Novelty Journals

ISSN 2394-7357

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 3, Issue 3, pp: (1-5), Month: September - December 2016, Available at: www.noveltyjournals.com

Cyclic Push-Over analysis of Self-Centering Isolated Post-Tensioned Steel Frame

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Abstract: **This paper presents the self-centering behavior of Isolated Post-Tensioned Steel Frame (SC-IPSF) which is designed to improve the structural response under seismic event. SC-IPSF frame is a lateral force resisting system which provides self-centering and mitigate the damage to the structure under earthquake force. SC-IPSF is a steel frame consists of rubber isolator and post tensioned strands. Rubber Isolator 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 provides the self-centering effect and assist the frame to go back to the plumb condition after subjecting to lateral force. Proposed system would avoid the damage to connections as well as beams and columns, instead damage would be localized in replaceable members (Isolator and Post-Tensioned strands).**

To study the behavior of a SC-IPSF, connection response of the frame studied under cyclic push-over analyses in Opensees software. 2D model has been created in Opensees and cyclic push over analyses were performed to study the response of the steel frame under lateral force and to achieve a better understanding of the system.

Keywords: **Self-Center, Isolator, Post-Tensioned, Steel Frame, Push-over, Static.**

1. INTRODUCTION

Self-Centering (SC) systems have been investigated by several researchers utilizing both analytical and experimental methodologies in the previous decade [1], [2], [3]. SC connections are typically embedded in different structural systems such as moment resisting frames [4] and braced frames [5] as well as different parts of a steel structure [5], reinforced concrete (RC) (Liang-Long Song 2015), and wooden frames with the aim of reducing deformation of the main structural member. The SC connection takes advantage of Post-tensioned elements (PT) to restore the structure back to the plumb situation and energy dissipation devices to serve as an energy dissipation device to dissipate the related energy.

Conventional structures designed based on available structural codes should have the capabilities for ductile inelastic response and lateral force energy dissipation. Energy is dissipated through hysteretic yielding of the main structural elements. This energy dissipation is directly associated with structural damage to the structure and can load to potentially large, permanent inelastic deformations. These permanent deformations lead to significant repair or replacement cost and associated expenses to regain normal operation, if possible. Under sever plastic deformation the repair cost maybe more than new structure construction cost. The advantage of SC connection in comparison with conventional structure is that the energy dissipation would be through special devices rather than hysteretic energy dissipation by main structural members. Damage reduction, or lateral displacement control, reduce the member's inelastic deformations and energy dissipation under lateral force which is produced by energy dissipation (ED) devices and not due to plastic deformation in members are advantages of SC connections [6], [7].

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. This paper presents a new self-centering

Isolated Post-Tensioned Steel Frame (SC-IPSF) system as a lateral force resisting system. SC-IPSF consists 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.

2. SYSTEM DESCRIPTION

Fig. 1. Schematically shows the SC-IPSF 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.

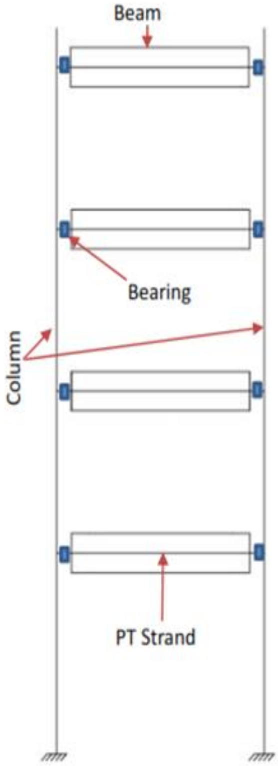

Figure 1: Schematic Isolated PT Beam Frame[10]

3. BEHAVIOR OS SELF-CENTERING ISOLATED STEEL FRAME

Detail of connection in SC-IPSF 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 SC-IPSF 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.

