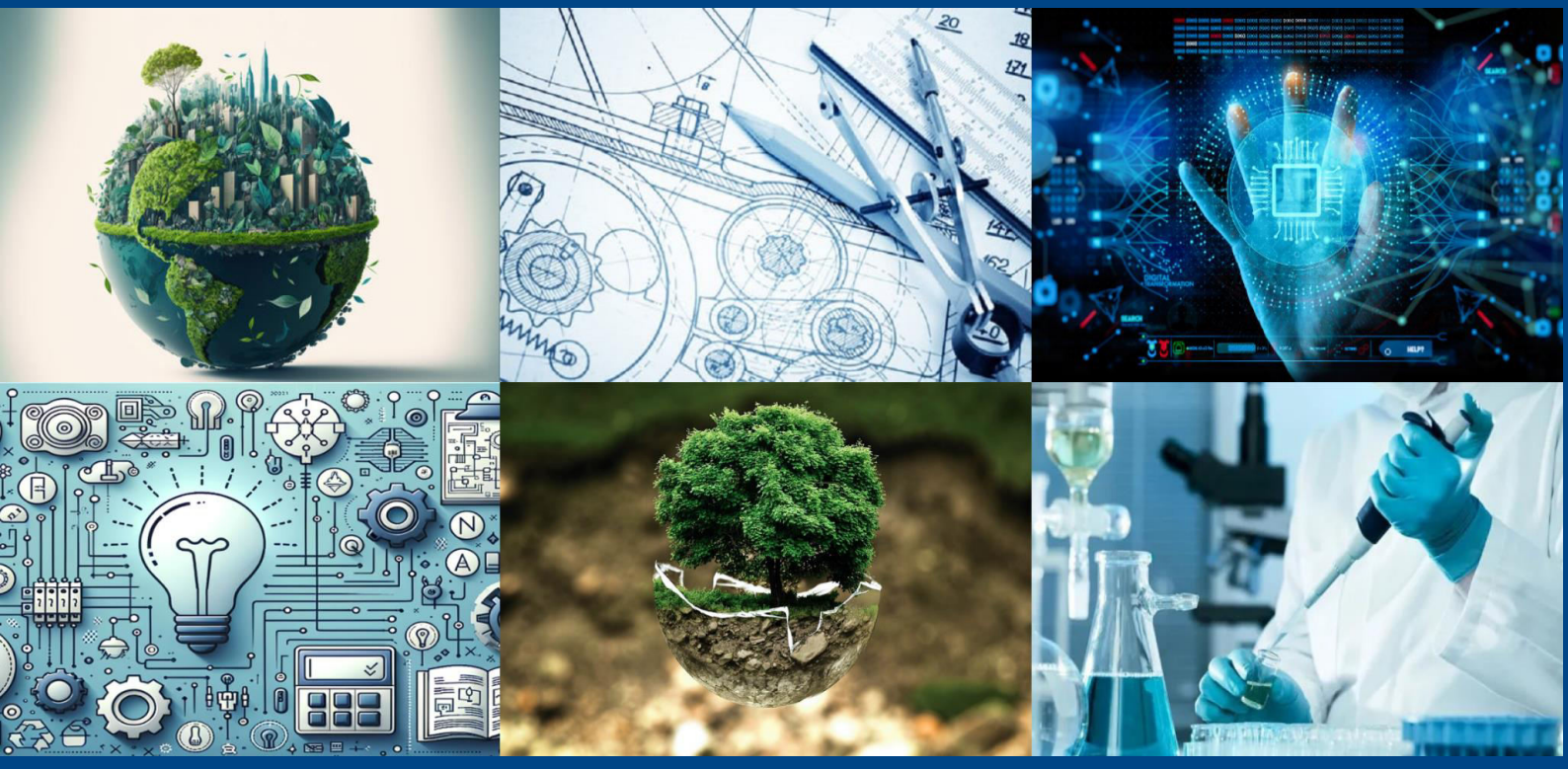
ISSN: 2582-7219



International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 9.864

Volume 9, Issue 11, November 2026

© 2026 IJMRSET | Volume 9, Issue 11, November 2026| DOI:10.15680/IJMRSET.2026.0911010

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

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Strengthening of Pre-Damaged RCC Column Using Glass Fibre Sheet with Epoxy: Experimental Study

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ABSTRACT: Reinforced concrete (RC) columns carry the vertical loads of a building to its foundation, so columns that are damaged or have insufficient capacity need strengthening methods that are quick to apply and do not enlarge the section. This paper reports an experimental study on the effect of external wrapping with glass fibre mat bonded with epoxy resin on the axial load reached by a pre-damaged RC column. A square column of 300 mm × 300 mm × 1000 mm was cast with M25 concrete and reinforced with eight 12 mm longitudinal bars and 8 mm ties at 170 mm centres. At the age of 28 days it was tested in two stages in a loading frame. In the first stage (C1) the column was loaded in axial compression until small cracks appeared and the test was stopped. The cracked column was then wrapped with two layers of glass fibre mat using an epoxy resin–hardener mixture of 3:1 by volume, cured for one day and loaded again (C2). The maximum load reached was 1002.5 kN in the pre-damaged stage and 1370.4 kN after strengthening, an increase of 36.7 % in the load reached. In the second stage the cracks developed at the same locations as before and the wrap showed no splitting or bulging, although a hollow sound on tapping indicated slight debonding that was not visible from outside. Neither stage was taken to failure, so the 36.7 % is a minimum value and not an increase in ultimate capacity. Because only one column was tested, in two stages, the findings are indicative and should be confirmed with larger test series loaded to failure.

