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Repair and Rehabilitation of Fireside Damaged Concrete Structure

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Abstract: This research work is completed to embrace the project work on rehabilitation and retrofitting of fireside damaged concrete buildings. This study explains the rehab process of fireside damaged concrete buildings in three basic categories; condition evaluation, higher cognitive process, rehabilitation & retrofitting. Evaluation method of damaged building has been based upon understanding of fabric properties at elevated temperatures, condition survey and condition assessment. Condition survey includes visual inspection, hammering and chiselling techniques whereas condition assessment includes both non-destructive and destructive tests that are selected upon the premise of efficiency, economy, and performance. Feasibility study is required to form right decisions for the rehab of fireside damaged building. Such a feasibility study should include all important aspects which will have a control within the future, therefore must be considered in higher cognitive process. The method and testing procedures can be used to evaluate the level of damage and feasibility of repair needed. The evaluation can be used to whether to repair or to demolish the structure .

Keywords: Fire, Damage, Evaluation, Decision, Analysis, Retrofitting, Rehabilitation.

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1. Introduction

Fire is one in all the foremost severe hazards that building structures may experience during their lifetime. If a structure is broken by fire, it's necessary to research the explanation for the hearth and evaluate the reusability of the damaged structure. In terms of economic efficiency, it's going to be a far better approach to retrofit the damaged components of the structure, rather than demolishing it partially or completely. This decision must be made supported the results of investigations like the visual inspection of the damaged structure, tests on the remaining material, and finite element simulations of the structure or its structural components. Concrete may be a structural material, which performs well under attack conditions because of its low thermal conductivity and incombustibility. Furthermore, a concrete (RC) structure with proper reinforcement details can effectively redistribute loads from damaged region to undamaged components whether or not the part of the structure is severely damaged by fire[6]. Therefore, it's not common for fire-damaged RC structures to completely collapse during or after an incident of fireside. For this reason, fire-damaged RC structures are often generally rehabilitated by applying proper retrofitting methods.

Based on the previous studies and case histories of fire hazard in buildings we will gather some information elaborate the identification of foreside damaged structure elements, safe access to the hazard location, will explain the methods and tools used in the investigation the level of hazard or loss of strength of structure members.[7]

We will also evaluate the condition of structure member whether it is need strengthening and repair or to replace the member. Jacketing of weekend members need to be done with the application of additional strengthening material like reinforcement etc.

2. Fire Damage on Concrete

Table-1, Fire Damage - Damage Mechanisms

(a) Concrete Damage Mechanisms	(b) Temperature Effect on
Surface Cracking/ Crazing	Color of Concrete
Chemical Decomposition	Compressive Strength of Concrete (f'c)
Microcracking and Spalling	Modulus of Elasticity (E)
	Steel Reinforcement

(a.1) Surface Cracking / Crazing

- Crazing: network of fine surface cracks in concrete which usually occurs in early ages of concrete due to shrinkage of the surface layer.
- Repairing of cracks is essential when the chloride ion exists in the concrete itself or its surrounding environment.
- Crazing and surface cracks are caused by:

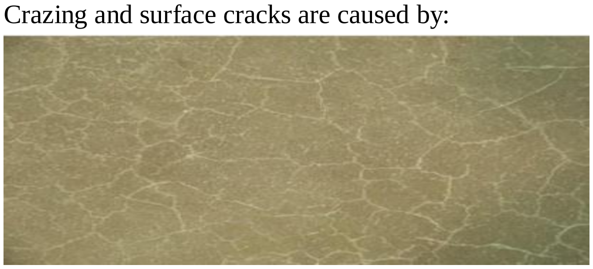

Figure-1. Surface Cracks

  (a) low humidity
  (b) fire
  (c) thermal incompatibility
  (d) hot sun
  (e) drying out

- Size of cracks:
  (a) Depth< 3 mm (1/8")
  (b) Diameter of grids of< 50mm (2")

(a.2) Chemical Decomposition

- The raise in temperature during fire will lead to water evaporation and dehydration in cement paste. This will cause decomposition of calcium hydroxide and calcium aluminates in concrete.
- Decomposition occurs after evaporation of free water and capillary water and will be initiated by the loss of physically bound water.
- The color of concrete will turn into pink as a result of this mechanism[5]

Figure-2. Chemical Decomposing of Concrete.

