**VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN**

**SECTION 3 GENERAL DESIGN**

## PART 14

## BD 13/06

# DESIGN OF STEEL BRIDGES. USE OF BS 5400-3:2000

### SUMMARY

This Standard implements BS 5400-3:2000 Steel, concrete and composite bridges – Part 3 : Code of practice for design of steel bridges. It supersedes BD 13/04, Design of steel bridges, Use of BS 5400: Part 3: 2000 (DMRB 1.3.14), which is now withdrawn.

### INSTRUCTIONS FOR USE

1. Remove Contents pages from Volume and insert new Contents pages for Volume 1 dated May 2006.

2. Remove BD 13/04 from Volume 1, Section 3 which is superseded by this Standard and archive as appropriate.

3. Insert BD 13/06 into Volume 1, Section 3.

4. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

THE HIGHWAYS AGENCY

TRANSPORT SCOTLAND

WELSH ASSEMBLY GOVERNMENT
LLYWODRAETH CYNULLIAD CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

# Design of Steel Bridges.
# Use of BS 5400-3:2000

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## REGISTRATION OF AMENDMENTS

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**PART 14**

**BD 13/06**

# DESIGN OF STEEL BRIDGES. USE OF BS 5400-3:2000

**Contents**

Chapter

# 1. INTRODUCTION

## General

1.1 This Standard implements BS 5400-3:2000 Code of practice for design of steel bridges. It supersedes BD 13/04 Design of Steel Bridges Use of BS 5400: Part 3:2000 which is now withdrawn.

1.2 The amendments contained in Annex A result from a review of the Code by the BSI Working Group B525/10/WG3 over several years. Eurocodes are being used on a trial basis in a number of European countries and will supersede the equivalent National Standards in a few years, but until then there is a need to maintain BS 5400.

1.3 This Standard corrects errors and contains minor amendments to BD 13/04. BD 13/06 amends BS 5400-3:2000 by providing replacement and new clauses, including additions and deletions to existing clauses. The amendments are given in Annex A and follow the clause numbering used in BS 5400-3:2000. This Standard complements the Specification for Highway Works (MCHW 1).

1.4 This Standard has been produced to modify parts of BS 5400-3:2000 so that it meets the requirements of the Overseeing Organisations.

1.5 The main technical changes in BS 5400-3:2000 compared to the earlier version are:

- partial factor for bending resistance of beams is reduced to 1.05 at the Ultimate Limit State;
- the clauses on notch toughness now take account of the recent research carried out on the subject;
- lateral torsional buckling rules are modified;
- the rules on bracing systems and frame restraints including rules on U-frames are substantially modified;
- patch loading rules are modified.

## Scope

1.6 This Standard covers the use of BS 5400-3:2000 for the design and strengthening of steel bridges and steel highway structures and it includes the Overseeing Organisations' requirements where these are either more comprehensive or differ from the British Standard.

1.7 The design of wires, cables, anchorages and saddles for suspension and cable stayed bridges and the design of orthotropic steel decks are not covered by this Standard. For guidance on the design of such items, designers should seek information from specialist literature.

## Equivalence

1.8 The construction of highway structures will normally be carried out under contracts incorporating the Specification for Highway Works (SHW) which is contained in the Manual of Contract Documents for Highway Works Volume 1 (MCHW 1). In such cases products conforming to equivalent standards or technical specifications of other Member States (MS) of the European Economic Area (EEA) or a State which is party to a relevant agreement with the European Union and tests undertaken in other MS of the EEA or a State which is party to a relevant agreement with the European Union will be acceptable in accordance with the terms of Clauses 104 and 105 (MCHW 1.100). Any contract not containing these Clauses must contain suitable clauses of mutual recognition having the same effect, regarding which advice should be sought.

## Implementation

1.9 This Standard shall be used forthwith on all schemes for the design and strengthening of highway structures on trunk roads, including motorways. For schemes in preparation the Standard should be used provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay.

**Mandatory Sections**

1.10 Sections of this document which form part of the Standards of the Overseeing Organisations are highlighted by being contained in boxes. These are the sections with which the Design Organisations must comply, or must have agreed a suitable departure from Standard with the relevant Overseeing Organisation. The remainder of the document contains advice and enlargement which is commended to Design Organisations for their consideration.

**Use in Northern Ireland**

1.11 For use in Northern Ireland, this Standard must be applicable to those roads designated by the Overseeing Organisation.

# 2. USE OF THE BRITISH STANDARD

2.1 The design and strengthening of all highway structures in steel shall be carried out in accordance with BS 5400-3:2000 as amended by this Standard. Reference to "bridges" or "highway bridges" in BS 5400-3:2000 shall be taken as a reference to all highway structures.

2.2 Where reference is made to any other British Standard this shall be taken as a reference to that part and edition implemented by the Overseeing Organisation.

2.3 The clauses in BS 5400-3:2000 that are expressed in the form of a recommendation using the word "should" or "may" shall be considered as mandatory unless provisions are given in the Code to deal with alternatives.