KEYWORDS: RC column; glass fibre; epoxy resin; strengthening; pre-damaged column; axial compression; debonding

I. INTRODUCTION

Columns are the primary vertical load-carrying members of reinforced concrete buildings. They receive loads from beams, slabs and other structural members and transfer them to the foundation, so a loss of column capacity directly affects the safety of the whole structure. During the service life of a building, columns may develop cracks and damage because of overloading, ageing, corrosion of reinforcement, poor construction quality, environmental exposure or a change in the use of the building. Replacing a column is disruptive and costly, and strengthening the existing member is often the preferred option.

Several techniques are available for strengthening RC columns. Concrete jacketing adds a new layer of concrete and reinforcement around the column, and steel jacketing encloses it in steel plates or sections. Both increase the size and self-weight of the member and need formwork or fabrication work on site. Fibre-based strengthening is a lighter alternative: a fibre fabric or mat is bonded to the concrete surface with a polymer resin, the original dimensions remain practically unchanged and, unlike steel, the fibre does not corrode. Design guidance for externally bonded fibre-reinforced polymer (FRP) systems is available in the literature [1]. Glass fibre is considerably cheaper than carbon fibre, which makes glass fibre reinforced polymer (GFRP) attractive for routine repair and for local applications.

When an axially loaded column approaches failure, the concrete expands laterally. An FRP wrap resists this expansion and confines the concrete, which changes the load–deformation behaviour of the column [1]. The effectiveness of the wrap depends on the fibre type and form, the number of layers, the resin and the bond between the wrap and the concrete. The epoxy resin has two roles: it bonds the fibre to the concrete surface and it impregnates the fibre so that the two act together as a composite.

Many experimental studies have been carried out on FRP-confined columns, but they differ widely in fibre type, resin, concrete grade and specimen size, which makes direct comparison difficult. Simple and well-documented test data

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International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

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obtained with commonly available materials and a conventional loading frame are therefore useful as a reference for preliminary assessment, especially in an educational and local-construction context. The present work reports such data for an M25 RC column strengthened with glass fibre mat and epoxy resin. The objective is to determine experimentally how the external glass fibre–epoxy wrap changes the axial load reached by a pre-damaged 300 mm × 300 mm × 1000 mm column, by loading the column until small cracks appear, wrapping the cracked column and loading the same column again.

The paper is organised as follows. Section II reviews related work and identifies the research gap. Section III describes the materials, specimen, strengthening procedure and test set-up. Section IV presents and discusses the results, and Section V gives the conclusions and the scope for further work.

II. LITERATURE REVIEW

A. FRP confinement and column behaviour

The behaviour and modelling of FRP-confined concrete under axial compression were studied by Teng and Lam [2], and the response under axial cyclic compression was examined by Lam et al. [3]. Wang et al. [4] investigated GFRP-strengthened RC columns under large eccentric compression. In other studies GFRP was used differently from external wrapping: Hadi and Youssef [5] tested GFRP-reinforced and GFRP-encased square specimens, Karim et al. [6] studied circular columns reinforced with GFRP bars and helices, and Sun et al. [7] tested GFRP-reinforced concrete columns under eccentric load. Zeng et al. [8] compared partially and fully FRP-confined circularised square columns under axial compression, Ahmed and Choudhary [9] examined the ultimate strength and axial strain of FRP-strengthened circular columns, and Zeng et al. [10] tested large-scale FRP-confined rectangular RC columns.

B. Recent work on rectangular and square columns

A state-of-the-art review of strengthening RC structures with FRP was presented by Siddika et al. [11]. Large-scale rectangular columns confined with FRP were also tested under eccentric compression [12]. Isleem et al. [13] developed an axial stress–strain model for rectangular RC columns confined with FRP wraps and anchors, and Fanaradelli and Rousakis [16] proposed a prediction of the ultimate strain of such columns under cyclic axial compression. Section curvilinearisation was studied for square [14] and large-scale rectangular [21] columns, and a cross-wrapping technique was compared with conventional wrapping by Zeng et al. [15]. Hui et al. [20] studied concrete-filled GFRP tube columns under cyclic axial compression.

Studies closer to the present work used GFRP applied with epoxy. Sai Madupu and Sai Ram [17] strengthened rectangular RC columns with GFRP strips bonded with epoxy resin and reported that GFRP wrapping improved the axial load capacity, with the arrangement and number of layers affecting the result. Natarajan and Senthil Selvan [19] tested 150 × 150 × 750 mm GFRP-wrapped square columns of nano-material concrete with single and double layers of GFRP laminate and reported improved strength in the wrapped specimens.

