Performance Evaluation of Post-Tensioned Concrete Beams with Bonded System

Shanmathi Sridhar, A. Leema Rose

Abstract*: Looking at the modern trend of construction, post-tensioning method is popularly used in commercial and residential sectors. The application of post-tensioning system is expanding because of its benefits over conventional method of construction, for example, more slender structural members, lighter in weight and smaller floor-to-floor heights.By employing post-tensioning method one can plan the most monetary and the safe structure.Prestressed concrete has been utilized as a replacement of reinforced concrete everywhere throughout the world for quite a long time. Presently, prestressed technology gives productive answers for different structural members and circumstances. The experimental results on the flexural behavior of post-tensioned concrete beams with bonded system are compared. Four rectangular post-tensioned beams were tested and analyzed. The beams were tested under single point monotonic loading condition and two point monotonic loading condition. The load-deflection behavior, stress-strain behavior and crack patterns are presented from the test results. Post-tension system effectively controlled deflection and crack due to the presence of tendons in addition to the reinforcing steel. All the four test outcomes were compared and they clearly showed good results over the conventional beams.

Key words: RAPT, Tendons, Post-tension, Bonded system, Prestressed concrete

I. INTRODUCTION

A. General

As the requirement for space is increasing nowadays, the development of high-rise buildings is also increasing and is turning into a fundamental piece of our current life style. The lack of space is constraining us to raise the elevation of the structures as much as possible to make room for greatest number of humankind and furthermore in concordance with the design necessities. Likewise with increment in tallness the need of opposing lateral loads like wind and earthquake additionally comes into thought. These multistoried structures can be established using different structural systems. Among all those systems, post-tensioning technique gives a proficient structure, which limits material utilization and subsides the financial range extend when related with reinforced cement.

The tensile strength of the plain concrete is just a small amount when compared to its compressive strength and this being the main disadvantage seems to have been the driving element in the advancement of the composite material known as "reinforced concrete."The improvement of early splits in reinforced concrete because of conflict in the strains of steel and concrete was perhaps the beginning stage in the advancement of another material like "post-stressed concrete."Post-stressed concrete can be defined as the concrete where the external stresses are counteracted to a desired degree by internal stresses that are accomplished by means of stressing the steel reinforcement such as tendons or strands or cables.The use of everlasting compressive stress to a material like concrete, which is extremely strong in compression and very weak in tension, increases the apparent tensile strength of that material. This is because the following application of tensile strength should initially compensate the compressive post stress.

In most of the situations, post-tensioning permits construction that would some way or another is impracticable due to either site compulsions or design necessary. Post-tensioning system is further divided into bonded and unbonded system.

B. Bonded system

Bonded system creates a bond between the concrete and the strands. The strands are equipped inside the galvanized steel or plastic ducts. The galvanized steel or plastic ducts are then cast into the concrete section at the required profile and form a voided path through which the strands can be installed. The shape of the ducts can be either oval or circular and it is also available in various sizes. Hence large number of steel strands can be installed within each duct. At the ends all the individual strands are combined in the anchorage casting and are held together tightly. Then the prestressing force is allowed to transfer from the stressing jack into the concrete through anchorage. The strands after being stressed, the voids are filled with a cementitious grout that gives the bonding nature and hence the system is defined as bonded system.

II. MATERIALS USED AND THEIR PROPERTIES

The materials that have been utilized for this investigation incorporates Cement, Fine Aggregate, Coarse Aggregate, wedge and wedge cap, tendon and anchorage casting.

A. Cement

The kind of concrete that was utilized in for the trial reason for existing was Ordinary Portland Cement (OPC) of grade 53. The accompanying tabular column shows the property of the concrete, which satisfies the states of IS: 12269 (1987).

S.No	Property of cement	Results
1.	Specific gravity	3.12
2.	Initial setting time	105 min
3	Final setting time	220 min
4.	Compressive strength of cement at 28 days	55.2 MPa

B. Fine Aggregate

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Locally accessible sand gathered from the close-by shop was utilized for testing. The properties of the collected sand are tabulated below.

Table 2 Properties of Fine Aggregate

S.No	Property of sand	Results
1.	Bulk density	1650 kg/m^3
2.	Specific gravity	2.56
3	Fineness modulus	2.83

C. Coarse Aggregate

The coarse aggregates of size 20mm that were bought from the nearby quarry were used for the experimental purpose. The properties of the 20mm coarse aggregate are listed below in the tabulation.

