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A Dual-Sided Harped Turnbuckle External Post-Tensioning (T-EPT) For Retrofitting Reinforced Concrete Beams

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Abstract: Deterioration of reinforced concrete structure is inevitable with the passing of time. Its structural members will eventually weaken due to long term exposure to environmental factors. Consequently, deflection can occur specifically in reinforced concrete (RC) beams, compromising the strength and serviceability of the structure. Thus, retrofitting is performed to strengthen these deteriorated members. As a continuation of a study that focused on retrofitting RC beams using turnbuckle type of external post-tensioning (T-EPT), this research is aimed to establish an improved design of the setup in terms of practicality and efficiency. This is attained by adopting a double-sided T-EPT resulting to a smaller and lighter T-EPT frame system. The setup consisted of two M16 turnbuckles that were used to prestress the steel cables attached to a smaller steel frame. In addition, the anchorage was adjusted into a horizontal orientation for easier application. Results from the experimental tests demonstrated an increase in the effectiveness of T-EPT specifically in increasing the load capacity of the beam and decreasing the deflection. The average increase in load capacity and the average decrease in deflection were 38.65% and 43.18%, respectively. Furthermore, it was determined that the jacking force generated from the T-EPT on each beam ranged from 29 to 32 kN. The results showed that this is sufficient to significantly increase the strength of the RC beam.

Key Words: Turnbuckle; post-tensioning; retrofitting; reinforced concrete beam

1. INTRODUCTION

Old and deteriorated reinforced concrete structures are now becoming societal concern. Reinforced concrete beams of these structures may have excessively deflected indicating compromised flexural strength and serviceability. This may be caused by long-term environmental exposure resulting to over stressing. This makes these beams susceptible against severe loading conditions such as earthquake forces. One of the solutions to this problem is retrofitting using post-tensioning (Daly and Witarnawan, 1997; Klaiber et al., 1981).

External post-tensioning is usually

accomplished using hydraulic jacks, but this is an expensive method. Previous studies of Adiaz et al., 2011 and Astillero et al., 2013 showed that simple turnbuckle may be used to apply the prestressing force on steel beams. Exterior post tensioning using turnbuckle to apply jacking force on reinforced concrete was investigated by Penamante et al., 2015. The T-EPT system was composed of braced steel frame and stranded wire steel cable with turnbuckle attached at the middle as shown in Fig.1. Experimental tests have proven that this method can improve the beam's serviceability and load carrying capacity. Performance of building frame can also be improved by the T-EPT based on the study of Toral et al., 2015. However, the steel frame used for the T-EPT was very large and cumbersome.

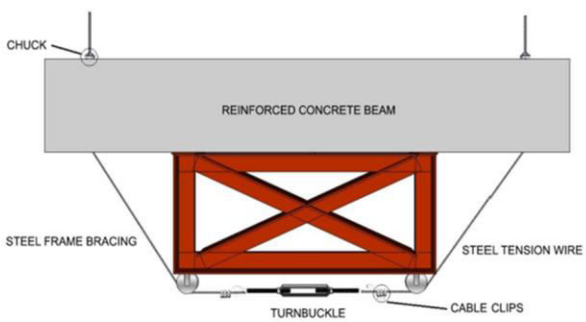

Fig. 1. T-EPT system in the previous study of Penamante et al., 2015

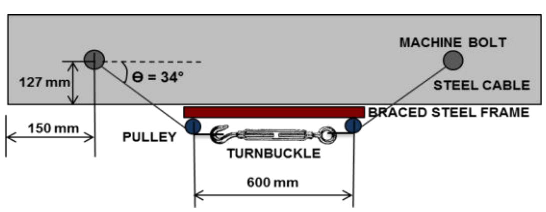

Fig. 2. Proposed T-EPT system with considerably smaller braced steel frame

This study aims to develop a practical configuration for the T-EPT that is more compact. Practicality was achieved by decreasing the size of the steel frame and changing the anchorage system as shown in Fig. 2. In the previous study (Penamante et al., 2015), the anchorage was placed by drilling holes from top to bottom of the beam and inserting the anchor bolts vertically. This presents some problem in actual application and aesthetics. The new anchorage adopted is done by drilling holes sideways at the mid-height of the beam and placing the anchor bolts horizontally. This is more practical since it is easier to access the beam in this manner and would eliminate the undesirable view of bolts protruding from the top of the beam. Since the prestressing cables are now on both sides of the beam, two M16 turnbuckles (diameter = 16mm) were used to apply the prestressing force to the beam, hence the term "double-sided". The turnbuckles are placed under the steel frame, which is now placed flat on the bottom surface of the beam.

