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Behavior of Smart Reinforced Concrete Beam Column Joints by Using Shape Memory Alloy Reinforcement Under Repeated Loading

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ABSTRACT

Using the super elastic materials in structures design is becoming very important in the research field because of their rare ability in sensing the around effect and reacting against the mechanical and thermal react. The major intent in this research is designing smart concrete beam column joints reinforced by Shape Memory Alloy (SMA) bars. The suggested systems use the (super elastic) Pseudo Elastic (PE) react of the SMA as reinforcement after being subjected under monotonic and repeated load. The behaviors of systems were explored experimentally and by using finite element simulation. In order to estimate load-displacement relationships of these specimens in this study, Analytical models were developed. A comparison of the reinforced specimens by SMA was carried out and it contained that the variation in percentage of the SMA in flexural reinforcement (25%, 50%, 75%) of the total flexural reinforcement by using this substitution get a clear effect on the failure load and the ultimate displacement of the specimens with these different ratios. The Finite Element models were developed by using the software ABAQUS. The models have been checked with the experimental results in the load-displacement terms in the top reinforcement. The models showed reasonable response. Where the ultimate load decreased by using SMA bars in (25%, 50%, 75%) percentage of total flexural reinforcement about (50.51%, 28.32%, 38.15%) respectively, in case of static loading and (20.7%, 10.7%, 9.3%) respectively in case of repeated loading, and the deflection is increasing by using SMA in (25%, 50%, 75%) percentage of total flexural reinforcement about (1.2%, 8.4%, 0.36%) respectively, in case of static loading and (9.6%, 5.28%, 10.9%) respectively in case of repeated loading.

1. Introduction

The earthquake amplitude designing technique is based first on the confirmation of failure in ductile state by dissipating energy in certain places in structure. These places are coded as plastic hinges (i.e., center of rotation) and are articulated to confirm bend failure and stop undesired failure in shear state. To prevent collapse by forming a so- called "beam mechanism", the places and advancement of the plastic hinges are designed. This technique refers to the formula Plastic hinges in all frameworks are in the face of the columns in the girders followed by plastic hinges crafting in columns in the primary framework [1].

The first preference in earthquake design is to reduce losses in lives, which need perhaps loss of the utilization of the structure when exposed to earthquake. But revolutionist design mechanisms related with the utilization of new texture materials can be utilized in order to accomplish a smart way of behaving with impressive produce of dissipation of energy in monolithic Reinforced Concrete (RC) structures.

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The SMA is a rare alloy had the capability to bear huge deformations and back to the original shape when stress removed (psuedoelasticity) or heating (shape memory effect) [2]. The cyclic response of SMA is shown in Figure 2.

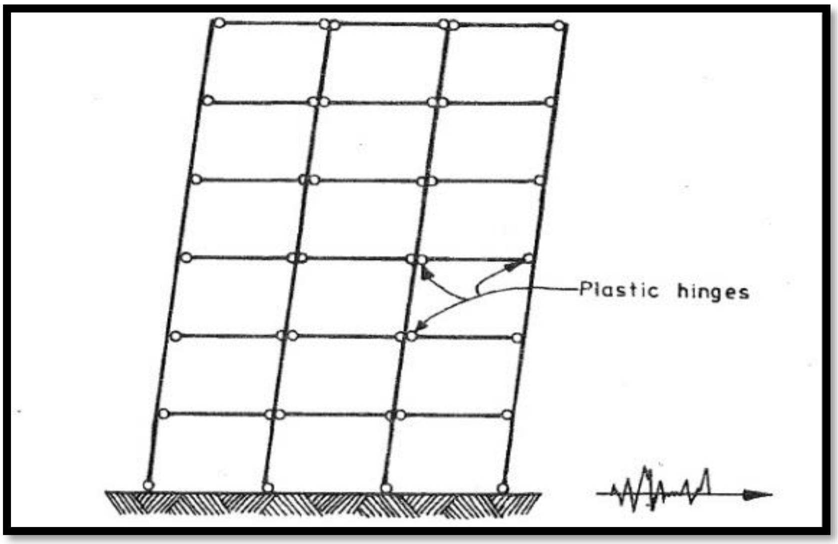

Figure 1. Beam sideway mechanism for a frame under seismic loading [3]

