Investigation of composite materials supported by carbon fiber fabric (TFC) in pre-cracked concrete beams

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Abstract. This work is a commitment to breaking down the conduct of pillars that strengthened by composite materials. The investigation was helped out through an exploratory and logical examination on eleven strengthened concrete and fortified solid components underneath and decently strengthened, pre-split and afterward strengthened utilizing nearby carbon-fiber texture utilizing epoxy pitches. So as to consider the impact of the underlying splitting condition on the conduct, one of the bars was strengthened without being broken ahead of time and contrasted with a pre-broken and fortified bundle and afterward to another stacked in any event, when broken without breaking or hardening. In this examination, four beams were pre-broken and reinforced in the all-inclusive part and as an afterthought part with U-formed pieces of various measurements to keep away from division on one side and the investigation of rebuilding of the compound at the impact of shear then again. At long last, a similar report was directed between the last estimated exploratory obstruction and that registered by expository models.

1. Introduction
Quakes cause the breakdown of many fortified solid structures or truly harm them. The subject of destroying those structures, reconstructing them again or reestablishing them as far as the expense of new works expanding more and raising the conditions for fix to an ever-increasing extent. An option in contrast to conventional fix strategies has as of late been created. This is the innovation of support by the on location outside holding of a polymer tissue type compound [1,2]. This method ends up being intriguing gratitude to the high weight-opposition proportion of composite materials and their consumption obstruction, and consequently ease in execution conditions gives a fast, prudent and sturdy answer for maturing or harmed structures [3]. This innovation is spreading increasing ly more in the field of structural designing. In any case, the utilizations of recovery are logically and actually constrained because of deficient information as far as conduct (hardness, disappointment, harm) just as inadequate strategies for figuring and scaling.

Various examination [4-6] has been completed on the strategy of fortification and/or bar fix on account of arch and shear on account of the most extreme and on account of as far as possible, on tear positions, on the division of the compound and on the weariness of the strengthened solid components with the composite texture. Along these lines numerous ends and suggestions were made, yet the investigation of improved
bundles on account of administration limits is uncommon [7, 8]. A few models have been proposed to anticipate the compound's commitment to reestablishing shear quality [5, 9].

These models rely upon numerous boundaries, for example, powerful stature, stress, territory, and elasticity of the compound [10]. It is obvious from the huge number of studies that have been directed that it is hard to locate an explanatory equation to effectively foresee the last quality of the pillar as for shearing the bar.

The trouble may lie in the unpredictable collaboration among cement and fortification in shear and shape states. As a rule, the most convoluted point is the decision of stress or powerful disfigurement and the successful stature of the compound extents. Then again, there gives off an impression of being no agreement to anticipate shear protection from the compound.

The point of this work is to add to the examination of the conduct of shafts fortified with carbon-fiber composite materials.

To accomplish this objective, a trial study and another expository investigation were performed on fortified concrete and solid shafts that were recently broken and afterward fortified via carbon fiber texture (TFC) and its factors are the fortification pace of the fortifications. Steel, starter splitting impact and distinctive support designs (obsession).

2. Materials of the study
The examination was created on two arrangement of tests:

- a first arrangement of five pillars assigned P1, P2, P3, P4, P5, with a rectangular area of 13x20 cm² and a range of 120 cm. These pillars were dimensioned as for as far as possible state as per BAEL 91 principles. A check was made at a definitive breaking point state with the goal that the disappointment occurred by [11].
- a second arrangement of six pillars which have been dimensioned utilizing a test body approach in measurements diminished by a factor of 1/3 contrasted with the bar (P2). The use of the mathematical similitude rules brought about a calculation of 5x7x40 cm³ [12, 13].

To save the conduct of the reference pillar (P2), the decrease scales on account of this investigation were adjusted by the representativeness of the test: measurements, support, concrete utilized, bleeding edges of the composite, machine of test… and so forth.

