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SEISMIC ANALYSIS OF STEEL MRF WITH SHAPE MEMORY ALLOY EQUIPPED BRACES

B. ANAGHA[*] and S. ELAVENIL

School of Mechanical and Building Sciences, VIT University,
CHENNAI – 600048 (T.N.) INDIA

ABSTRACT

Shape memory alloys (SMAs) are used in structural elements to improve the seismic stability of structures. The recentering and damping capacity, together makes SMA elements, the best alloy to go hand in hand with steel structural members in reducing permanent seismic deformations in the structure. In this paper an initiative is taken to try individual and composite arrangement of steel and SMA elements in both eccentric and concentric bracing patterns in the multi storied structure. Studying and comparing the inter story drift and permanent roof displacement values, the best performance in seismic stability is graded with respect to the bracing patterns and material of the conventional steel bracing system.

Key words: Steel MRF, Shape memory alloy, Bracing systems & patterns, and Finite element analysis.

INTRODUCTION

Steel structural buildings have already established their footprint in modern day construction industry. The mode of failure in steel framed structures under seismic loads has been widely studied nowadays to define the mode of failure under different bracing systems. In the previous studies it has been already proved, bracing elements in material, arrangement and there engineering properties contributes the dynamic load stabilization capability of the structure reducing the permanent deformation to a great extent. Shape memory alloys (SMAs) are superelastic materials with structural engineering capabilities in re-centering, high damping capacity, durability and fatigue resistance. Armed with their specialist properties like shape memory effect (SME) and super elasticity can provide and represent the functionality and viable performance to any bracing system. In this research project, SMA wire braces are used as connecting material of steel diagonal bracing into the moment resisting frame.

[*]Author for correspondence; E-mail: anaghabgm@gmail.com, elavenil.s@vit.ac.in

The idea in using innovative materials in bracing system prominently improve the performance of steel moment frame by limiting interstory drifts and permanent deformations within the allowable limits. The recentering and damping capacity together makes SMA alloy, the best material to create structural members which are more dominant in reducing the seismic deformations of the structure. Studying and comparing the interstory drift and permanent roof displacement values, the best performance in seismic stability is graded with respect to the bracing pattern and material of the conventional bracing system. So the present study can also estimate the benefits of concentric and eccentric bracing steel frames over the steel moment resisting frames.

Shape memory alloys

Shape memory alloys are introduced as a new isolation devices which perform two emerging properties namely, shape Memory Effect (SME) and Pseudo-Elasticity (PE). The ability of SMA materials to regain their original shape through heating is termed as SME, but the ability to recover large deformation after the removal of load is redirected to PE. SMA has two crystallographic phases, high symmetric parent phase known as Austenite, while the other with lower symmetry is called as Martensite. Martensite tends to stable at higher stresses and lower temperature, whereas austenite tends to stable at higher temperature and lower stresses. Austenite phase shows the temperature is above austenite finish temperature and the large strain induced by stress can be completely recovered by removal of stress. But martensitic phase shows the temperature is below martensite finish temperature and large residual strain will remain on the specimen after unloading which is also recoverable by means of heating above austenite finish temperature.

EXPERIMENTAL

Structural modelling

To study and analyze the braced frame structure in steel on performance-based framework provides the key to understand in detail the benefits of using SMA braces to improve their performance. The following section sketches an analytical study plotted to highlight the benefits of SMAs in concentrically and eccentrically braced steel frames.

To understand the structural behavior of steel bracing connected through SMA alloys in different bracing patterns such as x, v, inverted v, & diagonal as concentric conditions and k, v & diagonal as eccentric conditions on four, eight, twelve & sixteen stories. Each structure was then trialed with steel bracing individually, SMA mounted steel bracing in connections and then with composite arrangement of steel bracing and SMA mounted bracing system in alternative segments in all the seven bracing patterns to provide the load resistance capability. So all together eighty four structures has been analyzed by time history method of analysis employing ANSYS finite element analysis platform. The frame considered has beams of span 6 m and column of 3.4 m. The base end of the vertical members are assigned fixity. All other structural joints are assigned as pinned condition. The columns and beams are continuous for all buildings. Wide flange sections are used for beam and columns where as standard hollow tube sections are used for all conventional braces. In this study, in order to have a comparative study more comprehensively, the responses of three groups braced frame were compared. The braced frames with SMA bracing system also have the same beam and column design as the conventional steel braced systems. The steel braces are replaced as SMA bar segments in order to reduce the length of SMA required. The SMA bar consists of a single diameter of 20 mm.