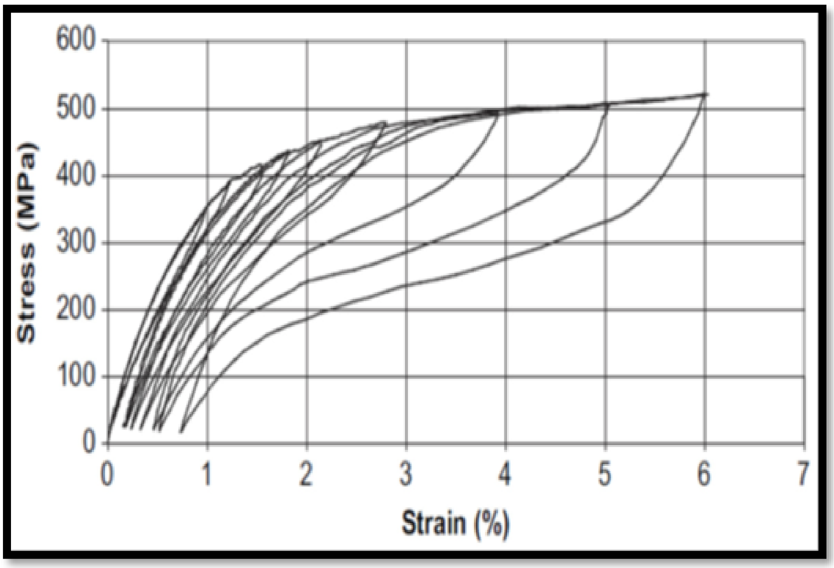

Figure 2. Relationship of Stress-Strain for SMA [4]

The practical application of nickel-titanium (NiTi) shape memory alloy has lateraly emerged as a hopeful solution in the field of seismic engineering. particularly, the capability of Shape Memory Alloys (SMA) to undergo inverse deformations of up to 8% strain (either by heating of martensitic SMA or by unloading austenitic SMA) and to dissipate a medium quantity of energy during repeated loading makes them a promising candidate for use as structural parts against seismic loading. Addition, the excellent corrosion resistance performance of SMA (stainless steel equivalent) may beat aging and toughness [5].

This study contains numerical analysis including simulation for experimental models that recently worked. The experimental program consisted of casting and testing two reinforced concrete beam-column joint specimens to study the effect of testing parameters (replacing 50%

of flexural steel reinforcement using SMA bars) on the repeated behavior of Beam Column Joints (periods of repeated loading were applied as shown in Figure 3. All the specimens were with the same cross-section and the same dimensions.

This alloy is capable of holding high amount of deformation and it's not permanent in opposite of steel so it has the ability to made a plastic hinge away from column which is the important criteria in seismic design in joints. The shape memory alloy bars are expensive comparing to construction materials, so work continued using numerical simulation by ABAQUS program and made a substitution with (25, 75%) percentage for flexural reinforcement.