C. Damaged columns and repair

Sai Madupu and Sai Ram [18] repaired fire-damaged short RC columns with GFRP wrap bonded with epoxy and found that the wrap improved the behaviour of the damaged columns. Otoom et al. [22] reported improved flexural behaviour of circular RC columns wrapped with GFRP. Gunarani et al. [23] used GFRP jacketing on damaged columns made with GGBS and industrial sand and evaluated them by compression tests and ultrasonic pulse velocity. Saeed et al. [24] developed a rapid repair of damaged RC columns using CFRP sheets and near-surface-mounted CFRP ropes. The review by Maheswaran et al. [25] covered FRP retrofitting of severely damaged RC members and pointed to the lack of standardised installation and design guidance.

Wang et al. [26] tested GFRP-wrapped square RC columns of different scales and reported that column size influences the effectiveness of the confinement. Lu et al. [27] analysed numerically preloaded FRP-strengthened columns under axial compression. Abbas et al. [28] and Elsanadedy et al. [29] studied wall-like RC columns retrofitted with FRP, the latter after preloading to simulate in-service conditions. Kavitha et al. [30] compared carbon and glass FRP for confining concrete columns with epoxy as the matrix and found that GFRP increased the load capacity compared with unconfined specimens, although CFRP gave higher confinement effectiveness.

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Table I summarises the studies that are closest to the present work in terms of material, specimen type or strengthening condition.

TABLE I.
SUMMARY OF CLOSELY RELATED STUDIES

Ref.	Strengthening and specimens	Reported outcome
[17]	Rectangular RC columns, GFRP strips bonded with epoxy, axial loading	Axial load capacity improved; arrangement and number of layers affected the result
[18]	Fire-damaged short RC columns repaired with GFRP wrap and epoxy	Performance of the damaged columns improved after repair
[19]	150 × 150 × 750 mm nanomaterial concrete columns, single and double GFRP layers	Strength improved in GFRP-wrapped specimens
[23]	Damaged columns with GGBS and industrial sand, GFRP jacketing	Condition before and after strengthening assessed by compression and ultrasonic pulse velocity tests
[26]	GFRP-wrapped square RC columns of different scales	Column size influenced the effectiveness of GFRP confinement
[29]	Two half-scale wall-like RC columns, FRP schemes after preloading	In-service preloaded condition studied experimentally and by finite element modelling
[30]	Concrete columns confined with CFRP or GFRP, epoxy matrix	GFRP raised capacity over unconfined specimens; CFRP was more effective

D. Research gap

The reviewed studies show that fibre wrapping is widely used to improve the strength of RC columns, but several points need further experimental work. First, most studies use fabrics, laminates or strips with specially prepared resin systems, and different fibre types, layers, resins and specimen sizes make direct comparison difficult; there is limited published data for glass fibre mat with a simple epoxy–hardener system on M25 columns. Second, many studies use advanced numerical modelling, hybrid FRP systems, special concrete mixes or complicated loading arrangements, whereas simple laboratory data from commonly available materials and equipment are scarce but useful for undergraduate research and preliminary evaluation. Third, a direct comparison of the same column before and after strengthening with the same procedure is not always reported with the full load history. The present study addresses these points by loading one M25 column until small cracks appeared, wrapping it and loading it again under the same loading arrangement.

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III. EXPERIMENTAL PROGRAMME

A. Scope and objectives

The work is limited to the experimental study of an M25 RC column of 300 mm × 300 mm × 1000 mm strengthened with glass fibre mat and epoxy resin and tested under axial compression. The objectives are: (i) to design and cast an RC column of the selected size with M25 concrete; (ii) to develop a pre-damaged condition by loading the column in axial compression until small cracks appear, and to record the load and the visible damage; (iii) to strengthen the cracked column with glass fibre mat and epoxy resin followed by curing; and (iv) to compare the load reached and the observed behaviour of the column before and after strengthening.

The experimental methodology is shown in Fig. 1. The same column was used in both stages, so no separate control specimen was tested.

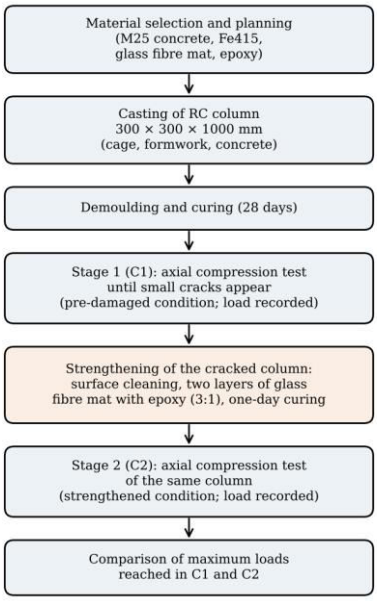


Fig. 1. Experimental methodology adopted in the present study.