Modelling for non-linear analysis

In order to determine the dynamic performance of the braced frames, non-linear time history analysis were carried out using the Ansys finite element analysis package. As suggested by the symmetry of the structure the frame has been modelled by cloning a single unit frame created with the required dimensions. All the beam column joints in the frame were considered as pin-ended. Therefore, beams will behave elastically under gravity loads and are not parts of the lateral resisting system. In this way, the earthquake lateral forces were carried only by the vertical braces. As noted before, braces were modeled as moment-released elements at both ends are supposed to behave as axial members. It was also assumed that the braces are able to undergo compressive loads without buckling. The following section is dedicated to the modelling of SMA braces and its assumptions.

Modelling and design of SMA braces

In this study, for representing the superelastic behavior of SMA braces a constitutive model proposed by Fugazza is chosen. The following parameters are used to design the proposed model for superelastic SMA, i.e. austenite to martensite starting stress (σ_s^{AS}), the austenite to martensite finishing stress (σ_f^{AS}), the martensite to austenite starting stress (σ_s^{SA}), the martensite to austenite finishing stress (σ_f^{SA}), modulus of elasticity for austenite and martensite phases (E^{SMA}) and superelastic plateau strain length (ε_L). The model is best in behaviour during seismic excitations. In this study superelastic Nitinol materials were selected as bracing elements. The designed values for the properties Shape memory alloy material like Ni-Ti are shown in the Table 1.

Table 1: Properties of Fugazza SMA model

Quantity	Value
E^{SMA} [kg/cm^2]	275790 MPa
σ_S^{AS} [kg/cm^2]	414 MPa
σ_f^{AS} [kg/cm^2]	550 MPa
σ_S^{SA} [kg/cm^2	390 MPa
σ_f^{SA}	200 MPa
$\square_L$	5%

Analysis

For conducting non-linear time history analyses on the frames implementing SMAs, three major ground motion (GM) records are used here, the details of these ground motion records are shown in Table 2. A detailed analysis view of steel moment resisting frame with not only various bracing configurations but also different patterns are discussed.

Table 2: Ground motion data for three major earthquakes

Earthquake	Year	PGA (g)	Duration (s)
EI Centro	1940	0.348	53.74
Kobe	1995	0.599	48
Tabas	1978	0.934	35

Case study: 12 Story steel MRF

To understand the behavior of steel bracing connected through SMA alloys, a detailed comparative study of the twelve- story braced steel MRF for EI Centro standard ground motions are discussed in this section. Deformations occur in the conventional steel braced frame 5.0166 cm, while the SMA equipped steel braces and Composite arrangement of both steel & SMA equipped steel braces were 0.22552cm and 0.36298 cm, respectively. From the Fig. 1 clearly observe the variation reached in structural response of steel MRF under different configurations and loadings. The frame with conventional steel bracing shows a great deviation from the other two, i.e. the deformation value of conventional X braced steel frames is far greater than that of SMA equipped steel braces as well as composite arrangement of steel braced & SMA equipped steel braced frames. The plot apparently proves the recentering capability of SMA elements guaranteed by the superelastic effect.

