Research Article

# Comparative study of dry, wet and monolithic precast beam-column connections under progressive collapse mechanism

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**Abstract:**

In any RCC & steel structures, connection plays a vital role, as they transfer forces from one element to another. The main objective of this study is to investigate the analytical behavior of precast beam-column connections under progressive collapse scenario. This paper comprises of one precast wet connection, one precast dry connection and one monolithic specimen. Reduced 1/3rd scaled precast beam-column connections were used for the analysis using ABAQUS software. Results are obtained in terms of load carrying capacity and vertical deflection. It is observed from the results that load carrying capacity of dry connection is higher than wet connection and monolithic connection.

**Keywords:** Finite Element Analysis, Abaqus, Monolithic Connection, Precast Wet Connection, Precast Dry Connection.

## INTRODUCTION

The Finite Element Method (FEM) is a numerical method to obtain solutions of boundary value problems which consists of partial differential equations. FEM is also helpful in engineering and mathematical physics to solve complicated problems including complicated geometries, loadings and material properties. ABAQUS is one of the most broadly used FEA tool, used in structural, mechanical and aerospace engineering industries. ABAQUS is absolute software which provides simple and consistent interface for analysis and is also known for its quality, performance and ability to solve problems through numerical replication. Both linear and non-linear analysis can be performed using ABAQUS [1].

In Present Study, three 1/3$^{rd}$ scale specimens, consisting of two end columns, two beams and one middle removal column are used for analysis which is proposed from G+5 storey building [2]. All the connections are modeled using ABAQUS software. A C3D4, 4-Node tetrahedron type of element is used for concrete and T3D2, 2-Node 3D Truss element is used for reinforcement. Loading is applied in the form of displacement at the top of the middle column and analysis is carried out. Results are validated with Experimental results in terms of displacement and load carrying capacity.

## FINITE ELEMENT ANALYSIS

Finite Element method is used to study non-linear behavior of beam-column connection and analysis is performed in ABAQUS/Standard.

***Material Properties and Geometry***

***1. Concrete***

Concrete is widely used material in construction industries. Concrete is made up of different ingredients like aggregates, cement, construction chemicals etc. so the property of concrete is varying in nature. Generally, concrete is strong in compression and weak in tension. Concrete part is defined as solid, homogeneous material for analysis. Solid concrete part is discretized into small 3-D element. The modulus of elasticity is 27286 MPa and poison's ratio is 0.2. Both properties are assigned in linear properties. Concrete Damage Plasticity is used to define the non-linearity in concrete.

*2. Steel*

Reinforcement bar and stirrups are defined as truss element in analysis. Reinforcement bars are assumed as embedded element in concrete and also assumed as linearly elastic material. T3D2, 2 node linear 3-D Truss in space element is used in ABAQUS. The modulus of elasticity is 200 GPa and poison's ratio is 0.3.

*Monolithic Connection*

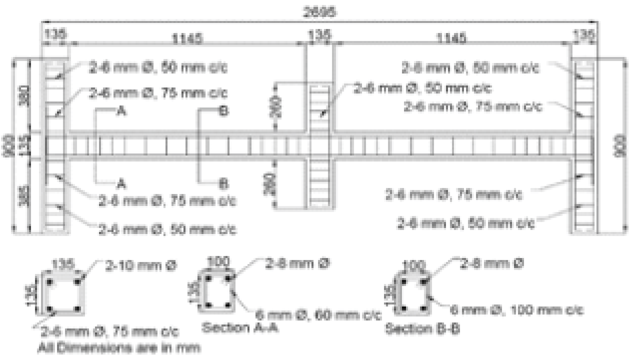
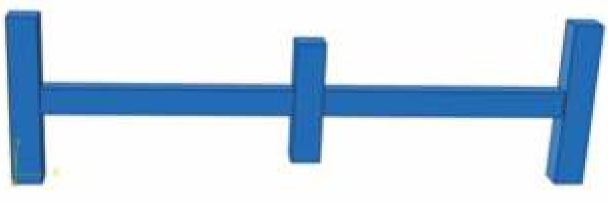



