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Seismic Resistant R.C.C Structure using NiTi Super Elastic Shape Memory Alloy

Joyal Joy[1], P. Anima[2]
[1]*PG Scholar, Department of Civil Engineering, Universal Engineering College, Thrissur, India*
[2]*Associate Professor, Department of Civil Engineering, Universal Engineering College, Thrissur, India*

***Abstract*: Super Elastic (SE) shape memory alloy (SMA) is an advanced material that may be used as an alternative to conventional reinforcing steel in civil engineering structures to control residual deformations. The most common SE SMA type is an alloy of nickel and titanium (NiTi). Different diameter SMA were introduced in the beam column model and studied analytically using the software ANSYS 16.1. Deflections of SMA reinforced beams column model were compared with deflections of similar beam column model reinforced with conventional steel to present the potential of SMAs in restricting seismic vibration and deflections. Importance of project is that, this analytical study is doing in an existing 5 storied commercial building part. Finally, a new scope of research work is proposed utilizing SMAs as reinforcement in RCC structure to resist seismic vibration and deflections.**

***Keywords*: SMA-Shape Memory Alloy, super elastic (SE), nickel and titanium (NiTi).**

1. Introduction

Shape memory alloy (SMA) is an advanced material with large strain recovery and high energy dissipation capacity that may be used as an alternative to conventional reinforcing steel in civil engineering structures. SMAs have found applications in many areas due to their high power density, solid state actuation, high damping capacity, durability and fatigue resistance. When integrated with civil structures, SMAs can be passive, semi-active, or active components to reduce damage caused by environmental impacts or earthquakes.

Chang and Read first observed a reversible phase transformation in gold–cadmium (AuCd) in 1932, which is the first record of the shape memory transformation. It was after 1962, when Buechler and co-researchers discovered the shape memory effect (SME) in nickel–titanium at Naval Ordnance Laboratory (they named the material Nitinol after their workplace), that both in-depth research and practical applications of shape memory alloys emerged.

Today many types of shape memory alloys have been discovered. Among them, Nitinol possesses superior thermomechanical and thermo electrical properties and is the most commonly used SMA. Nitinol SMAs have two unique properties: SME and super elasticity. The SME refers to the phenomenon that SMAs return back to their predetermined shapes upon heating. The super elasticity refers to the phenomenon that SMAs can undergo a large amount of inelastic deformations and recover their shapes after unloading. In this study different diameter SMA in beam column model were studied analytically using the software ANSYS 16.1.

2. Methodology

First we take a beam column model from an existing RCC framed structure. Then replace the reinforcement steel with Nitinol shape memory alloy. The replacement of steel with SMA will improves the seismic performance of the structure. In this paper different diameter SMA were studied using ANSYS 16.1, by comparing it with steel reinforcement and apply cyclic load to determine its seismic effects. 12mm, 16mm and 25mm SMA were provided for the study. For each size of SMA we compare it with steel reinforced structure. The cyclic analysis is done to determine its seismic performance.

3. Geometrical Details

The aim of the test is to determine the seismic resistance by different arrangements of SMA in the structure. In the project, I taking a 2 column 1 beam part of an existing building situated in Thrissur district, Kerala. It was a five stored commercial building. Column size is 600x300mm and 450x450mm with a full height of 375mm. Beam size of 200x550 with span 535mm. From the section drawing of beam and column, (SMA reinforcement is represented by green). There are six cases are studied for this three diameter SMA. First is SMA replaced in beam and column joint with lateral load only that is (All SMA LL), In the second case SMA replaced in beam and column joint with lateral and axial load that is (All SMA LL+AL), In the third case SMA replaced in column bottom joint with lateral load only that is (column SMA LL), In the fourth case SMA replaced in column bottom joint with lateral and axial load that is (column SMA LL+AL), In the fifth case SMA is provided by coupling with steel by applying lateral load only that is (SMA COUPLED REBAR- LL), In the sixth case SMA provided by coupling with steel by applying lateral and axial load that is (SMA COUPLED REBAR- LL+AL). Lateral load is applied as displacement controlled method up to 1% of drift. Vertical load is applied on the column as 1411kN on rectangular column and 1468kN on square column. This vertical load is the total load

