PRELIMANARY INVESTIGATION OF SMA-BASED RECENTERING BEAM-COLUMN CONNECTION

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ABSTRACT :

The conception, design, test setup, and predicted behavior of a SMA-based recentering beam-column connection are presented. Since the 1994 Northridge earthquake, many different research initiatives have been undertaken to create connections that have more robust performance under seismic loads. Numerous vulnerabilities in fully restrained connections resulted in the re-evaluation of their partially restrained counterpart (i.e. bolted connections). This re-evaluation has shown that properly detailed partially restrained connections have good seismic performance. The SMA-based partially restrained connection proposed in this research has the potential to create a connection with good strength, stiffness, and ductility. The key benefit to such a system is the superelastic SMA's ability to recenter the connection at the end of a loading event.

KEYWORDS: SMA, Recentering, Beam-Column Connection, Partially Restrained, NiTi

1. INTRODUCTION

In 1994 the Northridge earthquake struck Southern California causing an estimated $40 billion in direct damage (Eguchi et al., 1998) and exposing previously unknown vulnerabilies of welded moment connections. Over 150 buildings were observed to have damage, including hospitals, cultural and educational facilities, and government buildings (Mahin, 1998). In an effort to improve the performance of these steel moment resisting frames, a research initiative known as the SAC joint venture was launched in 1994 and concluded in 2000. Many different research centers participated in this venture, investigating welded moment connection behavior, repair and retrofit strategies, and new and improved moment connection systems.

Partially restrained connections were studied as part of this research. Partially restrained connections have been recognized in the codes for many decades, but not until after the Northridge earthquake did research interest turn towards using these connections in seismic resisting systems. Properly detailed partially restrained connections have been shown to provide equal or improved seismic performance compared to fully restrained connections (Leon, 1995). A partially restrained SMA-based connection is introduced in this paper (Figure 1). This connection not only provides large ductility expected in a properly designed bolted connection, but also provides recentering characteristics that result in little to no residual deformations in the joint. This research study is focused on recentering partially restrained connections constructed with Shape Memory Alloy elements.

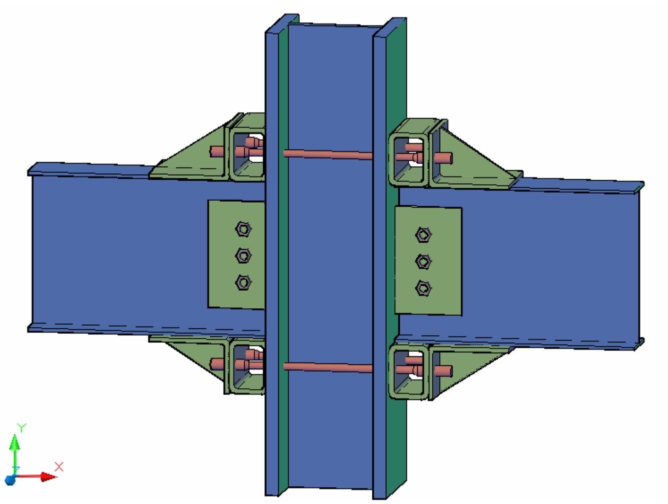

Figure 1 Schematic of SMA connection

2. BACKGROUND

Previous studies have experimentally and analytically investigated the performance of recentering beam-column connections. Cheok et al. (1993) investigated 1/3rd scale recentering post-tensioned (PT) precast concrete connections. They found that the PT assemblies increased ductility, decreased damage, and decreased residual drift in comparison to cast-in-place monolithic assemblages. Priestley et al. (1996) tested PT concrete connections in a 60% scale, 5-story building as part of the Precast Seismic Structural Systems (PRESSS) initiative. Again, excellent performance was reported for these systems.

Ricles et al. (2002) and Christopoulos et al. (2002) expanded the idea of PT connections by investigating its use in steel moment-resisting frames. A flag-shaped recentering behavior is produced by the synergy between some post-tensioning elements and dissipating angles. These types of connections were investigated analytically and experimentally. When subjected to large deformations, the PT systems displayed good energy dissipation, no damage to surrounding members, and zero residual drift.

Ocel (2002) reported on a steel beam-column connection using martensitic SMAs, which required heating in order to recover the material's shape, and thus recenter the connection. The connection performed well, displaying good energy dissipation and strength; however the drawback was noted in the cumbersome heating process to provide recentering (most likely due to the heat not properly penetrating the large bar diameter). Penar (2005) investigated a recentering connection using NiTi tendons. The connection showed potential but complications in the test setup and connection design produced inconclusive results. The research of this current paper expands upon that of Penar with modifications and improvements implemented.

