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Experimental Investigation on the Behavior of Reinforced Concrete Beams Retrofitted with NSM-SMA/FRP

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ABSTRACT: Re-centering is an exclusive characteristic of superelastic Shape Memory Alloys (SMAs) which can be used in manufacturing and retrofitting of reinforced concrete elements. Reinforced concrete beams retrofitted with SMA bars have more ductility and higher energy dissipation compared to conventional RC beams. Furthermore, these beams experience less damage in consecutive loading-unloading cycles. The current research aims to investigate the behavior of reinforced concrete beams retrofitted with SMA bars using Near-Surface Mounted (NSM) flexural retrofitting method. Eleven RC beam specimens with the cross section of 200*150 mm and length of 1150 mm were cast. Three of the specimens had no external strengthening, four of them were retrofitted with SMA bars and other four beams were retrofitted with GFRP reinforcements. The specimens were subjected to three-point bending test under either monastic or loading-unloading. Different parameters including load-carrying capacity, energy dissipation, deformation recovery and reduction capability of crack width were investigated. The results showed that RC beams retrofitted with SMA bars had more mid-span deflection and higher energy dissipation compared to other specimens under monotonic loading. Moreover, under loading-unloading, RC beams retrofitted with SMA bars method experienced less damage.

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1- Introduction

Concrete structures including bridges and buildings need be retrofitted due to various reasons such as exposure to corrosive environment [1]. FRP reinforcing bars are widely used for repairing and retrofitting the concrete structures. NSM method is a relatively new technique for installing the FRP bars in structural members. Nevertheless, some experimental investigations have been shown that due to linear elastic behavior of FRP bars, concrete structures retrofitted with NSM-FRP method may not have sufficient ductility. Recently, new kind of alloys called Shape Memory Alloys (SMA) have been used for structural applications. These materials are able to recover their initial shape upon unloading (superelastic property) or exposure to heat (shape memory property). The alloys have outstanding properties including recovery of high strains with minimum residual deformation, high corrosion resistance, high energy dissipation and desirable resistance against fatigue phenomenon. Using superelastic SMA bars in NSM method can be advantageous, since retrofitted RC elements with this material could dissipate more energy and experience relatively larger deformations. Therefore, they can have better performance during earthquakes [2].

In the present study, the flexural behavior of RC beams retrofitted with NSM-SMA method was evaluated and compared to that of retrofitted with NSM-FRP method and conventional beams. Several variables such as load-carrying capacity, energy dissipation, deformation recovery and reduction capability of crack width were investigated.

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2- Methodology

In the current study, 11 RC beam specimens with the dimensions of 1150*200*150 were cast and tested. Four of the specimens were retrofitted with NSM-SMA method, four of them were NSM-FRP retrofitted and three of them were without external strengthening. The specimens were subjected to three-point flexural tests either under static or loading-unloading. The details of the specimens are presented in Table 1. The geometries of beams, loading configuration and specimens' reinforcement arrangement are illustrated in Figure 1.

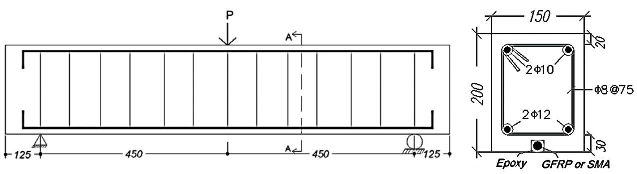

Figure 1. Geometries of beam specimens, reinforcement arrangement and loading configuration

Table 1. The characteristics of specimens

Specimen	Retrofitting method	Type of loading
BCM1	Without retrofitting	Monastic
BCC1	Without retrofitting	Loading-unloading
BCC2		
BFM1	NSM FRP	Monastic
BFM2		
BFC1	NSM FRP	Loading-unloading
BFC2		
BSM1	NSM SMA	Monastic
BSM2		
BSC1	NSM SMA	Loading-unloading
BSC2		

In order to retrofit the specimens with NSM method, a groove with the dimensions of 1020*15*15 was created on the tensile face of the specimens using diamond blade. Then, the dust was removed from the groove for preparing a suitable space for mounting the strengthening bars. Afterwards, an epoxy adhesive was utilized to install the bars into the grooves. For carrying out the flexural test, a load cell and two linear variable displacement transducers (LVDTs) mounted at the mid-span were installed to record load and mid-span deflections. The load cell and LVDTs were connected to a data logger acquisition system. The experimental load-deflection curves, mid-span deflections and load carrying capacity of the beams were obtained from the flexural test. In addition, observations of the crack propagation were recorded during the experiment.

