

Effect of Compressive Strength of Core and Precast Concrete on The Behavior of Column Retrofitted by Precast Segment and CFRP Wrapping - A Finite Element Study

Chandini G M^{1,*}, L. Manjunatha², H Sharada Bai³

Abstract

In the present investigation the effect of compressive strength of core and precast concrete on the behavior of columns retrofitted by attaching precast segments and followed by FRP wrapping through Finite Element Analysis. Rectangular columns converted into an elliptical column by attaching precast segment is modelled using ANSYS workbench, A Finite Element Analysis software. Finite Element Model is developed by considering various structural parameters such as grades of core and pre-cast concrete, number of CFRP layers. The concrete is modelled using Solid 186 element, CFRP is modelled using solid 186 element and reinforcement is modelled using REINF264 element. The interface between the precast segment and core concrete and between precast segment and CFRP is assumed to be fully bonded. The size of the columns considered is 100mm×150mm×900 mm. To simulate the contact between precast segment and FRP wrapping, columns heads of size 300mm×300mm×350mm are considered at the ends of the column. The column is reinforced with 6 bars of 8 mm in the longitudinal direction and 8mm ties at 100mm c/c in the lateral direction having Grade of steel as Fe500. The Finite Element Model developed in the present study is validated by comparing the existing experimental results. A detailed parametric study is carried out by considering the grades of core concrete and precast segments as combination of 20 MPa, 40 MPa and 60 MPa and number of layers of CFRP as 0, 1 and 2 layers. Incremental axial displacement up to failure is applied on the upper column head, corresponding reaction load obtained in the lower column head is considered axial load applied on the column. The failure load is considered as the load corresponding to CFRP wrapping reaching its ultimate strain of 1.5%. The axial displacement of the columns with respect to each incremental load is also obtained. From the Finite Element results it is observed that in case of CFRP wrapped columns as the core concrete grade increases, ultimate load carrying capacity of the column increases. However, the CFRP efficiency of columns with lower core concrete compressive strength is more, as core concrete under more dilation, hence CFRP confinement will be more active and effectively utilized. As the

concrete grade of precast segment increases the ultimate load carrying capacity of column increases. Also, the ultimate load carrying capacity of the column increases by increasing the number of layers of CFRP.

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INTRODUCTION

To enhance the overall strength of existing structures, retrofitting measures become necessary, particularly when chemical reactions induced by

environmental factors pose risks to concrete buildings. Various methods exist for fortifying structures, and one such approach involves the utilization of precast elements to reinforce columns. The evaluation and potential strengthening of existing structures become imperative when heightened load requirements are introduced. Typically, structural reinforcement is essential when a component's load-bearing capacity proves insufficient or has been compromised due to prolonged damage. Notably, the concept of axial reinforcement through the use of FRP composites deviates from conventional RC design principles, where increased cross-sectional area correlates with higher axial capacity. In this investigation, Finite Element Modelling using ANSYS is carried out on rectangular sectioned reinforced concrete columns retrofitted with elliptical edged precast segments [1,2] made using different grades of concrete and wrapped with carbon fiber wrapping. The proposed Finite Element Model is validated comparing with results of experimental study carried out by Chidanand et. Al.[3]. Various parameters considered are grades of core and pre-cast concrete, number of CFRP layers.

FINITE-ELEMENT MODELLING

ANSYS Workbench emerges as a standard problem-solving platform in engineering endeavors. It is typically employed for importing models from various sources, or utilizing an embedded tool such as SpaceClaim for modelling. Additionally, it assists in preparing models for design simulations via Design Modeler, conducting FEA simulations, and leveraging SpaceClaim for specific tasks. Ansys Workbench is versatile, encompassing tasks such as material configuration in Simulation, geometry generation, FE meshing, load and boundary condition assignment, problem-solving, and result analysis.

In this research, a reduced-scale model representing one third Scale of a column has been meticulously created and subjected to analysis through the utilization of ANSYS Workbench software [4,5]. The specific elements incorporated to construct the proposed Finite Element Model can be found in Table 2.1.

Table 1. Elements used in modelling.

