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Local buckling and concrete confinement of concrete-filled box columns under axial load

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ABSTRACT

Nine square concrete-filled box column (CFBC) specimens were fabricated and tested under monotonic axial loading. The loading tests were simulated with the commercial finite element program ABAQUS. The feasibility of the finite element models was verified. Based on tests and FEM simulation results, the following conclusions can be made. The development procedure of the concrete confinement mechanism of CFBCs was identified. After concrete crushing occurs, concrete confinement provided by the horizontal arch action starts to become noticeable. After buckling of the column wall, vertical arch action, which provides additional concrete confinement, is developed. Horizontal arch action acting together with vertical arch action provides significant confinement for the concrete to gain and recover its strength. A larger width-to-thickness ratio of the column wall results in the earlier development of vertical arch action. From the concrete confinement mechanism, there will be a strength drop and a strength recovery in the concrete component of the load versus axial strain curve. As a result of these findings, Mander's concrete confinement model and Sakino's concrete analytical model were not able to reasonably predict the stress–strain behavior of the concrete inside CFBCs.

1. Introduction

The use of concrete-filled hollow sections for columns presents many advantages. First, the concrete core can prevent the steel box from buckling inward. Second, the confinement provided by the steel box can enhance the mechanical properties of the concrete. Finally, no formwork is required to cast the concrete. As a result, these columns provide extra strength and stiffness in an economical and environmentally friendly manner.

Fig. 1 shows some of the different types of concrete-filled square hollow sections (SHS). The sections shown in Fig. 1(a) and (b), used in low- to mid-rise buildings, are usually called concrete-filled tubes (CFT), and their cross-sectional width rarely exceeds 400 mm. They have gradual transitions without welds at the corners of the cross section, and are thus less likely to develop longitudinal cracks near the section corners. The sections shown in Fig. 1(c) and (d) are often used in the columns of high-rise buildings in high-seismic zones, Fig. 1(c) especially. They are referred to as concrete-filled box (CFB) sections herein. This type of column section is usually more than 400 mm wide, has longitudinal welds near the corners of the section, and develops longitudinal cracks near the welds under load. The focus of this study is to investigate the behavior of square CFB columns (CFBC).

When the concrete compressive stress in CFBC is lower than 70% of its compressive strength, f_c', the steel and concrete are basically in the linear elastic range. In this range, the Poisson's ratio of steel (roughly 0.3 [1]) is greater than that of concrete (roughly 0.2 [1,2]). Therefore, the concrete confinement provided by the steel box should be very limited theoretically.

As concrete stress increases beyond $0.7f_c'$, its Poisson's ratio increases and may even exceed 0.5 after concrete crushing occurs [3]. The effects of concrete confinement should become more obvious after concrete crushing occurs since the Poisson's ratio of concrete becomes greater than steel. While the concrete confinement provider of CFBC, which is the column steel plate, is under two-dimensional stress state, the concrete confinement major provider of reinforce concrete member, which is the transverse steel bar, is mainly under one-dimensional stress state. Therefore, the concrete confinement development process and the mechanism behind CFBCs should be different from those of reinforced concrete members under compression. Consequently, Mander's concrete confinement model [4] may not be suitable for the concrete in CFBCs.

There exist many experimental and analytical studies focused on the behavior of concrete-filled SHS columns under axial loading. Most of the experimental research has been focused on CFT columns, with the size of the test specimens limited to 400 mm. The contribution of concrete confinement to the compressive strength of concrete-filled SHS was ignored in some studies [5–7]. Other studies [1,8–13] did consider the concrete confinement effect. Some of these used Mander's concrete confinement model, while others just provided semi-empirical formulae to account

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