Corus

Steel bridges – Material matters

Material selection and product specification

Contents

1. Introduction

Steel material is supplied in two product forms – ‘flat products’ (steel plate and strip) and ‘long products’ (rolled sections, either open beams, angles, etc or hollow sections).

Castleford Footbridge

This 131m long, 4m wide footbridge over the River Aire unites the north and south of Castleford’s riverside community. The simple, elegant structure with 'S' shaped curves follows the contours of the existing weir, restoring vitality to the waterfront and creating a new public space for visitors and locals.

Four identical 26m curved spans are joined by three 9m long support spans, two curved and the third straight (at the central point of contra flexure). The continuous structure comprises two 500mm x 400mm box beams fabricated from S355J2 steel to EN 10025-2, one of which increases in depth to 1000mm to provide the additional strength required for each main span.
This extra structure rises above the deck in a gentle curve to create generous benches in a wave-like rhythm over the length of the bridge, minimising structural depth and maintaining the 1 in 100 year estimated floodwater clearance required by the Environment Agency.

The deck is supported on three sets of striking 'V' shaped steel piers, which branch off foundation caps below the water level to minimise visual impact and disruption of river flow. Twinned stainless steel fins cantilever off the main spanning beams, between which bearers for the hardwood timber decking are fixed.
Concealed lighting within the handrails and spotlighting enhance visual impact, enabling the bridge to be the pinnacle of the regeneration that it represents.

Architect – McDowell + Benedetti
Concept Designer – Alan Baxter & Associates LLP
Structural Engineer – Tony Gee and Partners LLP
Steelwork Contractor – Rowecord Engineering Ltd
Main Contractor – Costain Ltd
Client – Wakefield Metropolitan Borough Council

For structural use in bridges these products are inevitably cut (to size and shape) and welded, one component to another. In the structure, the material is subject to tensile and compressive forces. Structural steel generally responds in a linear elastic manner, up to the ‘yield point’ and thereafter has a significant capacity for plastic straining before failure.
All these aspects of steel material are utilised by the designer of a steel bridge.

The selection of an appropriate grade of steel for a bridge requires an awareness of the steel manufacturing process, an appreciation of the relevant product standards and design specifications, and an understanding of several issues including material properties, availability and cost. This brochure is intended to give designers background information and specific guidance on how to select an appropriate steel grade and quality and on how the structural steel products for a bridge are specified in accordance with the Structural Eurocodes.

Left: Castleford Footbridge, River Aire
Cover: White Horse Bridge, Wembley
(Photo courtesy of Marks Barfield Architects)

2. Material properties

Steel derives its material properties from a combination of chemical composition, mechanical working and heat treatment.

2.1 General

The chemical composition is fundamental to the mechanical properties of steel. Adding alloys such as Carbon, Manganese, Niobium and Vanadium can increase the strength. However, such alloy additions increase the cost of the steel, and can adversely affect other properties (i.e. ductility, toughness and weldability). Keeping the Sulphur level low can enhance the ductility, and the toughness can be improved by the addition of Nickel. Hence, the chemical composition for each steel specification has been carefully chosen to achieve the required properties.

Plates and sections are produced by rolling steel slabs, blooms or billets (at a high temperature) until the required plate or section size is achieved. This rolling is the mechanical working that refines the grain structure and determines the mechanical properties. The more steel is rolled, the stronger it becomes. This effect is readily apparent in material standards, which specify reducing levels of minimum yield strength with increasing material thickness. However, although rolling increases the strength, it also reduces the ductility of the steel.

The effect of heat treatment is best explained by reference to the different production processes or rolling regimes that can be used in steel manufacturing, the main ones being:

- As-rolled steel
- Normalized steel
- Normalized-rolled steel
- Thermomechanically rolled (TMR) steel
- Quenched and tempered (QandT) steel

Below: Scunthorpe Plate Mill

Steel cools as it is rolled, and the typical rolling finish temperature is 750ºC, after which the steel cools naturally. Steel produced through this route is termed 'As-rolled'. Structural sections generally achieve the required mechanical properties through this efficient production route, but plates usually require further heat treatment.

Normalizing is the process where an 'As-rolled' plate is heated back up to approximately 900ºC, and held at that temperature for a specific time, before being allowed to cool naturally. This process refines the grain size and improves the mechanical properties, specifically the toughness. It renders the properties more uniform, and removes residual rolling strains.

Normalized-rolled is a process where the rolling finish temperature is above 900ºC, and the steel is allowed to cool naturally. This has a similar effect on the properties as Normalizing, but it eliminates a process. Normalized and Normalized rolled steels are denoted 'N'.

Thermomechanical rolled steel utilises a leaner chemistry, which requires a lower rolling finish temperature of 700ºC to put the strength in, before the steel cools naturally. Note that greater force is required to roll the steel at these lower temperatures, and that the properties are retained unless reheated above 650ºC. Thermomechanical rolled steel is denoted 'M'.

The process for quenched and tempered steel starts with an 'As-rolled' plate, heats it back to 900ºC and holds it at that temperature, as for normalizing, but then the steel is rapidly cooled or 'quenched' to produce steel with high strength and hardness, but low toughness. The toughness is restored by reheating it to 600ºC, maintaining the temperature for a specific time, and then allowing it to cool naturally ('tempering'). Quenched and tempered steels are denoted 'Q'.

Cambridge Riverside Footbridge

This unusual and striking footbridge using 200t of S355J2 steel to EN 10025-2 spans the River Cam and adjacent flood plain. It connects the two communities of Riverside and Chesterton to provide a vital link for cyclists. This iconic design was selected through a public competition in 2004. The bridge and approach ramps are some 200m in length and designed with no sharp turns or steep gradients so it is fully accessible to all.

The geometry of the bridge is particularly complex with a double curved and cantilevered steel deck. The main span over the river is supported by an inclined steel tubular arch, which rises up between separate decks for cyclists and pedestrians.

The main bridge span was fully assembled and site welded in an area on the North Bank of the river. A 1000t capacity crawler crane was then assembled on the site and used to pick up the bridge as a complete unit and place it in position during a short river closure.

Architect – Ramboll Whitbybird
Structural Engineer – Ramboll Whitbybird
Steelwork Contractor – Watson Steel Structures Ltd
Main Contractor – Balfour Beatty Civil Engineering
Client – Cambridgeshire County Council

2.2 Mechanical properties

The mechanical properties of particular importance to the bridge designer include:

- Yield strength
- Ductility
- Toughness

These are described along with the relevant design requirements in Section 3 of this brochure.

2.3 Weldability

All structural steels are essentially weldable. However, welding involves locally heating the steel material, which subsequently cools. The cooling can be quite fast, because the material offers a large 'heat sink' and the weld (and the heat introduced) is relatively small. This can lead to hardening of the 'heat affected zone' and to reduced toughness. The significance of this effect increases as the plate thickness increases.

The susceptibility to embrittlement also depends on the alloying elements, principally, but not exclusively, on the carbon content. This susceptibility can be expressed as the 'Carbon Equivalent Value' (CEV). The CEN product standards (e.g. EN 10025 [1]) give an expression for determining this value, and specify mandatory limits on the maximum CEV. Welding standards (e.g. EN 1011-2 [2]) will indicate what preheat, if any, is needed for a given CEV, material thickness and weld size.

