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Seismic Performance Evaluation of Post Fire affected Unconfined and Confined Reinforced Concrete – SMRF Structures

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ABSTRACT

Fires are relatively likely events in urban locations in India. The seismic zone map of Indian sub-continent emphasizes that more than 60% of the land is prone to moderate to severe earthquake. This paper presents the seismic performance of code-conforming (IS456-2000 and IS1893-2016) post fire affected special moment resisting frame (SMRF) structure with and without the effect of confinement. Simulation of stress vs strain behavior of unconfined and confined concrete is achieved with the Mander's stress strain model and the same has been modified by incorporating the thermal properties of materials as per BS EN 1992-1-2:2004 for elevated temperature conditions. The seismic performance of structural components in terms of target performance levels for various elevated temperatures were studied with nonlinear static analysis using SAP2000. The results reveal that the base shear strength of the unconfined and confined structure drastically reduced to 68% and 62% respectively at 800^{o}C w.r.t ambient condition. The seismic performance at various high temperatures were assessed by converting the capacity curves to capacity spectra and superimposed with the code conforming demand spectra.

1. INTRODUCTION

A potential but infrequently studied hazard is the sequential occurrence of fires and earthquakes. Fire mishaps are a very typical occurrence among the many that occur during the structure's lifetime for a variety of reasons. The consequences of a fire disaster on a reinforced concrete structure can be catastrophic. Based on the severity and duration of a fire, the structure is vulnerable to a variety of minor and major damages. The examination of post occupancy of fire-affected structures necessitates more investigation. India being a land with several regions of potential seismic zones, the

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assessments of these fire affected structures situated in these vulnerable zones receive immediate concern. Seismic analysis of these post fire damaged structures has become a key tool in the determination of their seismic performance. The structural behavior beyond the yield limit and up to its ultimate capacity could be investigated with the non-linear static analysis procedure. Ramaraju *et.al*. (2012), studied the seismic performance evaluation of existing RC buildings as per past codes of practice. A seismic performance evaluation of a 2D framed structure is included in the study. The current paper validates the seismic performance evaluation of the given 2D structure and extends the research to 3D structure under design ground motions as per IS 1893: 2016 and incorporates the effects of temperature varying from ambient to 800ºC with an interval of 100ºC. The design of SMRF structures and the non-linear analysis has been carried out as per the guidelines of IS:456-2000, IS:1893-2016, IS:13920-2016, ATC-40, FEMA356, FEMA 440. The effect of temperature on the mechanical and thermal properties of concrete and reinforcing steel have been incorporated into the study with the aid of BS EN 1992-1-1,2:2004. The effect of confinement in enhancing the core compressive strength of concrete has been modelled with reference to studies conducted by Mander et.al., (1988). The current paper emphasizes on the comparative study of the evolution of stress vs strain models over the years and adopting a suitable one for the modelling in SAP2000.

The current study incorporates a code conforming seismic study of G+6 storied reinforced concrete structure located in the city of Vadodara. The structure is analyzed both as an unconfined structure and as a confined one to signify the importance of enhancement of the structure's behavior when the effect of confinement is considered. The role of longitudinal and confining reinforcement in defining the core compressive strengths has been verified with several existing stress vs. strain models. The effect of temperature however can be crucial as the mechanical and thermal properties of the materials that contribute to the elemental behavior as a whole can be dependent directly on the temperature effects. The post fire affected nature of the buildings is being modelled in SAP2000 V23 by isothermal heating throughout the structure which is achieved by defining the degraded material properties at various elevated temperatures. The material behaviors at every 100ºC rise in temperature up to 800ºC were studied by programming the corresponding in order to have a better understanding. Siliceous type of aggregates has been considered in the concrete mixes that do not contribute to major loss of masses at elevated temperatures unlike calcareous aggregates. The seismic performance of structural components in terms of target performance levels for various elevated temperatures were studied with nonlinear static analysis. Default hinges have been used to study the damage mechanisms simulated in the frame elements. A 100% dead load combination and a 50% live load combination has been adopted to define the mass source for the structure. Base shear vs. displacement graphs for the various elevated temperature cases with and without the action of confinement effect have been plotted discretely. These capacity curves are then transformed into capacity spectra as per the guidelines prescribed in ATC-40. Similarly, the demand imposed upon the structure by the earthquake is also plotted as a demand curve which is then converted to a demand spectrum with the same source of reference ATC-40. The seismic performance of the structure is then evaluated as per the three prominent performance levels viz., immediate occupancy, life safety and collapse prevention. This is achieved by superimposing the capacity spectra over the acceleration response demand spectra

