Material Selection

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Material Selection

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). 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 structure.

1. Material Properties

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

The chemical composition is fundamental to the mechanical properties of steel. Adding alloys such as Carbon, Manganese, Niobium & Vanadium either during tapping or secondary steel making can increase the strength. However, such alloy additions increase the cost of the steel, and can adversely affect other properties (i.e. ductility, toughness & 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 has to be carefully considered to achieve the required properties.

Mechanical working is effectively rolling the steel. The more steel is rolled, the stronger it becomes. This effect is readily apparent in material standards, which specify several reducing levels of 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 perhaps 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
- Normalised steel
- Normalised-rolled steel
- Thermomechanically rolled (TMR) steel
- Quenched and tempered (Q&T) steel

Steel cools as it is rolled, and the typical rolling finish temperature is 750°C. Such steel is termed 'As-rolled' and usually requires more heat treatment to achieve the required mechanical properties.

Normalising is the process where an as-rolled plate is heated back up to approximately 900°C, 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 toughness. It renders the properties more uniform, and removes residual rolling strains.

Normalised-rolled is a process where the rolling finish temperature is above 900°C, and the steel is allowed to cool naturally. This has a similar effect on the properties as normalising, but it eliminates a process. Normalised & Normalised rolled steels are denoted "N"

Thermomechanically rolled steel utilises a different chemistry, which permits a lower rolling finish temperature of 700^{o}C, 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 650^{o}C. The implications of this are discussed further in Section 6.8. Thermomechanically rolled steel is denoted “M”

The process for Quenched & Tempered steel starts with a normalised plate at 900^{o}C. It is rapidly cooled or “quenched” to produce steel with high strength & hardness, but low toughness. The toughness is restored by reheating it to 600^{o}C, maintaining the temperature for a specific time, and then allowing it to cool naturally (“Tempering”). Quenched & tempered steels are denoted “Q”.

The properties of particular importance to the bridge designer include:

- Yield strength
- Ductility
- Toughness
- Modulus of Elasticity
- Coefficient of thermal expansion
- Weldability
- Corrosion resistance

These are described along with the specification requirements in the following section.

2. Specifications & Standards

BS 5400: Part 3, Section 6, *Properties of Materials* describes the specification requirements for the design of structural steel for bridgeworks, and contains the following clauses:

6.1 General
6.2 Nominal yield stress
6.3 Ultimate tensile stress
6.4 Ductility
6.5 Notch toughness
6.6 Properties of steel
6.7 Modular ratio

BS 5400: Part 6, *Specification for materials & workmanship* is also relevant, but deals mainly with steel supply and fabrication issues.

2.1 General

All new steel for structural purposes in bridges should be ‘hot-rolled’ manufactured to a CEN European Standard (EN). These 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-based material standards are relevant to bridge steelwork:

BS EN 10025 *(Plates & sections)**

- Part 2 - Non alloy structural steels
- Part 3 - Fine grain structural steels (Normalised / normalised rolled)
- Part 4 - Fine grain structural steels (Thermomechanically rolled)
- Part 5 - Weathering steels
- Part 6 - Quenched & tempered steels

BS EN 10210 *(Structural hollow sections)**

Additionally, the following British Standard has not yet been replaced by a CEN equivalent:

BS 7668*(Weather resistant hollow sections)**

(* For full titles of these Standards, see references at the end of these notes.)

In the CEN designation system for steel material all structural steels have the prefix “S”. This letter is followed 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 grades available in these standards, up to a yield strength of 460 N/mm^2, is given in Appendix A, Table 1.

BS EN 10025 has recently been revised (2004), and subsumes standards such as the 1993 versions of BS EN 10025, BS EN 10113, BS EN 10137 and BS EN 10155. Furthermore, designers may be more familiar with the material grades of old standards such as BS 4360, so comparisons are useful. However, it must be stressed that the new steels are not simply the old steels with new names - there are some differences in the production processes and properties. Current standards that are equivalent to the old BS 4360 grades are given in Appendix A, Table 2.

