

Steel structures, selected chapters

Fatigue: resistance, constructive details
(ref. TGC 10 sections 13.1 and 13.6)

Part 2

- **Fatigue normalized curves**
- **Types of details and diff. resistance curves**
- Bolted, riveted connections
- Welded Connections
- Hot-spot method
- Execution of welds

Reminder: fatigue check format (constant amplitude)

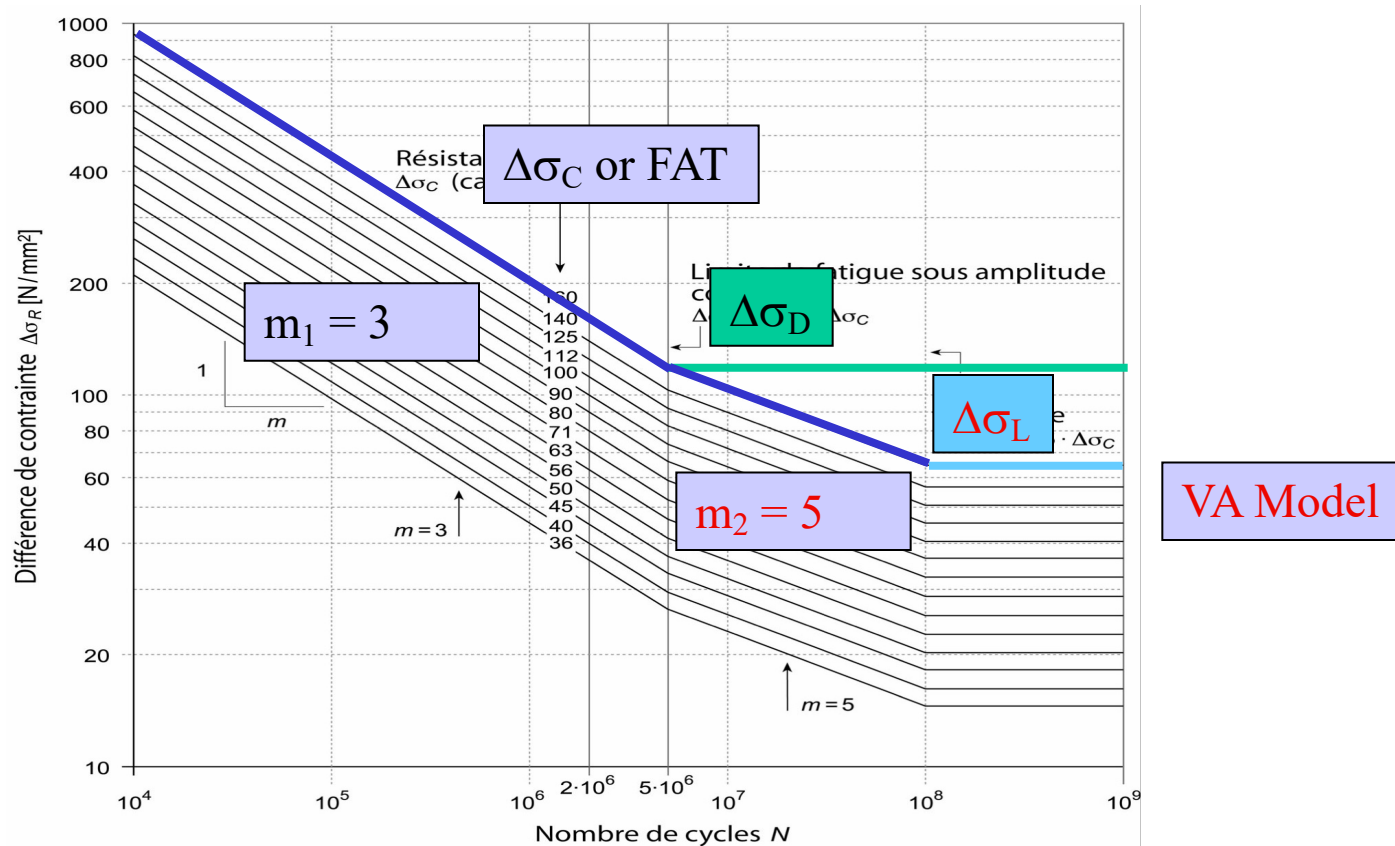
$$E_D \leq R_D \qquad \gamma_{Ff} \Delta\sigma_{E2} \leq \Delta\sigma_C / \gamma_{Mf}$$

- Basis of comparison **2 millions cycles (FAT)**
- Action load effects adjusted to **2 millions cycles**

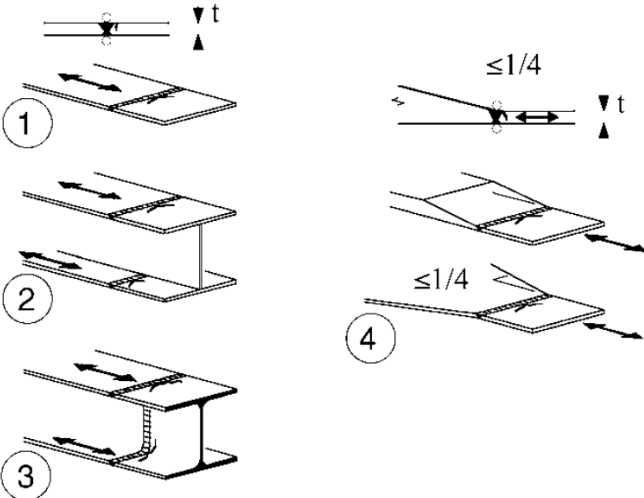
$$\Delta\sigma_{E2} = \left(\frac{N}{2 \cdot 10^6} \right)^{1/m} \cdot \Delta\sigma_N$$

- Fatigue loading factor $\gamma_{Ff} = 1.0$
- Fatigue Resistance factor $\gamma_{Mf} \geq 1.0$

Fatigue resistance curves (SIA, Eurocode 3)

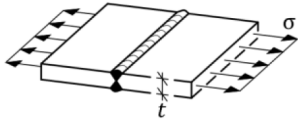
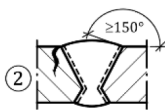
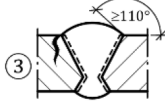
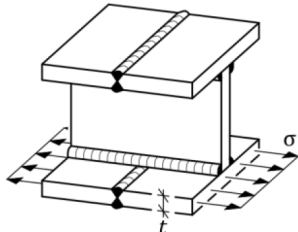
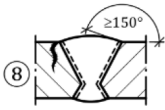
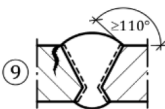


EN 1993-1-9: Table of Categories of Detail (extract)

Detail category	Constructional detail		Description	Requirements
FAT $\Delta\sigma_C$ 112	Size effect for $t > 25\text{ mm}$: $k_s = (25/t)^{0.2}$		<u>Without backing bar:</u> 1) Transverse splices in plates and flats. 2) Flange and web splices in plate girders before assembly. 3) Full cross-section butt welds of rolled sections without cope holes. 4) Transverse splices in plates or flats tapered in width or in thickness, with a slope $\leq 1/4$.	- All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. <u>Detail 3):</u> Applies only to joints of rolled sections, cut and rewelded.
			5) Transverse splices in plates or ...	- The height of the weld convexity ...

Size effect consideration: $\Delta\sigma_{C,red} = k_s \cdot \Delta\sigma_C$

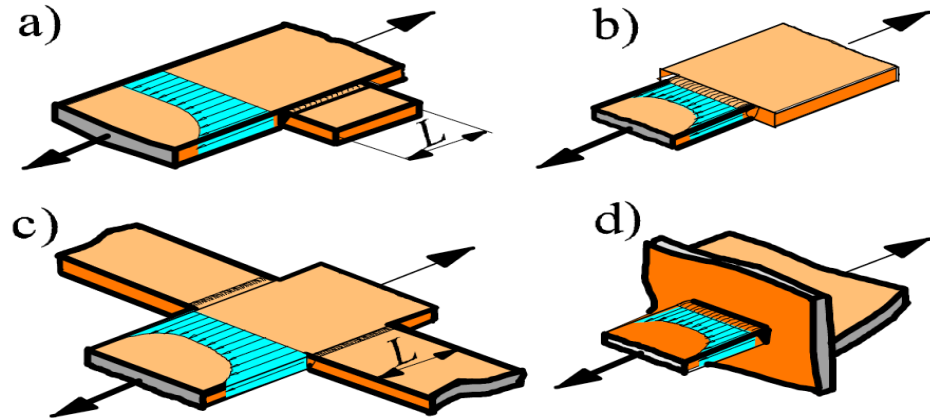
New EN (draft), improved tables of detail categories

Detail category	Constructional detail		Symbol	Description	Supplementary Requirements
112	 See NOTE 1 for size effect			① Splices in plates and flats of same thickness, welded from both sides, ground flush	Weld all-around ground flush with plate surface in direction of stress. Misalignment $\leq 5\%$ of plate thickness, see NOTE 2.
90				② as aforementioned, but as-welded with flank angle $\geq 150^\circ$	②: Welded in welding position PA acc. to EN ISO 6947. ②③: Weld ground flush at plate edges in direction of stress, where relevant, after removing weld run-off pieces. Misalignment $\leq 5\%$ of plate thickness, see NOTE 2.
80				③ as aforementioned, but as-welded with flank angle $\geq 110^\circ$	
112	 See NOTE 1 for size effect			⑦ Flange and web splices in plate girders, welded from both sides, ground flush	⑦⑧⑨: No full cross-section joint. Splices welded before assembly of girder.
90				⑧ as aforementioned, but as-welded with flank angle $\geq 150^\circ$	Longitudinal weld should be checked using Table 10.3 ⑦: see ①. ⑧: see ② ⑨: see ③.
80				⑨ as aforementioned, but as-welded, with flank angle $\geq 110^\circ$	

- Better drawings
- Weld descriptions, symbols
- Adding of details
- Review of detail categories wrt to state-of-art

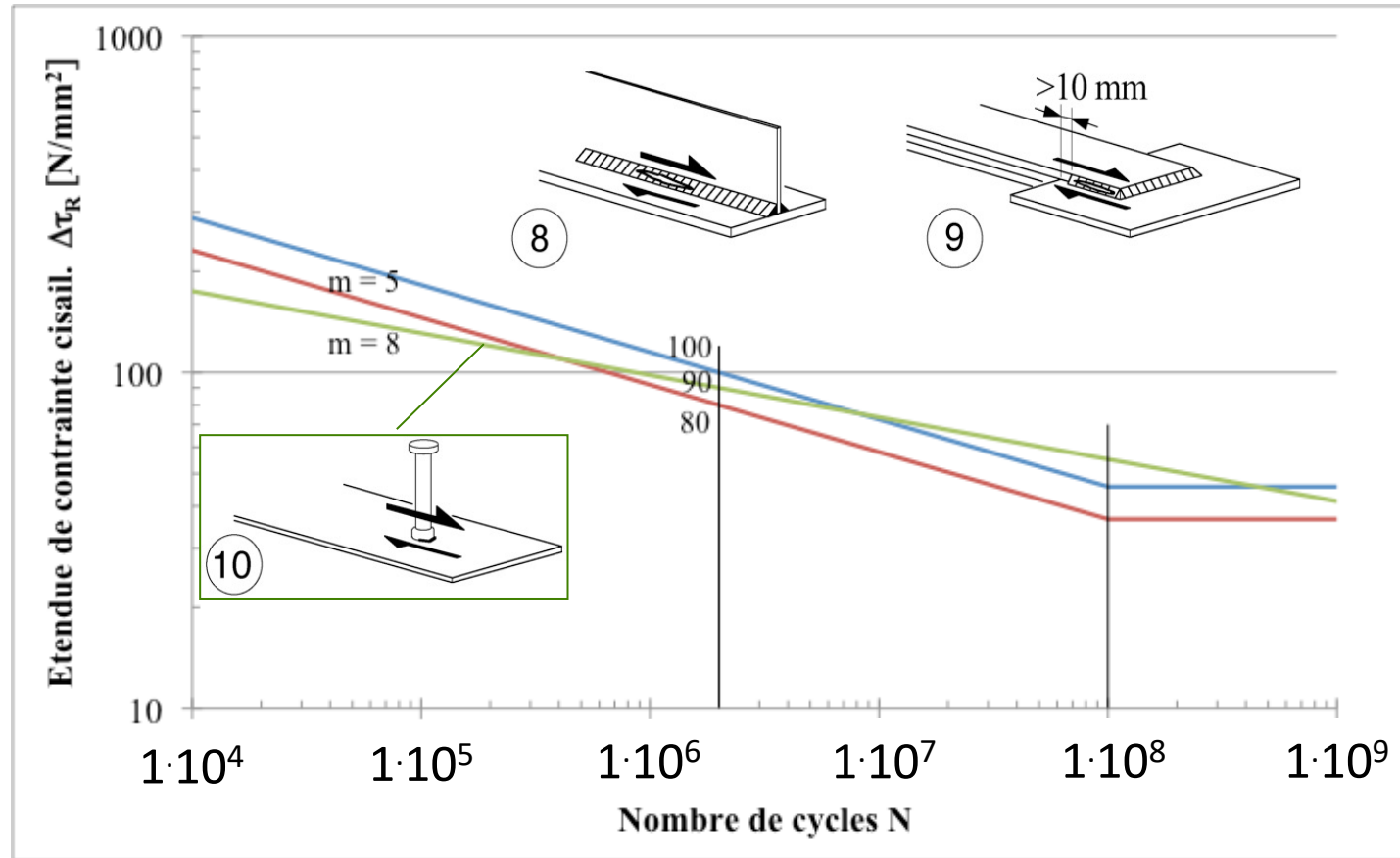
Types of Constructive Details

- Stress Concentration Rating (SCF)
- The higher it is, the worse the detail
- Influence of geometric parameters: width, length, thickness on the SCF, as well as type of weld, forces

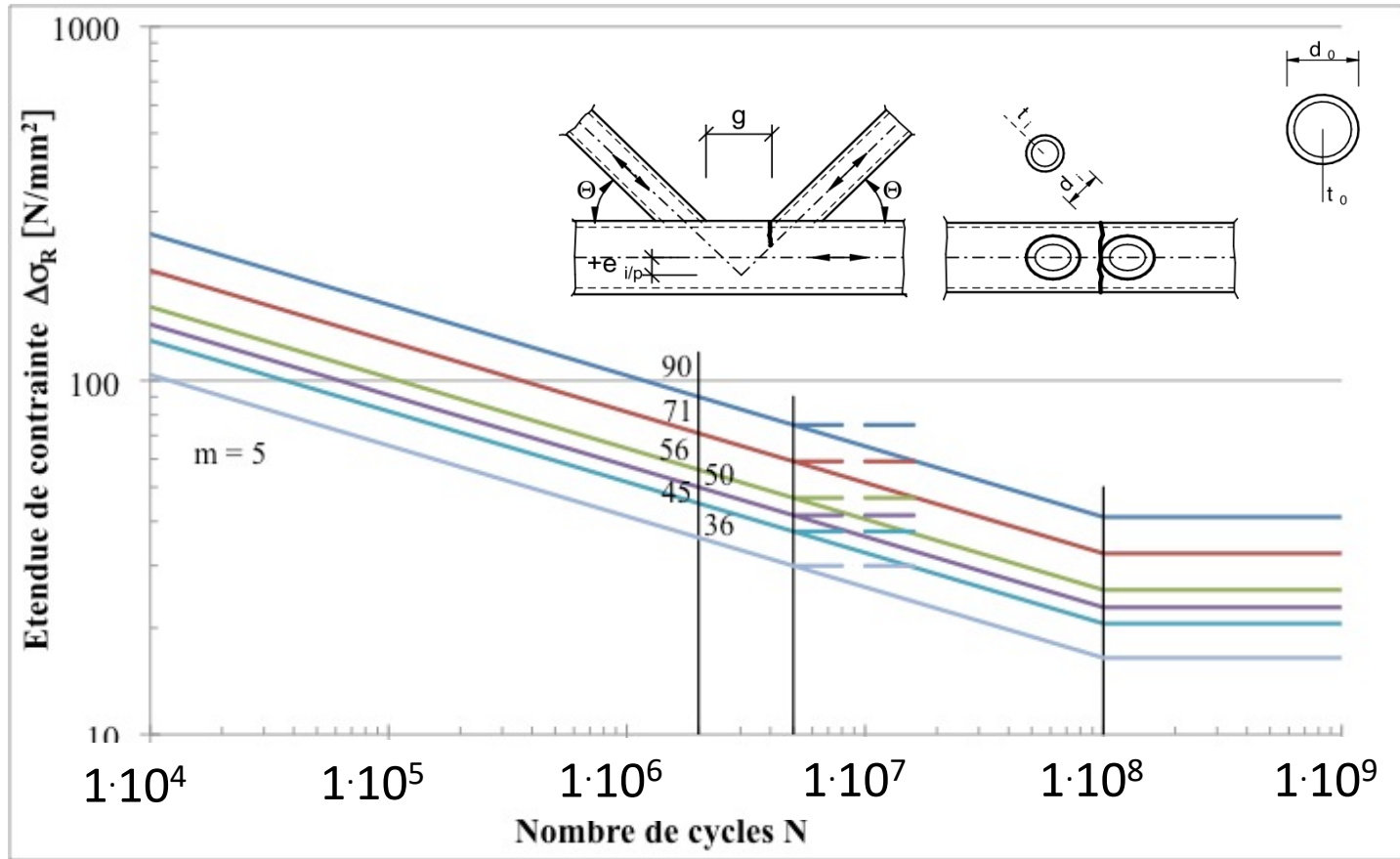


Réf. G. Marquis, AALTO univ.

