Numerical Modeling and Comparison of Precast Column to Column Connections

Vismay Nair, S Maheswaran, V Ramesh Kumar, Bharathi Raj

Abstract--Precast construction technology takes advantage of controlled manufacturing of structural elements with superior quality and which is why they are mostly adopted recently in constructions such as roof, slabs, beam, column, even the stairs etc. These elements are connected to themselves and/or each other by means of suitable connections. Columns in the buildings play an important role in transferring both the gravity and lateral loads. Since column being vertical member, the effect of out of straightness and sway have adverse effects in the load carrying capacity of column, so it should be carefully erected and connected. Due to limited availability of span for precast elements, multiple units have to be connected in order to attain required height of the structure. Precast Concrete Institute (PCI) has suggested some column-column connections which can be used for precast construction. The PCI has suggested this type of bolted/welded connections, because of their ease of installation and consumption of less erection time compared to grouted connection. The current study covers such precast columns with mechanical connections modeled and compared with the monolithic reinforced concrete column model under compression in finite element software (ABAQUS). The study shows efficiency of the connections to transfer forces as compared to monolithic RCC column.

Index Terms— precast column, column to column connection, prefabrication, numerical modeling, dry connection, axial behavior, moment behavior

1 INTRODUCTION

Precast construction is one of the emerging technologies used in construction fields nowadays. The idea of precast construction evolves from the difficulties faced in conventional concrete construction method, which takes so much of time for completion [1],[9]. Precast construction method mainly consists of assembling the structural elements (manufactured in precast elements factory) in the construction site [2]. From conventional concrete building construction, the precast construction is having advantages such as reduced construction time, less requirement of labors, controlled quality of structural elements etc. These advantages make it more comfortable for engineers than conventional concrete construction method [3]. One of the most important factor considered in this construction method is nothing but the connections used in this system. Since each elements are connected by means of a suitable connections according to the force transferred, the integrity of structure depends upon the connections mainly [2],[7]. Individual elements itself have to be connected together because of their limited availability of length. Columns, which play a vital role in imparting structural stability, are also erected using some precast column-column connections in cases where the available length do not meet the required length of column in site. Despite of all the advantages precast construction having and its vast scope in construction area, the studies of precast connections are very less in experimental point of view and much lesser in numerical point of view.

2 OBJECTIVE

The main objective of this conference paper is to compare the effectiveness of force transfer of different precast column connection proposed by Precast Concrete Institute with a monolithic reinforced concrete column in terms of axial load using FEA

The conference paper also gives an introduction to idea of precast construction technology to the audience. Apart from the conventional concrete construction process, the engineers can be made aware of this emerging construction technology.

3 COLUMN CONNECTIONS

Details of the column connections suggested in PCI manual [11] which has been modeled in the current study, are discussed in the below section.

Column connection CC1

This connection consists of flush or slightly undersized base plate with four corner pockets. and nuts apart fom monolithic RCC column. The fig.1.(a) shows schematic diagram of elevation and sectional plans of column CC1. Each column part(upper and lower column parts which are connected by means of the connection) is having metal plate at on of its end face. The lower column has metal plate with rebars protruding through it at its upper face. The upper column is having metal plate attatched to its bottom face (by welding reinforcement bars to the plate) and will be erected over the lower column such that the rebars from lower column also passes through metal plate on upper column. Then the bars are bolted at end. The axial load applied on the column top face. The upper concrete column part will transfer this load to the metal plate attached to it. The corner portion of metal plates occupies the rebars, which are bolted to them. Through metal plates and rebars bolted to them, the load is transferred to the lower column part.The free body diagram of the column is as given in fig.1.(b)