Table 3 Properties of Coarse aggregate

S.No	Property	Results
1.	Maximum nominal size	20mm
2.	Bulk density	1800 kg/m^3
3	Specific gravity	2.5
4.	Fineness modulus	4.4

D. Wedges and barrels

Anchor head wedges (3- piece wedge) have been used and barrels hold them together that make it easier to press the wedges onto the wire or strand. They consistently connect with the strand with less unwinding at low loads.

E. Tendon

A group of seven steel wires wound together are generally called as strand or tendon or cable, which are high strength steel rods. Tendons of size 0.5 inch or 12.7mm are used and the properties of the tendons used are listed below.

Table 4 Properties of Tendon

S.No	Property	Values
1.	Strand type	0.5"
2.	Nominal diameter	12.7mm
3.	Ultimate strength	1860 N/mm^2
4.	Weight	780 g/m
5.	Ultimate load	184 kN

F. Anchorage

Anchorages are utilized to fix the closures of the tendons in post-tensioning systems. They are steel blocks through which single or various strands pass and are tied down by wedges. The strands might be tensioned exclusively or as a gathering. The anchorages are thrown into the concrete and shift the whole burden from the strands into the concrete. This causes high local bursting forces.

III. EXPERIMENTAL PROGRAMME

The actual size of the beam that was analyzed using the software was 15m length, 900mm width and 700mm depth. But considering the practical difficulties such as lifting the beams and so on, the actual beam sizes (i.e. width and depth) have been scaled down to the ratio of 1:250 and hence the prototype beam of size 1500mm x 225mm x 175mm was considered for the experimental process. Also the experimental procedure is done only for the bonded system since there is no practice of unbounded system in India.

A. Mix Ratio

Generally the minimum mix ratio that has been in practice for Post-tensioning method is M35 and the same has been adopted for the testing for all four beams. The water cement ratio of 0.43 – 0.45 was adopted. The following table shows the amount of materials used for casting of beams.

Table 5 Materials Quantities

S.No	Materials	Quantities in kg/m^3
1.	Cement	30
2.	Water	13 liter
3.	Fine aggregate	47
4.	Coarse aggregate	86
5.	Water cement Ratio	0.43 – 0.45

B. Test specimens, casting and stressing

Four post tensioned concrete beams of length 1500mm; width 225mm and depth 175mm were designed and casted.Reinforcement details of the beams include 12mm diameter bars at tension zone and same 12mm diameter bars at compression zone and 8mm diameter stirrups. In addition to the rebar a 12.7mm strand has been provided for each beam. Generally in PT strands or tendons of small lengths, bulb creation is done on one end where the other end is allowed free to take the stressing operation. Figure 1shows the formation of bulb at one end of the strand, which is also called as dead end. On the other hand the end where stressing is done is called as the live end. Once the casting was done the beams were allowed to take 28 days process of curing and so the concrete gets hardened after when the PT strands are stressed or otherwise called the application of compressive stresses to counteract the external loads during loading. Figure 2 shows the application of prestressing force to the beams.

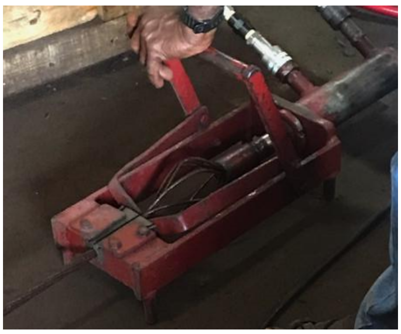

Fig.1 Bulb formation

Fig.2 Application of prestressing force to beams

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C. Test Setup

The beams were tested under monotonic loading up to failure using a hydraulic machine of 1000 KN capacity with simply supported conditions. The loads were measured using a digital meter attached to the hydraulic jack. Figure 3shows the actual loading test setup along with the locations of loading points. Two sets of loading conditions have been applied to the beams and testing has been carried out. Firstly, for two point loading condition, two beams were placed in the frame with 1300mm clear span between the roller supports and secondly, single concentrated load was applied on the beam at a mid span. The loads were increased by the increment of 4kN. The longitudinal and transverse strains of the specimens were measured by two different methods such as linear variable differential transducers (LVDT) and electric strain gauges. The strains of non-prestressed steel reinforcement were measured in the longitudinal direction. Deflection was measured at the mid-span using digital LVDT.

