FINITE ELEMENT SIMULATION OF THIN-WALLED BEAM TYPE- STRUCTURE BUCKLING UNDER CREEP REGIME

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Abstract: *This paper presents creep buckling finite element modeling of steel beam-type structure. For beams under sustained loads the loss of stability may occur during a period of exploitation of structure even for loads lower than critical buckling load. For that reason stability is characterized by critical buckling time instead the critical buckling load. The simulation is performed using four nodded Kirchoff-Love theory based shell finite elements. For a space frame, as the test example, critical buckling times are calculated for different levels of applied load, temperature conditions and steel chemical composition.*

Keywords: FINITE ELEMENT, THINN-WALLED BEAM, BUCKLING, CREEP, FRAME, STABILITY

1. Introduction

In the field of structural engineering beams and frames constitute a very important class of load-carrying components, where they are applied both in their stand-alone forms and as stiffeners for some plate or shell structures. An important consideration concerns the accurate prediction of their limit load-carrying capacity. Because such structures, especially those of thin-walled cross-sections, could display very complex structural behavior which comprises both geometric and material inelasticity, it has been a major activity of many structural engineering researchers in the recent years [1].

Columns under sustained loads are generally unstable in the regime of creep. That means that loss of stability may occur during a period of exploitation of structure even for loads lower than critical buckling load. Due to that reason stability is characterized by critical buckling time defined as load duration for which buckling deflections become infinitive [2]. Contrary to the linear stability analysis which is able to determine a creep buckling load for which the buckling deformation tends to infinite during the infinite time, the non-linear theory shows that the creep buckling can occur at a finite time, at which buckling deformation tends to infinity for any load less than the critical buckling load determined in elastic cases. The non-linear response of a load-carrying structure should be solved using numerical methods, e.g. the finite element method, and some of incremental descriptions.

Shell elements are especially useful when the behavior of large structures is of interest. The flat shell elements are the simplest ones due to their low computational cost, so such elements are very popular. Contrary to Mindlin–Reissner type, Kirchoff–Love type based shell elements neglect transverse shear deformation [3].

In this paper a beam finite element model is used to evaluate the critical buckling loads of the frame as eigenvalues. Afterwards, for geometrically and materially nonlinear creep buckling analysis shell finite element model is used.

2. Modelling of Creep

In the case of small strains the additive decomposition of the total strain tensor into an elastic part and an irreversible creep part is postulated. The constitutive equation is the following [4, 5]:

$$ {}^{2}S_{ij} = \frac{E}{1+\nu}\left({}^{2}\varepsilon''_{ij} - \Delta\varepsilon^{c}_{ij}\right), \tag{1}$$

where ${}^{2}S_{ij}$ and ${}^{2}\varepsilon'_{ij}$ are deviatoric parts of stress and strain tensors in current unknown configuration, ${}^{2}\varepsilon''_{ij} = {}^{2}\varepsilon'_{ij} - {}^{1}\varepsilon^{c}_{ij}$ while ε^{c}_{ij} denotes creep deformation tensor.

Creep deformation increment can be calculated as:

$$\Delta\varepsilon^{c}_{ij} = {}^{1}k\ {}^{1}S_{ij}\ , \tag{2}$$

where factor ${}^{1}k$ is:

$$ {}^{1}k = \frac{3}{2}\frac{{}^{1}\dot{\bar{\varepsilon}}^{c}}{{}^{1}\bar{\sigma}}\Delta t\ , \tag{3}$$

with $\dot{\bar{\varepsilon}}^{c}$ and $\bar{\sigma}$ as effective creep strain rate and effective stress.

Time increment Δt represents the real time passed during the element movement from last known configuration to current unknown configuration, so it is: $\Delta t = {}^{2}t - {}^{1}t$.

Effective creep strain rate $\dot{\bar{\varepsilon}}^{c}$ from equation (3) can be obtained according to some mathematical creep model eg. Norton power creep law as:

$$\dot{\bar{\varepsilon}}^{c} = K\bar{\sigma}^{n}\ , \tag{4}$$

where K and n are Norton material constants.