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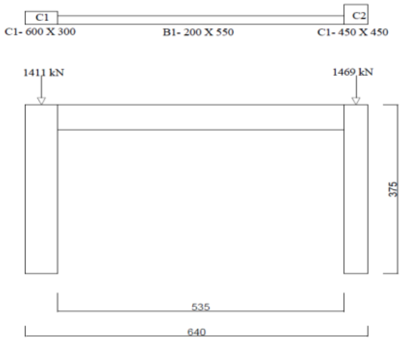
from the 5 stories of the commercial building.



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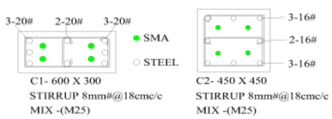

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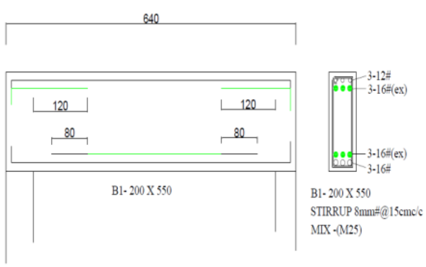

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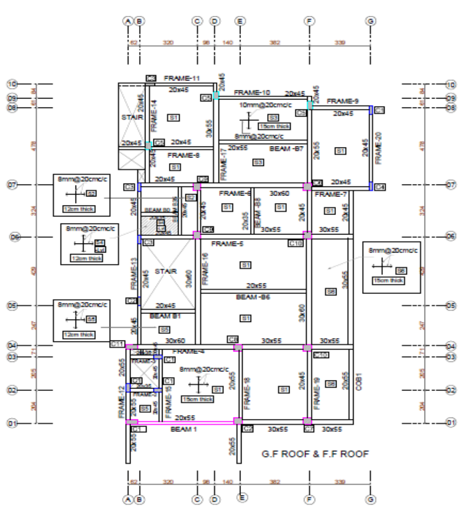

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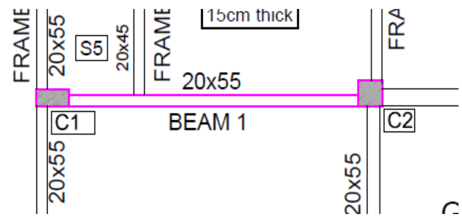

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Fig. 1. Proposed RCC structure [(i) column beam model, (ii) column section, (iii) beam section (iv) building plan, (v) enlarged view beam column plan]

4. Material properties

Table 1
Properties of Rebar and Concrete

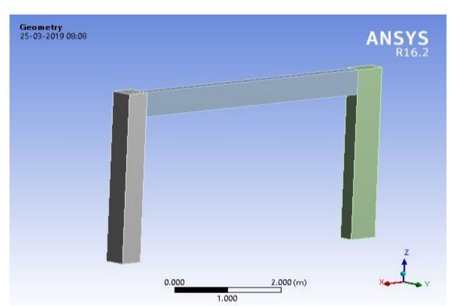
REBAR	CONCRETE
Grade – Fe415	Grade – M25
Poisson's Ratio – 0.3	Poisson's Ratio – 0.3
Yield strength – 415MPa	Compressive strength – 25MPa
Density – 7860 kg/m³	Density – 2400 kg/m³
Young's modulus – 200000 MPa	Young's modulus – 25000 MPa

Table 2
Properties of Shape Memory Alloy

Elastic stiffness of austenite E^A	70 GPa
Elastic stiffness of martensite E^M	30 GPa
Poisson's ratio ν	0.33
Coefficient of thermal expansion for austenite α^A	22 x 10^{-6} K^{-1}
Coefficient of thermal expansion for martensite α^M	22 x 10^{-6} K^{-1}
Martensitic start temperature M^{os}	291 K
Martensitic finish temperature M^{of}	271 K
Austenitic start temperature A^{os}	295 K
Austenitic finish temperature A^{of}	315 K
Maximum transformation strain H	0.05
Stress influence coefficient for austenite $\rho\Delta s^A$	-0.35 MPa K^{-1}
Stress influence coefficient for martensite $\rho\Delta s^M$	0.35 MPa K^{-1}

