Nat. Volatiles & Essent. Oils, 2021; 8(5): 12353-12364

Performance Evaluation of Shape Memory Alloys

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Abstract

Multi storey RC buildings may undergo catastrophic damage when they are subjected to severe earthquakes. Several studies have been carried out by various researchers in the field of construction of earthquake resisting structures. However super elastic shape memory alloys play a vital role when they are used in civil engineering domain. Present study is carried out on implementation of Iron based and Nickel titanium shape memory alloys in RC structures as rebar. Twenty storey building is modelled with and without shape memory alloys with different locations of shear walls and they were subjected to seismic analysis (Response spectrum and Time history) for both fixed base and flexible base. Comparative study is carried out for all the models with Iron based SMA, Ni-Ti SMA and Conventional Steel. Results obtained from the analysis shows that the deformation is lesser for Iron based SMA followed by Ni-Ti SMA as compared to Conventional Steel. Hence use of SMA as a smart material in RC buildings results in greater resistance against the earthquake effects.

Keywords: shape memory alloy, super elasticity, Iron based shape memory alloys, Nickel titanium shape memory alloy.

1. INTRODUCTION

Buildings, which are often built of reinforced concrete (RC), steel, or timber, are one of the most prevalent and essential civil engineering structures. Every year, structures are subjected to a variety of intense loads, including earthquakes, blast loads, unintentional fires, and unintentional car accidental loads. As a result, when reinforced concrete (RC) constructions are put under stress, severe aversion. In the 1930s, the initial steps toward the discovery of the shape memory effect were recorded. Various types of shape memory alloys were discovered based on type material used, properties etc. In the present study we considered two different types of shape memory alloys such as Nickel based and Iron based shape memory alloys in order to study the effects when they are used in concrete structures as rebars [1]. Shape memory alloys have distinct properties such as shape memory effect, super elastic effect [2] and negligible residual deformations etc. hence it is considered as smart material.

1.1 Shape Memory Alloys (SMA).

Shape memory alloys (SMAs) are unique materials that have the ability to undergo large deformation and return to a predetermined shape upon unloading or by heating. SMAs are gradually gaining appreciation and increasing reported applications in various engineering fields [3].

The most prevalent shape-memory alloys are

- Iron based shape memory.
- Nickel-titanium (NiTi).

SMAs can also be created by alloying zinc, copper, gold and iron. Although iron-based and copper-based SMAs, such as Fe-Mn-Si, Cu-Zn-Al and Cu-Al-Ni, are commercially available and cheaper than Ni-Ti.

Super-elasticity of SMA is a distinct property that makes it attractive for seismic reinforcement. A super-elastic (SE) SMA can restore its initial shape instantaneously, even from its inelastic range, upon unloading. Among various compositions, Ni–Ti has been found to be the most appropriate SMA for structural applications because of its large recoverable strain, super-elasticity and exceptionally good resistance to corrosion [8].

The shape memory effect (SME) in an Fe–Mn–Si alloy was discovered [4], and since then, new iron-based SMAs with improved SME properties have been developed. It is assumed that this progress will contribute to lowering the price of these materials and to making them much more competitive for civil engineering applications.

1.2 Characteristics of Shape Memory Alloys

1.2.1 Shape memory effect

The shape memory effect is defined as the ability of a material to change shape at low temperatures by loading it and then regaining that shape by heating it. The shape memory effect occurs in alloys when the crystalline structure changes with temperature and stress. At low temperatures, twinned martensite becomes deformed martensite. When heated, deformed martensite becomes austenite (shape recovery), and when cooled, it returns to twinned martensite.

