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Seismic Performance Assessment of Fire Affected Reinforced Concrete Building Using Non-Linear Static Procedure

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***Abstract:*— The occurrence of fire inside a building is an unexpected phenomenon and can break out at any time due to various reasons. Conflagrations following the 1906 San Francisco and 1923 Tokyo earthquakes lead to serious discussions among engineers about simultaneous safety of buildings against earthquake and fire. The correlative study of fire and earthquake can be done in two ways viz. structure subjected to fire following earthquake (post-earthquake fire) and fire affected structure subjected to an earthquake (Pre-earthquake fire). The present study focuses on seismic behaviour of building subjected to pre-earthquake fire. Often, buildings which are subjected to fire are made usable by performing non-structural and cosmetic repairs without proper seismic evaluation and retrofitting. In reality, the fire leads to material strength deterioration; however, the extent of reduction in strength depends on exposure time and temperature. Moreover, the reduction in overall strength of building is uncertain and therefore, the assessment of seismic performance of such fire affected structure becomes important. In this paper results of an analytical study on a five storey RC public building subjected to one hour standard fire is presented. The propagation of fire is considered in vertical direction (i.e. upward as well as downward direction) inside building. Seismic performance assessment of the fire affected models is performed by using non-linear static pushover (NSP) analysis. The lumped plasticity models of fire affected cross-sections are developed for various exposure durations for the standard fire as per Euro code (EC-2). Capacity curve results obtained from NSP shows that fire in bottom storey is more critical and capacity of structure reduces drastically with increase in exposure time. If building does not collapse during fire event, its post fire seismic performance assessment shall be made mandatory.**

***Index Terms* - Building Fire, Non-Linear Static Procedure, Seismic Performance Assessment, Travelling Fire**

I. INTRODUCTION

Fire is an unexpected phenomenon which causes severe loss of life and property. Fires are natural fires, house fire, fires in factories, etc. Generally house fires occur because of the electric appliances, kitchen stoves, candles, etc. Earthquake also plays vital role in fire accidents. The fires following the 1906 San Francisco and the 1923 Tokyo earthquakes led to major conflagrations, resulting in far greater damage than caused by the original shaking. Many researchers (Mousavi et al. [1]; Mostafaci et al. [2]; Taylor [3]; Behnam and Ronagh [4],[5] worked on the structures subjected to fire following earthquake. Major issue of concern in fire event is material strength degradation because of high temperature. Experimental studies evidenced that behavior of construction material viz. concrete and steel under loading (i.e. stress-strain relation) changes with temperature and fire exposure time. Nassif [6] did an experimental investigation of stress strain response of concrete in temperature range 217-4700C and in cooling regimes prepared using two ingredients viz. river gravel and limestone aggregate. Arioz [7] and Hager [8] studied physical properties of concrete subjected to elevated temperature and proposed a chart of surface texture and color change with respect to exposed fire state. This approximate method helps in predicting the exposed fire scenario of building fire. Though reinforcing bars in structural element (i.e. beams and columns) are embedded in the concrete, its properties changes with increase in the temperature. Topcu and Karakurt [9] enlighten the effect of temperature on the properties of reinforcing steel viz. yield strength, tensile strength, elongation and toughness. Tao et al. [10] developed simplified model for reinforcing steel exposed to high temperatures based on the statistical analysis of the collected test data. Furthermore, capacity of structural element reduces when subjected to fire due to material deterioration. Generally Interaction curve and moment rotation relations are used to inculcate the non-linearity of elements in the mathematical model. These lumped plasticity properties can be generated from the first principle. Law and Gillie [11], Pham et al. [12], Dwaikat and Kodur [13] and Pfrang et al. [14] emphasized on the effect of

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fire on the element capacity in terms of P-M interaction curve and moment rotation capacity of column along and moment rotation capacity of beam.

In present study six different models are considered based on the location of fire break out in the building. The first model building is considered at ambient temperature (i.e. No Fire case), whereas, in other five models location of fire break out (i.e. floor) has been altered. Linear dynamic analysis has been performed to identify the effect of fire on dynamic characteristics of building, followed by nonlinear static analysis on the same models to access their seismic performance.