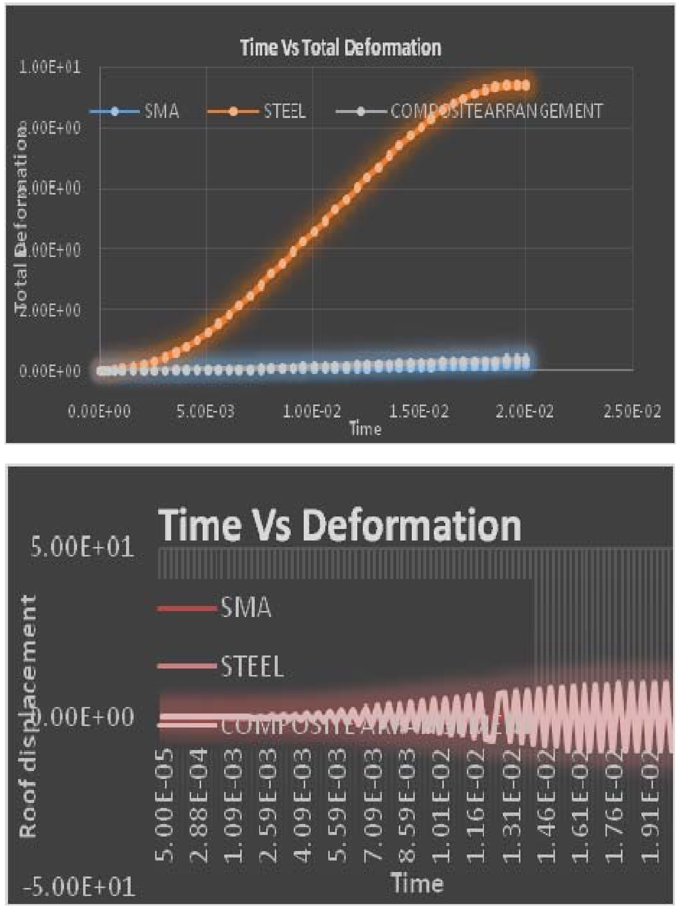
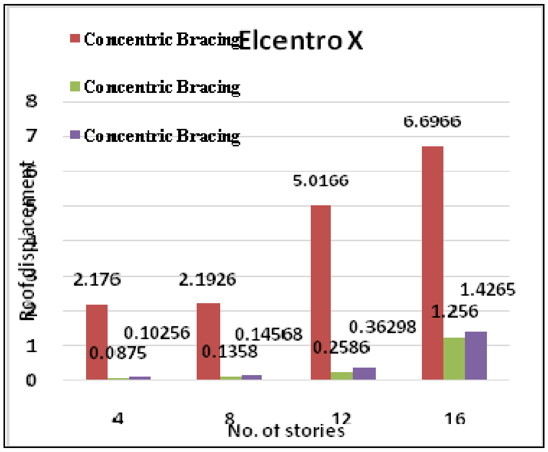


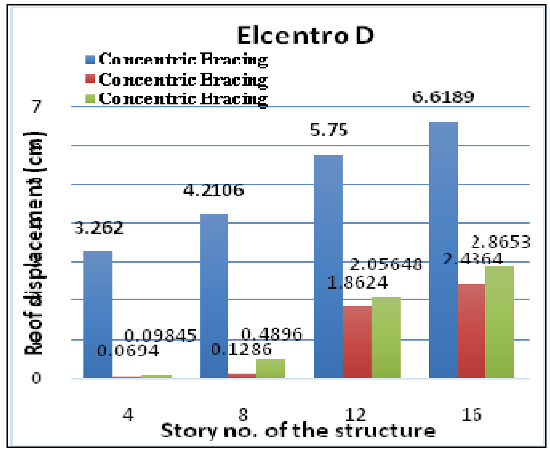
Fig. 1: Roof displacement of conventional steel braced, SMA braced and the frames with composite arrangement (12 story X braced frame) subjected to EI Centro ground motion

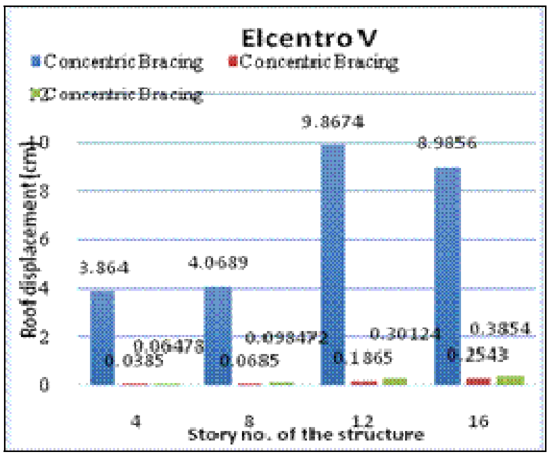
And also can see that, the deformation curve for SMA equipped steel braced frames and composite arrangement of conventional steel braced & SMA equipped steel braced frames lies over the other. It indicates the interstory drift for both configurations have almost similar values. By comparing the values of residual roof displacement, the use of SMA braces is more effective than the conventional steel braced frames. i.e. these results reveal the excellent performance of SMA braces in residual displacement on the top floor.

