Eurocodes – the need for evolution

A view from a user

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Eurocodes – the need for evolution

Introduction

- Speaking from Atkins and industry observations
- Eurocodes are functional and bring many benefits (e.g. economy, flexibility) but improvements possible
- Some new Eurocode material needed – assessment, FRP, structural glass, membrane structures
- Examples of why evolution needed

Eurocodes – the need for evolution

Purpose of Eurocodes:

- provide a common understanding regarding the design of structures between owners, operators and users, designers, contractors and manufacturers of construction products
- facilitate the exchange of construction services between countries
- facilitate the marketing and use of structural components and kits of parts in Member States
- a common basis for research and development in the construction sector
- allow the preparation of common design aids and software
- increase the competitiveness of the civil engineering firms, contractors, designers and product manufacturers in their world-wide activities
- BE READILY USABLE!

Eurocodes – the need for evolution

- New Eurocodes will aim to improve ease of use
- According to most designers, the hierarchy of priorities should be to:
  - Improve clarity and provide missing material
  - Reduce inconsistencies
  - Reduce NDPs
  - Reduce length
  - Update rules where more reliable material exist

Eurocodes – the need for evolution

Improve clarity and provide missing material

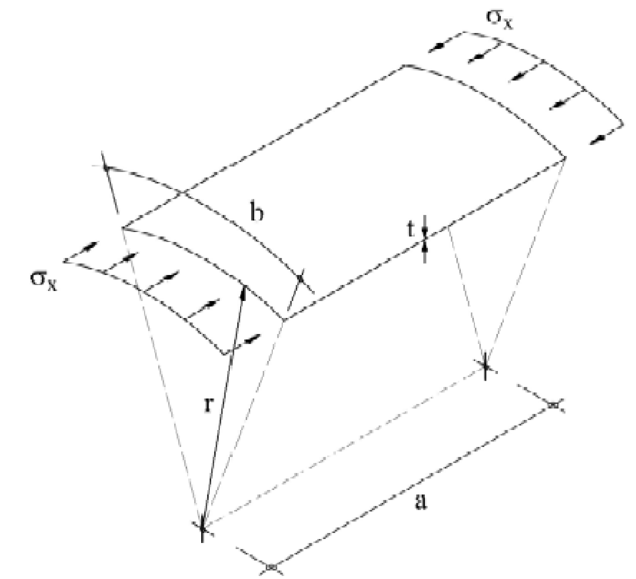
BRITISH STANDARD

BS EN 1993-1-5:2006

Incorporating corrigendum April 2009

Eurocode 3 — Design of steel structures —

Part 1-5: Plated structural elements



NOTE 4: Single plate elements may be considered as flat where the curvature radius r satisfies:

$$r \geq \frac{a^2}{t} \quad (1.1)$$

where a is the panel width

t is the plate thickness

- Clause is currently ambiguous about direction of application; “a” is usually “panel length”

Eurocodes – the need for evolution

Improve clarity and provide missing material

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BS EN 1993-1-5:2006

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Eurocode 3 — Design of steel structures —

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NOTE 4: Single plate elements may be considered as flat where the curvature radius r satisfies:

$$r \geq \frac{a^2}{t} \qquad (1.1)$$

where a is the panel width

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- Caused arguments on A465 for example; needs to be fixed

Eurocodes – the need for evolution

Improve clarity and provide missing material

BRITISH STANDARD

BS EN 1993-1-5:2006

Incorporating corrigendum April 2009

Eurocode 3 — Design of steel structures —

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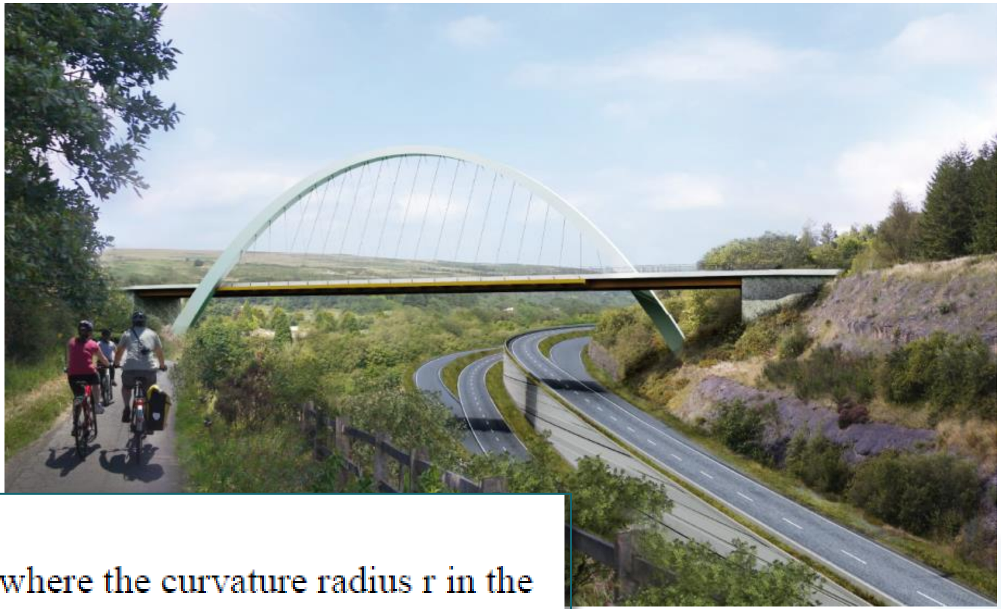


Replace NOTE 4 in clause 1.1(2) as follows:

Single plate elements may be considered as flat where the curvature radius r in the direction perpendicular to the compression satisfies:

$$r \geq \frac{b^2}{t}$$

where b is the panel width

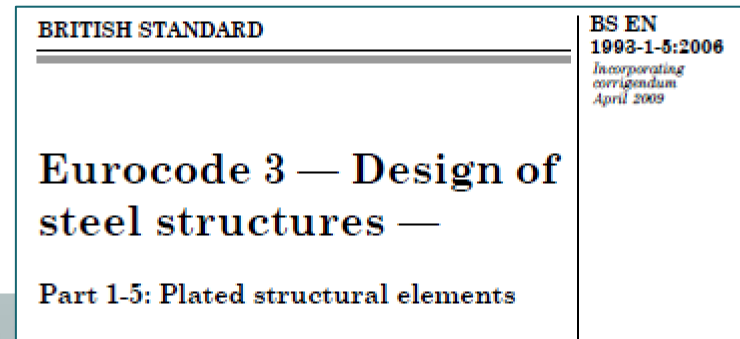
t is the plate thickness

- Caused arguments on A465 for example; needs to be fixed

Eurocodes – the need for evolution

Improve clarity and provide missing material

- Walton Bridge – continuously curved arch plates “not flat” to EN 1090-2
- No rules for section classification of curved panels in direction of stress or for considering additional bending