**Figure 1 Detailing of Monolithic Connection**

**Figure 2 Experimental Test Setup for Monolithic Specimen**

The reinforcement detailing of 1/3$^{rd}$ scale model is shown in Figure 1 and experimental test setup is shown in Figure 2 [2]. For the modeling of concrete section C3D4-linear Tetrahedron element is used and for reinforcement T3D2-Truss element is used. Embedded option from the Interaction module in ABAQUS is used for the interaction between steel and concrete. Model of monolithic connection and reinforcement cage is carried out in ABAQUS as shown in Figure 3.



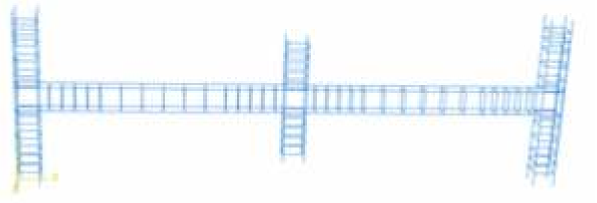


**Figure 3 Modeling of concrete section and Reinforcement**

To Simulate Actual boundary condition of experimental work, both the end columns are pinned at top and load is applied in the form of displacement i.e. 0.2 mm at the bottom of the end columns. 100 mm displacement is given at the top surface of the middle column as shown in Figure 4.

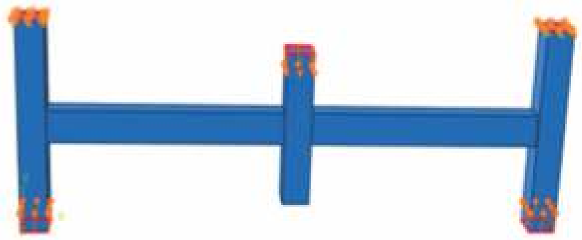


**Figure 4 Loading and Boundary Condition for Monolithic Connection**

*Meshing of model*

For meshing of monolithic connection, C3D8 Hexahedral element is used for concrete section and T3D2 Truss element is used for stirrups and steel bars. Figure 5 shows the details of meshing of monolithic frame.

*Precast Wet Connection*

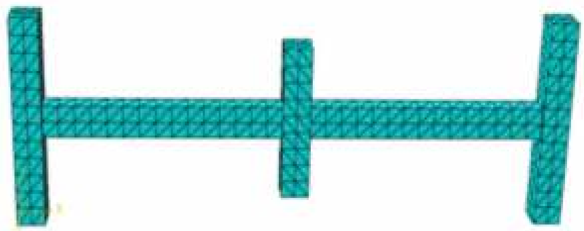


**Figure 5 Hexahedral Meshing of Concrete Section**

The reinforcement detailing of 1/3$^{rd}$ scale precast wet connection is shown in Figure 6.

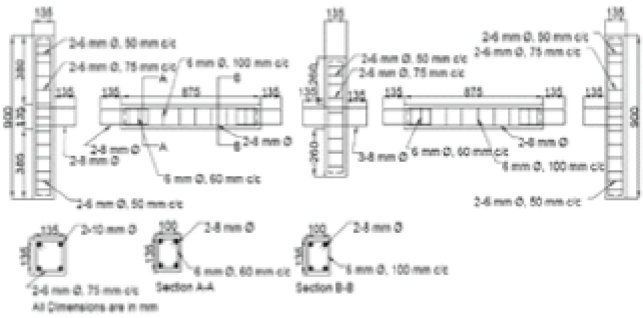


**Figure 6 Reinforcement Detailing of Precast Wet Connection**

**Figure 7 Experimental Test Setup for Precast Wet Connection**

Figure 7 shows the experimental test setup for precast wet connection [2]. The connection detailing of precast wet connection is shown in Figure 8. Model of precast wet connection and reinforcement cage is carried out in ABAQUS as shown in Figure 9.