Other resistance curves: shear stress cases



Other curves: tubular lattice girder node cases ($t \leq 8 \text{ mm}$)

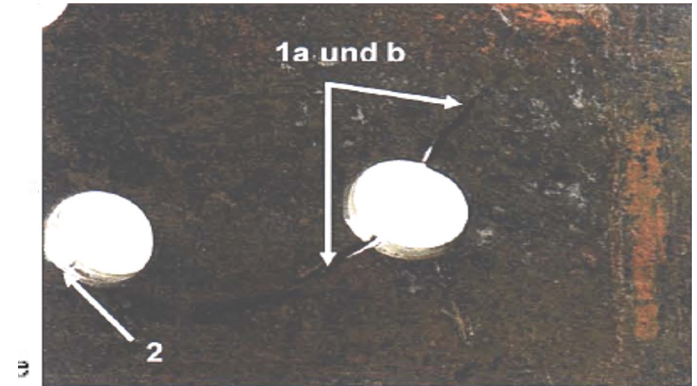
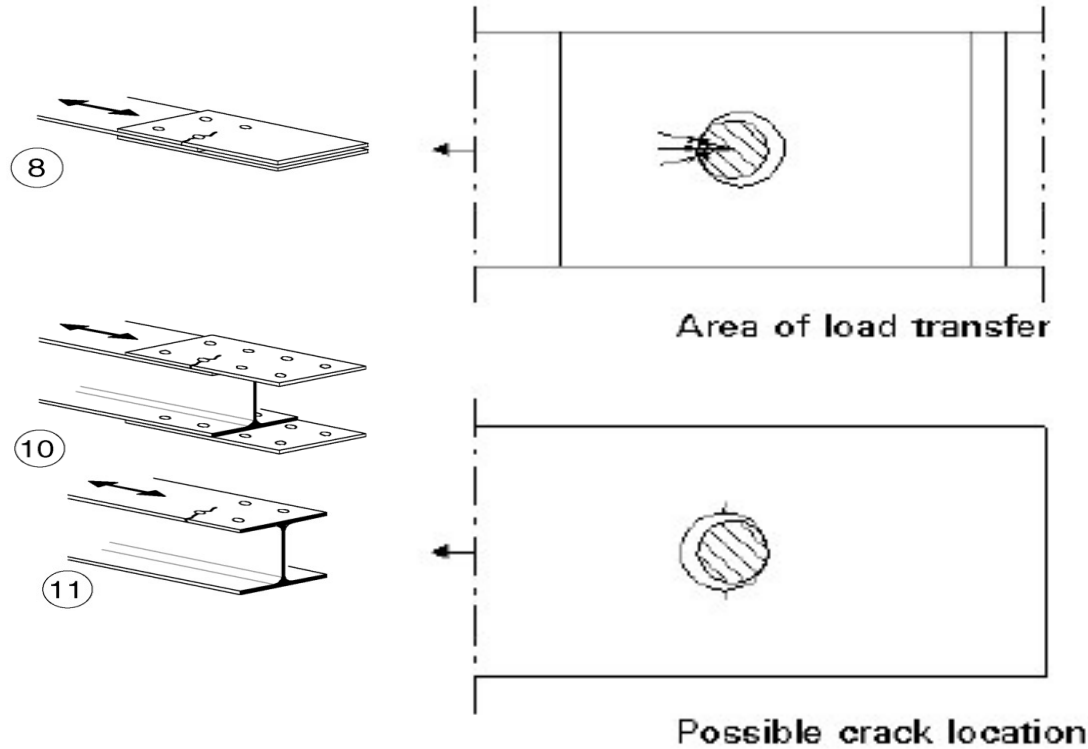


New EN, will
be raised to
 $t \leq 12.5 \text{ mm}$

①

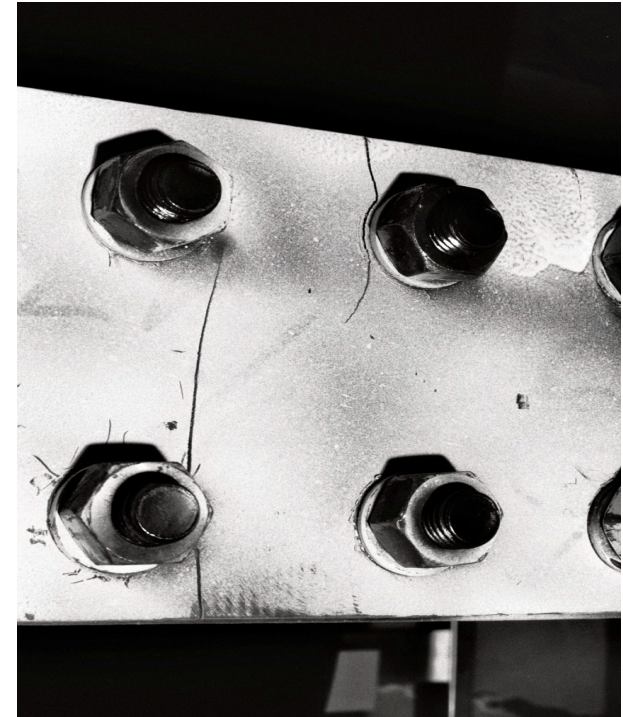
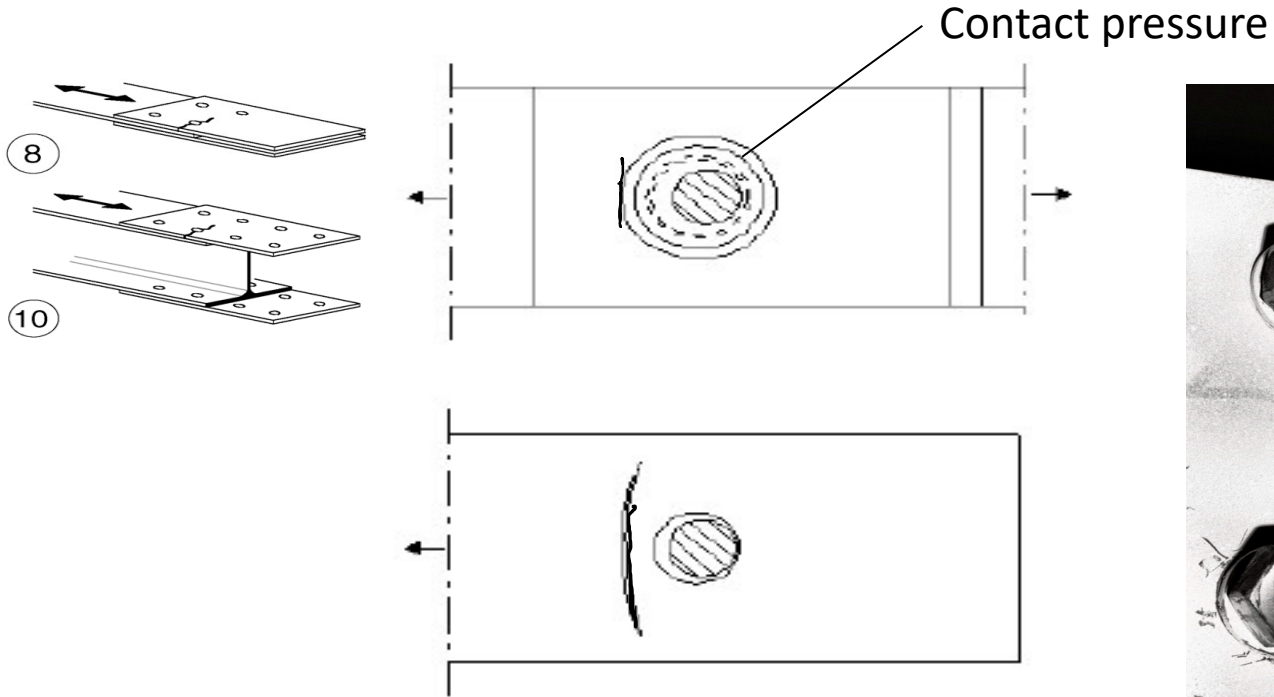
- Fatigue normalized curves
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Shear bolted joints



FAT between 50 and 90
($\Delta\sigma$ on the net cross-section)

Shear Prestressed Bolted Connections

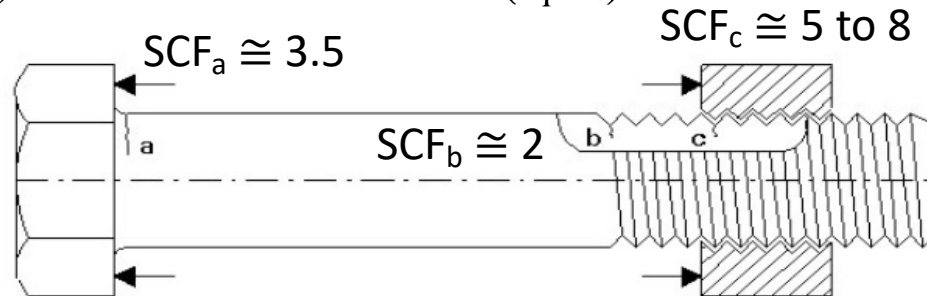
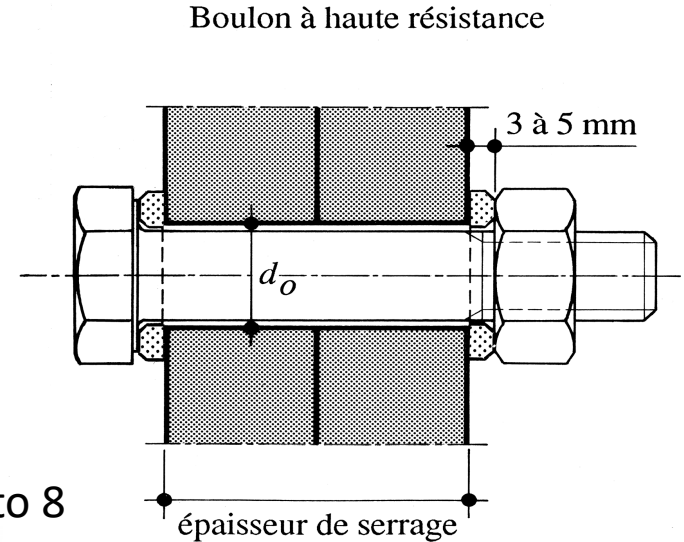
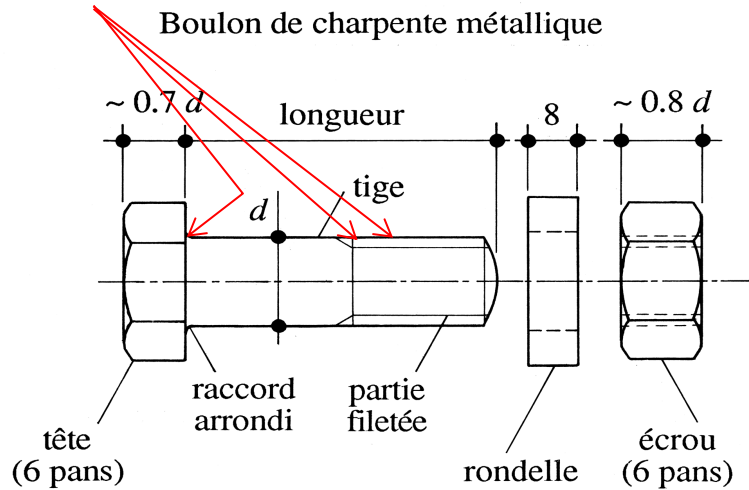


FAT between 90 and 112
($\Delta\sigma$ on gross cross-section)

Tensile bolted joints (FAT 50)

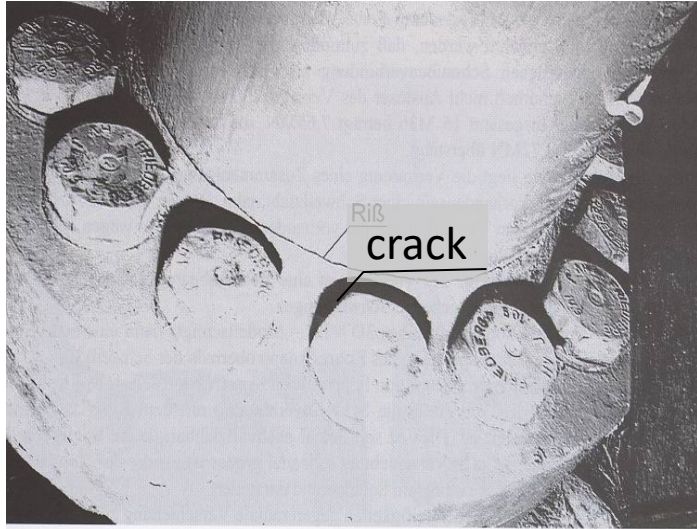
Critical areas for fatigue:

Small rays, intro. Strength = High Stress Concentration



Tensile bolted connections

Case a, crack in weld



Case b, crack in bolt (FAT 50)



Tensile bolted joints (FAT 50)

