NONLINEAR SEISMIC EVALUATION OF RC FRAMED STRUCTURES SUBJECTED TO ELEVATED TEMPERATURES

Babita sah1, Akanshu Sharma1, Y.Singh2, P.Bhargava3, G.R. Reddy1, K.K. Vaze1
1Reactor Safety Division, Bhabha Atomic Research Centre, Mumbai 400085, India
2 Department of earthquake Engineering, Indian Institute of Technology, Roorkee, Uttrakhand 274667,India
3Department of Civil Engineering, Indian Institute of Technology, Roorkee, Uttrakhand 274667,India
E-mail of corresponding author: babitasah68@gmail.com

ABSTRACT

Non-linear analysis of RC structures subjected to earthquake excitation is of great interest to researchers, which can be done either by non-linear Dynamic (time history) analysis or by non-linear static pushover analysis. As non-linear dynamic analysis is time consuming, complex and impractical for general use, non-linear static pushover analysis is gaining popularity, as it gives a good balance between accuracy and simplicity.

In the present study, seismic behaviour of RC framed structures at ambient and elevated temperatures is studied using pushover analysis. Analysis is performed on two buildings, one is experimental (three storey RC bare frame) and another is more realistic (five storey RC building with in-fills). Performance of the structures subjected to elevated temperature, under seismic load is obtained. Parametric study is conducted assuming that the structure lies in different seismic zones of our country. A comparison of Drift Ratio, Ductility demand and performance of the structure located in different seismic zones and at elevated temperatures has been shown.

INTRODUCTION

Concrete in structure is likely to be exposed to high temperature during fire, near furnaces or reactors, fire following an earthquake etc. When a structure is subjected to elevated temperature, its material properties get deteriorated. Concrete undergoes many physical and chemical changes like change in color, cracking, spalling, coarsening of pore structure, increase in permeability etc. Mechanical properties like strength and stiffness of concrete and steel get reduced. Therefore seismic behavior of the structure after exposure to elevated temperature is of great interest. The aim of the analytical work performed here is to understand the effect of elevated temperature on the capacity of the structure and its performance under seismic load at different seismic zones when it is subjected to different elevated temperature.

Assumptions:

a. It is not a case of fire
b. Hypothetical elevated temperature is considered
c. Uniform heating from all the four sides
d. Since sections are small, same temperature is assumed which is conservative
e. Since cover is small reinforcement temperature is also considered same as concrete surface.

DESCRIPTION OF THE BUILDINGS

Analysis has been performed on two buildings, one is experimental (three storey RC bare frame) and another is more realistic (five storey RC building with in-fills). Table 1 gives the details of both the buildings.

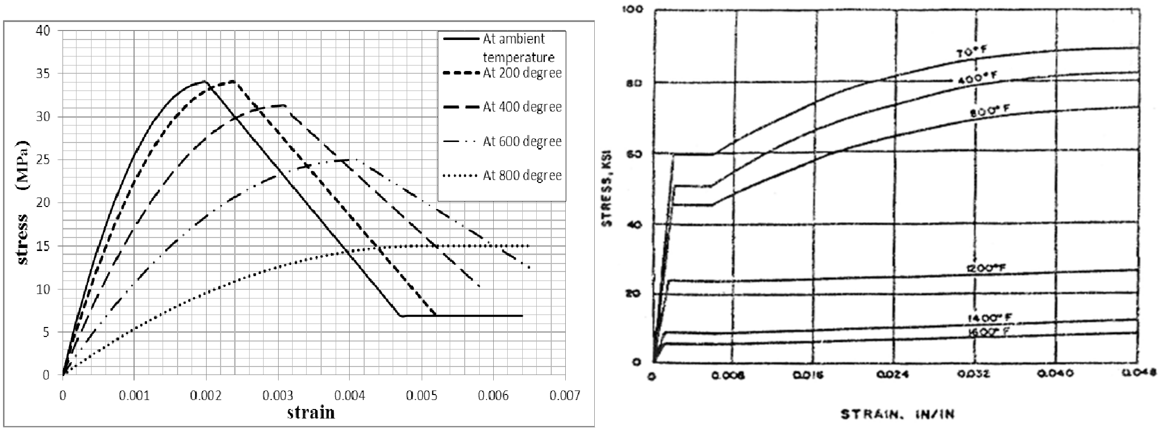
Table 1 : Details of both the buildings.

