# Comparative Performance of Prestressed Concrete Beams by FRP Wrapping

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***Abstract*—Comparative behavior of Prestressed concrete (PSC) beams subjected to two point loadings in terms of failure load, deflection & failure modes is evaluated. Effect of Glass fiber reinforced polymer (GFRP) strengthening on PSC beams before & after first cracking is measured. Experiment includes testing of nine simply supported PSC beams having cross-section 150 mm x 200 mm with effective span of 3.0 meter. Three unwrapped PSC beams, three PSC beams wrapped by GFRP after initial loading upto first crack & and three uncracked PSC beams strengthened using GFRP are tested upto failure.**

**Three different wrapping patterns are executed on beams. For (2L/7) span loadings, wrapping of full length at bottom and upto 1/3rd of depth is provided, forming a U-shape around the beam cross-section. For (2L/4) span loading, wrapping of full length at bottom and upto 1/3rd of vertical depth is provided and extra wrapping near the supports is provided. For (2L/3) span loading, U shape wrapping is provided near the supports, for full depth.**

**It is observed that in (2L/7) span loadings, compared to unwrapped PSC beams, the FRP wrapping along longitudinal direction, reduces deflections and increases the load carrying capacity for wrapped PSC beams. In (2L/4) span loading, combination of vertical and horizontal GFRP sheets, together with a proper epoxy adhesion, lead to increase the ultimate load carrying capacity for wrapped PSC beams. In (2L/3) span loading, presence of vertical GFRP sheets near support reduces the shear effects considerably and increase load carrying capacity.**

***Index Terms*—fully Prestressed beams; GFRP wrapping; different span loadings; load-deflection response; failure mode.**

## I. Introduction

Modern structural engineering tends to progress towards more economical structures through gradually improved methods of design and the use of higher-strength materials. Such developments are particularly important in the field of reinforced concrete; The limiting features of ordinary reinforced concrete have been largely over come by the development of prestressed concrete. A Prestressed concrete member can be defined as one in which is introduced internal stresses of such magnitude and distribution that the stresses resulting from the given external loading are counteracted to a desired degree. Concrete is basically a compressive material. Prestress applies a precompression to the member that reduces or eliminates undesirable tensile stresses that would otherwise be present. Cracking under service loads can be minimized or even avoided entirely. Deflections may be limited to an acceptable value.

## II. Design of PSC Beams

PSC beams are designed using limit state theory using IS: 1343-1984. All beams have same cross-section of 150 x 200 mm with effective length of 3.0 m. Requirement of reinforcement is evaluated by applying prestressing force of 85.47 kN in case of all the beams. Six high tensile 4mmΦ prestressing wires and 8mmΦ @ 300 mm c/c stirrups are used as lateral reinforcement in the beams. Two no of 10mmΦ bar at top and bottom respectively is used as non-prestressing reinforcement. Specimen detailing is shown in Fig. 1.

