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Seismic Behavior of Mid-Rise Precast Reinforced Concrete Building with Effect of Joints and Supports

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Abstract. Precast concrete structures are widely used in construction. It consists of prefabricated elements casted in industry and connected to each other to form a homogeneous structure. Connections function is to transfer moments and axial forces. Many engineers assume precast connection as pinned, but in reality, they are semi-rigid connections that transfer forces to other members. Lack of design and detailing of connection leads to improper behaviour of the structure, which then leads to the collapse of the building. Past earthquake studies show that many precast buildings performed poorly, and the main reasons were connections. This paper mainly focuses on understanding the seismic behaviour of mid-rise i.e seven-storey precast reinforced concrete buildings with various beam-column joints i.e rigid, semi-rigid, pinned and column-base supports i.e, fixed and hinged supports. Building is modelled and analyzed using ETABS v17 software. Rotational stiffness of precast billet connection is adopted for modelling of semi-rigid beam-column connections. Response spectrum and modal analysis are carried out. Results of displacements, storey drift, storey shear, storey stiffness, base shear, time periods and first mode shapes of models are discussed. It is observed, precast reinforced concrete building models with semi rigid connection performs better than building models with pinned connections and building models with fixed supports reduces the structural response to a great extent.

Keywords: Beam-Colum connection, Precast concrete structures, Response spectrum analysis, Supports.

I. INTRODUCTION

The precast concrete structure is a branch of structural concrete. Precast concrete structures are nowadays extensively used in construction as it is easy to construct, time-saving, durable, versatile, and require less labour. Precast concrete structures consist of members casted far in the industry and connected on site. The connection between members make importance in design as poor design and detailing leads to collapse of the building. Connections need to transfer forces between members. Many design engineers assume connections between precast members as pinned, i.e., no transfer of forces between members but in reality, it is different, connections fall under semi-rigid, i.e., they allow some amount of transfer of forces between members. The beam-column connection can be made by using a billet connection, dowel bars, corbel connection. Past studies show the poor behaviour of precast concrete buildings. The Armenian earthquake (1988) precast-frame buildings sustained a variety of damage. Infill masonry walls often fell out of the frame, resulting in a loss of stability. In the Northridge earthquake (1994) deficiencies in these structures include lack of proper diaphragm connections, beam-column connections. Precast concrete structures did not have adequate connections between beam and column. In Van earthquake (2011) precast concrete structures, as well as other types of structures, built in the region experienced light to severe damage. The improper design of connections leads to damage of buildings. Past literature studies show that critical area of failure in precast structure is near connection or in connections. And by increasing rigidity of connections, the performance of precast buildings can be made better. N Hashim, et al., (2017) investigated the rotational stiffness of precast billet connection using the finite element method to apply actual behaviour for frame design analysis. Authors modelled and analyzed the precast building with billet connection in ANSYS v12 software and concluded that precast billet connection is classified as a low strength semi-rigid connection with a rotational stiffness of 23,138 k-Nm/rad [8]. Nitesh M Jogdand et al**.,** (2015) modelled and analyzed a 3-storey precast RC building and compared the behaviour of precast RC building with dowel connection as semi-rigid connection and conventional RCC building in different ground motions. Results conclude that time period is increased for precast building compared to RCC building and flexibility of precast building is increased by considering the beam-column connection as semi-rigid. In time history analysis, it is found that due to the flexibility of the precast building compared to RCC building, the top displacement is increased whereas base shear has decreased [7]. A. Belleri et al. (2012), performed displacement-based analysis to a 3-storey precast concrete frame to define the inelastic deflected shape of the building. Authors made an attempt to describe the moment-rotation behaviour of typical Italian beam-column connections, which include an elastometric pad and dowel bars [1].

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Precast concrete building with various beam-column connections and column-based supports studies are minimal. The configuration of connection and response, including strength, rotational stiffness and ductility affect the building in several ways. This paper study the comparison of precast reinforced concrete buildings with various beam-column connections and column-based supports.

In this study, a seven-storey precast reinforced concrete building with various beam-column joints (Rigid, Semi-Rigid, Pinned) and column base support (Fixed, Hinged) is modelled and analyzed using ETABS v17 software. Response spectrum analysis is carried out on considered building models to understand the behaviour of buildings with various joints and supports.

II. OBJECTIVE OF WORK

The main objective of this study is to determine the seismic behaviour of 7 storey precast reinforced concrete buildings with different beam-column connections (Rigid, Semi-Rigid and Pinned connections) and base supports (Fixed base & Hinged base) in seismic zone V.