(ADRS) of the structure for the given design ground motion. The point of intersection describes the performance point of the structure.

2. DESCRIPTION OF THE STRUCTURE

A typical G+6 storied commercial structure of base plan area 22.5x22.5m located in the seismic zone III (Z=0.16) is considered for the study. The floor design is divided into three bays in each direction, with a center-to-center distance of 7.5 meters in both directions. The type of soil located in the region is Soil type II corresponding to IS 1893-2016. The zone and soil type as corresponding to UBC 1997 guidelines are zone 2A and stiff soil profile respectively. The plan and elevation of the building are as shown in Figure1. The building is analyzed and designed as per the load cases and combinations as mentioned in Indian Standard codes, IS:456-2000, IS:1893-2016. The section properties with reinforcement details are as pictured in Figure 2. In the present study Normal Strength Concrete of grade M25 were used for sub-structure and M30 for the super-structure. Reinforcing steel of yield strength 415N/mm^2 are used as longitudinal and transverse reinforcements.

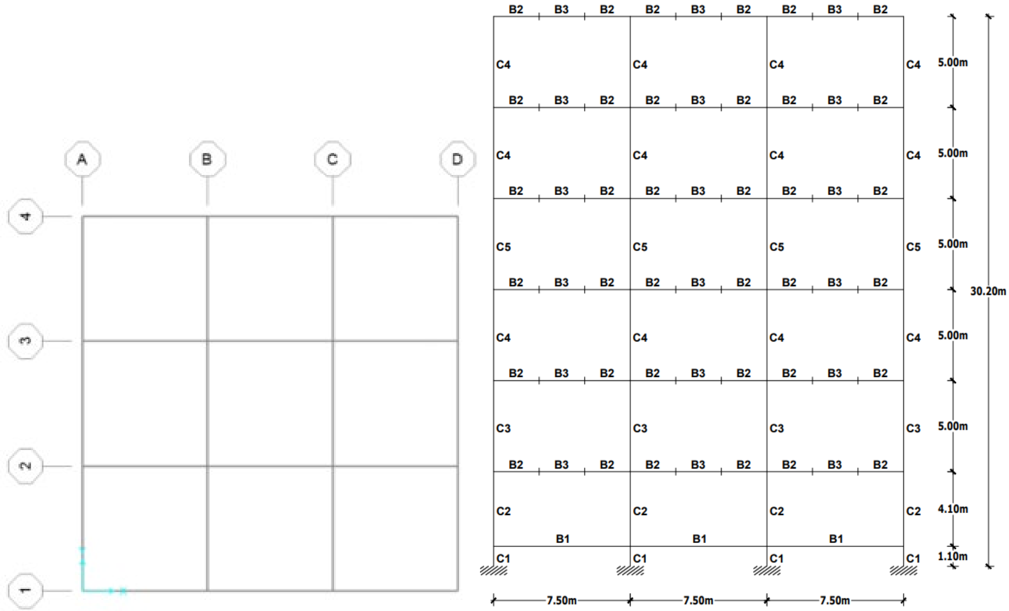

Figure 1. Base plan and Elevation of the building

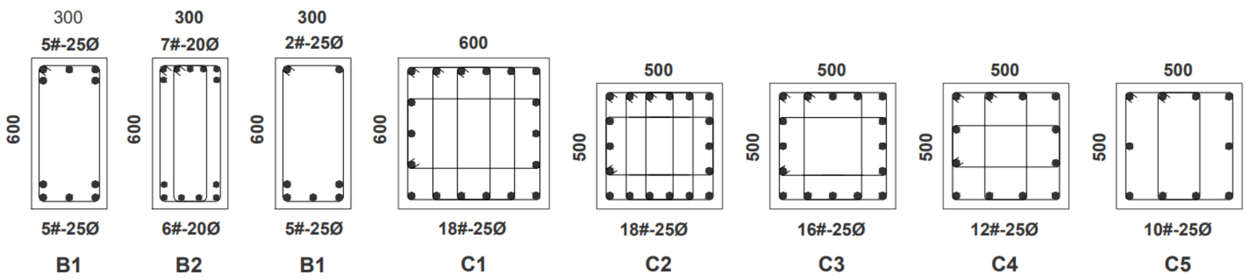

Figure 2. Section properties of the frame elements

(Note - All dimensions are in millimeters and all transverse reinforcements provided are of 8mm φ @100mm c/c spacing)
