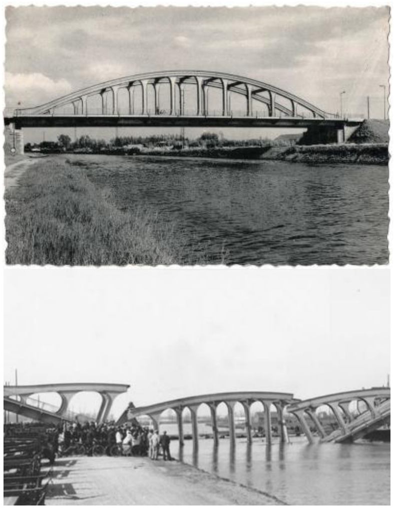
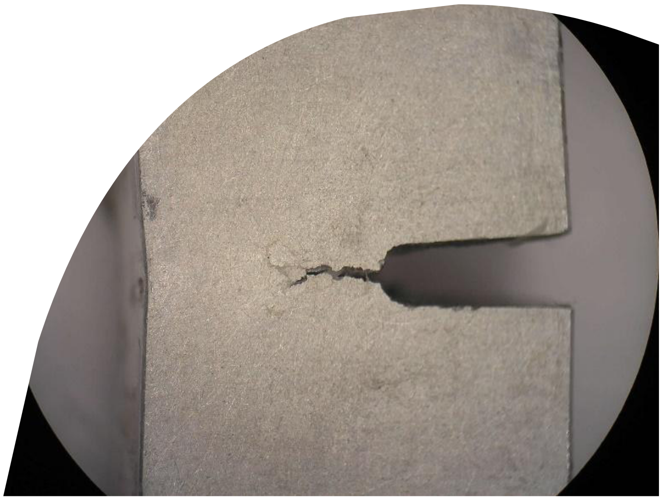
EUROPEAN CONVENTION
FOR CONSTRUCTIONAL
STEELWORK
Bridge Committee





How to properly select the steel grade concerning toughness requirements and how to extend the fatigue life of steel and steel composite bridges

ECCS Bridge Committee

Mike Tibolt, Francesco Profico, Mohammad Al-Emrani, Zuheir Barsoum,
Bertram Kühn, Pavel Ryjáček

PREFACE

An ECCS webinar was held on 4 November 2025 and gives the basis for this eBook that focuses on the on toughness and steel grade selection in prEN1993-1-10, that is included now in the 2nd generation of Eurocodes and explain the TTV tool, that can be for this application used. It also explains the basis of the HFMI (High Frequency Mechanical Impact) treatment, describe the advantages and possibilities of this method and give a practical example of the structural analysis of the bridge, designed with this method and related savings. Also, the quality control methods for the HFMI are described and explained.

Pavel Ryjáček
Bridge committee ECCS, Chair

CONTENTS

1. CHOICE OF STEEL GRADE CONCERNING TOUGHNESS REQUIREMENTS: BACKGROUND AND TTV TOOL DEMONSTRATION, (MIKE TIBOLT & FRANCESCO PROFICO)

ArcelorMittal Europe

Choice of steel grade concerning toughness requirements:

Background and TTV tool demonstration

Mike Tibolt

Francesco Profico

4 November 2025

Speakers

Mike TIBOLT

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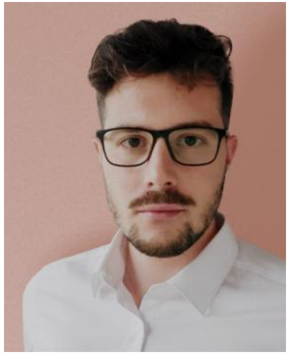
Senior Structural Engineer, Steligence Engineering

Mostly active in bridges, lattice towers and fracture mechanics problems.

Member standardization committee EN1993-1-9 and EN1993-1-10.



Francesco PROFICO

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Structural Engineer, Steligence Engineering

Mostly active in bridges and composite structures.

EN 1993-1-10:2005

Background of the verification method against brittle fracture

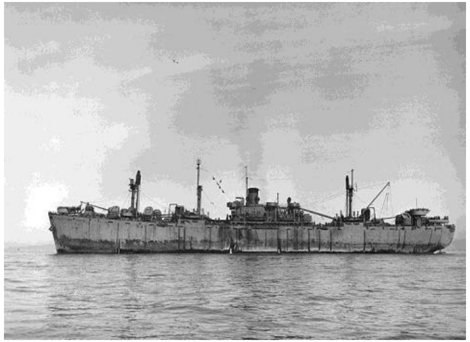
& Concept of TTV Tool

Brittle fracture – Discovering the phenomena

1919-1945: Sudden structural failures engaged by crack formation in different steel structures

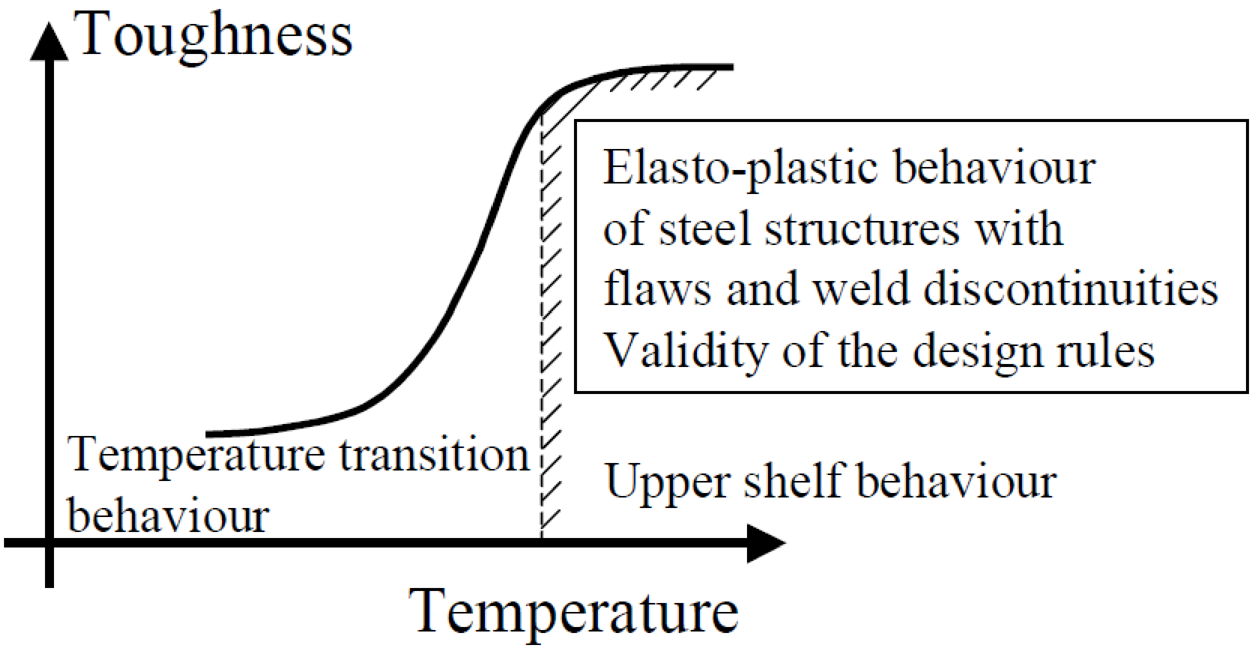
Pont Hasselt, Belgium, 1938

Liberty ships, US, 1941-45



Molasse tank, Boston, US, 1919

Toughness – The key property to avoid brittle fracture

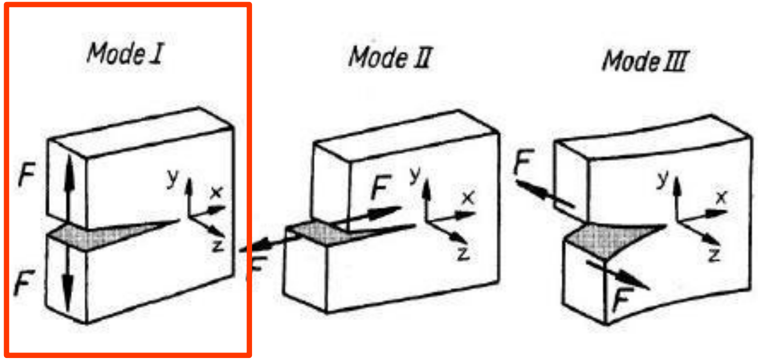


Linear elastic fracture mechanics (LEFM)

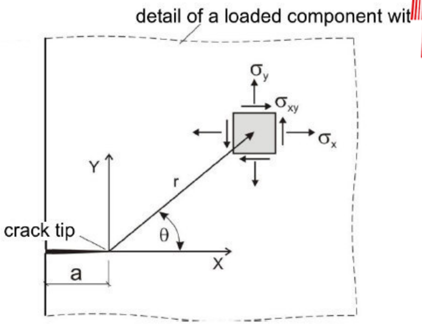
Verification according to LEFM:

$$K^{*}_{appl,d} \leq K_{mat,d}\,(T_{Ed})$$

$K^{*}_{appl,d}$	Stress intensity factor, mode I	$[MPam^{1/2}]$
$K_{mat,d}\,(T_{Ed})$	Fracture toughness	$[MPam^{1/2}]$



Linear elastic fracture mechanics (LEFM)



$$\sigma_x = \sigma\sqrt{\frac{a}{2r}}\cdot\cos\frac{\theta}{2}\left[1-\left(\sin\frac{\theta}{2}\cdot\sin\frac{3\theta}{2}\right)\right] = \frac{K}{\sqrt{2\pi r}}\cdot f_x(\theta)$$

$$\sigma_y = \sigma\sqrt{\frac{a}{2r}}\cdot\cos\frac{\theta}{2}\left[1+\left(\sin\frac{\theta}{2}\cdot\sin\frac{3\theta}{2}\right)\right] = \frac{K}{\sqrt{2\pi r}}\cdot f_y(\theta)$$

$$\sigma_{xy} = \sigma\sqrt{\frac{a}{2r}}\cdot\cos\frac{\theta}{2}\cdot\sin\frac{\theta}{2}\cdot\cos\frac{3\theta}{2} = \frac{K}{\sqrt{2\pi r}}\cdot f_{xy}(\theta)$$

Verification according to LEFM:

$$K^*_{appl,d} \leq K_{mat,d}\,(T_{Ed})$$

Stress intensity factor $K^*_{appl,d}$:

$$K^*_{appl,d} = \frac{\sigma_{Ed}\cdot\sqrt{\pi a_d}\cdot Y\cdot M_K}{k_{R6}-\rho}$$

σ_{Ed}	Nominal design stress in the member	[MPa]
a_d	Design size of the crack	[mm]
Y	Correction function for crack shape and position	[-]
M_K	Correction function for structural detail	[-]
k_{R6}	Plasticity correction factor	[-]
ρ	Factor for local residual stresses	[-]

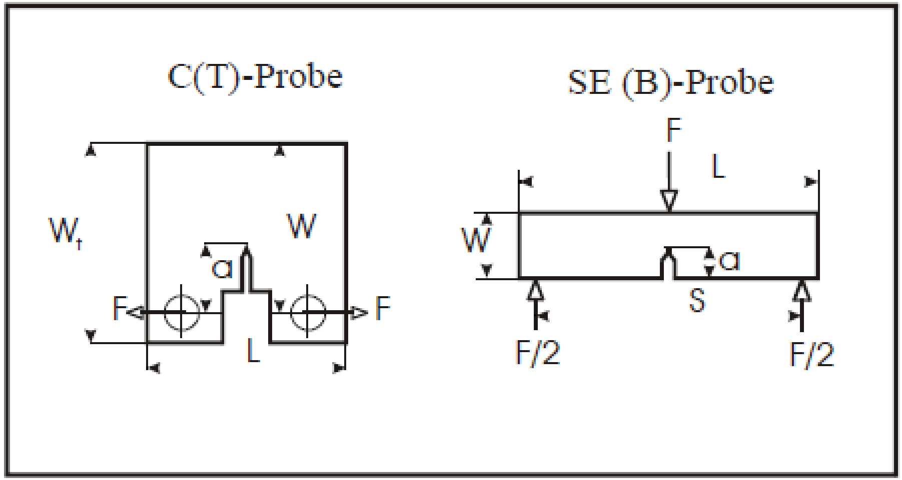
Linear elastic fracture mechanics (LEFM)

Verification according to LEFM:

$$K^{*}_{appl,d} \leq K_{mat,d}\,(T_{Ed})$$

Fracture toughness $K_{mat,d}\,(T_{Ed})$:

- Material property
- Temperature dependent
- Determination by tests

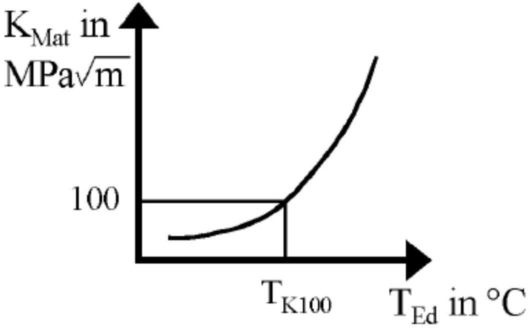


Practical verification method is required

Towards a temperature-based verification

1. Step: Master-Curve approach from *Wallin*

- Shape of the fracture toughness ***transition*** curve practically independent from material and yield strength
- Description as a function of temperature, specimen thickness and fracture probability
- Fracture probability of 50% -> mean value approach



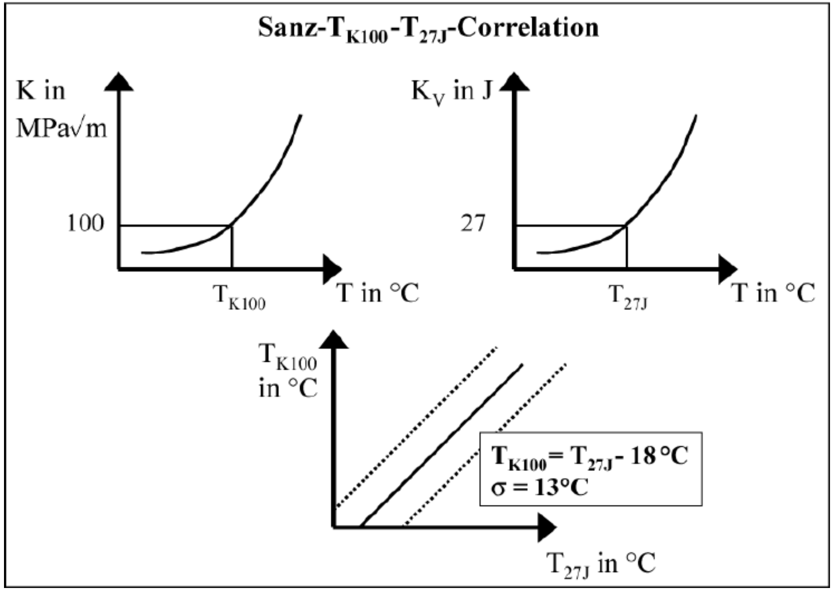
$$K_{Mat}(T_{Ed}) = 20 + [70\left\{exp\frac{T_{Ed} - T_{K100} + \Delta T_R}{52}\right\} + 10] \cdot \left(\frac{25}{b_{eff}}\right)^{1/4}$$

T_{Ed}	Test temperature $[°C]$
T_{K100}	Test temperature at which the measured fracture toughness is 100 $\mathrm{MPam}^{1/2}$ $[°C]$
ΔT_R	Additive safety element $[°C]$
$\left(\frac{25}{b_{eff}}\right)^{1/4}$	Effect of the crack front on the failure probability $[°C]$

Towards a temperature-based verification

2. Step: Correlation of *Sanz*

- Correlation between T_{K100} and T_{27J}



$$20 + [70\left\{exp\frac{T_{Ed} - T_{K100} + \Delta T_R}{52}\right\} + 10] \cdot \left(\frac{25}{b_{eff}}\right)^{1/4}$$

$T_{K100} = T_{27J} - 18°\ C$

σ = 13° C

$$20 + [70\left\{exp\frac{T_{Ed} - T_{27J} + 18°C + \Delta T_R}{52}\right\} + 10] \cdot \left(\frac{25}{b_{eff}}\right)^{1/4}$$

Towards a temperature-based verification

3. Step: Expression in terms of temperatures

$$K^*_{appl,d} \leq K_{mat,d}\,(T_{Ed})$$

$$K^*_{appl,d} = \frac{\sigma_{Ed}\cdot\sqrt{\pi a_d}\cdot Y\cdot M_K}{k_{R6}-\rho} \leq 20 + \left[70\left\{exp\,\frac{T_{Ed}-T_{27J}+18°C+\Delta T_R}{52}\right\} + 10\right]\cdot\left(\frac{25}{b_{eff}}\right)^{1/4}$$

$$\underbrace{T_{Ed} - 52\cdot ln\left(\frac{\left(K^*_{appl,d}-20\right)\cdot\left(\frac{b_{eff}}{25}\right)^{0,25} - 10}{70}\right)}_{\Delta T_\sigma} \underbrace{+\,\Delta T_R}_{\Delta T_R} \geq T_{27J} - 18°C$$

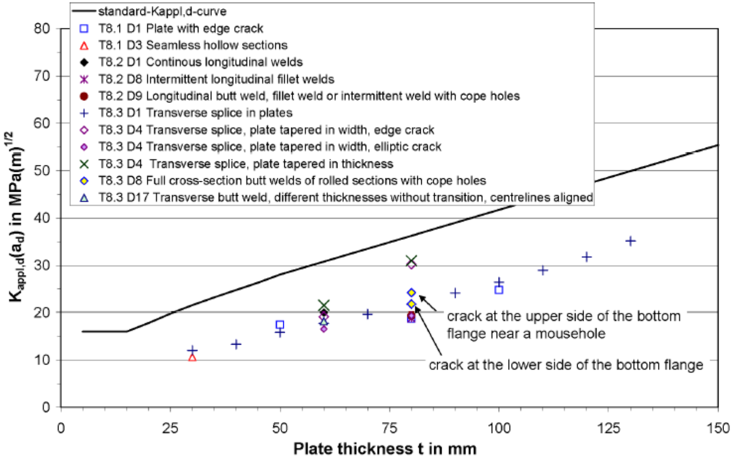
ΔT_σ:
function of the detail geometry
and
crack shape

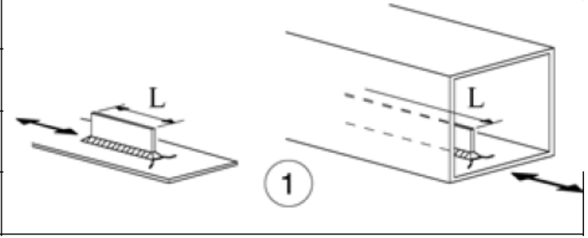
ΔT_R:
Additive safety
element

Towards a temperature-based verification

4. Step: Definition of a standard detail and crack shape

- Worst detail from EN 1993-1-9 and crack shape with regards to stress intensity factor $K^{*}_{appl,d}$
- Detail 1 in Table 4.1 in EN1993-1-9, Detail category 56

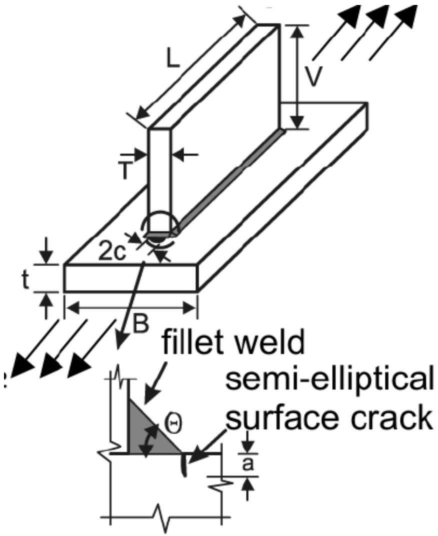


Detail category	Constructional detail	
80	L≤50mm	
71	50<L≤80mm	
63	80<L≤100mm	
56	L>100mm	

Towards a temperature-based verification

4. Step: Definition of a standard detail and crack shape

- Standardization of the geometry and crack shape and size



$L/t = 8{,}20$

$T/t = 0{,}15$

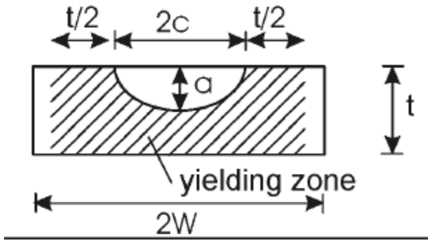
$B/t = 7{,}50$

$\Theta = 45°$

$a_0/c_0 = 0{,}40$

$$a_0 = 0{,}5 \cdot \ln\left(1 + \frac{t}{t_0}\right), t < 15\,mm, t_0 = 1\,mm$$

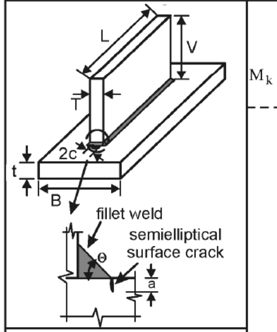
$$a_0 = 0{,}5 \cdot \ln\left(\frac{t}{t_0}\right), \mathrm{t} \geq 15\,mm, t_0 = 1\,mm$$

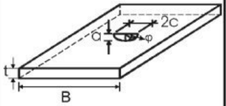


Towards a temperature-based verification

4. Step: Definition of a standard detail and crack shape

- Determination of $\Delta T_\sigma = 52 \cdot ln\left(\frac{(K^*_{appl,d} - 20) \cdot \left(\frac{b_{eff}}{25}\right)^{0,25} - 10}{70}\right)$ with $K^*_{\text{appl,d}} = \frac{\sigma_{Ed} \cdot \sqrt{\pi a_d} \cdot Y \cdot M_K}{k_{R6} - \rho}$

Case	Function M_k	Source
	$M_k = C \cdot \left(\frac{a}{t}\right)^k$ and $M_k \geq 1$ $C = 0.9089 - 0.2357 \cdot \frac{T}{t} + 0.0249 \cdot \left(\frac{L}{t}\right) - 0.00038 \cdot \left(\frac{L}{t}\right)^2 + 0.0186 \cdot \frac{B}{t} - 0.1414 \cdot \frac{\Theta}{45°}$ $k = -0.02285 + 0.0167 \cdot \frac{T}{t} - 0.3863 \cdot \frac{\Theta}{45°} + 0.1230 \cdot \left(\frac{\Theta}{45°}\right)^2$	Hobbacher
range of validity $0.5 \leq \frac{L}{t} \leq 40$ $0.15 \leq \frac{T}{t} \leq 2$ $2.5 \leq \frac{B}{t} \leq 40$ $30° \leq \Theta \leq 60°$		

Case	Function Y	Source
Surface crack 	$Y = \frac{F_s}{\sqrt{Q}}$ $Q = 1 + 1.464\left(\frac{a}{c}\right)^{1.65}$ $F_s = \left[M_1 + M_2 \cdot \left(\frac{a}{t}\right)^2 + M_3 \cdot \left(\frac{a}{t}\right)^4\right] \cdot g \cdot f_\varphi \cdot f_w$	Raju - Newman
range of validity $0 \leq \frac{a}{c} \leq 1$ $\frac{2c}{B} \leq 0.5$ $0 \leq \varphi \leq \pi$ $0 \leq \frac{a}{t} \leq 1$	$M_1 = 1.13 - 0.09 \cdot \left(\frac{a}{c}\right)$ $M_3 = 0.5 - \frac{1}{0.65 + \frac{a}{c}} + 14 \cdot \left(1 - \frac{a}{c}\right)^{24}$ $f_\varphi = \left[\left(\frac{a}{c}\right)^2 \cdot \cos^2\varphi + \sin^2\varphi\right]^{\frac{1}{4}}$ $M_2 = -0.54 + \frac{0.89}{0.2 + \frac{a}{c}}$ $g = 1 + \left[0.1 + 0,35\left(\frac{a}{t}\right)^2\right] \cdot (1 - \sin\varphi)^2$ $f_w = \left[\frac{1}{\cos\left(\frac{\pi \cdot c}{B}\sqrt{\frac{a}{t}}\right)}\right]^{1/2}$	

Towards a temperature-based verification

4. Step: Definition of a standard detail and crack shape

- Determination of $\Delta T_\sigma = 52 \cdot ln\left(\frac{(K^*_{appl,d} - 20)\cdot\left(\frac{b_{eff}}{25}\right)^{0,25} - 10}{70}\right)$ with $K^*_{appl,d} = \frac{\sigma_{Ed}\cdot\sqrt{\pi a_d}\cdot Y\cdot M_K}{k_{R6}-\rho}$

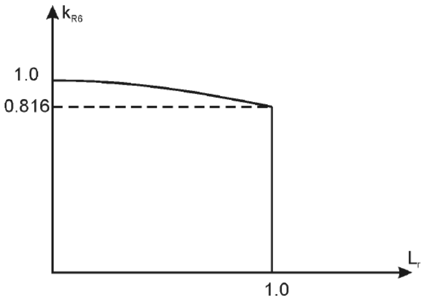
$$k_{R6} = \frac{1}{\sqrt{1+0.5\cdot L_r^2}}$$

where

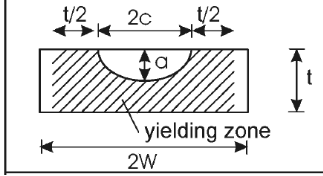
$$L_r = \frac{\sigma_{Ed}}{\sigma_{gy}},$$

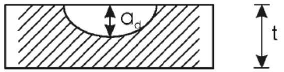
$$\sigma_{Ed} = \sigma_G + \psi_1 \cdot \sigma_Q \boxed{+100\ N/mm^2}$$

Remote restraints



Definition of ρ	
$L_r \leq 0,8$	$\rho = \rho_1$
$0,8 \leq L_r \leq 1,05$	$\rho = 4\ \rho_1\ (1,05 - L_r)$
$1,05 \leq L_r$	$\rho = 0$
Definition of ρ_1	
$\psi = \frac{\sigma_S\ L_r}{\sigma_P} \leq 0$	$\rho_1 = 0$
$\psi = \frac{\sigma_S\ L_r}{\sigma_P} \leq 5,2$	$\rho_1 = 0,1\ \psi^{0,714} - 0,007\ \psi^2 + 0,00003\ \psi^5$
$\psi = \frac{\sigma_S\ L_r}{\sigma_P} > 5,2$	$\rho_1 = 0,25$

Case	Function Y	Source
Surface crack 	$\sigma_{gy}(t) = f_y(t)\left(1 - \frac{\pi \cdot 2.5 \cdot a_d^2}{2 \cdot t \cdot (5 \cdot a_d + t)}\right)$	Harrison

Case	b_{eff} [mm]
Surface crack 	5 a_d

Towards a temperature-based verification

4. Step: Definition of a standard detail and crack shape

- Consideration of the crack growing due to fatigue by *Paris-Erdogan law:*

$$\frac{da}{dN} \approx \frac{\Delta a}{\Delta N} = C \cdot \Delta K^m$$

$\Delta a_i = C \cdot \Delta K_i^m \cdot \Delta N$ with $\Delta K_i = \Delta\sigma \cdot \sqrt{\pi \cdot a_i} \cdot Y_i \cdot M_{K,i}$

$\Delta\sigma = 56\, MPa$

$\Delta N = 500.000$

$$\left.\begin{aligned} C &= 1{,}8 \cdot 10^{-13} \\ m &= 3{,}0 \end{aligned}\right\} \text{For ferritic/pearlitic steels}$$

$$a_d = a_0 + \sum a_i$$

$a_i/c_i = 0{,}40$

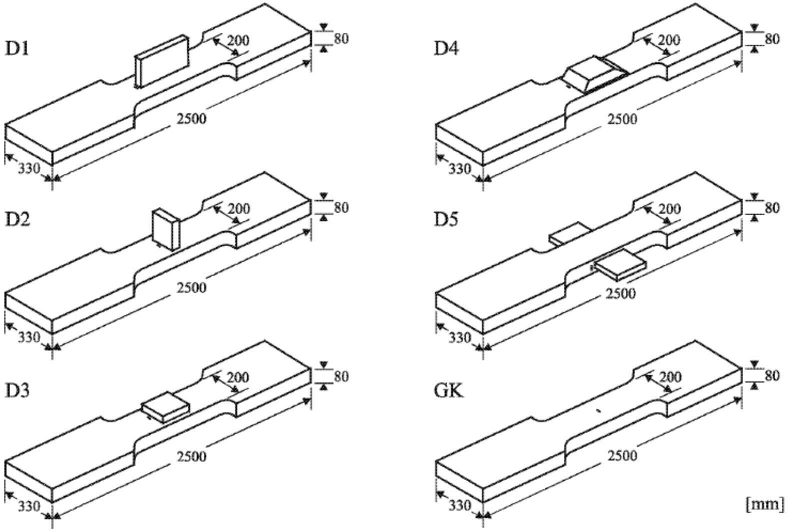
Towards a temperature-based verification

5. Step: Global Safety level

- Statistical evaluation of large-scale tests to determine ΔT_R:

1. Nominal values from product standards (EN 10025):
   $\Delta T_R = + 7$ K
2. Measured values from proper test campaign:
   $\Delta T_R = - 38$ K

- Effect from residual stresses from welding included in ΔT_R



Towards a temperature-based verification

6. Step: Verification in the temperature domain

$$\boxed{T_{Ed}} - \boxed{52 \cdot ln\left(\frac{\left(K^{*}_{appl,d} - 20\right) \cdot \left(\frac{b_{eff}}{25}\right)^{0,25} - 10}{70}\right)} + \Delta T_R \geq T_{27J} - 18°C$$

$$T_{md} + T_r + \Delta T_{\sigma} + \Delta T_R \geq T_{27J} - 18°C$$

T_{md} lowest air temperature (see EN 1991-1-5)

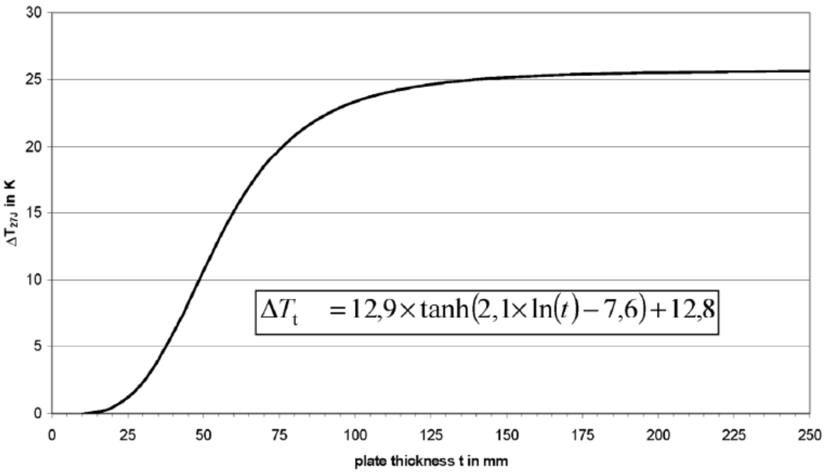
ΔT_r radiation losses ($-5^{\circ}C$)

$$T_{md} + T_r + \Delta T_{\sigma} + \Delta T_R + \left(\Delta T_{\dot{\varepsilon}} + \Delta T_{\varepsilon cf}\right) \geq T_{27J} - 18°C + \Delta T_t \quad \Rightarrow \quad T_{Ed} \geq T_{Rd}$$

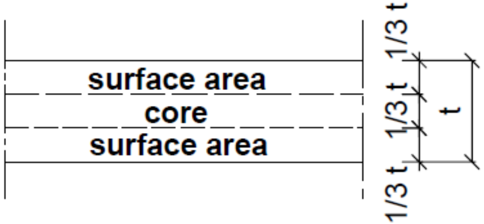
$\Delta T_{\dot{\varepsilon}}$	adjustment for strain rates other than $4*10^{-4}$/sec, EN 1993-1-10, 2.3, (2.3)
$\Delta T_{\varepsilon cf}$	adjustment for cold forming, EN 1993-1-10, 2.3, (2.4), $\Delta T_{\varepsilon cf}$ = 0 K if DCF ≤ 2 %
ΔT_t	adjustment for thick plates

Towards a temperature-based verification

Adjustment for thick plates ΔT_t

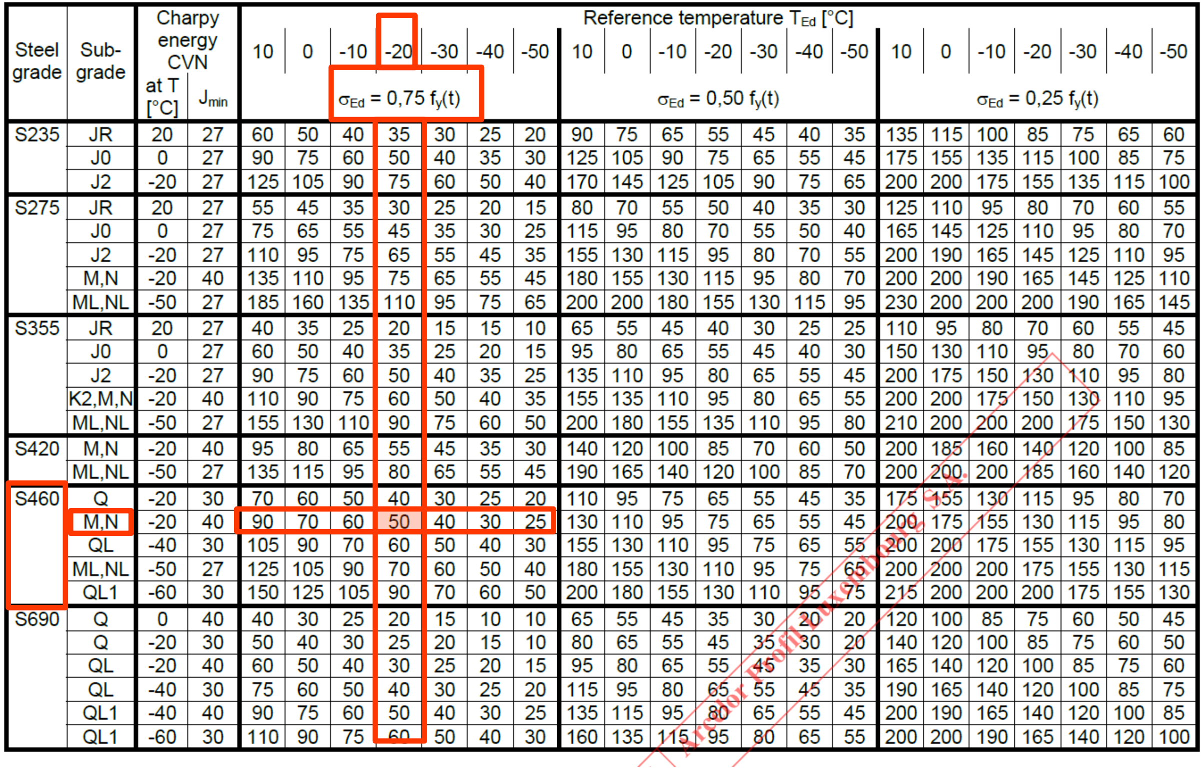


Applies if crack tip is located in core area

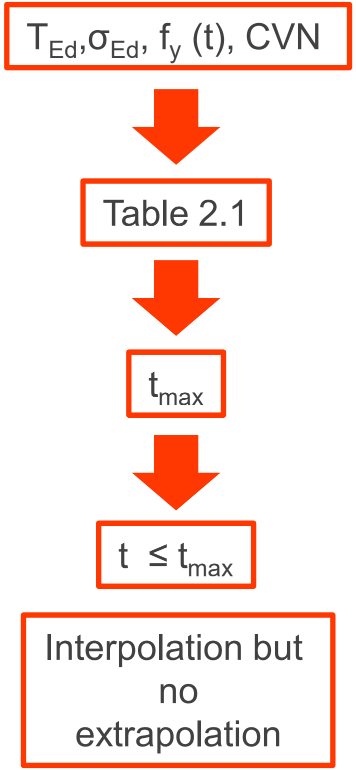


EN 1993-1-10: Clause 2.3 & Table 2.1

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



Steel grade	Sub-grade	Charpy energy CVN		Reference temperature T_{Ed} [°C]																				
		at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0{,}75\ f_y(t)$							$\sigma_{Ed} = 0{,}50\ f_y(t)$							$\sigma_{Ed} = 0{,}25\ f_y(t)$						
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



$T_{Ed}, \sigma_{Ed}, f_y\ (t)$, CVN

Table 2.1

t_{max}

$t \ \leq t_{max}$

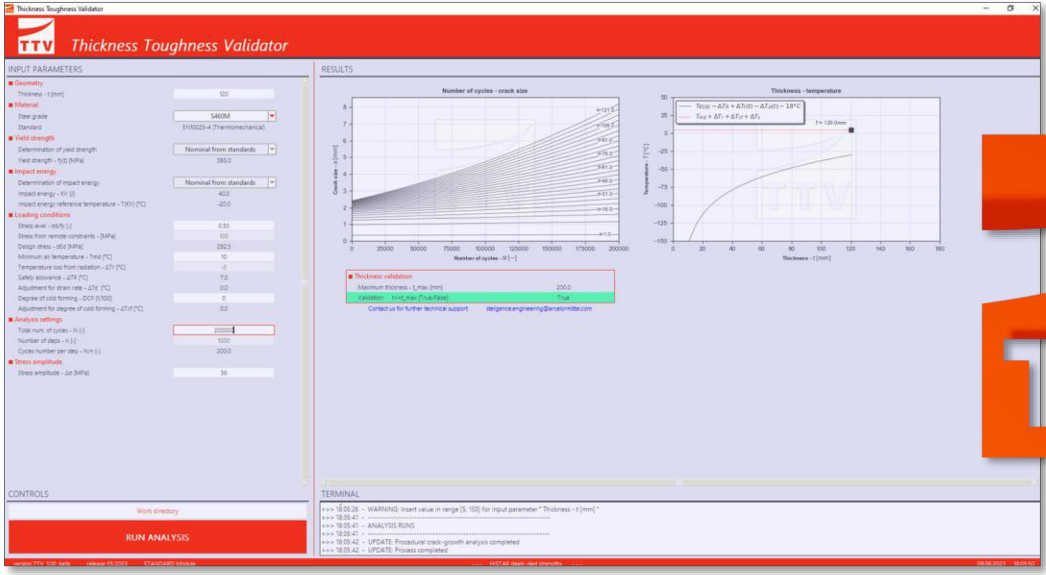
Interpolation but no extrapolation

Use of TTV - Thickness Toughness Validator

A free application for toughness requirements checks according to Eurocode

Introduction

- **Is a tool developed by ArcelorMittal, Steligence Engineering**
- **It allows to perform toughness checks acc. EN 1993-1-10**
- **It is available for free online**



INPUT PARAMETERS

Geometry
Thickness - t [mm]: 120
Material
Steel grade: S460M
Standard: EN10025-4 (Thermomechanical)
Yield strength
Determination of yield strength: Nominal from standards
Yield strength - fy(t) [MPa]: 385.0
Impact energy
Determination of impact energy: Nominal from standards
Impact energy - KV [J]: 40.0
Impact energy reference temperature - T(KV) [°C]: -20.0
Loading conditions
Stress level - σd/fy [-]: 0.50
Stress from remote constraints - [MPa]: 100
Design stress - σEd [MPa]: 292.5
Minimum air temperature - Tmd [°C]: 10
Temperature loss from radiation - ΔTr [°C]: -5
Safety allowance - ΔTR [°C]: 7.0
Adjustment for strain rate - ΔTε' [°C]: 0.0
Degree of cold forming - DCF [1/100]: 0
Adjustment for degree of cold forming - ΔTcf [°C]: 0.0
Analysis settings
Total num. of cycles - N [-]: 200000
Number of steps - n [-]: 1000
Cycles number per step - N/n [-]: 200.0
Stress amplitude
Stress amplitude - Δσ [MPa]: 56

Thickness validation
Maximum thickness - t_max [mm]: 200.0
Validation: t<=t_max [True/False]: True

Contact us for further technical support: steligence.engineering@arcelormittal.com

TERMINAL

```
>>> 18:05:26 - WARNING: Insert value in range [5; 150] for input parameter " Thickness - t [mm] "
>>> 18:05:41 - ------------------------------------------------------------
>>> 18:05:41 - ANALYSIS RUNS
>>> 18:05:41 - ------------------------------------------------------------
>>> 18:05:42 - UPDATE: Procedural crack-growth analysis completed
>>> 18:05:42 - UPDATE: Process completed
```

Scope and limitations of TTV

- Know **scopes and limits** of software and applications
- Know what the software does (**implementations + background**)

Scope and limitations of TTV

What it is conceived for

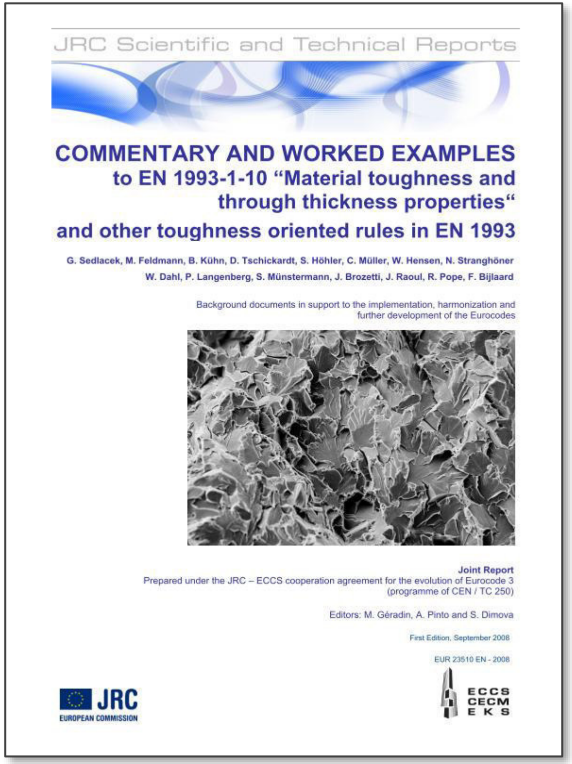
- More **advanced toughness checks compared to the “table” method**
- Requires **input which must be mastered** by the structural engineer user
- Use well-established **analytical formulas** framed by the BGD of Eurocode
- **New constructions** designed according Eurocode

What it doesn't do

- **Steel grades not covered** by the design standards
- **Execution imperfections or cracks**
- **Existing old structures** where other safety factors may apply

Other advanced methods are possible and may deliver more refined results *(e.g. numerical simulations with explicit crack propagation in non-linear fracture mechanics)*

Technical background and references



JRC Scientific and Technical Reports

COMMENTARY AND WORKED EXAMPLES to EN 1993-1-10 "Material toughness and through thickness properties" and other toughness oriented rules in EN 1993

G. Sedlacek, M. Feldmann, B. Kühn, D. Tschickardt, S. Höhler, C. Müller, W. Hensen, N. Stranghöner
W. Dahl, P. Langenberg, S. Münstermann, J. Brozetti, J. Raoul, R. Pope, F. Bijlaard

Background documents in support to the implementation, harmonization and further development of the Eurocodes

Joint Report
Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3
(programme of CEN / TC 250)

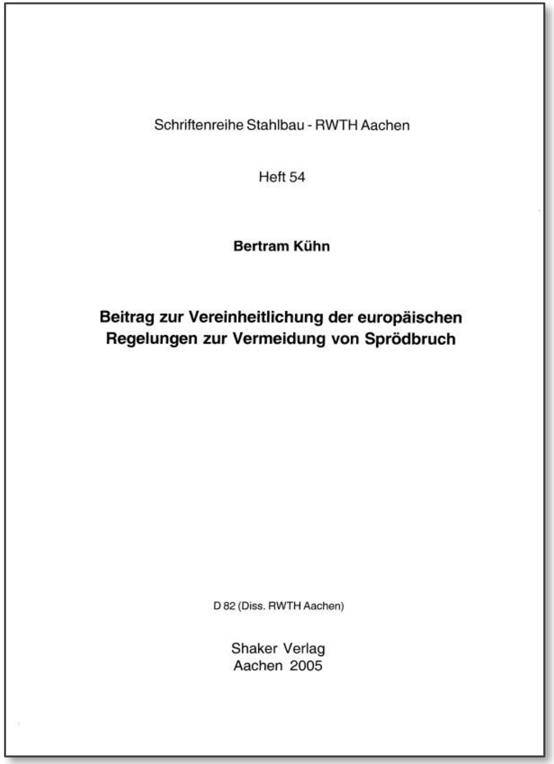
Editors: M. Géradin, A. Pinto and S. Dimova

First Edition, September 2008

EUR 23510 EN - 2008

JRC
EUROPEAN COMMISSION

ECCS
CECM
EKS



Schriftenreihe Stahlbau - RWTH Aachen

Heft 54

Bertram Kühn

Beitrag zur Vereinheitlichung der europäischen Regelungen zur Vermeidung von Sprödbruch

D 82 (Diss. RWTH Aachen)

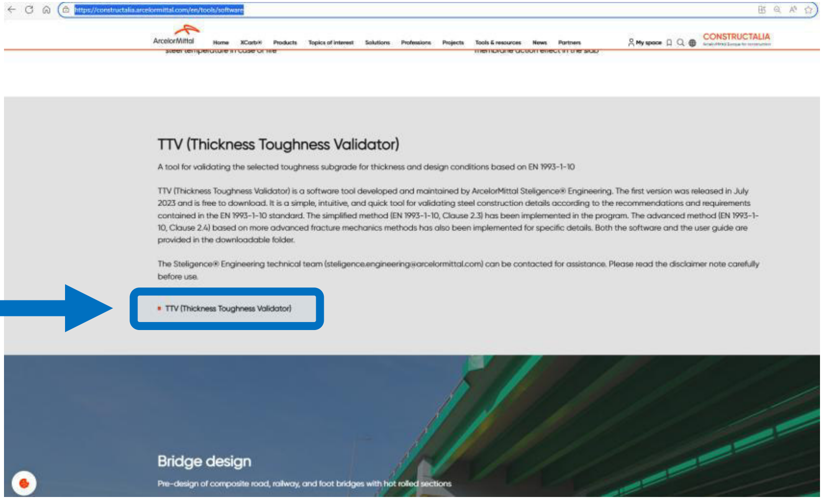
Shaker Verlag
Aachen 2005

Download and first use

1. Go to:

   constructalia.arcelormittal.com/en/tools/software

2. Download the folder
3. <u>Un-zip the folder</u>
4. In the un-zipped folder you will find the .exe file



TTV (Thickness Toughness Validator)

A tool for validating the selected toughness subgrade for thickness and design conditions based on EN 1993-1-10

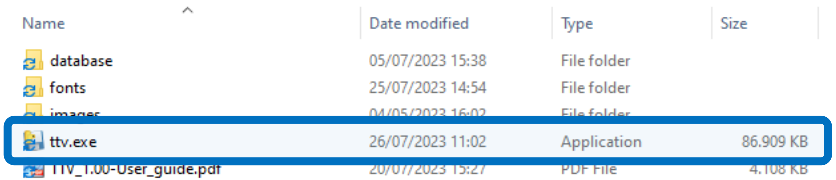
TTV (Thickness Toughness Validator) is a software tool developed and maintained by ArcelorMittal Steligence® Engineering. The first version was released in July 2023 and is free to download. It is a simple, intuitive, and quick tool for validating steel construction details according to the recommendations and requirements contained in the EN 1993-1-10 standard. The simplified method (EN 1993-1-10, Clause 2.3) has been implemented in the program. The advanced method (EN 1993-1-10, Clause 2.4) based on more advanced fracture mechanics methods has also been implemented for specific details. Both the software and the user guide are provided in the downloadable folder.

