

Numerical Investigation of Shape Memory Alloys and Side Plates Perforation Effect on Hysteresis Performance of Connections

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ABSTRACT

The most common disadvantage in moment connections is the brittle fracture of the welded area during an earthquake. One creative way to fix such disadvantages is to use Side Plates to connect the beam to column. Previous studies have focused more on the performance of connections with side plate and comparison of these connections with other types of moment connections. In this study, the effect of material type, thickness, and perforation of the side plates on the cyclic performance is investigated. For this purpose, in addition to using side plates of soft steel (ST37) and high strength structural steel (ST52), nickel-titanium shaped memory alloy (SMA-Ni-Ti) has also been used to investigate the superelastic effect to this alloy on the connection performance. Modeling and analysis was performed in ABAQUS finite element software under cyclic loading and the results showed that the increased capacity and ductility of the side plate connections with shape memory alloy and also revealed that optimal thicknesses can be obtained for side plate in order to create the maximum possible ductility at the connection and preventing the formation of plastic hinges. According to the results obtained by changing the configuration and cutting in connection and in general, the capacity of the connection decreased in 0.04 radian (moment frame acceptance limit) and stress concentration in the cutting corners had the greatest effect on the failure of the side plates.

KEYWORDS

Moment Connection, Side Plate, Brittle Fracture, Cyclic Performance, Shape Memory Alloy

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1. Introduction

The construction of steel moment-resisting frame structures underwent dramatic changes in the second half of the 20th century, resulting in the challenge of code design trends by earthquakes such as Northridge (1994) and Kobe (1995). The performance of steel structures in these two earthquakes was lower than expected in terms of ductility and the brittle failure was observed in steel moment-resisting frame joints. One of the connections that has become popular in recent decades is the connection of beams to columns using side plates. In side plate connections, a pair of steel plates connects the beam to the column. This removes the welded connection of the end of the beam to the wing of the column and the beam does not have a direct connection to the column. In this type of connection, steel plates at the top and bottom of the beam are used only to fill the gap between the width of the beam and the width of the column [1]. Studies on the side plate joints have often focused on determining seismic performance, comparison with other joints. Vaseghi Amiri et al. [2] investigated the seismic parameters of dual systems with side plate joints and calculated seismic parameters such as ductility coefficients, allowable stress and strength resistance parameters in this type of frame. Deylami and Shiravand [3] presented two samples of moment connections with the side plate under cyclic loadings were tested and their cyclic performance was investigated. Farmani and Ghassemieh [4] examined two categories of beam-to-column joints equipped with nickel-titanium shape memory alloy tendons and steel pins as complementary energy dampers and their role. They were determined in the seismic improvement of steel moment frame joints. Hashemi et al. [5] have modeled two frames with 6 and 12-story with buckling restrained braces in OpenSees software in two dimension in two modes with and without shape memory alloys, and finally the role of shape memory alloys has been investigated using incremental dynamic analysis (IDA) under 7 far-fault records. Based on the IDA curves, the collapse capacity of the frames is presented and finally the fragility curves are developed. The results showed that the collapse capacity of a buckling restrained braced frame equipped with shape memory alloys is higher than the buckling restrained brace. So far, most studies have focused on the bearing capacity and ductility of side plate connections. In this study, as a novelty, the effects of material, thickness and perforation of the side plate on the performance of the connection cycles are investigated using ABAQUS finite element software [6]. Also, in this study, by modeling nickel-titanium shape memory alloys, in addition to mild and high-strength low-alloy steels, the superelastic properties of these alloys in side plate joints were investigated and compared.

2. Methodology

In order to verify the studied models, the finite element model of an experimental sample tested by Deylami and

Shiravand [3] has been simulated in ABAQUS software. The configuration of model is presented based on Fig.1. then in the following, the shape memory alloy rod [7] is modeled in ABAQUS software.

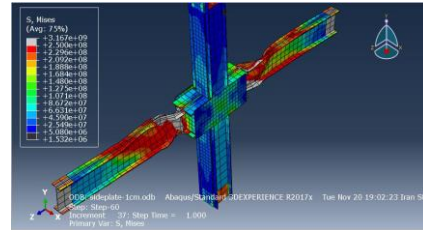


Figure 1. Experimental sample modeled in finite element ABAQUS software

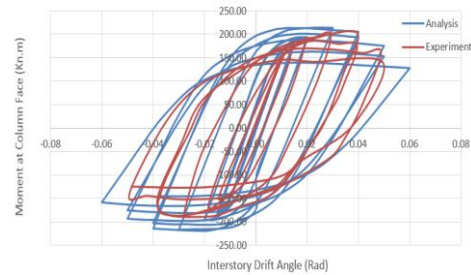


Figure 2. Comparison the moment-rotation hysteresis curve of Deylami and Shiravand's experimental sample [3] with analytical model in ABAQUS software

