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Repair and Rehabilitation of Structure after Fire Damage: A Case Study of an Industrial Building

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Abstract: *This paper presents a case study on a rehabilitation of a fire damaged industrial building. Detailed site investigation and NDT test are conducted to decide the repair methodology. The fire incident took place in a mixer unit of a 50 year old manufacturing unit. The fire ignited at ground floor due to short circuit in electric panel. The mixer building is (RCC framed) ground and two upper floor structure. Concrete core samples are taken and tested for residual strength. Rehabilitation plan is designed on the basis of site investigation and results of test conducted.*

Keywords: *Site investigation, Rehabilitation, NDT, Push over analysis*

1. Introduction:

After a severe fire, concrete structures generally capable of being repaired rather than demolished. Fire causes severe damages to the structures. If a structure is damaged by fire, it is important to evaluate the damage. Economically it is better to repair the structure and use it as early as possible. The decision of whether to repair or demolish will be based on an assessment of the status of the structure. This assessment is based on mapping of damage in the construction. This mapping of damage needs to be accurate to ensure both a good safety level and the best solution from an economic point of view can be found.

Concrete structures perform well under fire conditions due to its low thermal conductivity and incombustibility. Proper designed and detailed reinforced structures effectively redistribute loads from damaged region to undamaged components even if the part of the structure is damaged by fire. Therefore it is not common for fire damaged RC structures to completely collapse after a fire.

The aim of this paper is to provide an overview of interpretation of results from inspection and tests conducted. Design the rehabilitation plan and carry out structural analysis.

2. Visual inspection:

Visual inspection has been conducted for the all elements inside the building. All the RC member are checked for cover, concrete spalling, cracks, deflection and bond condition between steel and concrete. All surfaces are checked and inspected for colour change, surface crazing, cracking etc.

Visual inspection on ground floor shows that RC members are not affected by the fire. No colour change on surface is noticed. Plaster at certain location is cracked and spalled. Slab covers at certain panels are spalled cause of oxidation of steel. All structural steel members supporting the mixer unit are in good condition. Concrete floor surface is damaged due to wear and tear.

On the first floor reclaimed rubber, machine oil, FRP pallets and drums were kept. Rubber is burnt partially and pallets are partially melted. Remains of MS frame of oil drums neither bent nor melted. RC beam and slab in the grid B26-C27, D28-D29 were affected by fire and heat. Spalling of cover concrete is observed. Reinforcement is exposed in certain members. Inspection of mild steel reinforcement in RC members doesn't show any de bond condition. No powdered steel existence is observed. Freshly broken concrete shows grey colour. Plaster of all members is completely damaged on the first floor. Plaster surface shows crazing and cracking.

Carbon powder, whitening powder, silica and power oil stored on second floor. Entire surface area turned black due to smoke. No cracks, colour change, cracking, spalling of concrete is observed on second floor. Plaster surface at certain location was cracked. Material storedon second floor is not burnt.

