Performance Analysis of Precast Concrete Wall Joints

Ravindra R[1*], Rekha B[1], Nagesh M[2]

[1]Department of Civil Engineering, RV College of Engineering®, Bengaluru - 560059

[2]Research Scholar, NITK, Suratkal - 575025

Abstract

The vulnerabilities of precast concrete structures take place at its connections under lateral loading conditions. Although numerical analysis methods are economically viable for the analysis of structures, there are limited research data available in modelling of precast joints and connections due to the usage of patented elements in precast industry. The motivation of this work is to reduce the existing gap of analytical modeling of precast linkages. In this work, parameter modeling and analysis of precast wall-to-wall interlocking linkage are carried out. Also, three modeling mechanisms for interlocking connections of vertical wall joints - integrated, one link and three link - using ETABS are evaluated. The novelty of study is the identification of an appropriate numerical analytical model to represent wall-to-wall interlocking linkages. It is observed that three link analytical model better suits as a best linkage system in large panel precast construction-system considering in-plane shear, in-plane bending moment, axial force and storey displacements parameters.

Keywords: *Precast walls, Precast large panel, Precast joints, Linking system, Dynamic Analysis*

1.0 Introduction

With the increased pace of population, there is a tremendous demand of rapid quality infrastructure like housing and other amenities. To cater this tremendous demand, industrialized building construction, i.e. precast construction technology is to be adopted [1]. The performance and stability of precast structure depends on the continuity of structural and non-structural elements and their connections [1-2]. The design techniques and approaches should consider the performance of structure under gravity and lateral loading conditions. It should ensure having proper transference of loads to the foundation from the super structures through their structural/ non-structural elements and component connections/joints. Stability and continuity of joints in structure is the vital constituent for the performance of precast structures [2]. Inflexible or plastic behavior at joints limits the load transfer and affects overall structural performance. [1]

In the present study, analysis and behavior of precast structure and joint are carried out by analytical evaluation. The experimental analysis is costlier, and data is not available in academia due to its confidentiality. Numerical methods

**Mail address: Ravindra R, Associate Professor, Department of Civil Engineering, RV College of Engineering®, Bengaluru-560059*

Email: ravindrar@rvce.edu.in, Ph: +91 9448020175

are economically viable for the analysis of structures, but there are limited research data available in analytical modeling of precast joints and connections due to the usage of patented elements in precast industry. The existing mechanisms of wall-to-wall linkages are either by welding or interlocking. The best analytical model suited to these linkage mechanisms is one of the biggest challenges in precast industry. The novelty of this work is the identification of an appropriate analytical model for wall-to-wall linkages mechanism.

The precast concrete structures with load bearing wall panels studied by Bob van Gils [3] recommended as the best suited technology for multistoried residential and commercial buildings and advantageous compared to RCC frame structures. The work describes the practical and economical aspects of designing and constructing of large panel systems structures. The thematic literature survey was carried out on experimental study on precast structures and analytical modeling of precast panels/structures.

The experimental study on exterior and interior was carried out N Rossley et.al [4] to determine behaviour of loop bars connection and crack patterns under shear loading. It was concluded that the loops provided enough ductile resistance and inclined cracks observed near loops at ultimate loading points and recommended for medium rise precast building. The experimental study to evaluate the shear behaviour of vertical joint in precast wall panels was carried out by Aparup Biswal et.al [5]. It was evaluated that the strength and deformability of vertical joint directly affected by transverse reinforcement under load control and displacement control methods. Xueyuan Yan et.al [6] investigated the joints of a precast prestressed concrete frame structure and concluded that the precast prestressed concrete joint and the cast-in-place joint had a similar failure mode. The stiffness, bearing capacity, ductility, and energy dissipation were comparable. The experimental performance behavior of precast reinforced panels under seismic loading was conducted by Alberto Pavese et.al [7]. It was observed that the strong association between wall flexure and shear performance, such as the increased wall length results in enhanced shear resistance. But deformation capacity of the precast wall at failure was practically unchanged.

