STEEL BEAM BRIDGE DESIGN TO THE EUROCODES

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PRESENTATION OUTLINE

- Lecture 1: Steel bridge design rule
- Lecture 2: Structural Resistance of Steel Beam Bridge
- Lecture 3: Stiffener design
- Lecture 4: Connection design

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE

- GENERAL
- BASIS OF DESIGN
- PROPERTIES OF MATERIALS
- CLASSIFICATION OF CROSS SECTIONS
- SECTION PROPERTIES

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE: GENERAL

- This presentation only covers verification of beam elements and their connections, restraints and attachments.
- The design of trusses, box girders and Plate girders with longitudinal stiffeners are outside the scope of this presentation.
- The simplified procedures for the design of steelwork components, assemblies and connections are based on rules in EN 1993-2.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE : GENERAL

- Some Part on this presentation, refers to general rules in EN 1993-1-1 and to various other Parts, such as EN 1993-1-8 (for connection design).

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE : GENERAL

Fatigue design

- If a stress or range of stress is applied repetitively to an element of a structure, it may fail prematurely by fatigue at a stress below (sometimes well below) its static strength.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE : GENERAL

Fatigue design

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE: GENERAL

Fatigue design

- The loading to be considered in fatigue design is set out in EN 1991-2 and the rules for calculating fatigue resistance and verifying its adequacy are given in EN 1993-1-9.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE: GENERAL

Symbols

Some of the main variables used in the design of steelwork are:

M	Bending moment	A	Area
N	Axial force	I	Second moment of area
V	Shear force	W	Section modulus
T	Torsional moment	$\bar{\lambda}$	Normalized slenderness
F	Force	χ	Reduction factor (for buckling)

Some of the main subscripts are

Ed	design effect	b	buckling
Rd	design resistance	cr	critical
Rk	characteristic resistance	op	out of plane
el	elastic	c	related to cross section
pl	plastic	y, z	related to y-y or z-z axis

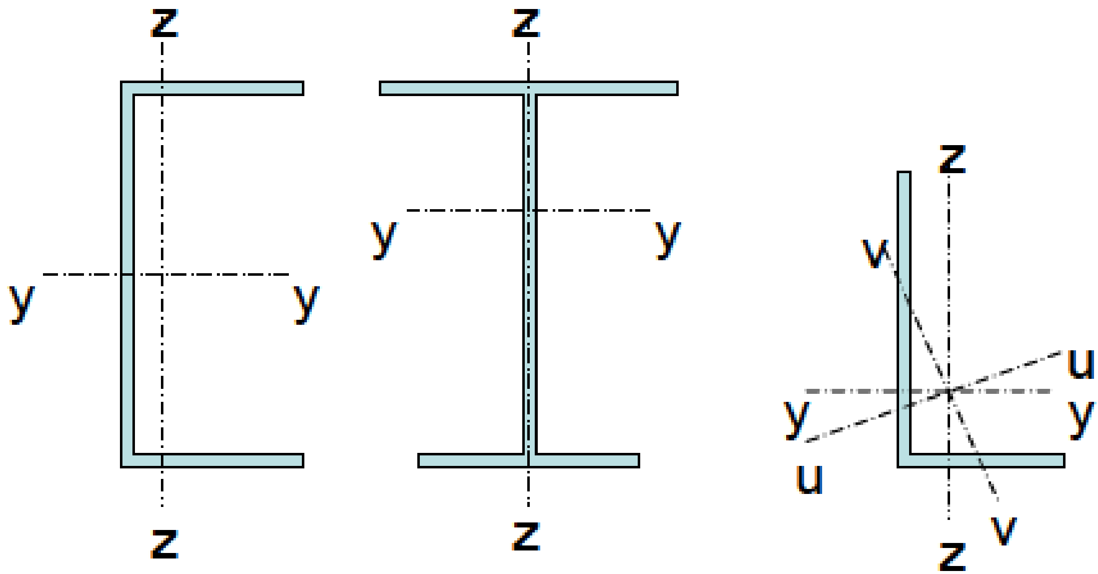
Thus:

N_{Ed} is the design value of axial force (an effect)

$N_{c,Rd}$ is the design resistance of the cross section

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE : GENERAL

x – along the member



LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :BASIS OF DESIGN

Ultimate limit state (ULS)

- All beams should be designed to provide adequate strength to resist the design effects of the actions, using partial factors that are appropriate to the ULS.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :BASIS OF DESIGN

Ultimate limit state (ULS)

- Material strength.
- Limitations on shape on account of local buckling of individual elements (i.e. webs and flanges).
- Moment resistance of cross sections.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :BASIS OF DESIGN

Ultimate limit state (ULS)

- Effective sections (reductions for compression buckling and holes).
- Lateral torsional buckling.
- Web buckling (governed by depth to thickness ratio of web and panel size).
- Combined bending and shear effects.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :BASIS OF DESIGN

Serviceability limit state (SLS)

- Beams should also be designed to ensure that no yielding or permanent deformation takes place under the (lower) design effects that are appropriate to SLS.

Serviceability limit state (SLS)

- When the beam has been designed at the ULS as a class 3 or class 4 section, the resistance is based on an essentially elastic behaviour; the requirements at the SLS are automatically satisfied and no further checks need be made.

Serviceability limit state (SLS)

- When the beam has been designed at the ULS as a class 1 or class 2 section, utilising the plastic moment capacity, it is quite possible that yielding could occur in extreme fibres under the SLS characteristic loading.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :BASIS OF DESIGN

Serviceability limit state (SLS)

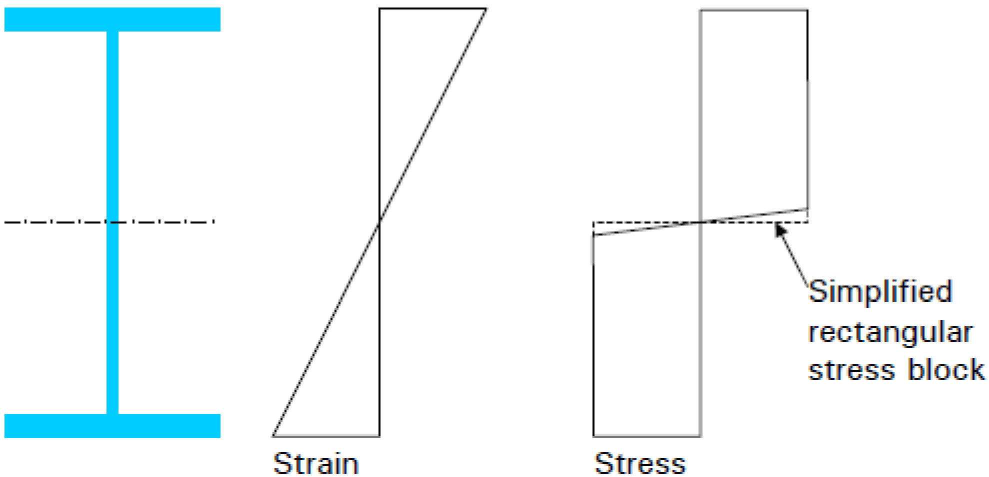


Figure 5.1 *Bending stresses and strains in a class 1 or class 2 cross section designed to plastic resistance*

Serviceability limit state (SLS)

- Beams of class 1 or 2 section must therefore be checked at the SLS, but in that case a linear elastic stress distribution must be used, i.e. the beams must be treated in the same manner as class 3 beams.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :BASIS OF DESIGN

Table 2.1 *Partial factors γ_M*

Partial factor on:		ULS	SLS
Resistance of cross sections	γ_{M0}	1.00	
Resistance of members to instability	γ_{M1}	1.10	
Resistance of joints	γ_{M2}	1.25	
Slip resistance (Category C joints)	γ_{M3}	1.25	
Slip resistance (Category B joints)	$\gamma_{M3,ser}$		1.10
Nominal stresses due to SLS characteristic loads	$\gamma_{M,ser}$		1.00

Yield strength

- The yield strength of steel manufactured in accordance with BS EN 10025 should be taken as:

  Grade S275 *fy* = 275 N/mm2

  Grade S355 *fy* = 355 N/mm2

- In most cases, grade S355 should be used, for economy.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :PROPERTIES OF MATERIALS

Mechanical properties of steel

- Modulus of elasticity, *E* = 210 000 N/mm2
- Shear Modulus *G* = 80 000 N/mm2
- Poisson's ratio V = 0.3
- Coefficient of thermal expansion

$$\alpha = 12 \times 10^{-6}/^{\circ}\mathrm{C}$$

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :GLOBAL ANALYSIS FOR LOAD EFFECTS

General

- Elastic global analysis should be used to determine the load effects (internal forces and bending moments).

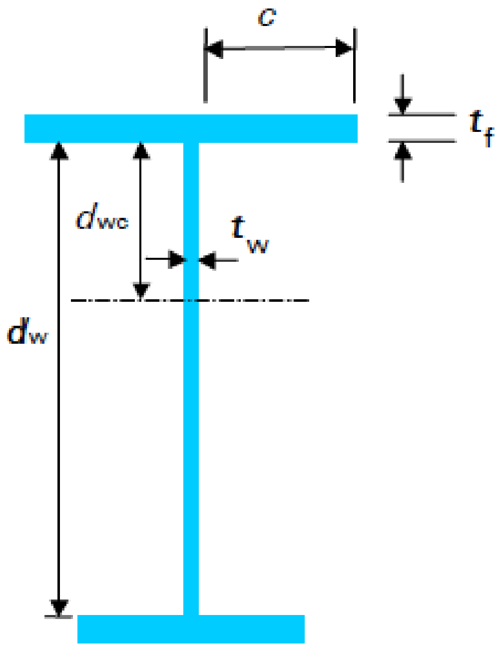
Section properties

- Gross section properties should be used in global analysis.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :CLASSIFICATION OF CROSS-SECTIONS

- The capacity of a section can be limited by local buckling of the flange or web in compression.
- The classification of a section depends on the width to thickness ratio of elements of the cross-section.

