Study of Equivalent Bending Moment Coefficient of Concrete Filled Steel Tubular under Lateral Force

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Abstract. In the hybrid structure of Concrete filled steel tubular columns and light steel frames, under horizontal loading, the secondary structure exerts two lateral forces on the main frame columns, resulting in a pronounced second-order deflection effect on the main structural columns. To investigate the influence of lateral forces on the second-order deflection effect, axial force and lateral force were taken as the main variables to conduct simulation analysis on medium-length circular concrete-filled steel tubular column. The results show that the specimens exhibited overall bending failure, and the ultimate load-bearing capacity of the structure decreased with the increase of the slenderness ratio and eccentricity; The lateral deflection increases rapidly during elastoplastic stage, and the second-order effect is significant; the equivalent bending moment coefficient increases with the increase of lateral force. After comprehensively considering the influence of the end bending moment ratio, axial force, and lateral force on the equivalent moment coefficient, a proposed formula for the equivalent moment coefficient of concrete-filled steel tubular column under different lateral force effects is derived through extensive parameter analysis, with the magnitude of lateral force as the primary influencing factor.

Keywords: concrete-filled steel tubular column; lateral forces; second-order effect; equivalent bending moment coefficient

1 INTRODUCTION

Traditional prefabricated high-rise reinforced concrete structures have many problems, including excessive reinforcement at beam-column joints, low assembly rate, difficulty in ensuring construction quality, and long construction period, among others [1]. The space utilization rate of low-rise light steel residential buildings is low, and their limitations are becoming increasingly apparent[2-3].

Our research team, drawing inspiration from the concept of "megastructures", proposes a high-rise hybrid primary-secondary structural system where the main structure adopts concrete-filled steel tubular column and the secondary structure employs light steel frames, the structure is shown in Fig.1(a). This system aims to enhance the

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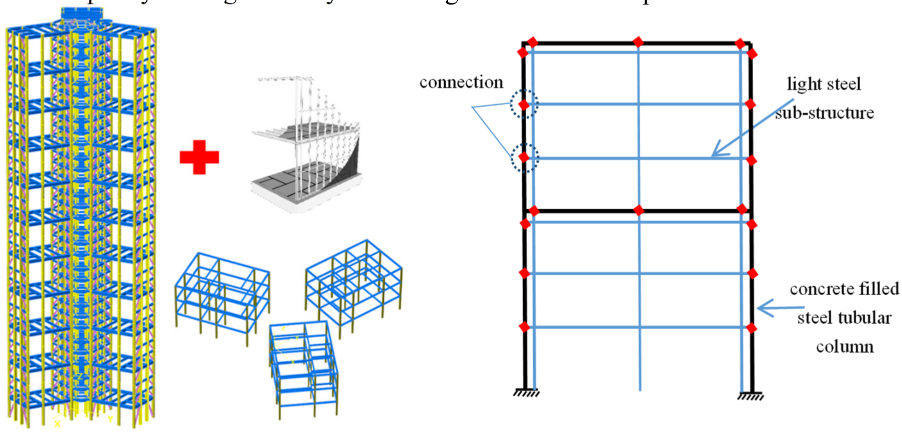
prefabrication rate of high-rise buildings and broaden the application scope of light steel structures.

The force on the main and secondary structures of this system is clear. Since the force situation of the secondary structure in the entire high-rise building changes very little, the forms of the secondary structures on different floors are similar, which allows for basic modular design. Both main and secondary structures can be prefabricated in factories and then transported to the site for assembly construction, thus improving construction quality and significantly shortening the construction period.



(a) hybrid structure (b) connections

Fig. 1. Schematic diagram of the structure

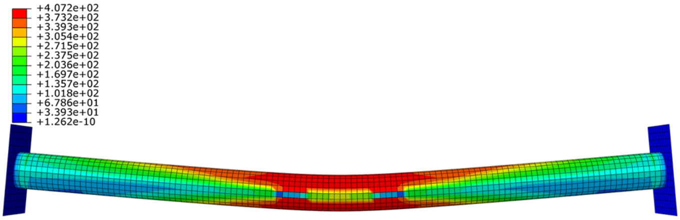
Due to the large slenderness ratio of the main structural columns, under wind load or seismic action, the secondary structure will exert two lateral forces at the trisection points of the column, as shown in Fig.1(b). These lateral forces will significantly increase the second-order deflection effect of the columns, resulting in an increase in the bending moment of the columns, which has adverse effects on the columns.

