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Seismic rehabilitation of bolted end plate connections using post-tensioned tendons

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ABSTRACT

Rehabilitation of existing steel structures is an inevitable work in the cases of contractor shortcoming in construction, adding new stories or change of construction code requirements. Bolted steel connections have been frequently used after Northridge earthquake. Rehabilitation of these connections without the need for changing or replacing their components is a problem that has been recently considered by engineers, since it is difficult to change or replace their components. In this paper, the use of post-tensioned tendons as a way to rehabilitate end plate bolted connections with weak end plate or bolts is studied constructing 6 experimental specimens of corner connections under SAC cyclic loading protocol. The results of the study show that this rehabilitation method improves the cyclic behavior of the weak connections. In addition, it provides specimens with better performance than that of the reference connection designed according to AISC. The moment capacity, initial rotational stiffness of the rehabilitated connections are averagely higher than those of the reference connection by 5 and 45 percent respectively. Furthermore, rehabilitation with post tension tendons adds the self-centering ability to the rehabilitated connection that in turn plays an important role in preventing permanent deformations in frame and thus, providing the potential for using frictional dampers in self-centering frames to increase energy dissipation. It should be noted that this rehabilitation method is more efficient for cyclic behavior of a bolted connections with weak end plate than a bolted connection with weak bolts, due to the participation of end plate in energy absorption and higher energy absorption capacity.

1. Introduction

After Northridge earthquake, bolted connections in steel structures were frequently used. Rehabilitation of existing steel structures is an inevitable work in the cases of contractor shortcoming in construction, adding stories or change of construction code requirements. Rehabilitation of frame components including column and beam can be easily done using welded steel plates to retrofit the existing profiles. However, rehabilitation of connections by changing their components is a difficult work. Rehabilitation of these connections without the need for changing or replacing their components is a problem considered by engineers in the recent years. In the followings, some investigations about the connections and rehabilitation ways are reviewed.

A series of five full-scale sub assemblages were tested by Kim et al. [1] to investigate the contribution of the slabs and the effects of three types of retrofit methods, no weld access hole, horizontal stiffener, and cover plate. The test result indicated that the strains near the bottom flange of the composite beam connections were several times larger than those of the bare steel beam connections, resulting in a higher potential of fracture. Horizontal stiffener detail of three retrofit schemes demonstrated very good potential in improving the ductility of composite connections in existing buildings.

Seismic performance of post-tensioned steel moment resisting frames with friction devices were studied by Rojas et al. [2]. It was determined that variability in the maximum friction forces that develop in the friction devices was determined not to have a significant effect on the MRF performance. The analyses indicate that the seismic performance of a MRF with PFDCs can exceed that of a MRF with conventional moment resisting connections.

Chou et al. [3] investigated behavior of post-tensioned steel connections including effects of a composite slab. The results showed that the presence of a composite slab corresponded to higher-achieved moments due to the tensile capacities of the metal deck flutes, wire mesh, and longitudinal reinforcement, which were placed parallel to the PT beam. However, the re-centering behavior could be maintained after fractures of the wire mesh in the proposed slab details.

