Evaluating the Effects of Plastic Hinge Location on Performance of the Moment Resisting Frames subjected to Seismic Loads

Mohammed Asif, PG Student, Department of Civil Engineering, MGM's College of Engineering, Nanded, Maharashtra, India. m17_mohammed_asif@mgmcen.ac.in

Mohd. Zameeruddin, Associate Professor, Department of Civil Engineering, Nanded, Maharashtra, India. md_zameeruddin@mgmcen.ac.in

Abstract - Performance-based seismic design has adopted nonlinear static analysis method for the performance evaluation of a structure subjected to seismic loads. In nonlinear static analysis, the structure is subjected to the incremental lateral loads, until the target displacement is reached. The inelastic properties of reinforced concrete sections are introduced by the use of plastic hinges. Many past researches have contributed towards the understanding the effects of location of plastic hinges in performance evaluation. These efforts were made on the basis of the structural characteristics of reinforced concrete members. With the development of finite element based computing tools it became easier to analyze such complex behavior of structures. For inelastic modeling it's needed to define the permissible limits of drift, curvature or rotations of structural components and the location of plastic hinges.The permissible limit of drifts, curvature and rotation are specified in the guideline documents along with the performance levels, but does not clarify about their locations. In this study efforts are made towards the finding out the approximate locations of plastic hinge, so as to attain the reasonable level of performance of the structure when subject to seismic loads. For this example moment resisting frames, designs for the gravity loads were subjected to the set of lateral loads and their parametric study is done.

Keywords **— Moment resisting frames, plastic hinges, nonlinear static procedures, parametric studies**

I. INTRODUCTION

With the development of nonlinear analysis procedures, the more complex seismic analysis became possible with an increase level of accuracy and reliability. The first generation (ATC 40 and FEMA 273), second generation (FEMA 356), and next-generation (ASCE 41and FEMA 440) have put forth the nonlinear static analysis procedures for the evaluation of performance of reinforced concrete (RC) structures.Finite element based software's namely SAP, ETABS, IDARC, DRAIN, etc., has adopted these procedures for the evaluation of nonlinear responses [1-7]. PBSE procedures include performance evaluation methods, named "Capacity Spectrum Method (CSM)" and "Displacement Coefficient Method (DCM)". In CSM and DCM procedures capacity of a structure is evaluated by applying the monotonically increasing predefined load pattern until the target displacement is reached. To obtain the nonlinear performance of the structure the capacity spectrum of the structure is compared with the demand spectrum during a seismic hazard [8].Fig 1(a) & (b) describes CSM and DCM procedures. Due to its simple process, the nonlinear structural analysis (Pushover Analysis, POA) has become common in practice.

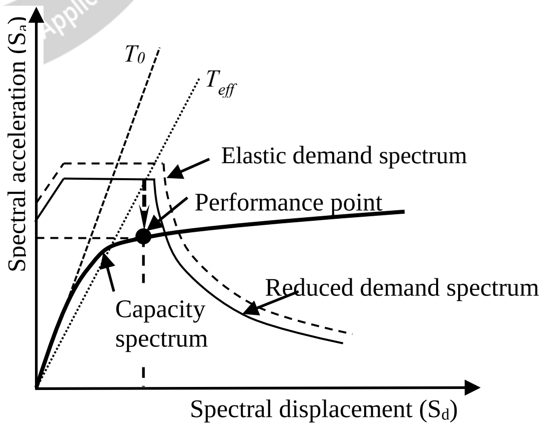


Fig 1(a): Determination of performance point by CSM [7]

Modeling of the reinforced concrete (RC) members for POA requires the determination of the nonlinear properties of each component in the structure, quantified by strength and deformation capacities which depend on the modeling assumptions [7].

 DOI : 10.35291/2454-9150.2021.0429

Since these RC members are assigned with plastic hinges. Most commonly in practice user-defined nonlinear hinges properties or default-hinge properties; defined in FEMA-356 and ATC-40 guidelines are used in the soft computing tools. These tools provide the hinge properties for several ranges of detailing, and implement the averaged values. Thus, it becomes necessary to understand the effects of default-hinge properties that may lead to unreasonable displacement capacities [9].

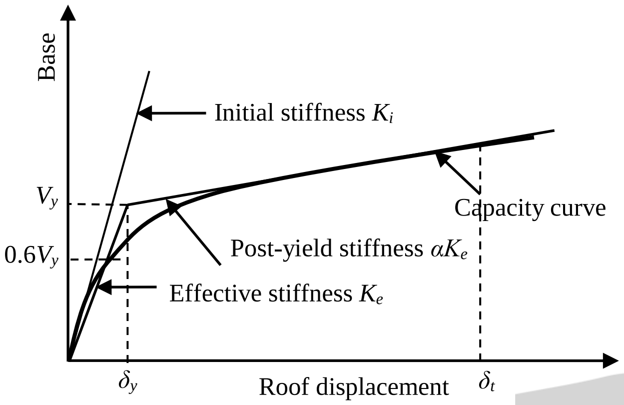


Fig. 1(b): Calculation of target displacement [7]

For MRFs, where lateral loads (for example, seismic) are predominant, the point of contra-flexure typically occurs close to the mid-span of a member. Many researchers suggested the use of the lumped plasticity model, with plastic hinge formation possibility at both ends of a member results in reasonable responses when used POA [10].