Cold formed hollow sections to BS EN 10219 are now available, but are not yet accepted in the design code, BS 5400: Part 3. Use of such sections would require a ‘Departure from Standard’; the particular consideration would then be the toughness of the material in the corners of rectangular and square sections.

2.2 Yield strength

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 European Standards for structural steels, the primary designation relates to the yield strength, e.g. S355 steel is a structural steel with a nominal yield strength of 355 N/mm^2. The number quoted in the designation is the value of yield strength for material up to 16 mm thick (or 12 mm for steel to BS 7668). Designers should note that yield strength reduces with increasing plate or section thickness. An example for common bridge steels to BS EN 10025 is given below.

Steel Grade	Minimum yield strength (N/mm2), 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
S460	460	440	430	410	400	380

The strength grades covered by the BS EN standards include; S235, S275, S355, S420 and S460. (BS 7668 covers one strength grade, S345.) Yield strengths above 460 N/mm^2 are available to BS EN 10025: Part 6, but BS 5400 or other design codes do not yet cover the use of these strengths. Grade S235 steel is rarely used in bridge steelwork.

Steels of 355 N/mm^2 yield strength are predominantly used in bridge applications in the UK because the cost-to-strength ratio of this material is lower than for other grades (Ref. Section 4). However, some of the higher strength grades offer other advantages and may be seen more frequently in the future. However, note that the use of higher strength steels confers no benefits in applications which are fatigue critical, or in which instability of very slender members is the overriding design consideration. S460 steels are also less readily available.

2.3 Ultimate Tensile Strength

BS 5400-3 requires that the specified minimum ultimate tensile stress of steel sections & plates should not be less than 1.2 x the nominal yield stress. This is not usually an issue for typical bridge steels, but would require more detailed consideration for high strength steels.

2.4 Ductility

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 process in welding, bending, & 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 normal to the direction of rolling) or perpendicular to the plane of the element. The two measurements have different significance for the designer.

In-plane ductility
Clause 6.4 of BS 5400-3 requires a ductility corresponding to an elongation of 15% or more, based on a standard proportional gauge length. All material complying with Standards such as BS EN 10025: Parts 2 to 5 meets this requirement, so no additional specification is usually needed.

However, Clause 6.4 requires a ductility equivalent to an elongation of 19% or more where plasticity is relied on in the design, e.g.

- Where the plastic moment capacity of a section is utilised.
- Where redistribution of tensile flange stress is assumed in the design.

Again this is not usually a problem for steels complying with the material standards, except for perhaps S460 steels & thick plates, as indicated with “grey” areas in the following table. In such cases, further specification of the ductility requirements of the designer will be needed.

		Elongation for thickness range (mm)			
		3-40	41-63	64-100	101-150
BS EN 10025: Part 2					
S275	Long.	23	22	21	19
	Trans.	21	20	19	19
S355	Long.	22	21	20	18
	Trans.	20	19	18	18
BS EN 10025: Part 3					
S275	N/NL	24	24	23	23
S355	N/NL	22	22	21	21
S420	N/NL	19	19	18	18
S460	N/NL	17	17	17	17
BS EN 10025: Part 4					
S275	M/ML	24	24	24	24
S355	M/ML	22	22	22	22
S420	M/ML	19	19	19	19
S460	M/ML	17	17	17	17
BS EN 10025: Part 5					
S355	Long.	22	21	20	18
	Trans.	20	19	18	18

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

For several reasons, a designer should try to avoid welded joint configurations in which plate material is subjected to high tensile stresses in the through-thickness direction (see Guidance Note 3.02 for further advice). Where there is such a joint carrying significant load, the specification of material with assured through-thickness properties is usually required.

Through thickness ductility may be specified as an ‘option’ (4) in BS EN 10025 in terms of one of three ‘levels’ (Z15, Z25 or Z35) according to BS EN 10164. These levels are expressed in terms of the percentage reduction of area obtained during through-thickness tensile tests on small 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. See Guidance Note 3.02 for detailed advice on specifying through thickness ductility.

