INVESTIGATION OF SEISMIC PERFORMANCE IN STEEL MOMENT RESISTING FRAME USING SHAPE MEMORY ALLOYS

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Abstract - *In this paper, performance of steel moment resisting frames (SMRFs) investigated by using shape memory alloy (SMA) is applied to 3D-steel moment resisting frames, designed according to Indian Standards. The considered SMRFs frame with or without SMA, is analysed in two phases, Static pushover analysis followed by Incremental Dynamic Analysis using SEISMOSTRUCT 2020 products. The effects of the horizontal components of five different ground motions, selected from the PEER NGA databases on the SMRFs were evaluated using incremental dynamic analysis (IDA). The proposed method accurately identified the severely damaged floors of SMRFs. SMAs can be used in steel structures to reduce the residual deformations due to their unique recentering capability, which can facilitate post-seismic retrofitting. The primary aim of this paper is to enhance the seismic performance of regular steel structures using certain amount of SMAs material in terms of maximum inter-storey drift, residual drift and damage scheme.*

Keywords – Steel moment resisting frame (SMRF), Shape memory alloy (SMA), Inter-storey drift (ID), Incremental dynamic analysis(IDA) and Maximum inter-storey drift (MID).

1. INTRODUCTION

The resulting seismic residual drifts complicate the repair of damaged structures or render them as irreparable which have forced researchers to innovate to find alternative design procedures. Although Shape memory alloys (SMAs) have widely attracted the attention of researchers in recent years because of their unique material properties, their self-centering capability as well as energy dissipation features has not been studied. Superelastic SMA has the ability to undergo large deformations and recover all the plastic deformations upon unloading. Their utilization in steel structures can significantly reduce seismic residual deformations, which can facilitate post- retrofitting. The two fundamental and characteristic properties of SMA are (a) Shape memory effect (SME)(b) Superelasticity (SE). SME is the ability of the material to recover from large mechanically-induced strains via moderate increase in its temperature. SE is the ability of the material to support relatively high inelastic strains and return to its original shape upon load removal. The study also explores the possibility of using SMA material economically at certain locations to minimize the cost and optimize the seismic performance. The primary aim of this paper is to enhance the seismic performance of regular steel structures using certain amount of superelastic SMAs material in terms of maximum inter-storey drift, residual drift and damage scheme. In this paper, steel moment resisting frames', with and without utilizing shape memory alloys, analysis is done.

2. P-DELTA EFFECT

P-delta effects are also known as second-order effects since their magnitude depends on the amount of initial displacement or deflection. The P-delta effect is a destabilizing moment equal to the force of gravity multiplied by the horizontal displacement a structure undergoes when loaded laterally.

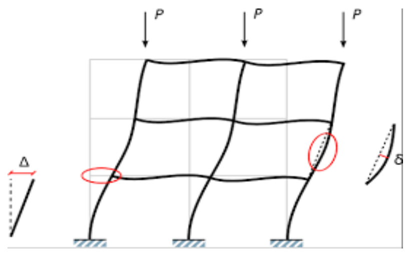


Fig 1:- P-Delta effect representation

3. METHOD OF ANALYSIS

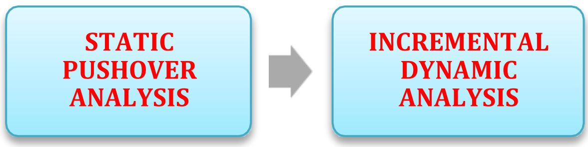


Fig 2:- Methods of analysis

Table 1:- Five selected earthquake data from PEER ground motion data base format

Earthquake	Date	Magnitude	Station	PGA(g) Horizontal
Imperial Valley	17-01-1994	6.7	Arleta-Nordhoff	0.344
Northridge	15-10-1979	6.9	El Centro Array#6	0.439
Tabas, Iran	18-10-1989	7.1	Tabas	0.451
San fernando	16-09-1978	6.9	Capitola	0.852
loma Prieta	02-02-1971	6.6	Pacoima Dam	1.23