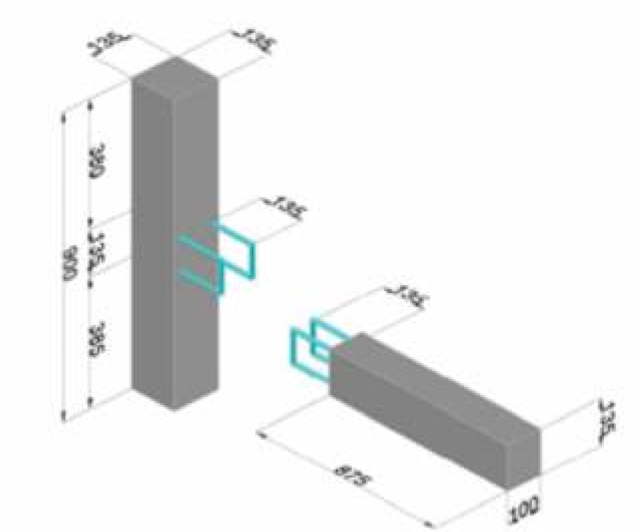



**Figure 8 Connection Detailing of Precast Wet Connection**

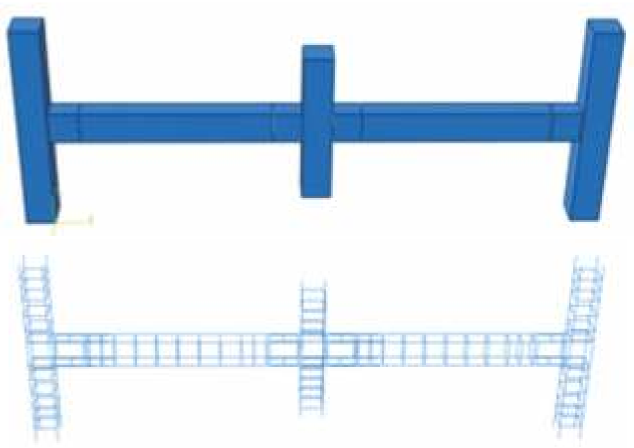


**Figure 9 Modeling of Precast Wet connection and Reinforcement**

Boundary conditions are applied according to experimental work as both the end columns are pinned at top and load is applied in the form of displacement i.e. 0.2 mm at the bottom of the end columns. 100 mm displacement is given at the top surface of the middle column as shown in Figure 10.

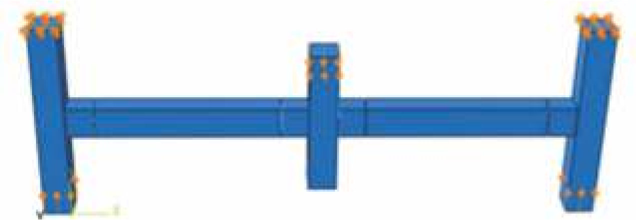


**Figure 10 Loading and Boundary Condition for Precast Wet Connection**

*Meshing of model*

Meshing used in precast wet connection is similar to that used in monolithic connection. Meshing of precast wet connection is shown in Figure 11.

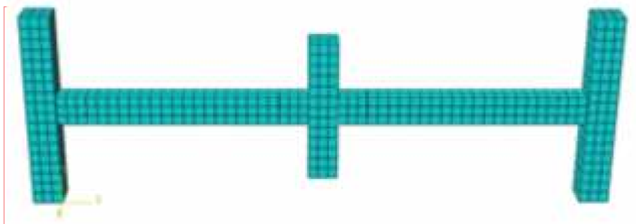


**Figure 11 Meshing of Precast Wet Connection**

*Precast Dry Connection*

The reinforcement detailing of 1/3rd scale precast dry connection is shown in Figure 12.