Generally, this study aims to evaluate the newly-designed T-EPT system in retrofitting overstressed reinforced concrete beams. The new configuration was tested to examine if it would still be effective despite its compact design. Specifically, the research aims to: (a) Enhance the T-EPT design of the previous study (Penamante et al., 2015) to come up with a more efficient and applicable tool for retrofitting. (b) Test and evaluate the load capacity of the beams with the new and improved design of T-EPT. (c) Compare the previous design (Penamante et al., 2015) with the new design in terms of strength, and overall effectiveness. (d) Determine the jacking force that can be applied by means of the turnbuckle and the maximum torque that can be applied by an average person on the turnbuckle.

2. METHODOLOGY

The new design of the T-EPT system was based on the numerical analysis conducted by Lejano, 2016 using the fiber method modeling. The study found out that the dimensions of the braced steel frame affected the effectiveness of the T-EPT. In general, better effectiveness is obtained when the slope of the cable is smaller. By placing the steel frame horizontally flat on the bottom surface of the beam, the slope of the cable is made smaller. The cables were in harped configuration that is they run from the anchorage which is located at 150mm from the end of the beam and passing through the pulleys in the steel frame which are 600mm apart (see Fig.2).

Eight reinforced concrete beam specimens, measuring 254mm x 152mm in cross section by 1.5m in length, were fabricated for the test. The details of the cross section of the beam are shown in Fig. 3. These beams were constructed considering the requirements of the National Structural Code of the Philippines, 2010. There were four different beam specimens, two concrete strengths (18 and 21 MPa) and two sizes of tension reinforcement (10mm and 12 mm rebar). These cases are tabulated in Table 1. For each case, two beam specimens were constructed and tested.

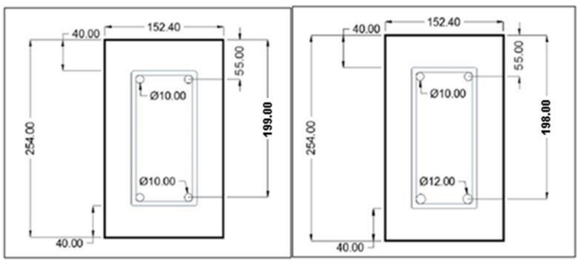

Fig. 3. RC beam cross section and reinforcement details

Table 1. Tabulated cases of the beam specimens

Beam type	Concrete strength (fc')	Top rebar size	Bottom rebar size
Case A	21 MPa	10mm	12mm
Case B	21 MPa	10mm	10mm
Case C	18 MPa	10mm	12mm
Case D	18 MPa	10mm	12mm

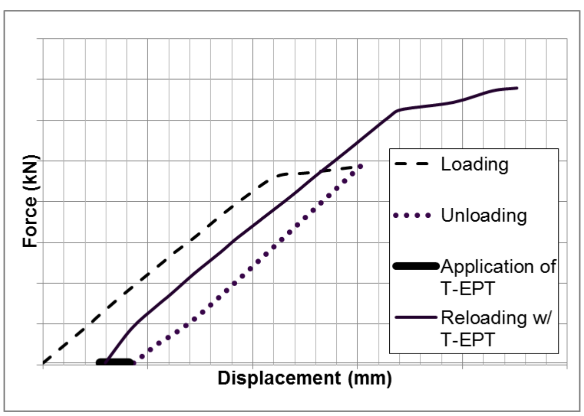

Fig. 4. Stages of loading applied on the beam

These beams were tested under prescribed loading stages. The beams were loaded with concentrated force applied at the midspan. This sequence of loading stages is graphically illustrated in Fig. 4. Specifically, a beam specimen was loaded up to its inelastic region to determine its yield strength and to measure the deflection produced. It was unloaded afterwards and it was observed that permanent deflection was produced. The T-EPT was then applied to counteract the deflection. The beam was then reloaded up to its ultimate condition, wherein the load capacity and yield strength could be observed to have increased compared to the first loading. The actual loading setup is shown in Fig. 5.

