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Behavior of Partially Strengthened RC Columns from Sides of the Perimeter Using Prefabricated Hybrid Composite Plates (HCP)

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Abstract - *A This study is to investigate the efficiency of partial strengthening of reinforced concrete columns using prefabricated hybrid composite plates (HCP) from sides of perimeter. It involves the use of ANSYS software to analyse the effect of different strategies of strength and durability on corner and edge rectangular columns that fully strengthening can't be executed. So effectiveness of partial strengthening studied by strengthen from one, two, three sides as edge columns have only three available sides and corner columns from one and two sides because of two sides availability. The composite plates were made up of different materials, including CFRP (Carbon fibre reinforced polymer) and SHCC (Strain hardening cementitious composites), the most suitable materials for strengthening of the columns. Chemical anchors were used to prevent or delay debonding of strengthening layer and these bolts used for attaching 25 mm plates to columns. The columns are then subjected to axial loading conditions and their response is analysed in terms of load-carrying capacity, stiffness and ductility. The optimal strengthening configuration is identifying by changing column sides and span conditions, changing HCP NSM (Near surface mounted) method CFRP embedded configurations. This paper contributes to the development of efficient and effective partial strengthening techniques by use of HCP on RC columns, particularly in terms of enhancing their strength and resisting external forces. Among these particular span condition and number of strengthening sides identified that provide high load carrying capacity than others.*

Key Words: Partial Strengthening, ANSYS, HCP, Axial Loading, NSM, SHCC, CFRP, Chemical Anchors

1.INTRODUCTION

Columns are the vertical structural member designed to support loads primarily in compression and transmit them to the foundation or the base. It is one of the most fundamental elements of a building's structural system. These are the primary load-bearing structural components in the building which makes them most likely vulnerable to deterioration. Over time, it requires strengthening to resist earthquake, increased loads, changing facility types of services or increased traffic volume in bridges, to add or restore ultimate load capacity. Structure types and loading schemes affect strengthening method. Collapse of reinforced concrete (RC) structures because of Increased Load Capacity, Deterioration, Structural Deficiencies, Seismic Upgrades, Change of use has become frequent so column strengthening is necessary to ensure the safety, durability, and longevity of RCC structures. Structural elements may need to be repaired or strengthened due to chemical and physical actions. For the past few years several techniques implemented used to strengthen reinforced concrete columns like reinforced concrete jacketing, steel jacketing, and FRP confining or jacketing.[1]

For some cases fully strengthening can't be executed so have to investigate the feasibility of partial strengthening on rectangular corner and edge columns to explore the possibility of achieving adequate strength and stiffness, which involves selectively reinforcing specific areas of the columns. Hybrid composite plates strengthening is an innovative technique used in structural engineering to enhance the performance of existing concrete structures. It involves the combination of two materials. The main combinations can be taken are SHCC (strain hardening cementitious composites) and CFRP (carbon fibre reinforced polymer) [2]. The application of prefabricated hybrid composite plates strengthening is particularly useful in strengthening existing concrete structures. These prefabricated plates of 25 mm thickness can be fixed to the existing column throughout the specimen by bolted connections. These chemical anchors were used to prevent or delay debonding of the strengthening layer. By adding the hybrid composite plates to the structure, the load-carrying capacity of the structure can be increased without the need for major structural modifications. This makes the technique a cost-effective solution for extending the lifespan of aging infrastructure. It offering a promising solution for improving the performance of concrete structures in a durable and sustainable manner.

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2. NUMERICAL MODELLING AND ANALYSIS OF COLUMNS

The main objective of this investigation is to partially strengthen the corner and edge rectangular column from sides of perimeter also to test the performance of HCP as a strengthening and retrofitting element.

2.1 GENERAL

In this study ten column models are considered. Here columns with 200x300mm cross-section and 3000mm height are taken [5]. In this study, finite element modelling and analysis is carried out using ANSYS workbench. It is a powerful software tool for performing finite element analysis (FEA) of structures and systems. it improves the quality of products by identifying and resolving potential design problems before the product is manufactured also reduces the cost of product development by minimizing the need for physical prototypes and testing.

Here a 3-dimensional model of a column strengthened with a 25mm hybrid composite plate made up of CFRP (Carbon Fiber Reinforced Polymer) strips and strain-hardening cementitious composites. The model can be created by importing the column geometry into the software and then adding the composite plate to it. The composite plate can be modelled using finite element analysis techniques that simulate the behavior of the material under different loading conditions.