Fig.1 Interior view of the damaged building

Fig.2 Interior view of the damaged building

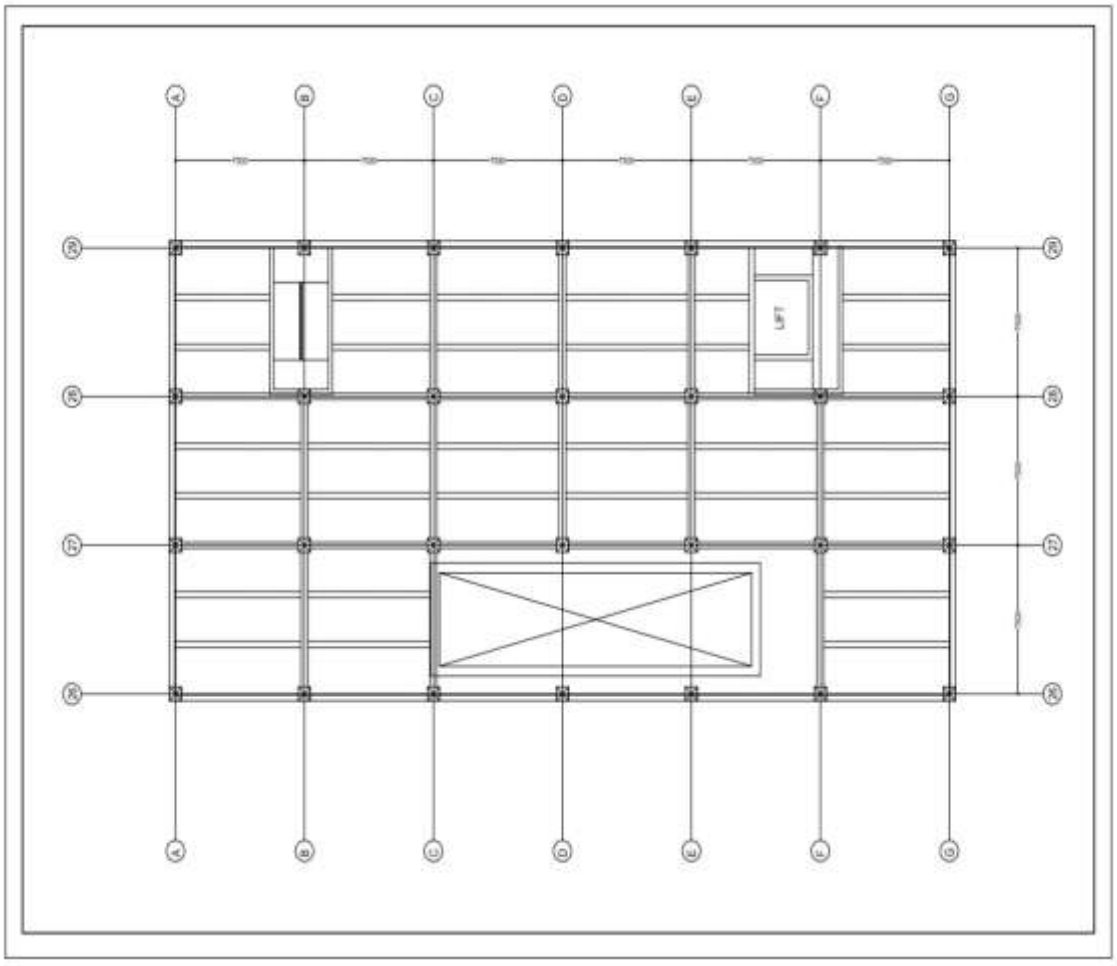


Fig.3 Grid line plan of typical floor

3. Strength test:

The purpose of core sample testing is to evaluate residual strength of concrete members. It is also helpful to determine the degree of retrofit required to regain the original strength.

75 mm diameter cores taken from the different structural members like beam, column and slab. The 8 samples taken from the directly fire affected area of the building, while 6 samples taken from unaffected area of the building. Compressive test of this specimen is conduced as per IS 516. As per IS 456, clause 17.4, acceptance criteria, core test shall be considered acceptable, if the average equivalent cube strength of the cores is equal to at least 85% of the cube strength and no individual core has strength less than 75% of grade of concrete. The grade of concrete used is M15. The average core strength of unaffected area is 15.03MPA, while that of affected area is 14.75 MPA. The core sample test shows 2% drop in strength of concrete in affected area. Refer Table.1

