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Numerical Analysis on Shear Behaviors of RC Beams Reinforced with SMA Bars Using ETS Method

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Immediate shear failure of the reinforcement beams could occur without any advanced warning about when it is going to fail. Shear failure could occur when there is insufficient strength between concrete and steel rebar. However, to make sure that the existing reinforcement concrete beams could resist more shear capacity upon increasing load, strengthening method is introduced for the shear strengthening. Moreover, since the shape memory alloy (SMA) has one unique phenomenon called superelasticity, it can be seen that the exploit of this effect could strengthen the reinforcement concrete beams. Shape memory alloys (SMA) are known as the smart materials which could remember it recovery shape upon heating or unloading, and it has special mechanical properties that could return to its initial shape upon unloading condition.Most importantly, limited researches studies focused on SMA on flexural strengthening rather than shear strengthening. Therefore, this whole paper is only investigated on strengthening in shear with reinforcing a new smart material (SMA) with embedded through sections method. Six reinforcement concrete beams models were analyzed with the assumption of 100kN of load. Out of them, two beams were identified as the reference concrete beams and the rest beams are the strengthening with SMA bars. ANSYS APDL (version 18.1) was used to simulate all models. Mid span deflection, shear stress pattern,crack and crush plot will be shown as the result which were collected from the software. Lastly,the effectiveness of strengthening SMA bars will be discussed.

***Keyword**: Shape Memory Alloys, Embedded Through Section Method, ANSYS APDL, Shear Strengthening, Reinforcement concrete beam.*

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I. INTRODUCTION

Skyscrapers, residential building, bridges, highways, dams, and other types of structure could become worse due to ageing of structures, aggressive naturals disasters, increasing the population, undesirable change in stiffness and different types of pollution. With concerning of these issues, the deteriorating structure therefore either need to be upgraded or demolished. By these reasons, it is a major part for engineers to decide which the deteriorated structures need to strengthen or retrofit according to methods which are safe, cost-saving, and the efficiency. A challenging part of construction industry is strengthening and retrofitting of existing structural elements which emerge with some methods including increasing in sections size, shortening the span of the structural elements, the externally bonded method and many existing methods like NSM and ETS.

For reinforcement concrete beams are designed for both bending moments, and shear force which is developed along the simple beam when it is loaded. Moreover, to design reinforcement concrete beams, engineer first consider the flexural design to established the dimensions of the beams' cross section and the longitudinal reinforcement. The RC beams are then designed for shear resistance. To provide enough shear resistance in RC beam, transverse rebars are used. However, when the RC beams are insufficiently to reinforced the shear stress due to high load, shear failure could occur immediately.

In 2014, Breveglieri et al have been developed a new technique which could strengthen or retrofit the shear strength in reinforcement called embedded through sections method (ETS). The process of this method is to drill hole in the specific zone to strengthen in the beam then materials will be inserted in the hole and bonded by epoxy adhesive to fix between the materials and the concrete. In this paper, the author used the steel bar as a specific material for strengthening in shear zone of the reinforcement concrete beams.

Similarly, in another research paper, the strengthening in shear mechanism has been studied by using 3 different methods with the uses of FRP; ETS (Embedded through section), NSM (Near surface mounted), EB

(Externally Bonded). According to (O. Chaallal et al, 2011), ETS method has shown many benefit results with cost-effectiveness and shear strengthening effectiveness. In that research was not only discussed the result by using ETS is performed better than NSM and EB but also indicated that the cost of using materials strengthening with ETS method is lower than other 2 methods. Moreover, it is discussed that the results of ETS method has shown the highest in shear strengthening capacity comparing to those 2 methods and by strengthening in shear region, shear stress could transfer to flexural stress. ETS method is expected to perform better in economic comparison than NSM and EB.

II. MATERIALS AND METHOD

1) Material

Superelasticity is known as pseudoelasticity and it is like a rubber behavior which phenomenon mostly introduced in the damping system. In ease of explanation, the superelasticity is the materials that could return to its initial shape upon unloading condition. The behavior of this phenomenon is associated with the stress-induced transformation that could have strain transformation during the loading condition and strain could recover when unloading condition of stress at the temperature above finished austenite phase. A superelasticity of thermomechanical loading path likely to start when enough temperature and where the stable of austenite existed, after that it will develop when the applied load is appeared at which the detwinned martensite is about to stable, and then it is finally return to the austenite phase when returned to the zero at the stress state.