II. SPECIFICATION OF BUILDING

Building plan selected (Fig. 1) is very similar to the plan of public building. The plan is symmetric in both longitudinal as well as transverse direction. To focus on changes in building due to localized fire, symmetrical building plan is selected to avoid interruption of other geometrical irregularities like torsion, re-entrant corner etc. The structure considered is 5 storey with storey height as 3 m. Preliminary sizes of the frame members have been considered based on the deflection criteria and fire resistance criteria given as per Indian standard IS 456-2000 [15] and IS 13920-1993 [16]. Response spectrum analysis of structure has been performed as per IS 1893 part 1-2002 [17]. Building is assumed to be situated on medium soil in seismic zone 5, having zone factor 0.36. Structure is subjected to gravity loads as per the clauses mentioned in Indian standards (IS 456, IS 875 part I [18] and part II [19]). In the proposed structure slab thickness and wall thickness is assumed equal to 150 mm and 230 mm respectively.

III. MODELLING AND ANALYSIS

Structural modelling, analysis and design have been performed in SAP 2000 version 14.2.4. Detailed mathematical model has been prepared to represent the distribution of structural geometry of elements and loading in plan as well as in elevation. Thickness of slab at all floor level and roof level have been assumed to be same and modelled as rigid diaphragm. Archetype building has been analysed by using response spectrum analysis and designed as special moment resisting frame as per the specifications IS 456:2000 [15] and IS 13920:1983 [16] code.

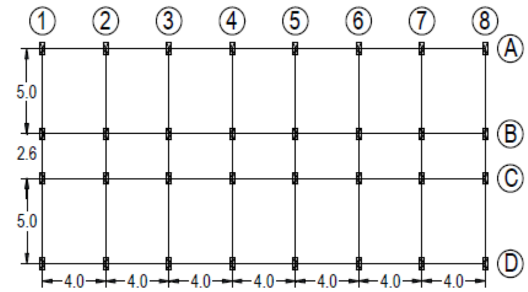

Fig. 1 : General layout of building

The effect of structural cracking is incorporated by modifying the stiffness properties of structural elements based on the equation proposed by ACI 318 [20].The beams have been assigned with moment (M3) hinges and columns with coupled axial moment (P-M2-M3) hinges at the two ends. Nonlinear lumped plasticity models for various fire exposures are generated using cross-sectional analysis software XTRACT and used for nonlinear analysis of frame. To access the performance of building nonlinear static procedure i.e. static pushover analysis has been performed.

Whenever fire occur in a building it is very rare that entire building is subjected to fire for same duration. Many researcher Cheng et al. [21], Law et al. [22], Platt et al. [23] and Stern-Gottfried [24] did study on pattern followed by fire in the building. It has been observed that fire travels with time delay of 6-8 minutes while travelling vertically upward and the same is 30 minutes in downward travel in building. In present study five different models of fire in building are considered for seismic performance assessment. To recognize the performance of building when there is material strength deterioration due to fire resulting in the reduction of member strength, standard fire of one hour is considered at five different possible locations of building. Table I gives the nomenclature of all six building models i.e. with and without incorporating fire with description of fire pattern in the building along with figure.

Generally the interaction curves for the typical cases at ambient temperature can be obtained using code based material properties and formulation. However in case of fire affected sections, interaction diagrams are not available and has to develop from the first principle. Similarly, moment curvature relationship for the section at ambient temperature can be generated but developing it for high temperature is a bit complicated. Euro code (EC 2) [25] gives the simplified method (i.e. 500^0C Isotherm Method) to incorporate the effect of fire on the structural