The Steligence® Engineering technical team (steligence.engineering@arcelormittal.com) can be contacted for assistance. Please read the disclaimer note carefully before use.

- TTV (Thickness Toughness Validator)

Bridge design

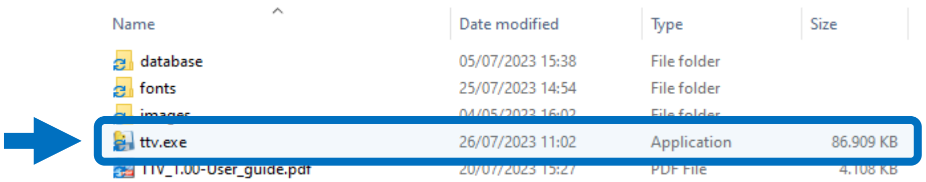
Pre-design of composite road, railway, and foot bridges with hot rolled sections



Name	Date modified	Type	Size
database	05/07/2023 15:38	File folder	
fonts	25/07/2023 14:54	File folder	
images	04/05/2023 16:02	File folder	
ttv.exe	26/07/2023 11:02	Application	86.909 KB
TTV_1.00-User_guide.pdf	20/07/2023 15:27	PDF File	4.108 KB

Download and first use

5. **Double click**
6. **Wait 20 seconds**
7. **Start window pops up**



Name	Date modified	Type	Size
database	05/07/2023 15:38	File folder	
fonts	25/07/2023 14:54	File folder	
images	04/05/2023 16:02	File folder	
ttv.exe	26/07/2023 11:02	Application	86.909 KB
TTV_1.00-User_guide.pdf	20/07/2023 15:27	PDF File	4.108 KB

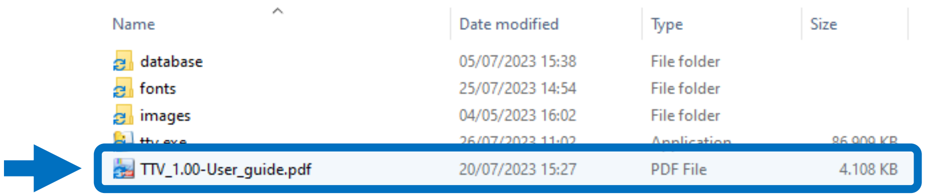
Thickness Toughness Validator

version TTV_1.00 release 07.2023

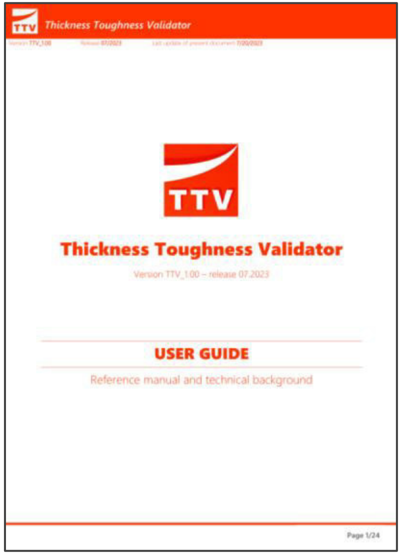
User guide

In this file you will find

- How to install
- First use
- Quick technical background
- Some examples of calculation and validation



Name	Date modified	Type	Size
database	05/07/2023 15:38	File folder	
fonts	25/07/2023 14:54	File folder	
images	04/05/2023 16:02	File folder	
ttv.exe	26/07/2023 11:02	Application	86.909 KB
TTV_1.00-User_guide.pdf	20/07/2023 15:27	PDF File	4.108 KB



Thickness Toughness Validator

Version TTV_1.00 Release 07/2023 Last update of present document 7/20/2023

TTV

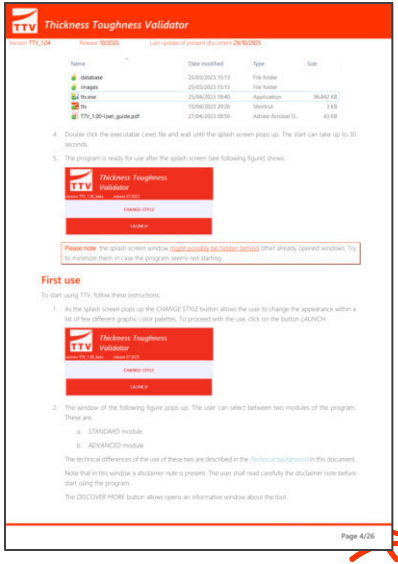
Thickness Toughness Validator

Version TTV_1.00 – release 07.2023

USER GUIDE

Reference manual and technical background

Page 1/24



Thickness Toughness Validator

Version TTV_1.04 Release 10/2025 Last update of present document 29/10/2025

Name	Date modified	Type	Size
database	25/03/2023 15:13	File folder	
images	25/03/2023 15:13	File folder	
ttv.exe	25/04/2023 18:40	Application	86.842 KB
ttv	15/04/2023 20:26	Shortcut	3 KB
TTV_1.00-User_guide.pdf	27/04/2023 08:59	Adobe Acrobat D...	43 KB

4. Double click the executable (.exe) file and wait until the splash screen pops up. The start can take up to 30 seconds.
5. The program is ready for use after the splash screen (see following figure) shows:

Please note: the splash screen window might possibly be hidden behind other already opened windows. Try to minimize them in case the program seems not starting.

First use

To start using TTV, follow these instructions:

1. As the splash screen pops up the *CHANGE STYLE* button allows the user to change the appearance within a list of few different graphic color palettes. To proceed with the use, click on the button *LAUNCH*.

2. The window of the following figure pops up. The user can select between two modules of the program. These are:
   a. *STANDARD* module
   b. *ADVANCED* module

The technical differences of the use of these two are described in the Technical background in this document.

Note that in this window a *disclaimer note* is present. The user shall read carefully the disclaimer note before start using the program.

The *DISCOVER MORE* button allows opens an informative window about the tool.

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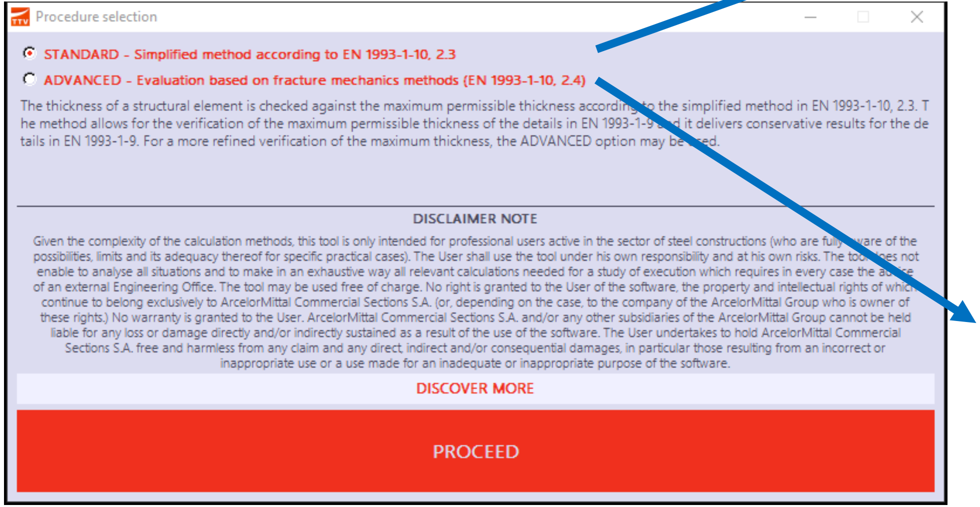
Modules



● STANDARD - Simplified method according to EN 1993-1-10, 2.3

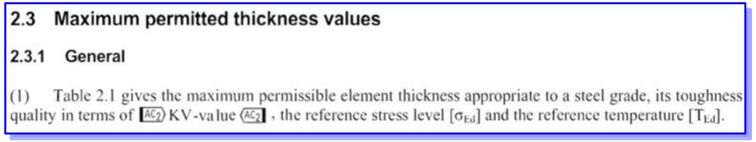
○ ADVANCED - Evaluation based on fracture mechanics methods (EN 1993-1-10, 2.4)

The thickness of a structural element is checked against the maximum permissible thickness according to the simplified method in EN 1993-1-10, 2.3. The method allows for the verification of the maximum permissible thickness of the details in EN 1993-1-9 and it delivers conservative results for the details in EN 1993-1-9. For a more refined verification of the maximum thickness, the ADVANCED option may be used.

DISCLAIMER NOTE

Given the complexity of the calculation methods, this tool is only intended for professional users active in the sector of steel constructions (who are fully aware of the possibilities, limits and its adequacy thereof for specific practical cases). The User shall use the tool under his own responsibility and at his own risks. The tool does not enable to analyse all situations and to make in an exhaustive way all relevant calculations needed for a study of execution which requires in every case the advice of an external Engineering Office. The tool may be used free of charge. No right is granted to the User of the software, the property and intellectual rights of which continue to belong exclusively to ArcelorMittal Commercial Sections S.A. (or, depending on the case, to the company of the ArcelorMittal Group who is owner of these rights.) No warranty is granted to the User. ArcelorMittal Commercial Sections S.A. and/or any other subsidiaries of the ArcelorMittal Group cannot be held liable for any loss or damage directly and/or indirectly sustained as a result of the use of the software. The User undertakes to hold ArcelorMittal Commercial Sections S.A. free and harmless from any claim and any direct, indirect and/or consequential damages, in particular those resulting from an incorrect or inappropriate use or a use made for an inadequate or inappropriate purpose of the software.

STANDARD
Clause 2.3, EN1993-1-10

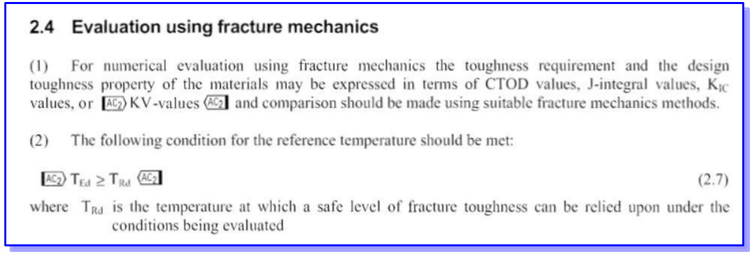


2.3 Maximum permitted thickness values

2.3.1 General

(1) Table 2.1 gives the maximum permissible element thickness appropriate to a steel grade, its toughness quality in terms of AC2 KV-value AC2, the reference stress level [σ_{Ed}] and the reference temperature [T_{Ed}].

ADVANCED
Clause 2.4, EN1993-1-10



2.4 Evaluation using fracture mechanics

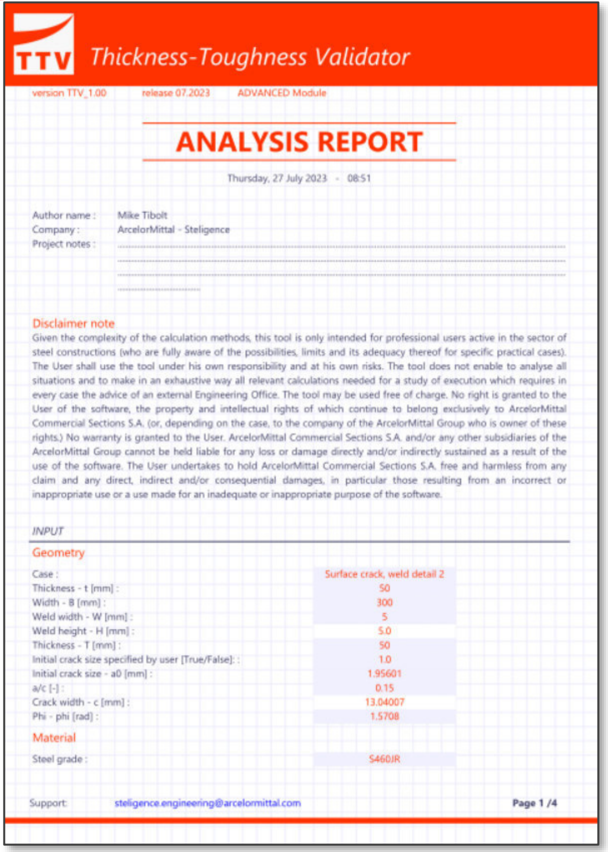
(1) For numerical evaluation using fracture mechanics the toughness requirement and the design toughness property of the materials may be expressed in terms of CTOD values, J-integral values, K_{IC} values, or AC2 KV-values AC2 and comparison should be made using suitable fracture mechanics methods.

(2) The following condition for the reference temperature should be met:

$$T_{Ed} \geq T_{Rd} \quad (2.7)$$

where T_{Rd} is the temperature at which a safe level of fracture toughness can be relied upon under the conditions being evaluated

Report printing



TTV Thickness-Toughness Validator

version TTV_1.00 release 07.2023 ADVANCED Module

ANALYSIS REPORT

Thursday, 27 July 2023 - 08:51

Author name : Mike Tibolt
Company : ArcelorMittal - Steligence
Project notes : ....

Disclaimer note

Given the complexity of the calculation methods, this tool is only intended for professional users active in the sector of steel constructions (who are fully aware of the possibilities, limits and its adequacy thereof for specific practical cases). The User shall use the tool under his own responsibility and at his own risks. The tool does not enable to analyse all situations and to make in an exhaustive way all relevant calculations needed for a study of execution which requires in every case the advice of an external Engineering Office. The tool may be used free of charge. No right is granted to the User of the software, the property and intellectual rights of which continue to belong exclusively to ArcelorMittal Commercial Sections S.A. (or, depending on the case, to the company of the ArcelorMittal Group who is owner of these rights.) No warranty is granted to the User. ArcelorMittal Commercial Sections S.A. and/or any other subsidiaries of the ArcelorMittal Group cannot be held liable for any loss or damage directly and/or indirectly sustained as a result of the use of the software. The User undertakes to hold ArcelorMittal Commercial Sections S.A. free and harmless from any claim and any direct, indirect and/or consequential damages, in particular those resulting from an incorrect or inappropriate use or a use made for an inadequate or inappropriate purpose of the software.

INPUT

Geometry

Case :	Surface crack, weld detail 2
Thickness - t [mm] :	50
Width - B [mm] :	300
Weld width - W [mm] :	5
Weld height - H [mm] :	5.0
Thickness - T [mm] :	50
Initial crack size specified by user [True/False]: :	1.0
Initial crack size - a0 [mm] :	1.95601
a/c [-] :	0.15
Crack width - c [mm] :	13.04007
Phi - phi [rad] :	1.5708

Material

Steel grade :	S460JR

Support: steligence.engineering@arcelormittal.com **Page 1 /4**

Example 1: butt weld joint – Clause 2.3

Context

- longitudinal butt-weld detail (t_f=60mm). The steel grade is S355J2.
- The stress level in the frequent design combination (EN 1993-1-10, 2.2(4), with temperature as leading action) is 0,63 fy.

  $\sigma_{\Delta T} = 50\ MPa$

  $\sigma_G = 85\ MPa,$

  $\sigma_Q = 100\ MPa,$

  $\psi_1 = 0{,}80$
- The minimum air temperature is $T_{md} = -25\ °C$

  $(T_{Ed} = T_{md} - 5°C = -30°C)$
- Cold forming can be neglected.

ArcelorMittal

Example 1: butt weld joint – Clause 2.3

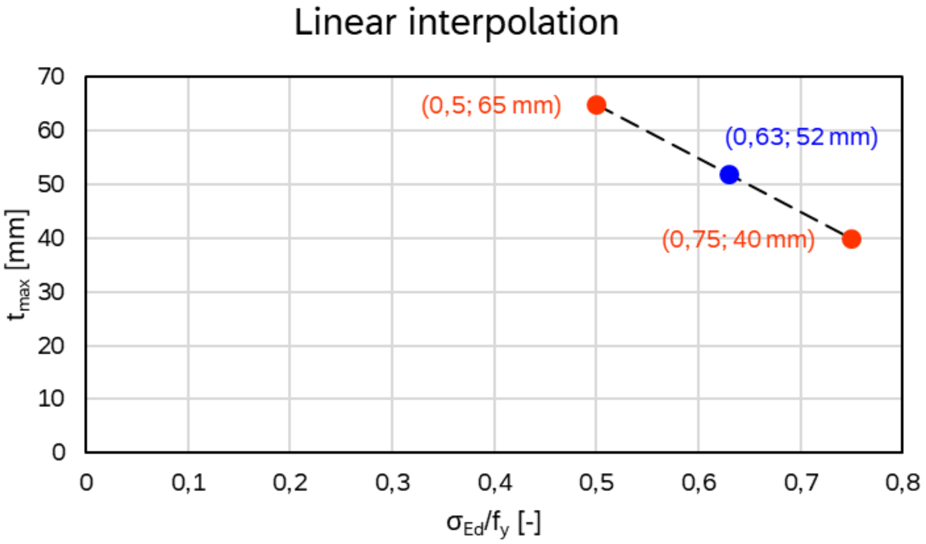
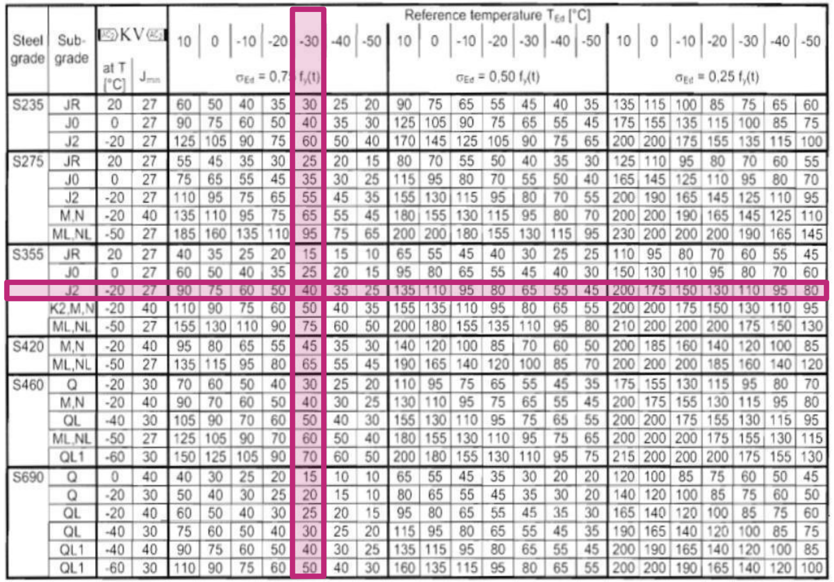


Table 2.1: Maximum permissible values of element thickness t in mm

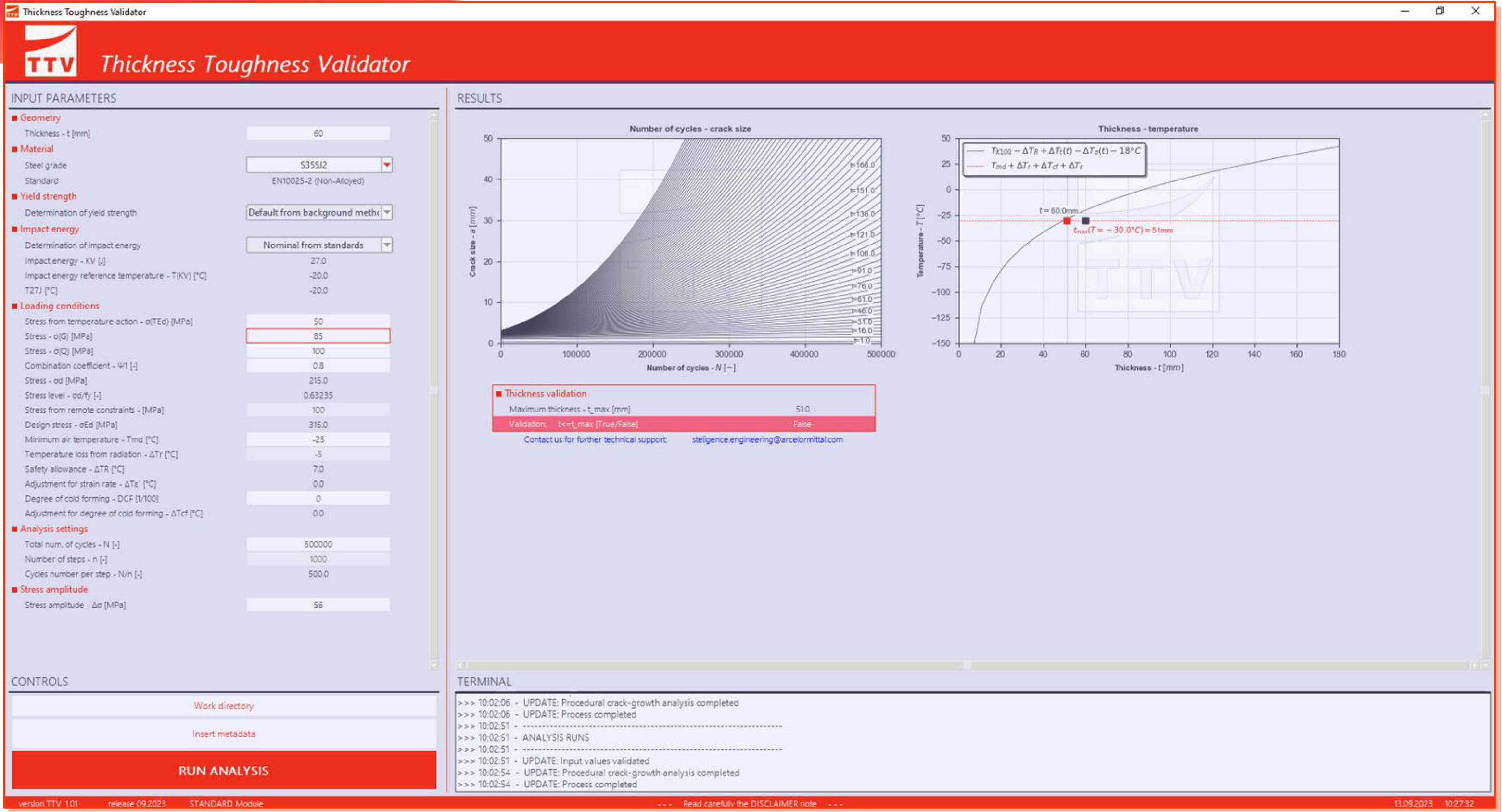


Steel grade	Sub-grade	KV		Reference temperature T_{Ed} [°C]																				
		at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0,75\ f_y(t)$							$\sigma_{Ed} = 0,50\ f_y(t)$							$\sigma_{Ed} = 0,25\ f_y(t)$						
S235	JR	20	27	60	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

$$t = 60mm \le t_{max} = 52mm \rightarrow \boldsymbol{False}$$

not verified

Example 1: butt weld joint – Clause 2.3



INPUT PARAMETERS

Geometry

Thickness - t [mm]	60

Material

Steel grade	S355J2
Standard	EN10025-2 (Non-Alloyed)

Yield strength

Determination of yield strength	Default from background meth

Impact energy

Determination of impact energy	Nominal from standards
Impact energy - KV [J]	27.0
Impact energy reference temperature - T(KV) [°C]	-20.0
T27J [°C]	-20.0

Loading conditions

Stress from temperature action - σ(TEd) [MPa]	50
Stress - σ(G) [MPa]	85
Stress - σ(Q) [MPa]	100
Combination coefficient - Ψ1 [-]	0.8
Stress - σd [MPa]	215.0
Stress level - σd/fy [-]	0.63235
Stress from remote constraints - [MPa]	100
Design stress - σEd [MPa]	315.0
Minimum air temperature - Tmd [°C]	-25
Temperature loss from radiation - ΔTr [°C]	-5
Safety allowance - ΔTR [°C]	7.0
Adjustment for strain rate - ΔTε' [°C]	0.0
Degree of cold forming - DCF [1/100]	0
Adjustment for degree of cold forming - ΔTcf [°C]	0.0

Analysis settings

Total num. of cycles - N [-]	500000
Number of steps - n [-]	1000
Cycles number per step - N/n [-]	500.0

Stress amplitude

Stress amplitude - Δσ [MPa]	56

CONTROLS

RESULTS

Thickness validation

Maximum thickness - t_max [mm]	51.0
Validation: t<=t_max [True/False]	False

Contact us for further technical support: steligence.engineering@arcelormittal.com

TERMINAL

```
>>> 10:02:06  -  UPDATE: Procedural crack-growth analysis completed
>>> 10:02:06  -  UPDATE: Process completed
>>> 10:02:51  -  ------------------------------------------------------------------
>>> 10:02:51  -  ANALYSIS RUNS
>>> 10:02:51  -  ------------------------------------------------------------------
>>> 10:02:51  -  UPDATE: Input values validated
>>> 10:02:54  -  UPDATE: Procedural crack-growth analysis completed
>>> 10:02:54  -  UPDATE: Process completed
```

version TTV 1.01 release 09.2023 STANDARD Module - - - Read carefully the DISCLAIMER note - - - 13.09.2023 10:27:32

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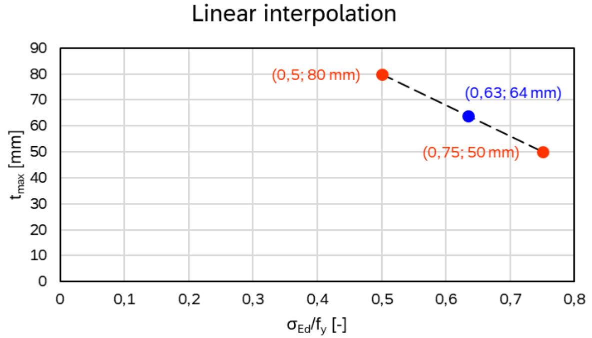
Example 1: butt weld joint – Clause 2.3



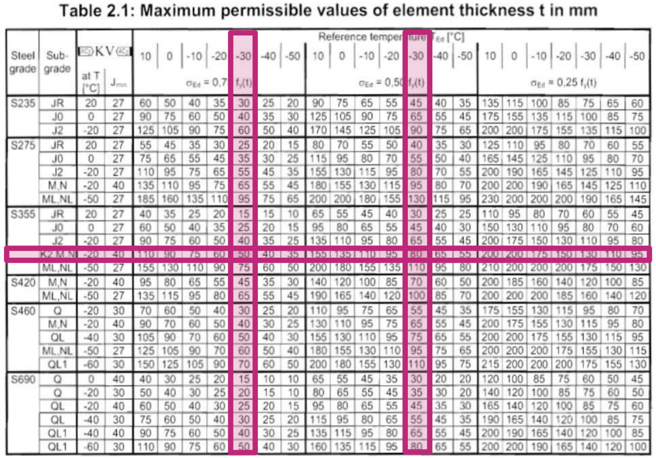
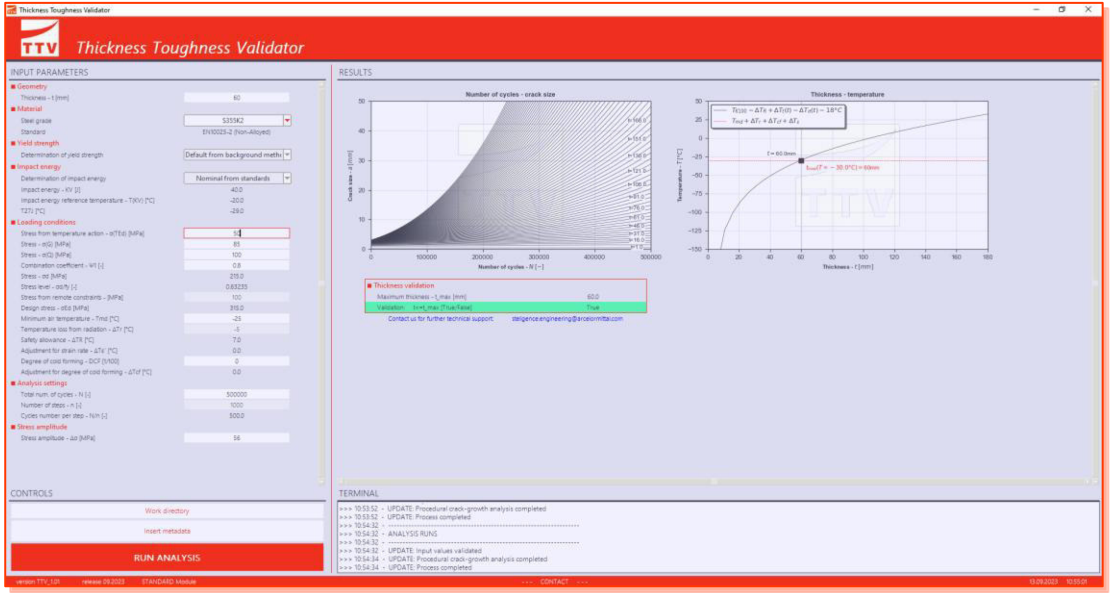


Table 2.1: Maximum permissible values of element thickness t in mm

Steel grade	Sub-grade	KV at T [°C]	J_{min}	Reference temperature T_{Ed} [°C]																				
				10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				σ_{Ed} = 0,7 $f_y(t)$							σ_{Ed} = 0,50 $f_y(t)$							σ_{Ed} = 0,25 $f_y(t)$						
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

Results for **changing to S355K2**: the toughness check for the detail is **satisfied** with both procedures with a difference in t_{max} of 4mm, likely due to linear interpolation and 5mm rounding of the EN 1993-1-10 table.



INPUT PARAMETERS

Geometry

Thickness - t [mm]	60

Material

Steel grade	S355K2
Standard	EN10025-2 (Non-Alloyed)

Yield strength

Determination of yield strength	Default from background meth

Impact energy

Determination of impact energy	Nominal from standards
Impact energy - KV [J]	40.0
Impact energy reference temperature - T(KV) [°C]	-20.0
T27J [°C]	-29.0

Loading conditions

Stress from temperature action - σ(TEd) [MPa]	50
Stress - σ(G) [MPa]	85
Stress - σ(Q) [MPa]	100
Combination coefficient - Ψ1 [-]	0.8
Stress - σd [MPa]	215.0
Stress level - σd/fy [-]	0.63235
Stress from remote constraints - [MPa]	100
Design stress - σEd [MPa]	315.0
Minimum air temperature - Tmd [°C]	-25
Temperature loss from radiation - ΔTr [°C]	-5
Safety allowance - ΔTR [°C]	7.0
Adjustment for strain rate - ΔTε' [°C]	0.0
Degree of cold forming - DCF [1/100]	0
Adjustment for degree of cold forming - ΔTcf [°C]	0.0

Analysis settings

Total num. of cycles - N [-]	500000
Number of steps - n [-]	1000
Cycles number per step - N/n [-]	500.0

Stress amplitude

Stress amplitude - Δσ [MPa]	56

Thickness validation

Maximum thickness - t_max [mm]	60.0
Validation: t<=t_max [True/False]	True

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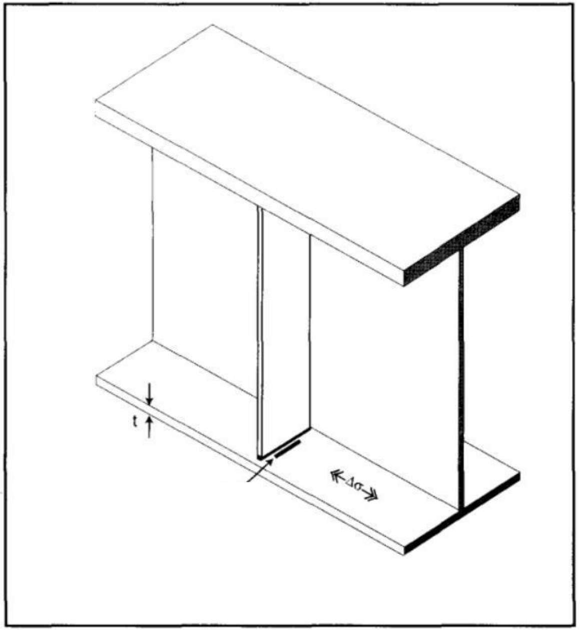
TERMINAL

```
>>> 10:53:52  -  UPDATE: Procedural crack-growth analysis completed
>>> 10:53:52  -  UPDATE: Process completed
>>> 10:54:32  -  ----------------------------------------------------------------
>>> 10:54:32  -  ANALYSIS RUNS
>>> 10:54:32  -  ----------------------------------------------------------------
>>> 10:54:32  -  UPDATE: Input values validated
>>> 10:54:34  -  UPDATE: Procedural crack-growth analysis completed
>>> 10:54:34  -  UPDATE: Process completed
```

Example 2: transverse stiffener – Clause 2.4



Context: a stiffener plate is welded on the side of a bridge girder (t_f=65mm, t_{stiff}=15mm, b=300 mm). The steel grade is **S460J0**.

The stress level in the frequent design combination (EN 1993-1-10, 2.2(4), with temperature as leading action) is 0,656 fy

$\sigma_{\Delta T} = 50\ MPa$

$\sigma_G = 185\ MPa,$

$\sigma_Q = 70\ MPa,$

$\psi_1 = 0{,}80$

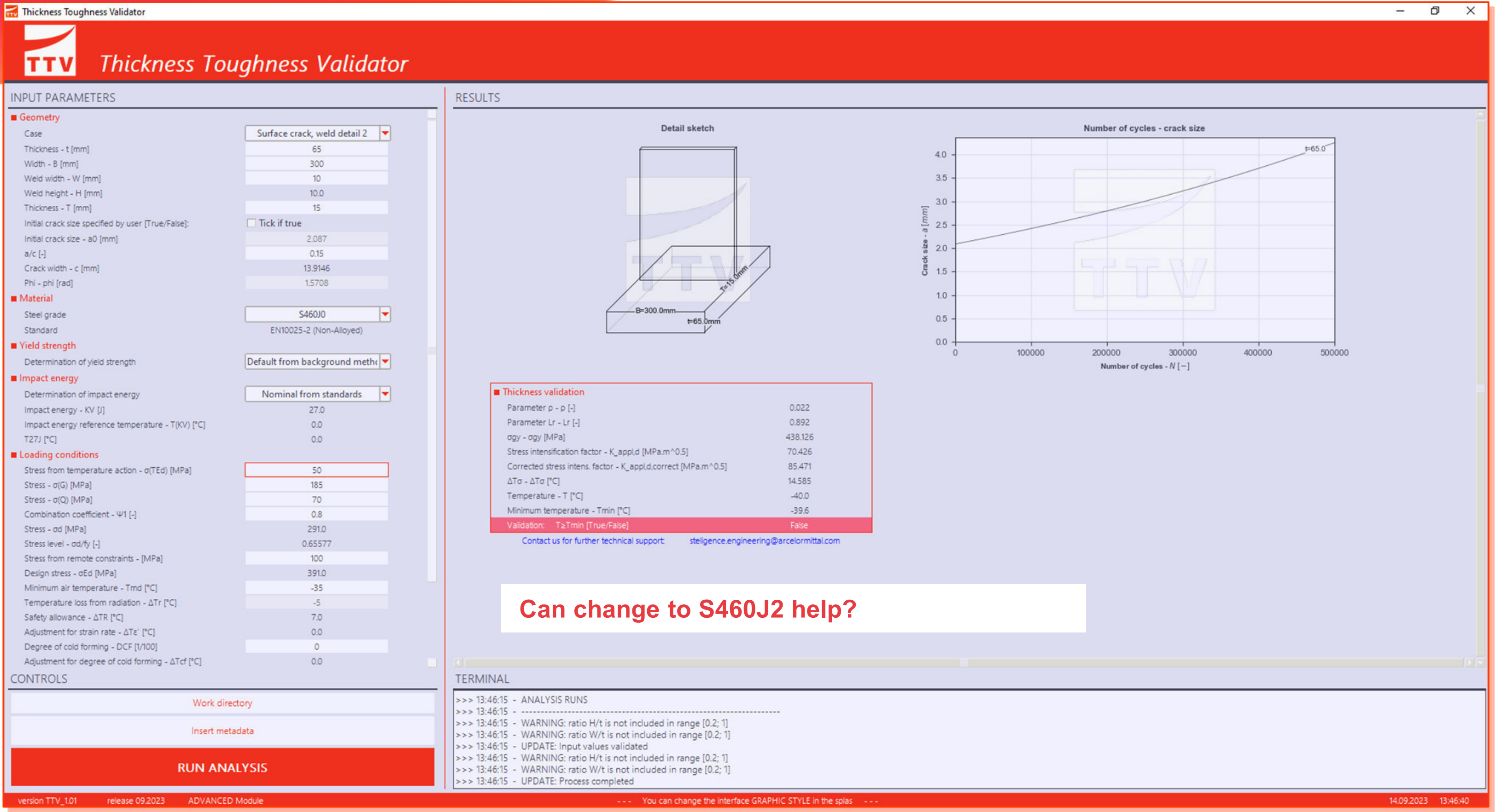
The minimum air temperature is $T_{md} = -35\ °C$
Cold forming can be neglected.

Every 25 years an inspection is foreseen to detect eventual cracks.

The stress range is $\Delta\sigma = 56MPa$

Use of TTV (Thickness Toughness Validator) tool

Example 2: transverse stiffener – Clause 2.4



INPUT PARAMETERS

Geometry

Case	Surface crack, weld detail 2
Thickness - t [mm]	65
Width - B [mm]	300
Weld width - W [mm]	10
Weld height - H [mm]	10.0
Thickness - T [mm]	15
Initial crack size specified by user [True/False]:	☐ Tick if true
Initial crack size - a0 [mm]	2.087
a/c [-]	0.15
Crack width - c [mm]	13.9146
Phi - phi [rad]	1.5708

Material

Steel grade	S460J0
Standard	EN10025-2 (Non-Alloyed)

Yield strength

Determination of yield strength	Default from background meth

Impact energy

Determination of impact energy	Nominal from standards
Impact energy - KV [J]	27.0
Impact energy reference temperature - T(KV) [°C]	0.0
T27J [°C]	0.0

Loading conditions

Stress from temperature action - σ(TEd) [MPa]	50
Stress - σ(G) [MPa]	185
Stress - σ(Q) [MPa]	70
Combination coefficient - Ψ1 [-]	0.8
Stress - σd [MPa]	291.0
Stress level - σd/fy [-]	0.65577
Stress from remote constraints - [MPa]	100
Design stress - σEd [MPa]	391.0
Minimum air temperature - Tmd [°C]	-35
Temperature loss from radiation - ΔTr [°C]	-5
Safety allowance - ΔTR [°C]	7.0
Adjustment for strain rate - ΔTε` [°C]	0.0
Degree of cold forming - DCF [1/100]	0
Adjustment for degree of cold forming - ΔTcf [°C]	0.0

RESULTS

Thickness validation

Parameter ρ - ρ [-]	0.022
Parameter Lr - Lr [-]	0.892
σgy - σgy [MPa]	438.126
Stress intensification factor - K_appl,d [MPa.m^0.5]	70.426
Corrected stress intens. factor - K_appl,d,correct [MPa.m^0.5]	85.471
ΔTσ - ΔTσ [°C]	14.585
Temperature - T [°C]	-40.0
Minimum temperature - Tmin [°C]	-39.6
Validation: T≥Tmin [True/False]	False

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Can change to S460J2 help?