In view of the above issues, based on experimental research conducted by the research team, a model for circular steel-reinforced concrete columns subjected to lateral forces at the trisection points was established using ABAQUS. The influence of lateral forces on the structural performance of the components was analyzed, and a simplified calculation formula was proposed to determine the equivalent bending moment coefficient of the component. Aimed at providing reference for engineering practice.

2 FINITE ELEMENT ANALYSIS

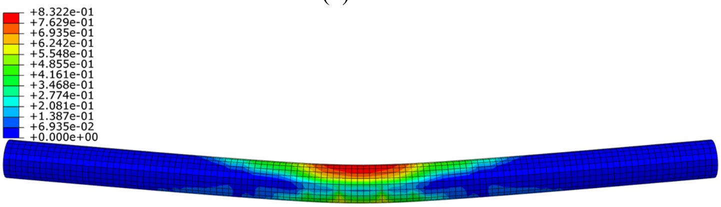
2.1 Model Verification

Fig.2 illustrates the comparison of failure modes between finite element analysis and test. All failures of the components occurred at the centre of the column, exhibiting overall bending instability. In the test, when the specimen failed, there were only a few longitudinal crushing cracks in the compressed zone of the core concrete, while there were numerous fine transverse cracks in the tensile zone. Comparing the damage cloud diagrams from finite element analysis, it was found that the tensile damage factor in the tensile zone exceeded 0.95, indicating complete cracking and failure of the concrete, while the damage factor in the compressed zone was 0.83, indicating fewer cracks. The comparative analysis of finite element failure modes is basically consistent with the experimental conclusions.

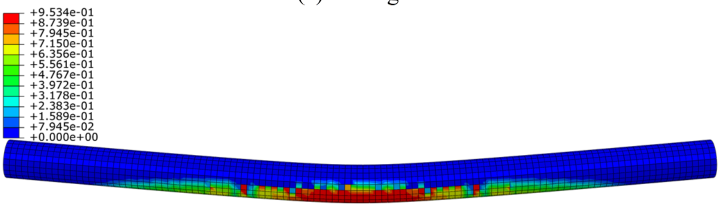


(a) Finite element

(b) Test



(c) Damagec



(d) Damaget

Fig. 2. Comparison of failure modes

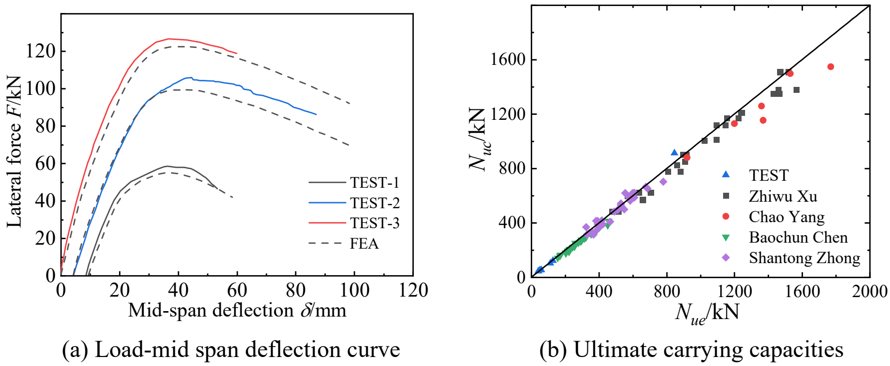


Fig. 3. Comparison of FE and test results

Fig.3(a) shows the comparison of load-deflection curves between finite element analysis and test results. It can be seen that the model accuracy is good, with an overall error of less than 5%.Similarly, the model was validated using experimental data from static loading tests in the literature[4-6]. The comparison between the simulated bearing capacity and experimental values is shown in Fig.3(b), with an average ratio of 0.95, a mean square deviation of 0.061, and a coefficient of variation of 0.064, indicating a high simulation accuracy.

