Residual post fire strength of non-prismatic perforated beams

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Abstract. The main aim of this study is to assess the performance and residual strength of post-fire non-prismatic reinforced concrete beams (NPRC) with and without openings. To do this, nine beams were cast and divided into three major groupings. These groups were classified based on the degrees of heating exposure temperature chosen (ambient, 400, and 700°C), with each group containing three non-prismatic beams (solid, 8 trapezoidal openings, and 8 circular openings). Experimentally, given the same beam geometry, increasing burning temperature caused degradation in NPRC beams, which was reflected in increased mid-span deflection throughout the fire exposure period and also residual deflection after cooling. But on the other hand, the issue with existing openings was exacerbated. The burned NPRC beams were then gradually cooled down by leaving them at ambient temperature in the laboratory, and the beams were loaded until failure to examine the effect of burning temperature degree on the residual ultimate load-carrying capacity of each beam by comparing them to unburned reference beams. It was found, increasing the exposure temperature leads to a reduction in ultimate strength about (5.7 and 10.84%) for solid NPRC beams exposed to 400 and 700°C, respectively related to unburned one, (21.13 -32.8) % for NPRC beams with eight trapezoidal openings, and (10.5 - 12.8) % for those having 8 circular openings. At higher loading stage the longitudinal compressive strain of Group ambient in mid-span of solid beams reach 2700 με, while the others with openings exhibit divergent strain higher than that, it’s about 3300 με meanwhile, the lower chord main reinforcements have been pass beyond yielding stress. Exposure to high temperatures reduces rafters’ stiffness causing a reduction in load carrying capacity, companion with premature failure consequently reduce the strain at the ultimate stage.

Keywords: compressive strain, reinforced concrete rafter; opening’s configuration; burning temperature, reinforcement bar strain.

1. Introduction

Reinforced concrete rafters can be used as an alternative preferred option to support wide space roofs of warehouses, industrial structures and aircraft hangars, because concrete has a low material cost, a strong reputation for great fire resistance, and low maintenance costs Fire resistance analysis is an essential component of any fire safety design. The goal is to guarantee that the fire-resistant design is greater than the severity of the fire.

Reference [1] Presented experimental and numerical research evaluating the effect of different designs of apertures on the flexural behavior of reinforced concrete gable roof beams. A nonlinear finite element software, ABAQUS, was used to validate the results of the tested beams (2018). In terms of failure loads and load-deflection relationships, comparisons are provided, and good agreement is demonstrated between the predictions of the numerical analysis and the experimental data. Reference [2] studied the behavior of simply supported RC beams with rectangular-section with numerous openings of varying sizes, numbers, and geometrical shapes was investigated. The experimental results show that beams with circular openings are more successful than other designs in terms of ultimate load capacity and stiffness.
of beam, but beams with parallelogram openings outperform beams with rectangular openings. In Reference [3] An experiment was carried out to examine the performance of an RC beam with varied forms of openings with changing diameters at various places. According to the test findings, the ultimate load-bearing capability of the RC beam at the shear zone with the opening was the greatest decrease, while at the flexure zone, it was a minimal reduction.

Experiments were carried out by the researchers to recognize the effect of fire harm on the material characteristics of concrete with several mixed proportions under different fire exposures; [4-7]. The characteristics of high-strength concrete (HSC) differ from those of normal-strength concrete (NSC) at elevated temperatures. This variance is more evident in mechanical characteristics, which are influenced by strength, moisture content, density, heating time, silica fume concentration, and porosity, [8]. The compressive strength of concrete at room temperature is determined by the water-cement ratio, the transition zone between the aggregate and the paste, the curing circumstances, the aggregate kind and size, the admixture kinds, and the type of stress [9]. The tensile strength of concrete is frequently overlooked when calculating strength at ambient and higher temperatures. Nevertheless, it is an essential characteristic since cracking in concrete is typically caused by tensile strains, and structural damage to tension members is frequently caused by the advancement of micro-cracking [10]. Tensile strength of concrete during fire circumstances might be even more important in instances when fire-induced spalling develops in a concrete structural element [11]. Reference [12] studied the degradation of mechanical characteristics of post-fire high strength steels. Tensile coupon tests were performed on two frequently used high-strength steel grades, 460 and 690 MPa after they have cooled down from extreme temperatures of up to 1000 °C. Two distinct sets of prediction equations for assessing the mechanical characteristics of S460 and S690 following fire were presented, and they accord well with the test findings. In Reference [13] The numerical ABAQUS model predictions have a high agreement with the response variables observed in experiments for assessing the residual capacity of fire-exposed beams. Based on the knowledge and present literature, no researches were found it, studying the behavior of the high-temperature resistance neither of non-prismatic reinforced concrete solid nor with openings beams. Accordingly, an experimental program was developed and carried out to study the behavior of simply supported NPRC beams with and without openings under the effect of high-temperature fire flame then they tested under monotonic static loading with their variables up to failure. In reference [14] The impact of high temperatures on concrete filled with glass waste-filled was explored, the results reveal that glassy concrete is less sensitive to high temperatures than normal concrete and has outstanding stability at temperatures about 900.0 °C.