		Realistic building	Experimental building
1	Frame system	Moment resisting frame	Moment resisting frame
2	Seismic zone	V	III
3	Zone factor	0.36	0.16

4	Plan size	25.6m x 14.05m	3m x 3m
5	Storey height	3.2m	1.8m
6	No. of stories	5 i.e. (G+4)	3(G+2)
7	Plinth level from the foundation level	1.5m	-
8	Slab thickness	150mm	150mm
9	Live load	4k N/m^2(floors & corridors) 1.5 k N/m^2(on roof)	3kN/m^2(floors) 1.5 k N/m^2(on roof)
10	Floor Finish	1k N/m^2	1k N/m^2
11	Roof treatment	1.5 k N/m^2	1.5 k N/m^2
12	Column size	500mm x 500mm(GF &Plinth) 450mm x 450mm (Remaining floors)	150mm X 200mm
13	Beam size	350mm x 350mm	150mm X 200mm
14	Wall Thickness	230mm(External) 150mm(Internal)	-
15	Density	25k N/m^3(concrete) 20k N/m^3(masonary)	25k N/m^3(concrete) 20k N/m^3(masonary)
16	Design material properties Concrete Grade	M25	M20
17	Reinforcement Grade	HYSD (Fe415)	HYSD (Fe415)
18	Actual material properties from tests Concrete Strength	34 MPa	-
19	Average Reinforcement yield stress:	478 MPa	-
20	Average Reinforcement ultimate stress:	665 MPa	

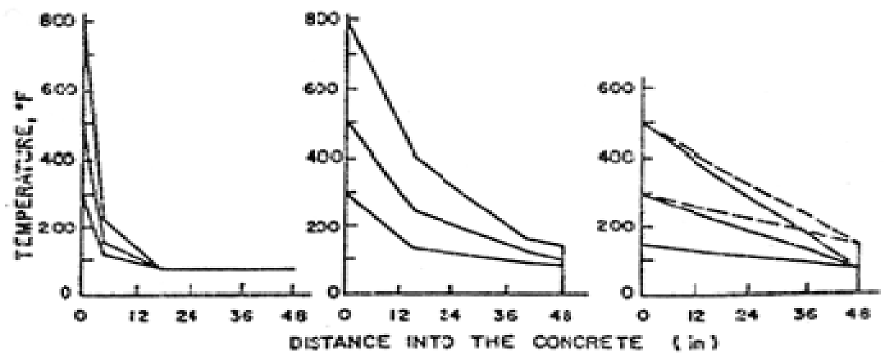
Stress-strain curves for concrete and steel at elevated temperature

It is seen that with increase in temperature strength of concrete and steel reduces.Fig. 1(a) and (b) shows the stress-strain relationship of concrete and steel at different elevated temperatures[2]. Shape of the curve at ambient temperature is similar to Kent and Park model which had been used earlier for analytical validation of the experimental result.



(a) (b)

Fig: 1 (a) **Stress-strain curve for concrete**; (b) **Stress-strain curve for steel**.



