The selection of steel subgrade

Richard Henderson of the SCI discusses the determination of the steel subgrade using BS EN 1993-1-10 and the UK National Annex. Examples are given where the temperature falls outside the values given in Tables 2, 3 and 4 of PD 6695-1-10: 2009.

The SCI Advisory Desk often receives calls from SCI members about the selection of steel subgrade and the application of the relevant documents. This article attempts to clarify the steps in the process of determining steel subgrade and show how the steps can be applied to service temperatures outside the ones usually met.

Published document PD 6695-1-10: 2009 provides non-contradictory complementary information (NCCI) for use in the UK with Part 1-10 of the Eurocode BS EN 1993 and its National Annex. It gives the preferred approach to selecting material subgrade and should be used unless features of the detail being considered fall outside the scope of the PD.

Part 10 of BS EN 1993-1 General Rules and Rules for Buildings and its UK National Annex deals with material toughness and through-thickness properties. According to BS EN 1993-1-1 clause 3.2.3, material "shall have sufficient fracture toughness to avoid brittle fracture of tension elements at the lowest service temperature expected to occur within the service life of the structure". The lowest service temperatures to be adopted for buildings and other quasi-statically loaded structures are given in the UK National Annex to BS EN 1993-1-1 as -5°C for internal steelwork and -15°C for external steelwork. For most bridges in the UK, the service temperature is -20°C or higher and Table 4 in the PD can be used. Otherwise the lowest service temperature should be determined according to the UK National Annex to BS EN 1991-1-5 for the bridge location. For other cases such as the internal steelwork in cold stores, the lowest service temperature should be taken as the lowest air temperature expected to occur during the design life of the structure.

The guidance in part 10 is to be used for the selection of material for new structures. The rules are applicable to tension elements, welded and fatigue stressed elements in which some portion of the stress cycle is tensile. According to part 10, the rules can be conservative for elements not subject to tension, welding or fatigue and fracture toughness need not be specified for elements only in compression. The UK National Annex covers elements in compression by including tensile stresses of less than zero.

The relevant design condition is given in clause 2.2(4)(i) which states the design actions should be the effects of the reference temperature (T_{Ed}) as leading action, in combination with the permanent actions (G_K), frequent variable actions ($\psi_1 Q_K$) and quasi-permanent values of the accompanying variable actions ($\psi_{2i} Q_{Ki}$) that govern the stress level in the material. The combination is considered to be an accidental combination because of the assumption of simultaneous occurrence of lowest temperature, flaw size and location and material property. The maximum applied stress should be the nominal principal stress at the location of the potential fracture initiation, calculated for the given combination. Note that the combination does not include any partial factors for permanent or variable actions.

T_{Ed} is defined in equation 2.2 as:

$$T_{Ed} = T_{md} + \Delta T_r + \Delta T_\sigma + \Delta T_R + \Delta T_\varepsilon + \Delta T_{ecf}$$

The UK National Annex to part 10 does not say so but the first two terms taken together: ($T_{md} + \Delta T_r$) are the lowest service temperature. $\Delta T_\varepsilon + \Delta T_{ecf}$ are for high strain rate (eg due to impact) and degree of cold forming respectively. The NA goes on to define ΔT_R in terms of a series of temperature adjustments as follows:

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

with the ΔT terms corresponding to detail type; gross stress concentrations; Charpy test temperature; applied stress level and strength grade respectively. Procedures in the NA are consistent with $\Delta T_\sigma = 0$ (cl. NA.2.1.1.1) which means adjustments for stress level are made through the ΔT_R value, specifically the choice of $\Delta T_{R\sigma}$.

Table 1 (over the page) summarizes the adjustments in the National Annex. The item numbers in the table are used for reference in the following examples.

Example 1

What is the limiting thickness for S355J2 used internally in a detail with moderate welding subject to a design tensile stress greater than half the yield stress?

