Guidance on the specification of CSP Schemes

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PFP Net – Barcelona, October 2023

PFP Net Conference – Barcelona, October 2023
Cryogenic Spill Protection Session

Agenda

1. Present the Part 1 document on Cryogenic Spill Protection

2. Gather ideas for development of Part 2 – Advanced CSP Guidance

3. Establish working group for Part 2

Problem statement – Determining thicknesses

Typical request:

- "What thickness do I need to protect for 15 minutes CSP?"

Problems:

- No release details
- Which CSP testing method should be used?
- Correlation between LN_2, LNG LH_2, etc
- No defined start temperature
- No defined limiting temperature
- No steelwork details
- Is duration correct – should it be 5, 10 15, 30 or 60 minutes?
- Does it also nee to be PFP?
- No clear guidance available – needs early engagement in design process

Workshop Session - Output

- Summary
- A workshop was held at the 2022 PFPNet conference in Manchester at which the subject of Cryogenic Spill Protection (CSP) was discussed.
- There is currently a test standard (ISO 20088) for the testing of cryogenic spill protection (CSP) under liquid, spray and jet release which was developed by the ISO TC/67 working Group but applying the standard without understanding its basis, applicability, or interpreting the results of the test correctly has resulted in a lack of consistency of specification across vendors and users, which is creating significant inconsistencies in the way CSP systems are used to mitigate cryogenic (and fire) hazards.
- PFPNet proposed the development of two resources, with accompanying training and exploitation opportunities, to improve competency in practitioners and reduce the level of variability in approaches which are currently seen. These resources are:
- Part 1- Fundamentals of Cryogenic Spill Protection.
- Part 2- Advanced Cryogenic Spill Protection Design and Specification

Workshop Session - Output

- Background
- Part 1 is proposed to be a short explanatory guidance document of 5 to 6 pages in length. This will cover the basic definitions and steps to be taken when specifying CSP, and the information needed and interpretations that are required to correctly specify a CSP system, or to supply a CSP that correctly meets a specification.
- This will cover the main areas where a lack of clarity or misunderstanding can lead to errors in the specification or supply, particularly with the correct understanding of ISO 20088 and how results from an ISO 20088 test should be used. The document will also cover the situation where fire follows the cryogenic spill, and the system may have both CSP and PFP functions.

Part 1 Guidance

What does it contain

Part 1

Cryogenic Spill Protection Requirements

- Introduction
- Guidance
- Scope
- Key information requirements for the specification of CSP Systems
- Enquiry Sheet - blank
- Appendix – Explanatory Notes
  - Acronyms and Definitions
  - Applicable part of the ISO 20088 standard to be used
  - Type of item being protected
  - Item shape and size
  - Credible Start Temperature
  - Limiting item temperature
  - Allowable Temperature drop
  - Cryogenic Protection Duration
  - CSP and mitigation of other hazards

1. Introduction

In facilities where low temperature liquids (such as Liquified Natural Gas (LNG) facilities) are handled, there is the risk that an accidental leak of liquid could cause embrittlement of the substrate, leading to its failure and the potential escalation of the incident. This occurs if the cryogenic liquid release is capable of reducing the temperature in the substrate below the ductile brittle transition temperature (DBTT).

To prevent failures due to embrittlement, Cryogenic Spill Protection (CSP) may be specified to protect safety and environmentally critical elements. The design of CSP requires matching up appropriate testing against a pre-determined duration and an allowable temperature drop limit.

The test standard ISO 20088 was developed to address typical LNG release scenarios, using liquid nitrogen as the cryogenic medium. Liquid nitrogen was chosen as a more inherently safe cryogenic liquid, which had a boiling point at atmospheric pressure lower than LNG. Using ISO 20088 to represent other cryogenic liquids needs to be appropriately validated.

2. This Guidance

This guidance describes the minimum information required to be provided to the CSP system manufacturer to allow them to specify the correct type and thickness of CSP required, based on the ISO 20088 test data. It should be noted that even slight changes in these variables can have a significant impact on the design and cost of the CSP.