2. Beams set up

The variables which have been chosen in this work include; configuration of the openings, in addition to the burning temperature. All of the NPRC beams were identical length, breadth, height, and reinforcing features, and they were all exposed to a mid-point concentrating load after burning. Figure 1 shows the details of the non-prismatic beams. The width of all beams is 100 mm, the overall horizontal lower chord length is 3000 mm, the mid-span height of the oblique upper chord is 400 mm, and the end height is 250 mm. All beams were reinforced identically with (4-Ø6 mm) arranged by 2 layers in the top chord and (2-Ø6+2-Ø 12mm) arranged by 2 layers in the bottom chord, (Figs. 2 to 4). The solid ends of the solid beam NPS and other samples are provided with transverse steel bars made of 6mm steel bars, and the openings are equally spaced 100mm. At the same time, shear stirrups made of 4 mm ordinary steel bars are provided over the entire span of the upper chord and lower chord of the test sample, with a spacing of 50 mm. The beam was tested in a simple scheme with an effective span of 2.8 m. The tested beams are divided into 3 main groups. These groups were categorized according to the degrees of heating exposure temperature were selected (ambient, 400°C, and 700°C), each group contains 3 non-prismatic beams (solid, and with 8 trapezoidal and 8 circular openings). Table 1 and Fig. 1 show the details of the tested beams, where the symbol NP denotes non-prismatic, the subsequent symbol S indicates solid beam without openings, whereas T or C designates beams with trapezoidal or circular shape openings, respectively. Figures 2 to 4 show the configuration of the test specimens and the schematic diagrams of the reinforcement arrangement of the control and other NPRC beams. In all
beams with openings, the length of the solid ends is 400 to 500 mm to override shear failure or end bearing failure, and directly under mid-span load, a 200 mm wide column was realized.

Figure 1. Schematic layout of non-prismatic beams (all dimensions are in mm).

Figure 2. Details of steel reinforcement of NPS, NPS-400, and NPS-700 (all dimensions are in mm).

Figure 3. Details of steel reinforcement of NPC, NPC-400, and NPC-700 (all dimensions are in mm).
Figure 4. Details of steel reinforcement of NPT, NPT-400, and NPT-700 (All dimensions are in mm).

Table 1. Details of tested non-prismatic beams

| Group ID | Beams ID | Configuration of openings | Num. of openings | Total area of opening (mm²) | Width of openings (mm) | Weight ratio weight gain | Fire Temp. °C |
|----------|----------|---------------------------|------------------|-----------------------------|------------------------|-------------------------|--------------|
| Group I  | NPS      | -                         | 0                | -                           | -                      | 1.0                     | Ambient      |
|          | NPC      | Circle-shaped             | 8                | 128000                      | 0.83D                  | 0.86                    | Ambient      |
|          | NPT      | Trapezoid-shaped          | 8                | 174000                      | 150                    | 0.81                    | Ambient      |
|          | NPS-400  | -                         | 0                | -                           | -                      | 1.00                    | 400          |
|          | NPC-400  | Circle-shaped             | 8                | 128000                      | 0.83D                  | 0.86                    | 400          |
|          | NPT-400  | Trapezoid-shaped          | 8                | 174000                      | 150                    | 0.81                    | 400          |
| Group II | NPS-700  | -                         | 0                | -                           | -                      | 1.00                    | 700          |
|          | NPC-400  | Circle-shaped             | 8                | 128000                      | 0.83D                  | 0.86                    | 700          |
Normal concrete has been used for pouring beams. The characteristics of concrete (modulus of elasticity, compressive and splitting tensile strength) were located using steel cylindrical molds (with 300- and 150-mm height, and diameter, respectively). The diameters of used reinforcing steel bars were: 4, 6, 12mm and the properties of the average yield, ultimate strength, and modulus of elasticity were determined according to the standard tests of steel bars. The characteristics of normal concrete and steel reinforcements used in this work are shown in Table 2.