B. Materials

Concrete. Concrete of grade M25, that is, a characteristic compressive strength of 25 N/mm² at 28 days as defined in IS 456:2000 [31], was used for the column. The mix proportion was 1:1.62:2.69 (cement : sand : aggregate) with Ordinary Portland Cement and a water–cement ratio of 0.45. **Reinforcement.** Fe415 steel bars were used. The column contained eight longitudinal bars of 12 mm diameter (total area 905 mm², approximately 1.0 % of the gross section) and 8 mm diameter ties at 170 mm centre-to-centre, with a clear cover of 40 mm, as shown in Fig. 2. **Strengthening materials.** The strengthening system consisted of glass fibre mat (Fig. 3a), epoxy resin (R 6022) and hardener (4111) (Fig. 3b). The resin and hardener were mixed in the proportion of 300 ml of resin to 100 ml of hardener, that is, 3:1 by volume, in each mixing batch. The materials and test parameters are summarised in Table II.

© 2026 IJMRSET | Volume 9, Issue 11, November 2026| DOI:10.15680/IJMRSET.2026.0911010

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TABLE II.
SUMMARY OF MATERIALS AND PARAMETERS

Item	Description
Concrete	Grade M25 (IS 456:2000)
Longitudinal steel	8 bars, 12 mm dia., Fe415
Lateral ties	8 mm dia. at 170 mm c/c
Clear cover	40 mm
Fibre	Randomly oriented glass fibre mat
Resin and hardener	Epoxy resin R 6022 and hardener 4111
Mixing ratio	300 ml : 100 ml (3 : 1 by volume) per batch
Wrapping	Two layers, four faces, full 1 m height; corners not rounded
Epoxy curing	1 day before testing
Age at testing	28 days

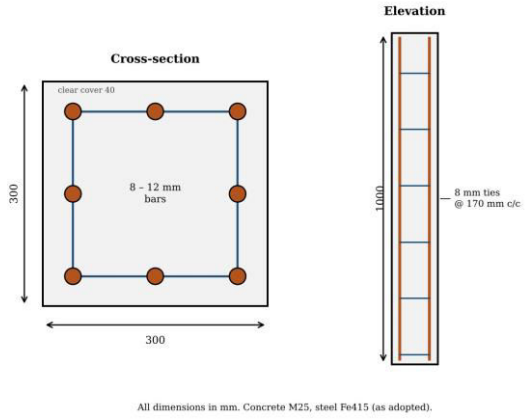


Fig. 2. Dimensions and reinforcement details of the column specimen (all dimensions in mm).



Fig. 3. (a) Glass fibre mat used for wrapping and (b) epoxy resin and hardener used for bonding.

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C. Specimen and test stages

One column was tested; its details and the two test stages are given in Table III. In the first stage (C1) the unwrapped column was loaded until small cracks appeared (pre-damaged condition). In the second stage (C2) the same cracked column, after wrapping with glass fibre mat and epoxy resin, was loaded again. C1 and C2 therefore denote the two stages of one column and not two different columns.

TABLE III.
DETAILS OF THE COLUMN AND THE TEST STAGES

ID	Condition of the column	Strengthening	Test stopped
C1	Pre-damaged: first loading of the unwrapped column, 300 × 300 × 1000 mm	None	When small cracks appeared
C2	Strengthened: same column after wrapping	Two layers of glass fibre mat with epoxy (resin : hardener = 3 : 1 by volume)	By the operator at 1370.4 kN, before failure

D. Casting and curing

The reinforcement cage was prepared as shown in Fig. 2 and placed in the formwork (Fig. 4). Concrete was mixed at site, placed in the column moulds (Fig. 5) and compacted. After casting, the specimen was demoulded and covered with gunny bags for curing (Fig. 6). The age of the column at the time of testing was 28 days.



Fig. 4. (a) Reinforcement cage prepared for placement and (b) formwork prepared for casting.



Fig. 5. (a) Mixing of concrete, (b) placing of concrete in column moulds and (c) column specimens after casting.

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Fig. 6. (a) Columns after demoulding and (b) columns under curing.

E. Glass fibre–epoxy strengthening procedure

Strengthening of the cracked column (stage C2) was carried out in the following sequence: (i) the concrete surface was inspected and cleaned of dust and loose material so that a suitable bonding surface was obtained; (ii) the epoxy resin and hardener were measured as 300 ml and 100 ml and mixed thoroughly, with fresh batches in the same proportion mixed as the wrapping proceeded; (iii) the mixed epoxy was applied on the prepared column surface; (iv) the glass fibre mat was placed on the epoxy-coated surface and impregnated with epoxy; (v) a final coat of epoxy was applied over the mat to ensure proper bonding; and (vi) the wrapped column was left to cure before testing. Two layers of glass fibre mat were applied around all four faces over the full 1 m height of the column. The sharp corners of the column were not rounded before wrapping. The curing period of the epoxy before testing was one day.

F. Test set-up and procedure

The column was placed vertically in the loading frame and loaded in axial compression through a hydraulic actuator acting on a steel bearing assembly at the top of the column (Fig. 7). In both stages the load was increased continuously until the test was stopped by the operator: in C1 after small cracks had appeared, and in C2 when cracking of the column was seen again through the wrap while the wrap itself showed no rupture or bulging. The column was not loaded to failure in either stage. The data acquisition system recorded time, load, two displacement channels and four strain channels at intervals of about one second. The same loading frame and procedure were used in both stages so that the results could be compared. Cracking, sound, damage to the wrap and the behaviour of the column were observed during the tests.