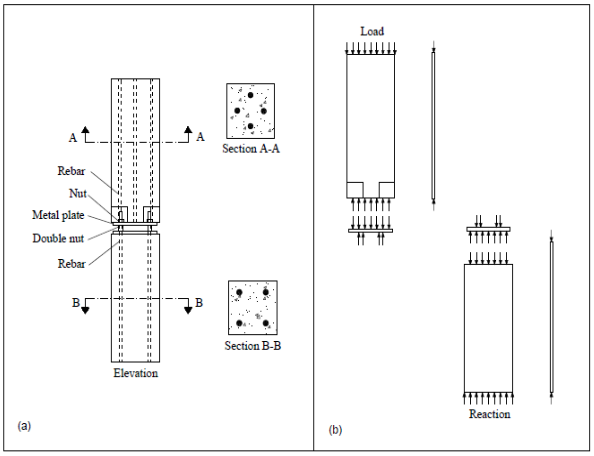

Figure 1: (a) Schematic diagram of model CC1 (b) Free body diagram for column CC1

Colum connection CC2

This connection is similar to connection CC1. It has flush or slightly undersized base plate with four side pockets, along with nuts. The column parts having metal plates attached to their faces, are erected one over the other. Reinforcement bars from lower column projecting through both metal plates are provided with nut at the ends. Fig.2.(a) shows the detail of this type of connection.This column also transfers load as done by CC1. The corners of upper metal plate will have more stress than center portion. Load transferred to the lower metalplate will be distributes to the lower column part. Free body diagram of this connection is as given in fig.2.(b)

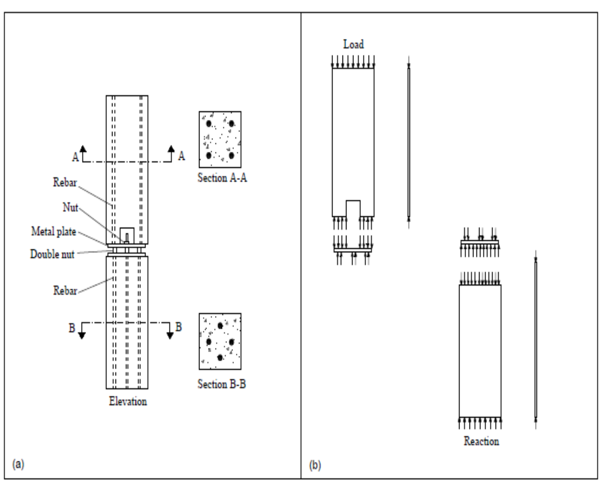

Figure 2: (a) Schematic diagram of model CC2 (b) Free body diagram for column CC2

Column connection CC3

This connection consists of a simple tube connecting lower column and upper column. A tube of fixed length will be projecting from lower column.The upper column will be erected above this and tube will be grouted if required. The tube consists of two portions, each to be accomodated by either of lower or upper column. Fig.3.(a) gives an idea of this type of connection. The transfer of load takes place from upper column to the lower column by direct contact. The tube inserted in between the lower and upper column parts provides the stability to the upper column part, while it transfers the load to the lower column part. Fig.3.(b) shows free b ody diagram of this column.

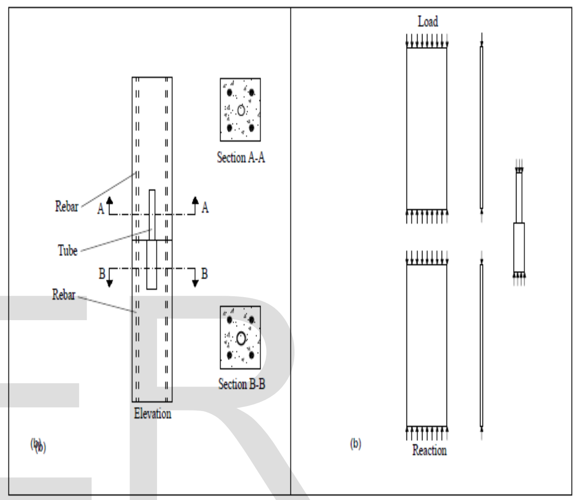

Figure 3: (a) Schematic diagram of model CC3 (b) Free body diagram for column CC3