Table E1

Temperature Adjustment	Comment	Item in table 1	Value and adjustment (°C)
$T_{md} + \Delta T_r$	Service temperature (internal)		-5
ΔT_{RD}	Detail type	3	0
ΔT_{Rg}	Stress concentration	8	0
ΔT_{RT}	Charpy test temperature (-20 – (-5) = -15 < 20)	12	0
$\Delta T_{R\sigma}$	Applied stress level	20	0
ΔT_{Rs}	Steel grade	26	0
			Use -5

From table 2.1 in EN 1993-1-10 maximum thicknesses are:

		Charpy Energy CVN		Reference temperature T_{Ed}		
				10	0	-10
Steel grade	Sub grade	at T(°C)	$= J_{min}$	$\sigma_{Ed} = 0.75 f_y(t)$		
S355	J2	-20	27	90	75	60

Interpolating for T_{Ed} = -5, the limiting thickness t = 67.5 mm.

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Table 1

Adjustments for detail type (NA.2.1.1.1.2 and Table NA.1)			
Detail		**Item**	**ΔT_{RD}**
Unwelded	As rolled, ground or machined surfaces	1	+30°C
	Mechanically fastened joints or flame cut edges	2	+20°C
Welded	Generally (described as 'moderate' in the PD)	3	0°C
	Attachment; transverse weld toe: length >150 mm; width ≤ 50mm (described as 'severe' in the PD)	4	-20°C
	Attachment; transverse weld toe: length >150 mm; width > 50mm (described as 'very severe' in the PD)	5	-30°C
	Member fabricated from plates: transverse butt weld	6	-20°C
	Rolled section: transverse butt weld	7	-30°C

Adjustment for gross stress concentration (Table NA.2)			
Stress concentration factor			**ΔT_{Rg}**
Guidance on stress concentration factors is given in PD 6695-1-9:2008	1	8	0°C
	1.5	9	-10°C
	2	10	-20°C
	3	11	-30°C

Adjustment for Charpy test temperature (Table NA.3)			
General (except bridges conforming to BS EN 1993-2). Obtain intermediate values by linear interpolation. The maximum difference between the Charpy test temperature and $T_{Ed} = (T_{md} + \Delta T_r)$ should be limited.	**$T - (T_{md} + \Delta T_r)$**		**ΔT_{RT}**
	≤ 20°C	12	0°C
	25°C	13	-10°C
	30°C	14	-20°C
	35°C	15	-30°C
Further restriction on joint types apply: see the NA	> 35 ≤ 40°C	16	-40°C
	> 40°C	17	Not permitted
Bridges conforming to BS EN 1993-2	≤ 20°C	18	0°C
	> 20°C	19	Not permitted

Adjustment for applied stress (Table NA.4)			
	σ_{Ed}		**$\Delta T_{R\sigma}$**
	$0.75 f_y(t)$	20	0°C
Use the values for $0.75 f_y(t)$ but adjusted for lower values of σ_{Ed}. Linear interpolation may be used for intermediate values.	$0.5 f_y(t)$	21	0°C
	$0.3 f_y(t)$	22	+10°C
	$0.15 f_y(t)$	23	+20°C
	≤ 0	24	+30°C

Adjustment for steel grade (Table NA.5)			
	steel grade		**T_{Rs}**
	< S355	25	+10°C
	S355	26	0°C
	> S355	27	-10°C

Example 2

What is the limiting thickness for S460N used externally in a detail with moderate welding subject to a design tensile stress greater than half the yield stress?

Table E2

Temperature Adjustment	**Comment**	**Item in table 1**	**Value and adjustment (°C)**
$T_{md} + \Delta T_r$	Service temperature (internal)		-15
ΔT_{RD}	Detail type	3	0
ΔT_{Rg}	Stress concentration	8	0
ΔT_{RT}	Charpy test temperature (-20 – (-15) = -5 < 20)	12	0
$\Delta T_{R\sigma}$	Applied stress level	20	0
ΔT_{Rs}	Steel grade	27	-10
			Use -25

From table 2.1 in EN 1993-1-10 maximum thicknesses are:

		Charpy Energy CVN		**Reference temperature T_{Ed}**		
				-10	**-20**	**-30**
Steel grade	**Sub grade**	**at T(°C)**	**$= J_{min}$**	**$\sigma_{Ed} = 0.75 f_y(t)$**		
S460	N	-20	40	60	50	40

Interpolating for T_{Ed} = -25, the limiting thickness t = 45 mm.

