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FLEXURAL-SHEAR PERFORMANCE AND SEISMIC DESIGN THEORY OF REINFORCED CONCRETE HOLLOW COLUMNS

W. Wei [(1)], C.J. Shao [(2)]

[(1)] *School of Civil Engineering and Architecture, Guangxi University, Nanning, China, weiw@gxu.edu.cn*
[(2)] *School of Civil Engineering, Southwest Jiaotong University, Chengdu, China, shao_chj@126.com*

Extended Abstract

Reinforced concrete hollow columns, particularly round-end hollow columns (REHCs), are widely used in railway bridges in seismically active mountain regions due to their material efficiency, reduced self-weight, and adaptability to complex terrains. However, compared to solid columns with the same external dimensions, hollow sections suffer from reduced concrete confinement and a smaller effective shear area, making them more vulnerable to flexural-shear damage or even brittle shear failure under strong earthquake excitations. This vulnerability is further complicated by the variable cross-section geometry along the column height, which is common in railway REHCs. Current seismic design codes, including Chinese railway standards, lack specific provisions for the flexural-shear strength and deformation capacity of such hollow columns, and existing shear strength models—mostly developed for solid or uniformly hollow sections—do not adequately capture the unique failure mechanisms of REHCs.

To address this knowledge gap, a systematic experimental and analytical study was conducted on the flexural-shear performance of REHCs. Seven 1/6-scale REHC specimens with variable cross-sections (external slope 45:1, internal slope 75:1) were designed and tested under quasi-static cyclic loading (Figure 1). The specimens had a shear-span ratio of 2.81 and a prototype column height of 24 m. Key design variables included longitudinal reinforcement ratio and stirrup ratio. The tests revealed distinct flexural-shear failure characteristics: flexural cracks first developed at the column base, then propagated diagonally after longitudinal reinforcement yielded. The angle between the diagonal cracks and the column axis was approximately 45° at the neutral axis. As cracking progressed into the compression-shear zone, stirrups yielded, and the column's shear capacity gradually decreased with increasing displacement.

What is particularly unique about this study is the identification of two previously overlooked mechanisms in hollow column flexural-shear failure: (1) non-uniform deformation of stirrups crossing the diagonal cracks, where crack width decreases along the crack path, leading to non-simultaneous yielding of stirrups; and (2) the tension shift effect in longitudinal reinforcement, where shear forces induce additional tensile forces in the longitudinal bars beyond those from pure flexure, which in turn suppresses diagonal crack growth and enhances shear transfer across cracked sections. These mechanisms are not accounted for in conventional shear strength models.

Based on these experimental observations, a new mechanical model for flexural-shear strength was developed, integrating the contributions of concrete, stirrups (accounting for non-uniform deformation), and longitudinal reinforcement (accounting for tension shift). The proposed model also incorporates the effects of displacement ductility, axial compression ratio, and shear-span ratio.

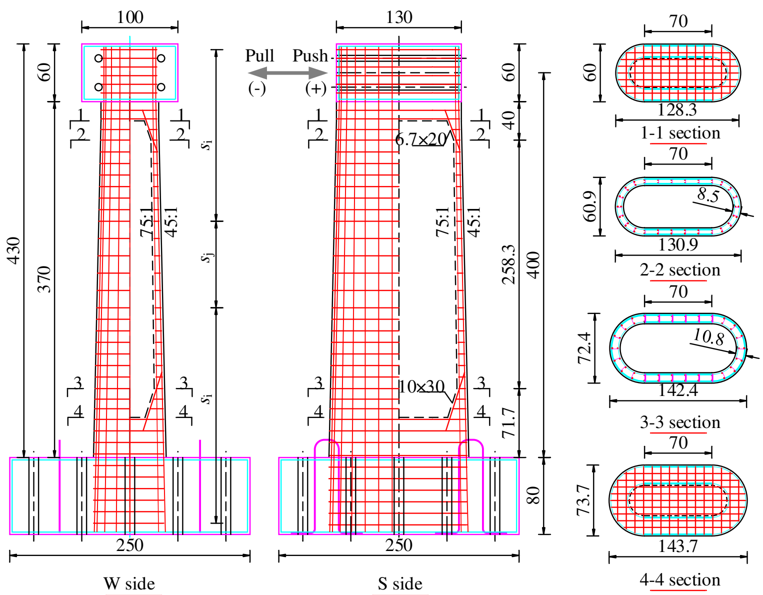

Figure 1- Configuration and reinforcement of the column specimens (Unit: mm).

Additionally, a deformation capacity design method was developed based on the plastic displacement equivalence principle, accounting for flexural, tension-shift, and slippage deformations. The proposed design framework provides, for the first time, a rational approach to evaluate both flexural-shear strength and deformation capacity of reinforced concrete hollow columns.

The highlights of the experimental program, observed failure mechanisms, development of the innovative strength model, validation against existing data, and practical design recommendations will be presented. The proposed model offers a significant improvement over current practice and is expected to enhance the seismic design of hollow columns in high-seismic regions.

Keywords*: Round-end hollow columns; flexural-shear strength; non-uniform stirrup deformation; tension shift; seismic design.*