EFFECT OF LONGITUDINAL TEMPERATURE GRADIENTS ON THE BEHAVIOUR OF STEEL BEAM-COLUMNS

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ABSTRACT

Steel structures used inside and outside buildings are often exposed to nonuniform heating as a result of actual fire action. Elevated temperature influences the material properties such as the yield strength and modulus of elasticity which affect the ultimate carrying capacity of steel members. The computations are performed by using a previously developed numerical model based on the finite element technique. A parametric study is performed to investigate the influence of idealized temperature gradient forms, slenderness ratio and end moments on the ultimate bearing capacity of columns and beam-columns. Longitudinal temperature gradients influence the ultimate bearing capacity of slender beam-columns at elevated temperatures. A comparison of the computed results and previously conducted experimental results shows a very good agreement.

INTRODUCTION

The structural behaviour of steel members subjected to elevated temperature gradients depends on the temperature distribution along the length of the member. The critical loads of exposed steel columns subjected to elevated temperature conditions is influenced by the distribution of the longitudinal temperature gradient (1,2). Several forms of temperature gradients along the length of the member are considered in this study to idealize those which may occur in a fire action. These forms of temperature gradients provide a means to assess their influence on the ultimate bearing capacity of steel members. The mechanical properties of steel at elevated temperature such as yield strength, modulus of elasticity and coefficient of thermal expansion are used in accordance to Eurocode (3). Also the influence of the residual stresses and initial imperfections are considered in this study.

The computational model (4) which simulates the nonlinear response of steel members subjected to elevated temperature is used in this study. Structural members are discretized by beam elements in the longitudinal direction and the five based-point Gauss integration is used to compute the resistance in the transverse direction. The numerical technique is based on an incremental-iterative procedure. The ultimate load carrying capacity of steel members can be evaluated for increasing gravity loads at elevated temperatures.

PROBLEM STATEMENT

Several forms of temperature gradients along the length of steel members are considered as shown in figure (1) to represent possible idealization of actual fire action. Figure (1-a) represents linear thermal gradient which could correspond to the case of heat input is maximum at the base and decreases toward the top. Figure (1-b) represents a case of maximum temperature at mid height and decreases toward the ends. Figure (1-c) represents the case of a maximum constant temperature input over the lower third and decreases linearly towards the top.

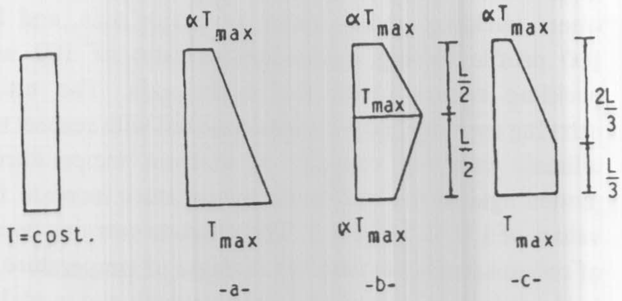

Figure 1. Longitudinal Temperature Forms.

The longitudinal temperature variation can be represented as

$$\alpha = T_{min}/T_{max}$$

where,

α = 1 represents a case of uniform temperature gradient

α = 0.5 represents a case of moderate temperature gradient

α = 0.1 represents a case of severe temperature gradient

The temperature is assumed, to be constant over the cross section due to the relatively thin elements of rolled sections, thus thermal bowing problems are not considered in this study.

The influence of creep with time may be important at elevated temperatures for sustained loading. Steel will creep when subjected to sufficiently high temperatures for sufficiently long durations. This effect is neglected because the time duration considered short compared to the time required for significant creep to occur.

Symmetrically distributed residual stresses with respect to the principal bending axes of the cross section are only considered herein (5). Initial imperfections of columns of magnitude of (1/1000) of the column length are considered (6). The longitudinal expansion of members due to heating is assumed to be unrestrained.

NUMERICAL RESULTS

1. *Influence of Temperature Distribution and Slenderness Ratio on the Ultimate Carrying Capacity of Columns*:

Results obtained are presented in Figures (2), (3) and (4) in the form of column curves for columns fabricated from HEA 300 profile having a slenderness ratio of 50 where buckling occurs about the major axis, and HEA 100 profile having a slenderness ratio of 100 where buckling occurs about the minor axis. The ultimate carrying capacity, non-dimensionalized with respect to the ultimate carrying capacity at ambient temperature, is plotted against the maximum temperature increase for α values of 1.0, 0.5 and 0.1. The ultimate carrying capacity of column decreases with the increase of temperature, due to the reduction in both the yield strength and modulus of elasticity. The ultimate carrying capacity of columns subjected to uniform temperature gradients is less than those subjected to other forms of temperature gradients as shown in Figures (2), (3) and (4). As the thermal gradient becomes steeper, the yield strength decreases and varies along the column length, but the whole column is not weakened by the same amount and thus columns behave like tapered ones. Thus the ultimate carrying capacity of columns subjected to very steep thermal linear gradients may exceed the plastic resistance of column section as shown in figure (2). But for other thermal gradient forms, shown in figures (3) and (4), the ultimate carrying capacity of columns does not increase significantly as the slope of the thermal gradient becomes steeper, and it may be equal to the ultimate carrying capacity of uniformly heated columns. For the case of maximum temperature which occurs at the mid length of the column, the ultimate carrying capacity is significantly reduced compared to the other forms of longitudinal temperature gradients.

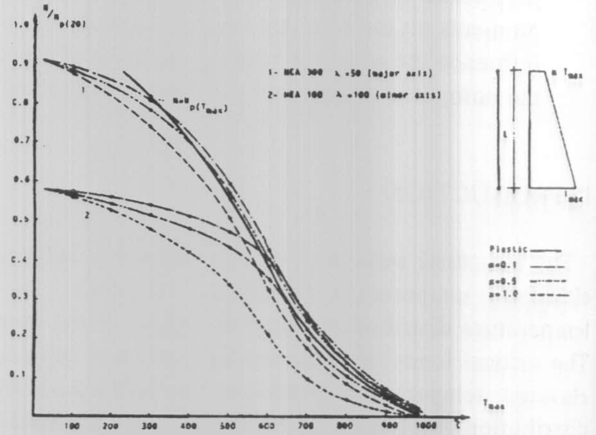

Figure 2. Column Curves - Linear Gradient.

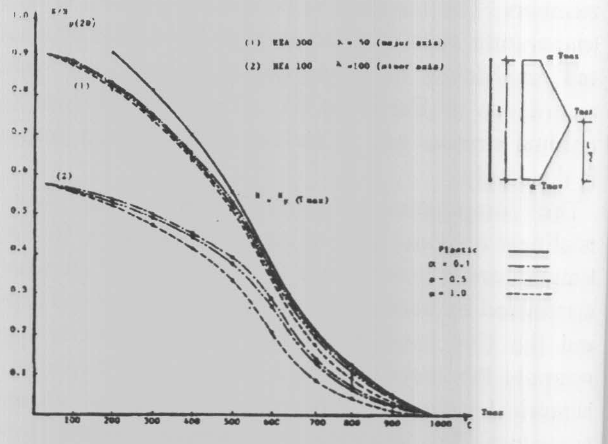

Figure 3. Column Curves - Maximum at Midheight.

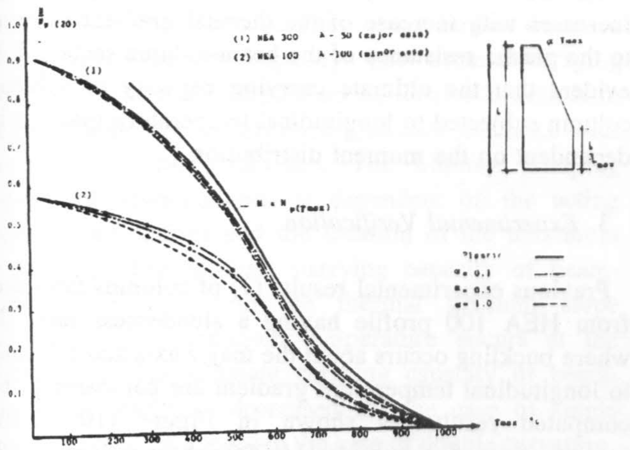

Figure 4. Column Curves - Maximum at the Lower third.

The results of pinned columns fabricated from HEA 300 profile having slenderness ratio taken equal to 30, 90 and 150 where buckling occurs about the major axis are shown in figure (5). These slenderrens ratios represent the practical ratios used in the design of steel columns. The ultimate carrying capacity decreases with the increase of column's slenderness ratio at elevated temperatures. It is evident that, the ultimate carrying capacity is dependent on the column's slenderness ratio and influenced by the longitudinal temperature gradients.