5. Finite element analysis

The ANSYS 16.1 software was used to model all the specimens for nonlinear analysis. SOLID 186 from ANSYS library was used for 3-D finite element modeling of the beam column model. Three different diameter SMA were studied using ANSYS 16.1. (12mm, 16mm and 25mm). Firstly, the lateral load is only provided. In the next step lateral and axial load is applied to the structure. A single cyclic analysis is done to determine its seismic performance.



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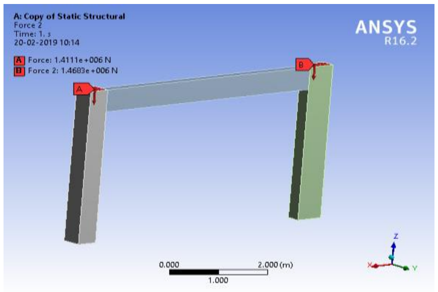

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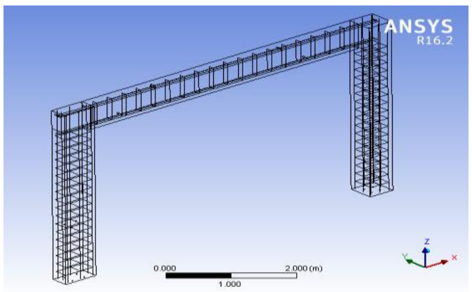

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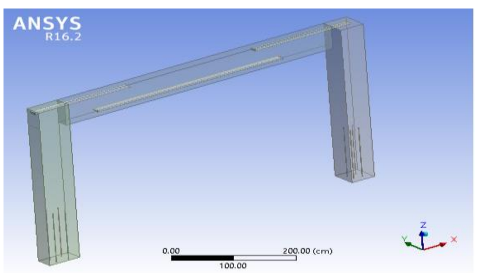

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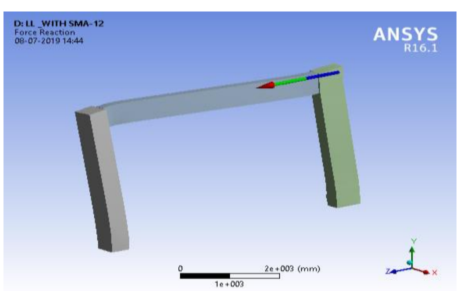

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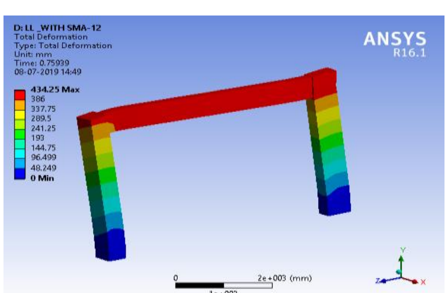


(vi)

Fig.2. Finite Element beam column models[(i) Beam column model in Ansys, (ii) Force position, (iii) Reinforcement view, (iv) SMA provided, (v)Lateral load applying, (vi) Total deformation

6. Results

A. Load Deformation for all SMA with lateral load and axial load

This analytical study shows that, replacing steel with 16mm diameter SMA is the best to take load and deflection. Load deflection curve of lateral, lateral with axial load are shown in the figure 3 and figure 4