The structure under investigation comprises of typical beam-column RC frames with tie beams and no shear walls. Slabs of 100mm thickness have been assigned. The ductile detailing of the frame elements has been carried out according to IS:13920-2016 in order to model realistic member behavior in pushover analysis. It is to be also noted that the building under analytical investigation is free of any vertical or torsional plan irregularities (viz., soft storey, floating or stub columns, any setbacks, re-entrant corners, geometrical shape irregularities). A master joint viz., a semi rigid diaphragm is created at every storey to connect all the constrained joints that are rigid in their own planes. These diaphragms which are horizontal elements play a major role in connecting all the vertical lateral load resisting elements rigidly thereby preventing their out of plane deformations. Thus, the transfer of lateral loads is achieved with these elements.

Table 1 - Distribution of lateral forces and determination of base shear

Storey level	Seismic weight, W_i	Storey height, h_i	$W_i h_i^2$	Design lateral force, V_i
	kN	m		kN
Ground floor	2271.40	1.1	2748.39	3.93
First floor	6130.17	4.9	147185.50	210.57
Second floor	6373.17	5	159329.38	227.95
Third floor	6373.17	5	159329.38	227.95
Fourth floor	6373.17	5	159329.38	227.95
Fifth floor	6373.17	5	159329.38	227.95
Terrace floor	5782.01	5	144550.38	206.81
	ΣW_i = 39676.29		931801.77	1333.12=V_{base}

3. VALIDATION PROBLEM

The methodology adopted for numerical modelling in SAP2000 has been validated with results reported in reference of Ramaraju *et.al*, (2012). The structure validated is a three bay, six storey 2D framed structure. The load patterns and calculations were also simulated according to the Indian Standard codes. The load vs deformation characteristics have been validated accordingly. The corresponding demand and capacity spectra for the validation are shown in the Figure 3.

