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DESIGN METHOD FOR RESTRAINED STEEL COLUMNS UNDER COMBINED AXIAL FORCE AND BENDING MOMENTIN FIRE

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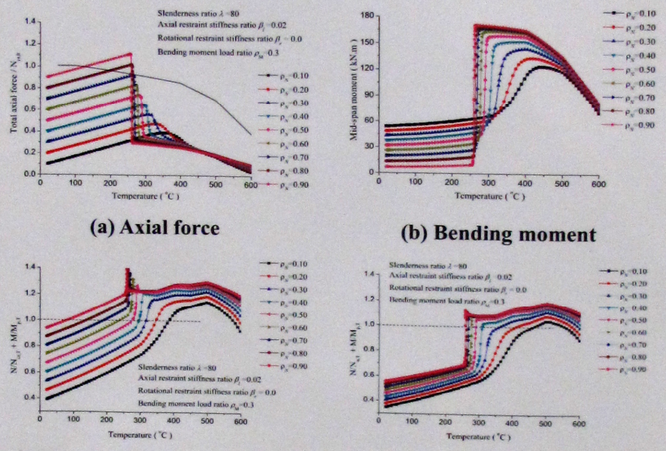
1. Introduction

Present fire resistance design codes are mainly based on isolated structural members; only adopt the design procedure at ambient temperature by using the reduced strength and stiffness of steel at elevated temperatures in fire. In fire situation, design method should consider the interactions among structural members. Despite many research results on the design of restrained columns in fire, a method is still necessary for axially and rotationally restrained columns under combined axial load and bending moment.

2. Behaviours

As shown in Fig.1 (a) and Fig.1 (b), before the restrained column buckles, the axial force in the restrained column increases linearly and the bending moment changes little. Hence, for determining the buckling temperature of the retrained column, the design equations for the unrestrained column can be used, but with increased column axial load due to restraint thermal expansion. After buckling, the axial force in the restrained column drops, and the bending moment increases. Again, as shown in Fig.1(c) and Fig.1 (d), at the column failure the $N/N_{cr,T}+M/M_{p,T}$ value is greater than 1.0, but the value $N/N_{u,T}+M/M_{p,T}$ is close to 1.0.



(a) Axial force (b) Bending moment

(c) $N/N_{cr,T}+M/M_{p,T}$ (d) $N/N_{u,T}+M/M_{p,T}$

Fig. 1 Behaviours of restrained columns in fire

3. Design Equations

1. Buckling Temperature:

$$\frac{N}{N_{cr,T}}+\frac{\beta_{mx}M_x}{\gamma_x W_{1x}\left(1.0-0.8\frac{N}{N'_{EX}}\right)}=1.0$$

$$N=P_0+k_l u_l$$

$$u_l=\frac{k_c}{k_c+k_l}\left(\varepsilon_{th}l-\frac{P_0}{k_c}+\frac{P_0}{k_{c,0}}\right)$$

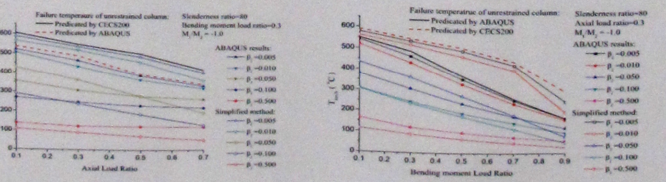
2. Failure Temperature:

$$\frac{N}{N_{u,T}}+\frac{N\cdot w+\beta_{mx}M_x}{M_{p,T}}=1.0$$

$$N=P_0$$

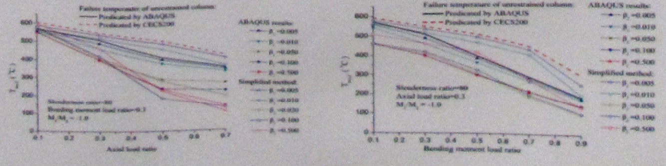
4. Verification

The design equations are verified by ABAQUS. The comparison of the buckling temperatures and failure temperatures are shown in Fig. 2 and Fig. 3. The results predicated by the proposed method agree well with the ABAQUS analysis results.



(a) Effects of axial force (b) Effects of bending moment

Fig.2 Verification of the buckling temperature equation



(a) Effects of axial force (b) Effects of bending moment

Fig. 3 Verification of the failure temperature equation

5. Conclusions

This paper has studied the behaviour and developed a new method for calculating the buckling and failure temperatures of restrained columns under axial load or combined axial load and bending moment in fire. The main works and conclusions of this paper are:

1. simplified methods to calculate the buckling and failure temperature of restrained columns under combined axial load and bending moment are proposed.
2. by including the additional axial force due to restrained thermal elongation, the design equation for unrestrained column is used to predict the buckling temperature of restrained columns. For calculating the failure temperature, the yield axial strength-plastic bending moment interaction curve is adopted. The failure criterion is defined as the temperature at which the axial force returns to its initial value.
3. for the restrained column with realistic parameters, the buckling and failure temperatures predicted by the proposed method agree well with those of ABAQUS.