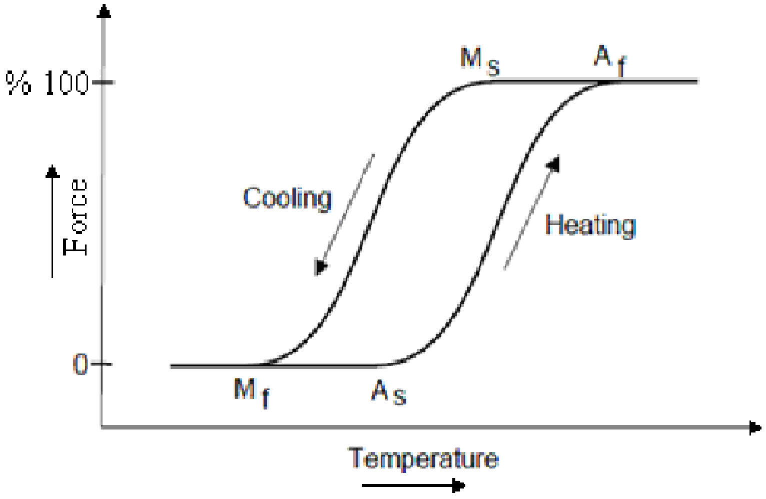
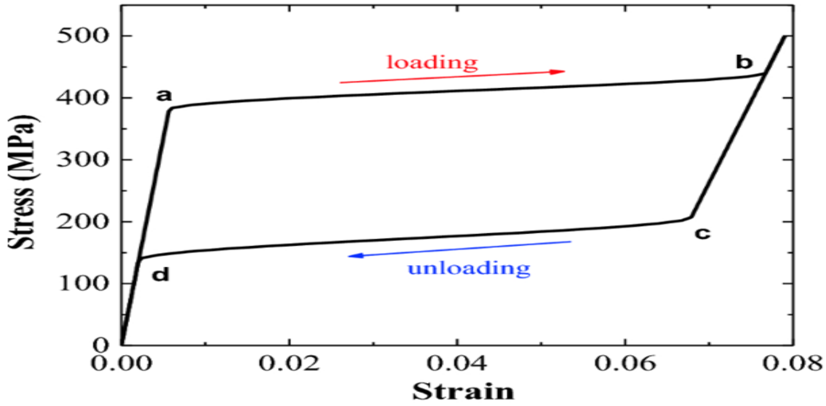


Fig 1: Force Vs Temperature

Super-elasticity effect

The deformation principle of the SMA on implementing high pressure and retaining form after taking off loading is called super-elasticity. Super-elasticity take place within SMAs, while the SMA is fully in austenite stage.



b Super elastic effect

Fig 2: Stress Vs Strain

2. METHODOLOGY

2.1 Properties and modelling.

The structures in addition to gravity loads are also subjected to lateral loads resulting from earthquakes which produce sway. When compared with buildings which are high rise the probability of sway is very much less in low rise buildings. Due to expansion of industries, economic factors, population and their way of life in urban areas results in buildings which are high rise and are more vulnerable to lateral loads.

Twenty storey building is modelled by using ETABS with different locations of shear wall [4] is subjected to dynamic loadings (Response spectrum and Time history analysis) Dynamic analysis is carried out in accordance with IS Code 1893 (Part-1):2016 [5] for high-rise and irregular buildings. The current research focuses on the investigation of a multi-story structure in Response spectrum analysis is used in the ETABS software [6].
Assigning the Iron based shape memory alloys [7] and Ni-Ti shape memory alloy [9] as rebar for building model by changing positions of shear walls at various locations. Comparative study is carried out between structures reinforced with shape memory alloy (SMA) and conventional steel under seismic load. The structure is also modelled with Soil Structure Interaction (SSI) for both RSA and THA.

The 3 different cases were considered in modelling are as follows
Case A: Without Shear Wall
Case B: With 2 side Shear Walls
Case C: With 4 side Shear Walls

Table 1: Mechanical Properties of SMA

Parameter	**Iron Based SMA**	**Ni-Ti SMA**
Material	Fe-28Mn-6si-5crSMA	NiTinol
Assigning type	Rebar	Rebar
Weight / Unit Volume.	72.7865 kN/m^3	63.2529 kN/m^3
Mass / Unit Volume	7300 kg/m^3	6450 kg/m^3
Modulus of Elasticity (E)	123.26 – 170 GPa	80 GPa
Co-eff of Thermal Expansion (A)	0.0000165/^{0}C	0.000011/^{0}C

Table 2: **Specifications of structure**

Parameter considered	**Data considered**
Height of the building	60 m
Floor to floor height	3 m
Soil type	Type 3 (soft)
Damping	5%
Support conditions	Fixed
Importance factor(I)	1
Response Reduction Factor	3
Size of Beam	300 mm X
Size of Coloumn	500 mm
Thickness of slab	500 mm X
Thickness of shear wall	600 mm