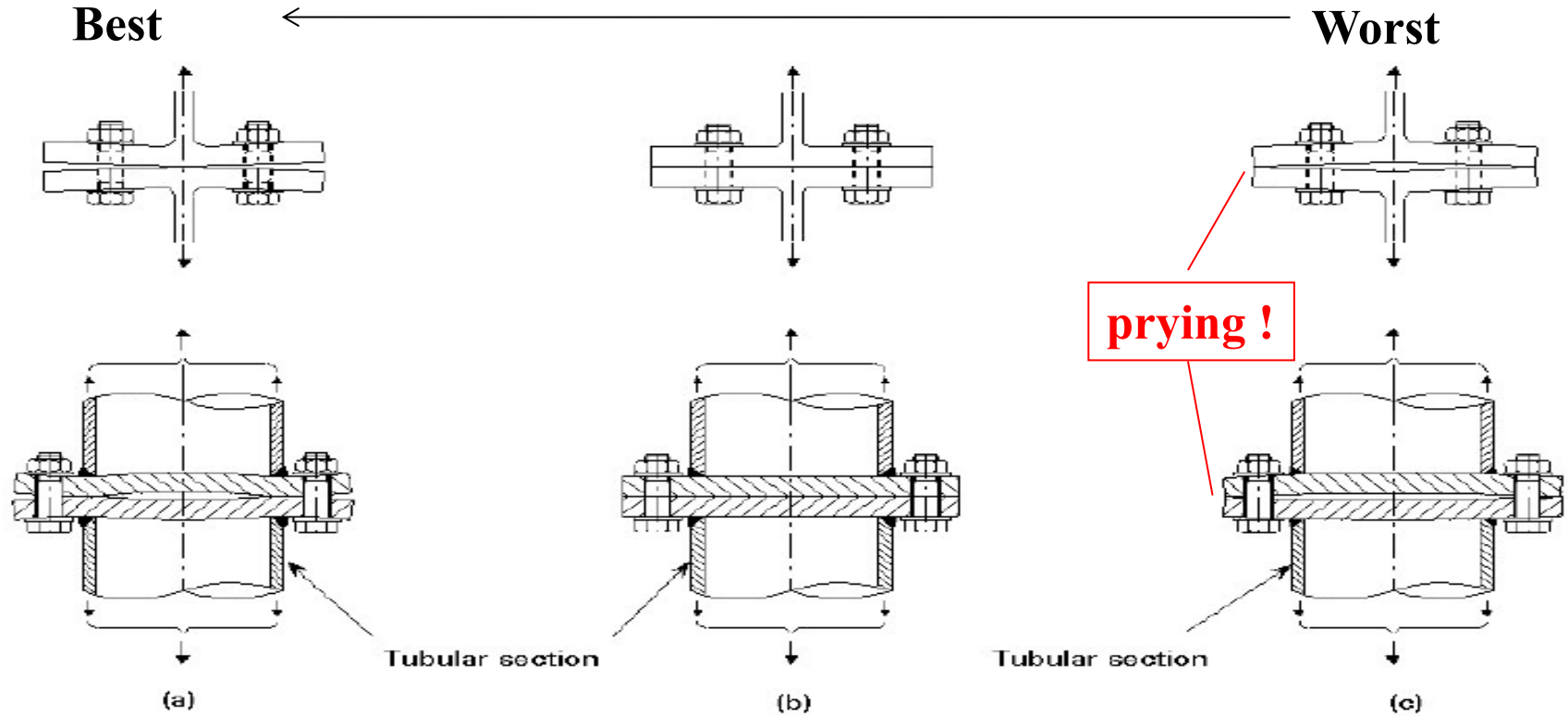


Fig. 8.28: Evolution of tension under external force

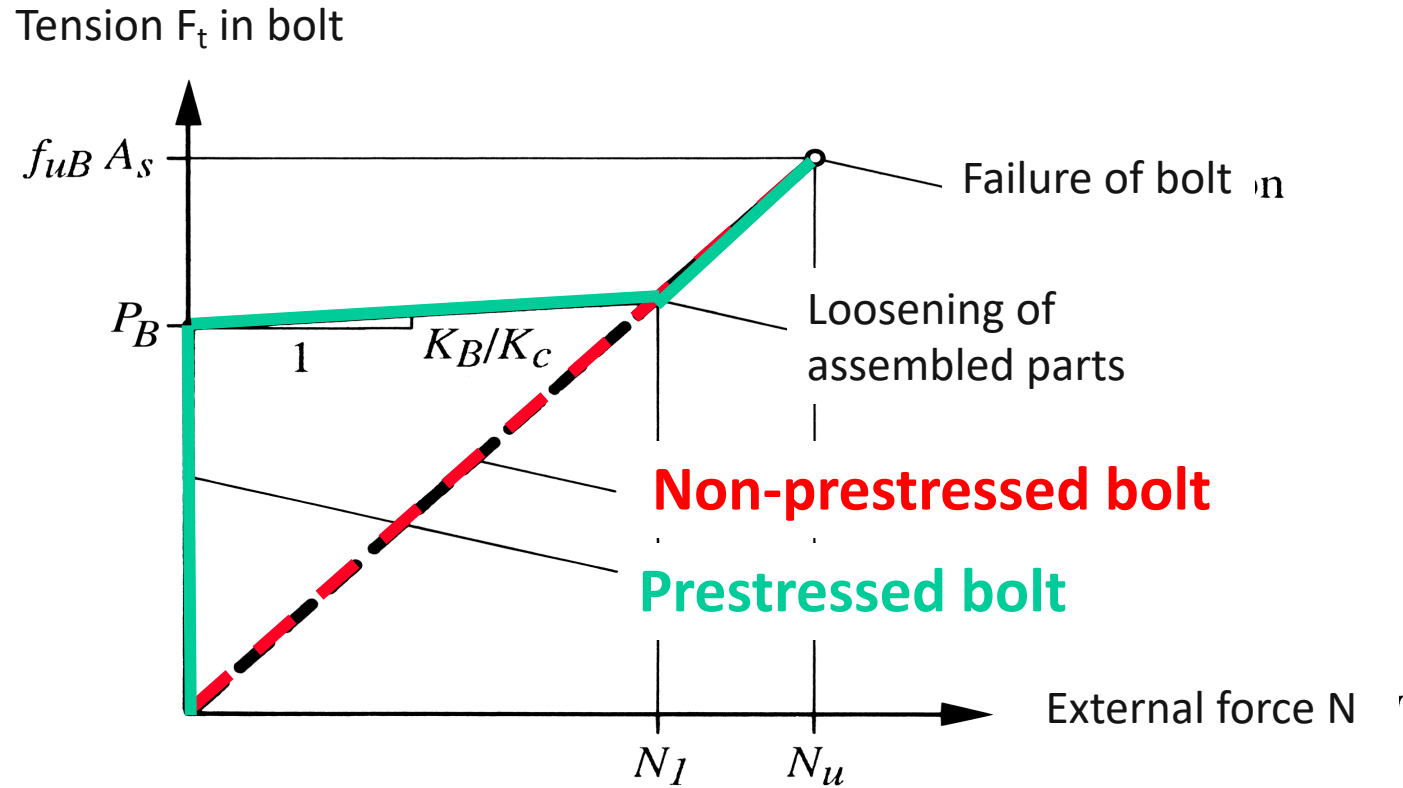
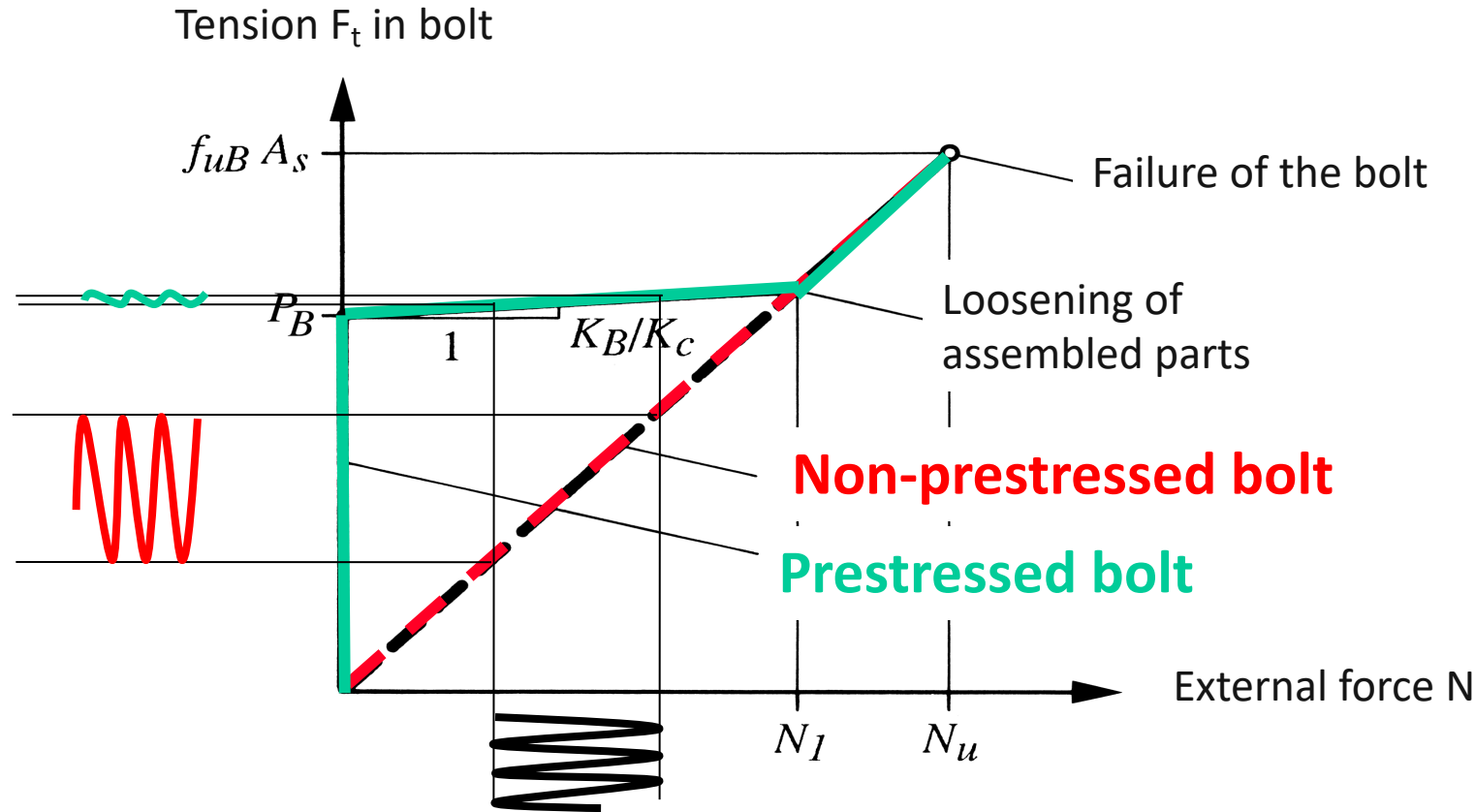
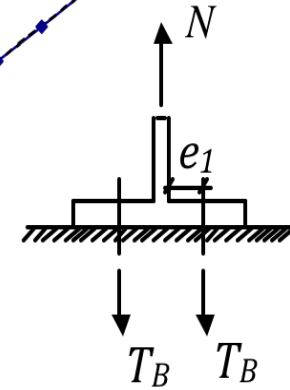
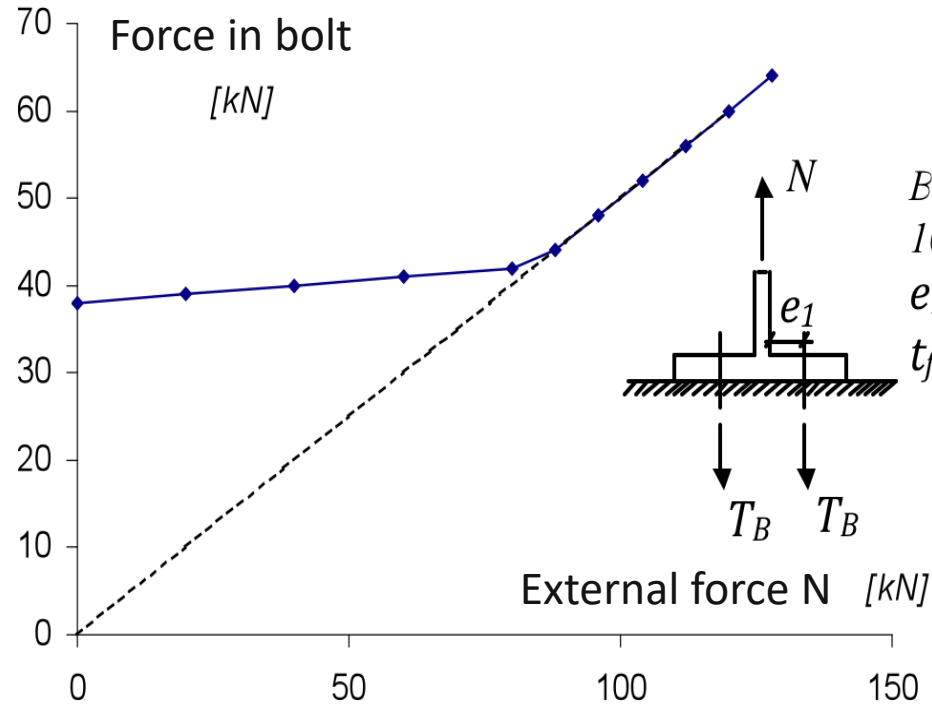
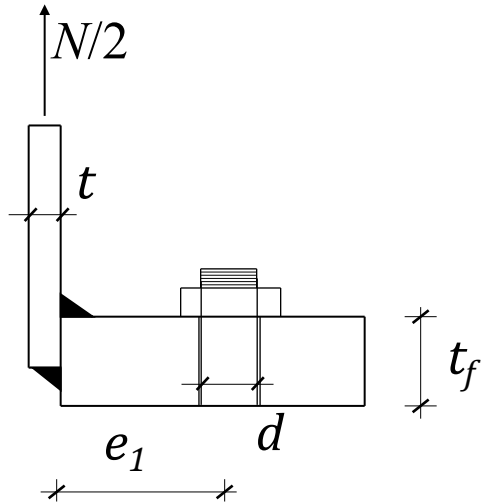


Fig. 8.28: Evolution of tension under external force

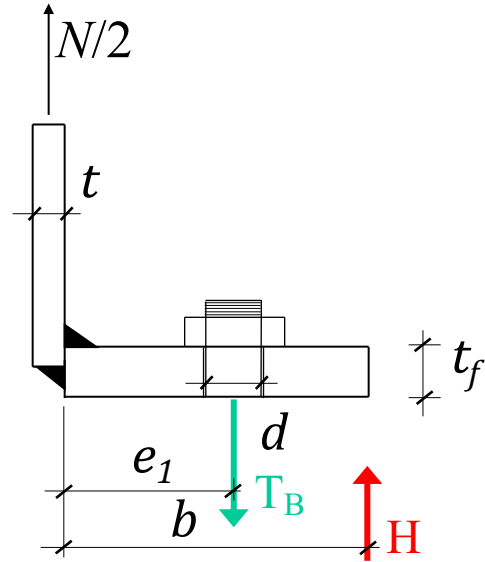


Bolted joints in tension, test with a rigid base plate



*Boulons M24 HR
10.9
 $e_1 = 45$ mm
 $t_f = 43$ mm*

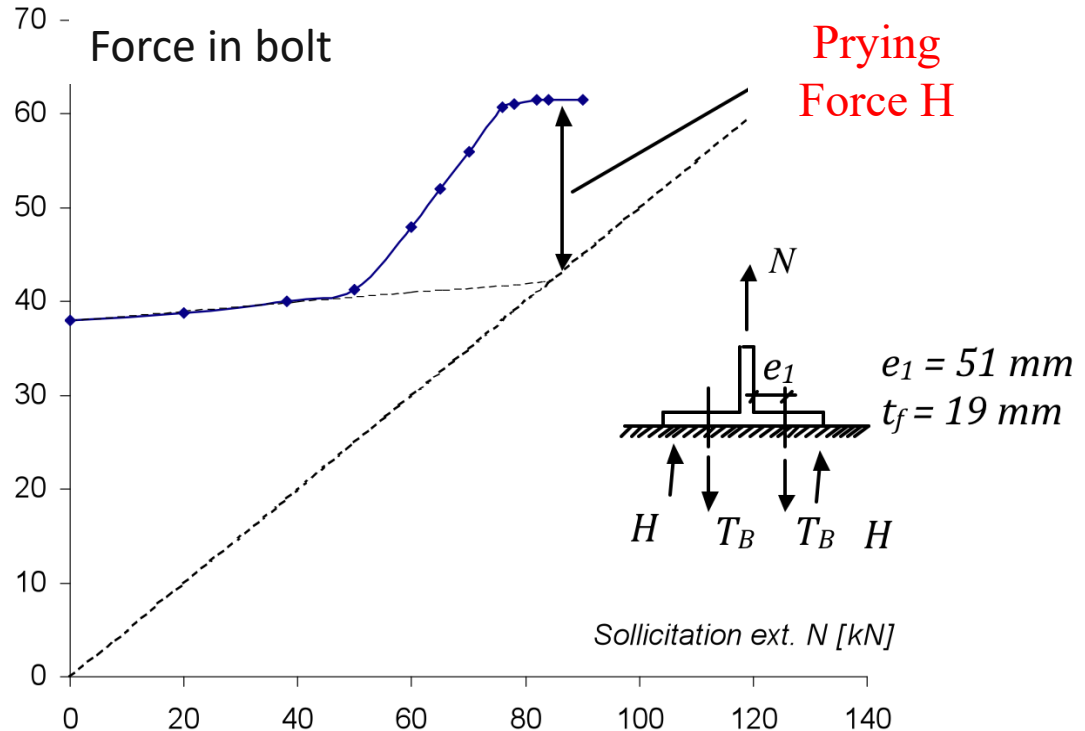
Bolted joints in tension, test with a flexible base plate