TERMINAL

```
>>> 13:46:15  -  ANALYSIS RUNS
>>> 13:46:15  -  ------------------------------------------------------------------
>>> 13:46:15  -  WARNING: ratio H/t is not included in range [0.2; 1]
>>> 13:46:15  -  WARNING: ratio W/t is not included in range [0.2; 1]
>>> 13:46:15  -  UPDATE: Input values validated
>>> 13:46:15  -  WARNING: ratio H/t is not included in range [0.2; 1]
>>> 13:46:15  -  WARNING: ratio W/t is not included in range [0.2; 1]
>>> 13:46:15  -  UPDATE: Process completed
```

version TTV_1.01   release 09.2023   ADVANCED Module   - - - You can change the interface GRAPHIC STYLE in the splas - - -   14.09.2023   13:46:40

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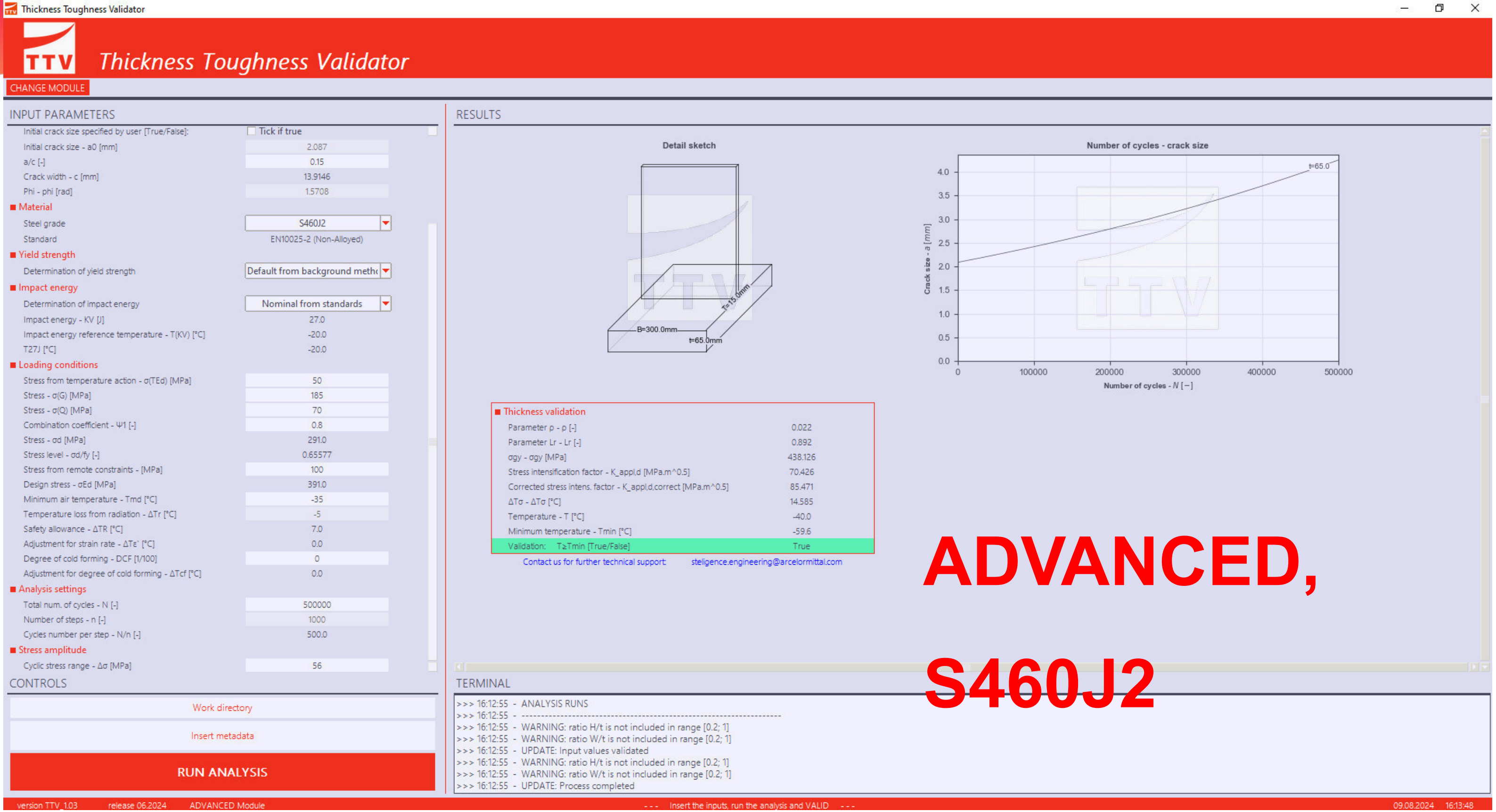
Use of TTV (Thickness Toughness Validator) tool

Example 2: transverse stiffener – Clause 2.4



INPUT PARAMETERS

Initial crack size specified by user [True/False]:	☐ Tick if true
Initial crack size - a0 [mm]	2.087
a/c [-]	0.15
Crack width - c [mm]	13.9146
Phi - phi [rad]	1.5708
Material	
Steel grade	S460J2
Standard	EN10025-2 (Non-Alloyed)
Yield strength	
Determination of yield strength	Default from background meth
Impact energy	
Determination of impact energy	Nominal from standards
Impact energy - KV [J]	27.0
Impact energy reference temperature - T(KV) [°C]	-20.0
T27J [°C]	-20.0
Loading conditions	
Stress from temperature action - σ(TEd) [MPa]	50
Stress - σ(G) [MPa]	185
Stress - σ(Q) [MPa]	70
Combination coefficient - Ψ1 [-]	0.8
Stress - σd [MPa]	291.0
Stress level - σd/fy [-]	0.65577
Stress from remote constraints - [MPa]	100
Design stress - σEd [MPa]	391.0
Minimum air temperature - Tmd [°C]	-35
Temperature loss from radiation - ΔTr [°C]	-5
Safety allowance - ΔTR [°C]	7.0
Adjustment for strain rate - ΔTε` [°C]	0.0
Degree of cold forming - DCF [1/100]	0
Adjustment for degree of cold forming - ΔTcf [°C]	0.0
Analysis settings	
Total num. of cycles - N [-]	500000
Number of steps - n [-]	1000
Cycles number per step - N/n [-]	500.0
Stress amplitude	
Cyclic stress range - Δσ [MPa]	56

CONTROLS

Thickness validation

Parameter ρ - ρ [-]	0.022
Parameter Lr - Lr [-]	0.892
σgy - σgy [MPa]	438.126
Stress intensification factor - K_appl,d [MPa.m^0.5]	70.426
Corrected stress intens. factor - K_appl,d,correct [MPa.m^0.5]	85.471
ΔTσ - ΔTσ [°C]	14.585
Temperature - T [°C]	-40.0
Minimum temperature - Tmin [°C]	-59.6
Validation: T≥Tmin [True/False]	True

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TERMINAL

```
>>> 16:12:55  -  ANALYSIS RUNS
>>> 16:12:55  -  ---------------------------------------------------------------
>>> 16:12:55  -  WARNING: ratio H/t is not included in range [0.2; 1]
>>> 16:12:55  -  WARNING: ratio W/t is not included in range [0.2; 1]
>>> 16:12:55  -  UPDATE: Input values validated
>>> 16:12:55  -  WARNING: ratio H/t is not included in range [0.2; 1]
>>> 16:12:55  -  WARNING: ratio W/t is not included in range [0.2; 1]
>>> 16:12:55  -  UPDATE: Process completed
```

version TTV_1.03 release 06.2024 ADVANCED Module --- Insert the inputs, run the analysis and VALID --- 09.08.2024 16:13:48

ADVANCED,

S460J2

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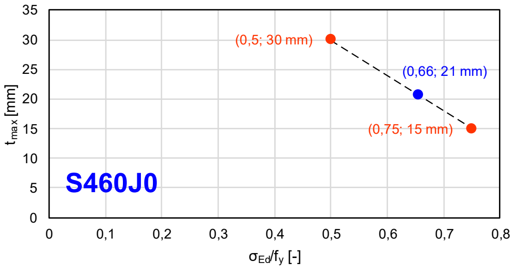
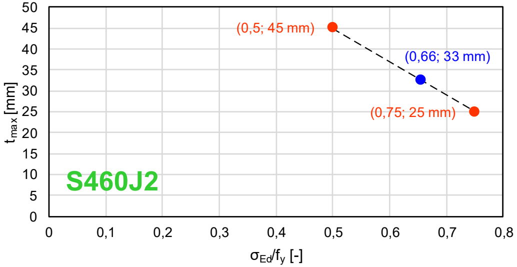
Example 2: transverse stiffener – Clause 2.4

Application of Clause 2.3, EN 1993-1-10 as comparison

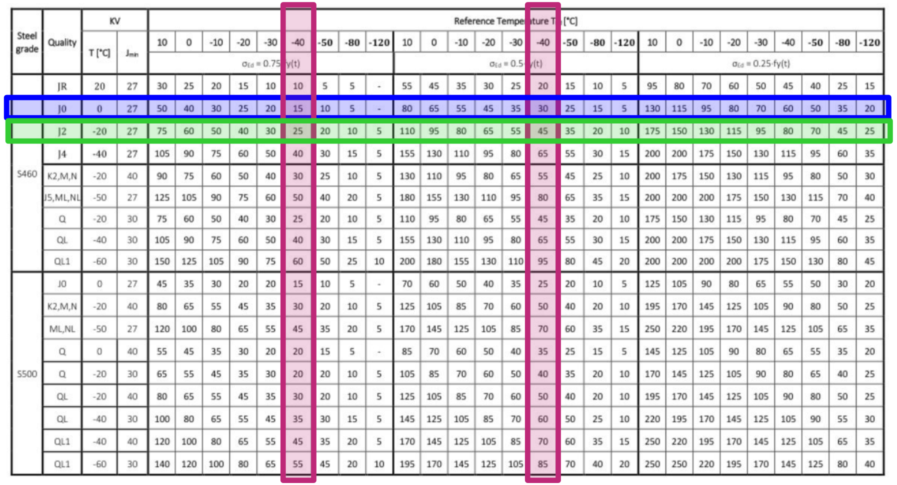
Linear interpolation





With **TTV (STANDARD module)** t_{max}=21mm

With **TTV (STANDARD module)** t_{max}=31mm



Steel grade	Quality	KV		Reference Temperature T [°C]																										
		T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	-80	-120	10	0	-10	-20	-30	-40	-50	-80	-120	10	0	-10	-20	-30	-40	-50	-80	-120
				σ_{Ed} = 0.75 fy(t)									σ_{Ed} = 0.5 fy(t)									σ_{Ed} = 0.25·fy(t)								
S460	JR	20	27	30	25	20	15	10	10	5	5	-	55	45	35	30	25	20	15	10	5	95	80	70	60	50	45	40	25	15
	J0	0	27	50	40	30	25	20	15	10	5	-	80	65	55	45	35	30	25	15	5	130	115	95	80	70	60	50	35	20
	J2	-20	27	75	60	50	40	30	25	20	10	5	110	95	80	65	55	45	35	20	10	175	150	130	115	95	80	70	45	25
	J4	-40	27	105	90	75	60	50	40	30	15	5	155	130	110	95	80	65	55	30	15	200	200	175	150	130	115	95	60	35
	K2,M,N	-20	40	90	75	60	50	40	30	25	10	5	130	110	95	80	65	55	45	25	10	200	175	150	130	115	95	80	50	30
	J5,ML,NL	-50	27	125	105	90	75	60	50	40	20	5	180	155	130	110	95	80	65	35	15	200	200	200	175	150	130	115	70	40
	Q	-20	30	75	60	50	40	30	25	20	10	5	110	95	80	65	55	45	35	20	10	175	150	130	115	95	80	70	45	25
	QL	-40	30	105	90	75	60	50	40	30	15	5	155	130	110	95	80	65	55	30	15	200	200	175	150	130	115	95	60	35
	QL1	-60	30	150	125	105	90	75	60	50	25	10	200	180	155	130	110	95	80	45	20	200	200	200	200	175	150	130	80	45
S500	J0	0	27	45	35	30	20	20	15	10	5	-	70	60	50	40	35	25	20	10	5	125	105	90	80	65	55	50	30	20
	K2,M,N	-20	40	80	65	55	45	35	30	20	10	5	125	105	85	70	60	50	40	20	10	195	170	145	125	105	90	80	50	25
	ML,NL	-50	27	120	100	80	65	55	45	35	20	5	170	145	125	105	85	70	60	35	15	250	220	195	170	145	125	105	65	35
	Q	0	40	55	45	35	30	20	20	15	5	-	85	70	60	50	40	35	25	15	5	145	125	105	90	80	65	55	35	20
	Q	-20	30	65	55	45	35	30	20	20	10	5	105	85	70	60	50	40	35	20	10	170	145	125	105	90	80	65	40	25
	QL	-20	40	80	65	55	45	35	30	20	10	5	125	105	85	70	60	50	40	20	10	195	170	145	125	105	90	80	50	25
	QL	-40	30	100	80	65	55	45	35	30	15	5	145	125	105	85	70	60	50	25	10	220	195	170	145	125	105	90	55	30
	QL1	-40	40	120	100	80	65	55	45	35	20	5	170	145	125	105	85	70	60	35	15	250	220	195	170	145	125	105	65	35
	QL1	-60	30	140	120	100	80	65	55	45	20	10	195	170	145	125	105	85	70	40	20	250	250	220	195	170	145	125	80	40

- **S460J0** $t = 65mm \leq t_{max} = 21mm \;\rightarrow False$ **not verified**
- **S460J2** $t = 65mm \leq t_{max} = 33mm \;\rightarrow False$ **not verified**

Thanks for your attention

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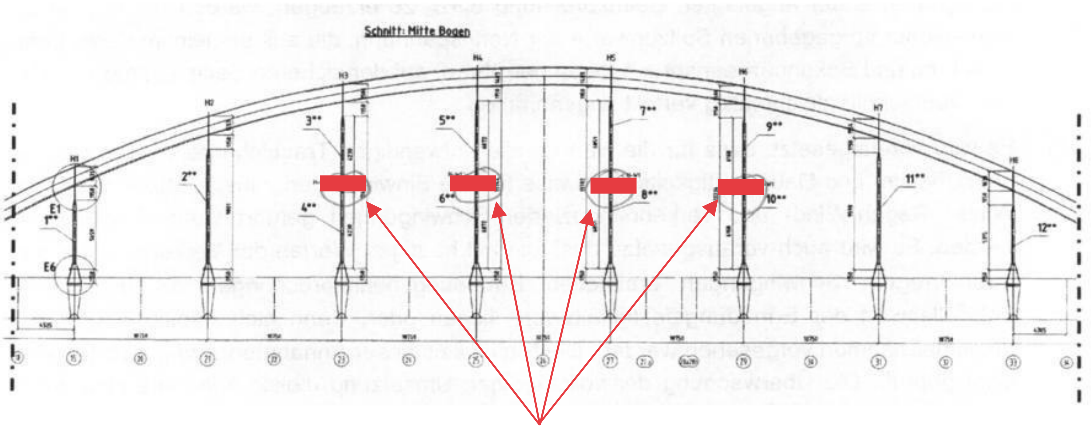
APPENDICE SLIDES

Example 3: butt weld on hanger – Clause 2.4

Source: Section 2.4.2 - COMMENTARY AND WORKED EXAMPLES to EN 1993-1-10 “Material toughness and through thickness properties“ and other toughness oriented rules in EN 1993 - G. Sedlacek, M. Feldmann, B. Kühn, D. Tschickardt, S. Höhler, C. Müller, W. Hensen, N. Stranghöner W. Dahl, P. Langenberg, S. Münstermann, J. Brozetti, J. Raoul, R. Pope, F. Bijlaard



Welded splice on hanger

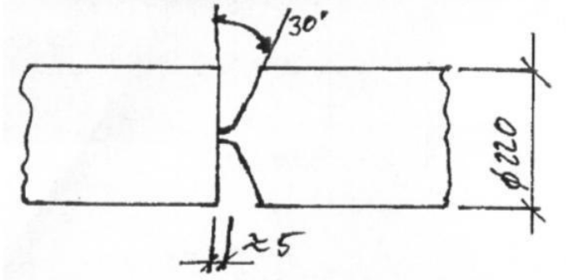
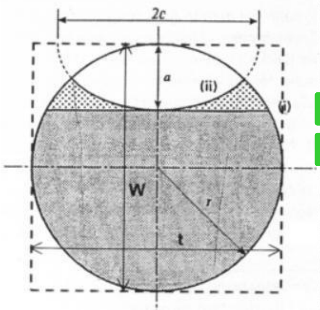
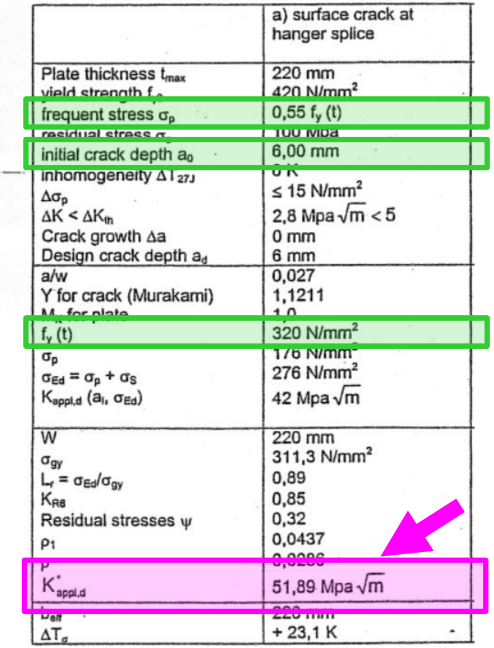


Fig. 2-73: Detail of welded splice

Context: in an arch bridge the central hangers have a welded splice in the middle. The hangers are **Φ220mm** rods in **S420NL**. The section in front of the splice constitutes one of the critical sections that needs to be checked.

Example 3: butt weld on hanger – Clause 2.4





	a) surface crack at hanger splice
Plate thickness t_{max}	220 mm
yield strength f_{y0}	420 N/mm²
frequent stress σ_p	0,55 f_y (t)
residual stress σ_s	100 Mpa
initial crack depth a_0	6,00 mm
inhomogeneity ΔT_{27J}	0 K
$\Delta\sigma_p$	≤ 15 N/mm²
$\Delta K < \Delta K_{th}$	2,8 Mpa $\sqrt{m}$ < 5
Crack growth Δa	0 mm
Design crack depth a_d	6 mm
a/w	0,027
Y for crack (Murakami)	1,1211
M_k for plate	1,0
f_y (t)	320 N/mm²
σ_p	176 N/mm²
$\sigma_{Ed} = \sigma_p + \sigma_S$	276 N/mm²
$K_{appl,d}$ (a_I, σ_{Ed})	42 Mpa $\sqrt{m}$
W	220 mm
σ_{gy}	311,3 N/mm²
$L_r = \sigma_{Ed}/\sigma_{gy}$	0,89
K_{R6}	0,85
Residual stresses ψ	0,32
ρ_1	0,0437
ρ	0,0286
$K^*_{appl,d}$	51,89 Mpa $\sqrt{m}$
b_{eff}	220 mm
ΔT_σ	+ 23,1 K

The section is modelled via an equivalent square section 220x220 mm and a single edge crack is considered with depth 6mm.

The fy(t) value is according to EN 10025-3

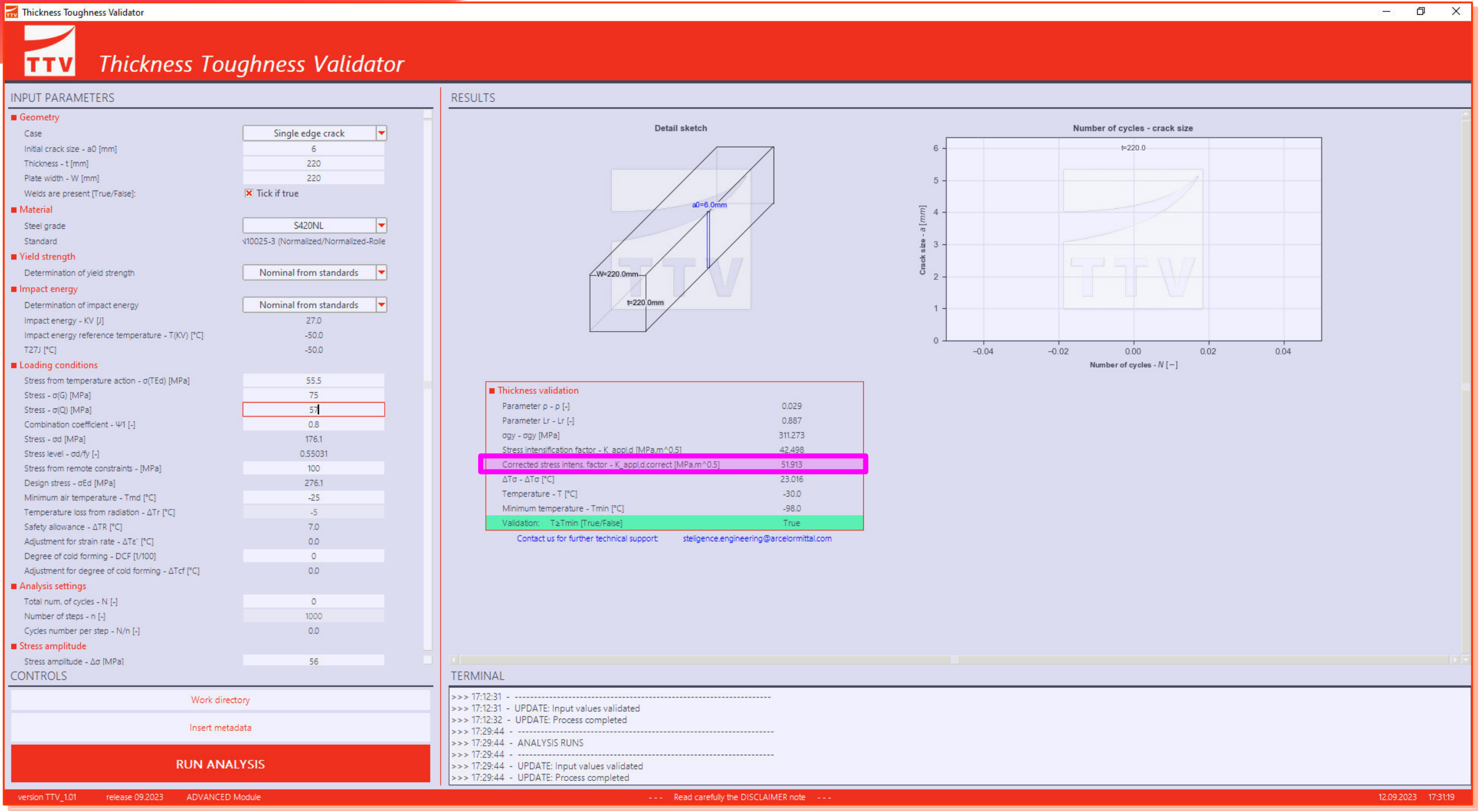
The stress level in the frequent design combination (EN 1993-1-10, 2.2(4), with temperature as leading action) is 0,55 fy

$$\sigma_{\Delta T} = 22°C \times 1{,}2 \cdot 10^{-5}°C^{-1} \times 210000 MPa = 55{,}5\ MPa \qquad \text{Estimated}$$
$$\sigma_G = 75\ MPa,$$
$$\sigma_Q = 57\ MPa,$$
$$\psi_1 = 0{,}80$$

The minimum air temperature is $T_{md} = -25\ °C$
No cold forming is present.

Use of TTV (Thickness Toughness Validator) tool

Example 3: butt weld on hanger – Clause 2.4



INPUT PARAMETERS

Geometry

Case	Single edge crack
Initial crack size - a0 [mm]	6
Thickness - t [mm]	220
Plate width - W [mm]	220
Welds are present [True/False]:	☒ Tick if true

Material

Steel grade	S420NL
Standard	\10025-3 (Normalized/Normalized-Rolle

Yield strength

Determination of yield strength	Nominal from standards

Impact energy

Determination of impact energy	Nominal from standards
Impact energy - KV [J]	27.0
Impact energy reference temperature - T(KV) [°C]	-50.0
T27J [°C]	-50.0

Loading conditions

Stress from temperature action - σ(TEd) [MPa]	55.5
Stress - σ(G) [MPa]	75
Stress - σ(Q) [MPa]	57
Combination coefficient - Ψ1 [-]	0.8
Stress - σd [MPa]	176.1
Stress level - σd/fy [-]	0.55031
Stress from remote constraints - [MPa]	100
Design stress - σEd [MPa]	276.1
Minimum air temperature - Tmd [°C]	-25
Temperature loss from radiation - ΔTr [°C]	-5
Safety allowance - ΔTR [°C]	7.0
Adjustment for strain rate - ΔTε˙ [°C]	0.0
Degree of cold forming - DCF [1/100]	0
Adjustment for degree of cold forming - ΔTcf [°C]	0.0

Analysis settings

Total num. of cycles - N [-]	0
Number of steps - n [-]	1000
Cycles number per step - N/n [-]	0.0

Stress amplitude

Stress amplitude - Δσ [MPa]	56

CONTROLS

RESULTS

Thickness validation

Parameter ρ - ρ [-]	0.029
Parameter Lr - Lr [-]	0.887
σgy - σgy [MPa]	311.273
Stress intensification factor - K_appl.d [MPa.m^0.5]	42.498
Corrected stress intens. factor - K_appl.d,correct [MPa.m^0.5]	51.913
ΔTσ - ΔTσ [°C]	23.016
Temperature - T [°C]	-30.0
Minimum temperature - Tmin [°C]	-98.0
Validation: T≥Tmin [True/False]	True

Contact us for further technical support: steligence.engineering@arcelormittal.com

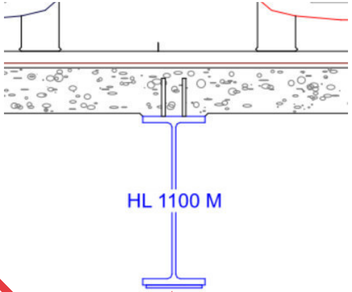
TERMINAL

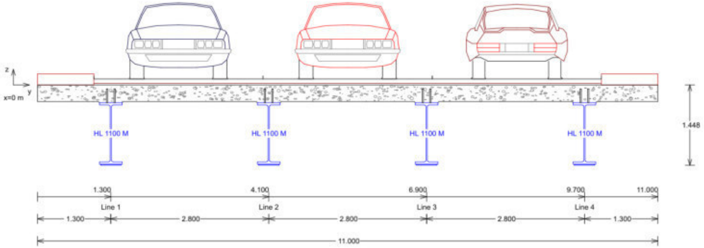
```
>>> 17:12:31 - ------------------------------------------------------------
>>> 17:12:31 - UPDATE: Input values validated
>>> 17:12:32 - UPDATE: Process completed
>>> 17:29:44 - ------------------------------------------------------------
>>> 17:29:44 - ANALYSIS RUNS
>>> 17:29:44 - ------------------------------------------------------------
>>> 17:29:44 - UPDATE: Input values validated
>>> 17:29:44 - UPDATE: Process completed
```

version TTV_1.01 release 09.2023 ADVANCED Module - - - Read carefully the DISCLAIMER note - - - 12.09.2023 17:31:19

ArcelorMittal

Example 4: plate on bottom flange – Clause 2.4





Strengthening plate at bottom flange

Context: a strengthening plate is welded on the bottom flange of a box girder out of HL 1100 M profiles in S460M. (t_f=40mm, t_p=20mm, b_{tot}=400 mm)

The fy(t) value is according to EN 10025-4

The stress level in the frequent design combination (with temperature as leading action is 0,284 fy

$$\sigma_{\Delta T} = 45\ MPa$$
$$\sigma_G = 40\ MPa,$$
$$\sigma_Q = 50\ MPa,$$
$$\psi_1 = 0{,}80$$

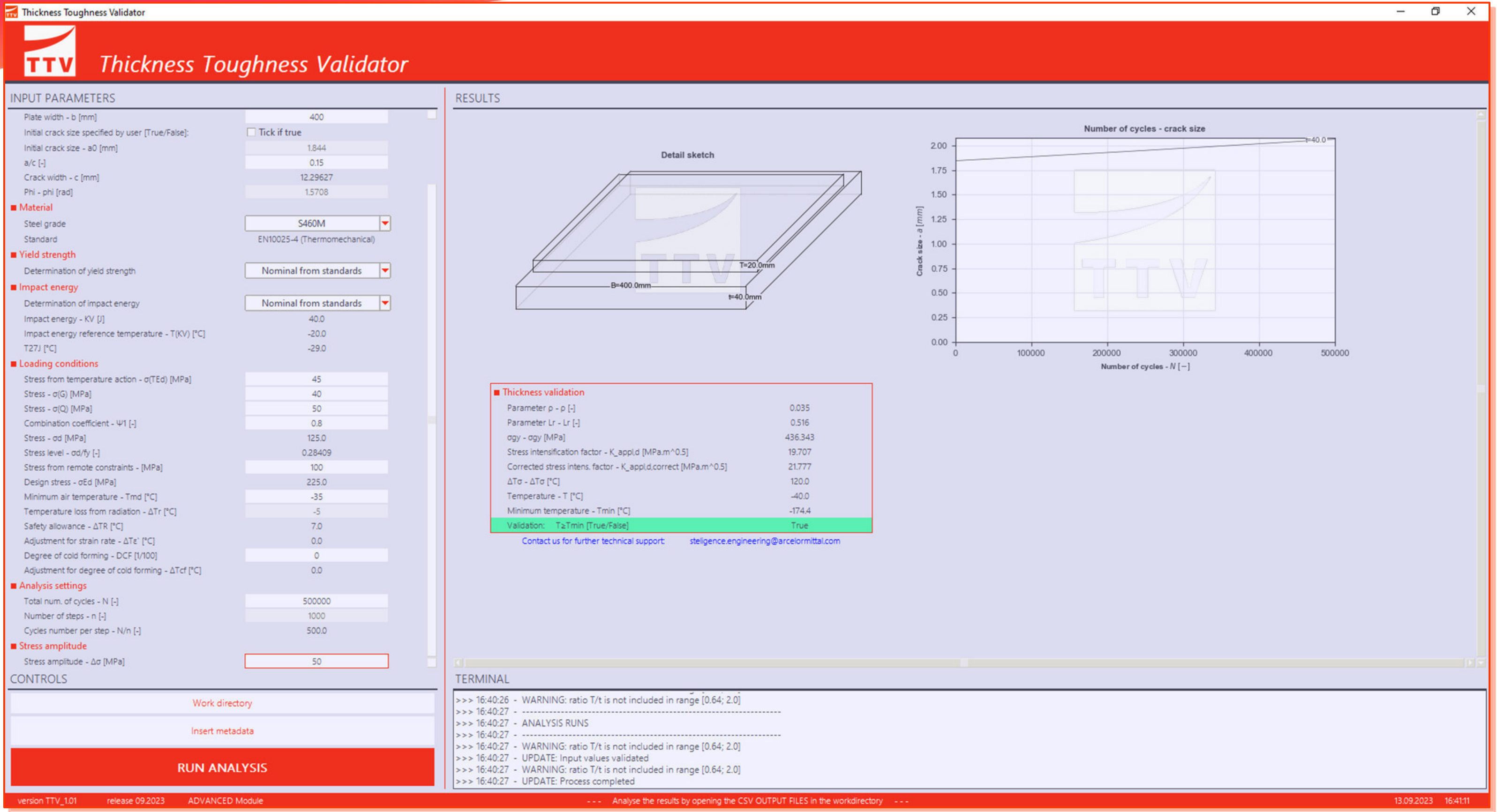
The minimum air temperature is $T_{md} = -35\ °C$

Every 25 years an inspection is foreseen to detect eventual cracks.

The stress range is $\Delta\sigma = 50MPa$.

Use of TTV (Thickness Toughness Validator) tool

Example 4: plate on bottom flange – Clause 2.4



INPUT PARAMETERS

Plate width - b [mm]	400
Initial crack size specified by user [True/False]:	☐ Tick if true
Initial crack size - a0 [mm]	1.844
a/c [-]	0.15
Crack width - c [mm]	12.29627
Phi - phi [rad]	1.5708
■ Material	
Steel grade	S460M
Standard	EN10025-4 (Thermomechanical)
■ Yield strength	
Determination of yield strength	Nominal from standards
■ Impact energy	
Determination of impact energy	Nominal from standards
Impact energy - KV [J]	40.0
Impact energy reference temperature - T(KV) [°C]	-20.0
T27J [°C]	-29.0
■ Loading conditions	
Stress from temperature action - σ(TEd) [MPa]	45
Stress - σ(G) [MPa]	40
Stress - σ(Q) [MPa]	50
Combination coefficient - Ψ1 [-]	0.8
Stress - σd [MPa]	125.0
Stress level - σd/fy [-]	0.28409
Stress from remote constraints - [MPa]	100
Design stress - σEd [MPa]	225.0
Minimum air temperature - Tmd [°C]	-35
Temperature loss from radiation - ΔTr [°C]	-5
Safety allowance - ΔTR [°C]	7.0
Adjustment for strain rate - ΔTε˙ [°C]	0.0
Degree of cold forming - DCF [1/100]	0
Adjustment for degree of cold forming - ΔTcf [°C]	0.0
■ Analysis settings	
Total num. of cycles - N [-]	500000
Number of steps - n [-]	1000
Cycles number per step - N/n [-]	500.0
■ Stress amplitude	
Stress amplitude - Δσ [MPa]	50

CONTROLS

RESULTS

■ Thickness validation	
Parameter ρ - ρ [-]	0.035
Parameter Lr - Lr [-]	0.516
σgy - σgy [MPa]	436.343
Stress intensification factor - K_appl,d [MPa.m^0.5]	19.707
Corrected stress intens. factor - K_appl,d,correct [MPa.m^0.5]	21.777
ΔTσ - ΔTσ [°C]	120.0
Temperature - T [°C]	-40.0
Minimum temperature - Tmin [°C]	-174.4
Validation: T≥Tmin [True/False]	True

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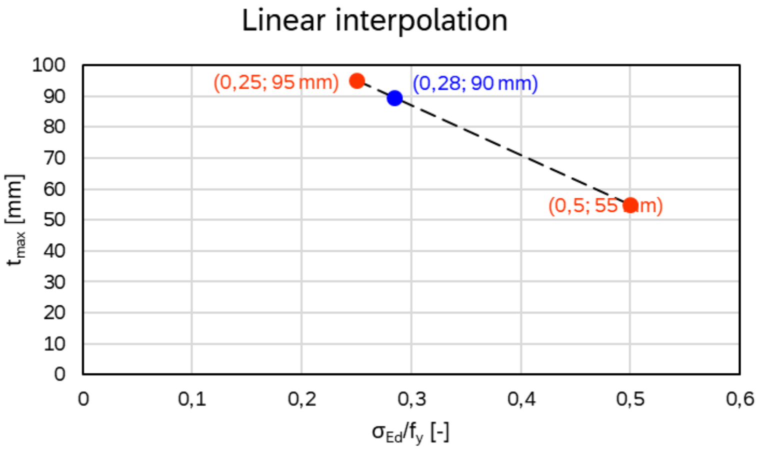
TERMINAL

```
>>> 16:40:26  -  WARNING: ratio T/t is not included in range [0.64; 2.0]
>>> 16:40:27  -  ------------------------------------------------------------------
>>> 16:40:27  -  ANALYSIS RUNS
>>> 16:40:27  -  ------------------------------------------------------------------
>>> 16:40:27  -  WARNING: ratio T/t is not included in range [0.64; 2.0]
>>> 16:40:27  -  UPDATE: Input values validated
>>> 16:40:27  -  WARNING: ratio T/t is not included in range [0.64; 2.0]
>>> 16:40:27  -  UPDATE: Process completed
```

version TTV_1.01 release 09.2023 ADVANCED Module --- Analyse the results by opening the CSV OUTPUT FILES in the workdirectory --- 13.09.2023 16:41:11

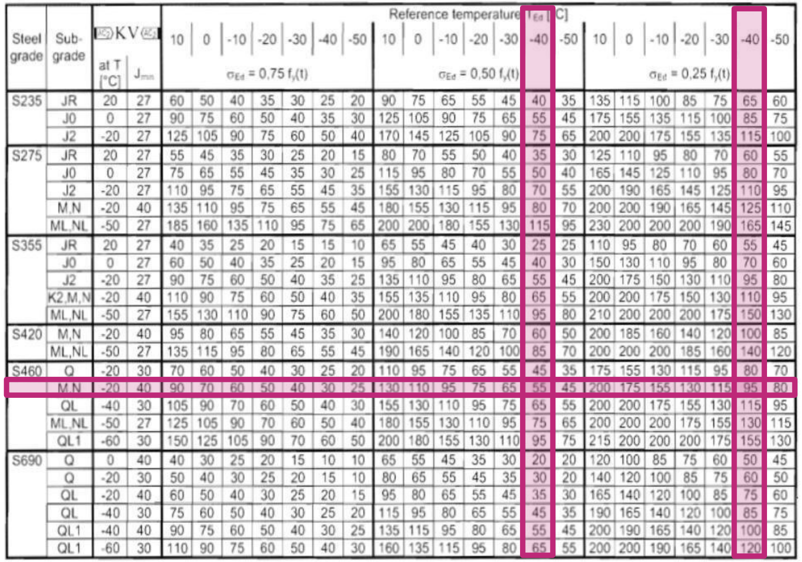
Example 4: plate on bottom flange – Clause 2.4

Application of Clause 2.3, EN 1993-1-10 as comparison



With **TTV (STANDARD module)** → t_{max}=87mm

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



Steel grade	Sub-grade	KV		Reference temperature T_{Ed} [°C]																				
		at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0,75\ f_y(t)$							$\sigma_{Ed} = 0,50\ f_y(t)$							$\sigma_{Ed} = 0,25\ f_y(t)$						
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

$$t = 40mm \leq t_{max} = 90mm \ \rightarrow True$$ **verified**

2. FATIGUE LIFE IMPROVEMENT OF WELDED BRIDGE DETAILS USING HIGH FREQUENCY MECHANICAL IMPACT TREATMENT (MOHAMMAD AL-EMRANI, CHALMERS UNIVERSITY OF TECHNOLOGY)

Fatigue life improvement of welded bridge details

using **H**igh **F**requency **M**echanical **I**mpact treatment

Mohammad Al-Emrani, Chalmers University of Technology

mohammad.al-emrani@chalmers.se

2025-11-04

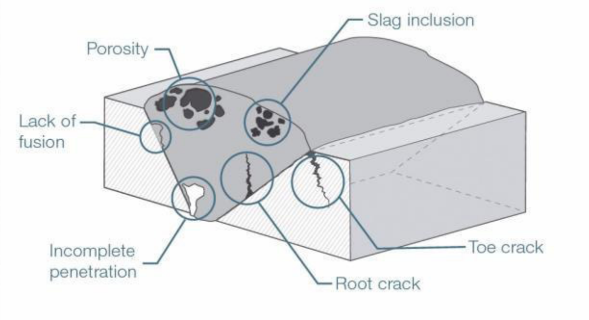
Agenda

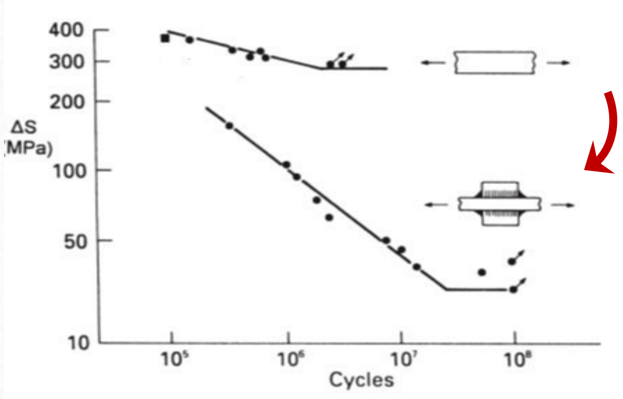
- What is HFMI and how it works
- Implications on design procedure and fatigue verification
- Design rules in prEN 1993-1-9 (Annex F)
- Potential weight and cost saving employing HFMI – a case study
- Design example

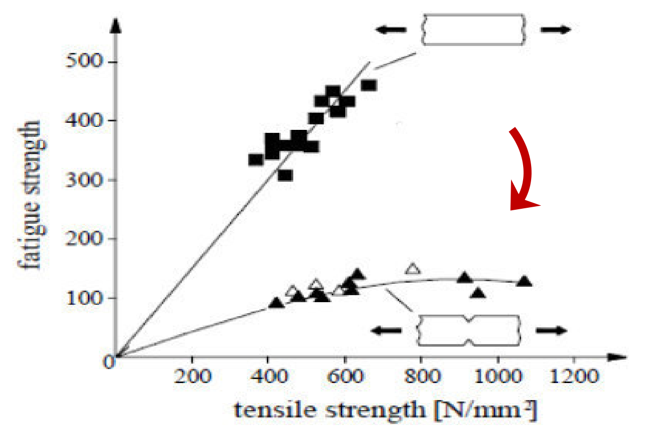
Welded details

Two serious implications of welding

- Weld defects (e.g. undercut)
- Residual stresses







- ”No” crack initiation phase
- Substantially reduced fat. strength

- Fatigue strength (practically) independent on:
  - Steel strength
  - Mean stress

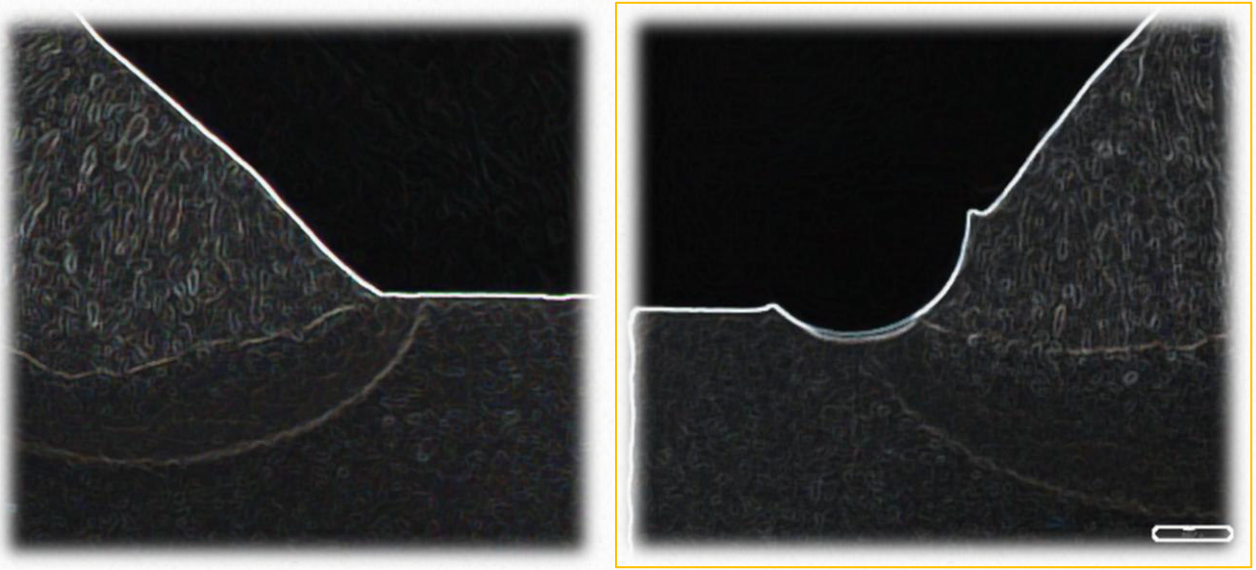
Post-weld treatment

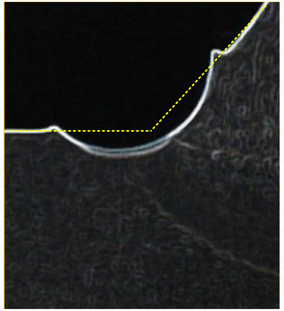
***H**igh **F**requency **M**echanical **I**mpact treatment (HFMI)*

Post-weld treatment

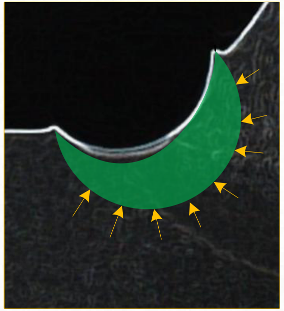
High Frequency Mechanical Impact treatment (HFMI)

Cold-working of the material at weld toe gives ..

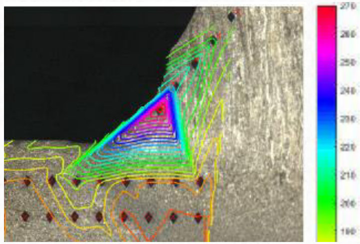




Reduced stress concentration



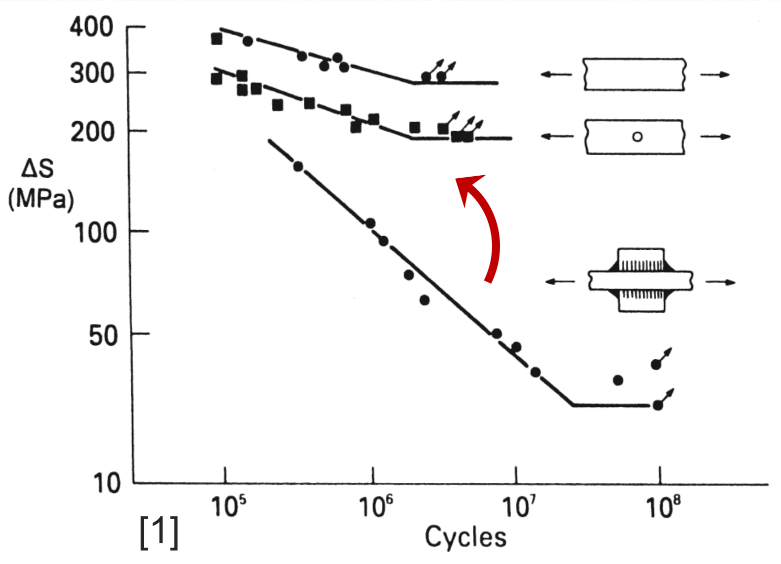
Local compressive residual stress



Increased hardness

HFMI treatment – Increase fatigue strength

0



[1]

"Restore" the fatigue strength of the steel metal

Considerable part of the fatigue life is ***crack initiation***

→ higher fatigue strength

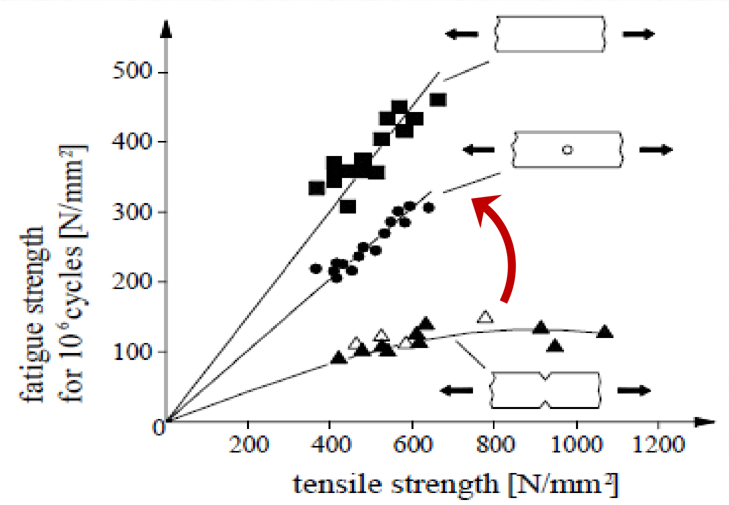
& shallower slope of the S-N curve

HFMI treatment – Increase fatigue strength

Particularities: f_y **dependency** 1

→ Restore the fatigue strength dependency on material strength.

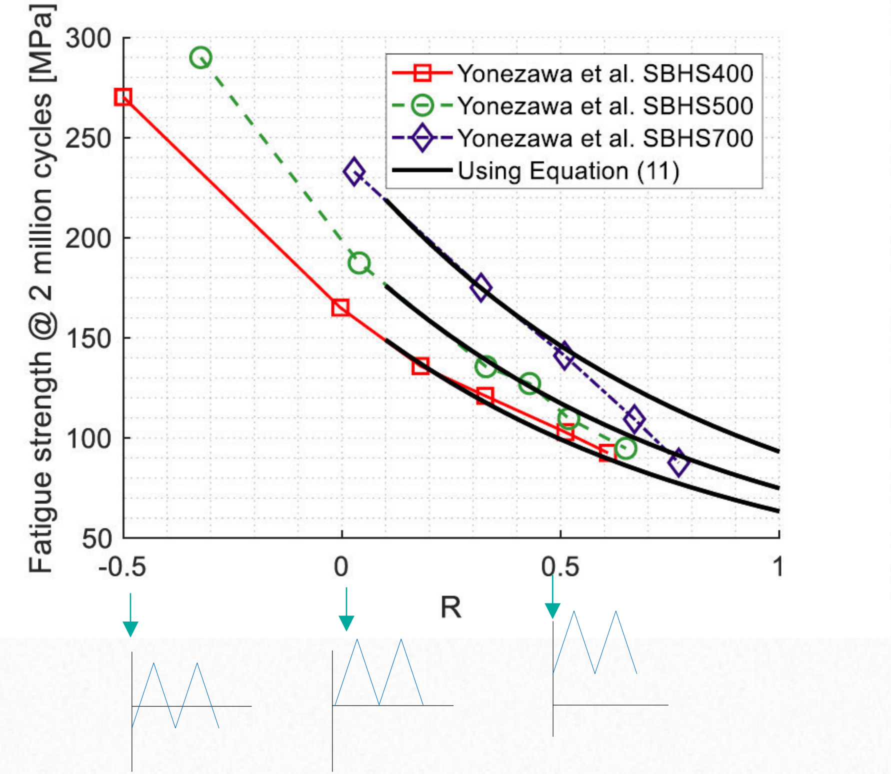
(HSS will have higher fatigue strength)



HFMI treatment – Increase fatigue strength, **but**

Particularities: *Fatigue strength dependency on the **R-ratio** (mean stress)* [2]

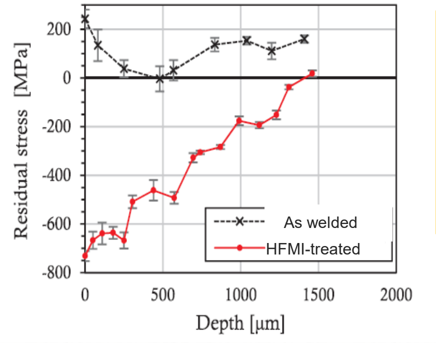
Load cycles with high ***R-ratio***
(mean stress) are more damaging!

