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Analyzing the Effectiveness of the Turnbuckle Exterior Post Tensioning as a Structural Retrofitting Method Using SAP2000

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Abstract: Nowadays the problem of aging and deterioration of reinforced concrete buildings are eminent and due to excessive loading, the flexural performance and serviceability of structures are affected. The Turnbuckle Exterior Post Tensioning (T-EPT) was developed as a retrofitting method wherein it was proven experimentally that it can be able to improve the serviceability and load carrying capacity of beams. The effectiveness of the T-EPT was further analyzed using SAP2000, and by utilizing the results from the experimental testing; cracking and degradation was considered by adjusting the stiffness modification factor, specifically, the moment of inertia of the beam section. A computer modeling method was developed to simulate the application of the T-EPT to full scale beam sections to determine its effectiveness with different cases. The behavior of the beams as observed from the experimental phase was attributed to the computer model to accurately simulate its behavior. Different T-EPT configurations were modeled and from there, the most efficient design that can be applied to structures was determined. Overall the T-EPT was effective in improving the serviceability and load carrying capacity of reinforced concrete beams.

Key Words: structural retrofitting; exterior post tensioning; reinforced concrete; computer modeling

1. INTRODUCTION

Due to the economic development worldwide, the increase in demand for different infrastructures becomes the trend in the construction industry. Therefore, more and more buildings and structures rise from every possible area for development. Together with the construction of new structures, worldwide deterioration and aging of reinforced concrete structures are also eminent (Galal and Mofidi, 2009). Due to the inevitable long term environmental exposure and excessive loading experienced by reinforced concrete structures as time passes by, the structural performance of reinforced concrete members may be affected. Specifically, reinforced concrete beams deflect in time whereas the flexural performance and serviceability of the beams are also affected.

Before, the initial response towards structures which are considered to have poor performance was to demolish it. But due to environmental concerns such as producing waste material from the demolition and concerns regarding high operational costs, the strengthening and retrofitting of these structures must first be considered in order to resolve these problems (Panian et al., 2007).

It has been a good thing that structural engineers design beams in such a way that it is under-reinforced wherein tension would tend to fail first allowing the beam to at least deform as a sign of overloading instead of the concrete suddenly crushing due to compressive failure. Therefore, structural engineers can retrofit a deformed reinforced concrete member before the case of its final failure. On the other hand, retrofitting methods may be applied as a form of structural strengthening wherein it is applied to reinforce structures against extreme loadings such as seismic loads as a safety measure.

The investigation of different retrofitting methods based on different purpose and applications are being conducted worldwide. Engineers still seek the most efficient way of retrofitting structures both incorporating the environmental effects and the cost while being able to serve its purpose. The study investigates the effectiveness of the turnbuckle exterior post tensioning (T-EPT) as a method of retrofitting reinforced concrete buildings.

1.1 Significance of the Study

Given the existing problems, the study was intended to provide a more economical and practical way of retrofitting deformed reinforced concrete beams due to its simple configuration and installation. The study would help to enhance the serviceability and flexural performance of structures. The application of exterior post tensioning would enhance the stability of structures therefore promoting mitigation and safety of structures to its intended community and surrounding environment even against seismic occurrences. Moreover, the basis of the analysis and methodology regarding the application of the T-EPT to structures is still a developing process wherein this study can contribute by designing a method of analyzing the structure using an integrated software.

1.2 Objectives of the Study

The study aims to determine and analyze the effectiveness of the turnbuckle exterior post tensioning in retrofitting reinforced concrete beams using SAP2000. Specifically, the study aims to; (i) analyze its effectiveness by means of testing and experimentation; (ii) evaluate the flexural strength and beam deformation characteristic of reinforced concrete beams retrofitted with the T-EPT; (iii) investigate the applicability and design of the T-EPT for buildings; and (iv) investigate the most efficient T-EPT configuration in retrofitting beams.

2. TURNBUCKLE-EPT (T-EPT)

The turnbuckle exterior post tensioning (T-EPT) is a retrofitting method which applies the concept of pre-stressing where a series of external tension wires and bracing resist moment from external loads applied on a beam. The only difference is that a turnbuckle mechanism would be used as the source of jacking force. Figure 1 illustrates the parts and configuration of the T-EPT.