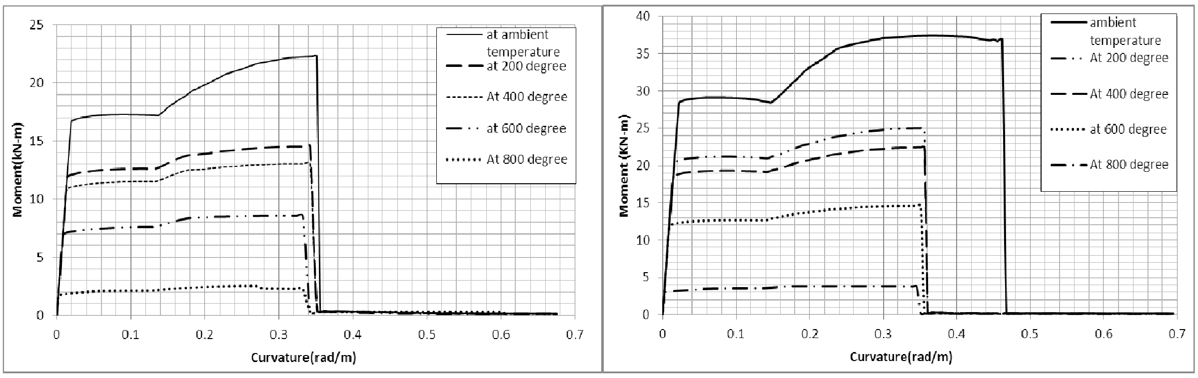
(a) (b) (c)

Fig: 2 Thermal gradients with depth into the concrete

Though concrete is bad conductor of heat still it possess thermal gradient with depth. Fig 2 has been taken from literature from which it is clear that with increase in depth, temperature of the concrete reduces. In the experimental building as the section size was small, temperature of the reinforcement is assumed same as that of the surface, unlike realistic building in which temperature of the reinforcement is less than that at the surface of the concrete. Fig 2(b) has been considered to determine the temperature of the reinforcement.

Moment-Curvature relationship:

Moment-curvature characteristics of a section are a representation of strength and deformation of the section in terms of moment and corresponding curvature of the section. M-Φ relationship of the sections have been evaluated using in-house programme and it is also validated using section designer method in-built in the package. Fig 3 (a) & (b) shows M-Φ relationship of beams and column sections subjected to different elevated temperature. From fig it is evident that with increase in temperature strength get reduced.The pleatue (constant moment with increase in curvature) shows the yielding of steel and the rise in moment with increase in curvature is due to strain hardening of steel. The fall in moment shows the complete collapse of the section.



(a) (b)

Fig: 3 (a) M-Φ relationships for beam subjected to elevated temperatures; (b) M-Φ relationships for column subjected to elevated temperatures.

The experimental building was analyzed first, to validate the procedure followed to obtain the non-linear hinge characteristics required to perform nonlinear static pushover analysis. Monotonically increasing Pushover Loads was applied along the height of the structure . The loads pattern were kept as parabolic with the load ratio of 1 : 4 : 9. Stress-strain curve was used as proposed by Kent and Park Model and strain hardening model for steel was used. Fig 4 shows a comparative result of pushover curve by assigning hinge properties obtained one by using in-house programme and another by section designer method in-built in the package. Fig.4 shows analytical validation of pushover curve with that of experimental result. The curve shows a good comparision both in terms of base shear and roof displacement with that of experimental one.Section designer method was used further to obtain moment-curvature although it gives similar result that has been obtained from in-house programme.