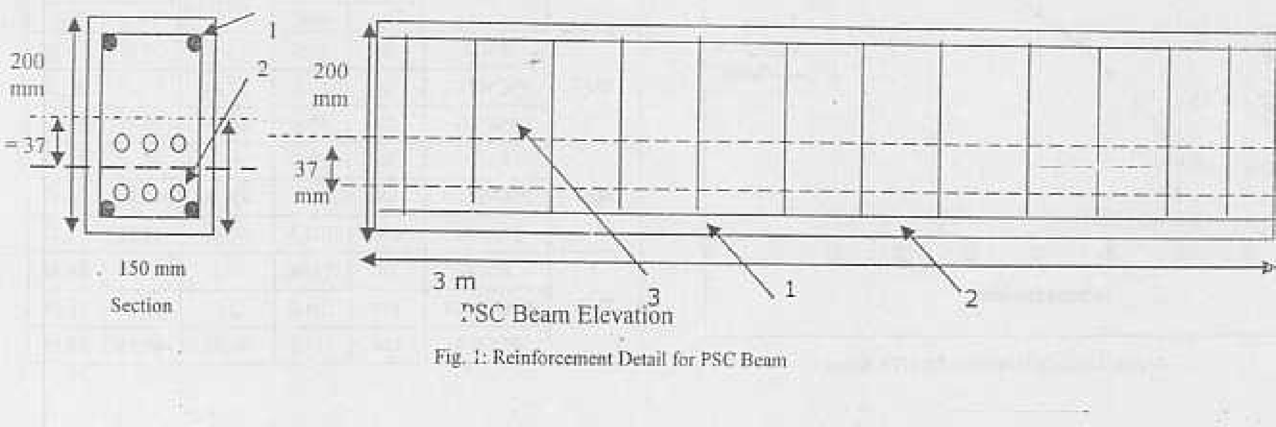



Fig. 1: Reinforcement Detail for PSC Beam

## III. Development of Prestressing Facilities

Prestressing system exclusively developed for this research work is shown in Fig. 2. Screw jack is provided for prestresing of HTS wires. For fixing of HTS wires, wire locking barrel is used. The screw jack along with moving anchor block is fixed to the jacking end side (stretching end). The steel plate mould is fabricated and put into place with bolted end plates having holes for pretensioning wires to pass through.

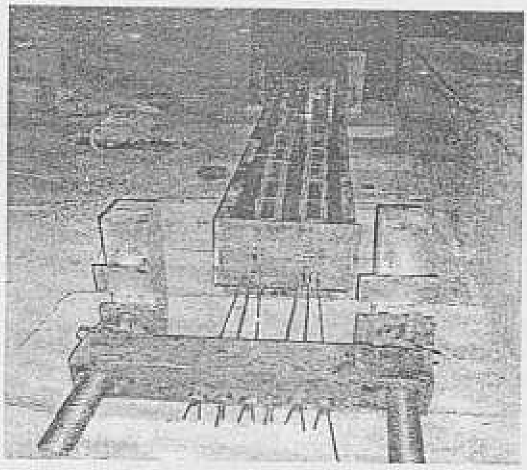


Fig.2: Prestressing Facilities

## IV. Materials

Selected proportion for M45 grade concrete mix is cement: sand: grit: kapchi: water 1:1.36:2.21:0.55:0.37. 4 mm HTS wires are used for prestressing. Tension test for the wire is performed on UTM and its ultimate strength is found as 2350 $N/mm^2$. Fig. 3 shows the load-deformation relationship for HTS wires. Test was carried to find out maximum tensile strength of the wire. GFRP laminate is used for wrapping on the beams.

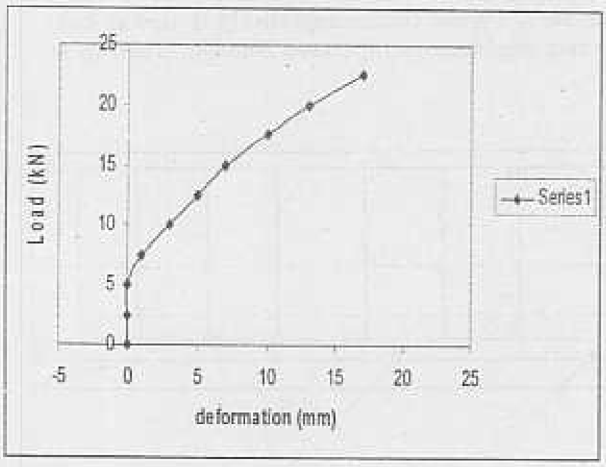



Fig. 3: Load-Deformation for HTS Wires

## V. GFRP Wrapping on Beams

Three PSC beams are tested up to first cracking. They are then strengthened using Glass fiber reinforced polymer (GFRP) laminates and again tested upto failure. Three uncracked control PSC beams immediately after giving the required curing, are strengthened using GFRP laminates and then tested. Different types of strengthening arrangement are provided based upon different span loadings. Fig.4 shows the different types of strengthening arrangements provided.

## VI. Testing of Beams

Total nine PSC beams are cast and tested by applying two point loading. The details of notations of PSC beams tested with three different loading positions are mentioned as below. Three PSC beams initially tested up to first cracking, after that they provided with wrapping are tested upto failure, which are denoted by PSCWFC1, PSCWFC3, & PSCWFC4 respectively. Three uncracked PSC beams are wrapped and tested, which are denoted by PSCW1, PSCW3, & PSCW4 respectively. Three different types of loading positions i.e. 2L/7, 2L/4 & 2L/3 span loadings respectively are employed for testing of beams and are denoted with notations 1, 3, & 4 respectively. As shown above 1, 3, & 4 etc. are generally written after category of specimen exhibits the loading span employed for the respective category of specimen. Fig. 5 shows the testing set up fabricated and prepared for testing of the beams.

