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Analysis and design of axially loaded ring-beam joints connecting steel tubed-RC column and RC beams

Yuekai Tao [a], Biao Yan [b], Dan Gan [c], Yunfei Zhao [c]

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Abstract

Abstract

This work proposes a reinforced concrete (RC) ring-beam joint system for connecting circular tubed-reinforced concrete (TRC) columns and RC beams. In the joint zone, a thin-walled core steel tube is embedded to reduce the size of the RC ring beam, which is beneficial to construction convenience and architectural layout. A simplified model is established to allow for both the confinement effect of the core steel tube and the load-carrying capacity contribution of the ring beam. This simplified model enables the analysis of the load-resisting mechanism underlying the proposed joint, along with the derivation of an equation for its axial compression capacity. Furthermore, a high-fidelity finite element model is established and validated through test results. Parameter analysis was then conducted to assess the effects of concrete strength, yield strength of the steel tube, thickness of the steel tube, and height of the core steel tube on both the core steel tube stresses and the axial load-capacity of the joints. Formulas for calculating circumferential stresses and longitudinal stresses of the core steel tube are also proposed. The predictions agree well with the results obtained from test and parameter analysis. Lastly, design recommendations and model enables the analysis of the load-resisting mechanism underlying the proposed joint, along with the derivation of an equation for its axial compression capacity. Furthermore, a high-fidelity finite element model is established and validated through test results. Parameter analysis was then conducted to assess the effects of concrete strength, yield strength of the steel tube, thickness of the steel tube, and height of the core steel tube on both the core steel tube stresses and the axial load-capacity of the joints. Formulas for calculating circumferential stresses and longitudinal stresses of the core steel tube are also proposed. The predictions agree well with the results obtained from test and parameter analysis. Lastly, design recommendations and procedures for the joint are proposed, and a design example is given with three types of joints details. The results demonstrate the advantages of the proposed joint in terms of convenient construction and favorable cost-effectiveness.

Introduction

Concrete-filled steel tubular (CFST) columns, formed by filling concrete into steel tube,

Introduction

Concrete-filled steel tubular (CFST) columns, formed by filling concrete into steel tube, possess high load and ductility capacities [1], [2], [3]. Circular tubed-reinforced-concrete (TRC) columns are a type of CFST columns [4], [5], [6], which are characterized by the disconnection of the steel tube at the joint zone (Fig. 1(a)) [7], [8], [9]. Therefore, the steel tube of a circular TRC column does not directly carry applied loads but primarily serves to confine the core concrete [10].When a TRC and CFST column are with the same amount of steel and concrete materials, a circular TRC column has a higher axial load capacity and better fire resistance [11], [12]. Engineering practices in buildings and bridge structures show that circular TRC columns have extensive application potential [13].

The detailing of the joint connecting the TRC column and RC beams can highlight the merits of reinforced concrete (RC) joints, i.e., the longitudinal steel reinforcing bars in RC beams can pass through the connection zone, which makes the joint integrate and robust [14], [15], [16]. However, experimental investigations demonstrated that the joint zone with densely can pass through the connection zone, which makes the joint integrate and robust [14], [15], [16]. However, experimental investigations demonstrated that the joint zone with densely arranged stirrups had a smaller axial load capacity than the TRC column, so the joint zone was crushed, as shown in Fig. 1(b) [17]. Therefore, to compensate for the reduction in the load capacity caused by the disconnection of the steel tube, it is crucial to propose an integrate, robust and construction-friendly joint system of for TRC structures.

There are three strengthening methods commonly used for enhancing the load capacity of circular TRC/CFST columns to RC beam joints: the joint zone with an external steel tube, the joint zone with a RC ring beam, and the joint zone with a core steel tube.

Fig. 2(a) illustrates the joint zone with an external steel tube. The external steel tube in the joint zone eliminates the requirement for formwork. However, the external steel tube needs to be perforated to accommodate the passage of longitudinal beam reinforcement, which potentially weakens the confinement effect [17], [18], [19].

Fig. 2(b) illustrates the joint zone with a RC ring beam, which enlarges the load-carrying area and provides confinement for the core concrete [20]. However, the construction of ring beams necessitates additional formwork and reinforcement, which increases construction costs and time consumption. Additionally, the significant size of the ring beam is aesthetic undesirable [21], [22].

Fig. 2(c) illustrates the joint zone with a core steel tube. This type of joint is known for its simplicity and ease of construction. However, it should be noted that the inclusion of through-length core steel tubes may increase construction costs and complexities for beams passing through joint zones [23], [24].

At present, there are some defects in the proposed joint. A better type of joint needs to be proposed. The compound joint can combine the advantages of various reinforcement methods, but it is often more complicated. Therefore, scholars need to consider on the basis of existing research, and propose a joint that can meet the requirements, which is simple in form and convenient for construction.

