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Seismic Behavior of Precast Column Foundation Connections: A Comprehensive Review of Methods, Performance, and Future Prospects

Yuvaraj Manickam D [a], Nandhakumar P[b]

[a] First year M.E. Structural Engineering, Department of civil engineering, Kumaraguru College of Technology, coimbatore-641049, Tamilnadu, India.

[b] Assistant Professor, Department of civil engineering, Kumaraguru College of Technology, coimbatore-641049, Tamilnadu, India.

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A B S T R A C T

This Precast concrete structures are increasingly preferred in modern construction due to their advantages in quality control, time savings, and cost efficiency. However, their performance during seismic events hinges on the strength and reliability of the connections between precast elements. In this literature review, we synthesize research findings on the seismic performance of different types of column-to-foundation connections, including grouted sleeve and pocket connections. This review explores experimental outcomes, current technological advancements, and the limitations of various connection methods. Additionally, future research directions to improve the resilience of precast systems in seismic regions are identified.

Keywords: Seismic behavior, precast concrete, column foundation connections, grouted sleeve, pocket connections, precast seismic performance, energy dissipation.

INTRODUCTION

The seismic behavior of precast concrete structures depends significantly on the design and performance of the connections between structural elements. As global construction trends increasingly favor precast systems due to their economic and operational benefits, understanding how these systems behave under seismic loads has become critical, especially for ensuring structural integrity and safety in earthquake-prone areas.

This literature review synthesizes research and experimental findings on various precast column-to-foundation connections, including the popular grouted sleeve and pocket connections, focusing on their seismic performance. The review also addresses the current state of knowledge, recent advancements, and future research areas for enhancing the seismic resilience of precast concrete structures.

Types of Precast Column Foundation Connections

Precast column foundation connections are critical components of precast structures. Several connection types have been developed to ensure the safe transmission of loads from columns to foundations. Among the most studied connection methods are:

1. Base Plate Connection: This method involves using a base plate that is bolted to the foundation. While it offers excellent stability, it requires precise alignment and careful handling to ensure that the column remains vertical and properly supported.
2. Grouted Pocket Connection: In this approach, the column is seated in a pocket formed within the foundation and is later filled with grout to ensure adequate bonding and load transfer. This type of connection offers good performance under both vertical and lateral loads, but it is vulnerable to grout layer damage during seismic events if not carefully constructed.
3. Grouted Sleeve Connection: This method involves inserting the column’s reinforcement bars into sleeves that are embedded in the foundation. The sleeve is filled with high-strength grout, ensuring load transfer between the column and foundation. Grouted sleeve connections have gained significant popularity due to their ease of assembly and their relatively good performance under seismic loading conditions.

Seismic Performance of Precast Connections

The seismic performance of precast connections is measured based on several criteria, including ductility, energy dissipation, and ultimate load capacity. Experimental studies on various precast column foundation connections reveal key insights:

1. Ductility and Energy Dissipation:
    - Grouted sleeve connections exhibit high levels of ductility, allowing for significant energy dissipation before failure. However, compared to cast-in-place monolithic connections, the overall energy dissipation is slightly lower due to the presence of the grout layer, which tends to degrade under large seismic displacements.
    - Pocket connections, due to their design, offer better cyclic stability and energy dissipation than grouted sleeves, making them an excellent choice for seismic zones, provided that they are carefully constructed to avoid premature failure due to grout degradation.
2. Load Capacity:
    - Experimental results indicate that while cast-in-place connections generally offer higher ultimate load capacities, specific precast solutions, such as those using improved grouted sleeve designs, can approach the same performance levels. Precast connections, like those in pocket or grouted sleeve designs, are especially advantageous for projects requiring faster construction without compromising on seismic safety.
3. Failure Modes:
    - In most precast specimens, failure occurred at the junction between the column and the foundation, with the grout layer in grouted sleeve connections cracking and degrading during large displacements. This highlights the importance of ensuring that the grout material is of high quality and properly installed to avoid premature connection failure during seismic events.
    - Pocket connections, while stable under cyclic loading, were found to be susceptible to cracking at the foundation-column interface. Proper detailing and reinforcement are necessary to mitigate such failures.