4. ASPECTS OF MODELLING

A 3-Dimetional 8th storey steel moment resisting frame is selected as case study and designed according to Indian standard in Etab-2017 software. SEISMOSTRUCT 2020 software is based on the fibre element approach is used for the further analysis of Frame. The Menegotto-pinto steel model material behaviour with 0.005 strain hardening parameter is considered using the distributed plasticity approach. For SMRFs, Soil B-medium or stiff soils was taken as per IS 1893(part-1):2016[1] for initial design considerations and to consider the same effects of soil type further, in this assessment methodology, Site class D (stiff soil) was chosen as soil type, as per ASCE/SEI41- 17[6]. Basic configuration of SMRF (Bay length 4m, Storey height 3m, Plot Area 12m*12m), ISWB 300 section [5] with grade Fe550 and modulus of elasticity (2.1*105) are considered [4]. Dead load and Live load values are compatible with IS 875(Part1):1987 [2] and IS 875 (Part2):1987 [3], respectively. Dead load is 9.62 KN/m2 for Stories and 5.5 KN/m2 for the roof. Live load is 3KN/m2 for Stories and 1KN/m2 for the roof. Equivalent static load procedure provided in IS 1893(part-1):2016[1] for buildings to be built in seismic zones is used during the earthquake resistant design. Model buildings are assumed to be in Seismic zone V with the soil class of B.

Fig 3 Elevation of typical 3D SMRF (Frame1)

5. SMA location

Table 2:- Properties of NiTi (SMA) alloy

Properties of NiTi Alloy (SMA)	Value
Composition *(%)*	55-45
Superelastic plateau stain length *(€s)*	6
Modulus of Elasticity *(E)*	62.5 GPa
Austenite to martensite starting stress *(fy)*	401 MPa
Austensite to martensite finishing stress *(fp1)*	510 MPa
Martensite to austensite starting stress *(fT1)*	370 MPa
Martensite to austensite finishing stress *(fT2)*	130 MPa

Table 3:- SMA location

Frame	SMA Location
Frame 2	All Storey
Frame 3	1st Storey
Frame 4	1-4th storey
Frame 5	1-7th storey
Frame 6	1-3-7th storey

To enhance the seismic performance of SMRF by utilizing SMA, different frames with different SMA locations are considered. Properties of (NiTi) SMA alloy and considered different SMA locations.

(according to IS code 1893:2016) is showed in following table.

6. RESULTS AND DISCUSSION

2) Calculation for drift checks of all stories of frame1

6.1Results obtained by Static Pushover Analysis 1

1) Minimum and Maximum fundamental time periods of different frames

Table 4:- Time period obtained by pushover analysis

Fundamental horizontal time period	Minimum	Maximum
Frame 1	0.125 sec	0.704 sec
Frame 2	0.160 sec	0.778 sec
Frame 3	0.158 sec	0.727 sec
Frame 4	0.134 sec	0.737 sec
Frame 5	0.136 sec	0.725 sec
Frame 6	0.136 sec	0.741 sec

Table 5:- Drift results of all stories of Frame1

Storey	Ht	Displacement	Drift	Allowable	Check
8th	24	0.279	0.006	0.012	Safe
7th	21	0.273	0.014	0.012	Unsafe
6th	18	0.259	0.021	0.012	Unsafe
5th	15	0.238	0.027	0.012	Unsafe
4th	12	0.211	0.032	0.012	Unsafe
3rd	9	0.179	0.04	0.012	Unsafe
2nd	6	0.139	0.059	0.012	Unsafe
1st	3	0.08	0.109	0.012	Unsafe