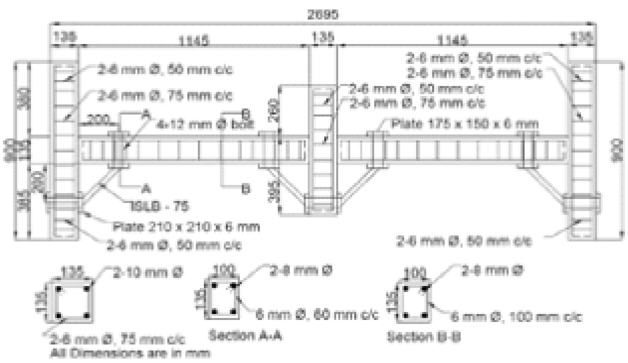



**Figure 12 Reinforcement Detailing of Precast Dry Connection**

**Figure 13 Experimental test setup for Precast Dry Connection**

Figure 13 shows the experimental test setup for precast dry connection [2]. The connection detailing of precast dry connection is shown in Figure 14. Model of precast dry connection and reinforcement cage is carried out in ABAQUS as shown in Figure 15.

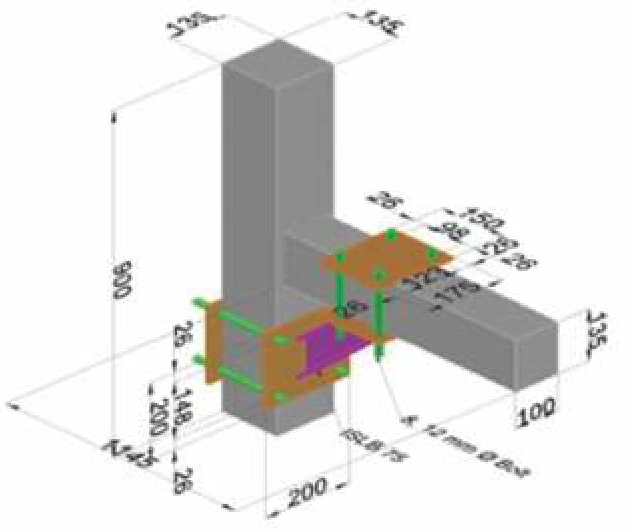



**Figure 14 Connection Detailing of Precast Dry Connection**

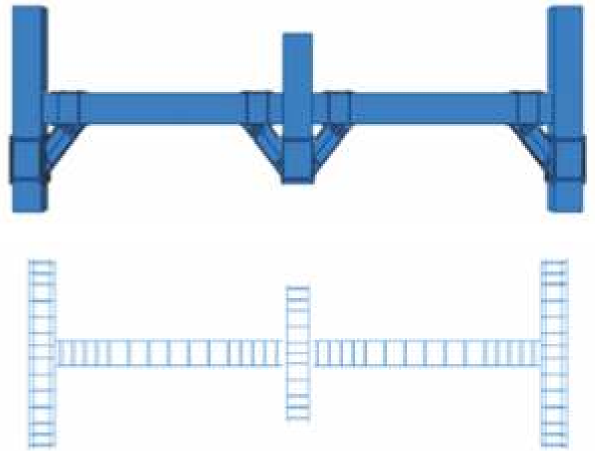


**Figure 15 Modeling of Precast Dry Connection and Reinforcement**

Boundary conditions are applied according to experimental work as both the end columns are pinned at top and load is applied in the form of displacement i.e. 0.2 mm at the bottom of the end columns. 100 mm displacement is given at the top surface of the middle column as shown in Figure 16.

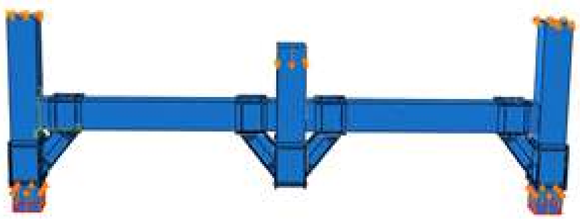


**Figure 16 Loading and Boundary Conditions for Precast Dry Connection**

### *Meshing of model*

Meshing used in precast dry connection is similar to that used in monolithic connection. Meshing of precast dry connection is shown in Figure 17.