3. Numerical example

Fig. 1 shows a one-storey space frame loaded by vertical force of intensity F at point B. The junction at B was performed in a manner to prevent warping of the beam members at the joint, as shown in detail of figure.

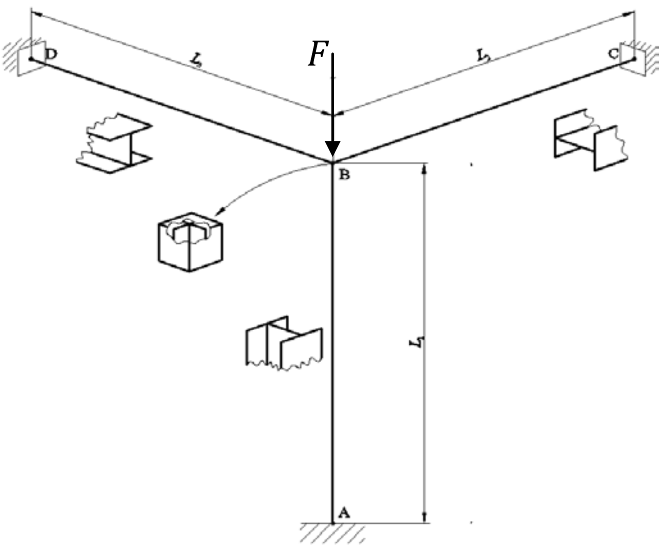

Fig. 1 *Space frame*

The material moduli are: elastic modulus E = 210 GPa and shear modulus G = 80.77 GPa; the Poisson ratio is ν = 0.3.The length of beam members are L_1= 4100 mm, L_2=3100 mm and L_3= 3100 mm. The boundary conditions of beam members are defined as clamped at points A, C and D while at the junction point, as it is already mentioned, the warping degrees of freedom are supposed to be restrained.

All frame members are made of European wide flange HEB profiles, with the following dimensions: flange weight b = 100 mm, web height h = 100 mm, flange thickness t_f = 6 mm and the web thickness t_w =10mm, (see Fig. 2).

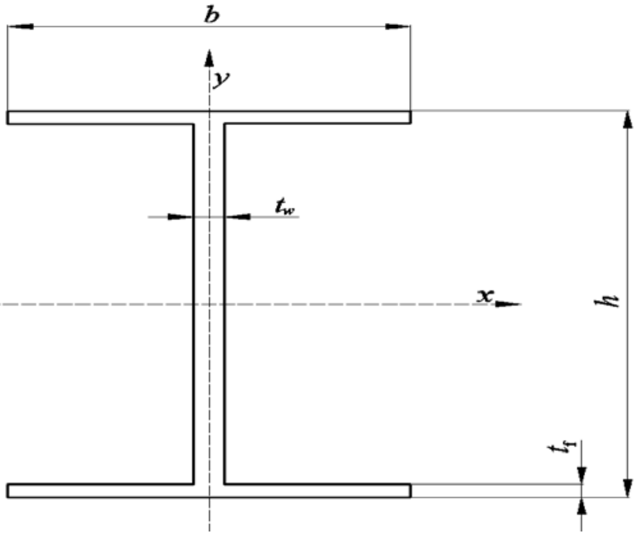

Fig. 2 *HEB beam members cross-section*

Three different finite element models are made. A shell finite element model with 4928 8-noded finite elements are made in computer software FEMAP.

The first deformation mode for space frame under consideration is shown on Fig. 3. This mode belongs to the group of so called sway buckling mods.