Table.1 Core sample test results

No	Member No	Element	Dia mm	Length mm	H/D	Wt Kg	Failure Load KN	Core Strength MPA	Correction factor IS:516	Equi. Cube strength MPA
	Core from Unaffected area by Fire									
1	BC1	BEAM	73	130	1.78	1.210	47.00	11.22	1.225	13.75
2	BC2	BEAM	74	120	1.62	1.250	54.50	12.68	1.200	15.00
3	BC5	BEAM	73	130.5	1.78	1.315	54080	13.00	1.225	16.00
4	BC6	BEAM	73	110	1.50	1.100	55.20	13.20	1.200	15.75
5	BC7	BEAM	74	90	1.21	0.940	56.30	13.00	1.163	15.25
6	S1	SLAB	73.5	130	1.77	1.350	48.40	11.42	1.225	14.00
7	S3	SLAB	73.5	130.5	1.78	1.380	50.10	11.82	1.225	14.50
8	C4	COL	74	112.5	1.52	1.200	57.40	13.35	1.200	16.00
	Core from affected area by Fire									
9	BC4	BEAM	73.5	95	1.29	0.950	54.30	12.80	1.163	14.75
10	BC3	BEAM	73	80	1.09	0.800	24.00	12.90	1.087	14.00
11	S2	SLAB	73	132	1.80	1.350	49.30	11.78	1.225	14.50
12	C1	COL	74	95	1.28	1.000	58.00	13.50	1.163	15.75
13	C2	COL	73.5	97	1.32	1.050	49.50	11.67	1.187	13.75
14	C3	COL	73.5	85	1.15	0.870	59.20	13.95	1.125	15.75

Fig. 4 Core samples taken at site

Fig. 5 Core sample from damaged beam

4. Push over Analysis:

Push over analysis is used to understand the existing capacity of structure for seismic and gravity loading, which will show different occupancy levels like immediate occupancy, life safety and collapse prevention. The seismic evaluation of existing buildings compares their capacity against earthquake demand at specific site and concerns the potential earthquake caused risk to the building system and elements that are closely related to human life safety.
Push over analysis (POA) and evaluation of performance of building using capacity spectrum method is widely used. The ATC 40 and FEMA 273 guides about seismic evaluation and retrofitting. Push over analysis is not included in Indian cods yet.

POA is non linear static analysis for a reinforced concrete framed structure subjected to lateral loading. This method is uses curve and reduced response spectrum to estimate maximum displacement. It provides a particularly rigorous treatment of the reduction of seismic demand for increasing displacement. The gravity loads are applied and then lateral loading is applied. The plastic hinge concept is extremely important in the non linear analysis.
Structural capacity is represented by a pushover curve. The easiest way to plot the force – displacement curve is by tracking the base shear and the roof displacement. Some non linear computer programs like ETABS are able to perform a Push over Analysis directly.

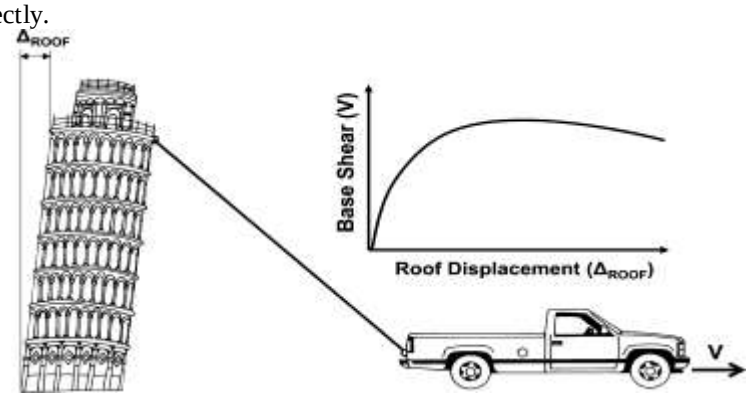
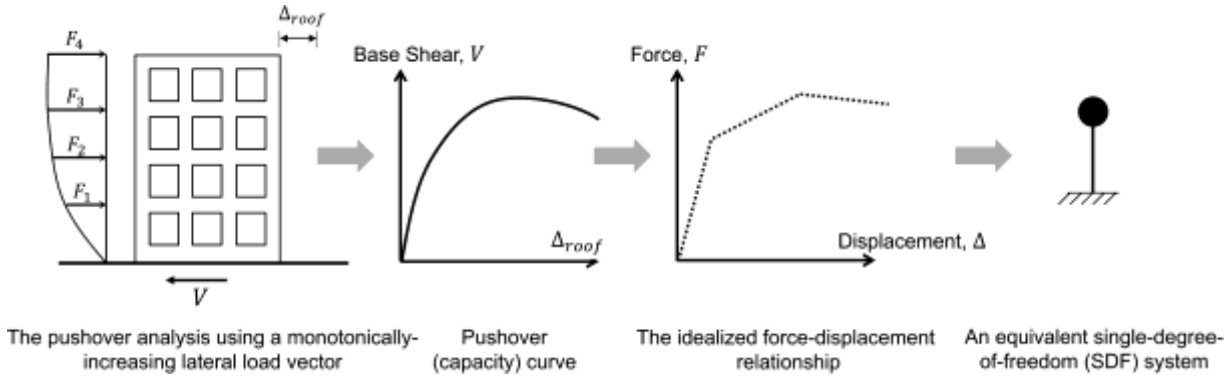