The amount of tensile reinforcement of the beams was varied between unreinforced, under reinforced and moderately reinforced beams where the percentages (ρ) are respectively 0%, 0.66% and 1.45%, with: $\rho = \frac{A}{b d}$.

A, b, d individually speak to the area of the fortifications, the width of the segment and the helpful tallness of the segment.

Four shafts viewed as control bars were stacked to disappointment without being remotely strengthened by the composite.

Six are pre-broken by applying a heap of 60% of a definitive quality of the control shafts, at that point emptied and strengthened again to then be reloaded until disappointment so as to contemplate the impact of the underlying pre-splitting on the mechanical conduct of pillars fortified with carbon fiber texture. One of the pillars was fortified before it was pre-broken.

Table 1 accumulates all the subtleties of the pillars utilized.

All the bars were tried in three-point twisting on two machines with pressure driven chambers: the first with a most extreme limit of 300 kN for the shafts and the second of 50 kN for the scale models.
Beams P1, P2, P3, P4 and P5 were manufactured utilizing normal cement with compressive quality estimated at 28 days of 30 MPa.

The decreased model shafts were manufactured utilizing smaller scale concrete with a grain size appropriate for the elements of the solid of the reference bar P2.

The prepares utilized for fortification are of two classes:

- high bond bars filling in as longitudinal support for stepping stool beams.
- smooth round bars filling in as longitudinal support for 1/3 scale bars and as cross over fortification for all examples.

Figure 1 shows the subtleties of the fortification.

Direct elastic portrayal tests were completed on examples 15 cm long drawn indiscriminately from the cluster of bars utilized for the assembling of the bars.

Physical portrayal tests were likewise completed on all the constituents of the solid.

The fundamental attributes of the prepares, the paste, the texture just as the composite material are summed up in Table 2. For all the examples, the thickness of the composite is 1 mm.

The widths, lengths and game plan of the groups of the composite utilized for the support are appeared in figure 2.

### Table 1. Details of specimens.

| Beams of (13*20*120) cm$^3$ | Beams | Frames | Reinforcement rate | Reinforcement in TFC | Pre-cracking | Reinforcement mode |
|-----------------------------|-------|--------|-------------------|---------------------|--------------|-------------------|
| P1                          | 3HA8  | 0.66   | 1 Fold            | Yes                 | a            |
| P2                          | 3HA12 | 1.45   | 3 Folds           | Yes                 | b            |
| P3                          | 3HA8  | 0.66   | 1 Fold            | No                  | a            |
| P4                          | 3HA8  | 0.66   | 1 Fold            | No                  |             |
| P5                          | /     | /      | /                 | Yes                 | /            |
| Model beams                 |       |        |                   |                     |              |
| P6                          | 2ø5   | 1.45   | 1 Fold            | No                  |             |
| P7                          | 2ø5   | 1.45   | 1 Fold            | Yes                 | /            |
| P8                          | 2ø5   | 1.45   | 1 Fold            | Yes                 | b            |
| P9                          | 2ø5   | 1.45   | 1 Fold            | Yes                 | c            |
| P10                         | 2ø5   | 1.45   | 1 Fold            | Yes                 | d            |
| P11                         | /     | /      | 1 Fold            | Yes                 | a            |

### Table 2. Characteristics of the materials used.

| Material | Young's modulus E (MPa) | Yield strength $F_e$ (MPa) | Stress at break $F_y$ (MPa) |
|----------|------------------------|---------------------------|-----------------------------|
| HA steels| 200000                 | 420                       | 400                         |
| Soft steel| 200000                | 400                       | 235                         |
| Glue     | 3800                   | 30                        | /                           |
| Tissue   | 230000                 | 3500                      | /                           |
| Composite| 55000                  | 750                       | /                           |
Figure 1. Diagram of beam reinforcement.

Figure 2. Methods of beam reinforcement.
3. Results and Discussion

3.1. Load-deflection curve of the control beams (control beams):

- **P5 beam**
  
  The development of the redirection as an element of the heap of the shaft P5 delineated in figure 3 recognizes two direct periods of various slant. The first mirrors the versatile conduct of the pillar and the second mirrors the appearance and advancement of harm inside the material volume as the heap increments until disappointment.