3 STUDY ON THE EQUIVALENT BENDING MOMENT COEFFICIENT UNDER LATERAL FORCE

3.1 Parameter Selection for Model Examples

The action of lateral forces will change the bending form of the member and have an impact on the second-order effect of bending. Therefore, considering lateral force as the primary influencing factor, the lateral bearing capacity of 0.25, 0.5, and 0.75 is applied as loads in the trisection of the column. To study the three situations of large eccentricity, limit eccentricity, and small eccentricity, the eccentricities are respectively taken as 3D/4, D/2, and D/4.

3.2 Parametric Analysis

Eccentricity.

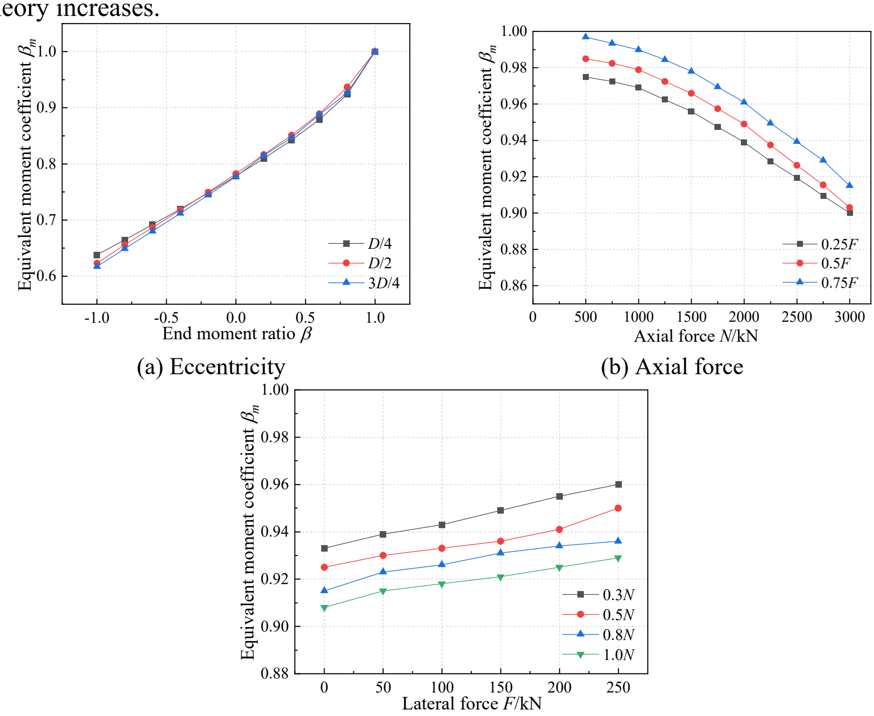
Under the action of lateral force and axial force, the equivalent moment coefficient is approximately linearly related to the end moment ratio. As the end moment ratio changes from 1 to -1, the coefficient value continuously decreases. The descent speed is relatively fast from 1 to 0.6, and relatively slow from 0.6 to -1. Regarding the influence of eccentricity, as shown in Fig.4(a), whether it is large or small eccentricity, the coefficient values are almost the same, indicating a limited effect of eccentricity.

Axial Force.

It can be seen from Fig.4(b) that, under the same lateral force, with the increase of axial force, the equivalent moment coefficient shows a gradually decreasing trend, and the rate of this decrease gradually accelerates. Axial force has a significant influence on the change of the equivalent moment coefficient. The reason for this may be that the larger the axial force, the more obvious the plastic development of the component under the same lateral force.

Lateral Force

It can be seen from Fig.4(c) that, under the same axial force, as the lateral force increases, the equivalent moment coefficient shows an increasing trend. After the component enters the elastoplastic stage, the deviation from the calculated values of elastic theory increases.



(a) Eccentricity (b) Axial force (c) Lateral force

Fig. 4. Effects of different parameters on β_m

4 METHOD FOR DETERMINING THE EQUIVALENT MOMENT COEFFICIENT

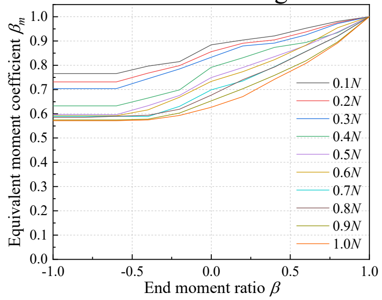
When it not subjected to lateral force, the equivalent bending moment coefficient of the member under unequal end moments can be obtained through derivation:

$$\beta_{\mathrm{m}} = \sqrt{\frac{(M_2/M_1)^2 - 2(M_2/M_1)\cos kl + 1}{2(1-\cos kl)}} \tag{1}$$