4 NUMERICAL MODELING

4.1 Specimens

A monolithic RCC column taken from (W. Li, 2019) [10] and the columns with mechanical connections provided by PCI manual were modeled. The RCC column is of 150 x 150 x 2180 mm size. Simulation was performed using available commercial FE tool, Abaqus. Material models available in Abaqus were used to define concrete and steel. Elasticity and concrete damage plasticity model were used for concrete whereas elastic and plasticity properties were used for steel for defining their material properties. C0, which represents monolithic RCC column, is kept as reference. CC1, CC2 and CC3, are the columns which contains the connections specified in PCI manual. Fig.4 shows the columns C0, CC1, CC2, CC3. All the models have same length and material properties. They were compared on basis of axial load v/s displacement.

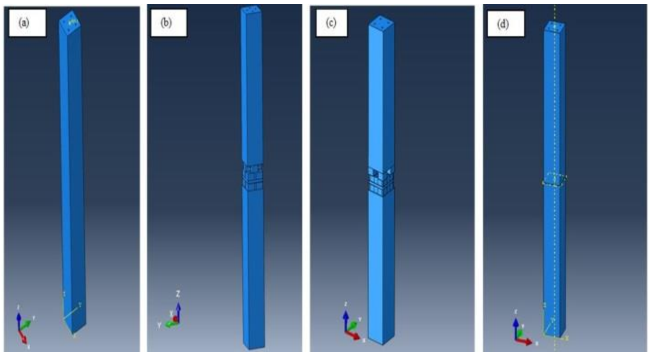

Figure 4: Assembled view of column models (a)without connection-C0 (b)CC1 (c)CC2 (d)CC3

4.2 Assembly of models

The more detailed view of connections used in the column models is as shown in fig.5. The figure shows the model without concrete part in case of CC1 and CC2. Whereas, for CC3 the upper column part has been hidden to show the tube projecting from lower column

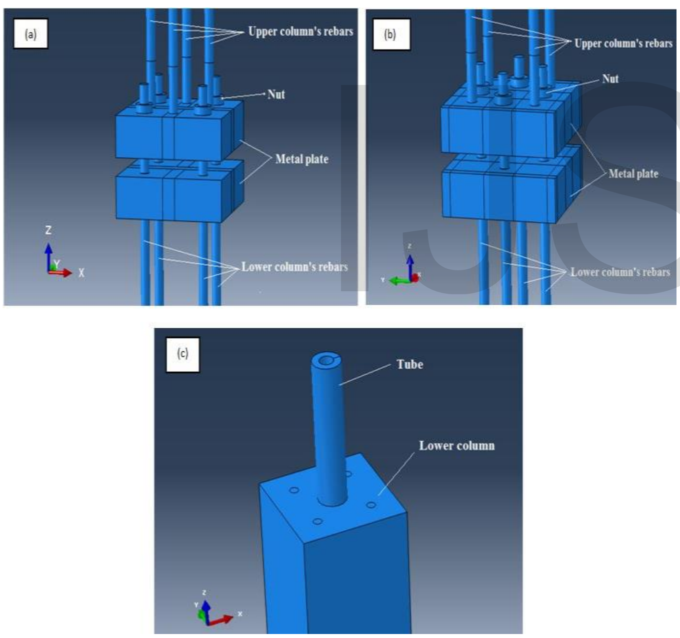

Figure 5: Detailed view of Connection region (a)CC1 (b)CC2 (c)CC3

4.3. Meshing of models

The parts were meshed using 8 noded brick element with reduced integration point(C3D8R). Suitable partitions were made in parts in order to reduce the mesh transitions. Mesh control is also used to further reduce mesh transitions. Typical meshing of column, metal plate, rebar, nut, tube is as shown in fig.6.