| Material | Ø (mm) | Yield stress (MPa) | Compressive strength (MPa) | Ultimate tensile strength (MPa) | Modulus of elasticity (GPa) |
|----------|--------|-------------------|---------------------------|-----------------------------|-----------------------------|
|          |        | Amb. 400 700      | Amb. 400 700              | Amb. 400 700                | Amb. 400 700                |
| Concret e| 4      | 390 352 262       | 25 12.6                   | 590 54 45                    | 26.8 20.1 13.1              |
| Steel    | 6      | 580 524 390       | --                        | 650 60 50                    | 200 200 194                 |
|          | 12     | 610 570 496       | --                        | 722 65 54                    | 200 200 194                 |

3. Testing procedure

The experimental program consists of casting and testing 9 non-prismatic (NPRC) reinforced concrete beams with and without openings monotonically loaded after exposing to high temperatures, as follows:

3.1. Burning stage

The burning process was conducted in a furnace manufactured by using a 4 mm thick steel plate just like box shape to enclose heat (Fig. 5), the inner clear space was 80 cm height by 200 cm width and 350 cm length, equipped with twenty fire flame from the methane sources (nozzles) and eight compressed air nozzles all positioned at the lower furnace level near the base to keep enough space underneath the NPRC beams to reach fire flame from the methane sources (nozzle) to the all burned NPRC beams simulating underneath fire disaster of simply supported NPRC beams. Also, many small openings for thermocouple wires (K-type) were positioned at the upper level of the furnace. The burning stage comprised, positioning the NPRC beam above its idealized simply supported ends, the dial gauge reading for mid-span deflection was recorded. Then the NPRC beams with their control specimens were exposed to the burning temperature of 400 or 700˚C following the fire standard rate of ASTM E-119 [15-16], which was supplied at the bottom level of the furnace for a similar exposure period of 60 minutes after reaching the target temperature. After that, the fire was turn off, the furnace cover removed and the NPRC beams were cooled gradually by leaving the beams at the ambient air.
The rate of the transition period to reach the target temperature 400 and 700°C was 7 and 10 minutes, respectively approximately similar to the rate of ASTM E-119 [15] as shown in Fig. 6.

3.2. Load test stage:
At the end of the burning and cooling cycle, NPRC beams were loaded till failure to investigate the influence of temperature degree on the residual ultimate load of each beam by comparing them with unburned reference ones. Figure 7 exhibits a schematic shape of the test setup. Steel rollers with a strong steel plate supported the NPRC beams. The one on the left was welded to the bearing plate to imitate hinge support, whereas the one on the right was not. To eliminate the difference in load due to the difference in openings’ configuration and locations, the load was delivered to a thick 100mm100mm bearing steel plate located at the tapering crest end of the horizontally flattened non-prismatic beam. A hydraulic jack of 50ton capacity was used to apply load on the beams. The applied load is controlled by using a load cell with a digital load reader. The load is applied in 2.5kN increments. The beam is loaded to failure, the deflection and the resulting strain are measured, and the crack propagation is marked at different load levels.
Concrete's constituent elements have varied thermal expansion coefficients, and fire-damaged concrete has spread contact-type flaws between the various constituents, resulting in visible or undetectable fractures. So, all NPRC beams have been post cracked and damaged in varying degrees through the burning and cooling cycle. At 400 °C surface hairline, pre-cracks begin to propagate and widen they are relatively short cracks. The cracks became very pronounced at 700 °C. It is worth noting that in the solid NPRC beams (save for burning fractures), only flexural cracks were found, but in the other perforated NPRC beams, flexural-shear cracks were found in addition to flexural cracks. Failure for all solid NPRC beams (NPS, NPS-400, and NPS-700) was by cracks that started from the soffit at the maximum bending moment, with the companion of steel yielding, these cracks spread to the higher fibers, followed by compression failure around the load point (flexural-failure).