It also provides the minimum information required for fire exposure when the protection system must provide mitigation against both cryogenic spill and fire.

Whilst allowable temperature drop (ΔT[illegible]) is a key factor in determining CSP thickness, providing the information on the credible initial temperature for release scenarios (T[illegible]), and the limiting steel temperature (T[illegible]) will assist in understanding that the needs of the project are correctly married against liquid cryogenic exposure test data.

Section 4 provides "key information requirements " with brief descriptions.

Section 5 provides a pro-forma enquiry sheet that follows the format of the "key information requirements table" given in Section 4. When completing the enquiry sheet, information should be provided for all items that are to be protected against the cryogenic spill, and where necessary the full range of section sizes or plate thicknesses should be provided.

Explanatory Notes are given in Appendix A .

3. Scope

The scope of this guidance covers:

- The use of CSP systems to protect structural components, barriers, process plant and pipework, and critical process control equipment such as valves.
- CSP systems that take the form of wet-applied coating systems (epoxy, phenolic, cementitious) and dry-fit insulation systems.
- Systems that might also provide other mitigative functions in addition to cryogenic spill protection (such as process insulation, acoustic or passive fire protection).

Part 1 - Cryogenic Spill Protection Requirements

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Part 1 - Cryogenic Spill Protection Requirements

Scope

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Part 1 - Cryogenic Spill Protection Requirements

Enquiry Sheet

Sec	Requirement	Response	
1	Applicable part of the ISO 20088 standard to be used.		
2	Type of item being protected		
3	Item size and shape		
4	Credible start temperature of the substrate (T_{start}) for release scenarios	4a substrate at ambient temperature	
		4b substrate at process temperature	define process conditions
5	Limiting item temperature ($T_{critical}$)		
6	Allowable temperature drop (ΔT_{drop})		
7	Cryogenic protection duration (minutes)		
8	Other hazard mitigation requirements		

Part 1 - Cryogenic Spill Protection Requirements

Key Information

Sec	Requirement	Purpose / Commentary
1	Applicable part of the ISO 20088 standard to be used	The correct part of the standard should be selected to represent the type of cryogenic release experienced by the item to be protected. 1. Part 1: Liquid Spill – **Liquid pool** that forms on horizontal surfaces 2. Part 2: Vapour Release – Exposure of a substrate to a pressurised cryogenic liquid jet where vaporisation of the liquid is almost complete (liquid content is minimal) 3. Part 3: Jet Release – Exposure of a substrate to a pressurized cryogenic **liquid** jet only (gaseous content is minimal)
2	Type of item being protected	The type of item to be protected should be identified, because: 4. This is an additional consideration when selecting which part of ISO 20088 to use. 5. The shape and configuration of the item being protected will strongly influence the required thickness of CSP needed to provide the necessary cryogenic protection.

Part 1 - Cryogenic Spill Protection Requirements

Key Information

Sec	Requirement	Purpose / Commentary	
3	Item size and shape	Heavier items will cool down less quickly than lighter items, and may require lower thickness of insulation. Therefore, the following key information is required: • For steel plate, the plate thickness. • For steel sections, the section factor (Hp/A; A/V; W/D or A/P). • For pipework, a pipe schedule enabling calculation of a section factor. • For items of equipment such as valves, the size, weight and materials information enable the calculation of an equivalent thermal mass.	
4	Credible start temperature (T_{start}) for release scenarios	4a substrate at ambient temperature	When the substrate is at the same temperature as the credible ambient temperature at the facility when the cryogenic liquid is released then this value is used as T_{start} in the calculation of allowable temperature drop.
		4b substrate at process temperature	When substrate operates at very high or very low in-service temperatures (for example thermal insulation for process pipework), then the value of T_{start} should be taken as the in-service temperature of the substrate.