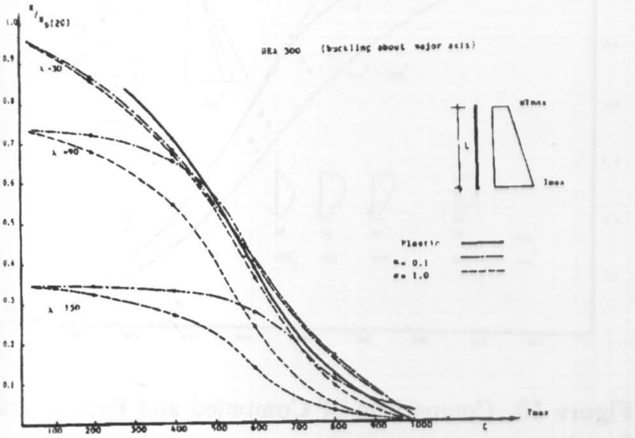

Figure 5. Column Curves - Major Axis.

2. *Influence of Moment Distribution on the Ultimate Carrying Capacity of Beam-Columns Subjected to Longitudinal Temperature Gradients*:

Four cases representing possible moment distributions are considered in the study to evaluate the influence of acting moments on the ultimate carrying capacity of beam-columns subjected to linear thermal gradients. Only the linear gradient is considered to take into account its beneficial effects compared to the other forms. The results of beam-columns fabricated from HEA 300 profile and having a slenderness ratio of 50, where buckling occur about the major axis are shown in figures (6) through (9). Figure (6) shows the interaction curves for beam-columns where the acting moment is applied at the more heated end. The ultimate carrying capacity decreases with the increase of the applied moment and it is almost equal to the ultimate carrying capacity of uniformly heated beam-columns.

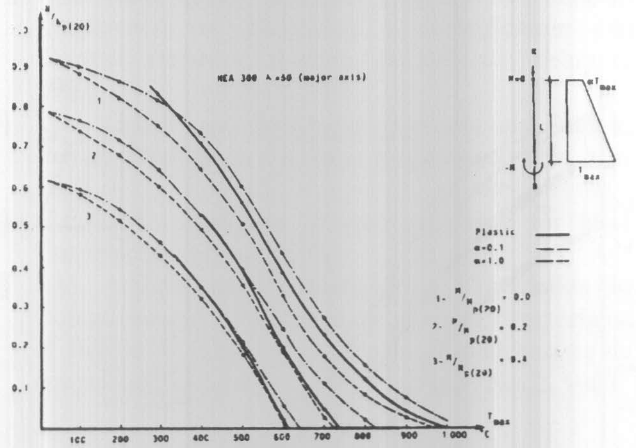

Figure 6. Interaction Curves - Single Moment at Base.

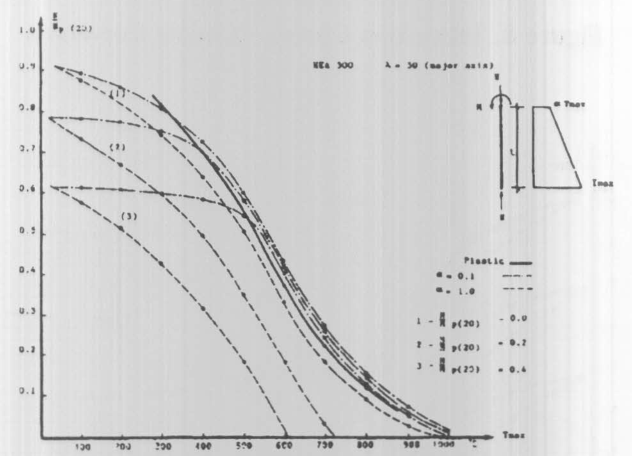

Figure 7. Interaction Curves - Single Moment at Top.

Figure (7) shows the interaction curves for beam columns where the acting moment is applied at the less heated end. As the slope of the thermal gradient becomes steeper, the ultimate carrying capacity increases and may be equal to plastic resistance of the section. It is evident that, the ultimate carrying capacity of beam-columns increases with the increase of the thermal gradient slope if the acting moment exists at the less heated end, and it decreases if the acting moment exists at the more heated end. Figure (8) shows the interaction curves for beam-columns subjected to equal and opposite moments at both ends (double curvature). The ultimate carrying capacity of beam-columns is less than those subjected to uniformly heated beam-columns. Figure (9) shows the interaction curves for beam-columns subjected to equal moments at both ends (single curvature). The ultimate carrying capacity of beam-columns subjected to linear thermal gradients is less then those of the previous case.

