SDC VERIFIER

Tutorial
F.E.M. 1.001 and Eurocode3 Fatigue

ANSYS®

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Content

- This step-by-step tutorial demonstrates how to implement the fatigue check according F.E.M. 1.001 and Eurocode 3 in SDC Verifier.
- FEM 1.001 Fatigue and Eurocode 3 detailed review;
- Implementation in SDC Verifier;
- Weld Finder Tool overview;
- Fatigue tables and plots;
- Report preparation and results.

Fatigue F.E.M. 1.001

Allowable Stress Design method

The following formulae give for all values of κ the permissible stresses for fatigue

a) $\kappa \leq 0$

- for tension : $\sigma_t = 5 \cdot \sigma_w / (3 - 2 \cdot \kappa)$ (1)

- for compression : $\sigma_c = 2 \cdot \sigma_w / (1 - \kappa)$ (2)

σ_w is given in table above.

b) $\kappa > o$

- for tension $\sigma_t = \sigma_O / [1 - \kappa \cdot (1 - \sigma_O / \sigma_{+1})]$ (3)

- for compression $\sigma_c = 1,2 \cdot \sigma_t$ (4)

where σ_O = tensile stress for $\kappa = 0$ is given by the formula (1) that is :

$$\sigma_O = 1,66 \cdot \sigma_w$$

σ_{+1} = tensile stress for $\kappa = + 1$ that is the ultimate strength σ_R divided by the coefficient of safety 4/3 :

$$\sigma_{+1} = 0,75 \cdot \sigma_R$$

σ_t is limited in every case to $0,75 \cdot \sigma_R$.

By way of illustration, fig. A.3.6.1. shows curves giving the permissible stress as a function of the ratio κ for the following cases :

- steel A.52 ;
- predominant tensile stress ;
- group E6 ;
- construction cases W_0, W_1, W_2 for unwelded components and cases of construction for joints K_0 to K_4.

The permissible stresses have been limited to 240 N/mm^2, i.e. to the permissible stress adopted for checking for ultimate strength.

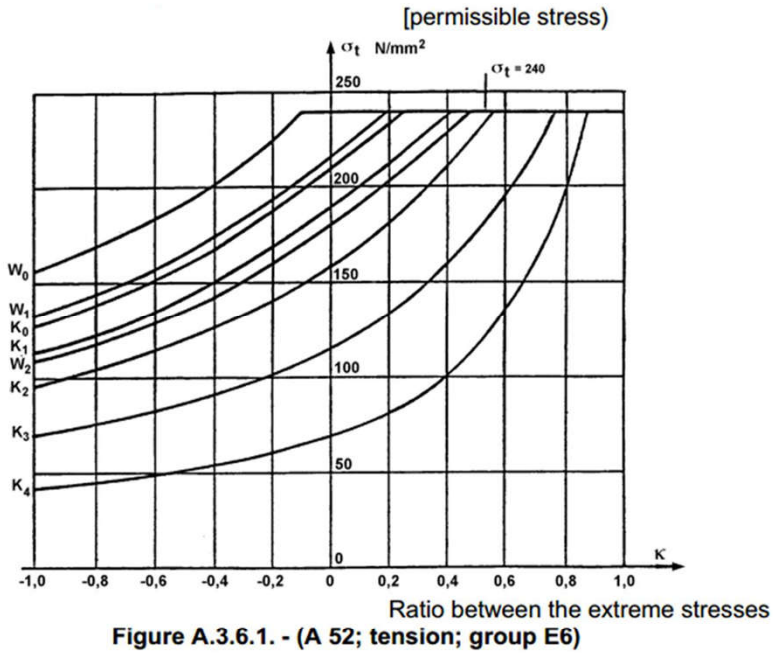


Figure A.3.6.1. - (A 52; tension; group E6)

Fatigue in SDC Verifier

Kappa Factor

$\kappa_x = \sigma_{x\,min} / \sigma_{x\,max}$

$\kappa_y = \sigma_{y\,min} / \sigma_{y\,max}$

$\kappa_{xy} = \tau_{xy\,min} / \tau_{xy\,max}$

Allowable Stress

a) $\kappa \le 0$

- for tension : $\sigma_t = 5 \cdot \sigma_w / (3 - 2 \cdot \kappa)$ (1)

- for compression : $\sigma_c = 2 \cdot \sigma_w / (1 - \kappa)$ (2)

σ_w is given in table above.

b) $\kappa > o$

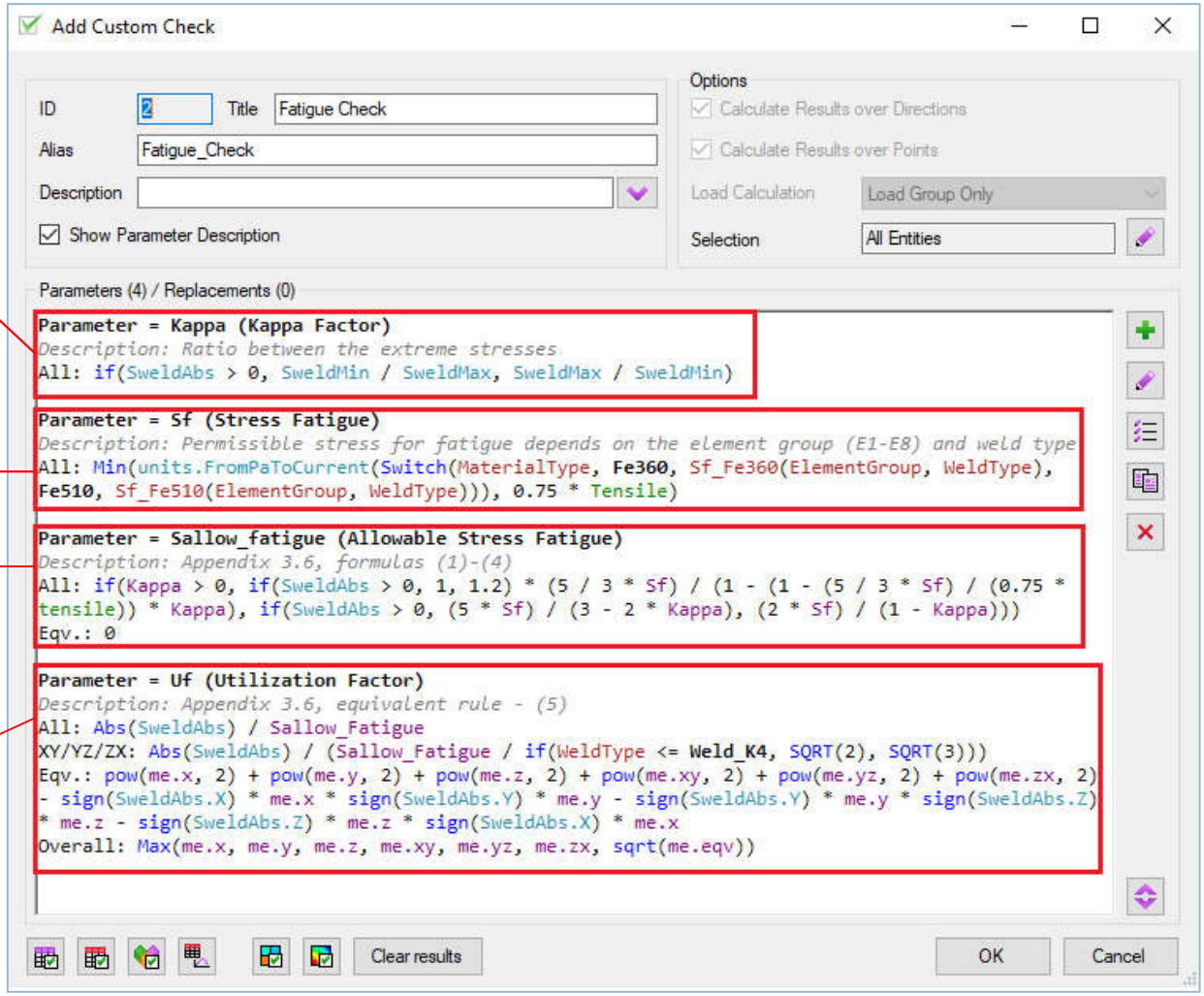
- for tension $\sigma_t = \sigma_O / [1 - \kappa \cdot (1 - \sigma_O / \sigma_{+1})]$

- for compression $\sigma_c = 1{,}2 \cdot \sigma_t$

Utilization Factor Combined

$$(\sigma_{x\,max} / \sigma_{xa})^2 + (\sigma_{y\,max} / \sigma_{ya})^2 - \sigma_{x\,max} \cdot \sigma_{y\,max} / (| \sigma_{xa} | \cdot | \sigma_{ya} |) + (\tau_{xy\,max} / \tau_{xya})^2 \le 1$$

where the stress values σ_{xa}, σ_{ya} and τ_{xya} are those resulting from the application of formulae (1), (2), (3) and (4) limited to 0,75 . σ_R.



Stress Fatigue

Stress Fatigue is used in Fatigue Allowable Stress calculations.

$\kappa \leq 0$

- for tension : $\sigma_t = 5 \cdot \sigma_w / (3 - 2 \cdot \kappa)$ (1)

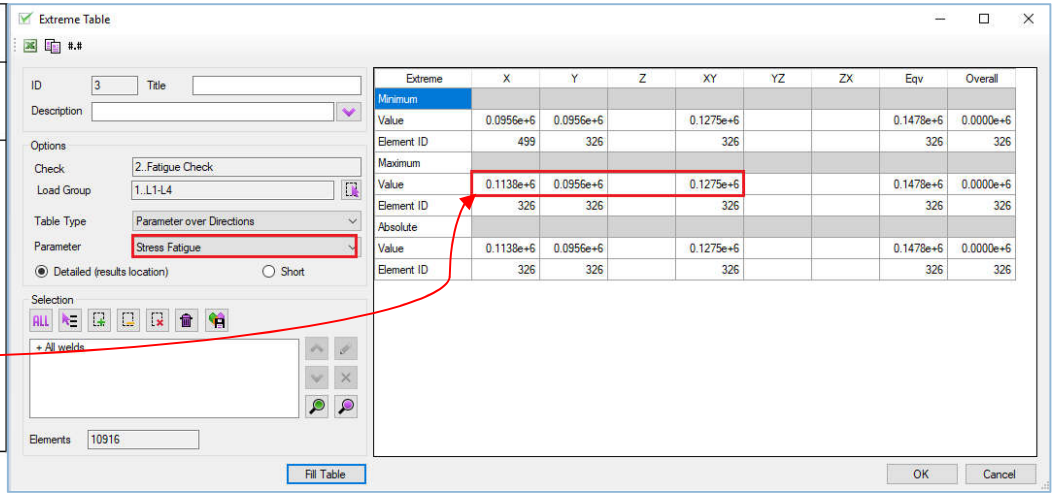
- for compression : $\sigma_c = 2 \cdot \sigma_w / (1 - \kappa)$ (2)

Stress Fatigue depends on:
- Weld Type (W0-W2, K0-K4);
- Element Group / Loading Group (B1-B6);
- Material Type (St360/St37, St510/St52).

Table T.A.3.6.1.
Values of σ_w depending on the component group and construction case (N/mm²)

Com-ponent group	Unwelded components Construction cases						Welded components Construction cases (Steels St 37 to St 52, Fe 360 to Fe 510)				
	W_0		W_1		W_2						
	Fe 360 St 37 St 44	St 52 Fe 510	Fe 360 St 37 St 44	St 52 Fe 510	Fe 360 St 37 St 44	St 52 Fe 510	K_0	K_1	K_2	K_3	K_4
E1	249,1	298,0	211,7	253,3	174,4	208,6	(361,9)	(323,1)	(271,4)	193,9	116,3
E2	224,4	261,7	190,7	222,4	157,1	183,2	(293,8)	262,3	220,3	157,4	94,4
E3	202,2	229,8	171,8	195,3	141,5	160,8	238,4	212,9	178,8	127,7	76,6
E4	182,1	201,8	154,8	171,5	127,5	141,2	193,5	172,8	145,1	103,7	62,2
E5	164,1	177,2	139,5	150,6	114,9	124,0	157,1	140,3	117,8	84,2	50,5
E6	147,8	155,6	125,7	132,3	103,5	108,9	127,5	113,8	95,6	68,3	41,0
E7	133,2	136,6	113,2	116,2	93,2	95,7	103,5	92,4	77,6	55,4	33,3
E8	120,0	120,0	102,0	102,0	84,0	84,0	84,0	75,0	63,0	45,0	27,0

Corresponding values of Stress fatigue in SDC Verifier:



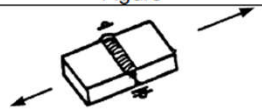
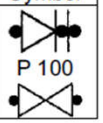
Weld Type

Weld Type – also called Notch Case, defines which elements belong to what weld type (K0-K4 – joints affected by welding, W0-W2 – elements and joints, not affected by welding). Weld Type depends on shape, structural design, whole pattern or type and quality of welds.

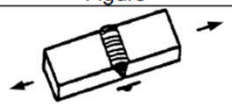
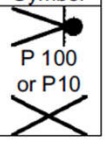
Case W_O

Reference	Description	Figure	Symbol
W_O	Parent metal, homogeneous surface. Part without joints or breaks in continuity (solid bars) and without notch effects unless the latter can be calculated.		

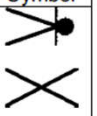
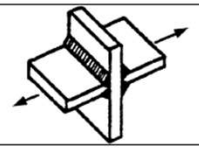
Case K_0 - Slight stress concentration

Reference	Description	Figure	Symbol
0,1	Parts butt-welded (S.Q.) at right angles to direction of forces		

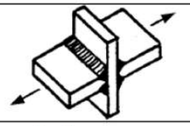
Case K_1 - Moderate stress concentration

Reference	Description	Figure	Symbol
1,1	Parts joined by butt welding (O.Q.) at right angles to the direction of the forces		

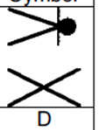
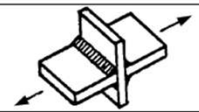
Case K2 - Medium stress concentration

Reference	Description	Figure	Symbol
2,1	Parts of different thickness butt welded (O.Q.) at right angles to the direction of the forces. Asymmetrical slope : 1 in 3 (or symmetrical slopes : 1 in 2)		
2,4	Cruciform joint made with K-welds (S.Q.) perpendicular to the direction of the forces		

Case K_3 - Severe stress concentration

Reference	Description	Figure	Symbol
3,11	Butt weld with backing strip and no backing run. Backing strip secured by intermittent tack welds		
3,4	Cruciform joint made with K-weld (O.Q.) at right angles to the direction of the forces		

Case K_4 - Very severe stress concentration

Reference	Description	Figure	Symbol
4,1	Parts of different thickness butt welded (O.Q.) at right angles to the direction of the forces. Asymmetrical position without blend slope		
4,4	Cruciform joint made with fillet weld (O.Q.) at right angles to the direction of the forces		

Element Group

Element Group also called Loading Group depends on: Class of Utilization, Load Spectrum.

