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NUMERICAL CREEP BUCKLING ANALYSIS OF THIN-WALLED STEEL FRAME

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Abstract: *Paper presents creep buckling numerical modeling of steel beam-type structure. Finite element simulation is applied using four nodded Kirchoff-Love theory based shell elements. For test example, one-storey one-bay space frame, critical buckling times are evaluated varying load levels, temperature as well as chemical composition of carbon steel.*
Key words: *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 assemblages. Because such structures, especially those of thin-walled cross-sections, could display very complex structural behavior which comprises both geometric and material inelasticity, has been a major activity of many structural engineering researchers in the recent years.

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 (Lanc et al., 2008).

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 (Nguyen-Thanh et al., 2008).

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. CREEP MODELING

Creep material behavior can be modeled according to equation (Lanc et al., 2006):

$$ {}^2\varepsilon_{ij}'' = {}^2\varepsilon_{ij}' - {}^1\varepsilon_{ij}^{c} \tag{1}$$

while ${}^2S_{ij}$ is deviatoric stress tensor in configuration C_2 and ε_{ij}^c denotes creep deformation tensor.
Creep deformation increment can be calculated as:

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

where factor

$${}^1k = 1.5\left({}^1\dot{\bar{\varepsilon}}^c / {}^1\bar{\sigma}\right)\Delta t \tag{3}$$

with $\dot{\bar{\varepsilon}}^c$ and $\bar{\sigma}$ as effective creep strain rate and effective stress. In the case of creep configurations C_1 and C_2 are real time configurations, and time increment Δt represents the real time passed during the element movement from configuration C_1 to configuration C_2. Effective creep strain rate $\dot{\bar{\varepsilon}}^c$ from equation (3) can be obtained according to Norton power creep law as:

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

where K and n are Norton material constants.

3. EXAMPLES

Figure 1 shows a one-storey one-bay space frame loaded by four vertical forces, each of intensity F. All the frame members are made of W10×49 section. The material moduli is E = 210 GPa. The length of each beam is l = 3900 mm and of each column is H = 3773 mm. Three different finite element models are made. A beam finite element model with 80 elements and a shell finite element model with 5984 elements are made in FEMAP. One beam model with 8 elements is made in THINWALL. To obtain critical buckling load, eigenvalue analyses are performed by beam and shell FEMAP as well as THINWALL computer solver. The elastic buckling loads obtained from the above mentioned models are listed in Table 1. The first two buckling modes are sway modes in X and Z-axis directions and the third one is twist mode (Fig. 1).

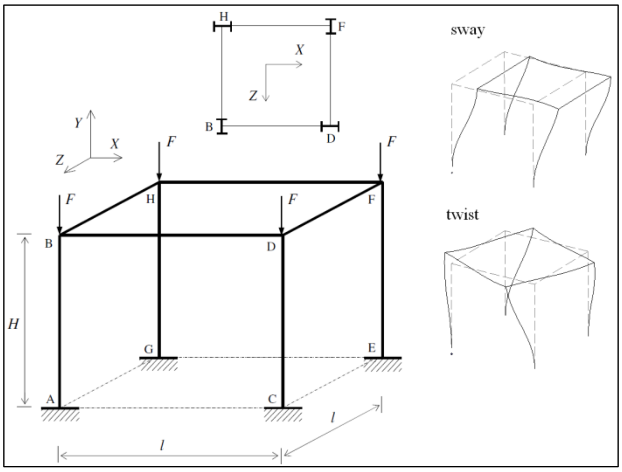

Fig. 1. One-storey one-bay space frame

FE model	No. of elements	Buckling load (MN)
FEMAP beam	80	8.1
FEMAP shell	5984	8.3
THINWALL	8	8.2

Tab. 1. Buckling loads for different finite element models

For a creep buckling analysis, the frame is loaded with three different constant forces: 4 MN (it is about $0.5F_{cr}$), 5.75 MN (it is about $0.7F_{cr}$) and 7.4 MN (it is about $0.9F_{cr}$). One set of perturbation forces, each of intensity $0.001F$, is applied at corners B and H in the positive X-direction to initiate the sway deformation shape. Another set is applied at corners H and D in the positive and negative X-direction, respectively and at corners F and B in the positive and negative *Z*-direction, respectively to initiate the twist deformation shape (Turkalj et al., 2009).

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 (Beljajev, 1959):

(1) material A - carbon steel (0.15 C, 0.50 Mn, 0.23 Si) at 538°C: n = 3.05, $K = 0{,}12 \cdot 10^{-13}$ $[10\ \mathrm{mm}^2/\mathrm{N}]^n \cdot \mathrm{h}^{-1}$;
(2) material A - carbon steel (0.15 C, 0.50 Mn, 0.23 Si) at 649°C: n = 2.85, $K = 0{,}16 \cdot 10^{-10}$ $[10\ \mathrm{mm}^2/\mathrm{N}]^n \cdot \mathrm{h}^{-1}$;
(3) material B - carbon steel (0.43 C, 0.68 Mn, 0.20 Si) at 649°C: n = 1.7, $K = 0{,}12 \cdot 10^{-8}$ $[10\ \mathrm{mm}^2/\mathrm{N}]^n \cdot \mathrm{h}^{-1}$.