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Eurocode 3 — Design of steel structures —

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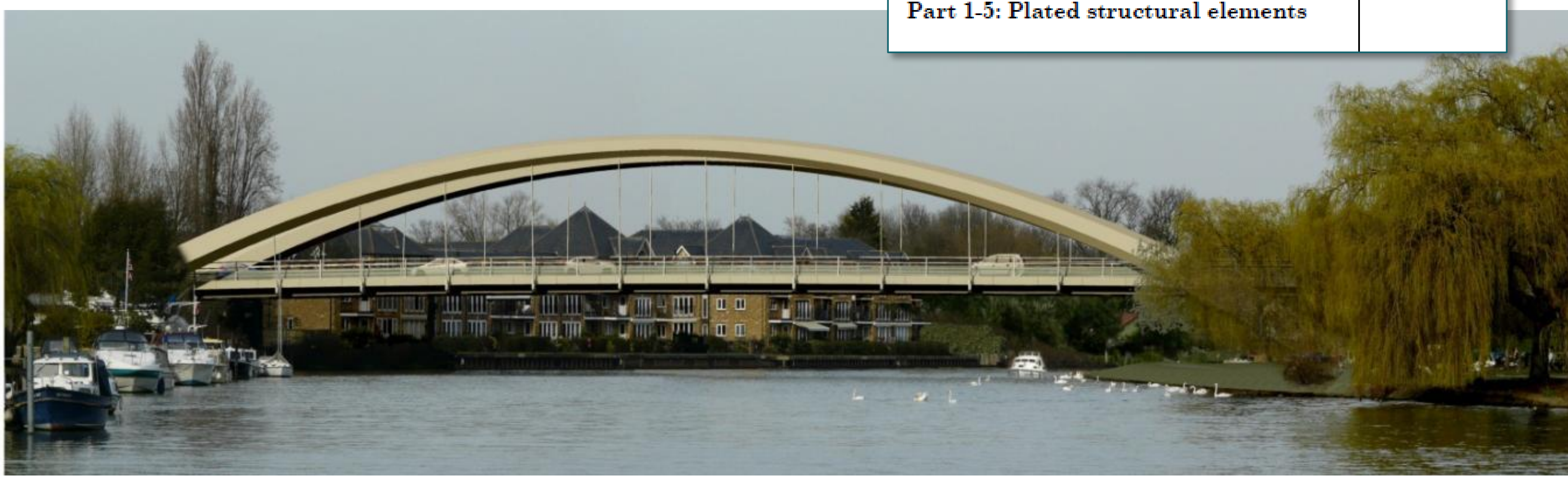
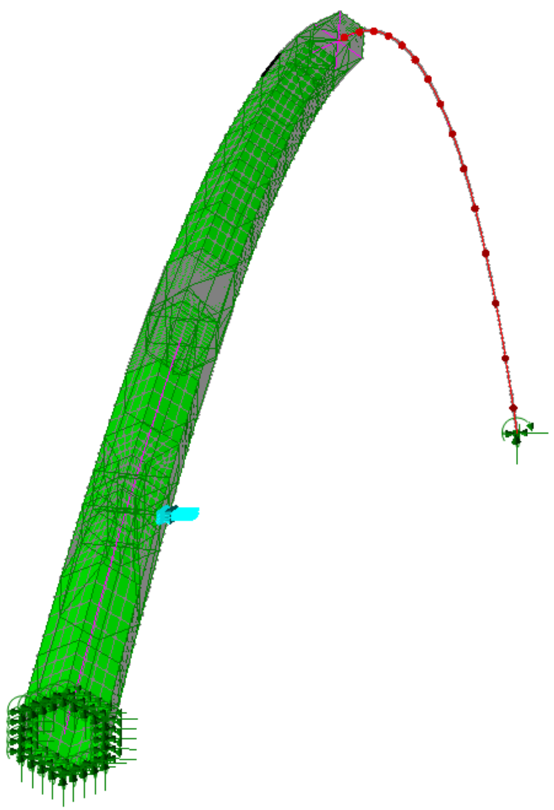


Eurocodes – the need for evolution

Improve clarity and provide missing material

- Walton Bridge – continuously curved arch plates “not flat” to EN 1090-2
- No rules for section classification of curved panels in direction of stress or for considering additional bending – Class 2 if flat on Walton