Material	Ansys Element
Concrete and CFRP	Solid186
Reinforcement	REINF264
Contact between CFRP and Concrete	Contact174 AND Targe170

Assumptions

Assumptions made in the current Finite Element Analysis are listed below

- Concrete and reinforcing bars are assumed homogenous with a multi-linear and bi-linear modulus of elasticity.
- Reinforcement bars in the concrete are modelled as 1-D elements, which take only compression and tensile stress/strain.
- The reinforcing element is firmly attached to its base element (Solid186). No relative movement between the reinforcing element and the base is allowed.
- Contact between core concrete and micro-concrete precast segment is fully bonded.
- The failure criteria of de-bonding, slipping of the contact between core concrete to micro concrete, and reinforcement is ignored in the model.
- The inertial force (dead load due to gravity) of the column and plates is not considered in the modelling.
- The CFRP is modelled as a uni-direction Fiber matrix in hoop direction (Orthotropic Elasticity).

Material properties

The model's material is defined in engineering data section in analysis system. Compressive Ultimate strength, tensile ultimate strength and Poisson's ratio of the core and the precast segments are 35 MPa, 4.14 MPa, 0.2 and 60 MPa, 5.42, 0.2 respectively and similarly calculate for different grade of core

concrete and precast segments i.e 20 MPa, 40 MPa, 60 MPa. Properties of FRP is illustrated. The material property considered in the parametric study are shown below: The reinforcement and concrete are modelled as bi-linear element in the ANSYS analysis. Drucker-Prager Concrete Model available under Geomechanics Non-Linear Material Models is used for modelling concrete. The Drucker-Prager material properties to be entered for defining concrete are listed in Table 2. Biaxial compressive strength is obtained from the model developed by Teng, J.G. et al [6].

Table 2. Drucker-Prager parameters considered

Material Property	
Modulus of Elasticity	29580 MPa
Poisson's Ratio	0.2
Density	2300 kg/m ³
Uniaxial compressive strength	35 MPa
Biaxial compressive strength	64.66 MPa
Dilatancy factor in tension	0.25
Dilatancy factor in compression	1
Relative stress level at start of nonlinear hardening	0.33
Residual relative stress level at transition from power law to exponential softening	0.85
Residual compressive relative stress	0.2
Mode I area-specific fracture energy	1000 N/m
Residual tensile relative stress	0.1

Geometrical Model

The core concrete column, precast segments and CFRP geometry are modelled as 3-D Solid and the reinforcement are modelled with line element and assigned with required cross-section. The modelling steps followed for 3-D modelling using Spaceclaim are as follows.

The concrete is modelled using Solid 186 element, CFRP is modelled using solid 186 element and reinforcement is modelled using REINF264 element. The interface between the precast segment and core concrete and between precast segment and CFRP is assumed to be fully bonded. The size of the columns considered is 100mm×150mm×900 mm. To simulate the contact between precast segment and FRP wrapping, columns heads of size 300mm×300mm×350mm are considered at the ends of the column. The column is reinforced with 6 bars of 8 mm in the longitudinal direction and 8mm ties at 100mm c/c in the lateral direction having Grade of steel as Fe500.

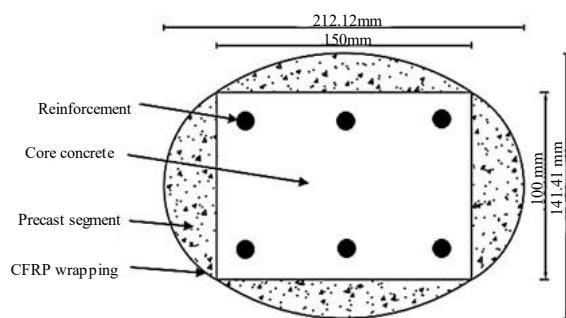
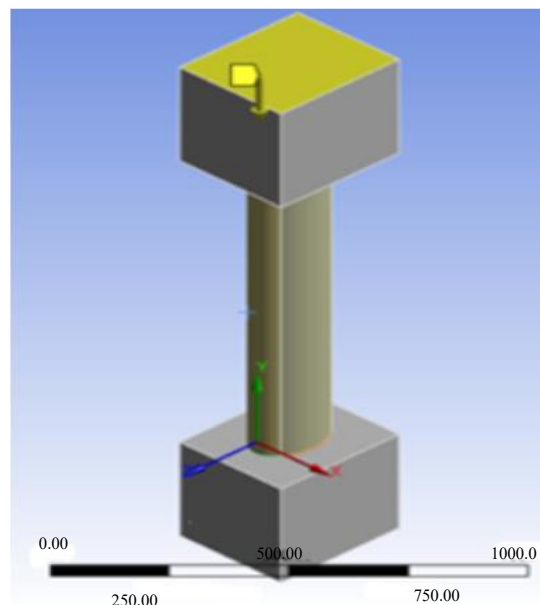
First, we have to model a core concrete column specimen with reinforcement and with this we can generate the model of precast segments and CFRP.