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :CLASSIFICATION OF CROSS-SECTIONS



Note: Strictly, the outstand width and the depth of the web should be measured clear of root fillets for rolled sections and welds for fabricated sections, but for simplicity the fillets or welds may be ignored.

Figure 5.2 *Parameters relevant to classification of cross section*

LECTURE 1 (4.00-4.30):
STEEL BRIDGE DESIGN RULE :CLASSIFICATION OF CROSS-SECTIONS

Flange outstand in compression

	Class 1	Class 2	Class 3
Grade S275	*(see text)*	$c/t \leq 9.2$	$c/t \leq 12.9$
Grade S355	*(see text)*	$c/t \leq 8.1$	$c/t \leq 11.3$

Webs - depth in compression

	Class 1	Class 2	Class 3
Grade S275	*(see text)*	$d_{wc}/t \leq 35$	$d_{wc}/t \leq 52$
Grade S355	*(see text)*	$d_{wc}/t \leq 32$	$d_{wc}/t \leq 45$

NOTES:

(1) These limits for webs are slightly more conservative than the detailed provisions in EN 1993-1_1.
(2) The class 3 limits for webs do not apply for cases where the web is wholly in compression (which can happen with axial compression) - more onerous limits of 39 (S275) or 34 (S355) should be used in such cases (instead of 52 and 45).


Coffee
Time

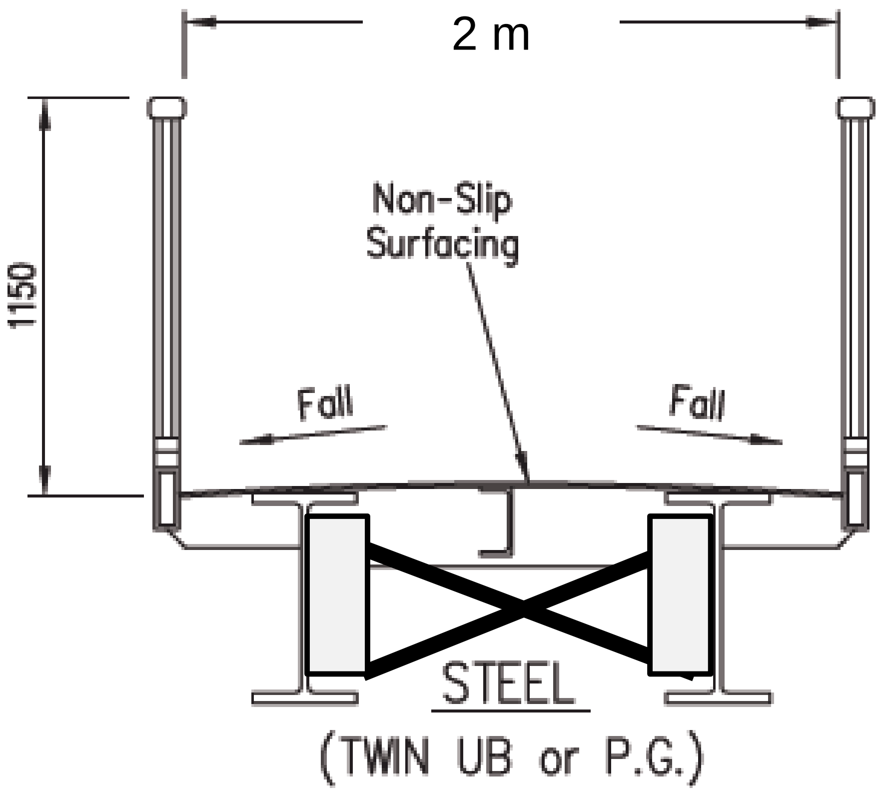
LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

- PROPOSED SUITABLE UB SECTION
- RESISTANCE OF BEAM CROSS SECTIONS
- BUCKLING RESISTANCE OF BEAMS - LATERAL TORSIONAL BUCKLING
- SLENDERNESS OF BEAMS
- RESTRAINTS TO BEAMS

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

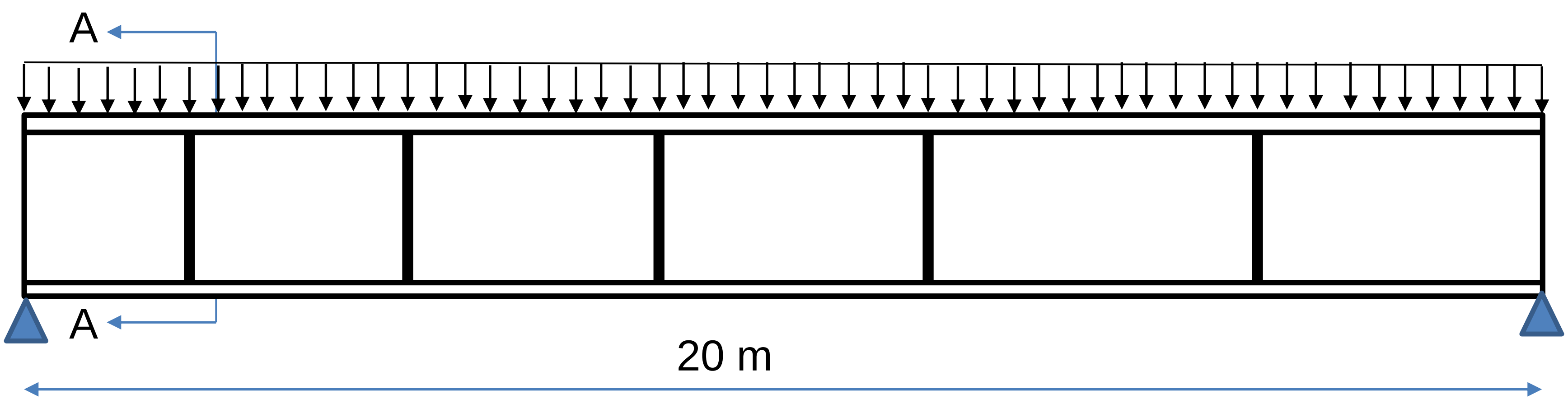
A simply supported twin Universal Beam (UB) footbridge bridge of 20 metres span is used for pedestrian and cycle traffic. Design the UB section at the center of the span, for grade S355 steel.

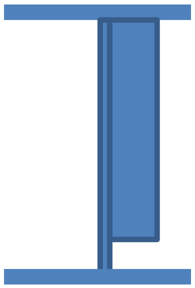
LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE



SPAN RANGE (METRES)	REMARKS
10 TO 50	Steel type may be erected complete.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE





SECTION A-A

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Permanent actions

According to EN 1991-1-1, the self weight (S/W) of the structural elements and the deck surface is classified as permanent fixed action.

- Self weight of structural members

S/W of the steel members is calculated from the nominal dimensions of the members (The cross-section area, A) and the characteristic value for the density of steel. The densities of structural materials are given in standards EN 1991-1-1.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

- Self weight of structural members
- ❑ For structural steel, the density is given within the range (77 kN/m^3) - (78.5 kN/m^3).
- ❑ In this work, we use 78.5 kN/m^3
- Deck cover
- ❑ The deck is covered with a wooden boards of thickness 5 cm. According to EN 1991-1-1, Appendix A, the characteristic design value for the density for timber strength class C40 be (5 kN/m^3).

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Variable actions

- Thermal loads

❑ The thermal actions are defined as a uniform temperature change over the whole cross-section of the bridge as well as temperature gradient across the height of the bridge deck. Due to small deck height, only the uniform temperature gradient of $\Delta T = 20^0$ is considered here.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

- Traffic loads

- According to EN 1991-2, Traffic load is considered as variable actions or accidental actions. For normal use, traffic load is considered as variable loads.
- The characteristic value of uniformly distributed load is in general defined as *qfk* = 5 kN/m^2

Step 1: Design actions

- Traffic loads

- ❑ According to EN 1991-2, Traffic load is considered as variable actions or accidental actions. For normal use, traffic load is considered as variable loads.
- ❑ The characteristic value of uniformly distributed load is in general defined as qfk = 5 kN/m^2
- ❑ The characteristic value of the concentrated load is equal to Q_{fwk}=10kN

Step 1: Design actions

- <u>Accidental loads</u>

- ❑ The accidental presence of the vehicle on the footbridge is considered as the accidental action if the access of such a vehicle on the footbridge is not restricted by a permanent device.
- ❑ If not specified otherwise the accidental load Q_A of this vehicle is represented by two-axel loading pattern with axle loads 80 kN and 40 kN.
- ❑ The horizontal force acting on the footbridge is either 10% of the total load corresponding to the distributed force *qw or* 60% of the total weight of the service vehicle QA and acting simultaneously with corresponding vertical load.