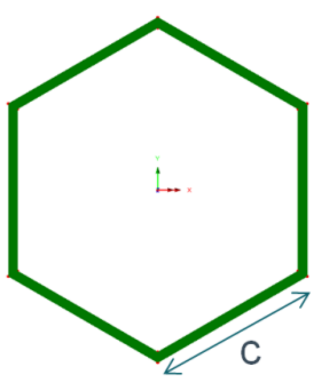


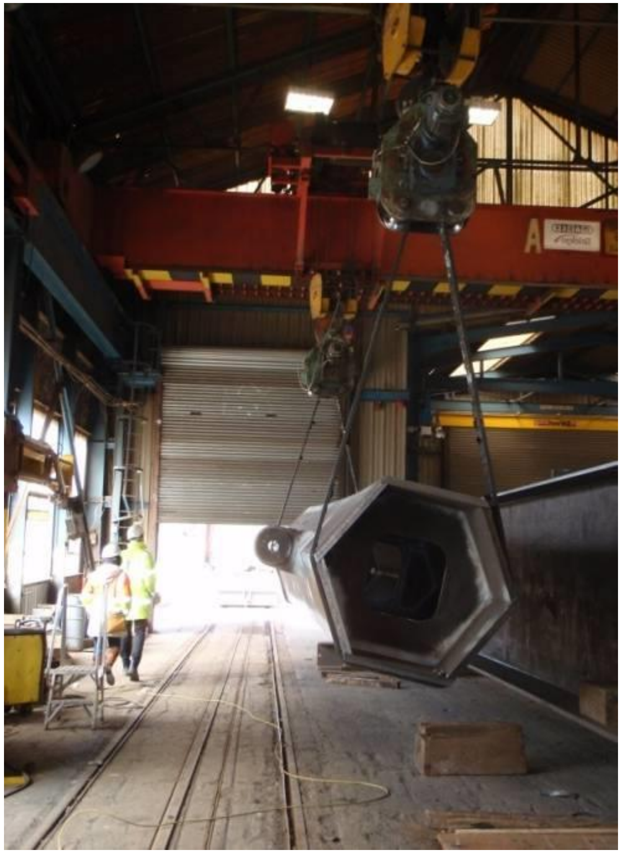
c = 1250 mm

a = 4250 mm

t = 45 mm

r = 125 000 mm





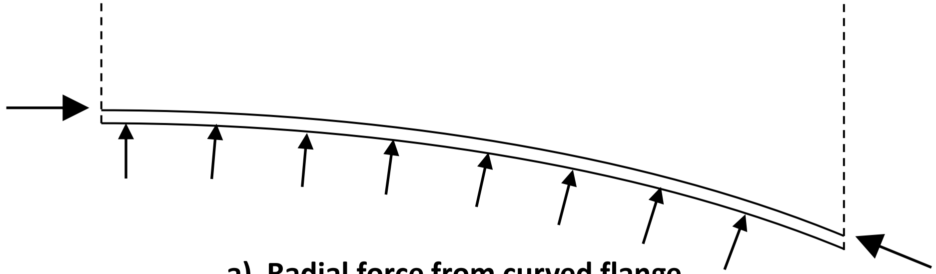
Eurocodes – the need for evolution

Improve clarity and provide missing material

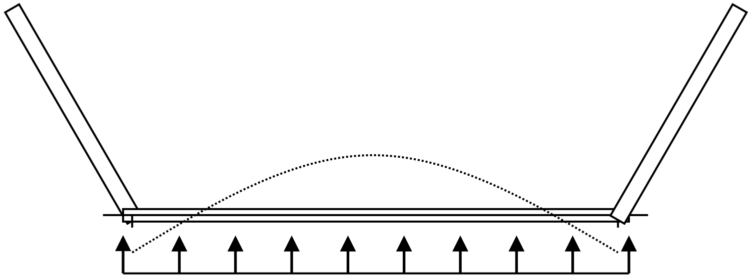
- Walton Bridge – continuously curved arch plates "not flat" to EN 1090-2
- No rules for section classification of curved panels in direction of stress or for considering additional bending – Class 2 if flat on Walton
- Current option is user-developed rules backed up by non-linear analysis; needs simpler treatment as more steel becomes continuously curved in plan and elevation – showed Class 2 still on Walton with reduced effective yield stress

$$\sigma_{\mathrm{T}} = 3\sigma_{\mathrm{eff,yd}} c^2 / 4rt \quad \text{and} \quad \left(\frac{\sigma_{\mathrm{eff,yd}}}{f_{\mathrm{yd}}}\right)^2 + \left(\frac{\sigma_{\mathrm{T}}}{f_{\mathrm{yd}}}\right)^2 - \left(\frac{\sigma_{\mathrm{eff,yd}}}{f_{\mathrm{yd}}}\right)\left(\frac{\sigma_{\mathrm{T}}}{f_{\mathrm{yd}}}\right) \leq 1.0$$

$$\sigma_{\mathrm{eff,yd}} = 0.97 f_{\mathrm{yd}}$$



a) Radial force from curved flange

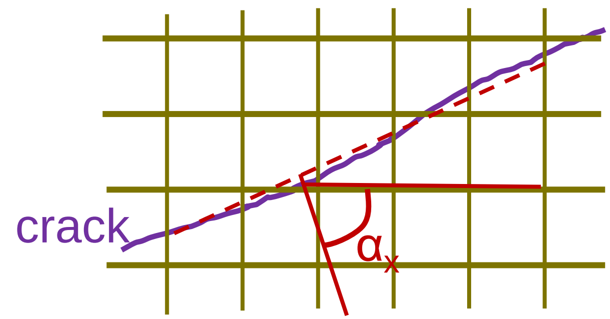


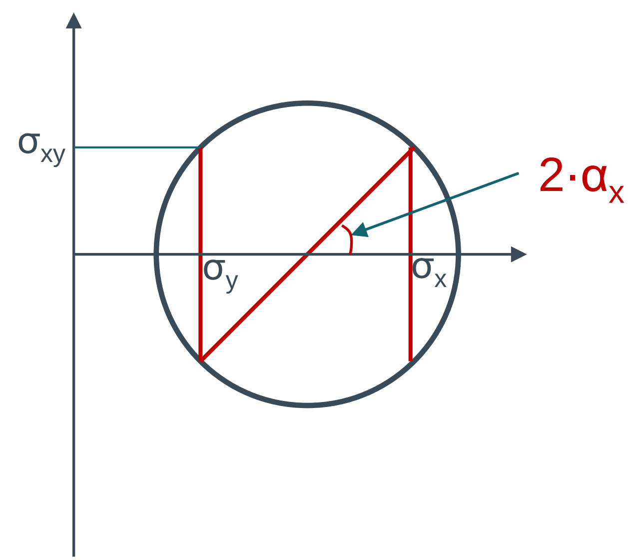
b) Transverse moments in internal flange

Eurocodes – the need for evolution

Improve clarity and provide missing material

- Practical cases not always covered e.g. calculating crack widths in slabs

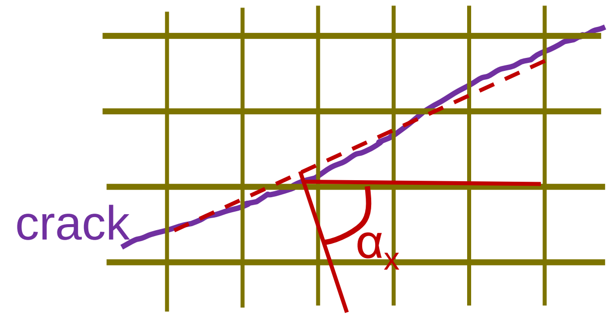




Eurocodes – the need for evolution

Improve clarity and provide missing material

- Practical cases not always covered e.g. calculating crack widths in slabs
- Crack width expression given and crack spacing formula given, but no expression for reinforcement ratio