Example of Load Cycles:

Load Cycles	Number	Total
Moves per hour	30	
Hours per day	10	300
Days per year	300	90000
Number of Years	20	1800000
Total	Million:	1.8

Load Spectrum

Table T.2.1.4.3. - Spectrum classes

Symbol	Spectrum factor k_{sp}				
P1			k_{sp}	≤	0,125
P2	0,125	<	k_{sp}	≤	0,250
P3	0,250	<	k_{sp}	≤	0,500
P4	0,500	<	k_{sp}	≤	1,000

$$k_{sp} = (\sigma_1/\sigma_{max})^c (n_1/n) + (\sigma_2/\sigma_{max})^c (n_2/n) + ... + (\sigma_r/\sigma_{max})^c (n_r/n) = \sum_{i=1}^{r} [(\sigma_i/\sigma_{max})^c (n_i/n)]$$

$$n_1 + n_2 + ... + n_r = \sum_{i=1}^{r} n_i = n$$

Class of Utilization **B7** (1.8 million < 2 x 10^6)

Table T.2.1.4.2. - Classes of utilization

Symbol	Total duration of use (number n of stress cycles)				
B0			n	≤	16 000
B1	16 000	<	n	≤	32 000
B2	32 000	<	n	≤	63 000
B3	63 000	<	n	≤	125 000
B4	125 000	<	n	≤	250 000
B5	250 000	<	n	≤	500 000
B6	500 000	<	n	≤	1 000 000
B7	1 000 000	<	n	≤	2 000 000
B8	2 000 000	<	n	≤	4 000 000
B9	4 000 000	<	n	≤	8 000 000
B10	8 000 000	<	n		

Element Group

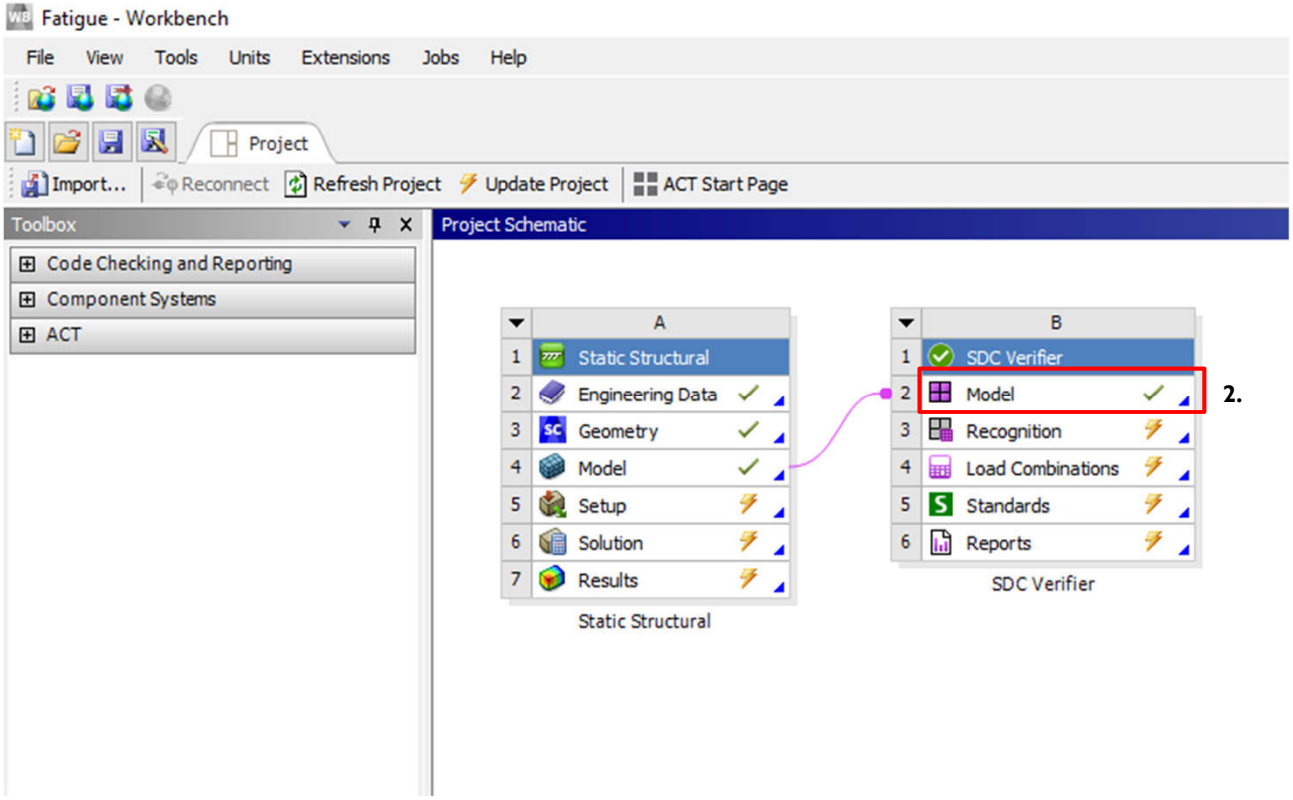
Table T.2.1.4.4. - Component groups

Stress Spectrum class	Class of utilization										
	B0	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
P1	E1	E1	E1	E1	E2	E3	E4	E5	E6	E7	E8
P2	E1	E1	E1	E2	E3	E4	E5	E6	E7	E8	E8
P3	E1	E1	E2	E3	E4	E5	E6	E7	E8	E8	E8
P4	E1	E2	E2	E4	E5	E6	E7	E8	E8	E8	E8

Open the starter model

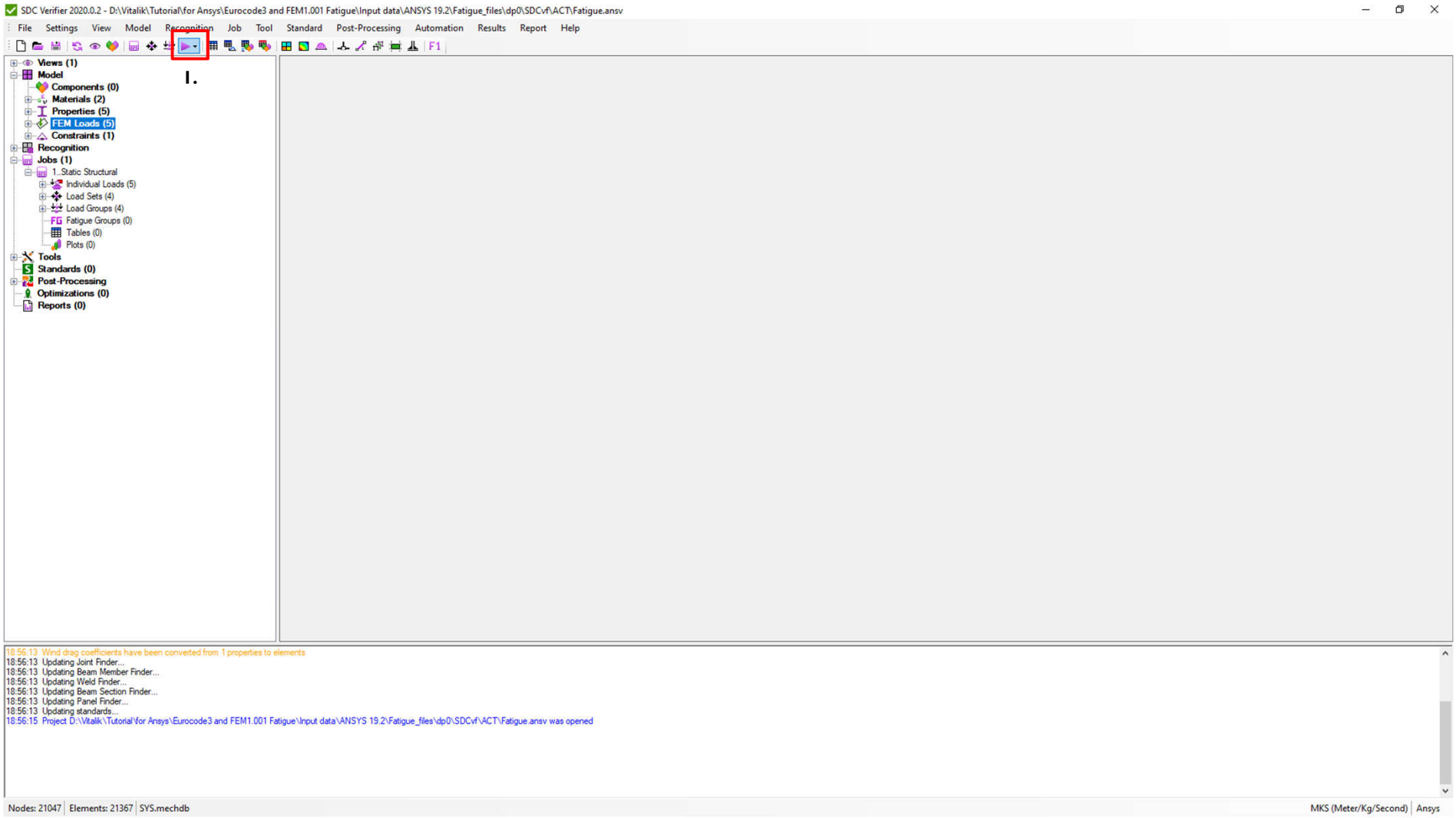
1. Open in **ANSYS Workbench** **FEM. 1.001 and Eurocode 3 Fatigue.wbpz**

2. Double Click on 2 Model or in context menu click **Edit**



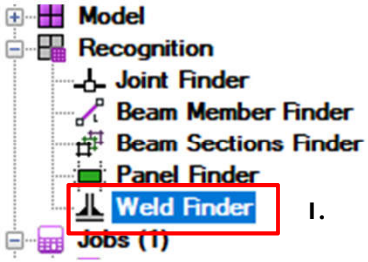
Run Analysis

1 Press ▶ to start Analysis in ANSYS

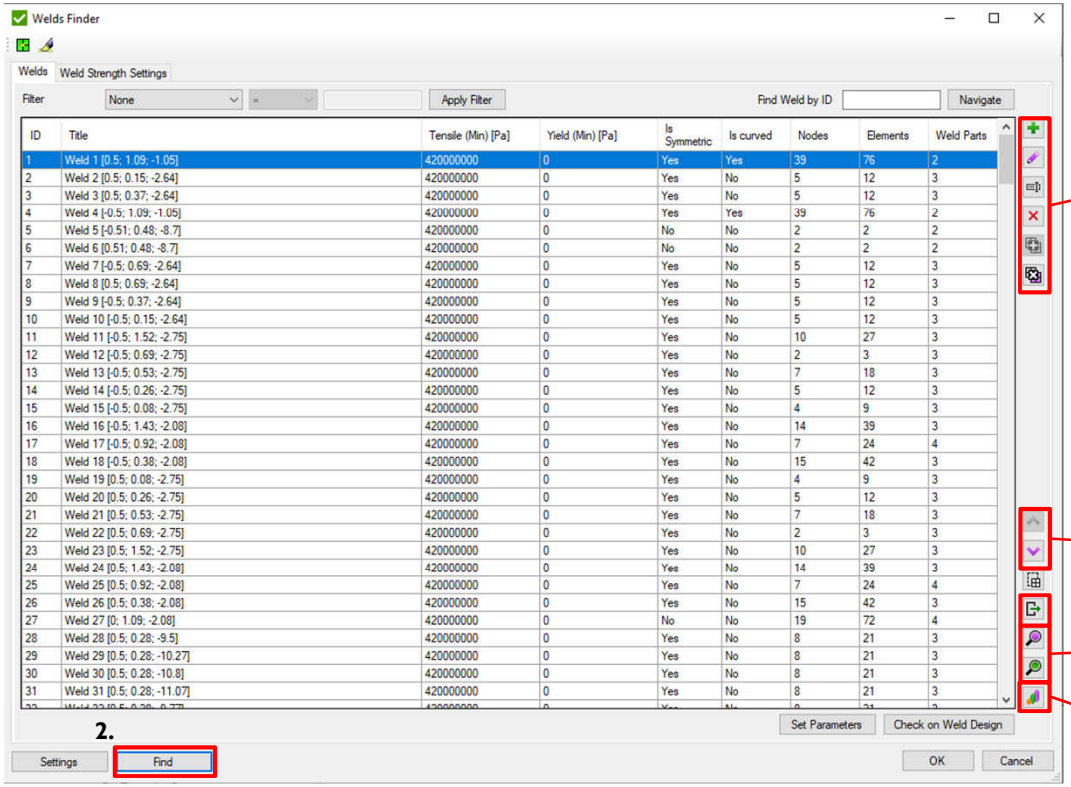


Weld Finder

1. Execute Recognition =>**Weld Finder => Edit…**
2. Press *Find.*
3. Press to Export selected sections *to* components



1.



3.

Add, Edit, Combine and *Remove* Welds.

Move Welds. Order is important when one element belongs to 2 welds.

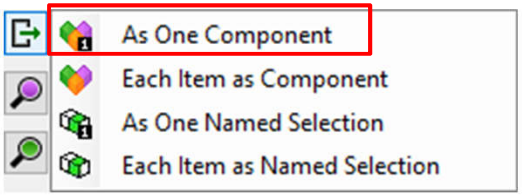
Preview selected welds

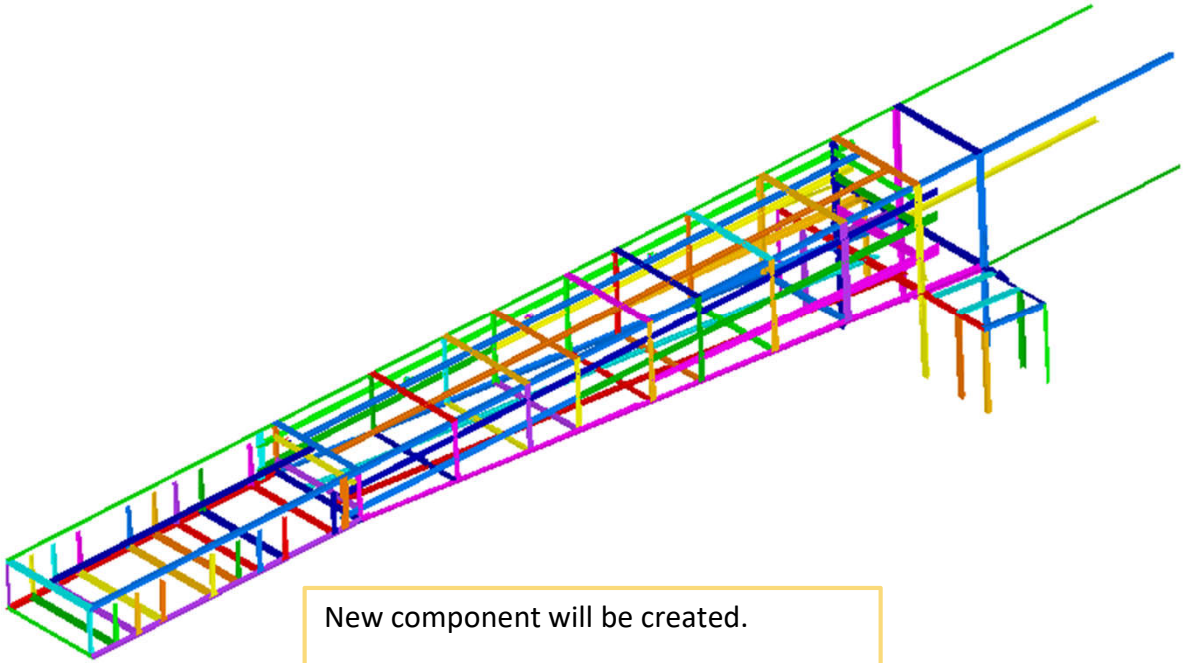
Plot of selected welds in colors and with labels of IDs

Weld Finder

4 Click *As One Component*

5 Press *OK*.

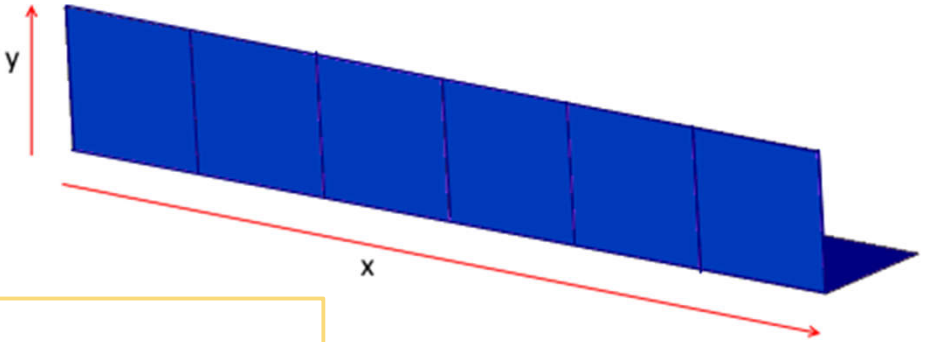




New component will be created.