In PBSD various performance levels are defined in terms of damages sustained by the structural and non-structural components in a seismic event. Namely, Operational level (OP), Immediate Occupancy level (IO), Life-safety range (LS), Collapse prevention (CP) and Collapse (C). The attainment of these performance levels are identified on the basis of drift. For global performance identification storey drift is referred, whereas; for local level inter-storey drifts are used. The accuracy and efficacy of these performance levels depend on modeling of the plastic hinges and their locations [11].

In this study, we performed POA on the example MRFs. These example MRFs were subjected to a three different sets of lateral loads. The collapse mechanism was studied for three different locations of plastic hinges, Viz. (a) at quarter span from both ends, (b) at mid span, (c) at the ends of the member. The results obtained from POA are used to identify the capability of example MRFs in terms of the ductility and strength.

II. Plastic Hinges

Under seismic action, two forms of plastic hinge are formed in a beam which depends on relative magnitudes of inertia loads and gravity loads. When the gravity load dominates, the structure sways backwards, generating negative sway moments at the column junction and positive moment at mid span. The deflection cause is proportional to the increment in the moment and is a function of one direction only, referred as unidirectional plastic hinge. This action shows little variation in the stiffness of the member.

When the inertia loads dominate the structure sways forward and backwards, generating the positive and negative moments at the column junction with the direction of rotation in each of these reversing the direction of motion. This is referred as reversing plastic hinges [13]. The plastic hinge mechanism of MRF is shown in figure 2.

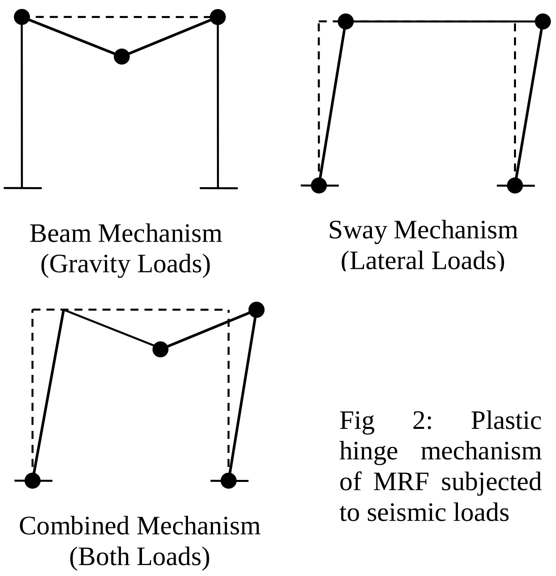


Fig 2: Plastic hinge mechanism of MRF subjected to seismic loads

The nonlinear behavior of the MRF frame depends primarily on the moment– rotation behavior of its members, which in turn depends on the moment–curvature characteristics of the plastic hinge section and the length of the plastic hinge.

The plastic hinge rotation of RC beams depends on a number of parameters including the definition of yielding and ultimate curvatures, section geometry, material properties, compression and tension reinforcement ratios, transverse reinforcement, cracking and tension stiffening, the stress-strain curve for the concrete in tension and compression, the stress-strain curve for the reinforcing steel, bond-slip characteristics between the concrete and the reinforcing steel, support conditions and the magnitude and type of loading, axial force, width of the loading plate, influence of shear, and the presence of column [13].

Structural failures due to the collapse of columns are more destructive comparable to those due to the collapse of beams, which has been learnt from the past earthquakes all over the world. The performance of the columns during earthquakes can be improved by improving deformability, strength, and energy dissipation at the location of plastic hinges through confinement. The confinement of the concrete can be achieved through transverse reinforcement or composite materials [14].

DOI : 10.35291/2454-9150.2021.0429

Plastic hinges form at the maximum moment region of reinforced concrete beams and columns. The determination of the length of plastic hinges length is a critical step in predicting the lateral load-drift response of the MRF. It is difficult to estimate the plastic hinge length by using computer programs, based on experimental data or by using empirical equations as a several factor influences the plastic hinge length [9-10] and [15-16]. The several factors influencing the lengths of plastic hinge area: 1) level of applied load; 2) moment gradient; 3) the value of shear stress in the plastic hinges region; 4) the amount and mechanical properties of longitudinal and transverse reinforcement; 5) strength of concrete; and 6) level of confinement provided in the potential plastic hinges zone [17]. The simplified equations put forth in the available literatures do not contain all or most of the aforementioned factors. Hence, large variations exist in the value of plastic hinge length, calculated using these empirical equations[9]. The modeling parameters defined in performance-based seismic design documents are adopted by FE based software, SAP 2000 [18] for nonlinear modeling of RC members [1-5]. These criterions are defined in term permissible limits of drift, moment-curvature or moment-rotation, but are silent about the plastic hinge length and plastic hinge location.