Advancements in Precast Connections

In recent years, significant advancements have been made in improving the seismic performance of precast column foundation connections:

1. Improved Grout Materials:
    - High-strength grouts with enhanced bonding characteristics have been developed to improve the seismic performance of both grouted sleeve and pocket connections. These grouts offer better adhesion between the column reinforcement and the sleeve or pocket, thereby enhancing load transfer during seismic events.
2. Threaded and Ribbed Sleeve Designs:
    - Research has shown that the use of threaded sleeves or sleeves with mechanical interlocks can significantly improve the bond strength between the reinforcement bars and the grout. These designs provide additional frictional resistance, reducing the likelihood of premature failure during seismic loading.
3. Hybrid Connection Systems:
    - The combination of precast and steel structural elements, particularly in hybrid connection systems, has proven to enhance both the ductility and load-bearing capacity of precast column-to-foundation connections. Hybrid systems offer improved performance in terms of energy dissipation and cyclic stability.
4. Numerical Modelling:
    - Advances in finite element modelling (FEM) and other simulation techniques have enabled engineers to better predict the seismic performance of precast connections, providing an opportunity to optimize designs before they are implemented in the field. These models have been shown to closely match experimental results, making them a valuable tool in the design of precast structures.

Future Research Directions

While significant progress has been made in understanding the seismic behavior of precast column foundation connections, several areas still require further investigation:

1. Grouting Defects:

- Research into the effects of grouting defects, such as voids or incomplete filling, on the performance of grouted sleeve connections is still limited. Future studies s Future Research Directions
- While significant progress has been made in understanding the seismic behavior of precast column foundation connections, several areas still require further investigation:
- Grouting Defects:
- Research into the effects of grouting defects, such as voids or incomplete filling, on the performance of grouted sleeve connections is still limited. Future studies should focus on identifying and mitigating these defects to ensure the reliability of precast systems under seismic loading.
- Fire Resistance:
- Fire resistance is an important consideration for precast structures, especially in urban settings. Future research should focus on understanding how high temperatures affect the performance of grouted sleeve and pocket connections, particularly in post-seismic fire conditions.
- Long-term Performance:
- The long-term performance of precast column foundation connections, particularly with respect to durability and fatigue under cyclic loading, needs further exploration. Understanding the effects of aging and material degradation over time will help improve the resilience of precast systems in seismic regions.
- Customized Sleeve Designs:
- The development of customized sleeve designs with improved mechanical properties, such as those incorporating shear keys or other interlocking mechanisms, could offer better performance under seismic loading. Future research should focus on optimizing these designs for real-world applications.
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This review paper has synthesized experimental investigations on the bond strength of steel bars embedded in various types of concrete, including conventional concrete, fibre-reinforced concrete (FRC), and high-strength concrete (HSC). The findings reveal that bond strength is significantly influenced by concrete type, with ultra-high-performance concrete (UHPC) demonstrating the highest bond strength compared to very high-strength concrete (VHSC) and high-strength concrete (HSC). The inclusion of different types of fibre-reinforced polymer (FRP) bars, such as basalt, glass, and carbon, also affects bond performance, with variations in bond strength observed due to differences in material properties.

Moreover, the review highlights the impact of factors such as embedment length and fibre content. For instance, shorter embedment lengths generally yield higher bond strengths, and increasing fibre volume in concrete can enhance bond performance, albeit to varying extents. Additionally, the grade and type of reinforcing bars play a crucial role, with higher-grade bars and appropriate aspect ratios for fibres contributing to improved bond strength.

Overall, the reviewed studies underscore the importance of selecting suitable concrete types, reinforcement materials, and design parameters to optimize bond strength in reinforced concrete structures. Future research should continue to explore these variables in diverse contexts to refine design guidelines and improve structural performance.