Stress Transformation

Stresses for weld elements are automatically transformed in the direction of the corresponding weld from Weld Finder Tool using the wedge method. Stresses are transformed only for plate type elements.



$$\sigma_{nn} = \frac{(\sigma_{xx}+\sigma_{yy})}{2} + \frac{(\sigma_{xx}-\sigma_{yy})}{2} * \cos 2\theta + \tau_{xy} * \sin 2\theta$$

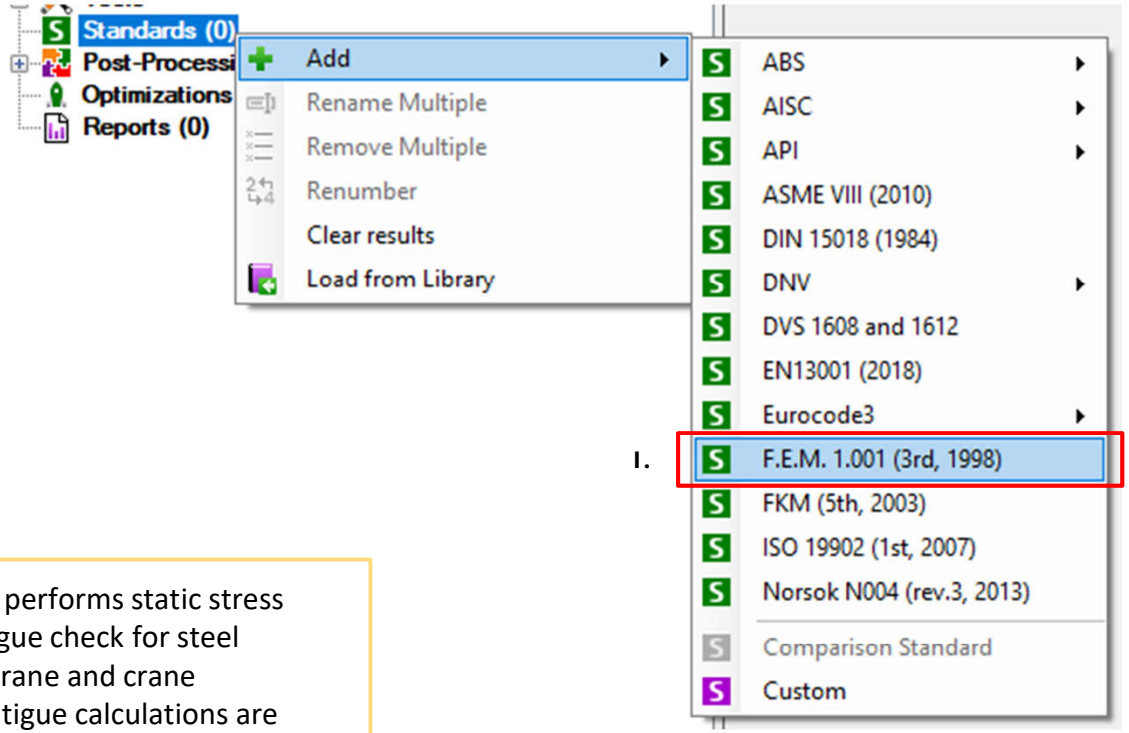
$$\tau_{nt} = -\frac{(\sigma_{xx}-\sigma_{yy})}{2} * \sin 2\theta + \tau_{xy} * \cos 2\theta$$

$$\sigma_{tt} = \frac{(\sigma_{xx}+\sigma_{yy})}{2} - \frac{(\sigma_{xx}-\sigma_{yy})}{2} * \cos 2\theta - \tau_{xy} * sin\ 2\theta$$

$\sigma_{xx}, \sigma_{yy}, \tau_{xy}$ – original x, y and shear stress in local element x, y and shear directions
$\sigma_{tt}, \sigma_{nn}, \tau_{nt}$ – transformed x, y and shear stress in weld x, y and shear directions
θ – angle between the element and weld x directions.

Add FEM 1.001 standard

1 Execute *Add* => **F.E.M. 1.001** in Standards context menu.



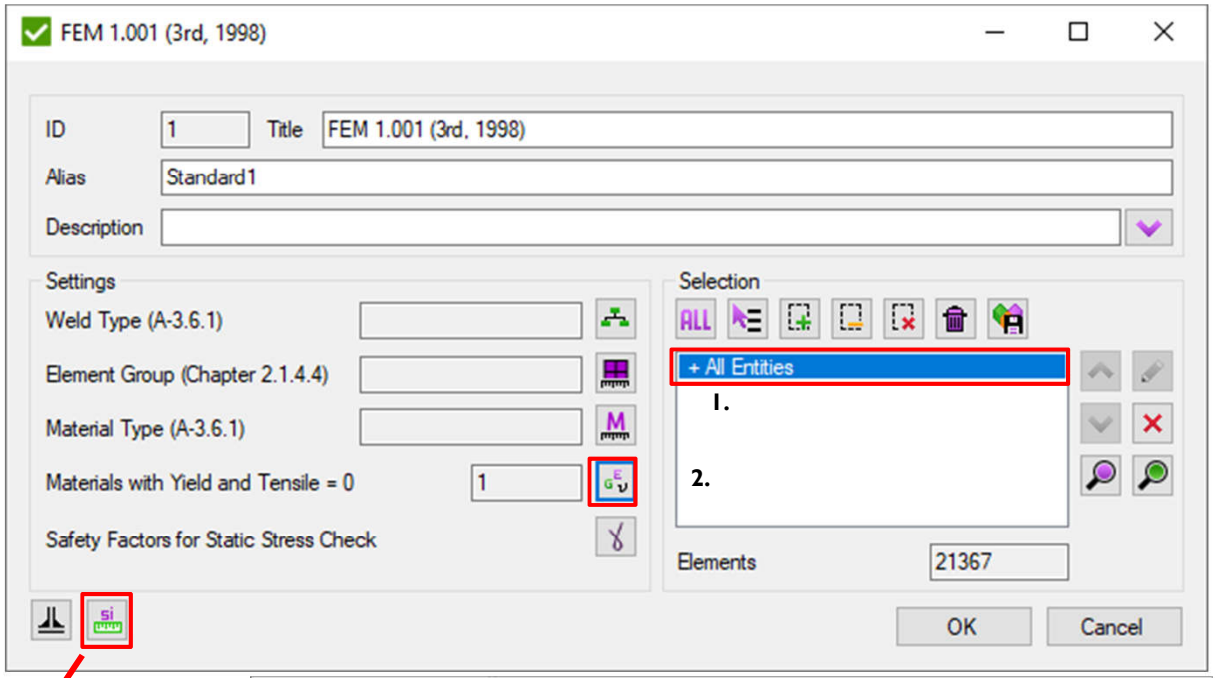
F.E.M. 1.001 - performs static stress check and fatigue check for steel structures of crane and crane equipment. Fatigue calculations are performed according to Allowable Stress Design method (ASD).

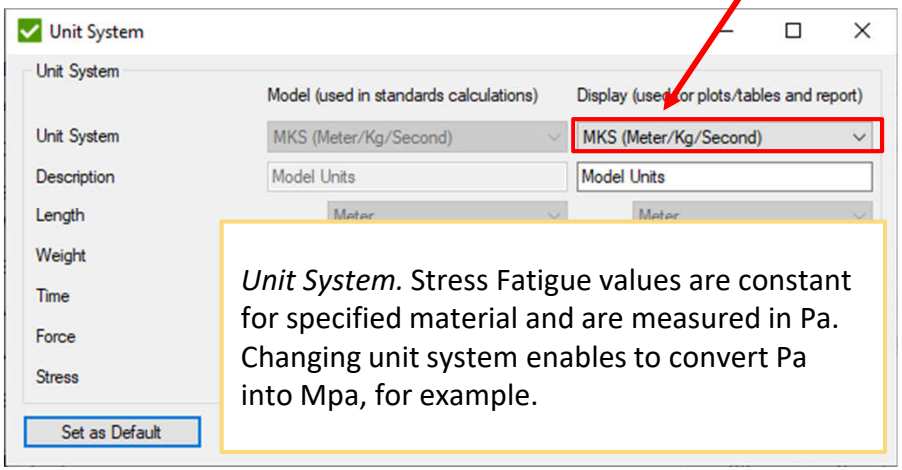
F.E.M. 1.001 Standard

1. Selection: **All Entities**
2. Press  to edit material properties.

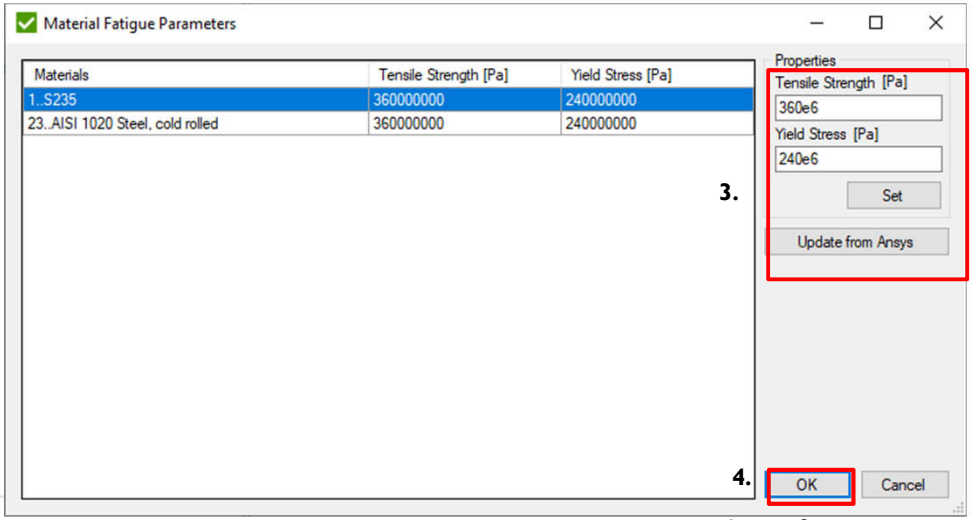
Amount of materials with not defined Tensile or Yield is displayed in the field

3. Tensile Strength: **360e6**
   Yield Stress: **240e6** and Press *Set.*
4. Press *OK*.





Unit System. Stress Fatigue values are constant for specified material and are measured in Pa. Changing unit system enables to convert Pa into Mpa, for example.



Definition of weld categories

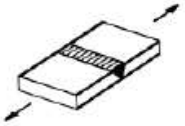
- Weld/notch category determines fatigue resistance
- Division in welds / non welds for FEM 1.001:
  - W category is for non welded parts
  - K category is for welded parts
- Fatigue resistance is further specified by adding classes
  - W0-W2 for non-welded parts
  - K0-K4 for welded parts
- Better fatigue resistance results in lower class number

Weld Classes depends on Weld Type

Non-weld group W0

nr.	description of the main types	symbol
W01	Part without hole and without joint, with a normal state of the surface, without notch behaviour. 	—

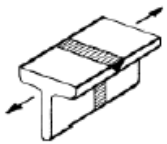
Slight notch behavior group K0

nr.	description of the main types	symbol
011	Parts, jointed by a butt weld of special quality, perpendicular to the direction of force. 	P 100 P 100

Moderate notch behavior group K1

nr.	description of the main types	symbol
111	Parts, jointed by a butt weld of ordinary quality, perpendicular to the direction of force. 	P or P 100 P or P 100

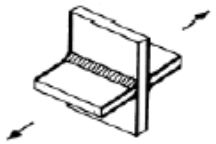
Medium notch behavior group K2

nr.	description of the main types	symbol
211	Profiles, jointed by butt welds of special quality, perpendicular to the direction of force. 	P 100 P 100

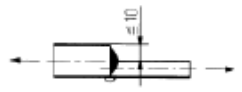
Great notch behavior group K3

311	Parts jointed by a butt weld with a backing strap, without sealing run and perpendicular to the direction of force. Backing strap fixed by tack welding. 	>

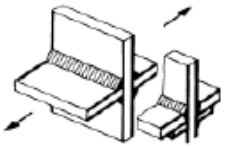
and a different connection type 351

nr.	description of the main types	symbol
351	Double bevel weld of ordinary quality, perpendicular to the direction of force, between crossing parts. 	D

Very great notch behavior group K4

nr.	description of the main types	symbol
412	Parts of different thickness, jointed by a butt weld of ordinary quality, perpendicular to the direction of force. Asymmetrical joint without slope. 	P P

and a different connection type 451

451	Fillet welds of normal quality or single bevel weld (included fillet weld) with backing, perpendicular to the direction of force, between crossing parts. 	D D

Weld Type – stress direction

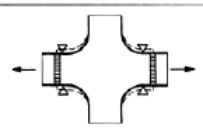
	Perpendicular to weld	Parallel with weld	Shear
Weld	K1	K2	K0
No weld	W0		$\tau_D(-1) = \sigma_D(-1) / sqrt(3)$

Steel Grade	$\sigma_D(-1)$ for κ=-1 element group 5 St 52-3							
Notch group	W0	W1	W2	K0	K1	K2	K3	K4
Stress amplitude	163.8	130.3	104.2	118.8	106.1	89.1	63.6	38.2

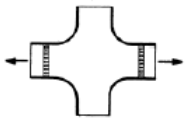
For beams SCF of connections can be included in the classification

Depends on Stress concentrations:

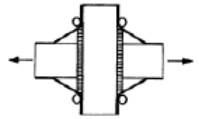
Slight notch behavior group K0

013	Gusset, jointed by butt welds of special quality, perpendicular to the direction of force.		P 100 P 100

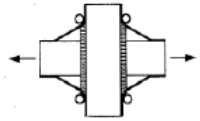
Moderate notch behavior group K1

113	Gusset, jointed by butt welds of ordinary quality, perpendicular to the direction of force.		P or P 100 P or P 100

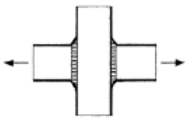
Medium notch behavior group K2

213	Butt weld of special quality and continuous part, both perpendicular to the direction of force, at a crossing of flanges with in-welded corner plates. The ends of the welds are ground to prevent them from notch behaviour.		P 100 P 100