In this case, axial loading would be applied to the column to simulate the behavior of the structure under vertical forces. The analysis can provide insights into the performance of the strengthened column, such as its load-carrying capacity, stiffness, and deformation characteristics. It can also help identify potential failure modes and stress concentrations that could lead to structural failure.

By using hybrid composite materials such as CFRP strips and strain-hardening cementitious composites, the strength and stiffness of the column can be improved. The composite plate can help distribute the load more evenly across the column and reduce the stress concentrations at critical points. This can result in improved overall performance and durability of the structure.

2.2 SPECIMEN CONFIGURATION AND MATERIAL PROPERTIES

All the ten columns hade a cross section of 200x300 mm and were 3000 mm in length. The conventional column were reinforced with 4 main bars of 10 mm diameter and 9 numbers of 4 mm stirrups with 150 mm spacing and have a nominal cover of 20 mm [1].

Table -1: Material Properties

Properties	Density (kg/m³)	Modulus of Elasticity (MPa)	Poisson's Ratio	Compressive Strength (MPa)	Yield Strength (MPa)
Concrete	2300	19000	0.12	40	-
Steel Reinforcement (Main Bar)	7850	$2X10^5$	0.3	-	445
Steel Reinforcement (Stirrups)	7850	$2X10^5$	0.3	-	280
CFRP	-	164700	0.3	-	2689
SHCC		23929	0.2	30	-
Anchorage Bolt	-	$2X10^5$	0.2	-	800

To make the strengthening layer of the hybrid composite plate of 25 mm thickness on the column the CFRP made in to strips of 10x1.4 mm and these strips are laid in the longitudinal direction also CFRP layer thickness of 10 mm laid at transverse direction as per reinforcement embedded technique. The other composite material in the HCP SHCC laid at a thickness of 5 and 10 mm as shown in figure 1.

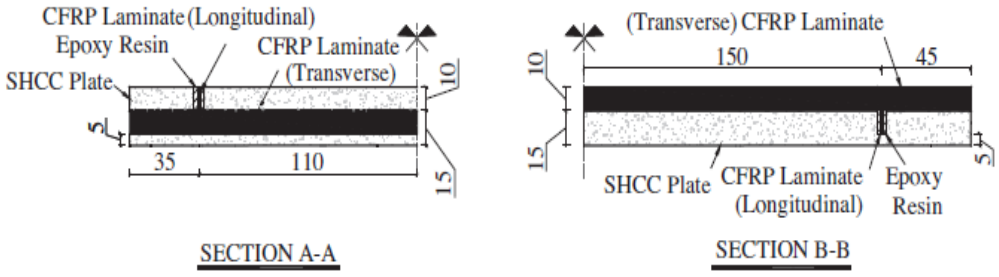

Fig -1: Composition of HCP [3]

The strengthening layers are mainly fixing to the specimen either by wrapping or using the bolted connections. Here the strengthening layer are fixing to the column by the high strength anchorage bolted connections. The M12 anchor bolts had a tensile strength of 800 MPa used [6].

CFRP (carbon fiber reinforced polymer) is a composite material that is widely used in various industries also they have high quality in performance and properties. The self-compacting SHCC was composed of cementitious mortar reinforced with 2% of volume short discrete PVA fibers. The PVA fiber used in this study had a length of 8 mm and was produced by Kuraray Company with designation of RECs15x8. The average tensile stress at crack initiation and the average tensile strength of the SHCC was 2.43 and 3.35 MPa respectively, with a minimum tensile strain capacity of 1.3% [4]. These models analysis are done under axial loading condition and the load carrying capacity of each column are noted. The generated mesh shown on figure 2 the selected mesh size is 50 mm after the mesh sensitivity analysis done and shape of the mesh is hexahedron due to 3d element shaping and elemental type is concrete - Solid 185 and rebar Beam 188.

Fig -2: Generated Mesh of the Column

2.3 PARTIAL STRENGTHENING USING PREFABRICATED HCP

Prefabricated hybrid composite plates have become a popular method for strengthening structures due to their numerous advantages. These plates are significantly lighter than traditional strengthening materials such as steel plates, yet have higher strength-to-weight ratios. This means that they can provide a similar level of strengthening while being much easier to handle and install. These are corrosion resistance and can be designed and manufactured to meet specific engineering requirements. Also composite materials have excellent durability and long-term performance. They do not degrade over time and have a low risk of failure, making them a reliable and cost-effective strengthening solution. Strengthening the RC structures are a necessary thing for extended lifespan of buildings. There are several strengthening techniques for RC columns but the study of partial strengthening on corner and edge columns needs further investigation. While strengthening the corner and edge rectangular columns fully sides aren't available for strengthening. So the corner column has available possible two sides are strengthening from two and one side on different span conditions. So corner columns are strengthening on a span condition of one longer and shorter span in case of 2 side strengthening and in case of 1 side strengthening one longer and one shorter span condition then in case of edge columns the columns are strengthened from three two and one sides of perimeter on different span condition respectively as shown on the Table 2. These models analysis are done under axial loading condition and the load carrying capacity of each column are noted.