III. STRUCTURAL MODELING

In this study, six-building models of 30 m×16 m size 7 storey precast reinforced concrete buildings are modelled with various beam-column connections i.e., rigid, semi-rigid, pinned connection and column-base supports, i.e., fixed, hinged supports as shown in Fig. 1. Building model consists of 6 bays along the X-axis and 4 bays along the Y-axis with 5 m and 4 m width respectively. Height of the storey is considered as 3 m and constant along with the height of the building. ETABS v17 software is used for modelling and analysis of building models. Building models designed with BS 8110 code [2] and K.S.Elliot et al. (2004) [6]. The geometry of all the models are the same and mentioned in table-I. Grade of concrete for beam and column is C35/45, the grade of concrete for the slab is 40/50 and H500B grade rebar is adopted. The frame is analyzed without any bracing. Seismic analysis is carried out on models using IS1893:2002 [4] and details are presented in table-II. The load applied on models are considered from IS 875 [5] and discussed in table-III.

Table-I Model Description

Type of building	Precast RC building
Size of beam	300mm x 350mm
Size of column	400mm x 400mm
Thickness of slab	150mm
The thickness of exterior walls	230mm
The thickness of interior walls	150mm
Thickness of parapet walls	150mm

Table-II Earthquake Details

Earthquake zone	V
Zone Factor (Z)	0.36
Importance factor (I)	1
Soil type	Type II
Damping ratio	5%
Response reduction factor (R)	5

Table-III Load details

Load type	Load value
Live load	2 kN/m^2
Floor finish	1 kN/m^2
Exterior wall load	12 kN/m
Interior wall load	9 kN/m
Parapet wall load	3 kN/m
Load combinations	As per IS 1893-2002 (clause 6.3.1.2)

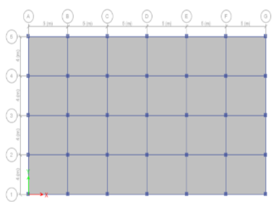
Table-IV presents the details of precast reinforced concrete building models considered for the study. Building model-1 consists of a bare frame building with rigid beam-column connection and fixed base support. Building model-2 consists of a bare frame building with semi-rigid beam-column connection and fixed base support. Precast billet connection is considered for beam-column connection. Building-3 model consists of a bare frame building with pinned beam-column connection and fixed base support. Building model-4 consists of a bare frame building with rigid beam-column connection and hinged base support. Building model-5 consists of a bare frame building with semi-rigid beam-column connection and hinged base support. Building model-6 consists of a bare frame building with pinned beam-column connection and hinged base support.

Table-IV Model Details

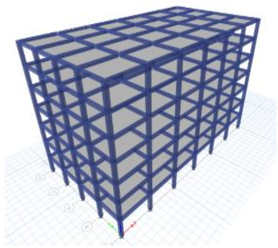
Building models	Descriptions	Notation
MODEL-1	Rigid connection and Fixed base	R-F
MODEL-2	Semi-Rigid connection and fixed base	SR-F
MODEL-3	Pinned connection and Fixed base	P-F
MODEL-4	Rigid connection and Hinged base	R-H
MODEL-5	Semi Rigid connection and Hinged base	SR-H
MODEL-6	Pinned connection and Hinged base	P-H

Semi-Rigid Connection Details:

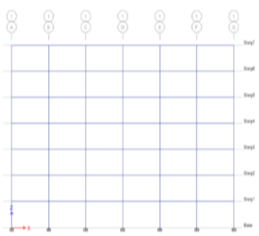
The precast building is modelled for rotation at beam-column joint. Rotational stiffness of precast billet connection is adopted for modelling of semi-rigid beam-column connections. The moment was released as per the values obtained at the beam start and endpoints [8], as shown in Fig. 1(d) and Fig. 1(g), respectively.