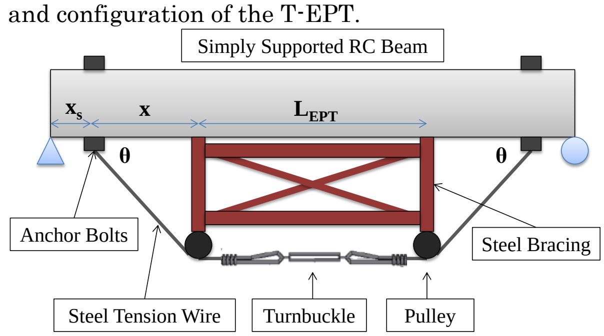

Fig. 1. Parts, configuration, and experimental setup of the T-EPT

2.1 T-EPT as a Retrofitting Method

Adiaz and Vidad, 2010 stated that the application of the turnbuckle type of exterior post tensioning has been effective and has definitely increased the load carrying capacity of the steel beam member. The study of applying the turnbuckle exterior post tensioning into steel wide flange beams verified the applicability of the said configuration in resisting the deflection of a beam structure. The easiness in terms of its application and anchorage was remarkable compared to conventional exterior post tensioning methods such as the jacking type as it only made use of a turnbuckle to apply the jacking force. Since it has been verified from recent studies that such configurations can be applied and that it is effective in applying resisting moment, it may not be far that it could also be applied upon deflected reinforced concrete structures. Therefore, the configuration and application of the exterior post tensioning method in retrofitting reinforced concrete beam was developed and assessed in the study.

The study of Astillero et al., 2012 was a further development of the study of Adiaz and Vidad, 2010 as they improved the anchorages with a harped configuration. Their study also applied and exterior post tensioning system using a turnbuckle but with a different configuration. In their study, they have proven that a harped system comprised of steel tendons welded and anchored at the end yielded more effective results. The results that they have yielded was used to determine the parameters that this study can perform. The study of Astillero et al.,2012 influenced the methodology of the study whereas instead of applying the series of turnbuckle and tension wires on a steel member, it was applied for a reinforced concrete beam.

3. THEORETICAL CONSIDERATIONS

The main theoretical principle involved in the T-EPT is to establish equilibrium in order to bring back the beam to its original condition. For the experimental phase, the total moment, M_{TOTAL} in the system is equal to the moment exerted by the external force, M_{EXT} to the beam plus the moment exerted by the exterior post tensioning, M_{EPT} which is shown in Eq. 1. To obtain the original condition with no deformation, equilibrium must be set wherein the total moment in the system is equal to zero (Eq. 2). Eq. 3 shows the equilibrium condition of the system. In order to control the loading setup, and to ensure that the beam only deforms and not fails, the external force that is applied based on the moment that can be resisted by the beam. Therefore, the moment produced by the point load, and the moment resisted by the beam, M_{BEAM} is presumed to be equal (Eq. 4). The moment that can be resisted by the beam is the nominal moment that is computed depending on the cross section design of the beam and its material properties (Eq. 5). The nominal moment, Mn is based on the ultimate strength design (National Structural Code of the Philippines - 2010) and is computed using the rectangular stress block method.

$$M_{TOTAL} = M_{EXT} + M_{EPT} \quad \text{(Eq. 1)}$$
$$M_{TOTAL} = 0 \quad \text{(Eq. 2)}$$
$$0 = M_{EXT} + M_{EPT} \quad \text{(Eq. 3)}$$
$$M_{EXT} = M_{BEAM} \quad \text{(Eq. 4)}$$
$$M_{BEAM} = Mn \quad \text{(Eq. 5)}$$

For the computer modeling phase, the influences of the actual effect of the EPT are now considered. Given the moment experienced by the beam that causes the deflection, the moment of the EPT that is required by the system could now be determined which includes the jacking force, Pj and the eccentricity, e. The T-EPT follows the same principle as pre-stressing wherein a certain amount of moment is applied on the beam with the use of tension cables to counteract the moments induced by the external loads on the beam. The application of a pre-stressing force increases the stiffness of a structural member specifically beams which attributes to the behavior of the structure against seismic loads.

4. METHODOLOGY

4.1 Experimental Phase

4.1.1 Experimental Setup

The experimental beam specimens were loaded in the beam rig testing apparatus which is the main test that would identify the flexural characteristics of the beam. The system is comprised of a series of tension wires and bracing which are anchored near the support. The turnbuckle mechanism is the source of jacking force for the T-EPT system and by turning and tightening the mechanism, tension is applied in the wires and the pre-stressing force is applied.