3. CONNECTION DESIGN

The beam-column connection is designed to provide recentering with equivalent strength, stiffness, and ductility that might be found in a similar partially restrained connection. Figure 2 shows the layout (b & c) of the connections in comparison to a previous connection (a) tested by Penar (2005). NiTi SMA tendons or bars (Figure 3) are used as the primary moment transferring elements to produce a superelastic recentering response. A cyclic load test was performed on a $\phi = 0.25$" bar. The response is shown in Figure 4. The loading plateau stress and the initial stiffness are found to be 52 ksi and 3600 ksi, respectively. The decreasing loading plateau stress, decreasing hysteretic damping, and increasing residual deformations as cycling continued are all trends noted here and supported by other reports (DesRoches et al., 2004).

The tendons are anchored to a combination of a stiffened L-shape and a HSS section. The HSS section is provided to (1) push out the pivot point and thus increase the moment arm and (2) to provide supplemental stiffening to the beam flange to prevent local buckling. In Penar's (2005) research, the SMA tendons were never taken into their superelastic range, thus the full benefit of the connection was not realized. Additionally, this setup uses bolts, in lieu of welding, to facilitate further testing with modified details as needed.

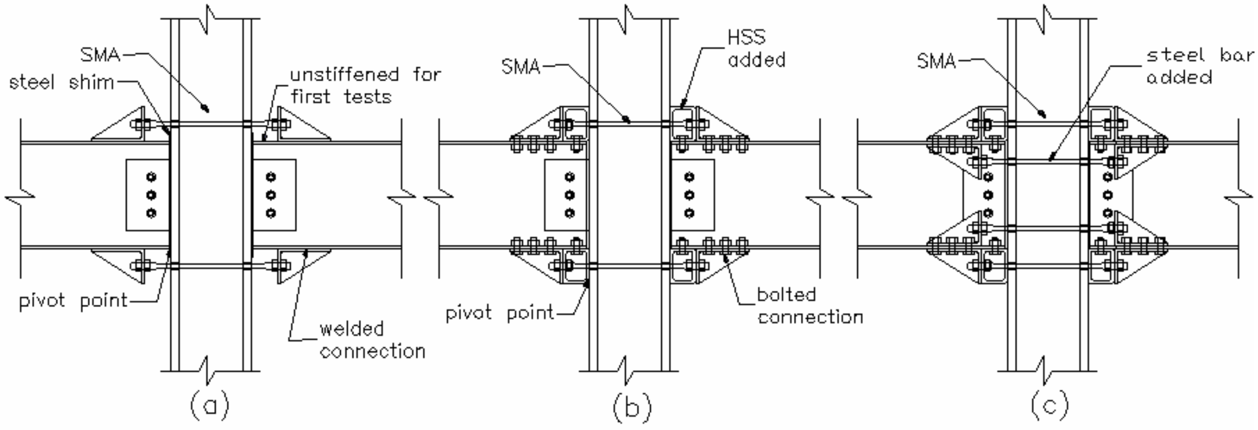

Figure 2 (a) Penar (2004) connection, (b) current connection, (c) proposed PARA connection

