CASE STUDIES ON CONDITION ASSESSMENT AND REPAIRS FOR FIRE DAMAGED REINFORCED CEMENT CONCRETE STRUCTURES

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Abstract. In India, the shift in the mode of construction of structures from load bearing walled to framed, started in the early eighties. Concrete is highly durable and has very good compressive strength, but is expensive compared to the materials used for load bearing walled structures. Inspite of the cost, since the durability is more, most of the structures being constructed are RCC structures. However, concrete structures are damaged due to the action of fire. Though concrete has good resistance to fire, it is not completely fireproof. This study presents two case studies on structures damaged by fire. The condition assessment, Non Destructive Testing for quality evaluation of the concrete and the suggested repair techniques are discussed.

Keywords. Repair, Rehabilitation, Non-Destructive Testing, Rebound Hammer, Ultrasonic Pulse Velocity

1. Introduction
Reinforced cement concrete constructions are highly durable. However, these structures are distressed either due to intrinsic causes like improper design, insufficient cover thickness, high water cement ratio used for concrete, improper centering and shuttering, poorly graded aggregates, inadequate compaction, inadequate curing, chemical attack due to chemicals in construction water etc or due to extrinsic causes like temperature changes, weathering, sudden external loads, chemical attack due to chemicals in atmosphere etc. In addition to the above, structures are also damaged due to fire and other accidents. RCC structures damaged due to one or more causes discussed above, deteriorate with time and hence the design life of the structure is decreased. The deterioration of structure typically starts with cracks, spalling of concrete leading to delamination and decrease in the strength of the structure. This deterioration, if not identified and properly repaired, will lead to demolition of the whole structure. Since the cost of construction of RCC structures is high, it is necessary to repair the damages to the structure before it leads to loss of the whole structure. For any repair technique, it is important to recognize the cause and extent of the damage to the structure in order to suggest suitable repair methods to rehabilitate the structures. In order to assess the extent of damage to the structure and the loss in strength of the structure due to various reasons, non-destructive testing can be used, since it is in-situ, relatively fast and doesn’t disturb the structure.

This paper focuses on the assessment of damage to RCC structures by using two non-destructive testing techniques: Rebound Hammer Test and Ultrasonic Pulse Velocity test. Two case studies were selected and the test results, interpretation of the results and the suggested repair methodologies are also presented.

Non-Destructive testing, as the name suggests, is a no damage test on the structure to assess its quality. These tests can be performed on both old and new structures: on new structures for quality assurance of concrete and for damage assessment in old structures. These tests are very helpful to assess the extent of damage to the structure since they can be successful used at high number of locations compared to other destructive tests like concrete core cutting since core cutting disturbs the structure and hence cannot be used at more locations. In this study, two non-destructive tests were...
used: Rebound Hammer Test for assessing the hardness of concrete and Ultrasonic pulse velocity test for assessing the uniformity of concrete.

The case studies selected in this study are damaged due to fire. Though concrete has good fire resistance, it is not completely fire proof. Concrete possess high resistance to fire damage and prevents reduction in mechanical strength against all other building materials due to its higher specific heat capacity and low thermal conductivity [1,2]. The conductivity decreases with increase in temperature and increase in occurrence of micro cracks [3]. The thermal conductivity of concrete with respect to Temperature is shown in Figure 1.

![Figure 1: Temperature dependant thermal conductivity][3]

Activity of fire on RCC structures causes various types of damages ranging from minor color change, severe cracking and spalling of concrete depending on the intensity of fire. Assessment of structure, evaluation and repair has to be carried out to the damaged structure [23]. The physical effects of the action of fire on Concrete structures are shown in Table 1.

| Temperature     | Color Change | Changes in Physical Appearance and Benchmark Temperatures                                      | Concrete Condition                |
|-----------------|--------------|------------------------------------------------------------------------------------------------|----------------------------------|
| 0 to 550 °F     | None         | Unaffected                                                                                     | Unaffected                       |
| 550 to 1100 °F  | Pink to red  | Surface crazing: 570 °F (300 °C); Deep cracking: 1020 °F (550 °C); Popouts over chert or quartz aggregate: 1070 °F (575 °C) | Sound but strength significantly reduced |
| 1100 to 1740 °F | Whitish Grey | Spalling, exposing not more than 25% of reinforcing bars; 1470 °F (800 °C); Powdered, light colored, dehydrated paste: 1650 °F (575 °C) | Weak and friable                 |
| 1740 °F+        | Buff         | Extensive spalling                                                                             | Weak and friable                 |