$$N/2 + H = T_B$$

$$(t/2 + e_1) \cdot N/2 = (b - e_1) \cdot H$$

$$H = \frac{\left(\frac{t}{2} + e_1\right)}{(b - e_1)} \cdot N/2$$

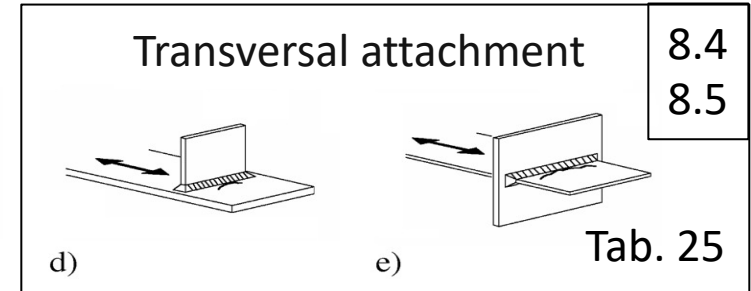
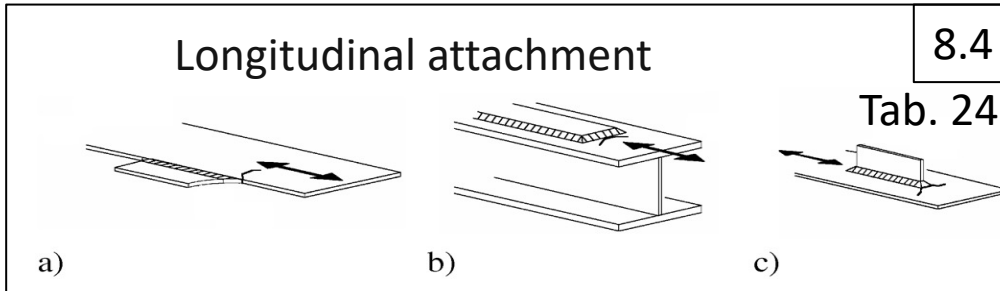
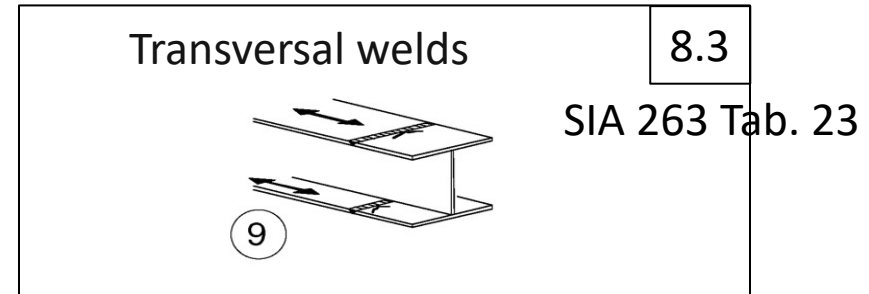
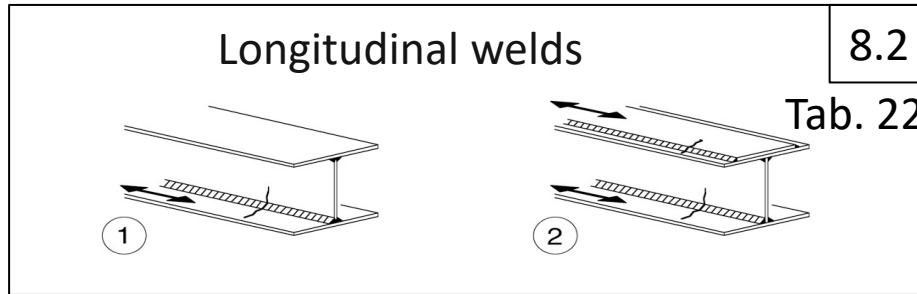


- Fatigue normalized curves
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Families of welded joints, influence of:

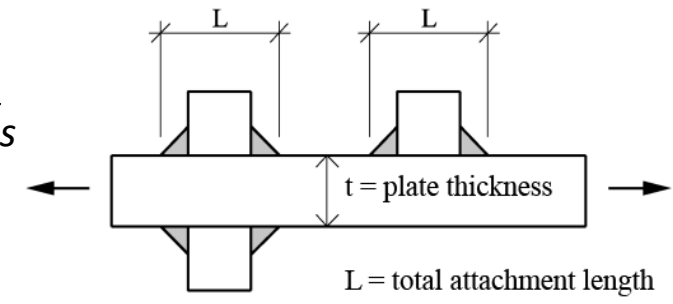
- Shape, Stress Concentration (SCF)
 - Length of attachment
 - Thicknesses of plates
 - Type of weld (fillets or full-penetration)
- } Via FAT or k_s

EN 1993-1-9

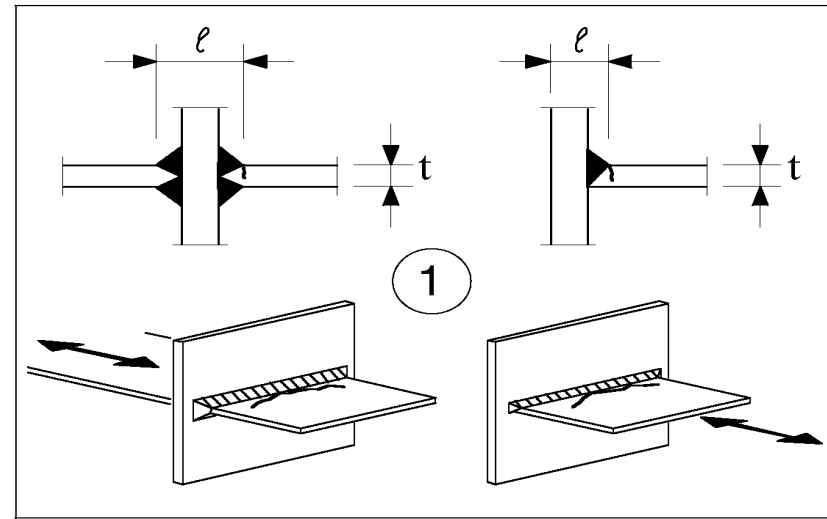


Families of welded joints, influence of:

- Shape, Stress Concentration (SCF)
 - Length of attachment
 - Thicknesses of plates
 - Type of weld (fillets or full-penetration)
- } Via FAT or k_s



Transversal attachment



FAT

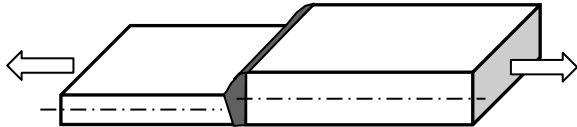
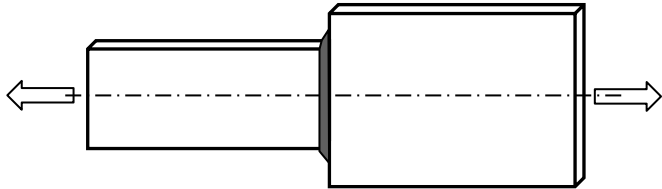
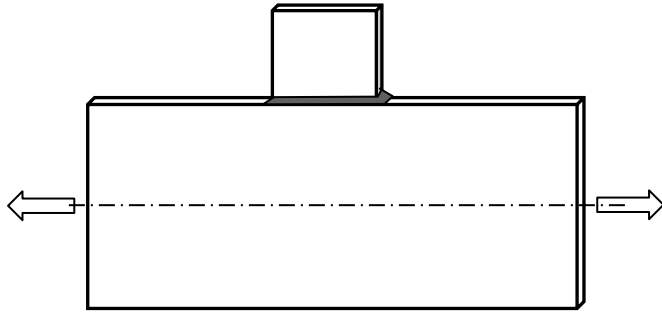
80	$l < 50 \text{ mm}$	all t [mm]
71	$50 < l \leq 80$	all t
63	$80 < l \leq 100$	all t
56	$100 < l \leq 120$	all t
56	$l > 120$	$t \leq 20$
50	$120 < l \leq 200$	$t > 20$
	$l > 200$	$20 < t \leq 30$
45	$200 < l \leq 300$	$t > 30$
	$l > 300$	$30 < t \leq 50$
40	$l > 300$	$t > 50$

$$\Delta\sigma_{C,red} = k_s \cdot \Delta\sigma_C$$

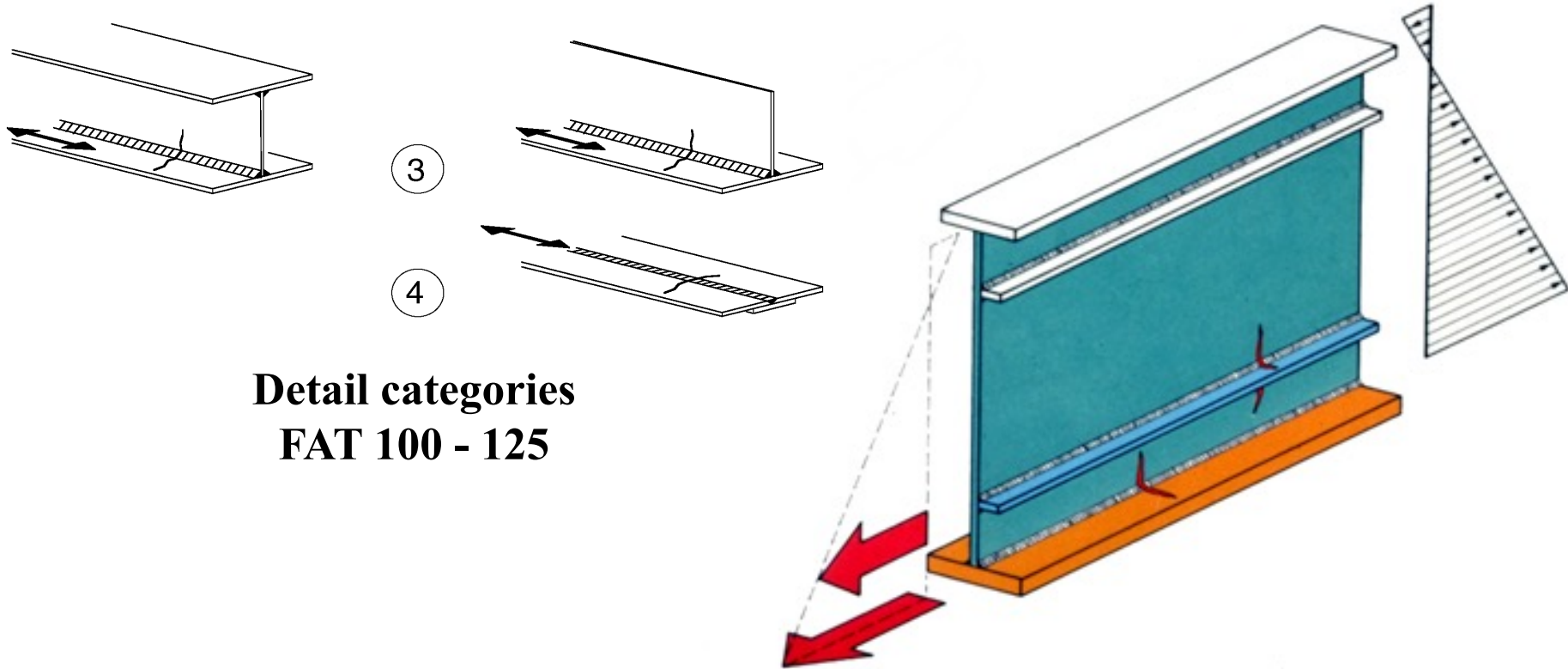
$$k_s = \left(\frac{t_{ref}}{t_{eff}} \right)^n$$

$\left\{ \begin{array}{l} L/t < 2 \text{ so } t_{eff} = t \\ \text{Otherwise} \\ t_{eff} = 0.5 \cdot L \text{ or} \\ t_{eff} = t \end{array} \right.$

Examples of geometry changes to improve FAT



Longitudinal welds, propagation from internal imperfection



**Detail categories
FAT 100 - 125**

Longitudinal welds, propagation from internal imperfection

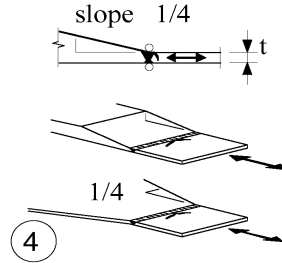
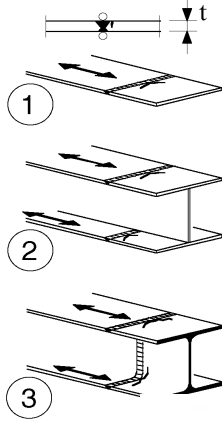


Longitudinal welds, propagation from internal imperfection

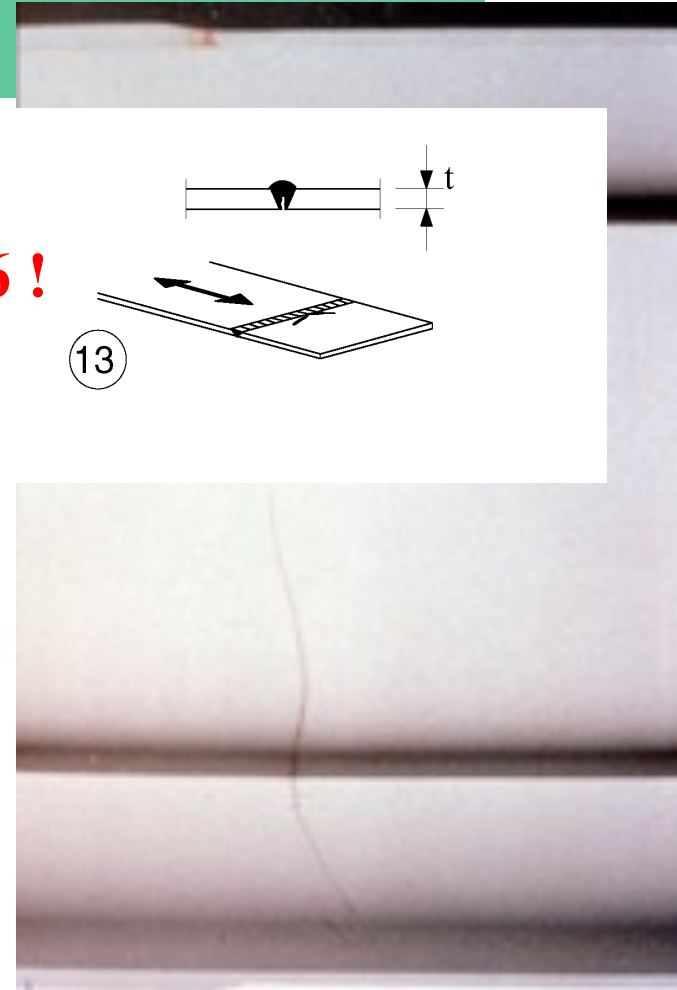
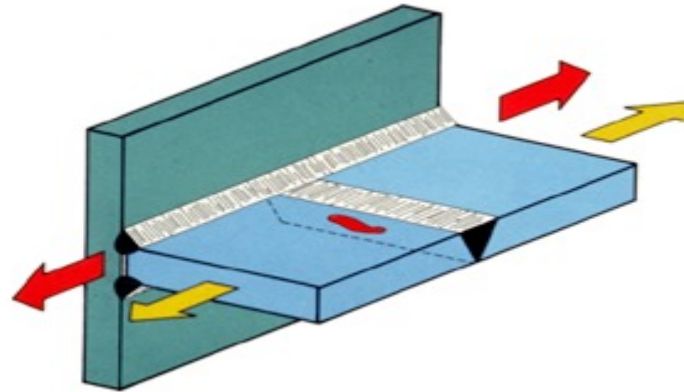
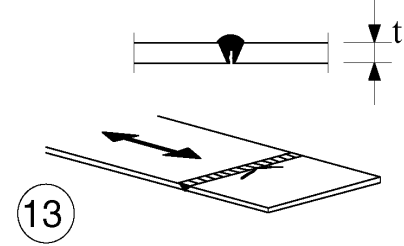


Transverse butt welds, propagation from imperfections

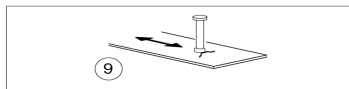
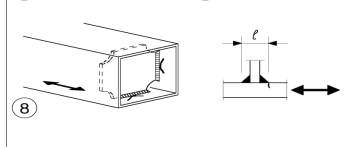
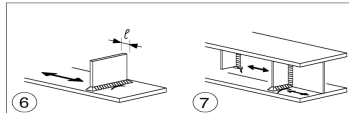
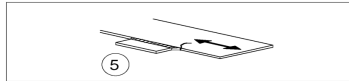
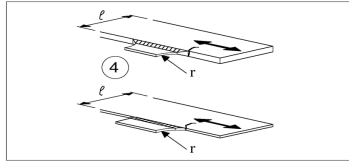
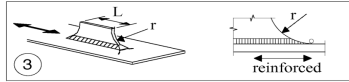
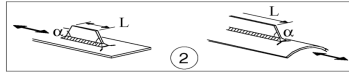
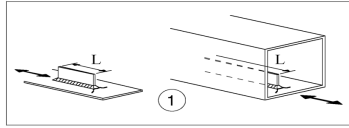
FAT 112
(meulage,
NDT checked)



FAT 36 !