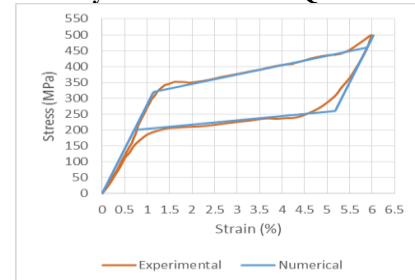


Figure 3. The numerical and experimental of shape memory alloy

As shown in Fig. 2 and 3 the moment-rotation hysteresis curve of side plate and stress-strain diagram of shape memory alloy in ABAQUS software are in good agreement with the experimental results, respectively [3, 7]. The outputs are extracted with Matlab software [8]. Therefore, dynamic analysis is performed under cyclic loading and the behavior of side plates are studied and investigated with regard to changes of material parameters, thickness and configuration on the cyclic performance of the joints. The first parameter is to investigate the effect of side plate material on the performance of the connection cycles in the models M-1, M-2, M-3. These specimens are made of ST37, ST52 and Ni-Ti shape memory alloys, respectively. In the following, the effect of side plate thickness is investigated on cyclic performance of connection. The models T-1 to T-5 are presented and finally, the effect of being perforated on the side plates (S-1 to S-4) are studied.

3. Results and Discussion

In the models M-1 and M-2, in which the side plate is made of ST37 and ST52, respectively, it can be seen that

the connection capacity during the 0.04 rad is highly dependent on the material of these steels. Basically with the increase of the moment somewhat higher than the plastic moment of the beams, the occurrence of local buckling in the wing and the beam, the hysteresis curve of these specimens has decreased. In the model M-3, considering the use of nickel-titanium shape memory alloy and the superelastic properties of this material, it can be seen that firstly, considering the modulus of elasticity is less than the slope of the curves M-2 and M-1, while the drop in the hysteresis curve M-1 and M-2 is also seen in the M-3 curve. In the model T-1, the thickness of ST37 has been reduced to 1 cm. This reduces the connection capacity during the 0.04 rad, however, in this case the moment drop after displacement of 0.04 rad is not as strong as in the models M-1 and M-2. In other words, as the thickness of the joint plate decreases, the joint stiffness decreases relative to the stiffness of the beam and less force is applied to the beam, but the stresses created on the joint plate will also be greater. In the model T-2, the thickness of the side plate has been reduced again to 0.5 cm. By doing this, there is practically no moment drop in relative displacements above 0.04 rad, because local buckling and large deformations do not occur as in the previous cases. In this case, only the local buckling can be low. Observed the beam in the last loading cycle (the reason for the lack of local buckling in the upper wing is that the lower connecting plate is one piece and therefore has more stiffness than the upper plates and more forces on the lower wing of the beam than the upper wing). In the model T-2, the stresses created in the side plate steel are very high, and unlike the side plates in the previous models, which had elastic behavior, in this case, the side plate shows the plastic behavior. Models T-3 and T-4 withstood up to 0.07 rad. In the models S-1 to S-4, the performance of the side plate is examined by creating a semicircular and rectangular section by changing the configuration. In the models S-1 and S-3, by creating two semicircular and rectangular cuts, the connection capacity was reduced by 3% compared to the non-cut plate mode. In models S-2 and S-4, four semicircular and rectangular cuts are made in the side plate and it is observed. In this case, the moment drop during 0.04 rad is significant and also the connection is only able. It can withstand up to 0.05 rad.

4. Conclusion

In this study, the effect of changes in the material, thickness and shape of the side plates have been investigated on the moment joints under the effect of cyclic loading with ABAQUS finite element software and Matlab software. In total, to evaluate the effect of mentioned changes, 12 numerical samples including 3 models for material effect, 5 models for thickness effect, and finally, 4 models were considered for the effect of configuration. The following results are summarized:

1- It was found that the side plates with nickel-titanium shaped memory alloy in the same thickness basically withstand a higher force capacity and absorb more energy.

2- In models that include changes in the thickness of the side plate, it was found that in steel plates, although the anchor capacity of the joint decreases, but still up to a thickness of 1 cm, the amount of ductility increases and the moment drop occurs less at higher displacements. .

3- By further reducing the thickness of steel side plates at high displacements, the side plate shows the behavior of plastic and does not cause much deformation in steel, but due to the fact that the amount of moment tolerated in the connection is more than 0.8 plastic moment, it can also be used in bending frames with special ductility.

4- Changing the configuration in the side plates such as being perforated until this change of configurations is not in stressful points (the central part of the connection plate and the area connected to the wing of the column) does not have much effect on the connection capacity, but changing the configuration in stressful areas, reduces connection capacity quickly.

5. References

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