

SEISMIC PERFORMANCE EVALUATION OF PRECAST CONCRETE STRUCTURES USING NONLINEAR PUSHOVER AND TIME-HISTORY ANALYSIS

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ABSTRACT:

The paper explores the design and seismic performance of precast concrete buildings especially concerning the use of precast building in the earthquake prone areas. Precast concrete system involves prefabricated structural elements like beams, columns, slabs, and wall panels that are manufactured in factories providing benefits that include better quality and construction is faster, more durable and less harmful to the environment. Nevertheless, their seismic behavior is very sensitive to the behavior of the connections between the elements which are also very critical in determining structural integrity and ductility. The study comprises of comprehensive review of the existing literature, international and Indian codal provisions, and observations of previous earthquakes like Alaska (1964), Mexico (1985), and Bhuj (2001) where failures of precast structures have been attributed to poor detailing, diaphragm action and poor beam-column joints, and well-designed structures have been shown to work comparably with monolithic reinforced concrete. The paper also examines the major structural elements such as frames, diaphragms and shear walls and how they act to seismic loads through the use of analytical tools such as nonlinear pushover analysis which is applied in software such as SAP2000. On this basis, the study highlights the significance of good connection design, observance of seismic detailing and that better and more unified design guidelines, especially in Indian context is required to facilitate safe, efficient and sustainable utilization of precast concrete construction.

Keywords: *Earthquake Engineering, Diaphragm Action, Seismic Design Codes, Performance-Based Design, Structural Analysis, Seismic Resilience.*

I INTRODUCTION

Precast concrete construction has proven as a tremendous breakthrough in the structural engineering especially due to the increased need of efficient, high quality

and speed of construction methodologies. In contrast to traditional cast-in-place concrete, precasting incorporates structural elements (beams, columns, slabs, walls, and stair units) which are designed and executed in controlled factory conditions and then transported to the construction site and assembled. This technique will guarantee high quality management, minimized time of construction, enhanced durability, and minimized environmental impact as a result of less activities on site. The use of precast concrete has also increased in the past decades worldwide with a higher rate of it being implemented in developed nations, where the industrialized construction practice is highly prevalent. Nevertheless, the use of precast concrete structures is to be considered carefully in seismic areas because the behavior of the connection between structural elements is a potent determinant of the performance of the precast concrete structures under the earthquake loading. Connections can be described as the important links that convey force and provide continuity and the absence of quality construction or installation can result in structural weaknesses. The growing urbanization and population increase, as well as the infrastructure pressure in such countries as India, also serve to underline the necessity of introducing precast technology to increase the efficiency of the construction process without sacrificing the safety and sustainability of the buildings. Regardless of the benefits, past experiences with precast construction in seismic regions have always been more reserved with respect to its behavior and design expectations, thus, requiring a further comprehension of the behavior and its design expectations.

Seismic performance of precast concrete structures has undergone a lot of studies especially after the occurrence of major earthquakes across the world. The Alaska (1964), Tangshan (1976), Mexico (1985), Armenia (1988), Northridge (1994), Kobe (1995), as well as the Bhuj (2001) and more recent earthquakes have furnished good knowledge on the strengths and weaknesses of precast systems. These studies indicate that failures of precast structures are mostly linked to the lack of detailing of connection, ineffective diaphragm action, load transfer mechanisms and ductility. In numerous situations, some of these factors contributed to the failure of hollow-core slabs that were not supported, or not capable of the necessary deformation requirements, at a beam-column joint resulting in partial or complete collapse. It is also necessary to add, however, that properly designed precast systems, with appropriate seismic detailing and mechanisms of strong connection, have shown to be

performing as well or even better in terms of their performance than traditional monolithic reinforced concrete structures. The studies have worked on methods of enhancing the connection technology, creation of composite systems and the knowledge about the load paths and deformation mechanisms in seismic forces. The application of the (capacity-based) design, ductile detailing, and energy dissipation by means of controlled yielding have become more and more applied in the precast design philosophy. Moreover, the development of analytical tools and numerical modelization methods, such as nonlinear pushover (which is a form of the static) analysis and time-history analysis, helped engineers predict the structural performance more precisely and develop systems that are safer.