Table -2: Models on Different Sides and Span Conditions

Models for Edge Columns	Models for Corner Columns
3s 2 long 1 short span	-
3s 1 long 2 short span	-
2s 1 long 1 short span	2s 1 long 1 short span
2s 2 short span	2s 2 short span
2s 2 long span	2s 2 long span
1s long span	1s long span
1s short span	1s short span

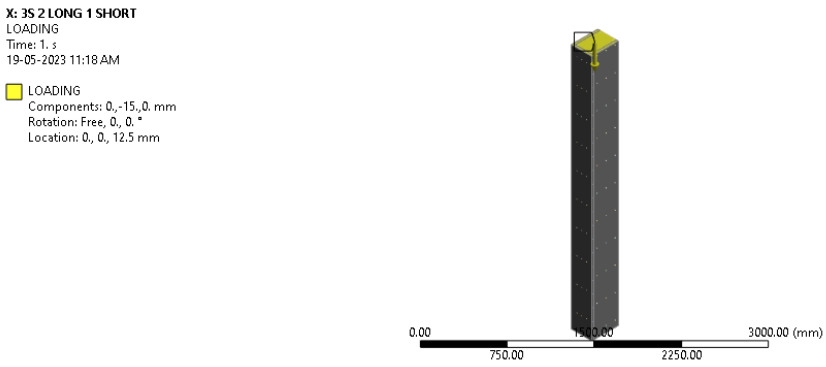

Fig -3: Boundary Condition of Strengthened Column Specimen

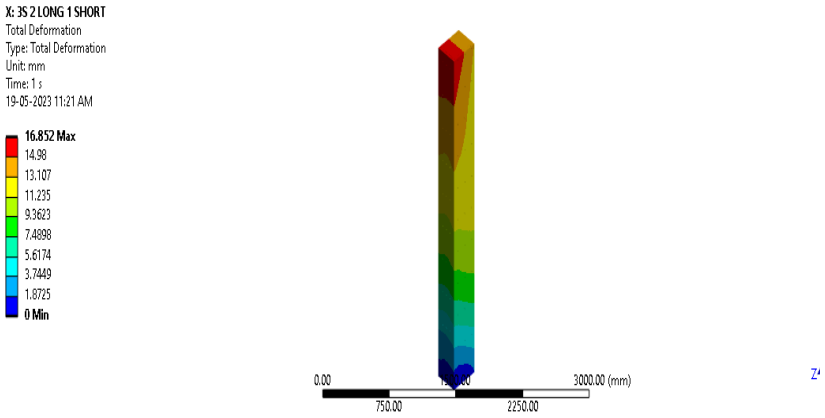

Fig -4: Total Deformation of Strengthened Column Specimen

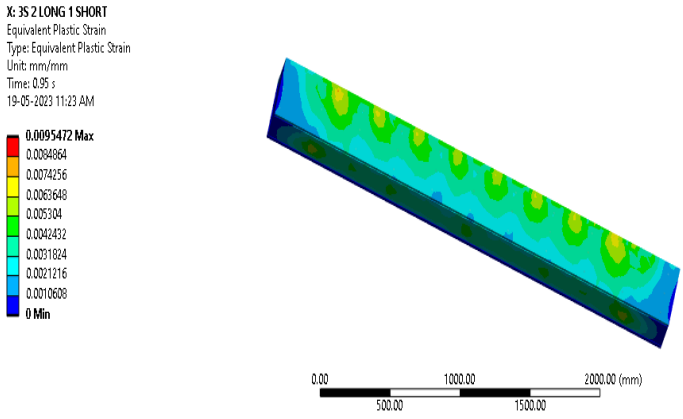

Fig -5: Equivalent Plastic Strain of Strengthened Column Specimen

Table -3: Comparison of Models

Models	Deflection (mm)	Load (kN)	% Increase in Load
CC	8.0676	3238.6	1
3s 2 long 1 short	8.0624	4568.3	41.06
3s 1 long 2 short	10.551	4474.9	38.17