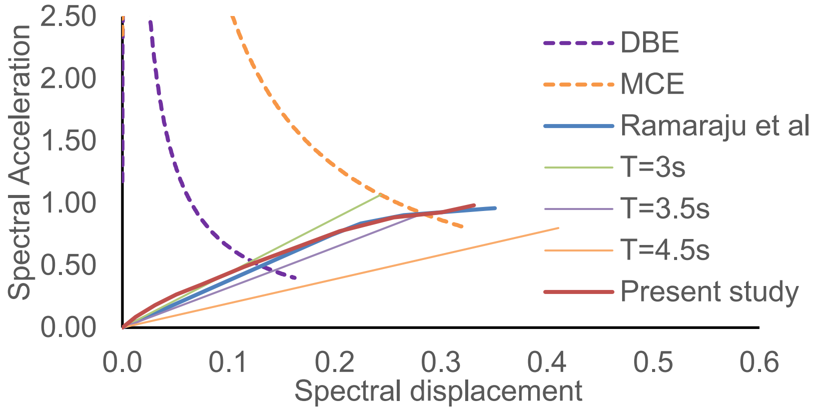

Figure 3 – Performance point determination for validation problem

4. STRESS vs. STRAIN BEHAVIOR OF CONFINED AND UNCONFINED CONCRETE

The effect of confinement due to transverse reinforcement on the core compressive strengths of the elements has not been given significant importance in the structural designs. The following study provides an insight on the enhancement of confined strengths in structural members when the transverse reinforcement is considered. In this paper an effort has been made to compare the stress vs. strain behavior proposed by Hognestad (1951), Kent and Park (1971), Mander *et al*., (1988), Chung *et* al., (2002) which is reflected in Table 2. Based on the comparative study, the factors effecting confined compressive strengths such as volumetric ratios of confining steel, stirrup effectiveness coefficient, materials grades and amount and orientation of reinforcement provided given, among the others. The study was further extended to elevated temperatures which involved the definition of material degraded parameters for various levels of fire exposures at elevated temperatures. User defined stress-strain models were fed as inputs to the model.

Table 2 - Summary of Stress vs. Strain Models

Model	Proposed Equations
Hognestad (1951)	$f_{cc} = f_c'(2x-x^2)$ where $x = 2\varepsilon_c/\varepsilon_{c0}$ and $\varepsilon c0 = 0.002$
Kent and Park (1971)	$f_{cc} = f_c'(2x-x^2)$, when $\varepsilon_c < \varepsilon_{c0}$ (Ascending part of graph) where $x = 2\varepsilon_c/\varepsilon_{c0}$ For descending part of the graph, $f_{cc} = f_c'(1-Z(\varepsilon_c-\varepsilon_{c0}))$ Unconfined concrete, $Z = 0.5/(\varepsilon_{50u}- \varepsilon_{c0})$ Confined concrete, $Z = 0.5/ (\varepsilon_{50u} + \varepsilon_{50h} - \varepsilon_{c0})$
Mander et al. (1988),	$f_c = x\ r\ f_{cc}/(r-1+x^r)$ where $x = \varepsilon_c/\varepsilon_{cc}$ and $r = E_c / (E_c - E_{sec})$ $f'_{cc} = f'_c\,(-1.254 + 2.254\sqrt{1 + \frac{7.94 fi}{f'c}} - 2\frac{fi}{f'c})$