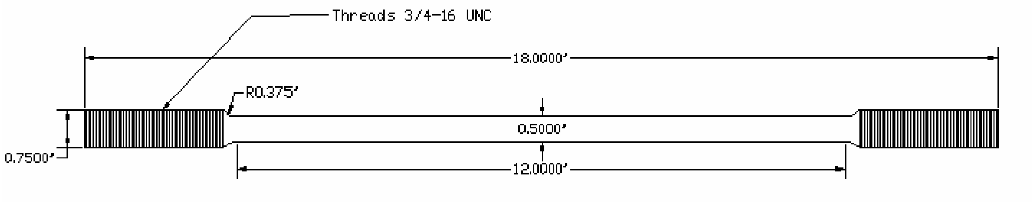

Figure 3 Details of SMA tendon

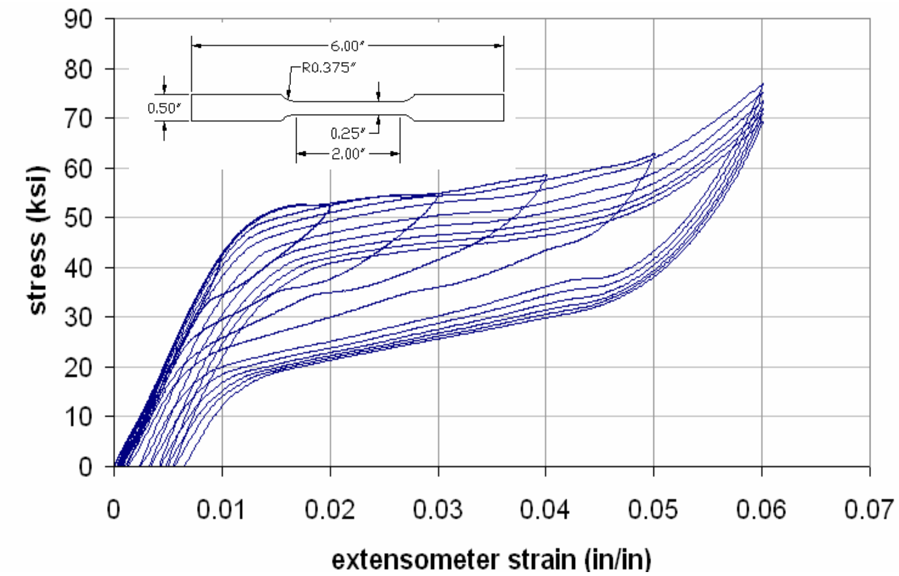

Figure 4 Stress-strain relationship of 0.25" diameter bar

5. TEST SETUP

A half-scale beam-column connection will be tested in the laboratory using an existing loading frame. The specimen is plugged into the frame as shown in Figure 5. The frame is loaded by a 220-kip hydraulic actuator with a +/- 10 inch stroke. The specimen beams are attached to the frame columns with slotted pins in order to relieve unwanted axial stress in the beams during testing. The specimen column is attached to transfer members which are in turn attached to the upper and lower loading frame beams. Due to the kinematics of the setup, motion in the frame will induce tension in the specimen column. Pretests have been performed to ensure that the induced forces are not too high. Due to the play in the column pins, most of the theoretical forces are relieved and the total force seen in the column was approximately 4 kips, which is an acceptable level for this experiment.

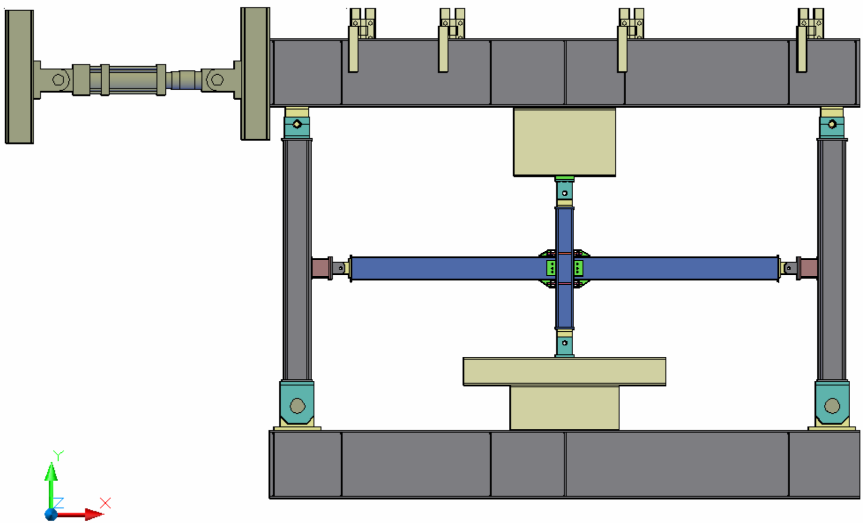

Figure 5 Schematic of loading frame setup

4. PREDICTED BEHAVIOR

The beam-column connection was modeled in OpenSEES, an open source finite element program. The SMA tendons are modeled using a one-dimensional constitutive model modified by Fugazza (2003). The joint was modeled as shown in Figure 6, and the predicted behavior is shown in Figure 7. The current connection details result in an increased strength and the stiffness of the connection primarily because of the addition of the HSS section. Additionally, the response of a system with mild steel tendons in parallel with the SMA tendons is demonstrated. The issue of softening around the origin will have to be addressed. One solution is to pretension the SMA tendons, which would force the steel tendons to yield in compression, assuming buckling is restrained (i.e. encase in concrete filled tube). This predicted behavior has ignored the friction effects caused by the shear tab, which will add to the hysteretic loop of the connection. The model will be modified after experimental data is obtained.