2.4 Corrosion resistance

All structural steels, with the exception of 'weathering steel', have a similar resistance to corrosion. In exposed conditions they need to be protected by a coating system. There are no special requirements of the steel material for ordinary coating systems, including both aluminium and zinc metal spray. However, if the steel is to be galvanized, then there is a need to control the alloy content (notably the Silicon content), this can be achieved simply by specifying that the steel be "suitable for hot dip zinc-coating" (option 5 in EN 10025 [1]). For further information on corrosion resistance issues, refer to the separate 'Corrosion protection' [3] publication in this Corus Steel bridges – Material matters series.

Weathering steel is a high strength low alloy steel that in suitable environments forms an adherent protective rust 'patina', to inhibit further corrosion. The corrosion rate is so low that bridges fabricated from unpainted weathering steel can achieve a 120 year design life with only nominal maintenance. For further information on the use of weathering steel, refer to the separate 'Weathering steel' [4] publication in this Corus Steel bridges – Material matters series.

Far left: Welder
Left: Painter
Above: A66 Surtees Bridge, Stockton
Below: Westgate Bridge, Gloucester

A66 Surtees Bridge Replacement

The old 5-span bridge carrying the A66 dual carriageway over the River Tees at Stockton was assessed in 2004 and found wanting in several areas. It was not strong enough to take the latest 40t trucks, nor wide enough to accommodate additional traffic from a new link road, and the substructures were deteriorating. Hence, in 2006, construction started on a replacement bridge.

The new 145m long three-span bridge has a steel composite deck with nine parallel haunched plate girders fabricated from S355J2 steel to EN 10025-2 and a total steel weight of 1936t. It was built in two phases to keep traffic on the A66 moving, with four girders being erected in phase one to replace the southern half of the old bridge, and five girders in phase two to replace the northern half. The bridge was opened to traffic in December 2007.

The 145m long main girders were erected in three sections. 57m long end span and cantilever girders were fabricated at Cleveland Bridge's facility at Darlington, then assembled into braced pairs and fitted with Omnia planks for the concrete slab. Transportation of these 7.6m wide sections the 20km to the bridge site was carried out at night to minimize traffic disruption. Once at the site, the 163.2t sections were erected from each bank, and the middle sections lowered in to complete the bridge using a 1200t capacity crane.

Structural Engineer – A-one Integrated Highway Services
Steelwork Contractor – Cleveland Bridge UK Ltd
Main Contractor – Edmund Nuttall Ltd
Client – Highways Agency

3. Design requirements

EN 1993-2 [5], Section 3, *Materials* describes the requirements for structural steel for bridgeworks, and contains the following clauses:

3.1 General
3.2 Structural steel
- **3.2.1** Material properties
- **3.2.2** Ductility requirements
- **3.2.3** Fracture toughness
- **3.2.4** Through thickness properties
- **3.2.5** Tolerances
- **3.2.6** Design values of material coefficients

EN 1993-2 [5] makes the assumption that execution, which includes supply of products as components of the structure, is carried out in accordance with EN1090-2 [6]. Guidance on matters related to specification of steel products is given in Section 5 of this brochure.

3.1 General
All new structural steel for use in bridges should be manufactured to a CEN European Standard (EN). These product standards are issued in the UK by BSI, with a short National Foreword (that occasionally makes minor modifications to the Standard), and consequently bear the BS EN designation before the reference number. The following CEN product standards are relevant to bridge steelwork:

EN 10025 [1] (For plates and open sections)
- Part 2 - Non alloy structural steels
- Part 3 - Fine grain structural steels (Normalized / Normalized rolled)
- Part 4 - Fine grain structural steels (Thermomechanical rolled)
- Part 5 - Weathering steels
- Part 6 - Quenched and tempered steels

EN 10210-1 [7] (For hot rolled structural hollow sections)
EN 10219-1 [8] (For cold formed structural hollow sections)

In the CEN designation system for steel material all structural steels have the prefix “S”. This letter is followed by a three digit reference that corresponds to the yield strength (in N/mm^2) and by various other letters and numerals that indicate other properties or process routes. A summary of the hot rolled steel grades available in these standards, up to a yield strength of 460 N/mm^2, is given in the Appendix, see Table A1.

3.2 Structural steel
3.2.1 Material properties
The yield strength is probably the most significant property that the designer will need to use or specify. The achievement of a suitable strength whilst maintaining other properties has been the driving force behind the development of modern steel making and rolling processes.

In the CEN product standards, the primary designation relates to the yield strength, e.g. S355 steel is a structural steel with a minimum yield strength (R_{eH}) of 355 N/mm^2. The number quoted in the designation is the value of yield strength for material up to 16 mm thick. Designers should note that yield strength reduces with increasing plate or section thickness.

An example for common steels to EN 10025 [1] is given in the table below.

In the UK, the nominal values of the yield strength (f_y) for structural steel, and hence the characteristic values used in design calculations, are obtained by adopting the minimum yield strength (R_{eH}) values direct from these product standards.

S275 steel is often used on railway bridges, where stiffness rather than strength governs the design, or where fatigue is the critical design case. S355 steel is predominantly used in highway bridge applications, as it is readily available, and generally gives the optimum balance between stiffness and strength.

Yield strengths for common steels to EN 10025 [1]

Steel Grade	Minimum yield strength (N/mm^2), Nominal thickness in mm					
	≤ 16	> 16 ≤ 40	> 40 ≤ 63	> 63 ≤ 80	> 80 ≤ 100	> 100 ≤ 150
S275	275	265	255	245	235	225
S355	355	345	335	325	315	295
S420	420	400	390	370	360	340
S460	460	440	430	410	400	380

Above: A1 Appleyhead – Typical highway bridge with S355 steel

S420 and S460 steels can offer advantages where self-weight is critical or the designer needs to minimise plate thicknesses. However, the use of such steels confers no benefits in applications where fatigue, stiffness or the instability of very slender members is the overriding design consideration. These steels are also less readily available in the UK for plate thicknesses exceeding 50mm.

Yield strengths above 460 N/mm^2 are available to EN 10025-6 [1], and additional design requirements for these higher strength steels are contained in EN 1993-1-12 [9]. The associated UK National Annex (NA) [10] specifies a minimum f_u / f_y ratio of 1.10 rather than the recommended value of 1.05 for these steels. However, this more onerous requirement is of limited relevance, because f_u and f_y are the specified ultimate tensile and yield strengths respectively, and steels to EN 10025-6 [1] meet this more onerous limit.

3.2.2 Ductility requirements

Ductility is of paramount importance to all steels in structural applications. It is a measure of the degree to which the material can strain or elongate between the onset of yield and eventual fracture under tensile loading. Whether it is realised or not, the designer relies on ductility for a number of aspects of design: redistribution of stress at the ultimate limit state; bolt group design; reduced risk of fatigue crack propagation; and in the fabrication processes of welding, bending, and straightening, etc.

Ductility tends to reduce with increasing yield strength. Fortunately, this effect is not significant enough to affect the design of the majority of bridges. Ductility of a steel plate or rolled section is measured in relation to behaviour either in plane (parallel to or transverse to the direction of rolling) or perpendicular to the plane of the element.

