Use of EN 1993-1-5 section 4 and 10 for biaxial stress

Chris Hendy, head of Bridge Design and Technology at Atkins and Chairman of SCI's Steel Bridge Group discusses the background to a proposed change to the rules for the design of plates subject to biaxial compression according to BS EN 1993-1-5. This article was written before the recent issue of a relevant draft for public comment (16/30340641 DC. BS EN 1993-1-5 AMD1).

1. Introduction

Generally, section 10 of EN 1993-1-5 will not be required in design and the effective width method of section 4 of EN 1993-1-5 will be used in preference. However, where the geometrical conditions for the use of the effective width method are not met or where the combination of stresses (e.g. biaxial stress) are not covered by section 4, it may be necessary to use section 10. This latter case can arise, for example, in box girder bridges at transverse support diaphragms where there is local load introduction, such as at intermediate piers or stay cable supports. In such cases, it is also possible to adapt the rules of section 4 to include biaxial effects, but EN 1993-1-5 currently gives no rules for this situation.

The choice of design method leads to two important observations that designers should be aware of as follows:

(i) Section 10 takes no account of the beneficial shedding of load from overstressed panels and stiffeners so is mostly conservative by comparison with section 4, although not always (see ii). The choice of method can therefore have a large impact on steel tonnage. A particular difficulty occurs when the majority of the length of bridge sees uniaxial direct stress but local zones of flange (e.g. adjacent to diaphragms) see biaxial direct stress. This leads to different designers taking different approaches which are essentially: (a) use section 4 throughout, without corrections for biaxial stress locations; (b) use section 4 throughout, making corrections for biaxial stress locations; (c) use section 4 generally and section 10 for biaxial stress locations; (d) use section 10 throughout. Reference 1 provides some guidance on the comparison of the methods.

At this stage, this note merely draws attention to the fact that method (a) is not conservative, method (b) is appropriate provided that suitable assumptions for the interaction are made and methods (c) and (d) are likely to lead to ever increasing quantities.

Method (b) could be informed by ECCS publication 44, section 2.625 for example, which recommends an interaction of the utilisations of the two direct stress such that the square root sum of the squares of the utilisations is less than unity. It was not however written with the express intent of then using EN 1993-1-5 for the further interaction of this combined utilisation with shear in section 7. Alternatively, the affected element could be checked for biaxial stress using section 10 to subsequently determine a reduction factor for that element for subsequent use in section 4 and 7. Detailing such calculation methods are outside the scope of the note.

(ii) EN1993-1-5 section 10 is typically more conservative than section 4, but ***is unconservative for cases of biaxial compression and should not be used for such cases in its current format.*** The sections below identify the problem and propose an interim modification until EN 1993-1-5 is itself modified.

2. Biaxial compression – the problem in EN 1993-1-5 section 10

Depending on plate slenderness, the behaviour under biaxial compression varies as follows:

(i) Where there is no tendency for buckling (stocky plates), the behaviour is accurately predicted by the Von Mises yield criterion:

$$\left(\frac{\sigma_{x,Ed}}{f_y/\gamma_{M1}}\right)^2+\left(\frac{\sigma_{z,Ed}}{f_y/\gamma_{M1}}\right)^2-\frac{\sigma_{x,Ed}}{f_y/\gamma_{M1}}\,\frac{\sigma_{z,Ed}}{f_y/\gamma_{M1}}+3\left(\frac{\tau_{Ed}}{f_y/\gamma_{M1}}\right)^2\le 1.0$$

In essence the presence of biaxial stress provides confinement which means that the allowable compressive stress in one direction may be increased by applying compressive stress in the other. Stresses in excess of yield can be reached.

(ii) For very high slenderness, the interaction between compressive stresses is essentially that for elastic buckling and is linear. The material strength itself is not relevant.

(iii) For intermediate slenderness, the behaviour is intermediate to the above and has to be determined by non-linear theory.

These three cases of interaction are shown in Figure 1 over the page.

EN 1993-1-5 chooses to use a form of the Von Mises equivalent stress criterion for verifying plates under in-plane stress fields, whether stocky or slender, via (10.5):

$$\left(\frac{\sigma_{x,Ed}}{\rho_x f_y/\gamma_{M1}}\right)^2+\left(\frac{\sigma_{z,Ed}}{\rho_z f_y/\gamma_{M1}}\right)^2-\frac{\sigma_{x,Ed}}{\rho_x f_y/\gamma_{M1}}\,\frac{\sigma_{z,Ed}}{\rho_z f_y/\gamma_{M1}}+3\left(\frac{\tau_{Ed}}{\chi_w f_y/\gamma_{M1}}\right)^2\le 1.0$$

