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Cyclic performance of steel and composite bracing members

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Abstract

This paper describes an experimental study on the response of hollow and filled steel members to monotonic and cyclic axial loading. Monotonic tests were first performed on short specimens to establish their compressive and tensile axial resistances and to investigate the effect of infill on local buckling and ductility. These were followed by cyclic tests on longer bracing members with three different cross-section sizes. The presence of concrete infill was observed to influence the mode of failure displayed by the specimens, as well as their compression and tension load responses. The ductility capacities of the individual specimens are compared, and the effects of slenderness, steel strength and infill are quantified. The experimental findings are compared with the recommendations of a number of international codes of practice and previous research studies on the seismic response of steel braces. It is found that the infill contributes to the compression resistance of the brace, even after multiple inelastic load reversals, and that it can improve ductility capacity by preventing or limiting local buckling.

Keywords: Bracing members; Earthquake resistance; Concrete infill; Buckling strength; Cyclic loading; Ductility capacity; Post-buckling resistance

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1. Introduction

The earthquake resistance of building structures can be effectively provided through the utilisation of braced-frame configurations. Rectangular (RHS) and square (SHS) hollow sections are often employed as bracing members for structural as well as aesthetic reasons. For a severe seismic event, the main design objective is to maintain overall structural integrity without collapse. As part of the capacity design philosophy, energy is dissipated through critical members and components, which are expected to undergo inelastic cyclic deformations without suffering significant loss of strength. Clearly, in the case of braced frames, these critical members are the diagonal braces, for which a detailed assessment of cyclic response is fundamental to the seismic design process.

Compared to other forms of steel member, hollow sections are very effective at resisting axial loads. However, when such sections possess thin walls, they are susceptible to local buckling at high compressive strains. Under cyclic loading, the onset of local buckling reduces the ductility of the brace member and may lead to brittle failure. This has been observed in a number of experimental studies on cold-formed hollow section bracing members (for example, [1–4]).

It was envisaged that filling hollow steel sections with concrete or mortar would improve their squash load but, more importantly, it would delay the onset of local buckling and improve the member's post-buckling response. In addition, the inherent improvement in fire resistance provided by composite members may also lend this member type as a viable option in practical design situations.

A large amount of research has been performed into the response of concrete-filled RHS stub columns, such as [5–16]. In summary, it was found that the presence of concrete infill eliminated or delayed local buckling in steel hollow sections, leading to increased ductility. At certain values of longitudinal strain, the infill begins to increase in volume due to microcracking, which induces concrete confinement by the steel tube. The confining pressure is less, and the material degradation greater, for square compared with circular sections. This is because for square columns, the lateral confining pressure is not uniformly applied to the concrete surface. As a result, the concrete core and steel tube are not in firm contact with each other, and local buckling of the tube may take place.

Comparatively little research has been performed on void-filled RHS braces subjected to cyclic axial loading. Earlier experimental work by Liu and Goel [17] on the cyclic behaviour of cold-formed steel RHS bracing members filled with concrete found that the infill improved specimen buckling, post-buckling and tensile capacity, reduced the severity of local buckling and hence delayed cracking of the steel, and ultimately increased ductility capacity. The presence of concrete infill led to the greatest improvement in performance for specimens with larger width-to-thickness ratios and smaller overall slenderness ratios, as these members are more susceptible to local buckling. It was noted that increasing the strength of the concrete infill over 28 MPa and/or using steel fibres did not affect the behaviour of the composite specimens. This was because the specimens were mainly governed by overall and local buckling of the steel tubes.

Liu and Goel [17] proposed an approximate method for computing the first buckling load based on the separate capacities of the steel tube and concrete, and assuming strain compatibility between the two materials.