Folić1. R, et.al [8] indicated the lack of feasibility on holistic modeling of structural behaviour i.e., ductility and shearing of prefabricated structures and proposed mathematical models for sufficiently accurate failure assessment of prefabricated reinforced concrete connections. The storey level impact of gravity and lateral loads for wind and earthquake on twelve storeyed precast building was analyzed by A.Surekha et.al [9], Chaitanya Kumar J.D et.al [10] and R. Uday Kumar et. al [11] using ETABS software and analysis of joints conducted according to IS 11447-1985. The axial force, out of plane moments, storey lateral load, shear force, storey drift, storey shear and tensile force on the shear wall with respect to different storeys were compared. It was concluded that the variation of axial force and out-of-plane moment with storeys were linear in nature whereas the variation of lateral loads, shear force, storey drifts and tensile forces with storeys were non-linear. The comparative analysis of large panel structure and a framed structure of a nine storeyed precast building was carried out by Karthick M et.al [12] using ETABS software. The parameters such as lateral loads, maximum deflection, maximum storey drifts, mode shapes, time periods and base shears were compared under loading conditions - dead load, imposed load wind loads, seismic load. It was concluded that the performance of both structures was satisfied and large panel model behaves better. Absar Khan et.al [13] illustrated large panel as a structural element for low cost frameless housing construction. The comparative study on conventional RCC structure and frameless large panel structure was carried out using ETABS-2015 software on parameters such as base shear, fundamental time period and displacement due to lateral load. Large panel structure showed less displacement as wall panel acts as a shear wall and resist the lateral load.

Engström [14] presented the role of the connection in the structural system, the flow of forces through the connections, and basic force transfer mechanisms. The factors include behaviour at normal loading and dynamic loading, performance of structure during the working condition, structural behaviour during the hazards. Bindurani P et.al [15] conducted an analytical study on the precast multi-storey structure located at Boiwada, Mumbai using ETABS. The study focused on two numerical analysis models for vertical joints analysis - a model adequate in moderate seismic zones having a discrete gap consisting of 20mm wide gap between wall panels, connected by diaphragm constraints and an another integrated conservative model with monolithic joints with a shell strip element of 100mm width, tie reinforcement, shear keys and reinforcing dowel bars. The effects - stress, deformation and absolute plastic strain of lateral ground movement on wall to wall connection in precast concrete structures was studied by Ramin Vaghei et.al [16] using non-linear 3D finite element models in ABAQUS software. Ehsan Noroozinejad Farsangi [17] studied the behaviour of connections in precast concrete structures due to seismic loading using the FEA software LUSAS and SAP2000. Finite element analysis was carried out for four types of precast connections - pinned, rigid, semi rigid and a new proposed connection. The beam to column connections were modelled and analyzed in LUSAS as corbel only model, corbel with bolt on beam top, corbel with plate and bolt on beam top and stiffener, and a new type of connection with 10mm plate and bolt of 22mm. The three storied building was modelled and analyzed in SAP2000. Stiffness of the connection was determined, and it was found to be a semi rigid connection and better when used as 10mm plate and bolt of 22mm. It was concluded from analysis that connection stiffness does have a significant effect to the frame member for moment and shear forces under time history loading.

There are limited data on numerical analysis of wall-to-wall joints. It is observed that the joints between prefabricated components should be engineered and installed properly. The important structural parameters considered for prefabricated building analysis are the bending moments, axial force, storey lateral load, shear force, storey drift, under lateral loads. Analysis and design of joints in the component level and connections in the global level of prefabricated structure using analytical methods is one of the thrust areas in the industry.

2.0 Present Work

In order to have a structurally safe system, it is necessary to know the variations of forces and locations of vertical joints in load bearing precast system by properly modeling the structure which is closer to actual behavior. The performance assessment of wall-to-wall joints is carried out as part of study. The scope of work is to identify a rational numerical analytical model to represent wall-to-wall interlocking linkages. The present work constitutes the following steps.

1. Identification of critical piers at walls without opening and walls with opening subjected to loading conditions - dead load, live load and earth quake load - as recommended in IS 875 part 1[18] & part 2[19] and IS: 1893-2016 [20]
2. Identification and analytical modeling of precast wall-to-wall joints as integrated, one link(1-link) and three links (3-link) using ETAB 2016 software
3. Analysis of axial force, in-plane shear and in-plane bending moments - of critical piers with no-joint, integrated, 1-link and 3-link joint systems between vertical wall panels.
4. Storey displacement analysis of complete structure with no-joint, integrated, 1-link and 3-link joint systems between vertical wall panels

Specifications – Building & Wall Structure

The structure considered is a residential apartment located near Devanahalli, Bengaluru. The location falls under moderate exposure condition and lies in earthquake zone II as per IS: 1893-2016 [20]. The specifications of the building considered are as given in Table 1.