Part 1 - Cryogenic Spill Protection Requirements

Key Information

Sec	Requirement	Purpose / Commentary
5	Limiting item temperature ($T_{critical}$)	The lowest temperature that the item is allowed to reach during the cryogenic release exposure duration. For example, steel is susceptible to fracture at temperatures below the DBTT, and the limiting temperature should be specifically determined based on the material grade used.
6	Allowable temperature drop (ΔT_{drop})	The difference between the credible ambient temperature (T_{start}) and the limiting item temperature below which the temperature of the item should not drop ($T_{critical}$). This is a key variable in the determination of CSP thickness.
7	Cryogenic protection duration (mins)	The duration of exposure of the cryogenic spill over which the cold temperature effects must be mitigated to prevent the limiting item temperature being reached is required for the calculation of CSP thickness.
8	Other hazard mitigation requirements	If the CSP system also mitigates other hazards such passive fire protection (PFP), hot or cold insulation, or acoustic insulation then the requirements and any ratings that describe these hazards should be provided to ensure that they are integrated with the CSP requirement.

Part 1 - Cryogenic Spill Protection Requirements

Appendix A – Explanatory Notes

Section 1: Applicable part of the ISO 20088 standard to be used

ISO 20088 has 3 parts that consider different forms of cryogenic release that may occur. The standard subjects the CSP systems to a prescribed test protocol to establish their ability to mitigate low temperature effects of a simulated cryogenic spill on the steel they protect. The test monitors the drop in temperature experienced by a protected substrate from the initial ambient temperature at the test site, over a prescribed duration when exposed to cryogenic liquid nitrogen (LIN) releases.

Selecting the correct type of cryogenic spill is important because it influences the required thickness of CSP to manage the allowable temperature drop. For a given duration of exposure, the required thickness of CSP generally increases as the phase changes from vapour to spray/jet to immersion/ponding.

As well as the influence of the release conditions, a consideration of the actual item which is exposed to the cryogenic liquid will also guide the selection of the correct part of ISO 20088 to be used. In general:

- Part 1 is normally specified for protection of horizontal surfaces such as decks or bunds where large pools of cryogenic liquid could accumulate.
- Part 2 is rarely specified in the LNG sector as vapour is assumed not to cool the steel sufficiently in open, ventilated areas.
- Part 3 is generally used specifically where no liquids will accumulate, such as for open and closed structural steel beam and column sections, vessel supports, vessels, process equipment such as valves, and pipework.

The appropriate test for CSP applied to vertical divisions is discussed in Section 2.

Part 2 Guidance

What does it need to cover

Areas for Optimisation / Improvement in Knowledge
Discussion

- What is correct limiting steel temperature? Grades, thickness, shapes, ect
- How far does a liquid jet extend?
- Should we pay more attention to vapour phase?
- Do we test at realistic pressure/release rates
- What Duration of protection is actually required – does not match fire cases?
- What starting temperature?
- What si the critical structure that needs CSP?
- Do we need a CSP test for CPCE?
- De we need better guidance on steel design for CSP risk?

Thank You

Discussion & Questions?

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Areas for Optimisation / Improvement in Knowledge

- What limiting steel temperature?
  - Dependant on DBTT
  - Typically -29°C used most commonly
    - some projects using -18°C (no Charpy testing)
    - Some using LT steel -46 or -65°C
  - Dependant on steel thickness
    - Thinner steel less susceptible to brittle fracture
    - Thicker steel cools down less
    - Impact is critical load

- What Duration?
  - FERC normally accepting 10 or 15 minutes
  - Based on NFPA 59A and/or API 521

- What starting temperature?
  - Normally average minimum temperature in coldest month
  - Not the lowest temperature every experienced at site – double jeopardy

Critical Steel Temperature

- ISO 20088-1

Guidance Notes
for
Risk Based Analysis:
Cryogenic Spill

August 2015

Lloyd's Register

D.4 Critical temperature drop

The limiting temperature drop is defined as the difference between the ambient temperature and the limiting temperature for the steel. As an example -20°C can be used for hull steel and -40°C for topsides structural and process equipment steel. The limiting temperature drop is specified in advance of the test, according to the protection criteria for the equipment, assembly or structure being protected. The sample meets the requirement provided the temperature does not exceed the limiting temperature.