Propagation from end of longitudinal attachment



FAT 56 - 80

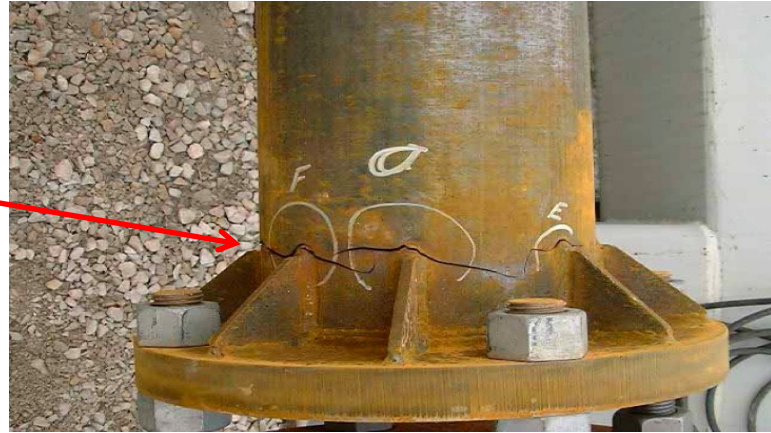
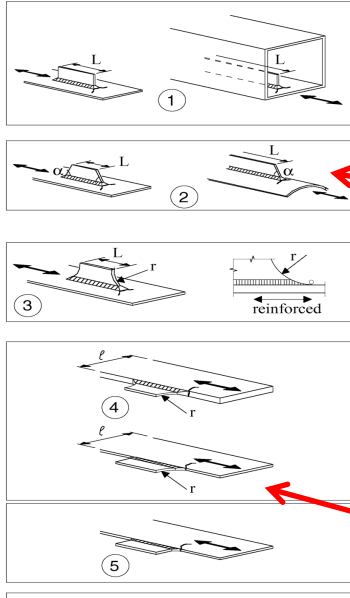
FAT 50 - 90

FAT 71 - 80



Propagation from end of longitudinal attachment

FAT 56 - 80

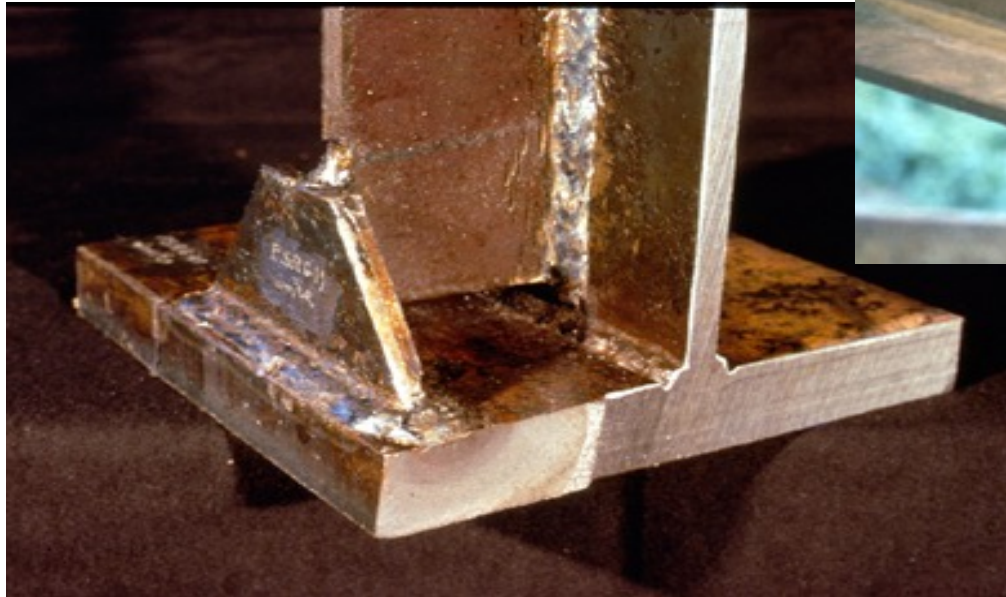


FAT 50 - 90



Propagation from end of longitudinal attachment

- Vertical stiffeners (transv. attachments) $\Leftrightarrow$ “bad detail”
- Detailing error (ca. 1970), add long. attachment on flange !



Enhanced detailing possibilities

- Bevelled end of T-stiffener



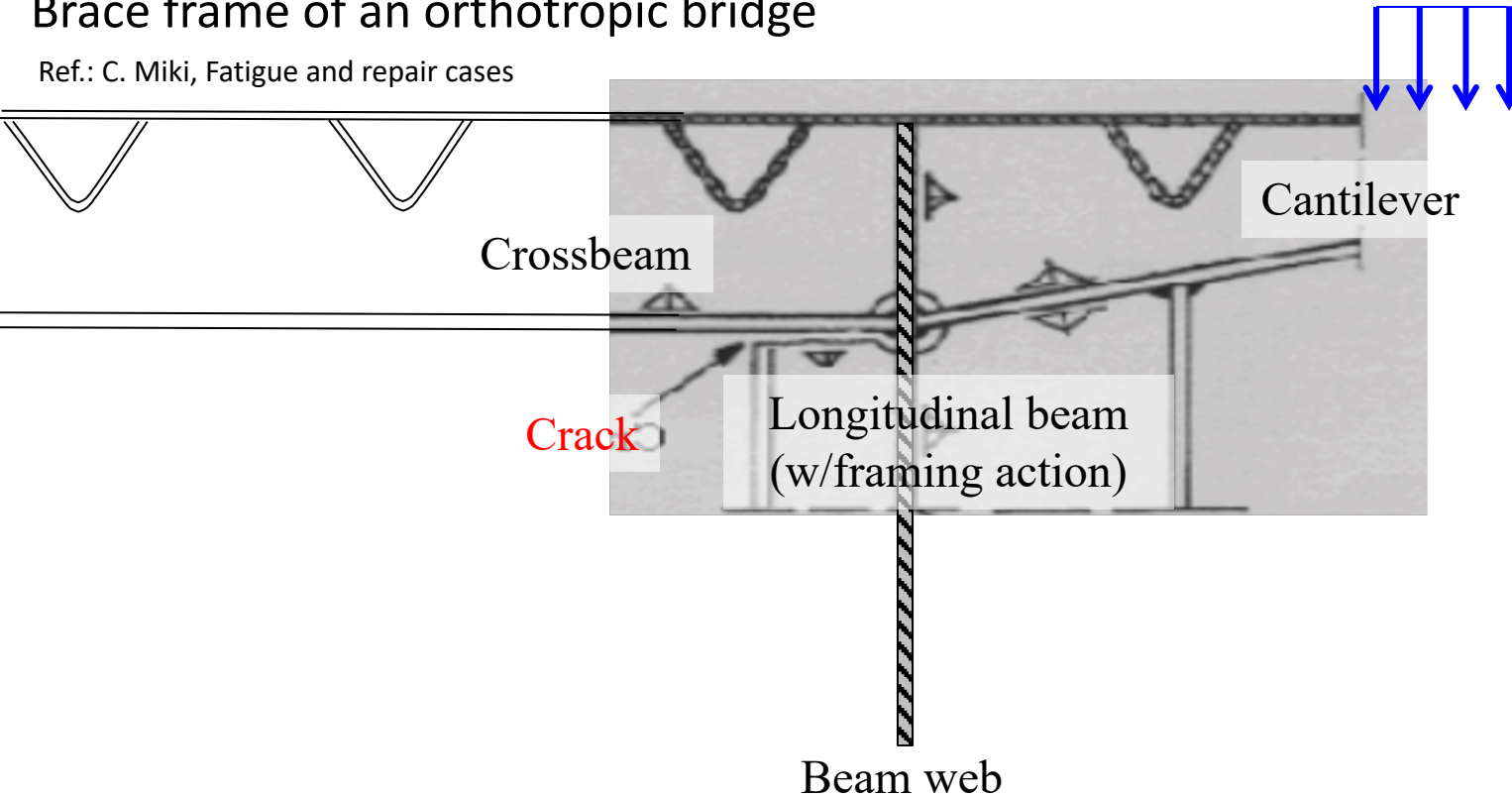
- Vertical stiffener welded to plate
- Plate mounted on base plate (without welding)



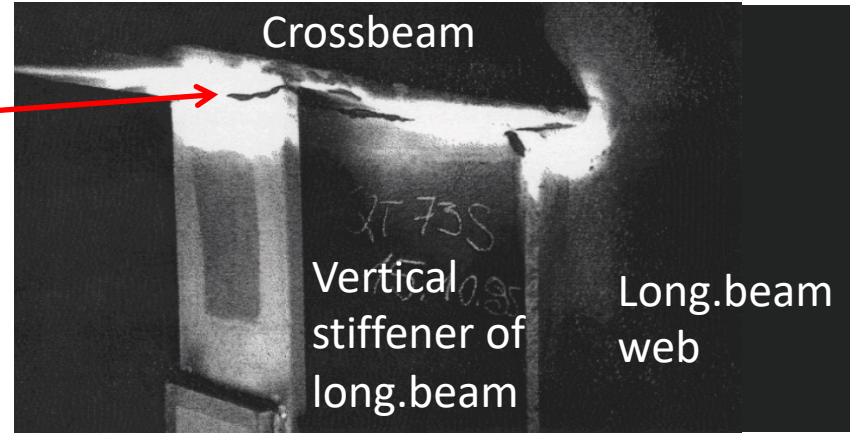
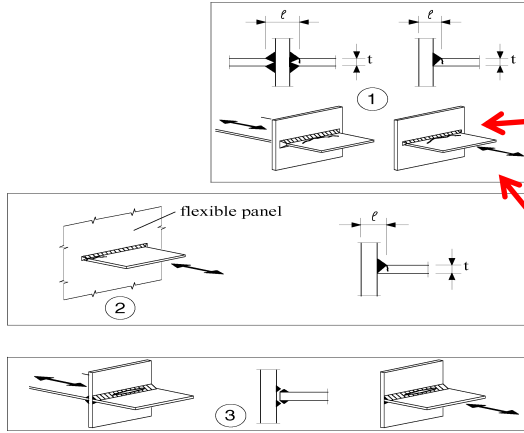
Propagation from loaded attachments

Brace frame of an orthotropic bridge

Ref.: C. Miki, Fatigue and repair cases

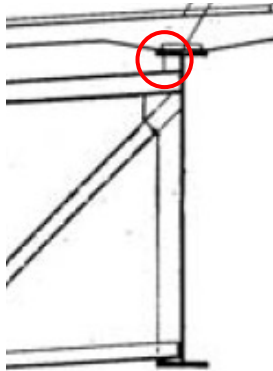


Propagation from loaded attachments



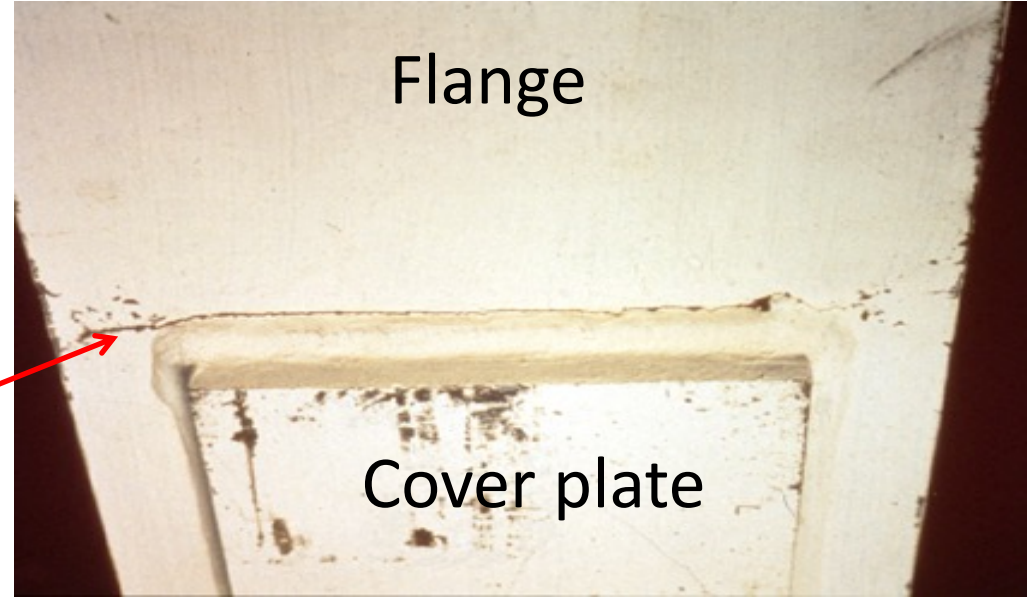
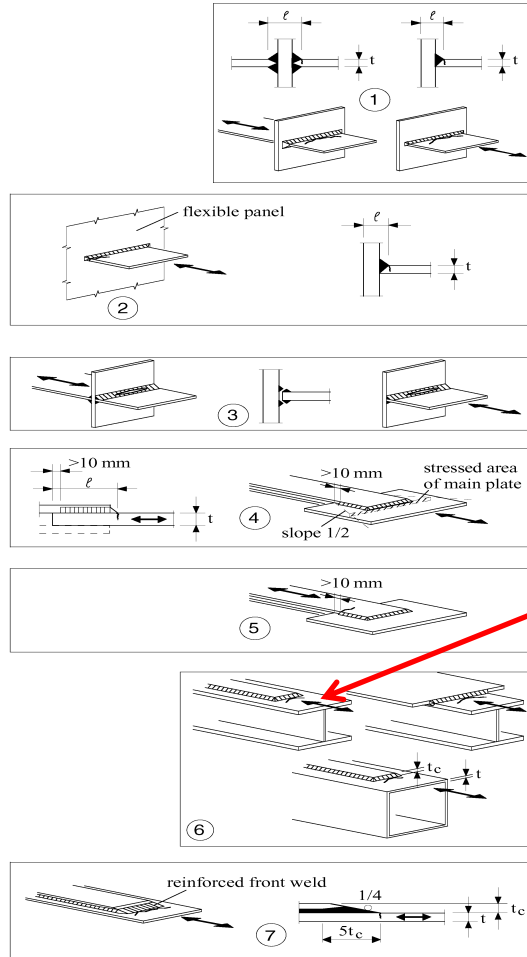
Ref.: C. Miki, Fatigue and repair cases