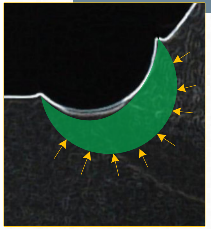


HFMI treatment - Increase fatigue strength, **but**

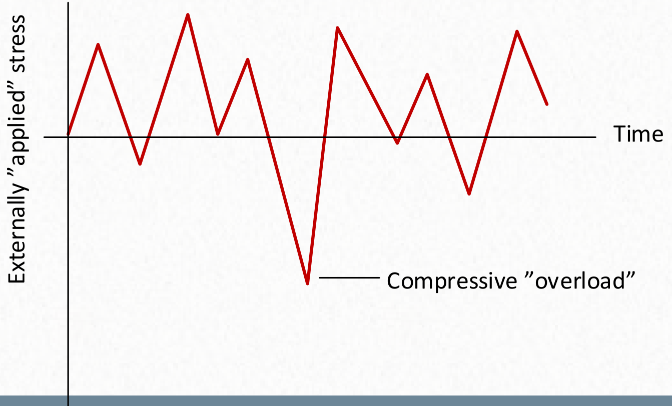
Particularities: *Limitations on **Max./Min.** allowable stress* 3

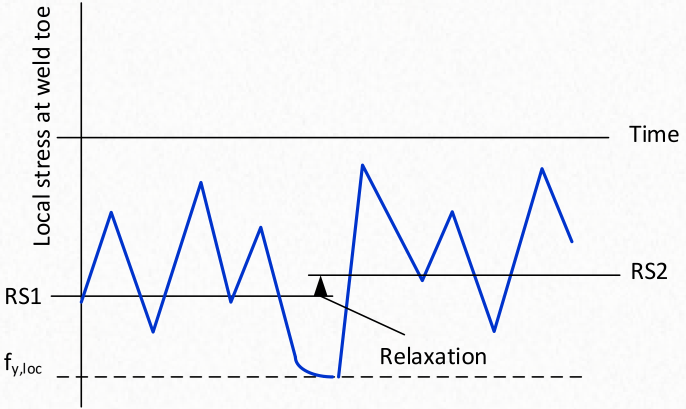
An ”overload” that is high enough to cause relaxation of these residual stresses would reduce the efficiency of HFMI





Compressive overloads are particularly harmful





Design of HFMI-treated welds

Rules in Annex F of prEN 1993-1-9

0 1 $\boldsymbol{\Delta\sigma}_{\mathbf{C,HFMI}} = \boldsymbol{f}(\boldsymbol{f}_{\boldsymbol{y}})$

2 $\Delta\sigma_{\mathrm{Ed}} = \boldsymbol{f}(\boldsymbol{R})$

3 $\Delta\sigma_{\mathrm{Ed}} \leq \boldsymbol{\Delta\sigma}_{\mathbf{allowable}}$

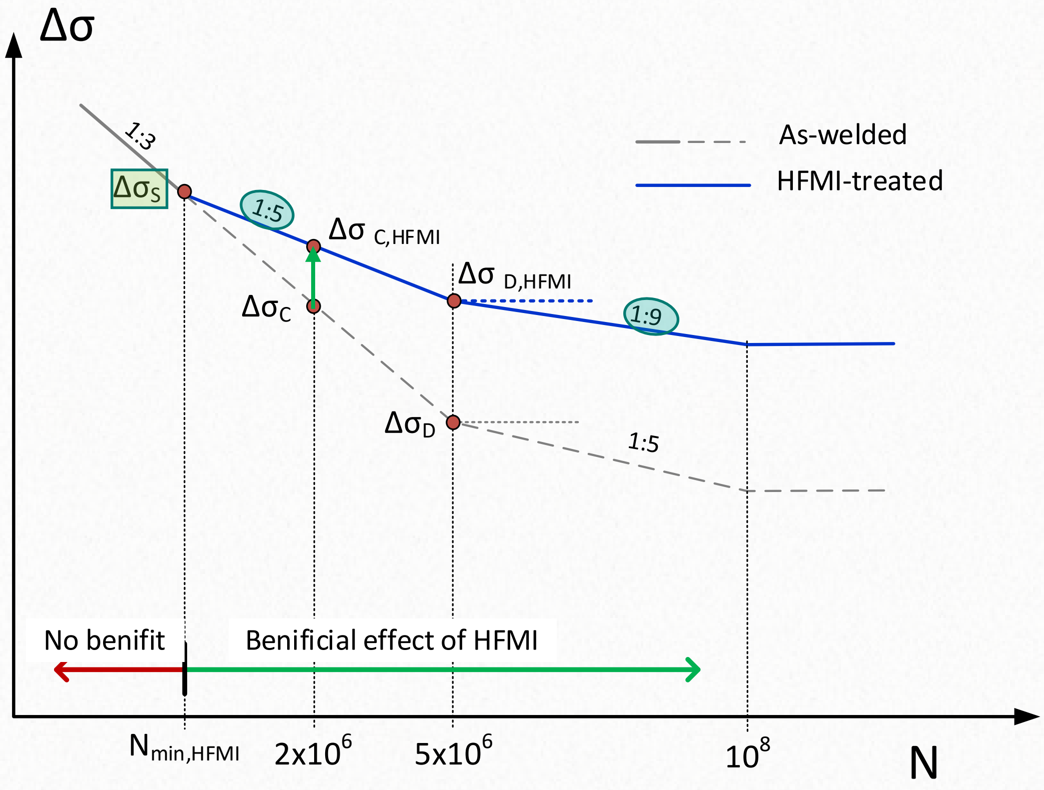
Other design recommendations:

Gary B. Marquis and Zuheir Barsoum (2016): IIW Recommendations for the HFMI Treatment for Improving the Fatigue Strength of Welded Joints. IIW collection, Springer.

Design of HFMI-treated welds

(the upcoming Annex F of EN 1993-1-9)

0

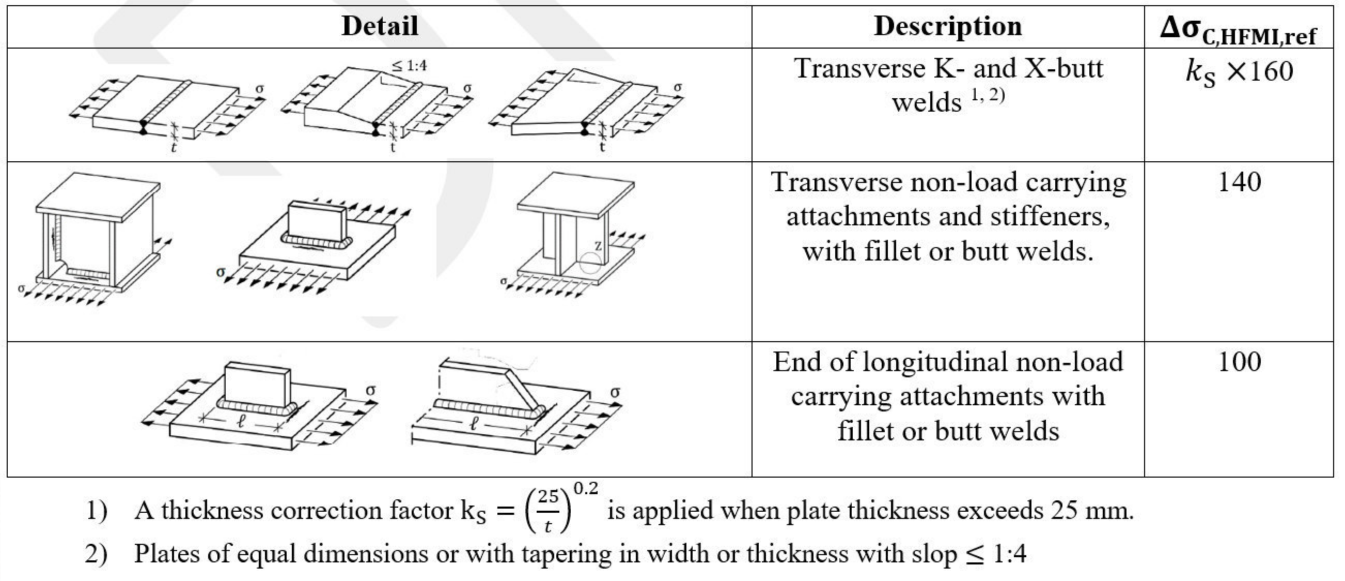


Design of HFMI-treated welds

(the upcoming Annex F of EN 1993-1-9) 0

Fatigue strength & covered details

$$\Delta\sigma_{C,HFMI,ref}\ (f_y = 355\ MPa\ \&\ R = 0.1)$$



Detail	Description	$\Delta\sigma_{C,HFMI,ref}$
	Transverse K- and X-butt welds [1, 2)]	$k_S \times 160$
	Transverse non-load carrying attachments and stiffeners, with fillet or butt welds.	140
	End of longitudinal non-load carrying attachments with fillet or butt welds	100

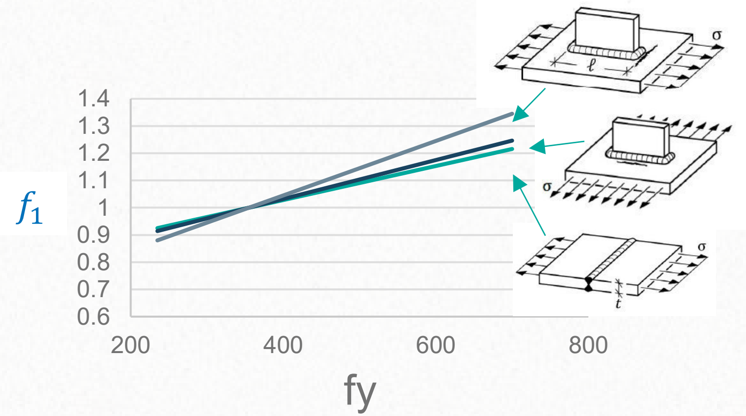
1) A thickness correction factor $k_S = \left(\frac{25}{t}\right)^{0.2}$ is applied when plate thickness exceeds 25 mm.

2) Plates of equal dimensions or with tapering in width or thickness with slop ≤ 1:4

Design of HFMI-treated welds
(the upcoming Annex F of EN 1993-1-9)

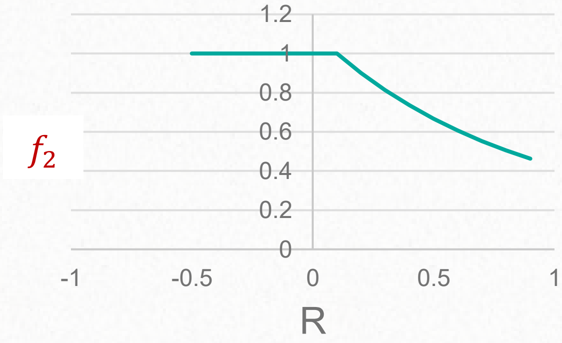
Modification of Fatigue strength – Derived from extensive fatigue testing

$$\boldsymbol{\Delta\sigma_{\mathrm{C,HFMI}}} = \boldsymbol{f_1 f_2}\ \boldsymbol{\Delta\sigma_{\mathrm{C,HFMI,ref}}}$$



1 Correction for $\boldsymbol{f_y}$

$$f_1 = 1 + \frac{0.1\left(f_y - 355\right)}{\Delta\sigma_{\mathrm{C,HFMI,ref}}}$$



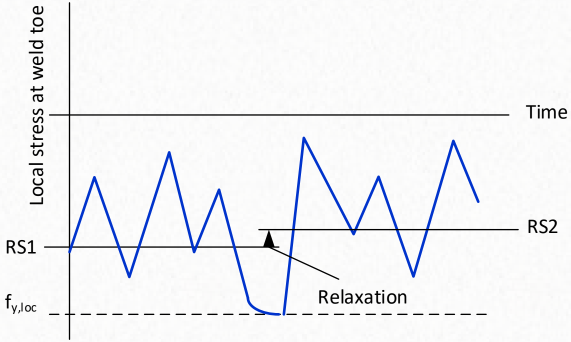
2 Correction for $\boldsymbol{R-ratio}$ ***[CAFL]***

$$f_2 = \frac{1}{0.5R^2+0.95R+0,9} \qquad \text{if } 0.1 < \mathrm{R} < 1.0\text{, otherwise, } f_2 = 1.0$$

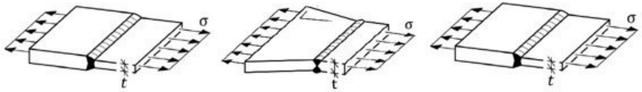
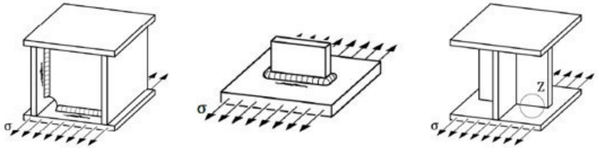
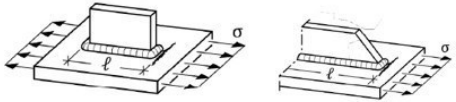
Design of HFMI-treated welds

(the upcoming Annex F of EN 1993-1-9)

Limits for permissible (nominal) stresses 3



Based on extensive experimental work and numerical analysis

Detail	Limits
	$-0.9f_y \leq \sigma_{max} \leq f_y$
	$-0.7f_y \leq \sigma_{max} \leq f_y$
	$-0.5f_y \leq \sigma_{max} \leq f_y$

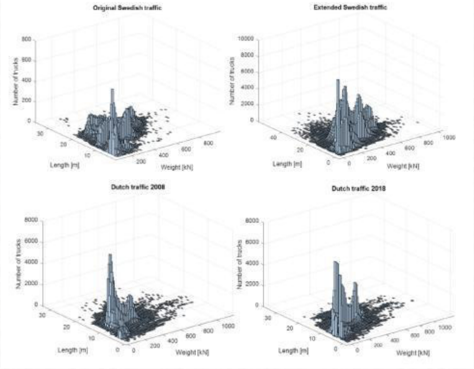
Design of HFMI-treated welds in bridges

Two main questions remain:

- What R-ratios are generated by “***Real***” traffic load (and permanent loads) on bridges?
- What load combination should be used to check max. permissible stresses?

Design of HFMI-treated welds

Derivation of **R-Ratio** effect for railway and road traffic

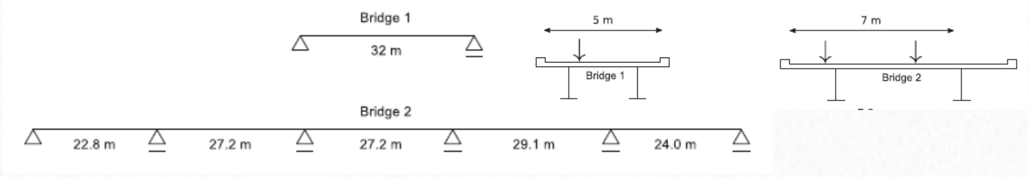


Measured traffic loads

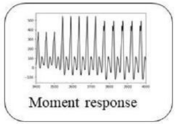
873,000 lorries in Sweden

446,000 lorries in the Netherlands

Simulations on bridges with different spans and influence lines



FLM4



Moment response

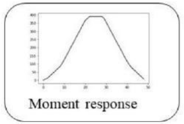
$$f_i = 0.5R_i^2 + 0.95R_i + 0.9$$

$$\Delta S_{eq} = \sqrt[m]{\frac{\sum (n_i \cdot \Delta S_i{}^m)}{\sum n_i}}$$

$$\Delta S_{eqR} = \sqrt[m]{\frac{\sum (n_i \cdot (\Delta S_i \cdot f_i)^m)}{\sum n_i}}$$

$$\lambda_{HFMI} = \frac{\Delta S_{eqR}}{\Delta S_{eq}}$$

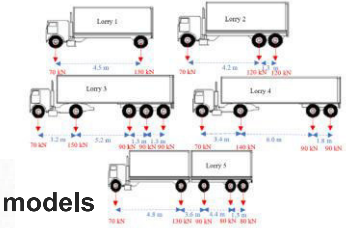
FLM3



Moment response

$$f = 0.5R^2 + 0.95R + 0.9$$

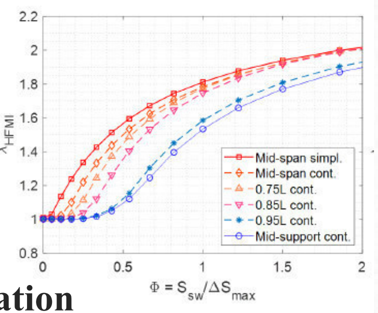
$$\lambda_{HFMI} = f$$

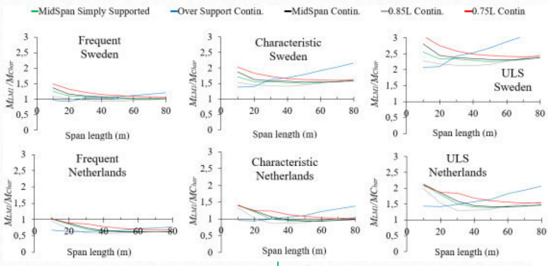


Correlation to fatigue load models

Derivation of "correction" factors

λ_{HFMI}





Use the **characteristic load combination**

Design of HFMI-treated welds

Fatigue verification method – Road bridges

$$\frac{\Delta\sigma_{e,2,HFMI,Ed}}{f_1 \times \Delta\sigma_{C,HFMI,ref}/\gamma_{Mf}} < 1.0$$

Reference fatigue strength modified wrt **f_y**

$$\Delta\sigma_{e,2,HFMI,Ed} = \lambda_1\lambda_2\lambda_3\lambda_4\boldsymbol{\lambda}_{HFMI}\Delta\sigma_{Ed}$$

Damage equivalent factor to account for mean stress effect (**R**)

Design of HFMI-treated welds

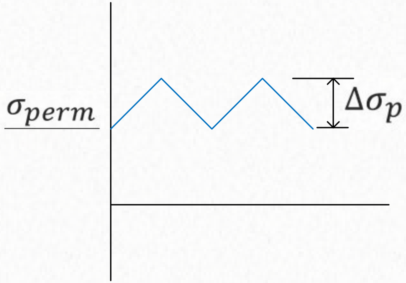
Fatigue verification method – **Road bridges**

For **road bridges**

$$\lambda_{HFMI} = \frac{2.38\Phi+0.64}{\Phi+0.66} \geq 1.0 \qquad \textit{Midspan}$$

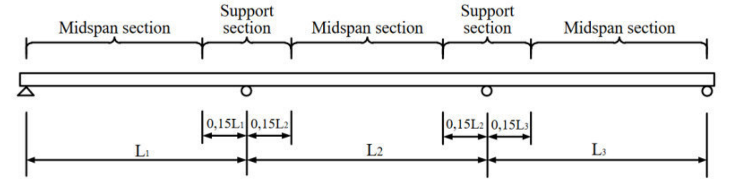
$$\lambda_{HFMI} = \frac{2.38\Phi+0.06}{\Phi+0.40} \geq 1.0 \qquad \textit{Mid-support}$$

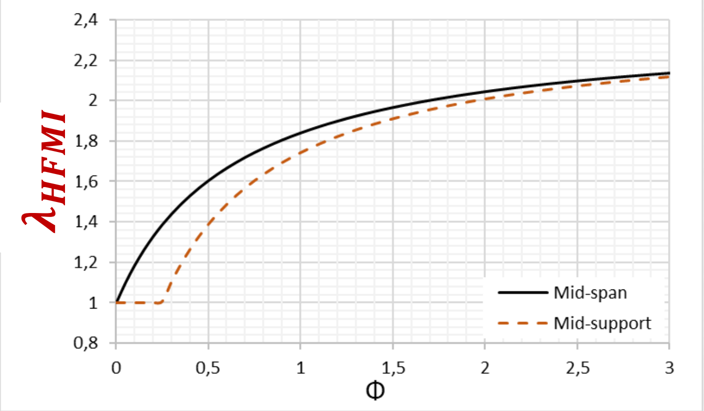
$$\Phi = \frac{\sigma_{perm}}{2\times\Delta\sigma_p}$$



$\Delta\sigma_p$ is the stress range generated by the passage of FLM3.

σ_{perm} is the stress from permanent loads.

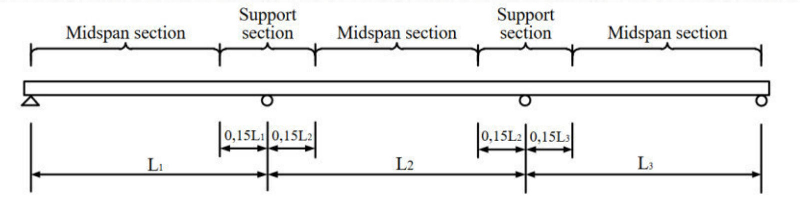




OBS! If HFMI-treatment is performed on-site (after bridge erection) λ_{HFMI} can be obtained from Φ = 0, i.e. no mean stress effect.

Design of HFMI-treated welds

Fatigue verification method – **Railway bridges**



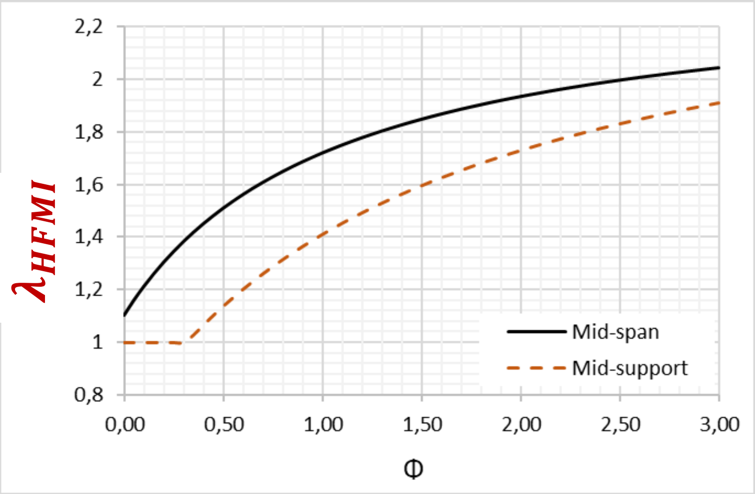
For **railway bridges**

$$\lambda_{HFMI} = \frac{2.38\Phi+1.18}{\Phi+1.07} \geq 1.0 \qquad \text{Midspan}$$

$$\lambda_{HFMI} = \frac{2.56\Phi+1.12}{\Phi+1.61} \geq 1.0 \qquad \text{Mid-support}$$

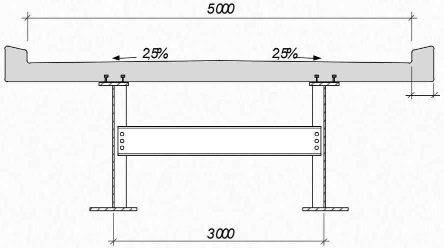
$$\Phi = \frac{\sigma_{perm}}{0.73\times\Delta\sigma_{LM71}} \qquad \text{(with FLM71)}$$

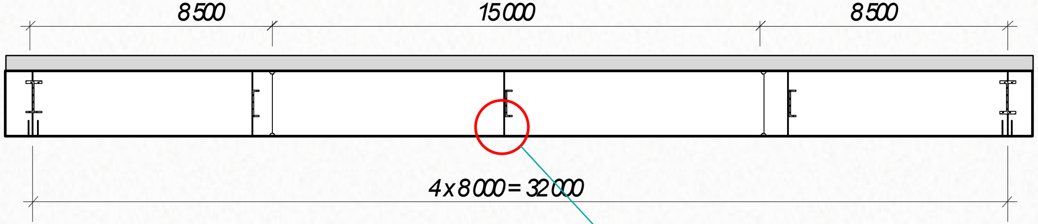
$$\Phi = \frac{\sigma_{perm}}{0.90\times\Delta\sigma_{max}} \qquad \text{(with train mixes)}$$



OBS! If HFMI-treatment is performed on-site (after bridge erection) λ_{HFMI} can be obtained from $\Phi = 0$, i.e. no mean stress effect.

Design example – Road bridge





HFMI performed in workshop

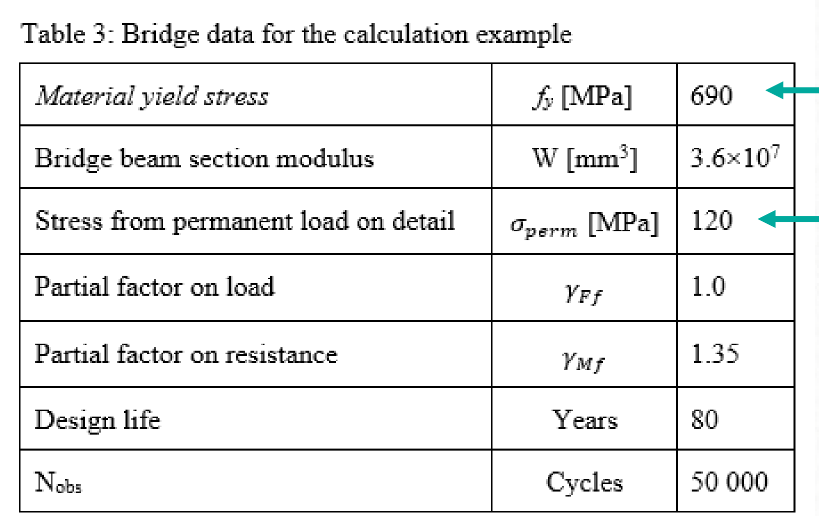
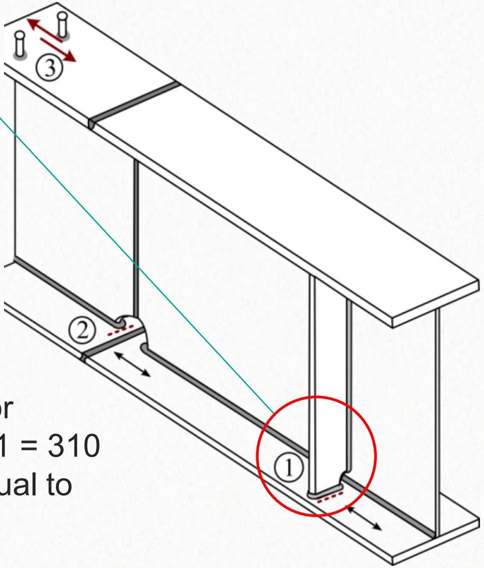


Table 3: Bridge data for the calculation example

Material yield stress	f_y [MPa]	690
Bridge beam section modulus	W [mm^3]	3.6×10^7
Stress from permanent load on detail	σ_{perm} [MPa]	120
Partial factor on load	γ_{Ff}	1.0
Partial factor on resistance	γ_{Mf}	1.35
Design life	Years	80
N$_{obs}$	Cycles	50 000



The average weight of the lorry for regional traffic is assumed to QM1 = 310 kN. The reference value Q0 is equal to 480 kN

Design example – Road bridge

1) $Find\ \boldsymbol{\Delta\sigma}_{C,HFMI,ref}\ for\ the\ governing\ detail\ (fy = 355\ och\ R = 0.1)$

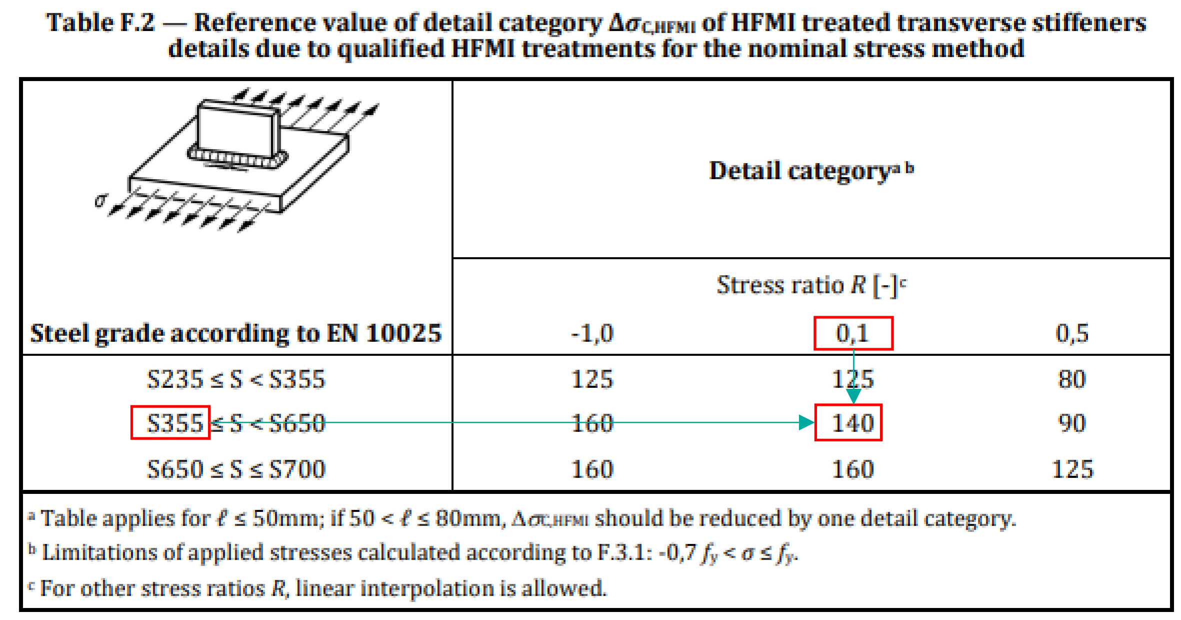


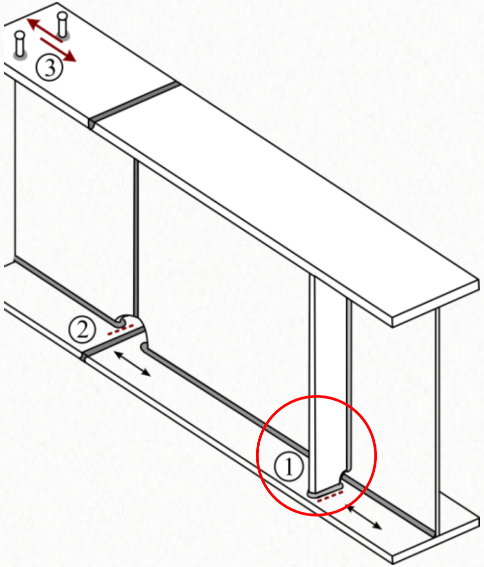
Table F.2 — Reference value of detail category $\Delta\sigma_{C,HFMI}$ of HFMI treated transverse stiffeners details due to qualified HFMI treatments for the nominal stress method

	Detail category[a b]		
	Stress ratio R [-][c]		
Steel grade according to EN 10025	-1,0	0,1	0,5
S235 ≤ S < S355	125	125	80
S355 ≤ S < S650	160	140	90
S650 ≤ S ≤ S700	160	160	125

[a] Table applies for $\ell \leq 50$mm; if $50 < \ell \leq 80$mm, $\Delta\sigma_{C,HFMI}$ should be reduced by one detail category.

[b] Limitations of applied stresses calculated according to F.3.1: $-0{,}7\ f_y < \sigma \leq f_y$.

[c] For other stress ratios R, linear interpolation is allowed.



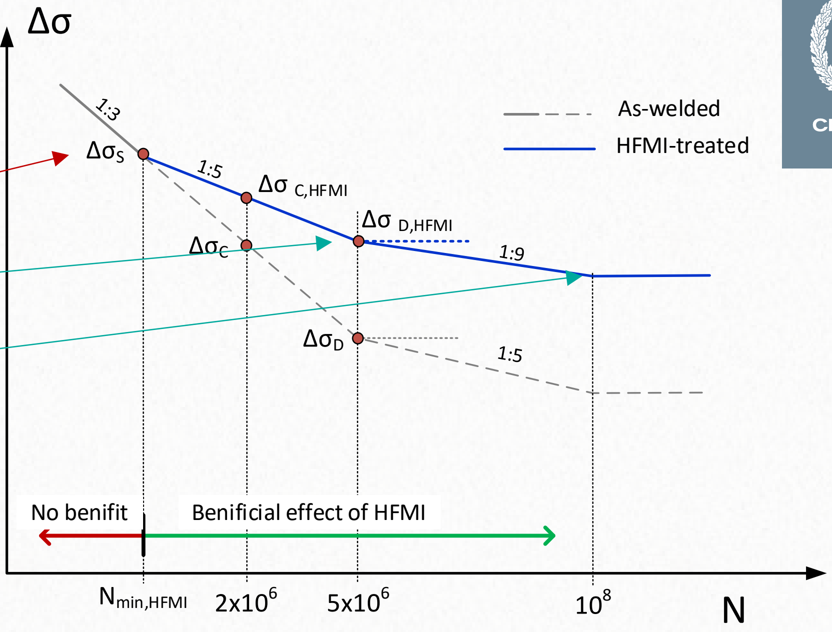
2) Construct the S-N curve

$$\Delta\sigma_{C,HFMI,ref} = 140\ \text{MPa}$$

$$\sigma_{D,HFMI} = 0.833 \times \Delta\sigma_{C,HFMI} = 116.6\ \text{MPa}$$

$$\Delta\sigma_{L,HFMI} = 0.717 \times \Delta\sigma_{D,HFMI} = 83.6\ \text{MPa}$$

$$\Delta\sigma_s = \left(\frac{\Delta\sigma_{C,HFMI}{}^5}{\Delta\sigma_C^3}\right)^{0.5} = 324.1\ \text{MPa}$$

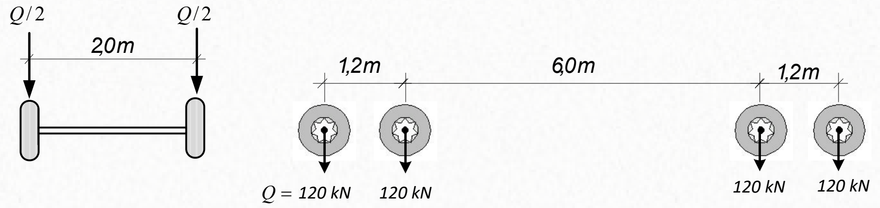


3) Correction for fy

$$f_1 = 1 + \frac{0.1\,(f_y - 355)}{\Delta\sigma_{C,HFMI,ref}} = 1 + \frac{0.1\,(690 - 355)}{140} = 1{,}24$$

OBS! 1,24 x 140 = 174 MPa → **Less than the fatigue strength of the base metal (DC180)**

(I) Fatigue verification with FLM3



$$M_{max}\ (FLM3) = 2976\ kNm$$

$$\Delta\sigma_{Ed} = \Delta\sigma_P = 82.7\ MPa$$

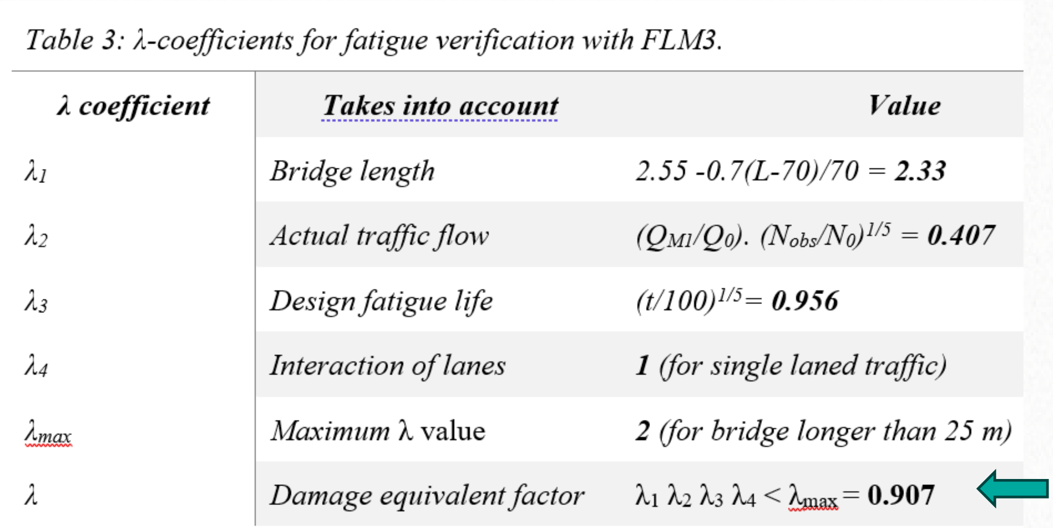


Table 3: λ-coefficients for fatigue verification with FLM3.

λ coefficient	***Takes into account***	***Value***
λ_1	*Bridge length*	$2.55 - 0.7(L-70)/70 = \mathbf{2.33}$
λ_2	*Actual traffic flow*	$(Q_{M1}/Q_0).\ (N_{obs}/N_0)^{1/5} = \mathbf{0.407}$
λ_3	*Design fatigue life*	$(t/100)^{1/5} = \mathbf{0.956}$
λ_4	*Interaction of lanes*	***1*** *(for single laned traffic)*
λ_{max}	*Maximum* λ value	***2*** *(for bridge longer than 25 m)*
λ	*Damage equivalent factor*	$\lambda_1\ \lambda_2\ \lambda_3\ \lambda_4 < \lambda_{max} = \mathbf{0.907}$

(I) Fatigue verification with FLM3

$$\frac{\Delta\sigma_{e,2,HFMI,Ed}}{f_1 \times \Delta\,\sigma_{C,HFMI,ref}/\gamma_{Mf}} < 1$$

f_1 → 1,24

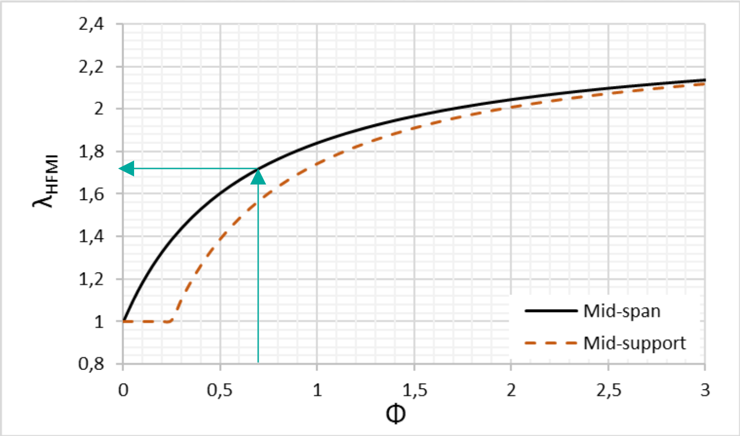
$$\Delta\sigma_{e,2,_{HFMI,Ed}} = \lambda \times \lambda_{HFMI}\,\Delta\sigma_E\gamma_{Ff}$$

λ → 0,907

$\Delta\sigma_E$ → $82.7\ MPa$

$$\lambda_{HFMI} = \frac{2.38\Phi+0.64}{\Phi+0,66} = \frac{2.38.\left(\frac{120}{2\times82.7}\right)+0.64}{\left(\frac{120}{2\times82.7}\right)+0.66} = 1,71$$

with $\Phi = \frac{\sigma_{perm}}{2\times\Delta\sigma_p} = \frac{120}{2\times82.7} = 0,73$



$$\Delta\sigma_{e,2,_{HFMI,Ed}} = 0.907 \times 1.71 \times 82.7 \times 1.0 = 128\ \text{MPa}$$

Verification: $\frac{128}{1,24 \text{ x } 140/1.35} = \mathbf{0.99} < 1.0$

Verification of permissible stresses

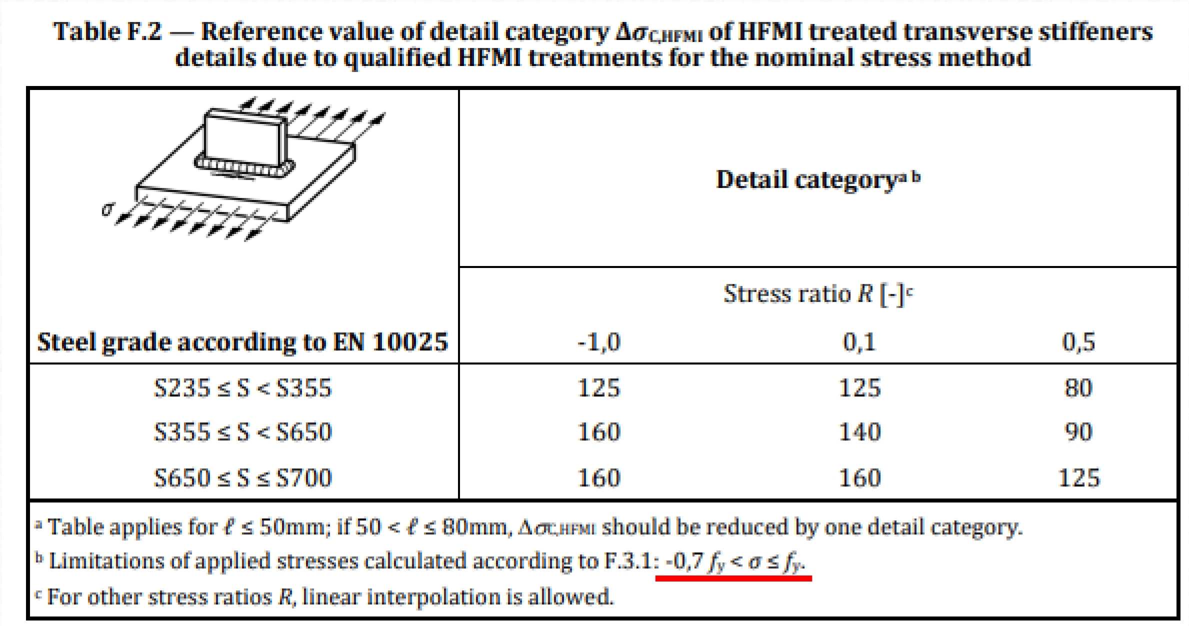


Table F.2 — Reference value of detail category $\Delta\sigma_{C,HFMI}$ of HFMI treated transverse stiffeners details due to qualified HFMI treatments for the nominal stress method

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[a] Table applies for $\ell \leq$ 50mm; if 50 < $\ell \leq$ 80mm, $\Delta\sigma_{C,HFMI}$ should be reduced by one detail category.

[b] Limitations of applied stresses calculated according to F.3.1: $-0{,}7\,f_y < \sigma \leq f_y$.

[c] For other stress ratios R, linear interpolation is allowed.

Characteristic load combination

$$SW + (1\ or\ 0) \times S + TS + UDL + 0.6 \times \max(F_w, T_k) = 300\ MPa = 0.45 f_y$$

(II) Fatigue verification with FLM4 (Local traffic)

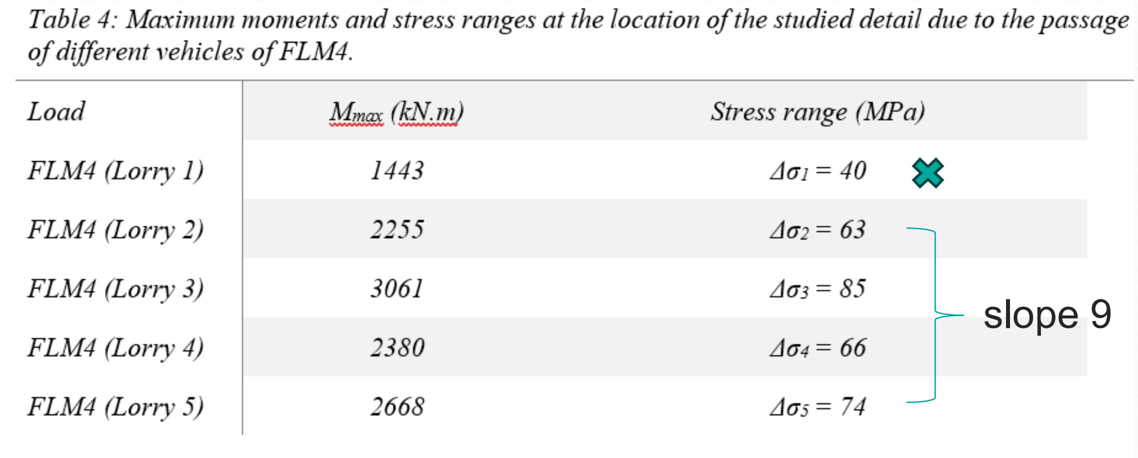
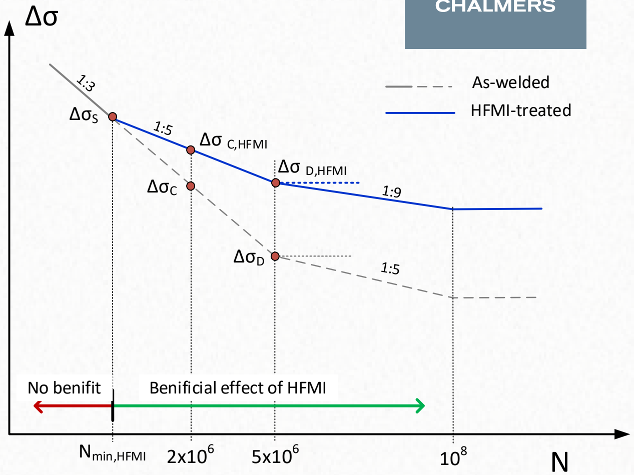


Table 4: Maximum moments and stress ranges at the location of the studied detail due to the passage of different vehicles of FLM4.