## VII. Results and Discussions

The overall comparison is obtained between the experimental observations & theoretical calculations for the beams. Results of Failure Load & Load-Displacement relationships for different span loadings in case of all the beams are given in Table 1. Basic beam theory is applied for calculating deflection and failure load in case of all the beams.

Table-I
Experimental results

| Loading Span | Specimen Type | Failure Load (kN) | | % variation (Exp.) | Max. Displacement (mm) | |
|---|---|---|---|---|---|---|
| | | Exp. | Cal. | | Exp. | Cal. |
| 2L/7 | PSC1 | 58 | 53.6 | - | 23.80 | 23.23 |
| | PSCWFC1 | 68 | 65.6 | 17.24 | 37.60 | 27.24 |
| | PSCW1 | 70 | 67.6 | 20.68 | 45.31 | 28.04 |
| 2L/4 | PSC3 | 76 | 72.3 | - | 33.10 | 27.27 |
| | PSCWFC3 | 88 | 84.2 | 15.78 | 42.49 | 31.57 |
| | PSCW3 | 106 | 102.3 | 39.47 | 48.51 | 38.03 |
| 2L/3 | PSC4 | 88 | 82.04 | - | 43.00 | 25.39 |
| | PSCWFC4 | 110 | 104.0 | 25 | 44.37 | 31.74 |
| | PSCW4 | 124 | 118.1 | 40.91 | 49.23 | 35.78 |