Fig.3a Test setup of beam for two point loading

Fig.3b Test setup of beam for single point loading

Table 6 Experimental programs for beams

Beams	Legend	Strand area (mm)	PT force (kN)
B1	B1-150-B	12.7	64
B4	B4-120-B	12.7	51
B3	B3-100-B	12.7	42
B2	B2-70-B	12.7	30
Where legend of the beams are as follows: Beam number- Prestress value (kg/cm^2)-Bonded (B)			

D. Test outcomes

The load deflection curves for all tested beams are given to discuss the effect of prestressing and the concrete compressive strength. Results are presented through Figure 5-9. Figure 5-9 shows the load-deflection of Beam 1, Beam 2, Beam 3 and Beam 4 with post-tension stress of 150 kg/cm^2, 70 kg/cm^2, 100 kg/cm^2 and 120 kg/cm^2. The initial cracking load (P_{cr}) of the Beam 1, Beam 2, Beam 3 and Beam 4 are 60kN, 56kN, 48kN and 44kN. This decrease in P_{cr} is due to the post-tension stress applied to each beam. Therefore it concludes that increase in cracking load is achieved by increasing the stress level.The maximum loads of specimens Beam 1 and Beam 4 were higher than the other two beams. This difference in the failure load is attributed to the slight variation in the loading condition of single point and two point loading pattern. The maximum deflection at the failure load of Beam 2 was the highest and it gradually decreases for Beam 3, Beam 4 and Beam 1. This is again due to the loading condition and prestressing force applied on to the specimens.

E. Crack pattern and Failure mode

Failure of all four specimens started by yielding of the main bottom steel reinforcement followed by cracking of concrete at the bottom surface. Early collapse or initial crack was noticed in Beam 2 and Beam 3. Failure modes of Beam 2 and Beam 3 were more ductile than that of other two specimens. All these are due to the loading condition and less prestressing force on the beams. The crack patterns of Beam 1 and Beam 4 are found within the two concentrated loads whereas in Beam 2 and Beam 3, it is found under the point load. The crack patterns of all the four beams are shown in figures below.

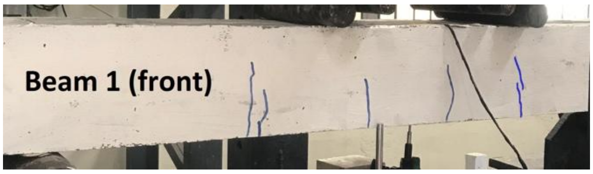

Fig.4a Crack patterns in specimen 1 (front side)

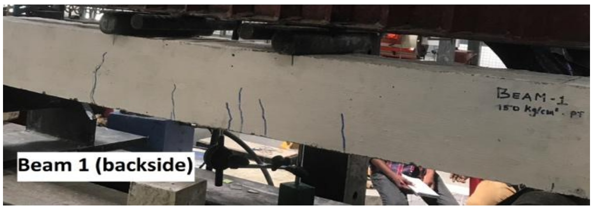

Fig.4b Crack patterns in specimen 1 (backside)

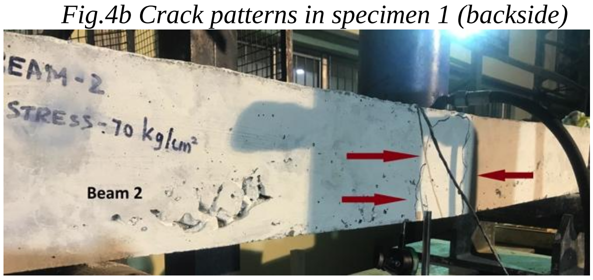

Fig.4c Crack patterns in specimen 2

Fig.4d Crack patterns in specimen 3

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Fig.4e Crack patterns in specimen 4

IV. RESULTS AND DISCUSSION

The variables considered in this study are loading type and post-tension force. Table 6 shows the experimental results of initial cracking load, its corresponding deflection, ultimate load and its respective deflection for all four beams. The further graphs show the load vs. deflection and load vs. strain for all four beams. Since Beam 1, Beam 4 are tested under two point loading condition and Beam 2, Beam 3 are tested under single point loading condition the graphs are compared respectively.

