8th International Conference on Seismology & Earthquake Engineering
11-13 Nov. 2019, Tehran, Iran

# ANALYTICAL INVESTIGATION ON THE SMA-BASED RETROFITTING OF SUBSTANDARD RC FRAMES

Burak DURAN
*M.Sc. Graduate, Dokuz Eylul University, Izmir, Turkey*
*burak.duran@deu.edu.tr*
Özgür AVŞAR
*Associate Professor Dr., Eskisehir Technical University, Eskisehir, Turkey*
*ozguravsar@eskisehir.edu.tr*

**Keywords:** Shape memory alloys, analytical model, seismic retrofitting, reinforced concrete, residual

A number of existing reinforced concrete (RC) structures are at risk due to their under-designed conditions considering old-fashioned principles. To upgrade the seismic performance of these buildings has been getting an increased attention in the last two decades. Shape memory alloys (SMAs) are getting popular in improving the seismic performance of deficient structures as an alternative to conventional materials owing to its superelastic behavior. In this study, analytical models were generated for three 2/3-scaled one-bay and one-story substandard RC frames tested under quasi-static displacement-controlled reversed-cyclic loading by Duran et al. (2019). Two of RC frames were upgraded with superelastic (SE) CuAlMn shape memory alloy (S-2-CuAlMn) and conventional steel bars (S-3-Steel) while one of the experiments was performed for as-built specimen (S-1-REF).

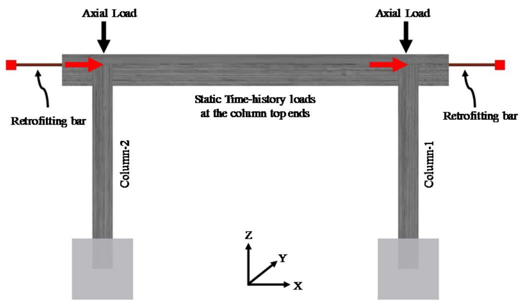
The constructed frames represented the existing building stock with some deficiencies such as low strength concrete, plain re-bars not satisfying the code requirements regarding the detailing, minimum amount and spacing criteria, strong beam-weak column phenomena etc. All these detailing caused the columns to have flexural plastic hinges before any plastic deformations at beam member. Moreover, it is significant to identify the material characteristics used in both construction and upgrading procedure to construct a proper model. All details related to the material tests can be found in Duran et al. (2019).

An analytical model representing the tested RC frames was constructed in SeismoStruct v.7.0.6 to make validation and comparison with the experimental results. The SeismoStruct is a structural analysis program predicting the seismic response of structures under various loading conditions by taking into consideration the geometric nonlinearities and material inelasticity. The structural members were modeled using 3D fiber-based modeling approach and also inelastic force-based element types were utilized. The fiber-based approach discretizes a RC section into a large number of fibers, whose stress-strain behavior under given loading conditions is individually introduced. Each of these section fibers represents the stress-strain behavior of the corresponding material. Afterward, the loading protocol used in the experiments was applied to the column top ends in the loading direction and static time-history analysis was conducted under the effect of axial load at the column top ends in the gravity direction. To represent the upgrading bars in the analytical model, two extra nodes are assigned to the left and right of the frame at the story level to connect the SMA rods to the beam-column joints (Figure 2-a). The SeismoStruct uses a uniaxial material model for SE SMAs developed by Fugazza (2003) and a constitutive relationship proposed by Auricchio and Sacco (1997). The nodes at the beam level were restrained such that only in-plane deformations were considered by preventing the out-of-plane movements to represent the actual conditions in the experiments. Furthermore, in the analytical modeling approach, upgrading bars were introduced to the system as truss members so that they only worked under axial loading.