2.5 Notch 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 use of the term "notch toughness" in BS 5400: Part 3). This test measures the impact energy (in Joules) required to break a small, notched specimen by a single impact blow from a pendulum. The test is carried out with the specimen at a specified (low) temperature. In the material standards, tests are specified typically at -20^{o}C and the required minimum value is typically 27J. Other temperatures and energy values are specified for different grades.

In the CEN steel standards there is not, unfortunately, a universal designation system for the notch toughness. In Standards BS EN 10025: Parts 2 & 5 and BS EN 10210 there is a two character alphanumeric code; there are four different codes that are used:

J0: 27J impact energy at 0^{o}C
J2: 27J impact energy at -20^{o}C
K2: 40J impact energy at -20^{o}C

Steels to BS EN 10025: Parts 3 & 4 and fine grain steels to BS EN 10210 may be one of two categories of impact strength, the lower-temperature one being designated by the code 'L'.

Steels to BS EN 10025: Part 6 (Q&T steels) may be one of three grades of toughness, the lower-temperature two grades being designated by the codes L and L1.

Clause 6.5.4 of BS 5400-3: 2000 describes the requirements for notch toughness in the form of an equation which relates the limiting thickness of a steel part to the following:

- Minimum effective bridge temperature
- Steel grade (yield strength & toughness)
- "k" factor

The effect of the nominal yield stress is described by the expression $(355/\sigma_y)^{1.4}$, with σ_y being defined as the minimum yield strength specified for the appropriate thickness.

The "k" factor classifies steel parts for fracture purposes, and is determined by the product of four sub-factors:

k_d – Construction detail
k_g – Stress concentration
k_σ – Stress Level
k_s – Rate of loading

For simplicity, BS 5400-3: 2000 contains a table (Table 3(c)), derived from the equation in clause 6.5.4 assuming a k-factor of unity. However, the values in Table 3(c) have been derived using the 'nominal' yield strength for thicknesses up to 16 mm. This conservatively ignores the fact that specified minimum yield strength reduces with increasing plate thickness, according to the material standards referred to in Clause 6.2. Using the minimum yield strength specified for the appropriate thickness would give a larger limiting thickness.

The values in the following table have been derived strictly in accordance with the equation in clause 6.5.4, and illustrate these larger limiting thicknesses. (See Guidance Note 3.08)

Limiting thickness for parts where K factor =1.0							
Strength Grade	Quality		Maximum thickness (mm) at service temperature U degrees C				
	Grade	T_{27J}	-10	-15	-20	-25	-30
S275	J0	0	70	60	55	0	0
	J2	-20	114	98	89	77	70
	N, M	-30	136	124	114	98	89
	NL, ML	-50	224	191	174	149	136
S355	J0	0	45	40	36	0	0
	J2	-20	68	59	54	50	45
	K2	-30	85	74	68	59	54
	N, M	-30	85	74	68	59	54
	NL, ML	-50	134	123	112	93	85
S420	N, M	-30	68	58	53	48	44
	NL, ML	-50	110	93	85	74	68
S460	Q	-20	42	38	35	32	29
	N, M	-30	55	50	46	42	37
	QL	-40	64	58	53	46	42
	NL, ML	-50	88	77	71	60	55
	QL1	-60	92	84	77	70	64

However, a word of caution must be expressed for the few cases where the k-factor is less than unity. In such instances, the thickness limits in the above table should not merely be factored by the actual k-factor. This would give a lower limiting thickness and for that thickness a higher nominal yield strength might apply, which may in turn lead to an even lower limiting thickness.

2.6 Properties of Steel

Clause 6.6 of BS 5400-3 simply states the properties of steel to be used in design:

- Modulus of elasticity, E = 205,000 N/mm^2
- Shear modulus, G = 80,000 N/mm^2
- Poisson's ratio, $\nu = 0.3$
- Coefficient of thermal expansion = $12 \times 10^{-6}/^{o}C$

2.7 Modular Ratio

Clause 6.7 of BS 5400-3 relates to composite construction, and defines the appropriate modular ratios to be used for global & stress analysis.