Great notch behavior group K3

313	Butt weld of ordinary quality and continuous part both perpendicular to the direction of force, at a crossing of flanges with welded corner plates. The ends of the welds have been ground to prevent them from notch behaviour.		P or P 100 P or P 100

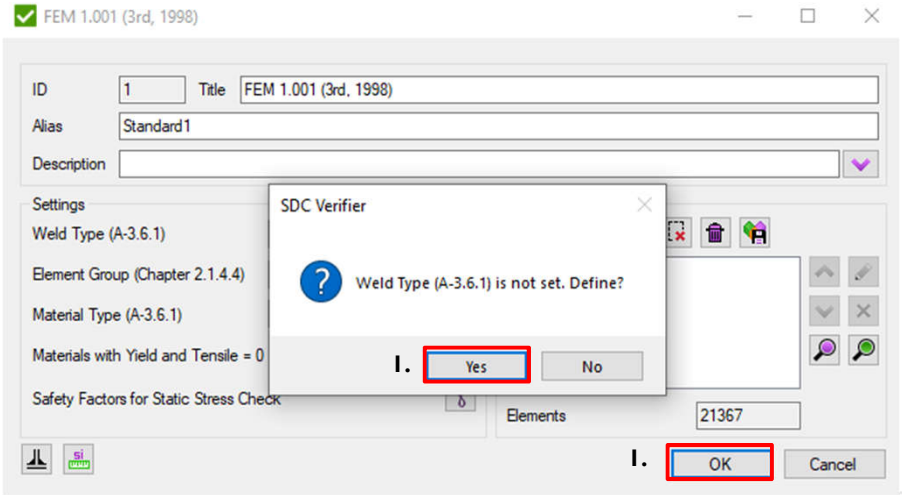
Very great notch behavior group K4

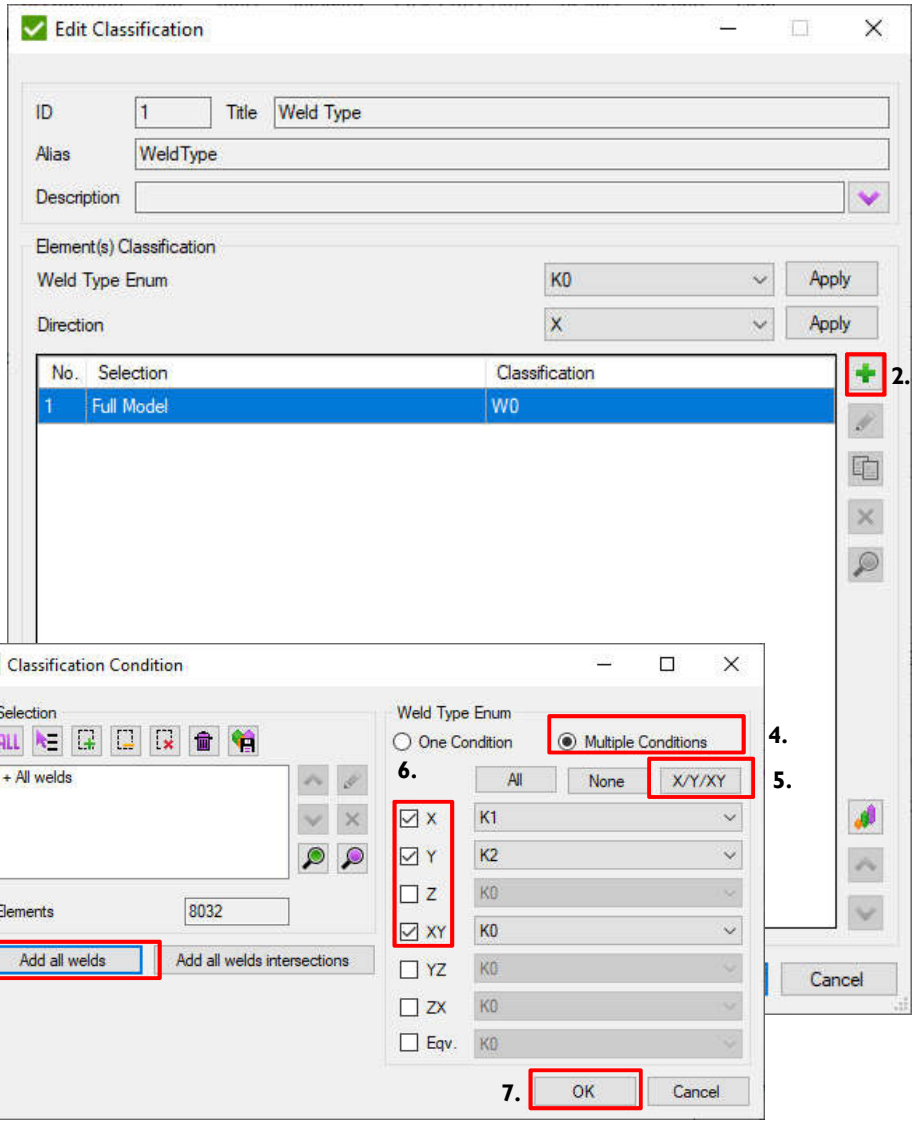
413	Butt weld of ordinary quality, perpendicular to the direction of force, at a crossing of flanges without corner plates.		P P

(not included in this tutorial)

Weld Type Classification

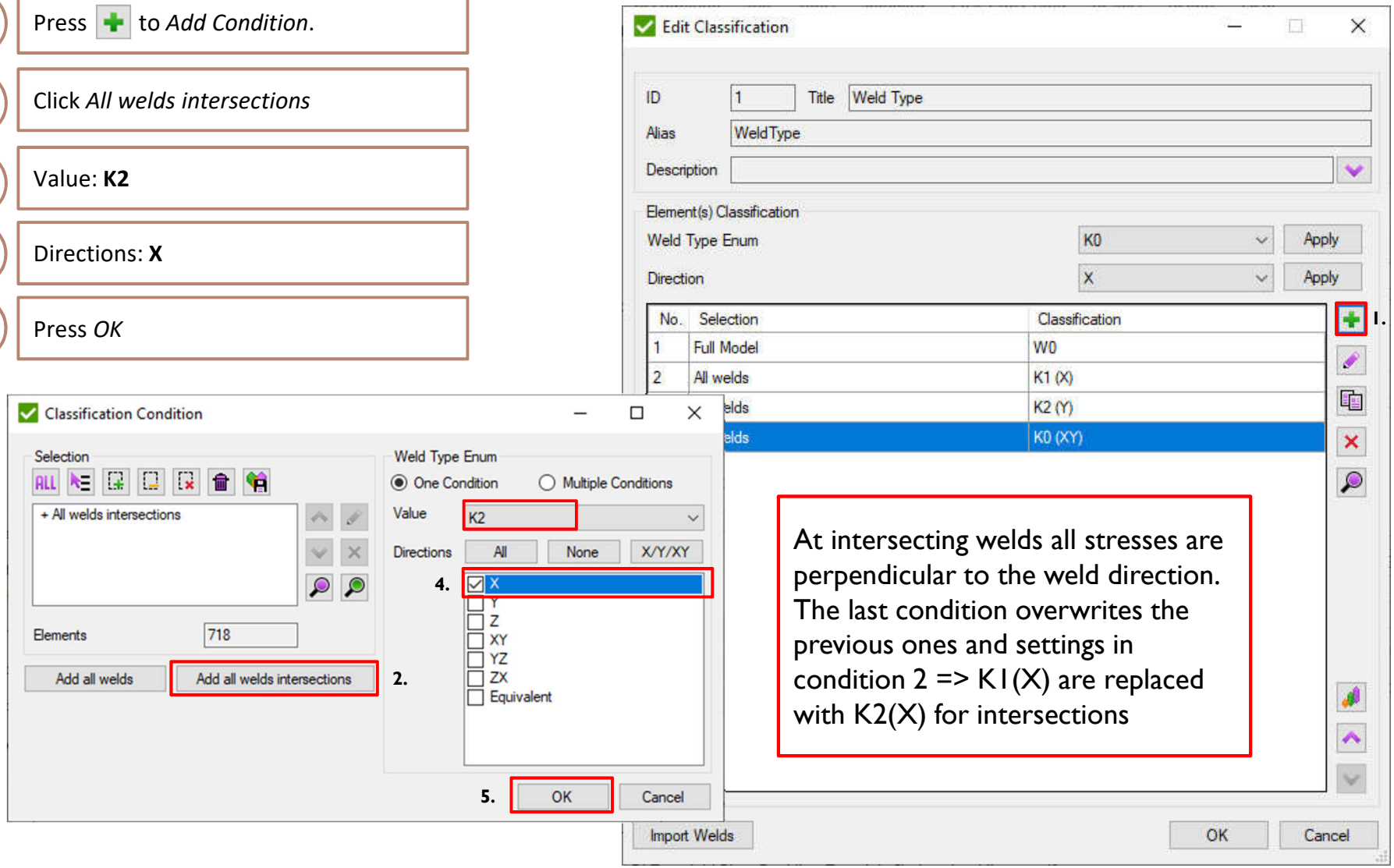
1. Press Ok-->Yes (*Define* for the Weld Type).
2. Press ➕ to *Add Condition*.
3. Press *Add all Welds*
4. Select *Multiple Conditions* options
5. Press *X/Y/XY*
6. X: **K1** Y: **K2** XY: **K0**
7. Press *OK*





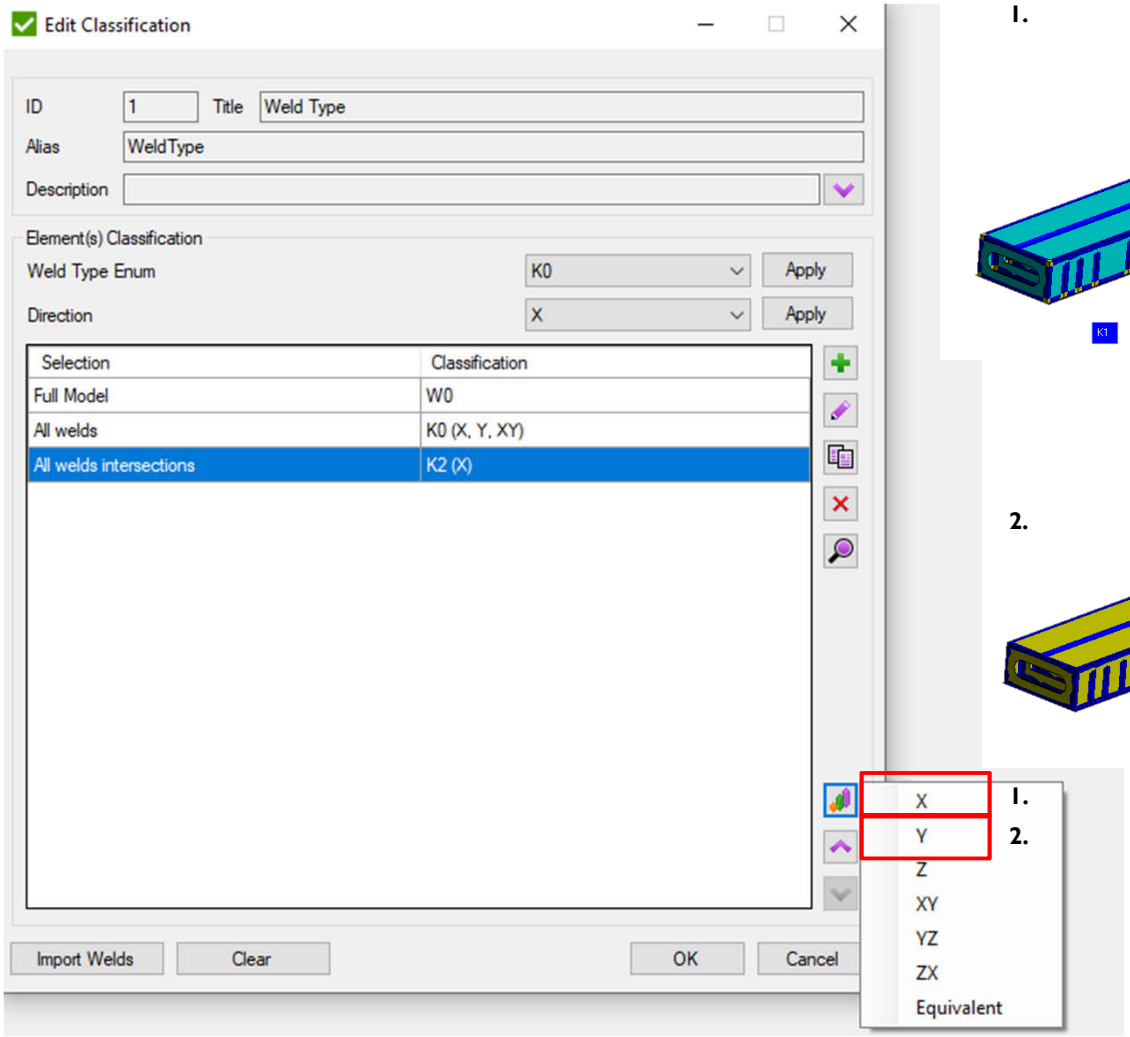
Weld Type classification intersecting welds

1. Press + to *Add Condition*.
2. Click *All welds intersections*
3. Value: **K2**
4. Directions: **X**
5. Press *OK*

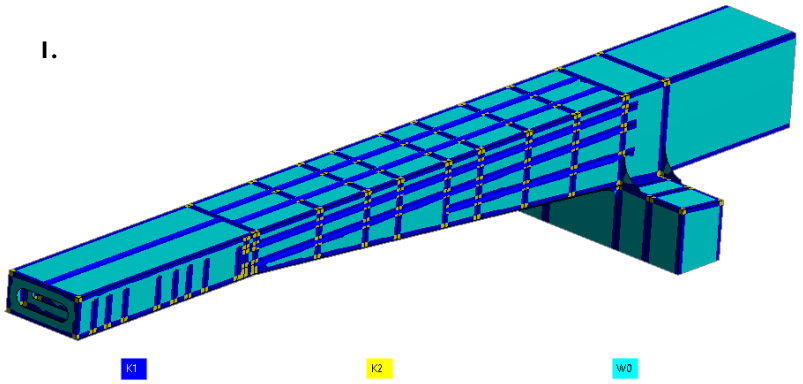


At intersecting welds all stresses are perpendicular to the weld direction. The last condition overwrites the previous ones and settings in condition 2 => K1(X) are replaced with K2(X) for intersections

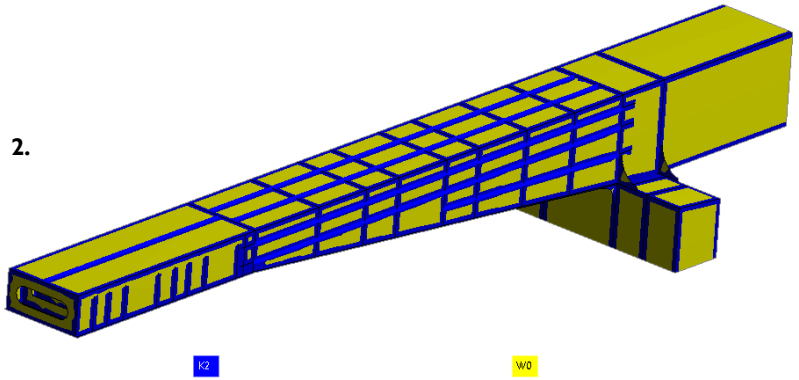
Check classification



1.