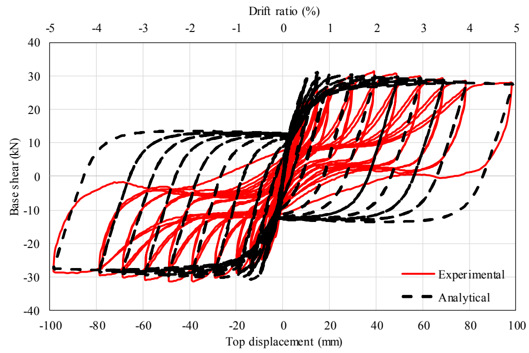
The results obtained from the analytical models generally match up well with the experimental ones in terms of ultimate load, envelope curves, ductile behavior and the variations of reinforcement and concrete strains during the cyclic response of RC frames. However, in given hysteretic curves in Figure 2, it is apparent that the hysteretic loops have a tendency to become narrow bands during the unloading process, which cannot be fully represented in the analytical models. Additionally, fracturing points of retrofitting steel bars are also compatible with the experimental ones on the hysteretic curve of S-3-Steel whereas the fracture of CuAlMn bars were not observed in the analytical hysteresis due to a constant modulus of elasticity assumption in both austenitic and martensitic phases of material model for SMAs.


(a) Overall picture of experimental setup (b) Front view of upgrading mechanism

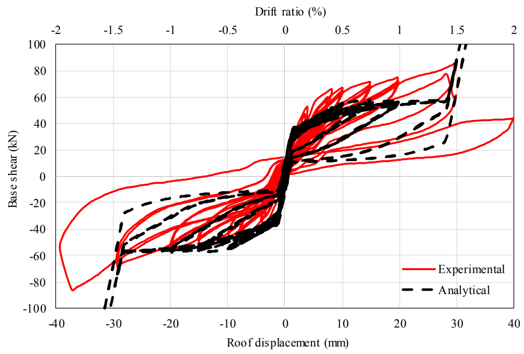
*Figure 1. Details of test setup and upgrading mechanism (Duran et al., 2019).*



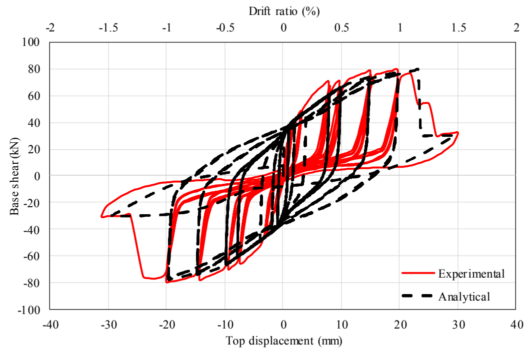

(a) Side view of the analytical model




(b) Hysteretic comparison for S-1-REF




(c) Hysteretic comparison for S-2-CuAlMn




(d) Hysteretic comparison for S-3-Steel

*Figure 2. Analytical model and comparison for hysteretic curves (Duran et al., 2019).*

In accordance with the purpose of the experimental study, re-centering property was clearly observed in both analytical and experimental hysteresis of S-2-CuAlMn due to the superelastic effect of SMA bars. This distinctive behavior gave opportunity to get negligible residual deformation limits upon unloading of RC frames. The reduction in the permanent deformation limits due to a recovery process is even beneficial to repair the damaged structures for minimizing the physical interventions.

## REFERENCES

Duran, B., Tunaboyu, O., Atli, K.C., and Avşar, Ö. (2019). Seismic performance upgrading of substandard RC frames using shape memory alloy bars. *Smart Materials and Structures*, *28*, 085007.

SeismoSoft (2011). SeismoStruct - A computer program for static and dynamic nonlinear analysis of framed structures, Available from: www.seismosoft.com.

Fugazza, D. (2003). *Shape-memory Alloy Devices in Earthquake Engineering: Mechanical Properties, Constitutive Modelling and Numerical Simulations*. M.Sc. Dissertation, European School for Advanced Studies in Reduction of Seismic Risk (ROSE School), Pavia, Italy.

Auricchio, F. and Sacco, E. (1997). A superelastic shape-memory-alloy beam model. *Journal of Intelligent Material Systems and Structures*, *8*(6), 489-501.