Fig. 5. RC beam test setup with T-EPT system

3. RESULTS AND DISCUSSION

The newly-designed T-EPT was more compact since the 600mm long steel frame was placed flat on the bottom surface of the beam. This resulted to less obstruction in the headroom, which was experienced in the previous design (Penamante et al., 2015) because the frame was placed vertically. It was easier to apply the jacking force since two turnbuckles were used. In addition, since the T-EPT is more compact, the material cost was also reduced.

The accuracy of the experimental test results was verified by comparing the theoretical and experimental load that will cause the tension rebar to yield. Shown in Table 2 is the comparison. It may be said that there is a good agreement between the experimental and theoretical predictions.

Table 2. Comparison between experimental and theoretical load at yield

Case	Load at yield (KN)		Percent difference
	Theoretical	Expt	
Case A	46.45	48.15	5.80%
Case B	32.4	31.2	4.30%
Case C	46.1	48.3	6.25%
Case D	32.3	33.05	6.65%

Shown in Table 3 is the summary of the experimentally obtained maximum load before and after application of the T-EPT. It can be seen that in all beam specimens the load capacity increased when the T-EPT was applied.

Table 3. Experimentally obtained maximum load capacity before and after application of T-EPT

Beam Specimens	Load Capacity (KN) Without T-EPT	Load Capacity (KN) With T-EPT	Increase in Load Capacity (KN)
Case A-Beam1	45.7	62.1	16.4
Case A-Beam2	50.6	62.2	11.6
Case B-Beam1	32.6	45.4	12.8
Case B-Beam2	29.8	41.6	11.8
Case C-Beam1	45.4	65.6	20.2
Case C-Beam2	51.2	70.9	19.7
Case D-Beam1	35.2	55.9	20.7
Case D-Beam2	30.9	40.1	9.2

Shown in Table 4 is the comparison between the old and the new T-EPT system in terms of the average percentage of load increase. The result of the experiment using the new T-EPT system reflected an average load capacity increase of 38.6%. This is higher than the 32.1% increase obtained in the previous study (Penamante et al., 2015). It was also observed that improved performance due to the application of T-EPT was higher for beams with lower concrete strength (case C and case D).

Table 4. Comparison between old and new T-EPT system in terms of average percentage load increase

Beam Type	New T-EPT Configuration	Old T-EPT Configuration
Case A	29.41%	27.48%
Case B	39.43%	41.92%
Case C	41.48%	37.03%
Case D	44.29%	22.03%
Average	38.65%	32.12%

As for the permanent or residual deflection fixed when the new T-EPT was applied, an average of 43.18% deflection recovery was observed. A summary of this is shown in Table 5. Deflection recovery is the amount of deflection that is reduced from the residual deflection that is produced by the load.

Table 5. Recovery of residual deflection

Beam specimens	Deflection recovered (mm)	Percent recovery (%)	Average recovery (%)
Case A-Beam1	0.640	36.99	34.24
Case A-Beam2	0.935	31.48	
Case B-Beam1	0.505	29.36	37.93
Case B-Beam2	0.865	46.51	
Case C-Beam1	1.590	42.40	71.07
Case C-Beam2	1.955	99.74	
Case D-Beam1	0.945	31.87	29.47
Case D-Beam2	0.735	27.07	
		Average	43.18%

To be able to determine the bending moment that is carried by the T-EPT, it is needed to establish the relationship between the jacking force and the torque applied to the turnbuckle. To do this, the magnitude of the jacking force exerted by the M16 turnbuckle is measured when a certain amount of torque is applied. Based on the test results, a linear relationship was observed. This relationship is shown in Fig. 6. In order to produce 1 kN of jacking force, a torque of 6.65 kN-mm was needed to be applied. It was also determined that the maximum torque that can be applied by a single person is 109 kN-mm which results to a jacking force of 16.4 kN per turnbuckle.

