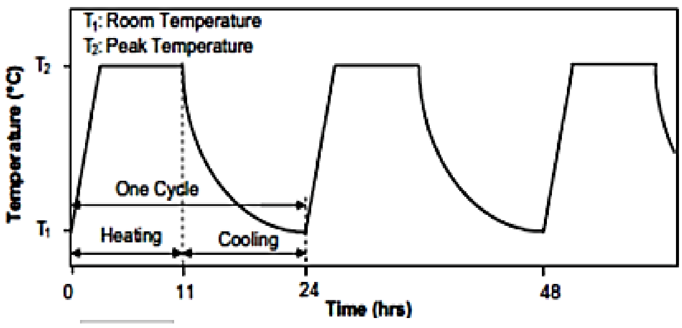

Fig. 6 Cycles of Heating and Cooling (T1 = 27 °C, room temperature) [12].

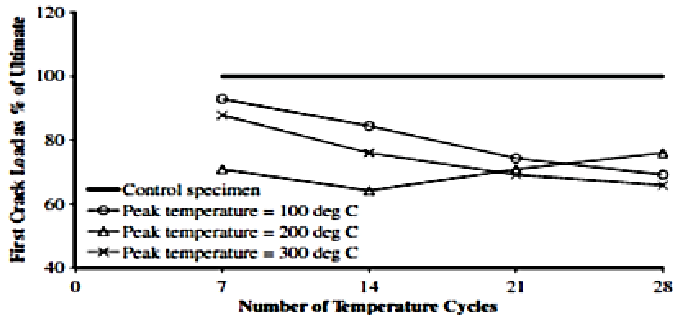

Fig. 7 Comparative differences in the shear capabilities of Khan et al. (2010)'s four heated beams with higher temperatures and cycle counts [12].

Six full-scale beams that were built using weak shear and strong bending were used in another investigation by Song et al. [13] to test their fire and load resistance. They were first exposed to an impact force, and then they were exposed to combustion from three sides with a fixed load. The effectiveness of the longitudinal reinforcement ratio and the stirrup ratio were the variables under investigation. It was discovered that the deflections rose gradually at first until they suddenly became acute. According to the findings of that observation, In other words, It is possible that the longitudinal reinforcement had a substantial pinning effect, increasing the sample's shear capacity at which the failure rate rose as the percentage of longitudinal reinforcement rose. The scientists came to the conclusion that the stirrup ratio had a very small uniform impact on the fire resistance of the reinforced concrete beam if the applied load ratio was constant, even if they were able to successfully reduce the brittle change of vertical displacement when the beam reached the failure phase. Using the concepts of "strong bending and weak shear," they ultimately determined at higher temperatures. An article provided them with a variety of methods to assess the capacity of interior reinforced concrete beams to withstand residual thermal strains following exposure to high temperatures typical of the fire scene [14]. A modified epoxy matrix was utilized to attach the three different types of FRP rods—"(1) basalt-FRP (BFRP)," "(2) hybrid FRP with carbon and basalt fibers (HFRP), and (3) nano-hybrid FRP (F.R.P.)"—to steel reinforcement. were unloaded and then heated in the furnace and left to cool. Following that, the beams were subjected to flexural reloading until they failed. A strange phenomena was seen in HFRP rods and nHFRP-reinforced rods, where the deflection reduced beyond a certain temperature. The authors found a connection between the occurrence and the carbon fibers' coefficient of thermal expansion. investigated how the strength of R.C. beams subjected to high temperatures was affected by the addition of steel and polypropylene hybrid fibers [15,16]. The testing beams were constructed with varying numbers of fibers. The temperature-time curve described in ASTM E119 was used to apply a service load to the beams after a controlled fire that lasted 120 minutes. Fibers improved the R.C. beam's resistance to high temperatures and decreased deflection, according to the data, which might significantly raise the fire's residual stiffness. The fire reaction of steel beams under bending and shear-dominating stress was experimentally investigated in a paper by Ibraheem and Abdullah [17].. All of the specimens were 1250 mm long. The complete scope of Test findings suggest that a substantial reduction in the ultimate strength and yield of steel beams may cause them to break rapidly of all diameters dramatically decreased as the temperature rose (for all tested groups). This was a 50% drop. Shear strength was also significantly decreased by fire exposure, falling by 38%. Additionally, only at mild temperatures could the design strength capabilities sustain stresses. This loss of power

2.2. concrete beam-slab assemblies reinforced by reinforcement.