In-plane ductility

The requirements for in-plane ductility of steel used in bridges in the UK are as follows:

- Ratio of the ultimate tensile strength to the yield strength (f_u / f_y) ≥ 1.10
- Elongation at failure based on a standard proportional gauge length ≥ 15%
- The ratio of the ultimate strain to the yield strain (ε_u / ε_y) ≥ 15

All steel conforming to the CEN product standards mentioned in Section 3.1 meets these requirements, so no additional specification is needed for in-plane ductility.

Through-thickness ductility

The properties of steel perpendicular to the plane of the element (often termed through-thickness) are different from those in plane. This is particularly true for ductility, which is generally lower in the direction perpendicular to the plane of rolling. Refer to Section 3.2.4 for further details.

Canning Town Flyover

Canning Town Flyover is a 330m long, 16-span viaduct carrying two tracks of the Docklands Light Railway (DLR) in East London. It provides grade separation of Canning Town Junction, connecting in the new extension to Stratford International, and improving journey times from Beckton / King George V to Bank / Tower Gateway.

The main span comprises a half through plate girder deck, 52m long, 12m wide with a skew angle of 46 degrees, fabricated from S355J2 and S355K2 steel to EN 10025-2. The main girder depth varies from 2.6m at the supports to over 4.5m at midspan. A trial erection of the two main girders and transverse beams was carried out at Rowecord's Newport works prior to site erection, which was completed within a single 50 hour rail possession using a 600t capacity crawler crane.

An unusual feature of this deck is the structural continuity with the adjacent precast beam spans, which was needed to avoid a highly skewed movement joint under the tracks. Such a joint would have resulted in unacceptable displacements of the permanent way under live loading. Continuity was achieved by connecting the two main steel girders to a substantial concrete diaphragm using post-tensioned bars. The precast beams of the adjacent deck are also cast into the diaphragm, and bearings between the diaphragm and substructure provide the required articulation.

Structural Engineer – Arup
Steelwork Contractor – Rowecord Engineering Ltd
Main Contractor – Taylor Woodrow Construction
Client – Docklands Light Railway

3.2.3 Fracture toughness

The nature of steel material is that it always contains some imperfections, albeit of very small size. When subject to tensile stress these imperfections (similar to very small cracks) tend to open. If the steel is insufficiently tough, the ‘crack’ propagates rapidly, without plastic deformation, and failure may result. This is called ‘brittle fracture’, and is of particular concern because of the sudden nature of failure. The toughness of the steel, and its ability to resist this behaviour, decreases as the temperature decreases. In addition, the toughness required, at any given temperature, increases with the thickness of the material.

A convenient measure of toughness is the Charpy V-notch impact test (hence the term “notch toughness” has been widely used in the past). This test measures the impact energy (in Joules) required to break a small, notched specimen by a single impact blow from a pendulum. The tests are carried out with the specimens at specified (low) temperatures, and the CEN product standards specify the required minimum impact energy values for different grades. Refer to Table A1 in the Appendix.

In the CEN product standards there is no universal designation system for the fracture toughness. In standards EN 10025: Parts 2 and 5 [1], EN 10210-1 [7] and EN 10219-1 [8] there is a two character alphanumeric code; there are three different codes that are relevant for bridges in the UK:

J0: 27J impact energy at 0°C
J2: 27J impact energy at -20°C
K2: 40J impact energy at -20°C

Steels to EN 10025: Parts 3 and 4 [1] and fine grain steels to EN 10210-1 [7] and EN 10219-1 [8] may be one of two categories of impact strength, the lower-temperature one being designated by the code ‘L’.

: 40J impact energy at -20°C
L: 27J impact energy at -50°C

Steels to EN 10025: Part 6 [1] (QandT steels) may be one of three grades of toughness; the lower-temperature two grades being designated by the codes L and L1.

: 30J impact energy at -20°C
L: 30J impact energy at -40°C
L1: 30J impact energy at -60°C

The requirements for fracture toughness are described in EN 1993-1-10 [11] and its associated UK NA [12]. The procedure requires the calculation of a reference temperature (T_{Ed}), which is then used to determine a maximum permitted thickness for the steel part from a set of tabulated values. The end result depends on the following:

- Steel material properties (yield strength and toughness)
- Member characteristics (shape, detail and stress concentrations etc)
- Design situation (steel temperature, stress and degree of cold forming)

The ‘accidental combination’ of actions to be considered for this design case is described in EN 1993-1-10 [11] and the design effects are expressed in equation 2.1 as:

$$E_d = E \{ A[T_{Ed}] + \sum G_K + \Psi_1 Q_{K1} + \sum \Psi_{2,i} Q_{Ki} \}$$

The effect of the reference temperature is not a stress but the susceptibility to brittle fracture. The effect of the other actions is the stress in the component being considered. In this combination, the reference temperature is considered the ‘leading action’ and the main accompanying action (Q_{K1}) is taken at its frequent value. The other accompanying actions are taken at their quasi-permanent values (which in most cases are zero). No partial factors are applied, since this is an accidental design situation (see EN 1990 [13], clause 6.4.3.3.)

Below: Charpy V-notch impact test piece

Calculation of the reference temperature (T_{Ed})
$T_{Ed} = T_{md} + \Delta T_r + \Delta T_\sigma + \Delta T_R + \Delta T_{\dot{\varepsilon}} + \Delta T_{\varepsilon cf}$

($T_{md} + T_r$) considered together represent the minimum effective temperature of the steel part, and should be determined according to EN 1991-1-5 [14] and its associated UK NA [15].

ΔT_σ is an adjustment for the relative level of stress, and should be taken as 0°C, as the UK NA [12] accounts for this in the determination of ΔT_R.

ΔT_R is a safety allowance, which is determined in accordance with the UK NA [12] as follows:

$\Delta T_R = \Delta T_{RD} + \Delta T_{Rg} + \Delta T_{RT} + \Delta T_{R\sigma} + \Delta T_{Rs}$

ΔT_{RD} is an adjustment for the detail type (UK NA 2.1.1.2)
ΔT_{Rg} is an adjustment for gross stress concentrations. (UK NA 2.1.1.3)
ΔT_{RT} is an adjustment for the Charpy test temperature. (UK NA 2.1.1.4)
$\Delta T_{R\sigma}$ is an adjustment for the applied stress level. (UK NA 2.1.1.5)
ΔT_{Rs} is an adjustment for the strength grade. (UK NA 2.1.1.6)

$\Delta T_{\dot{\varepsilon}}$ is an adjustment for high strain rates that would occur if, say, a vehicle struck the bridge. However, the coexistence of two accidental actions (i.e. min. temperature and vehicle impact load) is contrary to the combination of actions specified by EN 1993-1-10 [11] for the determination of fracture toughness. Hence, $\Delta T_{\dot{\varepsilon}}$ should generally be taken as 0°C.

However, there is an argument for applying $\Delta T_{\dot{\varepsilon}}$ for parts particularly prone to risk of accidental impact forces (e.g. edge girders on decks with substandard headroom, i.e. less than 5.3m)

$\Delta T_{\varepsilon cf}$ is an adjustment to allow for the degree of cold forming. This is significant, as typical inside bend radii for cold formed sections are 2x thickness, which results in a strain of 20% and a temperature shift $\Delta T_{\varepsilon cf}$ of -60°C. This could rule out the use of a cold-formed section.