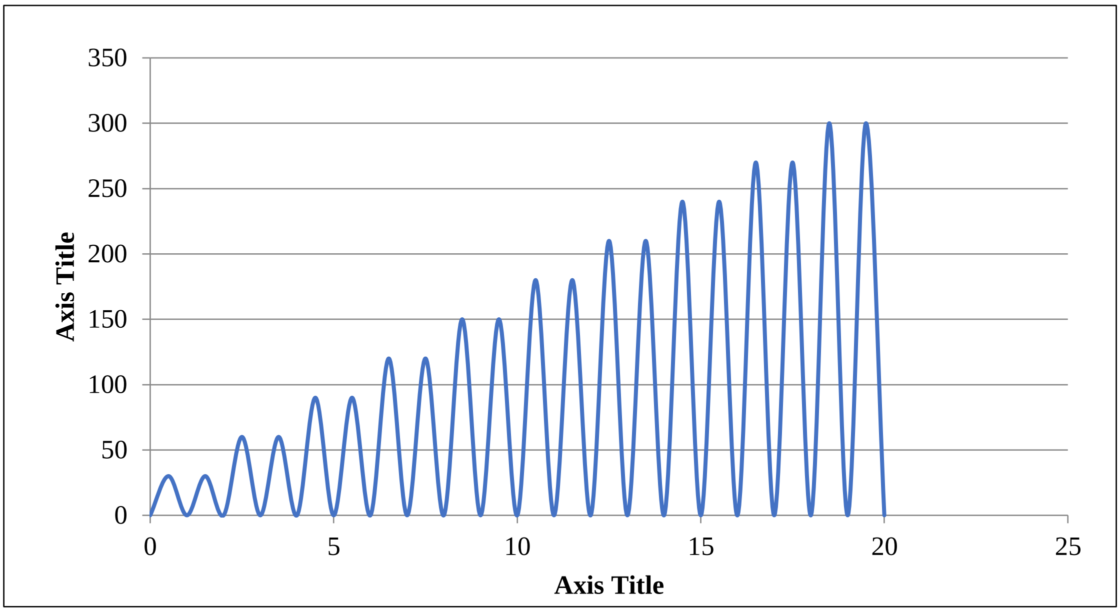

Figure 3. Loading history applied to the test specimens

Figure 4. SMA Bars

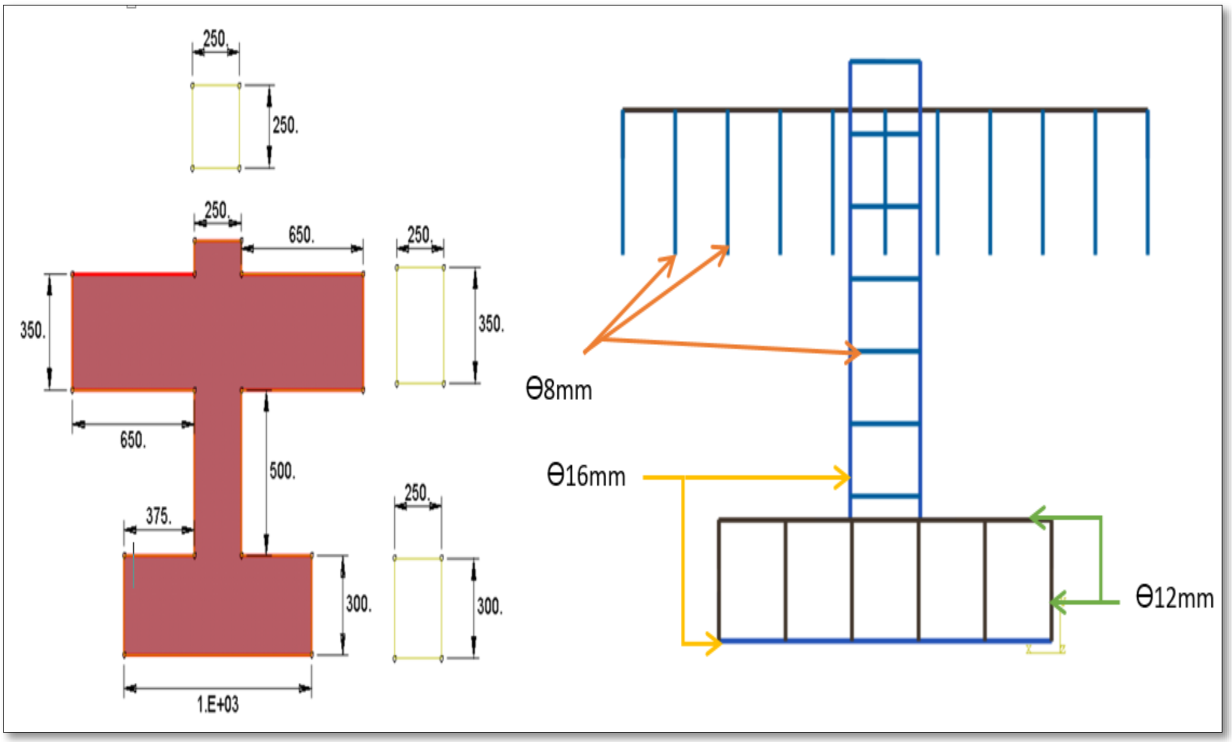

Figure 5. Geometry and dimensions for specimens (All dimensions in mm) (a) dimension and cross section for beam, column and foundation (b) Reinforcement details

Figure 6. Steel reinforcement of testing specimens

Many studies have been studying the impact of an earthquake in the contact area, including:

The SMA material was used in damping application due to its superior PE response and energy dissipation ability. The astounding damping property of SMA was used in the plan of primary dampers and base seclusion frameworks [6][7]. The capacity of the PE SMA to assimilate the energy initiated by the movement and to disseminate it as inactive hotness during the Martensitic and invert changes is capable of the rising utilization of PE SMA in damping applications.

A few studies concentrate on inspected the utilization of PE SMA wires and bars in the design of cement footers exposed to twisting tentatively and scientifically.