Demolition and rebuilding of a fire damaged structures is not a viable option, instead they can be repaired and rehabilitated [4 & 5]. Visual inspection, Non destructive testing has to be carried out on damaged structure which plays important role in condition assessment. This gives an understanding about the level of distress and proper restoration technique to be adopted to enhance the life of structure [19]. Selection of appropriate material and method to repair fire damaged RC members is important so that the RCC member can be restored to the original capacity economically and must be done with expertise using various techniques [6 & 15].

The condition assessment of the structure can be done in a process as provided by researcher [22]
The step by step process is shown below: [22]
1. Verify the structure is safe to enter
2. Perform preliminary site visit
3. Perform detailed evaluation
4. Analysis
5. Design Repairs

The Ultrasonic Pulse Velocity and Rebound hammer measurements in combination provides results with high accuracy and error below 10% in determination of modulus of elasticity and strength of concrete [17]. Researcher has studied rebound hammer, UPV technique and using synthetic simulation approach proposed a methodology in improving strength parameters. The reduction of compressive strength of RCC columns damaged due to fire will vary based on temperature conditions [18]. Repairing fire damaged structures is very important and it should be understood that not all repair techniques are suitable in all cases. The repair techniques vary based on the scenario. Shotcrete is more feasible to repair fire damaged structural elements and has various applications like tunnel support, slope support, underground structures. It gives high early strength and short setting time [7]. The shotcreting technique was successfully adopted to repair RC slab, joist of a stadium and RC joist of a school building [6, 8]. Column jacketing is another repair technique which gives more stiffness and improves load carrying capacity [14, 20, and 21]. Blanketing using CFRP and GFRP is also highly popular to repair defective structures and also they have more advantages including high strength to weight ratio, corrosion resistivity, resistance to chemical attack, ease of application and higher tensile strength compared to steel reinforcement [9-13]. In the present paper, two case studies are selected which are affected by fire. The condition assessment, Non Destructive Testing and the suggested repair methodologies are discussed.

2. Case Studies
The paper presents 2 case studies of structures which are damaged by fire. The process for repairing of the structure is detailed below.

2.1 Case Study 1
The project is a privately owned RCC framed structure in Turlapati Kutumba Rao Street, Labbipet, Vijayawada, Andhra Pradesh. The structure is a Stilt+G+3 structure with the first two floors being used as a Paper storage room for an educational institution and the top two floors are used as offices. The structure was constructed in 2011. The structure was damaged due to a fire in the first floor, caused by short circuit at around 1:30AM. The fire was active for a period of 3 hours before being subdued. This has caused major damage to the structural elements of the building in the first and second floors. To propose suitable repair techniques for the damaged structure, condition assessment was done. Since the structure is to be repaired, non destructive testing techniques were used to assess the quality of the structure. The plan of the structure is shown in Figure 2

2.1.1 Visual Inspection
The observations during the inspection of the structure are listed below:
- Columns provided only on the boundaries. Lateral and longitudinal beams provided connecting the columns.
- The fire was caused by short circuit. Due to the presence of paper stacks, the intensity of the fire has increased considerably
- The fire caused major damage to the columns and beams in the first floor
- The effect of fire was also observed in the second floor. The effect is low compared to the effect in the first floor
- The windows in the first floor, made of steel, were completely disfigured due to the fire
- Due to the intensity of the fire, cement has become parched causing loss of bonding
• Cracks were observed in the columns and beams of the structure

![Figure 2: Figure showing the plan of structure with column numbering](image)

2.1.2 Rebound Hammer Test
Rebound Hammer test involves finding the rebound number of a spring controlled mass attached to a plunger. The free end of the plunger is placed on the surface of concrete and is pushed so that the mass attached to it is pressed. At the maximum compressed position of the plunger, the mass snaps and rebounds off the concrete surface. The rebound value can be read from a graduated scale attached to the side. The harder the surface, the higher will be the rebound value. According to IS: 13311: Part 2, the accuracy of the rebound values obtained for concrete are in the range of +/- 25%. The Rebound Hammer Test was conducted using a Digital Schmidt Rebound Hammer – ST Type N of Proceq make. The results of the Rebound Hammer Test performed on the structure are presented in Table 2.