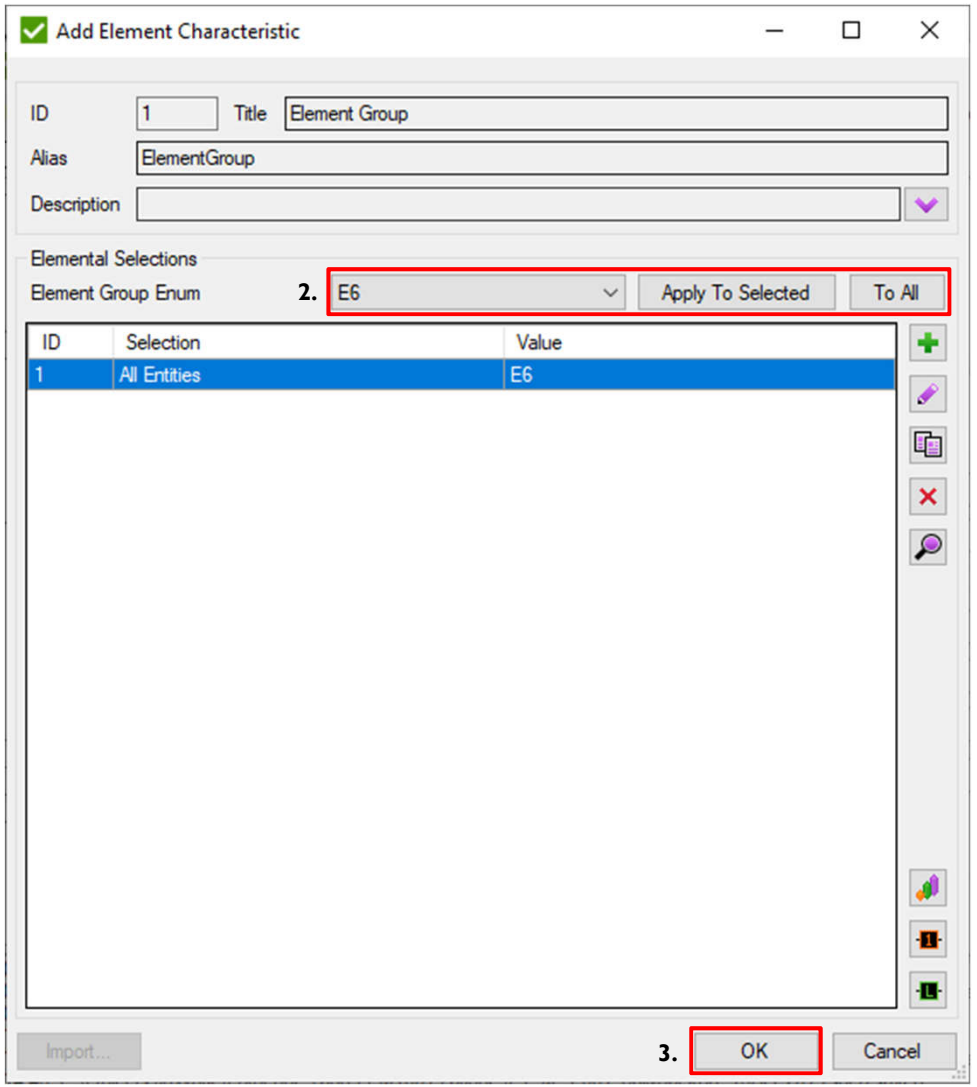
2.



2.

Element Group classification

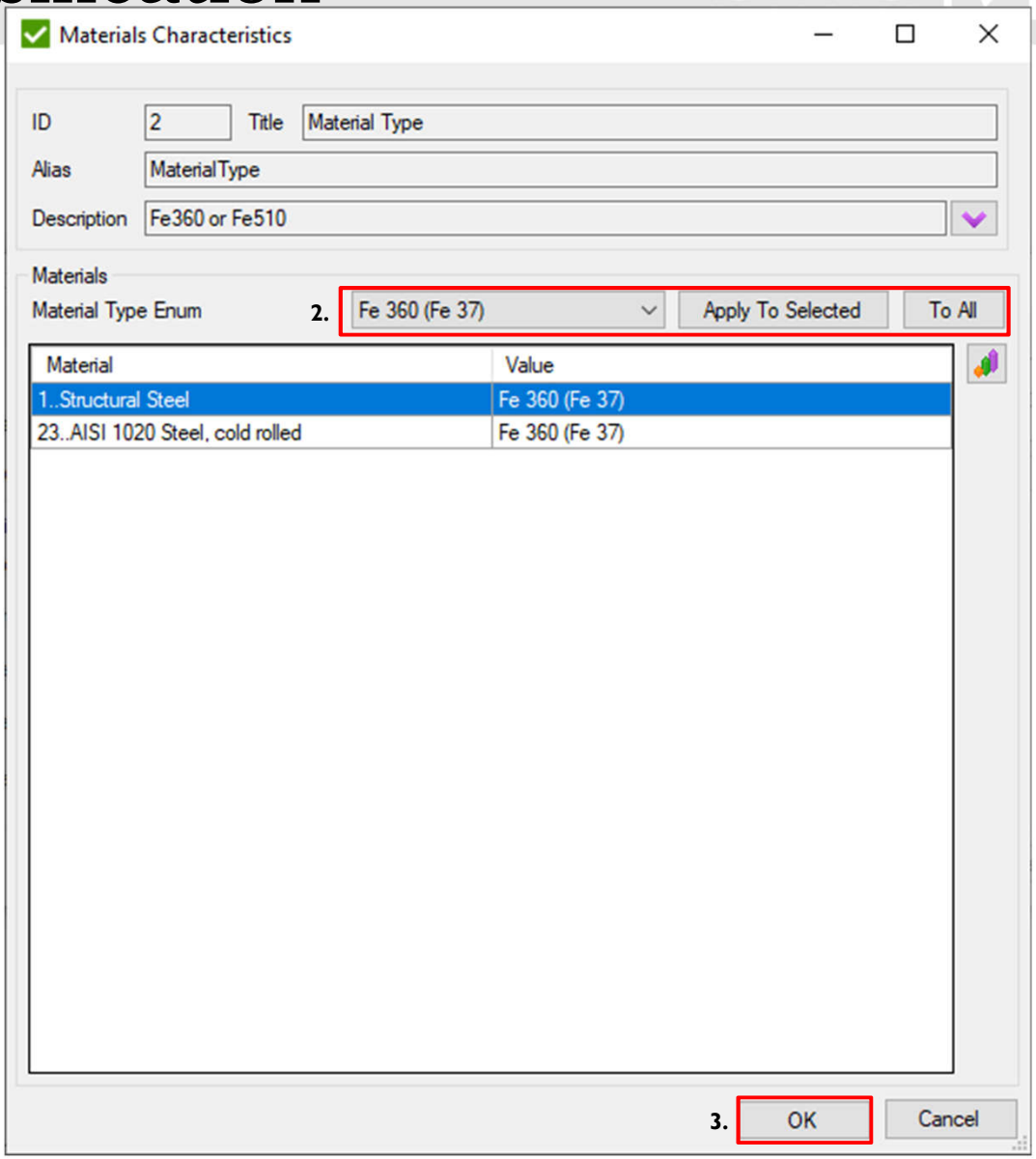
1. Press  for the Element Group.
2. Select Element Group: **E6.** Press *To All*.
3. Press *OK*.



Material Type classification

1. Press  for the Material Type.
2. Select Material Type: **Fe360 (Fe 37)**. Press *To All*.
3. Press *OK*.
4. Press *OK* to create Standard.

Material Type defines which steel is used: St37 or St52. Stress Fatigue values are different for different materials.

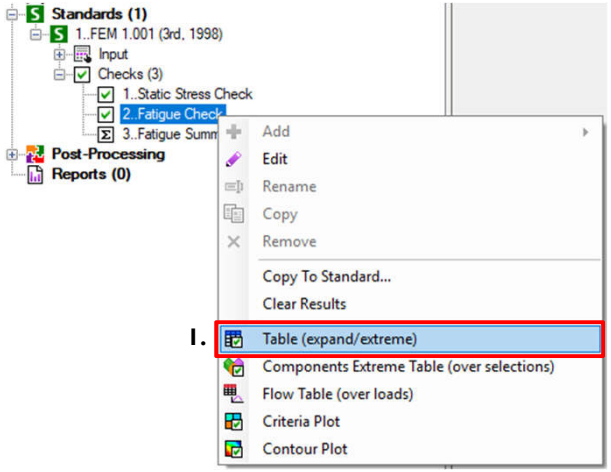


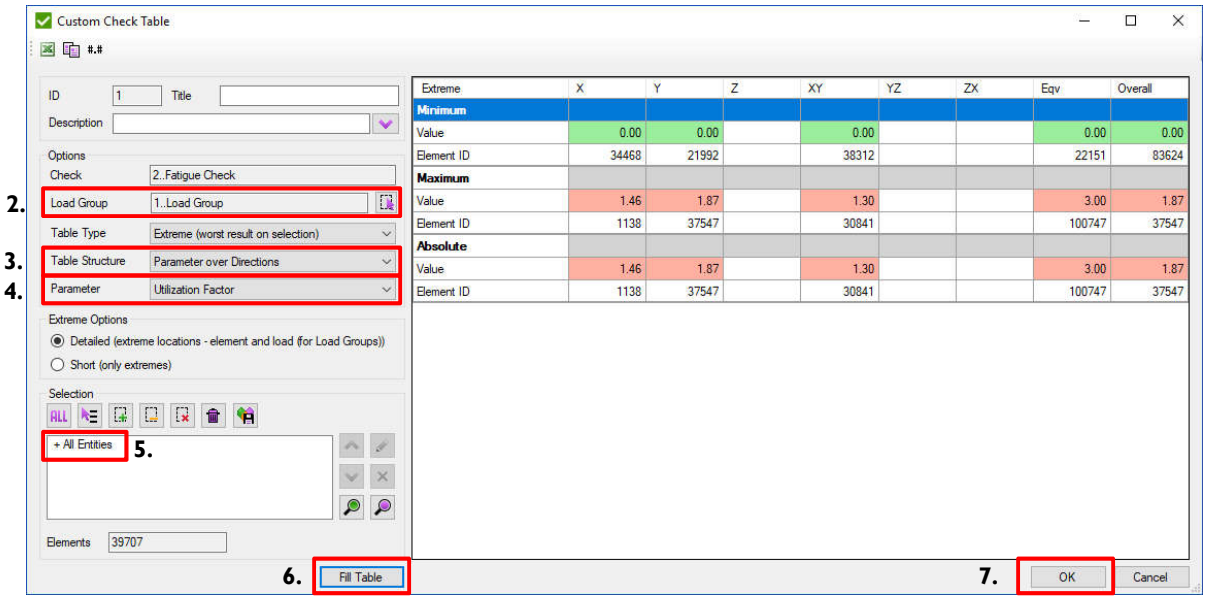
Create extreme table

1. Execute *Table (expand/extreme)* in **Fatigue Check** context menu.
2. Load: **1..Load Group1**.

Fatigue check supports only Load Groups. If only one load group exist in the project it will be selected automatically.

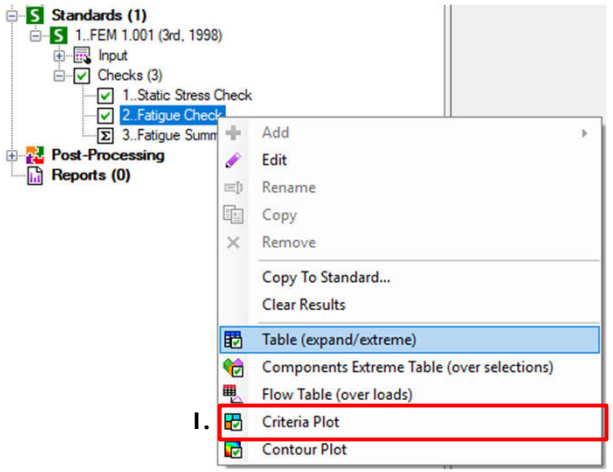
3. Table Type: **Parameter over Directions.**
4. Parameter: **Utilization Factor.**
5. Selection: ***All Entities.***
6. Press *Fill Table.*
7. Press *OK.*

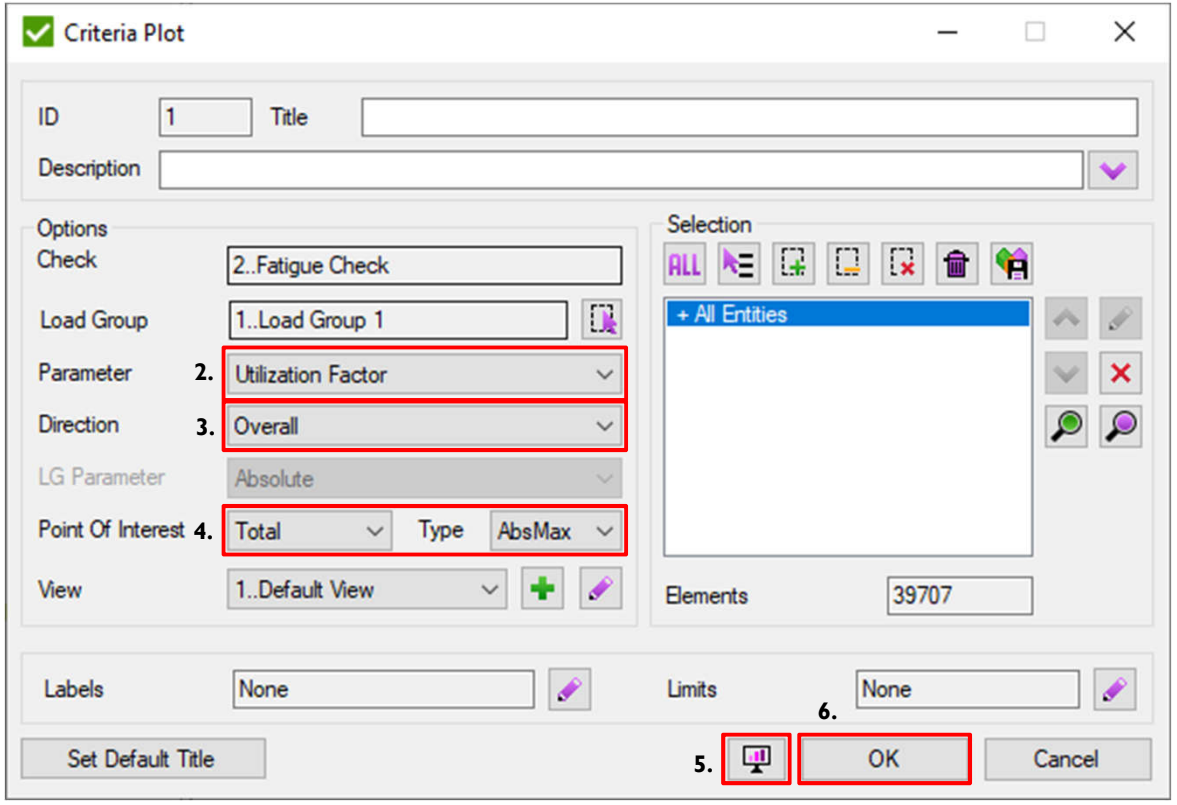




Create criteria plot

1. Execute *Criteria Plot* in **Fatigue Check** context menu.
2. Parameter: **Utilization Factor**
3. Direction: **Overall**
4. Point of interest: **Total** Type: **AbsMax**
5. Press *Preview*
6. Press OK