![Figure 3. Load-deflection curve of beam P5.](image)

- **Beams P4, P6 and P7**
  
  Figures 4 and 5 show the heap/diversion bends individually of the shaft P4 and the diminished models P6 and P7. These bends have comparative shapes regarding frame and can be isolated into three stages mirroring a fairly pseudo pliable conduct of the fortified pillars:
  
  - a practically straight part during which the advancement of the diversion is relative to that of the heap which speaks to the flexible reaction of the bars.
  - a second stage during which the bend strays from linearity and which brings about the presence of vertical small-scale breaks.
  - a last non-straight stage declaring the burst of the examples.

![Figure 4. Load-deflection curve (beam P4).](image)
It ought to be noticed that the tentatively decided breaking heap of strengthened light emissions is 43 kN. This worth is exceptionally near the worth determined by the BEL rules and which is of the request for 43.54 kN [14-17]. The estimation is awesome and the thing that matters is under 2%.

By applying the comparability rules on the light emission scale model P6, it appears that the reference bar would break at a heap esteem equivalent to 90 kN. Besides, the estimation of a definitive burden determined hypothetically by the BAEL rules is equivalent to 91.71 kN. In this manner, the estimate stays great, which means the legitimacy of the figuring technique as indicated by the BAEL leads yet additionally the legitimacy and unwavering quality of the similitude rules.

3.2. Cracking and failure modes of control beams
- P5 beam
  The failure of beam P5 was sudden and occurred in the middle of the sample (below the point of application of the load).
- Beams P4, P6 and P7
These fortified pillars experience various stages before disappointment. The accompanying perceptions can be made:

Steadiness stage:
This is the stacking phase of the pillar before the primary splits show up in the most secure filaments of the solid.
During this progression, the pillars stay stable (not broke).

Breaking stage:
At a particular burden level for bar P4 and bars P6 and P7, two vertical smaller scale breaks show up evenly about the pivot going through the purpose of utilization of the heap. The subsequent breaks are bowing splits.

Break advancement stage:
Under the expanded outside burden, the two breaks create long and profundity. These breaks slant towards the purpose of utilization of the heap because of the nearness of the shear power. As the ruin draws near, other little optional breaks show up close to the two fundamental splits.

Breakdown stage:
At a particular burden level, the bars are broken because of the bowing second (vertical splits) for pillar P4 and the shear power for shafts P6 and P7 with the pulverization of the packed cement beneath the purpose of utilization of burden as appeared in figures 6 and 7. It was noticed that the disappointment of packed cement at the purpose of burden application is more perceptible on model pillars.

This can be clarified by the mix of a little contact zone between the jack and the solid and a huge extreme burden to force outrageous contact worry under the heap, which made the solid squash. Furthermore, the second and the shear power are most extreme under burden which makes the pressure state in this area more serious.

3.3. Behavior of reinforced beams

- Beam P11

The heap avoidance bend identifying with shaft P11 (figure 7) presents two direct branches: a first semi versatile part reached out from the beginning of stacking up to 1.8 kN and the second by 1.8 kN until disappointment, comparing to 1 commencement of splits which report the beginning of partition of the composite. Be that as it may, in examination with the reference P5 pillar, this P11 shaft displayed less weak conduct with a non-huge decrease in redirection of 17%. The benefit of expanding extreme obstruction is by all accounts exaggerated.

Despite the fact that it is absurd to expect to recognize the specific causes, this conduct might be expected to:

- inaccurate use of the heap which was seen during the test on pillar P5.
- this shaft has a noteworthy scale impact given the delicate conduct of the P5 bar and this is legitimizied by depending on the most popular hypothesis among a few which have been created to portray the scale impact and which is the Khumaedi hypothesis [18]. The last gets from vitality contemplations and portrays the progress between two cutoff states. In addition, as per this hypothesis, if the conduct of the structure is flexible, mathematically comparable structures yet of various sizes will come up short at a similar degree of stress. On the off chance that the conduct is delicate, the scale impact can be critical; the ostensible obstruction diminishes as the size increments.
Figure 7. Load / deflection curve of beam P11.