3- Results and Discussions

The test results of the specimens subjected to monastic load are presented in Table 2. As seen in Table 2, although the specimen retrofitted with NSM-SMA method do not have higher load-carrying capacity, they experienced larger mid-span deflection and higher energy dissipation compared to other specimens. The maximum crack-widths after each loading-unloading cycle for the specimens subjected to loading-unloading test, are shown in Tables 3 and 4. As can be seen in the tables, the specimens retrofitted with NSM-SMA method had higher capability to reduce the crack widths. Additionally, the ability of specimens with different kinds of strengthening methods to recover their mid-span deflection is illustrated in Figures 1 & 2. As shown in these figures, NSM-SMA- retrofitted specimens had higher ability to recover their deformation under loading-unloading flexural test in comparison with the specimens with no external strengthening and specimens retrofitted with NSM-FRP method.

Table 2. Test results of the specimens subjected to monastic loading

Specimen	Maximum mid-span deflection (mm)	Maximum load-carrying capacity (kN)	Area under load-deflection curve (kN.mm)
BCM1	35	113	3035
BFM1	31	126	3108
BFM2	29	122	2858
BSM1	47	117	4599
BSM2	50	113	4932

Table 3. Maximum crack width of specimens BCC1, BFC1 and BSC1 after each loading-unloading cycle

Cycle	BCC1		BFC1		BSC1	
	W_{cr}* (mm)	R_{cr}* (mm)	W_{cr} (mm)	R_{cr} (mm)	W_{cr} (mm)	R_{cr} (mm)
$1\delta_y$	0.10	0.05	0.15	0.10	0.10	0
$2\delta_y$	0.85	0.70	1.40	1.00	0.60	0.15
$3\delta_y$	1.50	1.30	1.50	1.30	1.30	0.40
$4\delta_y$	2.00	1.60	1.60	1.30	2.50	1.60
$5\delta_y$	2.50	2.00	2.50	1.50	2.80	1.70
$6\delta_y$	3.00	2.60	2.50	2.20	3.10	2.30

* Wcr and Rcr represent the maximum crack width and residual crack width, respectively.

Table 4. Maximum crack width of specimens BCC2, BFC2 and BSC2 after each loading-unloading cycle

Cycle	BCC1		BFC1		BSC1	
	W_{cr}* (mm)	R_{cr}* (mm)	W_{cr} (mm)	R_{cr} (mm)	W_{cr} (mm)	R_{cr} (mm)
$1\delta_y$	0.15	0.10	0.10	0.05	0.05	0
$2\delta_y$	1.40	1.10	0.40	0.25	0.45	0.10
$3\delta_y$	1.50	1.30	0.80	0.55	1.20	0.40
$4\delta_y$	1.60	1.30	1.40	1.10	1.60	1.00
$5\delta_y$	2.50	1.70	2.00	1.50	2.10	1.30
$6\delta_y$	2.50	2.20	2.20	1.70	2.50	1.90

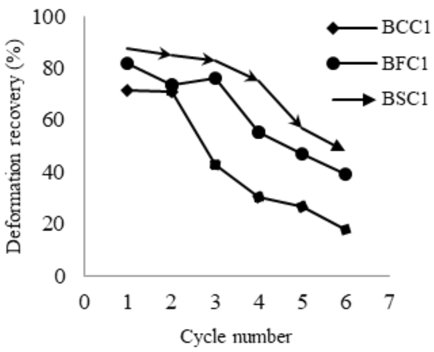

Figure 2. The ability of deformation recovery for the specimens BCC1, BFC1 and BSC1

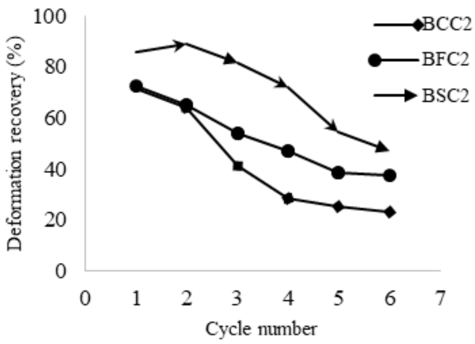

Figure 3. The ability of deformation recovery for the specimens BCC2, BFC2 and BSC2

4- Conclusion

Based on the test results obtained from the present experimental study, it can be concluded that RC beams retrofitted with NSM method by using NSM bars, have higher mid-span deflection and energy dissipation under monastic flexural test compared to conventional beams and NSM-FRP- retrofitted beams. Besides, the RC beams retrofitted with NSM-SMA method had higher capability to reduce the crack width and recover the deformation when subjected to loading-unloading test.

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