Jelan and Ali Laftah (2019) [8] assesses the seismic exhibition of steel frames with new sort of partially restrained utilizing shape memory alloy (SMA). The connection comprises of 16 steel bars and SMA bars (25.4 mm) in diameter. 3D Finite element simulation utilizing ABAQUS v.2017 programming is created. The consequences of mathematical review shows that the adding SMA bars in outline rather than steel bars with proportion of (100 percent, half) worked on solid recentring capacity, as contrasted and reference model, also the decrease in lingering rooftop removal in the event of casing outfitted with 100 percent SMA bars and casing prepared half SMA bars and half steel bars separately, as contrasted and reference model. Likewise adding SMA bars rather than steel bars in outline lead to great contribute towards diminishes the pressure and lingering pressure.

2. Geometry

Three-dimensional (3D) FEMs were developed using ABAQUS 6.11 software. The connection sections were sketched using 3D deformable solid extrusion. The steel plates were sketched using 3D deformable solid. The steel reinforcement, steel bars and the SMA bars were sketched using 3D wires as shown in Figure 6.

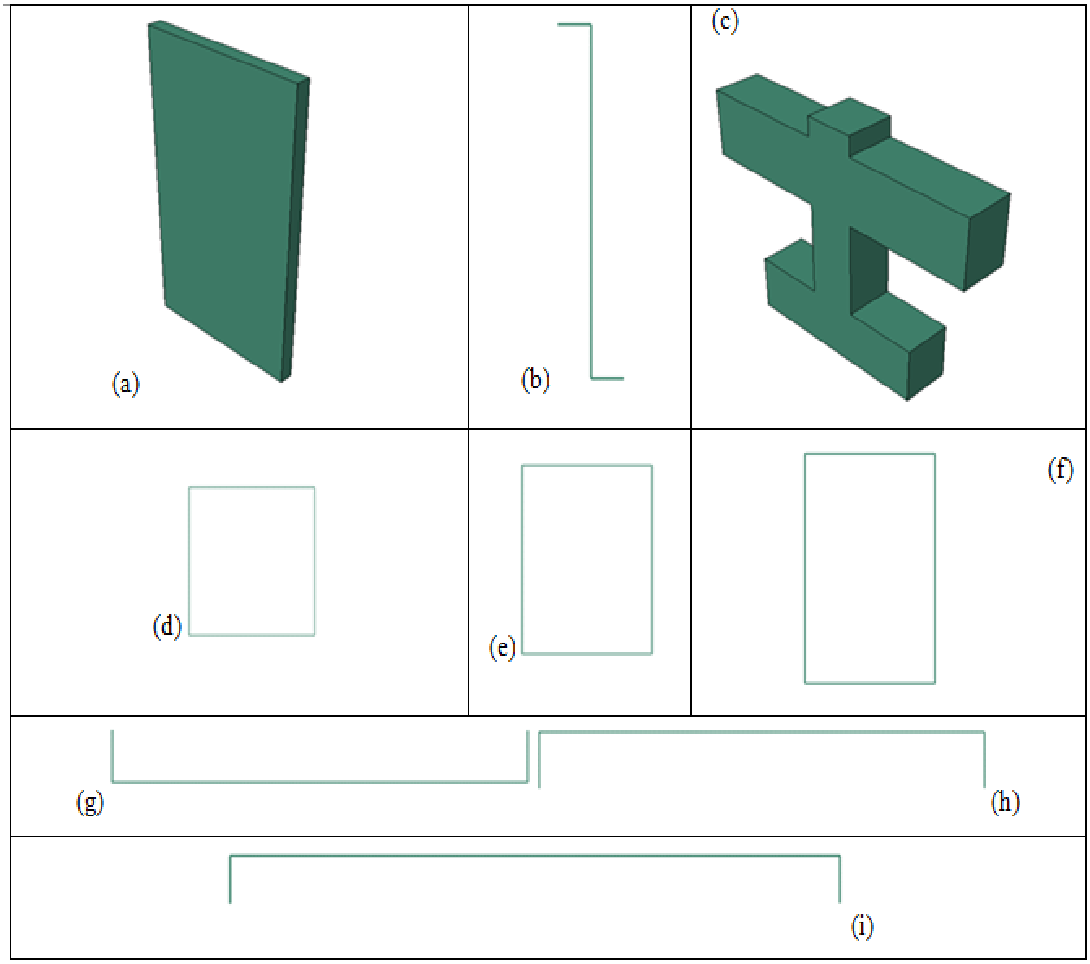

Figure 6. Three-dimensional (3D) FEM parts (a) Loading plate, (b) column reinforcement, (c) concrete part, (d) ties, (e) beam stirrups, (f) foundation stirrups, (g) foundation bottom reinforcement, (h)foundation top reinforcement, (i) beam longitudinal reinforcement