Grade of concrete	125 mm
Grade of steel	250 mm
	M30
	Fe 500

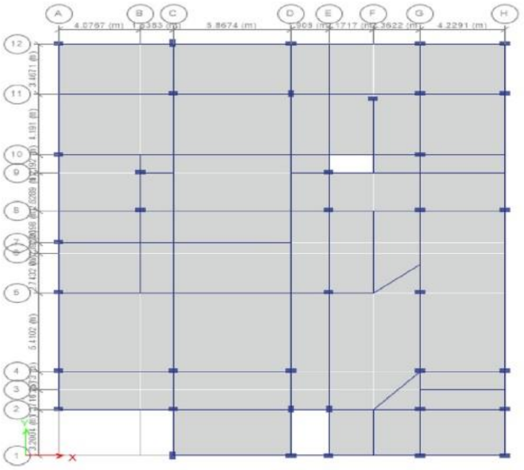


Fig 3: Plan of the building

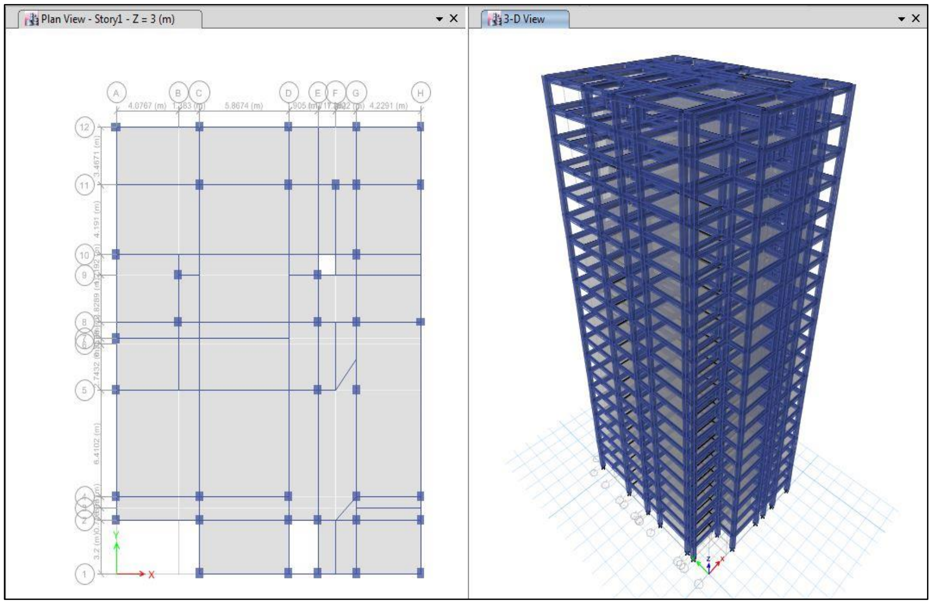


Fig 4: Case A: without Shear wall

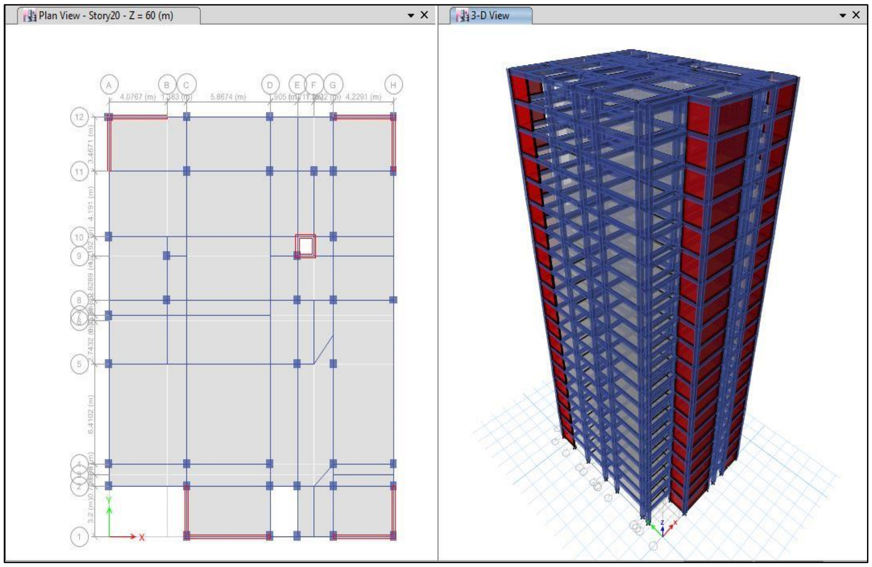


Fig 5: Case B: with 2 side shear wall

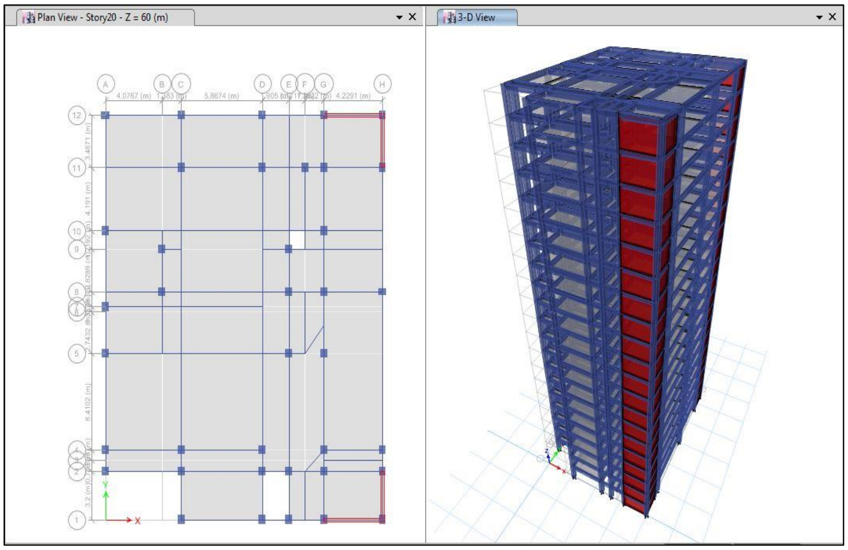


Fig 6: Case C: with 4 side shear walls

3. SOIL STRUCTURE INTERACTION

Soil Structure Interaction is performed for structures for all the cases. SSI is especially applicable to areas where there is more seismic activity. In our model the isolated footings are are not suitable because many of isolated footings were overlapped hence Rafts are realized to be a reasonable foundation system basically when the structural loads are high or the soil condition regarding its stiffness and strength is poor. The raft foundation is modelled by using ETABS and results were noted down after subjected to response spectrum analysis under given soil conditions [10].

Table 3: Soil parameters considered

Parameter	Data considered

Type of soil	Hard
N value	30
Cohesion C (kN/m^2)	22
γ_{sat}(kN/m^3)	21
Coefficient of curvature,C_c	0.093
Void ratio e_o	0.5
Shear modulus (G)	202598.22 KN/ m^2

4 Results and Discussions.

4.1 Displacements

The structure is subjected to response spectrum analysis and time history analysis for fixed base and flexible base (SSI). From the analysis the displacements were reduced to 40-50% for Iron based SMA and 30-40% for Ni-Ti SMA as compared to conventional steel because of their super elasticity property.