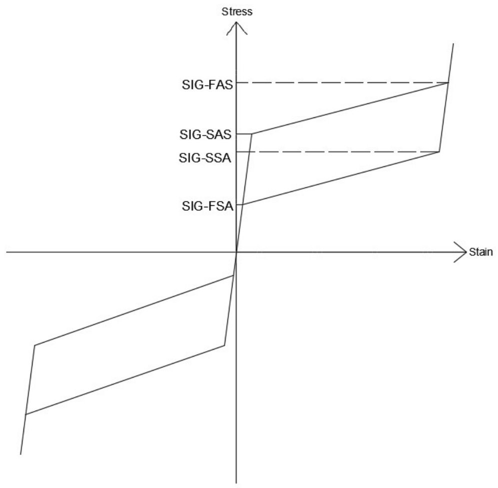


Figure 1. SMA Stress-Stain Diagram of superelasticity in ANSYS APDL

2) Embedded Through Section Method

ETS is the method mostly used for strengthen in shear capacity. The process of this method is quite similar to the NSM by cutting the beams. On the other hand, this technique is drill holes through the middle of the top of the beams then insert the materials through the holes. In figure 2 is all the existing strengthening method that O. Chaallal et al investigate with FRP.

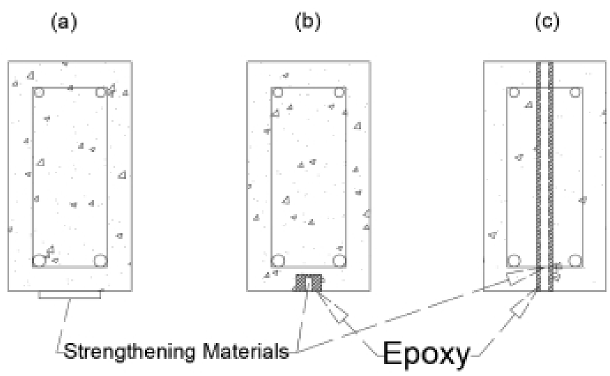


Figure 2. (a) The Externally Bonded, (b) The Near Surface Mounted Method (NSM), and (c) The Embedded Through Section Method

3) Reasons for Strengthening with SMA

Over the past decade, there have been significant interests to use shape memory alloys (SMAs) in various civil engineering applications (Junhui Dong et al, 2011). SMAs have excellent non-corrosion, perfect energy dissipation capacity, and high fatigue properties. Superelastic SMAs can gain in large strains, in up to approximately 7 to 8%, and ease with installation is also another benefit.

Most of research uses this SMA for flexural strengthening, damping, and seismic resistance of the bridge design, however, few researchers use this smart material for shear strengthening purpose in RC beams. Since there is less research papers that use SMA with shear strengthening in the reinforcement concrete beams, this research mainly investigates on using this smart material for reinforcing the shear capacity by using ETS (embedded through section) method simulated with ANSYS computer software.

III. NUMERICAL MODELING OF RC BEAMS

1) Classify the beam specimens

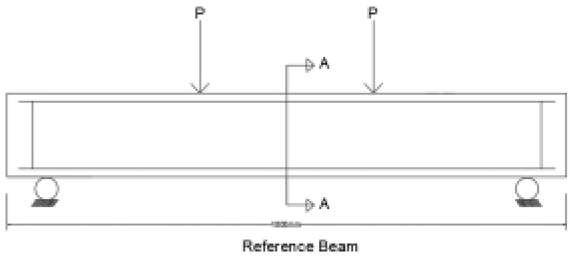
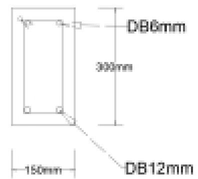
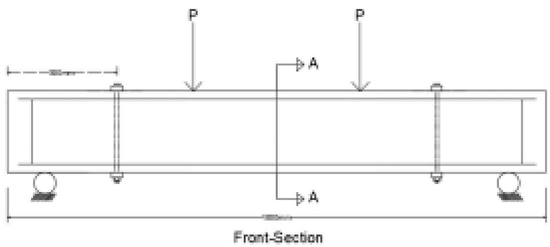
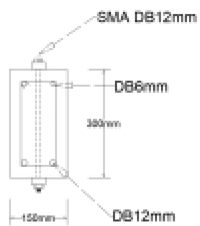
Reinforcement concretes beams are divided into 2 categories which differ in their transverse rebar of the beams. Different amounts of shape memory alloys bars with different spacing of the strengthening bars are used for strengthen in shear capacity with the embedded through section method. The total of six reinforcement concrete beams are investigated in this research and the beam model. There are 4 strengthening beams reinforced with 1 and 2 SMAs bar with 300mm and 200mm spacing.