2s 1 long 1 short	7.7825	3967.7	22.51
2s 2 short	9.0277	4303.9	32.89
2s 2 long	8.5759	4583.9	41.54
1s short	8.7647	3419.4	5.58
1s long	9.0124	4036.6	24.64

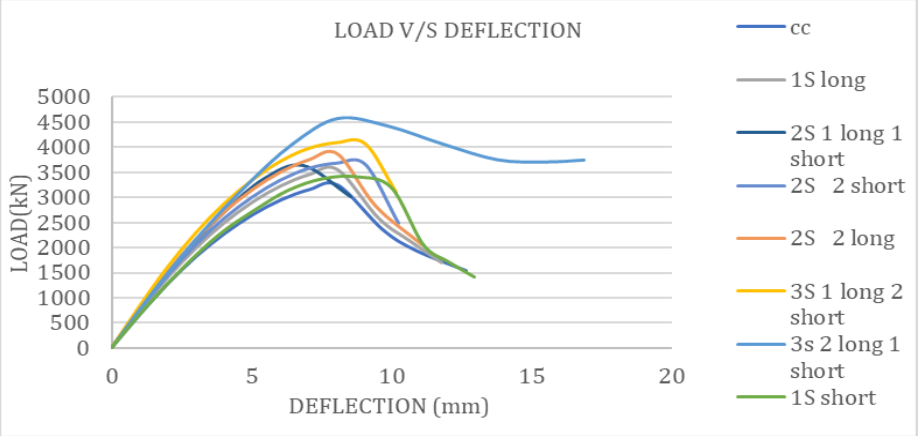

Chart -1: Load Deflection Curve of Strengthened Column Specimens

2.4 NEW DESIGN PROPOSAL

A parametric study is conducted to analyze the effectiveness of partial strengthening on RC corner and edge rectangular column under axial loading by changing the CFRP embedded configuration of strip layers one to two in longitudinal direction using size of 2.8x10 mm. Here the analysis is carried on the span direction based on better load carrying capacity shown.

Table 4. Comparison of Models

Models	Deflection (mm)	Load (kN)	% Increase in Load
CC	8.0676	3238.6	1
3s 2 long 1 short CFRP 2 layers	9.6238	4888.9	50.96
2s 2 long CFRP 2 layers	8.5759	4583	41.51
1s long CFRP 2 layers	9.0124	4036.6	24.64
3s 2 long 1 short	8.0624	4568.3	41.06
2s 2 long	8.5759	4583.9	41.54
1s long	9.0124	4036.6	24.64

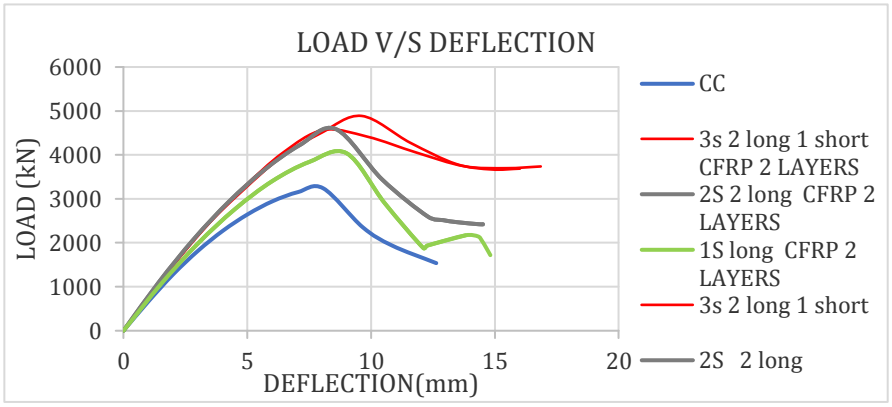

Chart -2: Comparison of Load Deflection Curve of Strengthened Column Specimens

3. RESULTS AND DISCUSSIONS

When compared with the control column the load carrying capacity of partially strengthened column from perimeter of sides increases and the 3 sides (2 longer 1 shorter span) 4568.3 kN shows better results than 3 sides (2 shorter 1 longer span) 4474.9 kN. In case of 2 sided strengthened column, 2 sides (2 longer span) shows high strength 4583.9 kN than the 2 sides strengthened (2 shorter span) 4303.9 kN and the 2 sides (1 longer 1 shorter span) 3967.7 kN also for 1 sided strengthened columns 1 longer span shows more load carrying capacity 4036.6 kN than 1 sided shorter span 3419.4 kN.

