Finite Element Analysis of Progressive Collapse on Precast Beam-Column Assembly

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***Abstract*— Precast buildings are extremely vulnerable to progressive collapse compared to reinforced concrete buildings due to lack of structural continuity. Progressive collapse is the spread of initial local failure from element to element which result in the collapse of an entire structure or disproportionately a large part of it. The goal of this study is to develop a finite element model for a precast beam-column assembly using ANSYS 19.0 software and compare it with a monolithic concrete frame under progressive collapse. The beam column connection consists of a demountable joint which comprises of a corbel rebar grouted with the beam.**

Keywords*— *Progressive collapse, finite element analysis, precast beam-column, demountable joints

I. INTRODUCTION

Progressive collapse is an event caused from the failure of one or more structural components due to design mistake, faulty construction or abnormal loadings such as internal gas explosions, blast, aircraft impact, vehicular collision, earthquake etc. It is one of the disastrous building failures, most often leading to possible loss of life, multiple injuries, and costly damages. For the past few decades there are many events of progressive collapse in the world such as the Ronan Point apartment tower collapse in England (1968), The Murrah Federal Office Building collapse in Oklahoma City (1995), The World Trade Center collapse in 2001[2] are few among them. .These incidents show that buildings are vulnerable to progressive collapse. But compared to reinforced concrete structures precast structures are vulnerable to progressive collapse due to lack of redundancy in the load transfer path and continuity of structures.

II. EXPERIMENTAL STUDY

To achieve the objective of this study, experimental test results need to be accessed for calibration purpose of finite element models. For this purpose a precast beam-column assembly which has been tested previously by Al-Salloum et al.[1] for progressive collapse under middle column removal scenario is used.

A. *Test specimen details and assembly*

The test frames were designed to be a half-scale of a two- bay prototype perimeter frame that was assumed to be a part of an existing RC building in Saudi Arabia. The test specimen consist of two specimens, the first one is (PC-C) which is a precast concrete control specimen and most common type of existing precast beam-column connection in Saudi Arabia. The second specimen is (MC-SMF) monolithic concrete special moment frame with continuous top and bottom beam rebars through the joint region.

The assembly consist of a two-bay beams and three columns. The geometric properties of the prototype frames are given in table 1. The beam and column were 350 mm size square cross-section. The corbel section was 350 × 250 mm and the column height was 1070 mm up to the soffit of the beam. The shear reinforcement in the beam was in the form of two legged stirrups of 8 mmϕ rebars provided at a spacing of 100 mm center-to-center.

The longitudinal reinforcement of the column consists of 8numbers of 16mmϕ rebars. 8 mmϕ ties were provided at a spacing that varied along the column height as shown in Fig. 1. The beam-column joint consisted of a 16 mmϕ rebar which protrude from the corbel. A circular hole of 60 mm diameter was provided at the beam ends for the corbel rebar to pass and finally grouted. A 20 mm thick neoprene pad was used to support the beam on the corbel. A non-shrinkable cementitious mortar was used for grouting hole with the corbel rebar. The members in the test frame of MC-SMF were same as that of PC-C frame, except that of corbels. The reinforcement detailing of MC-SMF specimen was also the same as PC-C specimen except that the bottom and top longitudinal beam rebars were continuous over the middle column.

B. *Properties of materials*

The test specimens were casted with ready mix concrete of compressive strength 37.3 MPa as per the ASTM C39/C39M. The tensile test for steel was carried out according to ASTM E8/E8M and the yield strength for steel rebars were 525 and 526 MPa for 8mmϕ and 16mmϕ bars respectively. However the average value of tensile strength was 550MPa and 651 MPa for 8mmϕ and 16mmϕ barsrespectively.

C. *Loading*

For the simulation of progressive collapse under a column removal scenario the support of the middle column was removed and a dynamic load was applied by an actuator of

TABLE 1: GEOMETRIC PROPERTIES OF TEST SPECIMENS

Type	Beam net span(mm)	Beam size(mm)		Column size(mm)	Corbel size(mm)	Type of connection
		Depth	Width			
Specimen PC-C	2650	350	350	350x350	350x250	Precast with grouting of corbel rebar
Specimen MC-SMF	2650	350	350	350x350	-	Monolithic

