Role of diameter and percentage of SMA bars as reinforcement in strength and residual displacement of concrete beams

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Shape memory alloy (SMA) is a smart material that is currently used in reinforced concrete members. This preliminary research aims to numerically investigate the role of diameter and percentage of SMA as the main reinforcement of concrete beam in increasing stiffness and reduction of residual displacement. To do so, eight beams with same geometry and boundary condition reinforced with superelastic SMA under two cycle of four-point bending loading in Ansys APDL have been simulated. Results showed that enhancement of ratio of SMA in the beams will reduce residual displacement and increase stiffness of the beams. Furthermore, for beams with same percentage of SMA bars, more number of bars with thinner diameters leaded to less residual displacement compared to less number of bars with thicker diameters.

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1 Introduction

Although Concrete reinforced with conventional steel bars is still used to construct a wide range of bridges and buildings around the world, appearing cracks at the early age of service life of the concrete structures is still counted as one of its weaknesses. This phenomenon is inevitable \cite{1}, but there are some ideas to mitigate its damage’s intensity and consequences. Use of intelligent materials like SMA within concrete members is one of those ideas. There are two forms of SMA; 1) superelastic shape memory alloy and 2) shape memory effect. Embeding superelastic SMA inside the concrete will help the beams recovering their initial form after undergoing to large deformations. Although many investigation in this regard have been done, there is still doubt in choosing suitable ratio, shape and thickness of the SMA bars. Therefore, this study aims to investigate the role of amount and diameter of the SMA bar in specifying stiffness, residual displacement, recovery ratio and cracking load of the beams.

2 Model setup and assumptions

Eight simply supported beams with minimum size based on the Euro-code \cite{2} for four point bending test in Ansys APDL have been simulated. As it is shown in figure 1 dimension of all specimens were 500, 100 and 100 mm in length, height and width, respectively. An impactor at L/3 distance from beams’ edge has been simulated to avoid creating highly distorted element and convergence issue. As it is shown in figure 3, two load cycles with value of 4.5 KN and duration of 60s for each cycle were applied on the impactor’s top surface. Each loading and unloading process was applied in 60 time steps; however, both time step prediction and time step bisection were utilized by the software. Two case studies were investigated; first case study contained six beams, B1-B6, with different percentages 0.5, 1.0, 1.5, 2.0, 2.5, 3.1\% of SMA bars, respectively, but the same diameter 8mm and second case study contained three beams, B3, B7 and B8 which had same percentage (1.5\%) of SMA, but different diameters 8, 10, 6 mm, respectively. Solid element 65 which has capability of cracking in tension and crushing in compression, plastic deformation and creep has been utilized to simulate concrete material. Cubic shape of the element is recommended to avoid convergence issues. Solid element 185 were utilized to simulate SMA bars. Contact element 174 and target element 170 were employed to define surface-to-surface contacts between concrete and SMA bars’ surface and between top surface of concrete beams and bottom surface of the impactor.

Young modulus and poisson’s ratio of the concrete were assumed to be 30 GPa and 0.2, respectively. Existing stress-strain diagram shown in figure 2 used as input data of non-linear material properties of the concrete; uniaxial cracking and crushing stresses of concrete were supposed to be 2.5 and 30 MPa, Respectively. Initial young modulus and poisson’s ratio of the SMA bars were assumed to be 60 GPa and 0.3, respectively. Starting and final for forward and reverse transformation were supposed to be 520, 600, 300, 200 MPa, respectively. Maximum residual strain of the alloy is also considered to be 0.05. In this research it is assumed to have a good bonding between surface of the SMA bars and concrete. To do so, contact algorithm of Multipoint constraints (MPC) has been followed and behaviour of contact surface was assumed to be bonded always.
3 Results and Discussion

As it is shown in figure 4, Stiffness of beam B6 reinforced with 3% SMA is greater than all other beams B2-B6 for first case study. Cracking load for beam B6 is 4.2 kN, while this value for beams B2-B5 reached 3.6, 3.9, 4.1, 4.2 kN, respectively. It can be seen that up to 2.5% whatever the SMA ratio increases, the corresponded stiffness and cracking load values increase. Furthermore, since all beams experienced cracks during the first load cycle and SMA bars carried whole applied load alone during second load cycle. Beams B5 and B6 with 2.5% and 3% SMA, respectively, have smallest residual displacement value 1.4mm. Upon loading maximum displacement of B6 reached 4.8cm, but upon unloading with help of smart behavior of SMA bars the value reduced to 1.4mm. The maximum displacement of beams B2-B4 at peak load value of the first load cycle were 6.1, 5.3, 5.0 cm respectively; while, the values at end of unloading reduced to 2.3, 1.8, 1.5 mm, respectively. Therefore, with increasing ratio of the SMA, the residual displacement will be correspondingly reduced.

Load-displacement behavior of beams B7, B3, B8 correspondig to second case study under first load cycle is shown in figure 5. Maximum displacement of the beam B7, B3 and B8 at peak load value of the first load cycle were recorded as 5.7, 5.4 and 5.2 cm, respectively. Superelastic behavior of the bars upon unloading assisted the concrete beams to recover their initial shape; consequently, the displacements reduced to 0.2, 0.18, 0.16 cm, respectively. It means that when same ratio of SMA used in concrete, the beam reinforced with thinner diameter but more number of bars will have smaller residual displacement compared to beam reinforced with thicker diameter but less number of bars. In addition, beam reinforced with more number of bars will provide stiffer beam so that cracking load value for B7, B3 and B8 recorded to be 4.1, 3.9 and 3.7 kN, respectively.

4 Conclusion

This preliminary research has been done due to uncertainty to use SMA bars as reinforcement of concrete beams. Two case studies, beams with different percentage ratios of SMA but same bar diameter and beams with same percentage ratio of the alloy but different diameters of the bar were investigated in order to observed influence of the percentage and diameter of SMA bars on the residual displacement, stiffness, recovery ratio of the beams. Obtained results demonstrated that: 1) Using larger percentage of the SMA bar in concrete beam will not only provide stiffer beam but also increase recovery ratio of the beam upon unloading that consequently lead to reduce residual displacement of the beam. Furthermore, when the ratio of used SMA in the beams are the same, using more number of bars with thinner diameters provides stiffer beam with higher cracking load and less residual displacement compared to beams reinforced with less number of bar with thicker diameters.

References

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