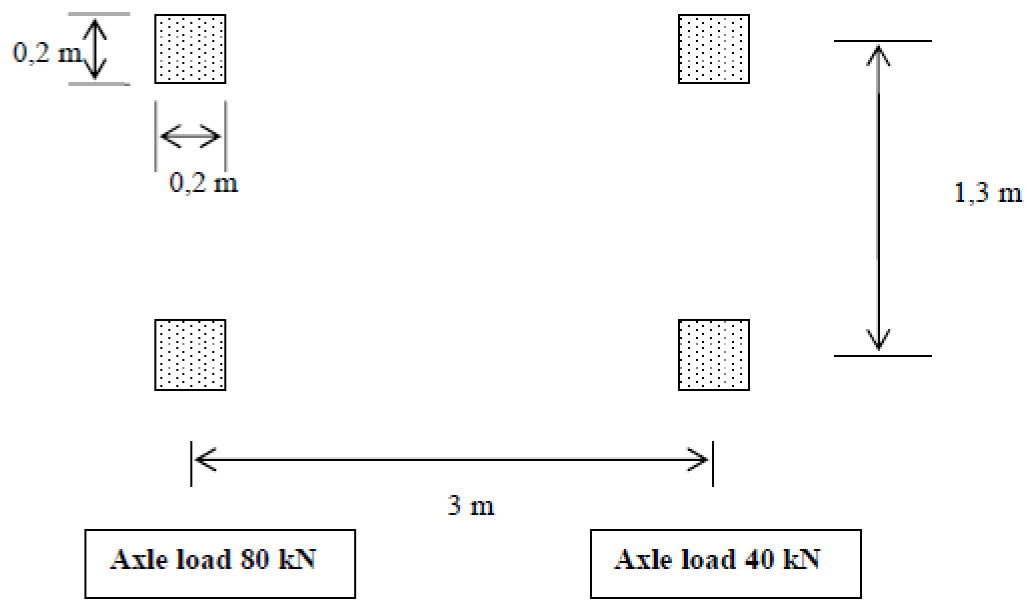
manent device. If
ted by two-axial

corresponding to
Q_A and is acting

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

- <u>Accidental loads</u>



LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Symbol	Description of the action	Type of action
G	Self weight of the structure	permanent
P	Deck cover	permanent
~~S~~	~~Snow load~~	~~variable~~
~~W~~	~~Wind load~~	~~variable~~
T	Thermal loads	variable
q	Uniform traffic load	variable
Q	Concentrated traffic load	variable
~~Q_A~~	~~Load due to accidental presence of a vehicle on the footbridge~~	~~accidental~~

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Combination of actions for the ULS verification

- $E_d < R_d$ as required by (EN 1990). In which E_d is the design value (internal forces and moments), and R_d (design value of the corresponding resistance)
- Combination of action according to EN 1990

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j} + \gamma_{Q,1} Q_{k,1} + \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$

Characteristic values of permanent loads, with corresponding partial factors

Characteristic values of variable loads, with corresponding partial factors

Combination factors (traffic loads, wind, temperature) in which $Q_{k,i}$ is the leading variable

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Combination of actions for the ULS verification

Possible combination of actions are;

- Leading Q: 1.35 Gk + 1.35 Q + 0W + 0.5 T+ 0q+ 0S
- Leading q: 1.35 Gk + 1.35 q + 0W + 0 T+ 0Q+ 0S
- Leading W: 1.35 Gk + 1.5 W + 0S + 0 T+ 0q+ 0Q
- Leading T: 1.35 Gk + 1.5 W + 0S + 0 T+ 0q+ 0Q

Step 1: Design actions

Combination of actions for the ULS verification for accidental actions

Possible combination of actions are;

- Leading Q: Gk + Q_A + 0Q + 0.5 T+ 0q
- Leading q: Gk + Q_A + 0.4 q + 0.5 T+ 0Q
- Leading T: Gk + Q_A + 0Q + 0.5 T+ 0q

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Let's calculate the design action for the proposed bridge

Noted: the effect of wind and snow actions are ignored.

Proposed rolled UB section: 914 x 419 x 388 kg/m

Permanent actions

- ❑ Self-weight of the beam = 78.5 kN/m^{3}x 0.0494 m^2 = **3.88 kN/m**
- ❑ Deck cover = 3m x 0.05m x 78.5 kN/m^3 = **11.8 kN/m**

Variable actions

- ❑ Uniform Traffic loads =5 kN/m^2 x 2m =**10 kN/m**

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Let's calculate the design action for the proposed bridge

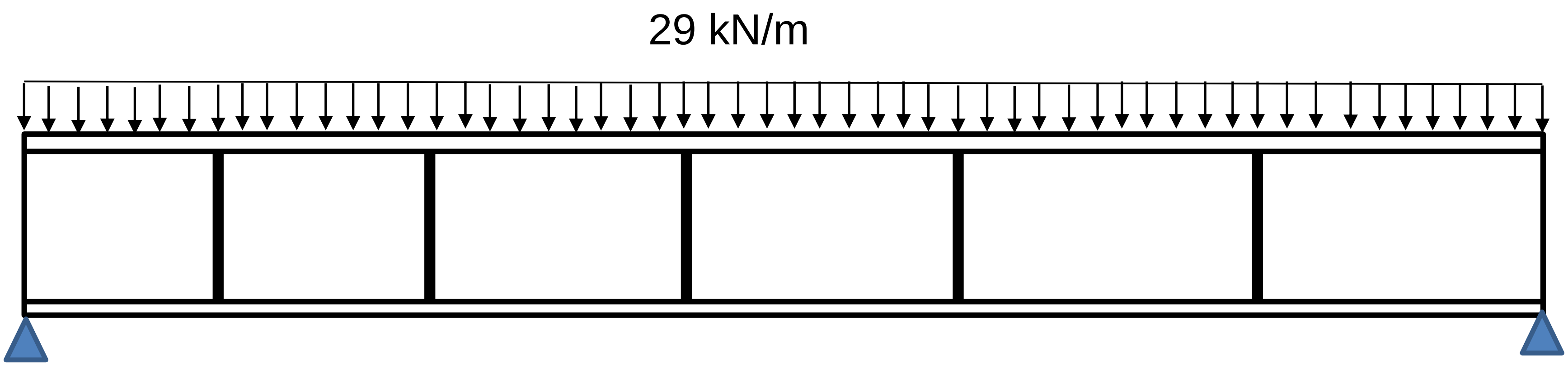
Choose load combination of action is;

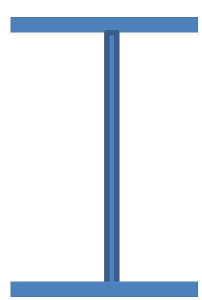
- Leading uniform traffic load (q): 1.35 Gk + 1.35 q + $\cancel{0}$W + $\cancel{0}$ T+ $\cancel{0}$Q+ $\cancel{0}$S
  :1.35 (3.88+7.85) + 1.35 (10)
  : **29 kN/m**

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Let's calculate the design action for the proposed bridge





LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 1: Design actions

Let's calculate the design action for the proposed bridge

- Design max Bending moment, Med =2900 kNm
- Design Shear force, Ved=290 kN

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 2: Classification of cross-section

- c/tw =37.4 < 45 (class 3)
- c/tf =4.79 < 8.1 (class 2)

Thus the section is class 3.

Step 3: Resistance of beam cross-section

- Bending resistance
- Shear resistance

LECTURE 2 (8.30-9.30): STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section

6.2.5 Bending moment

(1)P The design value of the bending moment M_{Ed} at each cross-section shall satisfy: AC1

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1{,}0 \tag{6.12}$$

where $M_{c,Rd}$ is determined considering fastener holes, see (4) to (6).

$$M_{c,Rd} = M_{el,Rd} = \frac{W_{el} f_y}{\gamma_{M0}} \quad \text{for class 3 cross sections}$$

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section

Bending resistance

The design bending resistance at ULS is given by:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma_{M0}} \text{ for class 1 or class 2 cross sections}$$

$$M_{c,Rd} = M_{el,Rd} = \frac{W_{el} f_y}{\gamma_{M0}} \text{ for class 3 cross sections}$$

$$M_{c,Rd} = \frac{W_{eff} f_y}{\gamma_{M0}} \text{ for class 4 cross sections}$$

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 2: Classification of cross-section

- ❑ c/tw =37.4 < 45 (class 3)
- ❑ c/tf =4.79 < 8.1 (class 2)

Thus the section is class 3.

Step 3: Resistance of beam cross-section (bending resistance)

- ❑ M_{ed}/M_{crd} =2900 kNm/5538 kNm

= 0.52<1.0 ok

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

Shear resistance

Generally, the design shear resistance of a web is given by:

$$V_{b,Rd} = V_{bw,Rd} + V_{bf,Rd} \text{ but} \leq \frac{f_{yw} h_w t_w}{\sqrt{3}\,\gamma_{M1}}$$

where:

$V_{bw,Rd}$	is the contribution from the web
$V_{bf,Rd}$	is the contribution from the flange
h_w	is the height of the web (the distance between the flanges)
t_w	is the thickness of the web
f_{yw}	is the yield strength of the web

LECTURE 2 (8.30-9.30): STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

Contribution from the web

The contribution from the web depends on its slenderness and thus on its tendency to buckle under shear loading. Usually in bridges transverse web stiffeners are provided at supports and at intermediate positions (intermediate transverse stiffeners are very effective in increasing the shear buckling resistance of a slender web by restricting the size of the rectangular panels within which buckling occurs - see further discussion below).

The non-dimensional slenderness of a web panel with intermediate transverse stiffeners is given by:

$$\bar{\lambda}_{w} = \frac{h_{w}}{34.4 t_{w} \sqrt{k_{\tau}}} \text{ for S275 and } \bar{\lambda}_{w} = \frac{h_{w}}{30.3 t_{w} \sqrt{k_{\tau}}} \text{ for S355 steel} \qquad (7.5)$$

Step 3: Resistance of beam cross-section (Shear resistance)

The parameter k_τ is a buckling coefficient that depends on the aspect ratio of the panel - i.e. the ratio of its depth hw to its width (between transverse stiffeners). The value of k_τ is given by the following expressions and by Figure 7.1:

$$k_\tau = 5.34 + 4.00(h_w/a)^2 \text{ when } a/h_w \geq 1$$

$$k_\tau = 4.00 + 5.34(h_w/a)^2 \text{ when } a/h_w < 1$$

Clearly, from the Figure, reducing the panel width (by reducing the spacing of intermediate transverse web stiffeners) can increase the buckling coefficient significantly. In multi-girder construction the aspect ratio is typically between 1.5 and 1.0 for regions of high shear. In ladder decks, the aspect ration may be 2.0 or more, although the web is thicker and thus its slenderness is lower.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

