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Behavior of Large-Scale Circular RCC Column with and without CFRP Wrapping

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***Abstract*: The strengthening of columns with circumferential wrapping of Carbon fiber-reinforced polymer (CFRP) sheets is one of the common applications for repair and rehabilitation. The paper presents the behavior of large-scale circular columns (150 x 1500mm) partially and fully wrapped with CFRP sheets are examined and compared with the unwrapped/reference column. Eighteen specimens in two groups M15 specimens and M20 specimens were cast by well-known technique and tested under axial loading with the help of video gauge Imetrum system. The first three specimens from each group were the reference specimen. The next three specimens from each group were fully wrapped with CFRP sheets. The last three specimens from each group were partially wrapped with CFRP sheets. The test results are presents that the wrapping of CFRP was very effective in increasing the ultimate axial compressive strength and deformability characteristics of the concrete columns.**

***Keywords*: CFRP, Video gauge, stress, strain, displacement.**

1.INTRODUCTION

When the structures are becoming old and old it increases the corrosion of the reinforcing bars, to maintain the strength and durability of the old structures it is necessary to retrofits to increase their life. To meet up these requirements new innovative materials and technologies of FRP wrapping in construction industry should be used effectively. The Engineers throughout the world have used Fibre Reinforced Polymer (FRP) to solve the structural problems in an efficient and economical manner. In the field of civil engineering, most of the use of FRP is confined to repairing and strengthening of the old structures. Use of FRP for confinement has proved to be effective retrofitting and strengthening application. The confinement in seismically active regions has also proved one of the early applications of FRP materials in infrastructure applications to enhance its earthquake performance.

FRP has high strength-to-weight ratio, corrosion resistance, non-magnetic, minimum change in column geometry and rapid installation process are some advantages over traditional repair techniques [1]. External confinement of concrete column by providing the FRP wrapping around the perimeter of the column [3]. Confinement with FRP is more effective in solid columns than hollow columns as wrapping hollow column with FRP subjects to bi-axial state of stress instead of triaxial state of stress [4]. The size of the specimen also impacts on the strength of the specimen.

It is also observed that the column can be strengthened by partially wrapping with carbon fibre reinforced polymer. The efficiency of FRP confinement is higher for circular columns as compared to non-circular such as square or rectangular columns. By changing the square column into a circular column before FRP wrapping may minimise the stress concentration and improve the confinement efficiency. The shape modification was the first experimentally investigated by bonding precast concrete bolsters to the square solid columns before FRP wrapping by Priestley and Seible. It was found that the confinement efficiency increased after the shape modification. Shape modification technique is also effective for strengthening CFRP confined square and rectangular hollow concrete columns.

The failure criteria of FRP wrapped columns are rupture of the FRP sheets. The FRP sheet ruptures when hoop strain at failure corresponds to ultimate strain obtained from direct tensile test. However, it can be clearly observed from the available research that the hoop strain at failure is between 30 and 50% of the ultimate strain obtained from direct tension coupon tests. This indicates that the behaviour of FRP-confined concrete is not yet established completely. One of the most critical research gaps in the literature is the strain variation over the height of FRP-confined concrete. This type of test data is very difficult to achieve using conventional foil strain gauges.

2. VIDEO GAUGE

Currently, there are new photogrammetric techniques such as the Video Gauge is an advanced software tool that manages the control, capture, processing, and analysis functions for the Imetrum portfolio of non-contact precision measurement systems. The software exploits proprietary sub-pixel pattern recognition algorithms that enable ultra-high-resolution measurements of strain, rotation, and displacement to be made. Video Gauge supports the use of multiple cameras for 3D measurements, and also offers an intuitive control interface which includes a feature allowing post-processing and analysis to be undertaken. With the ability to monitor objects ranging in size from microns to hundreds of metres, Video Gauge is a versatile tool and can be used in a very wide range of applications in the laboratory or the field, and in both high-volume production and in research environments, which establishes Video Gauge as a reliable and accurate method. The similar video technique has been validated and used by several researchers to measure strains from the surface of FRP-confined concrete (White et al. 2003; Bisby et al. 2007; Bisby and Take 2009; Bisby and Stratford 2010; Khaled Abdelraham and Raafat El-Hancha 2012). The test results indicate very good correlation between the strain readings from Video Gauge and conventional foil strain gauges.

The main aspect of the research is to investigate the feasibility and effectiveness of wrapping by CFRP large-scale circular columns with the Imetrum technique. The experimental results focus on the ultimate strength, ultimate strain, and stress-strain behaviour.