4.2 Cryogenic hazards for assets:

(a) The main hazards from cryogenic leaks to the assets are listed in Table 1. Carbon steel embrittlement due to cryogenic spills is the main concern, since it could lead to brittle fracture of main carbon steel structural elements with an eventual collapse of the structure and escalation of the initial accidental release to a catastrophic event.

(b) Suitable mitigation and/or protective measures for the parts of the hull, decks and support structures which may be exposed to cryogenic leaks shall be evaluated.

Hazard	Description
Carbon Steel Embrittlement	Carbon Steel loses it's ductility and becomes brittle when exposed to cryogenic vapour or liquid heat transfer loads (e.g. LNG). Hence the capacity of the structure might be impaired. Typical Ductile to Brittle Transition Temperature (DBTT) for low carbon steel design temperature is -40C.
High Heat Transfer Cooling Rates	Direct contact of LNG with structural steel rapidly cools the steel below the embrittlement temperature and safety measures such as early detection, isolation and blowdown might not to be able to manage the cryogenic hazard in the immediate area of the release. Because the cryogenic damage might be complete close to the release, such safety measures might only mitigate the cryogenic exposure to larger areas.

These are now recognised as out-dated

Critical Steel Temperature

- Ductile Brittle Transition Temperature (DBTT)
  - Dependant on steel grade and thickness
  - Plate more susceptible than sections

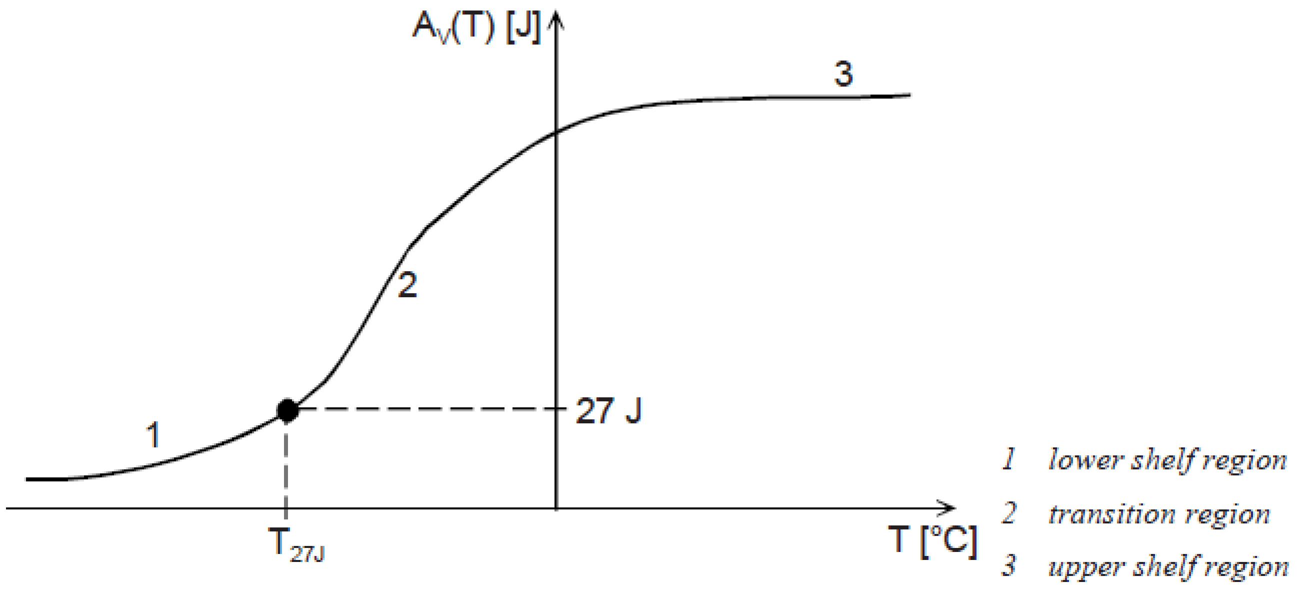
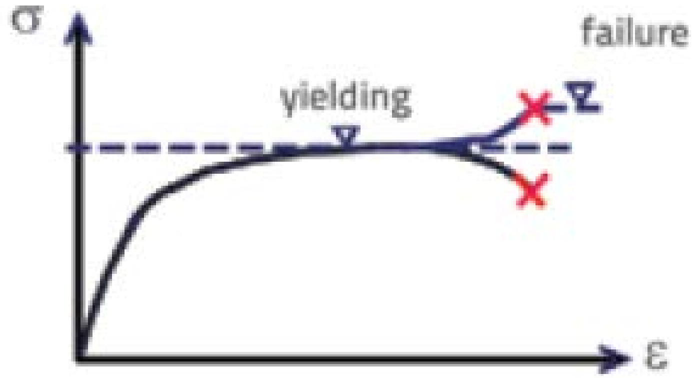
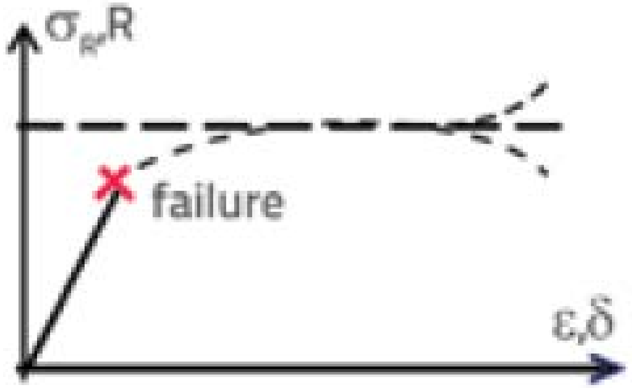