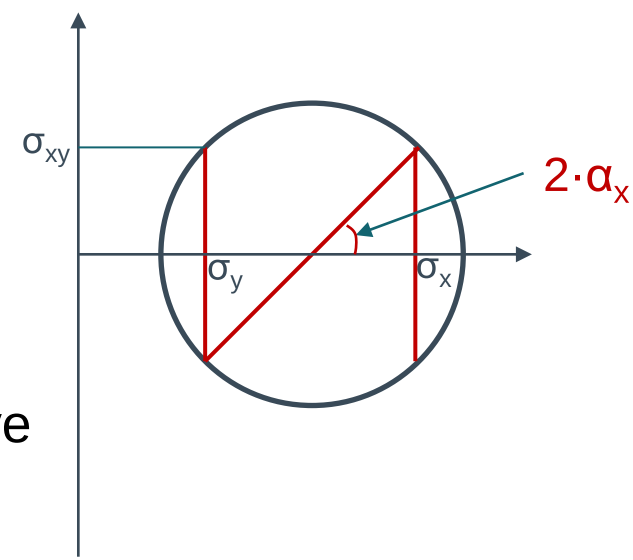
$$w_k = S_{r.max}(\varepsilon_{sm} - \varepsilon_{cm})$$

$$S_{r,max} = \frac{1}{\dfrac{\cos\theta}{S_{r,max,y}} + \dfrac{\sin\theta}{S_{r,max,z}}}$$

$$(\varepsilon_{sm} - \varepsilon_{cm}) = \frac{\sigma_s - k_t \cdot \dfrac{f_{ct.eff}}{\rho_{p.eff}}(1 + \alpha_e \cdot \rho_{p.eff})}{E_s} \geq 0.6\frac{\sigma_s}{E_s}$$

$$A_n = \sum_{i=1}^{N} A_i cos^4 \alpha_i$$

- Requirement for effective reinforcement ratio needed



Eurocodes – the need for evolution

Improve clarity and provide missing material

- Sometimes just improved writing of clauses would help e.g. rules for RC detailing in EN 1992-1-1 and laps in particular

Eurocodes – the need for evolution

Reduce inconsistencies

BRITISH STANDARD

BS EN 1993-1-5:2006

Incorporating corrigendum April 2009

Eurocode 3 — Design of steel structures —

Part 1-5: Plated structural elements

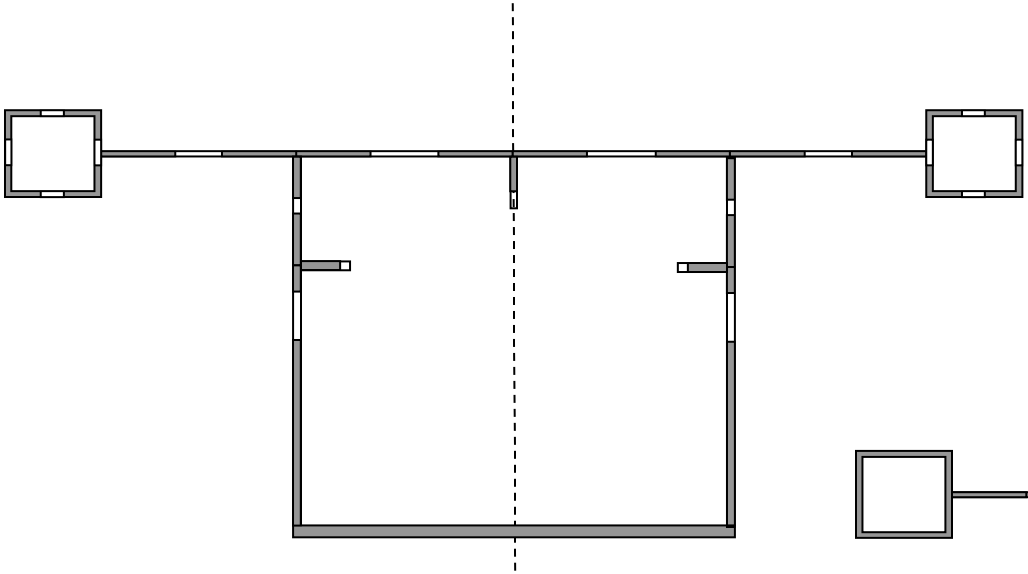
ICS 91.010.30; 91.080.10

British Standards

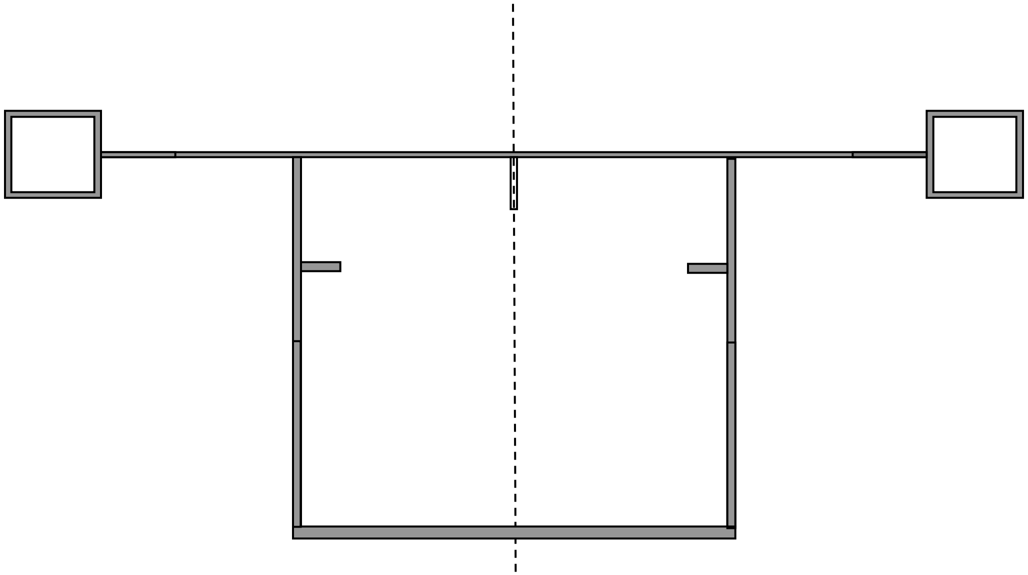
- There are currently two approaches to designing stiffened boxes in EN 1993-1-5: section 4 and section 10

Eurocodes – the need for evolution
Reduce inconsistencies

- The effective area method of EN 1993-1-5 clause 4 does not cover biaxial stress in plates but allows redistribution of stress around the cross-section