Codal provisions and design standards are also important in informing the safe application of precast concrete structures in seismic areas besides the methods of experimental and analytical studies. The international standards like the ACI, Eurocode, and NEHRP guidelines give detailed guidelines of the design and detailing of precast systems focusing on the factors of connection strength, ductility and transmission of loads and structural integrity. By comparison, Indian standards regarding precast construction and seismic design are also developing and need more improvement to tackle the peculiarities of precast systems. In India, where there is a rapid development of infrastructure with need to have uniform and updated design guidelines is critical, since effective construction practices should be adopted without jeopardizing the safety of people. The collective tools have included analytical methods like pushover analysis, which is commonly realized through the application of software like SAP2000, and are now an important tool of assessing the seismic performance of structures by estimating the capacity and deformation characteristics and failure mechanisms of the structure. The proposed study would fill the existing gaps by providing literature review and analysis of previous earthquake performance and codal provisions in order to suggest better design strategies to precast concrete buildings. Finally, the encouraging of precast constructions in seismic areas is a question that needs to be addressed to combine the real engineering activities and appropriate education and trainings, and the establishment of strong standards in order to provide these systems with the scope of safety, reliability, and sustainability they possess in contemporary building projects.

II SURVEY O RESEARCH

Ghosh and Hawkins (2016)- Seismic Design of Precast Concrete Structures (PCI Journal, Precast/Prestressed Concrete Institute)

Ghosh and Hawkins (2016) presented a new view of the seismic design methods to precast concrete structures with the aim of enhancing performance by increasing the detailing of the connections and designing the diaphragm. This study, which is published in the PCI Journal is a continuation of previous NEHRP-based provisions and integrates the current performance-based design ideas. The authors indicated that the connections should have the ability to maintain large deformations and cyclic loading without brittle failure. They pointed out that connection technology developments, including ductile connectors and hybrid systems are very effective in enhancing the energy dissipation capacity. Another topic discussed in the study was the flexibility of the diaphragm and its effect on the distribution of forces in the structural systems. The results of the experiment and analysis proved that a well-detailed precast system can perform as well in seismic as monolithic reinforced concrete structures. The authors suggested embracing the principles of capacity design and the provision of strong-column weak-beam behavior of precast frames. Moreover, the paper emphasized the need to incorporate codal text with practice in construction in order to be reliable. The work is extensively cited in the current seismic design standards and is also an important contribution to close the gap between the research and applications.

Pampanin et al. (2017) - Low-Damage Seismic Design of Precast Systems (Earthquake Engineering Structural Dynamics Wiley)

Pampanin et al. (2017) have developed a low-damage seismic design of precast concrete structure intending to minimize the cost of repairs in case of the earthquake without interfering with the structural safety of the building. This research was done by the Wiley and explored the new forms of connection such as rocking joints and post-tensioned frames. The systems allow the movement to be regulated during the times of earthquakes and this reduces the permanent damages and increases the reusability. It was found that precast constructions including self-centered forces would allow reducing residual movements compared to the traditional ones. There was experimental experiment and numerical simulation to show that these systems are structurally sound even when subjected to violent seismic loading. The other important point that the authors raised to enhance resilience is the energy dissipation devices and exchangeable components. The paper introduced the change in the life-

safety design approach to the performance-based and resilience-based design approaches. This can be best applied to the existing infrastructure whereby downtime and repair cost is a big issue. Pampanin work has tremendously influenced the present practices towards seismic design coupled with the creation of sophisticated precast system throughout the world.

Fleischman et al. (2018) - Diaphragm Seismic Design technique (Earthquake Spectra, Earthquake Engineering Research Institute)

Fleischman et al. (2018) also elaborated their previous results in the field of diaphragm behavior in their article published in Earthquake Spectra, EERI. The experiment was aimed at investigating the seismic behavior of precast diaphragms and their resistance with vertical lateral force-resisting systems. The authors provided evidence based on large scale experimental testing and nonlinear analysis that diaphragm flexibility is an important factor in seismic performance. They determined that poor design of the diaphragm may result in poor distribution of forces, and local failures. The study has proposed better analytical models and design suggestions that take into consideration the deformation of the diaphragm and conduct of the connection. Continuity of load path and correct anchorage of floor systems and supporting elements was also highlighted in the study. The results helped in the establishment of current seismic design requirements of building codes like ASCE 7. This is known to be a standard in the design of diaphragm and it has contributed a lot in enhancing precast floor systems in seismic areas.