For beams with openings, various modes of failure due to these cracking patterns were observed, three different modes of failure have happened in the post-fire NPRC beams with openings and those unexposed to fire. The first, which is the most prevalent mode, was diagonal splitting cracking at the corners of quadrilateral openings, propagated and developed toward the loading point and to the nearest support, followed by compression failure, such in unburned NPT. The next failure mechanism happened as a result of diagonal fractures developing from the top corner of the next to last opening (near the support), extended through the adjacent last posts toward the lower corner of the last openings, this crack progressively frequents from the last openings toward the middle one, then followed by concrete crushing of the last opening top, as in burned NPRC beams with trapezoidal openings NPT-400 and NPT-700. In all NPRC beams with circular openings (NPC, NPC-400, and NPC-700), diagonal splitting failure near the nearest circular opening to mid-span followed by compression failure. Figure 8 shows the failure mode and fracture patterns of all NPRC beams. It should be noted that there were no plastic hinges found in the posts here between openings.
4.2 Load-deflection and failure load
Mid-span deflection at different loading stages (20, 40kN, and ultimate load) are summarized in Table 3 and Fig. 9. At the ultimate load, the excesses mid-span deflection increases of the tested NPRC beams with openings, in comparison to the solid once, it was ranged about (42.3 -52), (41.6 -51.9) and (32.4 -33) % for unburned, 400, 700 groups, respectively based on the overall area and the configuration of the openings, besides the exposure temperature. It is clear that the stiffness of all NPRC beams decreases with increasing burning temperature due to the deterioration of concrete during exposure to fire, resulting in increasing the deflection of the NPRC beams. A high rate of defects happened at a burning temperature of 700 °C. Figure 10 illustrates the effect of burning temperatures on the behavior of these NPRC beams at the applied load of 20 and 40kN.

Figure 8. Failure mode and crack patterns
Table 3. Load and the corresponding deflection for tested NPRC beams at different loading stages and fire exposure conditions.

| Group ID | Beam NO. | Openings number | Total area of holes $A_{op}$ (mm²) | At 20 kN | At 40 kN | At ultimate load |
|----------|----------|------------------|------------------------------------|---------|---------|-----------------|
|          |          |                  | Deflection (mm) | Increasing Percentage (%) | Deflection (mm) | Increasing Percentage (%) | Deflections (mm) | Increasing Percentage (%) | Failure load $P_{ult}$ (kN) | Percentage of reduction (%) |
| Unburned |          |                  |                     |          |         |                 |                     |          |         |                  |                          |
| (I)      | NPS      | -                | 2.62                | -        | 6.4     | -               | 16.8               | -        | 90.0    | -                |                          |
|          | NPC      | 8                | 2.83                | 8        | 6.51    | 1.7            | 25.54              | 52       | 86.0    | 4.4               |                          |
|          | NPT      | 8                | 2.76                | 5.3      | 8.36    | 30.6           | 23.9               | 42.3     | 80.2    | 10.9              |                          |
| 400      |          |                  |                     |          |         |                 |                     |          |         |                  |                          |
| (II)     | NPS-400  | -                | 4.43                | -        | 8.32    | -              | 17.1               | -        | 84.9    | -                |                          |
|          | NPC-400  | 8                | 5.51                | 24.4     | 11.06   | 32.9           | 25.98              | 51.9     | 77      | 9.3               |                          |
|          | NPT-400  | 8                | 5.11                | 15.3     | 11.61   | 39.5           | 24.2               | 41.6     | 63.2/5 | 25.5              |                          |
| 700      |          |                  |                     |          |         |                 |                     |          |         |                  |                          |
| (III)    | NPS-700  | -                | 5.43                | -        | 10.4    | -              | 21.9               | -        | 80.2/4 | -                |                          |
|          | NPC-700  | 8                | 6.42                | 18.2     | 13.12   | 26.2           | 29.06              | 33       | 75      | 6.5               |                          |
|          | NPT-700  | 8                | 7.43                | 36.8     | 18.12   | 74             | 29.1               | 32.4     | 53.9    | 32.8              |                          |
Figures 11 and 12 show the relationship between the amount of concrete saved while manufacturing the tested NPRC beams and loss percentage in the load-carrying capability of these structural elements, as well as the influence of temperature. It must be noted that, in the case of tested NPCR beams with openings, the highest percentage of reduction of concrete consumption is 7.7 for NPC at ambient temperature and the lowest of 1.6 for NPT was 700 °C, as well the reduction in concrete consumption percentage to reduced load-carrying capacity decreases with increasing the burning temperature, due to the exposure circumstance the denominator (load-carrying capacity) decreases more than the numerator (concrete consumption). Figure 11 reveals that the percentages of reduction in weight are higher than that of failure load for all unburned beams (ambient NPRC beams have lesser slop) compared to the next two lower curves which represent the exposure temperatures of 400 and 700°C, respectively. Figure 12 demonstrates increasing fire exposure as the curves descend, these descending varied correspond to the configuration of the openings. Where, the lesser slop can be seen in solid NPRC beams followed by those with eight circular and eight trapezoidal openings, respectively.
Deflection along the tested beams at each post (node) has been measured at four loading stages (20, 30, 50 kN, and ultimate load) as demonstrated in Figs 13 and 14. These curves recognize that the high rate of descending in deflection was monitored at first and second posts next to the support because this region is characterized by the lowest beam height moreover, this deflection mainly occurred at the portions between the posts (openings portions) for that, highly drop-in beam stiffness occurs throughout these portions. Also, it can be observed from these figures that the curvatures consisted of segments curvature due to change in moment of inertia that affected by the presence of the openings.
4.3. Load verses mid-span concrete strains