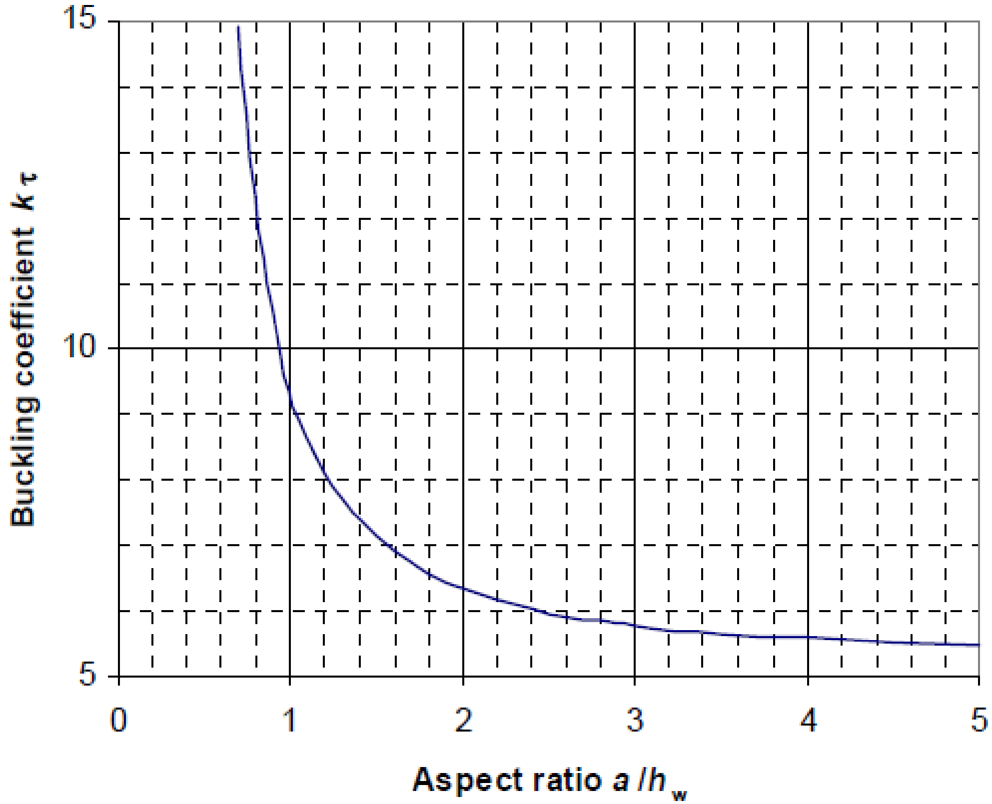


Figure 7.1 *Shear buckling coefficient k_τ*

Step 3: Resistance of beam cross-section (Shear resistance)

From the slenderness, a reduction factor χ_w is derived, according to expression (7.6) and Figure 7.2.

$$\chi_w = 1.0 \text{ for } \bar{\lambda}_w \leq 0.83$$

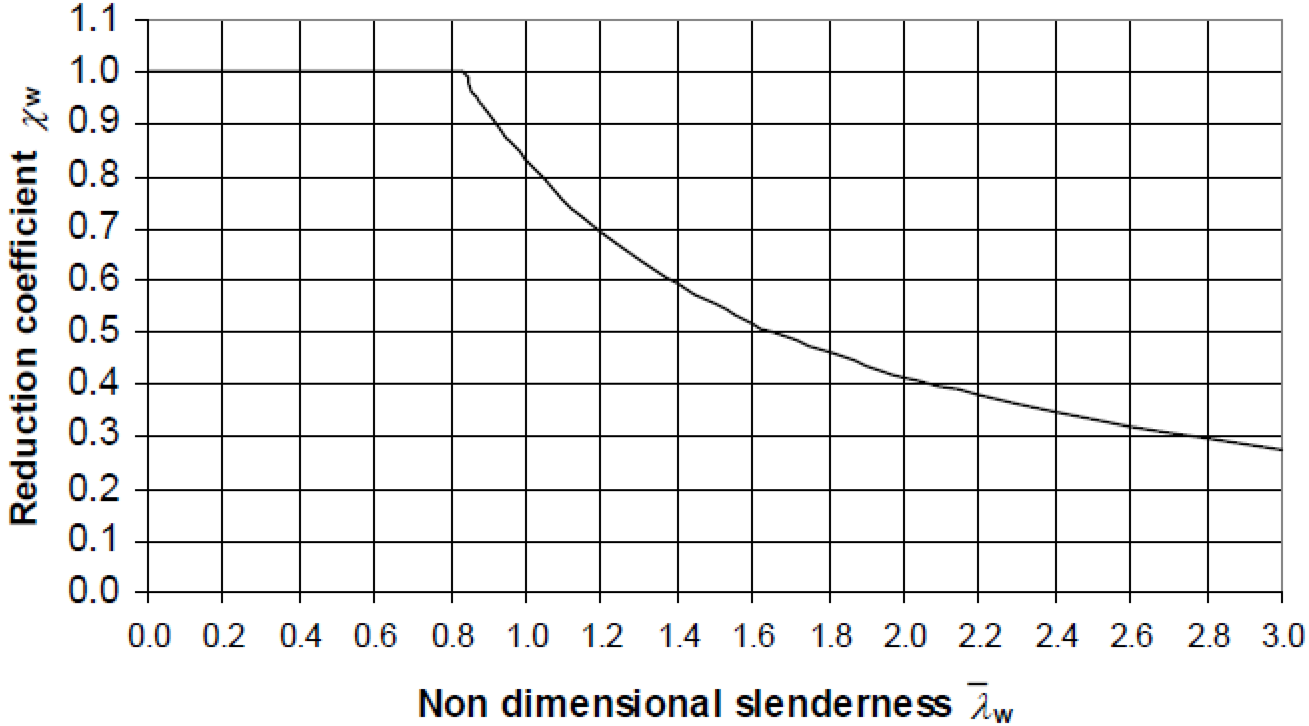
$$\chi_w = 0.83/\bar{\lambda}_w \text{ for } 0.83 < \bar{\lambda}_w \leq 1.08 \tag{7.6}$$

$$\chi_w = 1.37/(0.7 + \bar{\lambda}_w) \text{ for } 1.08 < \bar{\lambda}_w$$

These expressions apply where there is continuity of the web either side of the panel - at an end support there should be a 'rigid end post' (at the support the web continues beyond the centreline of the bearing and an endplate stiffener is provided - see Figure 7.3).

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)



igure 7.2 *Shear reduction factor* χ_w

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

The contribution of the web is then given by:

$$V_{\mathrm{bw,Rd}} = \chi_{\mathrm{w}} \frac{f_{\mathrm{yw}} h_{\mathrm{w}} t_{\mathrm{w}}}{\sqrt{3}\, \gamma_{\mathrm{M1}}} \tag{7.7}$$

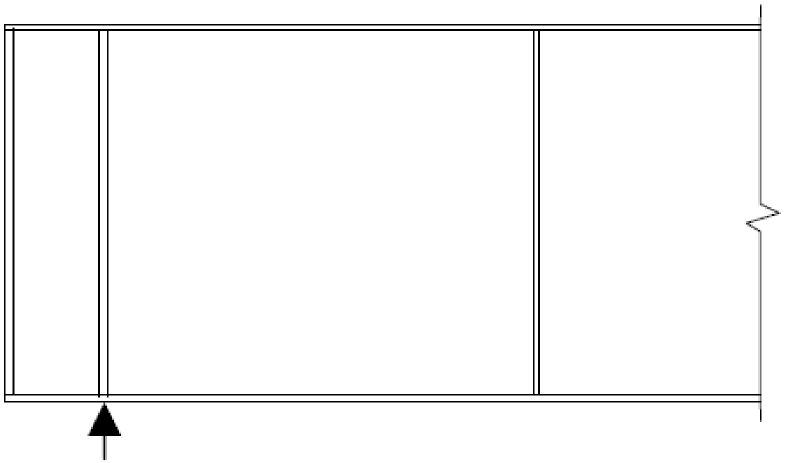


Figure 7.3 *End post detail at an end support*

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

Contribution from the flange

The contribution from the flange depends on the restraint from the local bending resistance of the flange to the tensile band that develops across the web panel. The value is given by the following expression in EN 1993-1-5:

$$V_{\mathrm{bf,Rd}} = \frac{b_{\mathrm{f}} t_{\mathrm{f}}^2 f_{\mathrm{yf}}}{c\,\gamma_{\mathrm{M1}}} \left(1 - \left(\frac{M_{\mathrm{Ed}}}{M_{\mathrm{f,Rd}}} \right)^2 \right) \tag{7.8}$$

Where b_{f} and t_{f} are the width and thickness of the flange (use the values for the smaller flange), c is a factor related to the panel width a, M_{Ed} is the coexisting design moment acting on the section and $M_{\mathrm{f,Rd}}$ is the bending resistance of a cross section comprising the flanges only.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