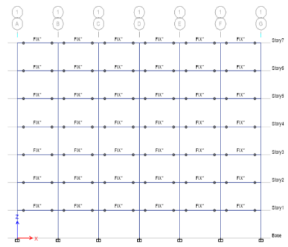
(a) Plan view



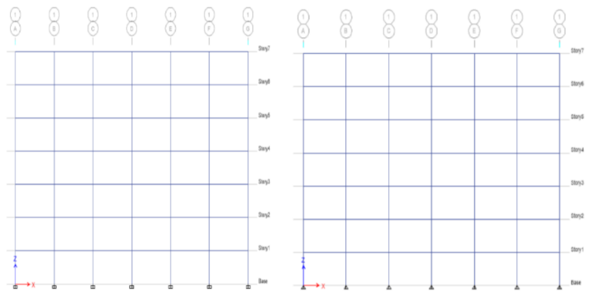
(b) 3D view



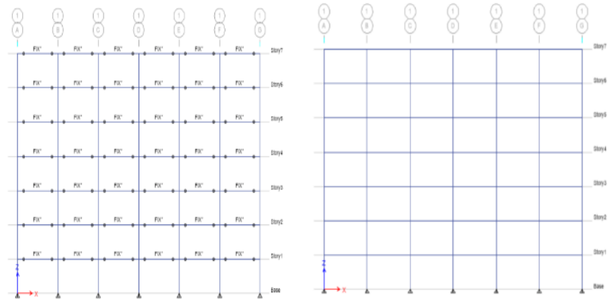
(c) R-F



(d) SR-F



(e) P-F **(f) R-H**



(g) SR-H **(h) P-H**

Fig.1: (a) Plan view (b) 3D view (c) Elevation view of model-1 (d) Elevation view of model-2 (e) Elevation view of model-3 (f) Elevation view of model-4 (g) Elevation view of model-5 (h) Elevation view of model-6

IV.ANALYSIS

An attempt is made to understand the seismic behaviour of the precast reinforced concrete building. The modelling and analysis of the buildings are carried out using ETABS v17. Response spectrum analysis is carried out, and seismic details have taken from IS 1893-2016.

V. RESULTS AND DISCUSSIONS

Results extracted from response spectrum analysis, base shear, storey displacement, storey drift, storey shear, and storey stiffness between models of rigid, semi-rigid and pinned beam-column connections with fixed and hinged base supports has discussed.

A.Modal Analysis

Model analysis gives the mode shapes and time period of building. From Fig. 2, It can be observed that time period for building models with precast billet connection (Semi-rigid connection) is between rigid and pinned connections in both types of base supports. Pinned connection shows the maximum natural period of 1.41 sec and 1.81 sec in fixed and hinged bases respectively and the lowest is found for rigid structure with 0.89 sec and 1.2 sec in fixed and hinged bases respectively, implying structure with a higher period of vibration have a low resistance to seismic action. Semi-rigid connections show a natural period of 1.09 sec and 1.37 sec in fixed and hinged bases, respectively.

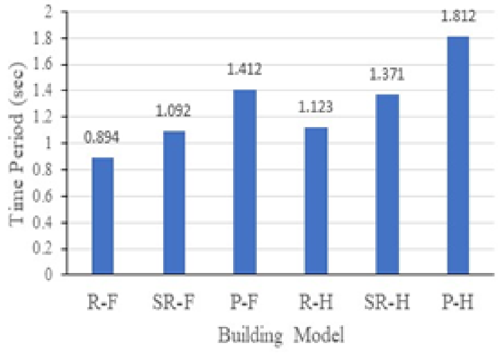
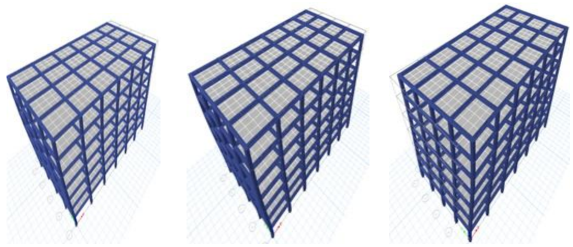
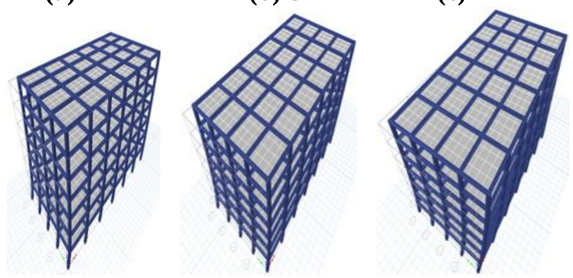


Fig. 2 Time period of different building models

Time period for building model with semi-rigid and the pinned connection is 1.2- and 1.5-times building model with a rigid connection in both types of supports. Building model with pinned connections with fixed and hinged base supports have longer period of vibration because it is a flexible and total transfer of moments between beam to column whereas building models with rigid connections with fixed and hinged base supports have a shorter period of vibration because it is stiff. Building models with a semi-rigid connection with fixed and hinged bases have a medium period of vibration, which implies building is neither as stiff as rigid nor as flexible as pinned. The first mode shape of building models is shown in fig.3.



(a) R-F **(b) SR-F** **(c) P-F**



(a) R-H **(b) SR-H** **(c) P-H**

Fig. 3 First mode shapes of different building models

From Fig. 3, it can be observed, for both the type of base supports, building models with rigid and semi-rigid connections 1st mode shapes are translation mode i.e, storey displacement in x or y direction is translation, but for pinned connection 1st mode shape are torsional mode i.e, storey displacement in both x & y direction is rotation. Deviation of the centre of rigidity from the centre of mass in building models with pinned connections, as shown in table-V, causes the torsional mode shapes.