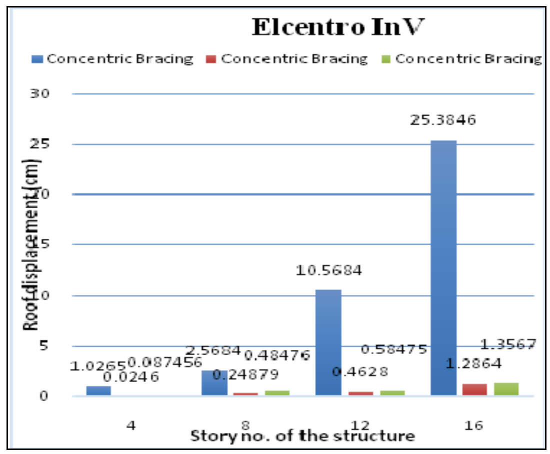
RESULTS AND DISCUSSION

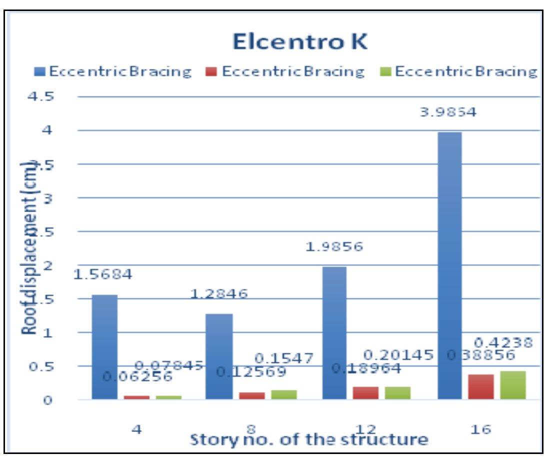
The comparison of steel structures with different bracing systems and patterns under EI Centro ground motions are done with the help of bar charts.

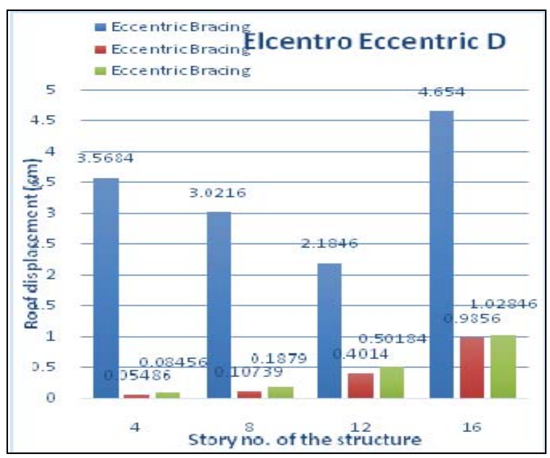

Elcentro X
Concentric Bracing
Concentric Bracing
Concentric Bracing
Roof displacement
No. of stories
4
8
12
16
2.176
0.0875
0.10256
2.1926
0.1358
0.14568
5.0166
0.2586
0.36298
6.6966
1.256
1.4265


Elcentro D
Concentric Bracing
Concentric Bracing
Concentric Bracing
Roof displacement (cm)
Story no. of the structure
4
8
12
16
3.262
0.0694
0.09845
4.2106
0.1286
0.4896
5.75
1.8624
2.05648
6.6189
2.4364
2.8653


Elcentro V
Concentric Bracing
Concentric Bracing
Concentric Bracing
Roof displacement (cm)
Story no. of the structure
4
8
12
16
3.864
0.0385
0.06478
4.0689
0.0685
0.098472
9.8674
0.1865
0.30124
8.9856
0.2543
0.3854


Elcentro InV
Concentric Bracing
Concentric Bracing
Concentric Bracing
Roof displacement (cm)
Story no. of the structure
4
8
12
16
1.0265
0.0246
0.087456
2.5684
0.24879
0.48476
10.5684
0.4628
0.58475
25.3846
1.2864
1.3567