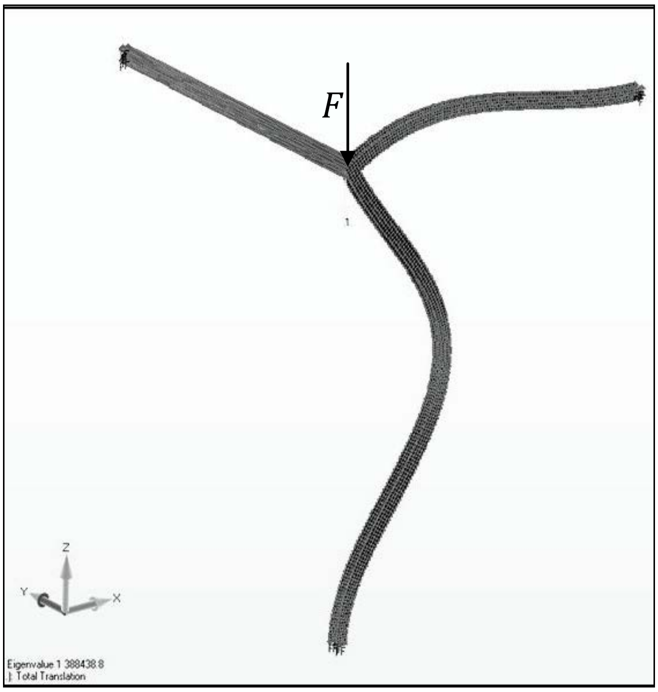

Fig. 3 *The first deformation mode for space frame*

To obtain critical buckling load, the analyses in an eigenvalue manner are also performed by beam MASTAN2 computer solver. This is important as the first step of simulation in order to determinate the static critical buckling load value. The buckling loads obtained from the above mentioned models are listed in Table 1. The number of finite elements used in both models is given for convenience.

Table 1: *Critical buckling loads and the number of finite elements used for space frame for different finite element models*

FE model	No. of elements	Buckling load [N]
MASTAN2 (beam)	3	381880
FEMAP (shell)	4928	388439

For a creep buckling analysis, the frame is loaded with three different constant forces:

$$F_1 = 0.85\ F_{cr} = 330173\ \text{N}$$

$$F_2 = 0.80\ F_{cr} = 310751\ \text{N}$$

$$F_3 = 0.75\ F_{cr} = 291329\ \text{N}$$

A perturbation forces of $0.001F$ intensity, is applied at the middle point of vertical column in the positive X-direction to initiate the deformation shape due to the inquirements of the non-linear buckling numerical modelling.

Two different chemical composition carbon steels are used and for the first carbon steel two different temperatures are used. Norton power creep law is adopted with following constants [6, 7]:

- material A - carbon steel (0.15 C, 0.50 Mn, 0.23 Si) at 538°C:

  $n = 3.05$, $K = 0{,}12\cdot10^{-13}$ [10 mm^2/N]$^n\cdot$h^{-1};

- material A - carbon steel (0.15 C, 0.50 Mn, 0.23 Si) at 649°C:

  $n = 2.85$, $K = 0{,}16\cdot10^{-10}$ [10 mm^2/N]$^n\cdot$h^{-1};

- material B - carbon steel (0.43 C, 0.68 Mn, 0.20 Si) at 649°C:

  $n = 1.7$, $K = 0{,}12\cdot10^{-8}$ [10 mm^2/N]$^n\cdot$h^{-1}.

Fig. 4 shows X-direction translational displacement of perturbation load point versus creep time for material A at constant temperatures levels of 538°C for applied load levels of $0.85F_{cr}$, $0.8F_{cr}$ and $0.75F_{cr}$. It should be pointed that all three values are smaller than the previously determinate critical buckling load.

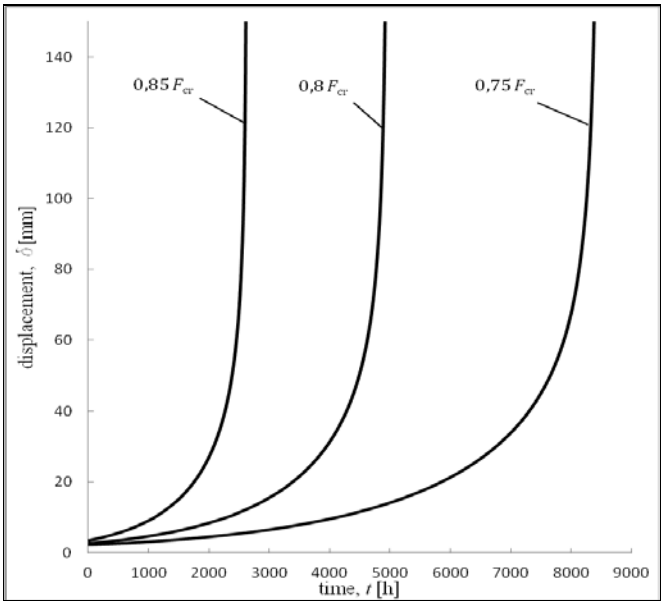

Fig. 4 *Creep buckling curves for material A at 538°C*

The Fig. 5 presents the creep buckling curves for material A at temperature of 649°C. The Fig. 6 show the diagram of buckling curves in the same manner but in this case for material B at constant temperature level of 649°C.

