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Effects of loading patterns on seismic behavior of CHS KK-connections under out-of-plane bending

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ABSTRACT

This paper deals with experimental investigations to study the seismic behavior of circular hollow section (CHS) KK-connections used in steel tubular structures. Cyclic out-of-plane bending (OPB) loading patterns were varied in testing two full-scale specimens in order to evaluate their effect on connection behavior. Test results indicated that the strength efficiency of these connections significantly depended on the loading patterns. CHS KK-connections under alternate opening and closing out-of-plane bending (AOCO) developed more satisfactory levels of ductility and energy dissipation than that under alternate clockwise aligned and counter-clockwise aligned out-of-plane bending (ACCO), although the final failure modes for both showed similar fracture initiated from the chord wall. This observation was further verified by the proposed simplified analytical model results. Finite element (FE) analyses were performed to simulate the experimental behavior and facilitate the interpretation of the important test observations. Additionally, it was found that the energy dissipation due to the ductile chord crack propagation could be utilized effectively to some extent for earthquake resistance.

1. Introduction

Single-layer reticulated shells have become a particularly popular choice for the large-span roof systems of steel structures because of their light weight, appealing architectural appearance and rapid erection. Circular hollow sections (CHS) are a common selection for primary load-carrying members of this type of onshore structures. In the practical applications, the sections are profiled and welded to form CHS unstiffened connections. The distributed load on the CHS members, especially when used in single-layer reticulated roof structures with very large span-to-rise ratio or with very small curvature, may generate significant out-of-plane bending (OPB) moments on the CHS KK-connections (as highlighted in Fig. 1 for a typical engineering application) under vertical excitations in the event of an earthquake. Many of successful large-span tubular structural applications now exist in regions of high seismic risk, leading to the great concerns of the engineering community about the behavior of CHS connections under seismic loading. Further, a US government report [1] concluded that “very little is known about the cyclic inelastic behavior of joints in offshore platforms subjected to either extreme storms or the earthquakes”. They designated the need for research into this area as a “highest priority” item.

Existing studies concerned with tubular connections focused on ultimate static capacity as their main target. Although some work has considered inelastic dynamic behavior in response to extreme wave events, it has consisted mostly of high cycle loads to investigate fatigue performance. On the other hand, limited studies on seismic behavior of tubular joints were almost restricted to the case under axial loads, which can be summarized as follows. Kurobane [2], Kurobane and Ogawa [3], and Kurobane et al. [4] accomplished 23 complete tubular truss tests. The emphasis was laid on the interacting behavior of connections and trusses. No significant effects due to different boundary conditions between actual joints in truss and isolated joints (e. g. secondary moments and end restraint) were found. Qin et al. [5] and Soh et al. [6] investigated the behavior of completely overlapped tubular joints used in the eccentrically braced offshore jackets. The energy analysis indicated that the local buckling at the intersection area was the main energy-dissipating mechanism. Finite element analysis showed that the completely overlapped joint performed better than N-joints under seismic loadings. Four multiplanar KK tubular joints were experimentally researched both under monotonic and repeated loads by Chen and Zhao [7]. A special loading device was designed to perform cyclic loading tests in order to produce greater internal forces in truss members and the joints. The research revealed the characteristics of the joints that plastic deformation accumulated in one direction in which plastic deformation occurred firstly, and monotonic load–deformation curves could generally envelop those under repeated loading conditions. Wang and Chen [8] and Wang et al. [9] carried out tests on CHS T-joints and X-joints to investigate failure modes and cyclic performance under varied loading conditions. It was found that a significant distinction existed in the energy dissipation mechanism for tubular joints under different loading

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