Evaluation of Fire Damage to Three Story Reinforced Concrete Building
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Abstract

This paper summarizes an engineering evaluation of the extent of fire damage to a reinforced concrete 3 story building. The building is located in Al-Baida city – Libya and it is used as a court yard for the public. The fire occurred in a portion of the reinforced concrete structure and visibly damaged some of its columns and to a less extent some of its beams and ribbed slabs. The purpose of the assessment was to promptly evaluate the in situ condition of the damaged elements and recommend necessary repair or replacement options prior to commencement of using the structure again to its intended function. The engineering assessment of the damaged elements included a nondestructive evaluation phase consisting of rebound hammer, ultrasonic pulse velocity testing as well as a set of laboratory physicochemical testing on the concrete cores removed from the damaged elements. Smaller concrete cores are retrieved from inner and outer faces of the damaged elements, this permitted assessment of the presence and degree of any damage along the element depth compared to the full size of a compressive strength core. Significant differences were not indicated by compressive strength of cores, however, the in situ nondestructive testing and laboratory testing of the different cores along the damaged element depth were effective in determining the depth of damage as a result of the fire. The results of the nondestructive and laboratory evaluation indicated that damage to the near surface to fire is relatively higher compared with that far from fire. Repair recommendations were based on removal and replacement of the affected concrete sections identified by the testing program.

Key words: Fire damage, Materials testing, Redesign, Rehabilitation.
Introduction

Although reinforced concrete is high fire resistance with very low combustibility compared with other building materials however, when exposed to fire, concrete is degraded and its stiffness falls. Heat also causes the concrete to crack, which further degrades its stiffness. In general strength of concrete and reinforcement decrease with increase of heating temperature this yields under capacity of the integrated structure [1, 2, 3]. This paper is based on the technical report prepared by Benghazi University on the request of the local authority to assess the central court building of Al-Baida city in January 2013. The paper presents the factual accounts of the study report to examine and evaluate the reinforced concrete structural elements of the main court building and to propose the necessary remedial measures for the building to be in service again after the damage induced by fire that took place in February 2011. The fire occurred in the right wing of the ground floor of the building, and as reported by witnesses it lasted approximately for an equivalent continuous time 3 to 4 hours, involving a lot of paper documents, furniture and other materials. The fire caused readily visible surface damage, see Figure (1).

The structural system

The building consists of ground floor and upper 3 typical floors, built in the early 1970s, each story is 3 m clear height and 1460 m² plan area. The structural framing made of conventional cast in-situ reinforced concrete. The framing system consists of grid of columns mainly of 40 cm square size, as shown Figure (2). The columns are reinforced with 8 φ18 longitudinal mild steel plain bars and φ8 lateral reinforcement spaced at 15 cm center to center. The maximum spacing between columns is 6m center to center in short direction and 4.5m spacing in long direction. The slabs of the building floors are hollow block type with total thickness 25 cm comprising
(approximately) 5 cm topping and 20 cm thickness hollow block. The ribs are 15 cm thickness and spaced at 55 cm center to center with 2 $\phi 18$ mm bars to resist negative and positive bending moments. The ribs are mainly constructed continuously in 3 spans 6m, 2m and 6m long respectively except at entrance lobbies where it is 6m long single spans. The main beams supporting the ribs are embedded beams with 25 cm thickness and 10 mild steel plain bars combination of $\phi 18$ and $\phi 20$ top and bottom provided with $\phi 8$ double stirrups spaced at 15 cm center to center. Conventional local type hollow block of 20 cm thickness is used for partitions.

Extent of fire

More reliable information about temperatures is obtained during on site surveys. All furniture, windows, doors, infrastructure are severely affected by fire. Most of the structural elements are grey to black in color. Examinations of rubble show all floor tiles are dismantled and burned, window glass is shattered but not melted. The electric wires are burned however the copper in electric wires had not been softened. These observations indicate that the temperature is in the range of 400 to 600 $^\circ$C [2, 4]. This is also assured by the grey to black color of the structural concrete elements surfaces. Concrete color provides a broad, general guide of temperatures [5].

Damage evaluation

We made frequent visits to the site in January 2013 for visual inspection to evaluate the structural elements affected by the fire and to determine the extent of damage and propose the required repairs. We noticed, in addition to the burning of the architectural finishing including floors, plasters etc., crazing, cracking and Spalling of the surface layers of reinforced concrete in most of the structural elements particularly of the ground and 1st floors of the right block. Cracks of partition walls extending longitudinally and across the walls are wide spread. Forms of cracking include those caused by differential thermal expansion, and thermal shock from quenching by fire-
fighting water. Surface crazing of concrete may be due to the differential incompatibility between aggregates and cement paste. The distribution of temperature in addition to weakening the concrete it yields uneven bending stresses that may contribute to the cross section under capacity at time of heating[3, 4]. The high increase in temperature, due to fire in the first floor of the right wing, yields deflection of the slab of this floor for a measured value 30mm, see Figure (3).

Reinforcement of some structural elements is exposed and sagging although visually, fire has no serious effect on this reinforcement. Temperature rise of 600 °C has a negligible effect on the yield strength of hot rolled reinforcement [1, 4].

Non destructive testing of concrete
A preliminary investigation of concrete properties mainly its strength characteristics is performed using non destructive testing to decrease the number of cores otherwise may be required for estimating the concrete strength which is an important input data for real evaluation of the structure. The non destructive testing follows the recommendation given in ACI 228-R10 [6].

Rebound number
It has been shown empirically that for a given concrete there is a correlation between compressive strength and the rebound number. All affected structural members are divided into grids with designation numbers and labels the rebound number is recorded following ASTM C 805 [7]. An average of at least ten rebound readings are taken for one test, see Figure (4).