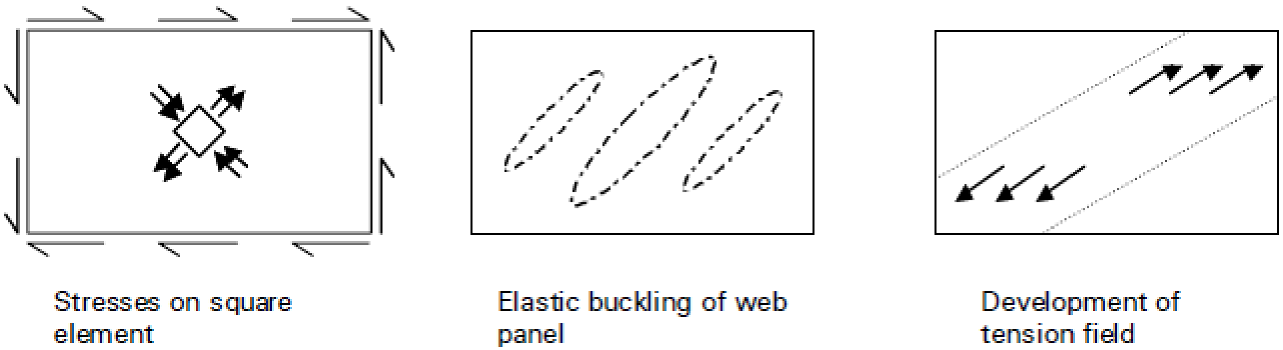


Figure 7.4 *Web Panels in shear: buckling and tension field action*

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

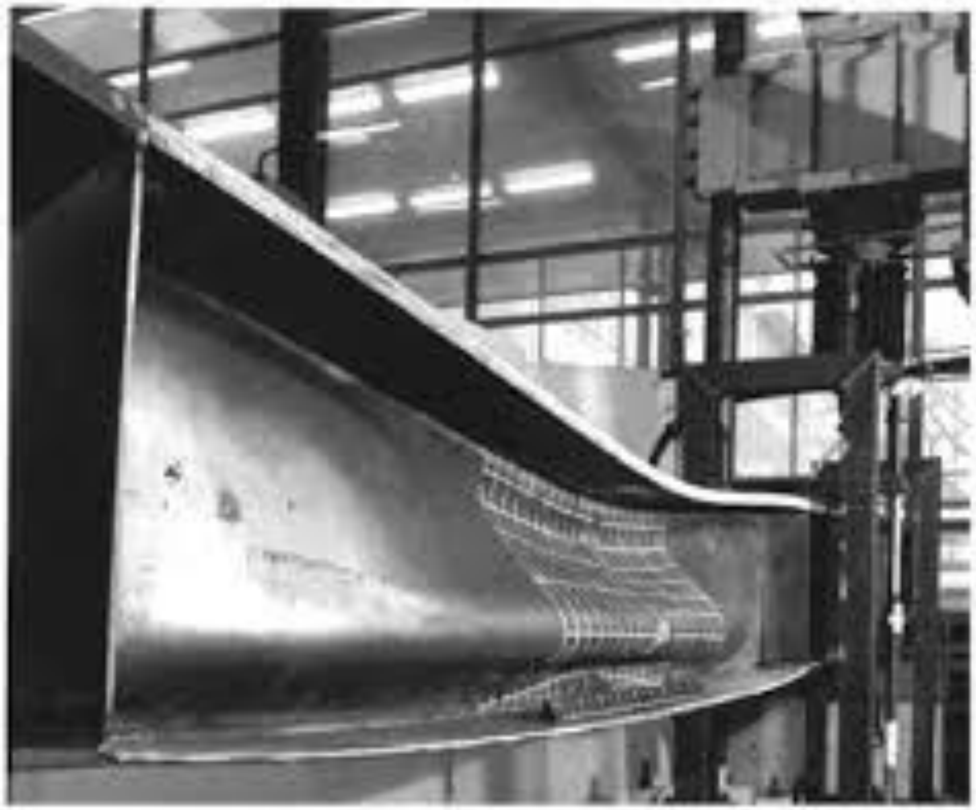


Figure 2. Vertical web buckling.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Shear resistance)

- ❑ V_{bwrd} = 3507 kN
- ❑ V_{bfrd} = 527.5 kN
- ❑ V_{brd} =3507 kN + 527.5 kN =4034.5 kN
- ❑ $\frac{\eta F_{yw}(h_w)(t_w)}{\sqrt{3}\gamma_m}$ = 4208.57 kN

Vbrd < $\frac{\eta F_{yw}(hw)(tw)}{\sqrt{3}\gamma_m}$ thus, ok

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 3: Resistance of beam cross-section (Combined Bending and Shear resistance)

Combined bending and shear

Under combined bending and shear, the values of the maximum moment within the panel, M_{Ed}, and the maximum shear force in the panel, V_{Ed}, should lie within the boundary shown on Figure 7.5. [NB the values to be considered are not necessarily at the same cross section, they are just the maximum values within the panel length.]

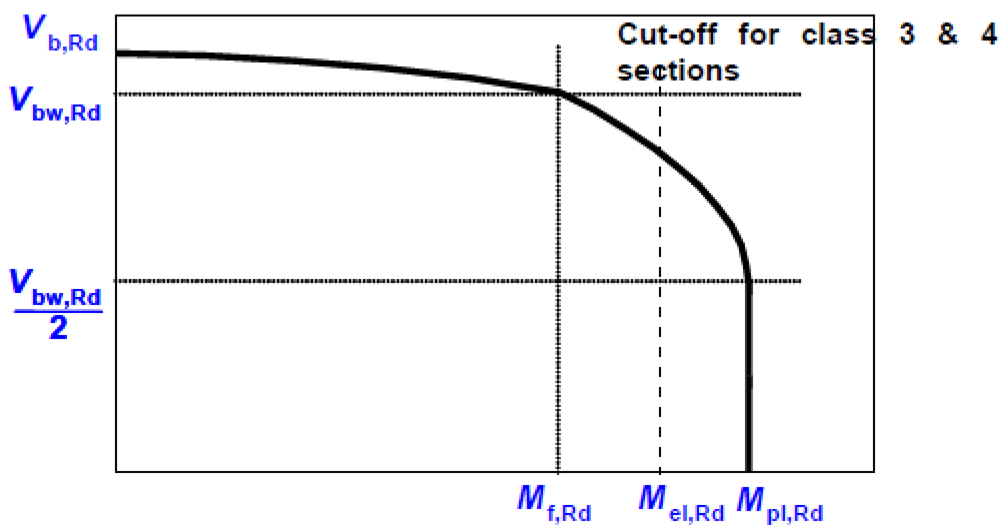


Figure 7.5 *Limiting interaction between moment and shear resistances*

Step 3: Resistance of beam cross-section (Combined Bending and Shear resistance)

In the diagram:

$V_{b,Rd}$	is the shear resistance of the panel ($= V_{bw,Rd} + V_{bf,Rd}$)
$V_{bw,Rd}$	is the contribution to the shear resistance from the web
$V_{bf,Rd}$	is the contribution to the shear resistance from the flange
$M_{pl,Rd}$	is the plastic bending resistance of the cross section (calculated regardless of the classification of the cross section)
$M_{el,Rd}$	is the elastic bending resistance of the cross section
$M_{f,Rd}$	is the bending resistance of the cross section ignoring the contribution from the web, and is calculated as:

Step 3: Resistance of beam cross-section (Combined Bending and Shear resistance)

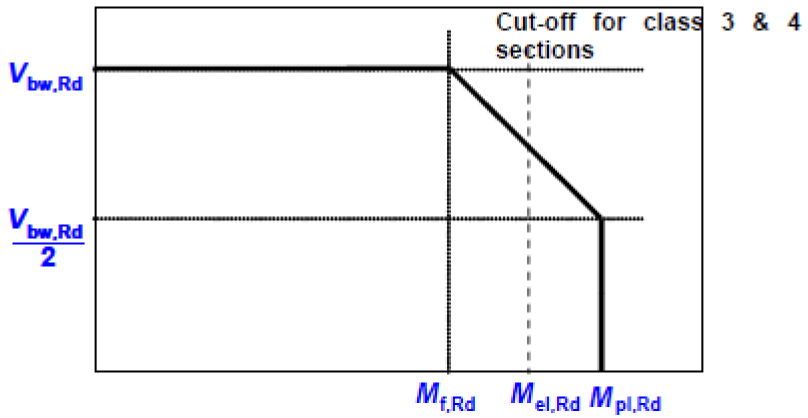


Figure 7.6 *Simplified interaction diagram*

Generally, for either interaction diagram, it may be noted that:

- Bending moments up to the value of $M_{pl,Rd}$ or $M_{el,Rd}$ (as appropriate) can be resisted by any beam if the shear force V_{Ed} does not exceed $0.5V_{bw,Rd}$.
- Shear forces up to the value of $V_{bw,Rd}$ can be resisted by any beam if the bending moment M_{Ed} does not exceed $M_{f,Rd}$.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