In the present study an attempt has been made to find out the nonlinear responses of example MRF with different location of plastic hinges along the RC beams and columns. The results obtained can be used for adopting acceptable location of the plastic hinges for an identified performance level of structure ensuring minimum damages and threat to life during a stated level of seismic hazard.

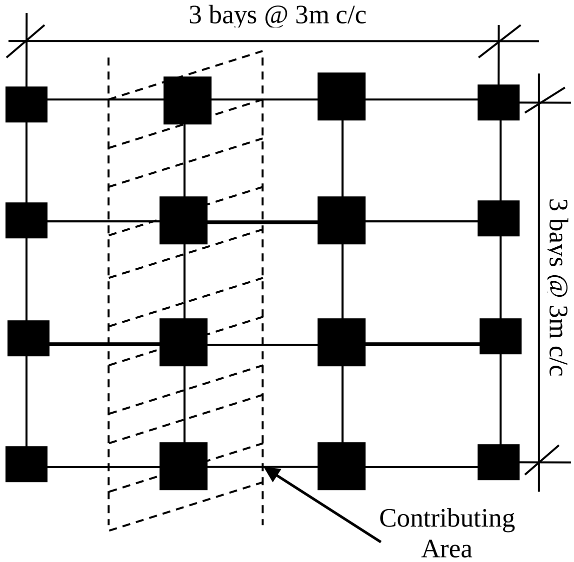
III. Example Moment Resisting Frame

In this study, we performed nonlinear static analysis on example bare MRF with no shear walls, which represents a general trend of construction of low-rise structures adopted in India. Fig. 3 depicts the typical layout of the example MRFs. These MRFs represent a commercial building located in seismic zone V, as per IS 1893[19], on a medium soil type. The height of each story of the model was assumed as 3 m, and the beam spanned 3 m. The spacing between the frames was 3 m. The characteristics of these MRFs are presented in Table 1.

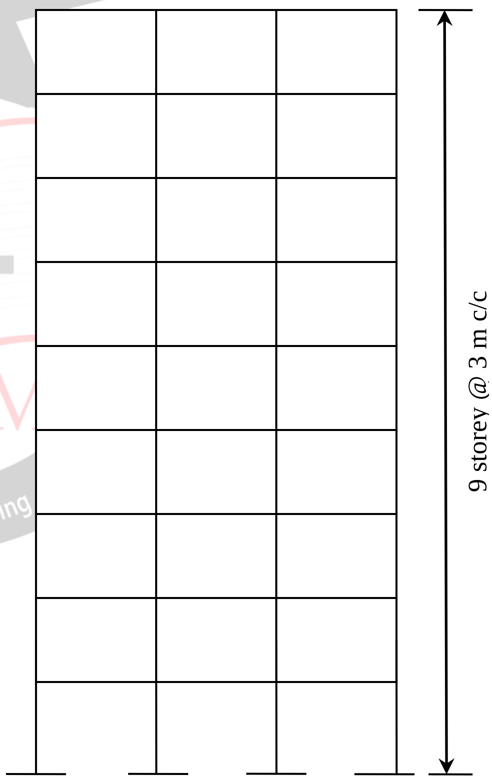
Table 1: Characteristics of the studied example MRFs

Example MRF	T_d (s)	T_m (s)	S_a/g	W_i (kN)	V_b (kN)
MRF	0.883	1.070	2.5	5645.93	313.05

For the analysis, dead loads, live (imposed) loads, and seismic loads were considered as per IS 875 (Parts 1 and 2) [20-21] and IS 1893, respectively. These MRFs are subjected to a mean dead load of 18 kN/m^{2}including finishes loadsand a mean live load of 3 kN/m^2, for all floors. The RC design of these MRFs was based on IS 456 [22] guidelines. The ductile (seismic) detailing of the RC section was based on IS 13920[23] provisions. The material properties considered in the design are presented in Table 2.



a) Typical Plan



b) Typical Elevation

Fig 3: Typical Layout of Example MRF

The structural design of the example MRFs is presented in Table 3-4. The structural design of the example MRFs is not a unique solution available for the calculated demand. Based on the same demand, different designers may select different solutions. The RC member sizes were selected by following a common practice adopted by engineers. All the columns and beams in a selected story are identical in cross

 DOI : 10.35291/2454-9150.2021.0429

ISSN : 2454-9150 Vol-07, Issue-05, AUG 2021

section. The column remained uniform in cross section up to three stories, depending on the height of the building.

IV. NONLINEAR STATIC ANALYSIS

The displacement-controlled nonlinear static analysis (also known as Pushover Analysis, POA) is performed on the example MRF by using SAP 2000 V 20.0. The target displacement used for each MRF was 4% of the height of the example MRF [1].

