Portal Frame Design Comparisons BS 5950 v Eurocode 3 using the Computer Program Quikport XP

Paul Bennett Bsc.(Hons.)

29-03-2011

Abstract

This paper presents direct comparisons between steel portal frame design in accordance with BS5950 and Eurocode 3 in the UK. The different approaches to in-plane stability are discussed and final frame sizes compared. The paper demonstrates that Eurocode design can yield greater economy than that achieved using BS5950.

1. Introduction

In the UK portal frame design accounts for some 90% of all single storey steel buildings and consume 50% of all steel used in construction. Traditionally this market has been hotly contested with designs being carried out using computer programs optimised for economy.

Prior to the introduction of BS 5950 in 1985 portal frames were designed in accordance with design guides and BS 449[1]. The design guides were the first in the UK to propose an ultimate limit state approach using a factor of 1.7 applied to both dead and imposed loads.

The introduction of BS 5950[2] properly codified the design of portal frames and was welcomed by steel fabricators, partly because of its clarity, but mainly because of the adoption of lower load factors (1.4xdead+1.6imposed) - resulting in greater design economy. However, along with this greater economy and lighter frames arose an awareness that the second order affects, in these relatively slender and flexible frames, could be significant. Hence, the introduction of BS 5950-1:2000[3].

BS 5950 and BS 6399 are now withdrawn and superseded by the following Structural Eurocodes:

- BS EN 1990:2002 Basis of Structural Design
- BS EN 1991-1-1:2002 General actions - Densities, self-weight, imposed loads for buildings
- BS EN 1991-1-3:2003 General actions - Snow loads
- BS EN 1991-1-4:2005 General actions - Wind actions
- BS EN 1993-1-1:2005 General rules and rules for buildings

BS EN 1990 load factors for Eurocode design are lower still (typically 1.25dead+1.50imposed) - promising even greater economy. However, the vast majority of portal frame design in the UK is still carried out in accordance with BS 5950. Why?

The design of modern portal frames is now very complex requiring the use of relatively expensive computer software, the majority of which is still only in accordance with BS 5950.

One exception is the computer program Quikport XP. Quikport XP can produce designs, and account for second order effects, to both BS5950 and the Eurocodes. It now has automatic imposed, snow and wind loading generators to both the Eurocodes and the older British standards. It is therefore a trivial matter to compare BS5950 and Eurocode designs..

2. Procedure

Two frames are designed:

1. A fairly typical portal taken from the real world, some 7.3 metres to eaves, 28.75metre span, 10 degree rafter pitch and 5.55m bay centres. The haunch length is taken as 10% of the span - the haunch material is assumed to be the same as the rafter and its depth calculated to make best use of the material.
2. The second example is essentially the same frame with an off centre column supporting a mezzanine floor. See Figure 1.

The first frame was input using Quikport XP's Input wizard, which may be used to quickly build the geometry of a range of portal frame types. Load generation is achieved by selecting either the BS 6399 or EN1991 option. In this case, the first run of the Input Wizard was carried out to BS 6399 resulting in a frame file 'bsFrame02.qp2' It was then quick and easy to re-run the Wizard (the geometry is retained) and select EN1991 resulting in a critical frame file 'enFrame02.qp2'.

For the Eurocode frame it was necessary to run Quikport's *Load Cases and Combinations Wizard* to build the combinations of actions in accordance with EN 1990. EN 1990 suggests two methods covered by equations (6.10), or (6.10a) and (6.10b). The later was chosen since it results in lower factors.

The second frame with the mezzanine was created by modifying the first. Quikport XP provides a user interface whereby construction lines, members, bases, haunches etc. may be added interactively by identifying points using the mouse. Three new section groups were added: Mez beam, Mez column and Mez post.