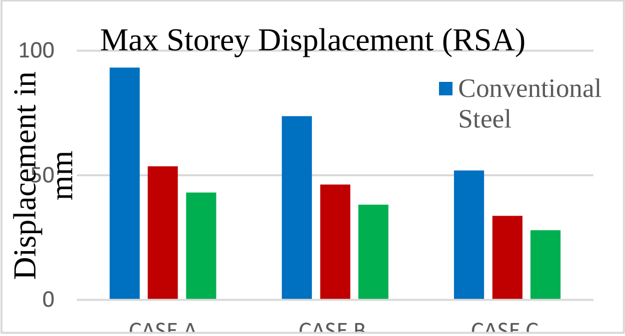


Fig 7: Max Storey Displacement (RSA) for fixed base analysis

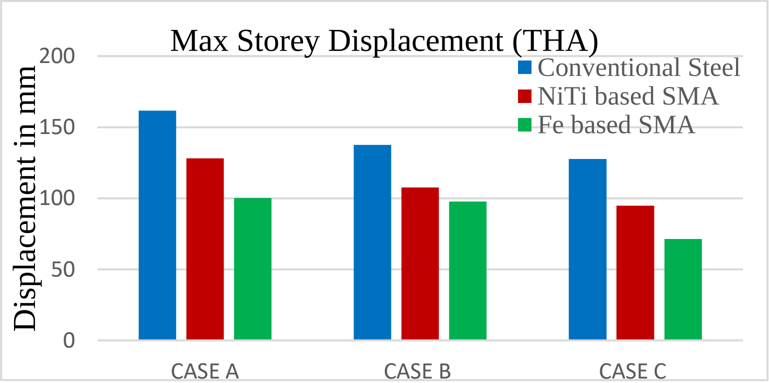


Fig 8: Max Storey Displacement (THA) for fixed base analysis

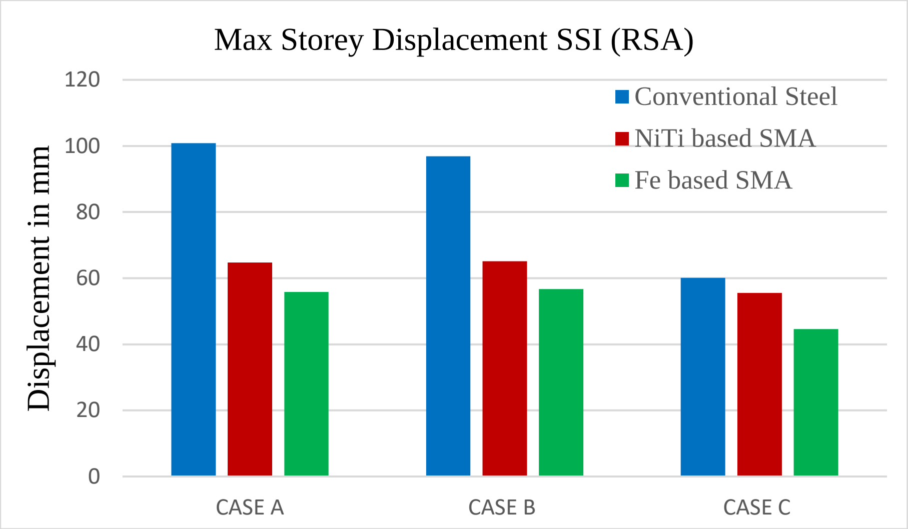


Fig 9: Max Storey Displacement (RSA) for SSI

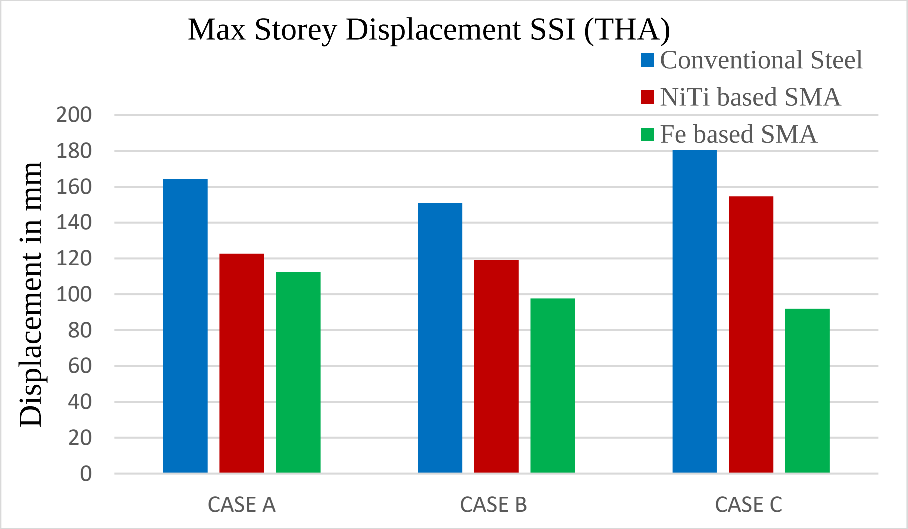


Fig 10: Max Storey Displacement (THA) for SSI

4.2 Maximum Storey Drift

From the Numerical analysis Maximum Storey drift was extracted. The obtained Storey drift shows that the Maximum storey drift was reduced from 40-50% for Iron based SMA and 30-40% for Ni-Ti SMA compared to Conventional steel.