To investigate the longitudinal strains in the mid-span section, two strain gauges (PL-60-12-5L) were fixed at the vertical centerline of the concrete surface mid-span, one at the top and the other at the bottom. The longitudinal tension strains are ignored because they gave inconsequential values.

In general, it can be detected that there was a significant increase in longitudinal compression strains throughout the loading test i.e. curves exhibit divergent behavior, as revealed in Figs. 15 and 16. The measured compressive strains at 20, 40 kN, and at ultimate load are tabulated in Table 4.

From Table 4 it can be recognized that the longitudinal compression strain (for each group: ambient, 400 or 700 °C) at rafters’ mid-span with openings exhibit an increase related to the solid rafter through loading stages as follows:
I. At 20 kN load

Till this loading stage, all rafters behave almost linear and the developed strains are small contrastingly to the rafters of Group ambient, where nonlinear behavior is the most prevalent. Rafters with trapezoidal openings have ratios 71, 138, and 248%, respectively for NPT, NPT-400, and NPT-700. Whereas, rafters’ existing circular openings reveal higher stiffness reflected by the lesser values of these ratios where they have been 19, 159, and 270%, respectively. On the other hand, at the exposure temperature circumstance of 400 °C, a slight increase in mid-span compressive strain was measured in contrast at 700°C, strain is excessively increased as illustrated in Fig. 11.

II. At 40 kN load

The similar previous behavior can be observed at this stage. Obviously, existing openings decrease the rafter’s stiffness, but rafters with circular openings exhibit higher stiffness compared to the others with different openings number of trapezoidal shape and they were the closest to that of the solid ones. Also increasing temperature exposure conditions led to increasing concrete deteriorations result in increasing top compressive strain, especially rafters exposed to 700°C as revealed in Figs. 11 and 12 and Table 4.

Table 4. Longitudinal concrete surface compression strain values at mid-span for all rafters

| Group ID | Beam No. | No. of Openings | Overall area of openings $A_{op}$ (mm²) | At 20kN load | At 40kN load | At ultimate load |
|----------|----------|----------------|----------------------------------------|--------------|--------------|-----------------|
|          |          |                |                                        | Strain, ε (με) | Increasing percentage of Strain% | Strain, ε (με) | Increasing percentage of Strain% | Strain, ε (με) | Increasing percentage of Strain% |
| ambient  |          |                |                                        |              |              |              |              |              |              |
| NPS      | 8        | 174000         | 210                                    | 620          | 2700         |
| NPT      | 8        | 128000         | 250                                    | 19           | 45           | 3300           | 22.15         |
| NPC      | 8        | 128000         | 544                                    | 159          | 2400         | 1278           | 106           | 2400         | 11.1          |
| 400      |          |                |                                        |              |              |              |              |              |              |
| NPS-400  | 8        | 174000         | 300                                    | 43           | 2280         | -15.6          |
| NPT-400  | 8        | 174000         | 500                                    | 138          | 2100         | -22.2          |
| NPC-400  | 8        | 128000         | 544                                    | 159          | 2400         | -11.1          |
| 700      |          |                |                                        |              |              |              |              |              |              |
| NPS-700  | 8        | 128000         | 723                                    | 244          | 2250         | -16.7          |
| NPT-700  | 8        | 174000         | 730                                    | 248          | 2000         | -25.9          |
| NPC-700  | 8        | 128000         | 776                                    | 270          | 2400         | -11.1          |
Finally, at higher loading stage the longitudinal compressive strain of Group ambient in mid-span of solid rafter reach to 2700 με, while the other rafters with openings exhibit divergent strain higher than that, it's about 3300 με. Exposure to high temperatures reduces rafters' stiffness causing a reduction in load carrying capacity, companion with premature failure consequently reduce the strain at the ultimate stage.

