AS 4100 DS04

Steel Structures – Elastic in-plane buckling of pitched roof portal frames

Written by: N.S. Trahair
Date: December 1992

Checked by: G.J. Hancock
Date: December 1992

ELASTIC IN-PLANE BUCKLING OF PITCHED ROOF PORTAL FRAMES

INTRODUCTION

In the design of steel pitched roof portal frames, it may be necessary to amplify the bending moments calculated using a first-order elastic method of analysis to allow for in-plane instability effects.

AS 4100 (Ref. 1) allows this to be done by calculating an amplification factor (δ_s) from the frame buckling load factor (λ), but does not specify a method of calculating λ, beyond using an elastic buckling analysis, which generally requires the use of a computer program.

This publication gives a simple approximate method for the hand calculation of the buckling load factor (λ) which does not require a computer buckling analysis program, and demonstrates its use in a worked example.

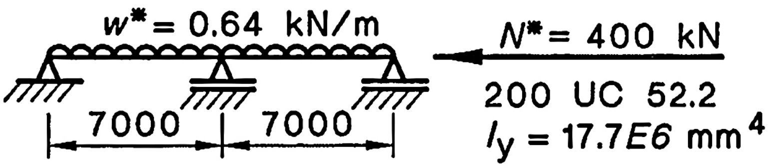

FIGURE 1 PINNED-BASE PORTAL FRAME

ELASTIC IN-PLANE BUCKLING

Pinned-base single bay frames

The buckling load factor of a symmetrical pinned-base portal frame (Figure 1) for the sway mode (Figure 2(a)) may be approximated by Refs 2 and 3)

$$\lambda_{sp} = \frac{3EI_r/(N_r^* l_r^*)}{[(1+1.2/R)(N_c^* l_c)/(N_r^* l_r)+0.3]} \qquad \text{...(1)}$$

in which $R = (I_c / l_c) / (I_r / l_r)$ ...(2)

and N_c^* and N_r^* are the design first-order compression forces in the columns and rafters. When N_c^* and N_r^* vary, average values should be used.

In some cases, the symmetric buckling mode shown in Figure 2(b) may occur. The buckling load factor for this mode may be approximated by treating the two rafters as a single member of length $2l_r$ which is elastically restrained by the columns, so that

$$\lambda_r = \frac{\pi^2 EI_r}{(2k_e l_r)^2 N_r^*} \qquad \text{...(3)}$$

in which the rafter effective length factor (k_e) is obtained from the braced member effective length factor chart of Figure 4.6.3.3a of AS 4100, by using

$$\gamma_{1p} = \gamma_{2p} = \frac{I_r / 2l_r}{1.5 I_c / l_c} \qquad \text{...(4)}$$

(a) Sway buckling mode

(b) Symmetric buckling mode

FIGURE 2 FRAME BUCKLING MODES

Fixed-base single bay frames

The sway buckling load factor of the symmetrical fixed-base portal frame shown in Figure 3 may be approximated (Ref. 2) by using Equation 2 in

$$\lambda_{sf} = \frac{(10 + R)5EI_r / (N_r^* l_r^2)}{2N_c^* l_c / (N_r^* l_r) + 5} \qquad \ldots(5)$$

The symmetric buckling load factor may be approximated by using Equation 3 in which the rafter effective length factor (k_e) is obtained from the braced member effective length factor chart of Figure 4.6.3.3a of AS 4100, by using

$$\gamma_{1f} = \gamma_{2f} = \frac{I_r / 2l_r}{2I_c / l_c} \qquad \ldots(6)$$

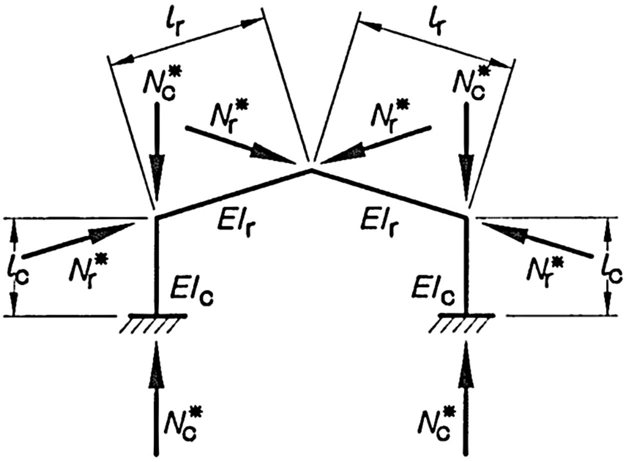

FIGURE 3 FIXED-BASE PORTAL FRAME

Multi-bay frames

Approximate methods for multi-bay frames are given in Ref. 3.