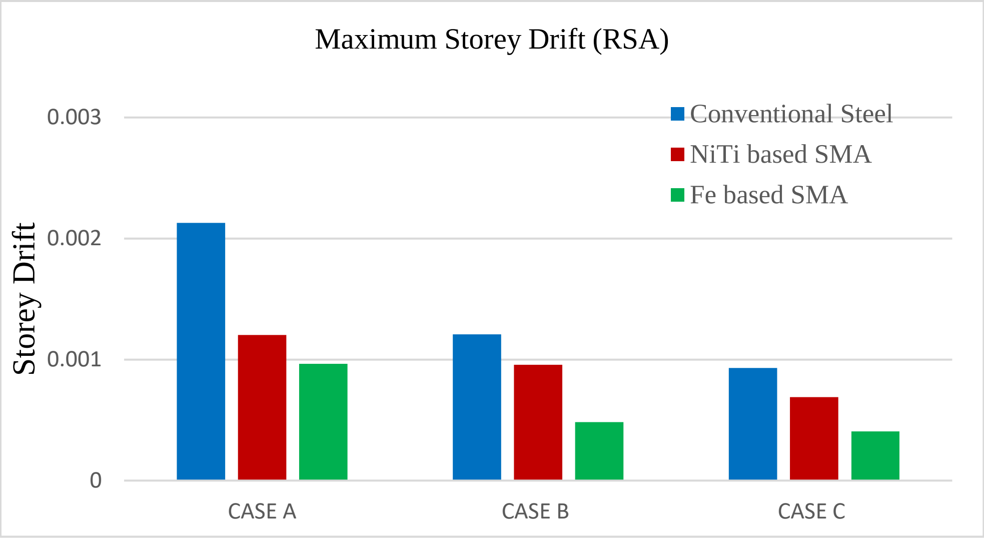


Fig 11: Max Storey Drift (RSA) for fixed base

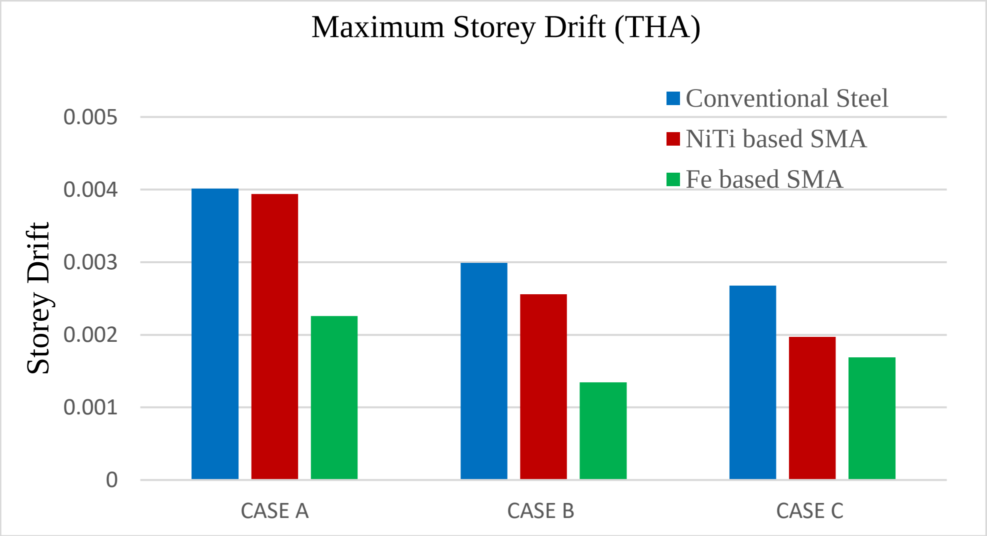


Fig 12: Max Storey Drift (THA) for fixed base

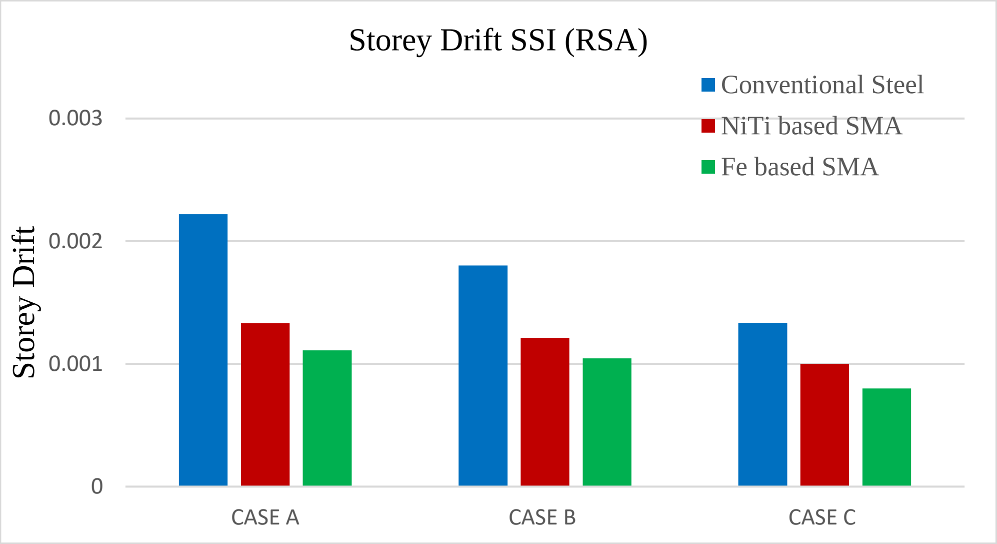


Fig 13: Max Storey Drift (RSA) for SSI.