Table 2: Material properties considered in the design of example MRFs

Material property	Concrete M 25 Grade	Steel Fe 415 Grade
Weight per unit volume (kN/m^3)	25	76.97
Mass per unit volume (kN/m^3)	2.548	7.849
Modulus of elasticity (kN/m^2)	25E+06	2E+08
Characteristic strength (MPa)	25000 (for 28 days)	415000 (yield)
Minimum tensile strength (kN/m^2)	-	485800
Expected yield strength (kN/m^2)	-	456500
Expected tensile strength (kN/m^2)	-	533500

Table 3: Design details of RC columns of example MRFs

RC Member	Storey Level	Cross-section	Rebar's details (mm2)
Column (EC1)	1-3	600 x 600	2880
Column (EC2)	4-6	530 x 530	2412
Column (EC3)	7-9	450 x 450	2412
Column (IC1)	1-3	680 x 680	3699
Column (IC2)	4-6	600 x 600	2880
Column (IC3)	7-9	530 x 530	2247

Table 4: Design details of RC Beams of example MRFs

RC Beams	Storey Level	Exterior Span Rebar's		Interior Span Rebar's	
		Top (mm^2)	Bottom (mm^2)	Top (mm^2)	Bottom (mm^2)
(BL1)	1	1035	378	1288	386
300 x	2	1728	518	1791	527
530	3	2090	647	2201	657
(BL2)	4	2163	662	2216	679
300 x	5	2309	702	2341	585
450	6	2299	702	2345	586
(BL3)	7	2237	661	2279	685
300 x	8	2099	615	2137	632
380	9	1752	516	1789	511

The analysis was conducted in two stages for the following: (i) gravity loads and (ii) predominant lateral loads. In stage I, gravity loads were applied as the distributed element loads on the basis of the yield line theory and concentrated loads from secondary beams. Gravity analysis was performed for full gravity load in a single step (i.e., force-control). The state of the structure in this analysis was saved and was subsequently recalled in stage II. In stage II, lateral loads were applied monotonically in a step by-step nonlinear static analysis. Because the lateral force profile in POA influences the structural response, a set of lateral loads were used [24].Three different lateral load cases are applied on example MRFs. (a) Lateral loads as per IS 1893, (b) Lateral loads for uniform distribution of inertia loads, and (c) First mode lateral load distribution. The lateral loads on the example MRF for POA are tabulated in Table 5.

Table 5: Lateral Loads on the example MRFs

Storey height	Lateral Loads		
	IS 1893	Uniform	First Mode
3	1.215	38.119	0.879
6	4.858	37.916	9.690
9	10.708	37.343	29.458
12	18.481	36.253	50.216
15	28.876	36.253	97.290
18	40.805	35.579	0.000
21	54.674	35.017	7.383
24	71.410	35.017	118.135
27	82.025	21.554	0.000

The nonlinear behavior of the frames primarily depends on the moment–curvature (M–ϕ) behavior of its members. The input required for nonlinear modeling in SAP 2000 is the moment–rotation (M–θ relationship instead of the moment–curvature relationship). To develop the M–θ curve of a default hinge, a stress–strain relationship described in ASCE 41 integrated in the software was used. For an MRF in which lateral loads are predominant, the contra-flexure point typically occurs in the mid span of the members. Many researchers suggested that for a lumped plasticity model, plastic hinge formation at both ends of the member is most suitable for pushover. To evaluate the effects of different position of the plastic hinge along the RC members, three different models were analyzed, Viz. (a) at quarter span from both ends, (b) at mid span, (c) at the ends of the member.

Beams and columns were modeled as nonlinear frame elements by assigning concentrated M3 and P-M3 plastic hinges. ASCE 41 guidelines related to modeling parameters and acceptance criteria were adopted. The acceptance criteria for the ultimate rotation capacity, labeled IO, LS, and CP, are illustrated in Fig. 4.

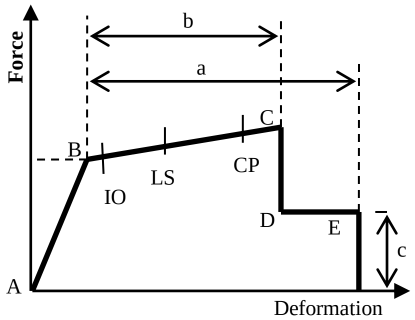
V. PERFORMANCE ASSESSMENT

The responses of the example MRF were studied in terms of the base shear, roof displacement, story displacement, and inter-story drift ratio. In POA, the example MRF was subjected to the gravity loads and predefined lateral loads for different position of plastic hinges on the RC members (refer Table 5-6). POA was performed in two stages; in first stage the example MRF was subjected to gravity loads

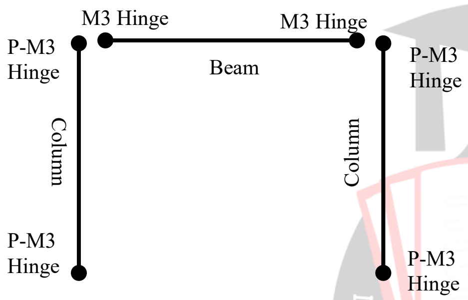
DOI : 10.35291/2454-9150.2021.0429

ISSN : 2454-9150 Vol-07, Issue-05, AUG 2021

for force-control condition. In the second stage the state of example MRF from stage 1 was recalled and lateral loads were applied monotonically in step by step increments till target displacement is reached. The P-delta effects were taken in account.The capacity curves obtained from POA of example MRF for different lateral load cases and locations of plastic hinge are shown in figure 5-8. Table 6 provides details of pushover load cases. In POA-0 load case the plastic hinges are assigned at ends of the RC columns and beams. In POA-10 load case the plastic hinges are assigned at 0.10L and 0.90L from the right end of RC members.