EN 1993-1-5
clause 4



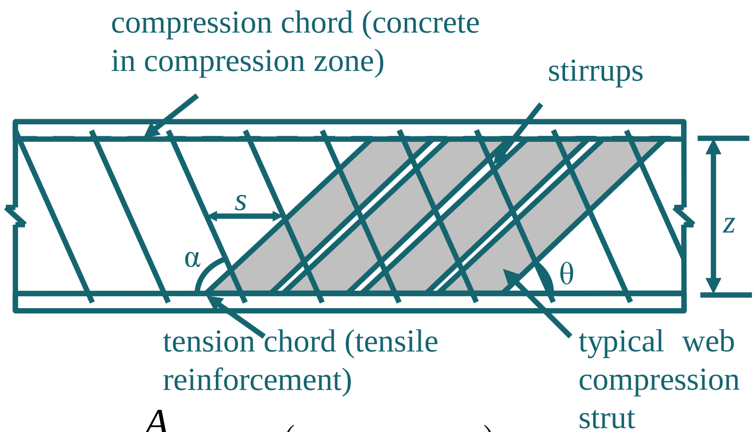
EN 1993-1-5
clause 10

Eurocodes – the need for evolution
Reduce inconsistencies

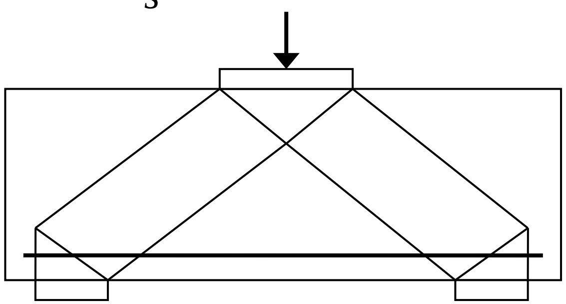
- Clause 10:
  - Clause 10 allows no redistribution between panels and shear has to be considered in panel buckling - very conservative
  - (Unsafe for biaxial compression until latest amendment made)
- Clause 4:
  - Need to amend clause 4 to include σ_2 – to avoid individual designers making it up
- Current two possible methods has led to arguments between designers, checkers and clients

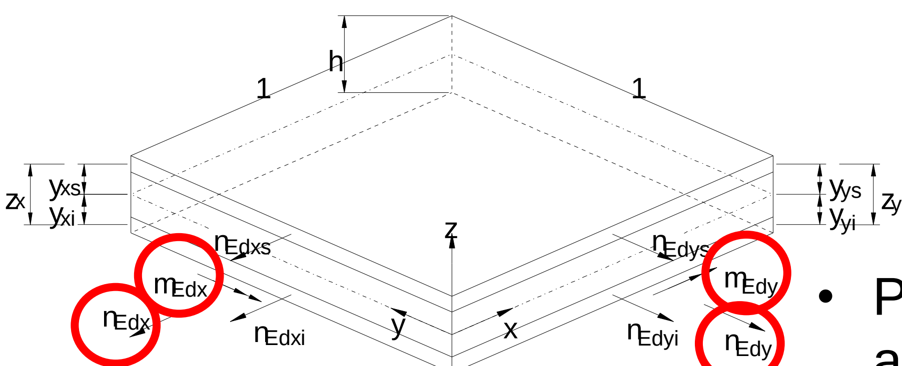
Eurocodes – the need for evolution

Reduce inconsistencies



$$V_{Rd,s} = \frac{A_{sw}}{s} z f_{ywd} (\cot\theta + \cot\alpha)\sin\alpha$$





- Eurocode 2 allows :
  - Member rules for bending, shear and torsion
  - Strut and tie rules
  - Sandwich model rules
- The rules can give quite different results e.g.:
  - Axial force increases shear resistance in member rules and reduces it with sandwich modelling
  - Strut and tie rules (and member rules) make no reduction to limiting compression stress with reducing strut angle but sandwich model rules make a large reduction
- Problems for designers and checkers and interface between rules

Eurocodes – the need for evolution

Reduce inconsistencies

- Inconsistencies between documents e.g.
  - EN1992-1-1 covers interface shear between concretes cast at different times when there is fatigue loading and so does EN1992-2; EN 1992-1-1 reduces the adhesion term while EN 1992-2 deletes it
  - Not always intuitive that one should go and check a part for a specific structure type when a rule seems to be quite adequate; one reason why EN 1994-2 reproduces all of EN 1994-1-1

Eurocodes – the need for evolution
Reduce NDPs

- Too many NDPs allows national practices to depart significantly and can create more documents – restricts trade and reduces ease of use e.g.
  - Variations in partial factors – relatively easy to adjust country to country but pitfalls for designers (software, relying on your memory etc)
  - Swedish NA introduces old standard's traffic models – foreign designers need to learn new models and rules
  - UK NA makes significant changes to fatigue and fracture and then introduces two PDs to explain them
- Reducing NDPs however requires greater European consensus

Eurocodes – the need for evolution

Reduce length

- A lot of documents, a lot of pages and a lot of cross-references
- But reducing length is generally not wanted if it reduces clarity or increases the need for other documents; in particular, needing to refer to PDs is not generally well-received, even though the guidance is sometimes valued

PUBLISHED DOCUMENT

Recommendations for the design of structures to BS EN 1992-2:2005

ICS 91.010.30; 91.080.40; 93.040

British Standards

7.3 Punching [BS EN 1992-1-1:2004, 6.4]

7.3.1 Distribution of shear with eccentric support reaction

The expressions for W_1 in BS EN 1992-1-1:2004, 6.4.3 are derived for the basic perimeter, u_1, at a distance $2d$ from the load. Theoretically, they need adjustment for other perimeters at a distance r_i from the load. However, these expressions for W_1 may be used for perimeters inside the basic perimeter at $2d$, except in the design of bases in accordance with BS EN 1992-1-1:2004, 6.4.4, because the punching rules were calibrated against tests basing W_1 on the u_1 perimeter.