Load	M_{max} *(kN.m)*	*Stress range (MPa)*	
FLM4 (Lorry 1)	*1443*	$\Delta\sigma_1 = 40$	✖
FLM4 (Lorry 2)	*2255*	$\Delta\sigma_2 = 63$	
FLM4 (Lorry 3)	*3061*	$\Delta\sigma_3 = 85$	
FLM4 (Lorry 4)	*2380*	$\Delta\sigma_4 = 66$	
FLM4 (Lorry 5)	*2668*	$\Delta\sigma_5 = 74$	

$$\underbrace{\Delta\sigma_2, \Delta\sigma_3, \Delta\sigma_4, \Delta\sigma_5}_{\text{slope 9}}$$



$$\frac{\Delta\sigma_{D,\mathrm{HFMI,ref}}}{\gamma_{\mathrm{Mf}}} = 86\ \mathrm{MPa}$$

$$\frac{\Delta\sigma_{L,\mathrm{HFMI,ref}}}{\gamma_{\mathrm{Mf}}} = 62\ \mathrm{MPa}$$

$$\frac{\Delta\sigma_S}{\gamma_{\mathrm{Mf}}} = \frac{\left(\frac{140^5}{80^3}\right)^{0.5}}{\gamma_{\mathrm{Mf}}} = 324\ \mathrm{MPa}$$

(II) Fatigue verification with FLM4

$$\sigma_{eq} = \sqrt[9]{\frac{\sum_{j=1}^{4}(n_j \times \Delta\sigma_j^9)}{\Sigma n_j}} = \sqrt[9]{\frac{(2500 \times 63^9 + 2500 \times 85^9 + 2500 \times 66^9 + 2500 \times 74^9)}{50{,}000}} = 63.5\ MPa$$

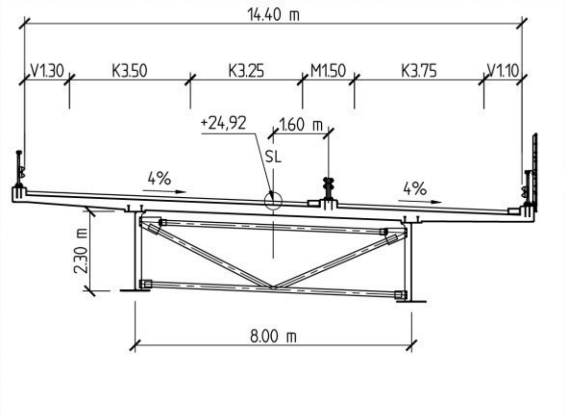
$$N_{eq} = 5.10^6 \left(\frac{f_1 \, . \Delta\,\sigma_{D,HFMI.ref}\ /\gamma_{Mf}}{\lambda_{HFMI} . \Delta\sigma_{eq} . \gamma_{Ff}}\right)^{m_2} = 5.10^6 \left(\frac{\frac{1.24 \times\ 116.6}{1.35}}{1.71 \times 63.5 \times 1.0}\right)^9 = 4.4 \times 10^6\ cycles$$

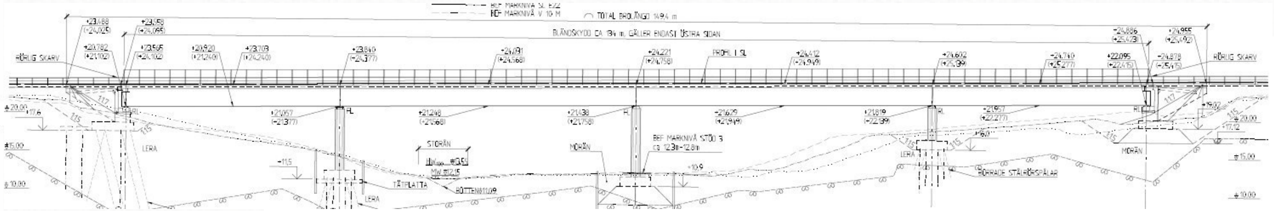
$$D = \frac{n}{N_{EQV}} = \frac{50{,}000 \times 80}{4.4 \times 10^6} = \mathbf{0.9}$$

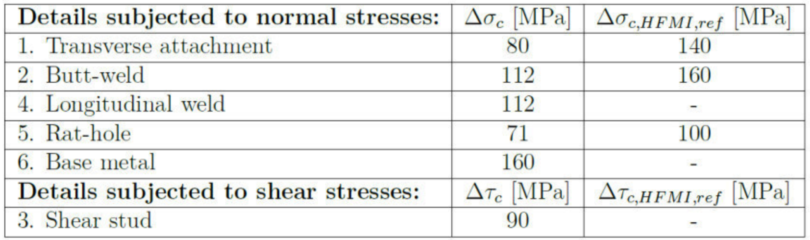
Compare to ***0.99*** with the simplified $\lambda -$ method

Potential weight and cost saving employing HFMI

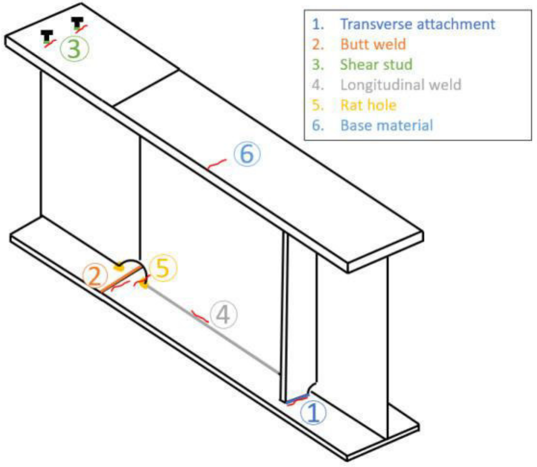
Case-study bridge (COWI)





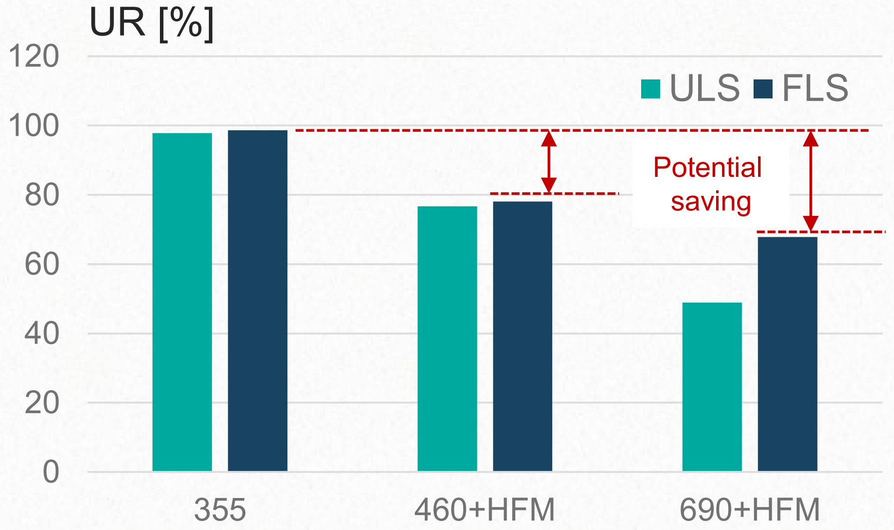


Details subjected to normal stresses:	$\Delta\sigma_c$ [MPa]	$\Delta\sigma_{c,HFMI,ref}$ [MPa]
1. Transverse attachment	80	140
2. Butt-weld	112	160
4. Longitudinal weld	112	-
5. Rat-hole	71	100
6. Base metal	160	-
Details subjected to shear stresses:	$\Delta\tau_c$ [MPa]	$\Delta\tau_{c,HFMI,ref}$ [MPa]
3. Shear stud	90	-



Potential weight and cost saving employing HFMI

Case-study bridge (COWI)

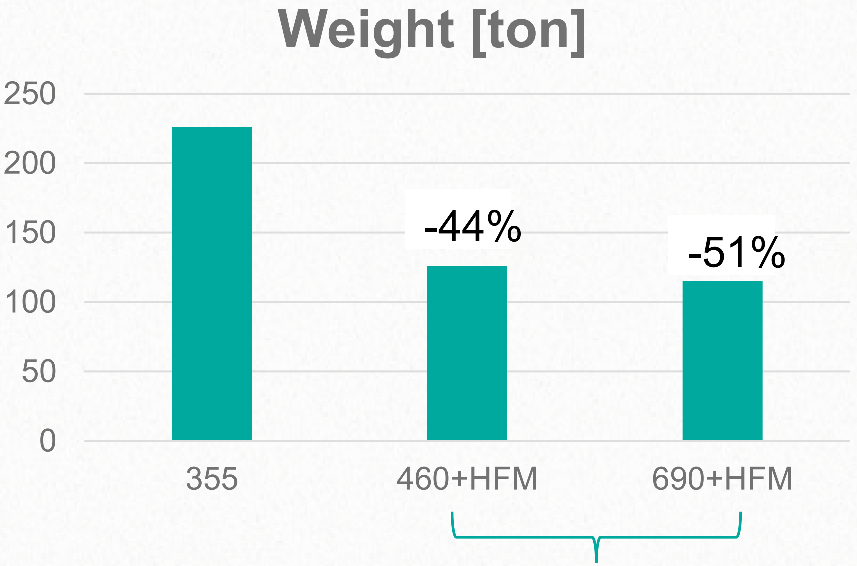


Utilization ratios with increased material strength and HFMI
(original bridge design / sections)

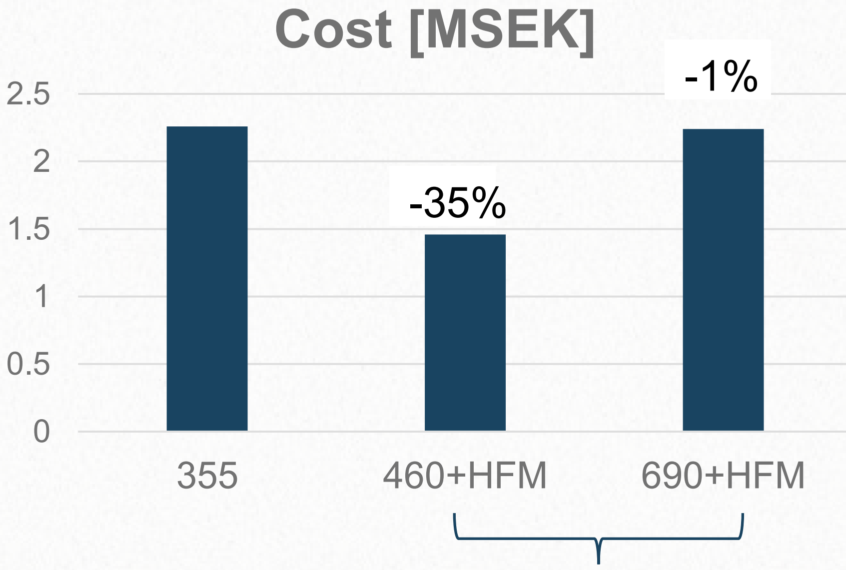
Potential weight and cost saving employing HFMI

Case-study bridge (COWI)

Material	Unit price
S355	1.000
S460	1.083
S690	1.924



Re-designed bridge sections



Re-designed bridge sections

Some references

1. Hassan Al-Karawi, John Leander and Mohammad Al-Emrani (2023): Verification of the Maximum Stresses in Enhanced Welded Details via High-Frequency Mechanical Impact in Road Bridges. Buildings 13(2):364. DOI: 10.3390/buildings13020364

2. Poja Shams-Hakimi, Hassan Al-Karawi, and Mohammad Al-Emrani. "High-cycle variable amplitude fatigue experiments and design framework for bridge welds with high-frequency mechanical impact treatment." Steel Construction 15.3 (2022): 172-187. DOI: 10.1002/stco.202200003

3. Hassan Alkarawi, Poja Shams-Hakimi and Mohammad Al-Emrani (2022): Mean Stress Effect in High-Frequency Mechanical Impact (HFMI)-Treated Steel Road Bridges. Buildings 12(5):545. DOI: 10.3390/buildings12050545

4. Poja Shams-Hakimi, Fredrik Carlsson, Mohammad Al-Emrani and Hassan Al-Karawi (2021): Assessment of in-service stresses in steel bridges for high-frequency mechanical impact applications. Engineering Structures 241(3):112498. DOI: 10.1016/j.engstruct.2021.112498.

5. Hassan Al-Karawi and Mohammad Al-Emrani (2021): The efficiency of HFMI treatment and TIG remelting for extending the fatigue life of existing welded structures. Steel Construction 14(4). DOI: 10.1002/stco.202000053.

6. Hassan Al-Karawi, Mohammad Al-Emrani and R.U. Franz von Bock und Polach.(2021): Fatigue life extension of existing welded structures via high frequency mechanical impact (HFMI) treatment. Engineering Structures 239(4). DOI: 10.1016/j.engstruct.2021.112234

7. Aldén, R., Zuheir Barsoum, Z., Vouristo, T. Mohammad Al-Emrani. (2020). Robustness of the HFMI techniques and the effect of weld quality on the fatigue life improvement of welded joints. Weld World (2020). DOI: 10.1007/s40194-020-00974-4.

8. Hassan Al-Karawi, Mohammad Al-Emrani and R.U. Franz von Bock und Polach.(2020): Fatigue crack repair in welded structures via tungsten inert gas remelting and high frequency mechanical impact. Journal of Constructional Steel Research 172:106200, September 2020. DOI: 10.1016/j.jcsr.2020.106200.

9. Gary B. Marquis and Zuheir Barsoum (2016): IIW Recommendations for the HFMI Treatment for Improving the Fatigue Strength of Welded Joints. IIW collection, Springer.

Thank you for your attention

3. HFMI FOR FATIGUE LIFE EXTENSION: GUIDELINES, DIGITAL QA, AND BRIDGE APPLICATIONS (ZUHEIR BARSOUM, KTH ROYAL INSTITUTE OF TECHNOLOGY)

EUROPEAN CONVENTION FOR CONSTRUCTIONAL STEELWORK
Bridge Committee

HFMI for Fatigue Life Extension: Guidelines, Digital QA, and Bridge Applications

Professor **Zuheir Barsoum**

KTH Royal Institute of Technology, Stockholm, Sweden

Research in collaboration with

SSAB

SWERIM

VINNOVA
Sweden's Innovation Agency

DEKRA

winteria

TOYOTA
MATERIAL HANDLING

HIAB

BROMMA
A Tradition of Innovation

VOLVO
Construction Equipment

A!
Aalto University

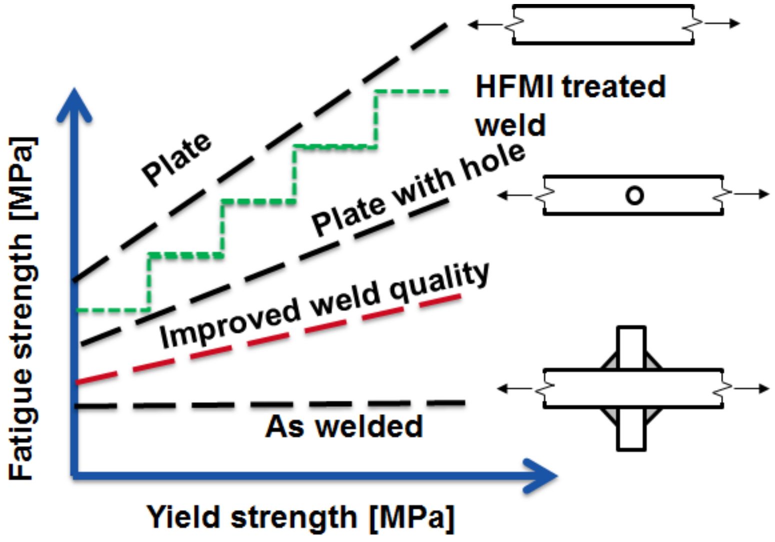
CHALMERS
UNIVERSITY OF TECHNOLOGY

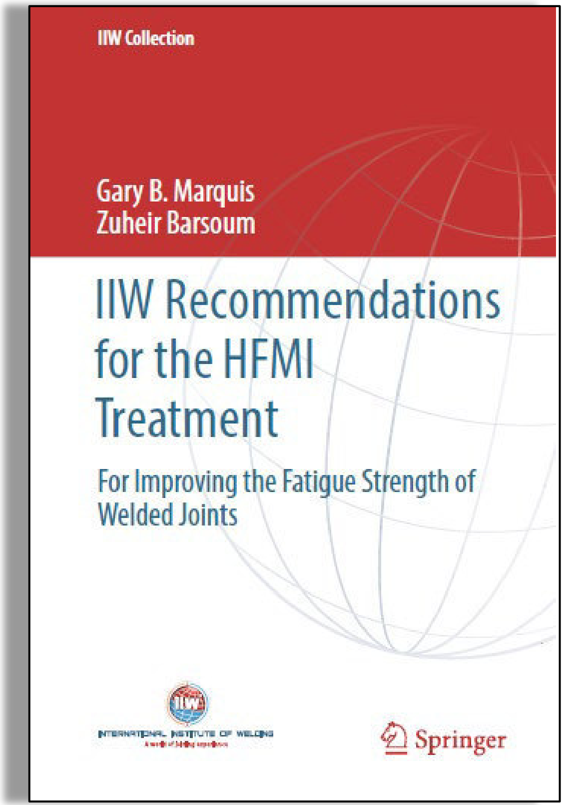
岐阜大学
GIFU UNIVERSITY

MONTAN
UNIVERSITÄT
LEOBEN

TRAFIKVERKET
SWEDISH TRANSPORT ADMINISTRATION

Fatigue Life Enhancement of Welded Structures




IIW Collection

Gary B. Marquis
Zuheir Barsoum

IIW Recommendations for the HFMI Treatment

For Improving the Fatigue Strength of Welded Joints

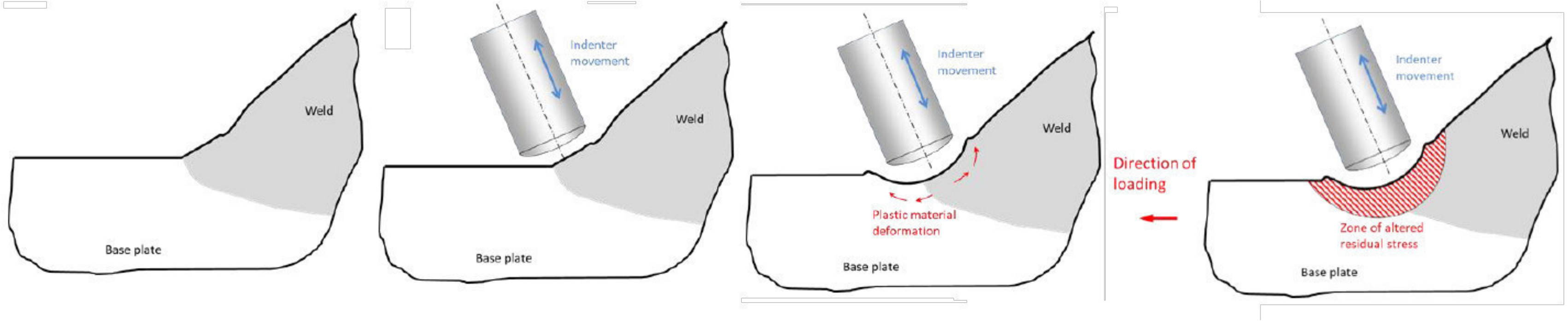
International Institute of Welding

Springer

Marquis & Barsoum, Springer (2016)

High Frequency Mechanical Impact (HFMI)

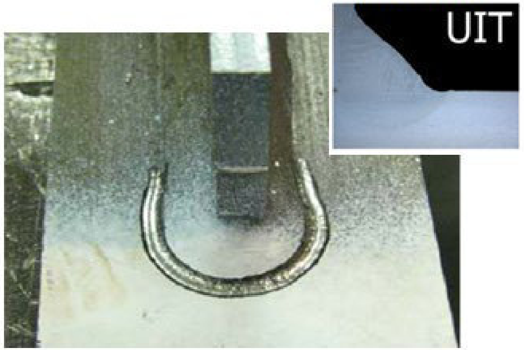
Principle of the HFMI treatment



Typical weld toe profile in the as-welded condition and following HFMI treatment

as-welded

after HFMI

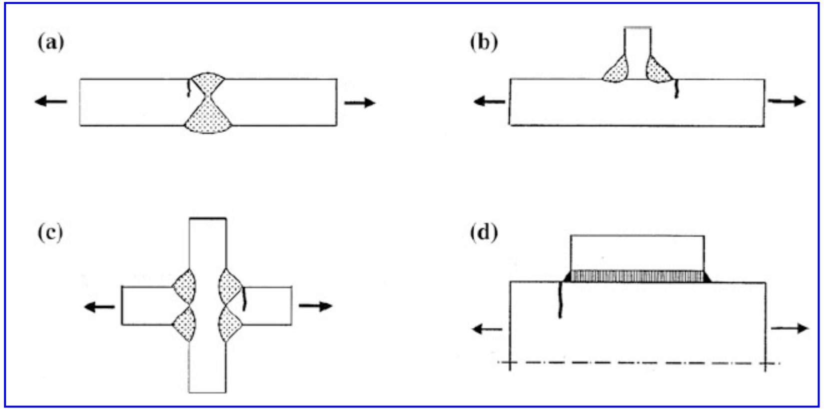


HFMI Fatigue Strength Improvement

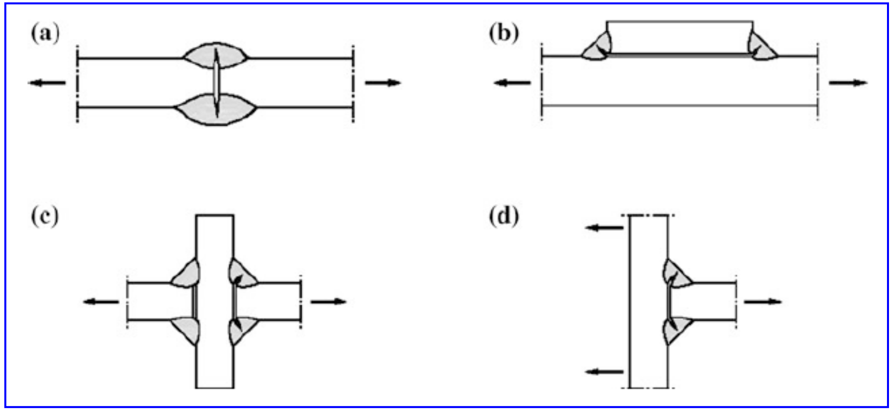
Some of Assumptions:

- The improvement method is applied to the ***weld toe***
- The fatigue strength (HFMI improved) is based on an S-N slope of ***m = 5*** defined at ***N = 2·10⁶ cycles***

Examples of joints suitable for HFMI improvement

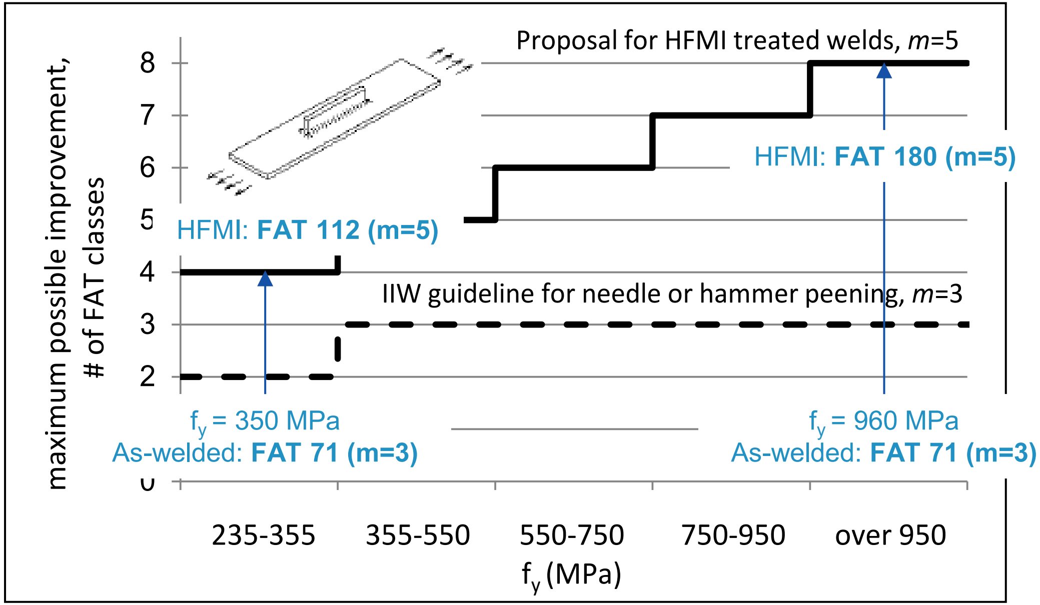


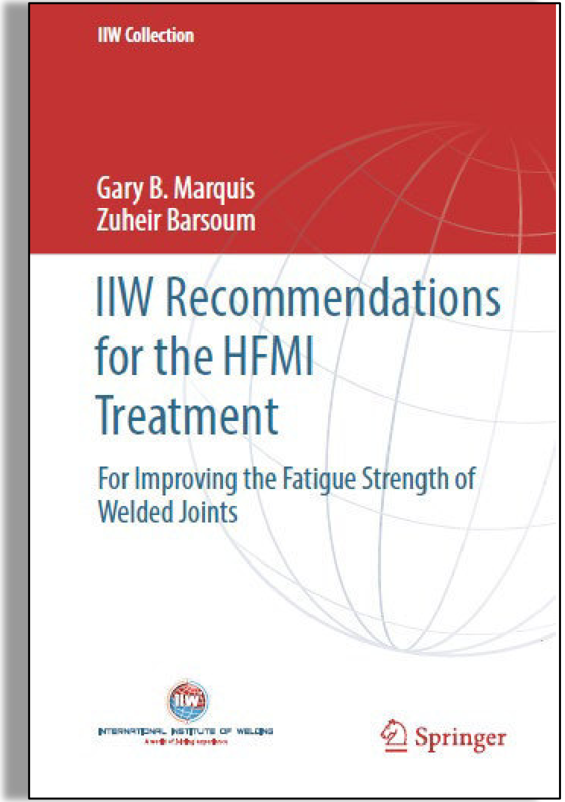
Examples of joints NOT suitable for HFMI improvement



HFMI Fatigue Strength Improvement

One fatigue class increase in strength (about 12.5%) for every 200 MPa increase in static yield strength is shown to be conservative with respect to available data.




IIW Collection

Gary B. Marquis
Zuheir Barsoum

IIW Recommendations for the HFMI Treatment

For Improving the Fatigue Strength of Welded Joints

INTERNATIONAL INSTITUTE OF WELDING

Springer

Marquis & Barsoum, Springer (2016)

HFMI Treatment – challenges and opportunities

- How robust is the HFMI treatment?

- Is the improvement guaranteed, regardless of the weld quality (ISO 5817) prior the treatment?

- Are the induced compressive residual stresses stable during cyclic loading?

- How does the IIW HFMI recommendations apply for life extension of existing structures?

- How can we, fast and accurately, quality inspect HFMI treatments?

HFMI
Stability of compressive residual stress during cyclic loading

Analytical model for S355/S960

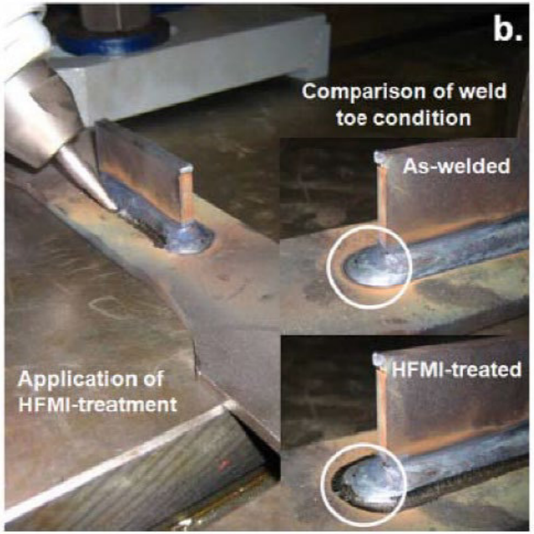
$$\frac{(\sigma_{res})_{relax}}{(\sigma_{res})_{1cycle}} = N^k$$

$$\text{for } ((\sigma_{res})_{ini} + \sigma_{app})/\sigma_y < 1$$

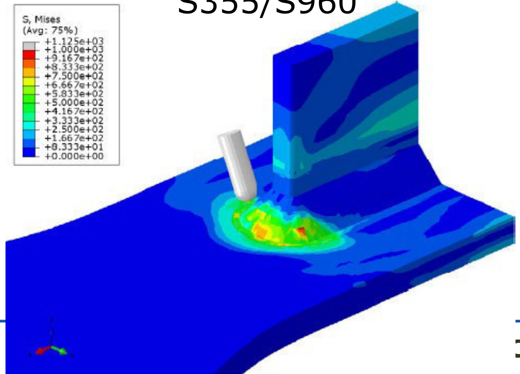
$$\frac{(\sigma_{res})_{relax}}{(\sigma_{res})_{ini}} = N^{-0.004}$$

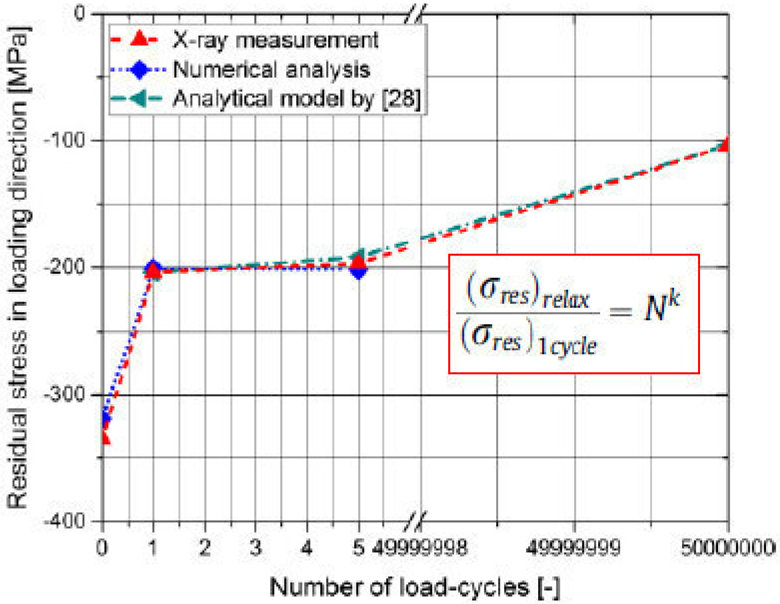
$$\text{for } ((\sigma_{res})_{ini} + \sigma_{app})/\sigma_y \geqslant 1$$

Experimental model for S355/S960



Numerical/FEM model for S355/S960



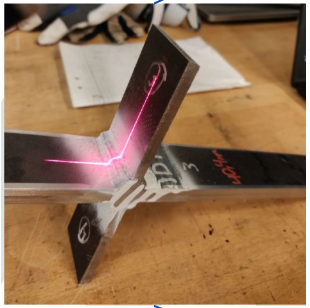


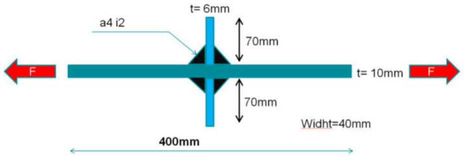
Leitner et al, Journal of *Engineering Structures (2017)*

HFMI Robustness of the treatment

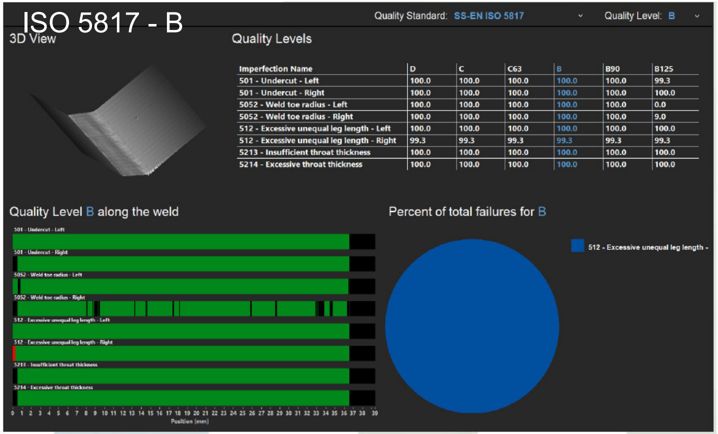
Background

- IIW HFMI recommendations prior treatment: ISO5817-B
- What happens with the fatigue performance when HFMI treatment is performed on welds which do not fulfill the ISO 5817-B?
- As welded quality B (ISO 5817)
- As welded quality D (ISO 5817)
- HFMI treated





ISO 5817 - B

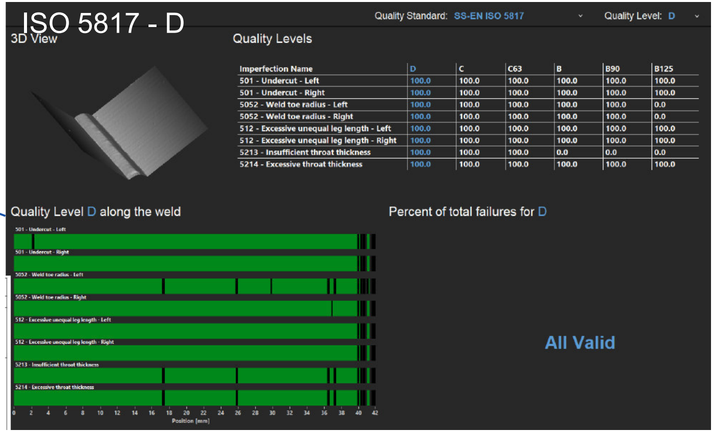


Quality Standard: SS-EN ISO 5817 Quality Level: B

Quality Levels

Imperfection Name	D	C	C63	B	B90	B125
501 - Undercut - Left	100.0	100.0	100.0	100.0	100.0	99.3
501 - Undercut - Right	100.0	100.0	100.0	100.0	100.0	100.0
5052 - Weld toe radius - Left	100.0	100.0	100.0	100.0	100.0	0.0
5052 - Weld toe radius - Right	100.0	100.0	100.0	100.0	100.0	9.0
512 - Excessive unequal leg length - Left	100.0	100.0	100.0	100.0	100.0	100.0
512 - Excessive unequal leg length - Right	99.3	99.3	99.3	99.3	99.3	99.3
5213 - Insufficient throat thickness	100.0	100.0	100.0	100.0	100.0	100.0
5214 - Excessive throat thickness	100.0	100.0	100.0	100.0	100.0	100.0

ISO 5817 - D



Quality Standard: SS-EN ISO 5817 Quality Level: D

Quality Levels

Imperfection Name	D	C	C63	B	B90	B125
501 - Undercut - Left	100.0	100.0	100.0	100.0	100.0	100.0
501 - Undercut - Right	100.0	100.0	100.0	100.0	100.0	100.0
5052 - Weld toe radius - Left	100.0	100.0	100.0	100.0	100.0	0.0
5052 - Weld toe radius - Right	100.0	100.0	100.0	100.0	100.0	0.0
512 - Excessive unequal leg length - Left	100.0	100.0	100.0	100.0	100.0	100.0
512 - Excessive unequal leg length - Right	100.0	100.0	100.0	100.0	100.0	100.0
5213 - Insufficient throat thickness	100.0	100.0	100.0	0.0	0.0	0.0
5214 - Excessive throat thickness	100.0	100.0	100.0	100.0	100.0	100.0

Aldén et al *Welding in the World* (2020)

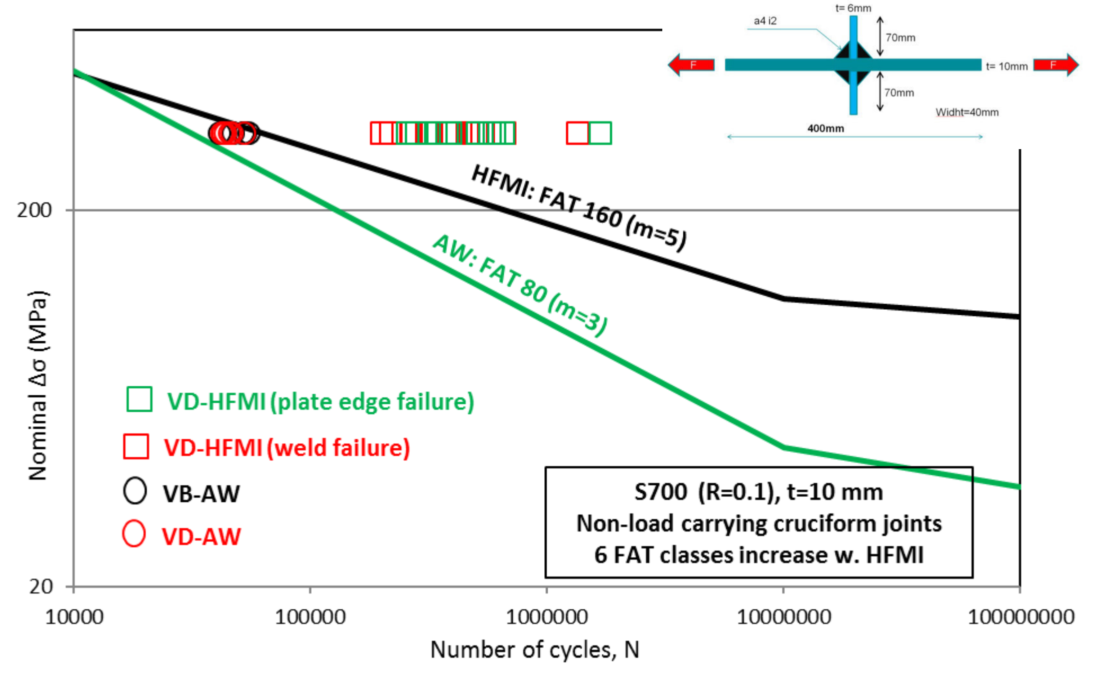
HFMI Robustness of the treatment

- **HFMI FAT 160 , m = 5** (S_Y = 700 MPa)

- **As-welded FAT 80, m = 3**

- The fatigue test results, HFMI, are in good agreement with the recommendations

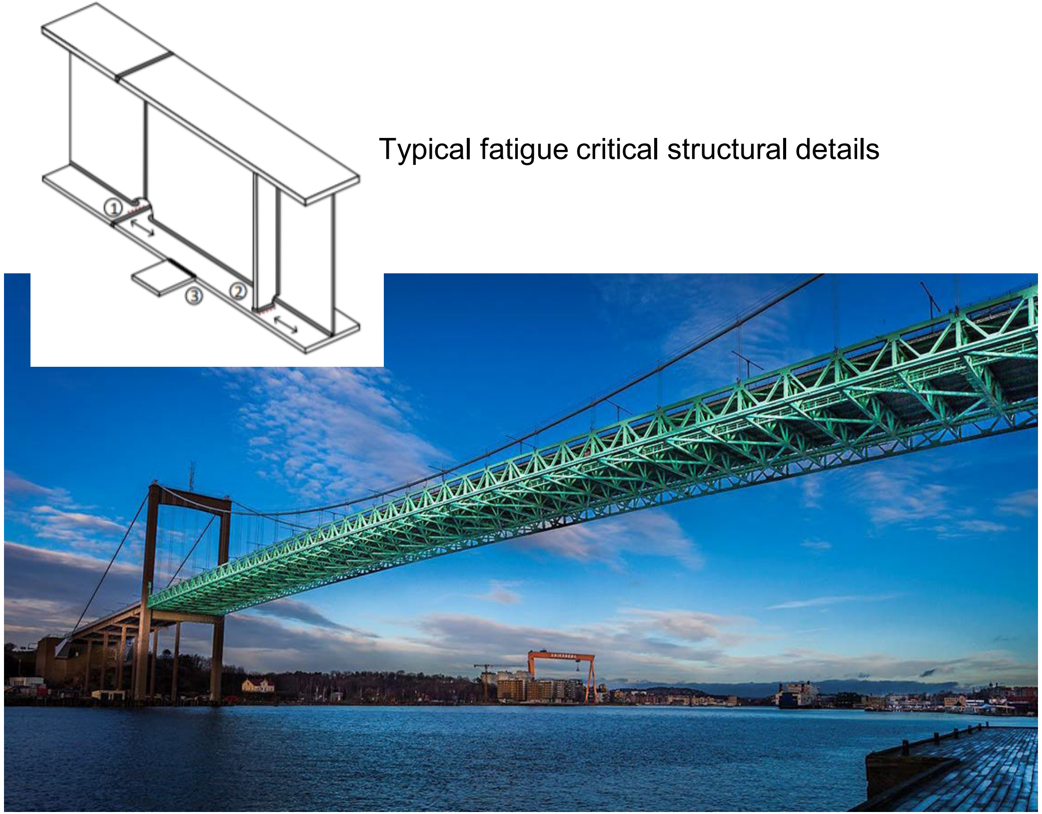
- HFMI treatment could be done on As-welded joints with **quality D** and still have the same benefits as recommended by IIW



Aldén et al *Welding in the World (2020)*

HFMI as a technique for Life extension of infrastructures

- Dramatical increase in the number of **aged steel bridge** is a societal challenge worldwide.
- Aged steel bridges has often **fatigue damages**.
- Utilization of **high-frequency mechanical impact (HFMI)** in fatigue-damaged steel bridges.
- However, **effect of HFMI treatment is sensitive to defect**

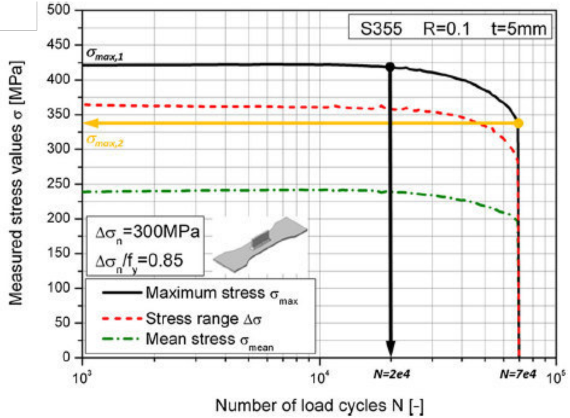


Typical fatigue critical structural details

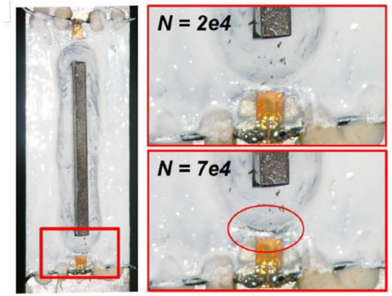
Rehabilitation by HFMI of pre-fatigued welded structures

At which crack sizes is HFMI effective for life extension?

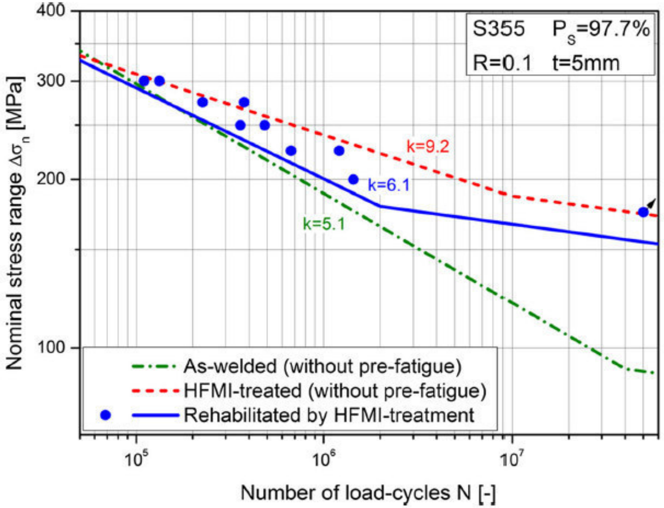
Strain gauge measurements



Surface crack detection



Pre-fatigued (crack depth of a~1 mm)

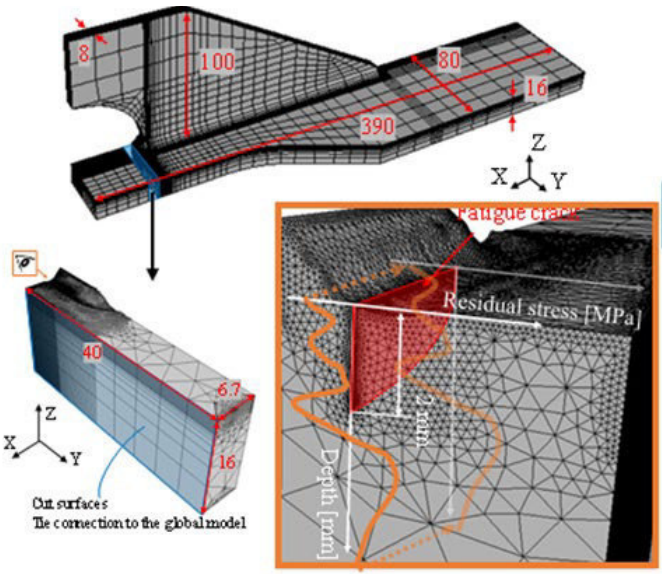


a conservative maximum crack depth of a_{max} = 0.5 mm can be recommended leading to an extension by the HFMI rehabilitation.