Fig. 6 The basic concept of the pushover analysis (Ref. 1)

Fig. 7 The basic conversion of a detailed structural model in to an equivalent SDF system (Ref. 1)



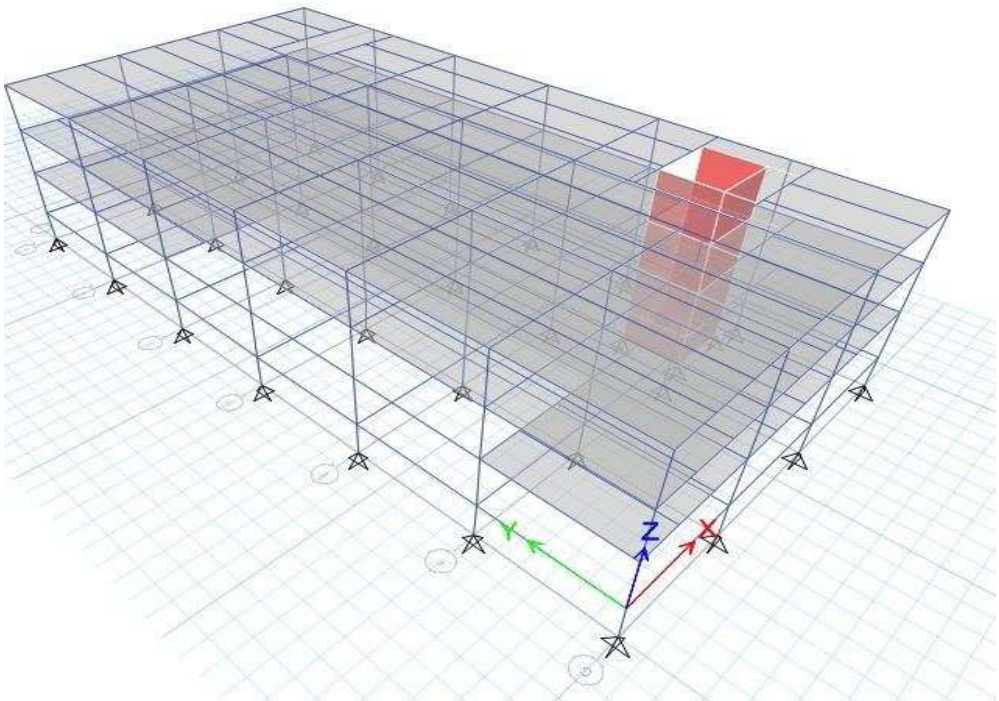
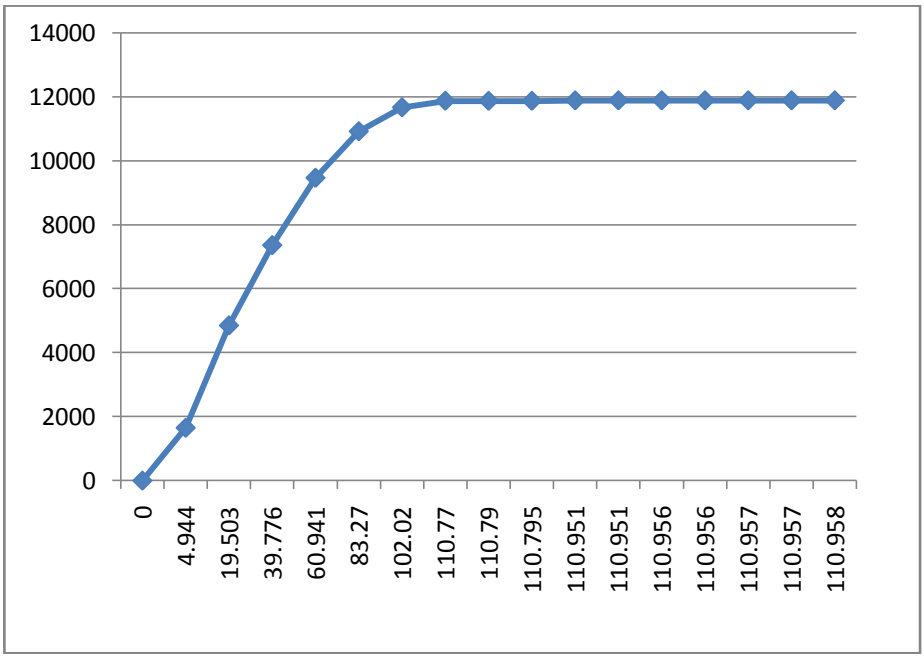