Determination of the maximum permitted thickness
Once the reference temperature has been determined, the next step is to refer to Table 2.1 of EN 1993-1-10 [11] to determine the maximum permitted thickness for the particular steel grade. Relevant parts of Table 2.1, and the extension to lower reference temperatures given in Table 1 of PD 6695-1-10 [16], are combined in Table A2 of the Appendix to these notes.

A simplified procedure is given in Table 4 of PD 6695-1-10 [16]. This assumes a minimum air temperature of -20ºC, which is expected to cover most bridge locations in the UK, and ignores the radiation loss (ΔT_r) which is conservative for steel composite decks.

However, use of this simplified procedure on the example opposite would have resulted in a requirement for the steel subgrade to be K2 rather than J2.

Lagentium Viaduct

This three-span viaduct carries the new A1(M) dual three-lane motorway over the River Aire to the east of Castleford (Roman name - Lagentium), and forms part of the A1 upgrade between Darrington and Dishforth.

The deck comprises eight plate girders fabricated from S355J2 steel to EN 10025-2 with a central span of 85m, and side spans of 35m. Elliptical columns provide the intermediate supports, at which point the girders are haunched up to 4.5 m deep.

The girders were assembled into braced pairs adjacent to the site, moved up to the erection crane by SPMT (self propelled modular trailer), and then lifted into position by a 1200t capacity AK680 strut jib crane positioned behind each abutment.

The 2009t of steelwork was erected during the summer of 2004, the viaduct was completed in October 2005 and the new A1(M) opened to traffic in January 2006.

Structural Engineer – Parkman
Steelwork Contractor – Fairfield-Mabey Ltd.
Main Contractor – RMG (A1) Construction Joint Venture
DBFO Company – Road Management services (Darrington) Ltd.
Client – Highways Agency

Example calculations

Consider a typical multi-girder steel composite bridge deck outside the Corus steelworks in Scunthorpe, and assume it has 100mm surfacing.

Minimum shade air temperature	(UK NA - Figure NA.1)	-14°C
Adjustment for height above sea level	(EN 1991-1-5, A.1, note 2)	0°C
Conversion for 120-year return period	(EN 1991-1-5, Figure A.1)	x1.14

Hence, T_{min} = 1.14 x (-14°C - 0°C) = -16°C

Minimum effective bridge temperature of the steel part,
For a Type 2 deck, and T_{min} = -16°C, from Figure 6.1 (EN 1991-1-5), $T_{e, min}$ = -12°C
Hence, ($T_{md} + \Delta T_r$) = -12°C

$\Delta T_R = \Delta T_{RD} + \Delta T_{Rg} + \Delta T_{RT} + \Delta T_{R\sigma} + \Delta T_{Rs}$
The welded details on the bottom flange of a typical fabricated plate girder include web / flange, the attachment of transverse web stiffeners, and (pre-assembly) transverse butt welds. However, none of these are 'severe' details described in Table NA.1.
Hence, ΔT_{RD} = 0°C
A well-detailed typical plate girder is unlikely to have any stress concentrations.
Hence, ΔT_{Rg} = 0°C
The adjustment for the Charpy test temperature applies only to buildings, as the use of steel at temperatures more than 20°C below the test temperature is not permitted for bridges.
Hence, ΔT_{RT} = 0°C
Conservatively assume that the bottom flange stress is $0.75f_y(t)$.
Hence, $\Delta T_{R\sigma}$ = 0°C
Assume that the steel grade is S355.
Hence, ΔT_{Rs} = 0°C
Consequently, ΔT_R = 0°C

$T_{Ed} = (T_{md} + \Delta T_r) + \Delta T_\sigma + \Delta T_R + \Delta T_{\dot{\varepsilon}} + \Delta T_{\varepsilon cf}$
Assuming that the deck complies with the minimum headroom criteria of 5.3m (i.e. $\Delta T_{\dot{\varepsilon}}$ = 0°C), that there is no cold bending of the bottom flange (i.e. $\Delta T_{\varepsilon cf}$ = 0°C), and remembering that ΔT_σ = 0°C.
Then, T_{Ed} = -12°C

The design calculations resulted in a requirement for a 55m thick bottom flange in grade S355 steel. So, for T_{Ed} = -12°C, and with reference to Table A2, the maximum permitted thicknesses are: J0 = 39mm, J2 = 58mm, and K2 = 72mm.
Hence, the required steel subgrade is J2.

3.2.4 Through thickness properties

Background

As mentioned previously, the properties of steel perpendicular to the plane of the element (often termed through-thickness) are different from those in plane.

The nature of the production process is such that any inclusions or discontinuities in the steel are essentially 'rolled-out' to be planar in extent and parallel to the surface of the plate. The result is that the mechanical properties in the through thickness direction are more susceptible to the influence of such inclusions or discontinuities.

There are two types of imperfection that affect through thickness behaviour:

- macro imperfections - thin layers of inclusions or discontinuities, extending over an area
- micro imperfections - numerous very small inclusions or discontinuities.

Macro imperfections are termed 'laminations' or 'laminar defects'. The presence and extent of such defects can be checked by ultrasonic testing, and acceptance levels are given in EN 10160 [17].

Micro imperfections are significant when the material is subject to through thickness stress, because they can lead to 'lamellar tearing' as a tear propagates from one inclusion to the next. The inclusions are small, so they cannot readily be revealed by ultrasonic testing. However, their effect may be assessed by carrying out through thickness tensile tests in accordance with EN 10164 [18].

These tensile tests are used to establish the through thickness ductility of the steel, and categorise it into one of three levels (Z15, Z25 or Z35). The letter 'Z' merely indicates the direction of the tensile test, i.e. perpendicular to the 'x-y' plane of the plate. The numerical value indicates the minimum percentage reduction of area at failure of the small test specimens of plate material. High ductility is indicated by a high percentage (e.g. Z35 corresponds to a 35% average reduction in area at failure).

The need for Z-grade steel
Improvements in steel manufacturing over the years mean that steel from modern mills is much cleaner, and less likely to contain significant levels of micro imperfections than in the past. The through thickness ductility of such steels is sufficient for most applications, and is typically equivalent to Z15 or Z25 material. Hence, there should be very little need to specify Z-grade steel in typical well-designed bridge steelwork.

Z-grade steel might be required where high loads are transmitted through T-section or cruciform details, and where large welds are specified on elements that are restrained against shrinkage. Refer to Guidance Note 3.02 [19] for detailed advice on situations where Z-grade steel is needed to minimise the risk of 'lamellar tearing'.

However, the requirements for Z-grade steel are usually very local in nature, and as such only small quantities will be needed. Additionally, Z-grade steel is more expensive and less readily available than conventional structural steel. Consequently, it is better to design details that do not require the use of steel with improved through thickness properties, if possible.

Nevertheless, if Z-grade steel is needed, it should be specified as 'option' (4) in EN 10025 [1] in terms of one of the three 'levels' (Z15, Z25 or Z35) of through thickness ductility according to EN 10164 [18].

River Eden Bridge, Temple Sowerby Bypass

This three-span multi-girder steel composite bridge carries the A66 Temple Sowerby Bypass over the River Eden and flood plain with a main span of 64m, and side spans of 34m. Weathering steel was specified for this low-lying bridge to help it blend into the rural surroundings, and to minimise future maintenance requirements.