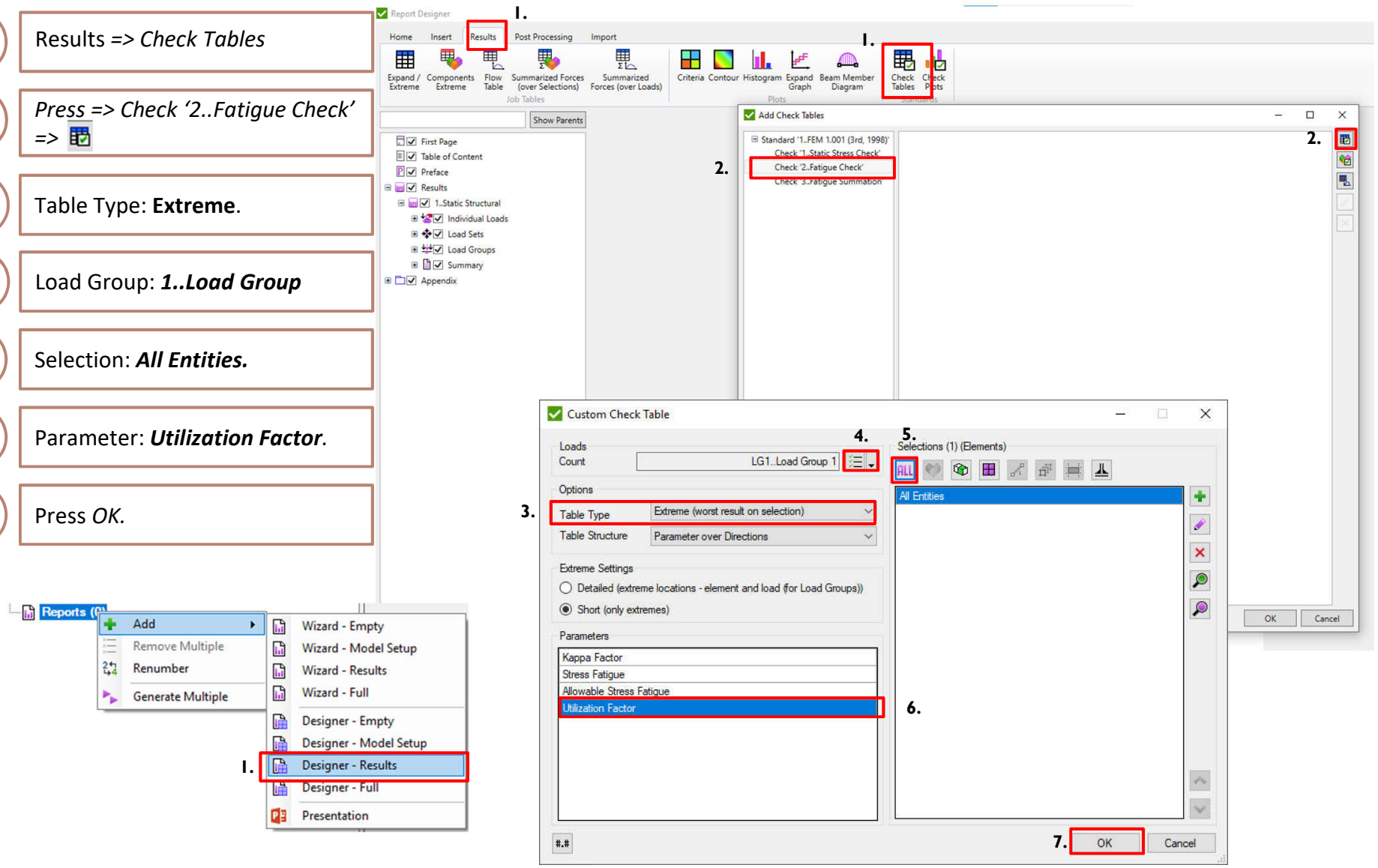




Point of interest = AbsMax Total is absolute maximum utilization factors among all point of interest.

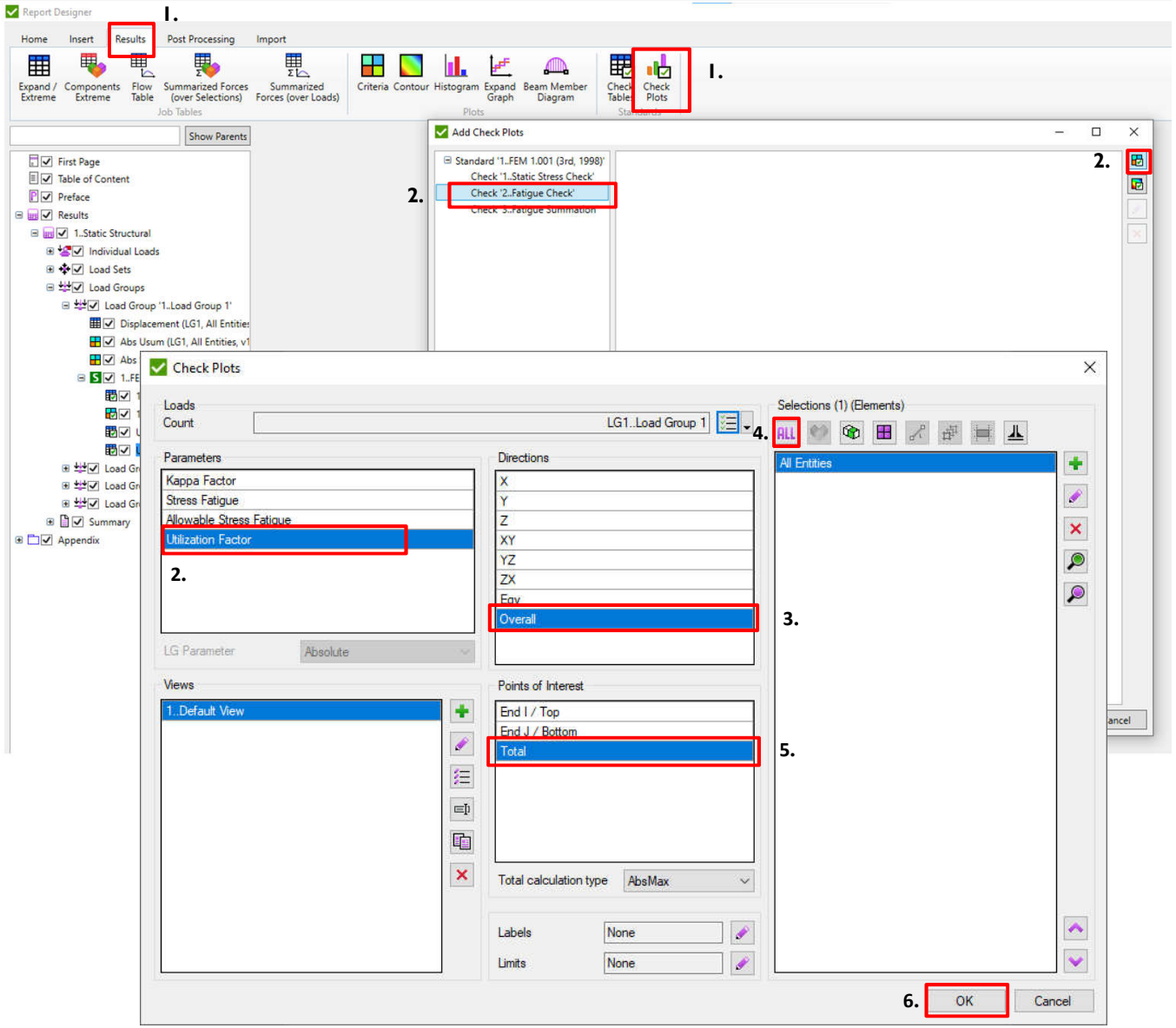
Report. Tables and plots

1. Results => *Check Tables*
2. *Press => Check '2..Fatigue Check' =>*
3. Table Type: **Extreme**.
4. Load Group: ***1..Load Group***
5. Selection: ***All Entities.***
6. Parameter: ***Utilization Factor***.
7. Press *OK.*



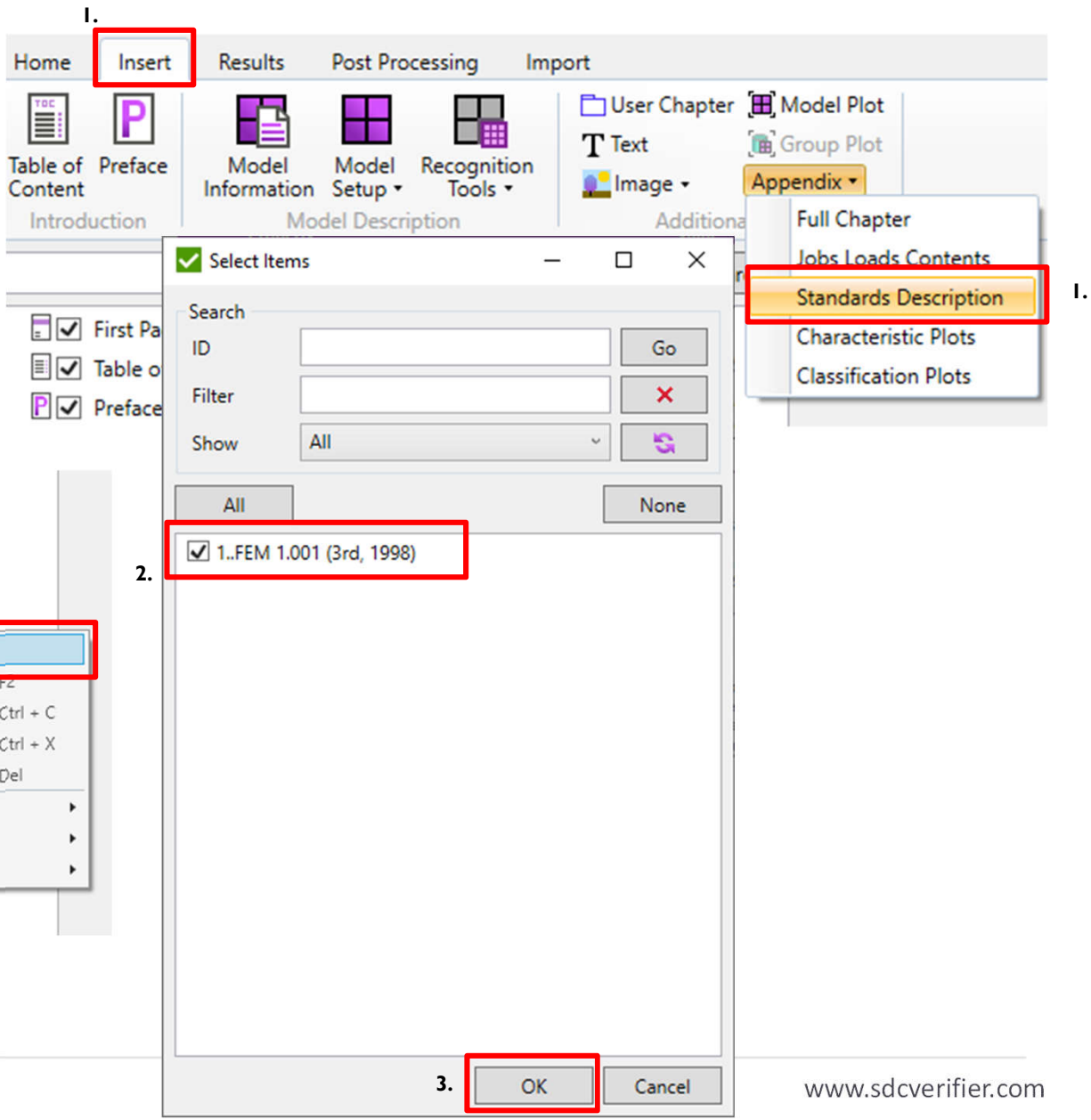
Report. Tables and plots

1. Results => *Check Plots*
2. *Press => Check '2..Fatigue Check' =>*
3. Direction: **Overall**
4. Point of Interest: **Total**.
5. Selection: ***All Entities***.
6. Press *OK*.



Report. Fatigue Check

1. Insert => *Appendix* => *Standards Description*
2. *Choose 1..FEM 1.001*
3. Press *OK.*
4. Expand standard 1..FEM 1.001 => *Generate* .



Report. Results

2..Fatigue Check

Property	Value
Category	Elemental Custom Check
Selection	All Entities
Parameters	4
Alias (Parameter)	**Kappa (Kappa Factor)**
Description	Ratio between the extreme stresses
All	if(SweldAbs > 0, SweldMin / SweldMax, SweldMax / SweldMin)
Alias (Parameter)	**Sf (Stress Fatigue)**
Description	Permissible stress for fatigue depends on the element group (E1-E8) and weld type
All	Min(units.FromPaToCurrent(Switch(MaterialType, Fe360, Sf_Fe360(ElementGroup, WeldType), Fe510, Sf_Fe510(ElementGroup, WeldType))), 0.75 * Tensile)
Alias (Parameter)	**Sallow_fatigue (Allowable Stress Fatigue)**
Description	Appendix 3.6, formulas (1)-(4)
All	if(Kappa > 0, if(SweldAbs > 0, 1, 1.2) * (5 / 3 * Sf) / (1 - (1 - (5 / 3 * Sf) / (0.75 * tensile)) * Kappa), if(SweldAbs > 0, (5 * Sf) / (3 - 2 * Kappa), (2 * Sf) / (1 - Kappa)))
Eqv	0
Alias (Parameter)	**Uf (Utilization Factor)**
Description	Appendix 3.6, equivalent rule - (5)
All	Abs(SweldAbs) / Sallow_Fatigue
XY/YZ/ZX	Abs(SweldAbs) / (Sallow_Fatigue / if(WeldType <= Weld_K4, SQRT(2), SQRT(3)))
Eqv	pow(me.x, 2) + pow(me.y, 2) + pow(me.z, 2) + pow(me.xy, 2) + pow(me.yz, 2) + pow(me.zx, 2) - sign(SweldAbs.X) * me.x * sign(SweldAbs.Y) * me.y - sign(SweldAbs.Y) * me.y * sign (SweldAbs.Z) * me.z - sign(SweldAbs.Z) * me.z * sign(SweldAbs.X) * me.x
Overall	Max(me.x, me.y, me.z, me.xy, me.yz, me.zx, sqrt(me.eqv))

1..FEM 1.001 (3rd, 1998)

Unit System

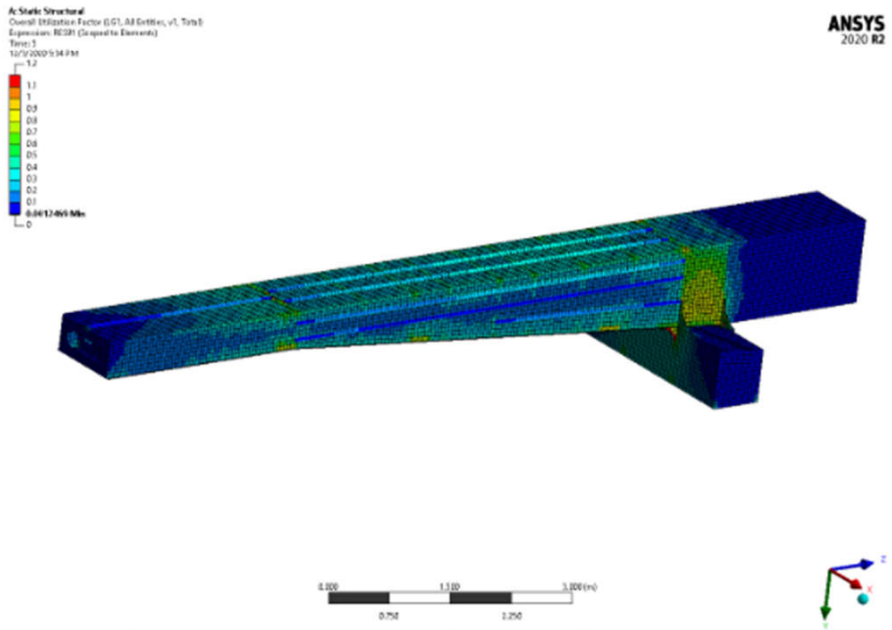
Current Unit System = MKS (Meter/Kg/Second). It is used in calculations for the following standards: API RP 2A, ISO 19902, Norsok N004, DIN 15018, FEM 1.001 and Eurocode3.