Elcentro K
Eccentric Bracing
Eccentric Bracing
Eccentric Bracing
Roof displacement (cm)
Story no. of the structure
4
8
12
16
1.5684
0.06256
0.07845
1.2846
0.12569
0.1547
1.9856
0.18964
0.20145
3.9854
0.38856
0.4238


Elcentro Eccentric D
Eccentric Bracing
Eccentric Bracing
Eccentric Bracing
Roof displacement (cm)
Story no. of the structure
4
8
12
16
3.5684
0.05486
0.08456
3.0216
0.10739
0.1879
2.1846
0.4014
0.50184
4.654
0.9856
1.02846

Cont…

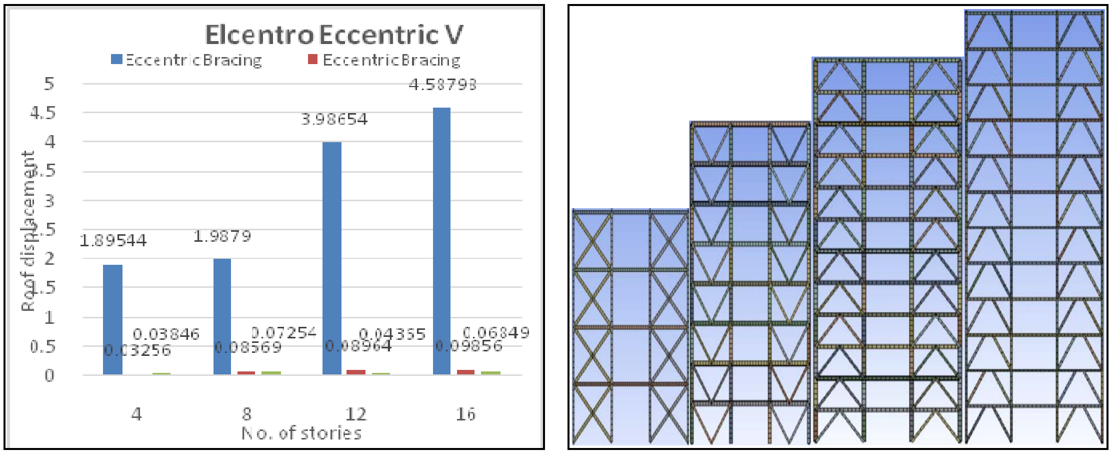


Fig. 2: Comparison in roof displacement of conventional steel braced, SMA braced and the frames with composite arrangement subjected to EI Centro ground motion & Elevation of structures with different bracing patterns

CONCLUSION

The selected frame models were analyzed using non-linear time history analysis. There are three categories with different bracing configurations and patterns, steel moment resisting frame braced with conventional steel braces, SMA equipped steel braces and composite arrangement of both conventional steel braces & SMA equipped steel braces. All the frames are braced in various patterns such as X, V, inverted V, diagonal as concentric pattern and K, V, diagonal as eccentric pattern. Through non-linear dynamic time history analyses, the effect of the unique flag shape and recentering behavior of the SMA braces on the performance of the concentrically braced frames as well as the eccentrically braced frames was evaluated and compared to the performance of the conventional steel bracing system with respect to interstory drift levels and permanent roof displacement.

- Composite arrangement of steel and SMA implemented steel bracing is found to have closer engineering values with that of SMA implemented steel bracing system.
- The success in composite arrangement is feathered with the cost effectiveness and increase in the overall stiffness of the framed structure with SMA implemented bracings.
- In eccentric bracing system the V shaped, followed by k shaped, and D shaped proved to be in decreasing order in inducing seismic stability to the structure.

- In concentric bracing system the X shaped followed by V type, inverted V type and D type proved to be in decreasing order inducing the seismic stability.

The end result of the study underlines the need for compositing conventional building material arrangements with innovative materials like shape memory alloy. Further work has to be conducted for real-time validation of the analytical results obtained with various bracing conditions to bring more efficient earthquake resistant structures in future. It is also recommended that the material study on alloys with pseudo- elastic property, comparable to elastic stiffness of the parent material should also be studied upon.

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