Meshing can be of various types and apply with respect to the geometry. Generally, a meshing size of about 20mm to 25mm is used for meshing the elements. Inserting type of meshing such as size, multizone. Selecting element for the inserted meshing type. Generating of mesh.

In the present study it is reasonable that assume the contact between the core concrete column to precast segments and contact between the concrete and CFRP are fully bonded. The contact between concrete and steel reinforcement is also assumed to be bonded. To apply boundary conditions the components must consist of either nodes or elements, whereas the elements can be of face, edge or whole component. In this study, boundary conditions applied in the static analysis are Support fixed, Displacement (UY in mm) – Apply 10mm displacements to the top surface, Remote Displacement (RY-0) on face-Rotational Constraint.

Table 3. Details of specimens

Sl No	Section	Material	Dimension
1	Column	M20 ,M40,M60	100x150x900mm
2	Column head	M20,M40,M60	300x300x350mm
3	Precast Segment	M20,M40,M60	Shorter direction - 20.705mm Longer direction - 31.06mm
4	FRP	Carbon	Layer Thickness - 0.11mm,0.22mm
5	Reinforcement	Fe-500	Main steel - #6-12mm dia Stirrups – 8mm dia @ 100mm spacing

**Figure 1.** Elliptical cross section**Figure 2.** FE model**Table 4.** Details of the columns considered for experimental work

Sl no	Section	Material	Dimension
1	Column	M35 Concrete	100x150x900mm
2	Column head	M35 Concrete	350x300X300mm
3	Precast Segment	M60	Central thickness Shorter direction - 20.705mm Longer direction - 31.06mm
4	FRP	CFRP	Layer Thickness - 0.11mm
5	Reinforcement	Fe-500	Main steel - #6-12mm dia
		Fe-500	Stirrups – 8mm dia @ 100mm spacing

VALIDATION OF FINITE-ELEMENT ANALYSIS MODELS

Finite-element models proposed in this investigation are validated with the experimental study carried out by the Chidanand et. al. The details of the columns considered in the experimental investigation are listed in the Table. The shape modified elliptical specimens with precast segments shown in Figure. 2 are considered for validation. Specimens without CFRP, with 1 and 2 layers of CFRP wrapping, concentric loading were modelled. Element types of concrete is modelled using Solid 186 element, CFRP is modelled using solid 186 element and reinforcement is modelled using REINF264 element. The interface between the precast segment and core concrete and between precast segment and CFRP is assumed to be fully bonded and material properties are adopted as mentioned in the Finite element modelling section. Load application method and boundary conditions are adopted as mentioned in the Finite Element Modelling section.

Experimental study involved effects of concentric loading [7]. and number of wrap layers on behaviour of shape modified elliptical members [8,9,10,11,12] using precast segments. As observed in Table 5.3, where ultimate load of RCS900, ESNF1.5-900, ES1.5-50-1-900 and ES1.5-100-1-900). In the experimental results of the specimens considered, finite elements results of the same using proposed FE model are listed and Percentage difference in ultimate loads are calculated. From the it is seen that maximum percentage variation in ultimate load predicted by proposed model for all the model is within 20%.

Table 5. Comparison of finite element analysis results with the experimental results

Specimen Designation	Cross Sectional Area(mm ²)	Experiment results	FEM Results using proposed model	Percentage variation
		Ultimate Load (kN)		
RCS900	15000	597	667.31	11.7%
ESNF1.5-900	23554.83	1047	1261.50	20.48%
ES1.5-50-1-900	23554.83	1248	1272.5	1.96%
ES1.5-100-1-900	23554.83	1318.8	1417.50	11.5%

Parametric Study

A detailed parametric study is carried out by considering the grades of core concrete and precast segments as combination of 20 N/mm², 40 N/mm² and 60 N/mm² and number of layers of CFRP as 0, 1 and 2 layers. Some models of varying the grades of core concrete with constant precast segments grade and other models are considering by varying precast segments grades with constant core concrete grade as combination of 20 N/mm², 40 N/mm² and 60 N/mm² and number of layers of CFRP as 0, 1 and 2 layers. Incremental axial displacement up to failure is applied on the upper column head, corresponding reaction load obtained in the lower column head is considered axial load applied on the column. The failure load is considered as the load corresponding to CFRP wrapping reaching its ultimate strain of 1.5%.