Example 3

What is the limiting thickness for S355JR used externally in the UK in a detail with severe welding subject to a design tensile stress greater than half the yield stress?

Table E3

Temperature Adjustment	**Comment**	**Item in table 1**	**Value and adjustment (°C)**
$T_{md} + \Delta T_r$	Service temperature (internal)		-15
ΔT_{RD}	Detail type	4	-20
ΔT_{Rg}	Stress concentration	8	0
ΔT_{RT}	Charpy test temperature (20 – (-15) = 35)	15	-30
$\Delta T_{R\sigma}$	Applied stress level	20	0
ΔT_{Rss}	Steel grade	26	0
			Use -65

Table 2.1 in EN 1993-1-10 does not have thicknesses for temperatures as low as this. However, such values are given in PD6695-1-10.

		Charpy Energy CVN		Reference temperature T_{Ed}		
				-50	-60	-70
Steel grade	**Sub grade**	**at T(°C)**	**$= J_{min}$**	**$\sigma_{Ed} = 0.75 f_y(t)$**		
S355	JR	20	27	10	10	5

Interpolating for T_{Ed} = -65, the limiting thickness t = 7.5 mm.

Example 4

What is the limiting thickness for S355J2 used externally where the service temperature is -40°C in a detail with moderate welding subject to a design tensile stress just less than 0.3 times the yield stress?

Table E4

Temperature Adjustment	Comment	Item in table 1	Value and adjustment (°C)
$T_{md} + \Delta T_r$	Service temperature (internal)		-40
ΔT_{RD}	Detail type	3	0
ΔT_{Rg}	Stress concentration	8	0
ΔT_{RT}	Charpy test temperature (-20 – (-40) = 20)	12	0
$\Delta T_{R\sigma}$	Applied stress level	22	+10
ΔT_{Rs}	Steel grade	26	0
			Use -30

From table 2.1 in EN 1993-1-10, maximum thicknesses are:

		Charpy Energy CVN		Reference temperature T_{Ed}		
				-20	-30	-40
Steel grade	**Sub grade**	**at T(°C)**	**$= J_{min}$**	**$\sigma_{Ed} = 0.75 f_y(t)$**		
S355	J2	-20	27	50	40	35

The limiting thickness t = 40 mm.

Example 5

What is the limiting thickness for S355JR used in a bridge where the service temperature is -20°C in a detail with moderate welding subject to a design tensile stress just less than 0.3 times the yield stress?

Table E4

Temperature Adjustment	Comment	Item in table 1	Value and adjustment (°C)
$T_{md} + \Delta T_r$	Service temperature (internal)		-20
ΔT_{RD}	Detail type		
ΔT_{Rg}	Stress concentration		
ΔT_{RT}	Charpy test temperature (20 – (-20) = 40 > 20)	19	Not permitted
$\Delta T_{R\sigma}$	Applied stress level		
ΔT_{Rs}	Steel grade		

Use of the proposed sub grade is not permitted.

Comparison of the results from examples 1 to 5 with the tables in PD6695-1-10 will show that the same values appear.

Conclusion

The determination of the maximum thickness for a given material subgrade and set of conditions has been illustrated, using EN 1993-1-10 and its National Annex and can be seen to correspond to the values given in PD6695-1-10.

It is noted in the JRC Scientific and Technical Report EUR 23510 EN – 2008 entitled Commentary and worked examples to EN 1993-1-10 by Sedlacek et al, September 2008, in section 1.4.3(1) that "As EN 1993-1-10, section 2 has been developed for structures subjected to fatigue (such) as bridges … , its use for buildings where fatigue plays a minor role would be extremely safe sided."