2.8 Supply Condition

The supply condition indicates which of the processes described in Section 1 is to be used. In some standards there is scope for choice, either by the manufacturer or by the specifier. In BS EN 10025: Parts 2 & 5 there are three different delivery condition grades that may be chosen, denoted by a suffix to the yield/impact strength designation. These are:

+AR	As rolled
+N	Normalised or Normalised rolled
+M	Thermomechanically rolled

Acceptance of 'M' and 'Q' steels
In the past there has been some reluctance to accept the use of 'M' and 'Q' grade steels because it was thought that the properties may be adversely affected by heat during fabrication, mainly as a result of welding or heating during fabrication, or because the steel might lose strength more quickly in fire than 'N' steels. In the UK 'M' steels have now been accepted by highway and railway authorities on the basis of tests at elevated temperatures, which have shown no significant difference. 'Q' steels are also now included in the latest version of BS 5400: Part 3.

2.9 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 greater the thickness of material, the greater the reduction of toughness.

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), and the standards give an expression for determining this value. Welding standards (such as BS EN 1011) will indicate what preheat, if any, is needed for a given CEV, material thickness and weld size.

The latest CEN material standards (BS EN 10025: 2004) specify mandatory limits on the maximum CEV, so the designer no longer has to invoke an 'option' for them to apply. Note also that steels to BS EN 10025: Parts 3 & 4 generally have a lower value of this maximum CEV than steels to BS EN 10025: Parts 2 & 5.

2.10 Corrosion Resistance

All structural steels, with the exception of the 'weather resistant steels', 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 galvanised, 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" (see option 5 in BS EN 10025). For further information on corrosion resistance issues, refer to the Corus brochure on the "Corrosion Protection of Steel Bridges".

Weather resistant steels are steels which, over a period of time, form a tightly adhering oxidised steel coating or 'patina' that inhibits further corrosion. When used in an appropriate environment, they do not require any protective coating. However, an allowance must be made for the oxidised surface layers, and this is made in design by subtracting a specified amount from all exposed surfaces when calculating the adequacy of the structural sections. See BD7, Guidance Note 1.07, and the Corus brochure "Weathering Steel Bridges" for further advice.

3. Availability of Steel

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

- Plate products, range of sizes.
- Structural sections to BS4.
- Celsius structural hollow sections.

3.1 Plate Availability

Plates may be obtained either direct from the mill, or through a steel stockist. The advantage of plates direct from the mill is that they are rolled to order, which minimises waste and maximises design efficiency, as any intermediate thickness is available. Steel from a stockist is more suited to small quantities, and will reduce lead times. However, it will be more expensive, and the size & quality required may not be readily available.

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 highlighting:

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 100mm.

Although the brochure illustrates plate weights & thicknesses beyond these limits, they are only available through the ingot route, which is very rarely used now (if ever) for structural steels, and would carry a heavy cost premium.

The following table illustrates the available thicknesses, and process routes for a range of typical grades used in bridgeworks.

Standard BS EN 10025	Designation	Normalised	Normalised Rolled	T.M.C.R.	Q & T
Part 2	S275	6-100	6-60		
	S355	6-100	6-60		
Parts 3 & 4	S275 (N/M)	6-100	6-60		
	S275 (NL/ML)	6-85			
	S355 (N/M)	6-100	6-60	10-50	
	S355(NL/ML)	6-100			
	S420 (N/M)	6-30	6-40	10-50	
	S420 (NL/ML)				
	S460 (N/M)	6-30		10-50	
	S460 (NL/ML)				
Part 6	S460				8-70
Part 5	S355	6-100	6-65		
(Low CEV)	S355	6-85			

3.2 Weathering Steel Availability

Many of the recent enquiries concerning the availability of steel have been in reference to weather resistant (WR) steel. The increase in the use of WR steel is due to a number of factors, including; beneficial revisions to BD7, an appreciation of the long term aesthetics, improved detailing, and a desire to minimise future maintenance. The general availability of WR steel from Corus may be summarised as follows.

Plates
Plates may be obtained direct from the mill, where a minimum quantity of 5T per width & thickness applies. Plate size limitations from the mill are outlined in the Corus brochure "Plate Products - range of sizes", and may be summarised in the following table.