Video Gauge operates by allowing the user to define a number of regions of interest called targets. These targets define a position and an area around that position that you would like to track during a test. Video Gauge learns what this region of interest looks like at the start of the test and then tracks how it moves over time in the form of a displacement. Using a number of these target points we can derive quantities such as point to point strains, extensions or rotations etc. A measurement is something that makes use of target points to produce a derived output. Some examples of measurements are strains, extensions, rotations, modulus etc. In Video Gauge measurements are added from your measurement toolbox. You can choose what you want to measure from the toolbox and then click in the video window to create an instance of that measurement type. This can then be positioned wherever you like in the image. In many situations, Video Gauge can track in excess of 200 points in real time. This means that hundreds of measurements can be made simultaneously on a single test. Video Gauge is able to perform measurements in real time using a video camera, but it is also able to save the footage from the camera to an AVI file for later re-processing. This AVI file can be viewed on any PC in Windows Media Player or any other video player of choice that Introduction to supports the AVI format. It also saves a copy of all of the analogue input values coming in to the system. This provides a complete snapshot of the test parameters that we call an archive. Video Gauge can open archives to perform offline measurements. New measurements can be added and old measurements changed before the test is repeated. This allows you to retrospectively go back and perform new measurements on an existing test to more fully understand what is happening. Video Gauge supports a variety of input and output options. It is able to utilize Signal Interface Units to read in analogue voltages and digital signals directly. These can be used to receive information from another piece of hardware that can output to an analogue voltage. Video Gauge is also able to output the results of its measurements as analogue voltages and digital signals using the same Signal Interface Unit. Measurement results can also be output to a network port that other software can listen to receive a live feed of the data

3. EXPERIMENTAL PROGRAM

3.1. Design of specimens

The total eighteen specimens made from normal strength concrete were cast and tested at the Walchand Institute of Technology, India. Due to the slenderness effect there may be chances of formation of secondary moments to avoid that axially short column was designed. However, dimensions of RCC columns were chosen by considering capacity and condition of loading frame at heavy structures laboratory. All the columns are provided with 20 mm cover on each side as well as at top and bottom. The column is designed as short column and longitudinal and transverse reinforcement were designed as per IS 456:2000. The columns are provided with six of number longitudinal reinforcement of 12 mm diameter. and 6 mm diameter stirrup spaced at 150mm c/c. Whereas the stirrups were spaced at 100mm c/c at both ends of column to prevent column from premature failure at the end location. The figure 1 shows the details of the reinforcement.

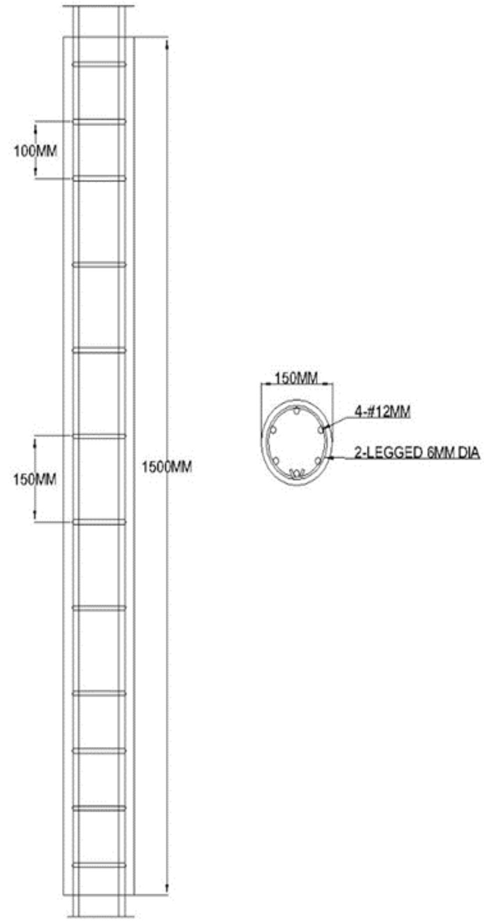


Fig.1. reinforcement detailing of column

As per the strength of concrete column specimens were divided into two groups: nine specimens of M15 grade and nine specimens of M20 grade. All the specimens were 1500 mm in height and 150 mm in diameter. As per Indian standards average of three specimens were taken. The first three specimens from each group are reference column specimen. The next three column specimens from each group were fully wrapped with CFRP sheets with single layer with extra 100 mm overlap length. The last three specimens from each group were partially wrapped (the wrapping of CFRP were 250mm at top and bottom and 500 mm at centre) along the column axis with 250mm overlap which simulates the conventional strengthening method. To allow curing of the epoxy resin the wrapped columns were placed in room temperature for minimum 14 days. The figure 2 shows the detail of the without wrapped, centrally wrapped and three side wrapped columns.

The test matrix is shown in Table 1. In column 1 of Table 1, the first letter of the specimens is either the 15 or 20, where 15 refers to M15 grade of concrete specimen and 20 refers to M20 grade of concrete specimen. The remaining letters refer to the strengthening method. NW refers to no modification, FW refers to fully wrapped with CFRP sheet and PW refers to partially wrapped with CFRP sheets. For example, Specimen 20PW refers to the specimen M20 grade specimen partially wrapped with CFRP sheets.