Figure 1.1: Relationship between impact energy and temperature



Ductile failure



Brittle failure

Critical Steel Temperature

EN 1993-1-10:2005

- Provides guidance on maximum steel thickness at given load factors at low temperatures

Example:

- For steel grade S355 J0 (one of the most commonly used steel grades) (equivalent to 50 k.s.i.)
- For σ (design stress) = 0.75 x yield strength
- For -50°C temperature limit
- Permissible deign allows use of steel thicknesses up to a maximum of 15 mm

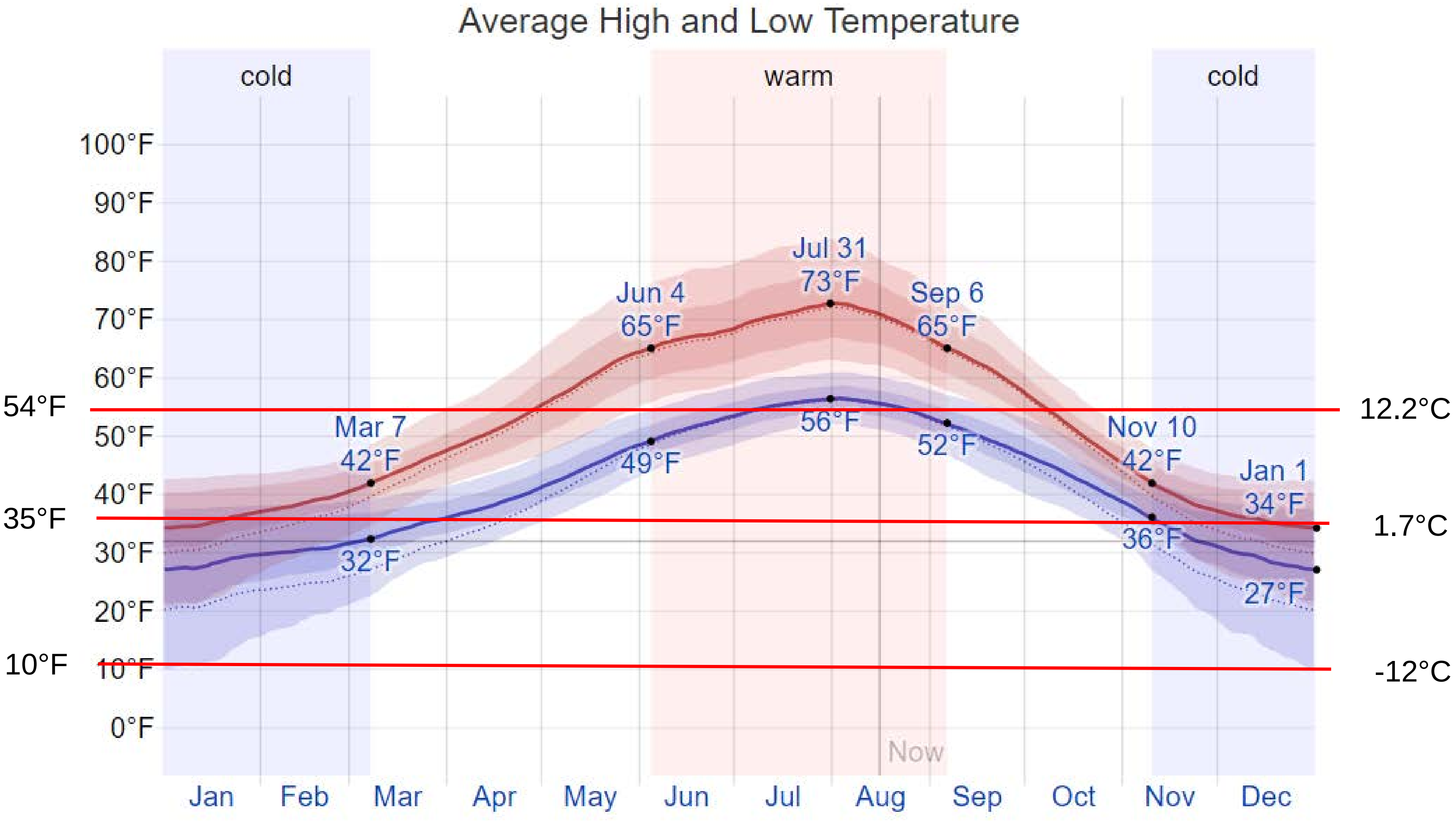
Table 2.1: Maximum permissible values of element thickness t in mm