Table-V Center of Mass and Center of Rigidity

MODEL	XCM (m)	YCM (m)	XCR (m)	YCR (m)	X-Ecc (m)	Y-Ecc (m)
R-F	15	8	15	8	0	0
SR-F	15	8	15	8	0	0
P-F	15	8	15.673	8.632	0.673	0.632
R-H	15	8	15	8	0	0
SR-H	15	8	15	8	0	0
P-H	15	8	15.719	8.684	0.719	0.684

B. Base shear

From Fig. 3, it can be observed, base shear for building with semi-rigid connection and pinned connection has less base shear compare to buildings with rigid connection in both type of base supports but building models with fixed base support has more base shear compare to building models with hinged base. Building model of semi-rigid connection with a fixed base and the hinged base has base shear of 997.54 kN and 757.64 kN respectively. Building model of pinned connection with a fixed base and hinged base has base shear of 759.40 kN and 578.94 kN respectively.

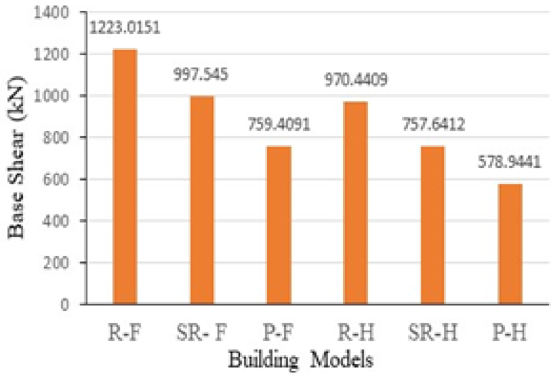


Fig. 3: Base shear for different buildings models

Base shear for building model with semi-rigid and pinned connection with fixed and hinged support is 0.81and 0.62 times of building model with a rigid connection in both types of supports. It concludes that structure with semi-rigid connection with fixed base support performs better and stiffer than pinned connection with fixed base support and acts similar to building model of rigid connection with hinge base support.

C. Storey displacement

It can be observed from fig.4 that, story displacement of pinned, semi-rigid and rigid connection with fixed support of building model is 32.86mm, 24.16 mm and 19.50mm respectively and similarly building models of pinned, semi-rigid and rigid connection with hinged support is 36.71mm, 26.54mm and 21.40mm respectively. The storey displacement of pinned and semi-rigid connection with fixed and hinged support is 1.6, 1.2, 1.7 and 1.2 times of rigid connection with fixed and hinged support respectively. The effect of supports, more displacement has been observed for hinged support as compared to fixed support at ground floor and it seems to be more flexible structure irrespective of connections. Support plays a vital role in the building as a seismic effect is a concern.

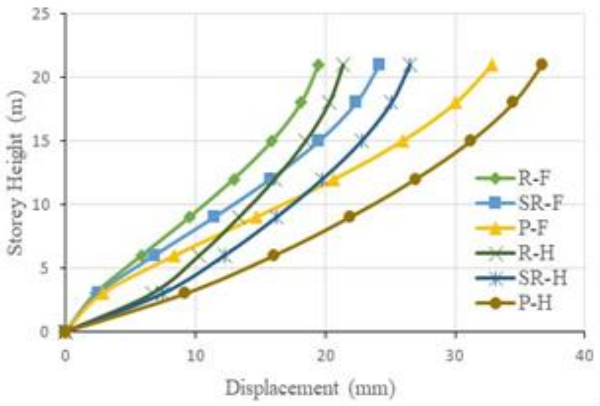


Fig. 4: Story displacements for different building models

D. Storey drift

From Fig. 5, it is observed, building models with fixed base support has a maximum drift in 3rd storey whereas building models with hinged base support has maximum drift in 1st storey. Building with semi-rigid connection with fixed and hinged bases has storey drift 0.0015 and 0.0024 respectively. Building with pinned connection with fixed and hinged bases has storey drift 0.0020 and 0.0030 respectively.

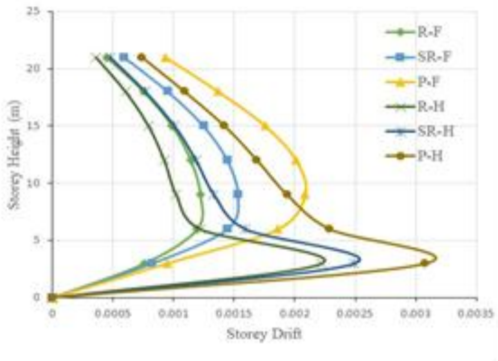


Fig. 5: Storey drifts for different building models

It is observed that building model of pinned connection with fixed and hinged base has maximum drift of 0.0020 and 0.0030 in third and first storey respectively, which is within the limit prescribed by the Eurocode 8 [3]. The code recommends a maximum drift value of 0.0075H, and permissible drift value is 0.0225.