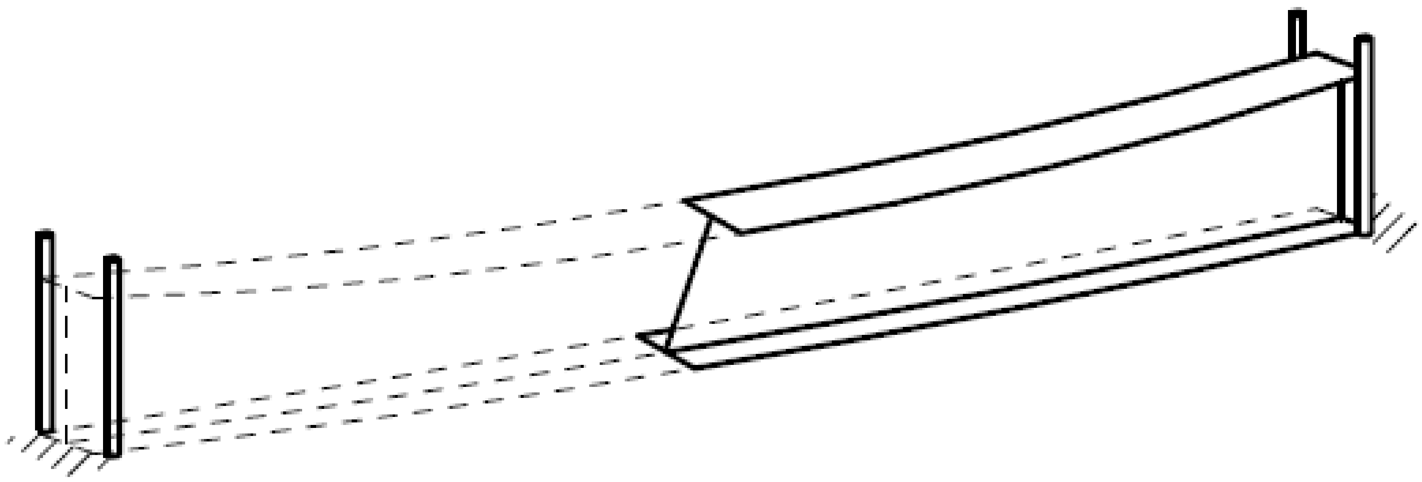
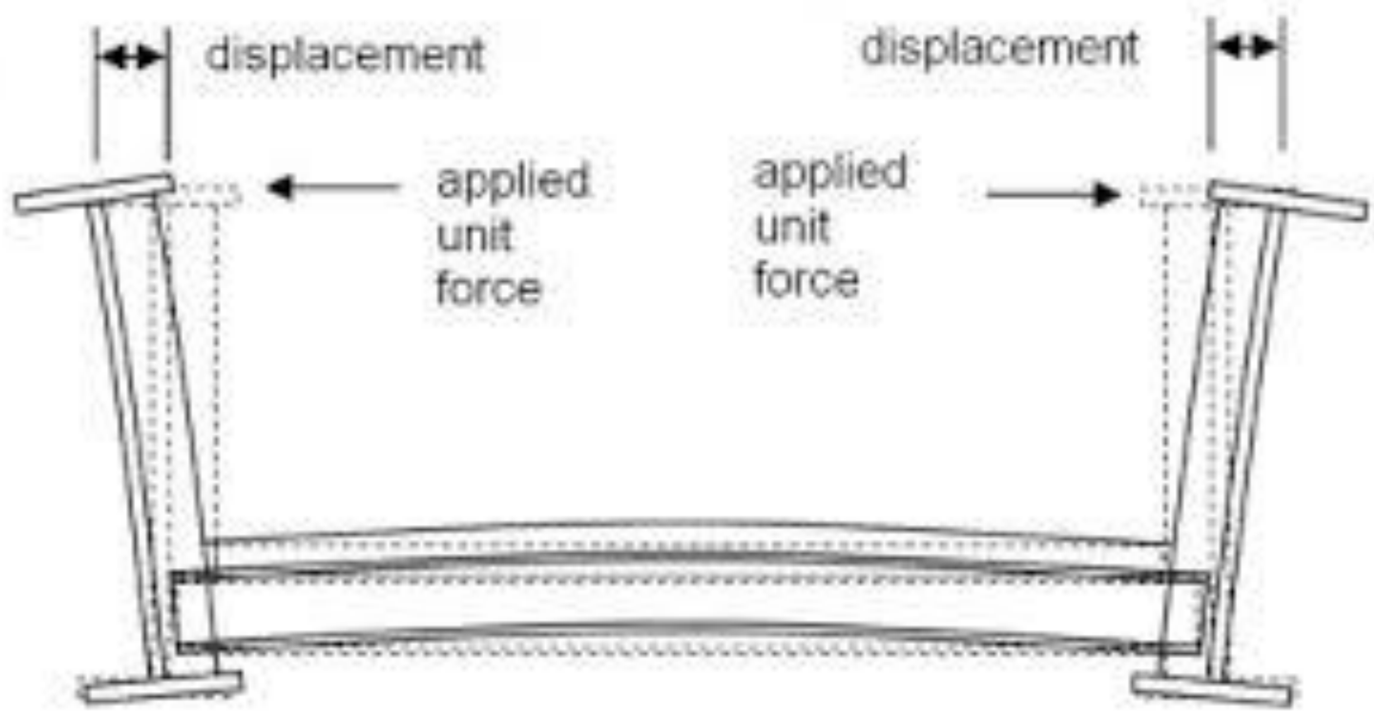


Figure 8.1 *Lateral torsional buckling of a simply supported beam*

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.



LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

6.3.2.1 Buckling resistance

(1) A laterally unrestrained member subject to major axis bending should be verified against lateral-torsional buckling as follows:

$$\frac{M_{Ed}}{M_{b,Rd}} \leq 1{,}0 \qquad (6.54)$$

where M_{Ed} is the design value of the moment

$M_{b,Rd}$ is the design buckling resistance moment.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

Buckling resistance

The design buckling resistance $M_{b,Rd}$ is then determined simply by:

$$M_{b,Rd} = \chi_{LT} \frac{W_y f_y}{\gamma_{M1}} \tag{8.3}$$

Where

W_y is the section modulus appropriate to the section class

Note that the γ_{M1} factor is applied, rather than the γ_{M0} factor that is applied in determining the bending resistance of the cross section, $M_{c,Rd}$ (see Section 7.1).

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

W_y is the appropriate section modulus as follows:

- $W_y = W_{pl,y}$ for Class 1 or 2 cross-sections
- $W_y = W_{el,y}$ for Class 3 cross-sections
- $W_y = W_{eff,y}$ for Class 4 cross-sections

χ_{LT} is the reduction factor for lateral-torsional buckling.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

Non-dimensional slenderness

The non-dimensional slenderness parameter $\bar{\lambda}_{LT}$ is given by:

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} \qquad (8.1)$$

where

W_y is the section modulus appropriate to the section class (see Section 7.1)

f_y is the yield strength of the compression flange

M_{cr} is the elastic critical moment for lateral torsional buckling

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

Reduction factor

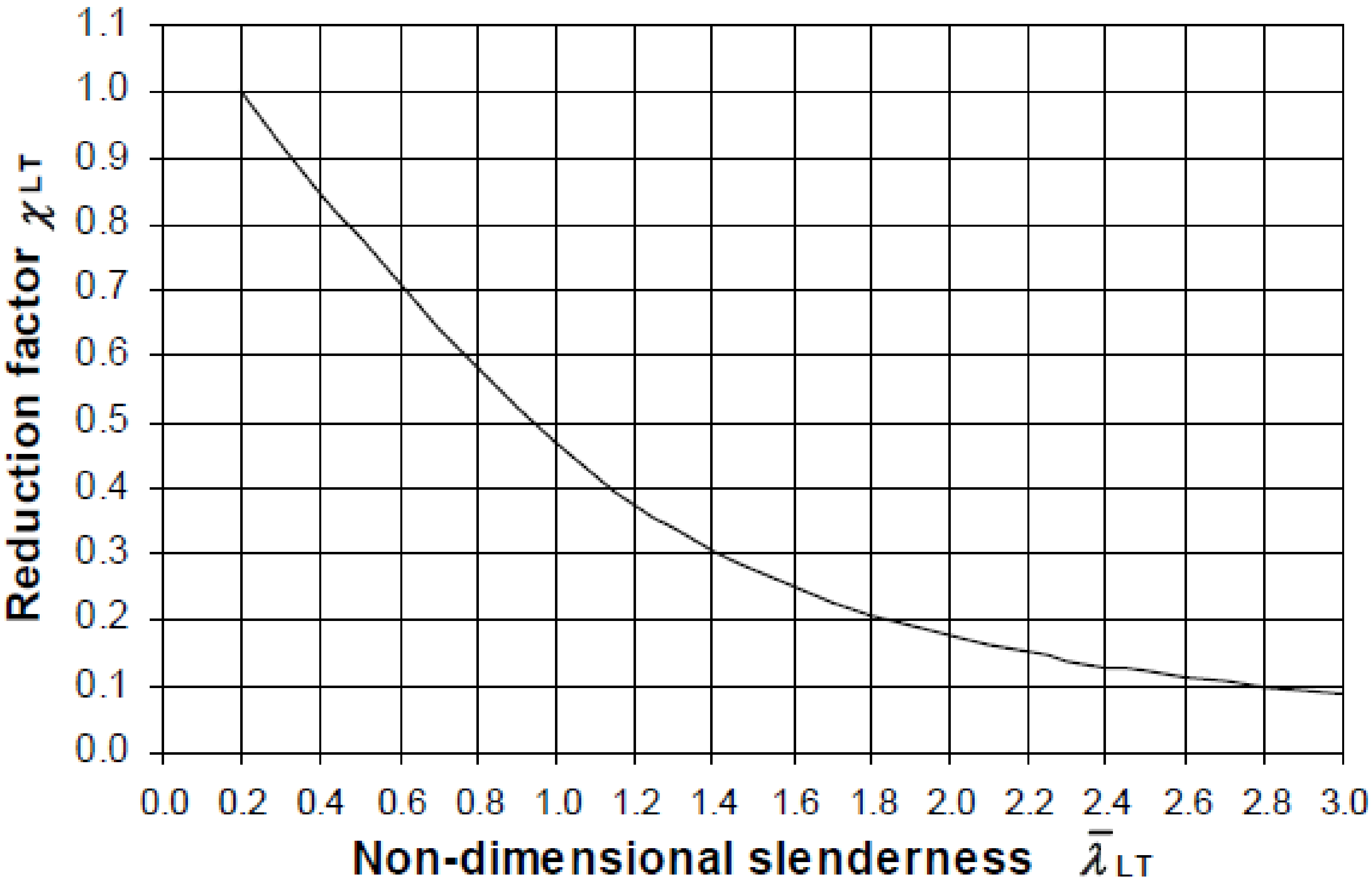
The reduction factor for lateral torsional buckling is given by expression (8.2) and by Figure 8.2.

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \overline{\lambda}_{LT}^2}} \text{ but } \chi_{LT} \le 1.0 \qquad (8.2)$$

Where $\phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\overline{\lambda}_{LT} - 0.2\right) + \overline{\lambda}_{LT}^2\right]$ and α_{LT} is an imperfection parameter.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.



LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

- $\frac{M_{ed}}{M_{brd}} < 1.0$
- M_{ed} = 2900 kNm
- M_{brd} = 177.3 kNm (without any bracing)
- $\frac{2900}{177.3} < 1.0$ **FAILED !!**

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (slenderness of beam)

- Beam segments between the effective restraints

Table 9.1 $\bar{\lambda}_{LT}$ *for beams between effective restraints*

	S 275	S 355
Class 1 and 2	$\bar{\lambda}_{LT} = \dfrac{L/i_{z,f}}{87}$	$\bar{\lambda}_{LT} = \dfrac{L/i_{z,f}}{76}$
Class 3	$\bar{\lambda}_{LT} = \dfrac{L/i_{z,f}}{100}$	$\bar{\lambda}_{LT} = \dfrac{L/i_{z,f}}{88}$

L is the distance between points of restraint of the compression flange

$i_{z,f}$ is the radius of gyration about the z-z axis of the gross cross-section of the compression flange plus one third of the height of the web in compression.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (slenderness of beam)

- Beam without intermediate restraints
- $$\bar{\lambda}_{LT} = \frac{1}{\sqrt{C_1}} V \frac{\lambda_z}{\lambda_1} \sqrt{\beta_w}$$

C_1 is a parameter dependent on the shape of the bending moment diagram, such that the value of M_{cr} for the segment with the actual bending moment diagram is equal to C_1 times that for the same segment with a uniform bending moment along its full length. Values of $\frac{1}{\sqrt{C_1}}$ are given in Table 9.3.