6.2 Results obtained by Incremental Dynamic Analysis2

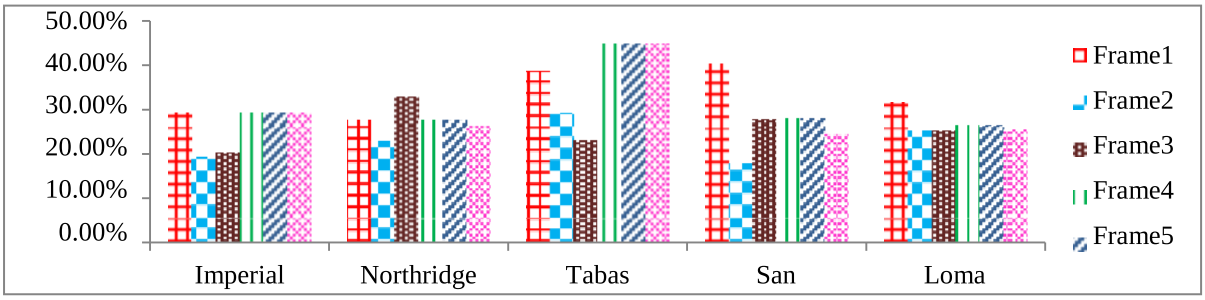
(a) Calculation for minimum and maximum drift for frame1, frame2, frame3, frame4, frame5 and frame 6 are given in following table.

Table 6:- Maximum and Minimum Drift values for all frames

Frames	Imperial Valley		Northridge		Tabas, Iran		San Fernando		Loma Prieta	
	MID	*MRID*	*MID*	*MRID*	*MID*	*MRID*	*MID*	*MRID*	*MID*	*MRID*
Frame1	29.30%	-	27.60%	-	38.70%	-	40.40%	-	31.70%	-
Frame2	19.30%	10.00%	22.90%	4.70%	29.10%	9.60%	17.90%	22.50%	25.20%	6.50%
Frame3	20.30%	9.00%	32.90%	-5.30%	23.00%	15.70%	27.80%	12.60%	25.10%	6.60%
Frame4	29.30%	0.00%	27.50%	0.10%	44.90%	-6.20%	28.00%	12.40%	26.40%	5.30%
Frame5	29.30%	0.00%	27.50%	0.10%	44.90%	-6.20%	28.00%	12.40%	26.40%	5.30%
Frame6	29.30%	0.00%	26.30%	1.30%	44.90%	-6.20%	24.50%	15.90%	25.40%	6.30%

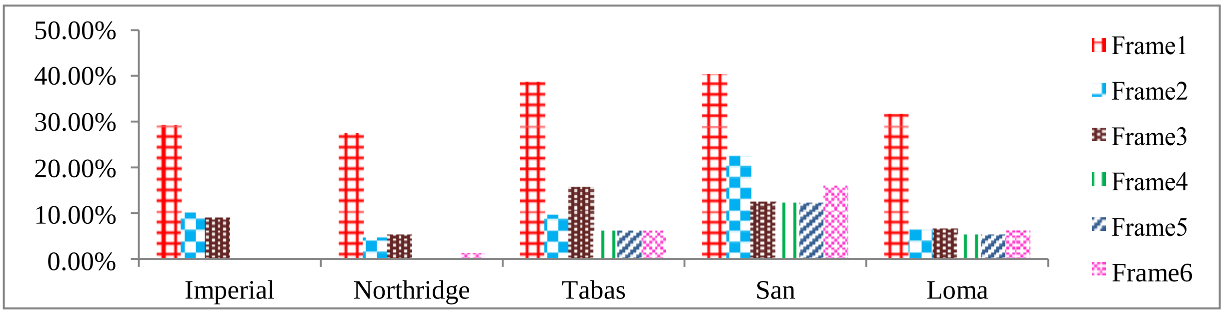
(b) (1) Comparison of Maximum Interstorey Drifts (MID) of different frames

Fig 4:- Comparison of maximum inter-storey drifts of different frames



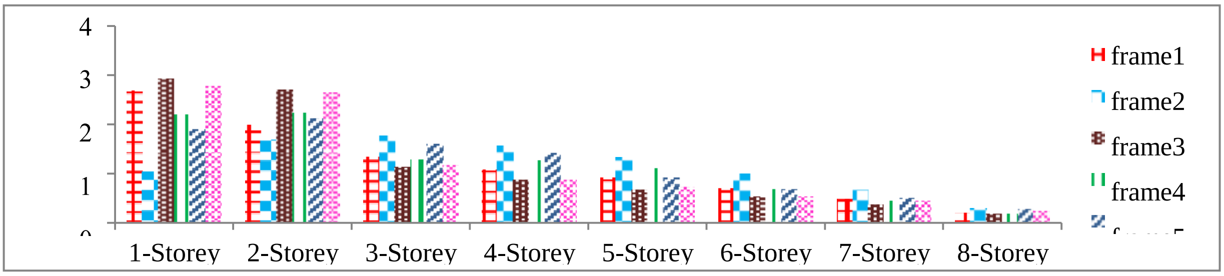
(2) Comparison of Maximum Reduced Interstorey Drifts (MRID) of different frames