Motorway bridge (Austria) 2008



Source: Greiner, R., Taras, A.,
ECCS_TC6_24.2.2010, Damage cases

Propagation from loaded attachments

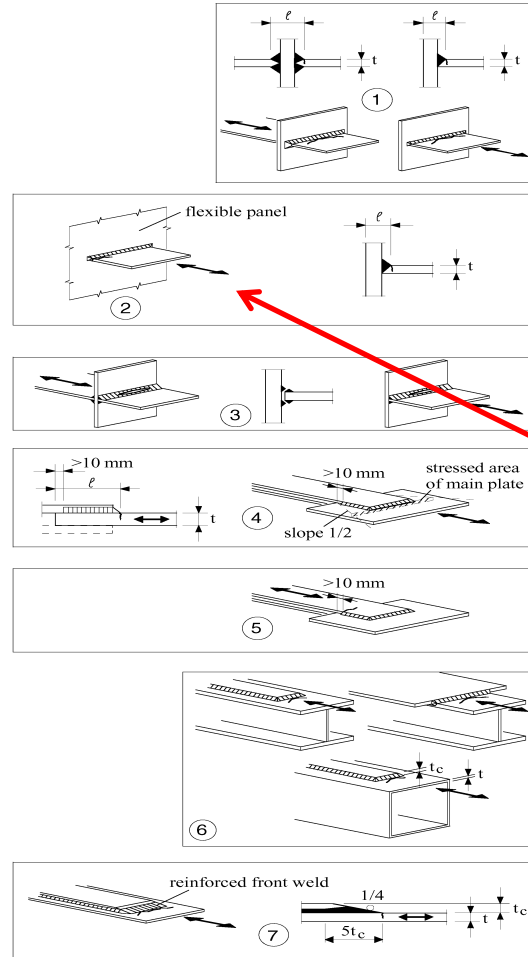


Ref.: C. Miki, Fatigue and repair cases

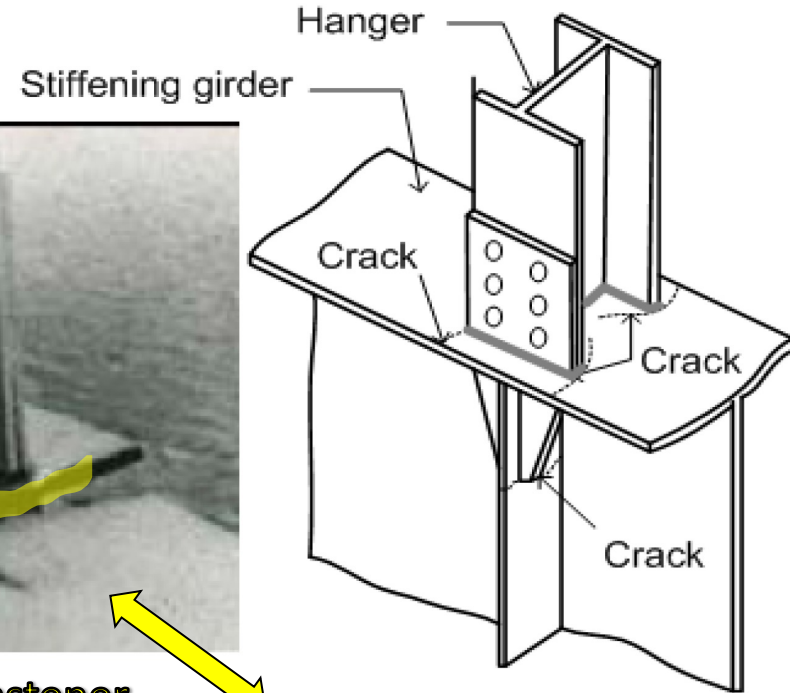
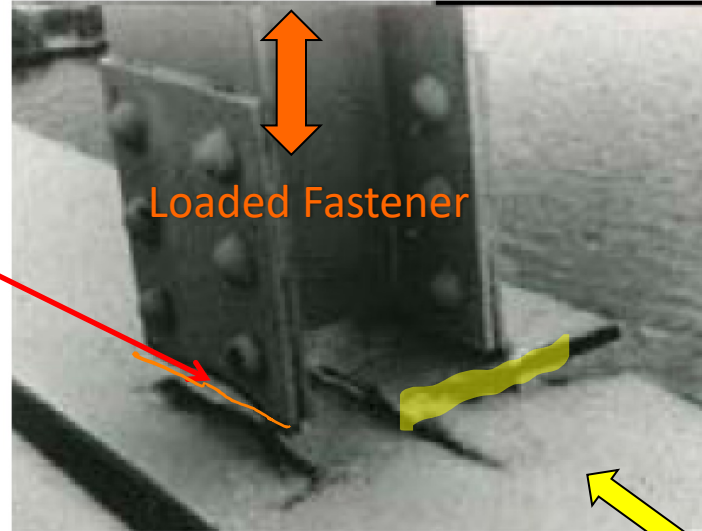
Propagation from loaded attachments



Propagation from loaded attachments



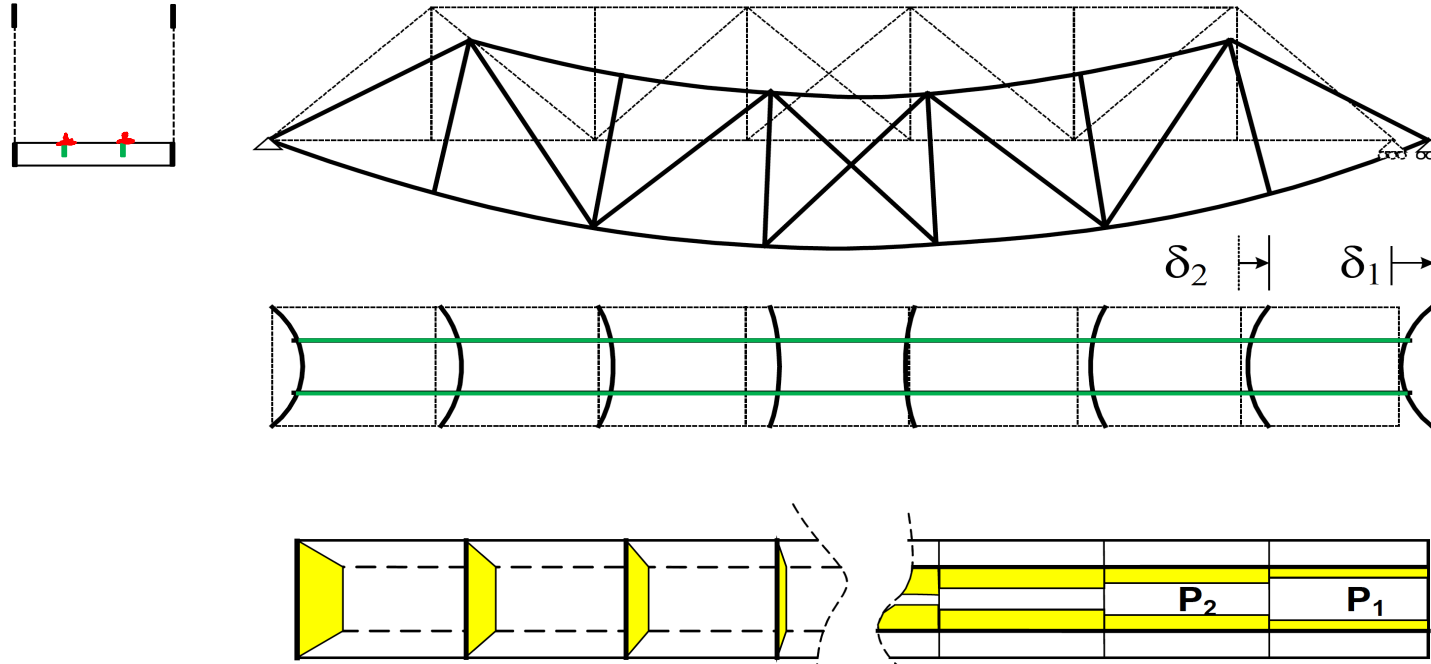
Hanger



Ref.: C. Miki, Fatigue and repair cases

3D effects and out-of-plane distortions: Responsible for many cracks !!

Example: Shear drag effect between primary and secondary truss beams



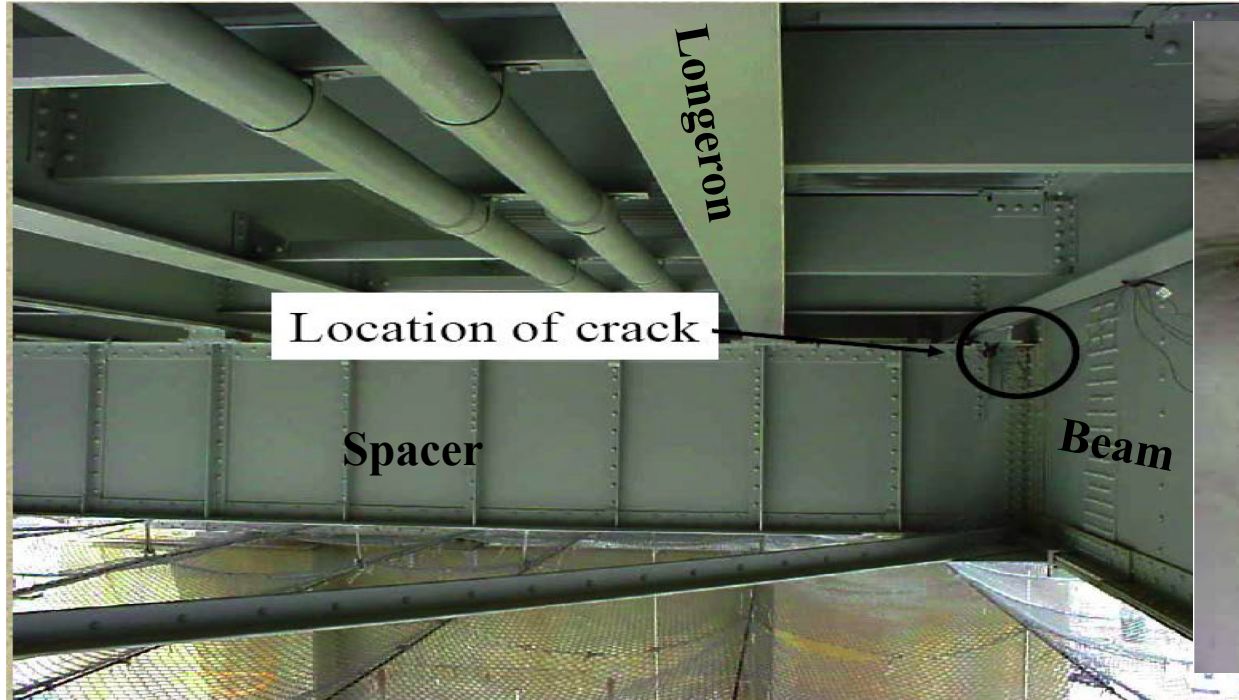
Transverse bending of the struts

Axial forces in the spars

Solution?
Understand the
fct of the
structures you
are studying

3D effects and out-of-plane distortions: Responsible for many cracks !!

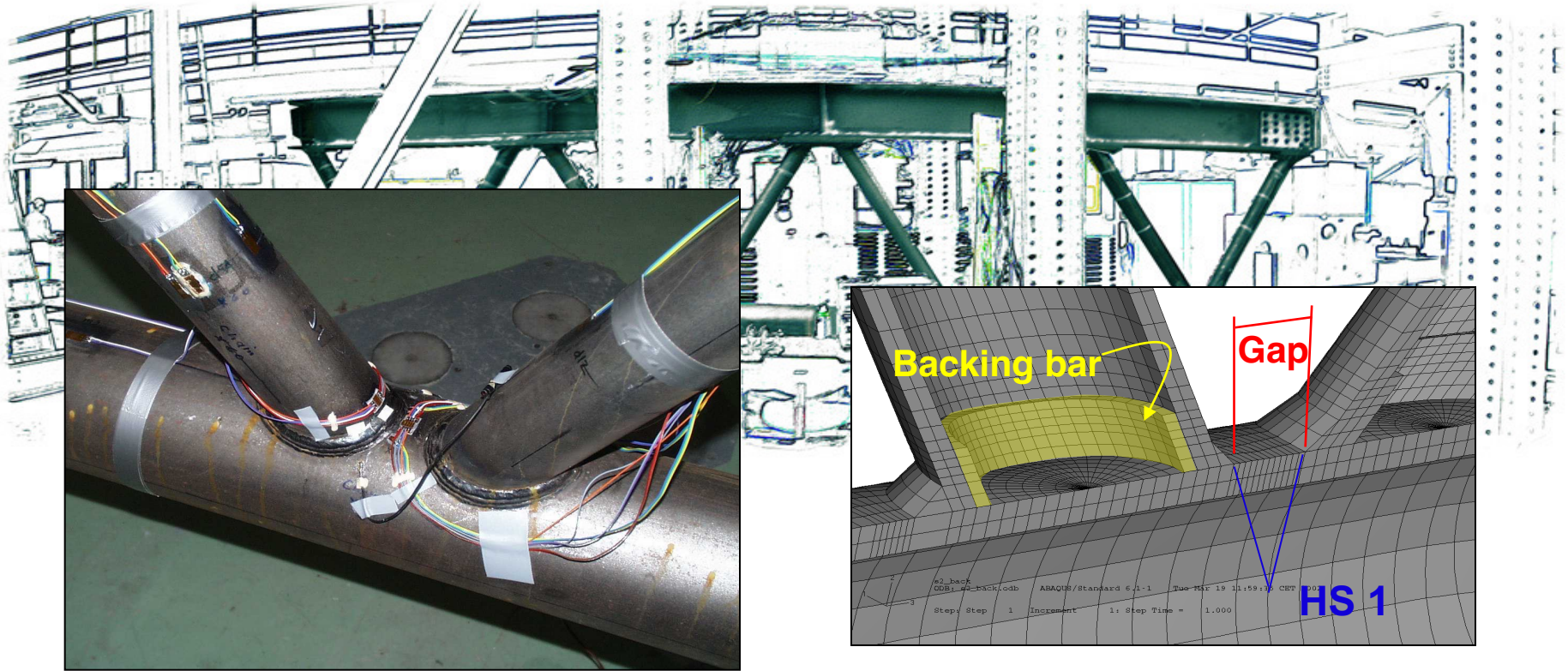
Example, Chesapeake City Bridge (arch bridge)



Ref.: Shenton III, H.W., Chajes, M.J., Finch, W.W., Ruzicidlo, M.C., Carrigan-Laning, J., Chasten, C.P. (2003).
"Field Test of a Fatigue Prone Steel Tied Arch," Proceedings of the 2003 ASCE Structures Congress.