2.4 Annexes in BS 5400-3:2000 generally contain provisions not specifically covered in the Code. When these provisions are used in designs as alternatives or additional to the recommendations contained in the Code, the informative annexes shall be mandatory.

2.5 Where reference is made to the relevant or appropriate "Bridge Authority" this shall be taken to be the Technical Approval Authority appointed by the Overseeing Organisation.

2.6 Where reference is made to "The Specification for Highway Works", this shall be read to include Volume 1, "The Specification for Highway Works (MCHW 1)" and Volume 2, the "Notes for Guidance on the Specification for Highway Works", (MCHW 2).

2.7 Clause references given in bold types in Annex A of this Standard refer to clauses in BS 5400-3:2000 as implemented by this Standard.

# 3. ADDITIONAL REQUIREMENTS

3.1 To make BS 5400-3:2000 contract neutral all references to the word "Engineer" shall be deleted.

**3.2 Weathering Steel**

3.2.1 The use of weathering steel in highway structures is covered in BD 7 (DMRB 2.3.8). The design of structures in weathering steel shall be carried out in accordance with BS 5400-3:2000 as implemented by this Standard and the following clauses.

3.2.2 The sectional properties to be used for global analysis (BS 5400-3:2000, **7.2**) shall be calculated assuming either the specified sizes or the specified sizes less the allowance for the loss of thickness in accordance with BD 7.

3.2.3 All dimensions for checking the adequacy of sections shall be taken as the specified dimensions less the allowance for the loss of thickness in accordance with BD 7 and BS 5400-3:2000.

**3.3 Notch toughness**

3.3.1 When considering impact loading from over height vehicles the value of $k_s$ to be used in **6.5.3.5** shall be taken as 1.0 providing that there is at least 5.3 m headroom available.

**3.4 Strength of fasteners**

3.4.1 For the application of **14.5.3.1**, all connections that are subjected to live or wind load effects shall be considered to be "permanent main structural connections".

3.4.2 High Strength Friction Grip (HSFG) bolts to BS 4395-2 shall not be used to resist applied axial tension.

# 4. REFERENCES

The following documents are referred to in the Standard.

**4.1 Design Manual for Roads and Bridges (DMRB). The Stationery Office**

BD 13/04 Design of steel bridges. Use of BS 5400:Part 3: 2000 (DMRB 1.3)

BD 7 Weathering Steel for Highway Structures (DMRB 2.3.8)

**4.2 Manual of Contract Documents for Highway Works (MCHW). The Stationery Office**

Volume 1 (MCHW 1): Specification for Highway Works.

Volume 2 (MCHW 2): Notes for Guidance on the Specification for Highway Works.

**4.3 British Standards**

BS 4395-2 Specification for high strength friction grip bolts and associated nuts and washers for structural engineering. Higher grade bolts and nuts and general grade washers

BS 5400-3:2000 Steel, concrete and composite bridges. Code of practice for design of steel bridges

BS EN 1011-1 Welding. Recommendations for welding of metallic materials. General guidance for arc welding

BS EN 1011-2 Welding. Recommendations for welding of metallic materials. Arc welding of ferritic steels

# 5. ENQUIRIES

All technical enquiries or comments on this Standard should be sent in writing as appropriate to:

| | |
|---|---|
| Chief Highway Engineer<br>The Highways Agency<br>123 Buckingham Palace Road<br>London<br>SW1W 9HA | G CLARKE<br>Chief Highway Engineer |

| | |
|---|---|
| Chief Road Engineer<br>Transport Scotland<br>Victoria Quay<br>Edinburgh<br>EH6 6QQ | J HOWISON<br>Chief Road Engineer |

| | |
|---|---|
| Chief Highway Engineer<br>Transport Wales<br>Welsh Assembly Government<br>Cathays Parks<br>Cardiff<br>CF10 3NQ | M J A PARKER<br>Chief Highway Engineer<br>Transport Wales |

| | |
|---|---|
| Director of Engineering<br>The Department for Regional Development<br>Roads Service<br>Clarence Court<br>10-18 Adelaide Street<br>Belfast BT2 8GB | G W ALLISTER<br>Director of Engineering |

# ANNEX A (NORMATIVE) AMENDMENTS TO BS 5400-3:2000 CODE OF PRACTICE FOR DESIGN OF STEEL BRIDGES

**2 Normative references**

Replace "BS 5135: 1984" as follows:

"BS EN 1011 Welding – Recommendations for welding of metallic materials

Part 1: General guidance for arc welding

Part 2: Arc welding of Ferritic steel"

**4.5.6 Thickness of weathering steel**

Delete the whole clause and substitute the following:

"To cater for the loss of structurally effective material due to the developing rust patina during the life of the structure, corrosion allowance should be made on each exposed surface, representing a loss of thickness of material used for structural purposes, as stated in Chapter 3 of BD 7 (DMRB 2.3.8). If weathering steel surfaces receive corrosion protective treatment, no corrosion allowance is necessary."