3. Model validation

The results obtained from the FEM models are compared with the experimental results under negative bending with respect to the load-displacement relationships, profile of beam rotation, and profile of strain variation in the bottom reinforcement. The comparison results are presented in Table (1) under negative bending, in terms of the load deflection in the upper reinforcement at the ultimate displacement. The percentage errors with respect to the experimental results are also included in the tables. The analysis of the comparison results included in the tables are discussed in the following paragraphs.

Table 1: Comparison of the FEM results with the experimental results

Specimen	Ultimate load			Ultimate displacement			No. of cycles	
	EXP	FEM	Err %	EXP	FEM	Err %	EXP	FEM
SR-S*	304.34	320.95	5.4%	27.37	22.49	17.82%	——	——
SMA-S	265.01	230.04	13%	36.78	29.67	19.3%	——	——
SR-R*	298.55	297.88	0.22%	18.85	24.03	27.4%	16	18
SMA-R	233.72	265.72	13.7%	27.57	25.309	8.2%	12	18

SR= Steel reinforced specimens
SMA= SMA Reinforced specimens
S= Static Loading
R= Repeated Loading
*= reference specimens

The maximum load of the experimental specimens (S-RSL, SMA-RSL, S-RRL and SMA-RRL) are (304.34, 265.01, 298.55 and 233.72) kN, while the maximum load of current finite element model is found is 320.95, 230.04, 297.88 and 265.72) kN. Thus, the percentage error of finite element simulation is (5.4, 13, 0.22 and 13.69 %). So, the analysis results show acceptable results for finite element simulation.

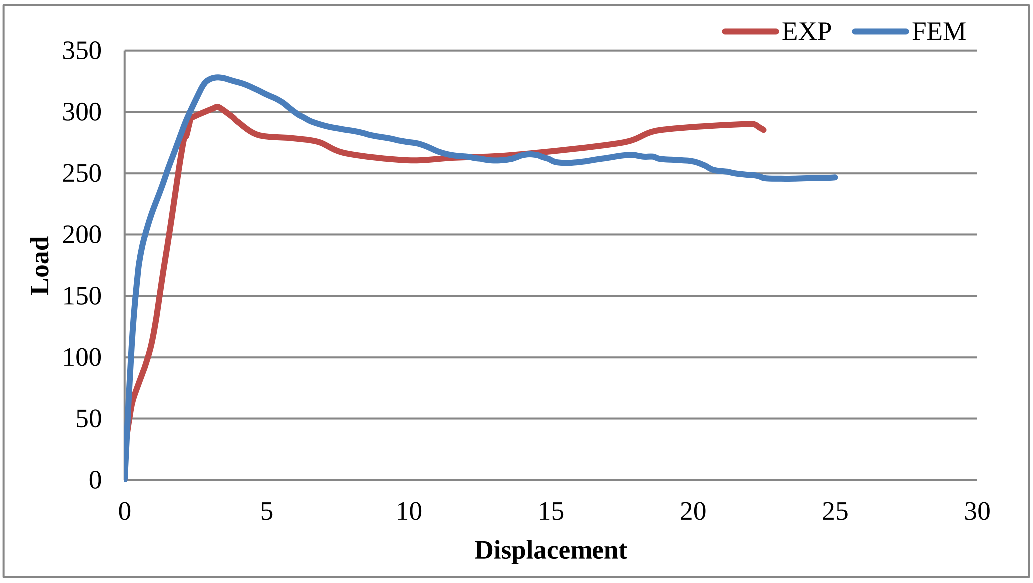

Figure 7. Comparison of the load deflection FEM results with the experimental results for reference specimen under static loading