Two full-scale reinforced concrete specimens in the form of beam-slab assemblies and two additional small-scale reinforced concrete slabs were evaluated for fire endurance in a single field research by Kodur et al. [18]. F.R.P. was used to strengthen the four specimens.

Without any applied load, the specimens were inspected to determine the thermal performance of the insulation/reinforcement system. After that, the beams were tested in a small chamber that served as a slab furnace to evaluate the overall Above a hole that supplied heat from below, two slabs were positioned.

The writers removed beam A.B. and slabs B1 and B2 from the third floor of Fig. 8(b) and regarded them as a beam-slab assembly.

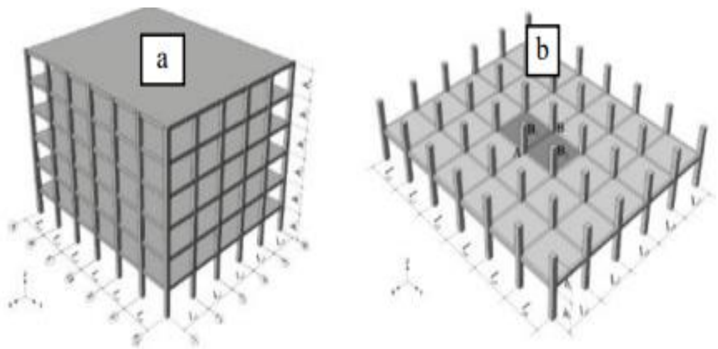

Fig. 8 Bo Wu and Rujia Zhang (2017) examined the multi-story building's full-scale reinforced concrete structural frame [19].

The entire frame (a) and the third storey (b). Wu and Zhang [19] used (finite element modeling) to expose the lower surface of significant restrictions. The researchers summed up the following closing thoughts based on their numerical results:

1) To more precisely calculate the rotational limiting stiffness at the end of the beam, the contribution of neighboring beams connected to and perpendicular to the particular fire exposure beam must be taken into account..

2) The rotational restriction stiffness at the beam end varied between 1.3 and 20.9. 3) The stiffness of the distributed rotation limitation at the center of the plate's edge rose in tandem with the plate thickness and the beam's sectional size. In contrast, as beam length rose, the restriction's stiffness decreased. 4) It was proposed that their numerical results were generally consistent with

3. The Response of Fire-Exposed Reinforced Concrete Slabs

3.1 General Fire-loaded

Numerous scholars have examined reinforced concrete slabs [20–22]. In a follow-up test, Bailey and Toh [23] assessed 22 small slabs at high temperatures and 26 small slabs at normal temperature. Similar experiments were conducted at ambient and increased temperatures in order to directly compare failure patterns, as illustrated in Fig. 9. Six varieties of 1.4301 (304) austenitic stainless steel and five varieties of mesh mild steel were used to achieve various reinforcing ratios. It was determined that more boost ratio increases and compression failure produced just a slight improvement. On the other hand, improvement occurred when the percentage of reinforcement increased. "which indicates the membrane workload defined as the maximum continuous load divided by theoretical yield load" . Additionally, it was determined that square slabs outperformed rectangular slabs for a certain amount of vertical displacement. of 1.1 m (Fig. 10). It's well knowledge that raising the temperature weakens the slab's fire resistance. Heat exposure causes physical and chemical changes in concrete, including aggregate disintegration, drying of the cement paste, and a dry atmosphere, which is why the reduction happened. Through internal microcracks, water evaporation, and concrete deterioration, these changes raise pore pressure [24]. Furthermore, when the temperature increases, the yield strength of the steel reinforcement decreases. When temperatures are high, [25, 26]. The stiffness and end restraint conditions have a significant impact on how concrete slabs behave while they are on fire. The compressive restraint provided by surrounding structures reduces the thermal expansion of slabs. [27–29] Consequently, unrestrained one-way slabs are typically less fire resistant than restrained slabs. Depending on the kind of steel and aggregate, codes of application state that temperature increases cause strength degradation in both concrete and steel reinforcement [30, 31]. However, according to these rules, the temperature of the steel reinforcement is mostly to blame for the strength degradation. According to [31] committee evaluated the slab's fire resistance. The aggregate type determined the cover's thickness. Depending on their size and the thickness of the concrete coating, the ECP 203-2007 [32] deemed "slabs, beams, and columns" to be fireproof.