Parameter	Production Process	
	Normalised	Normalised Rolled
Max. Plate Width	3.75m	3.9m
Max.Plate Length	17.0m	18.3m
Max. Gauge	100mm	65mm
Max. Plate Weight	14.5T	14.5T
CEV (Max. / Typical)	0.52 / 0.50	0.47 / 0.44

Sections
Obtaining rolled sections in weathering grades is more problematic. Corus have stopped production of rolled sections in weathering grades, as it is no longer commercially viable for us. This is not a problem for main girders, that are generally fabricated from plate, but care is required when determining an appropriate bracing strategy.

For 'ladder deck' bridges the only require bracing required is to the bottom compression flange at intermediate supports. 'Knee bracing' using short lengths of rolled sections is sometimes used, but the most economic solution is the use of a deep plate girder.

For 'multi-girder' bridges in weathering steel, 'X' or 'K' bracing should be avoided where possible, and the use of stiff transverse beams (fabricated from plate) in an 'H' configuration is recommended. However, for deep girders fabricated angles or channels may be required to form a triangulated bracing system.

Steelwork contractors have a wealth of knowledge and experience, and are pleased to assist in design development to achieve the most economic weathering steel bridge solution for any project.

Hollow Sections
Corus no longer roll hollow sections in weathering steel.

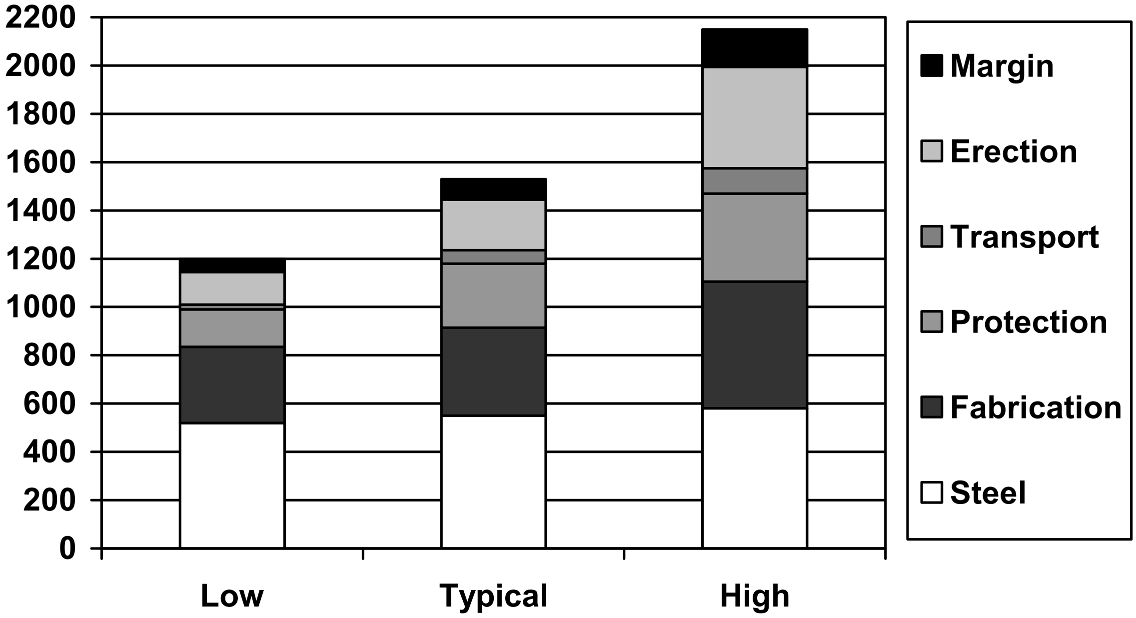
HSFG Bolts
Over recent years, Cooper & Turner (in the UK) have supplied weathering steel HSFG bolts into the bridge market. However, they have only a limited stock of M24 and M30 material left, and are unlikely to reorder material due to the low demand.

Hence, the industry is likely to revert to the imports route that existed before Cooper & Turner entered the market. The likely source will be North America, and the implications are that the weathering grade HSFG bolts will be in imperial sizes and to US specifications.