The study involves two sets of models: one set varies the core concrete grades while keeping precast segment grades constant, and the other set alters precast segment grades while maintaining a consistent core concrete grade across the three options of 20 N/mm², 40 N/mm², and 60 N/mm², alongside varying the number of CFRP layers as shown in Table 6.

These specimens encompass a range of characteristics, including distinct types denoted by codes such as "R" for rectangular columns and "P-E" for ellipticalized precast segments. The code also contains information about concrete grade, precast grade and CFRP layer. For example, specimens like "R-20-0" indicate rectangular columns with a core concrete grade of M20 and no CFRP layers. Similarly, specimens like "P-E-20/60-1" signify precast segments ellipticalized with core concrete grade M20 and precast grade M60, wrapped with 1 layer of CFRP. This comprehensive dataset offers insights into the structural properties of these specimens for analytical evaluation. The core concrete exhibits a cross-sectional area of 15,000 mm², while the modified column's cross-sectional area is adjusted to 23,554.83 mm² using Precast segments.

Table 6. Parameter of modelled specimens

Specimen Designation	Grade of concrete (Mpa)	Cross Sectional Area(mm ²)	Type of material	Number of Layers
R-20-0	20	15000	-	0
P-E-20/20-0	20/20	23554.83	-	0
P-E-20/20-1	20/20	23554.83	CFRP	1
P-E-20/20-2	20/20	23554.83	CFRP	2
P-E-20/40-0	20/40	23554.83	-	0
P-E-20/40-1	20/40	23554.83	CFRP	1

P-E-20/40-2	20/40	23554.83	CFRP	2
P-E-20/60-0	20/60	23554.83	-	0
P-E-20/60-1	20/60	23554.83	CFRP	1
P-E-20/60-2	20/60	23554.83	CFRP	2
R-40-0	40	15000	-	0
P-E-40/20-0	40/20	23554.83	-	0
P-E-40/20-1	40/20	23554.83	CFRP	1
P-E-40/20-2	40/20	23554.83	CFRP	2
P-E-40/40-0	40/40	23554.83	-	0
P-E-40/40-1	40/40	23554.83	CFRP	1
P-E-40/40-2	40/40	23554.83	CFRP	2
P-E-40/60-0	40/60	23554.83	-	0
P-E-40/60-1	40/60	23554.83	CFRP	1
P-E-40/60-2	40/60	23554.83	CFRP	2
R-60-0	60	15000	-	0
P-E-60/20-0	60/20	23554.83	-	0
P-E-60/20-1	60/20	23554.83	CFRP	1
P-E-60/20-2	60/20	23554.83	CFRP	2
P-E-60/60-0	60/60	23554.83	-	0
P-E-60/60-1	60/60	23554.83	CFRP	1
P-E-60/60-2	60/60	23554.83	CFRP	2

RESULTS AND DISCUSSION

The Table 7 presents the ultimate load-bearing capacities (in kN) and ultimate stresses (in MPa) of various specimens. The comparative analysis of load-bearing capacities, expressed as a percentage increase with respect to the reference rectangular columns “R-20-0”, “R-40-0”, “R-60-0”, having a core concrete grade of M20, M40, M60 with a precast grade of M60 and 0, 1, 2 layers of CFRP wrap, reveals notable enhancements across various specimens. The ultimate load carrying capacity columns in group are compared with respect to column without precast segments. From this comparison it is observed that column group with M20 without FRP wrapping the increase in the load carrying capacity increases by 2.18%, 26.067% and 72.58% with precast segment concrete grade of M20, M40 and M60 respectively. Similarly, for unconfined specimens with M40 core concrete grade these values are found to be - 1.26%, 16.49% and 33.06%. Also, for confined specimens with M60 grade core concrete and M20, M40 and M60 grade precast segments this value found to be 5.65%, 18.86% and 31.99% respectively.