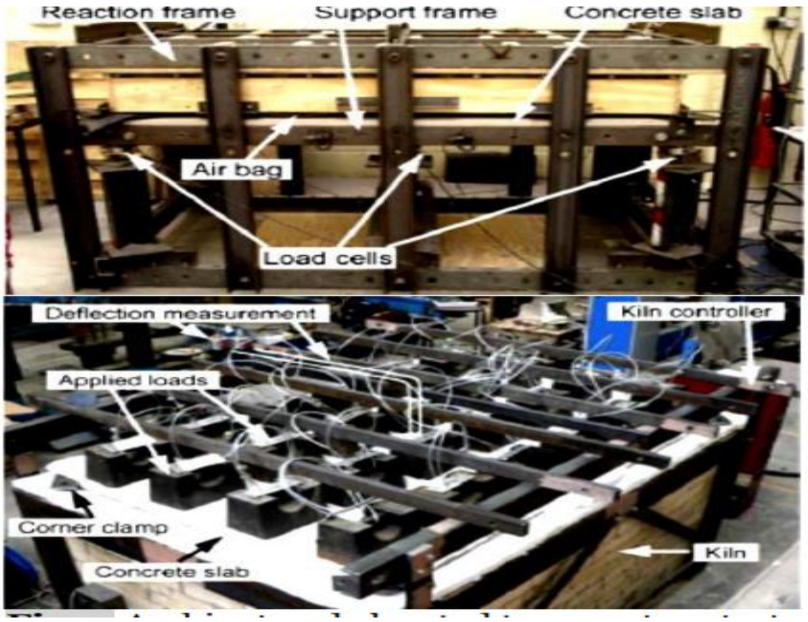

Fig. 9 Tests using ambient and increased temperatures [23].

3.2.One-Way Reinforced Concrete Slabs

The examination of the reinforced concrete slab was conducted using the same procedures used for room temperature concrete suitable for fire resistance tests, with the assistance of numerous test data from the Portland Cement Association. When exposed to fire from the bottom face, simply supported reinforced concrete slabs behave as shown in Fig. 11 [33]

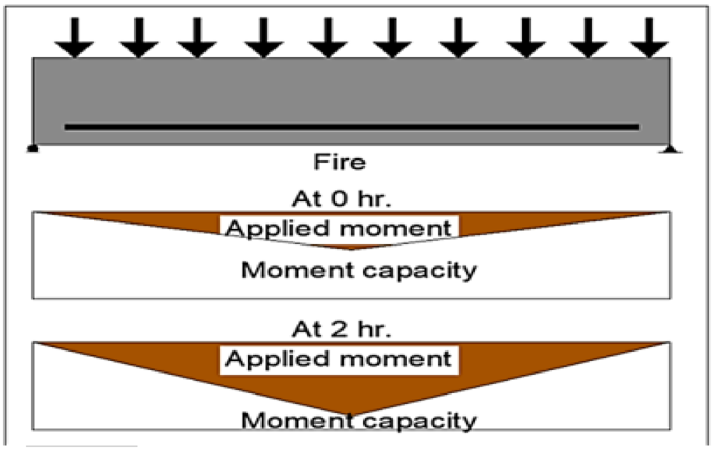

Fig. 11 Impact of Fire on a Reinforced Concrete Slab with Simple Support [33].