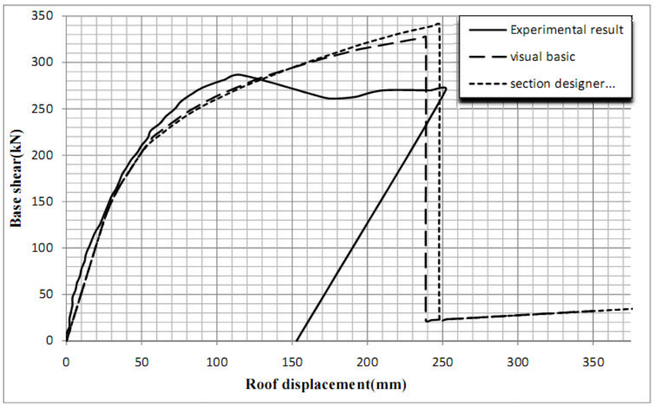


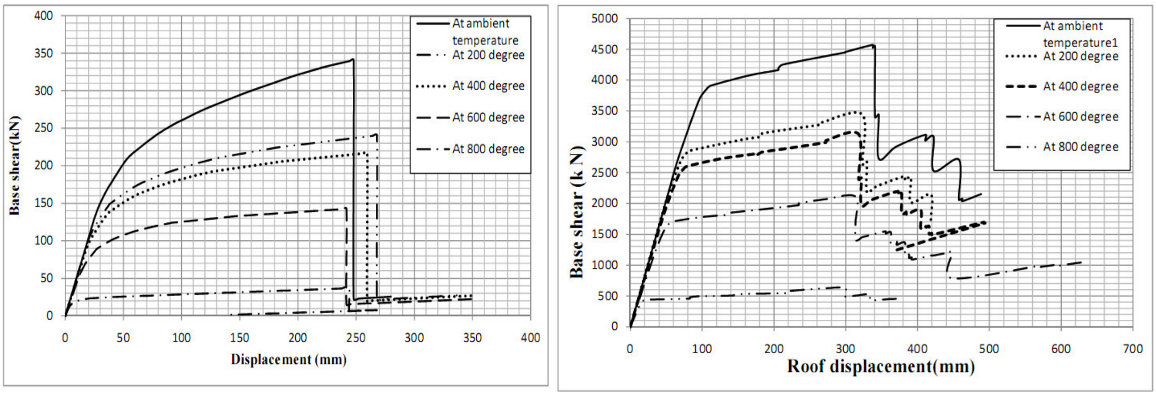
Fig.4 : Validation of analytically obtained pushover curve with experimental

It is then assumed that the structure is subjected to elevated temperatures. Temperature of 200˚ ˚C, 400˚ ˚C, 600˚ ˚C and 800˚C was considered in the work to obtain the capacity curve of the structures. As the analytical procedure was validated, the hinge characteristics at elevated temperatures were obtained using the same procedure and using modified constitutive relationships for concrete and reinforcing steel.

On conservative side the time of exposure was considered to be long enough to have uniform temperature throughout the section. For the given temperatures, the constitutive relationships for concrete and reinforcement at different elevated temperatures were taken from literature and Moment-Curvature (M-φ) curves were obtained.

M-Φ curve were obtained using in-house programme as well as by section designer method in-built in the package. User defined hinges has been assigned on the experimental set-up model and auto hinge has been assigned in the realistic building model.

The analysed result shows that when the building is subjected to elevated temperature capacity of the building reduces. Fig. 5(a) and Fig. 5(b) shows Pushover (capacity) curves of the experimental set-up and realistic building subjected to different elevated temperatures.



(a) (b)

Fig. 5: (a)) Pushover (capacity) curves of the experimental frame building subjected to elevated temperatures
(b) Pushover (capacity) curves of the realistic building subjected to elevated temperatures

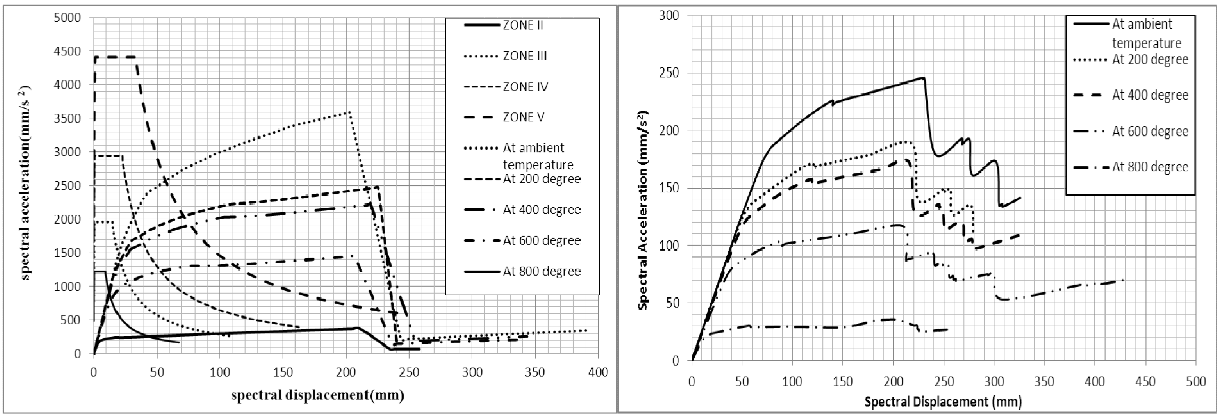
The comparative result shows that with increase in temperature overall capacity as well as roof displacement capacity of the building reduces. It is evident from Table 2 which has been obtained from fig.3 that ultimate load capacity and corresponding roof displacement capacity of the frame at ambient temperature is 4600 kN and 340mm respectively which get reduced to 3500k N and 325mm respectively at 200 ˚C. Table 2 shows the ultimate load capacity and corresponding roof displacement capacity against different elevated temperature.

