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Numerical Study of Isolated Post Tensioned Steel Beams as a Replacement of Steel Plate Shear Walls

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***Abstract* - This paper present Isolated PT Beams (IPB) which developed and designed to improve the lateral response of structure under ultimate loading comparing to steel plate shear walls response. IPB frame is a damage free structure that takes advantage of Elastomeric Isolated Bearings and post tensioned strands. Bearings are added at the connection of beam and column in order to minimize the damage to the lateral system and dissipate the energy. Post tensioned (PT) strands help the frame to be self-centered after subjecting to lateral force or during unloading. Proposed system would avoid the damage to connections as well as beams and columns, instead damage would be localized in replaceable members (Bearings and PT). IPB overcomes some drawbacks of shear walls such as yielding of the shear plate under seismic force and improve the response of structure under seismic force.**

In order to study the behavior of a proposed system, Opensees model was created and cyclic push over analyses were performed. To have a better understanding of the system damage reduction, local and global response of the system were discussed and the result were compared to an existing steel plate shear wall.

***Keywords*: Post-Tensioned, Bearing, seismic, shear wall, Push over**

Introduction

In the past decades the usage of Steel Plates Shear Wall (SPSW) has been increased as an appealing alternative in North America, Asia and other high seismic risk area [1] as part of seismic force resisting system in order to provide ductile seismic resistance [2]. SPSW system typically consists of vertical steel plate infill bounded by beams (horizontal boundary elements) and columns (vertical boundary elements). SPSW is installed between the columns (in frame bay) by the full height of structure. The whole system can be considered as a vertical cantilever plate girder, for simulation purpose plate can be considered as a web, columns as flange and beams as stiffeners. Steel plate shear wall (SPSW) dissipates the energy through cyclic yielding of the infill plates in tension [3].

Shear walls resist earthquake forces by developing diagonal tension field action after buckling of infill plate in shear. Afterwards, energy would dissipate through yielding of the infill plate in tension [3]. In order to avoid plate buckling, heavily stiffened infill plates were designed which were not economical in comparison with reinforced concrete shear walls [4].

During seismic events, the plates of steel plate shear wall buckle in shear and yield by developing a diagonal tension field, and creation of plastic hinges at the end part of the beams. While steel plate shear walls systems are desirable for their significant stiffness, strength, and energy dissipation, the hysteretic energy dissipation of this system, like other traditional seismic-resistant systems that inherently relies on yielding of steel, results in some level of structural damage and the likelihood of significant residual drifts of the structure after severe earthquakes [5]. Therefore, yielding in the boundary elements of conventional steel plate shear walls can result in significant residual drift deformations following a seismic event, which would cause costly-post-event repair and loss of building functionality.

Base isolation is one of the ways to encounter seismic forces which separate the structure from foundation. This system can minimize the damage to the structural member during the earthquake event. Lead rubber bearing or any kind of other isolator increase the damping of structures through hysteretic deformation.

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This paper presents a new Isolated PT Beam (IPB) system as a replacement of steel plate shear walls. IPB system consist of steel beams, rubber energy dissipation devices and PT strands. Energy would be dissipated through rubber bearings and by taking advantage of PT strand it would self-center after seismic event.

I. ISOLATED POST-TENSIONED BEAM

Fig. 1 schematically shows the IPB frame, it is a two story frame which consists of four beams, two beams located at story heights and the other two are at mid history heights. Beams are connected to bearings at each end which serve as energy dissipation devices and let the beams move upward and downward to let the frame deflect as expected under lateral load. PT elements are anchored to the column flanges and run parallel to the beam. During the lateral movement of the frame, PT strand stretches and during unloading it provides the self-centering capability to the frame which prevent permanent deformation in frame after seismic events.

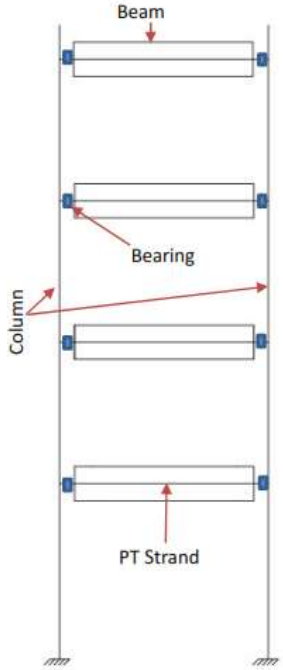

Figure 1. Schematic Isolated PT Beam Frame

A. Behaviour of Isolated Post Tensioned Beam

Details of IPB is shown in Fig. 2, system composed of steel frame beam that is connected to rubber bearing at both ends. These rubber bearings allow the beam to move vertically and base on the movement of the beam bearings would deflect and dissipate the energy. PT strands which connected to the column flange provide restoring force which would result in self-centering. Self-centering is an important factor of the proposed system as it prevents the permanent deformation of the frame.