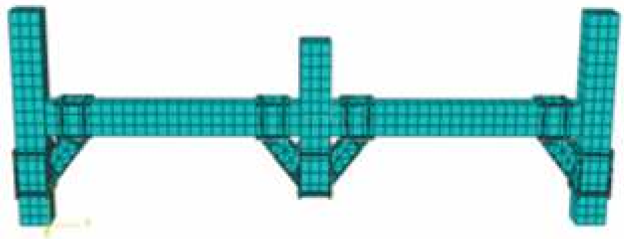


**Figure 17 Meshing of Precast Dry Connection**

## RESULTS AND DISCUSSION

Non-Linear Analysis is performed and results are carried out in terms of Load-Deflection for all the connections. Load is carried out from the reaction of columns and deflection is measured from bottom surface of the middle column. Figure 18, Figure 20 and Figure 22 shows the analysis result of monolithic connection, precast wet connection and precast dry connection respectively. Figure 19, Figure 21 and Figure 23 shows the load v/s deflection curves of monolithic connection, precast wet connection and precast dry connection respectively. Table 1, Table 3 and Table 5 shows the final values of load and deflection of FEM results and Experimental result of monolithic connection, precast wet connection and precast dry connection respectively. Table 2, Table 4 and Table 6 shows percentage difference in results of monolithic connection, precast wet connection and precast dry connection respectively.

### *Result Comparison*

In this section, results of monolithic connection, precast wet connection and precast dry connection are compared in terms of load deflection behavior and the curve shows quite similar results for both monolithic connection and precast wet connection but load carrying capacity and deflection of precast dry connection is higher than both monolithic connection and precast wet connection as shown in Figure 24.

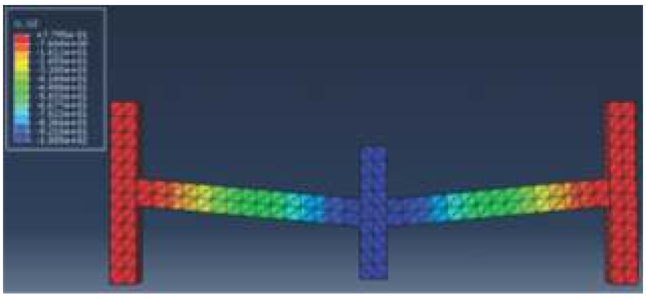


**Figure 18 Analysis Result of Monolithic Connection**

**Table 1 Result Comparison of Monolithic Connection**

| Monolithic Connection | | | |
|---|---|---|---|
| EXPERIMENTAL | | ANALYTICAL | |
| Load (kN) | Deflection (mm) | Load (kN) | Deflection (mm) |
| 0 | 0 | 0 | 0 |
| 2 | 4.5 | 2 | 3.48 |
| 4 | 10.2 | 4 | 10.35 |
| 6 | 13.2 | 6 | 13.74 |
| 8 | 18.7 | 8 | 18.19 |
| 10 | 24.5 | 10 | 25.17 |
| 12 | 28.4 | 12 | 29.02 |
| 15 | 37.5 | 14 | 37.97 |
| 16 | 55.5 | 16 | 56.18 |
| 17 | 68.1 | 17.6 | 68.9 |
| 16 | 99.4 | 18 | 100.46 |

**Table 2 Percentage Difference in Result of Monolithic Connection**

| | EXP | FEM | Difference |
|---|---|---|---|
| Load (kN) | 17 | 18 | 5.88% |
| Deflection (mm) | 99.4 | 100.46 | 1.06% |

