Seismic Performance of Self-Centering Sliding Hinge Joints using Posttensioned Strands

Introduction: Conventional seismic moment resisting frames (SMRFs) are designed to resist and dissipate seismic energy by transferring the loads and distributing permanent yielding to the primary members, such as beams and columns. While this design philosophy performs well in providing strength and collapse resistance to a structure, damage to major structural members presents a major drawback in economical repairs. Therefore, most recent alternative designs not only seek to dissipate seismic energy and avoid damage in the primary members, but also to mitigate damage in the connections themselves. In essence, the development of such a connection increases seismic resiliency in structures, avoiding expensive and disruptive replacement of entire members while also limiting excessive deformations at the connections. One such method is the sliding hinge joint (SHJ):[1] Figure 1 shows the proposed SHJ connection with modifications. The flanges of the beam are connected to sliding plates hinged to the column. Thus, as the column and beam rotate during seismic events, the connection's rotation causes the plates to slip, and energy is dissipated in the form of friction.

Because the moment resistance is dependent on the friction provided between the plates and flanges, challenges in their design include ensuring that the connections still provide adequate strength and safety under service. Additionally, the benefit in mitigating the need to replace connections after damage can only be realized by ensuring that the joint return to its original position. Since it is desired that the connection also be economical and simple to build, the proposed research will be the first to examine the performance of posttensioned (PT) strands as the self-centering mechanism coupled to a sliding hinge joint (SHJ-PT). The proposed study will be focused around the achievement of the following primary objectives: 1) develop models for the SHJ connection and PT strands, and 2) perform simulation and analyses on the models and, resources permitting, experimental testing of the subassembly.

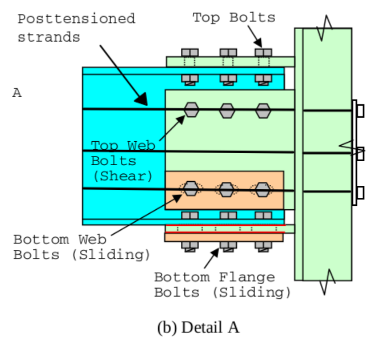

Figure 1: SHJ connection with PT strands[1]

Hypothesis: Posttensioned strands provide an economical, easily-constructable, and geometrically flexible mechanism of recentering for the sliding hinge joint connections.

Objective 1: Development of Models for SHJ and PT Strands The proposed connection consists of a beam and column connected with shear plates. The SHJ as described by Clifton (2005)[2] will be employed as the method of energy dissipation. As shown in Figure 1, steel strands parallel to the beam are anchored to the columns in order to stress the beam. While the experimental testing of full-scale structures under seismic loads is one method to examine response behavior, such tests are costly to perform and generally still require supplemental analyses to assess localized material response. Expanding on existing methods,[3] an analytical procedure will be developed to establish the relationship between the connection rotation and the mechanical response development in the PT steel strand. For a range of rotation induced by seismic loads, the response of the PT strand will be developed. Similar to work by Khoo (2012),[4] the SHJ can be modeled using a system of rotational springs, thus providing the SHJ's response to seismic load. When coupled with the previous method, the total structural response and behavior of the SHJ-PT can be studied; output

[1] GC Clifton et al. "Sliding hinge joints and subassemblies for steel moment frames". In: 2007.
[2] GC Clifton. "Semi-rigid joints for moment-resisting steel framed seismic-resisting systems". PhD thesis. 2005.
[3] Constantin Christopoulos et al. "Posttensioned energy dissipating connections for steel MRFs". In: (2002).
[4] Hsen-Han Khoo et al. "Development of the self-centering SHJ with friction ring springs". In: (2012).

strains and displacements from the PT strands model are passed to the SHJ spring-model's rotations and analyzed (and vice versa) in order to fully understand the interaction between the two systems. Additionally, finite element method analysis will be performed to check that the stresses on the plate do not exceed the failure limits of the plates[2].

Objective 2: Perform Seismic Simulations and Analyses on Models Working with Dr. Patricia Clayton (UT), I will numerically investigate the performance of the SHJ coupled with PT strands under earthquake simulations. Using the component models developed under Objective 1, building models will be constructed. These building models will be subjected to time-history analyses simulating a series of ground motions representing the maximum considered event and service level earthquake. In this objective, the goals are to arrive at adequate response results from which a procedure to determine design parameters could be established. As a metric of achievement, the results will be subjected to validation using existing test data from previous studies[5,6]. Upon the model structure's achievement of data validation and providing sufficient response to benchmark loads, the computational study can be expanded to observe the performance of the structures utilizing variations of the designed connection, such as usage at a specified spacings and bays or with varying strengths of the sliding hinge plates. Resources permitting, testing of the proposed SHJ-PT connection subassembly can be performed using the facilities at the Ferguson Structural Engineering Laboratory at the University of Texas.

Intellectual Merit: Though there is existing research on the development of the sliding hinge joint[6,1,2,4] and the analysis and testing of replaceable connections utilizing PT strands[7,8,5], *efforts to couple these concepts in a design have yet to be extensively studied.* Results[9,4] from previous simulations and physical testing have demonstrated the SHJ's ability to mitigate damage as well as its potential to be coupled with self-centering mechanisms and warrants further research into novel designs. As it stands, the SJH-PT's advantages are: 1) mitigation of damage to primary members and limiting damage on the connection; 2) construction using conventional material and skills; 3) ability to self-center after events. These benefits warrant further study into the connections' strength and serviceability potentials. The study also aims to address concerns based on practicality of PT strands in connections based on the effects of gap-opening and the compression that the strands induce in the beam flanges[1].

Broader Impacts: Drawbacks in current practice in SMRFs that employ welded connections include seismic damage to beams and columns that require disruptive and costly replacement of the component. The successful development of SMRFs using energy-dissipation methods means removing the need to replace connections after seismic events, leading to a more flexible recovery process for structures after natural disasters. This plays a huge role in presenting retrofitting options to boost resilience for structures in areas where seismic risks are rising due to environmental and industrial impacts. I will also work to increase the acceptance of the SHJ-PT connection in the structural engineering community through 1) publications in notable journals, such as Journal of Structural Engineering and Journal of Constructional Steel Research, 2) attending conferences in the discipline, and 3) working closely with industry entities, especially those already with proprietary work in semi-rigid moment connections such as Simpson Strong-Tie and Skidmore Owings & Merrill, in order to further develop and popularize energy dissipation based SMRF connections.

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[5] James M Ricles et al. "Posttensioned seismic-resistant connections for steel frames". In: (2001).
[6] HH Khoo et al. "Experimental studies of the self-centering Sliding Hinge Joint". In: (2012).
[7] Ying-Cheng Lin et al. "Seismic performance of a large-scale steel self-centering MRF". in: (2012).
[8] Patricia M Clayton et al. "Seismic design and performance of self-centering steel plate shear walls". In: (2011).
[9] Gregory A MacRae et al. "The sliding hinge joint moment connection". In: (2010).