Fig 5:- Comparison of maximum reduced inter-storey drifts of different frames



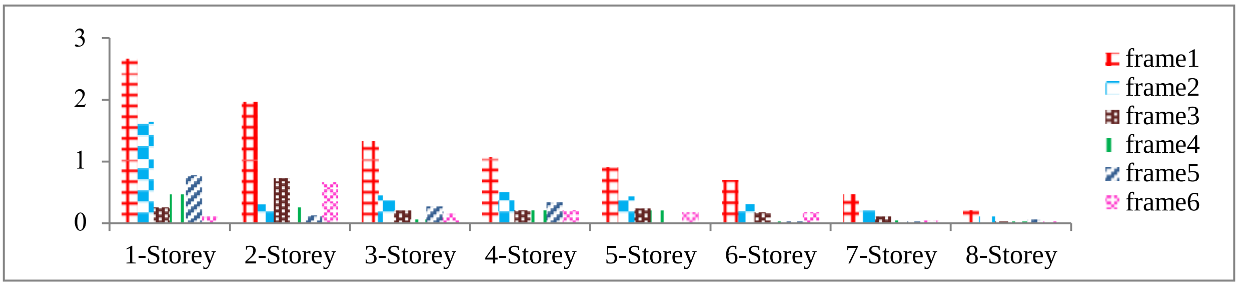
(c)(1) Comparison of Inter-storey Drifts (ID) of different frames

Fig 6:- Comparison of inter-storey drifts of different frames



(2) Comparison of Reduced Inter-storey Drifts (RID) of different storey

Fig 7:- Comparison of reduced inter-storey drifts of different frames



7. CONCLUSIONS

Conclusions drawn from the result of static pushover analysis and incremental dynamic analyses are summarized below:-

1) The locations of the SMA greatly affect the Base Shear, Inter-storey drift, Maximum inter-storey drift, Inter-storey reduced drift and maximum reduced inter- storey drift of a steel moment resisting frame.

2) Pushover curve obtained from frame2, frame3, frame4, frame5 and frame6 has reduced base shear values as compared to the frame1. i.e., Using SMA, maximum expected lateral force on the base of the structure due to seismic activity is reduced. For frame2, base shear value reduced by 500KN and for Frame 3, Frame 4, Frame 5 and Frame 6 base shear value reduced by 300 KN.

3) Maximum inter-storey drift (MID) and maximum reduced inter-storey drift (MRID) of Frame2, Frame3, Frame 4, Frame5, and Frame6 compared with the frame 1(without locating SMA) which represented by the graph as shown above.

4) Inter-storey drift (ID) and reduced inter-storey drift (RID) of Frame2, Frame3, Frame 4, Frame5, and Frame6 compared with the Frame1 (without locating SMA) which represented by the graph as shown above.

5) The Static pushover analysis and Incremental dynamic analysis show that the SMRFs severe damage scheme has

resulted from crushing the first floor columns. The highest damaged occurred in the beams of the 3th and 4th floor.

6) The reduction in the maximum reduced inter-storey drift (MRID) relative the steel frame is 53.30%, 49.20%, 24.00%, 24.00% and 29.70% for frame2, frame3, frame4,frame5 and frame6 respectively.

7 REFERENCES

1) IS 1893:2016, "Criteria for earthquake resistant designof structures-Part1: General provisions and buildings".

2) IS 875(Part1):1987, "Code of practice for design loadsfor building and structures", for dead load.

3) IS 875(Part2):1987, "Code of practice for design loadsfor building and structures", for live load.

4) IS 800:2007, "General construction in Steel-Code ofpractice" (Third Revision).

5) IS 808: 1989, "Dimension for hot rolled steel beam,column, channel and angle sections" (Third Revision).

6) ASCE 41-17, "Seismic evaluation and retrofit ofexisting building".