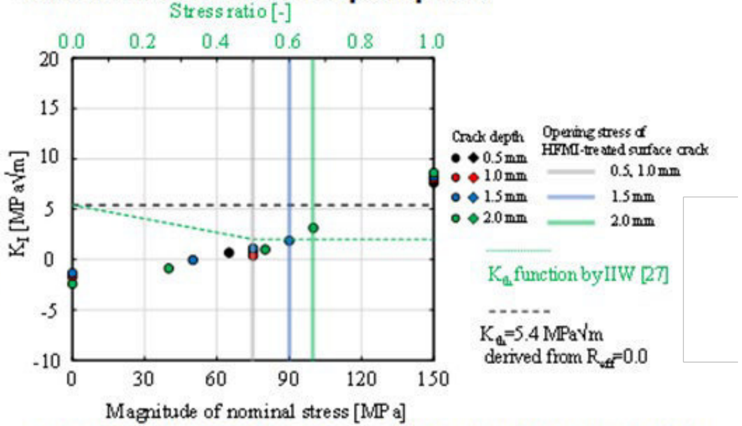
Leitner et al *Welding in the World (2016)*

Defect tolerance of HFMI life extended welds in bridge application

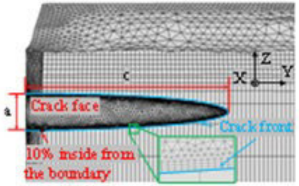
Link 3D HFMI simulation and linear elastic fracture mechanics



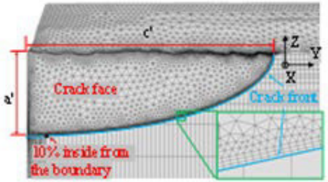
Investigation of crack opening and closing stress at the crack deepest point



Closed surface crack case



Opened surface crack case

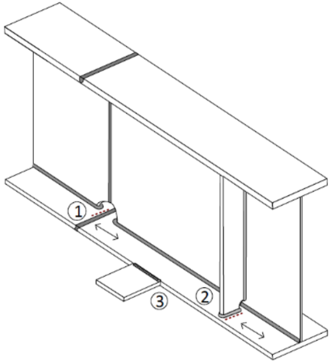


Fatigue cracks less than 1.5 mm in depth, HFMI could be applicable for an effective life extension, which also was **experimentally demonstrated by the study**

Banno et al *Welding in the World (2023)*

LifeExt Implementation – Prolonged life for existing steel bridges

- Life extension of welded details in a Bridge in Sweden, STÖDE.
- Cracks detection using UT- TOFD (Time of Flight Diffraction Technique)
- HFMI treatment of critical details
- Weld quality control using **Winteria®** system
    - Prior and post HFMI

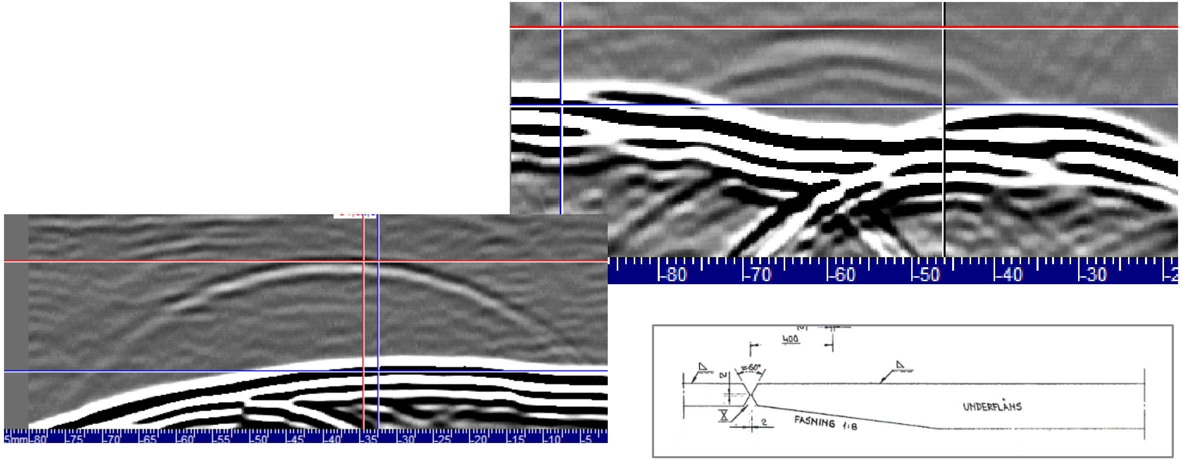


LifeExt Implementation – Prolonged life for existing steel bridges

- Estimation of crack depth – width/depth ratio – prior and after Life extension with HFMI

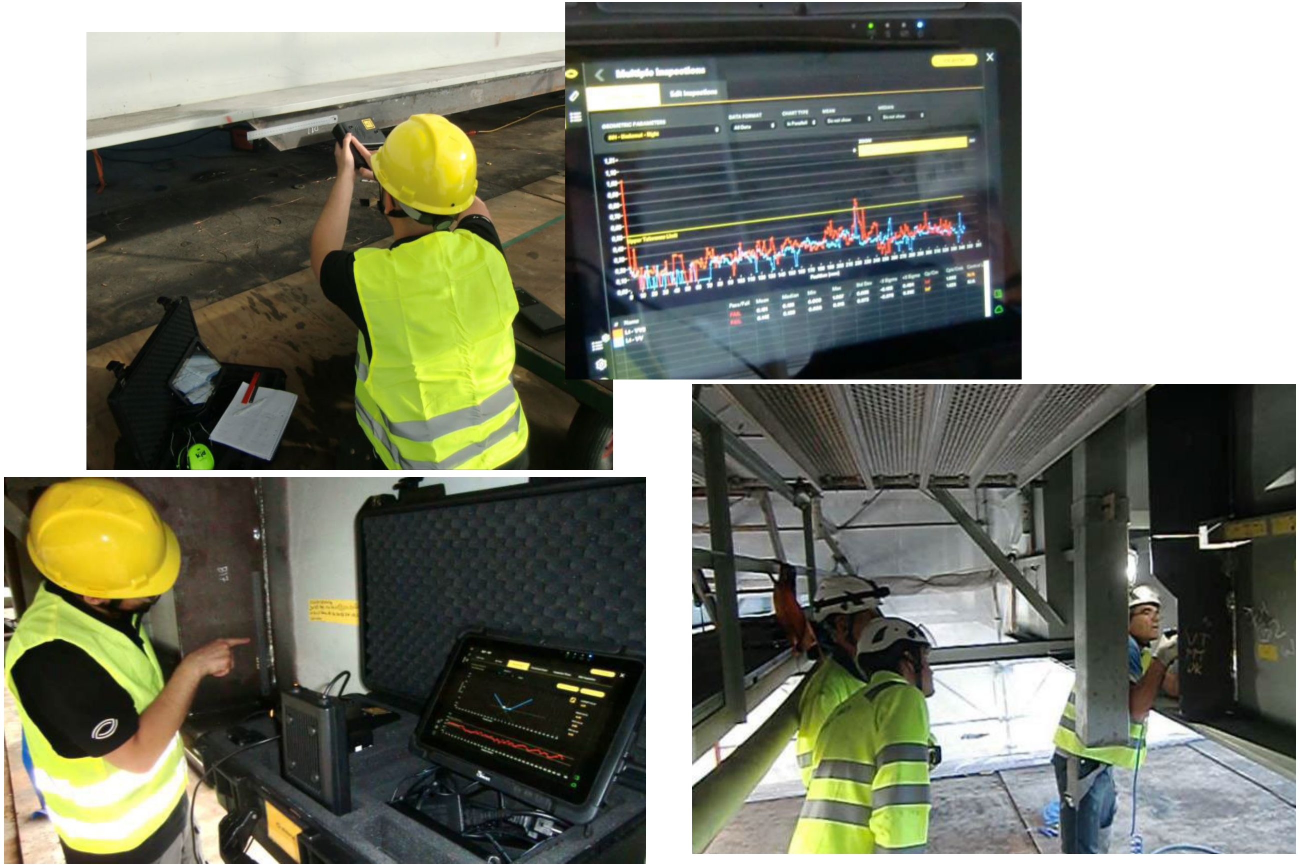
Example:

- Multiple positions with crack like indications, Possible crack – Depth 2.9 mm, width 15 mm

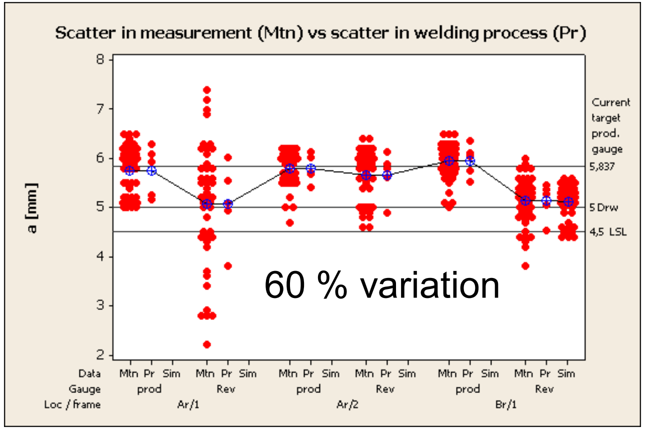


LifeExt Implementation – Prolonged life for existing steel bridges

- Life extension of welded details in a Bridge in Sweden, STÖDE.
- UT-TOFT Defect detection
- Winteria® weld quality inspection
- HFMI treatment
- Winteria® Post Weld Treatment quality inspection



Problems with manual weld quality inspection


Scatter in measurement (Mtn) vs scatter in welding process (Pr)

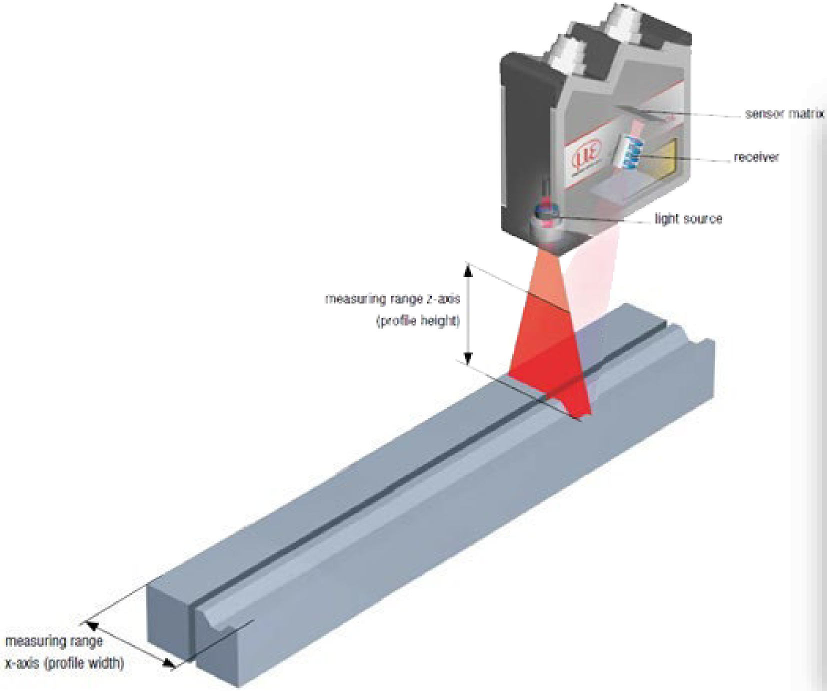
60 % variation

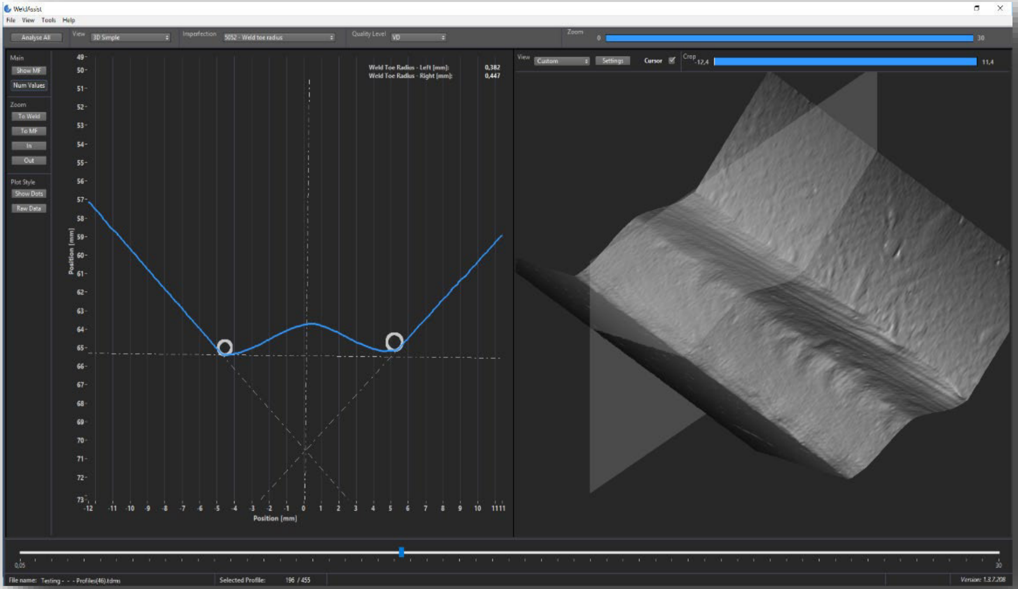
- Poor accuracy
- No data recording
- Slow process
- Repitative work
- Prone to human error

Stenberg et al, *Welding in the World (2017)*

Digitized Quality Assurance of Welded Structures

Winteria® solves the problem of automating digital weld inspection





View: 3D Simple

Imperfection: 5052 - Weld toe radius

Quality Level: VD

Zoom: 0 – 30

Weld Toe Radius - Left [mm]: 0,382

Weld Toe Radius - Right [mm]: 0,447

View: Custom

Cursor ☑

Crop: -12,4 – 11,4

File name: Testing - - - Profiles(46).tdms

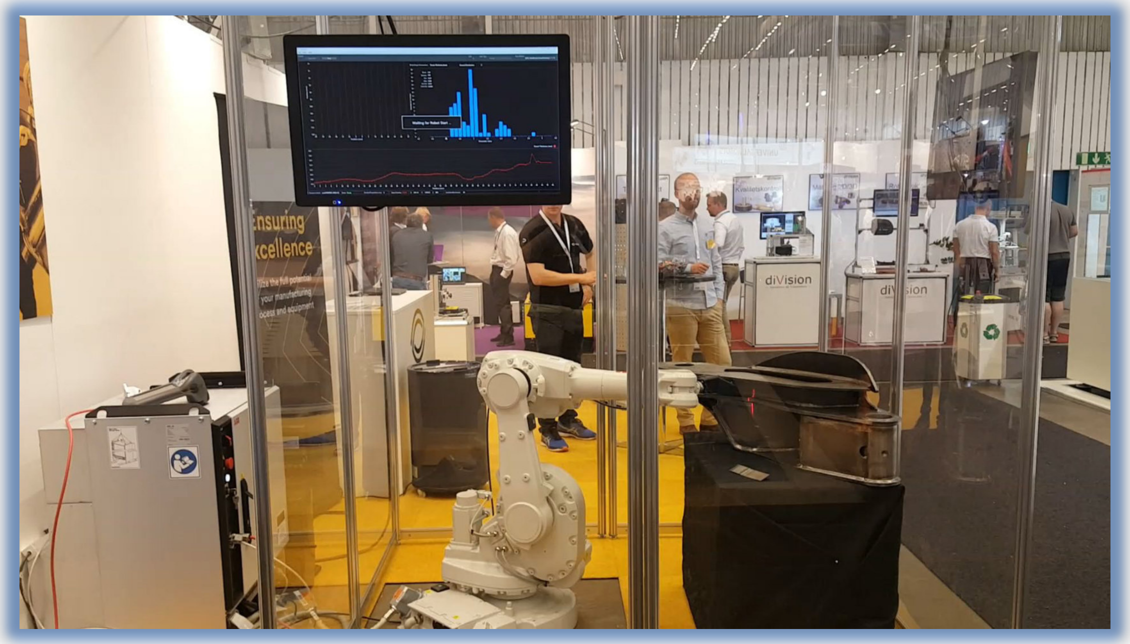
Selected Profile: 196 / 455

Version: 1.3.7.208

Digitized Quality Assurance of Welded Structures

Winteria® solves the problem of automating digital weld inspection

Robot installation



Digitized Quality Assurance of Welded Structures

Winteria® solves the problem of automating digital weld inspection

Winteria® FLEX™

Flexible and Easy to Use

Mobility

Outlook (1)

- HFMI have proven to be a robust post weld treament technique for both new structures and as life extension technique.
- The HFMI recommendations are incorporated in the general IIW recommendations and in EN 1993-3 (Eurocode 3).
- Digitized quality inspection (Winteria®) prior and after post weld treatment have proven to be a very effective tool, both robotized and handheld (FLEX^{TM}).
- IIW HFMI recommendations updated and will be published in 2026.

Outlook (2)

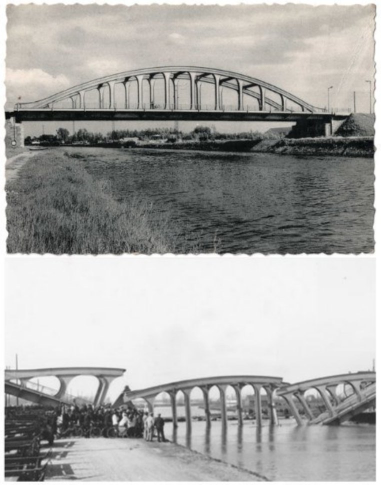
Recent Developments in HFMI Treatment Guidelines (Springer 2026), 2nd Edition

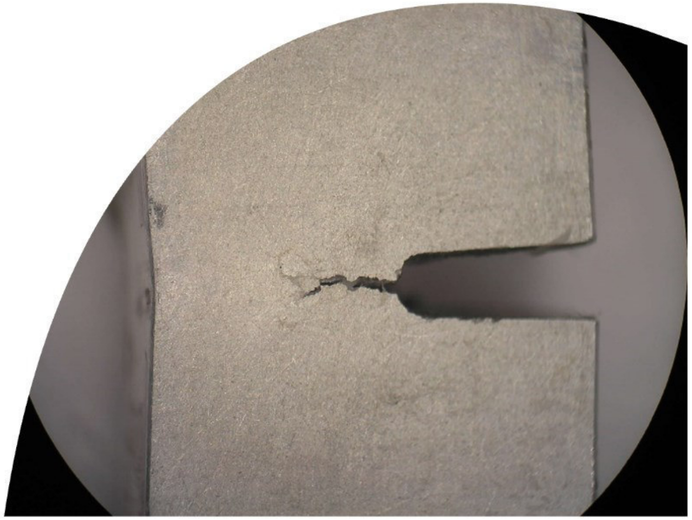
- Expanded material scope (yield strengths up to 1300 MPa, compared to 960 MPa in the previous edition)
- Relaxed weld geometry requirements (weld profiles prior to HFMI treatment, ISO 5817 Quality Level B, have been eased)
- Introduction of numerical fatigue strength modification factors
- Updated thickness correction factors
- Refined S–N curve descriptions
- Inclusion of guidelines for retrofitting pre-fatigued structures
- Standardized verification methodology for HFMI devices
- Updated recommendations for corrosive environments.

Thank you for your kind attention!

4. THE DEVELOPMENT AND CHANGES IN PREN1993-1-10 (BERTRAM KÜHN, TECHNISCHE HOCHSCHULE MITTELHESSEN)

EUROPEAN CONVENTION
FOR CONSTRUCTIONAL STEELWORK
Bridge Committee





How to properly select the steel grade concerning toughness requirements and how to extend the fatigue life of steel and steel composite bridges

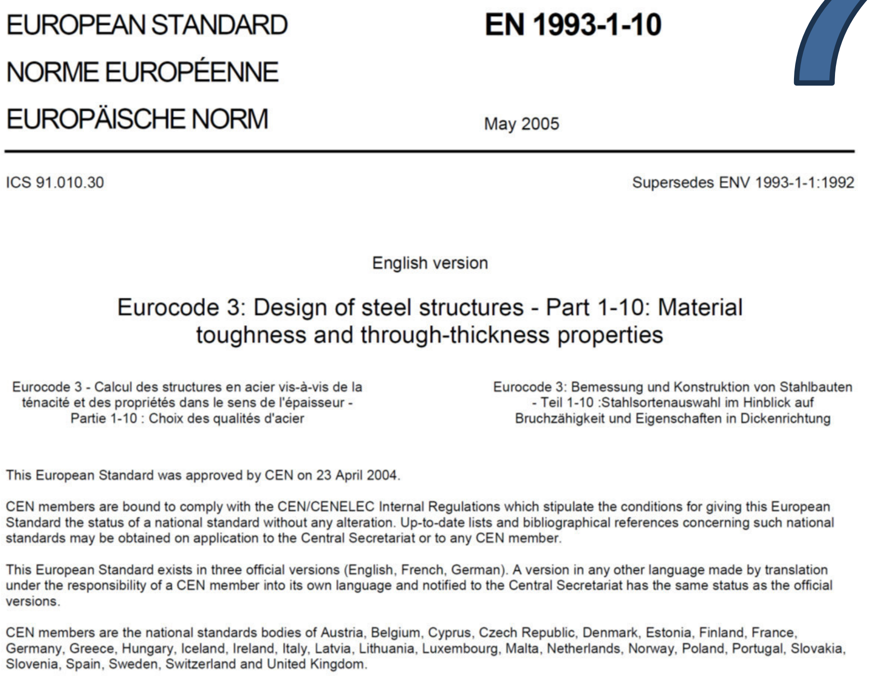
The development and changes in prEN1993-1-10

Prof. Dr.-Ing. Bertram Kühn

(Chairman of the project team SC3.PT9)

Agenda

1. Initial Situation
2. Revision Process and Stakeholders
3. Key Innovations
4. Outlook



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1993-1-10

May 2005

ICS 91.010.30

Supersedes ENV 1993-1-1:1992

English version

Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties

Eurocode 3 - Calcul des structures en acier vis-à-vis de la ténacité et des propriétés dans le sens de l'épaisseur - Partie 1-10 : Choix des qualités d'acier

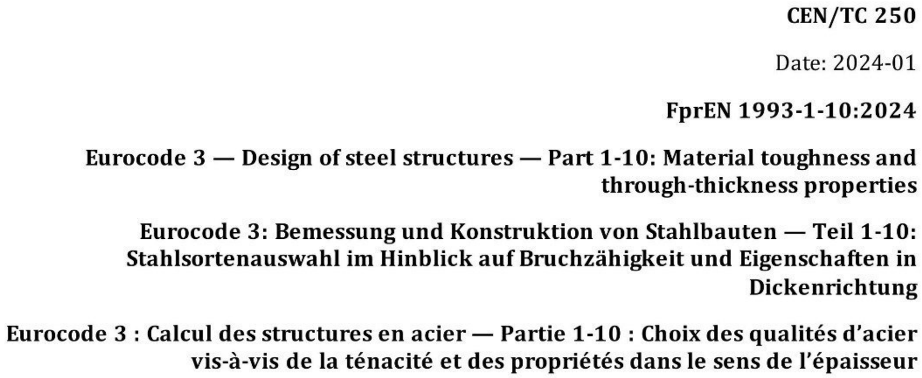
Eurocode 3: Bemessung und Konstruktion von Stahlbauten - Teil 1-10 :Stahlsortenauswahl im Hinblick auf Bruchzähigkeit und Eigenschaften in Dickenrichtung

This European Standard was approved by CEN on 23 April 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



CEN/TC 250

Date: 2024-01

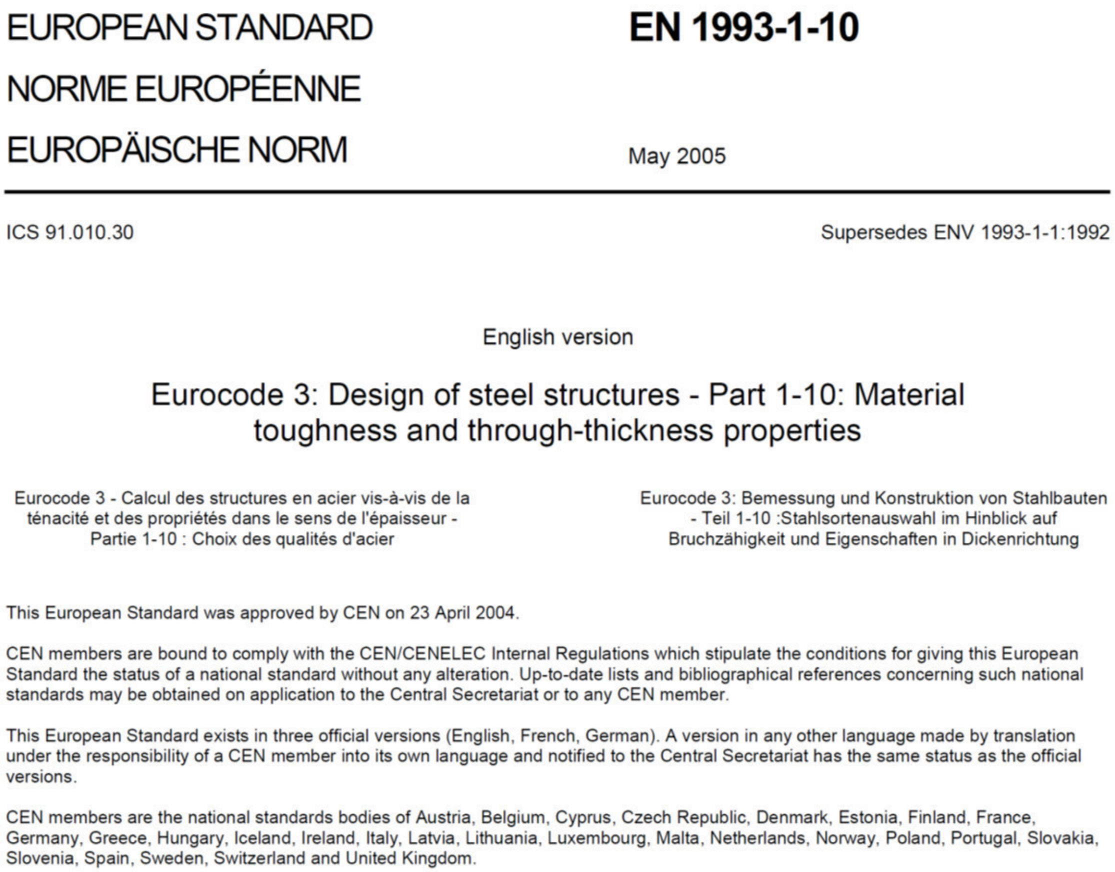
FprEN 1993-1-10:2024

Eurocode 3 — Design of steel structures — Part 1-10: Material toughness and through-thickness properties

Eurocode 3: Bemessung und Konstruktion von Stahlbauten — Teil 1-10: Stahlsortenauswahl im Hinblick auf Bruchzähigkeit und Eigenschaften in Dickenrichtung

Eurocode 3 : Calcul des structures en acier — Partie 1-10 : Choix des qualités d'acier vis-à-vis de la ténacité et des propriétés dans le sens de l'épaisseur

1. Initial Situation



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1993-1-10

May 2005

ICS 91.010.30

Supersedes ENV 1993-1-1:1992

English version

Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties

Eurocode 3 - Calcul des structures en acier vis-à-vis de la ténacité et des propriétés dans le sens de l'épaisseur - Partie 1-10 : Choix des qualités d'acier

Eurocode 3: Bemessung und Konstruktion von Stahlbauten - Teil 1-10 :Stahlsortenauswahl im Hinblick auf Bruchzähigkeit und Eigenschaften in Dickenrichtung

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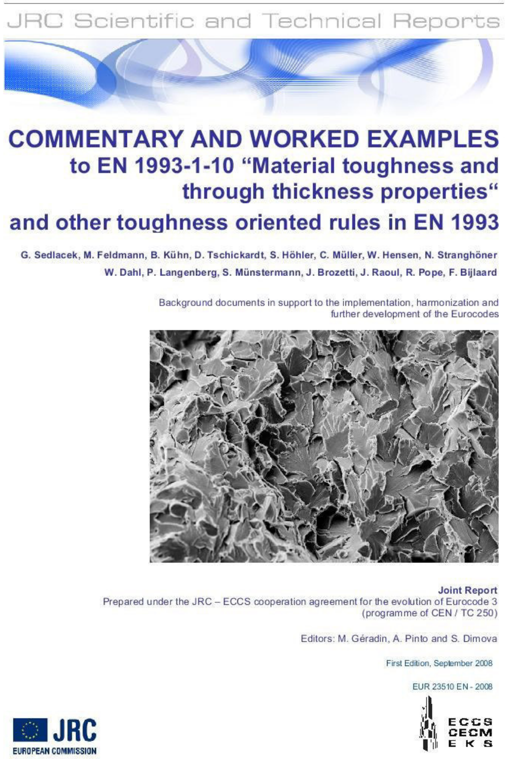


JRC Scientific and Technical Reports

COMMENTARY AND WORKED EXAMPLES to EN 1993-1-10 "Material toughness and through thickness properties" and other toughness oriented rules in EN 1993

G. Sedlacek, M. Feldmann, B. Kühn, D. Tschickardt, S. Höhler, C. Müller, W. Hensen, N. Stranghöner
W. Dahl, P. Langenberg, S. Münstermann, J. Brozetti, J. Raoul, R. Pope, F. Bijlaard

Background documents in support to the implementation, harmonization and further development of the Eurocodes

Joint Report
Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3 (programme of CEN / TC 250)

Editors: M. Géradin, A. Pinto and S. Dimova

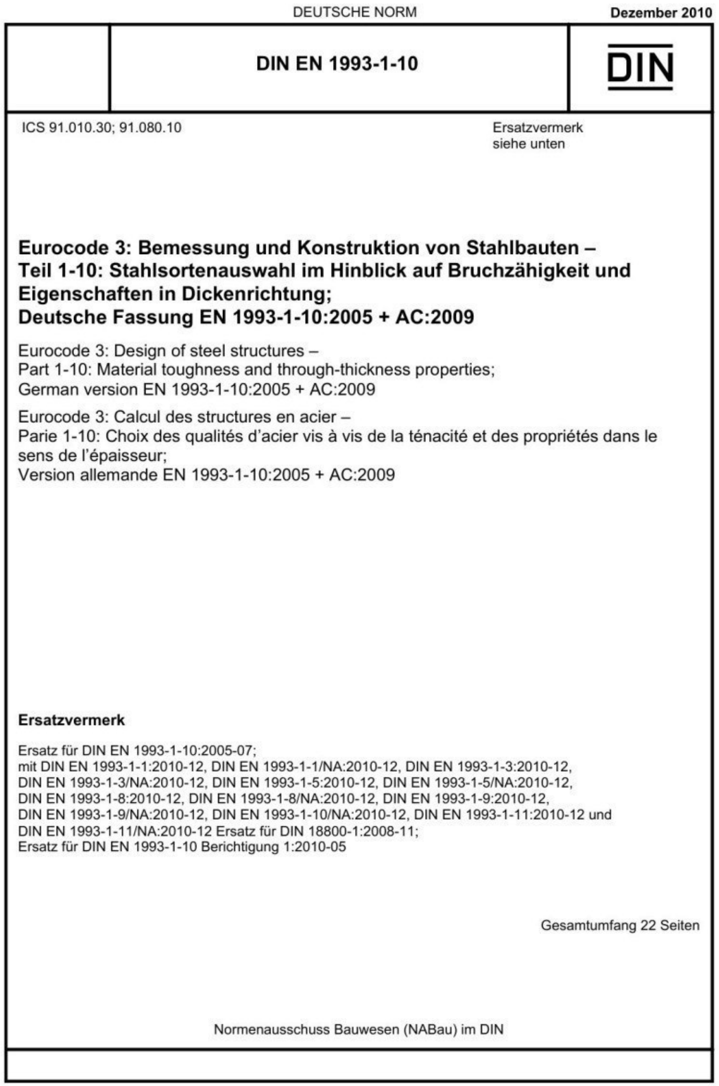
First Edition, September 2008

EUR 23510 EN - 2008

see also Sedlacek, G. et al.:
https://publications.jrc.ec.europa.eu/repository/handle/JRC47278

1. Initial Situation 2. 3. 4.

- In Germany and other European countries valid since 2012
- Mostly positive experiences in the past 13 years all over Europe
- Further applications also outside Europe (e.g. similar design rules in Australia / New Zeeland and 1st considerations in Canada)



DEUTSCHE NORM

Dezember 2010

DIN EN 1993-1-10

DIN

ICS 91.010.30; 91.080.10

Ersatzvermerk
siehe unten

Eurocode 3: Bemessung und Konstruktion von Stahlbauten –
Teil 1-10: Stahlsortenauswahl im Hinblick auf Bruchzähigkeit und Eigenschaften in Dickenrichtung;
Deutsche Fassung EN 1993-1-10:2005 + AC:2009

Eurocode 3: Design of steel structures –
Part 1-10: Material toughness and through-thickness properties;
German version EN 1993-1-10:2005 + AC:2009

Eurocode 3: Calcul des structures en acier –
Parie 1-10: Choix des qualités d'acier vis à vis de la ténacité et des propriétés dans le sens de l'épaisseur;
Version allemande EN 1993-1-10:2005 + AC:2009

Ersatzvermerk

Ersatz für DIN EN 1993-1-10:2005-07;
mit DIN EN 1993-1-1:2010-12, DIN EN 1993-1-1/NA:2010-12, DIN EN 1993-1-3:2010-12, DIN EN 1993-1-3/NA:2010-12, DIN EN 1993-1-5:2010-12, DIN EN 1993-1-5/NA:2010-12, DIN EN 1993-1-8:2010-12, DIN EN 1993-1-8/NA:2010-12, DIN EN 1993-1-9:2010-12, DIN EN 1993-1-9/NA:2010-12, DIN EN 1993-1-10/NA:2010-12, DIN EN 1993-1-11:2010-12 und DIN EN 1993-1-11/NA:2010-12 Ersatz für DIN 18800-1:2008-11;
Ersatz für DIN EN 1993-1-10 Berichtigung 1:2010-05

Gesamtumfang 22 Seiten

Normenausschuss Bauwesen (NABau) im DIN

1. Initial Situation 2. 3. 4.

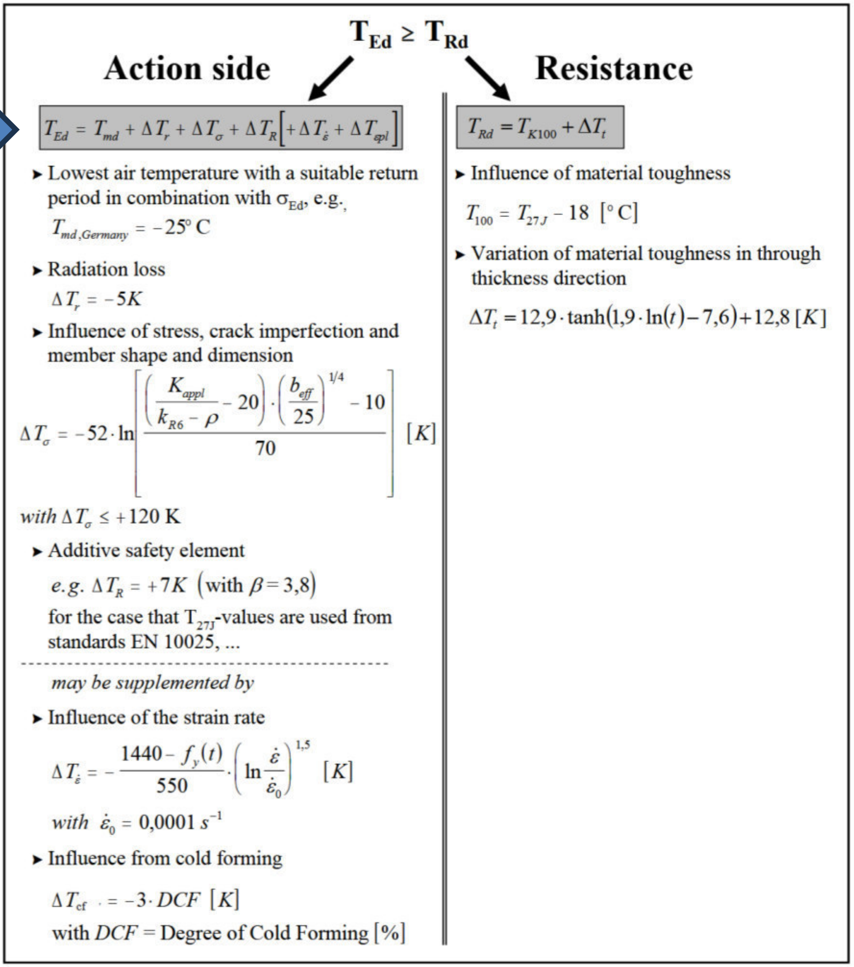
Fracture mechanics approach on temperature basis

$\boxed{K^*_{\mathrm{appl,d}} \le K_{\mathrm{mat,d}}}$ → **Transformation** → $\boxed{T_{\mathrm{Ed}} \ge T_{\mathrm{Rd}}}$

$$\boxed{T_{Ed} = T_{mdr} + \Delta T_{\sigma} + \Delta T_{R} + \Delta T_{\dot{\varepsilon}} + \Delta T_{\varepsilon cf}}$$

Reference temperature T_{Ed} also used as main input parameter for the simplified design approach using tabulated values.

Assessment scheme



$T_{Ed} \ge T_{Rd}$

Action side

$$\boxed{T_{Ed} = T_{md} + \Delta T_r + \Delta T_{\sigma} + \Delta T_R \left[+ \Delta T_{\dot{\varepsilon}} + \Delta T_{epl} \right]}$$

- Lowest air temperature with a suitable return period in combination with σ_{Ed}, e.g.,
  $T_{md,Germany} = -25^{\circ}\,C$
- Radiation loss
  $\Delta T_r = -5K$
- Influence of stress, crack imperfection and member shape and dimension

$$\Delta T_{\sigma} = -52 \cdot \ln \left[\frac{\left(\frac{K_{appl}}{k_{R6} - \rho} - 20 \right) \cdot \left(\frac{b_{eff}}{25} \right)^{1/4} - 10}{70} \right] \; [K]$$

with $\Delta T_{\sigma} \le +120$ K

- Additive safety element
  $e.g.\ \Delta T_R = +7K$ (with $\beta = 3{,}8$)
  for the case that T_{27J}-values are used from standards EN 10025, ...

---

may be supplemented by

- Influence of the strain rate

$$\Delta T_{\dot{\varepsilon}} = -\frac{1440 - f_y(t)}{550} \cdot \left(\ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right)^{1,5} \; [K]$$

with $\dot{\varepsilon}_0 = 0{,}0001\ s^{-1}$

- Influence from cold forming

$$\Delta T_{cf} = -3 \cdot DCF \; [K]$$

with DCF = Degree of Cold Forming [%]

Resistance

$$\boxed{T_{Rd} = T_{K100} + \Delta T_t}$$

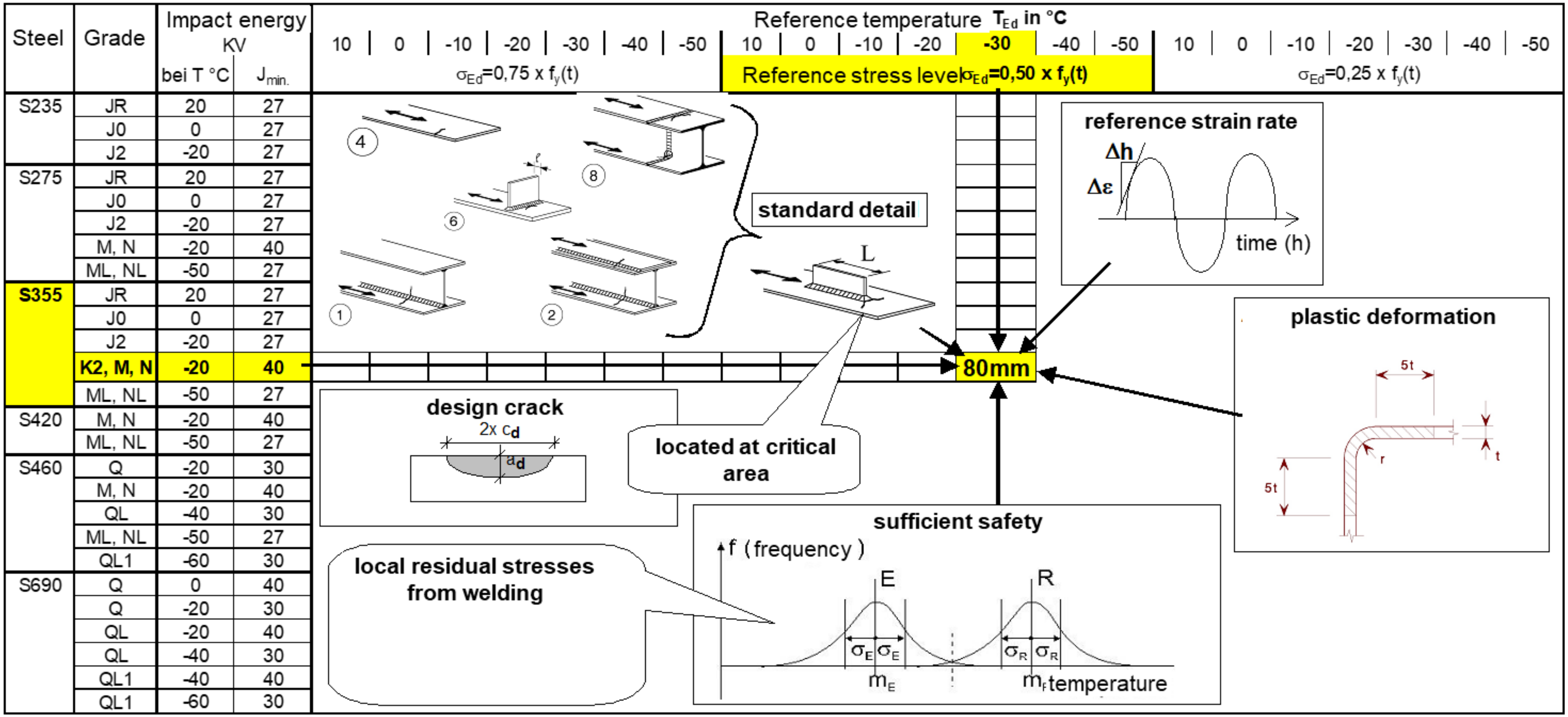
- Influence of material toughness

$$T_{100} = T_{27J} - 18 \; [^{\circ}\,C]$$

- Variation of material toughness in through thickness direction

$$\Delta T_t = 12{,}9 \cdot \tanh(1{,}9 \cdot \ln(t) - 7{,}6) + 12{,}8 \; [K]$$

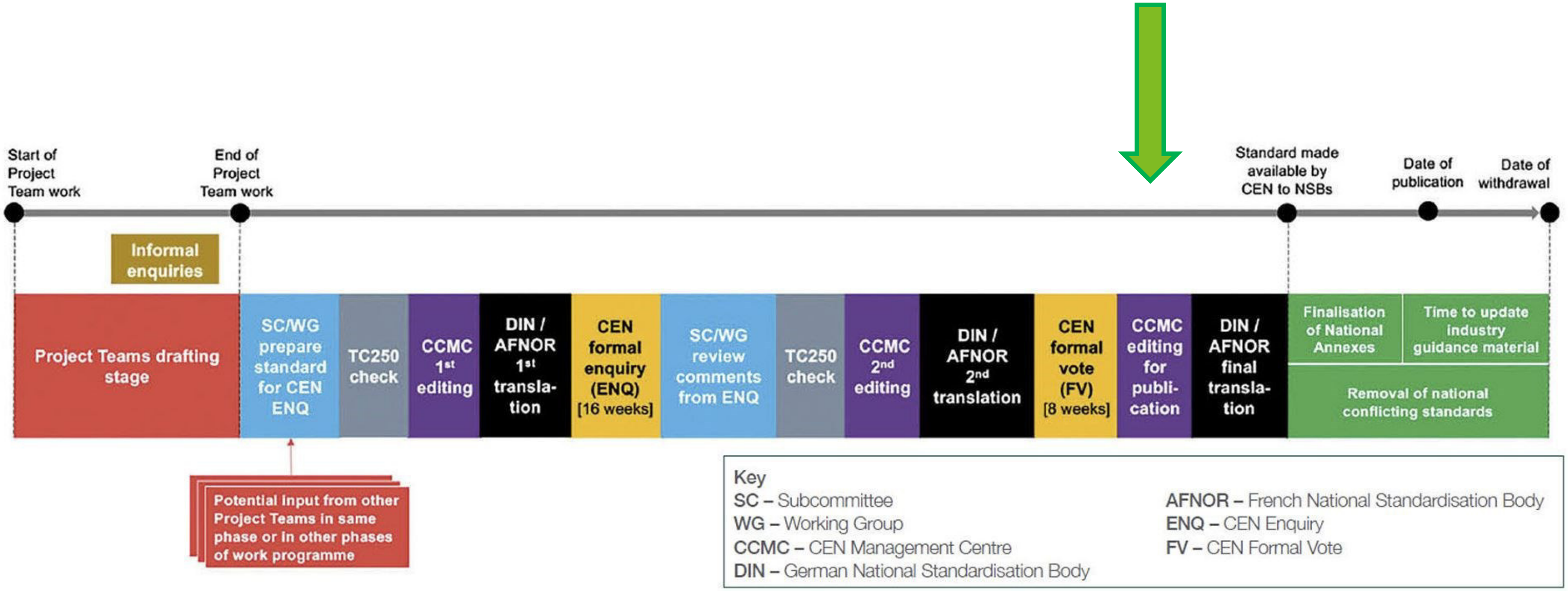
Simplified design approach (in general)



Steel	Grade	Impact energy KV bei T °C	Impact energy KV $J_{min.}$
S235	JR	20	27
	J0	0	27
	J2	-20	27
S275	JR	20	27
	J0	0	27
	J2	-20	27
	M, N	-20	40
	ML, NL	-50	27
S355	JR	20	27
	J0	0	27
	J2	-20	27
	K2, M, N	**-20**	**40**
	ML, NL	-50	27
S420	M, N	-20	40
	ML, NL	-50	27
S460	Q	-20	30
	M, N	-20	40
	QL	-40	30
	ML, NL	-50	27
	QL1	-60	30
S690	Q	0	40
	Q	-20	30
	QL	-20	40
	QL	-40	30
	QL1	-40	40
	QL1	-60	30

2. Revision Process and Stakeholders

1. **2. Revision and Stakeholders** 3. 4.



