SEISMIC DESIGN OF SOCKET CONNECTIONS: BRIDGING EXPERIMENTS, MODELLING, AND ENGINEERING PRACTICE

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Abstract

Socket connections in precast bridge systems are increasingly adopted within Accelerated Bridge Construction (ABC) to enhance constructability, resilience, and post-earthquake reparability. Among these, column–drilled shaft socket connections (CDSSCs) provide a highly efficient solution by directly connecting columns to single-pile foundations, eliminating the need for large pile caps. However, their design remains challenging due to the complex interaction between bending action and prying effects, as well as the sensitivity of their behaviour to geometric and reinforcement parameters. Existing design methods often exhibit significant inconsistencies, leading to either overly conservative designs or unsafe shaft-dominated failures.

This study presents a comprehensive investigation aimed at establishing a rational performance-based design framework for CDSSCs. The research integrates large-scale experimental testing, advanced finite element (FE) modelling, and analytical development. A total of nine half-scale reinforced concrete specimens were tested under quasi-static cyclic loading to examine the influence of axial load, shaft transverse reinforcement (STR), column embedment length, and shaft geometry. The test results demonstrate that CDSSC behaviour is governed by a coupled force-transfer mechanism involving flexural action and prying effects, which induce significant hoop tensile stresses in the shaft. The capacity-to-demand ratio for hoop forces emerges as a key parameter controlling the transition between undesirable shaft failure and the intended column-dominated failure mode.

The experimental campaign shows that insufficient STR leads to premature shaft failure characterised by circumferential cracking, concrete spalling, and bond degradation. In contrast, reducing axial load or enhancing shaft confinement—through increased STR area, embedment length, or wall thickness—promotes the formation of plastic hinges in the column, enabling ductile and predictable seismic response. Notably, the tests reveal that the compression side governs force transfer, and that low levels of axial load significantly reduce hoop tension demand.

Validated FE models developed in ABAQUS accurately replicate the observed global and local behaviour, including failure modes and crack patterns. These models allow an extensive parametric exploration, confirming that column-controlled failure can be consistently achieved without excessive reinforcement or embedment. The results further highlight that increasing STR area is more effective than modifying other parameters for improving shaft performance, while variations in column configuration have limited influence on the overall seismic response.

Based on these insights, a mechanics-based design methodology is proposed. The approach explicitly models the transfer of forces between column and shaft through inclined strut-and-tie mechanisms, enabling the calculation of lateral pressures, hoop stresses, and associated tensile demands. The framework accounts for the combined contributions of reinforcement and concrete in resisting hoop forces and introduces a clear capacity-to-demand verification criterion to ensure safe design. Importantly, the methodology replaces traditional reinforcement spacing rules with a unified parameter based on the total STR area, which is better suited to multi-parameter design scenarios.

Overall, the proposed framework provides a consistent, physically grounded basis for the design of CDSSCs, thereby resolving key limitations of current approaches. By linking experimental evidence, numerical simulations, and simplified analytical formulations, the study offers a practical pathway to achieving safe, predictable, and materially efficient socket connections. These findings contribute to improving the reliability and wider adoption of precast bridge systems in seismic regions.