**5.7 Camber**

Line 4, delete "or approved by the Engineer"

**6.1.1 Performance**

Line 1, delete "required by the Engineer"

**Table 3-Fracture classification**

Insert ", 2.8" after Detail type "2.7" under column 5, row 9

**9.4.2.4. Effective areas of compression flanges or planes in compression**

In the definition of $k_h$ delete "not" after "holes"

**9.6.1 General**

Para 2, line 3, insert "equal to or" after "bending is"

**9.6.2 Beams (other than cantilevers) without intermediate restraints**

Delete the existing definition of $v$ and substitute the following:

"$v$ is the value of $v$ calculated in accordance with **9.7.2.**"

**9.6.4.1.1.1 Beams with fully effective lateral restraints at the level of a compression flange**

Delete Para 2 and replace with:

"A discrete lateral restraint or a plan bracing system, may be taken as fully effective provided that it has a stiffness such that $\delta_R < \ell_R^3/(40\, EI_c)$ where $\delta_R$, $\ell_R$ , and $I_c$ are as defined in **9.6.4.1.1.2**."

Delete Para 3.

After Para 2, insert "NOTE" as follows:

"NOTE: Less conservative stiffness requirements may be obtained for a beam with $n$ intermediate restraints by first deriving the value of $M_R/M_{ult}$ from **9.8** for failure by buckling between restraints, with $\ell_e/\ell_w = 1.0$ and $\lambda_{LT}$ calculated with $\ell_e = \ell_R$. The restraint stiffnesses may also be derived by selecting a value of $\ell_e$ such that with $\lambda_{LT}$ calculated using the $\ell_e$ and with $\ell_e/\ell_w = \ell_e/L$ the same resistance for overall buckling is achieved. The required limit to $\delta_R$ is then $\ell_e^4/\ [EI_c\ell_R(k_2k_3k_5)^4]$ in which the terms are as defined in **9.6.4.1.1.2**."

**9.6.4.1.1.2 Beams with discrete lateral restraints to a compression flange which are not fully effective**

In "a)" add at end "nor greater than $L$"

In definition of "$\ell_R$" insert (twice) "or nodes in a plan bracing system" after "intermediate restraint"

In definition of "$\delta_R$" replace "the restraint" by "a lateral restraint". Add "With a plan bracing system the deflection is to be taken as the deflection of a node relative to adjacent nodes."

**9.6.4.1.2 Beams with discrete torsional restraints**

Line 1, insert "without lateral restraints" after "cross-section"

Line 3, insert "restraint" before "parameter" and replace parameter expression "$v^4 L^3/[EI_c \theta_R d_f^2]$" by

"$v_{eq}^4 \ell_w^3/[EI_c \theta_R d_f^2(1\text{-}i)]$"

Insert "for beams with distributed restraints $\ell_e$" after "but".

Line 4, replace "0.6$v$" by "0.7$v_{eq}$"

Insert the definition:

"$\ell_w$ is the assumed half wavelength of buckling. The value of $\ell_w$ should be taken as the span $L$ or a sub multiple of the span, whichever gives the lowest value of limiting moment of resistance $M_R$ in accordance with **9.8**."

Insert "NOTES" as follows at the end of the clause:

"NOTE 1 The effective length relationships in Figure 8 do not apply when considering buckling with a half-wavelength equal to $\ell_R$ (within which there are no restraints), for which $\ell_w = \ell_e = \ell_R$.

NOTE 2 The resistance of a beam with $\ell_e < \ell_R$ and $\ell_w > \ell_R$ may be less than for buckling between restraints with $\ell_w = \ell_e = \ell_R$.

NOTE 3 For beams with a single central restraint, $\ell_w$ should be taken as equal to $L$, unless the restraint parameter derived from that value is such that it is to the right of the vertical arrow on the appropriate curve for the value of $v_{eq}$, in which case either:

a) $\ell_e$ and $\ell_w$ should be taken as $L/2$

or

b) $\ell_w$ should be taken as $L$ and $\ell_e$ should be derived from Figure 8, whichever gives the lowest moment of resistance."

Delete the existing definitions for "$\theta_R$" and "$v$", and substitute the following:

"$\theta_R$ is the greatest value of the rotation of a restraint about the longitudinal axis of the beam, due to a torque equal to a unit torque multiplied by $1/m$, applied to each restraint. When restraint is provided by uniform diaphragms interconnecting beams, the value of $\theta_R$ should be taken as $\theta_{R1} + \theta_{R2}$ where:

$\theta_{R1}$ is the rotation due to the flexibility of the diaphragm calculated as the greatest rotation about the longitudinal axis of a beam at a connection between the diaphragm and the beam under unit moments in the plane of the diaphragm multiplied by $1/m$, applied to each connection in the same sense on each beam. (see Figure 8 A)

$\theta_{R2}$ is the greatest value of rotation of a beam at the middle of a half wavelength of buckling due to the vertical deflections of the beams. A unit torque multiplied by $1/m$ should be applied to each beam at each diaphragm connection, the diaphragms being assumed to be rigid for this calculation, in directions of opposite sense in consecutive waves and the same sense on each beam.