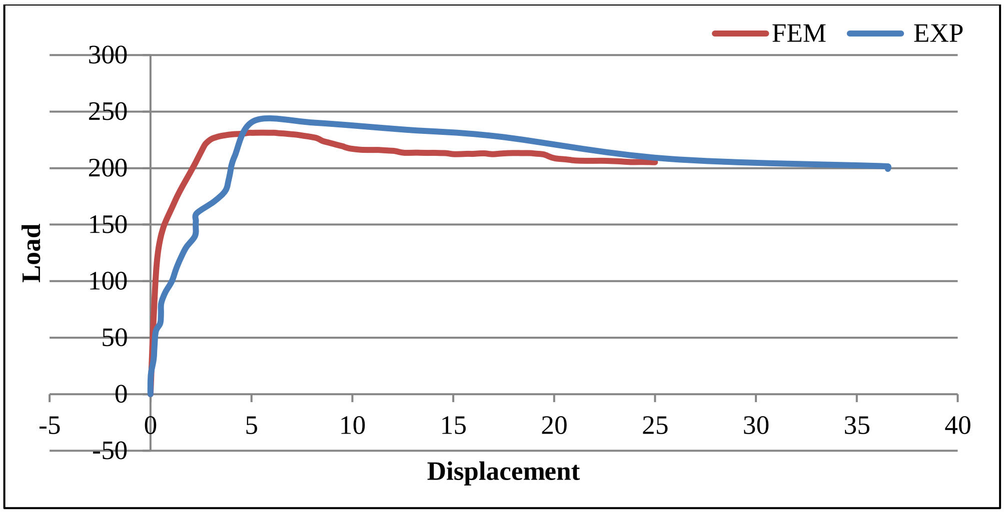

Figure 8. Comparison of the load deflection FEM results with the experimental results for SMA specimen under static loading

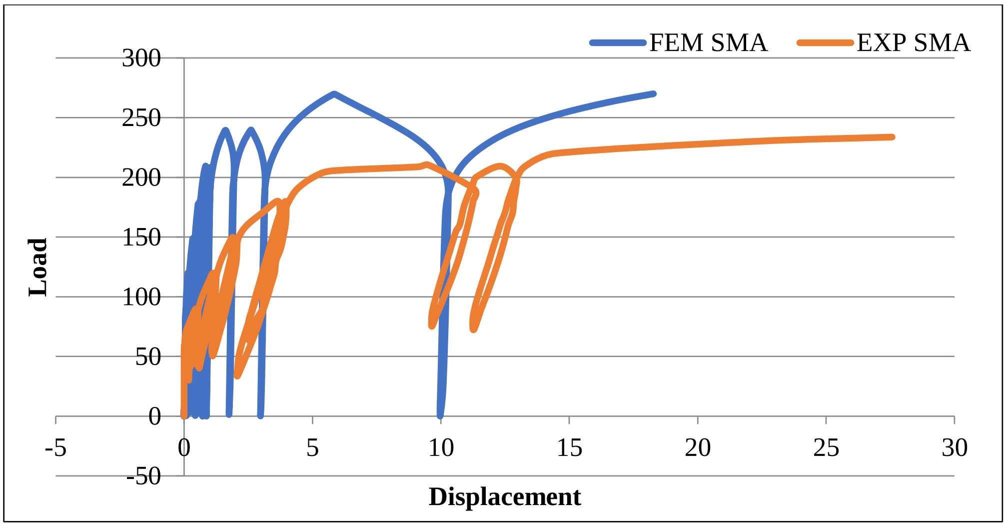

Figure 9. Comparison of the load deflection FEM results with the experimental results for SMA specimen under repeated loading G

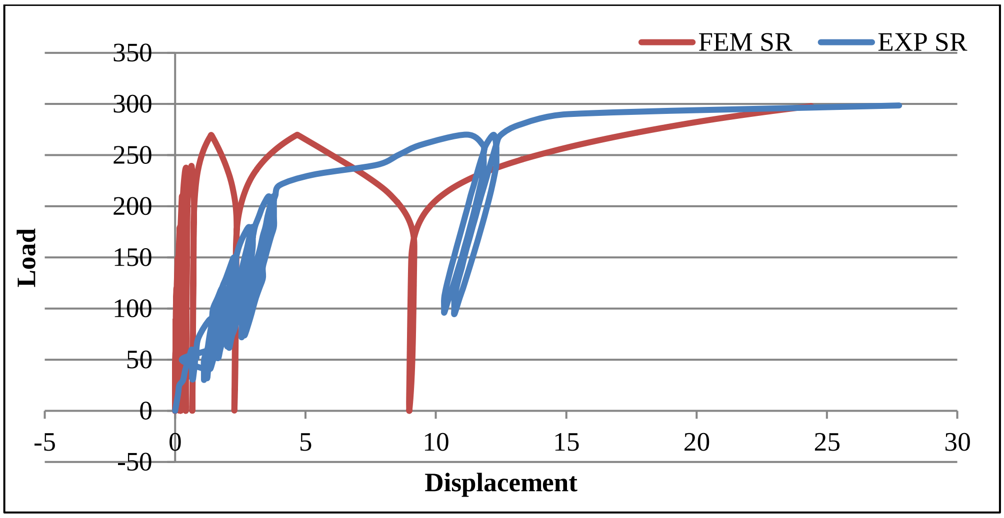

Figure 10. Comparison of the load deflection FEM results with the experimental results for reference specimen under repeated loading