Both these frames were then sized using *Quikport's Design Wizard*. Design Wizard starts by requesting the design method BS 5950, or Eurocode 3. It then uses full minimum weight design to automatically size the members. The method uses linear programing techniques to find the optimum rafter/column size before accounting for the out of plane stability of the members. During this phase, the designer can intervene and suggest sections for each group from a list of suitable sections sorted in cost order (S355 steel, a requirement of the fabricator was used throughout). The final phase of *Design Wizard* is the automatic addition of purlin and rail stays to satisfy the out of plane stability in accordance with the selected design code.

The next stage in the process was to asses the in-plane stability or second order affects in the frame. This was achieved by running Check Wizard. Again Check Wizard is automated. Once the design method (BS 5950/EN 1993) is selected, the Wizard calculates the elastic critical load factor for each ULS combination of actions. These can be reviewed and either moment amplification or advanced second order analysis selected.

2.1 Moment amplification BS 5950

An important difference between BS 5950 and Eurocode's in-plane stability checks is the representation of the merchant rankine equation. Clause 5.5.4.4 of BS 5950 *Amplified moment method* states:

$\lambda_r = 0.9\lambda_{cr} / (\lambda_{cr} - 1)$

λ_{cr} is the elastic critical load factor the frame and applied loading

λ_r is the required load factor for frame stability

The beneficial factor 0.9 is used to account for strain hardening. Where the elastic critical load factor is less than 10, BS 5950 suggests that the applied loading should be amplified by λ_r. Where the elastic critical load factor is less than 5, the merchant rankine approach is considered unreliable and second order analysis should be used *(or the frame stiffened).*

2.2 Moment amplification EN 1993-1-1

$\alpha_r = \alpha_{cr} / (\alpha_{cr} - 1)$

α_{cr} is the elastic critical load factor the frame and applied loading

α_r is the required load factor for frame stability

Note that the factor 0.9 is removed.

Clause 5.2.1(3) of EN 1993-1-1: 2005 states that second order effect may be neglected when:

$\alpha_{cr} > 10$ (for elastic analysis)

$\alpha_{cr} > 15$ (for plastic analysis)

It goes on to say that, when α_{cr} is less than 3 a more accurate second order analysis should be used. However, the UK national annex NA.2.9 states that for plastic analysis of clad structures, provided that the stiffening effects of masonry infill wall panels or diaphragms of profiled steel sheeting are not taken into account:

$\alpha_{cr} > 10$

And for plastic analysis of portal frames subject to gravity loads only with frame imperfections and provided that *span L < 5 x Mean column height* and the rise of the rafters is less than *0.25 x span*:

$\alpha_{cr} > 5$

Since the above frame without mezzanine conforms to these dimensions, it is assumed satisfactory to ignore second order affects for dead+imposed and dead+imposed+notional loads when the value of elastic critical load factor is greater then five.

References 4 and 5 further complicate matters by suggesting that frames be subdivided into categories A and B and that category B frames should suffer an additional 10% amplification. However for these examples only the provisions of EN 1993-1-1 and its UK national annex are considered.

2.3 Frame results (without mezzanine)

Frame without mezzanine, including wind loadings, ignoring deflections**:**

Code	Design type	Second order method	Colum size	Rafter size	Mass
BS 5950	Plastic	moment amp	457x152x60	406x140x46	2.218
Eurocode	Plastic	moment amp	457x152x60	406x140x46	2.218
Eurocode	Elastic	ignored	457x152x60	406x140x39	2.012
Eurocode	Elastic	using NA.2.9 α_{cr}>5	457x152x60	406x140x39	2.012
Eurocode	Plastic	advanced 2nd order	457x152x60	406x140x39	2.012

Design type 'Elastic' means no hinges formed at design loading. All steel grades S355