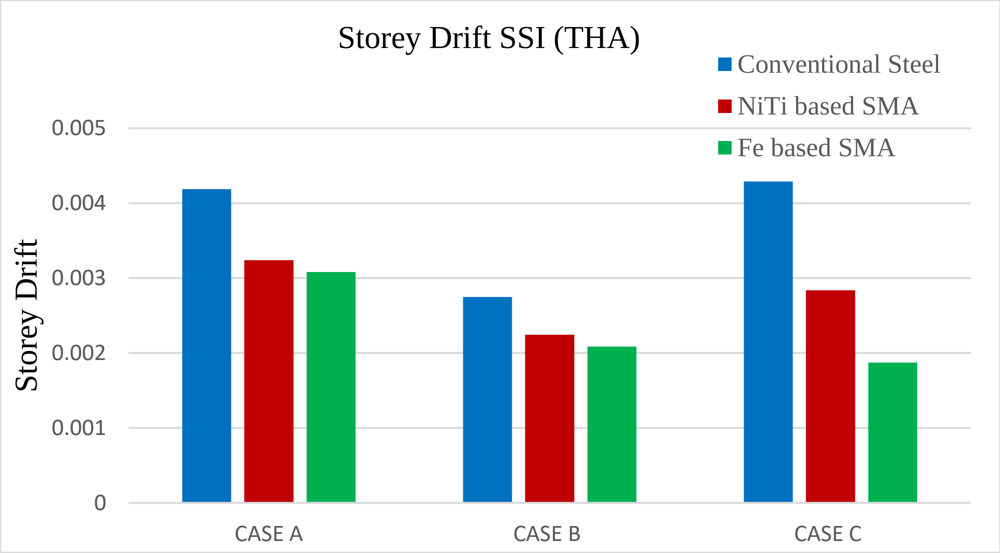


Fig 14: Max Storey Drift (THA) for SSI.

4.3 Fundamental time period

All building structures have a fundamental or natural time period, that is time taken by structure to naturally vibrate or oscillate back and forth. It is measured in seconds. Below graph shows time period for response spectrum analysis and time history analysis of fixed base and flexible base.

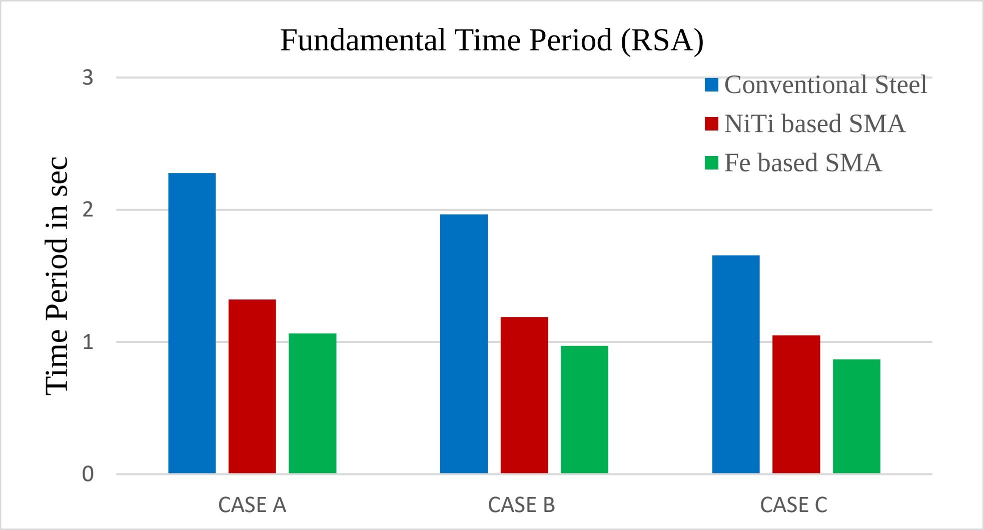
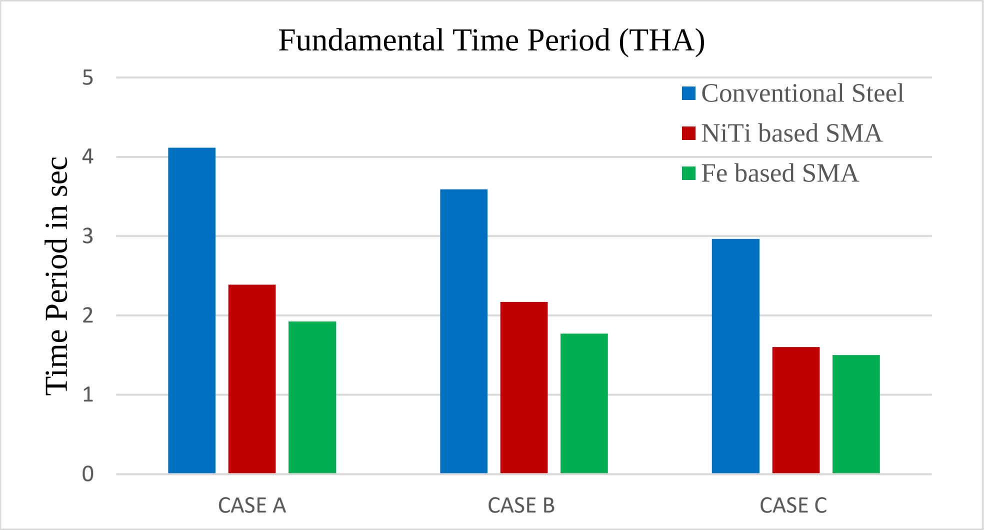


Fig 14: Fundamental time period (RSA) Fixed base.