Belleri, Riva (2019) - Seismic of Precast Industrial Buildings (Engineering Structures, Elsevier)

Belleri and Riva (2019) examined the seismic susceptibility of industrial buildings that have been precast, including failures that have occurred in recent earthquakes. The study was published in the Engineering Structures journal of Elsevier and examined the causes of frequent problems including inappropriate connections, poor continuity and poor anchorage of pre cast elements. Experimental and analytical studies were carried out by the authors to determine the performance of beam-column and roof connections in the case of seismic loading. Their results showed that most of the failures occurred because of poor detailing as opposed to aspect weaknesses of precast systems. The research pointed out the importance to retrofit the old structures

and enhance design measures in new structures. Suggestions were the application of mechanical connectors, better action of the diaphragms, and better quality control in construction. The study also emphasized the factor of integrating seismic consideration in the industrial structures that are normally constructed with gravity loading as the major consideration. The given work could be very helpful to understand the way of enhancing the resilience of the industrial structures that are precast.

Ertas and colleagues (2020) - Ductile Precast Frame Systems (American Concrete Institute, ACI Structural Journal).

Ertas et al. (2020) have undertaken an extensive study of ductile precast frame systems, which is published in the ACI Structural Journal. This study was geared towards developing connection systems, which were capable of achieving high level of ductility and energy dissipation in the seismic loading. The authors in the research compared the performance of the precast frames to the monolithic reinforced concrete systems through experimental testing and application of numbers. The precast connections that were well made were found to be able to perform equally or better in seismic performance. Hybrid structures which include precast and cast-in-place are also discussed, in order to encourage continuity of the construction. The authors put stress on the importance of confinement reinforcement, joint detailing and capacity-based design. In addition, the findings of the study also focused on the significance of the new materials and construction methods to improve on the structural performance. This will be done using the work to popularize the precast technology and help it to be applied in high seismic regions.

III WORKING METHODOLOGY

The methodology used in this work commences with a thorough determination of the research problem associated with seismic performance of precast concrete structures with specific attention to their use in the earthquake prone areas. The first stage is a comprehensive literature review that is conducted to know the level of current knowledge, past research contributions and gaps in the design and analysis of precast systems. There are also several international and Indian codal provisions which are discussed in order to determine their suitability in handling seismic requirements. This phase also aids in the formulation of the purpose of the study that comprises of structural behavior analysis, connection performance evaluation, and

recommend design practices. The information obtained based on the case studies of previous earthquakes also contributes to developing a systematic research strategy.

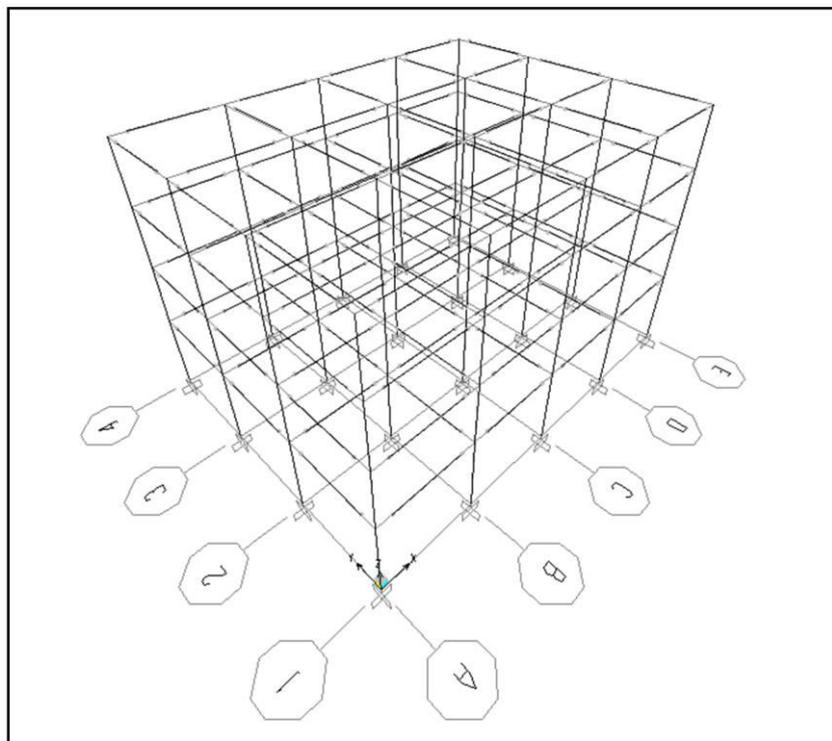


Fig.1. 2D image with modeling

The second step is a selective and modeling of a representative building structure with using precast concrete components. The conceptual model of the multi-storey building takes into account various structural elements that include beams, columns, slabs, diaphragms, and connection of the beam and column. Structural analysis software is used to perform the modeling, e.g. SAP2000, a definition of appropriate material properties, bound conditions and loading parameters is done. They load seismic using the appropriate standards and varied conditions of connection (rigid, semi-rigid, and flexible) are also taken into consideration to assess their effect on structural performance. This modeling phase is important in the simulation of realistic structural behavior under Earthquakes.