Table 1-Test matrix

Specimen	Height(mm)	External confinement
15NW	1500	No
15PW	1500	Top, Bottom and Centre
15FW	1500	Full Length
20NW	1500	No
20PW	1500	Top, Bottom and Centre
20FW	1500	Full Length

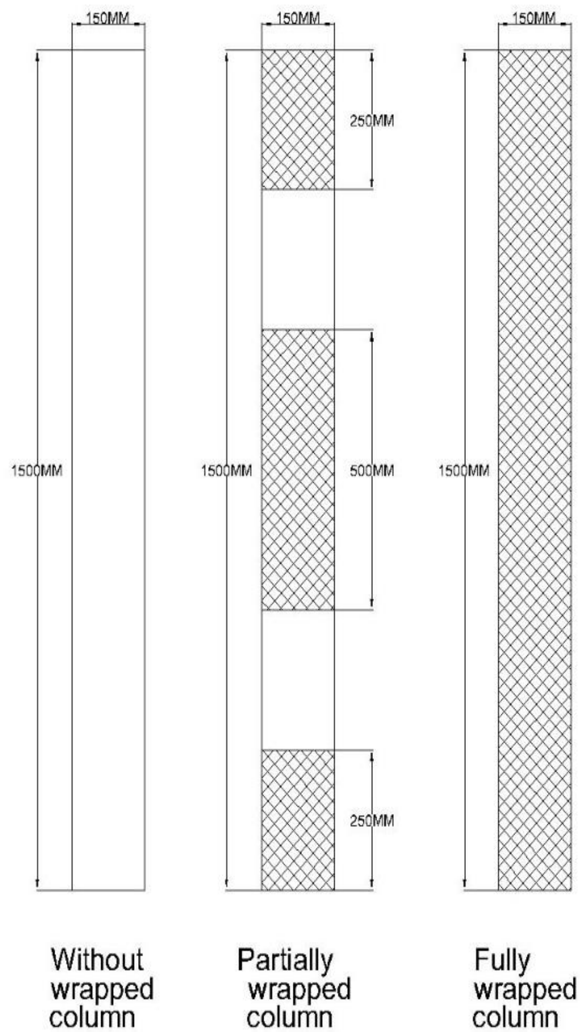


Fig.2 Wrapping conditions of CFRP

3.2. Material properties

A mix design was done for the M15 and M20 grade of concrete. The ordinary Portland cement (OPC) with grade 53 was used for mix design. The concrete was provided with 100 mm slump and maximum aggregate size of 20 mm. The strength of the concrete was determinedly testing small concrete cubes of 150mm x 150mmx 150mm according to IS 516. The average compressive strength of concrete after 28 days was 15 MPa and 20 MPa. Unidirectional CFRP of 100 mm width and 1.65 gm/cm3 density was used as confinement material. The total weight of sheet in main direction was 205 gm/m2. The mechanical properties of CFRP. The average maximum tensile force was 3850N/mm2. Modulus of elasticity was 235kN/mm2. Nominal fibre thickness is 0.118mm. The appearance of saturant was Gray liquid having maximum density 1.15kg/litre. Mixing ratio of saturant was 100:35. Pot life and setting time of the saturant at 25ºC was 25 minutes and 5 Hours resp. The compressive strength (ASTM C579) for one day was greater than 40MPa and for seven day it was greater than 60MPa. The tensile strength (BS:6319, pt 7) was greater than 19MPa. Flexural strength (BS:6319, pt 3) was greater than 31MPa.

3.3. Specimen Preparation

3.3.1. Surface preparation

Before the CFRP wrapping, the surfaces of the specimens were cleaned to remove any dust and to ensure that the surfaces are smooth. After the surface gets smooth the primer was applied so that saturant were spread evenly and rest on one day was given.

3.3.2. CFRP wrapping

Specimens M15FWand M20FW was wrapped with one layer of CFRP with overlapping length of 50mm. The specimens were wrapped using wet-layout method. The mixture of epoxy resin and hardener at ratio of 100:35 was used as an adhesive. At first, the primer was applied and then the epoxy resin was spread on the surface and the CFRP layer was attached. After that, the epoxy resin was then spread onto the CFRP layer. The same process was repeated for partially wrapped columns. But the CFRP confinement is only provided at the end of the column and central part of the column as shown in fig 2.

3.4 Instrumentation and test procedures

Total 18 RCC square columns are tested under axial compression. All the columns were tested with loading frame having capacity of 1000 KN capacity until the failure in the heavy structure laboratory of Walchand Institute of Technology, India. Before testing the columns under axial compression top and bottom faces of all the columns were levelled with the help of grinder to get the uniform distributed load while applying the axial compression load to the column. Then the column was placed in loading frame and with the help of Imetrum video gauge equipment lateral strains are located on the five locations on the column. This technique presents the insight into strain variation of large scale RCC square columns. This is photogrammetric technology that captures strain from any surface. After all the instrumentation done, columns were loaded in axial compression loading frame at a loading rate of 40 KN/min until the failure of column.