Fig. 7. Strengthened column in the loading frame for axial compression testing (stage C2).

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G. Data processing

The data acquisition system recorded compressive load as a negative value, and load magnitudes are reported in this paper. The maximum load of each stage was taken as the largest value in its record, and the time of this value was taken as the time to peak. The increase in the load reached due to strengthening was calculated as

$$\text{Increase } (\%) = (P_s - P_c) / P_c \times 100 \quad (1)$$

where Ps is the maximum load in the strengthened stage (C2) and Pc is the maximum load in the pre-damaged stage (C1). Readings logged after the completion of each stage, when the actuator had been unloaded, were excluded.

IV. RESULTS AND DISCUSSION

A. Load reached

The load–time records of the two stages are plotted in Fig. 8 and the main results are summarised in Table IV. In the pre-damaged stage (C1) the column reached a maximum load of 1002.5 kN after 66 s of loading. In the strengthened stage (C2) the same column reached 1370.4 kN after 78 s. The column therefore carried 367.9 kN, or 36.7 %, more load after strengthening than it had reached in the pre-damaged stage. The average rate of loading up to the peak was 15.2 kN/s for C1 and 17.6 kN/s for C2, so the two stages were carried out at different average loading rates, and the load–time histories should not be interpreted as a direct comparison of stiffness. Neither stage was taken to failure, so the maximum loads are the loads reached when each stage was stopped and not ultimate capacities.

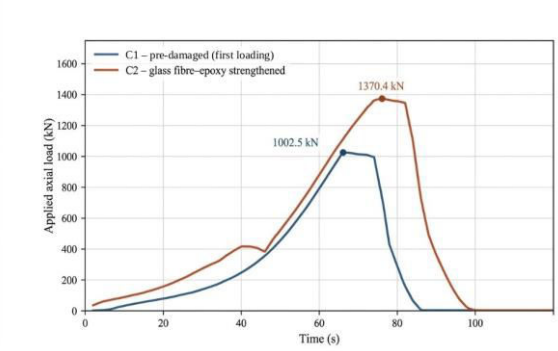


Fig. 8. Applied axial load versus time for the pre-damaged stage (C1) and the strengthened stage (C2).

TABLE IV.
MAXIMUM LOAD RESULTS

Stage	Maximum load (kN)	Time to peak (s)	Increase over C1 (%)
C1 (pre-damaged)	1002.5	66	–
C2 (strengthened)	1370.4	78	36.7

B. Load history

Table V lists the load recorded at selected times. The column carried a higher load in C2 than in C1 at each of these times. Because the loading was not applied at exactly the same rate in the two stages, and the column was already cracked before the second stage, these values describe the load history of each stage and should not be read as a comparison of stiffness.

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TABLE V.
LOAD AT SELECTED TIMES

Time (s)	C1 load (kN)	C2 load (kN)
20	76.3	155.6
40	241.6	414.9
60	776.6	879.7
Peak	1002.5 (at 66 s)	1370.4 (at 78 s)

C. Cracking and post-peak response

In the pre-damaged stage the first cracks were noticed at a load of about 1000 kN, which is close to the maximum load of 1002.5 kN of this stage. Two fine vertical cracks were visible running down from the top of the face, together with a fine inclined crack in the lower part of the face (Fig. 9). No spalling of cover concrete, crushing or exposed reinforcement was observed, so the column was in a cracked but intact condition. In the strengthened stage the earlier cracks could be seen through the translucent wrap. During loading the cracks developed at the same locations as in the first stage, and no crack at a new location was observed. Tapping the wrap gave a hollow sound, which indicated slight local debonding of the wrap from the concrete; this was not visible from outside. No splitting or rupture of the glass fibre mat and no bulging of the wrap were seen.



Fig. 9. Cracks on the column after the first loading (pre-damaged condition, C1).

After the peak, both records show a load close to the maximum for a few seconds before the load dropped sharply. In C1 the load was 973.2 kN (97.1 % of the peak) at 74 s and then fell to 728.6 kN and 417.6 kN in the next two records. In C2 the load was 1343.5 kN (98.0 % of the peak) at 82 s and then fell to 1095.1 kN and 726.1 kN in the next two records. These falls are due to the release of the load after the operator stopped each test and do not represent structural failure. In the record of C2, the load rose to 414.9 kN, dropped briefly to 381.0 kN at 46 s and then continued to increase steadily to the peak; the cause of this momentary drop was not recorded and it did not affect the maximum load. Since the tests were not displacement-controlled and axial deformation was not measured reliably, the post-peak response is not used here to judge ductility.

D. Deformation and strain records

The deflection channels recorded values not exceeding 0.01 mm and the strain channels recorded values not exceeding 2 microstrain throughout both tests. These readings are too small to describe the real axial shortening of a column of this size, so load–deformation curves, stiffness and ductility are not reported in this paper, and the comparison is made on the basis of load only.