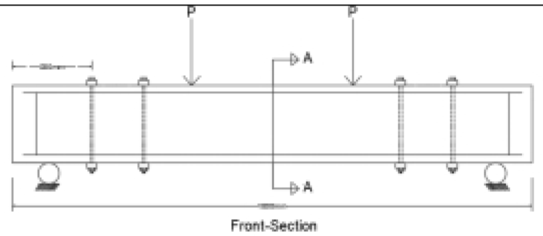
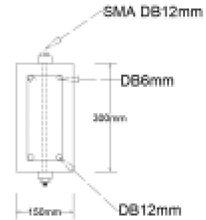
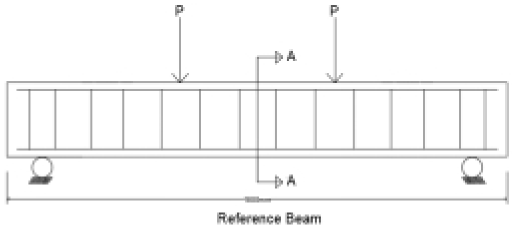
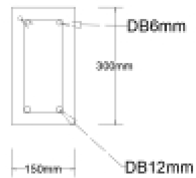
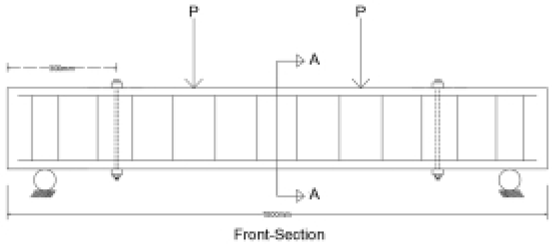
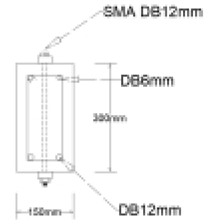
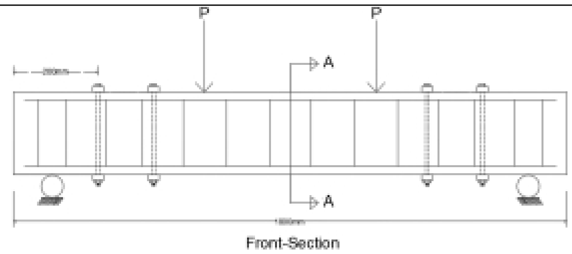
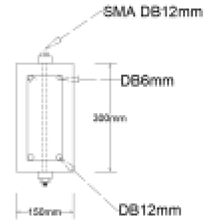
TABLE 1: BEAM CLASSIFICATION

Model	Beam Designation	Type	Strengthening	Number of SMA
Mode 1	A.1	No Stirrup	Reference	-
	A.2	No Stirrup	SMA	1 Bar
	A.3	No Stirrup	SMA	2 Bars
Mode 2	B.1	Less Stirrup	Reference	-
	B.2	Less Stirrup	SMA	1 Bar
	B.3	Less Stirrup	SMA	2 Bars

The different from mode 1 and mode 2 is the use of stirrup in the concrete beams. In mode 2, the less stirrup with 250mm of spacing are used. The cross-section of RC beam is 300depth, 150width and 1800mm long with 100mm of each reaction supports. 12mm and 6mm of longitudinal bars and stirrup are used in the beams which the assumption of 100kN load applied.

TABLE 2: BEAM DESCRIPTION

Model	Beam Designation	Beam Description	Cross Section
Mode 1	A.1		
	A.2		

	A.3		
Mode 2	B.1		
	B.2		
	B.3		

2) Material Input

Materials properties of concrete are shown in table 4. Meanwhile, the detail of the materials properties such as the yield strength, ultimate strength, young modulus of elasticity passion ratio of steel rebars and SMA bars are shown is table 3.

TABLE 3: MATERIAL PROPERTIES INPUT IN ANSYS APDL

Type		Diameter (mm)	f_y(MPa)	f_u (MPa)	E (GPa)	Possion Ratio	Density(kg/m^3)
Steel	Rebar	12	490	560	201	0.3	7850
	Stirrup	6	270	320	201	0.3	7850
SMA	-	12	460	1010	68	0.3	6700

According to ACI 318-14, young modulus of elasticity of concrete is calculated by $E_c = 4700\sqrt{f'_c}$ where the unit is in SI. The main approach of concrete is the ultimate uniaxial compressive strength (f'_c) where $f'_c = 25MPa$.

