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Seismic Behaviour of SMA for offshore Structure: Storey Position Elasticity Approach

Sankalp Shevale[1], S K Hirde[2]

1. *PG student, Structural Engineering, Government College of Engineering, Amravati Maharashtra, India*
2. *Professor & Head, Applied Mechanics Department, Government College of Engineering, Amravati, Maharashtra, India*

Abstract

Shape memory materials are a class of intelligent multifunctional materials that are employed in civil and structural engineering applications and are known for their capacity to remember their original shape. They can revert to their original shape after being deformed with the help of thermal properties. Recent innovations make everyone attracts to SMA alloys as per their compatibility and easiness in nature. SMA gains its original shape with respect to temperature. Every smart material in structural engineering plays a vital role in today's world as innovation is very important to balance our needs and actions. In this paper an effort has been made to discuss the work carried out with elasticity behaviour of SMA bracing on offshore structures to understand the impact of various parameters to study the time history, Base shear and displacement.

Keywords: SMA, SMA Bracings, Elasticity, Structure

Corresponding author.
Email address: sankalpshewale4445@gcoea.ac.in (Sankalp Shevale)

1. Introduction

Advanced materials and structures are a concept, which has received special interest among researchers during the last many years or some decades. There have been numerous techniques developed for these materials to make structure safe not in the strength point of view but as well in an eco-friendly manner. SMA are one of the widely used intelligent materials in the industry. They are different types of materials that can memorize their shape and return to it under stimuli, such as temperature, magnetic field, light, liquid, etc. Offshore platforms are subjected to different environmental loads during their lifetimes, such as earthquakes, waves, wind, and ice. Particularly, the seismic load should be taken into account comprehensively due to its unpredictability and randomness. Therefore, it is necessary to ensure the platform does not fall in the earthquake and decrease the loss of disaster to a minimum, so water retaining structure needs more safety regarding impact. For that purpose elasticity approach plays important role in serviceability and design of such structures.

2. Background & Literature

Various research has been carried out for SMA for the designing of offshore structures, but this research totally based on the limiting analysis. As we know that all the water retaining structure must design for working factor. The background of the SMA is follows

2.1 SMA crystalline Structure

In fig 1. Crystalline Structure at high and low temperature for different states of material as compared with only low and high rise temperature. This shows that how crystal in SMA behaves with respect to temperature

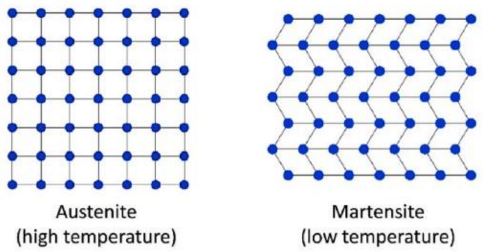

Fig.1 Crystalline microstructures [2]

We clearly saw that how twinned and detwinned martensite of SMA element behaviour with application of loading and cooling or unloading as per fig. 2. This helps to understand load deformation states of SMA element, the following structure showing same

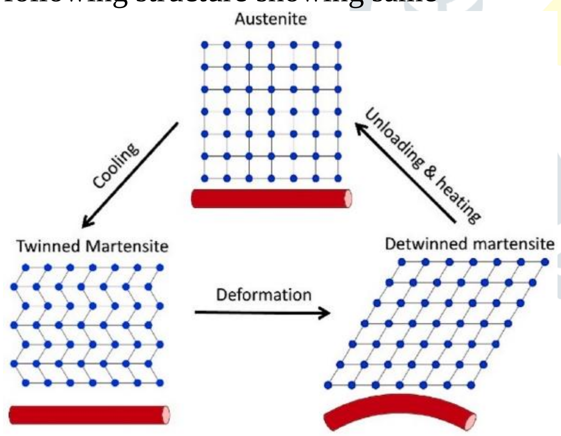

Fig.2 Basic Mechanism of SMA Structure [2]