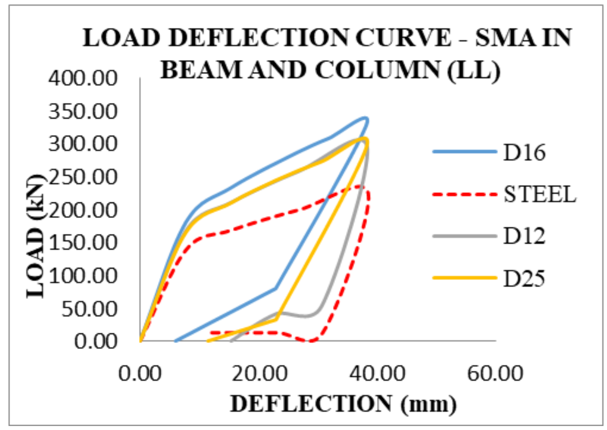


Fig. 3. Load Deflection curve of SMA in beam and column with lateral load

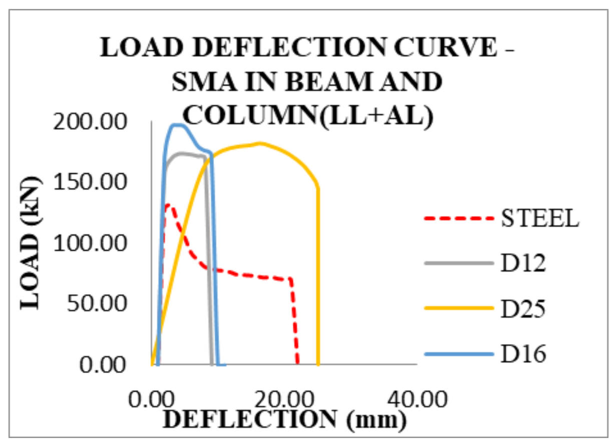


Fig. 4. Load Deflection curve of SMA in beam and column with lateral and axial load

B. Load deformation for SMA in column with lateral load and axial load

This analytical study shows that, replacing steel with 16mm diameter SMA is the best to take load and deflection. Load deflection curve of lateral, lateral with axial load are shown in the figure 5 and figure 6.

C. Load deformation for SMA coupled with rebar

This analytical study shows that, replacing steel with 25mm diameter SMA is the best to take load and deflection. Load deflection curve of lateral, lateral with axial load are shown in the figure 7 and figure 8.