Table: 2 Ultimate load and maximum displacement capacity of the Realistic building subjected to elevated temperature.

Temperature(˚C)	**Ultimate Load(k N)**	**Maximum displacement(mm)**
Ambient temperature	4600	340
200	3500	325
400	3160	320
600	2120	315
800	610	300

When the structure is subjected to elevated temperature, spalling in the concrete takes place which reduces or even eliminates the concrete cover on the reinforcement; thereby exposing the reinforcement to high temperature, leading to the reduction of the strength of the steel and hence deteriorates the capacity of the structure as a whole. It is evident from table 2 that the capacity (base shear) of the building is very low at the temperature of 800˚C, because at such a high temperature of 800˚C, the load bearing capacity of the steel reinforcement deteriorates. Hence the capacity of the structure which was goverened by steel reduces to about 20% of its design value which is proportional to the strength of the steel at this temperature.

To obtain the performance of the structure, capacity curve and the demand curve is converted to capacity spectrum and demand spectrum respectively following the procedures given in ATC-40.Capacity spectrum is super-imposed on demand spectrum to obtain the performance point. Fig. 6(a) shows Capacity spectrum for the experimental set-up superimposed over response spectra (ADRS format) (DBE) and Fig.6 (b) shows Capacity spectrum of the realistic structure subjected to elevated temperature. It is evident from Fig 6 that with increase in temperature the capacity of the structure deteriorates. With the increase in temperature, Ductility demand and Drift ratio of the structure in different seismic zone increases.Performance point of the building subjected to elevated temperature in different seismic zones for medium soil has been obtained. Table 3 shows Base shear and roof displacement at performance point of the realistic building subjected to elevated temperature in different seismic zones



(a) (b)

Fig. 6 : (a) Capacity spectrum for the experimental frame building with superimposed demand spectra (ADRS format) for DBE; (b) Capacity spectrum of the realistic structure subjected to elevated temperature

It is evident from Table 3 that with the increase in temperature the base shear of the structure deteriorates and roof displacement increases. It is also evident from the table 3 that as the structure is subjected to higher seismic zones its base shear as well as roof displacement increases. Table 4(a) and Table 4(b) shows the comparison of Drift ratio (i.e. ratio of Performance displacement to Height of the building), Ductility demand (i.e. ratio of Performance displacement to the yield displacement) and performance of the structure at different seismic zones of our country of experimental as well as realistic building and it is found that with the increase in temperature drift ratio and ductility demand in different seismic zones increases and performance of the structure deteriorates.

Table 3: **Base shear and roof displacement at performance point of the realistic building subjected to different elevated temperatures in different seismic zones**

	ZONE II		**ZONE III**		**ZONE IV**		**ZONE V**	
	Base shear(k N)	**Roof displacement(mm)**	**Base shear(k N)**	**Roof displacement(mm)**	**Base shear(k N)**	**Roof displacement(mm)**	**Base shear(k N)**	**Roof displacement(mm)**
	At ambient temperature							
DBE	1177.8	28.73	1884.472	45.97	2803.04	68.98	3774.29	101.62
MCE	2355.59	57.47	3543.68	91.55	3972	131.67	4140.09	194.59
	At 200 degree							
DBE	1177.8	28.73	1884.472	45.97	2646.13	68.73	2897.05	99.75
MCE	2275.39	57.49	2869.39	88.46	2977.46	132.56	3168.51	201.42
	At 400 degree							
DBE	1150.91	29.41	1828.03	47.1	2486.87	69.67	2659.69	101.06
MCE	2196.82	58.77	2631.63	90.22	2735.89	132.95	2879.84	209.73
	At 600 degree							
DBE	1090.65	31.03	1599.41	49.26	1728.08	71.26	1784.033	106.33
MCE	1705.91	59.52	1769.82	93.39	1857.62	146.08	2054.75	266.08
	At 800 degree							
DBE	442.262	33.75	449.73	59.82	497.35	107.51	564.44	231.88
MCE	455.79	80.98	539.71	185.57	N/A	N/A	N/A	N/A