For the design of bases in accordance with BS EN 1992-1-1:2004, 6.4.4, the expressions for W_i have to be modified for the actual perimeter before being used in BS EN 1992-1-1:2004, Expression (6.51). Therefore, from BS EN 1992-1-1:2004, Expression (6.40) it follows that for a general perimeter at r_i with length u_i, the simplified expressions BS EN 1992-1-1:2004, Expressions (6.41) and (6.42) need adjustment as follows:

For a square column and a general perimeter at r_i with length u_i:

$$W_i = \frac{c_1^2}{2} + c_1 c_2 + 2c_2 r_i + 4r_i^2 + \pi r_i c_1$$

For an internal circular column and a general perimeter at r_i with length u_i:

$$\beta = 1 + 0.6\pi \frac{e}{D + 2r_i}$$

7.3.2 Distribution of shear reinforcement [BS EN 1992-1-1:2004, 6.4.5]

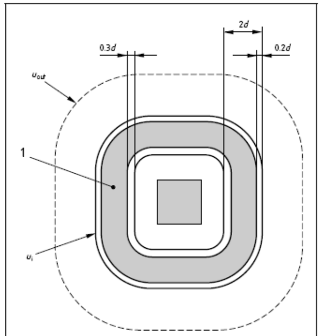
BS EN 1992-1-1:2004, Expression (6.52) has been presented assuming a constant area of shear reinforcement on each perimeter moving away from the loaded area as shown in BS EN 1992-1-1:2004, Figure 6.22. In cases where the reinforcement area varies on successive perimeters the required shear reinforcement may be determined by checking successive perimeters, u_i, between the basic control perimeter at $2d$ and the perimeter u_{out}, to ensure that shear reinforcement of area $\sum A_{sw}$ satisfies the following expression:

$$\sum A_{sw} = \frac{(v_{Ed} - 0.75 v_{Rd,c}) u_i d}{f_{ywd,ef} \sin\alpha}$$

where $\sum A_{sw}$ is the total shear reinforcement, shown in Figure 4, placed within an area enclosed between the control perimeter, u_i, chosen and one $2d$ inside it, except that shear reinforcement within a distance of $0.3d$ from the inner perimeter and $0.2d$ from the control perimeter should be ignored.

Further guidance and background are given by Hendy and Smith [2].

Figure 4 Reinforcement $\sum A_{sw}$ to include in punching check



Key

u_i is between u_1 and u_{out}

1 Reinforcement ΣA_{sw} to include for check on perimeter u_i

7.4 Design with strut and tie models [BS EN 1992-1-1:2004, 6.5]

7.4.1 Struts [BS EN 1992-1-1:2004, 6.5.2]

The compressive stress that a concrete strut can carry is strongly affected by its multi-axial state of stress. Transverse compression is beneficial while transverse tension reduces the concrete strut's compressive resistance. Therefore the two simplified and conservative limits are given in BS EN 1992-1-1:2004, 6.5.2.

The limit given in BS EN 1992-1-1:2004, Expression (6.56) relates to a safe lower bound stress that can be assumed for all compression struts, provided that the strut and tie idealization does not depart significantly from elastic stress trajectories. It is the same limit for strut compressive stress used in the calculation of $V_{Rd,max}$. This limit does not distinguish between cracking running parallel to the strut and the more detrimental cracking skew to the strut, or between applied transverse tensile forces that are carried by reinforcement and those which arise purely from an elastic bulging of the struts between nodes. Further, it does not account for the actual magnitude of tensile strain, which is also relevant.

Eurocodes – the need for evolution

Changing formulae for safety

BRITISH STANDARD

BS EN 1993-1-5:2006

Incorporating corrigendum April 2009

Eurocode 3 — Design of steel structures —

Part 1-5: Plated structural elements

- F-M-V interaction is not covered in EN 1993-1-5
- Important for bridge launches and cantilevers
- Needs addition for safety

Add the following clause in Chapter 7

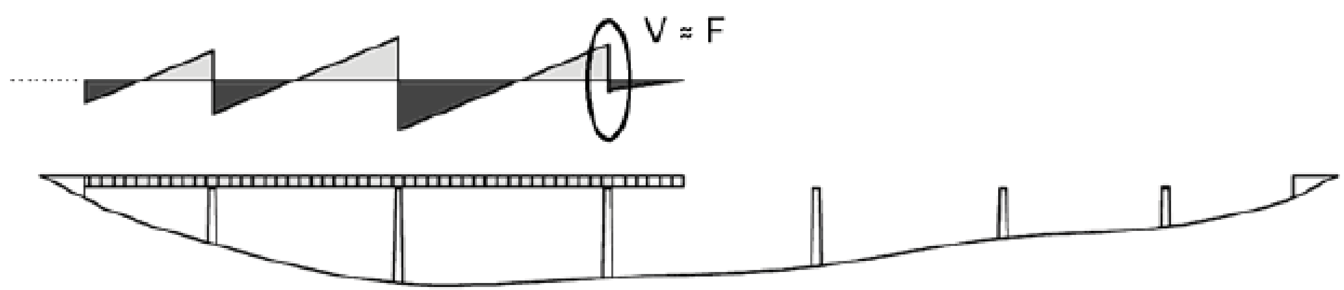
7.3. Interaction between transverse force, bending moment and shear force

(1) If the girder is subjected to a concentrated transverse force acting on the compression flange in conjunction with bending moment and shear force, the resistance should be verified using 4.6, 5.5, 6.6 and the following interaction expression:

$$\overline{\eta}_1^{\,3.6} + \left[\overline{\eta}_3 \cdot \left(1 - \frac{F_{Ed}}{2 \cdot V_{Ed}}\right)\right]^{1.6} + \eta_2 \leq 1.0$$

where: $\overline{\eta}_1 = \dfrac{M_{Ed}}{M_{pl,Rd}}$

$\overline{\eta}_3 = \dfrac{V_{Ed}}{V_{bw,Rd}}$



Eurocodes – the need for evolution

Changing formulae for safety

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Eurocode 3 — Design of steel structures —

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ICS 91.010.30; 91.080.10

British Standards

9.3.3 Intermediate transverse stiffeners

(1) Intermediate stiffeners that act as rigid supports to interior panels of the web should be designed for strength and stiffness.

(2) When flexible intermediate transverse stiffeners are used, their stiffness should be considered in the calculation of k_τ in 5.3(5).

(3) The effective section of intermediate stiffeners acting as rigid supports for web panels should have a minimum second moment of area I_{st}:

$$\text{if } a/h_w < \sqrt{2}: \quad I_{st} \geq 1{,}5\, h_w^3\, t^3 / a^2$$
$$\text{if } a/h_w \geq \sqrt{2}: \quad I_{st} \geq 0{,}75\, h_w\, t^3 \qquad (9.6)$$

NOTE: Intermediate rigid stiffeners may be designed for an axial force equal to $\left(V_{Ed} - \frac{1}{\bar{\lambda}_w^2} f_{yw} h_w t / \left(\sqrt{3}\,\gamma_{M1}\right)\right)$ according to 9.2.1(3). In the case of variable shear forces the check is performed for the shear force at the distance $0{,}5h_w$ from the edge of the panel with the largest shear force.