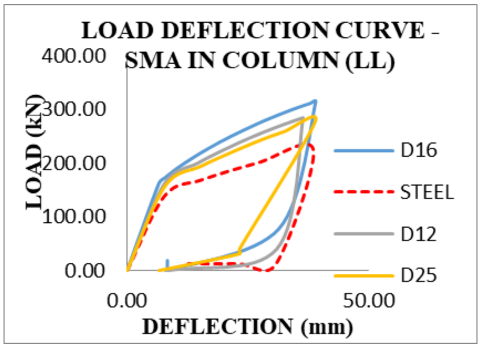


Fig. 5. Load Deflection curve of SMA in column with lateral load

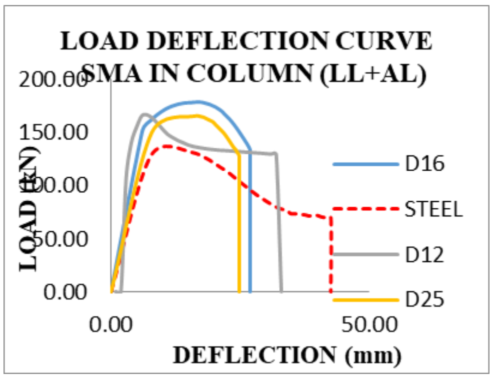


Fig. 6. Load Deflection curve of SMA in column with lateral load and axial load

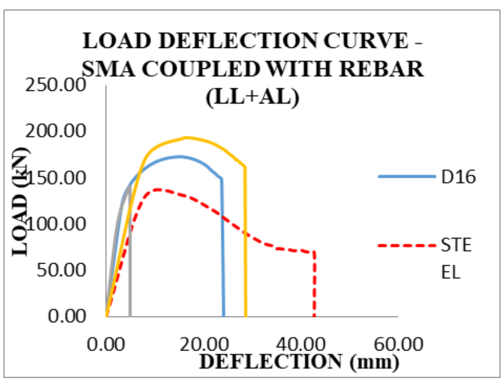


Fig.7. Load Deflection curve of SMA coupled with rebar during lateral load

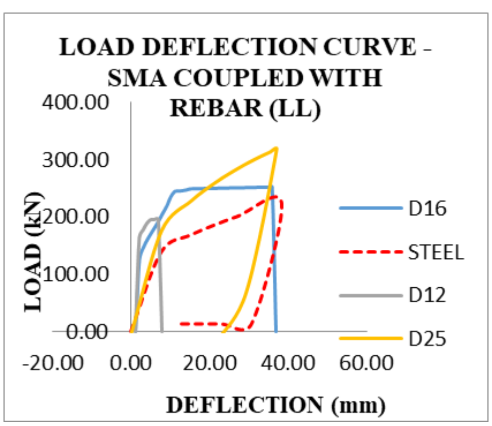
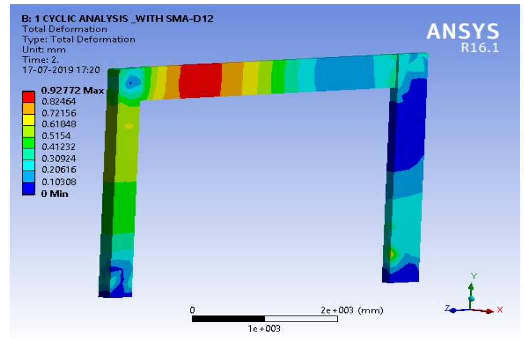


Fig. 8. Load Deflection curve of SMA coupled with rebar during lateral and axial load

D. Analytical models of SMA in beam and column lateral and axial load



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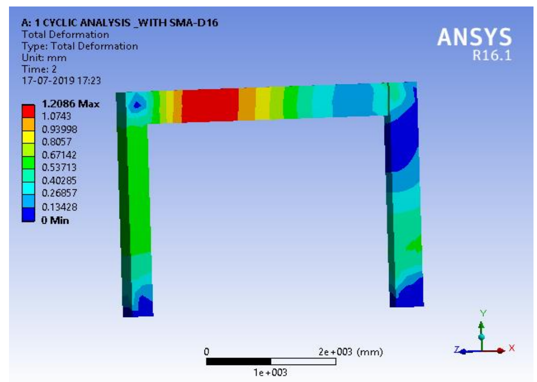

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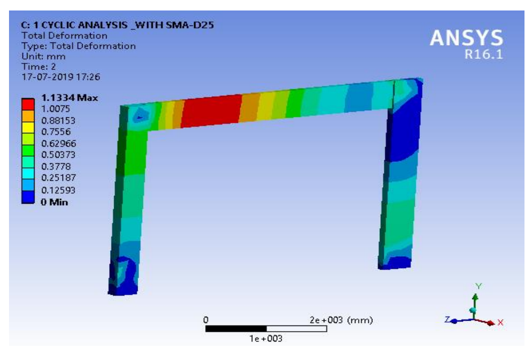

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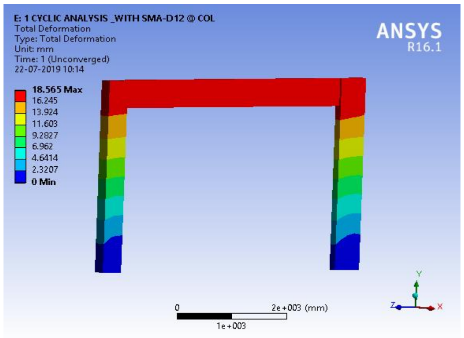
Fig. 9. Load deformation of Different diameter SMA Models [(i) 12mm, (ii) 16mm, (iii) 25mm, (iv) Steel]

E. Analytical modes of SMA in column only

Total deformation of SMA in column with lateral and axial load for 12mm, 16mm and 25mm are shown below. From the result it can be seen that replacing steel with 16mm SMA give the best result.