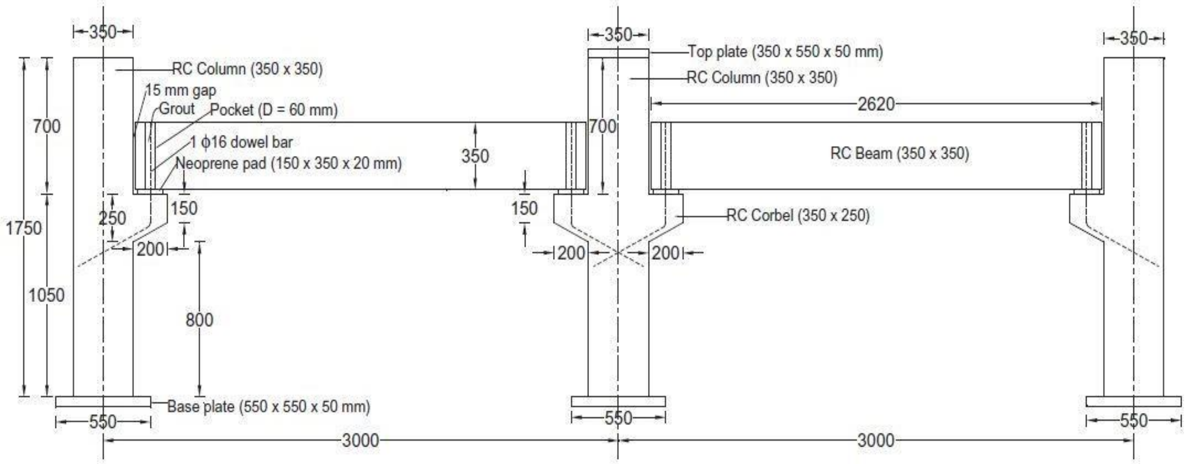

Fig 1: Details of monolithic specimen MC-SMF [1]

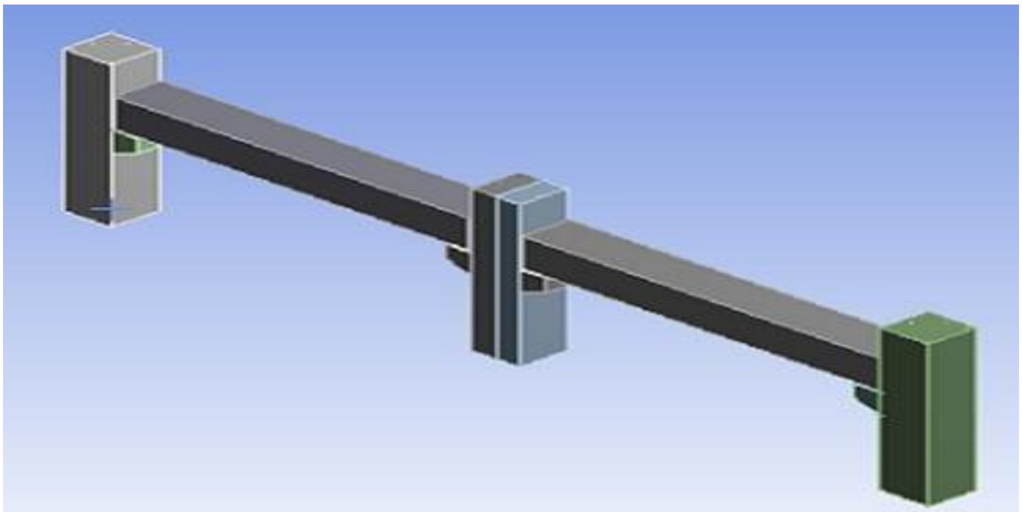

Fig 2: Finite element modeled beam-column assembly

1000 kN capacity in the experimental set up. But as the ultimate load capacity of the specimen is unknown a displacement controlled loading was adopted for middle column. The loading was done at a rate of 100 mm/s which is low compared to actual progressive collapse scenario. The loading rate of 100 mm/s was the maximum possible for the actuator as the inertial effects in the actual scenario is very large which cannot be generated in the experimental set up.

III. FINITE ELEMENT ANALYSIS

Finite element analysis is a numerical method of investigation used to solve problems in engineering needing special analysis. In this study finite element analysis has been carried out using ANSYS 19.0 package to predict the behavior of precast beam-column assembly and compared with the experimental data. Static structural tool in ANSYS Workbench was used in the modeling procedure.