Fig. 2a shows the configuration of the IPB system and Fig. 2b shows the deflected system under lateral force, as it can be seen there is a lateral displacement due to lateral force which make the space for lateral displacement of bearings in order to dissipate the energy.

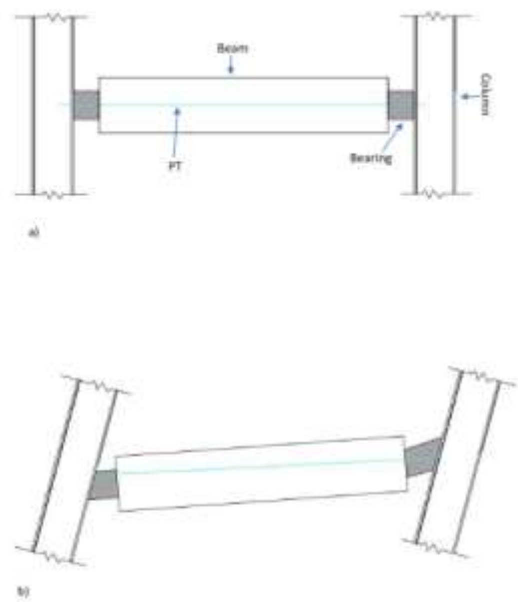

Figure 2. a) Isolated Post-Tensioned Beam b) Deformed IPB frame

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A. Prototype

In order to study the nonlinear static behavior of IPB, a two story narrow steel plate shear wall (Specimen RS) that studied by Li et al is chosen as prototype [6]. Li et al designed and tested four narrow SPSW specimens and alleviated the large out of plane deformation by using welded rib-stiffeners to the infill steel plates. Specimen RS is a restrained steel plate shear wall that was designed to assured that it can developed the desirable mechanism under lateral forces [6]. This frame contains two pairs of restrainers in each story; restrainers can restrain out-of-plane deformation of the infill plate as well as inward flexural deformation of the boundary columns induced from the panel forces [6]. Fig. 3 shows the detail of the prototype including the basic dimensions, boundary element member sizes and the detail of reduced sections on boundary elements. Frame has height and width equal to 6.5 and 2.14 m respectively. Sections that are used for frame elements are as follow: Top beam (TB): H350x175x9x12, middle beam (MB): H350x175x7x11, Bottom beam (BB): H400x200x8x13 and columns (C): H300x300x10x15 (sections are based on Japanese H sections (FISCO)) and a plate with 2.6 mm thickness is used as an infill panel. Reduced beam section was assigned to the beam-to-column connection of TB and MB in order to develop plastic hinges at these locations [6].

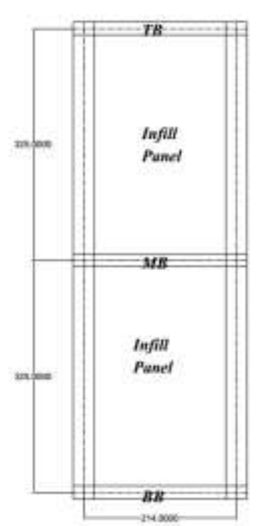

Figure 3. Details of Prototype (After Li et Al [6])

To model IPB frame based on the specimen RS shear wall and beams are replaced by group of Isolated Post-Tensioned Beams (IPB). In order to assign a section to isolated PT beams, sections equal to middle beam (MB) has been selected. Therefore, a 2-story frame has been built with four isolated post-tensioned beams. Isolated PT beams at mid height of the story are replacing the shear panels and the beams at roof level height and first story level height has been kept as is.

II. Modelling

In order to compare the proposed system response to the prototype specimen from Li et al [6], numerical model was built in OpenSees software. OpenSees is a software framework for developing applications to simulate the performance of structural and geotechnical systems subjected to earthquake.

Steel frame has a height of 6.5 and bay width of 2.14 meter. Nonlinear beam column element [7] and Elastic beam columns are used for modelling column and beams in frame. Elastic Beam Column Element used to construct the rigid part of connection and Nonlinear Beam Column Element to construct beam and column elements that consider to have nonlinear response under seismic force, nonlinear Beam Column element is based on the non-iterative (or iterative) force formulation, and considers the spread of plasticity along the element. Truss element with Elastic perfectly plastic material assigned to it was used to represent post-tensioned strands. To model bearings Isolater2spring section command assigned to zero lent elements [7], [8], [9].

Bilinear shear spring used to model expected shear behavior of the IPB frame under lateral force as well as dissipating the energy. As it can be seen in Fig. 4 bearing element is dissipating energy through the hysteretic loop.

III. Static Push over analysis

The pushover analysis of a structure is a static non-linear analysis under gravity loads and a gradually increasing lateral loads or a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behavior until an ultimate condition is reached. The equivalent static

lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. On a frame, plastic rotation is monitored, and lateral inelastic forces versus displacement response for the complete structure are analytically computed. This type of analysis enables weakness in the structure to be identified.