4.1.2 Loading Cycles

The beam specimens were loaded to reach the elastic, inelastic, and ultimate condition. The five loading applications would be done for all 3 loading cycles (elastic, inelastic, and ultimate). For each cycle the specimens were loaded with and without the T-EPT to determine if there were changes in the load carrying capacity of the beams after the T-EPT has been applied. This may be observed after the beam has been loaded to the same deformation (loading 4). The loading applications are as follows:

1 - Loading to specific elasticity condition
2 - Unloading
3 - Application of the T-EPT
4 - Loading to the same deformation with the T-EPT
5 - Unloading

4.2 Computer Modeling Phase

4.2.1 Modeling Procedure of the T-EPT

The T-EPT was modeled into the integrated software by translating the forces produced by the T-EPT into a series of concentrated loads on the beam. By static analysis and from the free body diagram of the T-EPT, the concentrated loads was derived as a function of the jacking force applied. Figure 2 illustrates the translated T-EPT forces along the beam.

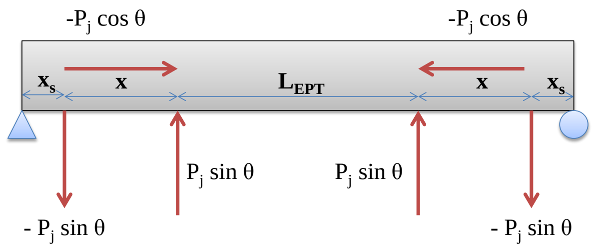

Fig. 2. Translated T-EPT forces along the beam

4.2.2 Adjustment Coefficient

An adjustment coefficient was incorporated into the computer model in order to characterize the behavior of reinforced concrete when loaded. An adjustment coefficient is needed in order to consider the effects of concrete cracking to beam deformation. Furthermore, concrete degradation due to external loading was derived based on the results of the experimental testing. The adjustment factor would be inputted as a stiffness modification factor for the beam section moment of inertia. The average of the computed degradation factor is 0.84 which would be used for the computer modeling (DEG Ratio = 0.84).

4.2.3 Different Configurations and Cases Modeled with T-EPT

In order to investigate the influence of different configurations and loading cases to the effectiveness of the T-EPT, several configurations were modeled and full scale beam dimensions were considered. The different cases simulated the application of T-EPT to full scale structural members. There were three factors that were investigated; the effects of different T-EPT length ratio; the effects of a uniformly distributed load; and lastly, the effects of increasing compressive strength and bar sizes. Figure 3 illustrates the configuration of the control model.

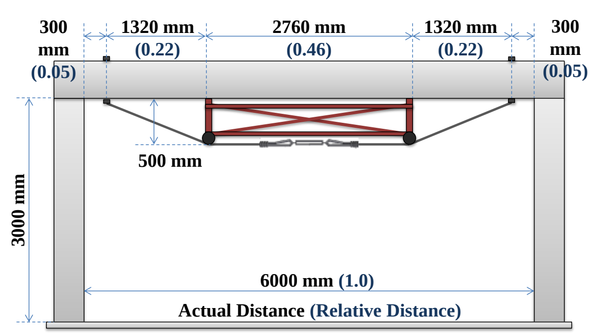

Fig. 3. T-EPT configuration for varying T-EPT length ratio

4.2.4 Inelastic Analysis of Beam with T-EPT

The investigation of the effectiveness of the T-EPT at the inelastic condition was considered as the behavior at this point is more critical. The inelastic behavior of reinforced concrete was characterized in the computer model by applying hinges on the beams. It was determined if the T-EPT could improve the load carrying capacity even at the inelastic stage.

5. RESULTS AND DISCUSSION

5.1 Experimental Results

Figure 4-A illustrates the increase in load carrying capacity after the application of the T-EPT during the elastic stage. All test samples were loaded up to 70% of the yielding point to ensure that the beam is in the elastic stage. For all test samples, the increase in load carrying capacity was observed in the elastic stage. At the elastic stage, the specimens were almost brought back to zero deformation. The increase in load given the same deformation may be attributed to the applied T-EPT.

Figure 4-B illustrates that for the inelastic stage of loading, the displacement was decreased given the same load after the application of the T-EPT. For the inelastic stage, the beams were retrofitted only to a certain extent due to excessive yielding of the steel and cracking of the concrete. However, for most of the specimens, even with a small amount of post-tensioning force, it still increased the capacity of the beam. For some specimens in the inelastic stage, anchorage slipping was observed which decreased the post-tensioning force applied on the beam.