Key

SC – Subcommittee

WG – Working Group

CCMC – CEN Management Centre

DIN – German National Standardisation Body

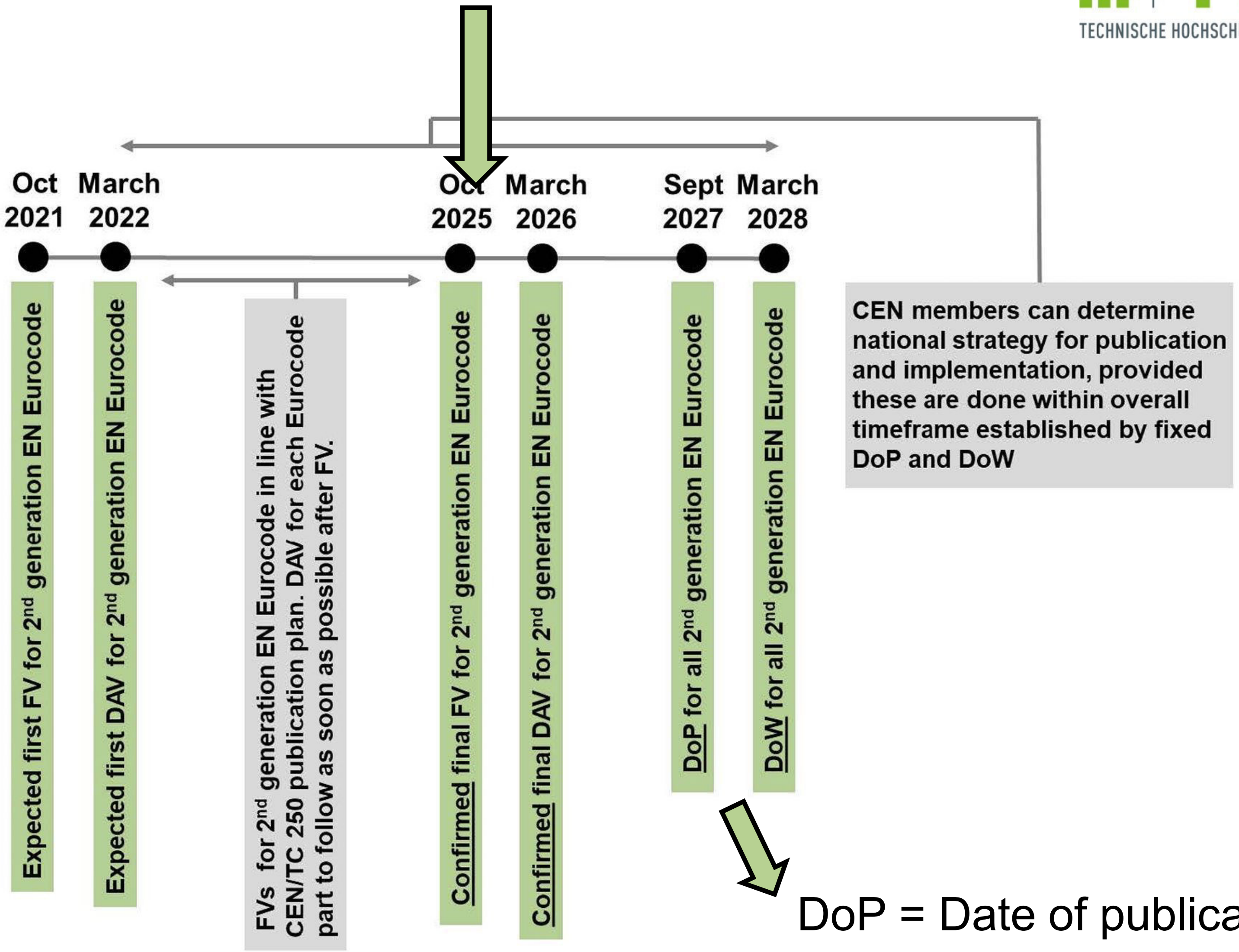
AFNOR – French National Standardisation Body

ENQ – CEN Enquiry

FV – CEN Formal Vote

FIGURE 1 — Eurocode development process

1. 2. Revision and Stakeholders 3. 4.



Oct 2021

March 2022

Oct 2025

March 2026

Sept 2027

March 2028

Expected first FV for 2nd generation EN Eurocode

Expected first DAV for 2nd generation EN Eurocode

FVs for 2nd generation EN Eurocode in line with CEN/TC 250 publication plan. DAV for each Eurocode part to follow as soon as possible after FV.

Confirmed final FV for 2nd generation EN Eurocode

Confirmed final DAV for 2nd generation EN Eurocode

DoP for all 2nd generation EN Eurocode

DoW for all 2nd generation EN Eurocode

CEN members can determine national strategy for publication and implementation, provided these are done within overall timeframe established by fixed DoP and DoW

DoP = Date of publication

DoW = Date of withdrawal

1. **2. Revision and Stakeholders** 3. 4.

Responsible for technical revisions ECCS / TC6 / WG10

1. **2. Revision and Stakeholders** 3. 4.

Responsible for technical revisions ECCS / TC6 / WG10

Role	Name	Send by
Convenor	Kühn, Bertram	CEN/TC 250/SC 3
Secretary	Kempa, Susan	DIN (DE)
Expert	Abakanov, Mirken	KAZMEMST (KAZ)
Expert	Baudet, Philippe	AFNOR (FR)
Expert	Bespayev, Aliy	KAZMEMST (KAZ)
Expert	Borges, Luís	IPQ (PT)
Secretary	Braner, Jessica	DIN (DE)
Monitor	Burgos, Dag	SN (NO)
Expert	Candeias, Miguel	ILNAS (LUX)
Expert	Chirea, Cristina	ASRO (RO)
Secretary	Clunie, Sandra	DIN (DE)
Expert	Davaine, Laurence	AFNOR (FR)
Expert	Desta, Asky	BSI (GB)
Expert	Dubina, Dan	ASRO (RO)
Expert	Engelhardt, Imke	DIN (DE)
Expert	Feldmann, Markus	DIN (DE)

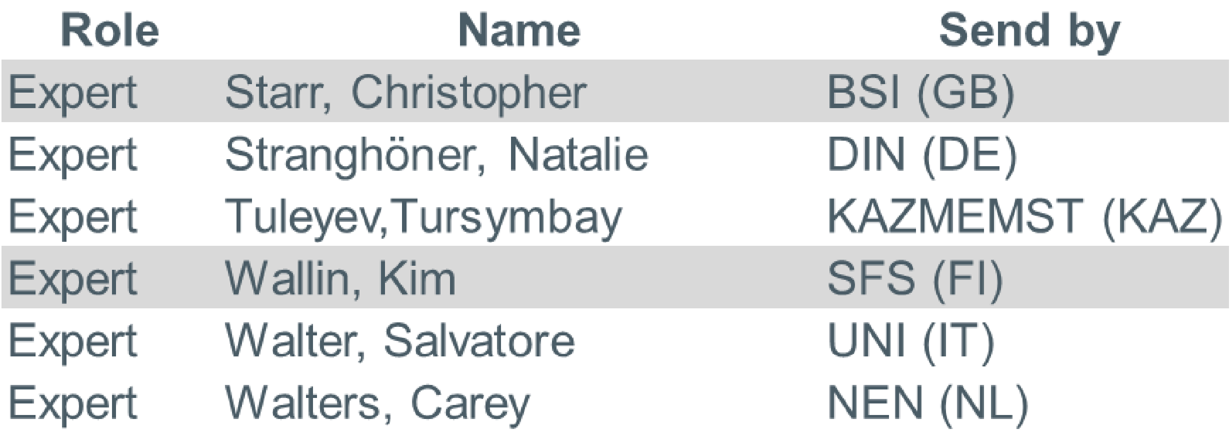
1. 2. Revision and Stakeholders 3. 4.

Responsible for technical revisions ECCS / TC6 / WG10

Role	Name	Send by
Expert	Imam, Boulent	BSI (GB)
Expert	Kortelainen, Pasi	SFS (FI)
Expert	Krabbe-Christensen, Peter	DS (DK)
Expert	Kuhlmann, Ulrike	DIN (DE)
Expert	Lochte-Holtgreven, Stephan	DIN (DE)
Expert	Lukic, Mladen	AFNOR (FR)
Expert	Ogle, Martin	BSI (GB)
Monitor	Operations Support Centre	BSI (GB)
Expert	Pope, David	BSI (GB)
Expert	Sandon, Stefano	UNI (IT)
Expert	Shahnovich, Alexandr	KAZMEMST (KAZ)
Monitor	Skajaa, Birgitte	SN (NO)
Expert	Skejic, Davor	HZN (HR)
Expert	Sleczka, Lucjan	PKN (PL)
Expert	Solland, Gunnar	SN (NO)

1. **2. Revision and Stakeholders** 3. 4.

Responsible for technical revisions ECCS / TC6 / WG10



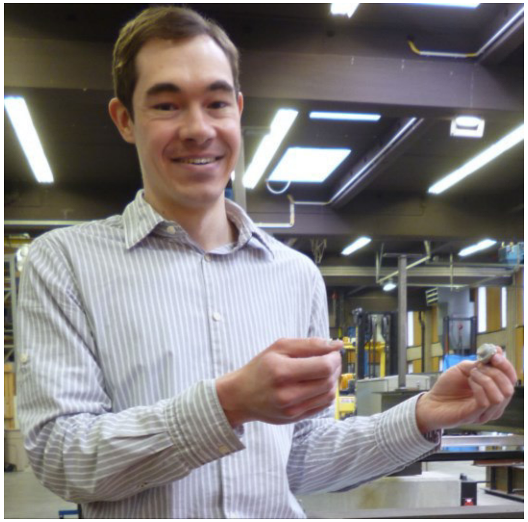
Role	Name	Send by
Expert	Starr, Christopher	BSI (GB)
Expert	Stranghöner, Natalie	DIN (DE)
Expert	Tuleyev,Tursymbay	KAZMEMST (KAZ)
Expert	Wallin, Kim	SFS (FI)
Expert	Walter, Salvatore	UNI (IT)
Expert	Walters, Carey	NEN (NL)

<u>The group consists of:</u>

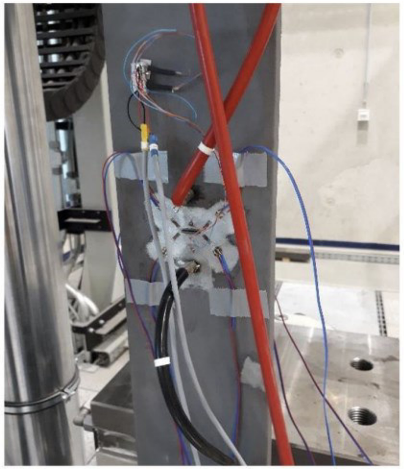
1 chairperson
3 secretaries
3 observers
<u>30 experts</u>
37 members from almost all over Europe

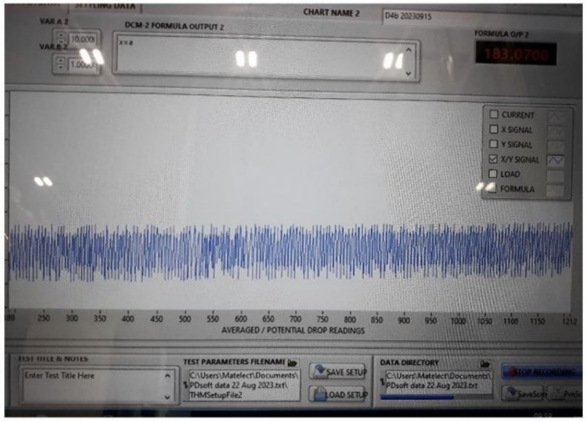
Responsible for text revisions TC250 / SC3 / PT9

Position	Name	First name	Init.	Country
PT leader	Kühn	Bertram	Kue	DE
PT member	Cosgrove	Thomas	Cos	UK
PT member	Solland	Gunnar	GSol	NO
PT member	Borges	Luis	Bor	CH
PT member	Tibolt	Mike	Tib	LUX



3. Key Innovations





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VAR B 2: 1.000

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FORMULA O/P 2: 183.0700

☐ CURRENT
☐ X SIGNAL
☐ Y SIGNAL
☑ X/Y SIGNAL
☐ LOAD
FORMULA

TEST TITLE & NOTES: Enter Test Title Here

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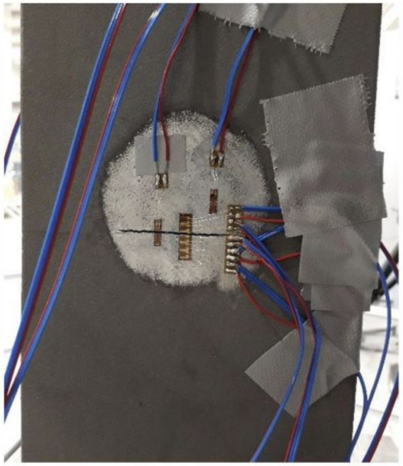
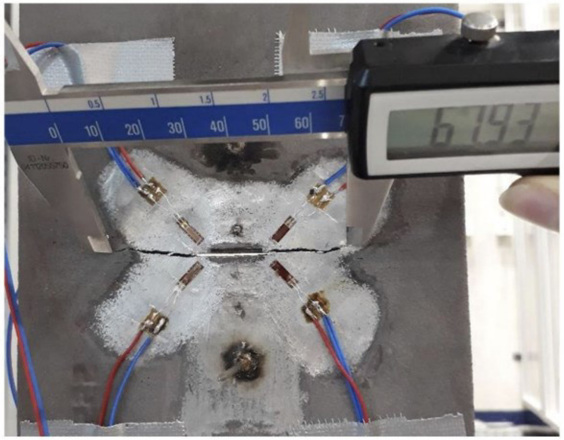
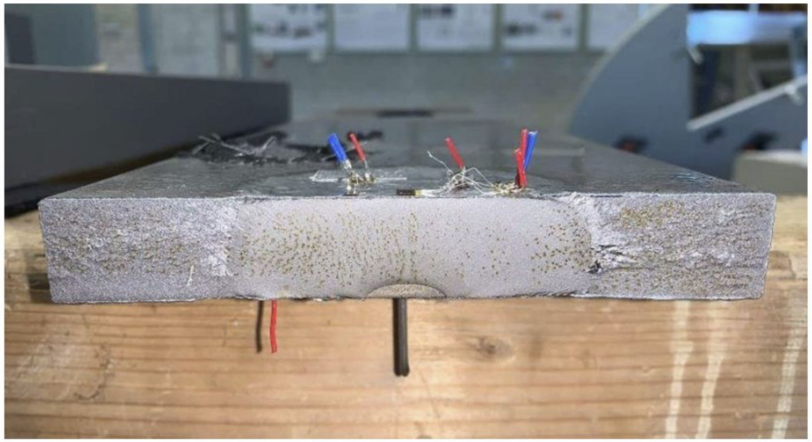
DATA DIRECTORY: C:\Users\Matelect\Documents\PDsoft data 22 Aug 2023.txt

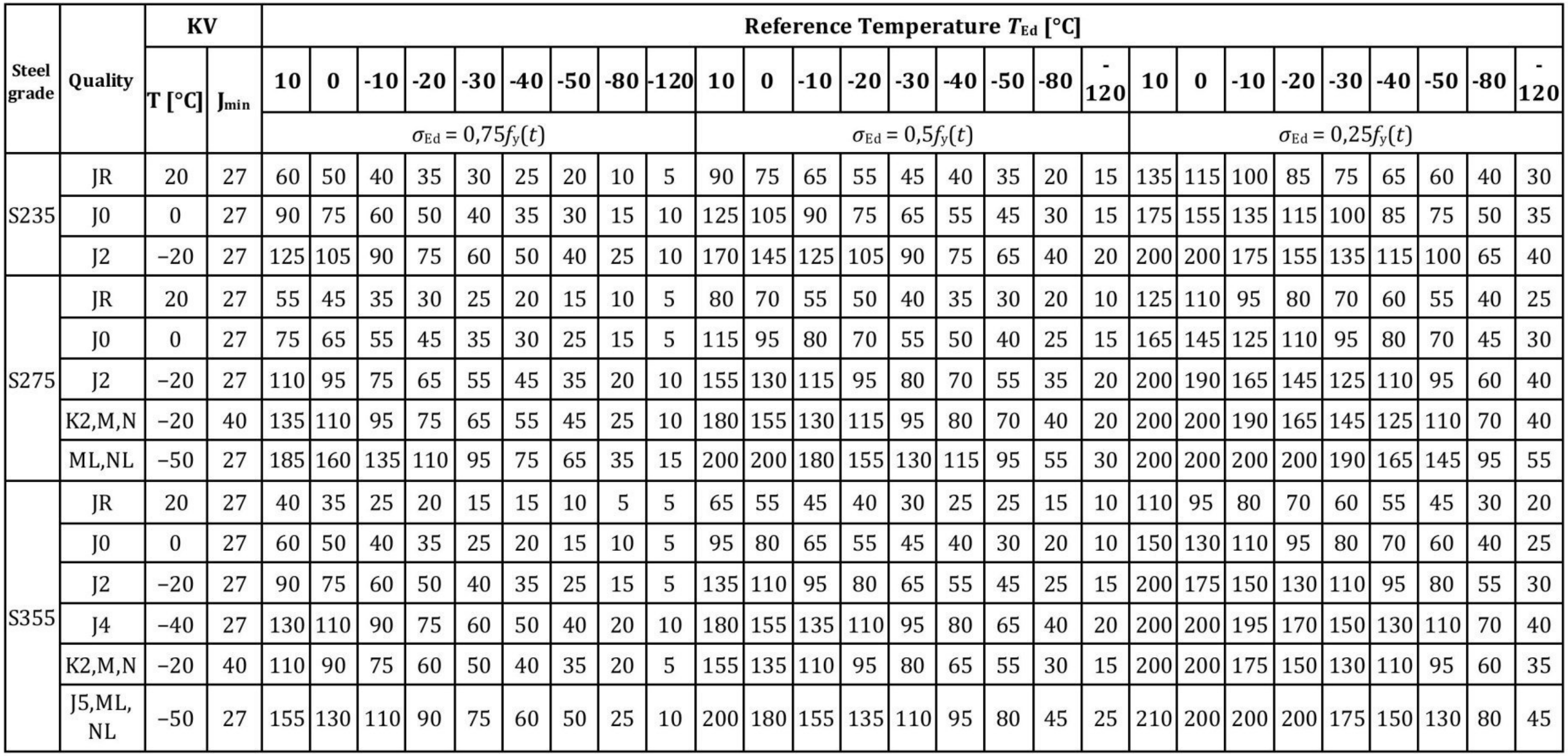






1. 2. 3. Key Innovations 4.

Well known simplified design method remains



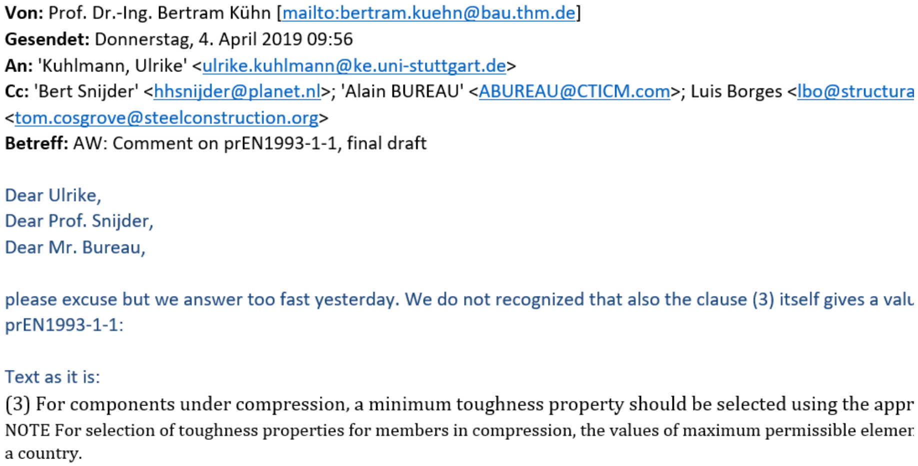
Steel grade	**Quality**	**KV**		**Reference Temperature T_{Ed} [°C]**																										
		T [°C]	**J_{min}**	**10**	**0**	**-10**	**-20**	**-30**	**-40**	**-50**	**-80**	**-120**	**10**	**0**	**-10**	**-20**	**-30**	**-40**	**-50**	**-80**	**-120**	**10**	**0**	**-10**	**-20**	**-30**	**-40**	**-50**	**-80**	**-120**
				$\sigma_{Ed} = 0{,}75 f_y(t)$									$\sigma_{Ed} = 0{,}5 f_y(t)$									$\sigma_{Ed} = 0{,}25 f_y(t)$								
S235	JR	20	27	60	50	40	35	30	25	20	10	5	90	75	65	55	45	40	35	20	15	135	115	100	85	75	65	60	40	30
	J0	0	27	90	75	60	50	40	35	30	15	10	125	105	90	75	65	55	45	30	15	175	155	135	115	100	85	75	50	35
	J2	−20	27	125	105	90	75	60	50	40	25	10	170	145	125	105	90	75	65	40	20	200	200	175	155	135	115	100	65	40
S275	JR	20	27	55	45	35	30	25	20	15	10	5	80	70	55	50	40	35	30	20	10	125	110	95	80	70	60	55	40	25
	J0	0	27	75	65	55	45	35	30	25	15	5	115	95	80	70	55	50	40	25	15	165	145	125	110	95	80	70	45	30
	J2	−20	27	110	95	75	65	55	45	35	20	10	155	130	115	95	80	70	55	35	20	200	190	165	145	125	110	95	60	40
	K2,M,N	−20	40	135	110	95	75	65	55	45	25	10	180	155	130	115	95	80	70	40	20	200	200	190	165	145	125	110	70	40
	ML,NL	−50	27	185	160	135	110	95	75	65	35	15	200	200	180	155	130	115	95	55	30	200	200	200	200	190	165	145	95	55
S355	JR	20	27	40	35	25	20	15	15	10	5	5	65	55	45	40	30	25	25	15	10	110	95	80	70	60	55	45	30	20
	J0	0	27	60	50	40	35	25	20	15	10	5	95	80	65	55	45	40	30	20	10	150	130	110	95	80	70	60	40	25
	J2	−20	27	90	75	60	50	40	35	25	15	5	135	110	95	80	65	55	45	25	15	200	175	150	130	110	95	80	55	30
	J4	−40	27	130	110	90	75	60	50	40	20	10	180	155	135	110	95	80	65	40	20	200	200	195	170	150	130	110	70	40
	K2,M,N	−20	40	110	90	75	60	50	40	35	20	5	155	135	110	95	80	65	55	30	15	200	200	175	150	130	110	95	60	35
	J5,ML, NL	−50	27	155	130	110	90	75	60	50	25	10	200	180	155	135	110	95	80	45	25	210	200	200	200	175	150	130	80	45

Only table 2.1 will become table 4.1!

1. 2. 3. Key Innovations 4.

Harmonizations…

…with part 1-1



Von: Prof. Dr.-Ing. Bertram Kühn [mailto:bertram.kuehn@bau.thm.de]
Gesendet: Donnerstag, 4. April 2019 09:56
An: 'Kuhlmann, Ulrike' <ulrike.kuhlmann@ke.uni-stuttgart.de>
Cc: 'Bert Snijder' <hhsnijder@planet.nl>; 'Alain BUREAU' <ABUREAU@CTICM.com>; Luis Borges <lbo@structura
<tom.cosgrove@steelconstruction.org>
Betreff: AW: Comment on prEN1993-1-1, final draft

Dear Ulrike,
Dear Prof. Snijder,
Dear Mr. Bureau,

please excuse but we answer too fast yesterday. We do not recognized that also the clause (3) itself gives a valu
prEN1993-1-1:

Text as it is:

(3) For components under compression, a minimum toughness property should be selected using the appr
NOTE For selection of toughness properties for members in compression, the values of maximum permissible elemer
a country.

… with part 1-8

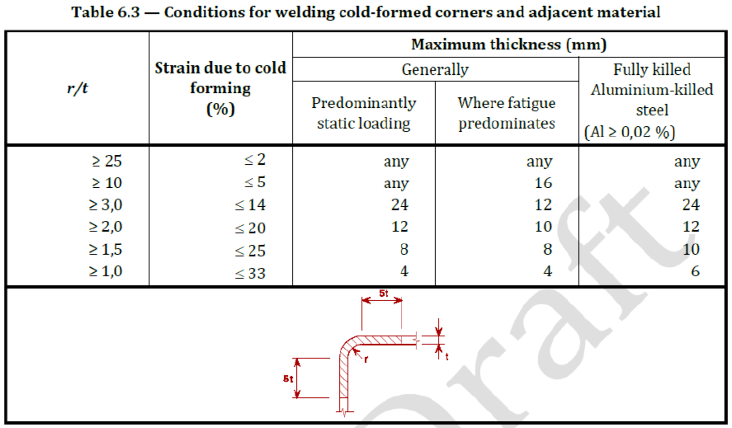
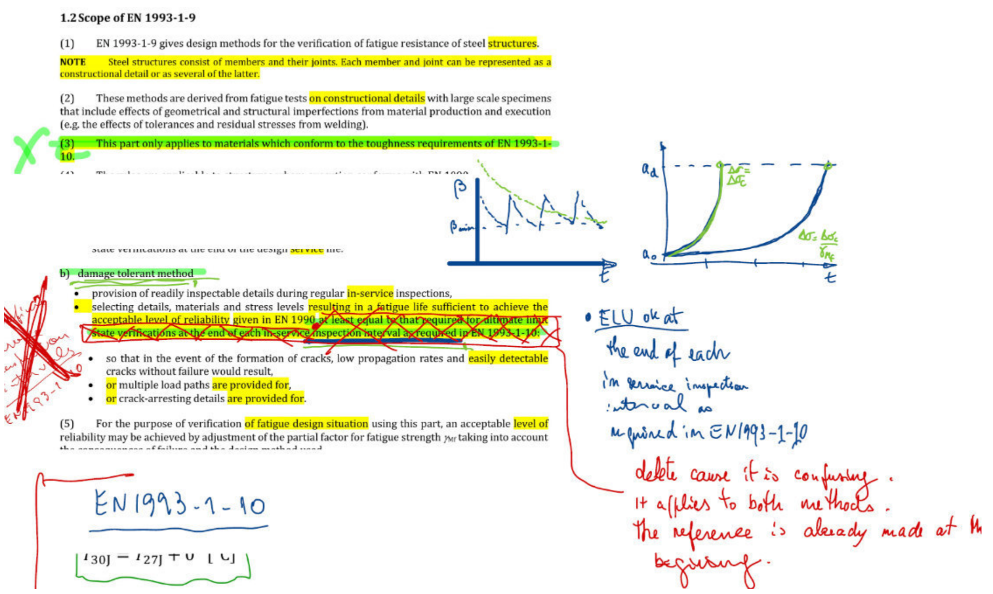


Table 6.3 — Conditions for welding cold-formed corners and adjacent material

r/t	Strain due to cold forming (%)	Maximum thickness (mm)		
		Generally		Fully killed Aluminium-killed steel (Al ≥ 0,02 %)
		Predominantly static loading	Where fatigue predominates	
≥ 25	≤ 2	any	any	any
≥ 10	≤ 5	any	16	any
≥ 3,0	≤ 14	24	12	24
≥ 2,0	≤ 20	12	10	12
≥ 1,5	≤ 25	8	8	10
≥ 1,0	≤ 33	4	4	6

… with part 1-9



1.2 Scope of EN 1993-1-9

(1) EN 1993-1-9 gives design methods for the verification of fatigue resistance of steel structures.

NOTE Steel structures consist of members and their joints. Each member and joint can be represented as a constructional detail or as several of the latter.

(2) These methods are derived from fatigue tests on constructional details with large scale specimens that include effects of geometrical and structural imperfections from material production and execution (e.g. the effects of tolerances and residual stresses from welding).

(3) This part only applies to materials which conform to the toughness requirements of EN 1993-1-10.

state verifications at the end of the design service life.

b) damage tolerant method

- provision of readily inspectable details during regular in-service inspections,
- selecting details, materials and stress levels resulting in a fatigue life sufficient to achieve the acceptable level of reliability given in EN 1990 ~~at least equal to that required for ultimate limit state verifications at the end of each in-service inspection interval as required in EN 1993-1-10:~~
  - so that in the event of the formation of cracks, low propagation rates and easily detectable cracks without failure would result,
  - or multiple load paths are provided for,
  - or crack-arresting details are provided for.

(5) For the purpose of verification of fatigue design situation using this part, an acceptable level of reliability may be achieved by adjustment of the partial factor for fatigue strength γ_{Mf} taking into account

EN 1993-1-10

- ELU ok at the end of each in service inspection interval as required in EN1993-1-10

delete cause it is confusing.
It applies to both methods.
The reference is already made at th
beginning.

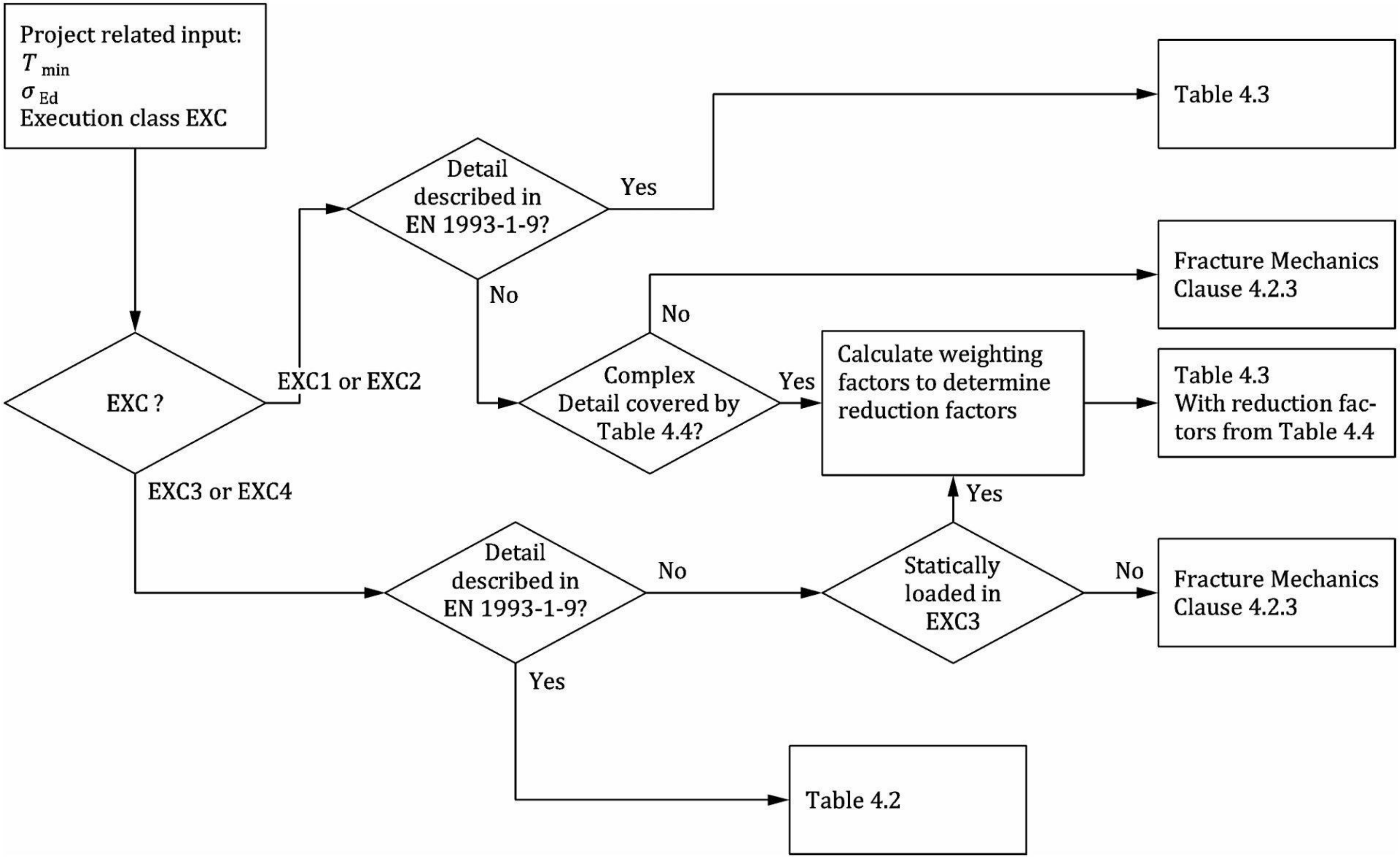
1. New rules for reused steel components

1.1 Scope of EN 1993-1-10 extended as follows:

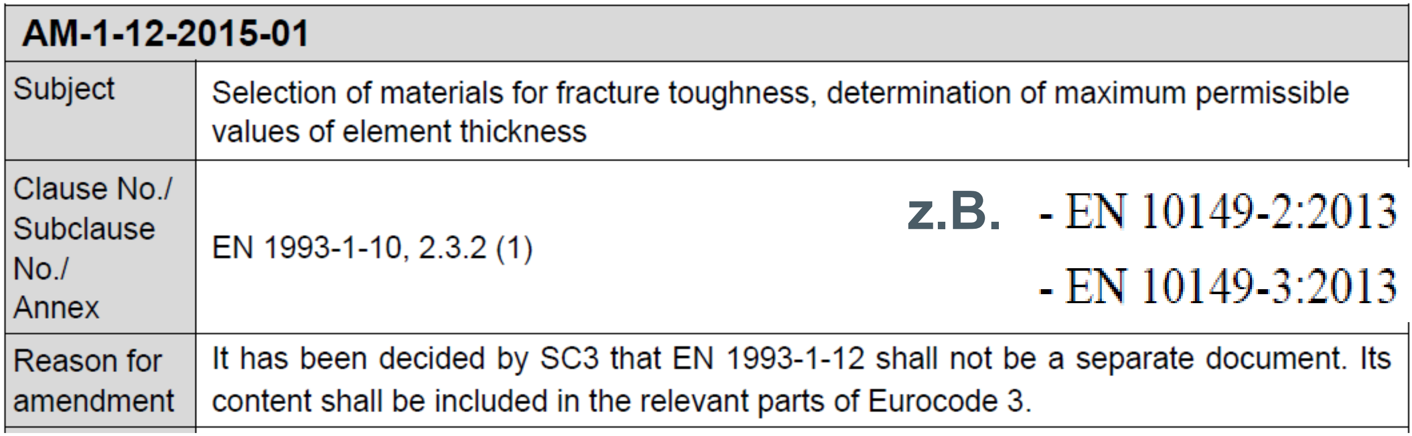
(6) EN 1993-1-10 specifies rules that apply to steel materials covered by EN 1993-1-1:2022, 5.1(3), provided that each individual piece of steel is tested in accordance with the requirements of EN 1993-1-1:2022, 5.2.1 and EN 1090-2:2018, 5.1.

(7) This document does not apply to material salvaged from existing steelwork subjected to fatigue or fire.

2. Increasing Ease-of-use by adding a new flowchart



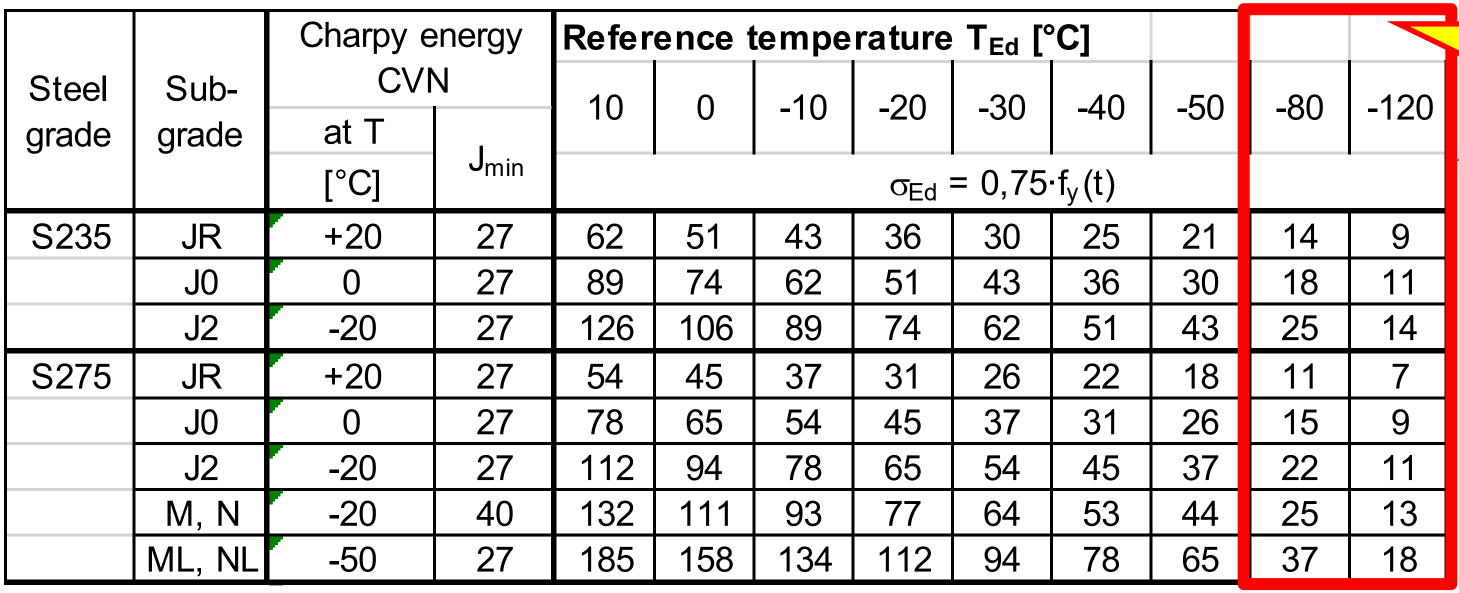
3. Extension to high-strength and new steel grades + cold formed hollow sections



AM-1-12-2015-01	
Subject	Selection of materials for fracture toughness, determination of maximum permissible values of element thickness
Clause No./ Subclause No./ Annex	EN 1993-1-10, 2.3.2 (1)
Reason for amendment	It has been decided by SC3 that EN 1993-1-12 shall not be a separate document. Its content shall be included in the relevant parts of Eurocode 3.

z.B. - EN 10149-2:2013 (S315MC – S960MC)

- EN 10149-3:2013 (S260NC – S420NC)



Steel grade	Sub-grade	Charpy energy CVN		**Reference temperature T_{Ed} [°C]**								
		at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	-80	-120
				$\sigma_{Ed} = 0{,}75 \cdot f_y(t)$								
S235	JR	+20	27	62	51	43	36	30	25	21	14	9
	J0	0	27	89	74	62	51	43	36	30	18	11
	J2	-20	27	126	106	89	74	62	51	43	25	14
S275	JR	+20	27	54	45	37	31	26	22	18	11	7
	J0	0	27	78	65	54	45	37	31	26	15	9
	J2	-20	27	112	94	78	65	54	45	37	22	11
	M, N	-20	40	132	111	93	77	64	53	44	25	13
	ML, NL	-50	27	185	158	134	112	94	78	65	37	18

New

4. Adding the option to consider consequence (execution) classes (EXC)

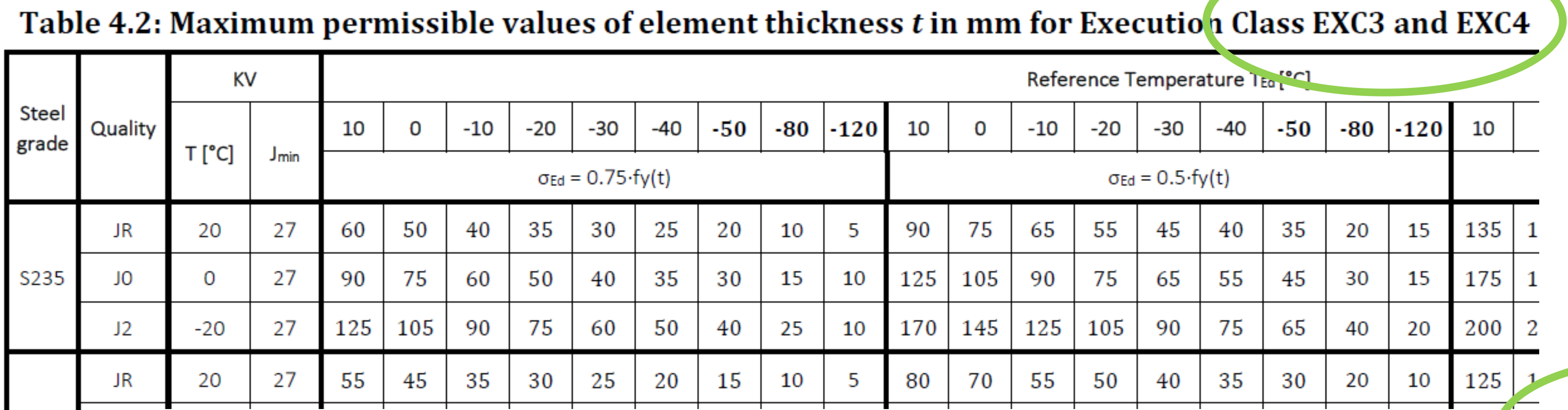


Table 4.2: Maximum permissible values of element thickness *t* in mm for Execution Class EXC3 and EXC4

Steel grade	Quality	KV		Reference Temperature T_{Ed} [°C]																			
		T [°C]	J_{min}	10	0	-10	-20	-30	-40	**-50**	**-80**	**-120**	10	0	-10	-20	-30	-40	**-50**	**-80**	**-120**	10	
				$\sigma_{Ed} = 0.75 \cdot f_y(t)$									$\sigma_{Ed} = 0.5 \cdot f_y(t)$										
S235	JR	20	27	60	50	40	35	30	25	20	10	5	90	75	65	55	45	40	35	20	15	135	1
	J0	0	27	90	75	60	50	40	35	30	15	10	125	105	90	75	65	55	45	30	15	175	1
	J2	-20	27	125	105	90	75	60	50	40	25	10	170	145	125	105	90	75	65	40	20	200	2
S275	JR	20	27	55	45	35	30	25	20	15	10	5	80	70	55	50	40	35	30	20	10	125	1

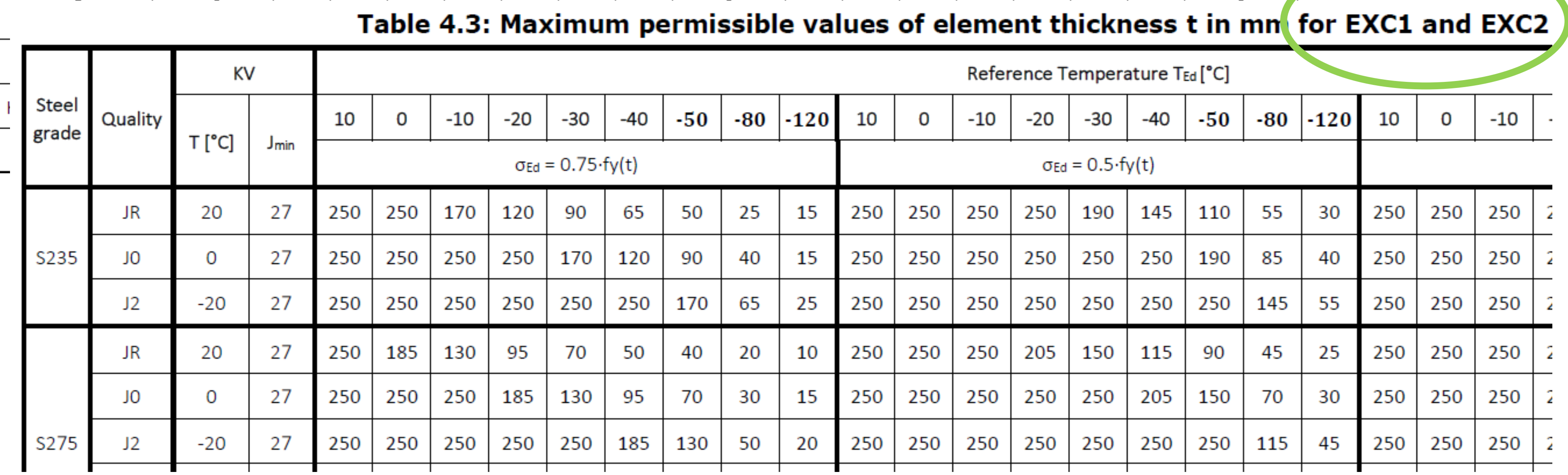
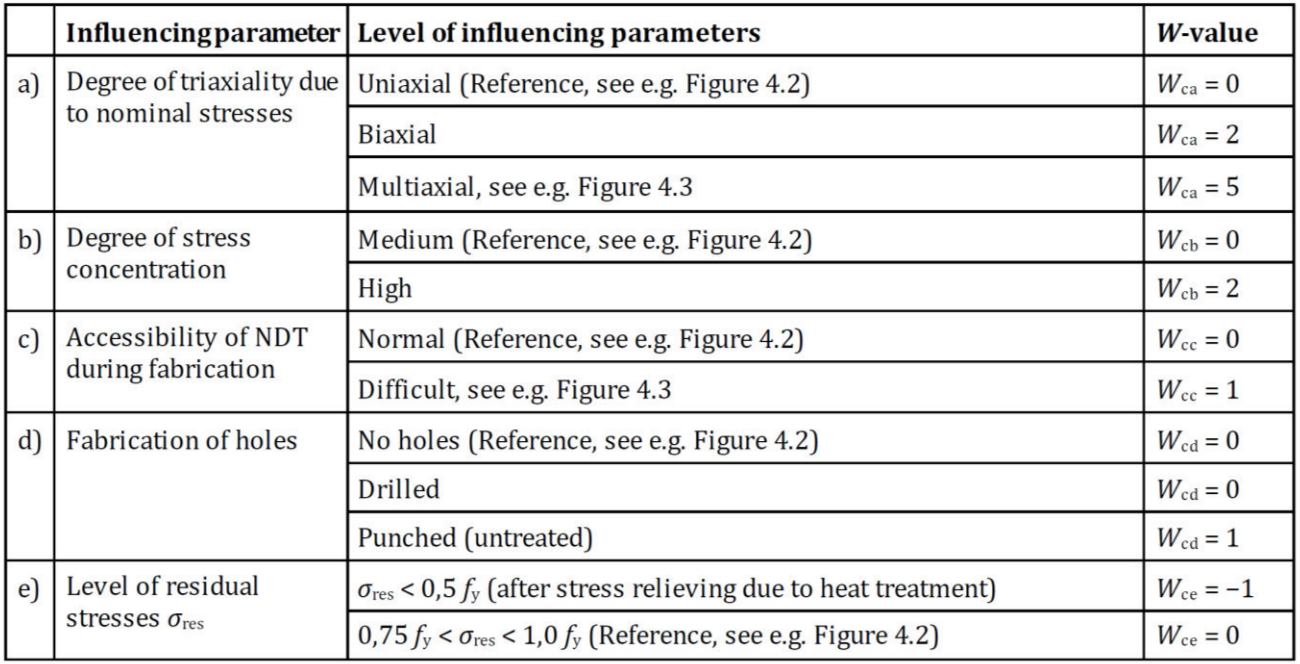


Table 4.3: Maximum permissible values of element thickness t in mm for EXC1 and EXC2