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E. Comparison with the estimated axial capacity

As a reference, the axial capacity of a short column of this section was estimated as per IS 456:2000 [31] (Clause 39.3), $P = 0.4\ f_{ck}\ A_c + 0.67\ f_y\ A_{sc}$, with $f_{ck} = 25$ N/mm², $f_y = 415$ N/mm², $A_g = 300 \times 300 = 90\,000$ mm² and $A_{sc} = 905$ mm² (eight 12 mm bars). This gives $P \approx 1143$ kN. This is a design value, which already includes the partial safety factors of 1.5 for concrete and 1.15 for steel, so a load above it is not unexpected. Since the minimum eccentricity of 20 mm exceeds 0.05 times the lateral dimension, the equation is used only as a reference estimate for a nominally concentric test. The loads reached were approximately 87.7 % (C1) and 119.9 % (C2) of this estimate. A value below the estimate is reasonable for the first stage, because that test was stopped as soon as small cracks appeared. No 28-day cube results are available, so the concrete strength actually achieved, the load-cell calibration and the concentricity of loading were not independently verified.

F. Discussion

The higher load reached in the strengthened stage (C2) is consistent with the purpose of external wrapping. A glass fibre–epoxy layer around the column restrains the lateral expansion of the concrete as it approaches failure and thereby delays the opening of cracks, which allows the section to carry a higher load [1]. Improvements in load capacity after GFRP wrapping have also been reported for rectangular columns strengthened with GFRP strips [17], for GFRP-wrapped columns of nano-material concrete [19] and for GFRP-confined concrete in the comparison of Kavitha et al. [30]. The last study also found that CFRP gave higher confinement effectiveness than GFRP, so carbon fibre could give larger gains than those observed here, but at a higher material cost. The specimens, concrete and strengthening arrangements in those studies differ from the present work, so the values are not directly comparable and only the trend is common.

The hollow sound on tapping showed slight debonding of the wrap at the end of the second stage, so the bond between the wrap and the concrete was probably approaching its limit; surface preparation and bond quality therefore need attention. The sharp corners of the column were not rounded, which reduces the confinement efficiency of a wrapped square section [10].

Two practical features of the method are worth noting. The glass fibre mat and epoxy were applied directly on the column surface without any formwork, and the wrapped column kept its original 300 mm × 300 mm section, in contrast to concrete or steel jacketing, which enlarge the member. A strengthening method of this kind can also reduce the need to demolish and rebuild a structural member, which saves new concrete, steel and construction waste. The actual economic and environmental benefit depends on material cost, labour, the condition of the existing structure and a proper structural assessment, and was not quantified in this study.

The result is relevant to practice in several ways. Existing buildings sometimes have to stay in service after damage or when the loading on them has increased, and an external wrap that raises the load a column can carry without enlarging the section can help in such cases after a proper structural assessment. For education and research, the load records of a pre-damaged and a strengthened stage made with locally available materials provide a simple reference for further student and research work on fibre-based strengthening.

G. Limitations

Only one column was tested, in two stages, so the variability between nominally identical columns could not be estimated, and the 36.7 % should be treated as indicative. It is the increase in the load reached by the same column, which was already cracked in the first stage, and not the increase over an identical control column. Neither stage was taken to failure, so the ultimate capacities were not reached. Axial deformation and strain were not recorded effectively, so the effect of strengthening on stiffness and ductility remains to be investigated, and crack development was not measured quantitatively. Only a single glass fibre–epoxy arrangement (two layers, full height, four faces, unrounded corners) and one resin–hardener ratio were considered. Long-term durability, cyclic loading and fire resistance were outside the scope of the work.

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

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V. CONCLUSIONS

Based on the experimental work on one M25 RC column of 300 mm × 300 mm × 1000 mm tested in two stages, the following conclusions are drawn:

1. The column was first loaded in axial compression until small cracks appeared on its surface (pre-damaged condition, C1) and reached a load of 1002.5 kN. No spalling, crushing or exposed reinforcement was observed at this stage.
2. After wrapping with two layers of glass fibre mat and epoxy resin (3:1 by volume) and one day of curing, the same column (C2) reached a maximum load of 1370.4 kN, which is 367.9 kN, or 36.7 %, more than the load reached in the pre-damaged stage. The cracks developed at the same locations as before, slight debonding that was not visible from outside was detected by a hollow sound on tapping, and the wrap showed no splitting or bulging.
3. Both stages were stopped by the operator before failure, so the ultimate capacity of the strengthened column was not reached and the 36.7 % is a minimum value for the increase in the load reached, not the increase in failure capacity.
4. Glass fibre mat and epoxy are lightweight and simple to apply, and the wrapping does not change the dimensions of the column. On the basis of this single specimen, glass fibre–epoxy wrapping appears promising for strengthening cracked RC columns, but further tests are needed before it can be recommended as a practical option.
5. The results are based on one column tested in two stages and are therefore indicative. Tests on replicate specimens, including loading to failure, are needed to confirm the observed increase.

