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Structural Retrofitting of Simply Supported Reinforced Concrete Beams Using Turnbuckle Exterior Post Tensioning

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Abstract: Due to long term environmental exposure and excessive loading experienced by aging structures, the structural performance of reinforced concrete members are affected; whereas RC beams deflect over time and eventually compromises the flexural performance and serviceability of the structure. Instead of demolishing structures considered to have poor performance, a turnbuckle type of exterior post tensioning system would be used as a retrofitting method in order to resolve the structural, environmental and cost problems. The turnbuckle exterior post tensioning (T-EPT) makes use of a turnbuckle mechanism to provide pre-stressing force to a flexural member. An experimental method was designed in order to determine the effectiveness of the T-EPT in terms of retrofitting RC beams back into its original condition and further increase its load carrying capacity. The experimental results proved that the effectiveness of applying the T – EPT depends on the elastic condition of the RC beams. The T- EPT was effective in retrofitting RC 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 RC beams were not brought back to its original condition (zero deflection), the experiment have presented further improvements. The pre – stressing force applied by the T – EPT increased load carrying capacity of the RC beams up to 40% for the elastic range, and up to 27% for the inelastic range. Based on the experiment made, recommendations were obtained to further improve some procedures in testing the T- EPT.

Key Words: reinforced concrete; retrofitting; exterior post tensioning; turnbuckle;

1. INTRODUCTION

Post tensioning is a retrofitting method applied in order to produce an active reinforcement in the beam to consequentially keep deflection at minimum under full loading and also increase the load carrying capacity of the beam. External tendons are anchored and placed as a support for a structural member experiencing flexural deformation. In this study, a turnbuckle mechanism is used to produce the prestressing force instead of the usual hydraulic jack.

The study aims to analyze the effectiveness of exterior post-tensioning method for regularly stressed reinforced concrete. Specifically, the study aims to:

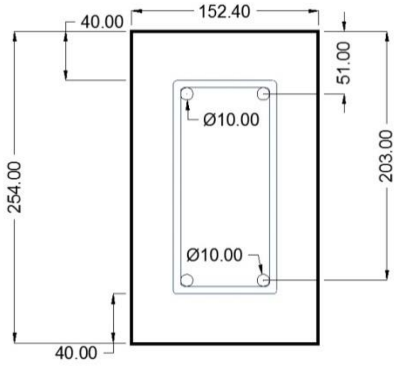
a. Compare the flexural strength characteristics of regularly reinforced concrete without the application of exterior post tensioning and RC beams retrofitted with EPT.
b. Evaluate the beam deflection characteristics of reinforced concrete beams after the application of EPT.
c. Evaluate the effects of the EPT to the RC beams in terms of load carrying capacity.
d. Determine the influences of the steel ratio and the compressive strength of the concrete to the effectiveness of the EPT.

2. METHODOLOGY

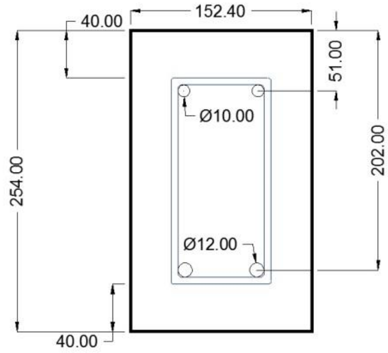
2.1 Determination of Number of Specimens

The study used two parameters such as the compressive strength of concrete and steel ratio which is based on the configuration of the steel bars on the reinforced concrete beam. The number of specimens was determined by producing the combinations of the variables.