The slabs are freely stretched (not thermally constrained) and their ends spin freely. Straight bars are used as reinforcements and are positioned close to the slab's bottom. The slab deflected downward due to further bending because the bottom face, which had been exposed to the fire, expanded more than the top. Furthermore, the concrete and reinforcing along the slab's bottom face lost strength as the temperature increased. Bending failure would happen if the reinforcement's strength fell below what was needed to support the slabs and any overlapping loads. [33]. The fire resistance of reinforced concrete slabs under fire exposure accounted for the majority of the study effort in the literature. Nonetheless, some research has been done to examine how cooling time affects the fire resistance of concrete slabs. Only the cooling initiation time on fire resistance was taken into account in these investigations [19,21,24]. To the best of the authors' knowledge, no studies have examined the risks associated with cooling times for fire resistance. The transition from cooling start to fire resistance is difficult. When the fire is extinguished (cooled) while the temperature in the concrete slab's core continues to rise, the concrete slab fails this difficult time if it cools down before it can withstand fire. Allam et al. [34] provided a finite difference method for monitoring the fire reaction of one-way reinforced concrete slabs with simple supports in accordance with ISO834 Fire standards. Among other things, the "thickness of the concrete cover, presence of plaster at the exposed surface, and the ratio of live load" were taken into account. The pattern is confirmed against experimental and numerical data by contrasting the expected and actual temperatures, as shown in the graph (Fig. 12). The cooling effect and fire resistance can be predicted by the pattern ahead of time. According to this investigation, the section capacitance fell as the reinforcement's yield strength declined as the temperature of the reinforcement rose. Figs. (13- 15),. The decrease in fire resistance, which was nearly always about 28% in all situations, was more pronounced the larger the live load.

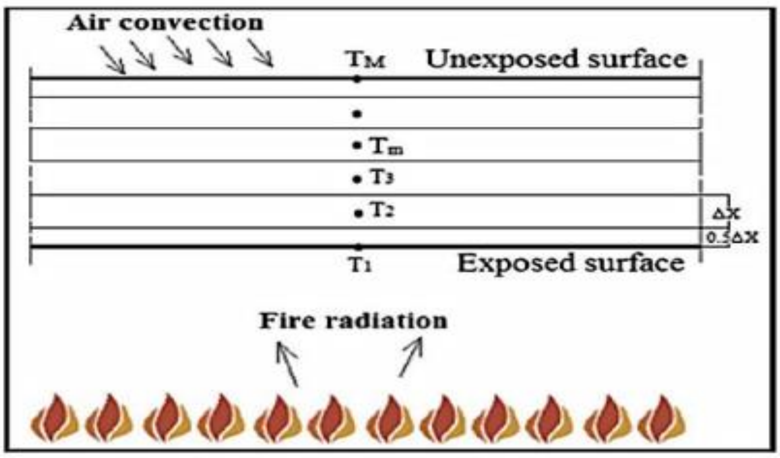

Fig. 12 Heat transfer Model [34].

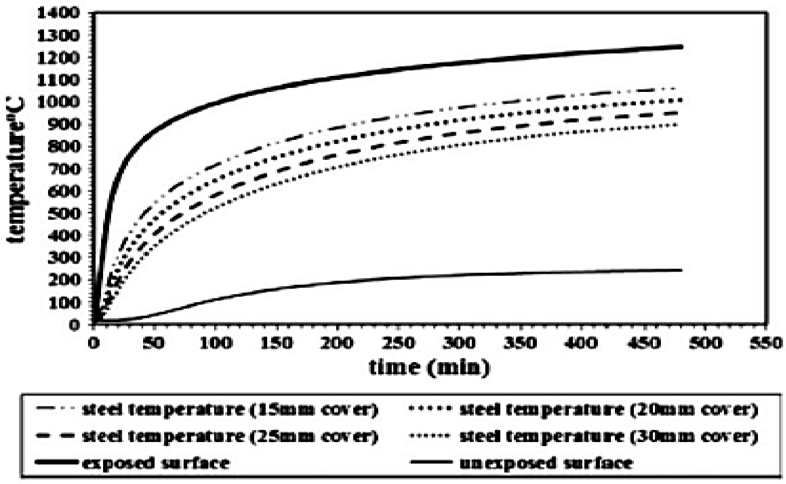

Fig. 13 Distribution of temperatures for steel and concrete slab surfaces (without plaster) [34].