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Fatigue of tubular structures, of tubular nodes



Fatigue of tubular structures, of tubular nodes

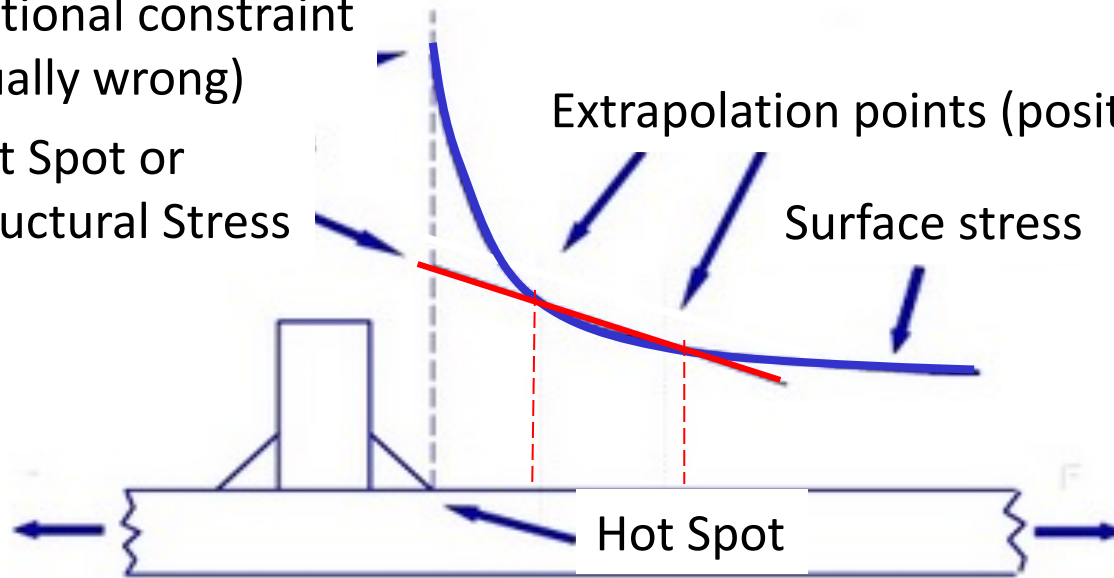
- Hot-Spot Method, from stress to hot spot, FEM calculations
- Eurocode EN 1993-1-9, Annex B
- CIDECT and IIW Guides

Computational constraint
(usually wrong)

Hot Spot or
Structural Stress

Extrapolation points (positions defined in guides)

Surface stress

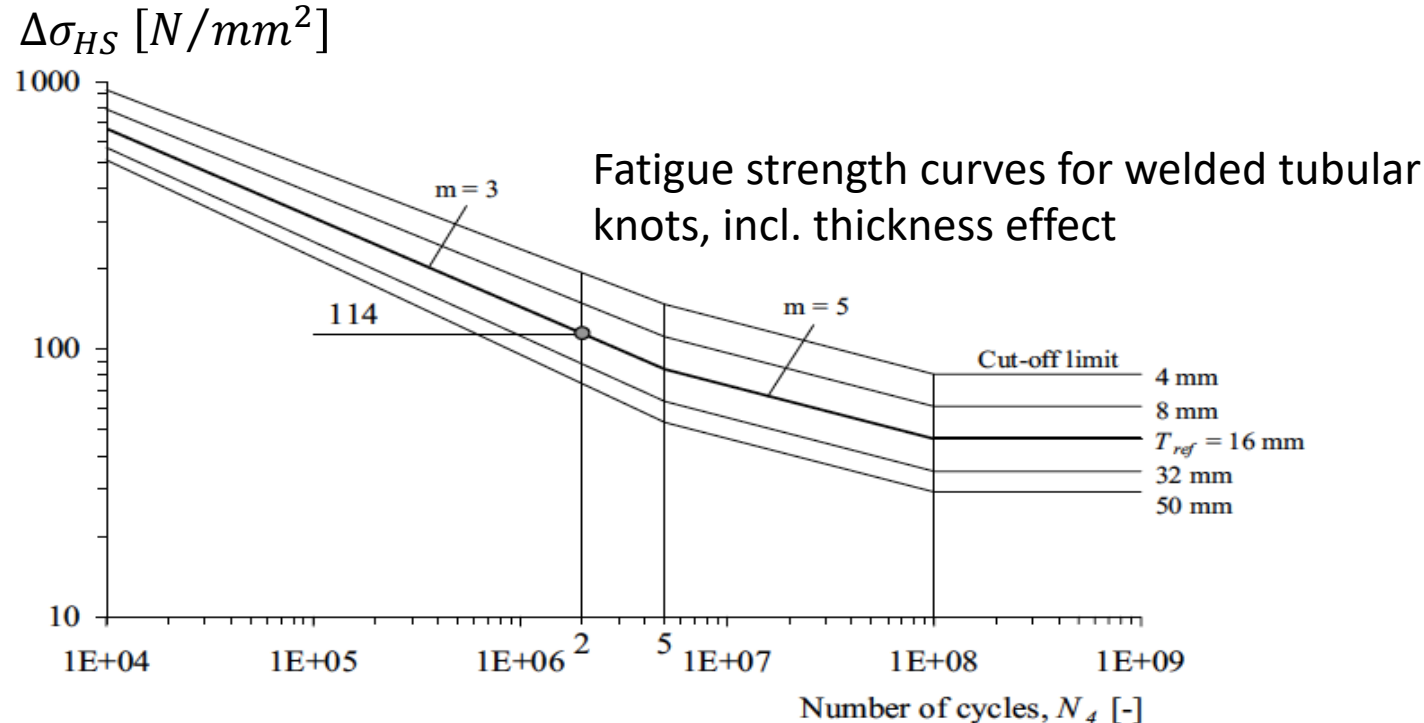


Getting started in SCF's FEM modeling:
IIW-doc. XIII-2650-16,
Round robin on local stress evaluation for fatigue by various FEM software (benchmark examples , with meshes given)

Fatigue of tubular structures, of tubular nodes

- Hot-spot method, from stress to hot spot, FEM calculations
- Eurocode EN 1993-1-9, Annex B
- CIDECT and IIW Guides

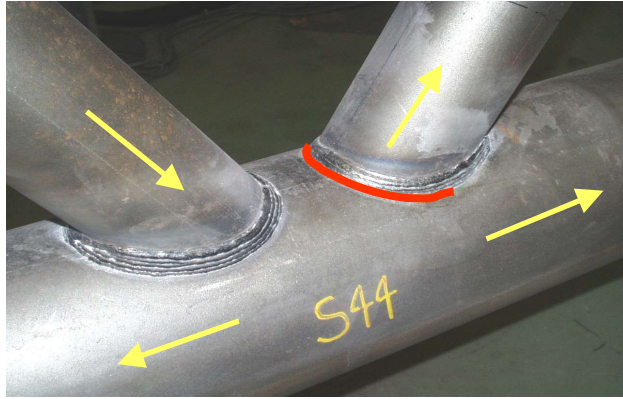
=> Determination of $\Delta\sigma_{Ed,HS}$



Tubular nodes:

Examples of design/strength improvement studies

- Fatigue always at the foot of the chord



Conventional
butt welds

- 1) Put the weld out of the stressed area



- 2) Use finishing methods to introduce residual compressive stresses



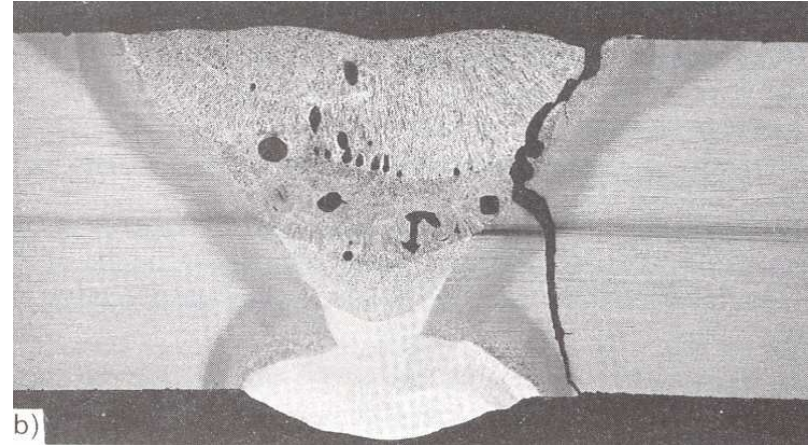
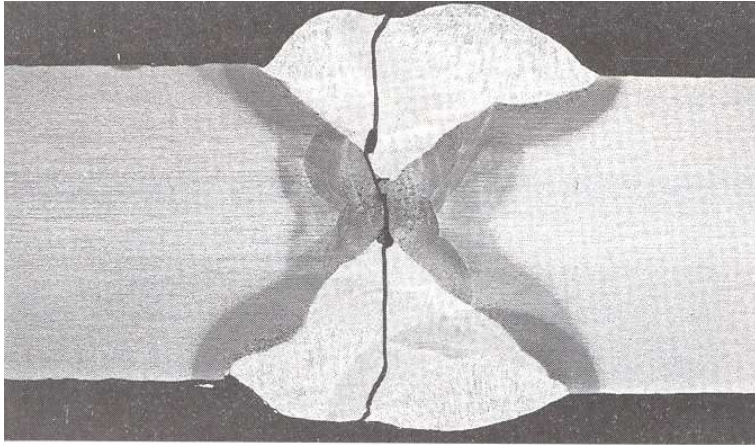
- Fatigue normalized curves
- Types of details and diff. resistance curves
- Bolted, riveted connections
- Welded Connections
- Hot-spot method
- **Execution of welds**

Execution of welds

Have a great influence on fatigue resistance:

- quality of the work
- Weld specifications (type, controls)

Example, butt welding:



Réf.: J. Maljaars, TNO

Quality control <=> guaranteed FAT classes

SIA 263

EN 1993-1-1

EN 1090-2
(Construction
métallique - acier)

7.6 Critères d'acceptation

7.6.1 Exigences de base

Les éléments soudés doivent répondre aux exigences spécifiées aux Articles 10 et 11.

Sauf spécification contraire, pour les classes d'exécution EXC1, EXC2 et EXC3, les critères d'acceptation relatifs aux défauts des soudures doivent être évalués par référence à l'EN ISO 5817 comme indiqué ci-dessous, à l'exception de « Défaut de raccordement » (505) et « Micro manque de fusion » (401) qui n'ont pas à être pris en compte. Toutes les exigences complémentaires spécifiées concernant la géométrie et le profil de la soudure doivent être prises en compte.

a) EXC1 niveau de qualité D, sauf niveau de qualité C pour « Gorge insuffisante » (5213) ;

b) EXC2 Niveau de qualité C sauf niveau de qualité D pour « Débordement » (506), « Amorçage accidentel » (601) et « Retassure ouverte de cratère » (2025) et niveau de qualité B pour « Gorge insuffisante » (5213) ;

c) EXC3 niveau de qualité B.

EN 15085-3
(Ferroviaire)

Tableau 4 — Comparaison entre catégories de contrainte, catégories de sécurité, classes de performance des soudures, niveaux de qualité par rapport aux défauts, classes de contrôle et essais

Catégorie de contrainte	Catégorie de sécurité	Classe de performance	Niveau de qualité par rapport aux défauts EN ISO 5817 ISO 15042	Classe de contrôle	Contrôles volumétriques RT ou UT	Contrôle de surface MT ou PT	Contrôle visuel VT
Élevée	Élevée	CP A	voir Tableau 5 ou Tableau 6	CT 1	100 %	100 %	100 %
Élevée	Moyenne	CP B	B	CT 2	10 %	10 %	100 %
Élevée	Faible	CP C2	C	CT 3	Non exigé	Non exigé	100 %
Moyenne	Élevée	CP B	B	CT 2	10 %	10 %	100 %
Moyenne	Moyenne	CP C2	C	CT 3	Non exigé	Non exigé	100 %
Moyenne	Faible	CP C3	C	CT 4	Non exigé	10 %	100 %
Faible	Élevée	CP C1	C	CT 2	10 %	10 %	100 %
Faible	Moyenne	CP C3	C	CT 4	Non exigé	Non exigé	100 %
Faible	Faible	CP D	D	CT 4	Non exigé	Non exigé	100 %

ISO 13480-5
(tuyauterie
métallique)

8.4 Méthodes d'essai

8.4.1 Généralités

Les méthodes de contrôle spécifiées dans les paragraphes suivants doivent être appliquées conformément à des procédures écrites et, le cas échéant, conformément à des instructions.

8.4.2 Niveau de qualité

Le niveau de qualité doit être conforme au Tableau B.4.2-1.

Tableau B.4.2-1 — Niveau de qualité selon l'EN ISO 5817:2014, en fonction des conditions de service et des méthodes de contrôle

Conditions de service	Imperfections de surface et imperfections dans la géométrie de l'assemblage		Imperfections internes
	Contrôle visuel VT	Contrôle de surface	
Niveau normal	C	B	C
Fatigue	B	B	C
Fusage	B	B	B

ISO 13445-5
(Récipient sou pression)

6.6.3.2 Niveau de qualité

Le niveau de qualité doit être le niveau C conformément à l'EN ISO 5817:2014 avec les prescriptions complémentaires suivantes pour certaines imperfections :

- coup d'arc (601) : enlèvement plus 100 % MT ou PT afin d'assurer qu'il n'y a pas d'imperfection ;
- projection (602) : la projection de soudure doit être retirée de toutes les parties sous pression et des soudures d'attache soumises à des charges ; une projection non systématique isolée est permise sur des composants faits de matériaux du groupe 1 ;
- amarrage local (603), coup de meule (604), coup de burin (605), ils doivent être arasés pour donner une transition progressive ;
- meulage excessif (606), il ne doit pas être autorisé. Aucun meulage excessif local ne doit affecter les caractéristiques de conception (épaisseur calculée + surpasseur de corrosion).

Pour les récipients avec chargement cyclique, voir Annexe G ; pour les récipients ou parties soumis au fluage, voir Annexe F.

N° de réf. ISO 5817	N° de réf. ISO 4520-1	Dénomination	Niveau 1	Niveau 2 (niveau de qualité selon l'ISO 5817)
1.1	100	Fissure	Non autorisé	B (non autorisé)
1.5	401	Manque de fusion (fusion incomplète)	Non autorisé	B (non autorisé)
1.6	4021	Manque de pénétration à la racine	Non autorisé	B (non autorisé)
1.7	5011	Craquelure superficielle	Pas d'évaluation spécifique	C
1.8	5012	Manœuvre cannelure déformante	Pas d'évaluation spécifique	C
1.9	502	Surpasseur excessif (soudure bond à bond)	Pas d'évaluation spécifique	C
1.10	503	Concavité excessive (soudure d'angle)	Pas d'évaluation spécifique	C
1.11	504	Exfoliation de pénétration	Pas d'évaluation spécifique	C
1.12	505	Défaut de raccordement	Pas d'évaluation spécifique	C
1.16	512	Défaut de symétrie excessif de soudure d'angle	à 3 mm	B
1.21	5214	Gorge excessive	Pas d'évaluation spécifique	B
...	...	Autres défauts	Pas d'évaluation spécifique	B

... La valeur par la norme d'application ou supérieure, les autres valeurs sont des valeurs maximales pour les défauts.

ISO 15614-1

7 Exigences d'acceptation des assemblages de qualification

Les assemblages de qualification doivent être évalués selon les exigences d'acceptation spécifiées pour les types de défaut considérés.

Avant tout essai, les points suivants doivent être vérifiés :

- élimination de tout le laitier et de toutes les projections ;
- absence de meulage sur les faces envers et endroit de la soudure (selon 6.3) ;
- identification des arrêts et reprises dans la passe de fond et la passe terminale (selon 6.3) ;
- profil et dimensions.

Les exigences d'acceptation des défauts découlent des contrôles et essais prévus par la présente partie de l'ISO 9606 doivent être, sauf spécification contraire, évaluées conformément à l'ISO 5817. Un soudeur est qualifié si les défauts découlent sont dans les limites admises par le niveau de qualité B de l'ISO 5817, sauf pour les types de défauts suivants : les surpasseurs excessifs (502), les concavités excessives (503), les gorges excessives (5214), les excès de pénétration (504) et les cannelures (501) pour lesquels le niveau C doit s'appliquer.