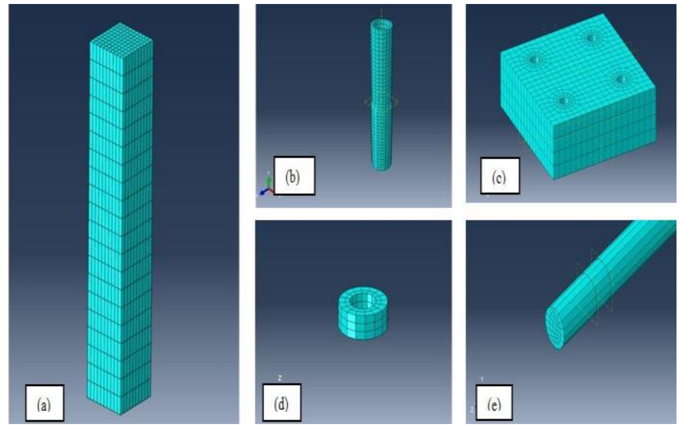

Figure 6: Meshing of (a) Column (b) Tube (c) Metal plate (d) Nut (e) Rebar

4.4 Material properties

The material properties assigned for steel and concrete are as shown in table1 and table 2 respectively. For steel, the elastic and plastic properties are given. The connection parts such as metal plates, nuts, tube etc. are assigned with material properties of Fe250 steel.

Table 1: Material property assigned for steel section

Rebar steel	
Elastic properties	
Young,s modulus (GPa)	Poisson's ratio
195	0.3
Plastic properties	
Yield stress (MPa)	Plastic strain
458	0
460	0.002041025
470	0.012246153
500	0.042861538
669.235	0.215568025
Connection steel	
Elastic properties	
Young,s modulus (GPa)	Poisson's ratio
210	0.3
Plastic properties	
Yield stress (MPa)	Plastic strain
250	0
251	0.00125
500	0.125

The plastic strain values of rebar section were calculated from the data given in journal. The graph used for calculating the strain values is as shown in fig.7. The plastic strain values to be given as input in Abaqus are obtained by calculating from the graph using the relation between plastic strain and elastic strain. The plastic strain is 0 at yield point (at stress = 458MPa). Plastic strain is nothing but the permanent strain measured in specimen after yield strain.

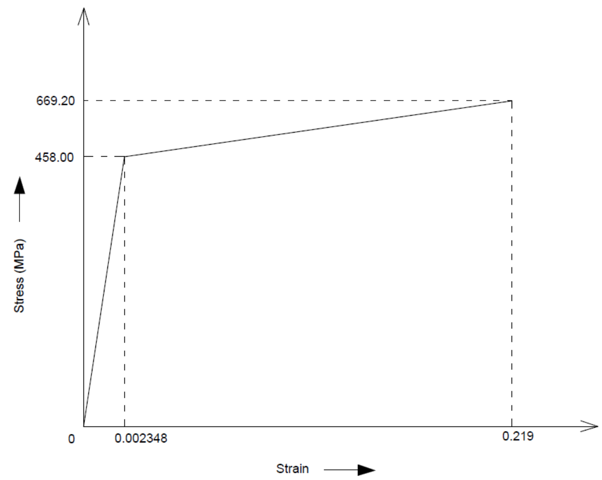

Figure 7: Stress vs strain graph for rebar steel section

The concrete damage parameters were taken according to Abaqus standard default [5] and values as mentioned in (M. Hafezolghorani,2017) [6]. CDP model is used in this analysis of columns.

Table 2: Material property assigned for concrete

Material parameter	M30	Plasticity parameters	
Concrete Elasticity		Dilation angle	31
E (GPa)	20.0	Eccentricity	0.1
		fb0/fc0	1.16
Poisson's ratio	0.2	K	0.667
		Viscosity parameter	0
Concrete compression behaviour		Concrete compression damage	
Yield stress (MPa)	Inelastic strain	Damage parameter (C)	Inelastic strain
15.3	0	0	0
19.2	4.82E-05	0	4.82E-05
22.5	0.000119844	0	0.00012
25.2	0.000214786	0	0.000215
27.3	0.000333074	0	0.000333
28.8	0.000474708	0	0.000475
29.7	0.000639689	0	0.00064
30	0.000828016	0	0.000828
29.7	0.001039689	0.01	0.00104
28.8	0.001274708	0.04	0.001275
27.3	0.001533074	0.09	0.001533
25.2	0.001814786	0.16	0.001815
22.5	0.002119844	0.25	0.00212
19.2	0.002448249	0.36	0.002448
15.3	0.0028	0.49	0.0028
10.8	0.003175097	0.64	0.003175
5.7	0.003573541	0.81	0.003574
Concrete tensile behavior		Concrete tension damage	
Yield stress (MPa)	Cracking strain	Damage parameter (T)	Cracking strain
3	0	0	0
0.03	0.001167315	0.99	0.001167