2.2 Super Elastic damper

M. Branco, Guerreiro, A. Campos costa, and P. Candeias [1] computed energy dissipation capacity of the NiTi SMA alloy was evaluated as part under series of shake table tests. A super elastic damper was used to take benefit of the hysteretic energy dissipation consider with this type of shape memory alloy. Experimental setup was created to make exact result rather than software mode results. This experiment showed result of super elastic effect of loading and unloading stage of SMA under stress-strain graph. It was very useful when we are designing under state of loading and unloading criteria and showed much better results as compare to normal loading. In fig. 4 showed super elastic loading and unloading behaviour of the SMA structure for the case of static loading and much positive under case of loading-unloading behaviour

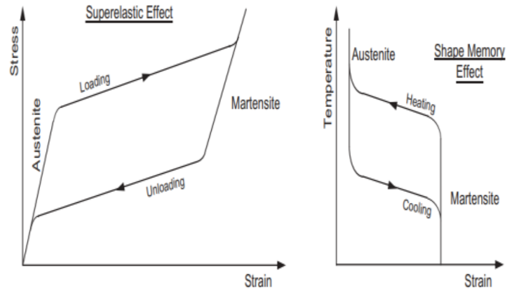

Fig.3 Super elastic effect curve. [1]

2.3 Passive control devices

Rohan Mujumdar and Aparna (Dey) Ghosh [3] found the potential of using SMAs as passive control devices for structures subjected to BIGM. This is done by a simulation study in standard FEM on a three-storied steel frame structure with SMA bracings, subjected to ground accelerations under underground blast. The investigation showed that SMA devices provide considerably good performance to that of the conventional steel bracings and may consumes great potential for sensitive structures situated near to underground blasting sources.As per fig.5 Passive control device equipped under steel based structure for actual model, as this model showed positive results under blast loading sources so it increased the passive capacity of the frame.

Fig.4. Passive Control Devices [3]

2.4 SMA as a Kernel Component

Can-Xing Qiu & Songye Zhu [5] investigated steel braced frames with self-centring braces that use shape memory alloys (SMA) as a kernel component. Seismic performance of the designed frames is examined at different seismic intensity levels. Results that of nonlinear time-history analysis indicated that the four SMABFs can successfully achieve the prescribed performance objectives at three seismic hazard levels. The comparisons among the designed frames reveal that the SMABs with greater hysteretic parameters resulted in a more economical design in terms of the consumption of steel and SMA materials. Under different loaded block as per fig.6 with SMA wires and small scaled prototype is modelled and this model showed very much active results under consumption of steel and SMA

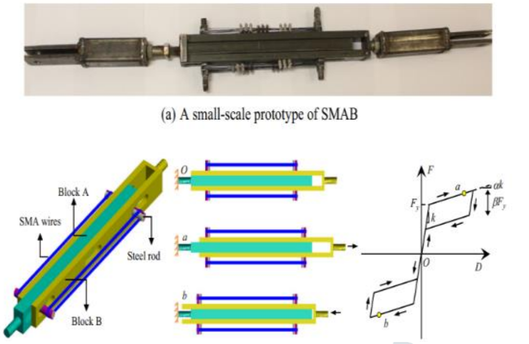

Fig.5 SMA as Kernel Component [5]

2.5 SMA Bracing

Mohammad Aghajani D., Mahsa Pahlavikhah V. & Khosro Bargi [7] investigated Seismic performance of offshore jacket-type platforms equipped with super-elastic SMA bracings. Nonlinear time history analyses of offshore jacket-type platform equipped with SMA subjected to three ground motion records have been performed using SeismoStruct software. But not used interaction of Soil-Pile. SeismoStruct software under deck type structure was used for each storey of 45 m high. This results in ground acceleration of structure with and without SMA bracing and structure with SMA bracing showed much greater results than without SMA

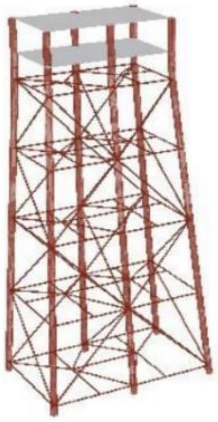

Fig.6. Modelling for SMA Bracing [7]

2.6 SMA Pall-typed frictional damper

Jigang Zhang, Zhehao Ma, Feifei Liu, Chunwei Zhang, Pezhman Sharafi and Maria Rashidi [9] investigated Pall-typed frictional damper (PFD) has more capacity of energy dissipation, as shape memory alloy (SMA) has very good super elastic performance. Thus, combining PFD and SMA together as a brace system has a inovative prospect in vibration control of structures and performance of offshore platform with different structural configurations including the SMA brace system, the ISO-SMA (where ISO stands for isolation) brace system, and the ISO-PFD-SMA brace system, which are subjected to seismic and ice-induced excitations examine with ANSYS software