**III. At ultimate load**

**Figure 15.** Load versus longitudinal compressive strains at mid-span

**Figure 16** exhibits the behavior of rafters at different exposure temperatures. It can be recognized that for Groups of ambient and 400°C circumstances wide range of deviation in compressive strains at all loading stages (Figs 16-a and b) whereas, this deviation can be observed at higher loading stages in Group 700°C. This indicates that for the first two exposure circumstances the shape of the openings is efficient more than the exposure temperatures, in contrast for Group 700°C the thermal deterioration was more influential than the shape of the openings.
The strain was measured in the lower layer of steel reinforcement (Ø12 mm), LVDT-KTR-100mm with high sensitivity was used to record the divergence displacements between two prepositioned bolts that have been fixed on the main bar at mid span to get the steel strain. (Fig. 17).

Figures 18 to 21 demonstrate the following results:
- The presence of openings in the rafter (perforated rafter) increases the steel bars strains at all loading stages, this increment can be interpreted by the fact that the creation of openings in the rafter reduced the cross-sectional area and moment of inertia, which leads to a decrease in rafter stiffness.
• All NPRC beams behaved approximately in a linear elastic manner, and the slope was different for the rafters in each group depending on the number and shape of the openings as well the exposure temperature. Whereas, Figs. 18 and 19 reveal posts strains in perforated rafters exposed to 400 and 700 °C, respectively, Figs 20 and 21 illustrate the effect of burning temperatures regarding each opening scheme.

• According to the tensile test results for steel reinforcements which were performed on 12mm bars diameter, the yielding strain is approximately 3000 Micro-strain thus, at ultimate load all burned rafter’s yields.

• For all rafters, increasing burn temperature leads to deterioration of concrete during exposure to fire, resulting in increasing the strain in steel bars, this increase developed with increasing burning temperature.

![Figure 18. Load versus steel strain for burned rafters (Group 400°C).](image1)

![Figure 19. Load versus steel strain for burned rafters (Group 700°C).](image2)

![Figure 20. Load versus steel strain for post fire rafters (Group NPC).](image3)

![Figure 21. Load versus steel strain for post fire rafters (Group NPT).](image4)

5. Conclusions

For all rafters, increasing burn temperature leads to deterioration of concrete during exposure to fire, resulting in increasing the strain in steel bars, this increasing developed with increasing burning temperature. The failure mode demonstrates that all solid NPRC beam (burned or unburned) failed in yielding in steel reinforcement followed by compression failure. The unburned NPRC beams with 8 trapezoidal openings failed in diagonal splitting failure at opening corners followed by compression failure, while the burned NPRC beams with 8 trapezoidal openings failed in diagonal crack started from the upper corner of the next to the last opening, extended through the adjacent last posts toward the lower corner of the last openings, this crack progressively frequent from the last openings toward the middle one, then followed by concrete crushing of the last opening top chord. In all NPRC beams with circular openings, diagonal splitting failure near the nearest circular opening to mid-span followed by compression failure. Increasing the exposure temperature leads to a reduction in ultimate strength.
about (5.7 and 10.84%) for solid NPRC beams exposed to 400 and 700°C, respectively related to unburned one, (21.13 -32.8) % for beams with eight trapezoidal openings, and (10.5 -12.8) % for those having 8 circular openings, respectively and exposed to the similar burning condition. In such circumstances, the recorded excessive mid-span deflection for the companion deflection was (2 -30.4), (1.3 -21.8), and (1.7 -13.8) % for the same groups and burning exposures, respectively. For the same extended beams length, changing the configuration of openings from trapezoidal to circular, led to an enhancement in flexural behavior where the load-carrying capacity for NPRC beams with circular openings increased by 7.2, 21.7, and 39.1% for ambient, 400, and 700 groups respectively relative to NPRC beams with trapezoidal openings. So the rafters with circular openings fulfill a higher stiffness than that of trapezoidal openings for burned or unburned beams. At higher loading stage the longitudinal compressive strain of Group ambient in mid-span of solid rafter reach to 2700 με, while the other rafters with openings exhibit divergent strain higher than that, it’s about 3300 με. Exposure to high temperatures reduces rafters’ stiffness causing a reduction in load carrying capacity, companion with premature failure consequently reduce the strain at the ultimate stage.

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