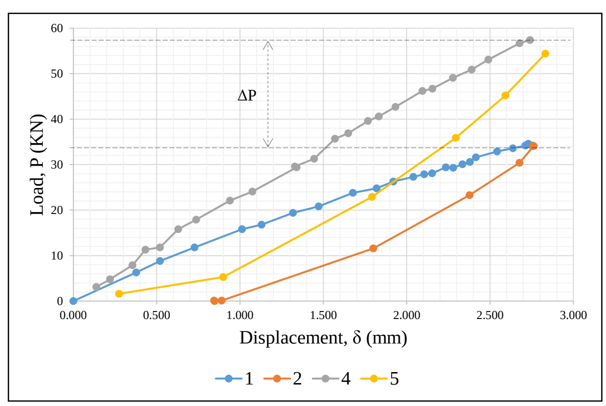

Fig. 4-A. Load vs. displacement diagram for elastic stage (representative specimen)

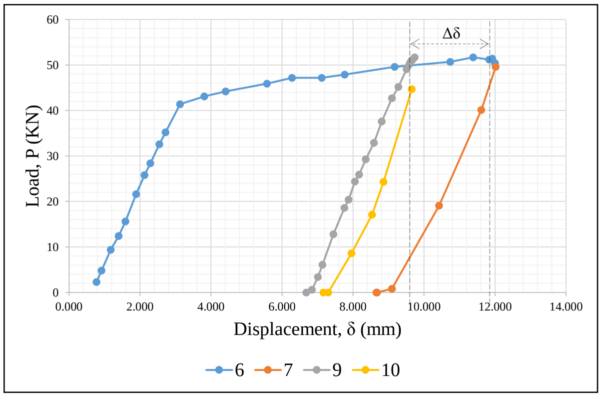

Fig. 4-B. Load vs. displacement diagram for inelastic stage (representative specimen)

Table 1. Percent increase in load carrying capacity for the experimental phase

Specimen	% Increase in Load Carrying Capacity		
	$0.7\delta_Y$	δ_Y	$\delta_{INELASTIC}$
Case 1	32.701	38.820	5.402
Case 2	55.980	55.980	59.551
Average 1-2	44.341	47.400	32.476
Case 3	65.592	82.839	62.373
Case 4	21.241	42.299	61.585
Average 3-4	43.417	62.569	61.979
Total Average	43.879	54.985	47.228
	49.432		

Table 1 shows the values of percentage increase in load carrying capacity for each experimental beam case. It shows that for the elastic stage, the beams that were retrofitted had an increase in load carrying capacity of 49.432% in average. On the other hand, 47.228% for the inelastic stage.

5.2 Computer Modeling Results

5.2.1 Computer Model Results for the Elastic Condition

Figure 5 illustrates the increase in load carrying capacity for the elastic condition. At a certain percentage of jacking force, there is a corresponding increase in load carrying capacity. As the percent jacking force decreased, its effectiveness in giving the expected result also decreased. For the elastic stage cases, it was observed that at a certain percentage of jacking force, it cannot be effective anymore. The results for the elastic stage yielded to significantly high increase in load carrying capacity (96.688% at 100% jacking force).