$m$ is the number of restraints in the half wavelength of buckling (= 1 for a single central restraint with a buckling half-wavelength equal to L)

$v_{eq}$ is a parameter that takes account of warping properties of the section and is calculated as follows:

a) for sections symmetrical about both their major and minor axis, $v_{eq} = v$ where the value of $v$ is determined in accordance with **9.7.2**

b) for sections symmetrical about their minor axis only,

$$v_{eq} = \left[\frac{2i\chi}{\left[\sqrt{4+\tau\chi} + \psi_i\sqrt{\chi}\right]^2}\right]^{0.25}$$

where

$$\tau = 4i(1-i) + \psi_i^2$$

(when $I_c \le I_t$ $\tau$ shall be taken as 1.0)

$i$ and $\psi_i$ are as defined in **9.7.2**

$$\chi = \frac{\pi^2 d_f^2 EI_y}{GJ\ell_w^2}$$

$I_y$ is the second moment of area of the beam about its minor axis

$J$ is the St Venant Torsional Constant"

Insert "NOTES" as follows at the end of the clause:

"NOTE 4 Where, for distributed restraints, the value of $v_{eq}^4 \ell_w^3/[EI_C \theta_R d_f^2(1\text{-}i)]$ exceeds the maximum value shown in Figure 8, the equation given in G.7 may be used to derive the appropriate value of $\ell_e/\ell_w$.

NOTE 5 When only pairs of beams are interconnected by diaphragms, $\theta_{R2}$ may be taken as $(m+1)\ell_w^3/24mEI_2B^2$ where $I_2$ is the second moment of area of each beam about its major axis, $B$ is the spacing of the beams and $m$ is the number of restraints within the half wavelength."

NOTE 6 Consideration should be given to the alternative strengths of the beams when buckling in modes in which adjacent beams rotate in opposite senses (See Figure 8A). These should be treated as beams restrained by the cross members in accordance with **9.6.4.1.3 or 9.6.4.2.**"

Replace "Figure 8" by the following revised figure:

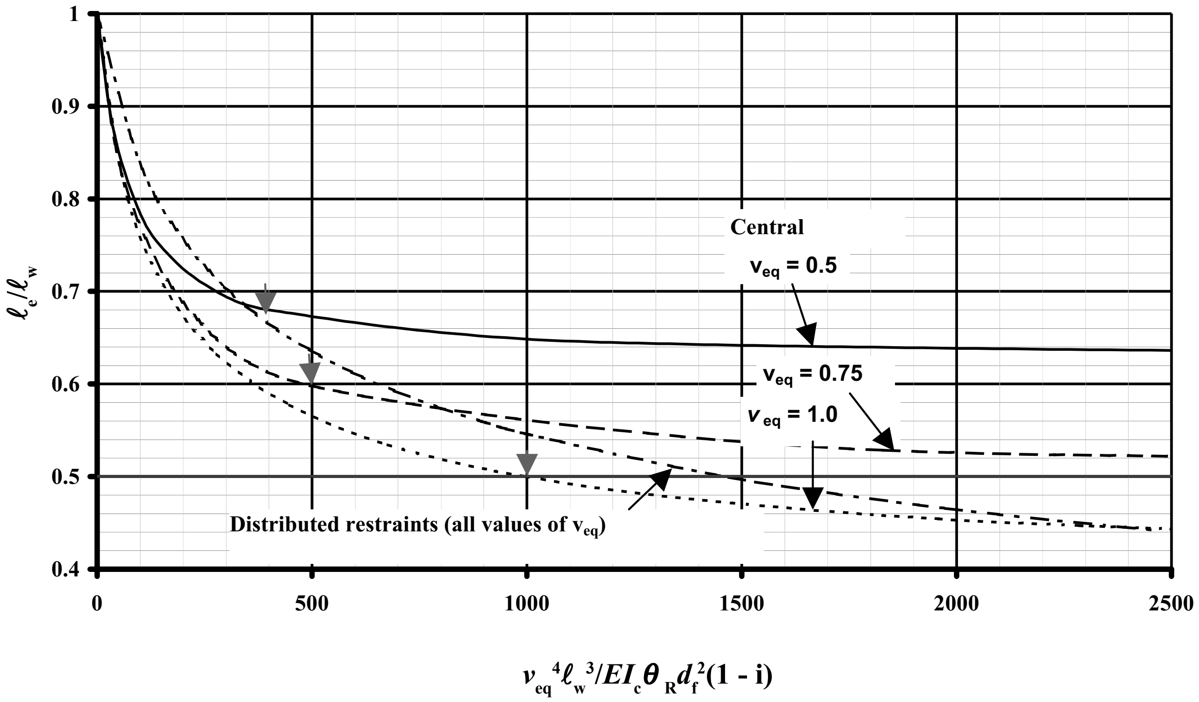
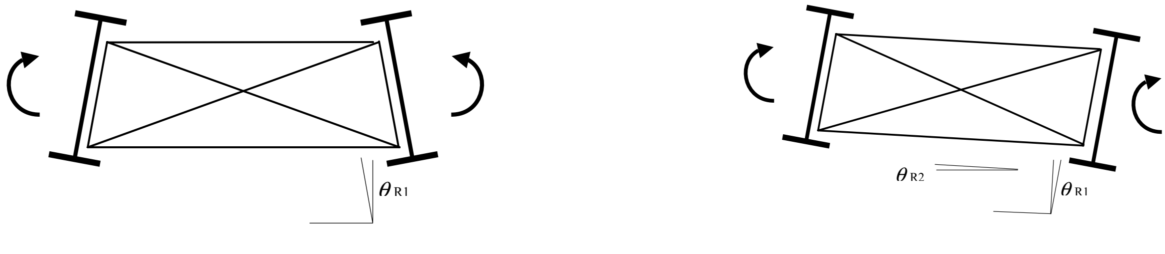