Table:4 (a) Performance of the experimental building subjected to different elevated temperatures in different seismic zones

ZONE ↓		AMBIENT TEMPERATURE			At 200 degree			At 400 degree			At 600 degree			At 800 degree		
		DRIFT RATIO	DUCTILITY DEMAND	PERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	PERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	PERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	PERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	PERFORMANCE
II	**DBE**	**0.04%**	**4.95%**	**ELASTIC**	**0.04%**	**3.87%**	**ELASTIC**	**0.04%**	**4.13%**	**ELASTIC**	**0.05%**	**6.21%**	**ELASTIC**	**0.06%**	**26.73%**	**IO**
	MCE	**0.08%**	**9.91%**	**ELASTIC**	**0.08%**	**7.75%**	**ELASTIC**	**0.08%**	**8.26%**	**ELASTIC**	**0.09%**	**12.42%**	**ELASTIC**	**0.11%**	**50.48%**	**IO**
III	**DBE**	**0.06%**	**8.09%**	**ELASTIC**	**0.06%**	**6.33%**	**ELASTIC**	**0.07%**	**6.61%**	**ELASTIC**	**0.07%**	**9.94%**	**ELASTIC**	**0.09%**	**41.29%**	**IO**
	MCE	**0.13%**	**15.85%**	**ELASTIC**	**0.13%**	**12.39%**	**ELASTIC**	**0.13%**	**13.22%**	**ELASTIC**	**0.15%**	**19.88%**	**ELASTIC**	**0.19%**	**83.33%**	**IO**
IV	**DBE**	**0.09%**	**11.89%**	**ELASTIC**	**0.09%**	**9.30%**	**ELASTIC**	**0.10%**	**9.91%**	**ELASTIC**	**0.11%**	**14.91%**	**ELASTIC**	**0.14%**	**61.01%**	**IO**
	MCE	**0.19%**	**23.26%**	**ELASTIC**	**0.19%**	**18.18%**	**ELASTIC**	**0.20%**	**20.37%**	**ELASTIC**	**0.22%**	**30.00%**	**IO**	**0.72%**	**325.00%**	**CP**
V	**DBE**	**0.14%**	**17.83%**	**ELASTIC**	**0.14%**	**13.94%**	**ELASTIC**	**0.15%**	**14.87%**	**ELASTIC**	**0.17%**	**22.36%**	**ELASTIC**	**0.24%**	**108.33%**	**IO**
	MCE	**0.28%**	**35.16%**	**ELASTIC**	**0.28%**	**27.49%**	**ELASTIC**	**0.30%**	**29.63%**	**IO**	**0.31%**	**42.50%**	**IO**	**1.44%**	**650.00%**	**C**

Table:4(b) Performance of the realistic building subjected to different elevated temperatures indifferent seismic zones