E. Storey Shear

From Fig. 6, Building models of semi rigid and pinned connections with fixed base has storey shear 984.6 kN and 773.04 kN respectively and building models of semi-rigid and pinned connections with hinged base has storey shear 801.06 kN and 625.77 kN respectively. It can be observed, storey shear for the semi-rigid and the pinned connection is 0.7 and 1.5 times the rigid connection with fixed support less than rigid connection in both types of support conditions.

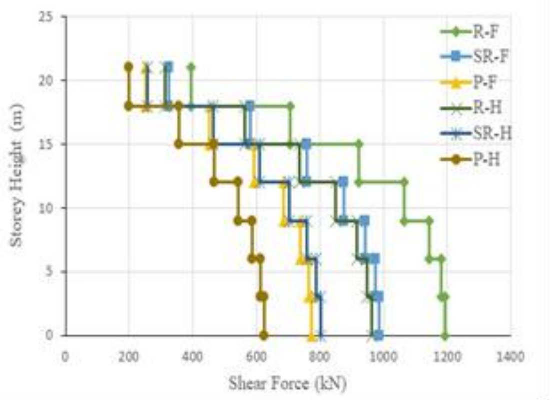


Fig. 6: Storey shears for different building models

F. Storey stiffness

Storey stiffness (kN/m) is the ratio of storey shear to the story drift. From Fig. 7, It can be observed, stiffness of building models with fixed base has higher storey stiffness in 1st storey whereas for building models with hinged base has higher storey stiffness in 6th storey. Building models of semi-rigid and pinned connection with fixed base has storey stiffness 397320 kN/m and 280237 kN/m respectively. Building models of semi-rigid and pinned connection with hinged base has storey stiffness 201855.3 kN/m and 113554.6 kN/m respectively.

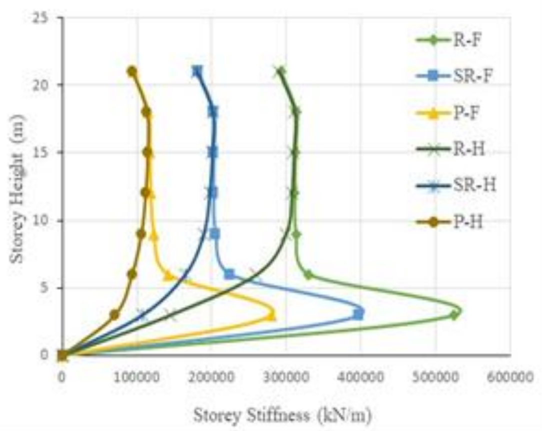


Fig. 7: Story stiffness for different building models

The storey stiffness of pinned and semi-rigid connection with fixed and hinged support is 0.75, 0.53, 0.36 and 0.64 times of rigid connection with fixed and hinged support respectively. The effect of supports, less stiffness has been observed for hinged support as compared to fixed support at ground floor.

VI. CONCLUSIONS

Based on the results and discussions made, the following conclusions are drawn for this study:

1. From the results mentioned above, it is observed that in precast reinforced concrete buildings use of semi-rigid connections performs better than pinned connections during earthquakes. The behaviour of buildings with semi-rigid connections is nearly similar to buildings with Rigid Connections because of partial moment transfer in the semi-rigid joint connects.
2. The base support also plays a vital role in buildings. Precast reinforced concrete buildings with fixed base perform better than buildings with the hinged base for seismic effect.
3. Time period, storey displacement, and storey drift of building models with semi-rigid connection and pinned connection with fixed and hinged support is more compare to building models of rigid connection with fixed and hinged base support.
4. Base shear, storey shears and storey stiffness of building models with semi-rigid connection and pinned connection with fixed and hinged support is less compared to building models of rigid connection with fixed and hinged base support.
5. From all the results it concludes, the seismic behaviour of semi-rigid connection with fixed base is same as of rigid connection with hinged base. It was observed, centre of rigidity deviates from centre of mass for pinned connection with fixed and hinged base and it causes rotation mode instead of translation mode as first mode shape.

Thus, it is concluded that precast reinforced concrete structure with a semi-rigid connection with fixed base reduces the structural responses to a great extent and helps in minimizing the damage.

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