	Parameter (strength of concrete; steel ratio based on reinforcement configuration)	**Number of Specimens**
CASE 1	21 MPa; 0.004880 (10-10)	2
CASE 2	21 MPa; 0.007027 (10-12)	2
CASE 3	18 MPa; 0.004880 (10-10)	2
CASE 4	18 MPa; 0.007027 (10-12)	2
Control Sample (1 for each case)		4
TOTAL NUMBER OF RC BEAM SPECIMENS		**12**

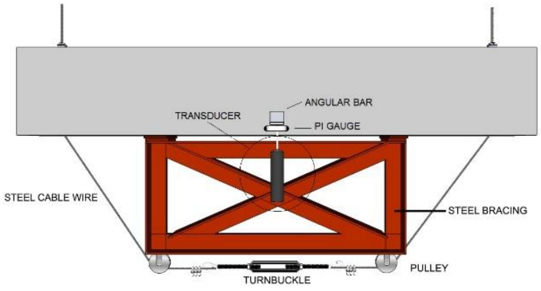


(10-10) Configuration



(10-12) Configuration

2.2 Experimental Setup



2.3 Test Cycle

Each specimen was subjected to three cycles of loading. First, the specimen is loaded without the EPT until a deflection limit which was predetermined through the properties of the reinforced concrete beam from the tested control samples. It is then unloaded and followed by the application of EPT. With this, prestressing force is produced and in turn decreases the deflection of the beam due to the initial loading. The beam is then loaded again to the same deflection limit. Same procedure is performed in every cycle with each one reaching elastic, inelastic and ultimate regions.

CYCLE	REGION	LOADING PHASE
1	ELASTIC	**Loading to 0.7δy**
		UNLOADING
		AFTER EPT APPLICATION
		Loading to 0.7δy with EPT
		UNLOADING
2	INELASTIC	**Loading to Inelastic Region**
		UNLOADING
		AFTER EPT APPLICATION
		Loading to Inelastic Region with EPT
		UNLOADING
3	ULTIMATE	**Load to Ultimate**

3. THEORETICAL FRAMEWORK

Since the study focuses on increasing the flexural strength of the member, the concept is to decrease the tension experienced by the cross section.

The primary principle of the study is given by Equation 1 in which it involves the different moments that are present when the given experimental set up is in place.

$$M_{total} = M_{external} + M_{EPT} = 0 \qquad \text{(Eq. 1)}$$
$$M_{external} = M_{beam}$$
$$M_{beam} = M_n$$

where:

M_{total} = Total moment in the system;
$M_{external}$ = Moment produced by the external force;
M_{EPT} = Moment produced by the EPT.
M_{beam} = Moment resisted from the beam.

With the equation in place, its relationship with the study is closely illustrated in Figure 1.0 given below as it shows the RC beam being retrofitted with the EPT and also shows how the beam is brought back to its original condition.

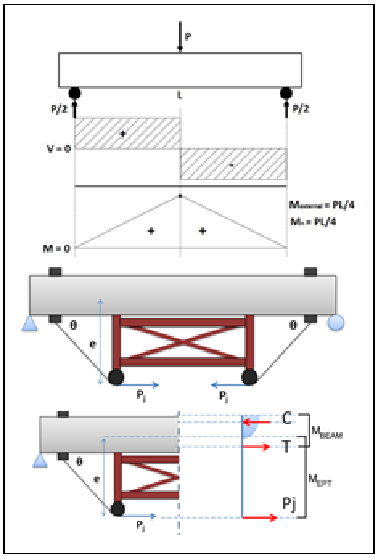
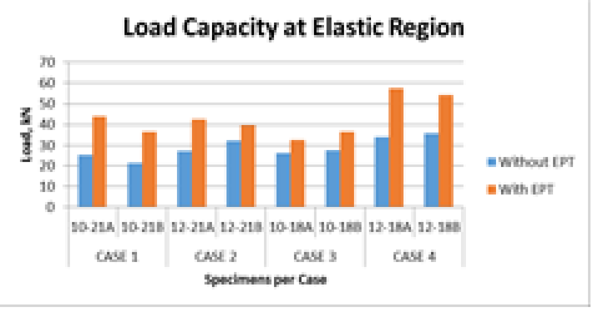


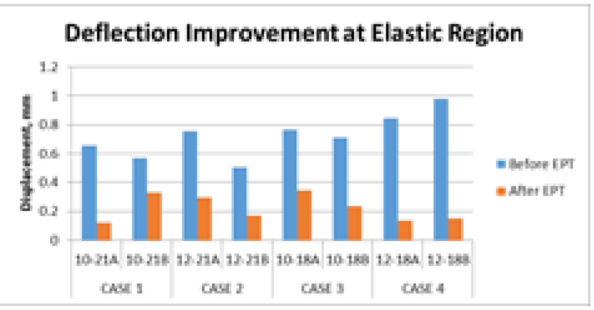
Fig. 1. Relation of the set - up as the EPT is placed under the RC beam