3.3.Two-Way Reinforced Concrete Slabs

Bailey and Moore developed a technique for figuring out the maximum load-carrying capacity of slabs, taking into account the effects of tensile membrane reinforcement at high temperatures, in their two studies [37–38]. A crack in the middle of the slab was considered a failure mode while employing this technique. The development of full-depth cracks at the yield line junction was the failure scenario that previous researchers [39, 40] described. Linus [41] used fire BRANZ to give. The slabs had four simply supported sides and were unbound horizontally. A continuous distributed load was applied to the slabs. The slabs were simultaneously heated from underneath using a furnace. The impact of mesh bar spacing on the deformation capacity of the slabs was assessed. of extensive and profound fissures, enabling the slabs to keep their reliability rating. The tests' cold-drawn mesh performed well and did not rupture since steel's ductility increased noticeably at high temperatures. By substantially supporting the loads above the expected yield line capabilities, the tests also showed how important the tensile membrane work is in maintaining the structural integrity of the floor slabs in the event of a fire. After that, a paper by Lim et al. [42] examined the fire behavior of two-way reinforced concrete slabs using the Nonlinear Finite Element Program, namely SAFIR. The modeling results were in agreement with the fire tests and demonstrated that the SAFIR shell element could be used to forecast the membrane action of two-way reinforced concrete slabs under fire circumstances.. Moss et al. [43] reported a numerical study that involved simulating the, the slabs reacted differently in decay fires. These membrane forces rise significantly throughout the four hours of constant fire exposure, surpassing what was

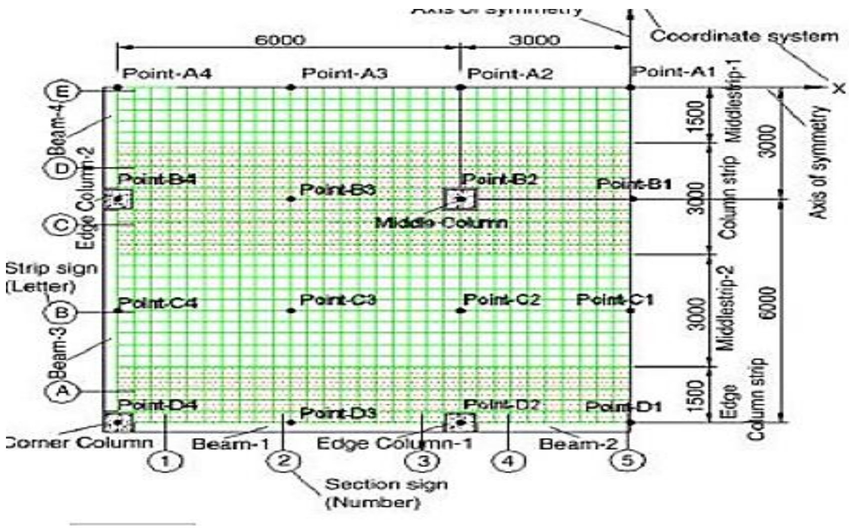

Fig. 18 A fourth of the nine-bay flat slab is depicted in the reference diagram. [43].