Response of IPB frame structure (Roof displacement versus base shear) under nonlinear-static push over analysis is shown in Fig. 4.

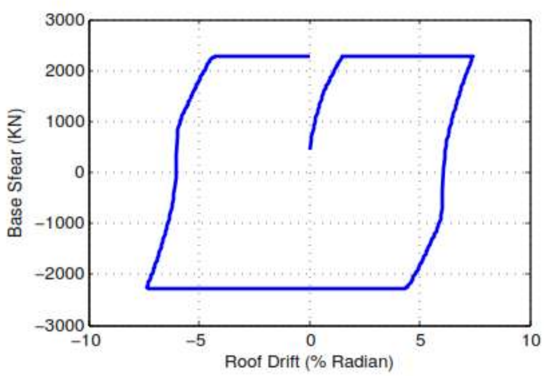

Figure 4. Roof Displacement versus Base shear

Fig. 5 shows the cyclic push over response after Li et al [6].

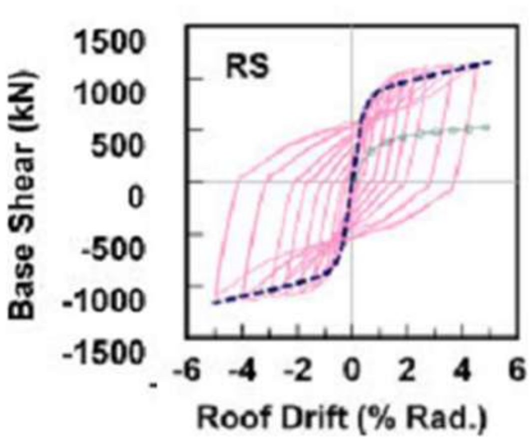

Figure 5. Cyclic push Response of SPSW (after Li et al) [6]

A. Comparing of IPB and SPSW

Push over response of IPB and SPSW are shown in Fig. and Fig. 8 respectively. By studying the push over analysis of IPB it can be seen that relative beam sliding are happens at roof drifts equal to 0.05%, 0.16%, 0.48% and 1.22 %. Yielding at outer flange of column base can be seen at roof rotation equal to 0.6% and 0.7% and PT ultimate stress reached at roof drift equal to 1.6% to 2.5%.

Based on the experimental result done by li et al on specimen RS, the visible out of plane bucking of the infill panels was observed at the roof drift of 0.4% radian. At a roof drift of 0.5% radian, notable yielding of the first floor infill panel was observed. At the drift level of 0.75%radian, a few slight yield lines were observed on the top beam flanges at the reduced beam section (RBS). At a roof drift of 1% radian, a few slight yield lines were also observed on the middle beam flanges at both RBS locations. During the 1.5% radian drift cycles, shear yielding lines appeared on the top beam web close to the shear tabs. At the drift level of 2% radian, both 1F columns had major flange yielding and some web yielding at the bottom ends. Continuing on to a 2.5% radian roof drift, slight flange local buckling occurred at the plastic zones at the bottom ends of the 1F column and the RBS locations. As the displacement increased, the flange local bucking became more severe, and slight web local bucking also started to appear at the stated plastic zones. The specimen reached its peak shear capacity of 1150KN at the first 5% radian roof drift. No notable fracture was observed at the conclusion of the testing.

I. Conclusion

This paper has been introduced an innovative system called IPB which can be used as a substitute for SPSW in order to improve the response of structure under earthquake forces.

One of the advantages of the IPB is that beams can remain undamaged and no yielding observed in the sections up to roof drift of 8% radian, while in SPSW structural damage observed at roof drift equal to 0.5% and becomes more sever as the r rotation increased. At the roof drift of 2% major yielding at column observed and at 2.5% plastic hinges appeared at column based.

PT elements in IPB remain elastic up to 1.6 % roof drifts and from this point PT strength start yielding which do not have any drawback on the operation of a frame .PT bars could be pre-tensioned again after the earthquake by retightening.

A significant advantage of IPB over SPSW is that the frame is damage free and structural damage cannot be seen in elements and there is not any need to change or repair the main structural members after earthquake while in SPSW in addition to deformation of a shear wall, damage in beams and columns can be seen. Also the frame can be self-centered which no permanent deformation can be seen after seismic event.

In conclusion, based on nonlinear result IPB frame can reduce damage of the frame under seismic forces in comparison to SPSW and has a better performance under lateral loads.

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Sara Vahid is a Ph.D. candidate in the University of Alabama in Huntsville, her research interests include mitigating damage under lateral forces as well as damage free structures under extreme loading conditions.

Beside her academic achievement, Sara has served as a structural engineer in different structural firms since 2004. She has experience in designing tall structures, bridges, seismic assessment and strengthening bridges and building structures.