Table 7 Experimental results

Specimen	**P_{cr}(kN)**	**Δ_{cr}(mm)**	**P_u (kN)**	**Δ_u(mm)**
B1	60	2.12	200	6.87
B4	56	2.36	180	9.06
B3	48	2.69	168	10.25
B2	48	2.86	152	11.25

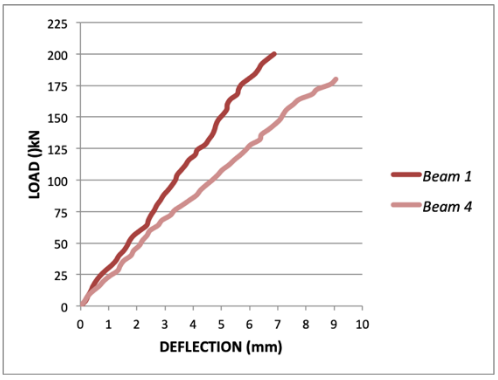

Fig.5 Load vs Deflection for Beams 1 and 4

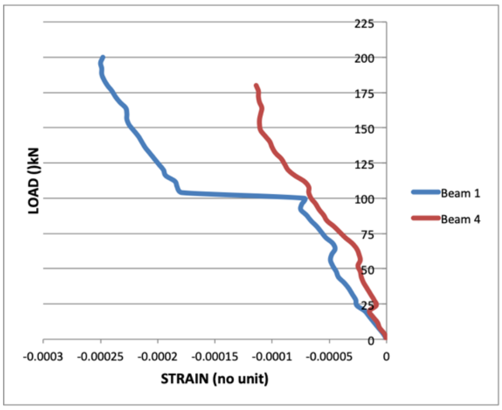

Fig.6 Load vs Strain for Beams 1 and 4

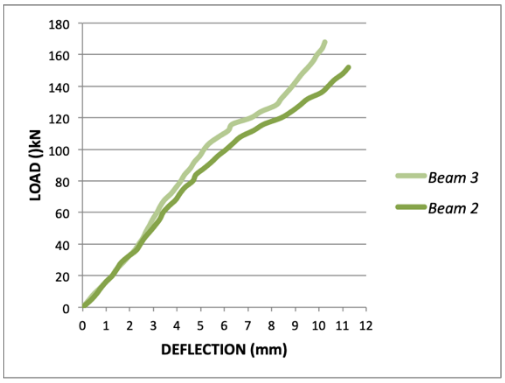

Fig.7 Load vs Deflection for Beams 2 and 3

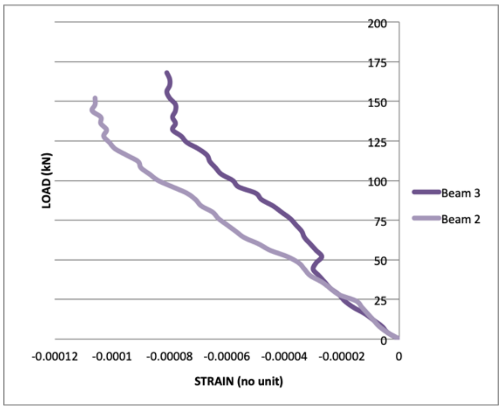

Fig.8 Load vs Strain for Beams 2 and 3

V. CONCLUSION

From the investigation and comparison of the test outcomes obtained from this paper, the accompanying ends can be drawn:

1. The prestressed concrete beam with high PT force (64kN and 42kN) achieved the maximum load when compared to other beam under two point loading and single point-loading condition respectively.
2. There was an increase in load by 11.11% when the PT stress is maintained at 150kg/cm^2 compared to 120kg/cm^2 under two point loading condition. As well as there was 10.52% increase in load when the PT stress is maintained at 100kg/cm^2 compared to 70kg/cm^2 under single point loading condition.
3. The deflection rate decreased by 24.17% when the PT force is maintained at 150kg/cm^2 compared to 120kg/cm^{2}under two point loading condition and it decreased by 8.8% when PT force is maintained at 100kg/cm^2 compared to 70kg/cm^2 under single point loading condition.
4. The crack widths seem to be lesser in beams with high prestressing force and it is vice versa in the beams with less prestressing force.
5. The cracks started to appear exactly under the loading points, which clearly showed that the beams failed under flexure.

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