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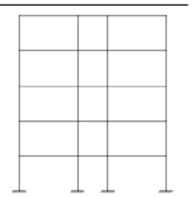
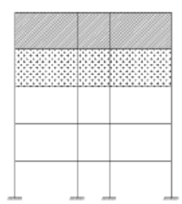
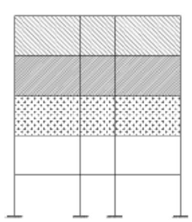
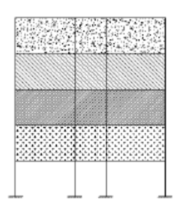
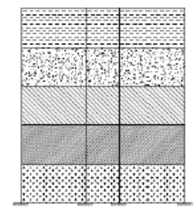
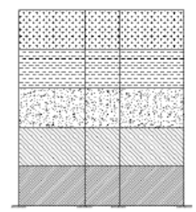
element. In 500₀C Isotherm method, the thickness of the damaged concrete, is made equal to the average depth of the 500°C isotherm in the compression zone of the cross-section. Damaged concrete, i.e. concrete with temperatures in excess of 500°C, is assumed as ineffective while estimating load bearing capacity of the member. While the residual concrete cross-section retains its initial values of strength and modulus of elasticity. The reduced moment inertia of fire affected elements are calculated based on the reduced cross section and calculated based on the isotherm method [25]. The reduced stiffness properties in mathematical model has been modified using element property modifier.

Table I: Nomenclature of models

Model	Model description	Figure
No Fire	Analysis model without considering fire (i.e. ambient temperature case)	
Fire 1	Fire breaks out at top (5th) storey and lasts for 1 hour, propagates to the 4th storey with time delay of 30 minutes.	
Fire 2	Fire breaks out at 4th storey and lasts for 1 hour, propagate to the 5th storey with time delay of 8 minutes and to the 3rd storey with 30 minutes delay.	
Fire 3	Fire breaks out at 3rd storey and lasts for 1 hour, propagate to 4th and 5th storey with time delay of 8 and 15 minutes and to the 2nd storey with 30 minutes delay.	
Fire 4	Fire breaks out at 2nd storey and lasts for 1 hour, propagate to 3rd, 4th and 5th storey with time delay of 8, 15 and 22 minutes and to the bottom storey with 30 minutes delay.	
Fire 5	Fire breaks out at bottom storey and lasts for 1 hour, propagates upward with time delay of 6-8 minutes at each storey.	

Exposure time to standard fire and color indicator

60 min. 52 min. 45 min. 38 min. 30 min.

IV. RESULT AND DISCUSSION

The results obtained from linear and nonlinear analysis of aforementioned fire scenario are compiled under modal analysis and nonlinear analysis result heading.

A. Modal Analysis Results

As fire in the building decreases strength and stiffness properties of structural elements which leads to the change in the modal parameters of structure. Therefore, the model analysis has been performed on all the considered building models. The effect of fire on the fundamental period of vibration of building have been determined and indicated in Table II. It can be observed from Table II that as the number of stories subjected to fire increases the fundamental period of vibration increases (maximum increase in time period is 15% for fire case 5). This increase in fundamental period is not same for all the models even though the fire breaks out for the same time and dependents on location of fire and amount of area affected by the fire.

Table II: Natural period (s) of different model

Models	Direction of Shift	Period (s)	Direction of Shift	Period (s)
No Fire	Tx	1.215	Ty	0.955
Fire 1	Tx	1.229	Ty	0.969
Fire 2	Tx	1.26	Ty	1.011
Fire 3	Tx	1.313	Ty	1.019
Fire 4	Tx	1.374	Ty	1.055
Fire 5	Tx	1.403	Ty	1.072

Very negligible change in time period has been observed (i.e. upto 1%) in case of fire is located in upper storey and area of building exposed to fire is relatively small.

B. Nonlinear Analysis Results

Nonlinear static analysis has been performed to access the performance of building. Pushover analysis estimates the capacity of structure along with sequential formation of hinges in the structure. The results of non-linear static pushover analysis obtained in the form of capacity curve for different cases of fire and no fire in longitudinal and transverse direction are shown in Fig. 2 and 3 respectively. The values of ductility capacity, yield base shear, yield and target displacement and over strength ratio of structure in both the direction is tabulated in Table III and IV. Building considered in the study has breadth comparatively smaller than height which makes building slender in transverse direction. Therefore the behavior in longitudinal direction is differ from transverse direction. Hence pattern of pushover curve obtained in both the directions viz. longitudinal and transverse is not same.