Figure 2 shows total translation of corner B versus creep time for material A at temperatures of 538°C and 649°C and applied load levels of $0.5F_{cr}$, $0.7F_{cr}$ and $0.9F_{cr}$. Deformation shape is sway.

Figure 3 shows total translation of corner B versus creep time for both, A and B materials at temperature of 649°C and applied load levels of $0.5F_{cr}$, $0.7F_{cr}$ and $0.9F_{cr}$. Deformation shape is sway.

Figure 4 shows total translation of corner B versus creep time for material A and material B at temperature of 649°C and applied load level of $0.5F_{cr}$ for different deformation shapes, sway and twist.

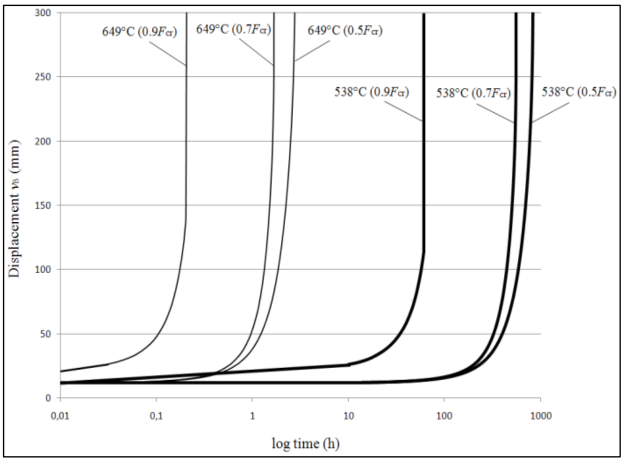

Fig. 2. Buckling curves for material A at 538°C and 649°C

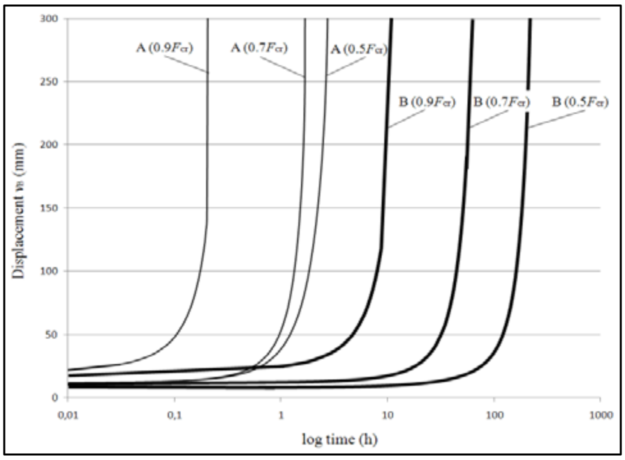

Fig. 3. Buckling curves for material A and B at 649°C

	Material A				Material B	
	T = 538°C		T = 649°C		T = 649°C	
	Sway	Twist	Sway	Twist	Sway	Twist
$0.5F_{cr}$	840	3820	3	11	228	242
$0.7F_{cr}$	560	616	1.5	2	55	63
$0.9F_{cr}$	60	76	0.2	0.2	9	11

Tab. 2. Critical buckling times (h)

The critical creep buckling times obtained for different chemical composition carbon steels at different temperatures are listed in Table 2.

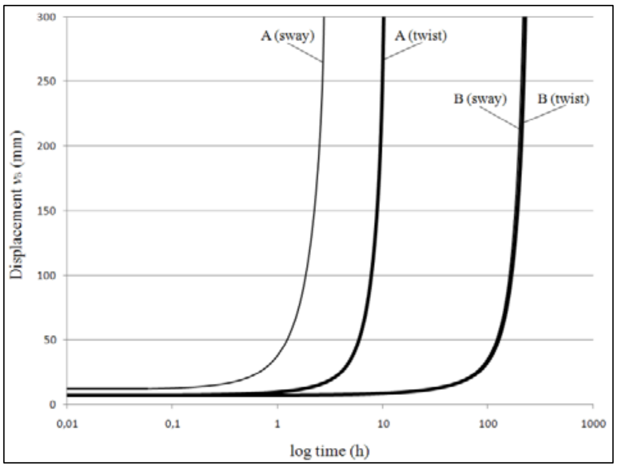

Fig. 4. Buckling curves for sway and twist modes at $0.5F_{cr}$

4. CONCLUSION

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. Change of deformation mode has also a great influence to decreasing critical buckling time for material A at lower load levels, while at higher loads this difference is negligible. Mode variation for material B does not change collapse time noticeably.

Even though this analysis includes only creep buckling at constant temperature levels, with slight modifications it is possible to expand it to non-constant temperature environment conditions e.g. in fire.

Future research will also encompass development of a creep buckling computer algorithm based on beam finite elements.

5. ACKNOWLEDGMENTS

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