(a) Deformation control (flexure failure)



(b) Location of hinges

Fig. 4: Idealized inelastic force–deformation relationship

Table 6: POA cases for example MRF

Load Case	Location of plastic hinges on RC beams and Columns
POA-0	At the ends of RC members
POA-10	At 0.15L from both ends
POA-25	At 0.25L from both ends
POA-40	At 0.40 L from both ends

L is the length of RC beams and Columns

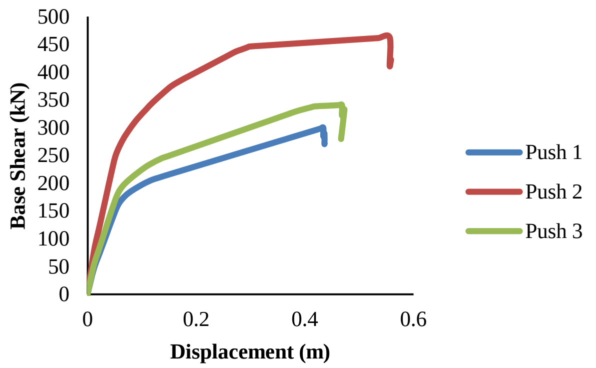


Fig. 5: Capacity curve for various lateral load case when hinges are assigned at ends

In POA-10 load case the plastic hinges are assigned at 0.25L and 0.75L from the right end of RC members. In POA-10 load case the plastic hinges are assigned at 0.40L and 0.60L from the right end of RC members. The nonlinear responses of example MRF for different PBSE cases are tabulated in Table 7-10.

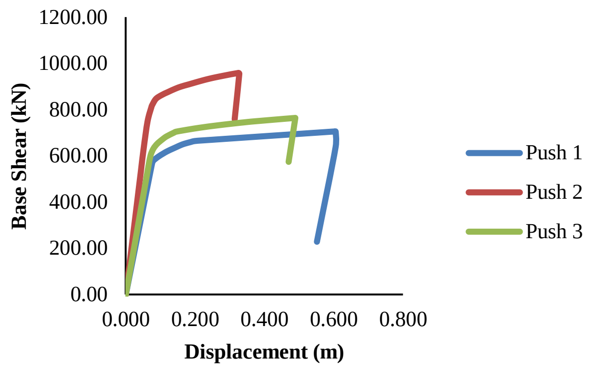


Fig. 6: Capacity curve for various lateral load case when hinges are assigned at 0.10 L from respective ends

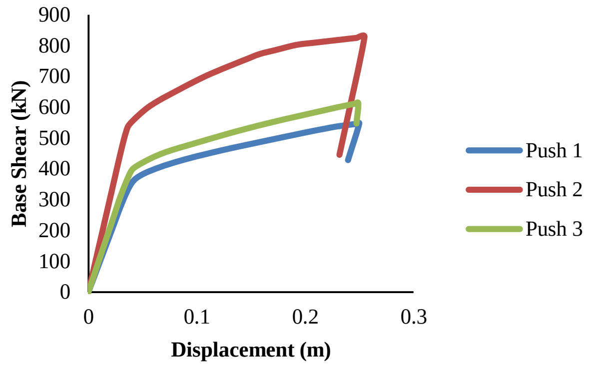


Fig. 7: Capacity curve for various lateral load case when hinges are assigned at 0.25L from respective ends

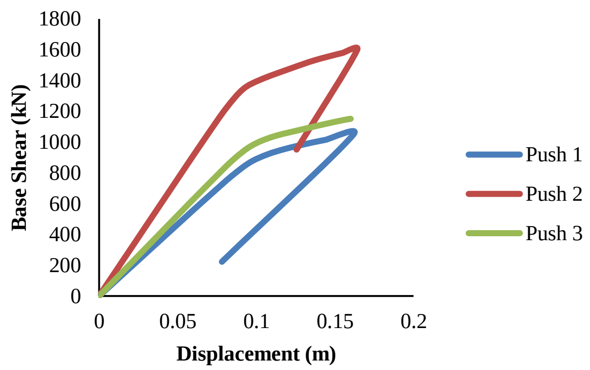


Fig. 8: Capacity curve for various lateral load case when hinges are assigned at 0.40L from respective ends

From the trends of capacity curve it is clear that the base shear capacity depends on the location of plastic hinges. A comparison of the displacement capabilities of example MRF under different load cases point out the dependency on the plastic hinge locations. With the change in the plastic hinge location the nature of failure shifts from ductile to brittle mechanism with significant increase in base shear for

DOI : 10.35291/2454-9150.2021.0429

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-07, Issue-05, AUG 2021

lower displacement yields. Plastic hinge patterns were studied at different displacement levels to understand the global and local failure mechanism of example MRF, subjected to different lateral load cases and position of plastic hinges. Figure 9-12 shows the plastic hinge mechanism of MRF at collapse for different lateral loads and plastic hinge location cases. From plastic hinge mechanism resulting from POA of example MRF, it may be concluded that location of plastic hinges leads towards generation of various collapse mechanisms in a structure.