4. RESULTS AND DISCUSSION

4.1. Failure mode:

All the columns were tested till the failure of columns occurred. The failure of columns which are without wrapped was failed marked by sudden loss of concrete cover that creates sudden release of energy that caused the concrete to be shattered in all the directions. Wherein the longitudinal reinforcement buckled outward and the rupture of ties takes place. Failure of the columns which are without wrapped are failed at top or bottom that means end bearing failure takes place. However, columns that are wrapped with CFRP are started to fail by the rippling of CFRP then snapping sound was heard when the load reaches the maximum load. Even after that strap-by-strap rupture of the FRP was took place. When the first rupture of CFRP takes place at the maximum load that results in the decrease in the load. But even after that columns were continued to be supporting the load until the deterioration of another CFRP followed by sudden release of energy that caused concrete to be exploded in all directions with explosion sound. It means that because of expansion of the concrete of column; the deterioration of the CFRP and deboning between the CFRP layer and the concrete happens. However, column that are wrapped with CFRP are failed at the top and bottom means here also end bearing failure occurred. Fig. 4, 5 and 6 shows failure of unwrapped, partially wrapped and fully wrapped columns, respectively.

Fig.3. without wrap column failure

Fig.4. partially wrap column failure

Fig.5. fully wrap column failure

4.2. Ultimate axial strength:
All the columns which are wrapped with CFRP observed an increase in the axial compressive strength, the results are shown in table.2 and Fig. 3 shows the graphical representation of the axial strength for group 1 and group 2 columns. For group 1, i.e. M15 grade of column, the fully wrapped and partially wrapped columns observed a percentage increase in the axial strength by 31.25% and6.875% respectively, compared to the unwrapped/reference column. By controlling the formation of cracks, the steel reinforcement contributes to increase in the concrete strength. For group 2 column i.e. M20 grade of column, the fully wrapped and partially wrapped column observed a percentage increase in axial strength by 63.69% and 33.92% respectively, compared to the unwrapped column. The fully wrapped column shows the best performance in the axial strength, with a percentage increase of 22.28% (group 1) and 22.22% (group 2) when compared to partially wrapped column.

Table 2. Ultimate axial Compressive strength of columns

Tested Columns	Avg. Axial compressive strength
15NW	320KN
15PW	342KN
15FW	420 KN
20NW	336KN
20PW	450 KN
20FW	550 KN

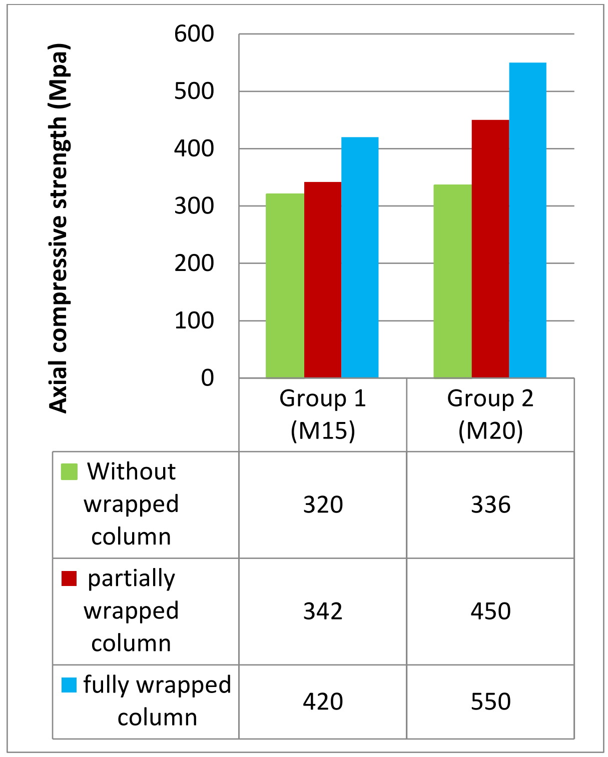


Fig.3. Axial compressive strength of group 1 and group 2

4.3. Behaviour of axially loaded RCC circular column:
In order to observe the behaviour of RC circular the Imetrum video gauge system for observing the lateral strain at different locations of the columns are shown in the Fig.8 below. For the comparison point of view of average strains, we have to consider minimum avg. axial compressive load and at that minimum avg. load we have to compare the avg. strain which are virtually located as lateral strains at five points of the column. The central displacement is also observed in the column as shown in Fig.4 for the group 1 and group 2.