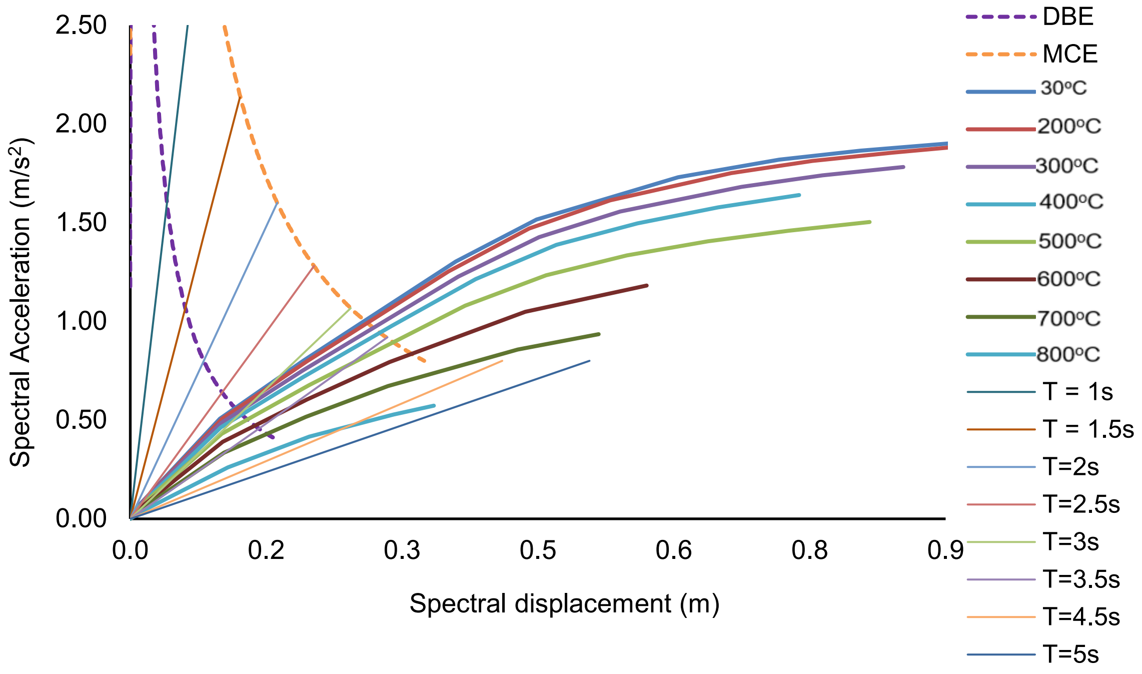

Figure 11 – Capacity spectra for DBE and MCE for elevated temperatures

8. CONCLUSIONS

In the present study seismic performance evaluation of post fire affected unconfined and confined Special Moment Resisting Frame structures as per the provisions of IS:456-2000, IS:1983-2016, IS:13920-2016, ATC-40, FEMA356, FEMA 440 and BS EN 19921-2:2004 is carried out. The post fire effect has been simulated by considering isothermal heating throughout the structure. The thermo-mechanical effect has been simulated by incorporating thermal parameters as per BS EN 19921-2:2004 in well-established Mander's stress vs strain model for reinforced concrete. The thermal effects on material characteristics were also modelled for various elevated temperatures such as 200ºC, 300ºC, 400ºC, 500ºC, 600ºC, 700ºC and 800ºC. The damage mechanism in beam and column members were carried out by modeling these members with default hinges (M3 for beams and P-M2-M3 hinges for columns) at their ends. The analysis was carried out by considering the default hinges as defined in SAP2000 V23. It was ensured that all the structural elements underwent uniform exposure to the elevated temperatures. The performance of the structure was assessed in terms of various performance levels as described in FEMA 356, FEMA 440 and ATC 40. From the results of the non-linear static analysis (Push over analysis), various capacity curves were plotted for elevated temperatures. These plots of base shear vs. roof displacement serve as a key tool in estimating the amount of damage the structure has undergone and the possible retrofitting strategies that could be implemented. In addition to the capacity curves, the demand spectra viz., a graph of spectral acceleration vs, spectral displacement (ADRS) was also plotted to simulate the demand imposed on the structure by a seismic action. Accordingly, demand spectra for Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) were plotted. To identify the performance point of the structure, the capacity curves were transformed into corresponding capacity spectra with the help of mass coefficient and modal participation factors as per ATC 40 and then super imposed on the demand spectra. The points of intersection define the performance point of the structure. It was observed that the global structural behavior for elevated temperatures followed a gradual reduction in capacity with increase in temperature levels. Accordingly, it was observed that the base shear strength for 800°C reduced to about 62% and 68% of the original value for confined and unconfined cases respectively. Also, from the capacity and demand spectra curves, it was observed that no performance point was achieved at 800°C.The structure has undergone a drastic reduction in capacity (strength and stiffness) thereby making the structure irrepairable or unfit for any repair through various retrofitting strategies.

NOTATIONS

f'_c - the unconfined compressive strength of concrete
f_{cc} - confined compressive strength of concrete
f_{hcc} – tie stress
f_l - Lateral Confining pressure
E_c – Tangent Modulus of Concrete
E_{sec} – Secant Modulus of Concrete
hi - height at i^{th} floor level
PF_1 - Modal participation factor for the first mode
V - Base shear
W_i – Seismic weight corresponding to structure at i^{th} floor level
W – total seismic weight of the structure
α - Modal mass coefficient
δ - roof displacements
ε_c - longitudinal compressive concrete strain corresponding to f_c
ε_{cc} - longitudinal compressive concrete strain corresponding to f_{cc}
ε_{co} - longitudinal compressive concrete strain corresponding to f'_c
ε_{50u} - strain corresponding to 50% of the maximum unconfined compressive strength
ε_{50h} - strain corresponding to 50% of the maximum confined compressive strength
$\varepsilon_{0.85}$ - longitudinal compressive concrete strain corresponding to $0.85f_{cc}$
ρ_s – Volumetric ratio of Confining steel
λ – confinement distance ratio
φ_1 – roof level amplitude at first mode

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