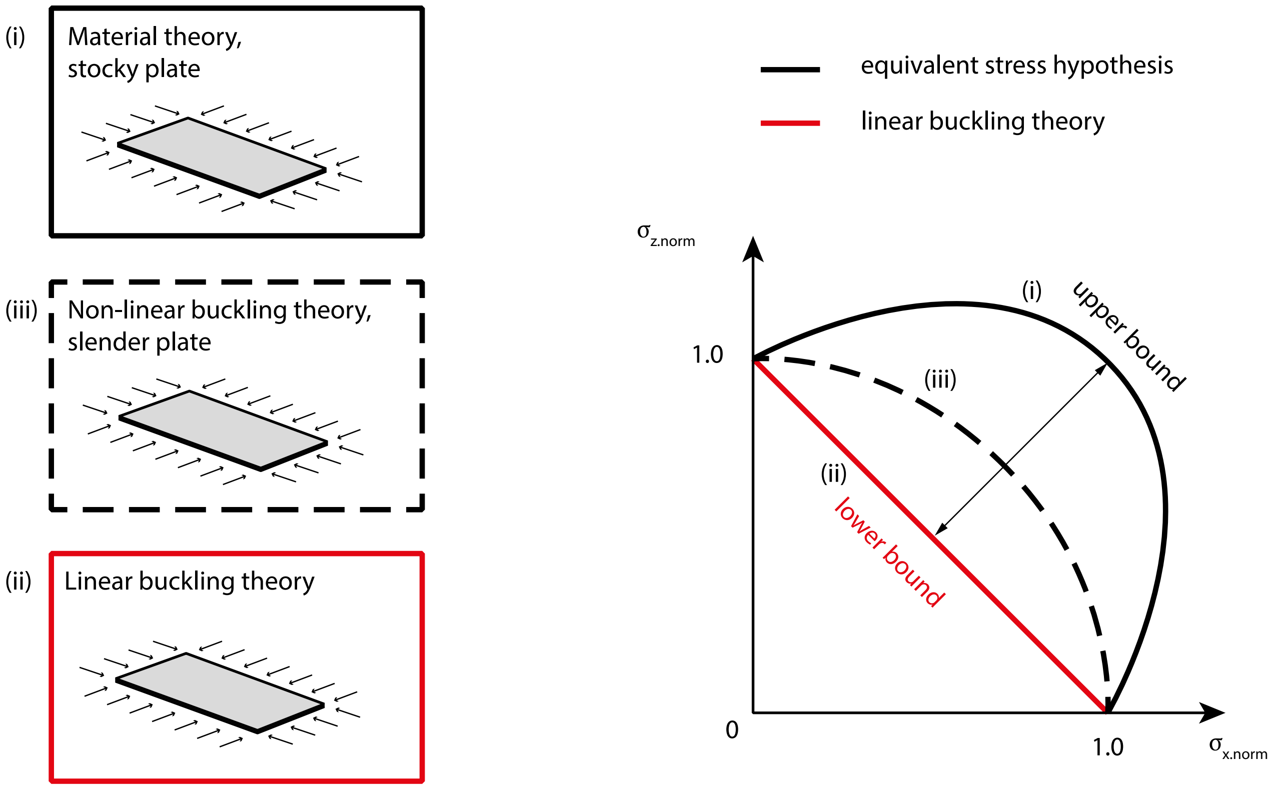

Figure 1: Different types of interaction for biaxial compression

The reduction factors ρ_x and ρ_z are introduced to allow for buckling. Their inclusion in all denominators means that the interaction between stresses is always convex, whilst at high slenderness it is known that the interaction should be almost linear as mentioned above. In simple terms, by applying the reduction factors ρ_x and ρ_z to the negative term (when both direct stresses are positive and compressive), this beneficial term becomes large and too much benefit is taken from it.

The results of EN 1993-1-5 (10.5) are shown for a square plate in biaxial compression with varying slenderness (*b/t* ratio) in Figure 2 and compared with the results of the German DIN 18800-3 code. It can be seen that at high slenderness, *b/t*=100, the EN 1993-1-5 prediction is still very convex, while the DIN code has a linear interaction. From non-linear studies it is known that EN 1993-1-5 is unsafe in this case and DIN 18800-3 is conservative. It is evident some correction is needed to the rules of EN 1993-1-5 for biaxial compression at high slenderness.

3. Biaxial compression – the interim correction to EN 1993-1-5 section 10

The following amendments should be made to EN 1993-1-5 section 10 until such time as the standard is itself modified. The amendments reduce the benefit of the negative term in expression (10.5) by eliminating the reduction factor terms in its denominator when both direct stresses are compressive. For this reason, the method of clause 10(5)a) should not then be used because the reduction factor is always automatically applied to all the stresses.