After the modeling process, nonlinear static pushover analysis is done to determine the seismic capability of the building. The approach assists in the kind of behavior of load-deformation, which performance point and the measurement of the capacity of the structure under the growing loads at the lateral. The analysis gives information on how plastic hinges are created, the capacity of the structural system to move and how it fails. Various levels of performance like immediate occupancy, life

safety and collapse prevention are tested to establish the structural response. Efforts made in pushover analysis are utilized by comparing various structural structures and types of connections.

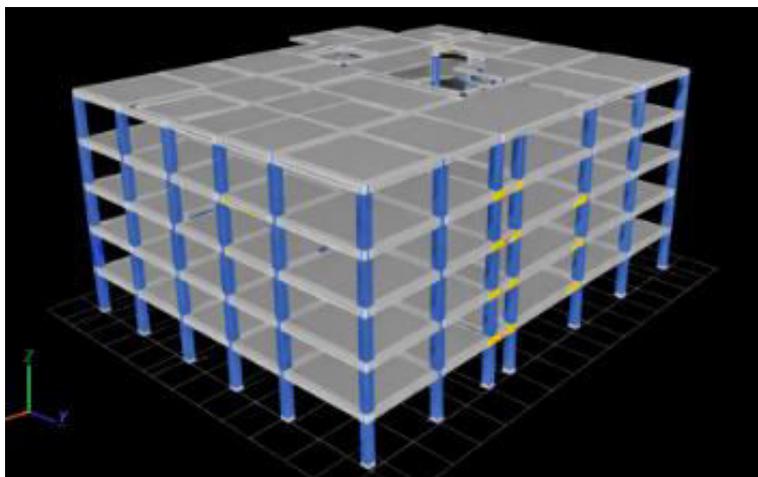


Fig.2. 3D images output

Besides the pushover analysis, time-history analysis is also done through the available record data of ground motion, in order to examine the dynamic behavior of the structure on the occurrence of a realistic earthquake. This analysis is a captive of the change in displacement, acceleration and internal forces with time which provides a detailed insight of the structural behavior. The results of the comparison of pushover and time-history can be used to validate the analytical model and make sure that the findings are reliable. Important parameters, including the base shear, drift, and energy dissipation, are taken into account in order to check efficiency in terms of performance. The action increases the validity of the research and benefits design methods based on performance.

At last, the outcomes of different analyses are discussed and summarized to make significant conclusions about the seismic behavior of pre cast concrete structures. The research determines the performance determinants to be important which include connection detailing, diaphragm action, and load transfer mechanisms. Upon this finding, suggestions are made on how the design practices and codal provisions can be enhanced especially in the Indian context. The methodology ends with the emphasis of the significance of incorporating sophisticated analytical technologies, adequate detailing, and universal requirements to make sure that use of precast concrete technology in the seismic areas is safe, efficient and sustainable.

TESTING AND IMPLEMENTATION

The testing part of this experiment aims at estimating the seismic performance of precast concrete buildings in terms of the analytical simulation and validation processes. An elaborated structural model is created with the help of software like SAP2000 whereby various precast elements such as beams, columns, slabs and connections are imported in with the correct material properties and boundary conditions. Different loading conditions such as dead load, live load, or seismic load as required by the relevant standards are loaded on the model. The main testing is based on the nonlinear static pushover analysis that assists in the determination of the load-carrying capacity, displacement behaviour and the formation of plastic hinges under the growing lateral loads. By this analysis, one gets a clear picture of the performance levels that include immediate occupancy, life safety, and collapse prevention that would allow evaluating the aspect of structural safety during the earthquake condition.