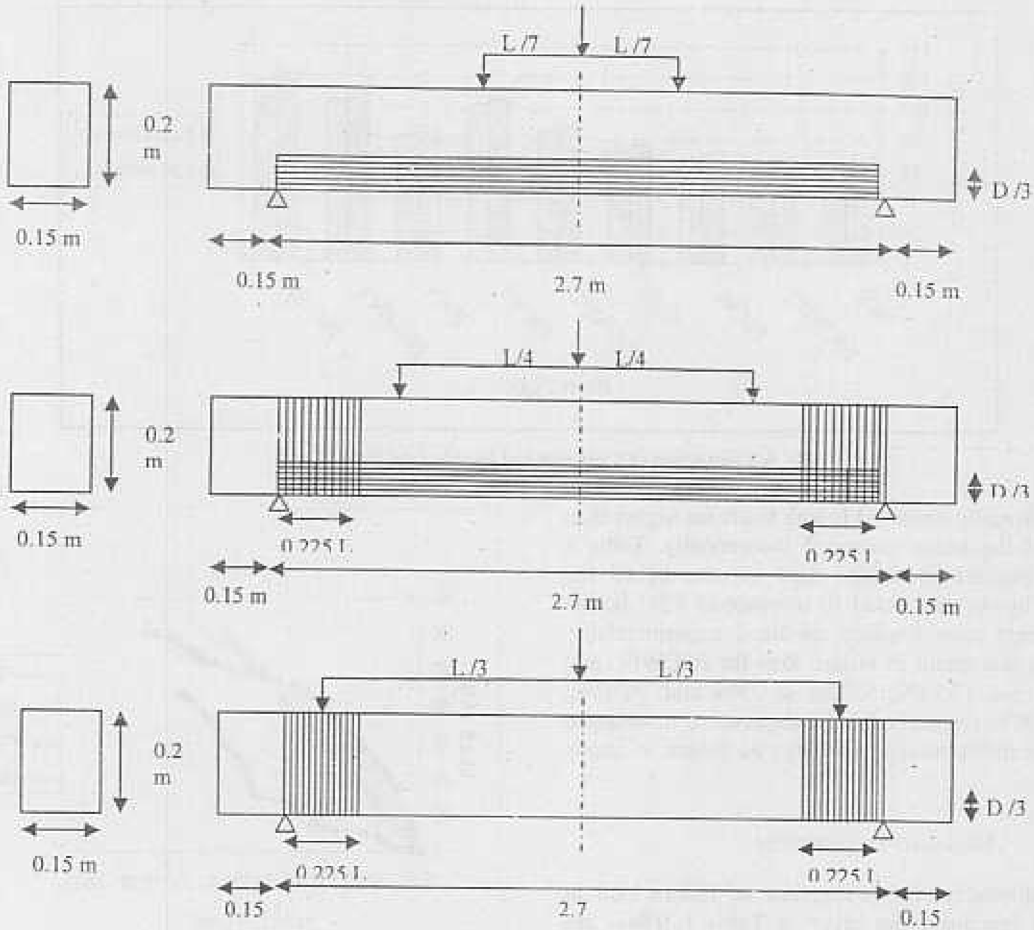



Fig. 4: GFRP Wrapping for 2L/7, 2L/4 & 2L/3 Span Loadings

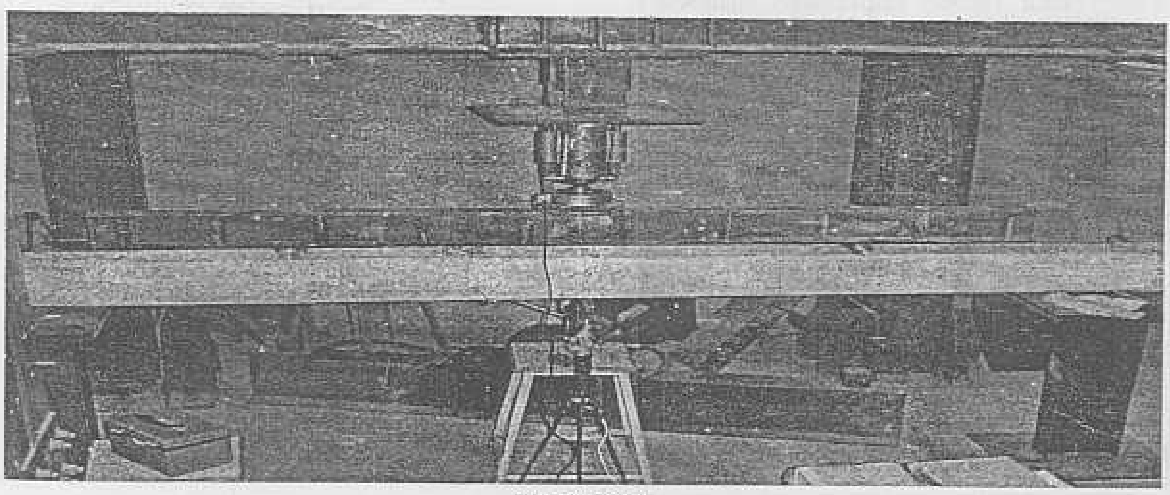


Fig. 5: Test setup

## VIII. Failure Load

The comparison of experimental & theoretical values of failure loads for all the beams is represented in Table 1 & figure 6 respectively. Load carrying capacity of unwrapped PSC beams is observed to be significantly less compared to the wrapped PSC beams. Higher load carrying capacity is evident in case of uncracked wrapped PSC beams compared to PSC beams wrapped after loading upto first visible crack.

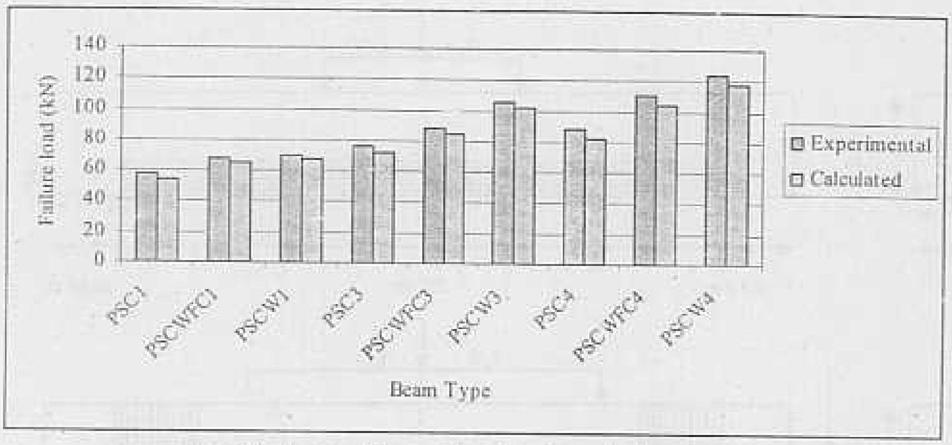
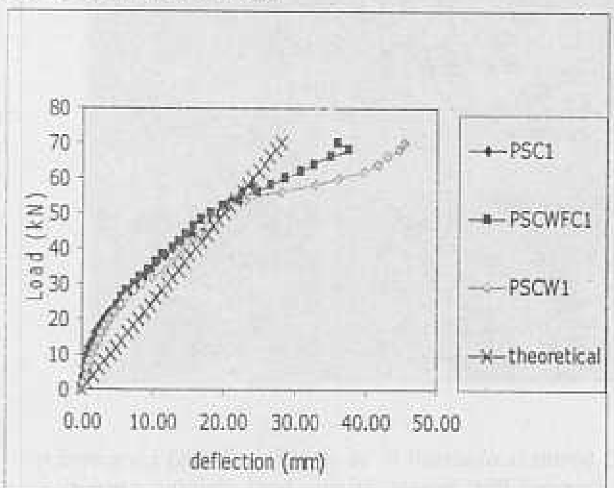