2.1.3 Ultrasonic Pulse Velocity Test
Ultrasonic pulse velocity test involves determination of the denseness of concrete which confirms the presence of voids. The test is conducted by sending and receiving an ultrasonic beam through concrete via two probes placed on either side of the concrete sample. The time of travel of the beam is noted and from the dimensions of the sample, the velocity of the beam is determined. The velocity of the beam is related to the denseness of the concrete and gives the presence of voids. Table 2 of IS: 13311: Part 1 gives the velocity criteria for concrete grading. The Ultrasonic Pulse Velocity test was performed using a Pundit Lab Ultrasonic Pulse Velocity Tester. The results of the UPV Test performed on the structure are also presented in Table 2.

| Sl.No | Location | Point Identification | Compressive Strength N/mm² | Pulse Velocity m/sec |
|-------|----------|----------------------|---------------------------|---------------------|
| 1     | First Floor | Column 1               | 28.00                     | ----                |
| 2     |           | Column 2               | 21.00                     | 1941                |
| 3     |           | Column 3               | 20.00                     | 2641                |
| 4     |           | Column 4               | 19.00                     | 2896                |
| 5     |           | Column 5               | 13.50                     | 2658                |
| 6     |           | Column 6               | 15.00                     | 758/1319            |
| No. | Beam/Column/Slab Description | Length (m) | Width (m) | Thickness (m) |
|-----|------------------------------|-----------|-----------|-------------|
| 7   | Column 7                     | 19.00     |           | 1884        |
| 8   | Column 8                     | 15.00     |           | 3064        |
| 9   | Column 9                     | 18.00     |           | 2801        |
| 10  | Column 10                    | 15.50     |           | 2545        |
| 11  | Column 11                    | 22.00     |           | 2980        |
| 12  | Column 12                    | 19.50     |           | 3184        |
| 13  | Beam adjacent to Column 12   | 22.00     |           | 2946        |
| 14  | C2-C10 Beam                  | 23.50     |           | 2475        |
| 15  | C4-C8 Beam                   | 15.50     |           | 1956/1282   |
| 16  | C6-C12 Beam                  | 15.00     |           | 1984        |
| 17  | Slab Near 4                  | 28.00     |           | 3229        |
| 18  | Beam Column Joint at Column 4| 18.50     |           | 3061        |
| 19  | Beam Column Joint at Column 2| 19.50     |           | 3453        |
| 20  | Slab Near Column 11          | 41.0      |           | ****        |
| 21  | C3-C9 Beam                   | ****      |           | 3071        |
| 22  | Second Floor Column 2        | 20.00     |           | 2137        |
| 23  | Column 3                     | 17.00     |           | 3344        |
| 24  | Column 10                    | 29.0      |           | 4127        |
| 25  | Column 7                     | 18.00     |           | 3685        |

### 2.1.4 Repair and Restoration Measures

Based on the test results of Rebound Hammer and Ultrasonic Pulse Velocity, it was ascertained that the effect of fire was severe in the columns and beams in the first floor. Also the UPV test results indicate the presence of voids in almost all structural elements in the first floor. Since the damage is in one of the bottom floors, retrofitting is mandatory to make the structure safe and durable. The following repair techniques were suggested for the retrofitting of structure:
Since the UPV test results indicate the presence of voids in all structural elements, it was suggested to grout the voids. Epoxy grouting was suggested because of the higher bonding.

The beams of the structure were also observed to have low strength and were hence retrofitted. Steel C-sections were attached to the beams in the lateral directions, to increase the strength. For the center longitudinal beam, a vertical support column in the form of a steel I-section was provided with shear connectors joining into the reinforcement of the roof and bottom slabs.

2.2 Case Study 2

The project is a privately owned RCC framed structure in Plot No. 169&170, 5th Road, Autonagar, Vijayawada, Andhra Pradesh. The structure is G+1 structure which is an industrial building used in the manufacturing of lubricants. The structure was constructed in 2007. The structure was damaged due to a fire in the first floor. The fire started around 7:00 AM and was active for a period of 4 hours before being subdued. To propose suitable repair techniques for the damaged structure, condition assessment was done. Since the structure is to be repaired, non-destructive testing techniques were used to assess the quality of the structure. The floor plan of the structure along with the column numbering is shown in Figure 3.