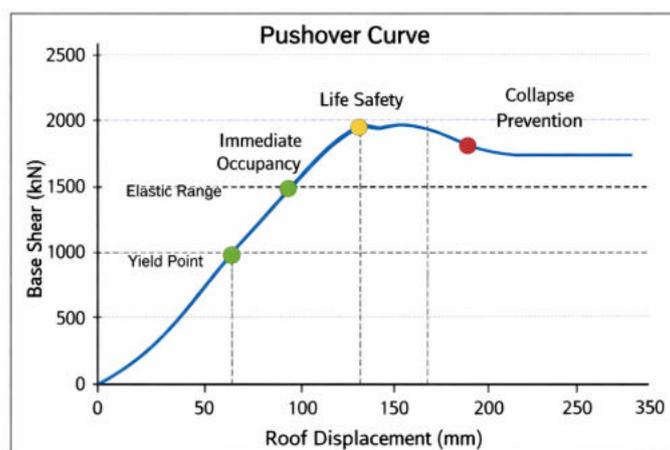


Fig.3. Output results

Besides the pushover analysis, time-history analysis is conducted using real earthquake ground motion records. The approach captures the true response of the structure with time, such as the change in the displacement, acceleration, and the internal forces. The various structural configurations and types of connections, which include rigid, semi-rigid and flexible connections are put to test to determine their contribution towards seismic performance. The findings made on both the analyses are compared in order to find which is the most efficient structural system. Important parameters like base shear, inter-storey drift and energy dissipation capacity are critically analyzed to make sure that the structure satisfies performance based design parameters. The method of testing improves the reliability and validity of the analysis because it recreates the conditions of realistic seismic.

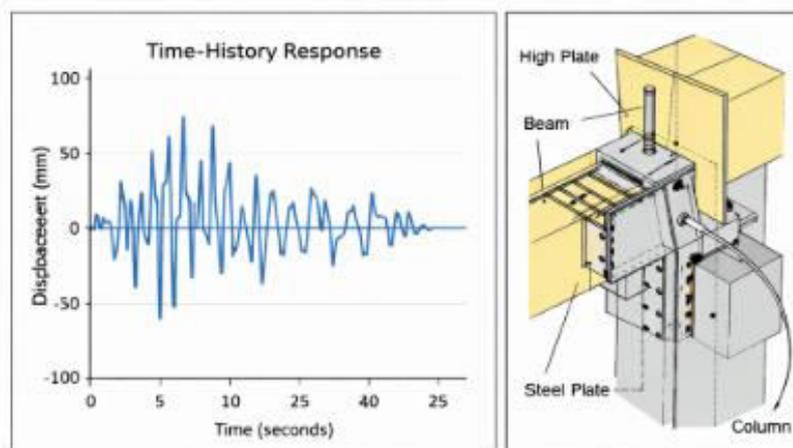


Fig.4. Output results

Implementation phase is to implement the test results to design and construction practice of precast concrete structures to enhance them. According to the result of the analytical works, it is recommended to optimize connection detailing, improve the action of diaphragms, and the mechanisms of loading transfer. The proposed change to embrace the principles of the capacity-based design approach and the implementation of more modern tools of analysis in the case of enhanced performance prediction can be also proposed by the study. Moreover, the results emphasize the importance of revising the current codal requirements, and particularly in the Indian scenario, to adopt new design practices and make structures safe. By applying these suggestions, it is possible to create even more resilient, efficient and sustainable precast concrete structures, which will be able to withstand the seismic forces.

CONCLUSION

To sum it up, this paper has critically discussed the seismic performance of precast concrete buildings, especially the importance of connection design, structural detailing and load transfer-mechanism in precast concrete safety under earthquake loading conditions. Precast building has many benefits including better quality management, quick construction, stability, and environmental, though its success in seismic areas is greatly subject to the right execution and development of structural elements connections. The literature review of previous earthquake case studies and literature indicates that most precast system failures are as a result of poor detailing, inadequate diaphragm action and lack of anchorage and not because the system itself was weak. Analytical studies, which employ techniques like nonlinear pushover, time-history analysis, etc., show that the performance of well-designed precast

structures in relation to seismic can be as good as or even better than the performance of conventional reinforced concrete systems. The results point to the need to apply principles of capacity-based design and guarantee ductile behavior and advance connection technologies to promote resilience of the structure. Moreover, the paper sees a necessity of revising the Indian codal provisions as per the new standards and practices in the world. Generally speaking, precast concrete buildings, with scientifically sound planning, analysis, and application, can be a viable, effective, and sustainable measure in the development of infrastructure in earthquake-prone areas and make their way as a valuable addition to the resilient and future-proof construction practice.

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