**Figure 8 - Effective length of beams with discrete torsional restraints**

Insert new "Figure 8A"as below:




Unit torques in the opposite sense Unit torques in the same sense

**Figure 8A – Directions of rotations of beams**

**9.7.1 General**

Para, 2, line 1, add "$\ell_w$" after "buckling".

In "b)", delete "and **9.6.4.1.1.2**"

Delete "c)" and replace by the following:

"c) Where intermediate lateral or U-frame restraints are provided which are not fully effective, in accordance with **9.6.4.1.1.2** or **9.6.4.1.3**, $\ell_w$ should be determined by taking $L/\ell_w$ as the next integer below $L/\ell_e$ but not less than unity."

Add "d) For beams with torsional restraints, $\ell_w$ should be taken as defined in **9.6.4.1.2**"

Add "L is the distance between the restraints at the supports of the span of the simply supported or continuous beam under consideration".

**9.7.2 Uniform I, channel, tee or angle sections**

In the definition of "$\lambda_F$" replace "$\ell_e$" by "$\ell_w$"

In "NOTE 2", line 2, replace "long term modulus for concrete" by "short-term or the long-term modular ratio of the concrete as appropriate to the type of loading."

Last paragraph, replace $l_e/r_{yc}$ by $\eta l_e/r_{yc}$.

**Table 9.**

In "NOTE 1", replace "$\ell_e$" by "$\ell_w$"

**9.8 Limiting moment of resistance**

Replace the definition of "$M_{pe}$" by "$M_{pe}$ is equal to $\sigma_{yc} Z_{xcgross}$ for beams restrained in accordance with **9.6.4.1.3** or **9.6.4.2** for which $l_e$ is greater than $l_R$ ,where $Z_{xcgross}$ is the elastic modulus of the effective section with respect to the extreme compression fibres without deduction for any holes in the flanges or webs, or for all other beams is as defined in **9.7.1**."

Replace the definition of "$\ell_w$", by "is the half – wavelength of buckling as defined in **9.7.1**."

Replace the definition of "$L$" by "is as defined in **9.7.1**."

Delete "NOTE……..taken as 1." at the end of the clause.

Replace Figures 11 a) and 11 b) by the following:

**Figure 11 - Limiting moment of resistance $M_R$**
**a) Beams fabricated by welding**

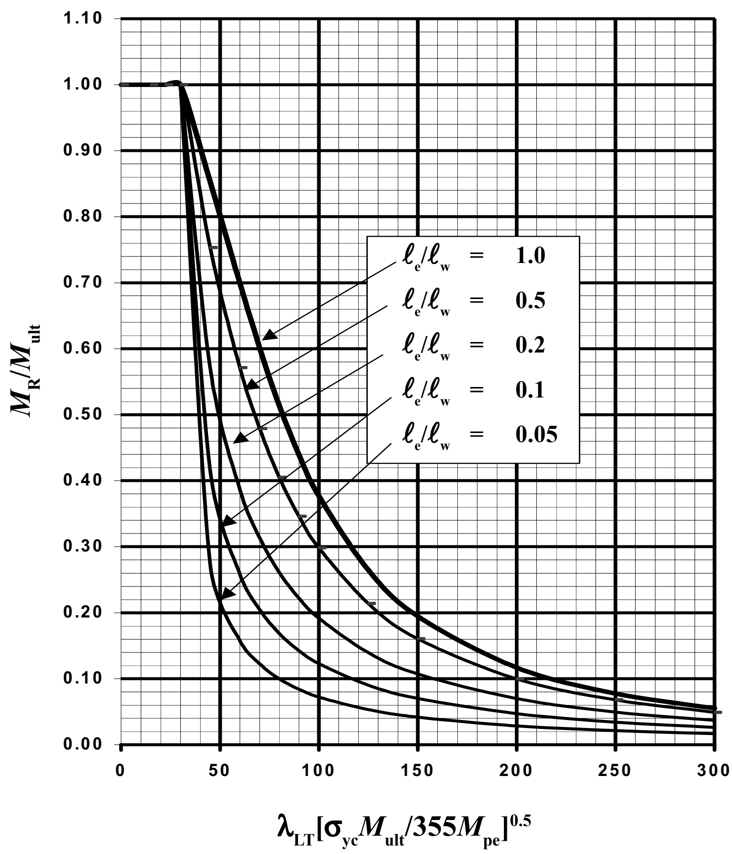
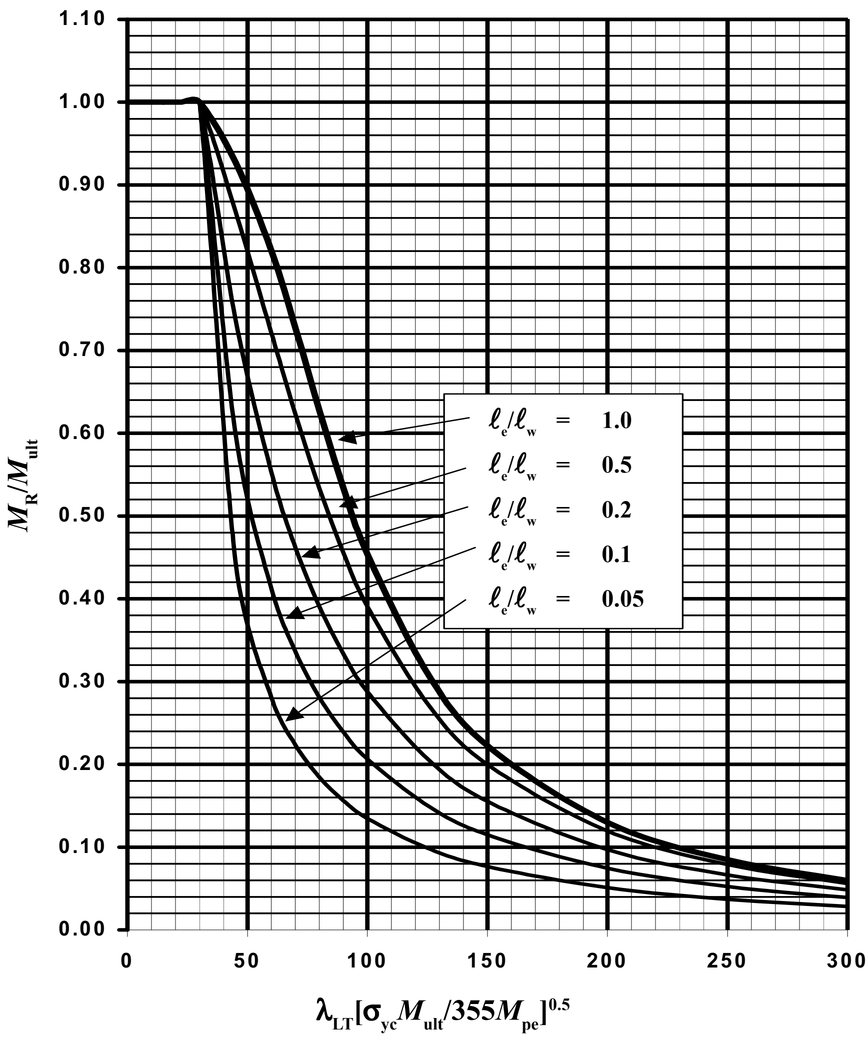


**Figure 11 - Limiting moment of resistance $M_R$**
**b) Beams fabricated by welding**




**9.9.4.2 Buckling of beams**

In the last sentence before “NOTE” delete “also”, after “should”

**9.10.2.3 Strength of longitudinal flange stiffeners**

Replace expressions in “a)” and “b)” with the following:

“a) $\sigma_a + 2.5\tau_1 k_{s2} \leq \frac{k_{\ell 2}\sigma_{ye}}{\gamma_m \gamma_{f3}}$

b) $\sigma_a + 2.5\tau_1 k_{s2} \leq \frac{k_{\ell 2}\sigma_{ye}}{\gamma_m \gamma_{f3}}$

In the definition of “$y_{Bs}$”, add at the end, “taken as positive when the neutral axis of the beam lies in the same direction from the centroid of the stiffener as that to the centroid of the beam cross-section”

**9.11.4 Buckling of web panels**

In “Figure 21 b), delete the column with the heading “w2 for use in D.2”

**9.11.4.3.3 Shear Coefficient $K_q$**

Line 3, delete the expression for “$K_q$” and replace by the following:

“ $K_q = 435000\left(\frac{t_w}{b}\right)^2 \frac{\left[1+(b/a)^2\right]}{\sigma_{yw}}$ ”

**9.11.4.4 Interaction buckling criterion**

Insert "NOTE" as follows at the end of the clause:

"NOTE In evaluating $m_c$ and $m_q$ in **9.11.4.4** when the values of $K_1$ and $K_q$ are limited to 1.0 by the Figures 23(a) and (b) respectively, values greater than 1.0 may be used following the equations given in **9.11.4.3.2** for $K_1$ and **9.11.4.3.3** for $K_q$ for low values of λ."