Fig. 8 3D model of the structure

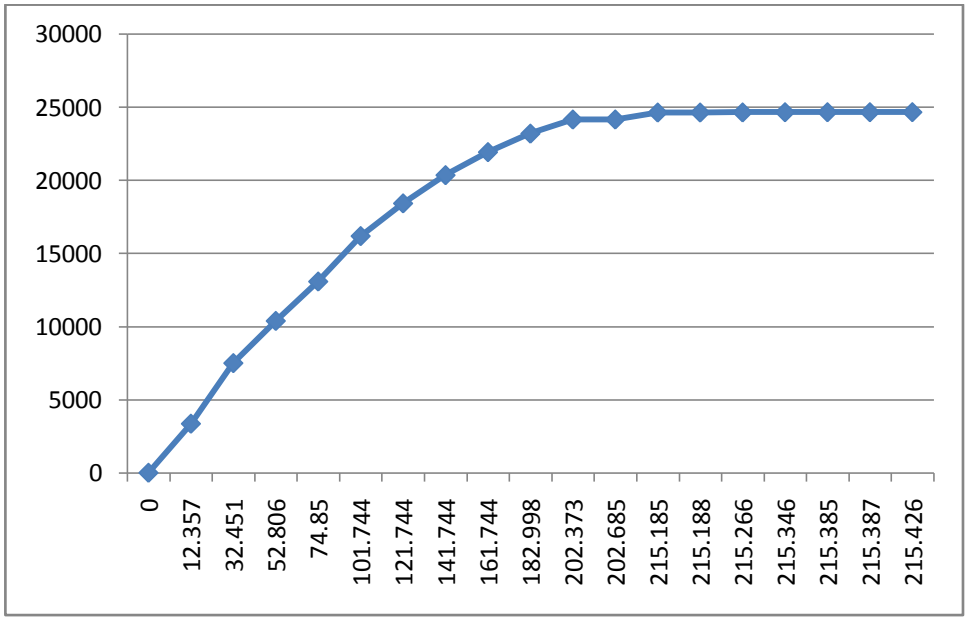
Force in Kn



Displacement in MM

Fig 9 Force Displacement Graph in X direction

Force in Kn



Dispalcement in MM

Fig 10 Force Displacement Graph in Y direction

5. Rehabilitation plan:

Based on the results of the visual inspection, NDT test, core test and push over analysis discussed in the previous sections, it is summarized that structural members are not affected much. Beam and slab are affected externally by fire. There is no appearance of server damage for RC members except spalling of cover concrete considering the serviceable life, as a precautionary measure it is necessary to strengthen some of the members, especially those are showing NDT results in poor class.