4. Results of FEM simulation

a. The Ultimate Load of the FEM model with different percentage substitution of SMA bars under static loading

In this comparison we study the effect of replacing (25, 50 and 75%) of flexural reinforcement by a shape memory alloy bars and compare it to the convenient reinforced model. The models are tested under static loading. Table (2) shows the results of this comparison as below: the ultimate load in (0, 25, 50 and 75%) replacement models are: 320.9, 155.38, 230.04 and 198.521 kN, and the different percentage from the reference model are (50.51, 28.32, 38.14%) sequency.

b. The Ultimate deflection of the FEM model with different percentage substitution of SMA bars under static loading

We study in this comparison the effect of flexural reinforcement replacing of by a shape memory alloy bars various percentage (25, 50 and 75%) and compare it to the convenient reinforced model. The models are tested under static loading.

Results in table (5-5) show the deflection in these models as below: for (0, 25, 50 and 75%) SMA reinforcement percentage there are (27.37, 27.7, 29.6, 27.47) mm deflection and yhey are differ from each other in (1.2, 8.4, 0.36 %) in sequence.

Table 2: The Ultimate Load and deflection of the FEM model with different percentage substitution of SMA bars under static loading

Specimen	Ultimate load	%diff in pu	Ultimate deflection	% diff in Δu
0% SMA	320.95		27.37	
25% SMA	155.38	50.51%	27.7	1.2%
50% SMA	230.04	28.32%	29.67	8.4%
75% SMA	198.521	38.145	27.47	0.36%

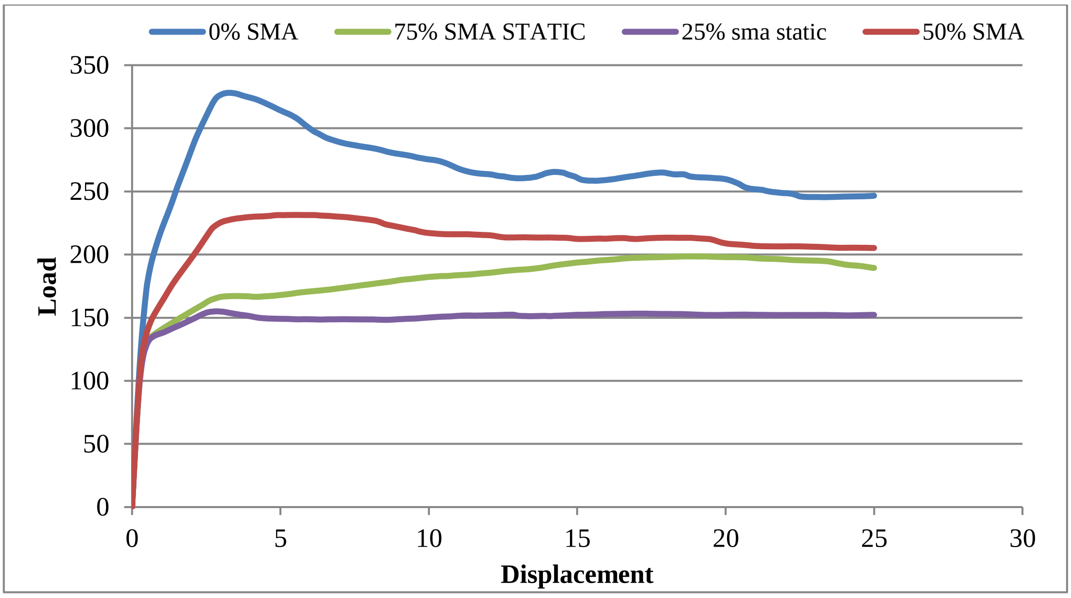

Figure 11. Load deflection of sma substitution models

c. The Ultimate Load of the FEM model with different percentage substitution of SMA bars under repeated loading

In this comparison we study the effect of replacing (25, 50 and 75%) of flexural reinforcement by a shape memory alloy bars and compare it to the convenient reinforced model. The models are tested under repeated loading.