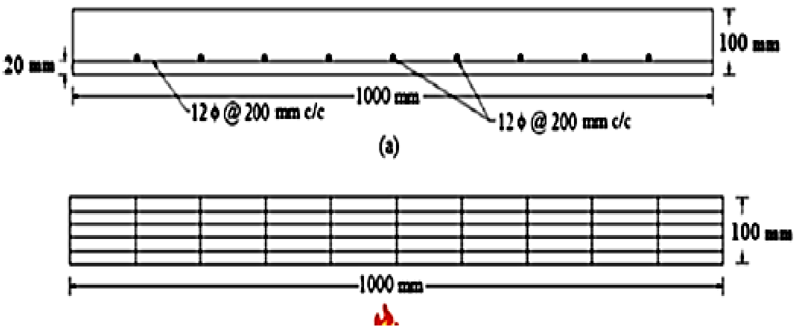

Fig. 19 Numerical analysis using discretization and geometric models [44].

4. An overview of the key elements in this review The following summary can be reproduced from earlier reviews.

Influence of Parameters on Structural Elements Fire Resistance				
Bottom Concrete cover	Lateral Concrete cover	Time exposure	Type of aggregate	Type of concrete
Increasing the thickness of the bottom concrete cover improved the fire resistance of the elements [5, 7, 10, 31, 33, and 34].	Had an insignific-ant practical effect on fire resistance [5].	Increasing the exposure time when the heating temperature had low enhanced the effect on strength [8,9].	The degradation of strength depended on the aggregate nature and the type of steel [29,30].	High temperatures reduced the strength of all types of concrete [45].

5. Conclusions

The free water in concrete changes from a liquid to a gasiform state due to an increase in temperature. The average heat transmission from the surface of the concrete ingredient to its inside varies as a result of this transformational state. As the temperature rises, both concrete and reinforcing steel lose strength and modulus of elasticity. However, the higher fire temperature rate and concrete insulating characteristics determine the rate of strength and modulus decline. being aware that concrete doesn't burn. The fire-resistance rating, as determined by testing or test-based methodologies, is the duration (usually in hours). whereby an assembly, component, or building element (a structural member) keeps its capacity to contain a fire, keeps up its performance of a certain structural function, or both. Previous examinations have generally found that the fire decreased the ultimate loads of structural components. Furthermore, the fire-induced deformation was more severe. According to the results, temperature distributions increase as load levels rise, which is in line with fracture diffusion. Nevertheless, the maximum beam deflection during the fire test decreases nonlinearly as the cross-section grows. Increased stress or prolonged exposure to fire causes the elasticity and hardness to deteriorate.. The beams become more flexible and rigid as their cross-sectional area increases. The structure's resilience to fire is increased by the thickness of the concrete in the slabs and beams. The load ratio has a little effect on the deflection of the slab but decreases the fire resistance of the column and the beam. Additionally, because of the axial restriction, the fire resistance of the beam increases while that of the column is drastically decreased. The aforementioned conditions may affect the behavior and performance of R.C. elements and put life and property at danger. Therefore, to guarantee optimal design, specific assessments of the behavior of each structural element must be acknowledged. According to the findings of the slabs' investigations,

1. The concrete and reinforcing steel at the bottom of the slab heat up more quickly than the concrete's surface and the steel's top. Boundary conditions indicate that the slab's thermal gradient attempts but is unable to produce thermal bowing, causing a large redistribution of bending forces.

2. The bottom steel's yield strength decreases as the temperature rises beyond 300 °C, which results in a decrease in both the membrane strength and the negative (sagging) bending strength of the concrete section. The bending moments in the slab reach their maximum when the bottom steel reaches 300 to 400 °C, and the slab becomes weaker as the bars continue to heat up.

3. Tensile membrane forces are inhibited by the heat-induced weakening of the reinforcing bars and increasing vertical deflections.

4. As the temperature drops, the concrete slabs bottom begins to cool. Consequently, the bottom reinforcing's yield strength rises and begins to decrease, as does the slab's lower portion.

5. The vertical deflections stop increasing when the fire is put out.

6. The average bending moments change from positive to negative as the slab cools and the temperature gradients decrease.

7. The membrane forces become tensile and rise even after the fire has been extinguished because of their enhanced strength and continuous thermal contraction. These membrane stresses significantly rise during the course of the four hours of continuous fire exposure.

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