NCCI: Practical analytical models for portal frames (plastic analysis)

This NCCI gives guidance on preparing structural models for portal frames designed using plastic analysis.

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1. General

Portal frames verified by plastic design are commonly fabricated from hot-rolled I-sections. It is generally most economic to have haunches to deepen the rafters at the columns as shown in Figure 1.1 below. It is essential that the section classification is Class 1 at all plastic hinge positions and so it is most common to use Class 1 sections throughout the columns and rafters. It is common to use Class 3 webs and Class 1 flanges for the haunches, provided that in the Class 3 portion of the web either the stress distribution remains elastic or the requirements of EN 1993-1-1 §6.2.2.4 are satisfied and no plastic hinge occurs.

![Figure 1.1 General arrangement of frame](image)

Key:
- 1 = rafter
- 2 = column
- 3 = eaves haunch
- 4 = base
- 5 = apex haunch

2. Frame idealisation for analysis

2.1 Initial imperfections

Sway imperfections should be applied as EN 1993-1-1 §5.3.2(3)(a). It is generally simplest to calculate the equivalent horizontal forces as §5.3.2(7). In some frames, initial bow imperfections might need to be included in the analysis, see SN033.

2.2 Frame geometry

The frame geometry in the analysis model is commonly the centre-line of the columns and the rafters, neglecting the haunches.

2.3 Base conditions

2.3.1 Pinned, nominally or truly

It is rare for bases to be truly pinned. Most bases are nominally pinned, comprising, for example, a simple end plate that is relatively thin with four holding down bolts (for safety during erection of the frame). Nominally pinned bases are commonly assumed to be pinned for response to vertical loading. When calculating $\alpha_{cr}$, they are commonly assumed to have
some small rotational stiffness, often assumed to be not less than $0.4EI_c/L_c$, where $I_c$ is the second moment of area of the column in the plane of the frame and $L_c$ is the height of the column, see [1] and [2]. When calculating deflections for the Serviceability Limit State, they are commonly assumed to have a slightly greater rotational stiffness, often assumed to be not less than $0.8EI_c/L_c$.

### 2.3.2 Fixed, nominally or truly

In practice, it is unlikely for bases to be truly fixed. Fixed bases are commonly assumed to be slightly flexible for analysis to find the ULS bending moments and forces. In the absence of more detailed information, this is often assumed to be $4EI_c/L_c$, where $I_c$ is the second moment of area of the column in the plane of the frame and $L_c$ is the height of the column, both for analysis to find the ULS bending moments and forces and for calculating $\alpha_{cr}$, see [1] and [2]. However, when calculating deflections for the Serviceability Limit State, the bases are commonly assumed to be truly rigid.

### 3. Cross-section Requirements

The cross-section requirements for plastic global analysis are given in EN 1993-1-1 §5.6.

### 4. Initial choice of sections

Good approximations to member sizes for portals with low roof slopes can be calculated as follows. This approach includes some allowance for second order effects.

- Columns and haunches – choose sections with $M_{pl} = WL/10$
- Rafters - choose sections with $M_{pl} = WL/20$

where

- $L$ is the span of the frame between columns (or valley beams)
- $W$ is the total load on the span at Ultimate Limit State
- $M_{pl}$ is the plastic moment of resistance of the cross section

### 5. Accounting for second-order effects

#### 5.1 General

EN 1993-1-1 §5.2.1(2) requires that “the effects of deformed geometry (second-order effects) should be considered if they increase the action effects significantly or modify significantly the structural behaviour”. Almost all competitive designs of portals will have $\alpha_{cr}$ less than 10 and so second-order effects will need to be considered. There are numerous methods which may be applied. All the methods must include checks of the cross-sectional resistance to ensure that the plastic hinges form and rotate where the moment reaches the moment of resistance $M_{c,Rd}$ at loading less than 100% ULS and that the rotation at each hinge is consistent with the rotation capacity of the cross-section. It should be noted that $M_{c,Rd}$, defined in EN 1993-1-1 §6.2.5, may be reduced by coexistent shear and/or axial forces as given in EN 1993-1-1 §6.2.8, §6.2.9 and §6.2.10, but this is very unusual in portal frames.
5.2 Second-order analysis routines

Analysis methods include stiffness matrix methods in which the second-order effects may be considered by reforming the geometry matrix, modifying the stiffness matrix, by energy methods or by a combination of these methods.

5.3 First-order analysis with amplified loads

Analyses methods include elastic-plastic software, the graphical method and virtual work assuming rigid plastic behaviour. These methods are shown in terms of application with ENV 1993-1-1 in refs [1] and [2].

Where $\alpha_{cr}$ is less than the limit set in the relevant National Annex for EN 1993-1-1 §5.2.1(3), recommended value $= 15$, second-order effects must be considered. This can be done using first-order analysis with amplified loads. The amplification of the loads must be appropriate to the geometry of the frames considered. SN033 gives suitable amplification factors and limits of application. The factors are derived from the second-order effects derived by the method known in many countries as Merchant-Rankine and have been verified for by elastic-plastic second-order analysis for the range of geometries given in SN033. This method has been used since its development in the 1950s, refs [3], [4], [5], [6], [7], [8], [9], [10] & [11].

5.4 Tied portals

Portal frames in which the rafters are inclined to the horizontal and there is a tie at or near the level of the rafters from one side of the span to the other are commonly called “tied portals”. The rafters and the tie act almost like a truss, so where the rafter inclination is small, the axial forces in the rafters and the tie are high and the effects of deformed geometry can be very severe. For these frames, it is recommended that analysis should only be undertaken with software that can consider both second-order effects and the special tendency of rafters to “snap-through”.

![Figure 5.1 General arrangement of a typical tied portal](image-url)
6. References


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