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Study on restraint coefficient of the stirrups-stiffened square concrete filled double-skin steel tube axial compression stub columns

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Abstract

This paper proposes a novel structural design for stirrups-stiffened square concrete-filled double-skin steel tubular stub columns (SCFDST) that offers high capacity and superior advantages in terms of low consumption of concrete and steel, as well as economic efficiency. The study includes an axial pressure test on two sets of 8 SCFDST columns with varying hollow ratios and stirrup ratios, with a specific focus on the influence of stirrups on mechanical properties. Experimental results demonstrate that stirrups significantly enhance the mechanical properties of SCFDST columns with large hollow ratios, including stiffness, bearing capacity, and ductility, with a more pronounced effect observed as the stirrup ratio increases. A three-dimensional solid finite element (FE) model of the SCFDST columns is developed and validated using ABAQUS software and appropriate constitutive models. Parameter analysis is then conducted based on the FE model, revealing that the stirrups not only restrain the concrete itself but also provide additional restraint by limiting the deformation of the steel tube. This improvement effect was more significant in the middle of steel tubes section. When stirrup ratio was 0.015, the steel tube had the highest constraint efficiency on the concrete. The study introduces a constraint enhancement factor to represent the enhanced restraining effect of stirrups on the steel tube, which is incorporated into a fresh equation for determining the maximum bearing capacity

determining the maximum bearing capacity (N_u) of SCFDST columns. The derived formula offers clear physical meaning and high accuracy, building upon the existing formula for CFDST columns.

Introduction

Driven by research in recent years, the excellent mechanical properties of concrete filled steel tube (CFST)[1], [2], [3], [4], [5] have been discovered and popularized it in various engineering structures, such as the columns in high-rise buildings, bridge piers, and pile foundations of construction. However, when CFST columns are used in high bridge piers or super high-rise giant columns, the weak link of the CFST column is its bending rigidity and self-weight. To address this issue, the concrete filled dual-layer steel tube, having a particular hollow ratio, has been developed and extensively utilized in recent years.

Considering the advantages of CFDST columns including light weight, large bending stiffness, and construction convenience, researchers have conducted various study on static properties of CFDST, for example, M. Pagoulatou [6], Kojiro Uenaka [7], Tao Z [8], [9], Elchalakani M [10], Han [11], Xie [12] respectively studied and weight. To address this issue, the concrete filled dual-layer steel tube, having a particular hollow ratio, has been developed and extensively utilized in recent years.

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However, earlier studies suggests that the thin walls of the steel tubes in CFDST columns and the lack of connection between them make them susceptible to local buckling. To strengthen restraint of core concrete in thin-walled specimens, Ding [18], [19], [20] conducted an axial compression test to identify an optimal arrangement of the stirrups. impacts of orthogonal, bidirectional, and loop stirrups were examined by comparing the peak load-bearing capability and the eventual failure form of the samples, and the influence of the contact mode between the stirrups and the steel tube on the performance of the walled specimens, Ding [18], [19], [20] conducted an axial compression test to identify an optimal arrangement of the stirrups. impacts of orthogonal, bidirectional, and loop stirrups were examined by comparing the peak load-bearing capability and the eventual failure form of the samples, and the influence of the contact mode between the stirrups and the steel tube on the performance of the reinforcement was compared. The outcomes showed that bidirectional stirrups most effectively enhanced the columns' overall performance, with loop stirrups ranking as the next best alternative. Moreover, for the square specimens, four-sided welding is the most efficient contact mode for improving the seismic performance. In the engineering practice, when column size is small, stirrup cages can also be used to make free contact with steel tube walls [18].

Existing research has shown that in square CFDST, the outer steel tube has a relatively small restraining effect on the concrete, and the inner steel tube only plays a supporting role, which does not greatly improve the mechanical properties. As the stirrups have a positive effect on delaying buckling of steel tube and strengthening constraint effect on concrete, stirrups can be applied to the CFDST columns in the hope of enhancing the stability of steel inner steel tube only plays a supporting role, which does not greatly improve the mechanical properties. As the stirrups have a positive effect on delaying buckling of steel tube and strengthening constraint effect on concrete, stirrups can be applied to the CFDST columns in the hope of enhancing the stability of steel tubes and strengthening the joint action of steel tubes and concrete. According to the current research status, the research on the hollow ratio is only concentrated between 0.2 and 0.5, and there has been no experimental study on the mechanical properties of CFDST columns with high hollow ratio. Moreover, there is still a lack of research on the structural form of stirrup-stiffened CFDST columns. Therefore, this paper puts forward in-depth study on stirrup-stiffened CFDST columns, more specifically, with a new structural form namely stirrup-stiffened CFDST stub columns (SCFDST). Experimental research about axial compression performance on SCFDST specimens in form of SHSO and SHSI with a hollow ratio greater than 0.5 was firstly carried out, and the influence of varying hollow ratios and stirrup proportions on the stiffness, N_u and ductility of SCFDST stub columns were examined and deliberated. The ABAQUS finite element software and reasonable constitutive models were used to establish and verify 3D out, and the influence of varying hollow ratios and stirrup proportions on the stiffness, N_u and ductility of SCFDST stub columns were examined and deliberated. The ABAQUS finite element software and reasonable constitutive models were used to establish and verify 3D solid model of SCFDST columns under axial loading. Once the model's precision has been confirmed, finite element analysis of different parameters was carried out to explore the stress changes in the SCFDST specimens with different stirrup ratio and hollow ratio. Finally, a new formula to calculate the N_u of SCFDST columns was proposed. The formula considers the reinforcement of the restraining effect of the stirrups on steel tubes combined with the existing formula of ordinary CFDST columns.

Section snippets

Manufacturing of specimens

This experiment includes 8 test specimens with main parameters of hollow ratio and equivalent stirrup ratio. Compared with experiments from previous literatures where the hollow ratio was usually 0.25–0.5, the hollow ratio for this study is much larger at 0.5. As is shown in Fig. 1, the stirrup ratio. Compared with experiments from previous literatures where the hollow ratio was usually 0.25–0.5, the hollow ratio for this study is much larger at 0.5. As is shown in Fig. 1, the stirrups are placed between double steel tubes of CFDST columns.

The parameters of SCFDST specimens include concrete strength and yield strength of steel, wall thickness of steel tubes, section hollow ratio, and...

Finite element model parameter setting

The three-dimensional solid FE models of axially compressed SCFDST stub column were modeled by ABAQUS. In the process of modeling, the settings of the element type and contact method were shown in Table 2. The structured model grid is created as shown in Fig. 8. Reasonable constitutive used in modeling include material property parameters and stress-strain relationships are detailed in Ref. [24]....

Model verification

Full-scale modeling and analysis of 8 sets of the SCFDST specimens were performed by using

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Parameter value

In order to make the formula have a better guiding significance for engineering practice, finite element modeling analysis was performed according to the common conditions in engineering, and the influence of the material strength, section hollow ratio, stirrup ratio, cross section steel ratio on the ultimate bearing capacity was taken into account. 144 models were established for research and their main parameters were as follows: the external tube section width B_0 was fixed at 2000 mm; the...

Conclusions

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This paper proposes a new structure of SCFDST columns which have the advantages of light weight, low material consumption, high bearing capacity. A combined experimental, numerical and analytical study of 8 SCFDST stub columns with two hollow ratios and four sets of stirrup ratios was carried out. The experimental findings illustrate that stirrups significantly boost the stiffness, load-bearing capacity, and ductility of SCFDST columns. They also enhance the mechanical characteristics of...

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared toinfluence the work reported in this paper....

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