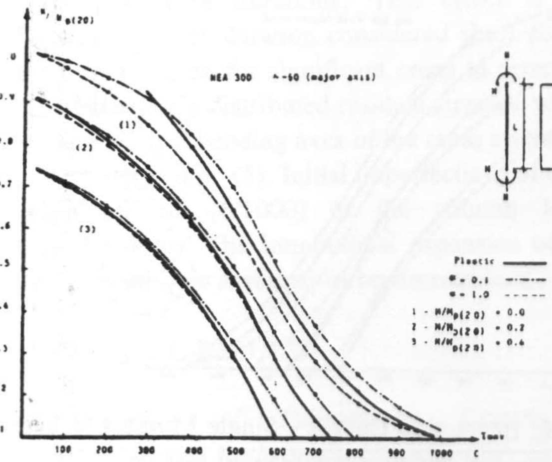

Figure 8. Interaction Curves - Double Curvature.

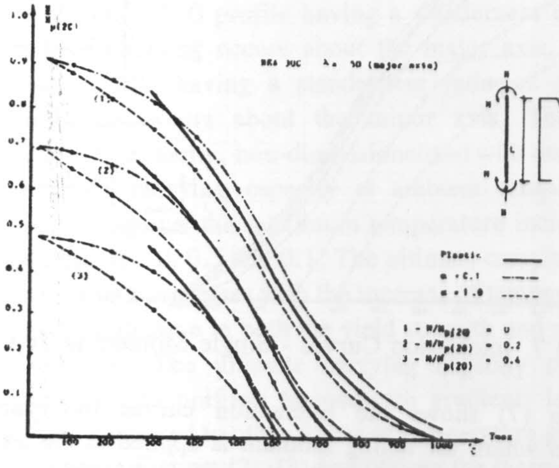

Figure 9. Interaction Curves - Single Curvature.

On the other hand, the ultimate carrying capacity increases with increase of the thermal gradient slope up to the plastic resistance of the beam-column section. It is evident that the ultimate carrying capacity of a beam-column subjected to longitudinal temperature gradients is dependent on the moment distribution.

3. *Experimental Verification*

Previous experimental results (7) of columns fabricated from HEA 100 profile having a slenderness ratio 73, where buckling occurs about the major axis and subjected to longitudinal temperature gradient are compared to the computed results as shown in Figure (10). Initial imperfection of magnitude (1/1000) of the column length and residual stresses of the experimental investigation are included in the computed results. Figure (10) shows the extreme boundaries of the computed ultimate carrying capacity of column subjected to linear thermal gradient and uniform temperature. The experimental results are located between the computed curves. The comparison of the computed and experimental results shows very good agreement.

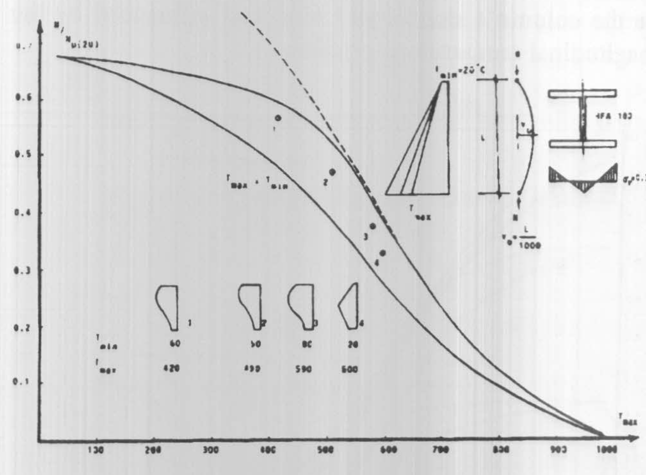

Figure 10. Comparison of Computed and Experimental Results.

CONCLUSION

The influence of longitudinal temperature gradients on the ultimate carrying capacity of steel columns and beam-columns is investigated in this study. The forms of longitudinal thermal gradients along the length of the member has an effect on its ultimate carrying capacity.

The case where the maximum temperature occurs at the midheight of the column resulted in the largest decrease in the ultimate carrying capacity. The ultimate carrying capacity of columns is dependent on its slenderness ratio as the influence of temperature gradients increases with the slenderess ratio increase. The ultimate carrying capacity of beam-columns is dependent on the acting moment distributions and the location of the maximum temperature. The ultimate carrying capacity of beam-columns increases with the thermal gradient slope increase, if the maximum temperature occurs at the pinned base. The ultimate carrying capacity of beam-columns is markedly decreased for the case of single curvature when compared to the case of double curvature. The computed ultimate carrying capacity of columns subjected to longitudinal thermal gradients compares well with the previously conducted experimental results. For design purposes, it may be necessary to take into account the beneficial effects of longitudinal thermal gradients as opposed to the assumed worst case of uniform temperatures in view of the uncertainties associated with actual temperature distributions which occur for beam-columns in actual fire action.

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