SMA bracing and those combination of PFD and SMA gives very good results under vibration as SMA gives return shape property as per fig. 8

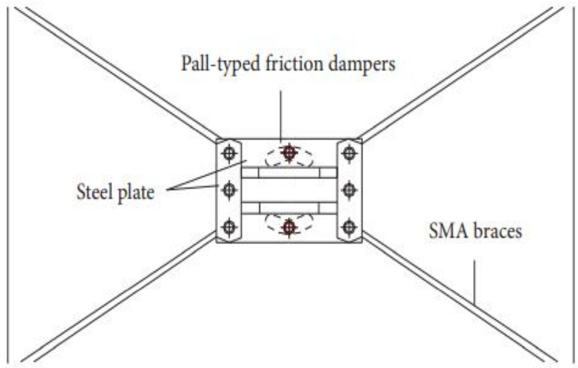

Fig.7. PFD-SMA brace system including. [9]

2.8 Optimized SMA Dampers

Mohammad Reza Ghasemi, Naser Shabakhty & Mohammad Hadi Enferadi [11] found out control wave-induced vibrations of fixed jacket platforms with the use of optimized shape memory alloys dampers with model the hysteretic behaviour of SMA elements and performing dynamic analysis an efficient isothermal idealized constitutive model is developed in this research and direct integration time history analysis is carried out. In the fig 10. SMA dampers are erected at the nodal points and connection for bracing is normal as used during normal steel erection building. In this work result found was that, vibration of structure is much less as compare to structure without SMA Dampers and gives more hysteresis behaviour.

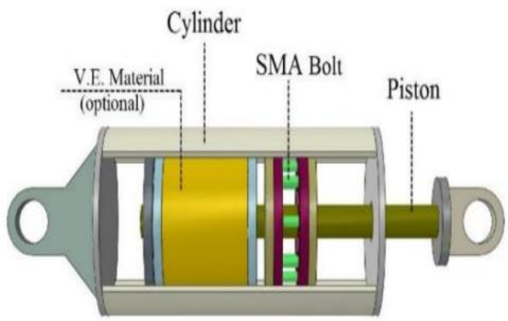

Fig.8. SMA Dampers

3. Research Gaps

- With reference to above literature survey, the all the research has been carried out with martensite state of SMA material. The elastic behaviour of the material is neglected.

- The approach for design is totally based on limiting factor, but water retaining structures required more safety. So it is design for working modular ratio condition.
- There is no specific position for bracing has been described for getting accurate and permissible deflection and nodal forces.
- Martensite to Austenite state of material is totally ignored, as this stage described more realistic behaviour of SMA for regaining its shape.

4. Methodology

- The dynamic time history analysis is done for further work using SeismoStruct 2022 FEM based software. The above work is compared between the SMA bracing and its optimization with respect to structures with normal steel bracing.
- Before proceeding towards the analysis method, the material properties of designing material should be known. Table 1 shows the material properties of steel and Table 2 shows the material properties of steel respectively.

Name	σ_y	E	γ	ϵ_f
St_bl2	500 MPa	200000 MPa	78 kN/m^3	0.2

Table 1. Properties of steel.

Name	E	γ	σ_y
Se_SMA	1000000 MPa	65 kN/m^3	300 MPa

Table 2. Properties of SMA.

Where,

σ_y = Yield strength

E = Modulus of Elasticity

γ = Specific weight

ϵ_f = Fracture strain

4.1 Dynamic Time History Analysis

The dynamic time history preferred for analysis, as existing structures have similarities and output refers to displacement and base shears. The two Indian EQ has been selected for the analysis as Andaman EQ 2008 & Utakarshi EQ 2008 as Andaman EQ has similar wave propagation in marine structures. As shown in fig.11 & fig.12