4. RESULTS AND DISCUSSION

4.1 Elastic Region



Graphical Representation of Load Capacity Improvement

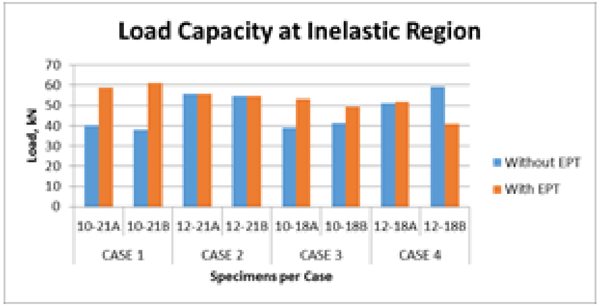


Graphical Representation of Displacement Improvement

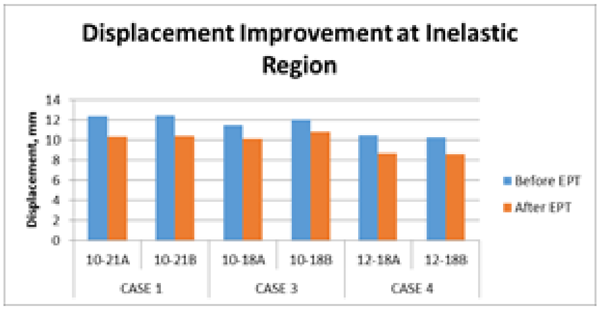
	ELASTIC RANGE					
	Load Capacity Improvement			Deflection Improvement		
	Load Capacity Increase for SPECIMEN A (%)	Load Capacity Increase for SPECIMEN B (%)	Average Load Capacity Increase (%)	Decrease in Deflection SPECIMEN A (%)	Decrease in Deflection SPECIMEN B (%)	Average Decrease in Deflection (%)
CASE 1	42.63	41.21	41.92	81.68	42.29	61.99
CASE 2	35.83	19.14	27.49	61.06	66.34	63.70
CASE 3	20.43	23.63	22.03	55.37	67.02	61.20
CASE 4	40.42	33.64	37.03	83.73	84.66	84.20

From the graphs and table presented, it is evident that the beam has improved in terms of both load capacity improvement and deflection improvement. The beams were generally able to carry a greater load capacity after the EPT has been applied along with the decrease in deflection.

4.2 Inelastic Region



Graphical Representation of Load Capacity Improvement

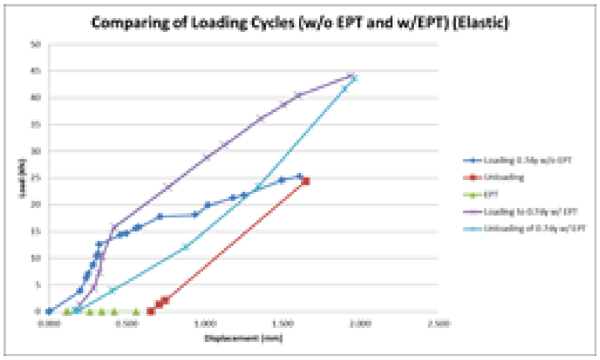


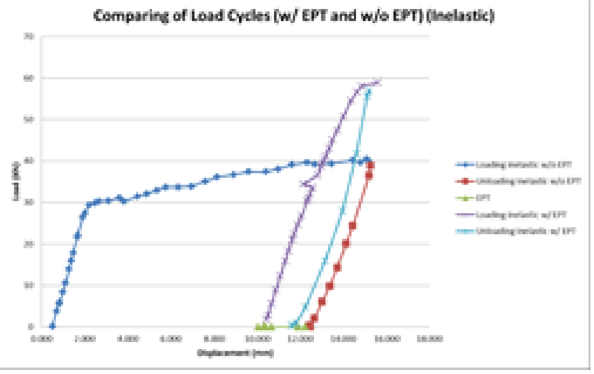
Graphical Representation of Displacement Improvement

From the graphs and table presented, it is clear that the beam has improved in terms of both load capacity improvement and deflection improvement but not as great as those in the elastic region.