Current industry advice is to standardise on M24 bolts, but use bolt spacings to suit 1" bolts as this will maximise the options available to fabricators. In addition, it is advisable to talk to a fabricator at an early stage in the design process.

4. 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 material, degree of fabrication, site location, corrosion protection system & access for erection. This is clearly illustrated in the following chart for plate girder bridges. Hence, for cost comparisons at critical stages in a project's development it is suggested that designers contact a major steel fabricator, most of who would be pleased to advise on budget estimates.



The cost of the steel itself depends on the steel grade (i.e. S355J2+N or S460NL etc.), the plate size (i.e. length, width, thickness & weight), and the market conditions.

With regard to the cost of weathering steel, a comparative study in ECCS publication no. 81, *The Use of Weathering Steel in Bridges (2001),* concluded that the initial capital cost of fabricated & erected steelwork for a weathering steel bridge would be approximately 5% less than the conventional painted alternative. The study was based on comparative designs for 8 typical steel composite highway bridges in the UK, and demonstrated that the additional costs of the steel itself were more than offset by the savings resulting from the elimination of the corrosion protection system.

5. References

Standards

- BS 5400, Steel concrete and composite bridges.
  Part 3: 2000, Code of Practice for design of steel bridges.
  Part 6: 1999, Specification for materials & workmanship, steel
- BS 7668: 1994, Specification for weldable structural steels. Hot finished structural hollow sections in weather resistant steels.
- BS EN 1011, Welding recommendations for welding of metallic materials.
  Part 1: 1998, General guidance for arc welding.
  Part 2: 2001, Arc welding of ferritic steels.
- BS EN 10025: 2004, Hot rolled products of non-alloy structural steels
  - Part 1 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 thermomechanically 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 productsof high yield strength structural steels in the quenched and tempered condition
- BS EN 10164: 1993, Steel products with improved deformation properties perpendicular to the surface of the product - technical delivery conditions.
- BS EN 10210, Hot finished structural hollow sections of non-alloy and fine grain structural steels.
  Part 1: 1994, Technical delivery requirements.
- BS EN 10219, Cold formed welded structural sections of non-alloy and fine grain steels.
  Part 1: 1997, Technical delivery requirements.

Other publications

- Steel Bridge Group: Guidance Notes on Best Practice in Steel Bridge Construction, The Steel Construction Institute, 2000. A series of 60 separate notes, the ones referred to in this lecture being:
  1.07 Use of weather resistant steel
  3.01 Structural steels
  3.02 Through thickness properties
  3.08 Notch toughness and material thickness
- BD 7/01, Weathering steel for highway structures, Highways Agency, 2001.
- BD 13/04, Design of Steel Bridges - Use of BS 5400: Part 3: 2000, Highways Agency, 2004.
- Specification for Highway Works, Series 1800, Structural steelwork, The Highways Agency.
- Corus brochure, Weathering Steel Bridges.
- Corus brochure, Corrosion Protection of Steel Bridges.

Appendix

- Table 1: Summary of grades of structural steel suitable for bridgework
- Table 2: Current steel grades equivalent to former grades in BS 4360: 1990

Table 1 *Summary of grades of structural steel suitable for bridgework*

BS EN 10025: Hot rolled products of structural steels: Part 2: Technical delivery conditions for non-alloy structural steels		
Designation	Impact strength t= 10 -150mm	Max CEV* t= 40 -150mm
S275J0+N S275J2+N	27J @ 0°C 27J @ -20°C	0.42 0.42
S355J0+N S355J2+N S355K2+N	27J @ 0°C 27J @ -20°C 40J @ -20°C	0.47 0.47 0.47
Delivery conditions: generally normalised/normalised rolled for bridge steelwork.		