The deck comprises four main girders, fabricated from S355J2W steel to EN 10025-5, that are haunched up to 3.3 m deep at the intermediate piers. In total, 1351t of steelwork was erected using a TC3200 strut jib crane in autumn 2006. The west span and pier girders were assembled into 'span and cantilever' lengths adjacent to the site, moved up to the erection crane by SPMT (self propelled modular trailer) and then lifted into position.

The 800t capacity mobile crane then moved to the East side of the bridge where the span girders were erected onto temporary trestles. The east pier girders were then lifted into position to form 'span and cantilever' lengths. Finally, the 36m long central span girders, each weighing 62t, were lowered into position at a radius of 58m.

Structural Engineer – Scott Wilson
Steelwork Contractor – Fairfield-Mabey Ltd
Main Contractor – Skanska Construction (UK) Ltd
Client – Highways Agency

Which Z-grade to specify?
EN 1993-1-10 [11] contains a numerical method for determining the required Z-grade according to the weld size, detail type and level of restraint. However, the UK NA [12] indicates that this need not be used. The view of the UK experts is that this numerical method is unduly conservative, requires extensive calculations, and would lead to the unnecessary specification of Z-grade material. Instead, the UK NA refers designers to a BSI document, PD 6695-1-10 [16], which gives:

- Options for the fabricator. The risk of 'lamellar tearing' can be mitigated by following certain fabrication control measures such as procuring material from a modern mill known to produce clean steel.

- Options for the designer. The PD says that Z-grade material need not be specified for low and medium risk situations. It recommends that designers should specify Z35 quality to BS EN 10164 [18], only for high risk situations and defines such high risk situations as:

  - T (tee) joints, $t_z > 35$mm
  - X (cruciform) joints, $t_z > 25$mm
  - L (corner) joints, $t_z > 20$mm

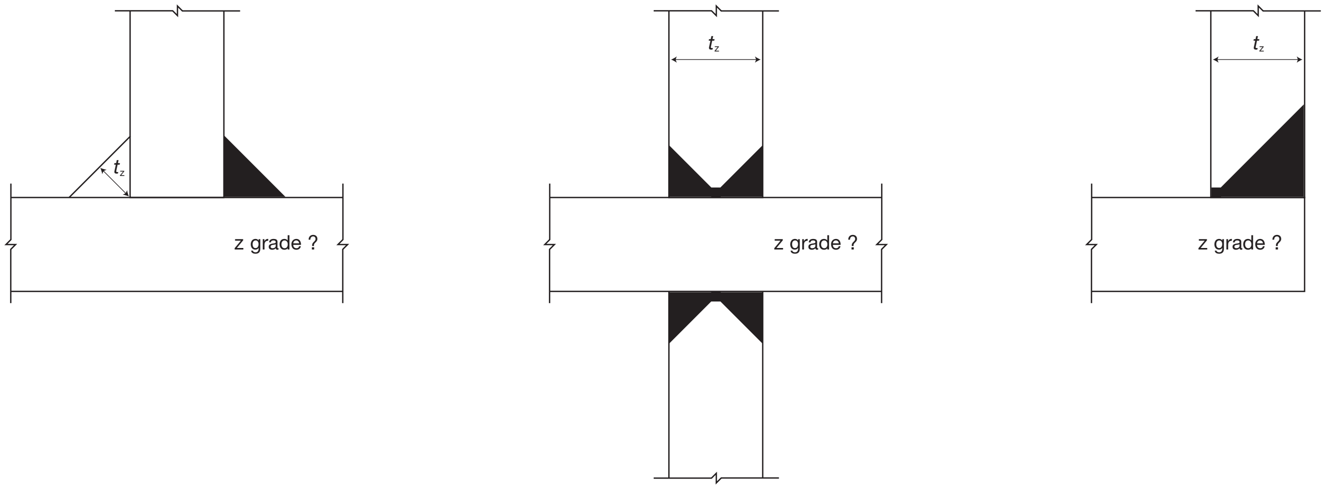
Where t_z is the thickness of the incoming plate for butt welds and deep penetration fillet welds, and for fillet welded joints, t_z is the throat size of the largest fillet weld.

3.2.5 Tolerances
This clause in EN 1993-2 [5] merely states that rolled steel products should conform to the tolerances in the relevant product standard and that for fabricated components the tolerances in EN 1090-2 [6] should apply.

3.2.6 Design values of material coefficients
The material coefficients to be used in the design calculations for steel bridges are:

- Modulus of elasticity, $E = 210{,}000$ N/mm^2
- Shear modulus, $G = 80{,}000$ N/mm^2
- Poisson's ratio in elastic stage, $\upsilon = 0.3$
- Coefficient of linear thermal expansion = 12 x 10^{-6}/°C

However, for calculating the structural effects of temperature difference (vertical and horizontal temperature gradients in the cross section) in steel-concrete composite bridge decks to EN 1994-2 [20], the coefficient of linear thermal expansion should be taken as 10 x 10^{-6}/°C.



Above: Definition of t_z

Hunslett Moor Footbridge

This striking cable-stayed footbridge on the M621 Leeds Inner Ring Road project comprises a 103m long x 5m wide deck supported from a single A-frame tower by 14no. 65mm diameter spiral wound cables supplied by Bridon. A further 150m of approach ramps and stairs provide access to the East end of the bridge. The handrail was a specific architectural feature of the bridge, and included a top rail formed from a Corus Oval section 150 x 75 x 4mm. This produced a clean aesthetic detail that complemented the modern design of this footbridge.

A total of 259t of steel was used on this structure, including steel plates up to 60mm thick and 457mm diameter CHS tubes for the stringers on the main deck. The steel specified for the plates included both S275J2 and S355J2 grades to EN 10025-2, and S355J2H to EN 10210 was specified for the hollow sections.

The steelwork was fabricated during the latter part of 2007, ready for installation early in 2008. The bridge was erected during a series of night time road closures that coordinated with the intricate phasing of the road improvement works underneath. The largest individual component to be erected was the A-frame tower at just over 39m tall, and this was lifted into place using a 200t capacity mobile crane.

Structural Engineer – Mouchel Parkman
Steelwork Contractor – Nusteel Structures Ltd.
Main Contractor – Alfred McAlpine
Client – Leeds City Council

4. Availability and cost of structural steel

The general availability of structural steel for bridgeworks from Corus is outlined in the following product brochures, all of which can be ordered via our literature hotline (01724-404400):

- Plate products, range of sizes [21]
- Advance® sections [22]
- Celsius® 355 technical guide [23]

N.B. Celsius® structural hollow sections are only available as S355J2H to EN 10210 [7].