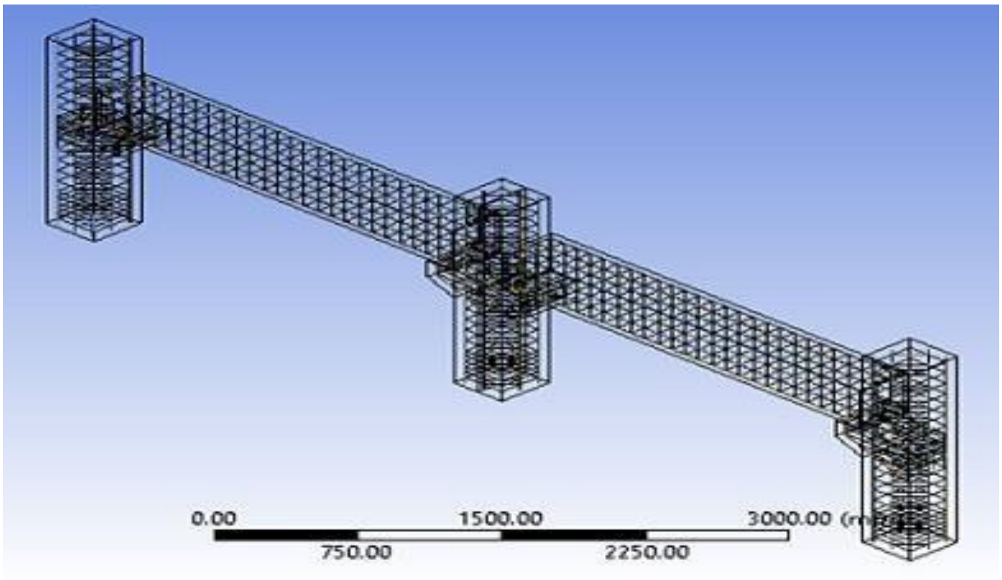

Fig 3: Reinforcement modelling

FEA comprises of three steps to solve the problem. They are pre-processing, solution and post-processing. Pre- processing includes modeling using design modeler, material properties, element type meshing and cross section details (used for 1D analysis only). The solution stage consists of applying boundary condition, support, loading and finally solving. Post processing which is the output phase consists of graphs, tables, and report generation.

The material properties used in the FE modeling were fromthe experimental data used.

A. *Modes of failure*

The modes of failure for the test specimen are shown in fig
4. Failure of the PC-C specimen was due to rotation of the beam ends until the interior ends come in contact with the middle column and the ultimate mode of failure was due to concrete crushing at the interior location of beam-column connection. The rotation was due to the simulation of hinge behavior as the neoprene pad in the beam end allows free rotation.

B. *Load displacement characteristics*

The result of the specimen from experimental and finite element analysis are shown in table 2.

From the experimental study it was found that the peak loadresisted by the PC-C specimen is 12.8 kN for a middle column displacement of 145mm mm whereas for MC-SMF specimen it was 228 kN for a middle column displacement of 144 mm which is about 17.8 times higher than that of PC-C specimen. Hence it can be inferred that PC-C specimen that is precast concrete buildings are extremely vulnerable to progressive collapse in the event of a supporting column loss scenario.

From analytical study conducted by FEA on precast beam column assembly the results obtained are the peak load attainedby PC-C specimen is 11.76 kN for a middle column displacement of 146.99 mm. The analytically obtained results go well with the experimentally obtained results. There is a variation of about 8.125% in peak load obtained for PC-C specimen and a variation of about 1.37% for middle column displacement corresponding to peak load.

Both experimental and analytical studies suggest that precast concrete buildings are very weak in resisting loads at the event of column loss and are severely vulnerable to progressive collapse. Hence proper mitigation strategies must be adopted to strengthen the precast structures. The main vulnerability is caused due to lack of continuity of rebars in the beam-column joint and lack of alternate load paths. Hence strengthening of beam-column joints by alternate strengthening methods needs to be done.

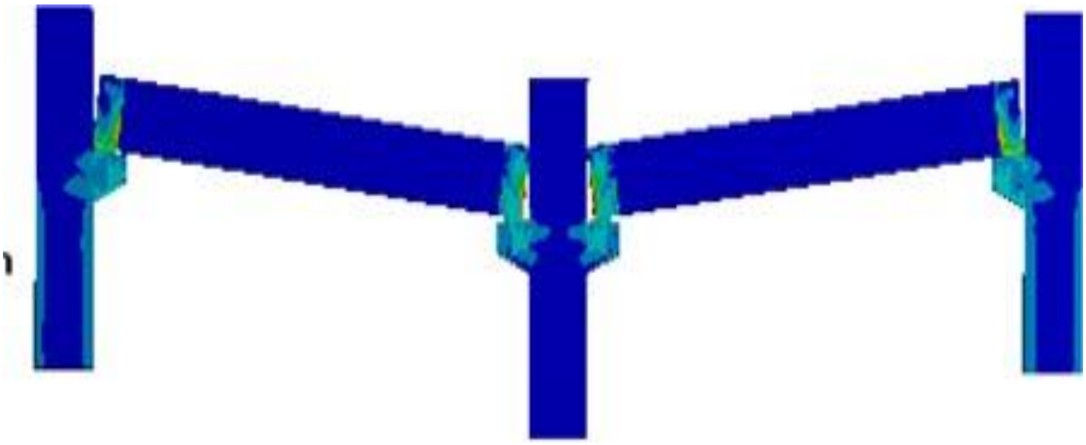

Fig 4: Final deformed shape of PC-C specimen by FEA

TABLE 2: RESULTS OF FEA

Properties	**FEA**	**Journal**	**Variation%**
Peak load	11.76 kN	12.8 kN	8.125%
Middle column displacement at peak load	146.99mm	145mm	1.37%

IV. CONCLUSIONS

- Analytical investigations on precast beam-column assembly shows that precast specimen can resist a peak load of 11.76 kN whereas for monolithic specimen it is 228 kN which is 19.3 times greater compared to precastspecimens.
- Precast specimens are extremely vulnerable to progressive collapse in the event of loss of a structural member.
- The vulnerability is caused due to lack of continuity of rebars in beam-column joint. Hence alternate load paths do not exist to transfer the loads in the event of loss of structural members like columns.
- Strengthening of precast beam-column joint is the only solution to mitigate progressive collapse event.
- Strengthening methods for progressive collapse mitigation like strengthening using steel plates by bolted or welded connections can be adopted.

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