2.3 Mezzanine frame results

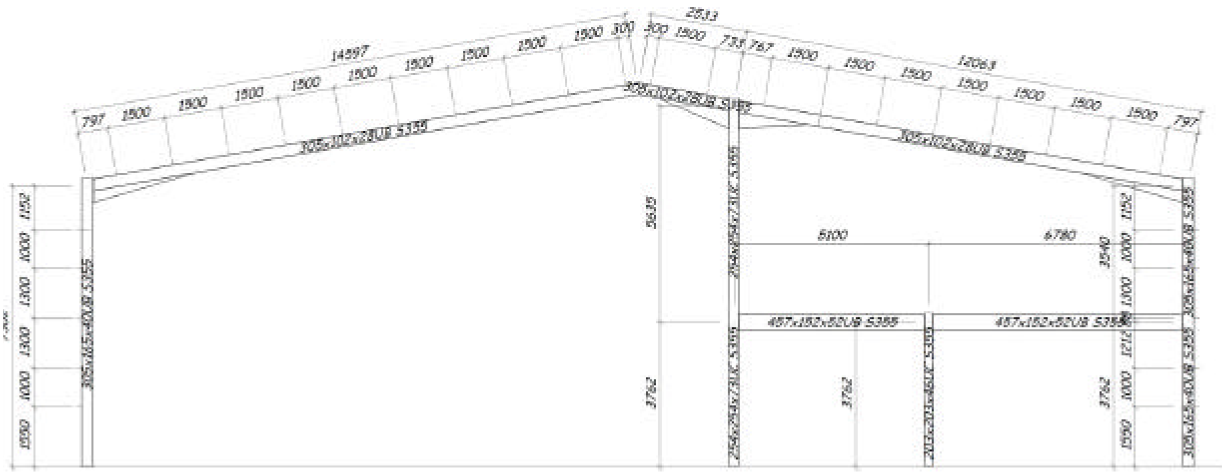

Figure 1

Frame with mezzanine, including wind loadings, ignoring deflections**:**

Code	Design type	Second order method	Mass	See Note
BS 5950	Elastic	moment amp	3.218	1
Eurocode	Elastic	moment amp	3.218	1
Eurocode	Elastic	ignored	2.892	
Eurocode	Elastic	advanced 2nd Order	2.892	

Note 1 - α_{cr} is very low for this frame, causing large amplification. If the mezzanine prop is stiffened, the α_{cr} rises rapidly. This is an interesting observation as it is the prop that causes the low value of α_{cr} making moment amplification costly against advanced second order.

2.4 Deflection criteria

The deflection problem is essentially the same for both BS 5950 and Eurocode. Increasing the size of the the external columns to 356x171x 45 (S355) meets deflection criteria but increases the frames mass to 3.287Mg.

Conclusion

In both cases the frames designed in accordance with Eurocode showed a significant 10% saving in steel tonnage.

When checking for second order affects and where a frames geometry satisfies the conditions of NA 2.9 a) and b) and its elastic critical load factors for gravity and gravity with notional loads can be shown to be greater than 5, the Eurocodes yield excellent results.

In other cases the loss of the strain hardening factor (0.9) in the formulation of Eurocode's Merchant-Rankine equation results in designs of similar weight to BS 5950. However the economies may be restored by adopting advanced second order analysis.

NA.2.9 only considers plastic analysis. With a plastic analysis, if no hinges have formed at design load, the *frame (and the analysis)* may be considered to be elastic. In the opinion of the author it would seem to be sensible to apply these rules to both elastic and plastic analyses.

References

1. BS 449: Part 2: 1969 Specification for the use of structural steel in building, London, British Standards Institution,1969
2. BS 5950: Part 1: 1985 Structural use of steelwork in building. Code of practice for design in simple and continuous construction: Hot rolled sections, London, British Standards Institution, 1985
3. BS 5950-1: 2000 Structural use of steelwork in building. Part 1: Code of practice for design - Rolled and welded sections, London, British Standards Institution, 2001
4. Lim, *et al*. Eurocode 3 and the in-plane stability of portal frames
5. Access Steel NCCI: Simple methods for second order effects in portal frames. SN033a-EN-EU