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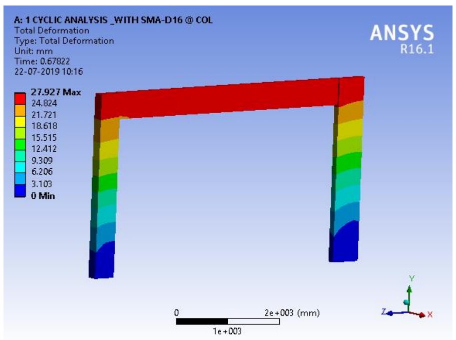

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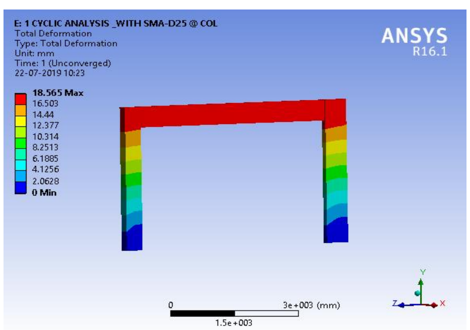

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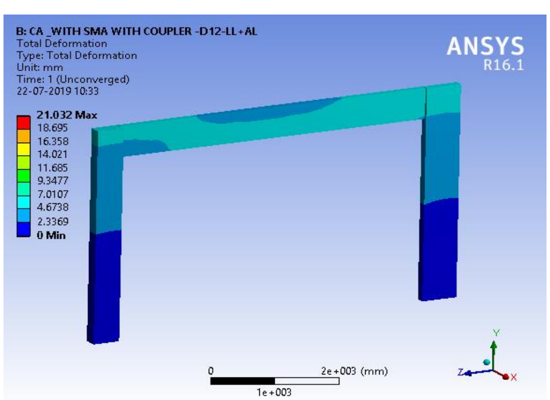
Fig.10. Load deformation of Different diameter SMA Models [(i) 12mm, (ii) 16mm, (iii) 25mm] in column

F. Analytical models of SMA coupling with rebar



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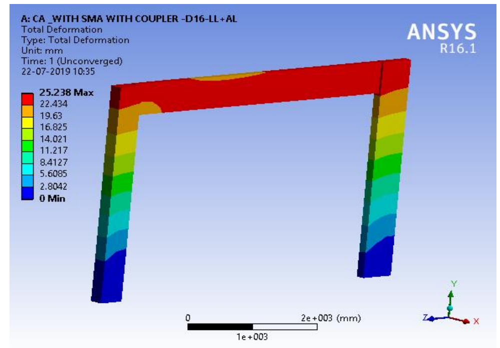

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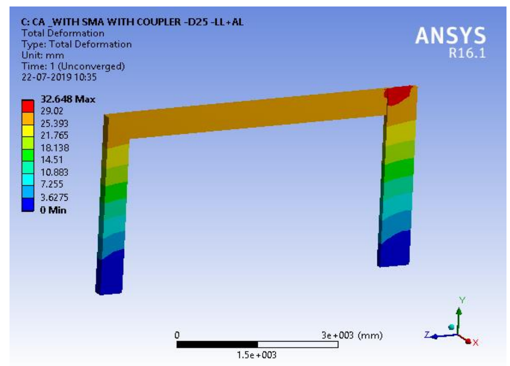

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Fig.11. Load deformation of Different diameter SMA Models [(i) 12mm, (ii) 16mm, (iii) 25mm] by coupling method

G. Comparison of SMA and Steel

Comparison of different diameter SMA and Steel of six cases in terms of deflection and load are shown in table 3, table 4 and table 5.

Table 3
Comparison of SMA in beam and column

ALL SMA -LL				ALL SMA- LL + AL		
Model	Deflection mm	Load kN	%	Deflection mm	Load kN	%
D12	38.247	295.32	31	15.635	172.97	31
D16	38.25	330.84	47	17.99	197.04	50
D25	38.29	297.64	32	23.79	157.26	20
STEEL	38.468	224.96	1	15.614	131.01	1

Table 4
Comparison of SMA in column

COLUMN SMA- LL				COLUMN SMA -LL+AL		
Model	Deflection mm	Load kN	%	Deflection mm	Load kN	%
D12	36.535	283.32	26	19.995	166.62	27
D16	39.064	315.06	41	16.90	178.96	36
D25	38.91	275.96	23	15.81	164.65	25
STEEL	38.468	224.96	1	15.614	131.01	1

H. Load and deformation comparison of SMA

Load and deformation of SMA in beam and column, SMA in column and SMA provided by coupling with lateral and axial load are compared in terms of bar chart is shown in figure 6 and figure 7.