**9.11.5.2 Strength of longitudinal web stiffeners**

In the definition of "$A_{se}$" replace "action" by "section"

**9.12.2 Elements providing discrete intermediate restraints**

In a), replace Para 2 by the following:

"For a lateral restraint or plan bracing system to be fully effective it should comply with the requirements in **9.6.4.1.1.1**

In b), para 3, replace the expressions after "The forces $F_R$ should be taken as:" by the following:

"1) for lateral restraints

$$F_R = \left(\frac{\sigma_{fc}}{\sigma_{ci} - \sigma_{fc}}\right)\frac{\ell_w}{667\delta_R}$$

but not greater than

$$F_R = \left(\frac{\sigma_{fc}}{\sigma_{ci} - \sigma_{fc}}\right)\frac{(n+1)EI_c}{16.7n\ell_R^2}$$

2) for torsional restraints

$$F_R = \left(\frac{\sigma_{fc}}{\sigma_{ci} - \sigma_{fc}}\right)\frac{\ell_w}{667\delta_{R\theta}}$$

or when $\ell_w > 13.3D$

$$F_R = \left(\frac{\sigma_{fc}}{\sigma_{ci} - \sigma_{fc}}\right)\frac{D}{50\delta_{R\theta}}$$

Modify the existing definitions as follows:

"$\ell_{w,}$ $L$ are as defined in **9.7.1**"

"$\theta_R$, $d_f$, $n$ and $v_{eq}$ are as defined in **9.6.4.1.2**"

In the definition for "$\delta_R$" delete the text "for lateral restraints … torsional restraints"

Insert the new definition:

"$\delta_{R\theta} = n\theta_R D d_f$

where D is the overall depth of the beam"

Insert "NOTE" as follows at the end of the clause:

"NOTE Where torsional restraints are provided by diaphragms between two beams and the half wavelength (as given in **9.7.1**) is the distance between support restraints $L$, the additional vertical forces and bending moments arising from the application of forces $F_R$ may be derived assuming that the equal and opposite transverse forces $F_R$ on each beam are shared between the restraint positions. (That is, there is in total only a single couple (=$F_R \times d_f$) on each beam.)"

**9.13.3.3 Axial force representing the destabilizing influence of the web**

Add the following note at the end of the clause

"NOTE. When *F*wi is to be factored by $\eta_s$, the values *of F*wi and $\eta_s$ should be determined using (1) the value of 'a' defined above and (2) using a value of 'a' that is the sum of the panel widths on each side of the stiffener. The axial force is to be taken as the larger of the two factored values."

**9.13.5.3 Buckling of effective stiffener section**

In the definition of "$P$, $M_{xs}$", 3rd line, replace "fiven" by "given"

**12.6 Lateral bracing**

Last sentence, replace "cords" by "chords"

**14.5.4.4**

Last line, delete "to the satisfaction of the Engineer"

**14.6.1 General**

Line 1, replace "BS 5135:1984" by "BS EN 1011-1 and BS EN 1011-2"

**14.6.3.8 Effective length of fillet welds**

Line 1, replace "BS 5135" by "BS EN 1011-1 and BS EN 1011-2"

**14.6.3.9 Effective throat of a fillet weld**

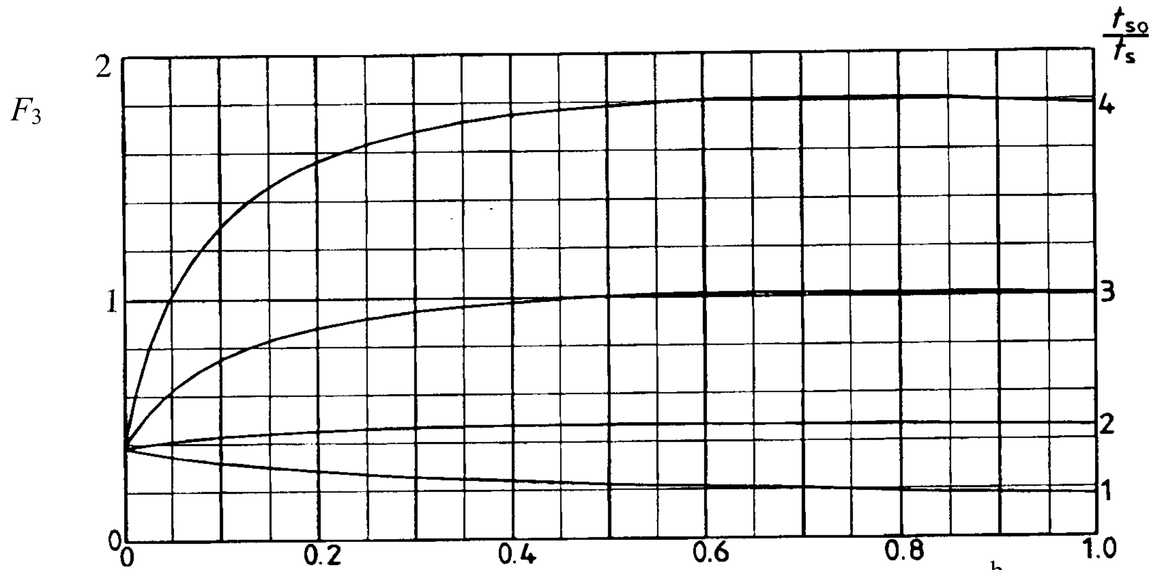
Para 2, line 2, delete "to the satisfaction of the Engineer"

