Creep Buckling of a Steel Column in a Temperature-Time History Simulating a Fire

Flambage par fluage d'un poteau en acier selon un diagramme température-temps simulant un incendie

Kriechknicken von Stahlstützen in einem Temperatur-Zeit Verlauf, der einen Brandfall simuliert

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1. INTRODUCTION

At temperatures exceeding 500°C ordinary carbon steels show a high creep rate even at low tensile or compressive stresses. In a paper published in the Preliminary Report of the 10th Congress of IABSE [1] the author presented results of creep buckling calculations for a steel column of section HE 240B with a yield strength of 300 MPa. A computer programme prepared at the Aeronautical Research Institute of Sweden [2] was used to obtain the creep buckling life of columns of various lengths subjected to a number of different mean compression stresses assuming a constant temperature of 600°C. A diagram was given where the buckling stress was plotted versus the slenderness ratio λ for times of exposure to this temperature ranging from 0.2 to 2.0 h. The diagram showed quite clearly that time is an important parameter which must be considered when analysing the buckling strength of a steel column at elevated temperatures.

The temperature during a fire varies, however, with a rise from room temperature to a maximum, determined by the fire load, after which the cooling starts, usually at a much lower rate than the heating. The computer programme mentioned was therefore modified to allow variations in temperature. A few calculations with such temperature histories assuming maximum temperatures 600° and 650°C respectively were carried out and presented already in Ref [1]. This investigation has been continued. By repeated life calculations, the compression stress was determined which just resulted in creep buckling collapse at the end of a temperature-time history with a maximum of 600°C. This was done for the slenderness ratios λ = 30, 45, 60 and 90.

2. CALCULATIONS

The modified version of the creep buckling computer programme is able to take into account a linear increase in temperature from an initial value to a maximum ϑ_{smax}, then a constant period and finally a linear decrease in temperature. The creep law of Norton-Odqvist is utilized

$$\dot{\varepsilon} = k\sigma^n$$

where the exponent n = 4.9 is assumed to be constant for all temperatures considered, while the creep coefficient k varies with the temperature T^oK

$$k = 1.88 \times 10^{-11} \exp (44.7 - 39000/T)$$

Young's modulus, including elastic and plastic deformation, as well as primary creep, is determined by the relation

$$E_o = 325000 - 404\ \vartheta_s \text{ MPa}$$

The numerical calculations were performed for a temperature-time history shown in Fig 1 with heating and cooling rates $1000^oC/h$ and $333^oC/h$ respectively, and further $\vartheta_{smax} = 600^oC$ lasting for a period of 0.2 h. The radius of gyration in the buckling direction of the chosen column section HE 240B is i = 0.10 m. The assumed lengths were 3.0, 4.5, 6.0 and 9.0 m.

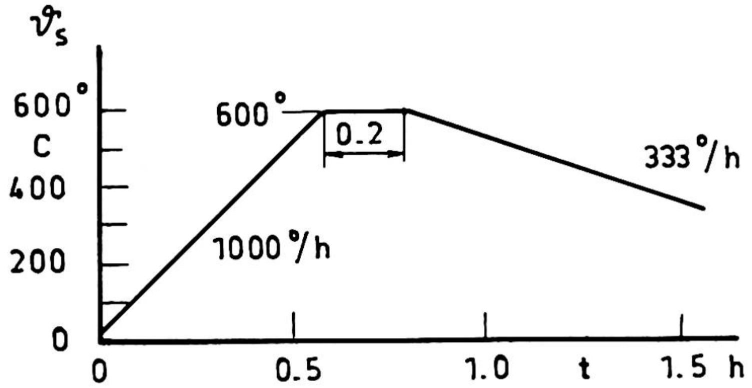

Fig 1 Temperature- time history introduced into computer programme

3. RESULTS AND DISCUSSION

After a number of trials with different loads on the column section it was found that for the slenderness ratios λ = 30, 45, 60 and 90 the mean stresses σ = 60, 51, 41 and 28 MPa respectively would result in creep collapse just at the moment of the temperature-time history during the cooling phase where creep had practically ceased. The results have been plotted in Fig 2 together with the creep buckling curves obtained earlier [1] for constant temperature exposure times. It was discovered that the value determined before with λ = 45, for a history with the maximum temperature 600^oC, was somewhat too high due to an unconservative interpolation. The temperature-time history of Fig 1 seems to have about the same effect as if the column had been exposed to a constant temperature of 600^oC during 0.5 h. This result is not surprising since the temperature in Fig 1 exceeds 500^oC, where the rapid creep starts, during 0.6 h. Further investigations are likely to show the feasibility of using constant temperature buckling curves to determine the critical stress of a column subjected to a fire temperature history.