BS EN 10025: Hot rolled products of structural steels: Part 3: Technical delivery conditions for normalized/ normalized rolled weldable fine grain structural steels		
Designation	Impact strength t= 10 –150mm	Max CEV t= 63 -100mm
S275N S275NL	40J @ -20°C 27J @ -50°C	0.40 0.40
S355N S355NL	40J @ -20°C 27J @ -50°C	0.45 0.45
S420N S420NL	40J @ -20°C 27J @ -50°C	0.50 0.50
S460N S460NL	40J @ -20°C 27J @ -50°C	0.54 0.54

BS EN 10025: Hot rolled products of structural steels: Part 4: Technical delivery conditions for thermomechanically rolled weldable fine grain structural steels		
Designation	Impact strength t= 10 –150mm	Max CEV t= 63 -150mm
S275M S275ML	40J @ -20°C 27J @ -50°C	0.38 0.38
S355M S355ML	40J @ -20°C 27J @ -50°C	0.45 0.45
S420M S420ML	40J @ -20°C 27J @ -50°C	0.47 0.47
S460M S460ML	40J @ -20°C 27J @ -50°C	0.48 0.48

BS EN 10025: Hot rolled products of structural steels: Part 5: Technical delivery conditions for structural steels with improved atmospheric corrosion resistance		
Designation	Impact strength	Max CEV
S355J0W+N S355J2W+N S355K2W+N	27J @ 0°C 27J @ -20°C 40J @ -20°C	0.52 0.52 0.52
Delivery conditions: generally normalised/normalised rolled for bridge steelwork.		

BS EN 10025: Hot rolled products of structural steels: Part 6: Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition		
Designation	Impact strength	Max CEV t= 50 -100mm
S460Q S460QL S460QL1	30J @ -20°C 30J @ -40°C 30J @ -60°C	0.48 0.48 0.48

BS EN 10210:Hot finished structural hollow sections of non-alloy and fine grain structural steels		
Designation	Impact strength	Max CEV* t= 16 -40mm
Non-alloy S275J0H S275J2H	 27J @ 0°C 27J @ -20°C	 0.43 0.43
S355J0H S355J2H	27J @ 0°C 27J @ -20°C	0.47 0.47
Fine grain S275NH S275NLH	 40J @ -20°C 27J @ -50°C	 0.40 0.40
S355NH S355NLH	40J @ -20°C 27J @ -50°C	0.45 0.45
S460NH S460NLH	40J @ -20°C 27J @ -50°C	- -
Delivery conditions: J0, J2, hot finished N, normalised/normalised rolled		

BS 7668: Hot finished structural hollow sections in weather resistant steels		
Designation	Impact strength	Max CEV*
S345J0WPH S345J0WH S345GWH	27J @ 0°C 27J @ 0°C 27J @ -15°C	n/a 0.54 0.54
Delivery conditions: hot finished or normalised		

Table 2 *Current steel grades equivalent to former grades in BS EN 10025: 1993, BS EN 10113: 1993, BS EN 10137: 1993, BS EN 10155: 1993, and BS 4360: 1990*

BS 4360: 1990	1993 Steel Standards		BS EN 10210: 1993	BS EN 10025: 2004 Standards	
	Grade	Standard		Grade	Part
43A	S275	BS EN 10025	-	-	-
43B	S275JR	BS EN 10025	-	S275JR	2
43C	S275J0	BS EN 10025	S275J0H	S275J0+N	2
43D	S275J2G3	BS EN 10025	S275J2H	S275J2+N	2
43DD	S275N	BS EN 10113-2	-	S275N	3
43EE	S275NL	BS EN 10113-2	S275NLH	S275NL	3
50A	S355	BS EN 10025	-	-	-
50B	S355JR	BS EN 10025	-	S355JR	2
50C	S355J0	BS EN 10025	S355J0H	S355J0+N	2
50D	S355J2G3	BS EN 10025	S355J2H	S355J2+N	2
50DD	S355K2G3	BS EN 10025	-	S355K2+N	2
50DD	S355N	BS EN 10113-2	-	S355N	3
50EE	S355NL	BS EN 10113-2	S355NLH	S355NL	3
55C	S460N	BS EN 10113-2	-	S460N	3
55EE	S460NL	BS EN 10113-2	S460NLH	S460NL	3
WR50B	S355J0W	BS EN 10155	-	S355J0W+N	5
WR50C	S355J2G1W	BS EN 10155	-	S355J2W+N	5
WR50D	S355K2G1W	BS EN 10155	-	S355K2W+N	5