Plastic hinge formation starts with beam ends at higher stories, then propagates to lower stories, and continues with the yielding of base columns. However, there are significant differences in hinging patterns in the ultimate state. POA-0 and POA-10 showed combined failure envelopes, that is sway and beam mechanism. POA-25 showed ductile beam mechanism, while POA-40 resulted in beam mechanism with shear failure. POA-25 and POA-40 showed the damage concentration at beams representing strong column weak beam concept, thereby providing warning before the collapse.

Table 7: Nonlinear responses of MRF for various PBSE cases and POA-0 case

PBSE Cases	POA-1-0		POA-2-0		POA-3-0	
	V_P	D_P	V_P	D_P	V_P	D_P
ATC 40-CSM	259.3	0.29	404.8	0.21	291.2	0.27
FEMA 356-DCM	289.5	0.39	433.8	0.32	325.5	0.38
FEMA 440-CSM	263.2	0.31	421.2	0.24	297.7	0.29
FEMA 440-DCM	289.5	0.39	433.8	0.32	325.5	0.38

Table 8: Nonlinear responses of MRF for various PBSE cases and POA-10 case

PBSE Cases	POA-1-10		POA-2-10		POA-3-10	
	V_P	D_P	V_P	V_P	D_P	V_P
ATC 40-CSM	635.0	0.14	866.6	0.10	696.0	0.13
FEMA 356-DCM	671.7	0.27	917.1	0.20	729.1	0.24
FEMA 440-CSM	637.4	0.14	867.1	0.11	698.1	0.13
FEMA 440-DCM	671.7	0.27	917.1	0.20	729.1	0.246

Table 9: Nonlinear responses of MRF for various PBSE cases and POA-25 case

PBSE Cases	POA-1-25		POA-2-25		POA-3-25	
	V_P	D_P	V_P	V_P	D_P	V_P
ATC 40-CSM	481.9	0.15	709.7	0.11	526.7	0.14
FEMA 356-DCM	541.0	0.23	796.2	0.18	594.6	0.22
FEMA 440-CSM	487.3	0.15	744.0	0.13	533.6	0.14
FEMA 440-DCM	541.0	0.23	807.8	0.20	594.6	0.22

Table 10: Nonlinear responses of MRF for various PBSE cases and POA-40 case

PBSE Cases	POA-1-40		POA-2-40		POA-3-40	
	V_P	D_P	V_P	V_P	D_P	V_P
ATC 40-CSM	987.4	0.13	1421.2	0.10	1070.3	0.12
FEMA 356-DCM	1046.6	0.23	1696.8	0.19	1150.	0.22
FEMA 440-CSM	1001.7	0.13	1439.5	0.11	1085.	0.13
FEMA 440-DCM	1046.6	0.23	1596.8	0.19	1150.7	0.22

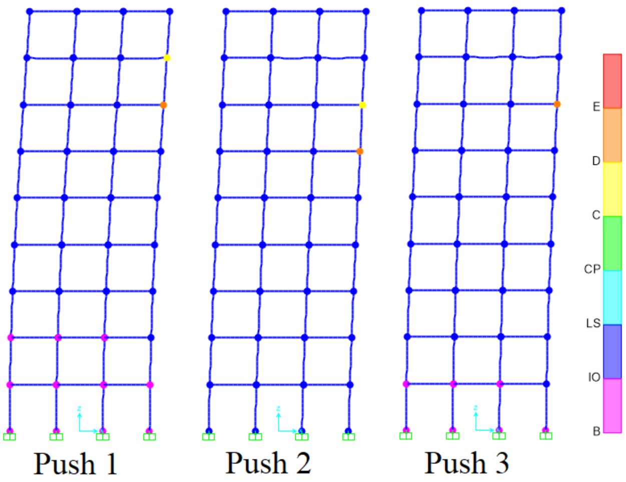


Fig. 9: Plastic hinge mechanism of MRF for various PBSE cases and POA-0 case

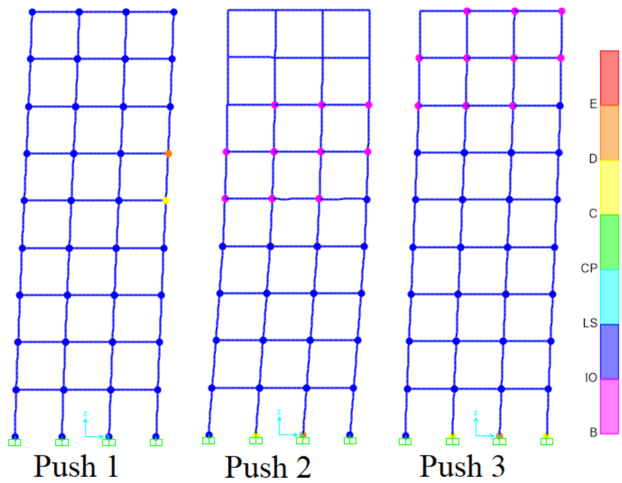


Fig. 10: Plastic hinge mechanism of MRF for various PBSE cases and POA-10 case

Plastic hinge location has considerable effects on the base shear and displacement capacities of example frame. Amongst the considered POA cases and location of plastic hinge, POA 25 has resulted into a promising behavior of example MRF under seismic loads.