TABLE 4: CONCRETE PROPERTIES INPUT IN ANSYS APDL

Linear Isotropic	
Young's Modulus E (MPa)	23500
Density (kg/m^3)	2300
Possion Ratio	0.2
Compressive Strength (MPa)	25

Based on Shreya Kaduskar et al, the properties input of superelasticity of SMA in ANSYS APDL were taken according to the table 5.

TABLE 5: MATERIAL PROPERTY OF SUPERELASTICITY

Nonlinear Superelasticity	
SIG-SAS (N/mm^2)	520
SIG-FAS (N/mm^2)	600
SIG-SSA (N/mm^2)	300
SIG-FSA (N/mm^2)	200
EPSILON	0.07
ALPHA	0

3) Finite Element Modeling

In Finite Element Method, input property, use the element type and model the dimension are the key point to consider to have the accurate result. ANSYS APDL has successfully applied in many civil engineering analysis and it has good development functions with new materials like shape memory alloy (Bo Zhou et al, 2019).

TABLE 6: THE ELEMENT TYPE OF EACH MATERIALS IN ANSYS APDL

RC Beams Component	Used Element from ANSYS Library	Element Characteristics
Concrete	SOLID65	8 nodes Brick Element (3 translation of DOF per node)
Steel Reinforcing Bars and Strengthening Bars	Link180	2 nodes Discrete Element (3 translation of DOF per node)
Bearing Steel Plates	SOLID185	8 nodes Brick Element (3 translation of DOF per node)
Dowel Action (Shear Connection inside interface)	COMBIN39	2 nodes zero length non-linear spring element with one translation of DOF each node

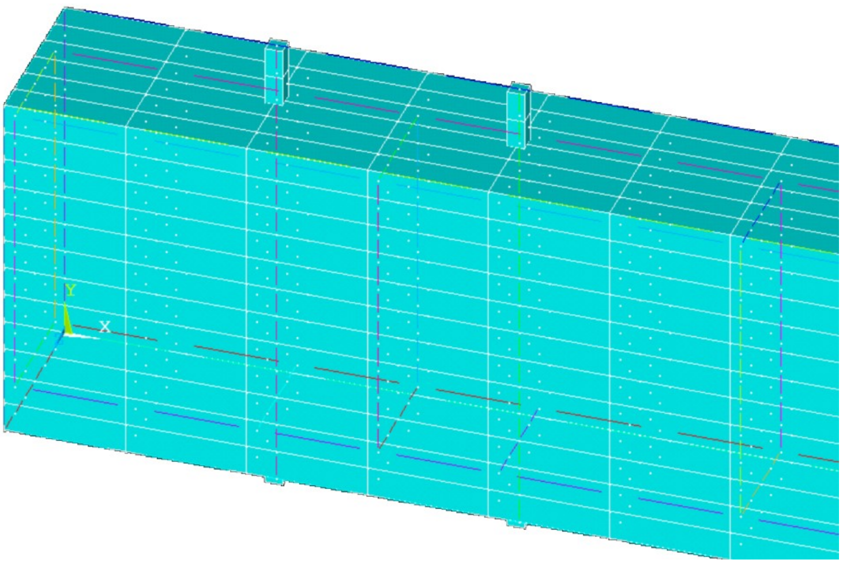


Figure 3. SMA bars embedded in the RC beam by using COMBIN39

4) Boundary Condition

100kN of load was divided to 10 nodes on the beams which is 10kN in each node, plus roller and pin are fixed on the 100mm each edge of the beams to simulate the 4-point bending load analysis. Moreover, different types of meshing method were used for the accuracy of the results. The overall modeling is shown in the figure 4.