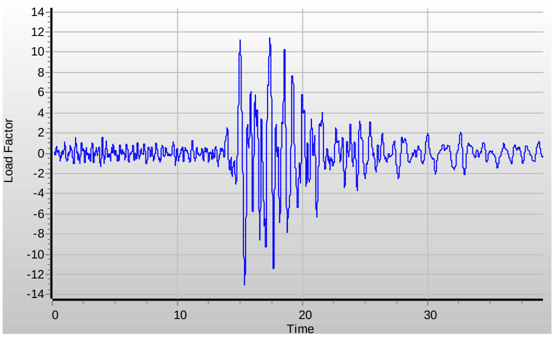

Fig.9. Andaman EQ time history curve

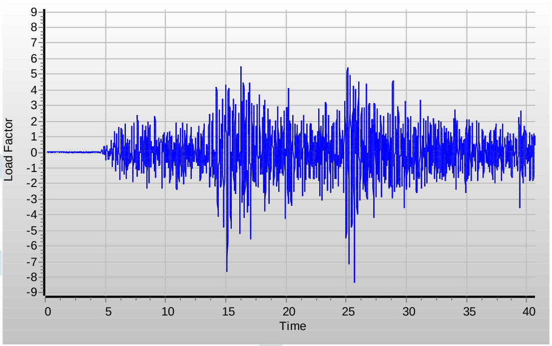

Fig.10. Utakarshi EQ time history curve

As shown in respective figures the PGA for Andaman and Utakarshi EQ is 13.079 cm/sec^2 and 8.342 cm/sec^2 respectively. The above data has been taken from PESMOS server of Indian Institute Technology, Roorkee.

4.2 Model Drafting

The plan dimension of the platform at the sea bed is 23.8 x 38.26 m at the base and total height of the structure is 70.8 m from the base as shown in fig.13.

The elasticity approach for equivalent transformation of steel and SMA area is totally based on yielding of both the materials. If modulus of elasticity is considered for transformation, then it would not be realistic because SMA changes its elastic property frequently as temperature changes. So it is based on yielding of both the material. The first yielding of SMA is based on the state of Austenite to Martensite transformation.

The following equations shows the equivalent area transformation.

- $tranformation\ factor = \frac{\sigma_y\, steel}{\sigma_y\, SMA}$

As shown in table 1 and 2 respectively, we have

- $tranformation\ factor = \frac{500}{300} = 1.67$

As per ISO 19900 provisions, the safety and serviceability of offshore oil and marine structure should be achieved when it will be designed with minimum diameter of solid circular section of 15 cm. so based on this we have derived following equations

- $A_{SMA} = 1.67 A_{Steel}$

Using 15 cm diameter of steel section, we have got diameter of our SMA bracing section was 19.40 cm. So the prescribed model is draft with 15 cm diameter of all the steel structural members and 19.4 cm diameter of bracing section. With SMA bracing over whole structure and on second and third storey provided respectively.

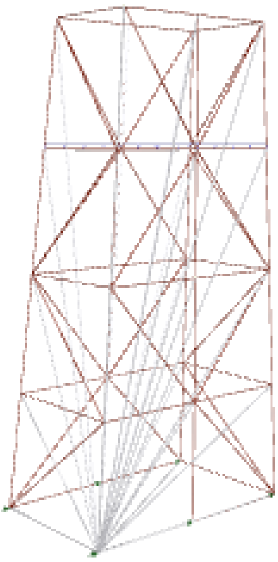

Fig. 11. Modelling of Structure with Bracing

The connection provided in the structure is rigid type and have equal degree of freedom along all the direction as shown in fig.12

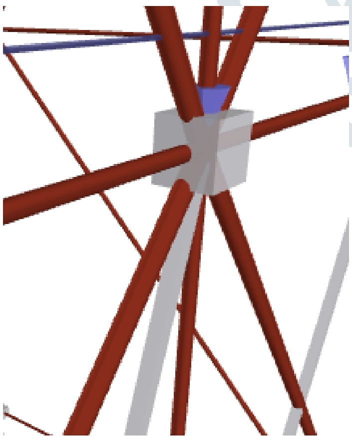

Fig. 12. The connection restrains in structure

5. Results

After completing the time history analysis of the structure for both the SMA braced structure and without SMA braced structure, we have got following results for the Base Shear &

Results	Base Shear (Peak) X	Base Shear (Peak) Y
SMA Bracing	6794 kN	4737.2 kN
Steel bracing	7098 kN	5688.4 kN

Results	Displacement (X)	Displacement (Y)
SMA Bracing	69 mm	39 mm
Steel bracing	82 mm	89 mm

Displacement.