Table 5
Comparison in coupling of SMA and Steel

SMA COUPLED REBAR- LL				SMA COUPLING REBAR- LL+AL		
MODEL	DEFLECTION mm	LOAD kN	%	DEFLECTION mm	LOAD kN	%
D12	11.799	196.07	-12	4.9443	140.85	7
D16	23.717	252.44	13	14.51	172.52	31
D25	37.17	318.42	42	17.16	192.39	46
STEEL	38.468	224.96	1	15.614	131.01	1

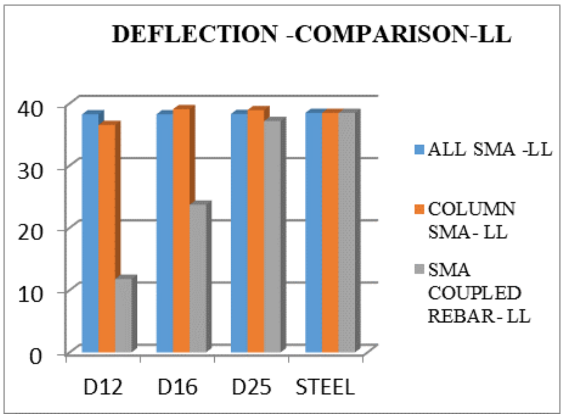

Fig. 12. Deflection Comparison of SMA with lateral load

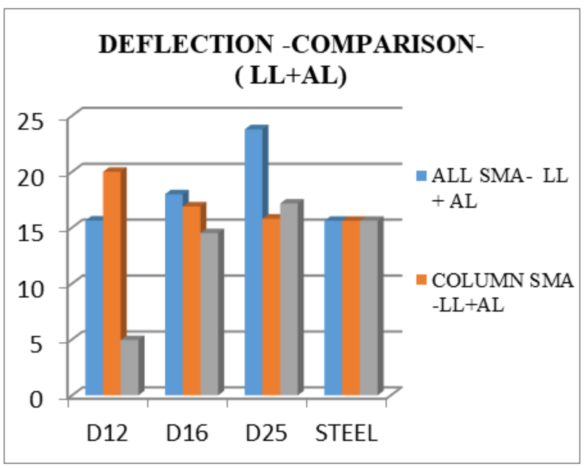

Fig. 13. Deflection Comparison of SMA with lateral and axial load

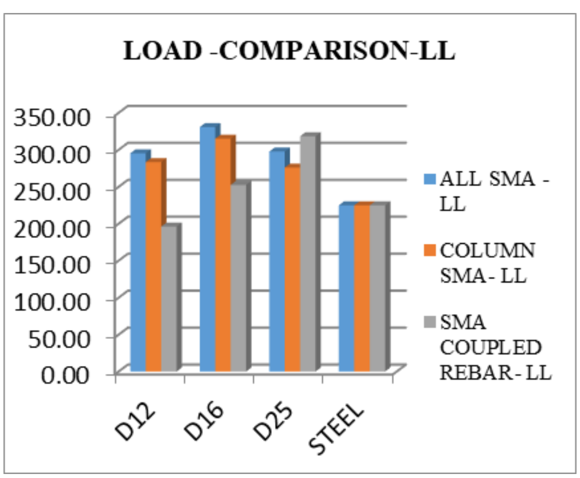

Fig.14. Load Comparison of SMA with lateral load

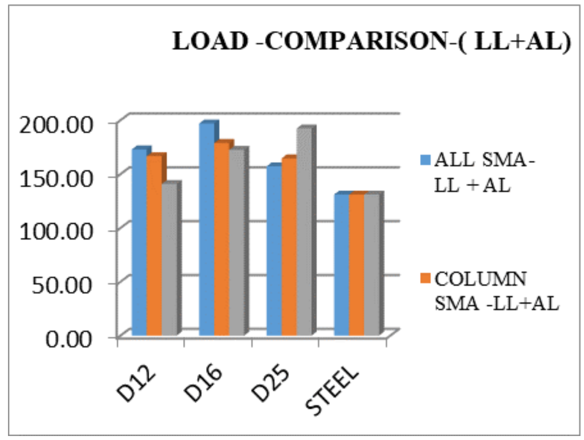

Fig.15. Load Comparison of SMA with lateral and axial load

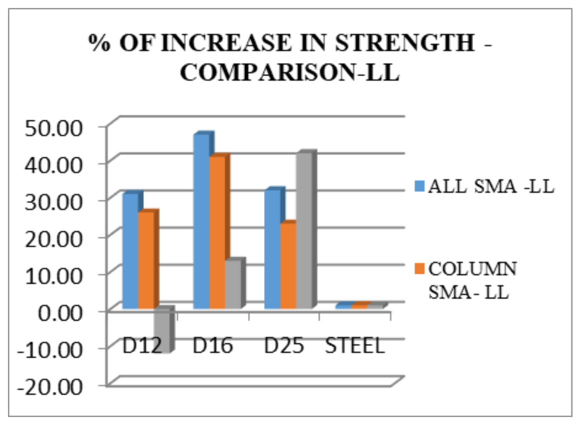

Fig. 16. percentage of increase in strength Comparison of SMA with lateral and axial load

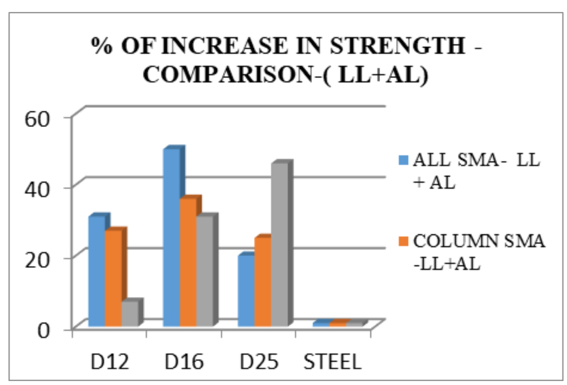

Fig. 17. Percentage of increase in strength Comparison of SMA with lateral and axial load

7. Conclusions

- From the analysis of SMA in lateral load case. It is observed that D16 diameter SMA giving higher percentage strength of 47% comparing with conventional reinforcement. D12 and D25 gives 31% to 32% strength.
- Comparing to D12 and D25, D16 take 47% more strength when comparing with steel
- In the column SMA lateral load case, it is observed that D16 diameter SMA gives 41% increase in strength. Comparing with D12 and D25 SMA D16 gives more strength.