Table (5-3) shows the results of this comparison as below: the ultimate load in (0, 25, 50 and 75%) replacement models are: 297.88, 239.9, 265.72 and 269.956 kN, and the different percentage from the reference model are (20.7, 10.7, 9.3%) sequence.

d. The Ultimate deflection of the FEM model with different percentage substitution of SMA bars under repeated loading

It has been studied in this comparison the effect of flexural reinforcement replacing of by a shape memory alloy bars various percentage (25, 50 and 75%) and compare it to the convenient reinforced model. The models are tested under repeated loading.

Results in Table (5-5) show the deflection in these models as below: for (0, 25, 50 and 75%) SMA reinforcement percentage there are (27.37, 24.03, 21.7, 25.3, 21.4) mm deflection and they are differing from each other in (9.6, 5.28, 10.9 %) in sequence.

Table 3: The Ultimate Load of the FEM model with different percentage substitution of SMA bars under repeated loading

specimen	Ultimate load	% diff u	Ultimate def.	Diff%	No. of cycles
0% SMA	297.88		24.03		18
25% SMA	239.9	20.7%	21.7	9.6%	15
50% SMA	265.72	10.7%	25.3	5.28%	18
75% SMA	269.956	9.3%	21.4	10.9%	18

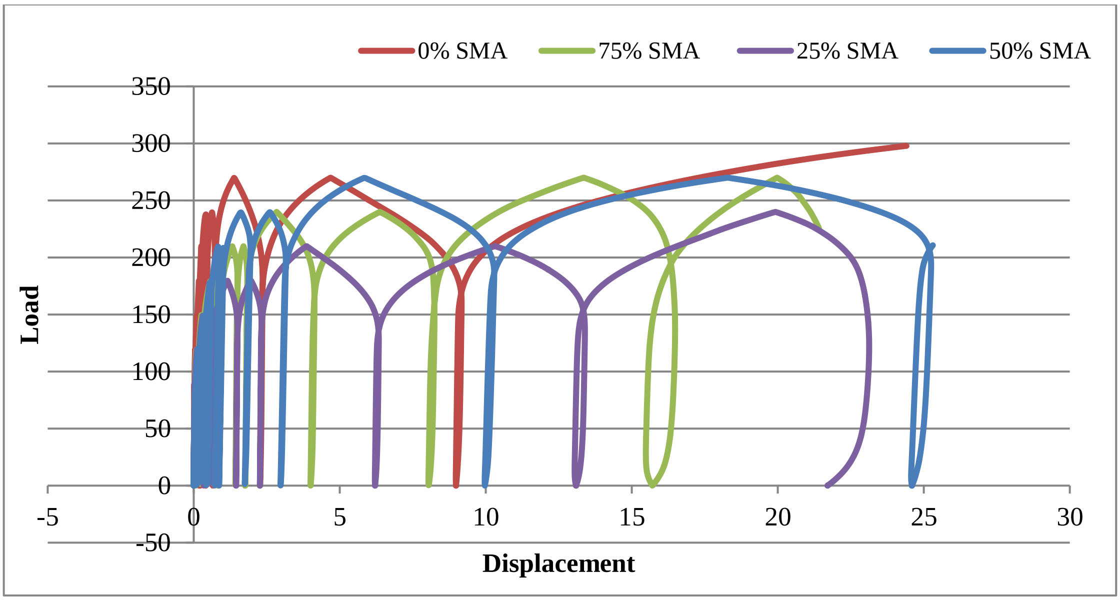

Figure 12. load deflection for SMA substitution models under repeated loading

5. Conclusions

Based on the results presented in this research and the observations obtained from the numerical analysis, the conclusions drawn from this work can be summarized as follows:

For the numerical analysis the results show that:

1. The ultimate load will be decreased by using SMA bars in (25%, 50%, 75%) percentage of total flexural

reinforcement about (50.51%, 28.32%, 38.15%) respectively, in case of static loading and (20.7%, 10.7%, 9.3%) respectively in case of repeated loading.

2. The deflection is increasing by using SMA in (25%, 50%, 75%) percentage of total flexural reinforcement about (1.2%, 8.4%, 0.36%) respectively, in case of static loading and (9.6%, 5.28%, 10.9%) respectively in case of repeated loading.

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