Table 3. Base Shear Andaman EQ

Table 4. Displacement Andaman EQ

Results	Base Shear (Peak) X	Base Shear (Peak) Y
SMA Bracing	3524.1 kN	1078.67 kN
Steel bracing	4431.8 kN	2671.4 kN

Table 5. Base Shear Utakarshi EQ

As shown in table 3, 4, 5 & 6 described the Base shear and displacement results of SMA braced and Steel braced structure and fig.15 described the load and corresponding relation

Results	Displacement (X)	Displacement (Y)
SMA Bracing	57.52 mm	29.78 mm
Steel bracing	67.23 mm	46.58 mm

Table 6. Displacement Utakarshi EQ

Now as shown in fig. 13 the comparison of base shear when SMA is provided at Second storey

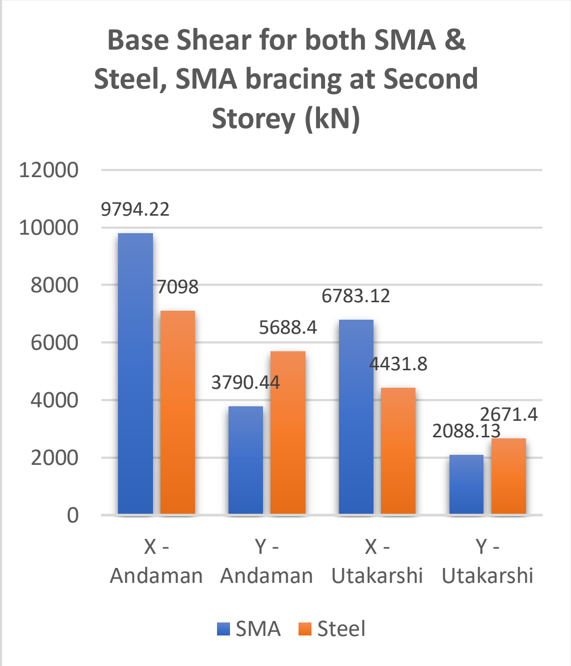

Fig. 13.Base Shear SMA at second storey

Now as shown in Fig. 14, we have clear idea about the displacement of structure, when SMA bracing is provided at second storey

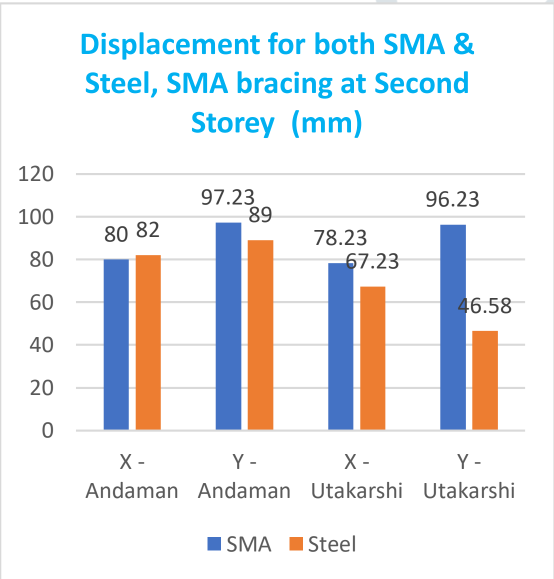

Fig. 14. Displacement due to SMA at second storey

Similarly Fig. 15 and 16 shows the result of base shear and displacement, when SMA bracing is provided at third storey.ie. Between 40m to 60m