VI. SCOPE FOR FURTHER WORK

Further work should include replicate specimens, an unstrengthened control column and a pre-damaged, wrapped column loaded to failure so that the actual gain in ultimate capacity can be measured, different numbers of layers and wrapping patterns, and reliable measurement of axial deformation and strain so that stiffness and ductility can be evaluated. The effect of surface preparation (for example grinding and a primer coat), rounding of the column corners and the bond quality, checked by tapping or non-destructive methods, should be studied because slight debonding was observed. Crack development and failure patterns should be documented, and columns damaged by corrosion, fire or eccentric loading and the effect of different resin–hardener ratios should also be investigated.

VII. ACKNOWLEDGMENT

The authors thank the Department of Civil Engineering, SVERI's College of Engineering, Pandharpur, for providing the laboratory facilities and the loading frame used in this work.

REFERENCES

[1] ACI Committee 440, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (ACI 440.2R-17)," American Concrete Institute, 2017.
[2] J. G. Teng and L. Lam, "Behavior and Modeling of Fiber Reinforced Polymer-Confined Concrete," Journal of Structural Engineering, vol. 130, no. 11, pp. 1713–1723, 2004.
[3] L. Lam, J. G. Teng, C. H. Cheung, and Y. Xiao, "FRP-confined concrete under axial cyclic compression," Cement and Concrete Composites, vol. 28, no. 10, pp. 949–958, 2006.
[4] J. Z. Wang, Y. F. Wang, and S. Y. Wang, "Behavior of GFRP Strengthened Reinforced Concrete Columns under Large Eccentric Compression Load," Advanced Materials Research, vols. 446–449, pp. 311–317, 2012, doi: 10.4028/www.scientific.net/AMR.446-449.311.
[5] M. N. S. Hadi and J. Youssef, "Experimental Investigation of GFRP-Reinforced and GFRP-Encased Square Concrete Specimens under Axial and Eccentric Load, and Four-Point Bending Test," Journal of Composites for Construction, vol. 20, no. 5, 04016020, 2016.
[6] H. Karim, M. N. Sheikh, and M. N. S. Hadi, "Axial Load-Axial Deformation Behaviour of Circular Concrete Columns Reinforced with GFRP Bars and Helices," Construction and Building Materials, vol. 112, pp. 1147–1157, 2016, doi: 10.1016/j.conbuildmat.2016.02.219.
[7] L. Sun, M. Wei, and N. Zhang, "Experimental study on the behavior of GFRP reinforced concrete columns under eccentric axial load," Construction and Building Materials, vol. 152, pp. 214–225, 2017, doi: 10.1016/j.conbuildmat.2017.06.159.

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International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