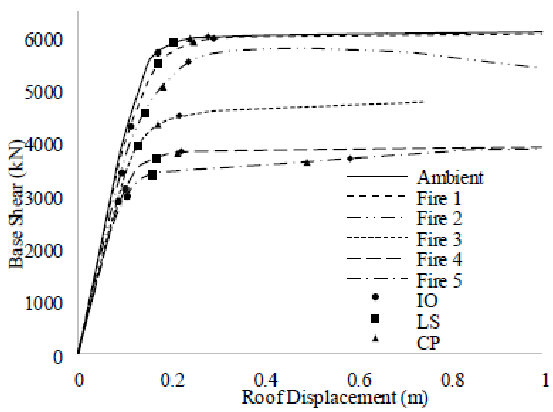


Fig. 2:Comparison of capacity curves in longitudinal direction

When top storey of building is subjected to fire (i.e. fire 1 case) the effect of fire is not significant and building perform like no fire case. In all fire scenario first hinge is formed in the beam at a storey affected by fire breaks out. Which indicates the influence of fire on formation of weak links inside the building due to the element strength reduction. Base shear capacity of building reduces as number of stories subjected to fire increases (from ambient temperature case to fire 5 case). Similar trend of reduction in base shear capacity has been observed from the capacity curve results along transverse direction.

Table III: Comparison of capacity curve results in longitudinal direction

Model	Ductility	Yield force (kN)	Displacement (m)		Over strength ratio
			Yield	Target	
No fire	7.4	5850	0.135	0.206	2.74
Fire 1	6.67	5800	0.15	0.21	2.71
Fire 2	3.08	5150	0.13	0.214	2.41
Fire 3	6.0	4400	0.13	0.224	2.06
Fire 4	8.69	3775	0.115	0.234	1.77
Fire 5	10	3390	0.1	0.24	1.59

The reserved strength of building (i.e. over strength) reduces by 1.1% to 42% and 5.6% to 27 % along longitudinal and transverse direction respectively when fire scenario changes from fire case 1 to fire case 5 in comparison with ambient temperature model.

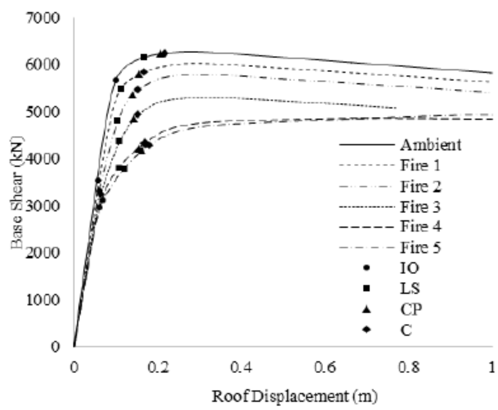


Fig. 3:Comparison of capacity curves in transverse direction

The stiffness properties of fire affected structural element is less than that of ambient temperature frame elements. As fire moves from top storey to bottom stores and area exposed to fire increases the number of structural elements affected by fire increases.

Table IV: Comparison of capacity curve results in longitudinal direction

Model	Ductility	Yield force (kN)	Displacement (m)		Over strength ratio
			Yield	Target	
No fire	3.11	5950	0.09	0.081	2.65
Fire 1	2.95	5600	0.095	0.166	2.5
Fire 2	3.76	5200	0.085	0.172	2.32
Fire 3	4.24	4700	0.085	0.174	2.09
Fire 4	8.5	4400	0.08	0.178	1.96
Fire 5	12.5	4350	0.077	0.182	1.94

This elemental stiffness reduction results in change in initial stiffness of structure i.e. reduces by 5% to 27% and

17% to 36% (in comparison of No Fire case) along longitudinal and transverse direction respectively.

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