Pulse velocity
The pulse velocity is another non destructive method to estimate the compressive strength of concrete, it is based on measuring the time it takes for a pulse of vibrational energy to travel through a concrete member for this reason it can be used to detect any cracks in the concrete. The
procedures for this method are given in ASTM C 597 [8], see Figure (5). Table (1) shows typical results.

Testing concrete for compressive strength

20 core samples have been extracted from the different structural elements affected by fire. Locations of the concrete core samples are established based on results of non-destructive tests and visual inspection of the structure. Strength of concrete cores taken from the structural elements is determined in accordance with ASTM C 42[9]. For core length-to-diameter ratios different than 2.0, we apply the appropriate strength correction factors given in ASTM C 42[9].

Two types of concrete cores are extracted, full core length diameter 70 mm, and smaller size of diameter 25 mm. The small size cores are used to depict the concrete strength along the structural member from the near surface to fire and the far surface to estimate the extent of fire damage to the cross section. The equivalent specified concrete strength is calculated according to ACI 562-12[10]. Typical results are shown in Table (2). Results of compressive strength testing reveals:

- The average equivalent compressive strength of unaffected concrete by fire is 17 Mpa.
- The most affected structural elements by fire (Column C007 of the ground floor) has an average equivalent compressive strength 9.6 Mpa.
- The tested core sample to the near surface to fire of the same element (Column C057 of ground floor) gives an equivalent compressive strength of 11.8 Mpa, whereas the tested core from the far surface to fire gives a equivalent compressive strength of 15.3 Mpa.
- The maximum recorded under capacity of concrete compressive strength due to effect of fire is measured as 42%.
Reinforcing steel

Removal of reinforcement samples and the laboratory destructive testing is permitted as a method of determining existing steel reinforcement properties. The yield and tensile strength for reinforcing steels is obtained in accordance with ASTM A370 [11], where minimum of three sample coupons, taken from different segments of tested reinforcement are retrieved from exposed reinforcement. The average yield strength value from the tests is obtained using the coefficient of variation determined from testing as per ACI 562-12[10], Table (3) shows typical values for the equivalent yield strength of some tested reinforcement samples. We noticed that insignificant effect of fire on the yield strength and ductility values of the tested samples taken from affected members by fire.

Chemical testing

Chemical analyses were performed to determine contamination of the surfaces so as to prepare cleaning and the following on corrosion protection. When the chloride content of the concrete at the level of the reinforcing steel exceeds 0.2 percent by weight of cement, the normal passivation characteristics of the concrete are destroyed and corrosion of the steel can occur. Sulfate concentration in excess of 5% by weight of cement is considered to be harmful to concrete. Carbon dioxide can also cause concrete to deteriorate by reacting with the cement paste at the surface and converting very alkaline components to less alkaline carbonates. Carbonation normally occurs only at the surface, but it can extend to the level of the steel in poor-quality concrete [12, 13]. All extracted cores from elements affected by fire are chemically analyzed along the depth of concrete. Summary of all chemical results pertinent to concrete safe guard against contamination indicate no major threat of chemical contamination is noticed.
Conclusion

As it appears from the previous sections, the fire has an effect on the concrete compressive strength which yields under capacity of the affected structural elements. We noticed that the extent of damage is related to the distance from the heated surface. At a distance 200 mm from the heated surface the damage is much smaller. The damage to reinforcement is negligible. With the equivalent strength values of concrete and reinforcement as calculated in the previous sections, a typical part of the building representing the right block which is more damaged than the left block has been analyzed and redesigned to check its integrity. Output of the design shows that slab elements, ribs, beams and columns appear to be still with sufficient reinforcement, however under capacity of defected concrete due to fire shall follow the treatment recommended in ACI 228.1R-03 and ACI 526-12 [6, 10].

The proposed treatment is based on chipping away all concrete weakened by the fire as compared to the strength required by redesign. High pressure water is then used in order to remove all loose and defective concrete as well as to clean reinforcing bars before the application of epoxy bonding agents. For treatment of slabs we recommend the use of shotcrete or guinte in layers of 30 to 40 mm thickness. To ease construction we recommend using a non shrinkage concrete of maximum size aggregate 10 mm with characteristics of a self compacting and 20Mpa compressive strength. The use of additives to enhance workability is recommended. We recommend also the use of folding forms and sliding props of adequate capacity when treating columns.

All structural analysis, design and detail drawings of the rehabilitation related to the structure are submitted with the technical report to the authority emphasizing that all constructional repairs shall be under the supervision of competent and expert consultant engineers.
Figure 1 General view of the building after fire
Figure 2 Plan of Ground Floor
Figure 3 Selected photos showing extent of damage due to fire
Figure 4 Sample photos of testing columns and slabs using rebound hammer
Figure 5 Sample photos of testing columns and slabs using ultra sound
Figure 6 Selected photos of extracting concrete core samples
Table 1 Typical results of ultra sonic testing

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Table 2 Typical result of compressive strength testing

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<th>Wight</th>
<th>Density</th>
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<td>grm</td>
<td>grm/cm³</td>
<td>Mpa</td>
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<td>2.49</td>
<td>610.4</td>
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<td>2.204</td>
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<tr>
<td>S111</td>
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Table 3 Typical results of steel bar testing

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<th>Elongation (%)</th>
<th>Yield Strength (Mpa)</th>
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Acknowledgment

The authors wish to thank Eng. Haitham M. Elshatiti and Eng. Aiman M. Elfatisi for their help in conducting the field and laboratory testing and sorting all results.
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