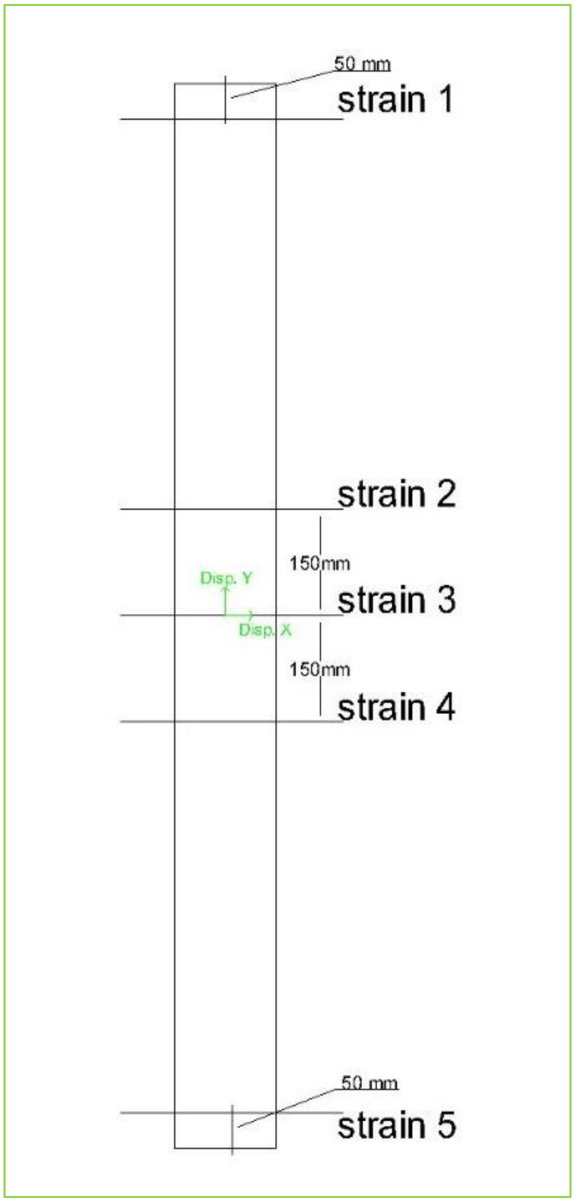
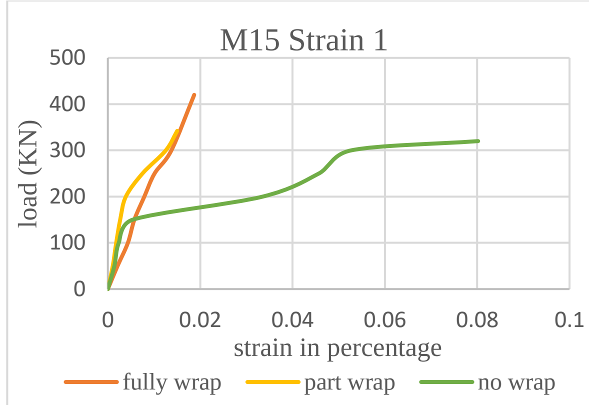


Fig. 4 Virtual strain gauges and the locations

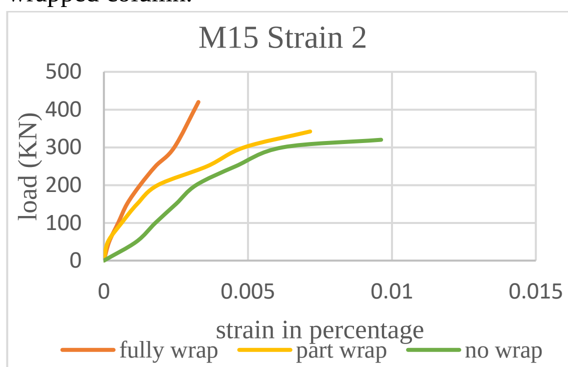
4.4 Combined average results for M15 columns

Group 1

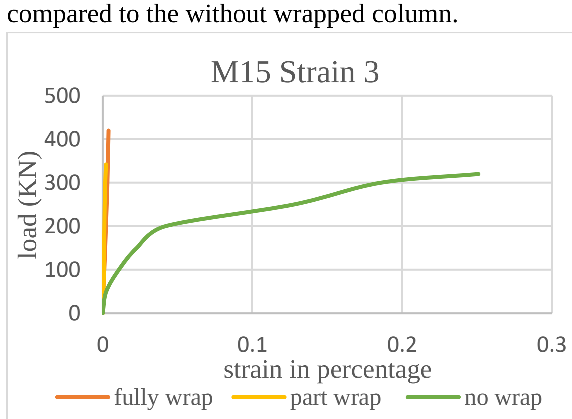
M15 grade of column, values of the average maximum strain at point 1 are 0.080214, 0.015022 and 0.018706 for without wrapped, partially wrapped and fully wrapped CFRP column, respectively. For point 1 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 81.272% and 76.679% respectively, compared to the without wrapped column.