- From the analysis of coupling of SMA with steel. D25 diameter SMA gives higher percentage of strength. In coupling we can reduce the amount of steel, but D12 and D16 are not suitable for coupling SMA case and the result showing it is under reinforced.
- From the analysis of lateral load case D16 is suitable for all SMA and column SMA case. In the coupling SMA case D25 is suitable
- From the analysis of cases undergo with lateral and axial load, in all SMA case D16 diameter SMA gives 50% of higher strength comparing to conventional reinforcement.
- In the column SMA case also D16 SMA gives 36% of higher strength
- In the case of coupling of SMA D25 gives 46% of higher strength comparing to conventional reinforcement.
- From the cyclic analysis evaluation, it is observed that using SMA gives higher recovery of strain
- During unloading D16 diameter SMA giving 36% of recovery comparing to steel and D25 gives 30% of recovery
- From all lateral and axial load cases D16 gives more recovery percentage, that is plastic strain forming in the structure is reduced
- By using SMA plastic hinge forming in the structure is reduced during seismic vibrations
- By using SMA in building structure it can take more lateral and axial load, more deflection without fail, that make civil structures high efficient and safe during earthquake load
- From the all evaluation it is observed that using SMA, the structure can resist more seismic vibrations during earthquake and the recovery of structure happening after earthquake.

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