 DOI : 10.35291/2454-9150.2021.0429

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-07, Issue-05, AUG 2021

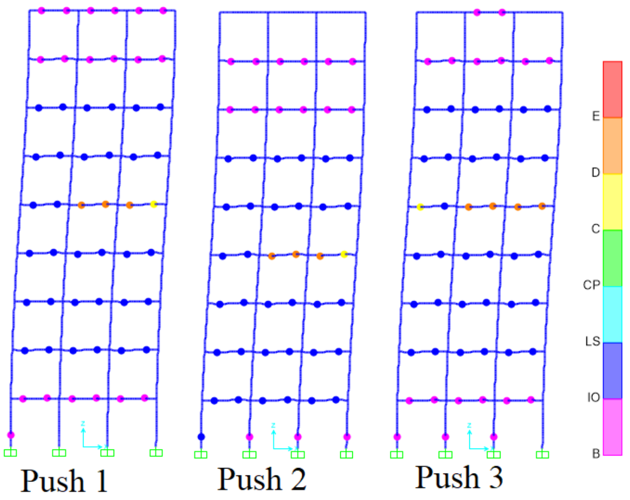


Table 11: Nonlinear responses of MRF for various PBSE cases and POA-25 case

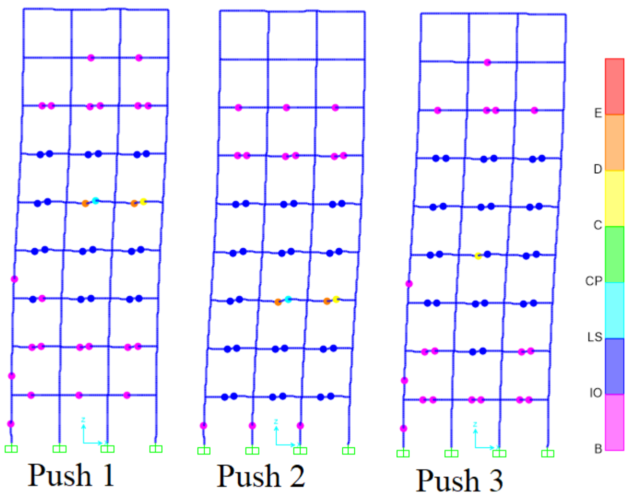


Table 12: Nonlinear responses of MRF for various PBSE cases and POA-40 case

Conclusion

The prime intention of the performance evaluation of RC structures is to assess the capability of the structure under design seismic loads. The present seismic design codes provide design methodology, which ensures that the RC structures to sustain minor damages during the minor and moderate earthquakes. When these structures were subjected to seismic loads got heavily damaged or collapsed. PBSD has emerged as the best alternative towards these design codes. PBSD has provided various nonlinear analysis procedures and associated performance levels. These performance levels state the damages sustained by structural and non-structural components. To evaluate the nonlinear responses of the RC components, it required to model plastic hinges.

Various modeling parameters have been described in PBSD first generation, second generation and next generation documents.The moment-rotation relationship and plastic length associate with plastic hinges are defined in PBSD documents and adopted by the finite element based software. In past many research work has been done to find the efficacy of hinge properties defined in relevant software's. Very few research attempts have been made in regards to the positioning of these plastic hinges along the length of the RC members.

In this study, we have attempted to optimize the location of plastic hinges along the length of RC members for example MRF. For this, various possible location of plastic hinges were considered Viz; (a) at the ends, (b) at 0.1L from both ends (c) at 0.25L from both ends and (d) at 0.40L from both ends. The capacity of example MRF was evaluated using the capacity spectrum method and displacement coefficient method defined in the PBSD documents. From the trends of capacity curve obtained from POA following conclusions are drawn:

1. Significant differences have been observed in the base shear value at performance point for different positions of plastic hinges.
2. Comparison of the displacement capabilities of example MRF under different POA cases points out the dependency on the plastic hinge locations.
3. With the change in the plastic hinge location the nature of failure of example MRF shifts from ductile to brittle mechanism.
4. POA of example MRF, it may be concluded that location of plastic hinges leads towards generation of various collapse mechanisms in a structure. POA-0 and POA-10 showed combined failure envelopes, that is sway and beam mechanism. POA-25 showed ductile beam mechanism, while POA-40 resulted in beam mechanism with shear failure. POA-25 and POA-40 showed the damage concentration at beams.
5. Amongst the considered POA cases and location of plastic hinge, POA 25 has resulted into a promising behavior of example MRF under seismic loads. Wherein strong column weak beam failure envelope is achieved.