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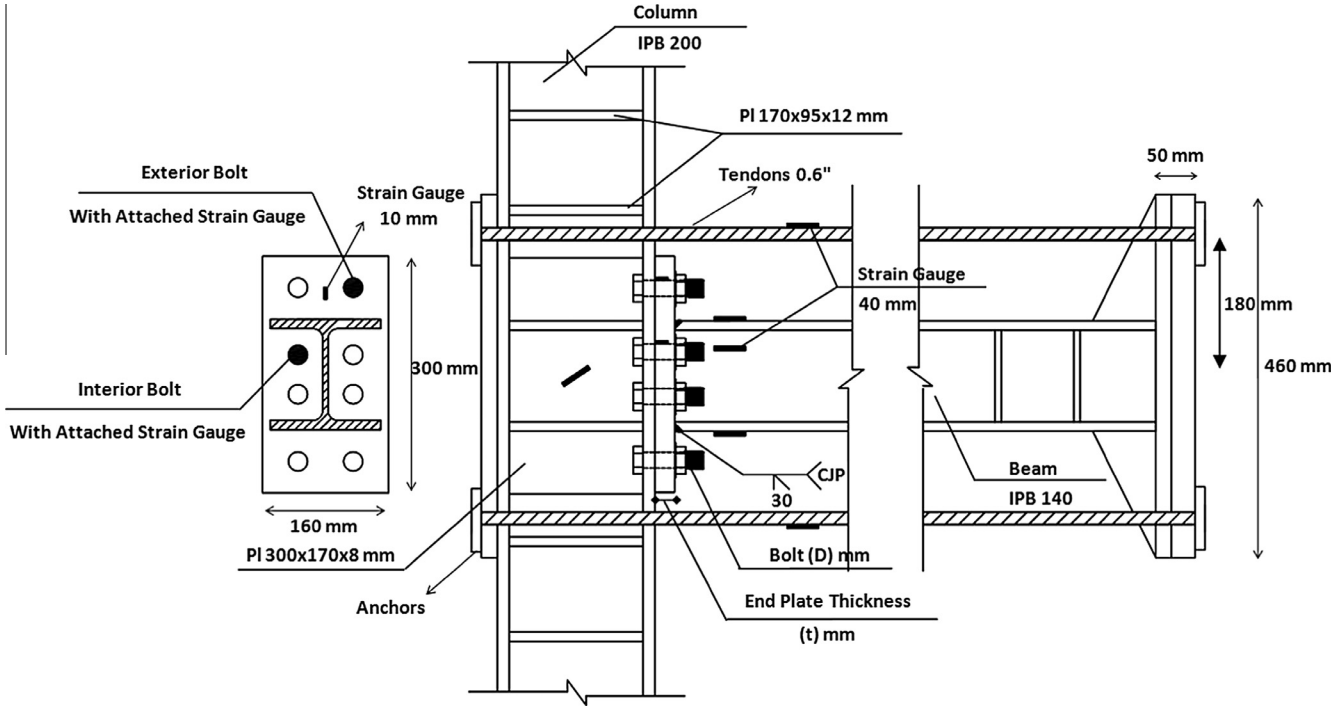

Fig. 1. Definition of specimen fabricating parameters and location of strain gauges.

Influence of design parameters on seismic response of post-tensioned steel MRF systems were studied by Garlock et al. [4]. The analyses indicated that the panel zone strength does not significantly affect the seismic response, and that increasing the connection strength in the upper floors improves the seismic response of the frame.

To provide a clear set of guidelines for the modeling of post-tensioned steel frames, for practicing engineers as well as researchers, Kim and Christopoulos [5] presented three types of numerical models of increasing complexity. Furthermore, detailing requirements were proposed to assure that flexural hinges form in the beams in order to improve the cyclic response of steel self-centering connections when drifts exceeding the design drifts are imposed to the system.

Guo et al. [6] numerically simulated the seismic behavior of self-centering steel beam-column connections with bottom flange friction devices in OpenSees.

A self-centering steel post-tensioned connection with web hourglass pins has been proposed by Vasdravellis et al. [7]. Their large-scale experimental tests showed that the connection has robust self-centering behavior by eliminating residual drifts and beam damage for drifts lower or equal to 6%.

Saberi et al. [8] have explored comparison of bolted end plate and T-stub connection sensitivity to component thickness on cyclic behavior. The results showed that the bolted T-stub connections are more sensitive to component thickness rather than end plate connections. Hence, the bolted end plate connections are recommended where the imperfection in construction or changes in function of the building is probable.

A prefabricated post-tensioned (PT) self-centering beam–column connection using a bolted web friction device (PSC connection) has been proposed by Zhang et al. [9]. Eight PSC connections were designed with various combinations of design parameters. The results indicated that the maximum PT force at

Table 1
Details of the test specimens.

Group	Specimen	Bolt diameter (mm)	Bolt layout	End plate thickness (mm)	[a]Weld type	Tendons diameter (in)
Ref	EP-R	20	Tight	25	CJP	–
Weak	EP-PW	20	Tight	25	PJP	–
	EP-WB	12	Tight	25	CJP	–
	EP-WP	20	Tight	8	CJP	–
Retrofitted	EP-WB-T0.6″	12	Tight-relaxed	25	CJP	0.6
	EP-WP-T0.6″	20	Tight	8	CJP	0.6

[a] Type of beam to end plate weld (complete joint penetration, partially joint penetration).

Table 2
Mechanical properties of the used material.

Material	Application	Measured average yield strength (MPa)	Measured average ultimate strength (MPa)	Measured average elastic modulus (MPa)
ST37	Beam, column	245	372	194,163
ST37	End plate	237	364	186,137
Gr.10.9	Bolts	–	1009	–
Gr.8.8	Bolts	–	803	–
Gr.250	Tendons	–	1726	–

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