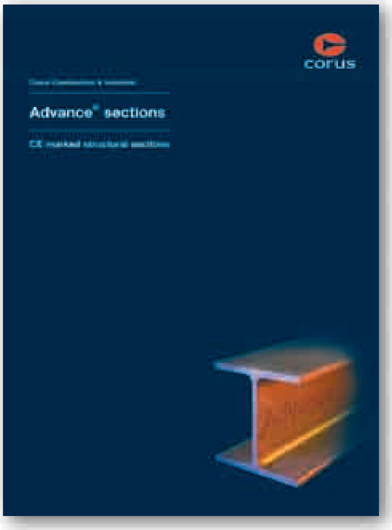
4.1 Availability of plates

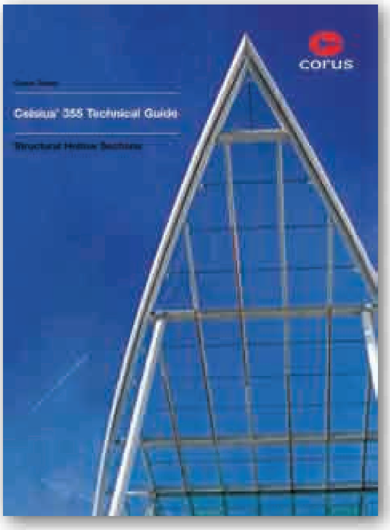
Plates may be obtained either direct from the mill, or through a steel stockholder.

The advantage of obtaining plates direct from the mill is that they are rolled to order, specifically to a chosen size, which minimises waste and maximises design efficiency, as any intermediate thickness is available. Web and flange plates are generally procured through this route, so maximum efficiency is achieved by specifying the actual thickness required according to the design calculations. Rounding up to the nearest 5mm is not advisable as it merely increases the cost of the steelwork.

Steel from a stockholder is more suited to small quantities, and will reduce lead times. However, it will be more expensive, and the size and quality required may not be readily available. It is important to trace the source of the steel and obtain the appropriate mill certificates. Typical stock sizes are illustrated below, and thicknesses are generally in 5mm increments. Plates for stiffeners are typically procured from stockholders, so the thickness of stiffeners should be rounded up to the nearest 5mm.

Stock Sizes (mm)		
4000 x 2000	5000 x 2500	6000 x 2000
6000 x 3000	8000 x 2000	9000 x 3000
10000 x 2500	12000 x 2500	





Above: Brochures

Plates direct from Corus are available in a wide range of sizes and material grades, and although the brochure mentioned previously gives general guidance, there are some specific points that need to be highlighted:

1. Plates are available in any intermediate thickness.
2. The maximum weight of an individual plate through the 'concast' route is 14.5t.
3. The maximum plate thickness through the 'concast' route is 150mm.

The 'concast route' is a process that produces steel slab (for subsequent rolling into plate) by continuous casting. The size of the slab produced in this way is limited. The alternative 'ingot route' is able to produce larger slabs and thus larger plates than the limiting sizes mentioned above. However, the ingot route is very rarely used now for structural steels, and would carry a very heavy cost premium.

The steel grades and thickness range table below illustrates the available thicknesses (mm), and process routes for a range of typical grades used in bridgeworks.

The current lead time (at November 2009) for plates direct from the mill is typically 6-9 weeks.

The maximum plate length depends on the process route, and which mill is used. For example, the maximum Normalized length is 17m at the Scunthorpe Plate Mill (SPM) and 19m at the Dalzell Plate Mill (DPM), due to constraints on the furnace lengths. The maximum length for Normalized Rolled is 18.3m on the Light Shear Line at SPM, and the corresponding limit at DPM is less. However, Corus can accommodate up to 31m single plate lengths (width and gauge dependant) on the Heavy Shear Line at SPM, but there are movement/transport issues with such lengths and only a limited number of orders can be taken.

Steel Grades and Thickness Range (mm)

Standard EN 10025	Grade	Normalized	Normalized Rolled	T.M.R	Q and T	CE Mark Limits
Part 2	S275J0	6-150	6-60			125
	S275J2	6-150	6-50			125
	S355J0	6-150	7-60			125
	S355J2	6-150	7-60			125
	S355K2	6-150	7-50			125
Part 3	S275N	6-150	6-50			100
	S275NL	6-100				100
	S355N	6-150	6-50			100
	S355NL	6-125				100
	S420N	6-30	6-30			60
	S420NL	6-30				60
	S460N	20-50				60
	S460NL					60
Part 4	S355M			10-50		50
	S355ML			10-50		50
	S420M			10-50		50
	S420ML			10-50		50
	S460M			10-50		50
	S460ML			10-50		50
Part 5	S355J0W	6-100	10-65			125
	S355J2W	6-100	10-65			125
	S355K2W	6-100	10-65			125
Part 6	S460Q				8-80	100
	S460QL				8-80	100

East Coast Mainline Bridge for High Speed 1

This 1577t through truss girder bridge has a clear span of 75m and carries the new twin track High Speed 1 over the busy East Coast Mainline approximately 1km north of Kings Cross station.

In order to minimise construction risk and the need for very costly rail possessions, required for the installation of the intermediate supports between tracks, a cost effective single span structure was chosen. The bridge is clad primarily to reduce the impact of noise on local residents, but this also enhances the aesthetics of the bridge. The cladding is an external 'cassette' type system for ease of replacement and has an internal fire and acoustic lining. Weathering steel was used for the steelwork below the composite slab, as access for future maintenance will be difficult.

The main steel grades used are listed below. There was also a requirement for some of the weathering steel to have guaranteed through thickness ductility, i.e. Z35 to EN 10164.

- S355J2 to EN 10025-2 for plates up to 65mm thick.
- S355J2W to EN 10025-5 for plates up to 65mm thick.
- S355NL to EN 10025-3 for plates 80mm thick and over.

The structure was assembled online adjacent to its final position using a combination of site welding and bolted joints, and then launched across the busy East Coast Mainline during a 72-hour possession at Christmas 2003, to minimize disruption to rail users.

Architect – Rail Link Engineering
Structural Engineer – Rail Link Engineering
Steelwork Contractor – Watson Steel Structures
Main Contractor – Kier Nuttall JV
Client – Union Railways

4.2 The cost of steelwork

The cost of fabricated and erected steelwork in terms of £/tonne is highly variable, and dependent on a number of factors including the state of the market, grade of steel, degree of fabrication, site location, corrosion protection system and access for erection. Hence, for cost comparisons at critical stages in a project's development it is suggested that designers contact a major steelwork contractor, most of whom would be pleased to advise on budget estimates.

In terms of the cost of the steel itself, the pricing structure is surprisingly complex. The following is a simplification (at November 2009), but should give a reasonable 'feel' for the relative costs of different grades:

Steel Grade Costs

Steel	Cost per t
Standard S355J2 Bridge Steel	£500/t
Additions:	
Weathering steel	+£60/t
Z35 Grade	+£50/t
NL Grade	+£50/t
Thick plates (50mm - 100mm)	+£20 - £60/t
Thin plates (12mm - 8mm)	+£10 - £30/t

5. Product specification

5.1 General
The execution standard for steel bridges designed to the Eurocodes is EN 1090-2 [6]. It includes requirements related to the supply of products and refers to the appropriate product standards for their specification. EN 1090-2 [6] has numerous provisions where additional requirements or decisions on optional requirements may be specified; some of these relate to the steel products. Different projects will almost certainly have different execution specifications, but the use of the Steel Bridge Group's Model Project Specification (SCI publication P382 [24]) is recommended to ensure consistency across the industry. The MPS [24] reflects best practice guidance.

The following sections describe the key requirements relating to steel products that are specified in either EN 1090-2 [6] and its reference standards or in the MPS [24].