Table 7. Effect of grade of core concrete on ultimate load carrying capacity and ultimate stresses

Specimen Designation	Grade of core/ precast concrete (MPa)	Cross Sectional Area(mm ²)	Number of Layers	Ultimate Load (kN)	Percentage increase in load	Ultimate Stresses (MPa)
P-E-20/20-0	20/20	23554.83	0	713.19	-	30.27
P-E-40/20-0	40/20	23554.83	0	1014.8	42.29%	43.08
P-E-60/20-0	60/20	23554.83	0	1299.5	82.21%	55.17
P-E-20/20-1	20/20	23554.83	1	862.66	-	36.62
P-E-40/20-1	40/20	23554.83	1	1100.6	27.58%	46.72
P-E-60/20-1	60/20	23554.83	1	1469.5	70.35%	62.39
P-E-20/20-2	20/20	23554.83	2	1178	-	50.02
P-E-40/20-2	40/20	23554.83	2	1512	28.35%	64.19
P-E-60/20-2	60/20	23554.83	2	1743.4	48.00%	74.01
P-E-20/40-0	40/40	23554.83	0	879.94	-	37.36

P-E-40/40-0	40/40	23554.83	0	1167.4	32.67%	49.56
P-E-60/40-0	60/40	23554.83	0	1462.1	66.16%	62.07
P-E-20/40-1	20/40	23554.83	1	1103.1	-	46.83
P-E-40/40-1	40/40	23554.83	1	1335.3	21.05%	56.69
P-E-60/40-1	60/40	23554.83	1	1589.6	44.10%	67.48
P-E-20/40-2	20/40	23554.83	2	1374.5	-	58.35
P-E-40/40-2	40/40	23554.83	2	1626.7	18.35%	69.06
P-E-60/40-2	60/40	23554.83	2	1856.2	35.05%	78.8
P-E-20/60-0	20/60	23554.83	0	1204.6	-	51.14
P-E-40/60-0	40/60	23554.83	0	1333.4	11%	56.6
P-E-60/60-0	60/60	23554.83	0	1623.5	35%	68.92
P-E-20/60-1	20/60	23554.83	1	1254.3	-	53.25
P-E-40/60-1	40/60	23554.83	1	1477.9	18%	62.74
P-E-60/60-1	60/60	23554.83	1	1722.8	37%	73.14
P-E-20/60-2	20/60	23554.83	2	1558.3	-	66.16
P-E-40/60-2	40/60	23554.83	2	1766.5	13%	74.99
P-E-60/60-2	60/60	23554.83	2	1986.7	27%	84.34

From Table 8 the ultimate loads of columns specimens tested keeping concrete grade constant and varying grade of precast segments (M20, M40 and M60) and each group wrapped with 0, 1 layer and 2 layer of FRP. The ultimate load carrying capacity columns in group are compared with respect to column without precast segments. From this it can be observed that as the precast segment compressive strength increases the load carrying capacity of columns increases. But this increase is found to be less for columns with higher grade of Concrete. Similar behaviour is observed FRP wrapped column specimens also.

The presented Table 9 provides the ultimate load capacities and ultimate stresses of various specimens along with the corresponding specimen designations. To understand the percentage increase in load-bearing capacity for each configuration in relation to the baseline precast elliptical column (P-E-20/60-0), it is observed that the precast elliptical column P-E-20/60-1 demonstrated a notable increase of approximately 4.13%, while P-E-20/60-2 exhibited increases of around 29.34%. From this it can be observed that as the precast segment compressive strength increases with number of CFRP layers the load carrying capacity of columns increases.

Table 8. Effect of grade of precast segment on ultimate load carrying capacity and ultimate stresses

Specimen Designation	Grade of core concrete	Grade of precast concrete (MPa)	Cross Sectional Area(mm ²)	Number of Layers	Ultimate Load (kN)	Percentage increase in load	Ultimate Stresses (MPa)
R-20-0	M20	-	15000	0	697.98	-	46.532
P-E-20/20-0		20	23554.83	0	713.19	2.18%	30.27
P-E-20/40-0		40	23554.83	0	879.94	26.06%	37.36
P-E-20/60-0		60	23554.83	0	1204.60	72.58%	51.14
P-E-20/20-1		20	23554.83	1	862.66	23.59%	36.62
P-E-20/40-1		40	23554.83	1	1103.1	58.04%	46.83
P-E-20/60-1		60	23554.83	1	1254.30	79.70%	53.25
P-E-20/20-2		20	23554.83	2	1178	68.77%	50.02
P-E-20/40-2		40	23554.83	2	1374.5	96.93%	58.35
P-E-20/60-2		60	23554.83	2	1558.30	123.25%	66.16
R-40-0	M40	-	15000	0	1002.10	-	66.8