(Conservatively, C_1 may be taken as 1.0.).

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (slenderness of beam)

- Beam without Intermediate restraints

V is a parameter related to the slenderness and section geometry, and is given by Table 9.2, which is derived from the following expression:

$$V = \left[\left\{ 4i(1-i) + 0{,}05\lambda_F{}^2 + \psi_i{}^2 \right\}^{0,5} + \psi_i \right]^{-0,5}, \text{ in which}$$

$\psi_i = 2i - 1$ when $I_{z,c} < I_{z,t}$ and $\psi_i = 0.8(2i-1)$ when $I_{z,c} \geq I_{z,t}$.

For these expressions and for the Table, the following two parameters are required:

$$i = \frac{I_{z,c}}{I_{z,c} + I_{z,t}}$$

$$\lambda_F = \frac{L}{i_z} \cdot \frac{t_f}{h}$$

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (slenderness of beam)

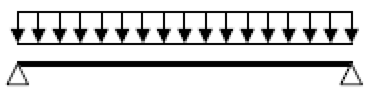
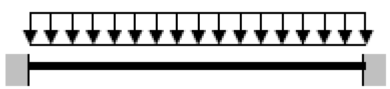
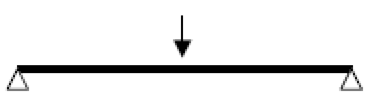
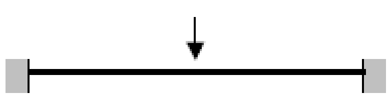
- Beam without Intermediate restraints

h	is the depth of the cross section;
L	is the span of the beam
t_f	is the mean thickness of the two flanges of the section
$I_{z,c}$, $I_{z,t}$	are the second moments of area of the compression and tension flanges, respectively, about their z-z axes.
λ_z	$= \dfrac{L}{i_z}$
i_z	is the radius of gyration of the section about the minor axis
β_w	$= \dfrac{W_y}{W_{pl,y}}$
W_y	is the modulus used to calculate $M_{b,Rd}$
	For Class 1 and 2 sections $W_y = W_{pl,y}$
	For Class 3 sections $W_y = W_{el,y}$
	For Class 4 sections $W_y = W_{eff,y}$
λ_1	$= \pi\sqrt{\dfrac{E}{f_y}}$ in which f_y is the yield strength of the steel
	($\lambda_1 = 87$ for S275 and $\lambda_1 = 76$ for S355 steel)

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (slenderness of beam)

Table 9.3 *Values of* $\frac{1}{\sqrt{C_1}}$ *for cases with transverse loading*

Loading and support conditions	Bending moment diagram	$\frac{1}{\sqrt{C_1}}$
		0.94
		0.62
		0.86
		0.77

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 5: Restrain to beam

To carry the forces associated with the restraining function, the bracing system or any individual restraint should be capable of resisting a force F_R plus the effects of any wind or other lateral forces. The force F_R is given by:

$$F_R = \frac{\Sigma N_{Ed}}{80} \qquad (10.1)$$

where:

ΣN_{Ed} is the sum of the greatest forces in the compression flanges of the two beams connected by the bracing.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 5: Restrain to beam

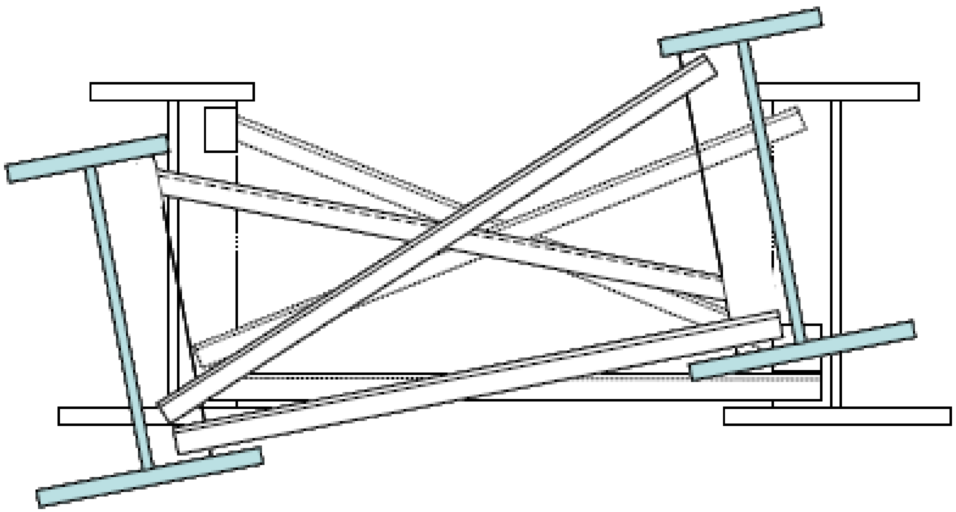


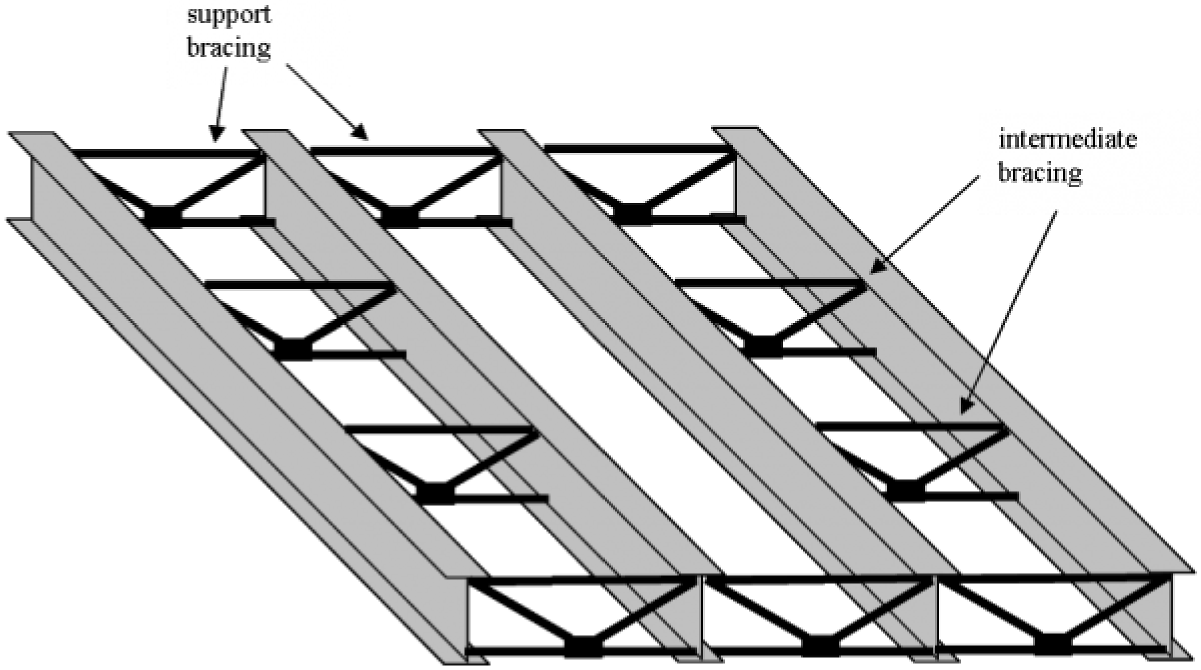
Figure 10.1 *Buckling mode for paired beams - torsional restraints*

If the effects of such torsional restraints are to be considered in a student design, a simplified method of determining a value of non-dimensional slenderness is given in Section 9.3 above.

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (Restraint to beam)

- Effective Intermediate Lateral restraints



LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (slenderness of beam)

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling (slenderness of beam)

LECTURE 2 (8.30-9.30):
STRUCTURAL RESISTANCE OF STEEL BEAM BRIDGE

Step 4: Buckling Resistance of beam lateral torsional buckling.

- $\frac{M_{ed}}{M_{brd}} < 1.0$
- $M_{ed} = 2900$ kNm
- $M_{brd} = 5538$ kNm (Provide bracing at 1.2m)
- $\frac{2900}{5538} < 1.0$ **PASSED!!**

LECTURE 3 (9.30-10.30):
STIFFENER DESIGN

STIFFENER DESIGN

LECTURE 3 (9.00-9.30): STIFFENER DESIGN

- **Step 5: Stiffener design.**

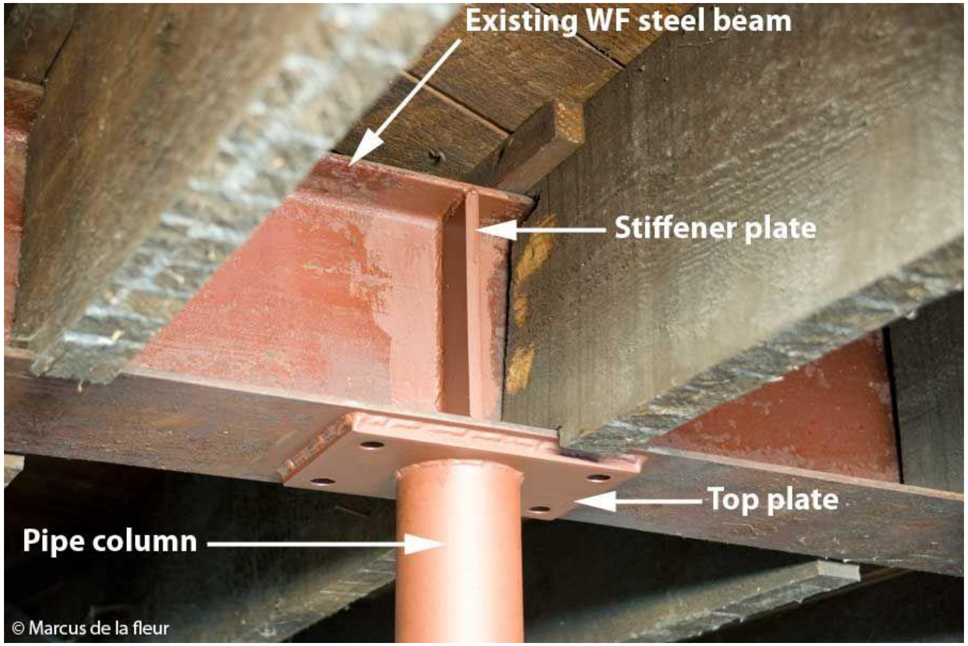
❑ Intermediate transverse web stiffeners