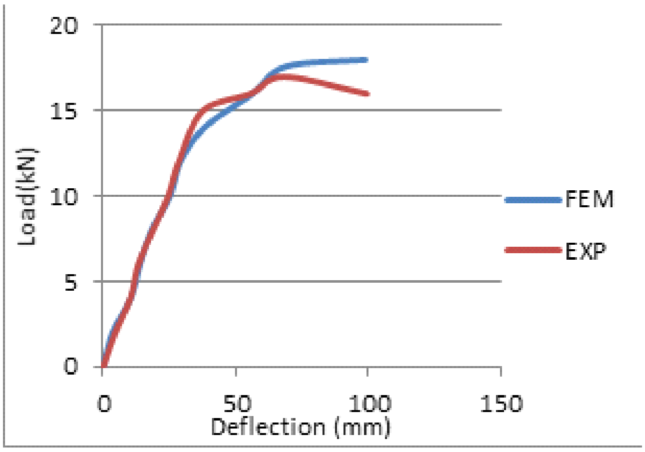



**Figure 19 Load v/s Deflection of Monolithic Connection**

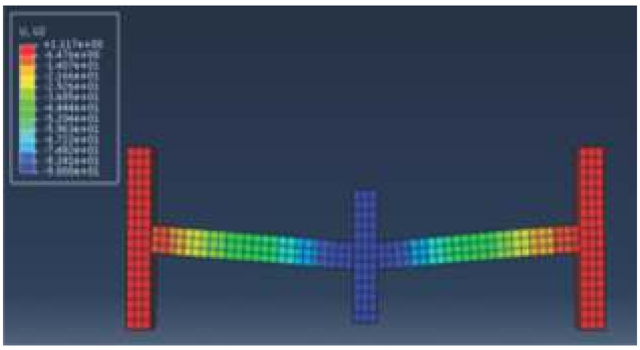


**Figure 20 Analysis Result of Precast Wet Connection**

**Table 3 Result Comparison of Precast Wet Connection**

| Precast Wet Connection | | | |
|---|---|---|---|
| EXPERIMENTAL | | ANALYTICAL | |
| Load (kN) | Deflection (mm) | Load (kN) | Deflection (mm) |
| 0 | 0 | 0 | 0 |
| 2 | 1.02 | 0.77 | 1.125 |
| 4 | 3.16 | 4.08 | 3.23 |
| 6 | 6.4 | 7.85 | 6.55 |
| 8 | 10.5 | 9.04 | 10.71 |
| 10 | 14.1 | 10.58 | 13.56 |
| 12 | 18.9 | 12.66 | 18.52 |
| 14 | 22.7 | 14.39 | 22.99 |
| 13.5 | 87.7 | 17.884 | 89.99 |

**Table 4 Percentage Difference in Result of Precast Wet Connection**

| | EXP | FEM | Difference |
|---|---|---|---|
| Load(kN) | 14 | 17.8 | 27.14% |
| Deflection(mm) | 87.7 | 89.99 | 2.61% |