- P1 and P3 beams

We watch for the pillars P1 and P3 that the bends of the advancement of the bolts as a component of the heap have a comparative appearance. They are separated into two straight periods of various slants associated by a "knee point" like what occurs in SMC composite materials and known as the "knee point". The initial segment is portrayed by a little increment in redirection and with no appearance of smaller scale breaks and speaks to the versatile period of the material. The subsequent stage, of lower slant, is portrayed by a quicker increment of the redirection and by the presence of splits slanted at 45° because of the shearing power and which in this way report the break of the pillar as the shows figure 8. The strengthened bars P1 and P3 display an unbending conduct regarding the pillar P4 with an addition of a definitive burden individually of 49% and 51%, and a huge decrease of the lick. On the off chance that we characterize the plasticization load as the purpose of crossing point of the two straight lines of various inclines in the watched constitutive law, we note that the plasticization was deferred by the utilization of the composite (figures 8 and 9).

Figure 8. Comparison of behavior between P4, P3 and P1.
The propagation of the cracks of beams P1 and P3 is very different from that of beam P4. Beams P1 and P3 show many more shear cracks of smaller width with reduced spacings, while the cracks shown in beam P4 (control) are bending cracks with larger widths and spacings.

Comparison between P1 and P3 (influence of pre-cracking): A comparison of the mechanical behavior at equal moments of the beam P3 initially reinforced in its tensioned part and of the repaired beam P1 shows that the behavior curves (load/deflection) of the two beams do not present a big difference. The breaking load is almost the same. The development of the deflection is also identical up to a load value of about 18 kN. Between 18 and 60 kN, a reduction in the deflection of P1 relative to that of P3 is noted. This reduction decreases as fracture approaches (figures 8 and 9).

Figure 9. Comparison between deflections at cracking, plasticization and failure of beams P1, P3 and P4.

Figure 10. Comparison of the stiffness to cracking, plasticization and fracture of beams P4, P3 and P1.
The apparent stiffness of the skins was evaluated from the load / deflection curves. For the comparison of the latter, we presented the differences by histograms at three important stages of loading. From the start of loading to the cracking load, the stiffness of P1 and that of P3 are almost the same. At the plasticization load the stiffness of P1 increases by 19.08% compared to that of P3, but this increase decreases as the load at break approaches (figure 10). Generally, the rigidity of P1 and that of P3 do not present large differences. However, it should be noted that the plasticization load of P3 was delayed compared to that of P1 (figure 11). This delay increases the level of plasticity of P1 and this shows the good behavior of the initially pre-cracked beam compared to P3 in the ultimate state and in the level of the state of service which is explained by the reduction of the rigidity with the decrease in deflection before plasticization load.

As respects the splits, they are nearly of a similar number, on the off chance that we don't consider the previous breaks as of now in the pre-breaking period of bar P1. By a straightforward unaided eye correlation of split widths, apparently breaks at most extreme applied burden are more open on pillar P1 (fixed). They are of the request for 1 to 2 mm in the sidelong part. In the extended part, these openings can arrive at a width of 10 to 12 mm. These splits have a more prominent length and decreased spacings contrasted with those saw on P3. The greatest width of breaks on shaft P3 is around 1mm. This is clarified by the presence of splits toward the beginning of the test on P1, in light of the fact that the complete conclusion of these breaks is beyond the realm of imagination because of the rubbing of the solid on the steel bars regardless of good attachment between them. For bar P3, breaks just showed up from a heap estimation of around 49 kN, while for P1 they showed up at a heap of around 27 kN.

P2, P8, P9 and P10 beams (reinforced in the taut and side sections).