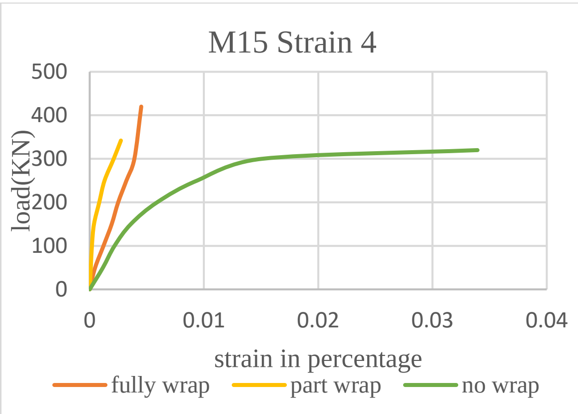
Values of the average maximum strain at point 2 are 0.009627, 0.007162 and 0.003283for without wrapped, partially wrapped, fully wrapped CFRP column, respectively. For point 2 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 25.597% and 65.900%respectively, compared to the without wrapped column.



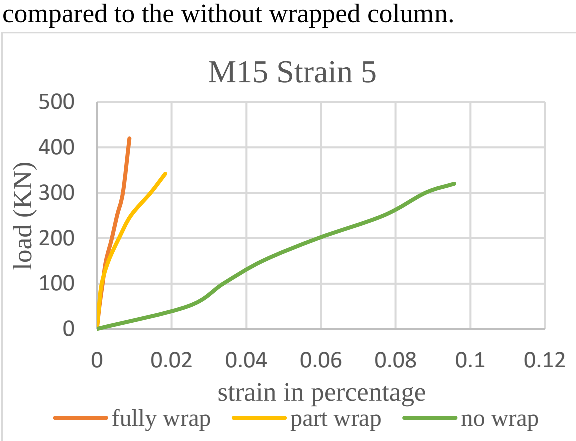
Values of the average maximum strain at point 3 are 0.251, 0.002273 and 0.004513 for without wrapped, partially wrapped and fully wrapped CFRP column, respectively. For point 3 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 99.111% and 98.44% respectively, compared to the without wrapped column.



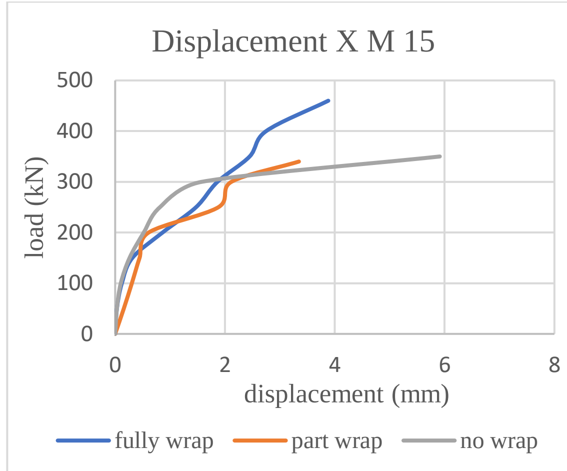
Values of the average maximum strain at point 4 are 0.033938, 0.00273 and 0.004513 for without wrapped, partially wrapped and fully wrapped CFRP column, respectively. For point 4 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 91.95% and 86.70% respectively, compared to the without wrapped column.



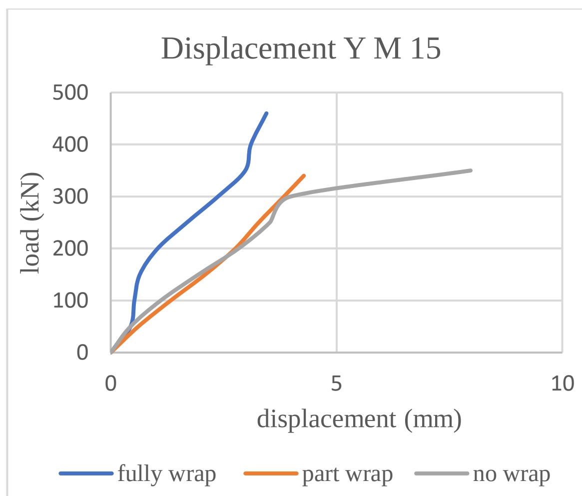
Values of the average maximum strain at point 5 are 0.095693, 0.018275, 0.008689 for without wrapped, partially wrapped, fully wrapped CFRP column, respectively. For point 5 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 80.90% and 90.92% respectively, compared to the without wrapped column.



Values of the average maximum displacement in X direction i.e. in lateral direction at the centre of the column are 5.912763333, 3.346535667 and 3.8815523333for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. Displacement in X direction partially wrapped, and fully wrapped column observed percentage decrease of 43.4014% and34.353%respectively, compared to the without wrapped column.