[8] J. J. Zeng, Y. C. Guo, W. Y. Gao, J. Z. Li, and J. H. Xie, "Behavior of partially and fully FRP-confined circularized square columns under axial compression," Construction and Building Materials, vol. 152, pp. 319–332, 2017, doi: 10.1016/j.conbuildmat.2017.06.152.
[9] S. K. Ahmed and A. K. Choudhary, "Ultimate strength and axial strain of FRP strengthened circular concrete columns," Cogent Engineering, vol. 5, no. 1, 1501971, 2018, doi: 10.1080/23311916.2018.1501971.
[10] J. J. Zeng, G. Lin, J. G. Teng, and L. J. Li, "Behavior of large-scale FRP-confined rectangular RC columns under axial compression," Engineering Structures, vol. 174, pp. 629–645, 2018, doi: 10.1016/j.engstruct.2018.07.086.
[11] A. Siddika, M. A. A. Mamun, W. Ferdous, and R. Alyousef, "Performances, challenges and opportunities in strengthening reinforced concrete structures by using FRPs – A state-of-the-art review," Engineering Failure Analysis, vol. 111, 104480, 2020, doi: 10.1016/j.engfailanal.2020.104480.
[12] G. Lin, J. J. Zeng, J. G. Teng, and L. J. Li, "Behavior of large-scale FRP-confined rectangular RC columns under eccentric compression," Engineering Structures, vol. 216, 110759, 2020, doi: 10.1016/j.engstruct.2020.110759.
[13] H. F. Isleem, M. Tahir, and Z. Wang, "Axial stress–strain model developed for rectangular RC columns confined with FRP wraps and anchors," Structures, vol. 23, pp. 779–788, 2020, doi: 10.1016/j.istruc.2019.12.020.
[14] J. Y. Zhu, G. Lin, J. G. Teng, T. M. Chan, J. J. Zeng, and L. J. Li, "FRP-Confined Square Concrete Columns with Section Curvilinearization under Axial Compression," Journal of Composites for Construction, vol. 24, no. 2, 04020004, 2020, doi: 10.1061/(ASCE)CC.1943-5614.0000999.
[15] J. J. Zeng, Z. J. Duan, Y. C. Guo, and L. J. Li, "Novel fiber-reinforced polymer cross wrapping strengthening technique: A comparative study," Advances in Structural Engineering, vol. 23, no. 5, pp. 979–996, 2020, doi: 10.1177/1369433219884451.
[16] T. D. Fanaradelli and T. C. Rousakis, "Prediction of Ultimate Strain for Rectangular Reinforced Concrete Columns Confined with Fiber Reinforced Polymers under Cyclic Axial Compression," Polymers, vol. 12, no. 11, 2691, 2020, doi: 10.3390/polym12112691.
[17] L. N. K. Sai Madupu and K. S. Sai Ram, "Performance of axially loaded reinforced concrete rectangular columns strengthened with GFRP strips," Materials Today: Proceedings, vol. 43, Part 2, pp. 1784–1791, 2021, doi: 10.1016/j.matpr.2020.10.454.
[18] L. N. K. Sai Madupu and K. S. Sai Ram, "Repair of Fire Damaged Axially Loaded Short RC Columns Using GFRP Wrap," Civil Engineering and Architecture, vol. 9, no. 6, pp. 2039–2054, 2021, doi: 10.13189/cea.2021.090632.
[19] S. Natarajan and S. Senthil Selvan, "Experimental study on axial compression behaviour of glass fibre reinforced polymer (GFRP) wrapped nano material concrete columns," Materials Today: Proceedings, vol. 39, Part 1, pp. 748–757, 2021, doi: 10.1016/j.matpr.2020.09.444.
[20] C. Hui, Y. Li, Z. Zhou, and R. Hai, "Behavior of concrete-filled GFRP tube columns under cyclic axial compression," Construction and Building Materials, vol. 294, 123566, 2021, doi: 10.1016/j.conbuildmat.2021.123566.
[21] J. J. Zeng, J. G. Teng, G. Lin, and L. J. Li, "Large-Scale FRP-Confined Rectangular RC Columns with Section Curvilinearization under Axial Compression," Journal of Composites for Construction, vol. 25, no. 3, 04021020, 2021, doi: 10.1061/(ASCE)CC.1943-5614.0001129.
[22] O. F. Otoom, W. Lokuge, W. Karunasena, A. C. Manalo, T. Ozbakkaloglu, and M. R. Ehsani, "Flexural behaviour of circular reinforced concrete columns strengthened by glass fibre reinforced polymer wrapping system," Structures, vol. 38, pp. 1326–1348, 2022, doi: 10.1016/j.istruc.2022.02.071.
[23] G. I. Gunarani, B. Karthikeyan, A. Priyadharshini, S. K. Selvaraj, and S. Jose, "Sustainable Concrete Columns with GGBS and Industrial Sand: A Comparative Study on Destructive and Nondestructive Tests on Damaged Columns Strengthened with GFRP Jacketing," Advances in Civil Engineering, 2022, 6716511, doi: 10.1155/2022/6716511.
[24] Y. M. Saeed, W. A. Aules, and F. N. Rad, "Post-strengthening rapid repair of damaged RC columns using CFRP sheets for confinement and NSM-CFRP ropes for flexural strengthening," Structures, vol. 43, pp. 1315–1333, 2022, doi: 10.1016/j.istruc.2022.07.073.
[25] J. Maheswaran, M. Chellapandian, N. Arunachelam, et al., "Retrofitting of severely damaged reinforced concrete members using fiber reinforced polymers: A comprehensive review," Structures, vol. 38, pp. 1257–1276, 2022, doi: 10.1016/j.istruc.2022.02.059.
[26] Z. Wang, Z. Li, J.-Q. Yang, F. Huang, and P. Feng, "Axial compressive and seismic performance of GFRP wrapped square RC columns with different scales," Journal of Building Engineering, vol. 62, 105342, 2022, doi: 10.1016/j.jobe.2022.105342.
[27] S. Lu, J. Wang, J. Yang, and L. Wang, "Numerical analysis of preloaded FRP-strengthened concrete columns under axial compression," Construction and Building Materials, vol. 357, 129297, 2022, doi: 10.1016/j.conbuildmat.2022.129297.

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

[28] H. Abbas, S. M. Ibrahim, N. Al-Hazmi, H. Elsanadedy, T. Almusallam, and Y. Al-Salloum, "Axial Compression Behavior of Wall-like Reinforced Concrete Columns Retrofitted Using Different FRP Schemes," Buildings, vol. 13, no. 1, 26, 2023, doi: 10.3390/buildings13010026.

[29] H. Elsanadedy, H. Abbas, T. Almusallam, and Y. Al-Salloum, "Behavior of FRP-Retrofitted Wall-like RC Columns after Preloading to Simulate In-Service Conditions," Buildings, vol. 14, no. 1, 61, 2024, doi: 10.3390/buildings14010061.

[30] S. S. Kavitha, L. Joseph, M. K. Madhavan, and K. Jayanarayanan, "Comparative study of carbon and glass fiber reinforced polymer composites for the confinement of concrete columns," Materials Today: Proceedings, vol. 103, pp. 352–357, 2024, doi: 10.1016/j.matpr.2023.09.010.

[31] Bureau of Indian Standards, IS 456:2000, Plain and Reinforced Concrete – Code of Practice, New Delhi, India, 2000.



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