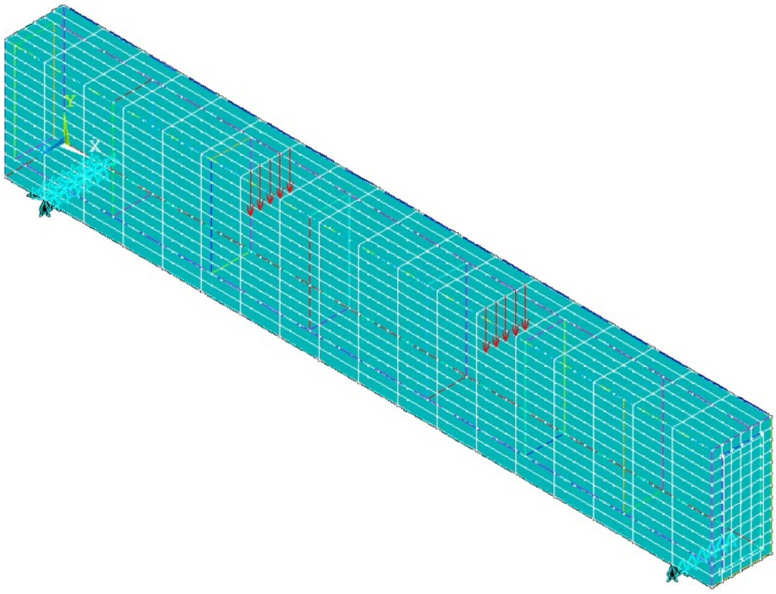


Figure 4: The boundary condition of RC beam

IV. RESULT AND DISCUSSION

1) Result Analysis

a. Mid-Span Deflection

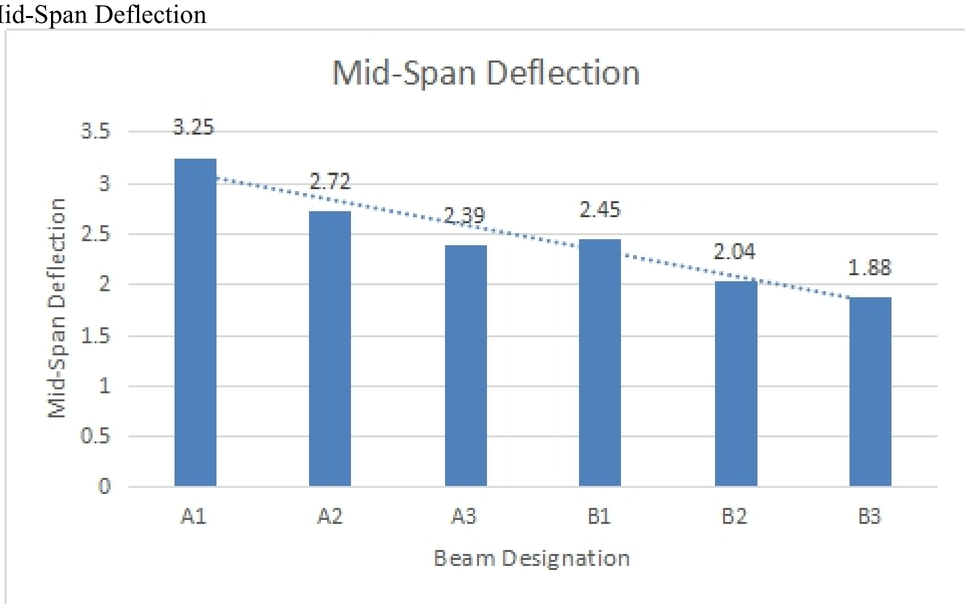


Figure 5. The mid-span deflection result from ANSYS APDL

Under 100kN of load, the mid-span deflection has different value according to the result from the ANSYS APDL. The beam without stirrup which is in mode 1 of modeling have shown that the reference beam without any strengthening bar has 3.25mm in displacement while the strengthening beam with 1 SMA bar and 2 SMA bars has approximately 2.72mm and 2.39mm respectively. The percentage for the mid span deflection of the strengthening beams could resist the deflection between 16% to 26% in 1 SMA strengthening bar and 2 strengthening SMA bar, respectively. The beam with stirrup which identify as mode 2 of the modeling have illustrated that the reference beam without strengthening bar has recorded of 2.45mm while the strengthening beam with 1 SMA and 2 SMA bars have data of 2.04mm and 1.88mm respectively. The percentage for the mid span deflection of the strengthening beams could resist the deflection between 16% to 23% in 1 SMA strengthening bar and 2 strengthening SMA bar, respectively.