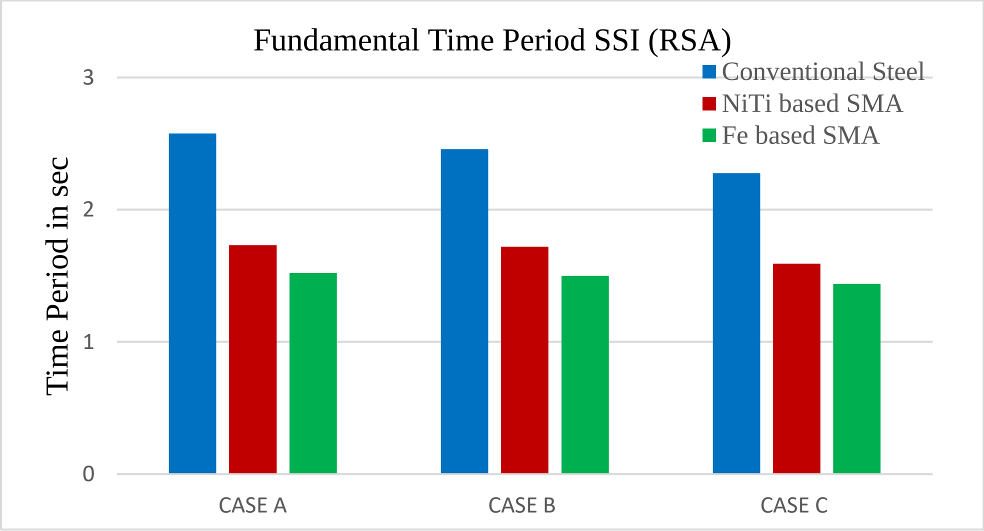


Fig 15: Fundamental time period (THA) Fixed base.

Fig 16: Fundamental time period (RSA) for SSI.

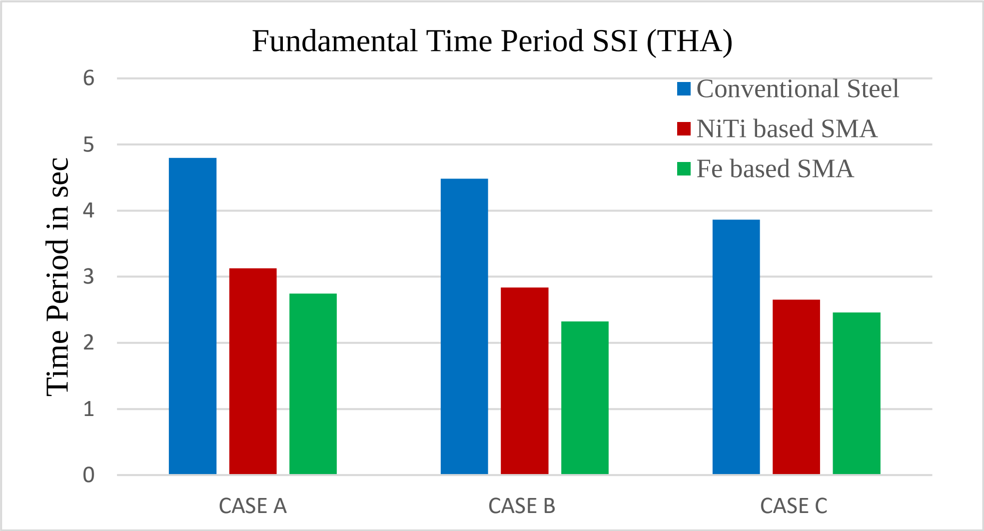


Fig 17: Fundamental time period (THA) for SSI.

5 Conclusions

Based on the present study, the following conclusions were drawn.

1. Ni-Ti SMA was very much effective than the conventional deformed steel in minimizing residual displacements and story drifts of RC structure.
2. Iron based SMA was superior than the Ni-Ti SMA in preventing lateral displacements and story drifts.
3. The fundamental time period of the structure decreases when Iron based SMA is used, followed by Ni-Ti SMA as compared to Conventional steel.
4. The natural frequency of the structure increases by the use SMA which is a very important factor in design of earthquake resistant structures.
5.

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