Utilization Factor (LG1, All Entities)

Standard	1..FEM 1.001 (3rd, 1998)	**Check**	[S1] 2..Fatigue Check
Load Group	LG1..Load Group 1	**Parameter**	Utilization Factor
Selection	All Entities		

Extreme	X	Y	Z	XY	YZ	ZX	Eqv	Overall
Minimum								
Value	0.00	0.00		0.00			0.00	0.00
Element ID	7637	2010		3978			7270	4355
Maximum								
Value	1.58	1.36		1.04			2.58	1.61
Element ID	12005	17235		12011			12005	12005
Absolute								
Value	1.58	1.36		1.04			2.58	1.61
Element ID	12005	17235		12011			12005	12005

Overall Utilization Factor (LG1, All Entities, v1, Total)

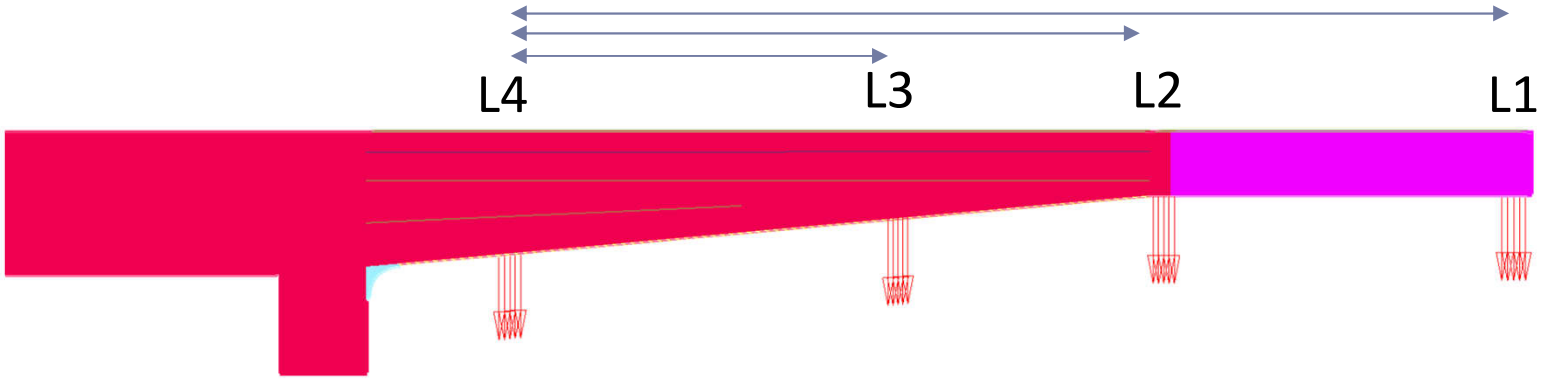


Check	[S1] 2..Fatigue Check	**Point**	Total
Load Group	LG1..Load Group 1	**Parameter**	Overall Utilization Factor
Selection	All Entities	**View**	1..Default View

Eurocode3 Stress history

- A better fatigue damage can be made if load cycles are specified more accurately.
- Instead of 2 million load cycles from start to end:

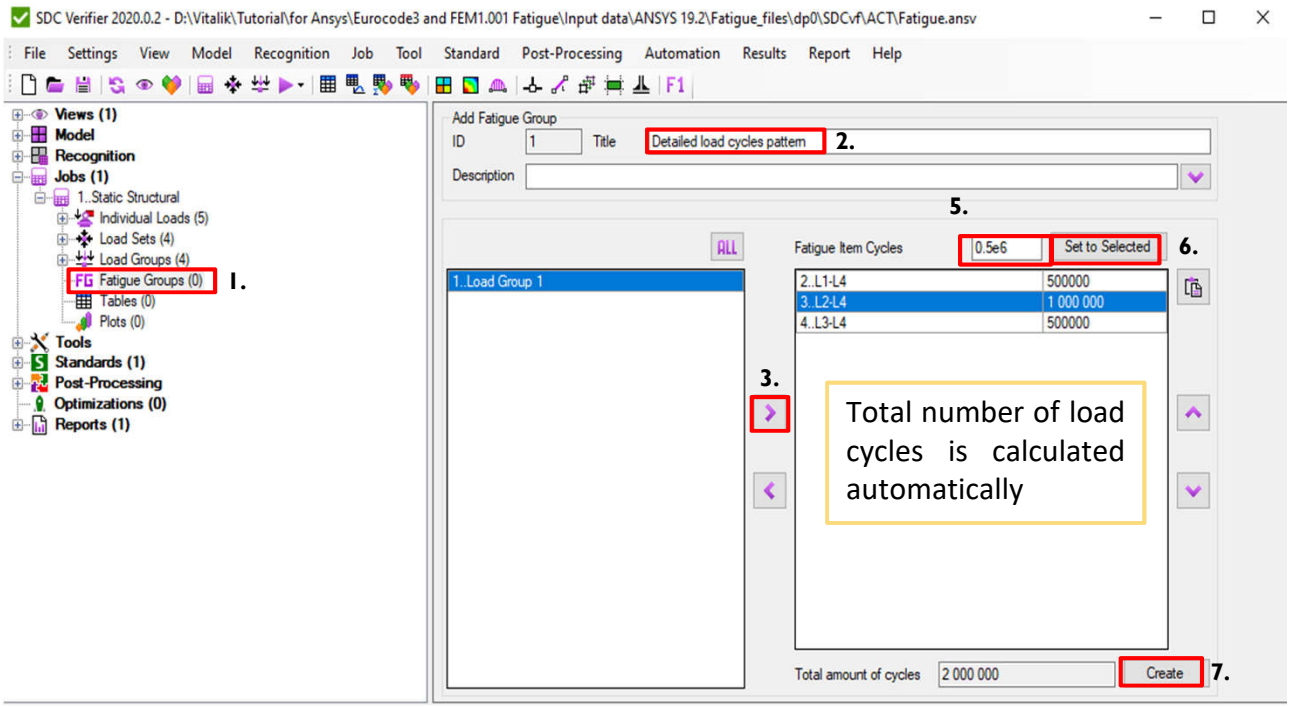
Load cycle	Number of cycles	Content
L4-L1	0,5 e6	LS4, LS3, LS2, LS1, IL1
L4-L2	1,0 e6	LS4, LS3, LS2, IL1
L4-L3	0,5 e6	LS4, LS3, IL1

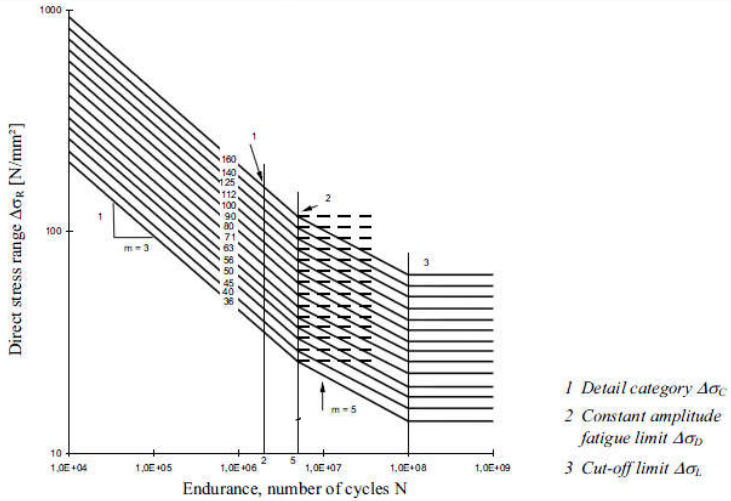


NB gravity load is also included because the stress variation determines the fatigue damage

Add Fatigue Group (stress history)

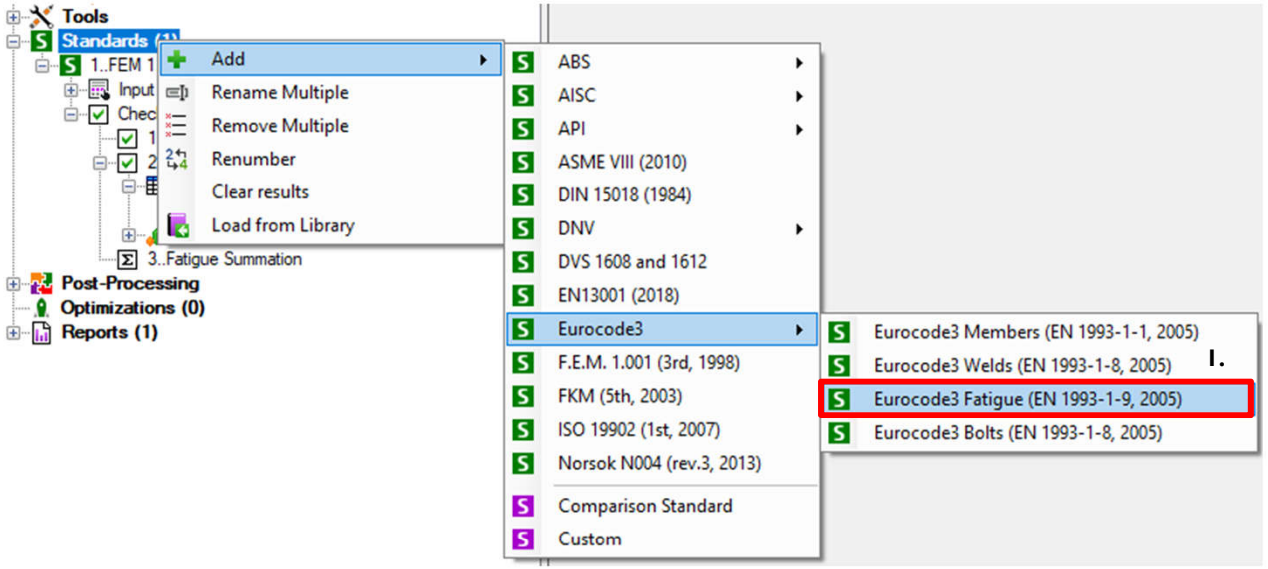
1. Select **Fatigue Groups** in Navigation tree
2. Title: **Detailed load cycles pattern**
3. Select all groups and press ›
4. Select **1..L1-L4** and **3..L2-L4**
5. Fatigue Item Cycles: **0.5e+6** and *Set*.
6. Set **1e+6** cycles for 2..L3-L4
7. Press *Create*

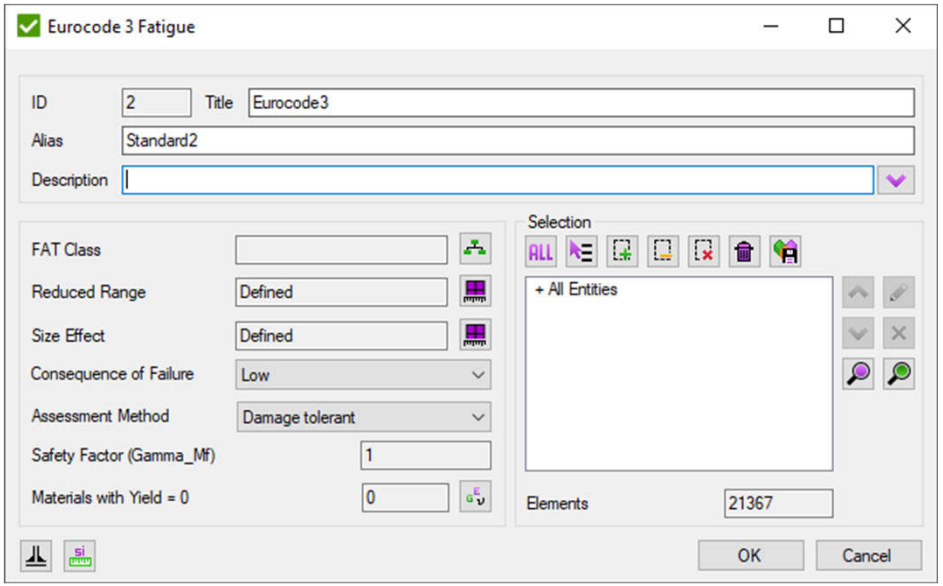




Fatigue calculation with Eurocode 3

1. Execute *Add* => **Eurocode 3 Fatigue (EN 1993-1-9)** in Standards context menu.
2. Consequence of Failure: **Low**
3. Assessment Method: **Damage tolerant**





Safety Factor	Low consequence	High consequence
Damage tolerant	1.0	1.15
Safe life	1.15	1.35

FAT classes Eurocode3

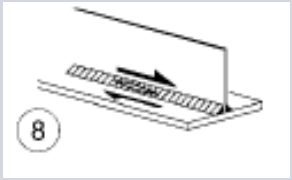
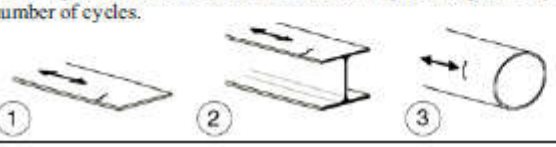
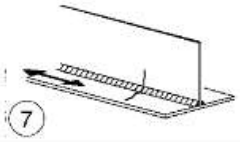
	Perpendicular to weld	Parallel with weld	Shear
Weld	**80** 	**100** 	**80** 
No weld	**160** 		**100** 