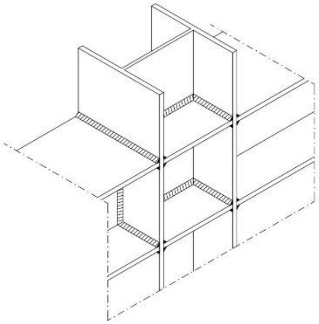
Steel grade	Quality	KV		Reference Temperature T_{Ed} [°C]																				
		T [°C]	J_{min}	10	0	-10	-20	-30	-40	**-50**	**-80**	**-120**	10	0	-10	-20	-30	-40	**-50**	**-80**	**-120**	10	0	-10
				$\sigma_{Ed} = 0.75 \cdot f_y(t)$									$\sigma_{Ed} = 0.5 \cdot f_y(t)$											
S235	JR	20	27	250	250	170	120	90	65	50	25	15	250	250	250	250	190	145	110	55	30	250	250	250
	J0	0	27	250	250	250	250	170	120	90	40	15	250	250	250	250	250	250	190	85	40	250	250	250
	J2	-20	27	250	250	250	250	250	250	170	65	25	250	250	250	250	250	250	250	145	55	250	250	250
S275	JR	20	27	250	185	130	95	70	50	40	20	10	250	250	250	205	150	115	90	45	25	250	250	250
	J0	0	27	250	250	250	185	130	95	70	30	15	250	250	250	250	250	205	150	70	30	250	250	250
	J2	-20	27	250	250	250	250	250	185	130	50	20	250	250	250	250	250	250	250	115	45	250	250	250

5. Option for predominantly statically loaded components of EXC 1 and EXC 2 to take into account the complexity of connections

Table 4.4 — Selection of weighting values for detail complexity



	Influencing parameter	**Level of influencing parameters**	***W*-value**
a)	Degree of triaxiality due to nominal stresses	Uniaxial (Reference, see e.g. Figure 4.2)	$W_{ca} = 0$
		Biaxial	$W_{ca} = 2$
		Multiaxial, see e.g. Figure 4.3	$W_{ca} = 5$
b)	Degree of stress concentration	Medium (Reference, see e.g. Figure 4.2)	$W_{cb} = 0$
		High	$W_{cb} = 2$
c)	Accessibility of NDT during fabrication	Normal (Reference, see e.g. Figure 4.2)	$W_{cc} = 0$
		Difficult, see e.g. Figure 4.3	$W_{cc} = 1$
d)	Fabrication of holes	No holes (Reference, see e.g. Figure 4.2)	$W_{cd} = 0$
		Drilled	$W_{cd} = 0$
		Punched (untreated)	$W_{cd} = 1$
e)	Level of residual stresses σ_{res}	$\sigma_{res} < 0{,}5\, f_y$ (after stress relieving due to heat treatment)	$W_{ce} = -1$
		$0{,}75\, f_y < \sigma_{res} < 1{,}0\, f_y$ (Reference, see e.g. Figure 4.2)	$W_{ce} = 0$



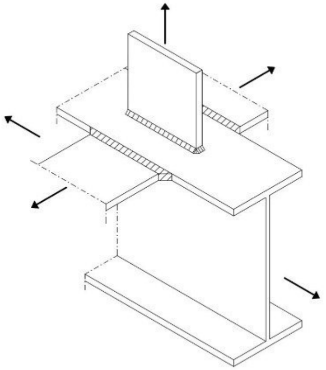
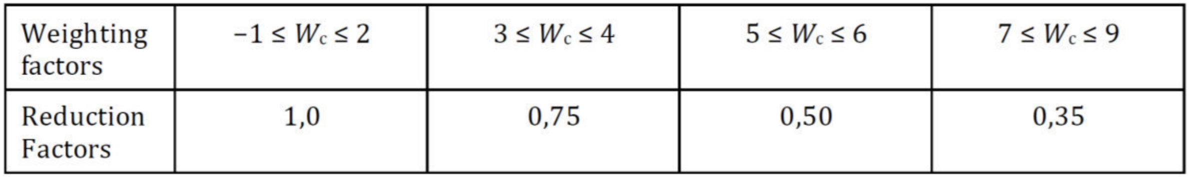
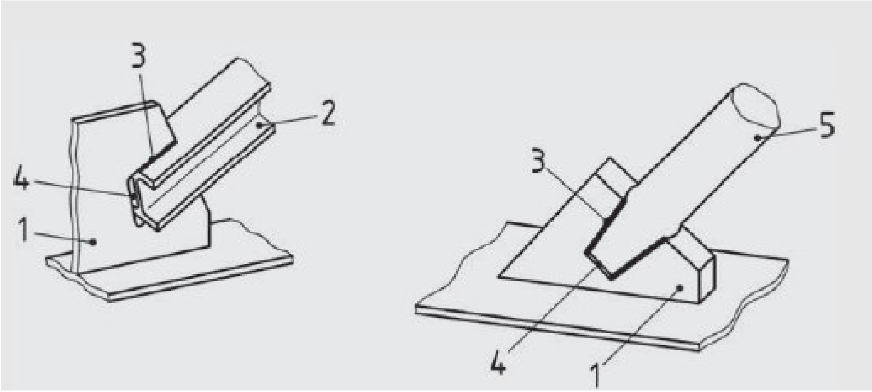


Table 4.5 — Reduction factors



Weighting factors	$-1 \leq W_c \leq 2$	$3 \leq W_c \leq 4$	$5 \leq W_c \leq 6$	$7 \leq W_c \leq 9$
Reduction Factors	1,0	0,75	0,50	0,35

6. Additional rules for spaded details given in a new informative annex A



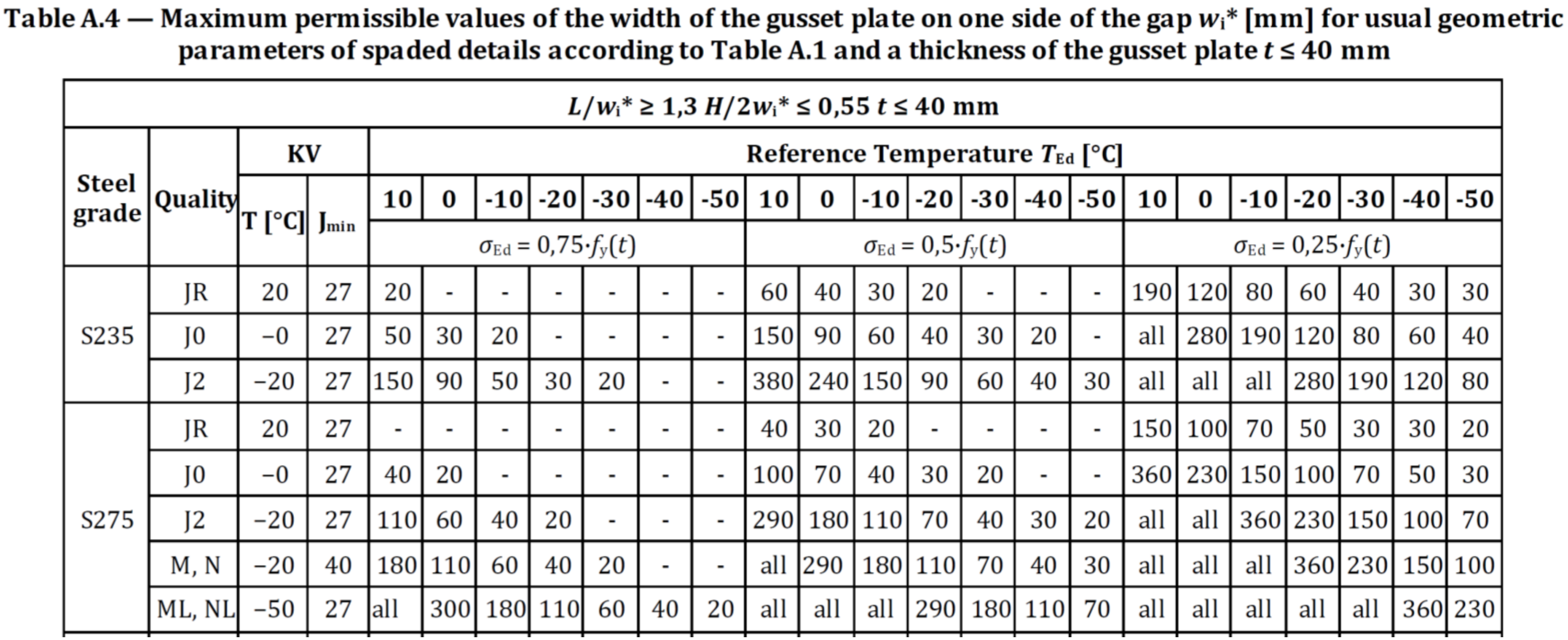
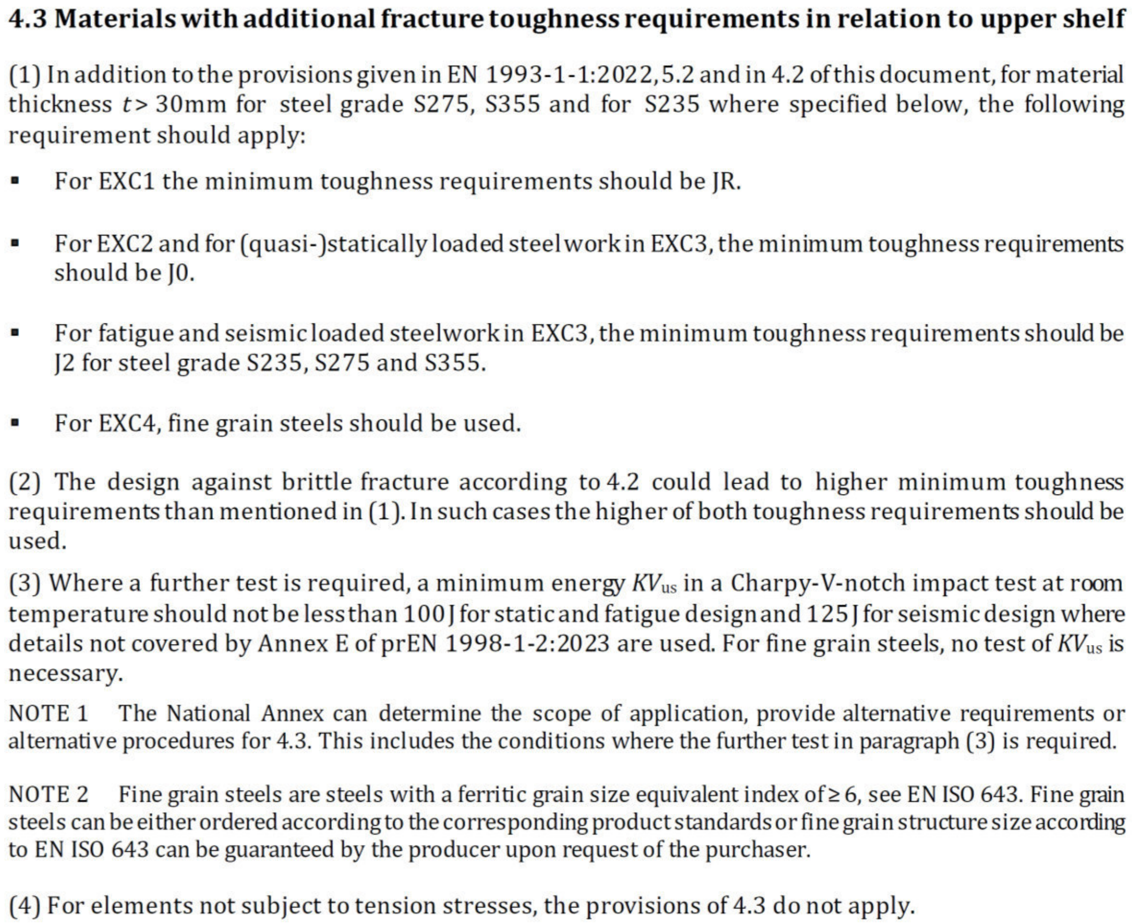


Table A.4 — Maximum permissible values of the width of the gusset plate on one side of the gap w_i* [mm] for usual geometric parameters of spaded details according to Table A.1 and a thickness of the gusset plate $t \leq 40$ mm

$L/w_i^* \geq 1{,}3$ $H/2w_i^* \leq 0{,}55$ $t \leq 40$ mm																								
Steel grade	Quality	KV		Reference Temperature T_{Ed} [°C]																				
		T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0{,}75 \cdot f_y(t)$							$\sigma_{Ed} = 0{,}5 \cdot f_y(t)$							$\sigma_{Ed} = 0{,}25 \cdot f_y(t)$						
S235	JR	20	27	20	-	-	-	-	-	-	60	40	30	20	-	-	-	190	120	80	60	40	30	30
	J0	−0	27	50	30	20	-	-	-	-	150	90	60	40	30	20	-	all	280	190	120	80	60	40
	J2	−20	27	150	90	50	30	20	-	-	380	240	150	90	60	40	30	all	all	all	280	190	120	80
S275	JR	20	27	-	-	-	-	-	-	-	40	30	20	-	-	-	-	150	100	70	50	30	30	20
	J0	−0	27	40	20	-	-	-	-	-	100	70	40	30	20	-	-	360	230	150	100	70	50	30
	J2	−20	27	110	60	40	20	-	-	-	290	180	110	70	40	30	20	all	all	360	230	150	100	70
	M, N	−20	40	180	110	60	40	20	-	-	all	290	180	110	70	40	30	all	all	all	360	230	150	100
	ML, NL	−50	27	all	300	180	110	60	40	20	all	all	all	290	180	110	70	all	all	all	all	all	360	230

7. Incorporation of new rules to ensure upper-shelf behaviour where needed



4.3 Materials with additional fracture toughness requirements in relation to upper shelf

(1) In addition to the provisions given in EN 1993-1-1:2022, 5.2 and in 4.2 of this document, for material thickness $t > 30$mm for steel grade S275, S355 and for S235 where specified below, the following requirement should apply:

- For EXC1 the minimum toughness requirements should be JR.
- For EXC2 and for (quasi-)statically loaded steelwork in EXC3, the minimum toughness requirements should be J0.
- For fatigue and seismic loaded steelwork in EXC3, the minimum toughness requirements should be J2 for steel grade S235, S275 and S355.
- For EXC4, fine grain steels should be used.

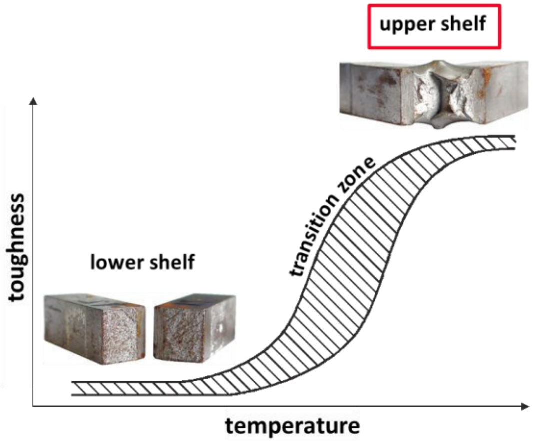
(2) The design against brittle fracture according to 4.2 could lead to higher minimum toughness requirements than mentioned in (1). In such cases the higher of both toughness requirements should be used.

(3) Where a further test is required, a minimum energy KV_{us} in a Charpy-V-notch impact test at room temperature should not be less than 100 J for static and fatigue design and 125 J for seismic design where details not covered by Annex E of prEN 1998-1-2:2023 are used. For fine grain steels, no test of KV_{us} is necessary.

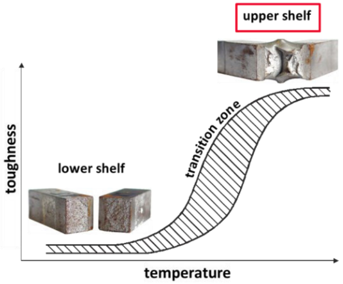
NOTE 1 The National Annex can determine the scope of application, provide alternative requirements or alternative procedures for 4.3. This includes the conditions where the further test in paragraph (3) is required.

NOTE 2 Fine grain steels are steels with a ferritic grain size equivalent index of ≥ 6, see EN ISO 643. Fine grain steels can be either ordered according to the corresponding product standards or fine grain structure size according to EN ISO 643 can be guaranteed by the producer upon request of the purchaser.

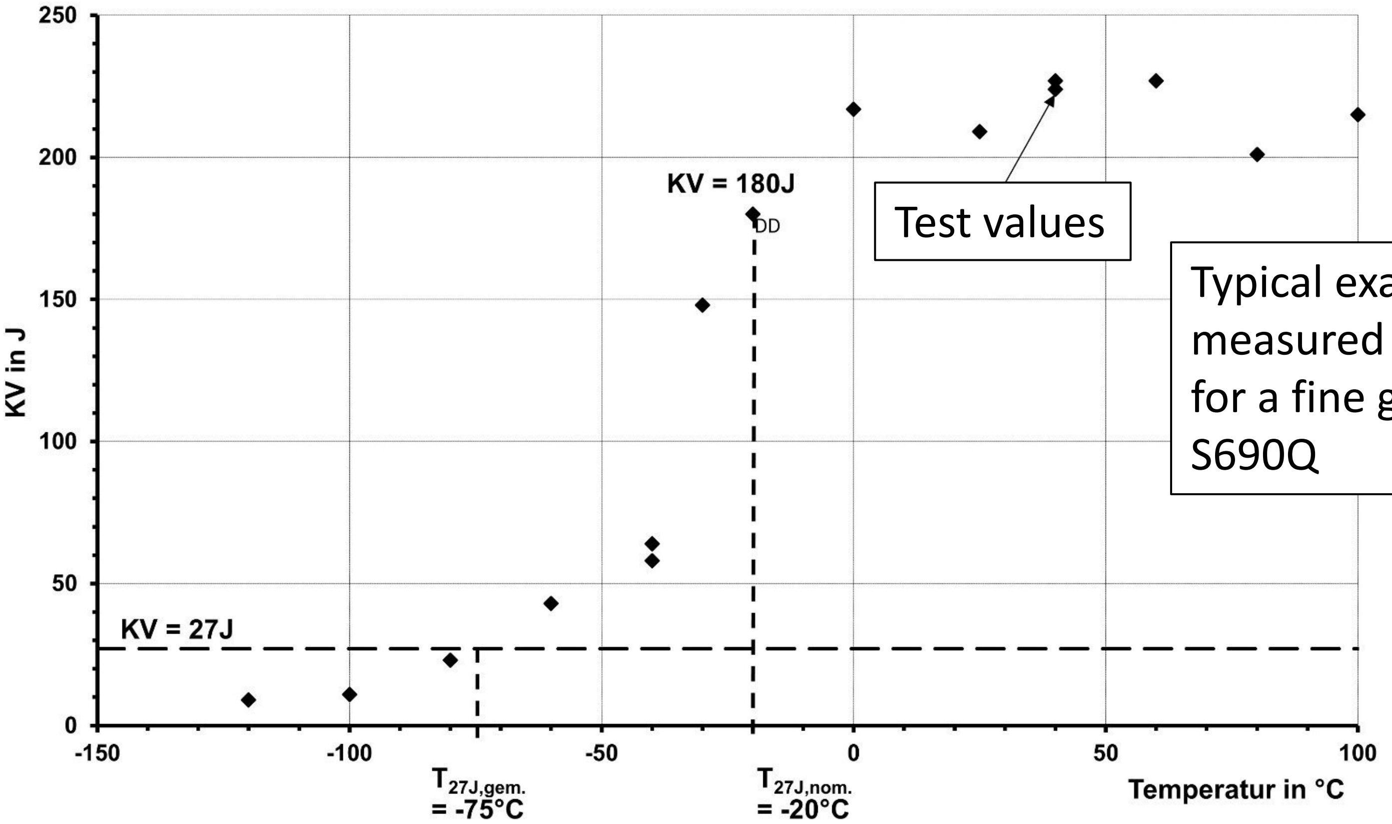
(4) For elements not subject to tension stresses, the provisions of 4.3 do not apply.



7. Incorporation of new upper-shelf rules

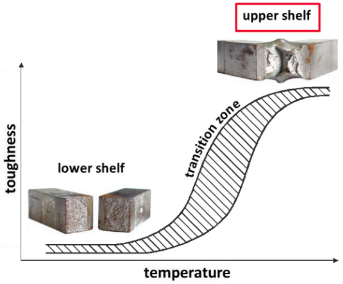


Need of such rules



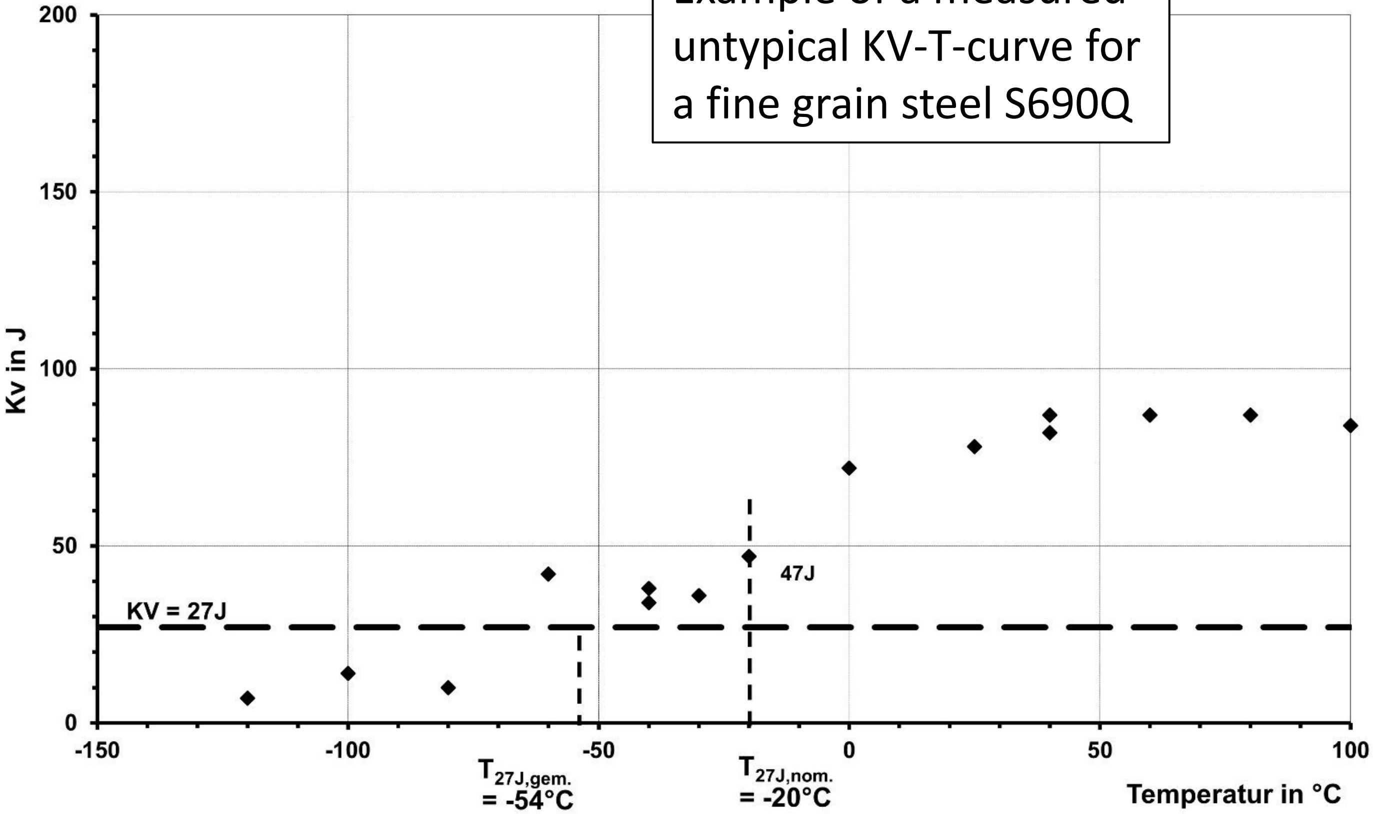
Typical example of a measured KV-T-curve for a fine grain steel S690Q

7. Incorporation of new upper-shelf rules

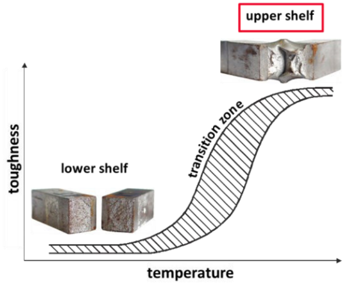


Need of such rules

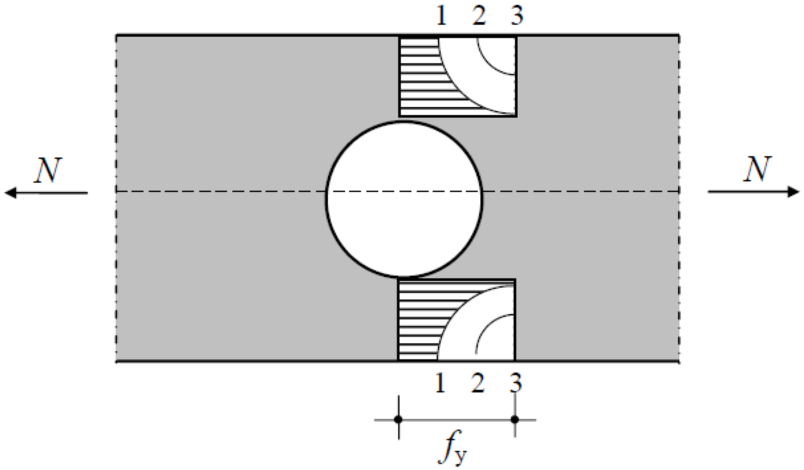
Example of a measured untypical KV-T-curve for a fine grain steel S690Q

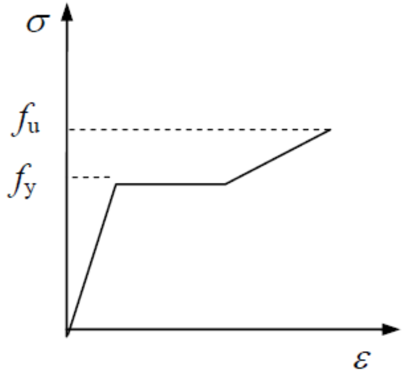


7. Incorporation of new upper-shelf rules



Need of such rules



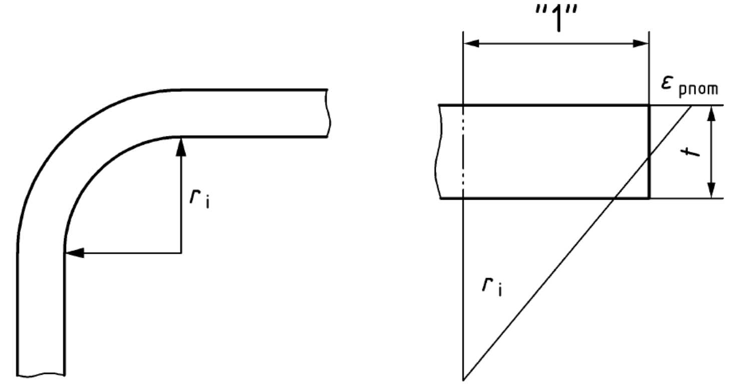
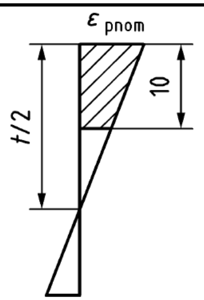


$$N_{u,2,Rd} = 0{,}9 \cdot A_{2,net} \cdot \frac{f_u}{\gamma_{M2}}$$

because some design rules rely on upper shelf behaviour!

8. Inclusion of hints for determining of ε_{pl} and ε_{eff} for sufficient consideration of the negative effect of cold forming

Table 4.1 — Definition of ε_{pnom} and ε_{eff} for radius r_i of cold bend

		$\varepsilon_{pnom} = \frac{t}{2r_i + t}$
Determination of effective strain ε_{eff}		
t	ε_{pnom} distribution	ε_{eff}
≥ 20		$\varepsilon_{pnom}\left(1 - \frac{10}{t}\right)$

9. Simplification of the method for the selection of material to avoid lamellar tearing

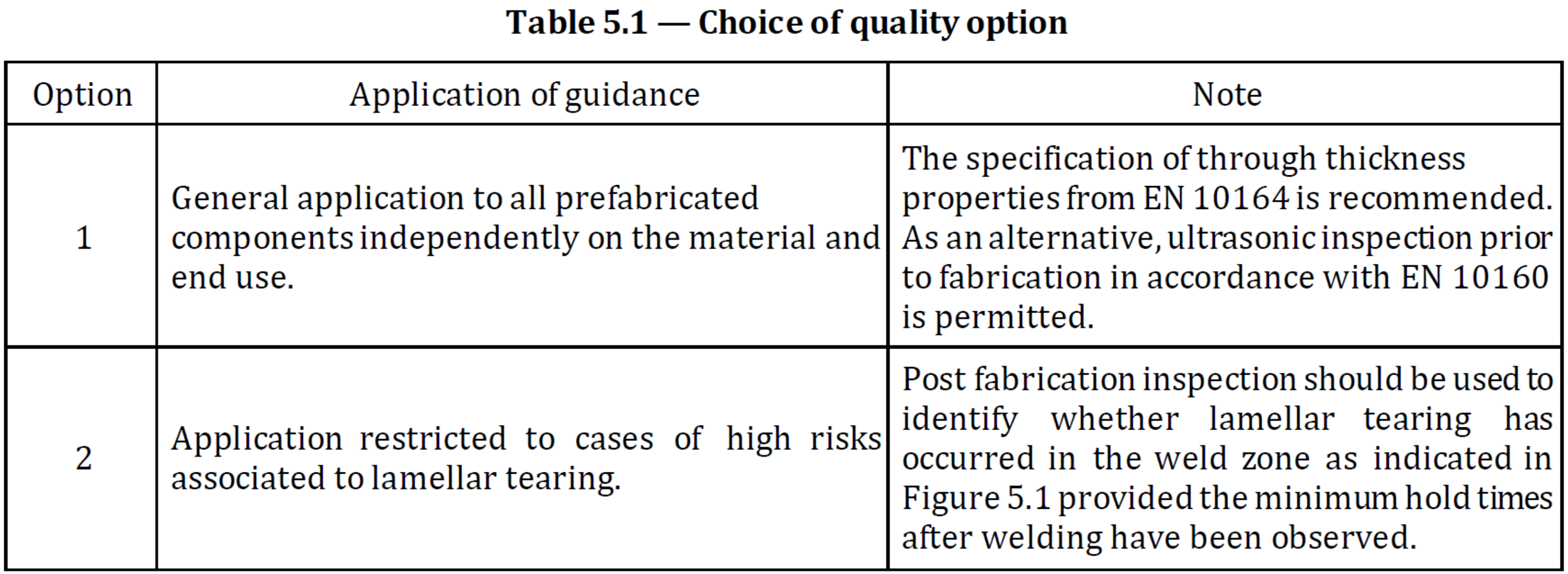
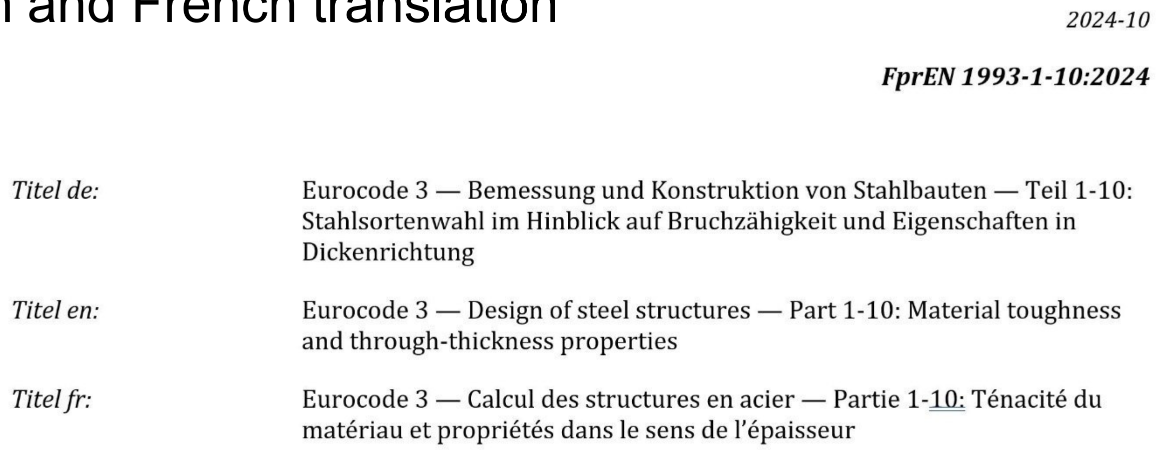


Table 5.1 — Choice of quality option

Option	Application of guidance	Note
1	General application to all prefabricated components independently on the material and end use.	The specification of through thickness properties from EN 10164 is recommended. As an alternative, ultrasonic inspection prior to fabrication in accordance with EN 10160 is permitted.
2	Application restricted to cases of high risks associated to lamellar tearing.	Post fabrication inspection should be used to identify whether lamellar tearing has occurred in the weld zone as indicated in Figure 5.1 provided the minimum hold times after welding have been observed.

4. Outlook

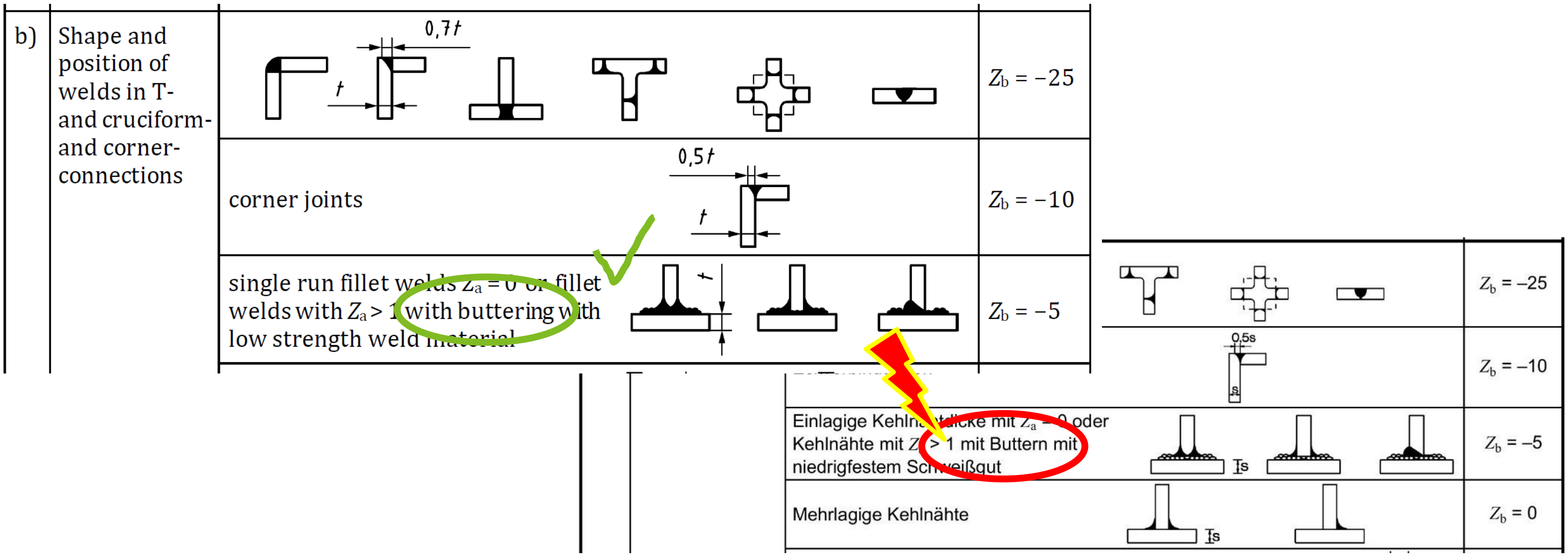
Review / refine of German and French translation



2024-10

FprEN 1993-1-10:2024

Titel de:	Eurocode 3 — Bemessung und Konstruktion von Stahlbauten — Teil 1-10: Stahlsortenwahl im Hinblick auf Bruchzähigkeit und Eigenschaften in Dickenrichtung
Titel en:	Eurocode 3 — Design of steel structures — Part 1-10: Material toughness and through-thickness properties
Titel fr:	Eurocode 3 — Calcul des structures en acier — Partie 1-10: Ténacité du matériau et propriétés dans le sens de l'épaisseur

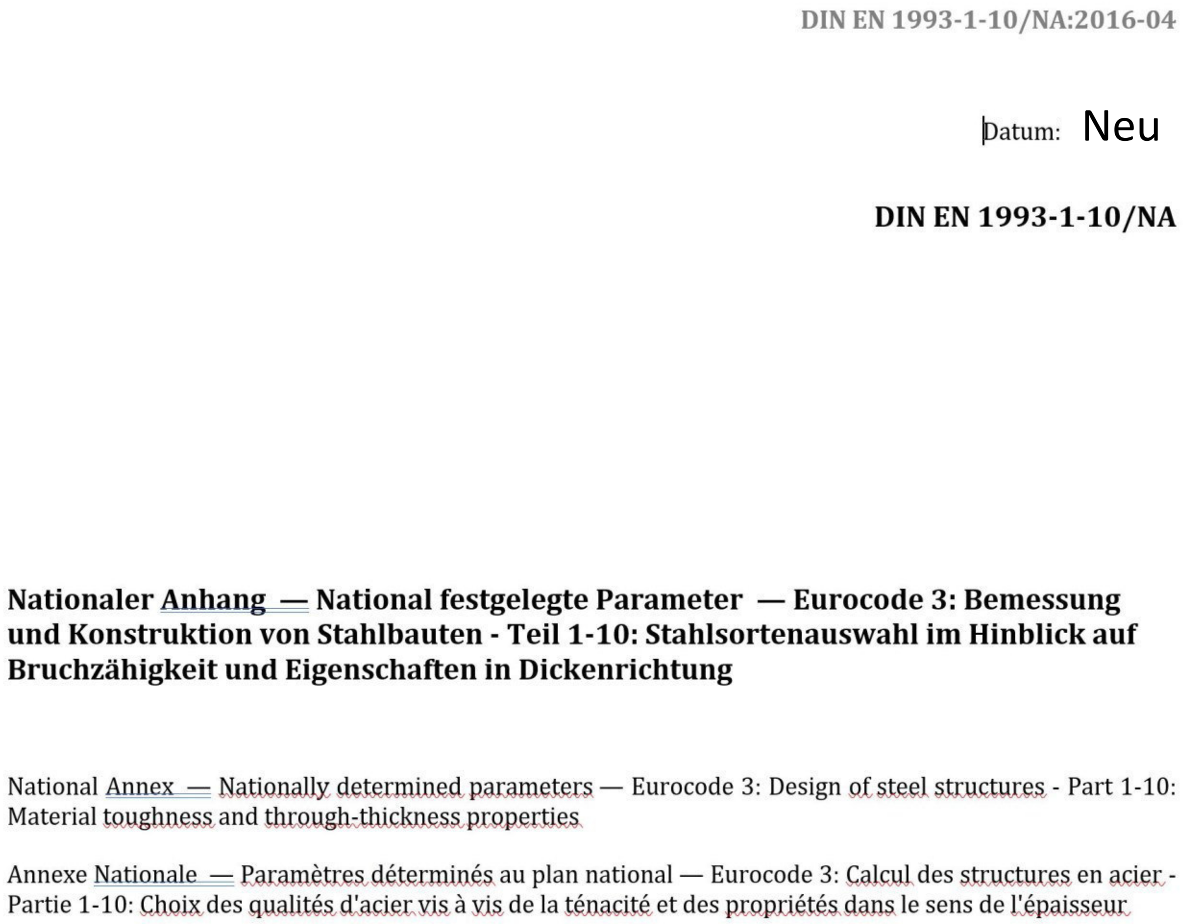


b)	Shape and position of welds in T- and cruciform- and corner-connections		$Z_b = -25$
		corner joints	$Z_b = -10$
		single run fillet welds $Z_a = 0$ or fillet welds with $Z_a > 1$ with buttering with low strength weld material	$Z_b = -5$

	$Z_b = -25$
	$Z_b = -10$
Einlagige Kehlnahtdicke mit $Z_a = 0$ oder Kehlnähte mit $Z_a > 1$ mit Buttern mit niedrigfestem Schweißgut	$Z_b = -5$
Mehrlagige Kehlnähte	$Z_b = 0$

1. 2. 3. 4. Outlook

Support for the development of National Annexes



~~DIN EN 1993-1-10/NA:2016-04~~

Datum: Neu

DIN EN 1993-1-10/NA

Nationaler Anhang — National festgelegte Parameter — Eurocode 3: Bemessung und Konstruktion von Stahlbauten - Teil 1-10: Stahlsortenauswahl im Hinblick auf Bruchzähigkeit und Eigenschaften in Dickenrichtung

National Annex — Nationally determined parameters — Eurocode 3: Design of steel structures - Part 1-10: Material toughness and through-thickness properties

Annexe Nationale — Paramètres déterminés au plan national — Eurocode 3: Calcul des structures en acier - Partie 1-10: Choix des qualités d'acier vis à vis de la ténacité et des propriétés dans le sens de l'épaisseur

1. 2. 3. **4. Outlook**

Final transmission error corrections

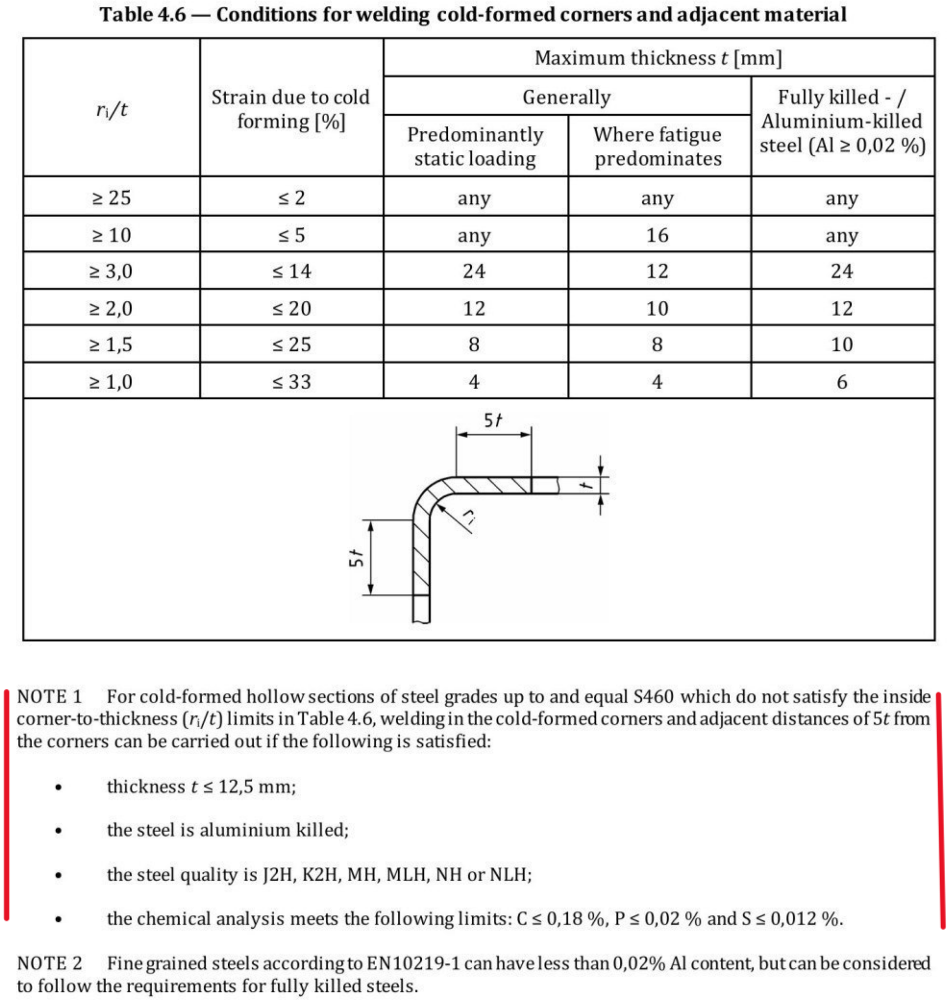


Table 4.6 — Conditions for welding cold-formed corners and adjacent material

r_i/t	Strain due to cold forming [%]	Maximum thickness t [mm]		
		Generally		Fully killed - / Aluminium-killed steel (Al ≥ 0,02 %)
		Predominantly static loading	Where fatigue predominates	
≥ 25	≤ 2	any	any	any
≥ 10	≤ 5	any	16	any
≥ 3,0	≤ 14	24	12	24
≥ 2,0	≤ 20	12	10	12
≥ 1,5	≤ 25	8	8	10
≥ 1,0	≤ 33	4	4	6

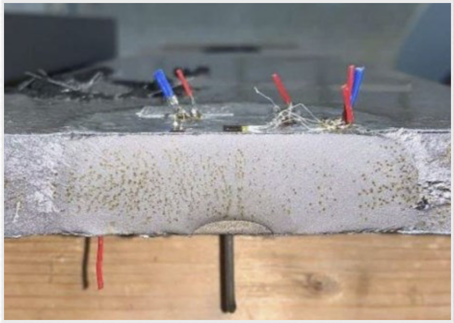
NOTE 1 For cold-formed hollow sections of steel grades up to and equal S460 which do not satisfy the inside corner-to-thickness (r_i/t) limits in Table 4.6, welding in the cold-formed corners and adjacent distances of 5*t* from the corners can be carried out if the following is satisfied:

- thickness $t \leq 12{,}5$ mm;
- the steel is aluminium killed;
- the steel quality is J2H, K2H, MH, MLH, NH or NLH;
- the chemical analysis meets the following limits: C ≤ 0,18 %, P ≤ 0,02 % and S ≤ 0,012 %.

NOTE 2 Fine grained steels according to EN10219-1 can have less than 0,02% Al content, but can be considered to follow the requirements for fully killed steels.

Limitation on ≤ S460 may not correct

Thank you for your attention!



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