5.2 Identification, inspection documents and traceability
A record should be maintained of the source of, and test certificates for, main structural steel elements including each flange and web in order to provide traceability. This requirement is implemented by the MPS [24].

5.3 Constituent steel products
5.3.1 General
The chosen grade(s) of steel are specified to the standards listed in EN 1090-2 [6] and the grade (and subgrade) should be stated on the drawings.

5.3.2 Thickness tolerances
For plates, Class A to EN 10029 [25] is usually sufficient, even where Execution Class 4 is specified. Class A is the default in EN 10025 [1] and its selection is confirmed in the MPS [24]. The thickness tolerances in Class A increase with the nominal thickness as follows:

Tolerances (mm)

Nominal thickness / mm	Lower tolerance	Upper tolerance
≥ 8 < 15	-0.5	+1.2
≥15 < 25	-0.6	+1.3
≥25 < 40	-0.8	+1.4
≥40 < 80	-1.0	+1.8

5.3.3 Surface conditions
Class A3 (for plates) and Class C3 (for sections) to EN 10163 [26] are generally appropriate.

Although steel is visually inspected before it leaves the mill, it is not usually blast cleaned and still has mill scale adhering to it. Consequently, the surface that is revealed after grit blasting may show surface discontinuities that were not visible before. EN 10163 [26] defines the requirements relating to surface condition and refers to 'imperfections' (discontinuities that may be left without repair) and to 'defects' (discontinuities that shall be repaired).

For plates, Class A means that shallow depth imperfections are acceptable, but defects, including cracks, shell and seams, must be repaired (i.e. ground out). EN 10163 [26] defines 'shallow depth', and sets limits on the depth and areas of ground repairs. Sub-class 3 means that repair by welding is not allowed. This is appropriate for bridges because there would be no control over the location of any repairs, which could end up in fatigue-prone zones.

For further information on surface defects on steel materials, refer to Guidance Note 3.05 [27].

5.3.4 Internal discontinuities
The locations where internal discontinuity quality Class S1 (to EN 10160 [17]) is required should be shown on the drawings. Guidance on where this is needed is given in EN 1090-2 [6], the MPS [24], Guidance Note 3.06 [28] and examples include:

- A band width of 4x the plate thickness either side of a welded attachment in a cruciform joint transmitting tensile stress through the plate thickness
- A band width of 25x the web or flange plate thickness either side of a bearing diaphragm if attached by welding
- A band width of 25x the web plate thickness either side of a single-sided bearing stiffener if attached by welding

Class S1 is an acceptance level for macro imperfections (termed 'laminations' or 'laminar defects'), the presence and extent of which are checked by ultrasonic testing (see section 3.2.4). Scanning comprises a continuous examination along the lines of a 200mm square grid parallel to the edge of the plate. If a discontinuity is encountered, its extent is then established. The acceptable limits for discontinuities (for Class S1) are:

Individual - Area ≤ 1000mm^2
Clusters - 15 in the most populated 1m x 1m square (individual discontinuities < 100mm^2 are ignored)

The MPS [24] also advises that edge discontinuity class E1 should be specified for the edges of plates where corner welds will be made on to the surface of such plates.

For further information on surface defects on steel materials, refer to Guidance Note 3.06 [28].

A8 Gogarburn Bridge

This spectacular two-lane highway bridge provides the main access from the A8 into the site of the world headquarters of the Royal Bank of Scotland. The 400t steel superstructure comprises a tubular parabolic arch, which spans diagonally across the carriageway and supports the suspended deck via an asymmetrical arrangement of tie rods.

The main steel grades used are listed below. There was also a requirement for some of the S355J2 material to have guaranteed through thickness ductility, i.e. Z25 to EN 10164.

- S355J2 to EN 10025-2 for plates up to 50mm thick.
- S355NL to EN 10025-3 for plates 85mm thick and over.

Interestingly, the radar signature, as seen from Edinburgh Airport, influenced the positioning of the bridge, as did the location of existing mature trees.

The arch is a 1300mm diameter tube made from 40mm thick plate, which was rolled into a circular section then curved along its length prior to fabrication. The site joints were formed by insitu welding to maintain the smooth appearance of the arch. The hangers are 100mm diameter solid bars connected via fork ends at the top and bottom with adjustable turnbuckles.

The bridge was erected in a series of overnight closures to minimize disruption to the busy A8, and was opened in 2005.

Architect – Michael Laird and RHWL
Structural Engineer – Anthony Hunt Associates
Steelwork Contractor – Watson Steel Structures
Main Contractor – Sir Robert McAlpine
Client – Royal Bank of Scotland

6. References

1. BS EN 10025: 2004, Hot rolled products of structural steels, British Standards Institution,
   - Part 1 General technical delivery conditions.
   - Part 2 Technical delivery conditions for non-alloy structural steels.
   - Part 3 Technical delivery conditions for normalized/ normalized rolled weldable fine grain structural steels.
   - Part 4 Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels.
   - Part 5 Technical delivery conditions for structural steels with improved atmospheric corrosion resistance.
   - Part 6 Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition.

2. BS EN 1011-2, Welding recommendations for welding of metallic materials. Part 2: 2001, Arc welding of ferritic steels. British Standards Institution.

3. Corus brochure, Corus Steel bridges, Material matters, Corrosion protection, 2009.

4. Corus brochure, Corus Steel bridges, Material matters, Weathering steel, 2009.

5. BS EN 1993-2: 2006, Eurocode 3: Design of steel structures – Part 2: Steel Bridges, British Standards Institution.

6. BS EN 1090-2: 2008, Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures. British Standards Institution.

7. BS EN 10210-1: 2006, Hot finished structural hollow sections of non-alloy and fine grain structural steels. Part 1: Technical delivery requirements. British Standards Institution.

8. BS EN 10219-1: 2006, Cold formed welded structural sections of non-alloy and fine grain steels. Part 1: Technical delivery requirements. British Standards Institution.

9. BS EN 1993-1-12: 2007, Eurocode 3 - Design of steel structures - Part 1-12: Additional rules for the extension of EN 1993 up to steel grades S700. British Standards Institution.

10. NA to BS EN 1993-1-12:2007, UK National Annex to Eurocode 3: Design of steel structures - Part 1-12: Additional rules for the extension of EN 1993 up to steel grades S700.

11. BS EN 1993-1-10: 2005, Eurocode 3: Design of steel structures – Part 1-10: Material toughness and through-thickness properties. British Standards Institution.

12. NA to BS EN 1993-1-10: 2005, UK National Annex to Eurocode 3: Design of steel structures – Part 1-10: Material toughness and through-thickness properties. British Standards Institution.

13. BS EN 1990:2002, Eurocode - Basis of structural design. British Standards Institution.

14. BS EN 1991-1-5:2003, Eurocode 1: Actions on structures - Part 1-5: General actions – Thermal actions. British Standards Institution.

15. NA to BS EN 1991-1-5:2003, UK National Annex to Eurocode 1: Actions on structures – Part 1-5: General actions – Thermal actions. British Standards Institution.

16. PD 6695-1-10:2009, Background paper to the UK National Annex to BS EN 1993-1-10. British Standards Institution.

17. BS EN 10160:1999, Ultrasonic testing of steel flat product of thickness equal to or greater than 6mm (reflection method). British Standards Institution.