From the heap avoidance bends in figure 12, apparently these pillars have a similar shape as those identifying with bar P1. These pillars show an increase in obstruction contrasted with the control shafts P6 and P7 being somewhere in the range of 6% and 36%. In examination with the fortified shafts in HA8, this addition in obstruction stays restricted yet the avoidances are diminished. For model pillars, no scale impact was watched, particularly somewhere in the range of P2 and P8 which have a similar technique for
fortification. The thing that matters is under 6%. This legitimizes the legitimacy of the similitude rules followed.

![Load-deflection curves of reinforced beams P8, P9 and P10.](image)

**Figure 12.** Load-deflection curves of reinforced beams P8, P9 and P10.

### 3.4. Failure modes of reinforced beams:

- **Beam P11**
  Beam P11 was broken by partial separation of the composite under a bending crack located at the load application level.
- **P1 and P3 beams**
  The failure of beams P1 and P3 is due to the shear force with the partial separation of the composite. During the test, observations related to failure can be gathered as follows:
  
  - the creation of new diagonal shear cracks at the end of the composite plate on beam P1. These cracks propagate to the point of application of the load at an angle of 45° with the horizontal axis of the beam.
  - at a load value of 53 kN for P1 and 51 kN for P3, the separation of the composite was characterized by a cracking-type noise.
  - in the central part of the beam, the cover layer under the reinforcement was slightly torn off in blocks delimited by vertical bending cracks.
  - in the detachment zone, between the loading point and the support, a thin layer of concrete or even small pieces of concrete remain stuck on the detached plate.
  - despite the partial separation of the composite, the failure of the beams was as expected (the beams broke under a shear effect) which shows the effectiveness of TFC in the repair and reinforcement of reinforced concrete structures.

- **P2, P8, P9 and P10 beams**
  For the most part, these shafts fizzled by shear. The disappointment of pillar P2 is brought about by inclining shear splits. These splits start toward the finish of the TFC sideband and slant toward the purpose of burden application at a point of around 45°. We additionally see on this shaft, close to the furthest limit
of the longitudinal strip, shear splits engendering on a level plane in the solid causing a slight obliteration of the spread layer between the solid and the longitudinal fortifications.

The disappointment of bar P9 starts over the TFC strip and inclines towards the purpose of use of the heap causing annihilation of the solid spread layer at the help level with the division of the strip sidelong TFC. Beam P10 is broken by large shear cracks, as is the case with beam P2, without destroying the concrete cover.

4. Discussion

All in all, it rises up out of Table 5 contrasting the qualities determined scientifically concurring with the various models introduced and those deliberate tentatively that the various techniques proposed overestimate the estimations of the commitment of the shearing power. The correlation was made by considering the two kinds of disappointment saw on the bars, in particular the detachment of the composite and the disappointment of the solid, realizing that all the models utilized in the estimations of the commitment of the parallel composite are for the most part molded by the powerful strain or stress and the successful stature. Of the six strategies proposed, it was discovered that Freyssinet's methodology is near the test results for the four pillars P2, P8, P9, P10. This model gives the best gauges (from 2.08% to 10%). It ought to be noticed that for the strategies for ACI, Wu and AFGC, the estimations of the \( \frac{V_{cal}}{V_{exp}} \) proportion, on account of solid disappointment, are higher contrasted with the qualities found on account of division of the solid. composite, which prompted compute \( V_f \) for the instance of shafts P2, P8 and P10 considering the decrease coefficient. The outcomes found from this methodology are nearer to our trial results with the exception of the instance of Wang's strategy [19]. The last gives great reports (1.15 and 1.08) contrasted with these techniques in the event that one thinks about the method of disappointment of the solid. The FIB announcement strategy gives the most noteworthy assessments (34.66% to 60%) when contrasted with every single other technique. For the most part, the overestimation of the quality determined scientifically contrasted with the trial results is clarified by the overestimation of either the powerful stature or the compelling strain, or the successful burdens. The viable stature is taken equivalent to 0.9d of the valuable tallness of the segment of the bar. The coefficient \( R \) for this situation is the most minimal recorded among the estimations of every single other strategy. The last gives great reports (1.15 and 1.08) contrasted with these techniques in the event that one thinks about the method of disappointment of the solid. The FIB announcement strategy gives the most noteworthy assessments (34.66% to 60%) when contrasted with every single other technique.