The buckling analysis presented in Fig 2, although considering a realistic fire history of the mean temperature of the steel column, still neglects other complications met in practice such as temperature gradients and residual stresses within the column, as well as restraining forces from other structural elements. Thus, it is not claimed that Fig 2 may be used directly for design purposes. It seems to represent a substantial improvement, however, in comparison with the two dotted curves given by the general reporters, Theme III, in the Introductory Report of the Congress [3]. The analysis clearly shows that creep has to be taken into account at fire temperatures exceeding 500 °C, where time is consequently an important parameter. This conclusion was supported in the Prepared Discussion contribution by Fukumura [4].

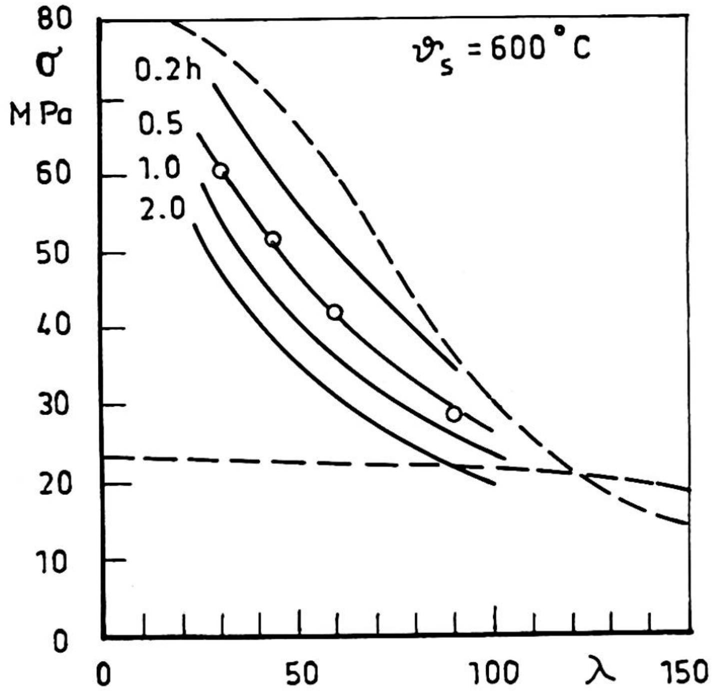

Fig 2 Buckling stress versus slenderness ratio for various times of exposure to 600 °C and for temperature-time history with maximum temperature 600 °C

REFERENCES

1. Eggwertz, S: Creep buckling of steel column at elevated temperatures. IABSE 10th Congress, Preliminary Report, Zürich 1976, p 235-240
2. Samuelson, Å: Creep deformation and buckling of column with an arbitrary cross section. FFA Report 107, Stockholm 1967
3. IABSE 10th Congress, Introductory Report, Zürich 1975, p 117 and 135
4. Fukumura, F: Inelastic behavior of protected steel column in fire. IABSE 10th Congress, Prepared Discussion, to be published in the Final Report, 1977

SUMMARY

The creep buckling stress was determined by computer analysis for steel columns subjected to a realistic fire temperature history with a maximum of 600 °C. The results were compared to earlier calculations with constant temperature of 600 °C. The influence of creep was still found to be important.

RESUME

La contrainte de flambage par fluage de poteaux en acier a été déterminée par des calculs numériques selon un diagramme température-temps simulant un incendie avec un maximum de 600 °C. Les résultats sont comparés aux calculs déjà faits pour une température constante de 600 °C. On constate que l'influence du fluage reste importante.

ZUSAMMENFASSUNG

Die Kriechknickspannung wurde für Stahlstützen durch ein numerisches Programm für einen Temperatur-Zeit Verlauf mit maximum 600 °C bestimmt, der einen Brandfall simuliert. Das Resultat wird mit früheren Berechnungen mit einer konstanten Temperatur von 600 °C verglichen. Der Einfluss des Kriechens ist von Bedeutung.