WORKED EXAMPLE

A uniform 360UB44.7 portal frame (Ref. 4) of Grade 250 steel is shown in Figure 4, together with the first-order axial forces (kN) in the members. The maximum first-order moment is M_{m3}^* = 151.8 kN at the knee.

$l_r = \sqrt{(12000^2 + 3000^2)}$ = 12369 mm

The average axial forces are

N_c^* = (51.4 + 69.1) / 2 = 60.3 kN

N_c^* = (58.1 + 48.0 + 43.0 + 53.0) / 4 = 50.5 kN

For sway buckling,

R = (121 x 10^6 / 4000) / (121 x 10^6 / 12369) = 3.09

$$\frac{N_c^* l_c}{N_r^* l_r} = \frac{60.3 \times 10^3 \times 4000}{50.5 \times 10^3 \times 12369} = 0.386$$

$$\lambda_s = \frac{3 \times 200000 \times 121 \times 10^6 / (50.5 \times 10^3 \times 12369^2)}{[(1 + 1.2/3.09) \times 0.386 + 0.3]}$$

$$= 11.2$$

For symmetric buckling,

$$\gamma_{1p} = \gamma_{2p} \approx \frac{(121 \times 10^6 / 2 \times 12369)}{(1.5 \times 121 \times 10^6 / 4000)} = 0.11$$

$k_e \approx 0.55$ (from Figure 4.6.3.3a)

$$\lambda_r = \frac{\pi^2 \times 200000 \times 121 \times 10^6}{(2 \times 0.55 \times 12369)^2 \times 50.5 \times 10^3} = 25.6 > 11.2$$

For moment amplification

$\delta_s = 1/(1 - 1/11.2) = 1.10$

$M_3^* = 1.10 \times 151.8 = 167$ kNm

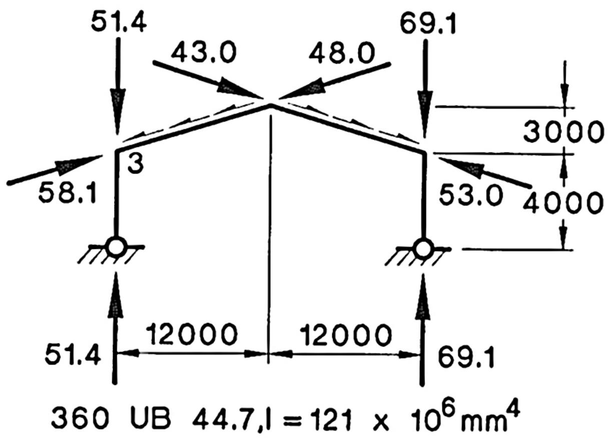

FIGURE 4 AXIAL FORCES (kN) ON EXAMPLE FRAME (Ref. 4)

DISCUSSION

A computer elastic frame buckling analysis (Ref. 5) of this frame predicted a buckling load factor of 13.3, compared with λ = 11.2.

A computer elastic second-order analysis (Ref. 5) of this frame predicted M_3^* = 155.8 kNm, N_{r3}^* = 58.4 kN, compared with the approximate values obtained above.

The amplification factors for rectangular portal frames may be determined by using Clause 4.4.2.3(a) of AS 4100 (Ref. 1).

Amplification factors are not required when a second-order analysis (Refs 5, 6 and 7) is carried out.

REFERENCES

1 SA (1998), AS 4100 *Steel structures*, Standards Australia, Sydney.

2 Davies, JM (1990), 'In-plane Stability of Portal Frames', *The Structural Engineer*, Vol. 68, No. 8, April, pp 141 – 147.

3 Davies, JM (1991), 'The Stability of Multi-Bay Portal Frames', *The Structural Engineer*, Vol. 69, No. 12, June, pp 223-229

4 Bridge, RQ, Clarke, MJ, Hancock, GJ, and Trahair, NS (1991), 'Trends in the Analysis and Design of Steel Building Frames', *Civil Engineering Transactions*, Institution of Engineers, Australia, Vol. CE 33, No. 2, April, pp 87-95

5 Hancock, GJ (1991), *PRFSA User's Manual*, Centre for Advanced Structural Engineering, University of Sydney.

6 Engineering Systems (1990), *MicroSTRAN-3D User's Manual*, Engineering Systems Pty Ltd, Sydney.

7 Integrated Technical Software (1992), *SPACEGASS 5.2—Reference Manual*, Integrated Technical Software Pty Ltd, Melbourne.