4.5 Interactions provided

After assembling each of the parts to their respective positions, the interactions are assigned. Interactions mainly given are surface to surface contact, tie constraints, and embedded constraint. Usual surfaces in contact such as metal plate to column, rebar to metal plate, etc. are assigned surface to surface contact. Surface to surface contact properties were three types viz. steel-steel contact [4], steel-concrete contact [8], and concrete-concrete contact [10] which defined contact between steel and steel surface, concrete and steel surfaces, concrete and concrete surfaces respectively. Tie constraints were given to areas of weldings such as between rebar and metal plate surfaces. Embedded constraint was given to rebars in concrete region. The surface contact properties defined are as given in table.3.

Table 3: Interaction properties and details of interactions provided

Interaction Properties					
Steel to steel contact		Concrete to steel contact		Concrete to concrete contact	
Normal behavior	Tangential behavior	Normal behavior	Tangential behavior	Normal behavior	Tangential behavior
Hard contact	Penalty with friction coefficient of 0.65	Hard contact	Penalty with friction coefficient of 0.57	Hard contact	Penalty with friction coefficient of 0.4

Table 4: Surfaces on which interactions are provided

Interactions provided					
	Metal plate-Column	Metal plate-Nut	Metal plate-rebar	Grout-Metal plate	Rebar-Nut
Master:	Column	Nut	Metal plate	Grout	Nut
Slave:	Metal plate	Metal plate	Rebar	Metal plate	Rebar

In Abaqus, the loadings are done in steps. So to define a load, first it is required to define a step in which it will be applied. A static general procedure was adopted for step definition. In this step only, the loading will be propogated. Abaqus by default has an initial step in which the boundary conditions for column were applied. A pressure load of 35N/mm2 was applied in loading step.

5 OBSERVATIONS

In case of monolithic column, the damage in concrete was mostly seen near to top and bottom faces as shown in fig.9. At these regions itself, the rebars were experiencing maximum stresses which can be seen in fig.10.

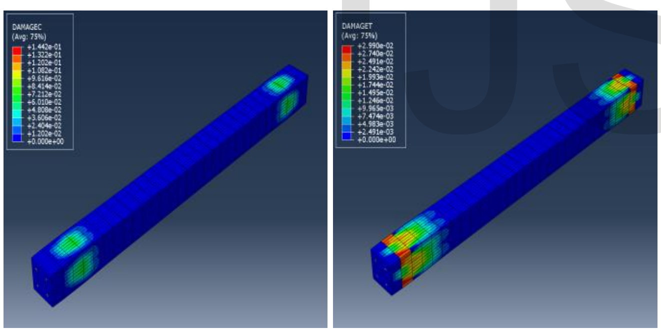

Figure 9: Compression damage and tension damage profile in concrete material of C0

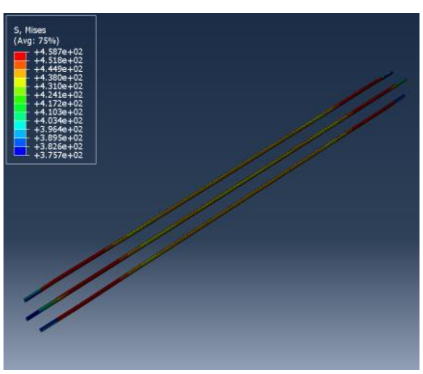

Figure 10: Stress profile in steel reinforcement bars

Same is the case with all models. The damage was mostly seen at places were the steel reinforcement experienced larger stress. The strain profile in models of CC1, CC2, CC3 are as shown in fig.11. The area with high strain was having rebar portions with high stress. The concrete touching with metal plate experienced high strain because of load transfer in case of CC1 and CC2. For CC3, more strain was at bottom of steel tube region, which could be due to presence of steel tube only.