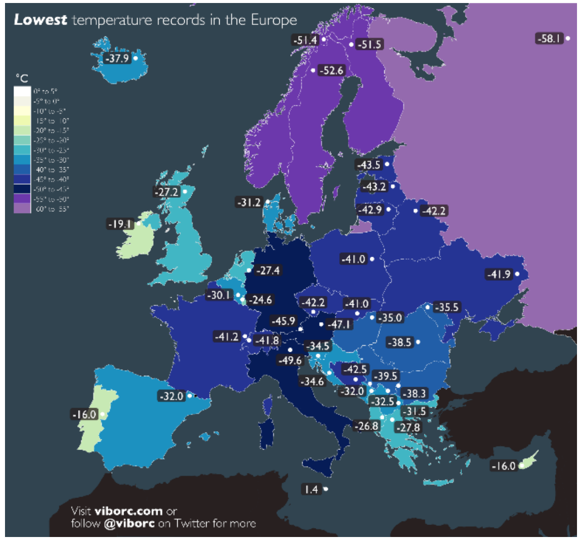
Steel grade	Sub-grade	KV at T [°C]	KV J_{min}	Reference temperature T_{Ed} [°C]																				
				$\sigma_{Ed} = 0,75\ f_y(t)$							$\sigma_{Ed} = 0,50\ f_y(t)$							$\sigma_{Ed} = 0,25\ f_y(t)$						
				10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
S235	JR	20	27	60	50	40	35	30	25	20	90	75	65	55	45	40	35	135	115	100	85	75	65	60
	J0	0	27	90	75	60	50	40	35	30	125	105	90	75	65	55	45	175	155	135	115	100	85	75
	J2	-20	27	125	105	90	75	60	50	40	170	145	125	105	90	75	65	200	200	175	155	135	115	100
S275	JR	20	27	55	45	35	30	25	20	15	80	70	55	50	40	35	30	125	110	95	80	70	60	55
	J0	0	27	75	65	55	45	35	30	25	115	95	80	70	55	50	40	165	145	125	110	95	80	70
	J2	-20	27	110	95	75	65	55	45	35	155	130	115	95	80	70	55	200	190	165	145	125	110	95
	M,N	-20	40	135	110	95	75	65	55	45	180	155	130	115	95	80	70	200	200	190	165	145	125	110
	ML,NL	-50	27	185	160	135	110	95	75	65	200	200	180	155	130	115	95	230	200	200	200	190	165	145
S355	JR	20	27	40	35	25	20	15	15	10	65	55	45	40	30	25	25	110	95	80	70	60	55	45
	J0	0	27	60	50	40	35	25	20	15	95	80	65	55	45	40	30	150	130	110	95	80	70	60
	J2	-20	27	90	75	60	50	40	35	25	135	110	95	80	65	55	45	200	175	150	130	110	95	80
	K2,M,N	-20	40	110	90	75	60	50	40	35	155	135	110	95	80	65	55	200	200	175	150	130	110	95
	ML,NL	-50	27	155	130	110	90	75	60	50	200	180	155	135	110	95	80	210	200	200	200	175	150	130
S420	M,N	-20	40	95	80	65	55	45	35	30	140	120	100	85	70	60	50	200	185	160	140	120	100	85
	ML,NL	-50	27	135	115	95	80	65	55	45	190	165	140	120	100	85	70	200	200	200	185	160	140	120
S460	Q	-20	30	70	60	50	40	30	25	20	110	95	75	65	55	45	35	175	155	130	115	95	80	70
	M,N	-20	40	90	70	60	50	40	30	25	130	110	95	75	65	55	45	200	175	155	130	115	95	80
	QL	-40	30	105	90	70	60	50	40	30	155	130	110	95	75	65	55	200	200	175	155	130	115	95
	ML,NL	-50	27	125	105	90	70	60	50	40	180	155	130	110	95	75	65	200	200	200	175	155	130	115
	QL1	-60	30	150	125	105	90	70	60	50	200	180	155	130	110	95	75	215	200	200	200	175	155	130
S690	Q	0	40	40	30	25	20	15	10	10	65	55	45	35	30	20	20	120	100	85	75	60	50	45
	Q	-20	30	50	40	30	25	20	15	10	80	65	55	45	35	30	20	140	120	100	85	75	60	50
	QL	-20	40	60	50	40	30	25	20	15	95	80	65	55	45	35	30	165	140	120	100	85	75	60
	QL	-40	30	75	60	50	40	30	25	20	115	95	80	65	55	45	35	190	165	140	120	100	85	75
	QL1	-40	40	90	75	60	50	40	30	25	135	115	95	80	65	55	45	200	190	165	140	120	100	85
	QL1	-60	30	110	90	75	60	50	40	30	160	135	115	95	80	65	55	200	200	190	165	140	120	100

Reference: EN 1993-1-10:2005 *Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties*

Ambient Environmental Conditions

Annual, Seasonal or Daily? Absolute or Average?





Annual average temperature

Average temperature in coldest month

Coldest Temperature at site

Limiting Steel Temp : -65°C (-85°F) chosen for the project