From the selected span conditions the CFRP layer changed 1 to 2, then the 3 sided strengthened column (2 longer 1 shorter span) 4568.3 kN in to 4888.9 kN made the further strength improvement in columns. But in the 2 sided (2 longer span) and 1 sided strengthened column (1 longer span) there is no further improvement in column strengthening. So the results shows that only in increasing the sides with increasing the CFRP layers and continuous effect of plates will increase the load carrying capacity (in case of 3 sides) increase in load up to 9.9%.

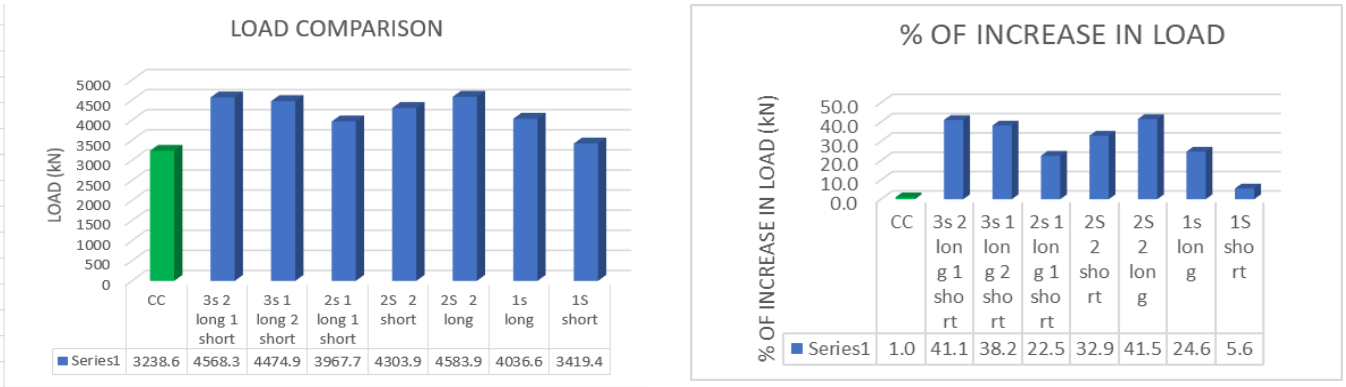

Chart -3: Load Comparison and % Increase in Load Graph of Specimens

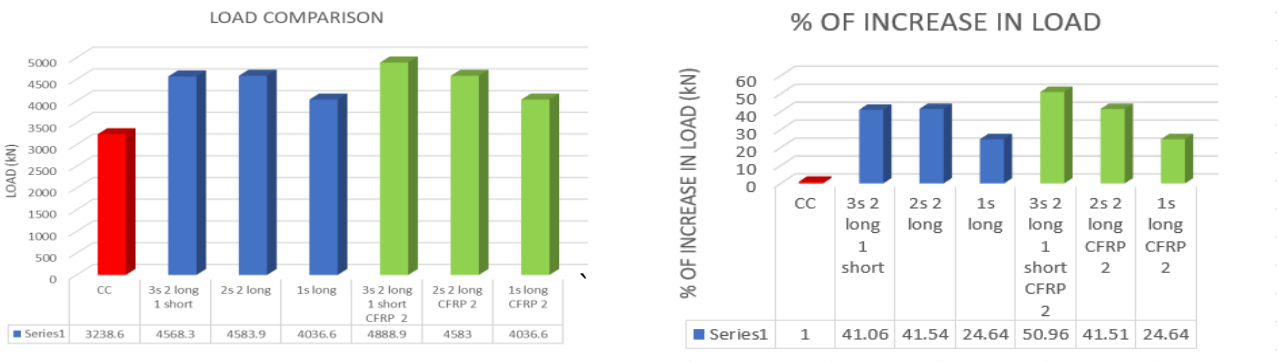

Chart -4: Load Comparison and % Increase in Load Graph of Specimens

4. CONCLUSIONS

- The partial strengthening under axial loading on corner and edge rectangular columns from sides of perimeter using prefabricated HCP showed an acceptable increase in load carrying capacity compared to control column.
- The results shows that 2 longer side strengthening giving high strength than 3 sided (2 long 1 short) span and 1 longer side strengthening have high increase in load carrying capacity than 2 side (1 long and 1 shorter) span so we can provide that type of partial strengthening on particular sections for better performance.
- Focused on the number of sides strengthening on different span conditions and further studies conducted on selected high strength span conditions.
- Changing and increasing the CFRP layer embedded configuration in each perimeter of column does not show any much improvement in strength.

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