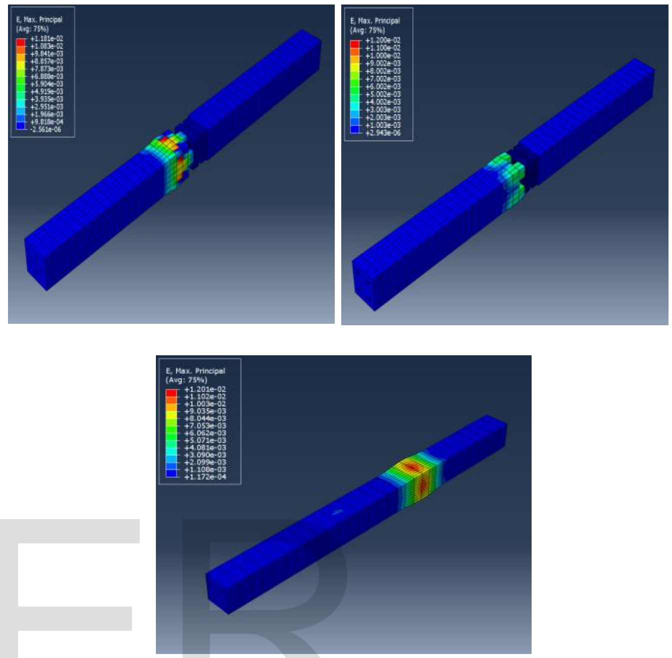

Figure 11: Strain profiles for connection models CC1, CC2, CC3

6 RESULTS

The models were compared on axial load vs displacement graph. Fig.8 shows the graph of axial load vs displacement of the models. The monolithic RCC column could take higher load than all others which had connections. The model CC3 showed a better performance as compared to connection CC1 and CC2.

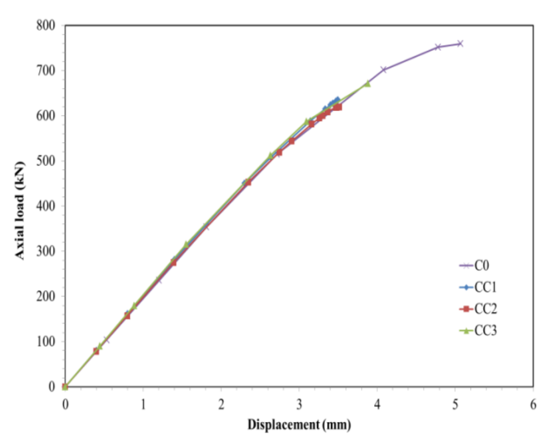

Figure 8: Axial load vs Displacement graph for monolithic RCC column and that with different column connections

6 SUMMARY AND CONCLUSIONS

As it is seen that the monolithic rcc column could take more load than that of all other models with precast connection. This indicates that introduction of connections affects the performance of column. Eventhough the time and materials can be saved by adopting precast construction technology, proper care has to be given for connection design and erection of components while assembling. From the fig.7, it is understood that the connection model CC3 could take more axial load than CC1 and CC2. The complexity of connections in case of CC1 and CC2 can be the reason for this. Following are the summary and conclusions made from current study..

- Study on precast column connections is very few.
- Introduction of connections reduces the load carrying capacity of the column.
- Connections' introduction does not affect the elastic behavior of column much.
- All models with precast connections could take approximately 85-90% of load taken by monolithic specimen.
- Connections have to be designed and implemented properly in order to perform well.

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