Table 1. Precast Building Specifications

No of stories	9
Storey height	3m
Foundation to plinth height	1.5m
Category	Residential
Type	Precast panel system
Area of each flat	$35m^2$

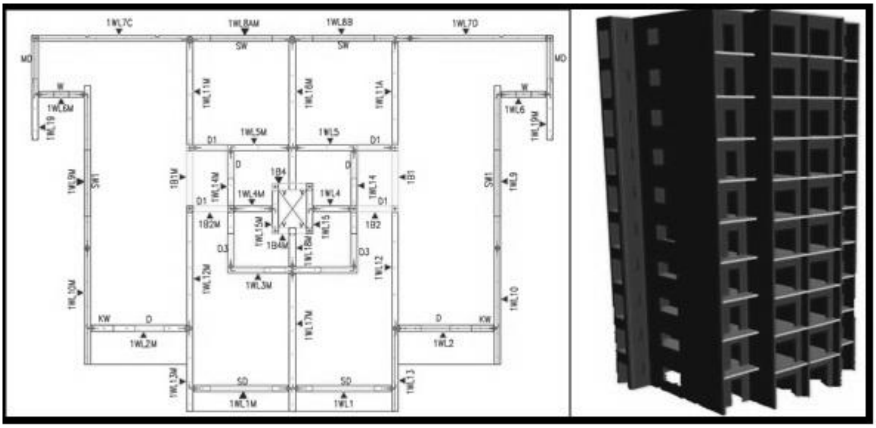

Fig. 1. Precast Building **(a)** Plan and **(b)** 3D View in ETABs

Fig.1a shows the plan of ten storeyed building and Fig.1b depicts its 3D view developed using ETAB Software. Models considered include walls without opening and walls with opening, are considered in the study. The parameters of wall and slab considered in the model are as given in Table 2. In Fig. 2a walls are integrally positioned without any linkage. In Fig. 2b an integrated link having continuous wall-to-wall linkage with 20mm width and 3000mm depth i.e. storey height is shown. Likewise Fig.2c shows a wall-to-wall linkage with single link having 20mm width and 600mm depth at each floor level. Fig. 2c shows wall-to-wall linkage with 3 links of 20mm width and 600mm depth at top, middle and bottom of each storey.

Models with no-link, integrated link, 1-link and 3-link wall-to-wall connection were analyzed under dead load, live load and earthquake load combinations as specified by Indian Standard Codes and the results are compared. The performance of integrated link, 1-link and 3-link wall-to-wall connection were compared with no-link model, which has no wall-to-wall linkage, was considered as a benchmark for results and discussion.

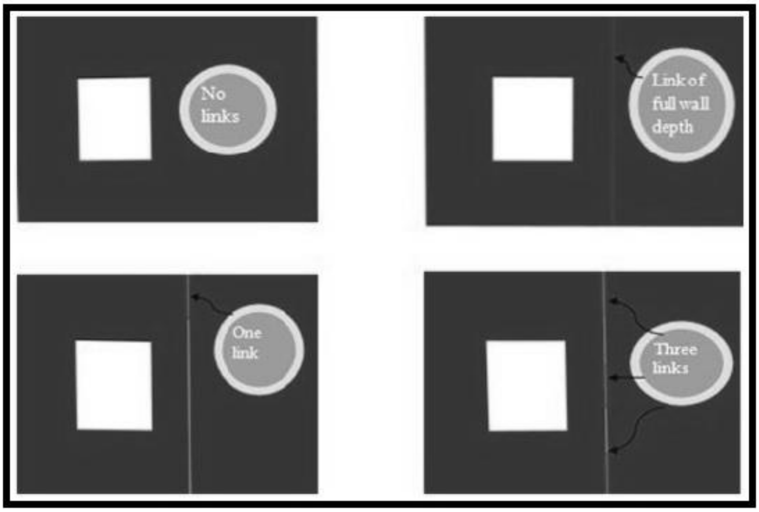

Fig. 2 Wall-to-wall linkage **a)** no-link, **b)** integrated link, **c)** 1-link and **d)** 3-link

Table 2 Wall and Slab Parameters

Section	WALL	SLAB
Material	Concrete	Concrete
Concrete Grade	M40	M40
Steel Grade	Fe 415	Fe415
Type	Shell thin	Membrane
Thickness	160 mm	150 mm

3.0 Results and Discussion

The response spectrum analysis is carried out for analyzing the structure in earthquake zone- II. The analysis is carried out in 3 steps - identification of critical piers, behavior analysis of critical piers in terms of axial force, in-plane shear, in-plane and out-of-plane moments with no-link, integrated-link, 1-link and 3-link wall-to-wall connections and storey displacements.