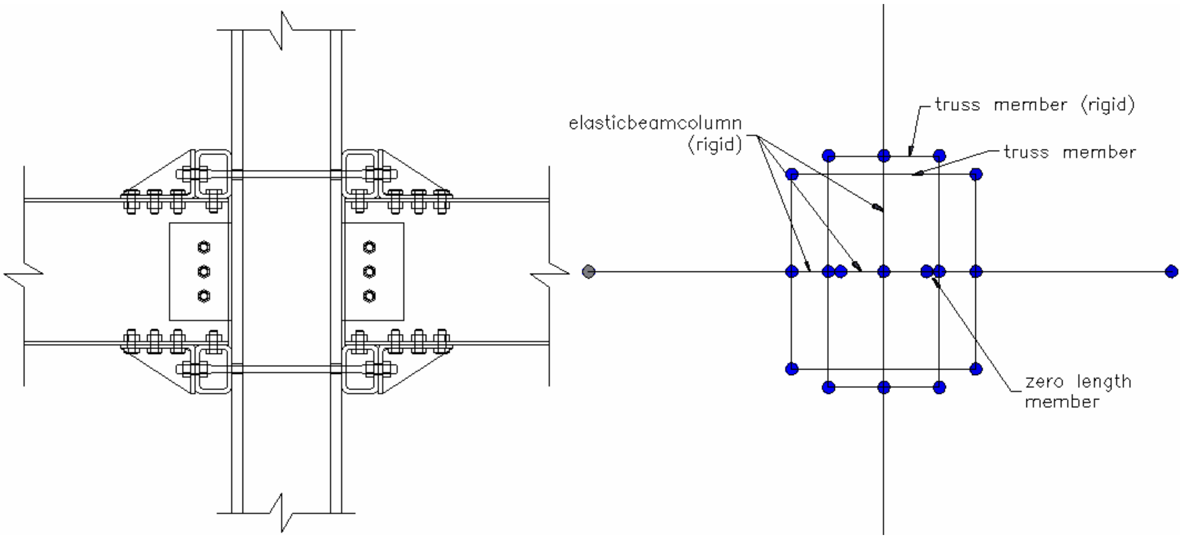

Figure 6 Joint modeled in OpenSEES

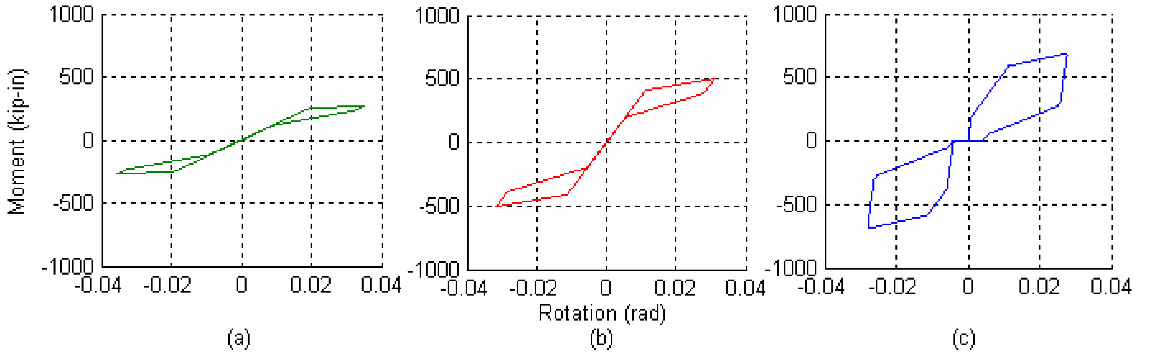

Figure 7 Predicted moment rotation (a) Penar (2005) connection, (b) current connection, (c) proposed PARA connection

5. SUMMARY

An overview of the proposed SMA-based beam-column connection was given. This connection was modified from a previous study in order to improve performance and fully cycle the SMA through their superelastic range. Modifications included addition of an HSS section to prevent flange local buckling and the shift the pivot point further from the centroid. The test setup was described and the theoretical expected behavior is shown. The connection design has great potential to create a SMA-based recentering system. Future work will include the half-scale testing of this connection in order to calibrate computer models.

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