The load capacity still exhibited a significant amount of increase while the decrease in deflection was minimal.

4.3 Comparison of Loading Cycles

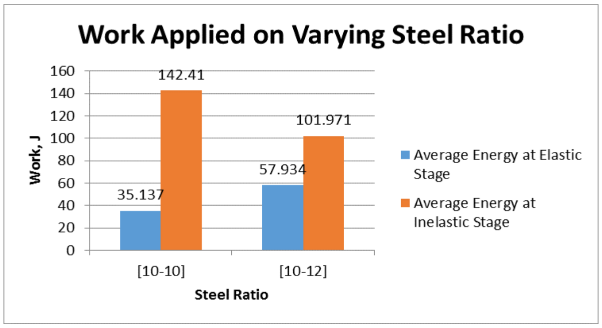




The graphs above represents the loading cycle of specimen 10-21A with and without EPT at elastic and inelastic stages. The graph for the elastic stage shows that the behavior without and with EPT is generally the same but the latter reaches a greater load capacity and deflection. For the inelastic stage, there is a minimal increase in the load capacity while producing a great amount of deflection at the same time, without the EPT. However, the load capacity has increased significantly but producing less deflection after the EPT has been applied.

4.4 Energy Dissipation

The actual values of work or energy dissipated during the application of the EPT are obtained by getting the area under the curve from the load versus displacement graphs.



The graph presents an overview of the energy dissipation after the application of the turnbuckle type of exterior post tensioning method at different stages and varying steel ratio.

5. CONCLUSIONS

From the testing phase, the T-EPT was effective in bringing the RC beam back to its original condition while still in the elastic region of the RC beam. The group managed to bring the beam back to at least near zero deflection or even zero deflection which is the primary objective of the mechanism. It also showed a significant increase in its load capacity based on calculations given the properties of the beam specimens.

In the inelastic region of the RC beam, the T-EPT was only able to go up to a certain extent to bring back the beam back to the original condition with at least 2mm in deformation, on average. The beam cannot carry load further as the bracing used in retrofitting became the only support of the beam.

It is also concluded that the force produced by the T-EPT was able to resist the load applied to the beam hence shows an increase to the flexural strength of the beam.

In terms of steel ratio and compressive strength, it is concluded that the higher the steel ratio, the higher energy output that the T-EPT must produce in order to meet the original conditions of the beam.

From the results yielded by the elastic and inelastic regions of the RC beams, the T-EPT is then concluded to be an effective method of retrofitting deformed beams through the use of tension wires and a turnbuckle mechanism to produce an upward force that resisted the load applied to the beam and consecutively increased its loading capacity.

With these results at hand, the beam is deemed repaired and therefore returned to its original state in which it has the capacity to carry the original load. It is also established through the results that with the addition of the T-EPT, the beam can now carry additional load as it receives added support and force from the T-EPT.

6. ACKNOWLEDGMENTS

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From a single idea, we were able to create a new and entire concept through hard work of proposing and pursuing such idea. We are eternally grateful for the following people, who that led the way in creating the masterpiece of our college life and without their help, our efforts would not have come to fruition:

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7. REFERENCES

Astillero, C.J., Baretto I. G. H., Brillante, C.C.B. and Provido W. A. (2012), Analysis of Deformed Wide-Flanged Beam with Harped Exterior Post Tensioning, Department of Civil Engineering, De La Salle University, Philippines.

Grimares, A. D. L., Peñamante, M. S. and Roxas, J. R. S.J. (2014),Structural Retrofitting of a Simply Supported Reinforced Concrete Beam using a Turnbuckle Type of Exterior Post Tensioning Method, Department of Civil Engineering, De La Salle University, Philippines.

ASEP (2010). National Structural Code of the Philippines (NSCP). Quezon City: Association of Structural Engineers of the Philippines, Inc. (ASEP).