The present study is preliminary attempt to identify the possible location of plastic hinges to obtain desire collapse mechanism. For the same example frame different results may be obtained by other designers, which depend on modeling parameters of plastic hinge. For a complete understanding of the effects a set of example frames is need to be analyzed under PBSD frame work.

Acknowledgment

The authors of this paper acknowledge the research contributions of all the citations under reference and the support of faculty members and by the Chairman, MGM College of engineering, Nanded, India.

References

[1] ATC 40, "Seismic evaluation and retrofit of the existing concrete building", *Applied Technical Council*, Redwood City (CA), 1996.

[2] FEMA 273, "NEHRP guidelines for the seismic rehabilitation of buildings", *Federal Emergency Management Agency*, Washington (DC), 1996.

[3] FEMA 356, "Pre-standard and commentary for seismic rehabilitation of buildings", *Federal Emergency Management Agency*, Washington (DC), 2000.

[4] FEMA 440, "Improvement in nonlinear static seismic analysis procedures", *Federal Emergency Management Agency*, Washington (DC). 2005.

 DOI : 10.35291/2454-9150.2021.0429

[5] ASCE 41, "Seismic rehabilitation of existing buildings", *American society of civil engineers*, Reston, Virginia, 2006.

[6] Boroujeni, A.R.K., "Evaluation of various methods of FEMA 356 compare to FEMA 440*", J. Civil Eng. Constr. Technol.* 4 (2), pp 51–55, 2013. https://doi.org/10.5897/JCECT 12.082.

[7] Zameeruddin, M. and Sangle, K.K., "Review on recent developments in performance-based seismic design of reinforced concrete structures", *Structures* 6, 119–133, 2016. https://doi.org/10.1016/j.istruct.2016.03.001.

[8] Akanshu Sharma, K.N., Vaity, G.R., Reddy, K.K., and Vaze Ghosh, A.K., "Seismic Requalification of RLG Building", *Reactor Atomic Research Center*, Mumbai, India, 2005.

[9] Mehmet Inel and Hayri Baytan Ozmen, "Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings", *Engineering Structures* 28, pp 1494–1502, 2006.

[10] Apurba Mondal, Siddharta Ghosh and G. R. Reddy, "Performance-based evaluation response reduction factor for ductile RC frames", *Engineering Structures*, 56. Pp 1808-1819, 2013.

[11] Zameeruddin, M and Sangle, K. K,"Damage assessment of reinforced concrete moment resisting frames using performance-based seismic evaluation procedure",*Journal of King Saud University-Engineering Sciences*, 33, pp 227-239.

[12] Douglas K. T, Davidson B. J. and Fenwick R. C., "Modeling of reinforced concrete plastic hinges", *11th World Conference on Earthquake Engineering*, Paper No. 468 (1996).

[13] Ali Kheyroddin and Hosein Naderpour, "Plastic hinge rotation capacity of reinforced concrete beams," *International Journal of Civil Engineering*, 5(1), pp 30–47, 2007.

[14] Munawar A. H and Robert G. D, " Modelling of plastic hinges in externally confined reinforced concrete columns", *13h World Conference on Earthquake Engineering*, Paper No. 1458 (2004).

[15] Mohd. Zameeruddin and Keshav K. Sangle, "Seismic performance evaluation of reinforced concrete frames subjected to seismic loads". *Journal of the institution of engineers (India)-series A*, 98 (1-2) pp 177-183, 2017.

[16] Mohd. Zameeruddin and Keshav K. Sangle, "Seismic damage assessment of reinforced concrete structure using non-linear static analyses". *KSCE Journal of civil engineering*, 21(4), pp 1319 – 1330, 2016.

[17] Subramananian N, "Plastic hinge length of reinforced concrete columns", Disc. 105-S28/from the May-June 2008, ACI Structural Journal, p 290.

[18] Wilson, E.L., Habibullah, A., SAP 2000/NL-push version 20 software, computer and structures, Inc, Berkeley, CA, USA. 2000.

[19] IS 1893, *Indian standard for earthquake resistant design of structures (part 1): general provisions and buildings.* Bureau of Indian standards, New Delhi, 2016.

[20] IS 875, Code of practice for design loads (other than earthquake) for buildings and structures: part 1 dead loads. Bureau of Indian standards, New Delhi, 1987.

[21] IS 875, Code of practice for design loads (other than earthquake) for buildings and structures: part 2 imposed loads. Bureau of Indian standards, New Delhi, 1987.

[22] IS 456, Indian standard plain and reinforced concrete – code of practice (fourth revision). Bureau of Indian standards, New Delhi, 2000.

[23] IS 13920, "Ductile detailing of reinforced concrete structures subjected to seismic force-code of practice", Bureau of Indian standards, New Delhi, 2016.

[24] Zameer Ahemad and Mohd Zameeruddin, " Performance evaluation of moment resisting frames with SCWB and WCSB configurations using Performance-based Seismic Procedures", *International Journal for Research in Engineering Application & Management*, 7 (03), pp 102-109, 2021.

 DOI : 10.35291/2454-9150.2021.0429