Values of the average maximum displacement in Y direction i.e. in linear direction at the centre of the column are 7.970296667, 4.276701 and 3.44856for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. Displacement in Y direction partially wrapped, and fully wrapped column observed percentage decrease of 46.3420% and 56.732% respectively, compared to the without wrapped column

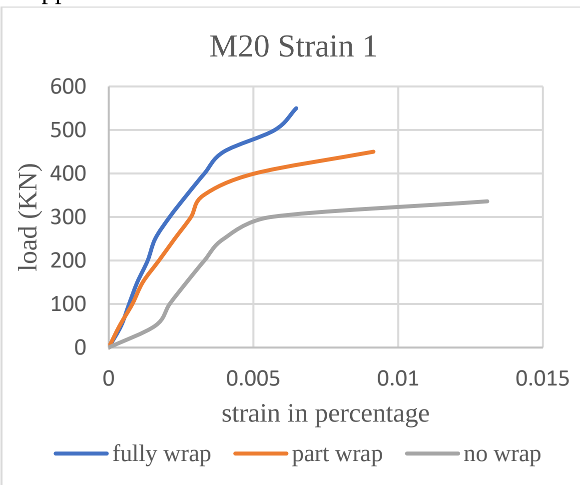


4.5 Combined average results for M20 column

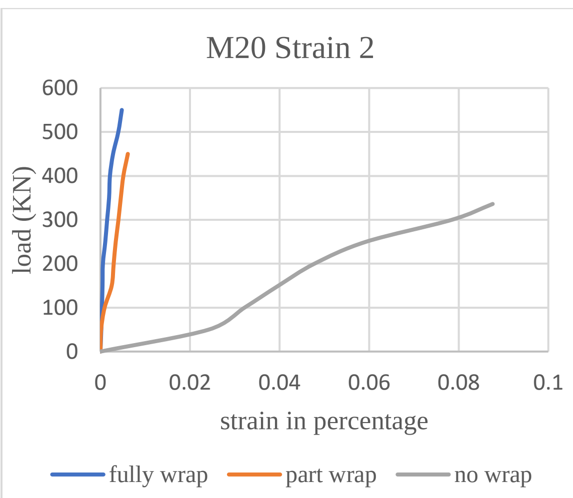
Group 2

M20 grade of column, values of the average maximum strain at point 1 are 0.013079, 0.009146 and 0.006479 for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. For point 1 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 30.07%

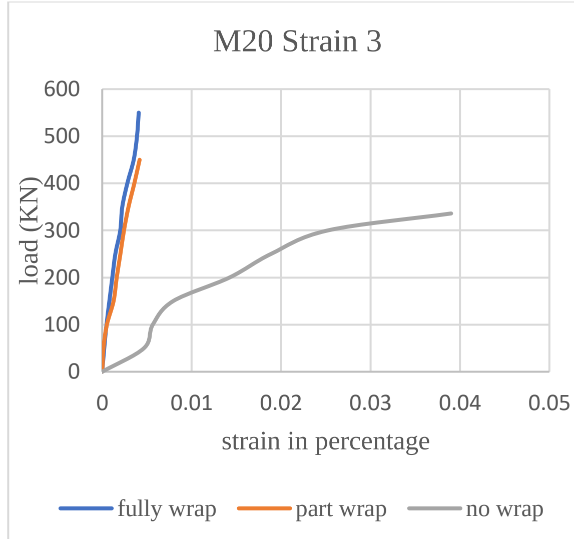
and 50.46% respectively, compared to the without wrapped column.



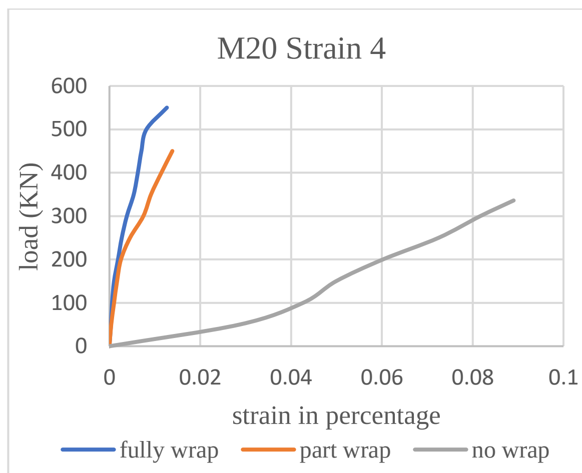
Values of the average maximum strain at point 2 are 0.08758, 0.006118 and 0.004769for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. For point 2 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 93.01% and 94.555% respectively, compared to the without wrapped column.



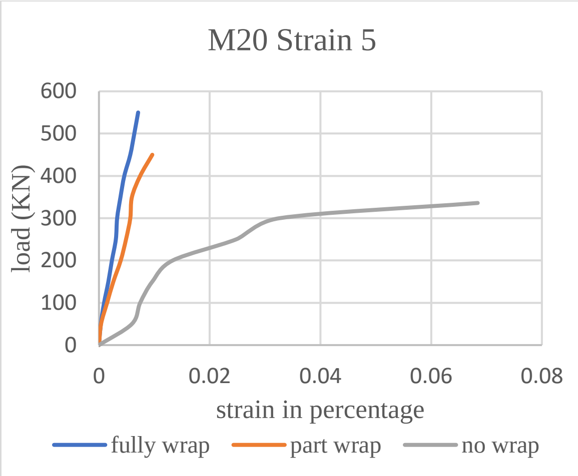
Values of the average maximum strain at point 3 are 0.038007,0.00418 and 0.004084for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. For point 3 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 89.289% and 89.53% respectively, compared to the without wrapped column.