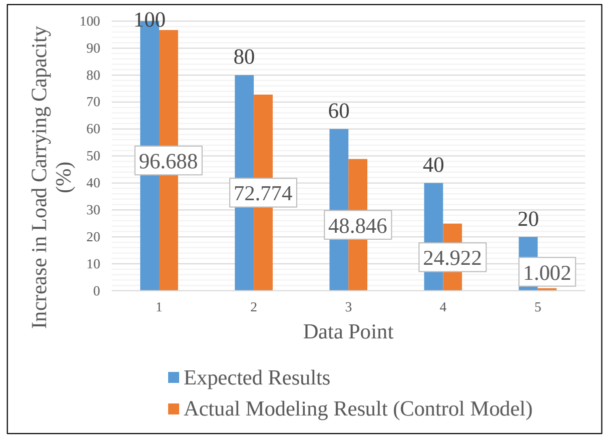

Fig. 5. Increase in load carrying capacity for the elastic condition

5.2.2 Computer Model Results for the Inelastic Condition

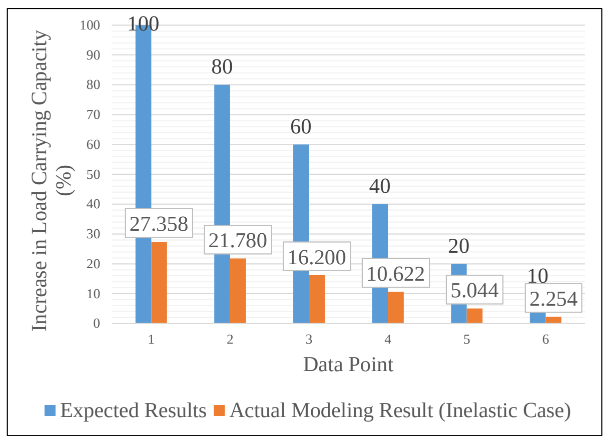

Fig. 6. Increase in load carrying capacity for the inelastic condition

Figure 6 illustrates the increase in load carrying capacity for the inelastic condition. Compared to the results in the elastic condition, the increase in load carrying capacity for the inelastic stage was lower (27.358% at 100% jacking force). This may have been caused by the inelastic behavior of the concrete and the computer model was limited to model the elastic influence of the T-EPT.

6. CONCLUSIONS

The experimental results proved that the effectiveness of applying the T-EPT depends on the elasticity condition of reinforced concrete beams. The T-EPT was effective in retrofitting reinforced concrete beams deflected until the elastic range; however, for beams deflected up to the inelastic range, the turnbuckle mechanism only provided 15% decrease in permanent deformation. Even if the inelastic beams were not brought back to its original condition (zero deformation), the pre-stressing force applied by the T-EPT increased up to 49% of load carrying capacity for the elastic range and up to 47% for the inelastic range. This was based on the experimental tests where the jacking force applied was based on the limitation to turn the mechanism. The application of the T-EPT also affected the load carrying characteristic of the beam even if it has already reached ultimate condition. The effectiveness of the T-EPT depends on the elasticity condition of the beams wherein for the inelastic case, it became more difficult to be applied due to the excessive cracks formed on the beam. Moreover, the reinforcing steel bars have already yielded for the inelastic stage and permanent elongation has already occurred which limits the amount of retrofitting that can be applied.

The computer modeling phase proved that the effectiveness of the T-EPT decreases as the percent jacking force decreased. It was verified that for the elastic condition, the T-EPT was highly effective in increasing the load carrying capacity. However for the inelastic condition, a different trend was observed compared to the experimental results since the effects of the tension wires in keeping the beam to behave elastic was not considered in the modeling due to the limitations of the software. Thus only increasing carrying capacity of inelastic beams up to 27%. A case study applying the T-EPT to a structural model was conducted and the results show that applying a uniformly distributed load made the application of the t-EPT more effective. Overall the T-EPT was effective in improving the serviceability condition and load carrying capacity of reinforce concrete beams.

7. RECOMMENDATIONS

In terms of improving the experimental setup, the use of a better and a more appropriate anchorage system is advised in order to avoid pre-stress losses from anchorage slipping. Moreover, for further studies and actual applications of the T-EPT, the use of a turnbuckle with finer screw threads and smaller thread angle may provide easiness in turning the screws especially when applying in higher stresses. A study regarding the development of the material for the turnbuckle is recommended in order to improve it for its retrofitting application.

The resulting optimal configuration from the computer modeling phase could be tested and verified by means of experimentations. Further computer analysis such as finite element modeling may be done which could be focused more on the characteristics of the anchorage or the inelastic behavior of the beams to further improve the T-EPT system.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

Adiaz, P., Vidad, D., and Lejano, B.A. (2010). Effects of exterior post-tensioning on retrofitting deformed wide flange steel beams. Thesis, Department of Civil Engineering, De La Salle University, Manila, Philippines.

Astillero, C., Baretto, I., Brillante, C., Provido, W., and Lejano, B.A. (2012). Analysis of deformed wide-flanged beam with harped exterior post tensioning. Thesis, Department of Civil Engineering, De La Salle University, Manila, Philippines.

Galal, K., and Mofidi A. (2009). Strengthening RC beams in flexure using new hybrid FRP sheet - ductile anchor system. *ASCE*, *13(3)*, 217-225.

Panian, L., Steyer, M., and Tipping, S. (2007). Post-tensioned shotcrete shearwalls. Concrete International, 23, 39-45. Retrieved July 20, 2013, from http://search.proquest.com/docview/198704577?accountid=28547