**14.7.2 Other combinations**

Line 3, delete "to the satisfaction of the Engineer"

**Annex C (Informative)**

Replace " Figure C.1 –Coefficients for torsional buckling" by the following:




(c) **Coefficient $F_3$** $\frac{b_s}{d_s}$

NOTE For basis of curves, see G.18.

**Figure C.1 – Coefficients for torsional buckling**

**Annex G**

**G.1 General.**

Add "with the exception of that in G.7" after "equations".

**Annex G.7 Figure 8 – Effective length of beams with discrete torsional restraints**

Replace the entire Annex by the following:

"For beams with distributed torsional restraints

$$\ell_e = \ell_w \left[1 + \frac{\nu_{eq}^4 \ell_w^3}{\pi^4 E I_C d_f^2 \theta_R (1-i)}\right]^{(-0.25)}$$

The relationships in Figure 8 for beams with a single central restraint buckling with a half wavelength L have been derived from the following equation:

$$2\pi^2\left(1-\nu_{eq}^4\right)\left[\frac{\alpha\left(2\mu(nL)^3 Cosh\frac{nL}{2} - (mL)^3 Cos\frac{mL}{2}\right)}{\left(Sin\frac{mL}{2} + 2\mu Sinh\frac{nL}{2}\right)}\right]$$

$$= \frac{\nu_{eq}{}^4 L^3}{\theta_R E I_c d_f{}^2 (1-i)}$$

where

$$mL = \sqrt{-\frac{1}{2\alpha} + \sqrt{\frac{1}{4\alpha^2} + \frac{\pi^2 c^2 (1+\pi^2\alpha)}{\alpha}}}$$

$$nL = \sqrt{\frac{1}{2\alpha} + \sqrt{\frac{1}{4\alpha^2} + \frac{\pi^2 c^2 (1+\pi^2\alpha)}{\alpha}}}$$

$$\alpha = \frac{\nu_{eq}{}^4}{\pi^2(1-\nu_{eq}{}^4)} \text{ for } \nu_{eq} \leq 0.999 \text{ or otherwise} = 25$$

$$\mu = -\frac{mLCos\left(\frac{mL}{2}\right)}{2nLCosh\left(\frac{nL}{2}\right)}$$

$$c = \left(\frac{L}{\ell_e}\right)^2$$

NOTE This may be used directly to derive the restraint stiffness parameter required to achieve a given effective length for buckling with a half wavelength equal to *L*.

The value of the effective length at which the critical buckling moment for a beam with a central restraint and a half-wavelength equal to *L* equals that for buckling in the second mode with a half-wavelength equal to *L*/2 is given by:

$$\frac{\ell_e}{L} = \left[\frac{1+\pi^2\alpha}{4(1+4\pi^2\alpha)}\right]^{0.25}$$

These values are shown by the three vertical arrows on the left hand side of Figure 8 for three values of $v_{eq}$."

**Annex G.8**

Replace the existing heading by the following:

**"G.8. Limiting moment of resistance $M_R$"**

Insert below the heading "Figures 11a) and 11b) - The basis for Figures 11a) and 11b) is as follows:"

Line 1, replace "when $\beta\ell_w/\ell_e > 30$" by " when $\beta > 30$"

Line 2, replace "when $\beta\ell_w/\ell_e \leq 30$" by "when $\beta \leq 30$"

In definition of "$\eta$"

replace "$0.008(\beta\ell_w/\ell_e - 30)$" by "$0.008\ \ell_w/\ell_e\ (\beta - 30)$"

replace "$0.0035(\beta\ell_w/\ell_e - 30)$" by "$0.0035\ \ell_w/\ell_e\ (\beta - 30)$"

**G.12 Figure 23 –Buckling co-efficients $K_1$, $K_2$, $K_q$, $K_b$**

Insert "NOTE" as follows at the end:

"NOTE In using the interaction buckling criterion in **9.11.4.4** the values of $K_1$, $K_q$ may be increased to a value greater than 1.0 using equations in **9.11.4.3.2** and **9.11.4.3.3** respectively."