- Current force requirement for transverse stiffeners too high
- Needs amendment for economy

Eurocodes – the need for evolution

Changing formulae for safety

BRITISH STANDARD

BS EN 1993-1-5:2006

Incorporating corrigendum April 2009

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ICS 91.010.30; 91.080.10

BSI British Standards

- Some researchers have suggested that the current formulation for M-V is unsafe
- But it seems this is the case only for certain geometries, if any

7.1 Interaction between shear force, bending moment and axial force

(1) Provided that $\bar{\eta}_3$ (see below) does not exceed 0,5 , the design resistance to bending moment and axial force need not be reduced to allow for the shear force. If $\bar{\eta}_3$ is more than 0,5 the combined effects of bending and shear in the web of an I or box girder should satisfy:

$$\bar{\eta}_1 + \left(1 - \frac{M_{f,Rd}}{M_{pl,Rd}}\right)\left(2\bar{\eta}_3 - 1\right)^2 \le 1{,}0 \quad for\ \bar{\eta}_1 \ge \frac{M_{f,Rd}}{M_{pl,Rd}} \tag{7.1}$$

where $M_{f,Rd}$ is the design plastic moment of resistance of the section consisting of the effective area of the flanges;

$M_{pl,Rd}$ is the design plastic resistance of the cross section consisting of the effective area of the flanges and the fully effective web irrespective of its section class.

$$\bar{\eta}_1 = \frac{M_{Ed}}{M_{pl,Rd}}$$

$$\bar{\eta}_3 = \frac{V_{Ed}}{V_{bw,Rd}}$$

AC1 for $V_{bw,Rd}$ see expression (5.2). AC1

Eurocodes – the need for evolution
Changing formulae for safety

Thelwall Viaduct

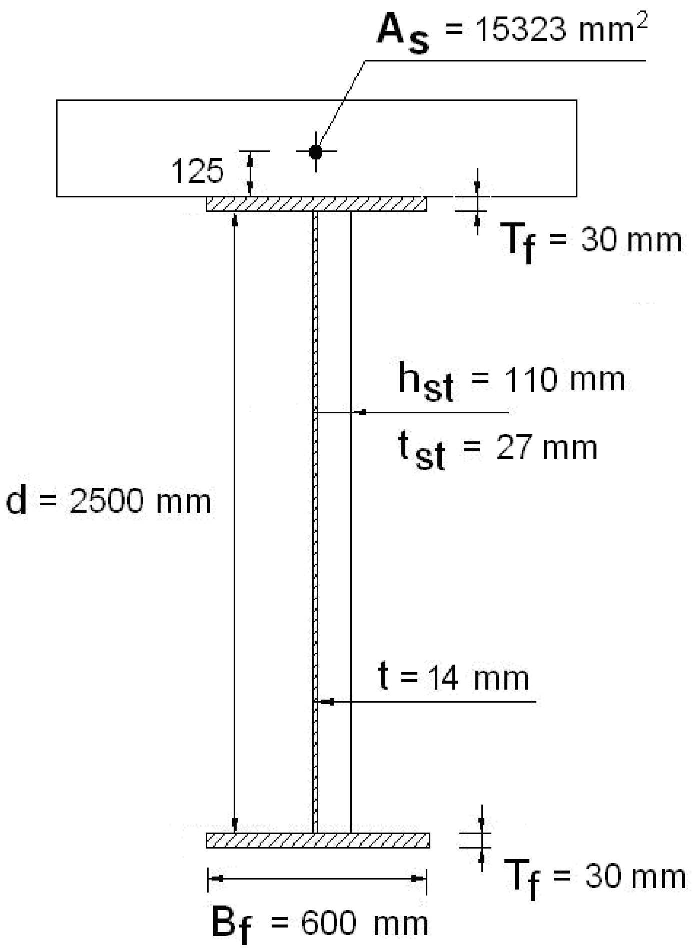
- Bearing problems identified at a routine inspection
- Replacement project initiated which required overall structural assessment

Eurocodes – the need for evolution

Changing formulae for safety

Thelwall Viaduct

- First necessary to strengthen the bridge with jacking stiffeners
- This work revealed that, according to UK design codes, the plate girders were under-strength in bending and shear by up to 40%
- Consequently, non-linear analysis undertaken