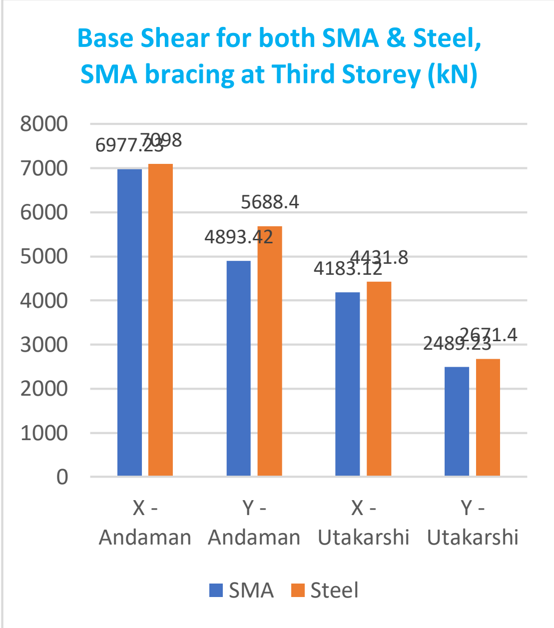

Fig. 15.Base Shear SMA at third storey

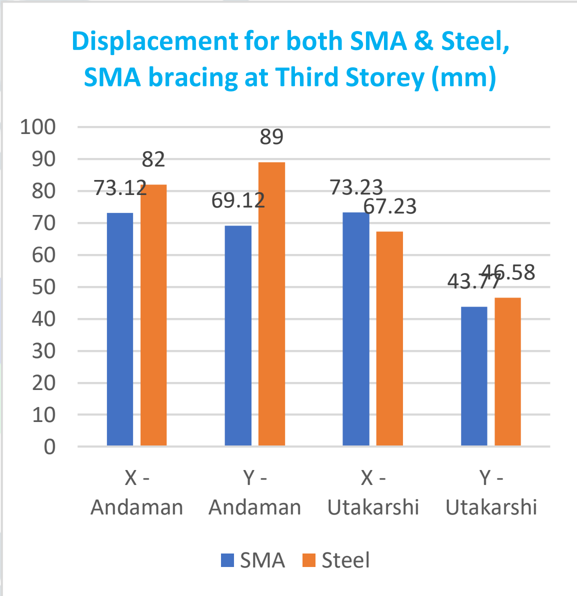

Fig. 16. Displacement due to SMA at third storey

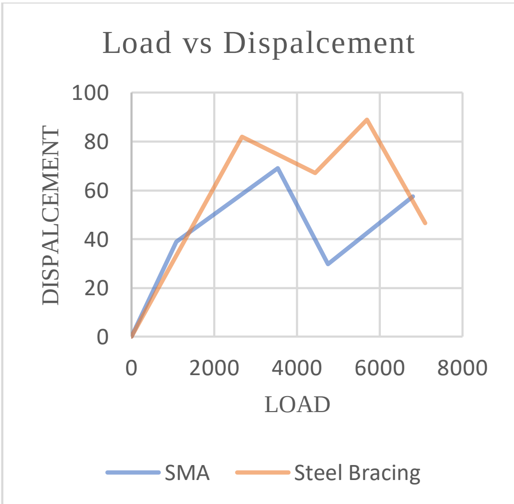

Fig. 17. The Load vs Displacement Graph

6. Conclusion

- The dynamic time history analysis shows the variation in results of SMA and Steel braced structure along both X and Y direction.
- The elasticity yielding approach shows the lesser value of base shear along both the X and Y direction as compared to steel braced structure.
- The displacement occurred in the structure is much lesser for SMA braced structure as compared to Steel braced structure.
- The transformation factor 1.67, which is based on yielding and elasticity approach shows more effective in designing offshore structures with SMA bracings.
- The elasticity yielding approach shows the more value of base shear along X direction for SMA braced structure and along Y direction lesser value of base shear when we provide SMA bracing at second storey. (i.e. from 20 m to 40 m from base)
- The elasticity yielding approach shows the more value of displacement along X & Y direction for SMA braced structure as compare to steel braced structure. when we provide SMA bracing at second storey (i.e. from 20 m to 40 m from base)
- The elasticity yielding approach shows the less value of base shear along X & Y direction for SMA braced structure as compare to steel braced structure. when we provide SMA bracing at third storey (i.e. from 40 m to 60 m from base)
- The elasticity yielding approach shows the less value of base shear along X & Y direction for SMA braced structure as compare to steel braced structure. when we provide SMA bracing at third storey (i.e. from 40 m to 60 m from base)
- It is very efficient when we provide SMA braced structure at height of 40 m to 60 m from base. Which gives less displacement and base shear.

Conflict of interest: - There is no conflict of interest

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