Fig. 6: Comparison of Theoretical and Experimental Failure Loads

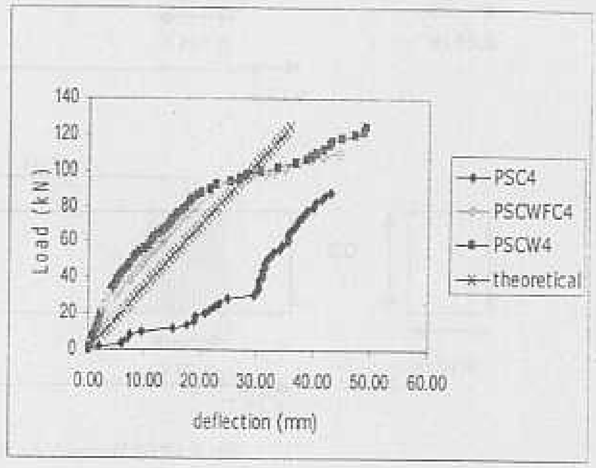
The experimentally observed failure loads are higher than the capacity of the beam evaluated theoretically. Table 1 gives the % increase in failure load in case of all the wrapped PSC beams compared to unwrapped PSC beams tested at different span loadings obtained experimentally. The percentage increment in failure load for PSCWFC and PSCW beams are 17.24%,15.78% & 25% and 20.68%, 39.47% & 40.91% respectively as compared to unwrapped PSC beams for different span loadings as shown in above table.

## IX. Load-Deflection

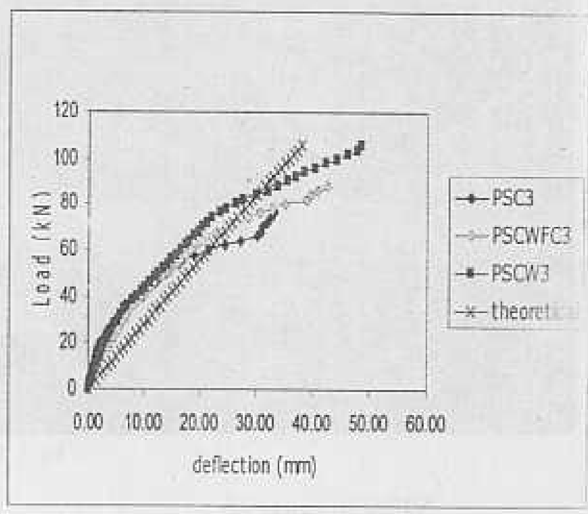
Maximum displacements at the time of failure load in case of all the specimens are given in Table 1. These are observed at the centre of the beams during the testing by using LVDT (Linear variable displacement transducer). Figures 7(a), 7(b) & 7(c) represent the load- displacement relationship for all the beams tested at 2L/7, 2L/4 and 2L/3 loading spans respectively.