Step 1: Identification of Critical Piers

Based on the bending moment values observed in analyzed model using ETABs Software, the critical piers are identified for models without opening and with opening. The pier P1, the critical pier of walls without opening, i.e. there is no windows and doors. Similarly, pier P2, the critical pier of walls with opening i.e. with windows and doors fixed in walls.

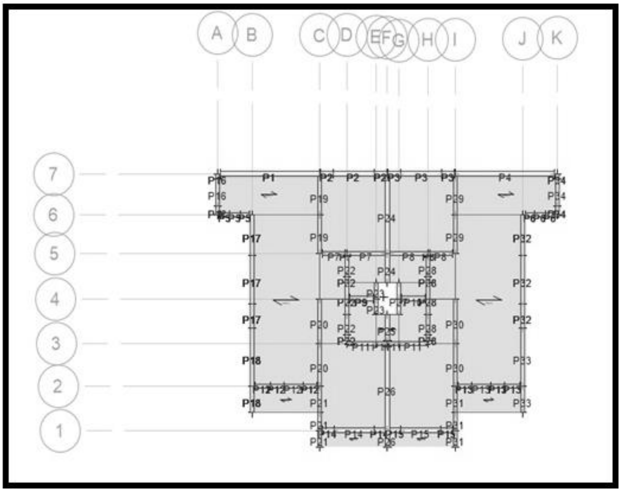

Fig. 3. Precast Building – Critical Pier Identification

Step 2: Behaviour Analysis

The variation of stress variants - axial force, in-plane shear, in-plane bending moment and out-of- plane bending moments are analyzed in this step. The analysis is carried out only on identified critical pier P1 in walls without openings and P2 in walls with openings. The following describes the variations of the stress variants in the walls.

Axial Force

It is observed from Fig.4, that the axial force variation is nearly same in both types of walls at upper floors. But in walls of lower storeys, the variations in axial force upto 19% in integrated link, 17% in 1-link and 25% in 3-link are observed with respect to no-link linkage mechanism of wall-to-wall connections.

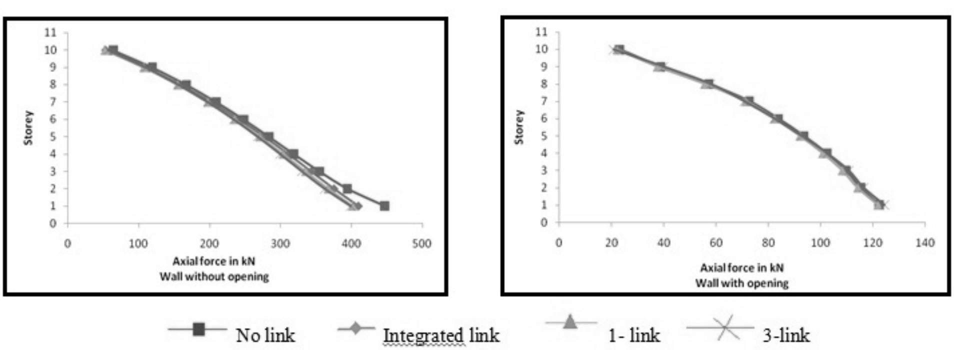

Fig. 4. Axial force variation in critical piers

In-plane shear force

The in-plane shear force variation shown in Fig. 5 for the 3- beam link model, is same in the upper storeys and has lesser variations in bottom storeys in comparison with model without links i.e. upto 39%. Whereas the variations in 1-beam link model is upto 94% and in integrated wall link model is upto 96%.All the variations are compared with respect to no-link linkage mechanism of wall-to-wall connections.