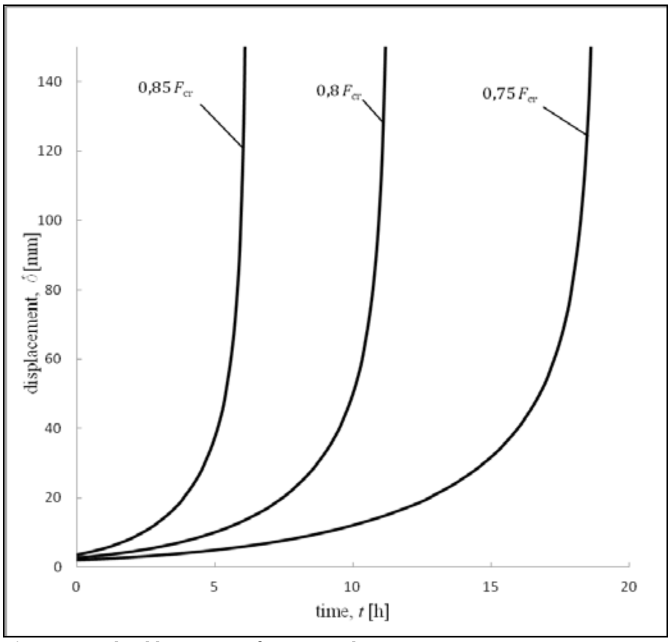

__Fig. 5__ Creep buckling curves for material A at 649°C

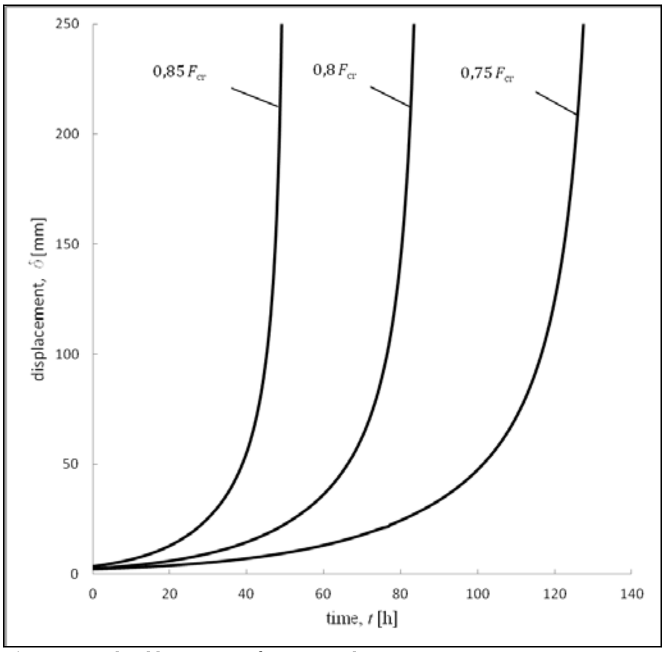

__Fig. 6__ Creep buckling curves for material B at 649°C

***Table 2:** Critical buckling times (h)*

Load level	Material A		Material B
	T = 538°C	T = 649°C	T = 649°C
0.85 F_{cr}	2550	6	50
0.80 F_{cr}	4950	11	85
0.75 F_{cr}	8300	19	125

The approximate critical creep buckling times obtained for two different chemical composition of carbon steels at the different temperatures are listed in Table 2. This times can be recognized as the values to which buckling curves asymptotically tends in the infinity.

Fig. 7 shows the comparison of material A buckling curves at both temperatures levels, 538°C and 649°C, while on the Fig. 8 the creep buckling curves of both materials A and B at the same temperature level condition 649°C are displayed for clearer comparison.