b. Shear Stress Result

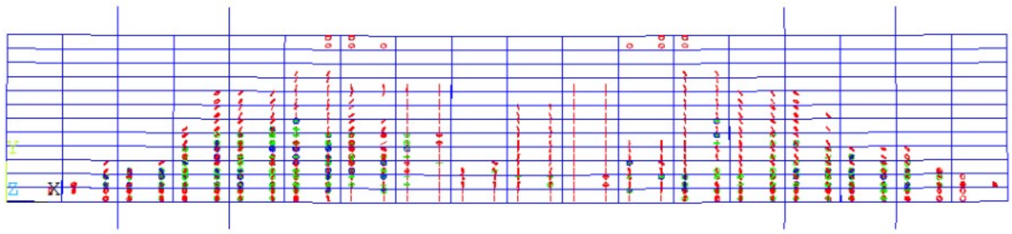
The precise shear stress data of all reinforcement concrete beam are recorded in the table 7. The data show that the more reinforcement in the beams, the less shear stress could occur.

TABLE 7: SHEAR STRESS DATA FROM ANSYS APDL

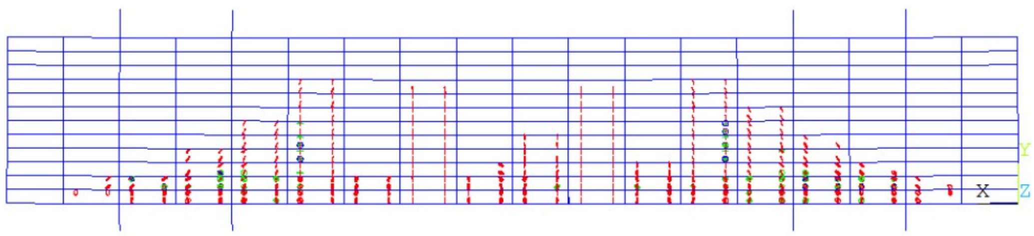
Model	Beam Designation	Max Shear Stress (MPa)
1	A1	2.92
	A2	2.58
	A3	2.36
2	B1	2.39
	B2	2.003
	B3	1.84

c. Crack and Crush plot

The comparative fracture of the RC beams reinforced with 2 SMA bars are shown in figure. It can be seen that after carrying the 100kN of load on the beams the mode 2 beam with stirrup and 2 SMA bars have less crack and crush than the first picture without stirrup.



a)



b)

Figure 6: crack and crush plot a). 2 SMA bars reinforced in RC beams without stirrup b). 2 SMA bars reinforced in RC beams with stirrup

2) Discussion

The use of SMA with embedded bars for shear strengthening proved to have a significant amount of resisting the failure of mid span deflection as well as the shear stress. In table 8 below have shown the data of the effectiveness by using SMA reinforced in RC beams with ETS method.

TABLE 8: THE EFFECTIVENESS OF USING SMA REINFORCED WITH ETS METHOD

Model	Beam Designation	Deflection(mm)	Shear Stress (MPa)	Δ_{def}/def_{ref}(%)	$\Delta\delta_{max}/\delta_{ref}$(%)
1	A1	3.25	2.92	-	-
	A2	2.72	2.58	16	11.64
	A3	2.39	2.36	26	19.17
2	B1	2.45	2.39	-	-
	B2	2.04	2.003	16	16.31
	B3	1.88	1.84	23	23.01

a. Mid-span Deflection

The absolute mid span deflection in the finite element modeling at the ultimate load of 100kN in each specimens proved that the strengthening bars with 1 embedded bar and 2 embedded could resist the deflection of the reinforcement concrete beam up to 16% and up to 26%, respectively comparing to the reference beams of each model designation.

b. The Effective of Using SMA for Strengthening

The improvement of strengthening SMA bars have been shown as the effectiveness from resisting the deflection and shear stress in the reinforcement concrete beam. With under 100kN of load, both 1 SMA strengthening beams could resist the deflection up to 16% while the resistance of shear stress could have efficiency up to 23% comparing to the reference beam of each model designation. At the same time, with the same load applied, both 2 SMA strengthening beams identify to be resist the deflection up to 26% while the resistance of shear stress could have the effectiveness of strengthening by 23%.

V. CONCLUSION

This whole paper is the investigation of shear behavior reinforcing with shape memory alloy by using ANSYS APDL program which has provided the efficiency evidence of the embedded through section method. The program is known to have enough accuracy with the high level of reliability that so many authors use for simulation for structural analysis. These results presented the efficiency between the method and the strengthening material.

These improvement of the strengthening with the SMA embedded bars demonstrated that the use of SMA as superelasticity could be effective for using as strengthening bars with the traditional steel rebar in the existing concrete structure works for the civil structure.

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