

Discussion: Lateral buckling of plate girders with flexible restraints

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It is unusual and pleasing to read a paper proposing simpler methods of analysis (Hendy and Jones, 2009). There seems to be a relentless addition of complicated methods of analysis in codes, many of which have little intuitive meaning to the average designer. At times, one wonders what proportion of these calculations are carried out accurately or whether any studies have been undertaken on the risks of misinterpretation of complicated clauses.

I was particularly interested in the authors' comments about buckling of braced pairs with torsional bracing, and carried out a series of finite element (FE) runs with bracings at varying centres. The runs have a 1555 m deep girder pair with a single-span of 48 m, girders at 3 m centres, with 600 × 50 top flange, 20 web, 800 × 60 bottom flange and 150 × 15 angle bracing. Loads due to self-weight and wind were included in the runs.

Five analysis methods for bracings at 6, 8, 12 and 16 m centres were compared:

- (a) BS 5400 Figure 11 using bracing centres as the effective length
- (b) BS 5400 clause 9.6.4.1.2 for torsional restraints
- (c) eigenvalue buckling analysis with FE analysis in conjunction with BS 5400 clause 9.7.5
- (d) non-linear FE analysis with span/150 initial imperfection (Eurocode initial imperfection)
- (e) non-linear FE analysis with span/500 initial imperfection (approx 2 × BS 5400: Part 6 tolerance).

The results are plotted in Figure 16. Utilisations shown are based on loads and capacities that do not include gamma factors.

As noted in the original paper, the results appear to show that the use of BS 5400 clause 9.6.4.1.2 is very conservative. The results based on back-calculation of eigenvalue buckling loads are generally conservative compared with the non-linear runs. There is a significant increase in capacity if the initial imperfection is reduced from the value of span/150 shown in the Eurocode.

A casual examination of the deflected shape of the non-linear runs appears to suggest that the half wavelength might be of a

similar order of magnitude to the bracing centres, and not comparable with the values obtained from clause 9.6.4.1.2 and the eigenvalue back-calculation.

Although this is a limited series of runs, it seems possible that the simple method using bracing centres as effective length might not necessarily be particularly unsafe, and could explain how the 'previous incorrect approach ... allowed girders to be constructed safely'.

It would be interesting to hear the authors' views on the appropriateness of the BS 5400 and Eurocode equations used for the eigenvalue back-calculation. Also of interest would be the authors' views on the appropriateness of the initial imperfections stated in the Eurocode, which are often of a similar order of magnitude to half the top flange width, and significantly greater than fabrication tolerances and lateral deflections due to wind.

AUTHORS' REPLY

Two main questions have been raised:

- (a) whether the buckling design could be based simply on the spacing of bracings
- (b) the appropriateness of the initial imperfections used.

The replies are as follows.

- (a) The arrangement of the girders and bracing determines whether the lowest elastic buckling mode is buckling of the whole span or of a length of flange between bracings. When the bracings are closely spaced, the girders fail with global buckling of the span. As the distance between bracings is increased, the load for buckling between bracing members decreases and at some point this will usually become the critical mode of buckling. The point at which this occurs will depend on several factors. Using the bracing centres may be safe in many practical cases, even where the actual buckling waveform involves the whole span due to other built-in conservatism (e.g. ignoring restraint from formwork), but there will be exceptions to that rule. One of the original intentions of the work was to try and establish a simple safe rule, such as using bracing spacing for the effective length. During the course of the study, however, it was found that the global mode could produce a considerably lower critical

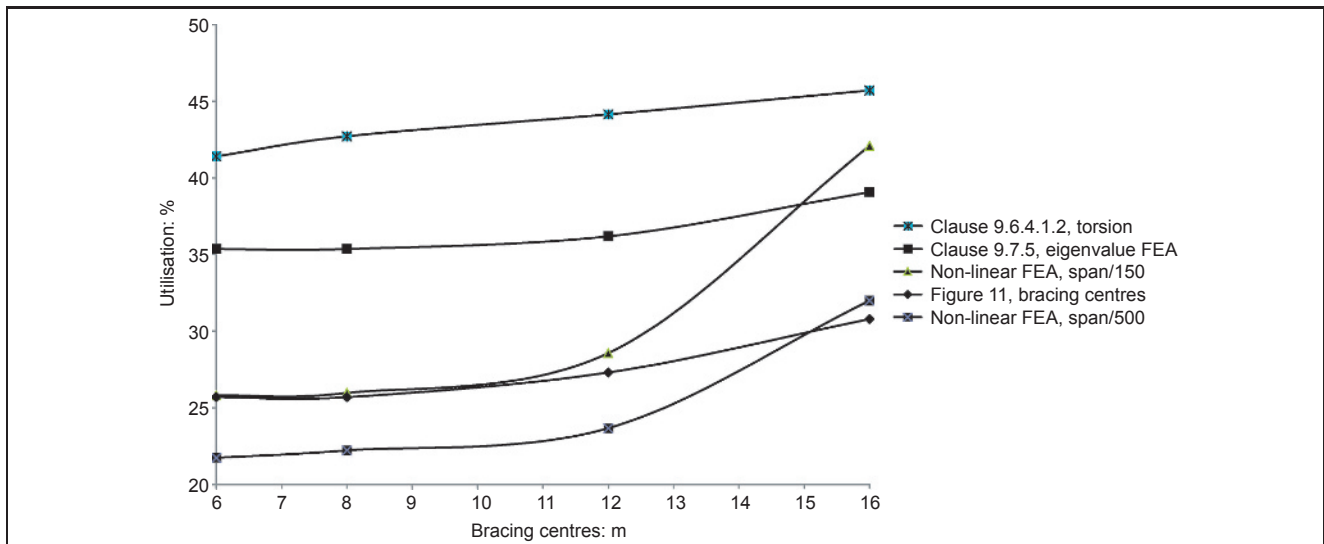


Figure 16. Utilisation curve for a pair of 48 m girders

moment for some geometries and that the elastic critical buckling analysis was quicker and simpler to perform so the need for such an approximate solution was diminished.

- (b) The initial imperfections used in non-linear analysis need to allow for both residual stress and tolerance on out of straightness. For this reason they are greater than fabrication tolerances alone and Eurocode 3 gives a simplified imperfection relating only to length. The code buckling curves are based on test results, however, and incorporate initial imperfections that are dependent on slenderness. It would be possible to obtain more accurate results from a non-linear analysis by determining an imperfection appropriate to the slenderness from the buckling curves. This, however, adds an additional level of complexity. (Chris Hendy is involved in work through the European Convention for Constructional Steelwork that is investigating codifying this possibility for plates as well as beams.)

The values for initial imperfection given in Eurocode 3 are conservative but, as our analysis and that carried out by Chris Booth show, still give a significant benefit compared to the BS 5400 empirical equations or EN 1993 elastic critical analysis approaches.

The authors also agree with the questioner's suggestion that some code rules are so complicated and lacking in transparency that there is a heightened risk of error. The rules in BS 5400 Part 3 were considered to be such cases.

REFERENCE

Hendy CR and Jones RP (2009) Lateral buckling of plate girders with flexible restraints. *Proceedings of the Institution of Civil Engineers, Bridge Engineering* 162(1): 25–33, doi: 10.1680/bren.2010.162.1.25.

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