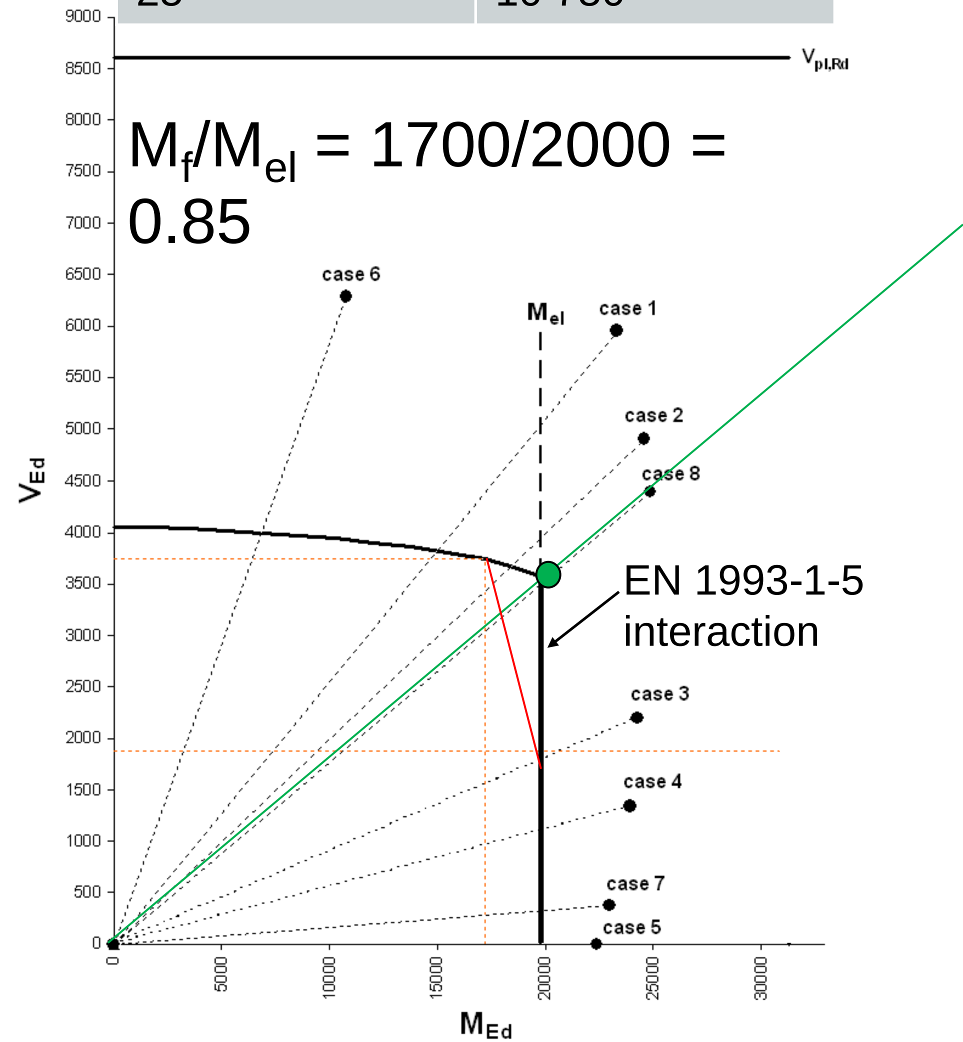
Eurocodes – the need for evolution

Changing formulae for safety

Thelwall Viaduct

- Different M-V ratios investigated
- All strengths were found to be greater than the envelope predicted by Eurocode 3
- Interaction between shear and moment was weak
- Moment resistance actually increased by the presence of small amounts of shear
- Typical M-V action effect

Cost of analysis (£K)	Cost of strengthening saved (£K)
25	10 750

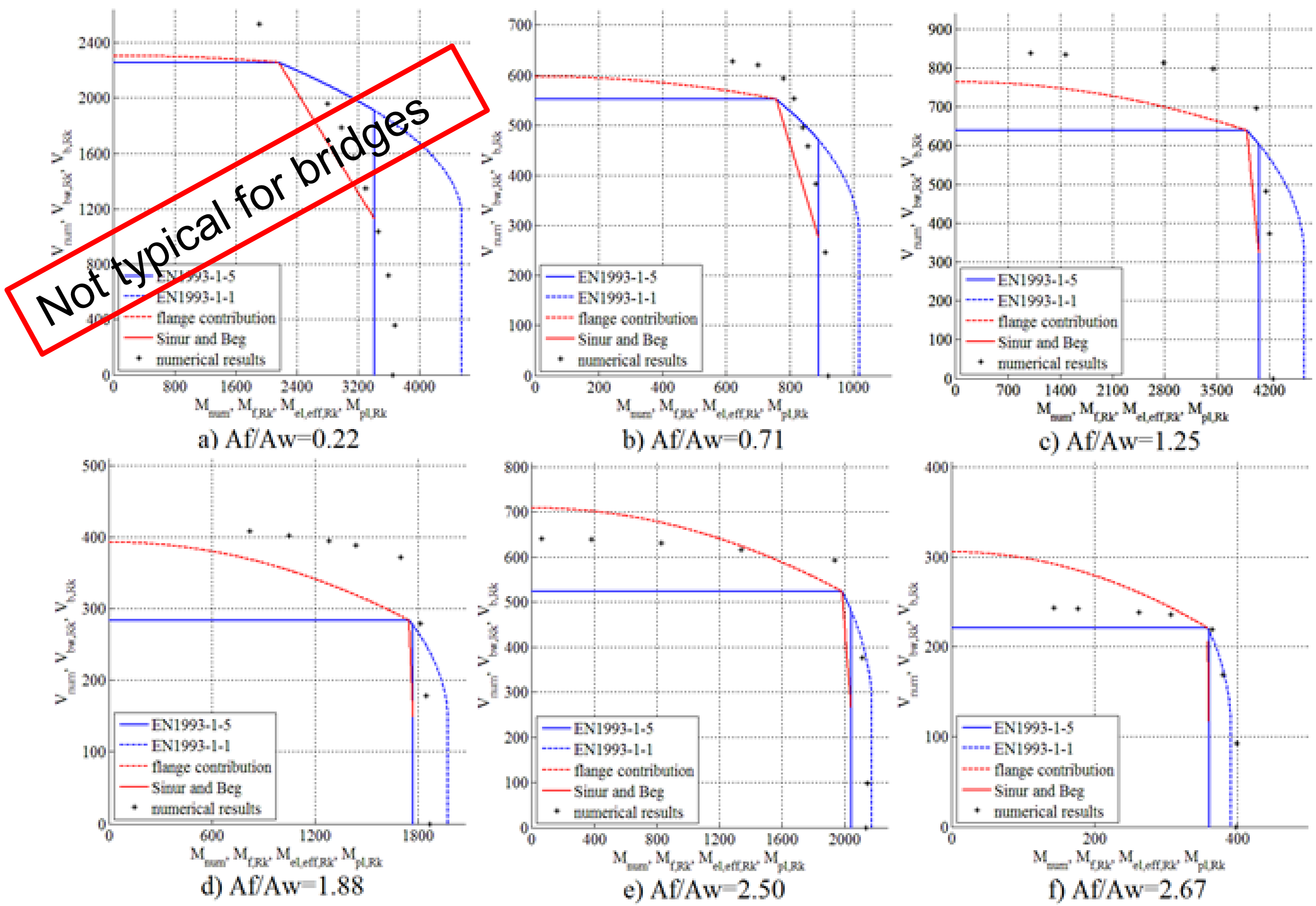


ATKINS

Eurocodes – the need for evolution

Changing formulae for safety

Recent research has shown that the interaction is not conservative for some M_f/M_{el}; wholesale change proposed for this case which will impact on economy of all bridges



a) Af/Aw=0.22
b) Af/Aw=0.71
c) Af/Aw=1.25
d) Af/Aw=1.88
e) Af/Aw=2.50
f) Af/Aw=2.67

Eurocodes – the need for evolution
Summary

- New Eurocodes will aim to improve ease of use:
  - Improve clarity and provide missing material – prevent mistakes, alternative interpretations and proliferation of additional national documents
  - Reduce inconsistencies – as above
  - Reduce NDPs – make it easier to work across countries, limit preferential engineering and increased documentation
  - Reduce length – not at expense of needing more guidance documents
  - Update rules where more reliable material exists – only for safety
- Evolution not revolution; wholesale change to methods and formulae would:
  - Cause extensive rework of design guides and software
  - Require re-education of designers
  - Create situations where recently designed structures are no longer “adequate”