(a) 2L/7 Span Loading




(b) 2L/4 Span Loading



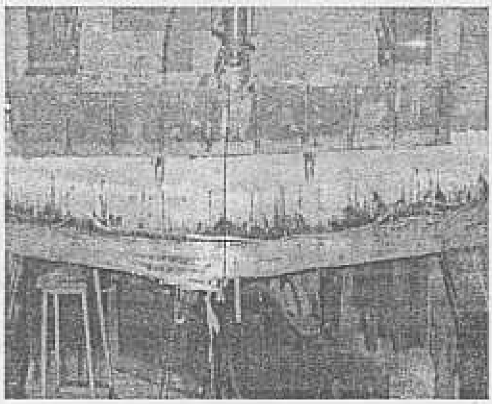

(c) 2L/3 Span Loading

Fig. 7: Load-Deflection Relationship

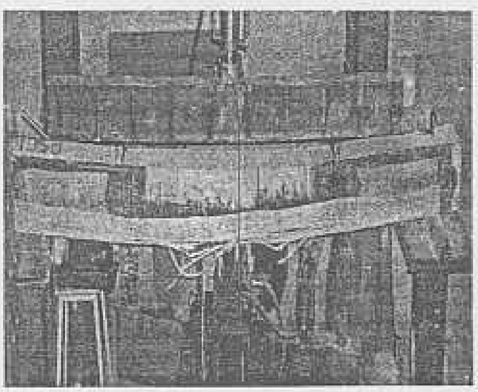
From Figs. 7(a) to 7(c), it can be seen that as the span loading increases, the tendency of the beams to deflect under lesser loading decreases. This is primarily due to the reduction in the moment caused by the point loads. It is apparently shown by above figures that the load carrying capacity of the beam increases as the loading span increases. But actually it is the reduction in the moment that causes the beam to deflect lesser as the span increases. Because of the increase in loading span, the load required inducing same amount of moment increases, and hence for the same loading the deflection observed is lesser than the load for the smaller loading spans.

## X. Failure Mode

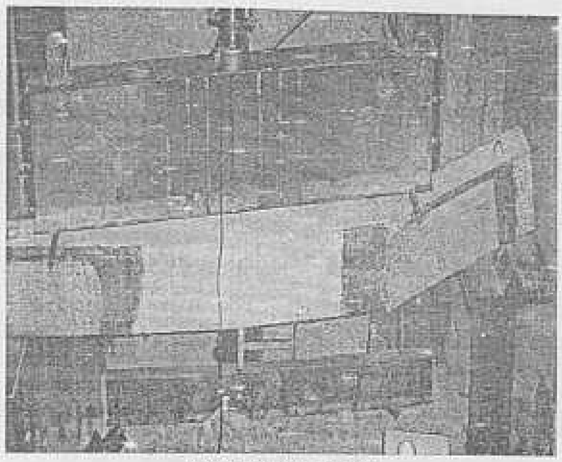
Catastrophic failure, i.e. failure with large sound is observed in wrapped beams during the experiment due to the sudden failure of the fibers in tension. Specimens also fail due to the de-bonding of the fibers from the concrete surface. Figs. 8(a), 8(b) & 8(c) show mechanism behind failure observed in case of the PSC beams wrapped after first crack respectively. Here load is given in the form of push, due to which bottom fibers are in tension. Due to this, bottom fibers of the beam get de-bonded in tension as shown in Fig. 8(a) respectively, as the tension carrying capacity of the wrapping system is more than its bonding capacity.



(a) 2L/7 Span Loading



(b) 2L/4 Span Loading



(c) 2L/3 Span Loading

Fig. 8: Failure modes for PSC Beams

## XI. Concluding Remarks

- In PSC beams, due to the high tensile strength tendons present in the tension zone bonded well with the high strength concrete of grade M45. The pretension in the tendons prevents the widening of the cracks at the earlier stages.
- The highest failure load is observed in wrapped uncracked PSC beams compared to other beams. This is due to the transfer of stresses from concrete to the fibres through bonding, thus preventing the beam to fail even after the strain in concrete crosses the allowable limit. The wrapping acts as an external reinforcement and takes complete tensile load after the concrete fails to transfer effectively the stresses to the tendons/ reinforcement.
- Theoretical failure load is higher compared to experimentally observed failure load due to assumption of linear stress distribution in the side reinforcement. But in reality very few amount of side fibers at extreme bottom faces take part during the loading. Parabolic stress distribution is generally observed in case of the fibers.
- The wrapping also helps the PSC beams to take up more shear load compared to unwrapped PSC beams. This is clear from the fact that the beams loaded with higher span loadings in anticipation of shear failure have actually failed in flexure.
- Failure modes observed in all unwrapped PSC beams are closely matching with expected flexural & shear failure. De-bonding of bottom fibers and tension failure of side fibers are observed as failure mode in case of all the wrapped beams.
- Also in case of wrapped beams, the failure takes place primarily due to bond failure, i.e. de-bonding between concrete surface and FRP and/or due to tension failure of the FRP sheets. This avoids the local failure or failure of the concrete in compression.

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