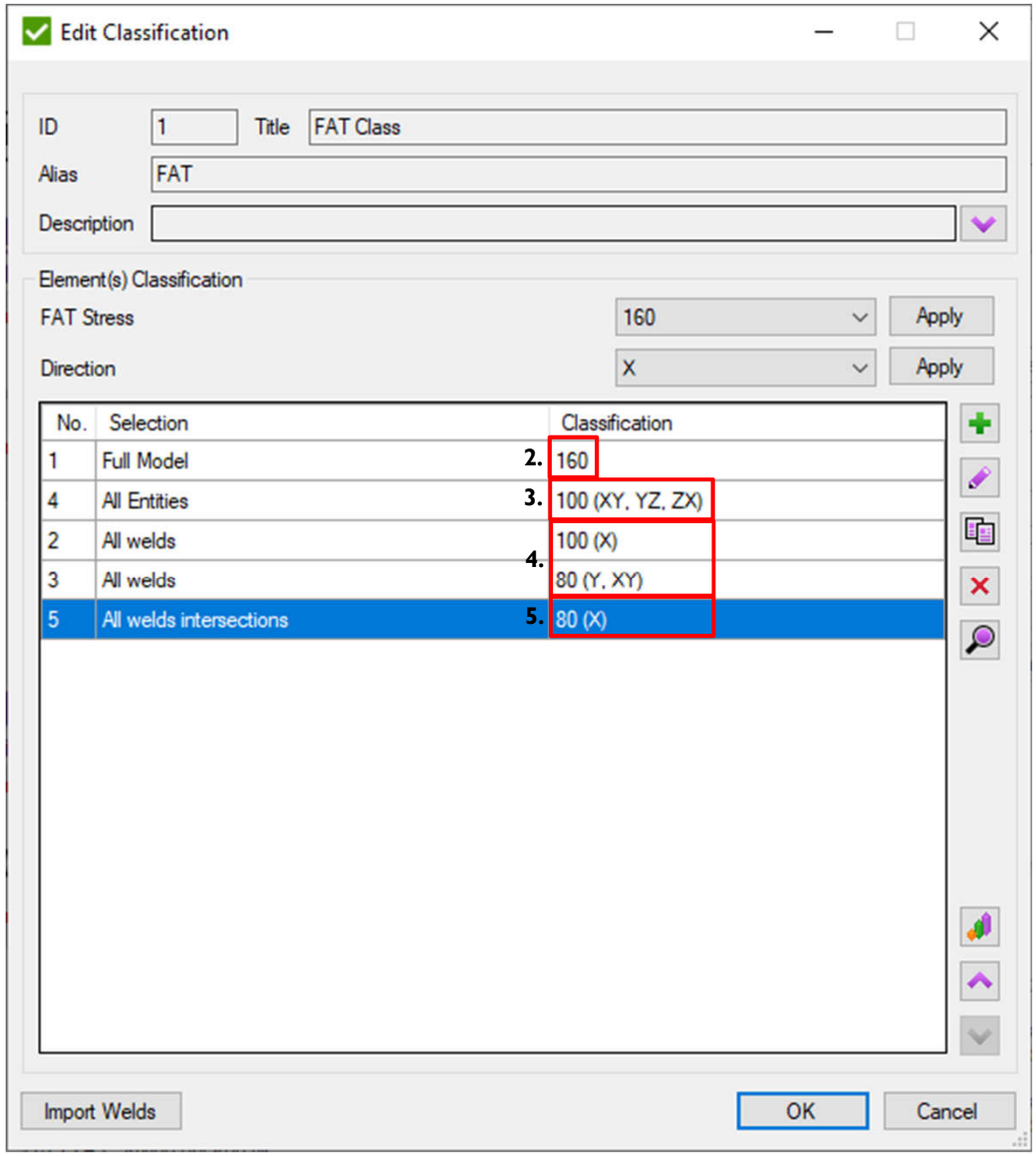
Table 8.1: Plain members and mechanically fastened joints

Detail category	Constructional detail	Description	Requirements
160	**NOTE** The fatigue strength curve associated with category 160 is the highest. No detail can reach a better fatigue strength at any number of cycles. 	Rolled and extruded products: 1) Plates and flats; 2) Rolled sections; 3) Seamless hollow sections, either rectangular or circular.	Details 1) to 3): Sharp edges, surface and rolling flaws to be improved by grinding until removed and smooth transition achieved.
100		7) Repaired automatic or manual fillet or butt welds for categories 1) to 6).	7) Improvement by grinding performed by specialist to remove all visible signs and adequate verification can restore the original category.

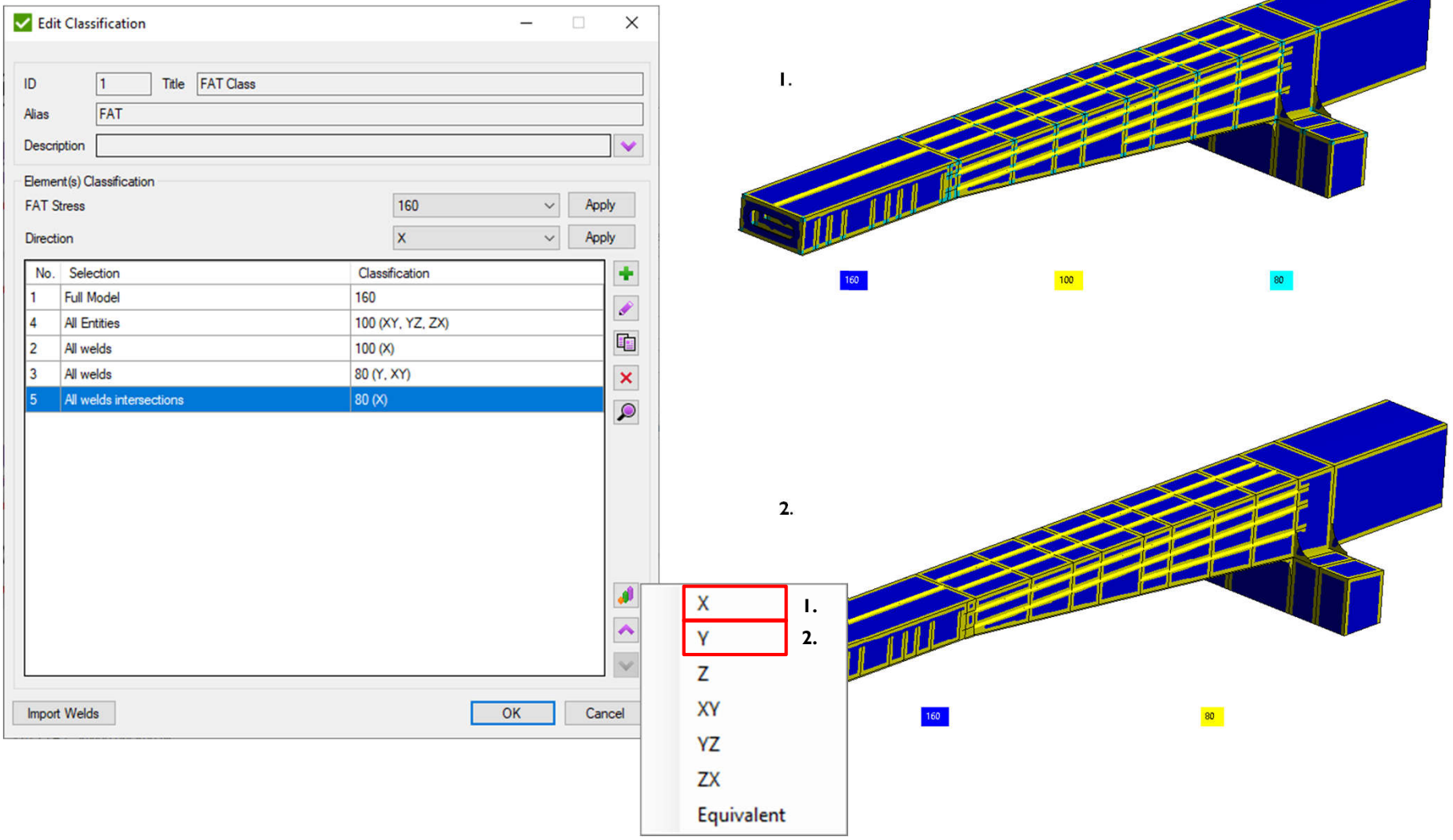
For determination of FAT classes check standard!
In this tutorial only examples are given

Eurocode3 Fat Class

1. Press *Define* for the FAT Class.
2. Full Model: **160**
3. All Entities: **100** (No weld)
4. For welds: X: **100**; Y/XY: **80**
5. For welds intersections: X: **80**

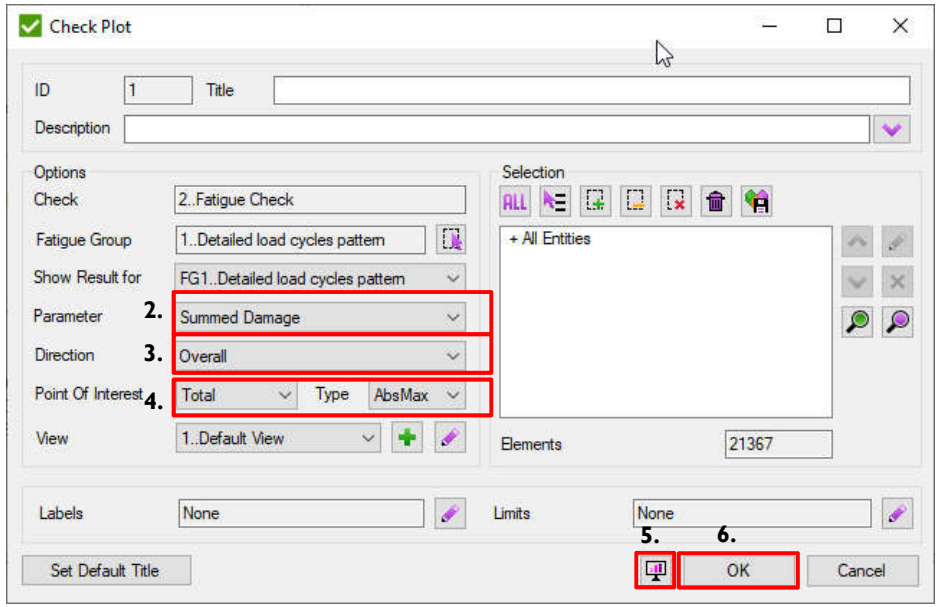


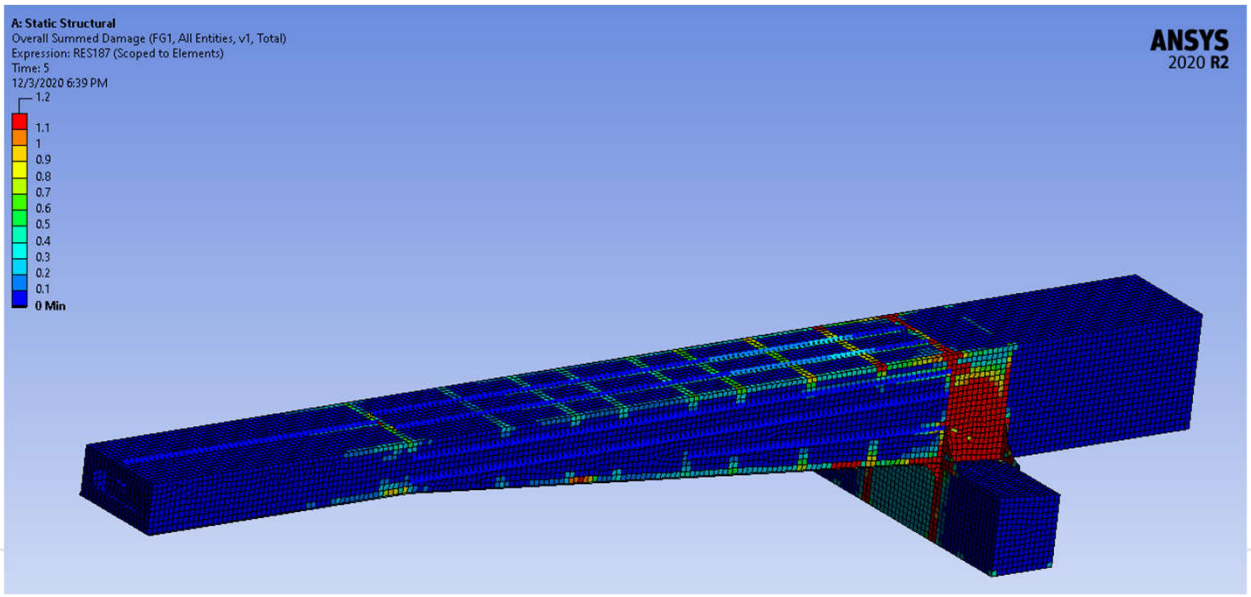
FAT classes plot



Fatigue Damage Plot

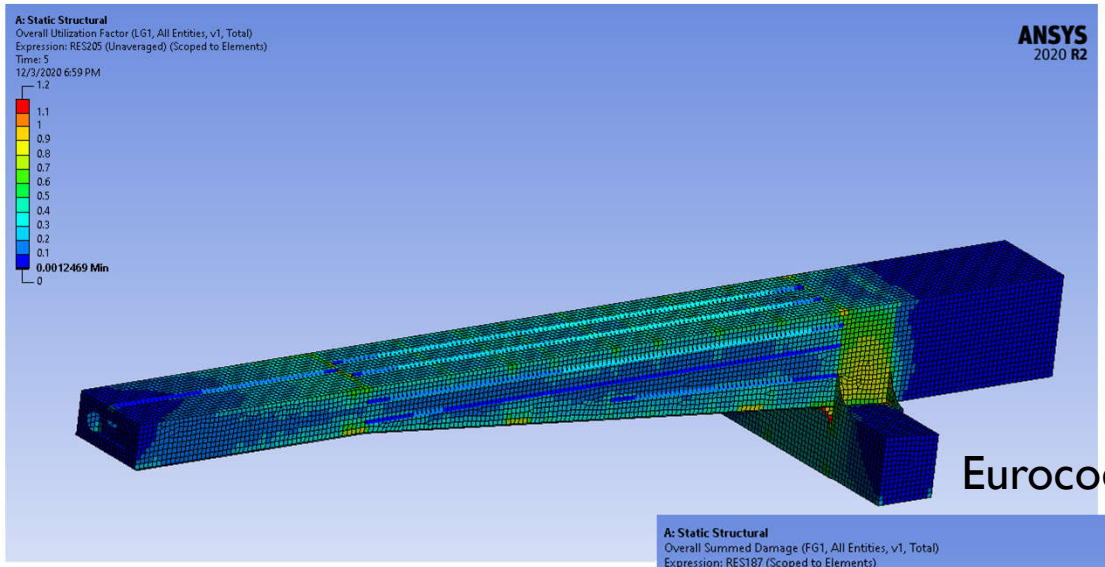
1. Execute *Criteria Plot* in **Fatigue Check** context menu
2. Parameter: **Summed Damage**
3. Direction: **Overall**
4. Point of interest: **Total** Type: **AbsMax**
5. Press *Preview*
6. Press *OK*





Comparison

FEM 1.001 utilization factor



Eurocode 3 utilization factor at 2 million cycles