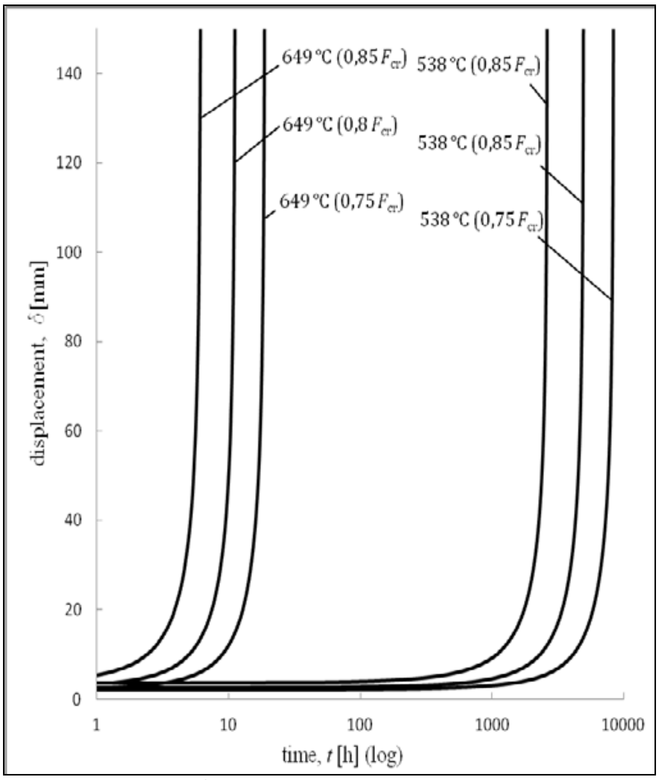

__Fig. 7__ Buckling curves for material A at 538°C and 649°C

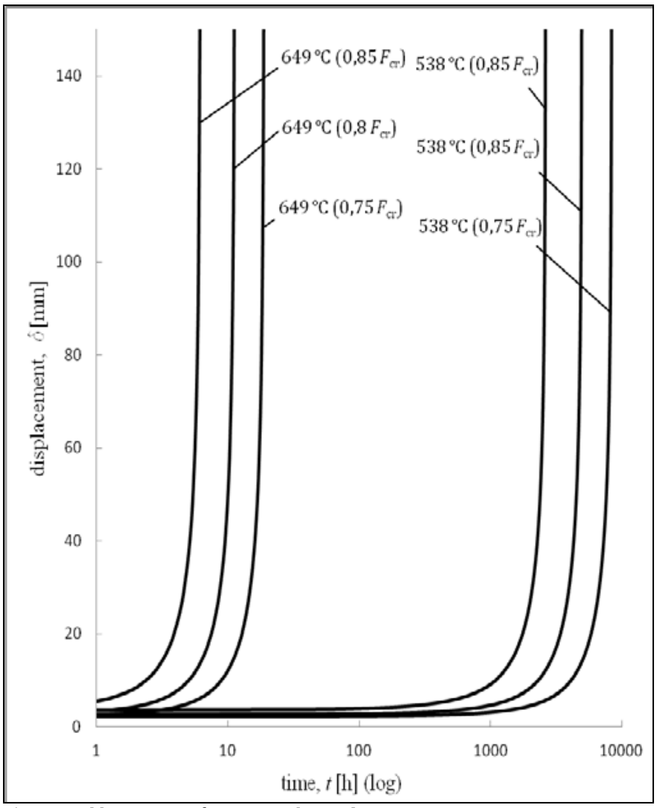

__Fig. 8__ Buckling curves for material A and B at 649°C

4. Concluding remarks

High temperatures which are caused e.g. by fires have significant influence to collapse time of frame structures. Numerical simulation of creep buckling is a fast way of prediction of such phenomena. From obtained results it can be concluded that material B is more creep resistant than material A. Furthermore, critical buckling time of material A rapidly decreases by temperature growth from 538°C to 649°C. Future research will encompass development of a creep buckling computer algorithm based on beam finite elements.

5. Acknowledgement

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6. References

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