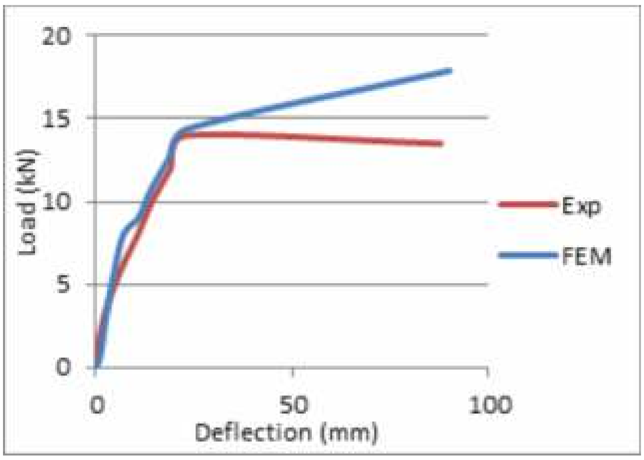



**Figure 21 Load v/s Deflection of Precast Wet Connection**

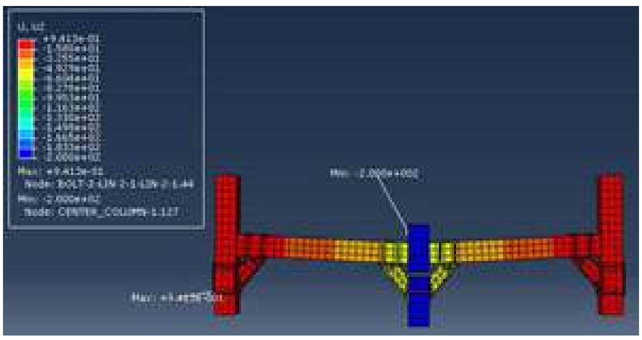


**Figure 22 Analysis Result of Precast Dry Connection**

**Table 5 Result comparison of Precast Dry Connection**

| Precast Dry Connection | | | |
|---|---|---|---|
| EXPERIMENTAL | | ANALYTICAL | |
| Load(kN) | Deflection (mm) | Load (kN) | Deflection (mm) |
| 0 | 0 | 0 | 0 |
| 3 | 6.2 | 3.64 | 6.39 |
| 4 | 12.3 | 4.79 | 13.9 |
| 5 | 16.5 | 6.37 | 20.66 |
| 6 | 21.4 | 8.73 | 23.19 |
| 7 | 30 | 12.07 | 32.69 |
| 8 | 39.9 | 13.23 | 30.73 |
| 9 | 47.8 | 17.9 | 47.24 |
| 10 | 52.7 | 18.36 | 52.6 |
| 11 | 55.9 | 19.62 | 55.5 |
| 12 | 66.9 | 20.89 | 67.73 |
| 13 | 81.2 | 24.28 | 82.37 |
| 14 | 96.4 | 24.67 | 95.55 |
| 15 | 111.7 | 24 | 115.33 |
| 14.2 | 221.7 | 22.2 | 200 |

**Table 6 Percentage Difference in Result of Precast Dry Connection**

| | EXP | FEM | Difference |
|---|---|---|---|
| Load(kN) | 15 | 24 | 37.5% |
| Deflection(mm) | 221.7 | 200 | 9.79% |

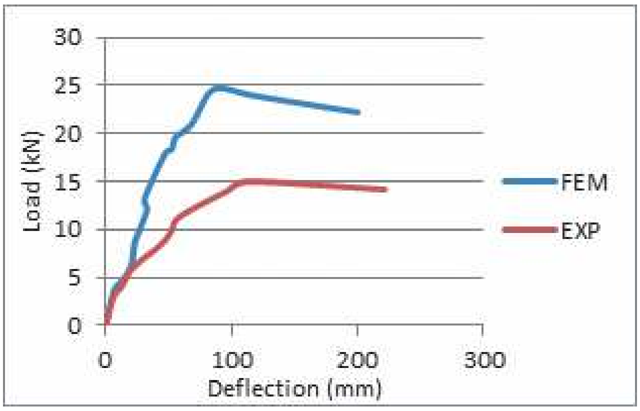



**Figure 23 Load v/s Deflection of Precast Dry Connection**

- Experimental results and analytical results are compared in terms of load and displacement at the bottom of middle column.
- The ultimate load carrying capacity of monolithic connection is 17 kN experimentally and 18 kN based on FE Analysis. So, the difference is 5.88%. Deflection of middle column from experimental result is 99.4 mm and 100.46 mm from FE Analysis. So, the difference is 1.06%.
- The ultimate load carrying capacity of precast wet connection is 14 kN experimentally and 17.8 kN based on FE Analysis. So, the difference is 27.14%. Deflection of middle column from experimental result is 87.7 mm and 89.99 mm from FE Analysis. So, the difference is 2.61%.
- The ultimate load carrying capacity of precast dry connection is 15 kN experimentally and 24 kN based on FE Analysis. So, the difference is 37.5%. Deflection of middle column from experimental result is 221.7 mm and 200 mm from FE Analysis. So, the difference is 9.79%.
- It is observed from FEM results that load carrying capacity and deflection of monolithic connection is faintly more than that of precast wet connection.
- It is observed from FEM results that load carrying capacity and deflection of precast dry connection is higher than that of monolithic connection and precast wet connection.

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