18. BS EN 10164: 2004, Steel products with improved deformation properties perpendicular to the surface of the product - technical delivery conditions. British Standards Institution.

19. GN 3.02, Through thickness properties, Guidance Notes on Best Practice in Steel Bridge Construction, SCI-P-185, The Steel Bridge Group, The Steel Construction Institute, 2009.

20. BS EN 1994-2:2005, Eurocode 4 - Design of composite steel and concrete structures - Part 2: General rules and rules for bridges. British Standards Institution.

21. Corus brochure, Plate products range of sizes, Plates and profiling slabs, 04/2008.

22. Corus brochure, Advance® sections, CE marked structural sections. 11/2007.

23. Corus brochure, Celsius®, 355 technical guide, Structural hollow sections, 04/2008.

24. Model project specification for the execution of steelwork in bridge structures, SCI-P382, The Steel Construction Institute, 2009.

25. BS EN 10029:1991, Specification for Tolerances on dimensions, shape and mass for hot-rolled steel plates 3mm thick or above. British Standards Institution.

26. BS EN 10163:2004, Delivery requirements for surface condition of hot-rolled steel plates, wide flats and sections, British Standards Institution.
    Part 1: General requirements.
    Part 2: Plate and wide flats.
    Part 3: Sections.

27. GN 3.05, Surface defects on steel materials, Guidance Notes on Best Practice in Steel Bridge Construction, SCI-P-185, The Steel Bridge Group, The Steel Construction Institute, 2009.

28. GN 3.06, Internal defects in steel materials, Guidance Notes on Best Practice in Steel Bridge Construction, SCI-P-185, The Steel Bridge Group, The Steel Construction Institute, 2009.

Shiremoor Bypass

This 49m span integral weathering steel bridge carries the Shiremoor bypass over a busy railway line, and serves the Earsdon View housing development built by Bellway Homes in North Tyneside. One of the key criteria for selecting this form of construction was to minimize future maintenance requirements.

The 25m wide deck comprises ten plate girders, each fabricated in three lengths 10m, 29m and 10m, using S355J2W steel to EN 10025-5 for the range of plate thicknesses required. Five pairs of girders, each weighing 85t, were assembled on site with bolted connections using some 4,000 weathering grade Tension Control Bolts (TCBs). GRC permanent formwork was placed between the assembled pairs, and cantilever falsework was fitted to the outer girders prior to the lift to minimize work over the railway. All five pairs were lifted into position by a 1000t capacity crane during two 6 hour rail possessions, which limited disruption to rail traffic during the construction period.

The steelwork contract took a mere 6 months from award in September 2007 to completion. Profiling of the steel plates started just before Christmas, fabrication was completed early in February, and the girders were erected in March 2008.

Structural Engineer – Fairhurst
Steelwork Contractor – Allerton Bridges Ltd
Main Contractor – Lumsden and Carroll
Client – Bellway Homes

Appendix

Table A1 – Hot rolled steel grades suitable for bridges

EN 10025-2: Hot rolled products of structural steels: for non-alloy structural steels

Designation	Impact Strength	Max CEV* t=40-150mm
S275J0	27J @ 0°C	0.42
S275J2	27J @ -20°C	0.42
S355J0	27J @ 0°C	0.47
S355J2	27J @ -20°C	0.47
S355K2	40J @ -20°C	0.47

EN 10025-3: Hot rolled products of structural steels: for normalized / normalized rolled weldable fine grain structural steels

Designation	Impact Strength	Max CEV t=63-100mm
S275N	40J @ -20°C	0.40
S275NL	27J @ -50°C	0.40
S355N	40J @ -20°C	0.45
S355NL	27J @ -50°C	0.45
S420N	40J @ -20°C	0.50
S420NL	27J @ -50°C	0.50
S460N	40J @ -20°C	0.54
S460NL	27J @ -50°C	0.54

EN 10025-4: Hot rolled products of structural steels: for thermomechanical rolled weldable fine grain structural steels

Designation	Impact Strength	Max CEV t=63-150mm
S275M	40J @ -20°C	0.38
S275ML	27J @ -50°C	0.38
S355M	40J @ -20°C	0.45
S355ML	27J @ -50°C	0.45
S420M	40J @ -20°C	0.47
S420ML	27J @ -50°C	0.47
S460M	40J @ -20°C	0.48
S460ML	27J @ -50°C	0.48

EN 10025-5: Hot rolled products of structural steels: for structural steels with improved atmospheric corrosion resistance

Designation	Impact Strength	Max CEV
S355J0W	27J @ 0°C	0.52
S355J2W	27J @ -20°C	0.52
S355K2W	40J @ -20°C	0.52

EN 10025-6: Hot rolled products of structural steels: for flat products of high yield strength structural steels in the quenched and tempered condition

Designation	Impact Strength	Max CEV t=50-100mm
S460Q	30J @ -20°C	0.48
S460QL	30J @ -40°C	0.48
S460QL1	30J @ -60°C	0.48

EN 10210: Hot finished structural hollow sections of non-alloy and fine grade structural steels

Designation	Impact Strength	Max CEV* t=16-40mm
Non-alloy		
S275J0H	27J @ 0°C	0.43
S275J2H	27J @ -20°C	0.43
S355J0H	27J @ 0°C	0.47
S355J2H	27J @ -20°C	0.47
Only S355J2H is readily available from Corus in the UK		
Fine grain		
S275NH	40J @ -20°C	0.40
S275NLH	27J @ -50°C	0.40
S355NH	40J @ -20°C	0.45
S355NLH	27J @ -50°C	0.45
S420NH	40J @ -20°C	0.52
S420NLH	27J @ -50°C	0.52
S460NH	40J @ -20°C	0.55
S460NLH	27J @ -50°C	0.55

(* only of agreed at time of order)

Table A2 – Maximum permissible values of element thickness (t / mm)

Steel Grade	Sub-grade	Charpy Energy CVN		Reference Temperature T_{Ed} (°C)									
				10	0	-10	-20	-30	-40	-50	-60	-70	-80
		T (°C)	J_{min}	$\sigma_{Ed} = 0.75f_y(t)$									
S275	J0	0	27	75	65	55	45	35	30	25	20	15	10
	J2	-20	27	110	95	75	65	55	45	35	30	25	20
	M,N	-20	40	135	110	95	75	65	55	45	35	30	25
	ML,NL	-50	27	185	160	135	110	95	75	65	55	45	35
S355	J0	0	27	60	50	40	35	25	20	15	15	10	10
	J2	-20	27	90	75	60	50	40	35	25	20	15	15
	K2,M,N	-20	40	110	90	75	60	50	40	35	25	20	15
	ML,NL	-50	27	155	130	110	90	75	60	50	40	35	25
S420	M,N	-20	40	95	80	65	55	45	35	30	25	20	15
	ML,NL	-50	27	135	115	95	80	65	55	45	35	25	20
S460	Q	-20	30	70	60	50	40	30	25	20	15	10	10
	M,N	-20	40	90	70	60	50	40	30	25	20	15	10
	QL	-40	30	105	90	70	60	50	40	30	25	20	15
	ML,NL	-50	27	125	105	90	70	60	50	40	30	25	20
	QL1	-60	30	150	125	105	90	70	60	50	40	30	25

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