2.2.1 Visual Inspection

The observations during the inspection of the structure are listed below:

- The intensity of the fire was high due to the chemicals placed in the structure
- The fire caused major damage to the columns slab in the first floor
- The effect of fire was also observed in the ground floor, especially in the slab. The effect is low compared to the effect in the first floor
- Due to the intensity of the fire, cement has become parched causing loss of bonding
- Cracks were observed in the slab, columns and beams of the structure

![Figure 3: Figure showing the plan of the structure with column numbering](image)

2.2.2 Rebound Hammer Test

The results of the Rebound Hammer Test performed on the structure are presented in Table 3.

2.2.3 Ultrasonic Pulse Velocity Test

The results of the UPV Test performed on the structure are also presented in Table 3.
### Table 3. Rebound Hammer and UPV Test Results for Structure in Case Study 2

| Sl.No | Location               | Point Identification       | Compressive Strength N/mm² | Pulse Velocity M/Sec |
|-------|------------------------|----------------------------|----------------------------|----------------------|
| 1     | Ground Floor           | C12 Column                 | 18.00                      | 2956                 |
| 2     |                       | C13 Column                 | 17.00                      | 2854                 |
| 3     |                       | C4-C7 Beam                 | 16.00                      | 3106                 |
| 4     |                       | C14 Column                 | 17.00                      | 3251                 |
| 5     | Ground Floor           | Bay C7-C8-C13-C14 Slab     | 19.00                      | 2961                 |
| 6     |                       | C14-C15 Beam               | 20.50                      | 3248                 |
| 7     |                       | Bay C6-C7-C14-C15 Slab     | 15.00                      | 2874                 |
| 8     |                       | Bay C4-C5-C6-C7 Slab       | 18.50                      | 2796                 |
| 9     |                       | C7-C8 Beam                 | 19.00                      | 3029                 |
| 10    | Ground Floor           | Ground Floor Roof Slab     | 24.50                      | 2938                 |
| 11    |                       | Ground Floor Roof Slab     | 20.00                      | 2864                 |
| 12    | First Floor            | C11 Column                 | 19.00                      | 3425                 |
| 13    |                       | C10 Column                 | 21.00                      | 3569                 |
| 14    |                       | S1 Staircase Column        | 14.00                      | 3152                 |
| 15    |                       | S2 Staircase Column        | 7.50                       | 2243                 |
| 16    |                       | C3 Column                  | 13.50                      | 2686                 |
| 17    |                       | C4 Column                  | 16.00                      | 2732                 |
| 18    |                       | C6 Column                  | 17.50                      | 2894                 |
| 19    |                       | C7 Column                  | 19.00                      | 3018                 |
| 20    |                       | C14 Column                 | 7.00                       | 1953                 |
2.2.4 Repair and Restoration Measures

Based on the test results of Rebound Hammer and Ultrasonic Pulse Velocity, it was ascertained that the effect of fire was severe in the columns and beams in the first floor. Also the UPV test results indicate the presence of voids in almost all structural elements in the first floor and also the first floor roof slab. The following repair techniques were suggested for the retrofitting of structure:

- To fill the voids caused due to the fire, epoxy grouting was recommended for all the columns and beams
- RCC jacketing with shear connectors was recommended for the columns with low strength as identified from the rebound hammer test. New reinforcement bars were anchored, from the foundation and continued till the first floor. Shear connectors were used to connect the new reinforcement to the old column reinforcement. Micro concrete was suggested for filling the column.
- For the first floor roof slab, on the interior side, plastering was removed and the surface was cleaned. Shotcreting was done by placing a wire mesh as reinforcement. Bonding chemical was applied on the surface before shotcreting. The total thickness of the shotcreting was around 25-30mm
3. Conclusions
The paper discusses case studies of two RCC structures damaged by fire. The condition assessment and the repair techniques adopted were discussed. The following conclusions can be drawn from the case studies:

1. Visual inspection should be carried out to understand the present state of the structure. Based on the visual inspection, suitability of the tests required to be performed can be assessed
2. Non Destructive testing can be used for condition assessment since it doesn’t cause further damage to the structure. However, the results obtained from the Non-Destructive tests are only indicative of the concrete quality and cannot be taken as certain. Also, not all Non-destructive tests give the required quality data.
3. The same repair strategy cannot be used for all the structures. Depending on the loading and in-situ conditions, the repair strategy will vary

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