(a.3) Micro cracking and Spalling

- Spalling: the small cracks and separation of surface layers of concrete due to rapid change in temperature (such as fire) and leads to exposition of steel reinforcement and its rapid deformation due to heat.[5]
- Spalling caused by high temperature can be:
  (a) full destruction at slow rates
  (b) Sudden exploding of smaller or larger pieces of concrete with thickness less than few centimeters at early ages of heating.

Figure-3. Spalling of the concrete cover during a moderate fire.

(b) Fire Damage - Temperature Effect

(b.1) Color of Concrete

- Due to the chemical and physical changes and dehydration of the cement paste, the color of the concrete will vary during a fire, depending on the fire temperature[1].
- Color Change can be a used as an indicator of the exposure temperature and thus, the corresponding fire damage of concrete can be estimated [3].

(b.2) Compressive Strength of Concrete

- The compressive strength of concrete will not change up to 300°C, however, this is threshold temperature for speed of strength loss in mortars, which it will become more rapid after that.
- Although the f'c will not drastically change till 300°C, the strength of the concrete will significantly reduce by 30-40% due to internal cracks caused by thermal expansion. [5]
- The strength of concrete will not be recovered after cooling.

(b.3) Modulus of Elasticity of Concrete

- Up to 300°C, the loss in modulus of elasticity is in the same order of loss of concrete strength, about 40%.
- The loss of E around 550°C, is about 50%.

(b.4) Steel Reinforcement

- The yield strength of steel reinforcement can be reduced up to 50% of its initial value when the fire temperature rises to 600°C.
- The steel strength can be completely recovered when the rebar cools down from 450°C - 600°C, depending on the steel rebar manufacturing type.(3)
- The modulus of elasticity of steel is also reduced with raise in temperature, as expected.

3. Evaluation Methods - Preliminary Investigation

IS the Structure Safe to Enter?

- Data on Structure
- Data from fire department
- Information interviews
- Observations and other in-site information

Preliminary Investigation:

- **Cleaning the structure**

- Physical appearance
- Estimation of fire intensity
- Observations and in-site information
- Melting temperature of different material
- Other material's condition
- Field Tests:
- Ordinary hammer
- Chisel or screwdriver

Detailed Investigation:

- Destructive Tests
- Coring
- Petrographic
- Differential Thermal Analysis (DTA)
- Micro Hardness

- Non-Destructive Test (NDT)

Pulse-velocity (Soundscape)

- Impact-Echo
- Magnetic and Microwave (Radar)
- Penetration Resistance (Windsor Probe)
- Rebound (Scmidt) Hammer

Testing:

- Before repair
- After Repair

(1) Cleaning

- Smoke deposits and soot usually hides the spalling and cracks due to fire and cleaning of the structure will result in more clear observations and more accurate identification of the deflected and distorted members.
- Cleaning can be done using various methods such as water blasting, dry ice blasting, chemical washing and etc.
- These methods might cause secondary damages to the structure and the dry ice blasting or chemical washing is the safest method The loss of E around 550°C, is about 50%.[4]

(2) Inspecting Physical Appearance of Structure (Visual Inspection)

- The cracks, spalling, deformations, misalignments, distortions and exposure of steel reinforcements is documented
- The deflection and geometry of some suspicious members are measured and documented.

(3) Fire Intensity

- Fire intensity can be estimated by observing the building contents and the post-fire condition of the other materials.
- Knowing the melting point of some material and inspecting the building content, one can estimate the local and maximum fire temperature.
- The debris condition in different fire temperatures is an additional source for estimating the fire temperature.