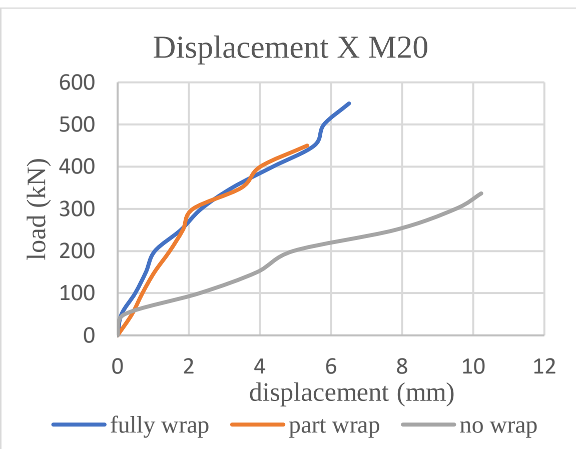
Values of the average maximum strain at point 4 are 0.089015, 0.013854 and 0.012648 for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. For point 4 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 84.83% and 85.79% respectively, compared to the without wrapped column.



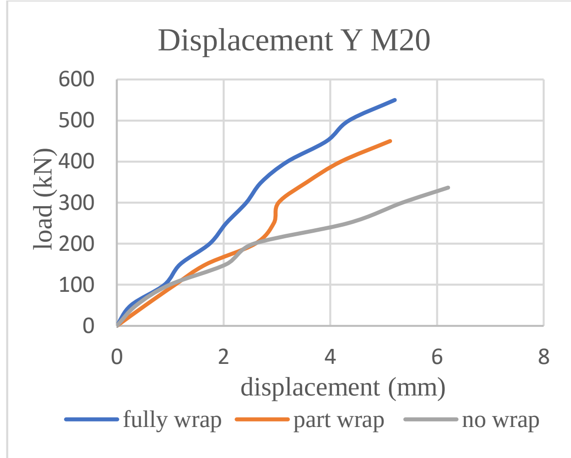
Values of the average maximum strain at point 5 are 0.068409, 0.009636 and 0.007077 for without wrapped, partially wrapped, fully wrapped CFRP column, respectively. For point 5 partially wrapped and fully wrapped column observed percentage decrease in the lateral strain by 85.91% and 89.65% respectively, compared to the without wrapped column.



Values of the average maximum displacement in X direction i.e. in lateral direction at the centre of the column are 10.22600333, 5.331376667 and 6.50768for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. Displacement in X direction partially wrapped, and fully wrapped column observed percentage decrease of 47.864% and 36.3614% respectively, compared to the without wrapped column.



Values of the average maximum displacement in Y direction i.e. in linear direction at the centre of the column are 6.209286667, 5.1215 and 5.209286667for without wrapped, partially wrapped, and fully wrapped CFRP column, respectively. Displacement in Y direction partially wrapped, and fully wrapped column observed percentage decrease of 17.5187% and 16.1049% respectively, compared to the without wrapped column



5 CONCLUSIONS

18 numbers of RCC columns were tested under axial loading in heavy structure lab at WIT, India. These columns were divided into 2 groups M15 and M20 these both grades having without wrapped column, partially wrapped column, and fully wrapped column. Photogrammetric technology called Imetrum video gauge device is used to measure the strain variations from the surface of the FRP wrapped concrete columns. The following conclusions are be made based on the experimental results:

1. The experimental results clearly explain and shows that the wrapping of CFRP was very effective in increasing the ultimate axial compressive strength and deformability of concrete columns.
2. In the M15 as well as M 20 grade of concrete columns it is observed that compressive strength of columns which are fully wrapped and partially wrapped were more than that of without wrapped columns. Fully wrapped columns shows more increase in the compressive strength compared to the partially wrapped column.
3. The study of the strain readings of individual columns for group 1 and group 2 it is observe that lateral strain readings are maximum at point 1, 3 and 5 i.e. at top, centre and bottom of column and minimum at strain point 2 and 4 of column. This is because the column shows combination of bulking failure and compression.
4. Strain induced in fully wrap columns and partially wrapped columns were nearly same and less is than the unwrapped columns. It is also observed that the confinement provided at the areas where

maximum stress in induced i.e. at top, bottom, and centre enhances the load carrying capacities of the columns.

5. Based on the experimental result for both M15 and M20 average central displacement in both direction of unwrapped columns were more as compared to partially wrapped and fully wrapped columns. As well the wrapped columns show ductile behaviour as compared to partially wrapped and unwrapped columns.
6. The bursting failures are observed in fully wrap columns.

So, it is concluded that columns wrapped with CFRP ultimately increase the strength and deformation characteristics of the columns. Based on the test result partial wrapping technique can also be effective wherein the economy needs to be achieved.

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7. I.S. 5816-1999 Method of Test for Splitting Tensile Strength of Concrete

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