Conclusion

Precast concrete structures have proven to be a viable and efficient alternative to traditional cast-in-place construction, especially in earthquake-prone regions. The seismic performance of these structures is heavily dependent on the strength and reliability of the connections between structural elements. Through advancements in grouted sleeve and pocket connections, as well as the development of new materials and designs, precast systems have shown considerable promise in withstanding seismic forces. However, continued research and innovation are needed to address existing challenges, such as grouting defects, fire resistance, and long-term durability, to further enhance the resilience and safety of precast structures.

References

1. Martin, L.D. & Perry, C.J. (2004). *PCI Design Handbook: Precast and Prestressed Concrete*. Vol. 1, Prestressed Concrete Institute.
2. Taylor, G.R., Neu, I.D., & Neu, I.D. (1956). *The American Railroad Network, 1861-1890*. University of Illinois Press.
3. Henin, E. & Morcous, G. (2015). *Reinforcing Bar Splice Sleeve for Precast Concrete Construction*. Engineering Structures, 83, 154-162.
4. Yuan, Z., Sun, C., & Wang, Y. (2018). *Design for Manufacture and Assembly-Oriented Parametric Design of Prefabricated Buildings*. Automation in Construction, 88, 13-22.
5. Mohammed, H.A. (2016). *Precast Concrete Precast Building System Solutions*. The Masterbuilder.
6. Lu, Z., et al. (2019). *Mechanical Behaviour of Grouted Sleeve Splice Under Uniaxial Tensile Loading*. Engineering Structures, 186, 421-435.
7. Elliott, K.S. (2016). *Precast Concrete Structures*. CRC Press.
8. Engström, B. (2008). *Structural Connections for Precast Concrete Buildings*. FIB: Commission C, 6.
9. Darwin, D., Dolan, C.W., & Nilson, A.H. (2016). *Design of Concrete Structures*. McGraw-Hill Education.
10. Breccolotti, M., et al. (2017). *Wet-Joint Techniques for the Construction of Precast Concrete Pipe Rack Structures in Remote Seismic Zones*. PCI Journal.
11. Prasad, C. & Patchigolla, P. (2015). *Structural Connections for Precast Concrete Buildings - Review of Seismic and Other Design Provisions in Various International Codes*. The Masterbuilder.
12. Nimse, R.B., Joshi, D.D., & Patel, P.V. (2014). *Behavior of Wet Precast Beam Column Connections Under Progressive Collapse Scenario: An Experimental Study*. International Journal of Advanced Structural Engineering, 6(4), 149-159.
13. Cai, G., et al. (2019). *A Demountable Connection for Low-Rise Precast Concrete Structures with DfD for Construction Sustainability-A Preliminary Test Under Cyclic Loads*. Sustainability, 11(13), 3696.
14. Taher, S.E.-D., Atta, A., & Sharkawi, A.E.-D. (2016). *Wet vs. Dry Techniques in Connecting Piecewise Precast Reinforced Concrete Beam-Column Elements in Moment Resisting Frames*. Journal of Structural Engineering.
15. Alias, A., et al. (2013). *Structural Performance of Grouted Sleeve Connectors with and Without Transverse Reinforcement for Precast Concrete Structure*. Procedia Engineering, 53, 116-123.
16. Lu, Z., et al. (2017). *Studies on Seismic Performance of Precast Concrete Columns with Grouted Splice Sleeve*. Applied Sciences, 7(6), 571.
17. Hosseini, S.J.A. (2015). *Bond Behaviour of Grouted Spiral and Splice Connection Under Direct Axial and Flexural Pullout Load*. Universiti Teknologi Malaysia.
18. Qiong, Y. & Zhiyuan, X. (2017). *Experimental Study of Grouted Sleeve Lapping Connector Under Tensile Load*. Građevinar, 69(6), 453-465.
19. Pantelides, C.P., Ameli, M., & Reaveley, L.D. (2017). *Evaluation of Grouted Splice Sleeve Connections for Precast Reinforced Concrete Bridge Piers*. PCI Journal.
20. Rahman, A.B.A. & Yee, O.H. (2018). *Grout Filled Steel Pipe Integrated with Shear Key for Precast Concrete Connection*. E3S Web of Conferences.
21. Levitt, M. (1982). *Precast Concrete: Materials, Manufacture, Properties, and Usage*. CRC Press.
22. Hua, L.J., et al. (2008). *Performance of CS-Sleeve Under Direct Tensile Load: Part I: Failure Modes*. Malaysian Journal of Civil Engineering, 20(1).
23. Lin, F. & Wu, X. (2017). *Effect of Sleeve Length on Deformation Properties of Grouted Splices*. Građevinar, 69(7), 537-546.
24. Einea, A., Yamane, T., & Tadros, M.K. (1995). *Grout-Filled Pipe Splices for Precast Concrete Construction*. PCI Journal, 40(1), 82-93.

