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ORIGINAL ARTICLES

Effect of post tensioning on strengthening different types of steel frames

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Abstract The aim of this paper is to study the effect of post tensioned cables on strengthening steel frames and improving their load carrying capacity, giving more resistance against the external load (dead plus live or wind load). Different types of frames are analyzed: simple frame, double bay frame and double story frame. The analysis and the results are obtained using ANSYS finite element (FE) program. Different techniques were used to apply post tensioning to steel frame. Comparisons are made between these techniques to determine which technique is better in strengthening each type of frame. The results show that using post tensioned cables increases significantly the load capacity of the steel frame.

1. Introduction

Strengthening and repairing structures are common procedures that may be considered if the service loads on the structures are increased or the structure exceeds its lifetime. Strengthening and repairing can be applied for both steel and concrete structure as presented by Soudki et al. (2012). Post tensioning is one of the most effective methods for strengthening an existing structure to overcome the increase in service load without replacement of parts of the structure. The aim of this paper is to study the effect of post tensioning in strengthening different types of steel frames and find the suitable way to apply post tensioning in each type. Many researchers studied the effect of post tensioning on strengthening different types of structures.

Many researchers studied the effect of post tensioning on strengthening steel beams, especially in bridges. Dunker et al. (1985) presented a research concerning strengthening of existing single-span steel-beam with concrete deck bridges. Klaiber et al. (1990) studied the effect of post tensioning on strengthening an existing continuous-span steel-beam with concrete deck bridge. It was concluded that post tensioning is a viable, economical strengthening technique. Ayyub et al. (1990) studied the pre-stressing of a composite girder subjected to a positive moment. It was concluded that using strands is preferable than using bars in post-tensioning. Ayyub et al. (1992a, 1992b) presented an experimental and analytical study for prestressing composite girder subjected to negative moment. The research shows that using post tensioning decreases the crack in the negative moment region and reduces the required steel.

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Phares et al. (2003) presented a research on strengthening of steel girder bridges using post tensioned rods of carbon fiber reinforced polymers (CFRP). The research shows the significant effect of using post tensioned CFRP in increasing the load capacity of the bridge. Nazir (2003) shows that using post tensioned cable for a pre-stressed arch steel bridge has a great effect in reducing stresses on the arch girder.

Han and Park (2005) studied the elastic behavior of post tensioned steel trusses with straight and draped tendon profiles. The effect of different parameters on the working load and the deflection of truss were studied. These parameters were: tendon profile, truss type, pre-stressing force and tendon eccentricity. It was concluded that post tensioning enlarges the elastic range, increases the redundancy and reduces the deflection and member stresses. As a result, the load carrying capacity of the truss was increased. Nowadays, there are a lot of applications of post tensioned steel trusses for long span roofs especially in stadiums such as Telstra Stadium in Australia Manley (2006).

As the effect of post tensioning cables in strengthening different types of structure becomes obvious, many researchers (Petty (1999), Ricles et al. (2006), Wang and Filiatrault (2008) and Rojas et al. (2008)) used post tensioning cable in earthquake-resistant structural steel moment resisting frame (MRF) system, which are known as self-centering moment-resisting frame (SC-MRF) structural system. This type of connection uses high strength post tensioned cables to pre-compress the beams to the columns and to close the gaps that were developed under earthquake loading, returning the frame to its initial position (Lin et al., 2013). Vasdravellis et al. (2013) proposed a new self-centering beam-to-column connection. The connection used post tensioned high strength steel bars to provide self-centering capability and designed energy-dissipation (ED) elements that consist of steel cylindrical pins with an hourglass shape. The connection performance was experimentally validated under quasi-static cyclic loading. The experimental results show that the proposed connection eliminates residual drifts and beam damage for drifts lower than or equal to 6%. A simplified analytical method was proposed, which predict accurately the connection's behavior. From the experimental results, it was found that the proposed ED elements can be easily replaced without welding or bolting, which means that the proposed connection can be repaired without disturbance to the uses or occupation of the building.

From the literature, it can be concluded that using post tensioned cables is one of the most effective ways in strengthening different types of buildings and structures. It was also observed that post tensioned cables were used in self-centering moment-resisting frame (SC-MRF) to resist earthquake load. In the SC-MRF usually cables are concentric with the horizontal beam of the frame. However, using post tensioned cable with an eccentricity from the beam's or column's center line to resist the working load (dead and live load) was not studied before. All researches that have been carried out before to strengthen steel frame were concentrating in strengthening steel frame corner connection against earthquake load and decreasing their lateral drifts, there is shortage in the researches that study improving the load capacity of the frames' beams and columns using post tensioned cables. The aim of this paper is to introduce new techniques that can be used in strengthening different types of steel frame. These techniques aim to increase the load capacity of steel frames' beams and columns using eccentric post tension cables. This paper is considered as a continuation of the work that has been done by Mahmoud et al. (2014) which shows that post tensioning can increase the load capacity of single bay frame by 30%. As mentioned in this paper, different types of steel frames were strengthened using post tensioned cables. The types of these frames are: single horizontal roof, double bay and two story frame. The geometrical and material properties of these frames were selected as they represent typical properties of a previously designed factory buildings in Egypt.

2. Finite element (FE) Model

Nonlinear analysis using ANSYS 10.0 (2005) finite element program was adopted to simulate the behavior of the post tensioned frames. The analysis was done according to two loading cases, one loading case include the acting loads (dead plus live or wind loads) without post tensioned force. The other case includes the acting load plus the post tensioned load. The post tension force in the cable was increased gradually till failure occurs in the frame section or in the bracket where the cables are attached. The failure was determined when the stress in the steel section reached its yielding strength or if failure occurred due to local or global buckling in compression elements.

The FE model used in this study was verified against field measurement of an existing bride in Iowa, USA, which was strengthened using post tensioning technique as presented in Klaiber et al. (1993). The details, description of the bride and the verified FE model results are presented by Ghannam et al. (2014). Shell element (63) is used to model the columns, beam and the stiffeners. Beam element (4) is used to model bolts at the beam column joints. Each bolt is modeled using 8 beam element arranged at the circumference of the bolt diameter as shown in Fig. 1. This arrangement has been considered to avoid concentration of the stress that would occur if the bolt is model through only one beam element. It should be noted that the total area of the 8 beam element used to simulate the bolt is equal to the actual bolt area.

Beam element (4) is used to represent the cable in the finite element model. It should be noted that only axial stiffness is considered while the flexural stiffness is ignored when modeling the cable. Pretension element (179) is used to simulate the post tensioned load in the cable. Similar to the bolt simulation, the connection between the cable and the bracket is represented by eight Beam element (4) connected to 8 nodes in the bracket to avoid concentration of the stresses that would occur if the cable connection with bracket is simulated through one point, as a result of the high tensile force in the cable.

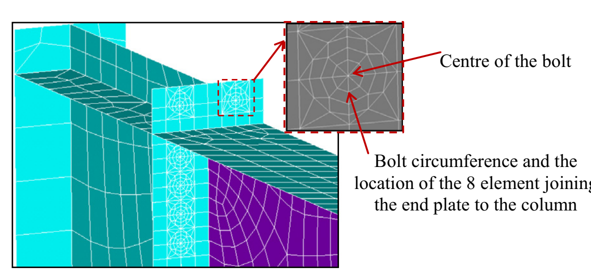

Figure 1 Details of the bolted connection simulation.