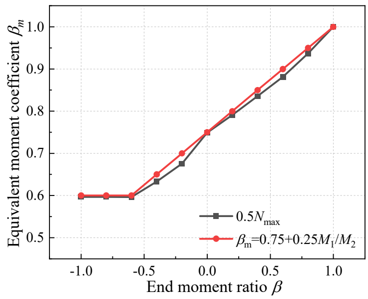
The relationship curve between β_{m} and M_2/M_1 can be plotted, and Austin W.J. suggests using a solid line composed two straight lines for convenient design use:

$$\beta_{\mathrm{m}} = 0.6 + 0.4(M_2/M_1) \tag{2}$$

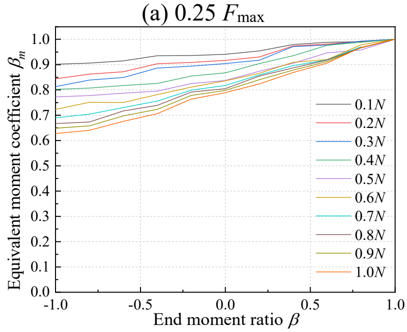
To investigate the influence of lateral force on the equivalent bending moment coefficient, the equivalent bending moment coefficients are separately calculated for cases of $0.25F_{\max}$, $0.5F_{\max}$, and $0.75F_{\max}$ under different axial forces. The results are shown in the Fig.5. Based on the experience of the American Institute of Steel Construction, the curve at $0.5N_{\max}$ is selected as the recommended value for β_{m}, resulting in a simplified formula with two straight lines.



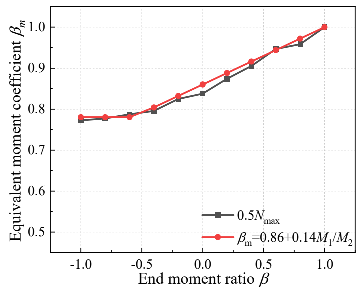
(a) 0.25 $F_{\max}$



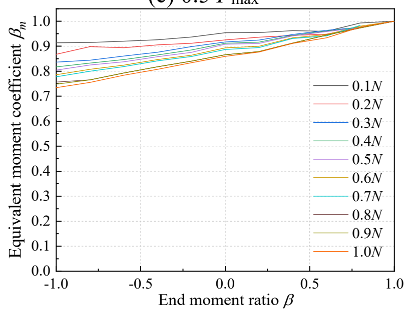
(b) simplified formula



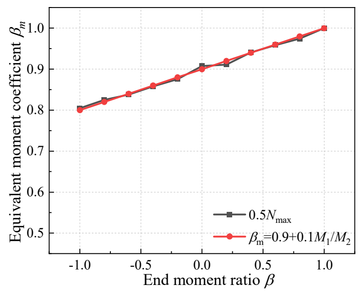
(c) 0.5 $F_{\max}$



(d) simplified formula



(e) 0.75 $F_{\max}$



(f) simplified formula

Fig. 5. Equivalent bending moment coefficient value

In summary, the coefficients under the action of lateral force can be summarized as follows:

$$\beta_m = \begin{cases} 0.75 + 0.25\beta \geq 0.6 & F = 0.25F_{\max} \\ 0.86 + 0.14\beta \geq 0.78 & F = 0.5F_{\max} \\ 0.9 + 0.1\beta \geq 0.8 & F = 0.75F_{\max} \end{cases} \tag{3}$$

5 CONCLUSIONS

(1) Lateral forces will increase the flexural second-order effects of concrete-filled steel tubular column, and may even cause specimens initially subjected to biaxial bending to gradually transition to uniaxial bending under the influence of lateral forces. It is necessary to consider the effect of lateral forces on slender columns during the design phase to ensure structural stability and safety.

(2) As the lateral force increases, the equivalent bending moment coefficient also increases. Parameter analysis derived the calculation formula for the equivalent moment coefficient of concrete-filled steel tubular column subjected to lateral forces, providing a practical calculation method for the design of the structures.

(3) This study is limited to concrete-filled steel tubular column. Future research could expand to other types of structures and explore the influence of more parameters on the equivalent bending moment coefficient.

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