(4) Field Tests

- When the previous phases of preliminary investigation will not reveal enough information to evaluate the fire's severity and to decide about future activities and further examination, simple on-site testing methods are used as adjunct to visual assessment of the damaged structure.
- Striking hammer to the concrete material and taking the sounding is one of the common methods. In this method the material will be good and hard when it tends to be solid and "ring" and the weekend concrete tends to be "dull thud" and hollow [2].
- Use of chisel is another method which is used to inspect the softened regions on the surface of the concrete

(b)Evaluation Methods - Detailed Investigation

(1) Destructive Test Methods

- These methods will require more time and effort rather than NOT test methods and caution is necessary during the sampling process.
- They will provide more detailed information about the strength and mechanical properties of the material as well as the depth of the fire and cracks location.
- Destructive test methods are generally performed either in field or lab and there are various methods available for this purpose [2].

(2) Coring

- It is mainly used to determine the poison ratio, modulus of elasticity and compressive strength of the concrete. The samples will be tested in the lab.

(3) Petrographic Test Coring

- This test is a deterministic testing method in determining the fire damage depth in concrete and is usually performed on core samples. Petrographic test will also offer valuable information about the location and orientation of the cracks and microcracking, loss of rebar-cement bond and cement-aggregate bond, dehydration, carbonation depth, water/cement ratio, etc.[4]

4. Rehabilitation

(a). Rehabilitation-Decision Making Process Governing Factors:

- Economical
- Current Code requirements
- Life span of proposed structure
- Historical importance
- Government building(matter of national security

(b). Rehabilitation-Essential Parameters for Repair Materials

- Workability
- Low shrinkage properties
- Aesthetics
- Requisite setting/hardening properties
- Good bond strength
- Coefficient of thermal expansion should be compatible
- Compatible mechanical properties and strength to that of the sub-strata
- No curing requirement
- Alkaline character
- Low permeability

(c). List of Rehabilitation Methods

- Surface Cleaning and smoke removal
- Breaking Out : replacing the damage concrete+ undisturbed reinforcement
- Ferro cement : Using mesh + Plasticizers +polymers for sealing pores
- Plate Bonding: MS plates+ epoxy glue for bonding + Bolting.
- Shotcrete : Pneumatically applied concrete or mortar placed directly on to a Surface
- Epoxy bonded concrete (fresh concrete +resin bond coat on hardened surface (depth 40mm or more) may be reinforcement/ shear keys etc.,
- Silica Fume concrete: Portland cement with silica fumes in case High strength requirement mostly used with super plasticizers.
- RCC jacketing :Composite action with old and new : ensure old concrete is good.[1,2,4]

(d). Guidelines Prior to design:

- The design should meet the demand of local building regulations and it needs approval from the local authority.
- Also design of the repair sections should comply with the current design codes. As in some cases the priory design of the structure may have been design to the codes which are revised in the meantime. So the code used in the past was out of date.

- In some cases it can be inferred from the investigation that the structure was deficient in the original design. Original design should be obtained as it will help to plan strategy to assess the "as built" properties of the structure.[1,3,4]

Typical Examples of Column Repair by Guniting:

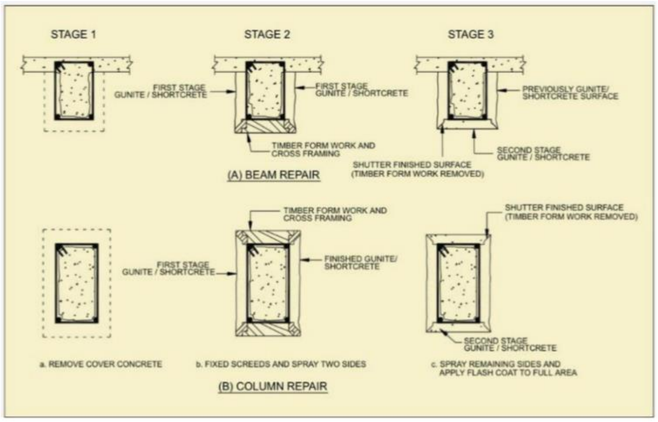

Figure-5. Slab Strengthening: Concrete Overlay

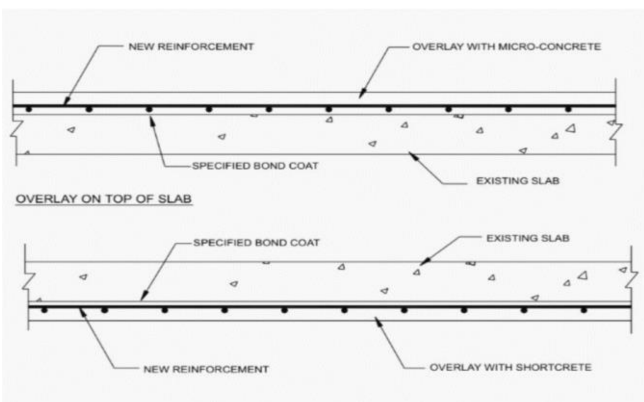

Figure-6. Beam strengthening: concrete overlay And section enlargement

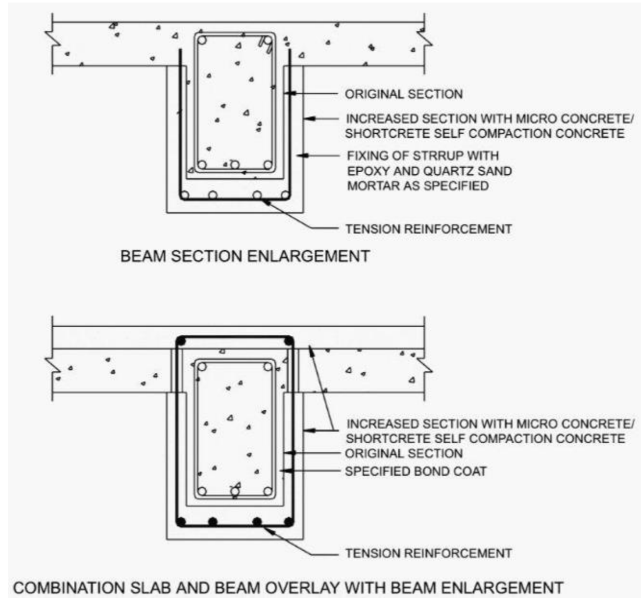

Figure-7. Combination Slab and Beam Overlay With Beam Enlargement.

5. Conclusion & Literature Review

a. This paper presents a case study on establishing a rehabilitation plan for a fire-damaged reinforced concrete structure. A team of structural and material researchers/engineers in concrete inspected the structure in the earliest possible time after the fire, and carried out both on-site and laboratory tests on the damaged concrete and rebar. The following is the conclusion of the study and the recommended rehabilitation methods:

b. Through visual inspection of the structure, the mostly damaged structural elements were identified as the slabs d because they are located at the highest elevation of the room where they are exposed to the highest temperature during the fire.

c. The judgment from the visual inspection is supported by the material test using the indicator method, where the concrete beneath the surface proved to retain its alkaline property for the girders, beams, walls, and even for the slabs.

d. Strength tests on concrete cores and rebar coupons obtained from the slabs, girders and beams showed that the reinforcing bars in the slab had considerably degraded in their structural capacity and therefore could not be used any longer.

e. It is recommended that the slabs be replaced with new ones, and the girders and beams be retrofitted. The columns and walls only needs surface treatment without a structural retrofit.
f. The decision about whether to rehabilitate and retrofit the structure or to reconstruct after demolishing the structure is influenced by many factors like technical, financial, safety, physical, Etc.
g. Repair strategies should be planned based on the results of evaluation phase and also various available rehabilitation methods.
h. Current building design code specifications should be considered

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