Each of the above-mentioned methods has its own advantages and disadvantages in terms of load-carrying capacity, construction complexity, and cost. Therefore, it is attractive and applicable to combine the merits of both load-carrying capacity, construction complexity, and cost. Therefore, it is attractive and applicable to combine the merits of both the ring beam and the core steel tube to provide a joint system of connecting circular TRC columns and RC beams.

The proposed joint system is illustrated in Fig. 3. The proposed joint consists of the joint zone with a core steel tube and the joint zone with a RC ring beam. Both the core steel tube and the ring beam can contribute to the axial compression capacity of the joint zone. The core steel tube can reduce the size of the ring beam, and the ring beam can not only reduce the steel consumption of the core steel tube but also avoid the weak cross-section of the joint zone. The core steel tube is placed around the longitudinal reinforcement of the column, effectively confining both the longitudinal reinforcement and the core concrete. The beam longitudinal reinforcement passes through the gap between the core steel tube and the steel tube of the column, eliminating the need for openings in the core steel tube and simplifying the construction process. To enhance the bond between the core steel tube and the concrete, shear connectors are welded on the outer surface of the core steel tube. The ring beam can increase the load-carrying area of the joint zone in addition to improving the confinement gap between the core steel tube and the steel tube of the column, eliminating the need for openings in the core steel tube and simplifying the construction process. To enhance the bond between the core steel tube and the concrete, shear connectors are welded on the outer surface of the core steel tube. The ring beam can increase the load-carrying area of the joint zone in addition to improving the confinement on the joint concrete, and hoops are arranged in the ring beam to prevent surface cracking. The thin-walled core steel tube facilitates providing a strong joint zone, so the size of the ring beam is largely reduced, which leads to cost savings.

This work proposed a simplified model and load-capacity calculation formulas for the joint under axial compression. Then, a detailed finite element (FE) model was established, which enabled the analysis and evaluation of variables to assess their influence on the load capacity. The FE model is divided into scale model and prototype model. The validity of the FE model is verified by experiments with the existing joints. The prototype model is used to compare and verify the conclusions of the scale model, and the influence of the small size of the FE model on the conclusion is excluded. The formulas for calculating the average circumferential stress and longitudinal stress of and the influence of the small size of the FE model on the conclusion is excluded. The formulas for calculating the average circumferential stress and longitudinal stress of the core steel tube at the peak load were proposed. Lastly, a comprehensive design method was proposed. A comparative design was conducted between the proposed joint and the two types of joints recommended in the technical standard for steel tube confined concrete structures [25]. The axial load performance, construction difficulty, and economic cost of the three types of joints were compared and assessed.

Section snippets

Three zones of TRC joint

As shown in Fig. 4(a), the joint is composed of three zones with different load capacities: TRC Column zone, Zone I and Zone II, as shown in Fig. 4(b)....

Effective confinement pressure and load capacity of TRC column zone

The axial load capacity N_c of a circular TRC

Materials

A three-dimensional nonlinear FE model was developed using software ABAQUS to investigate the behavior of the joints under axial compression [29].

Both the steel tube and reinforcing bars are assumed to be the elastic perfectly-plastic and the stress–strain relationship is given by:

$$\sigma_s = \begin{cases} E_s \varepsilon_s & \varepsilon_s < \varepsilon_y \\ f_y & \varepsilon_s \geqslant \varepsilon_y \end{cases}$$

where, ε_s is axial compressive strain; ε_y is yield strain, taken as f_y/E_s, E_s is modulus of elasticity of steel.

The Concrete Damaged Plasticity Model (CDPM) was adopted in the analysis. The...

Axial load calculation formula verification

The axial load capacity of the proposed joint of circular TRC column to RC beam (N_{cu}) is the smallest of three zones:

$$N_{cu} = \min \begin{cases} N_c = f_{cc} A_c + f_b A_b + \sigma_v A_s \\ N_I = f_{ccI} A_{cI} + f_b A_b + \sigma_{vI} A_{sI} + N_{cbI} \\ N_{II} = f_{ccII} A_{cII} + f_b A_b + N_{cbII} \end{cases}$$

The comparison between the proposed calculation method and the FE results regarding

Conclusions

This work proposes a joint system to connect TRC columns and RC beams. Theoretical analysis and extensive FE analysis were conducted to explore the load-carrying mechanism. The design methodology for the joint was proposed and examined. The following conclusions can be draw:

(1) The utilization of a steel tube within the ring beam joint enhances the confinement of the core concrete and reduces the size of the ring beam. This approach combines the advantages of both the ring beam joint and the core...

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Declaration of Competing Interest

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

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