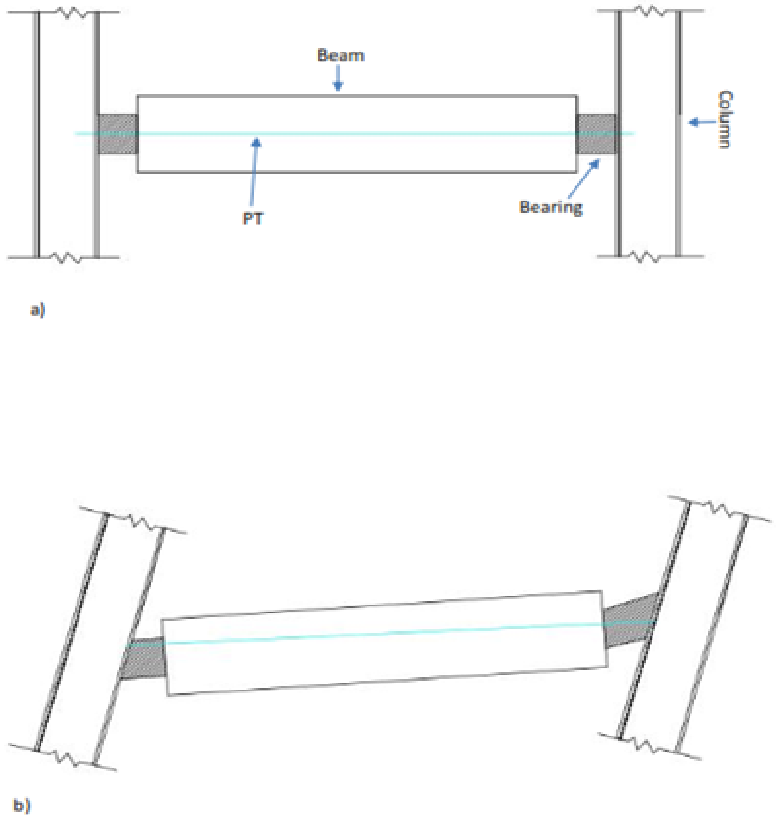

Figure 2: a) Isolated Post-Tensioned Beam b) Deformed IPB frame [10]

4. MODELLING

To study the behavior of SC-IPSF 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 is a two story frame with the height of 21 ft and bay width of 7 ft. Nonlinear beam column element [8] 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 [9]. Bilinear shear spring used to model expected shear behavior of the SC-IPSF frame under lateral force as well as dissipating the energy.

5. EXPECTED BEHAVIOR

Error! Reference source not found. 3. Shows a typical moment-relative rotation relationship for a SC-IPSF connection. The response is characterized by relative movement of bearings which causes a vertical movement of the beam at the beam-column connection. when frame subjected to lateral force, after initial post tensioning force overcomes the design force, bearing would be activated and relative displacement of beam and column would occur. During unloading the PT strands would provide self-centering and bring back the structure to the plumb condition and the area disclosed in moment-rotation shows the hysteretic loop and demonstrate the amount of energy dissipated by bearings.

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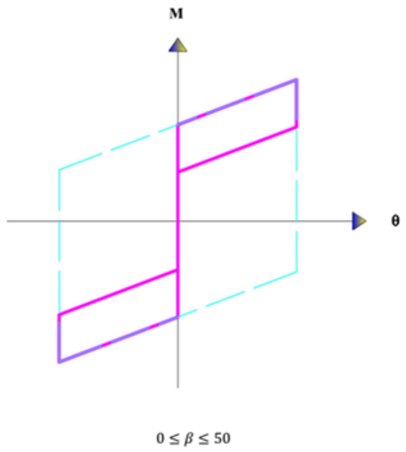

Figure 3: Conceptual Behavior of SC-IPSF Connection

6. CYCLIC PUSH OVER ANALYSIS

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.

Cyclic push over analysis was conducted on SC-IPSF structure by the purpose of studying the hysteretic response. Fig. 4. shows the behavior of the SC-IPSF connection under 2 full cyclic loading which produce a hysteretic loop. The area enclosed in moment rotation graph in Fig. 4. shows the energy dissipated by the rubber isolation also self-centering

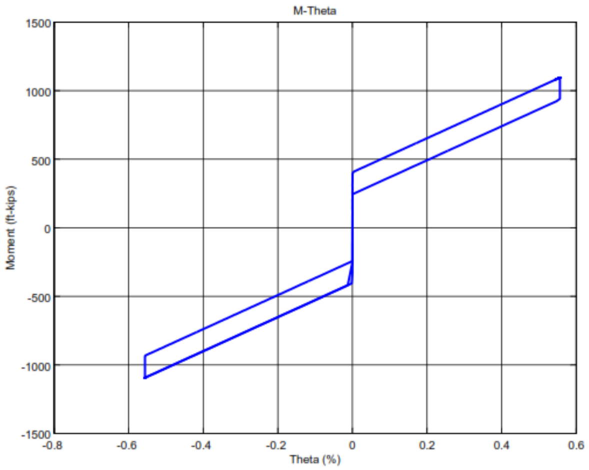

Figure 4: Moment-Rotation response of the beam column connection of SC-IPSF

7. Conclusion

This paper has been studied the cyclic pushover response of the Isolated Post-Tensioned Steel Frame which can be used as a lateral force resisting system in order to improve the response of structure under earthquake forces. One of the advantages of the SC-IPSF is that frame can remain undamaged and the building will be ready to serve right after

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earthquake and beam and columns and the connection will remain undamaged. Frame should be checked after earthquake to see if PT strands need to be post tensioned again and also to check the bearings.

In conclusion, based on cyclic push over analysis the SC_IPSF is a damage free lateral resisting system that can significantly reduce damage of the steel frame under seismic forces in comparison to conventional steel frames and also the advantage of this system is bringing back the frame to the plumb situation and eliminating the permanent deflection of the frame.

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