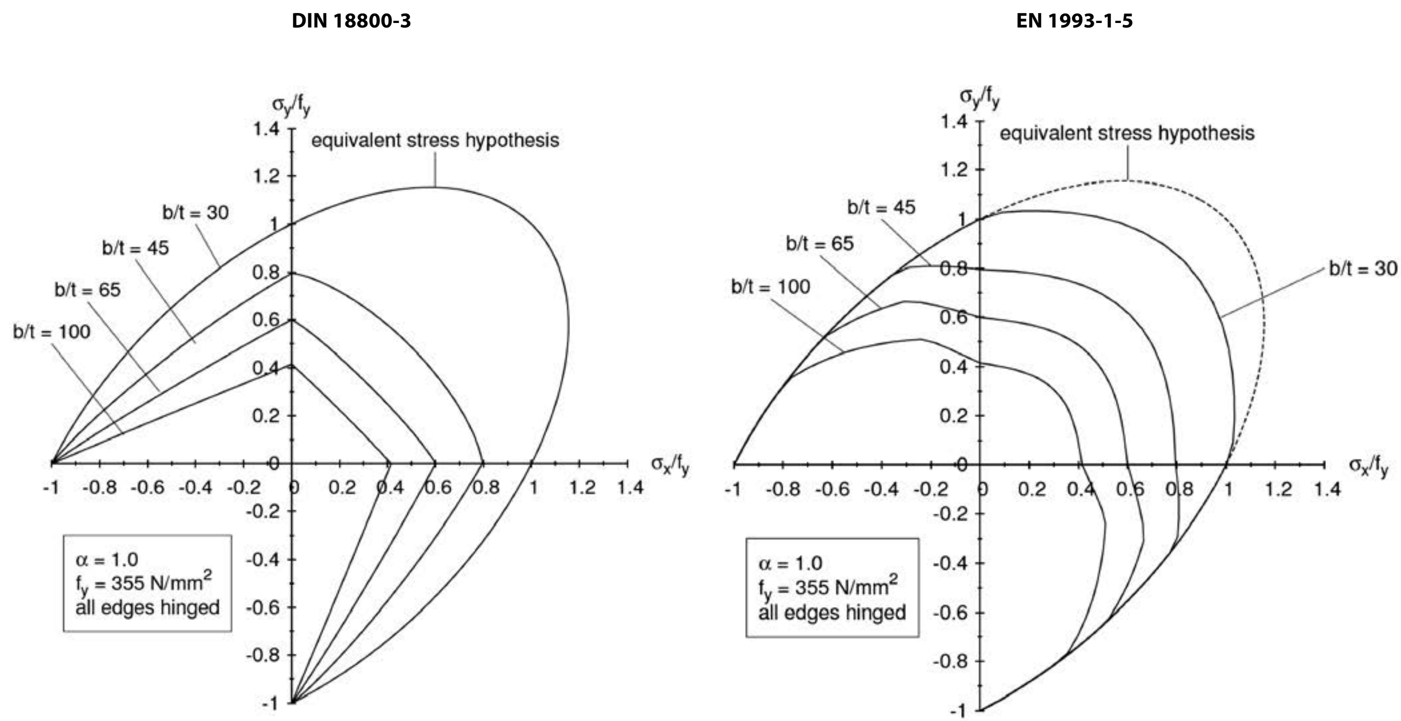

Figure 2: Interaction for biaxial compression according to DIN 18800-3 and EN 1993-1-5

The method in EN 1993-1-5 clause 10(5)a) should not be used.

In clause 10(5)b), expression (10.5) should be replaced with the following:

$$\left(\frac{\sigma_{x,Ed}}{\rho_x f_y/\gamma_{M1}}\right)^2 + \left(\frac{\sigma_{z,Ed}}{\rho_z f_y/\gamma_{M1}}\right)^2 - V\,\frac{\sigma_{x,Ed}}{\rho_x f_y/\gamma_{M1}}\;\frac{\sigma_{z,Ed}}{\rho_z f_y/\gamma_{M1}} + 3\left(\frac{\tau_{Ed}}{\chi_w f_y/\gamma_{M1}}\right)^2 \leq 1.0$$

where:
$V = (\rho_x \rho_z)$ when $\sigma_{x,Ed}$ and $\sigma_{z,Ed}$ are both compressive, or $V = 1.0$ otherwise.

References

1. Hendy, C R, Murphy, C.J, *Designers' Guide to EN1993-2: Design of steel structures Part 2, Steel bridges,* Thomas Telford (2007)

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