ZONE ↓		AT AMBIENT TEMPERATURE			At 200 degree			At 400 degree			At 600 degree			At 800 degree		
		DRIFT RATIO	DUCTILITY DEMAND	ERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	ERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	ERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	ERFORMANCE	DRIFT RATIO	DUCTILITY DEMAND	ERFORMANCE
II	**DBE**	0.18	30.53	ELASTIC	0.18	44.62	IO	0.18	44.62	IO	0.19	62.00	IO	0.21	226.67	LS
	MCE	0.36	60.00	IO	0.36	87.69	IO	0.37	90.77	IO	0.38	120.00	IO	0.51	540.00	LS
III	**DBE**	0.29	48.42	ELASTIC	0.29	70.77	IO	0.29	72.31	IO	0.31	98.00	IO	0.38	400.00	LS
	MCE	0.58	96.84	IO	0.55	135.38	IO	0.56	138.46	IO	0.58	186.00	IO	1.16	1240.00	LS
IV	**DBE**	0.43	72.63	IO	0.43	106.15	IO	0.44	107.69	IO	0.44	142.00	IO	0.68	720.00	LS
	MCE	0.83	138.95	IO	0.83	204.62	LS	0.83	204.62	LS	0.91	292.00	LS	N/A	N/A	N/A
V	**DBE**	0.64	107.37	IO	0.63	153.85	IO	0.63	155.38	IO	0.66	212.00	LS	1.45	1546.67	CP
	MCE	1.22	205.26	LS	1.26	309.23	LS	1.31	323.08	CP	1.66	532.00	CP	N/A	N/A	N/A

IO-Immediate occupancy
LS-Life safety
CP-Collapse prevention
DBE-Design basic earthquake
MCE-Maximum considered earthquake

SUMMARY

Analysis has been performed on two buildings, one is experimental (three storey RC bare frame) and another is more realistic (five storey RC building with in-fills). The experiment was conducted to obtain the pushover curve on a three storey (G+2) RC bare frame structure at ambient temperature. The structure was analyzed to validate the procedure followed to obtain the non-linear hinge characteristics required to perform nonlinear static pushover analysis. The experimental plot is compared with the analytically obtained Pushover curve and is shown in the work. Once the analytical procedure was validated, the hinge characteristics at elevated temperatures were obtained using the same procedure and using modified constitutive relationships for concrete and reinforcing steel. The constitutive relationships for concrete and reinforcement at different elevated temperatures were taken from literature.
To generate the nonlinear hinge characteristics for the RC sections, on conservative side, the time of exposure was considered to be long enough to have uniform temperature throughout the section. For given temperature considered, stress-strain curves for concrete and steel were read from literature and Moment-Curvature (M-Φ) curves have been obtained.

CONCLUSION

The aim of the work was to understand the effect of elevated temperature on the capacity of the structure and its performance at different seismic zones. It was observed that with increase in temperature the capacity of the structure deteriorates. Tthe performance of the same building changes as it moves to different seismic zones. With increase in temperature its performance changes. It was found that with the increase in temperature, Ductility demand and Drift ratio of the structure in different seismic zone increases. Finally it can be concluded that with the increase in temperature the seismic performance of the structure deteriorates. Based on the evaluated performance, decision on retrofitting can be effectively made. Using the procedure followed in the work, seismic performance of a fire effected structure can be evaluated with a little extra considerations.

REFERENCES

[1] ATC-40, "Seismic Evaluation and Retrofit of Concrete Buildings", Report No. SSC96-01, Applied Technology Council, California Seismic Safety Commission,California November 1996.
[2] G.N.Freskakis,"Behaviour of Reinforced concrete at Elevated temperature,"Paper 3-4,Second ASCE Conf. on civ. Eng. And Nuclear Power.Vol.1,Paper 3-5,pp.3-5-1to 3-5- 21 , Knoxville,Tennessee,September 15-17,1980.
[3] Hognestad, E., "A study of combined bending and axial load in reinforced concrete members," University of Illinois Engineering Experimental Station, Bulletin No.399,1951, p.128.
[4] IS 456:2000, "Indian Standard PLAIN AND REINFORCED CONCRETE - Code of Practice (Fourth Revision)", Bureau of Indian Standards, New Delhi, July 2000.
[5] IS 1893 (part1): 2002, "Indian Standard CRITERIA FOR EARTHQUAKE RESISTANT DESIGN OF STRUCTURES, PART 1 GENERAL PROVISIONS AND BUILDINGS (Fifth Revision)", Bureau of Indian Standards, New Delhi, June 2002.
[6] Park, R. and Pauley, T., "*Reinforced Concrete Structures*", John Wiley & Sons, New York, 1975.