The slab needs to be repaired by surface repair method using epoxy-injection or mortar grouting. Beam and slab in grid lines B28- C26-C 28 are retrofitted by anchoring steel members to the damaged surface as below.

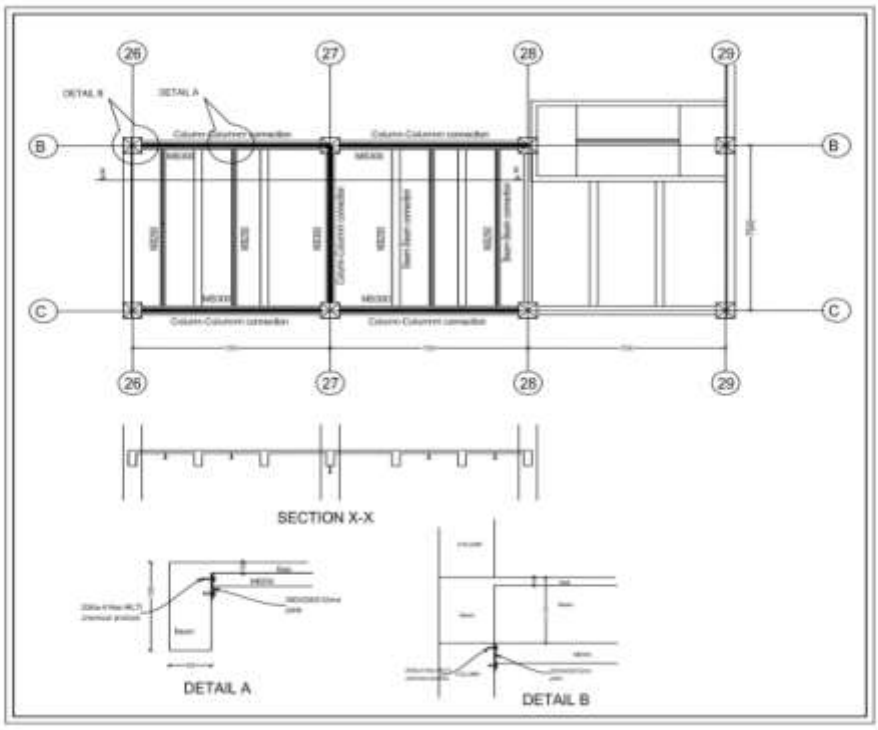


Fig. 11 Retrofitting plan

6. Conclusion:

It is summarized from visual inspection and NDT testing those reinforced concrete elements inside the building are not majorly affected externally by the fire. Comparison of colour and texture shows that the elements experienced less than 600° C temperature. Push over analysis for earthquake stability of the structure shows immediate occupancy.
RC members were affected externally only. There is no appearance of severe damage for RC members except spalling of plaster and cover concrete at certain parts of beam and slab. No cracks found on concrete surface. The concrete to steel bond is determined to be in good condition. Strength of concrete in affected area as shown by NDT estimates appears to be higher than unaffected area. This is due to hardening of surface. But compression test on core cut samples show 2 % drop in strength. Observation on beam said to be directly caught in fire for portion of exposed cover show that even the binding wire was not affected by fire, ruling out possibility of damage to R/F bars. As a overall conclusion it can be stated that strength of concrete is unaffected by the fire. Age of structure being more than 50 years, it is considered that it has served the useful service life. Being located in seismic zone IV, it is necessary to take precautionary measure for strengthening of some of the members, especially those showing NDT results in poor class.

7. Recommendations:

1. Beam and slabs at grid location B26-B28-C26-C28 needs to be strengthened as per drawing.
2. Slab surface at grid location D28-D29-E28-E29 and column E29 need to be repaired as per suggested repair methodology.
3. Lintel beams, External RC fins damaged during fire control needs to be repaired and restored.
4. Considering the life of structure and test results, it is recommended to limit the live load on the floor to 500 kg/m^2 though structure is designed for 750 kg/sq mt (as per reference of drawings).

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