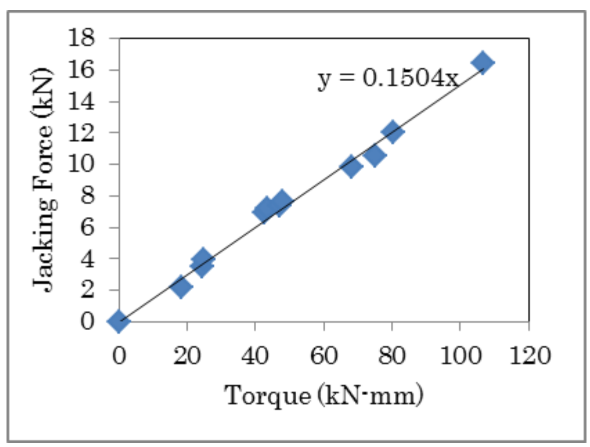

Fig. 6. Relationship between applied torque and resulting jacking force in turnbuckle

The bending moment that is carried by the T-EPT can be calculated if the jacking force is known. With the applied torque measured, the jacking force may be calculated from the relationship shown in Fig. 6. The bending moment carried by the T-EPT is equal to the jacking force multiplied by the eccentricity of the turnbuckle reckoned from the plastic centroid of the beam. The results of this calculation are presented in Table 6. This calculation is important because this can serve as the design calculation technique for this retrofitting method.

Table 6. Theoretical bending moment carried by the T-EPT system (Theoretical M_{TEPT})

Beam specimens	Torque applied (KN-mm)	Jacking force (KN)	Theoretical M_{TEPT} (KN-m)
Case A-Beam1	96.65	29.1	4.8
Case A-Beam2	99.98	30.1	5.0
Case B-Beam1	104.26	31.4	5.2
Case B-Beam2	105.36	31.7	5.2
Case C-Beam1	105.28	31.7	5.2
Case C-Beam2	107.20	32.2	5.3
Case D-Beam1	103.20	31.0	5.1
Case D-Beam2	99.12	29.8	4.9

To verify the correctness of the theoretical bending moment carried by the T-EPT, it will be compared to the experimental values. Tabulated in Table 7 is the experimentally-obtained bending moment carried by the T-EPT (Experimental M_{EPT}).

Table 7. Experimentally-obtained bending moment carried by the T-EPT system (Experimental M_{TEPT})

Beam specimens	Increase in load capacity (KN)	Experimental M_{TEPT} (KN-m)
Case A-Beam1	16.40	5.33
Case A-Beam2	11.60	3.77
Case B-Beam1	12.80	4.16
Case B-Beam2	11.80	3.84
Case C-Beam1	20.20	6.57
Case C-Beam2	19.70	6.40
Case D-Beam1	20.70	6.73
Case D-Beam2	9.20	2.99

The experimentally-obtained bending moment carried by the T-EPT (Experimental M_{TEPT}) is determined from the increase in the load capacity. Since the increase in load capacity is caused solely by the application of the T-EPT, then the experimental value for bending moment is the moment increased due to the increase in load capacity. This means that the experimental M_{TEPT} is determined from the moment diagram produced by the increase in load capacity.

Shown in Table 8 is the comparison between the experimentally-obtained and theoretical bending moment carried by the T-EPT. It may be said that there is relatively good agreement between the theoretical prediction and the experimentally-obtained moment. This serves as verification that the theoretical calculations may be used to predict the increase in strength due to the application of T-EPT. This also supports the findings that the applied jacking force is generally adequate to increase the strength of the reinforced concrete beam.

Table 8. Comparison between experimental and theoretical bending moment carried by the T-EPT

Beam Type	Experimental M_{expt} (KN-m)	Theoretical M_{calc} (KN-m)	M_{expt}/M_{calc}
Case A	5.01	4.92	1.02
Case B	4.00	5.25	0.76
Case C	6.48	5.32	1.21
Case D	4.86	5.06	0.96

4. CONCLUSIONS

A new configuration of the T-EPT that is more practical and efficient, without compromising its strength, was presented. With the decrease in size and change in anchorage orientation, the new configuration is more economical and easier to implement. Furthermore, the decrease in the inclination of steel cables due to the horizontal orientation of the steel frame of the T-EPT system, greatly contributed to the improvement of the system in terms of strength increase. The utilization of two turnbuckles also resulted to more effective way of applying the jacking force. This modified T-EPT configuration was able to produce an average of 43.2% decrease in deflection and increased the load capacity by 38.7%.

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