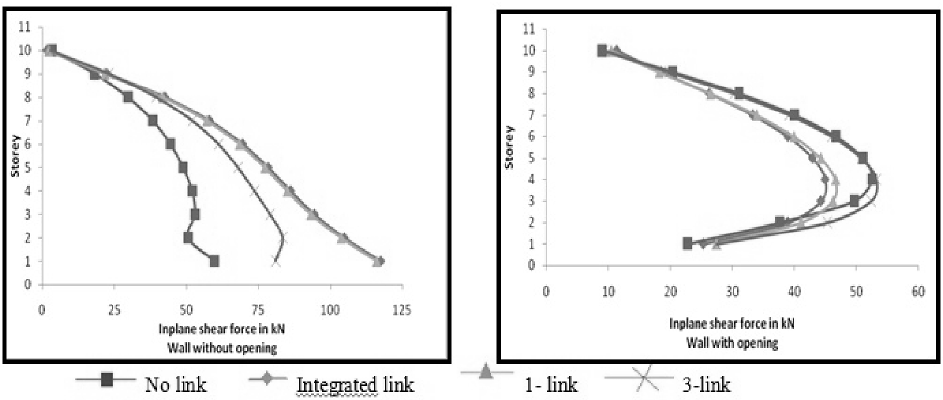

Fig. 5. In-plane shear force variation in critical piers

In-plane bending moment

In-plane bending moment shown in Fig. 6 for the 3-beam link model has variations same in upper storeys and has lesser variations at bottom storeys in comparison with model without links i.e. upto 57%. Whereas the variations in integrated wall link model is upto 110% and in 1- beam link model is upto 109% with reference to the benchmark problem.

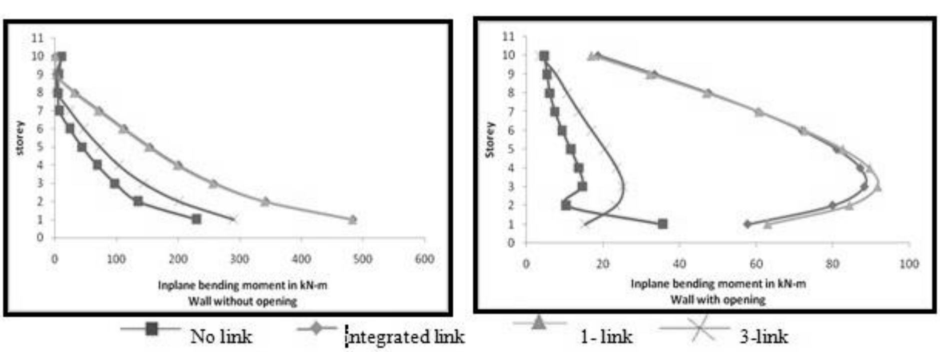

Fig. 6. In-plane bending moment variation in critical piers

Step 3: **Storey Displacements**

In this step, storey displacements with respect to the base of a structure were assessed. The storey displacements in Fig.7 corresponding to the models with no-link, integrated link, 1-link and 3-link wall-to-wall connections are conservative and do not exceed h/500 where h is building height.

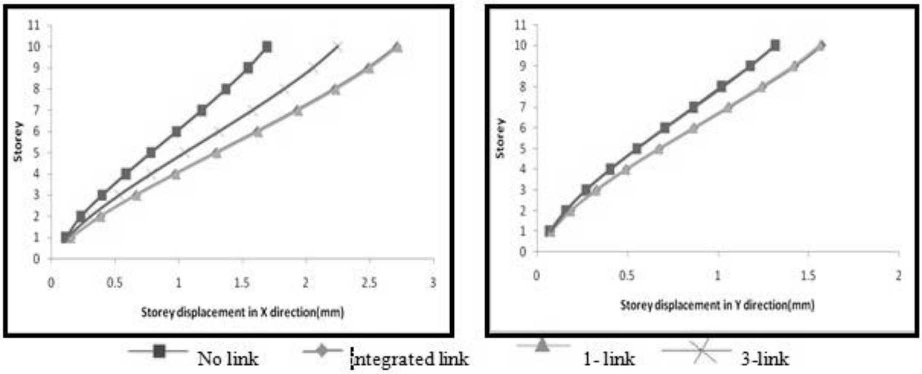

Fig.7. Storey displacement **a)** X-Direction and **b)** Y-Direction

The model with 3-link wall-to-wall connection shows better behavior with a variation of about 32.6% in X direction and matches in Y direction as that of model with no wall-to-wall linkage. Whereas the other linking systems viz, integrated wall link model, 1- beam link model exhibits larger displacements up to 60% in X direction and 20% in Y direction.

4.0 Conclusion

The conclusion of the study on the three types of mechanisms of linkages- integrated, 1- link and 3- link for wall-to-wall interlocking connections are as follows.

It is observed that the 3-link model shows 32%,39% and 57% variation in storey displacements in X-direction, in-plane shear force and in-plane bending moment respectively. It is also observed that the behavior of axial force and storey displacement in Y-direction of 3-link wall-to-wall connection was same as that no-link wall-to-wall connection. Based on the analysis and interpretation of results, wall-to-wall linkage with 3-link is best suited for modeling and analysis of precast wall-to-wall vertical joint compared to integrated wall link model and 1-link model. The outcome of the work will help the structural designer to perform a rational analysis and design of precast concrete walls.

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