❑ Bearing stiffeners at supports

LECTURE 3 (9.00-9.30):
STIFFENER DESIGN

- **Step 5: Stiffener design.**

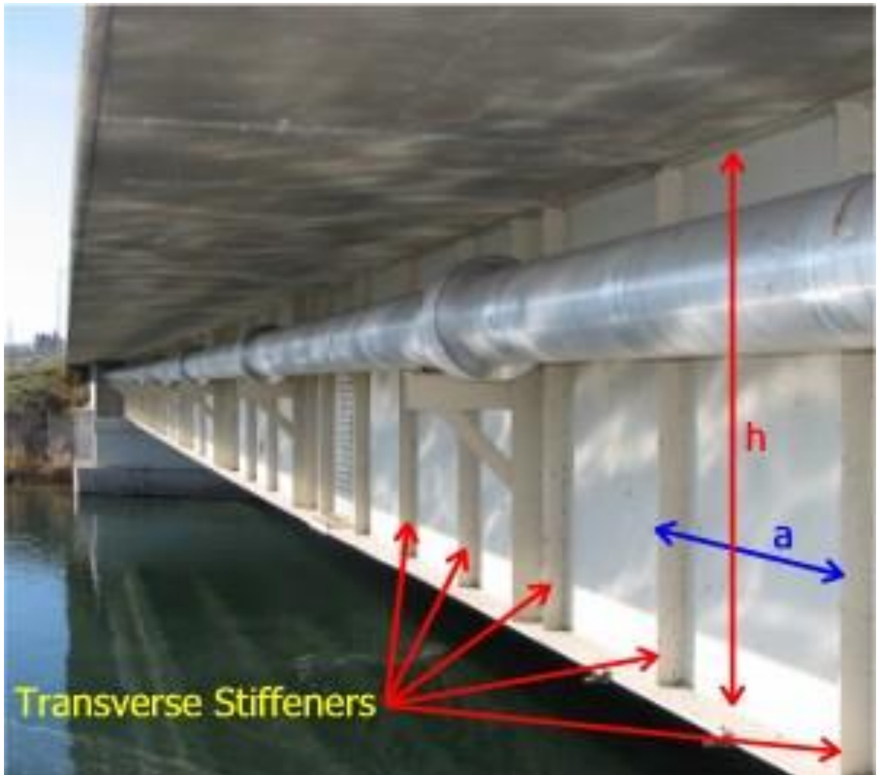
❑ Intermediate transverse web stiffeners



LECTURE 3 (9.00-9.30):
STIFFENER DESIGN

- **Step 5: Stiffener design.**

❑ Intermediate transverse web stiffeners



LECTURE 4 (9.30-10.30): TUTORIAL

- **Step 5: Stiffener design.**

❑ Intermediate transverse web stiffeners

Geometric proportions

Flat plates welded to the face of the web should be used to create intermediate transverse web stiffeners. The proportions of the plate outstand should be limited as follows:

$$\frac{h_o}{t_s} \leq 12.0 \text{ for S275 and } \frac{h_o}{t_s} \leq 10.5 \text{ for S355} \qquad (11.1)$$

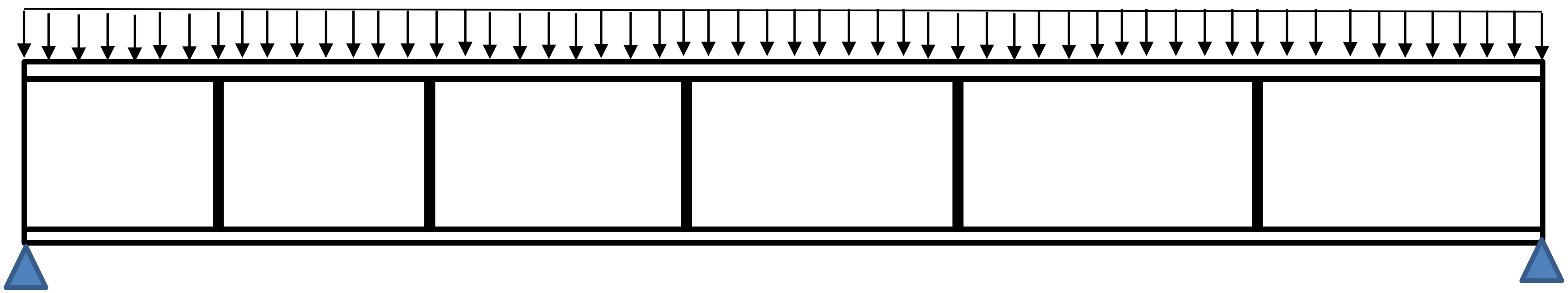
Where h_o is the height of the outstand and t_s is the thickness of the stiffener.

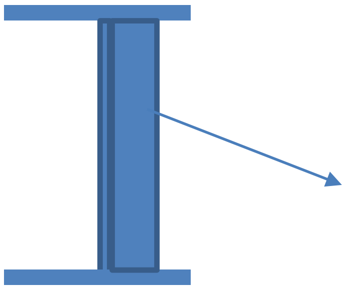
Stiffeners outstands are typically just less than the outstand of the narrower flange, though the required size depends on criteria for stiffness and strength. 'Rounded dimensions' (e.g. 150×15, 200×20, 250×25) are normally specified.

LECTURE 4 (9.30-10.30): TUTORIAL

- **Step 5: Stiffener design.**

❑ Intermediate transverse web stiffeners





LECTURE 4 (9.30-10.30): TUTORIAL

- **Step 5: Stiffener design.** Cl 9.3.3, EC3-1-5

❑ Intermediate transverse web stiffeners

The force $N_{s,Rd}$ to be resisted by a stiffener is given by

$$N_{s,Rd} = V_{Ed} - \chi_w h_w t \frac{\frac{f_{yw}}{\sqrt{3}}}{\gamma_{M1}} \tag{5.176}$$

Note, χ_w is calculated for the web panel between adjacent stiffeners assuming the stiffener under consideration is removed. In the case of variable shear, then the check is performed at a distance $0{,}5h_w$ from the edge of the pane with the larger shear force.

To determine the buckling resistance of the stiffener a portion of the web may taken into account (Rockey *et al.*, 1981). A section of the web in length equal to $15\varepsilon t$ either side of the stiffener may be considered (cl 9.1, EN 1933-1-3) (Fig. 5.23)

Design of Stiffeners

Cl 9.3.3, EC3-1-5

Intermediate Transverse Stiffeners

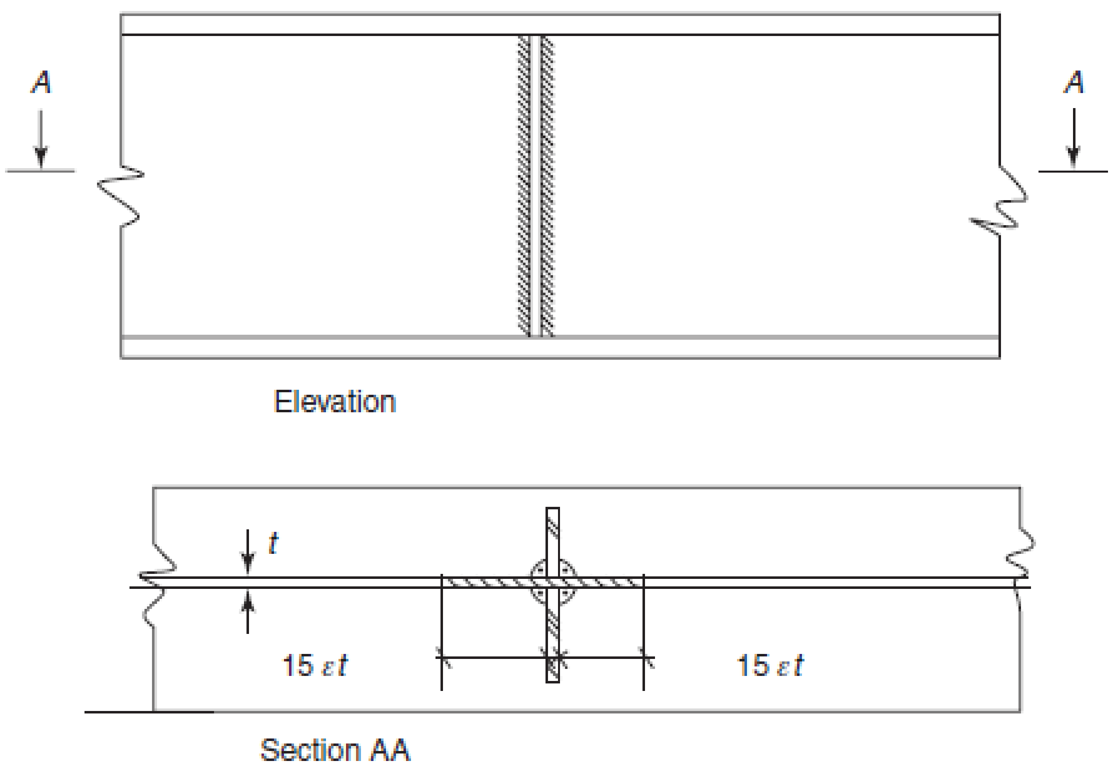


FIGURE 5.23 Stiffener geometry

LECTURE 4 (9.30-10.30): TUTORIAL

- **Step 5: Stiffener design.**

Intermediate transverse web stiffeners


Coffee
Time

LECTURE 4 (11.00-12.00): CONNECTION DESIGN

- WELDED CONNECTIONS
- BOLTED CONNECTIONS