The equation utilized by the International Concrete Federation (FIB) [20] relies basically upon the viable misshapening of the composite which is an element of the compressive quality of the solid, of the Young's modulus of the composite and of the width and thickness. composite thickness. The technique doesn't consider the powerful tallness of the composite. The estimation of the decrease coefficient got by this strategy is the most elevated and the powerful stature is that of the valuable tallness of the segment of the pillar (d). This strategy doesn't altogether decrease the impact of the composite. The strategy proposed by ACI legitimately brings the coefficient \( R \) into the recipe for computing \( V_f \) to diminish the rigidity of the composite. The coefficient \( R \) relies upon the compressive quality of the solid (fcm) and specifically on the powerful width of the portion of the composite which relies upon what is classified "viable length lfe (or move length). The second significant boundary associated with this technique is the compelling stature of the composite (df) which is an element of the viable tying down length (deff = hf - c). Notwithstanding the coefficient of decrease of the tractable worries of the composite in the AFGC and Wu techniques and the restriction of the shear worry of the Freyssinet strategy, the idea of powerful stature intercedes in these three strategies. This stature is the equivalent for the AFGC and Freyssinet. It is characterized by the expulsion of the holding length of the composite which is set by Freyssinet at 10 cm from the stature of the texture of
the parallel composite (heff = df - 10). Between these two techniques, the estimation of the coefficient R given by the AFGC is higher (0.406), while for the Freyssinet strategy R is of the request for 0.107. Be that as it may, with the correlation of the Vcal/Vexp proportion, Freyssinet's technique gives results near understanding. Notwithstanding expelling the grapple length which is set at 7cm, WU's technique evacuates 0.1d, which adds up to heff = df - lfe - 0.1d. The estimation of the coefficient R of the last is equivalent to 0.3 (esteem between that given by Freyssinet and that given by ACI). Be that as it may, the estimations of the Vcal/Vexp proportion given by Wu are between the qualities found by these two strategies, which connotes the significance of picking the compelling tallness of the composite.

Examination of the methods of support of bars P2, P8, P9 and P10, the d mode (horizontal composite covering the whole stature of the pillar) gives the best Vcal/Vexp proportions for all strategies. On account of Freyssinet's methodology, the proportion is near 1.

5. Conclusion
This first study allows us to draw the following conclusions:

- An extreme addition in quality of the pillars fortified with TFC of up to 51% contrasted with the control is watched. This increase in opposition stays constrained for ordinarily strengthened pillars contrasted with pitifully fortified ones.
- Reinforced beams exhibit more rigid behavior with a significant reduction in deflection
- A good behavior of the initially pre-cracked beams compared to the reinforced beam directly at ULS and SLS due to the reduction in stiffness with the decrease in deflection before the plasticization load is noted.
- The propagation of cracks is restricted. The crack openings are also reduced. Crack widths can be reduced by a factor of 2 to 3 (depending on whether the beam is initially reinforced or pre-cracked) for maximum loads.
- The shear opposition can be improved by utilizing U-molded strips stuck remotely, as appeared in investigative computations and by test results. Be that as it may, it stays hard to set up a model to anticipate the commitment of the composite itself. Further diagnostic and test examines stay to be performed by modifying the successful mooring stature of the parallel composite and the coefficient of decrease of stresses or compelling disfigurement of the composite.
- Finally, the reinforcement of beams using composite materials remains a subject of interest, in particular from the point of view of calculation and dimensioning methods, of the mode of failure and of anchoring, as well as from the point of view of the 'evaluation of their durability in service.

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