P-E-40/20-0		20	23554.83	0	1014.8	1.26%	43.08
P-E-40/40-0		40	23554.83	0	1167.4	16.49%	49.56
P-E-40/60-0		60	23554.83	0	1333.40	33.06%	56.6
P-E-40/20-1		20	23554.83	1	1100.6	9.82%	46.72
P-E-40/40-1		40	23554.83	1	1335.3	33.25%	56.69
P-E-40/60-1		60	23554.83	1	1477.90	47.48%	62.74
P-E-40/20-2		20	23554.83	2	1512	50.88%	64.19
P-E-40/40-2		40	23554.83	2	1626.7	62.32%	69.06
P-E-40/60-2		60	23554.83	2	1766.50	76.27%	74.99
R-60-0	M60	-	15000	0	1230	-	82
P-E-60/20-0		20	23554.83	0	1299.5	5.65%	55.17
P-E-60/40-0		40	23554.83	0	1462.1	18.86%	62.07
P-E-60/60-0		60	23554.83	0	1623.50	31.99%	68.92
P-E-60/20-1		20	23554.83	1	1469.5	19.47%	62.39
P-E-60/40-1		40	23554.83	1	1589.6	29.23%	67.48
P-E-60/60-1		60	23554.83	1	1722.80	40.06%	73.14
P-E-60/20-2		20	23554.83	2	1743.4	41.73%	74.01
P-E-60/40-2		40	23554.83	2	1856.2	50.91%	78.8
P-E-60/60-2		60	23554.83	2	1986.70	61.52%	84.34

Table 9. Effect of number of CFRP layers on behavior of columns retrofitted by precast segments and CFRP wrapping

Specimen Designation	Grade of core/ precast concrete (MPa)	Cross Sectional Area(mm ²)	Type of material	Number of Layers	Ultimate Load (kN)	Percentage increase in load	Ultimate Stresses (MPa)
P-E-20/60-0	20/60	23554.83	-	0	1204.60	-	51.14
P-E-20/60-1	20/60	23554.83	CFRP	1	1254.30	4.13%	53.25
P-E-20/60-2	20/60	23554.83	CFRP	2	1558.30	29.34%	66.16
P-E-40/60-0	40-60	23554.83	-	0	1333.40	-	56.61
P-E-40/60-1	40-60	23554.83	CFRP	1	1477.90	10.84%	62.73
P-E-40/60-2	40-60	23554.83	CFRP	2	1766.50	32.5%	74.99
P-E-60/60-0	60-60	23554.83	-	0	1623.50	-	68.93
P-E-60/60-1	60-60	23554.83	CFRP	1	1722.80	6.11%	73.14
P-E-60/60-2	60-60	23554.83	CFRP	2	1986.70	22.37%	84.34

CONCLUSIONS

Finite Element models were employed to simulate the behaviour of columns, strengthened through shape modification by precast segments using CFRP wrapping. These models were subsequently subjected to axial loading conditions for analysis. The effect of strengthening with 0,1 and 2 CFRP layers, considering variations in core concrete grade of M20, M40, M60 in relation to Precast grade of M20, M40 and M60 were investigated. The subsequent findings are outlined as follows:

- From the Finite Element results it is observed that in case of CFRP wrapped columns as the core concrete grade increases, ultimate load carrying capacity of the column increases. However, the CFRP efficiency of columns with lower core concrete compressive strength is more, as core concrete undergo more dilation, hence CFRP confinement will be more active and effectively utilized.
- From the present Finite Element results, it can be observed that as the compressive strength of precast segment increases the load carrying capacity of columns increases. But this increase is

found to be less for columns with higher grade of Concrete because the ultimate strain of higher grade of concrete is less, hence the failure occurs early stage. Similar behaviour is observed FRP wrapped column specimens also.

- From the results it can be observed with number of CFRP layers the load carrying capacity of columns increases. The percentage increase in the load carrying capacity with number of layers is lesser columns with higher grade concretes compared to that of lower grade of concrete.
- The increase in the stiffness is found be more for columns with precast segments having 40 MPa and 60 MPa compressive strength compared to that having 20 MPa.
- With increase in the grade of core concrete the stiffness of the column increases, in combination with higher grade of precast segments the stiffness enhancement is even higher. However, the deformation at failure loads is more for columns with lower grades of concrete which is indication of higher ductility for columns with lower grade.
- With increases in the number of CFRP layers the stiffness of the specimens increases irrespective of grade of core and precast segments.

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