25. Henin, E. & Morcous, G. (2015). *Non-Proprietary Bar Splice Sleeve for Precast Concrete Construction*. Engineering Structures, 83, 154-162.

26. Kim, H.-K. (2012). *Bond Strength of Mortar-Filled Steel Pipe Splices Reflecting Confining Effect*. Journal of Asian Architecture and Building Engineering, 11(1), 125-132.

27. Zheng, G., et al. (2020). *Mechanical Performance for Defective and Repaired Grouted Sleeve Connections Under Uniaxial and Cyclic Loadings*. Construction and Building Materials, 233, 117233.

28. Xu, F., et al. (2018). *Experimental Bond Behavior of Deformed Rebars in Half-Grouted Sleeve Connections with Insufficient Grouting Defect*. Construction and Building Materials, 185, 264-274.

29. Li, Z., et al. (2019). *Ultrasonic Detection Method for Grouted Defects in Grouted Splice Sleeve Connector Based on Wavelet Pack Energy*. Sensors, 19(7), 1642.

30. Yan, H., Song, B., & Wang, M. (2019). *Ultrasonic Testing Signal of Grouting Defect in Prefabricated Building Sleeve*. Ekoloji, 28(107), 945-953.

31. Wang, J., et al. (2016). *Experimental Study on Bond Slip Relationship of Steel Sleeve*. MATEC Web of Conferences.

32. Sayadi, A.A., et al. (2014). *The Relationship Between Interlocking Mechanism and Bond Strength in Elastic and Inelastic Segment of Splice Sleeve*. Construction and Building Materials, 55, 227-237.

33. Brenes, F.J., Wood, S.L., & Kreger, M.E. (2006). *Anchorage Requirements for Grouted Vertical-Duct Connectors in Precast Bent Cap Systems*.

34. Zheng, Y., Guo, Z., & Ming, X. (2015). *Pullout Bond Properties of Grout-Filled Mechanical Splice for Precast Concrete Construction*. 5th International Conference on Civil Engineering and Transportation, Atlantis Press.

35. Ling, J.H., et al. (2012). *Behavior of Grouted Pipe Splice Under Incremental Tensile Load*. Construction and Building Materials, 33, 90-98.

36. Zhao, X.-L., Grundy, P., & Lee, Y.-T. (2002). *Grout Sleeve Connections Under Large Deformation Cyclic Loading*. International Offshore and Polar Engineering Conference.

37. Zhao, X.L., et al. (2006). *Behavior of Grouted Sleeve Connections at Elevated Temperatures*. Thin-Walled Structures, 44(7), 751-758.

38. Wu, Y.C., Sheng, L.P., & Zhao, W.J. (2018). *Research and Development Status of Grouted Splice Sleeve in Precast Concrete Structure*. E3S Web of Conferences.

39. Elsayed, M., Nehdi, M.L., & Ghrib, F. (2019). *Predicting Behavior of Grouted Dowel Connections Using Interfacial Cohesive Elements*. Applied Sciences, 9(11), 2344.

40. Alias, A., et al. (2014). *Performance of Grouted Splice Sleeve Connector Under Tensile Load*. Journal of Mechanical Engineering and Sciences, 7, 1096-1102