ISO 9606-1

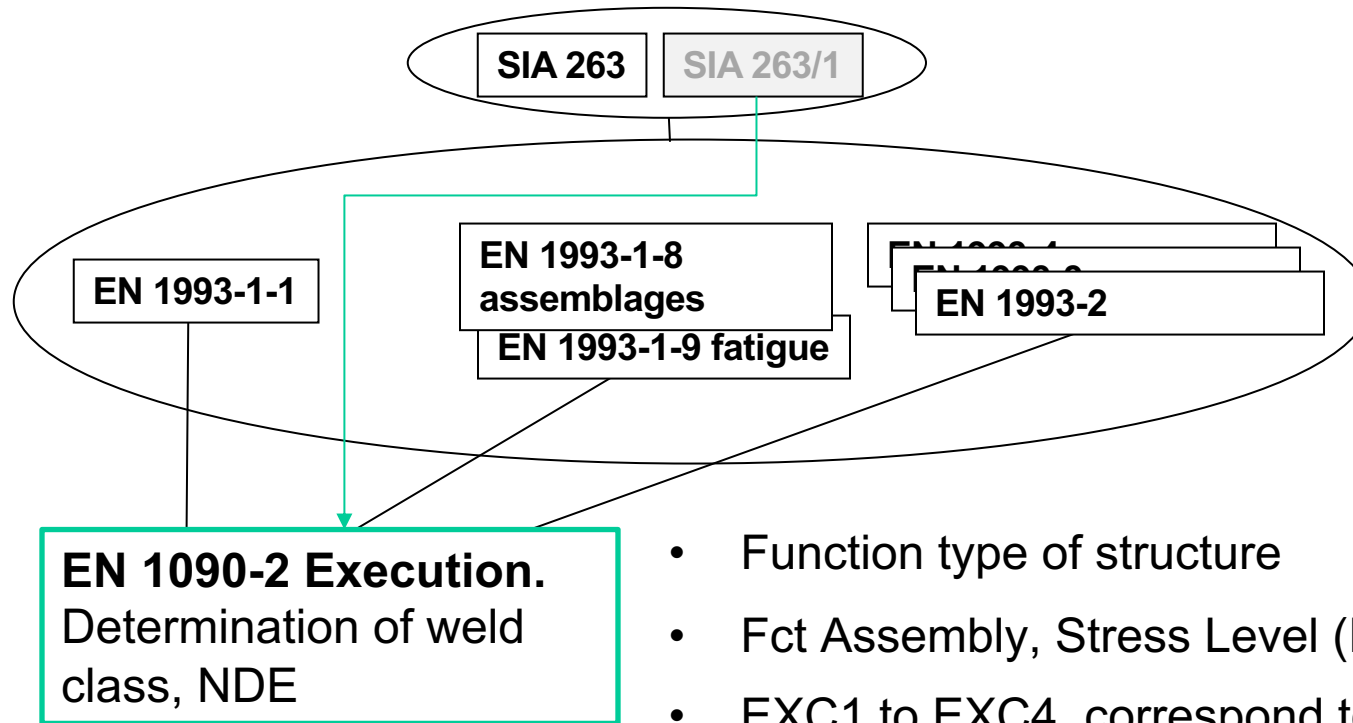
EN ISO 5817

ISO 17635
(critères pour CND)

Contrôle non destructif (CND)



Quality control $\Leftrightarrow$ guaranteed FAT classes



- Function type of structure
- Fct Assembly, Stress Level (FAT)
- EXC1 to EXC4, correspond to classes B, C, D + levels of imperfection control, etc.
- **In fatigue, by default require B (EXC 3)**

END
of part 2

Appendices of Part 2

EN 1994-1-1: When is fatigue verification required ?

- Given in § 8.1
- Shall be verified where the structures are subjected to repeated fluctuations of stresses
- In bridges, in crane runways, masts, always required
- In buildings : only required where
 - Structural steel, shear connection, EN 1993-1-1 § 4(4) applies
 - Concrete, reinforcement, EN 1992-1-1 § 6.8.1 does not apply
- In other types of structures, silos, piling, ... see relevant code parts

EN 1994-1-1: When is fatigue verification required ?

EN 1993-1-1 § 4(4):

For building structures no fatigue assessment is normally required except as follows:

- a) Members supporting lifting appliances or rolling loads
- b) Members subject to repeated stress cycles from vibrating machinery
- c) Members subject to wind-induced vibrations
- d) Members subject to crowd-induced oscillations.

EN 1992-1-1 § 6.8.1:

Verification conditions

- The resistance of structures to fatigue shall be verified in special cases. This verification shall be performed separately for concrete and steel
- A fatigue verification should be carried out for structures and structural components which are subjected to regular load cycles (e.g. crane-rails, bridges exposed to high traffic loads).

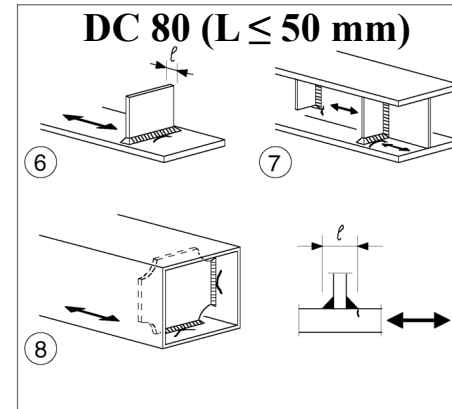
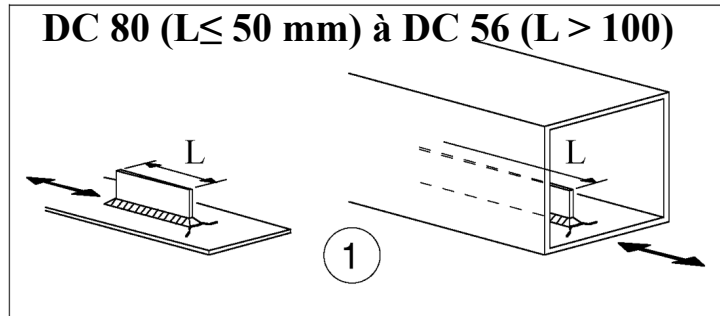
Annex: Implementation, quality control

- According to EN 1090-2 since 2014 (replaces SIA 263/1)
- For welding in particular:
 - Requirements according to class of execution:
 - EXC1: EN ISO 3834-4 «Basic Quality Requirements »
 - EXC2: EN ISO 3834-3 «Normal Quality Requirements »
 - EXC3 et EXC4: EN ISO 3834-2 «Comprehensive Quality Requirements »
 - Acceptance criteria, reference to ISO 5817:2014. EXC4 must meet, at a minimum, the EXC3 requirements. Additional requirements to be specified (on a case-by-case basis)
 - Static loads, EXC2 $\Leftrightarrow$ EN 1993-1-8
 - Fatigue loads as a function of detail category (DC) $\Leftrightarrow$ EN1993-1-9
 - Note: Corner cords can only satisfy EXC2



Fatigue requirements

- The Specification shall specify the relevant acceptance criteria in relation to the DCs for the location of the welded assembly
- EXC2, EXC3 and EXC4, in addition to the criteria specified under soll. (EN ISO 5817):
 - DC not exceeding 63: quality level C63
 - DC greater than 63 and not exceeding 90: quality level B90
 - DC greater than 90 and not exceeding 125: quality level B125
- Must meet performance requirements in Tables EN1993-1-9, EN1993-2



Weld controls and basic tests

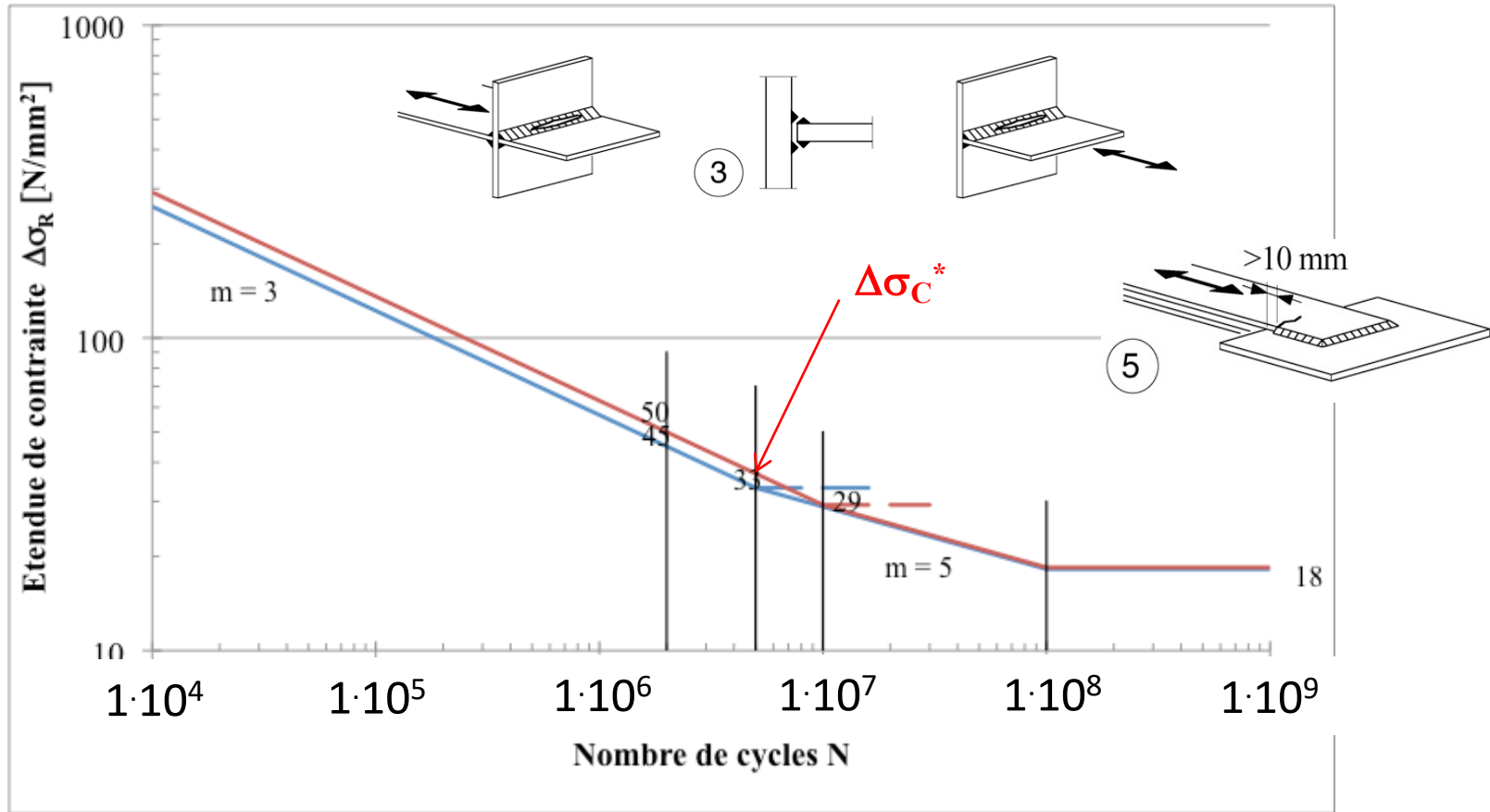
- EXC1, EXC2 and EXC3, scope of testing according to EN1090-2, Table 24
- EXC4, range of additional controls to be specified for each identified weld
- Testing and testing: basic or project-specific



EN1090-2, Table 24: Scope of Type Controls

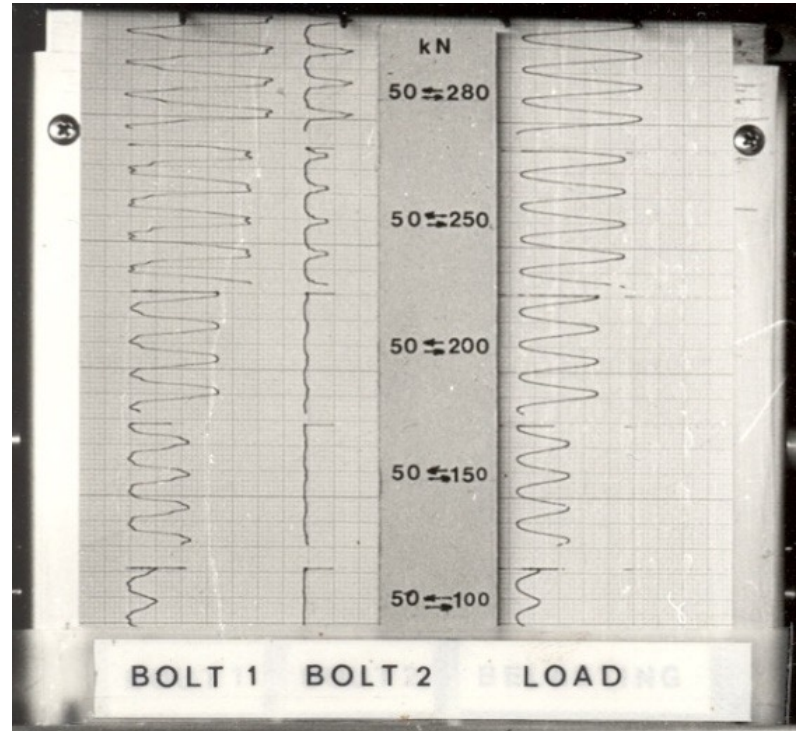
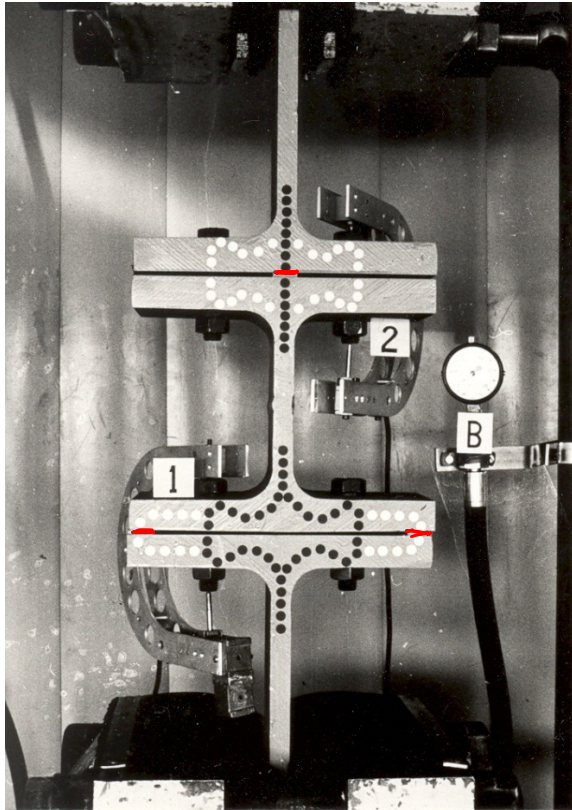
Type de soudure	Soudures d'atelier et de chantier		
	EXC1	EXC2	EXC3 ^a
Soudures transversales à pleine pénétration et soudures à pénétration partielle dans les assemblages en bout :	0 % ^b	10 %	20 %
Soudures transversales à pleine pénétration et soudures à pénétration partielle : — dans les assemblages en croix — dans les assemblages en T	0 % ^b 0 %	10 % 5 %	20 % 10 %
Soudures d'angle transversales ^c : avec $a > 12 \text{ mm}$ ou $t > 30 \text{ mm}$ avec $a \leq 12 \text{ mm}$ et $t \leq 30 \text{ mm}$	0 % 0 %	5 % 0 %	10 % 5 %
Soudures longitudinales à pleine pénétration entre l'âme et la semelle supérieure des poutres de ponts roulants	0 %	10 %	20 %
Autres soudures longitudinales ^d , soudures de raidisseurs et soudures spécifiées comme étant en compression dans le cahier des charges d'exécution	0 %	0 %	5 %
^a Pour la classe EXC4, l'étendue des contrôles en pourcentage doit être au moins celui donné pour la classe EXC3. ^b 10 % pour de telles soudures exécutées en acier $\geq S420$. ^c Les termes a et t se rapportent respectivement à l'épaisseur de gorge et à l'épaisseur du matériau le plus épais devant être assemblé. ^d Les soudures longitudinales sont celles réalisées parallèlement à l'axe de l'élément. Toutes les autres sont considérées comme des soudures transversales.			

Annex: other curves, details classified as DsC*

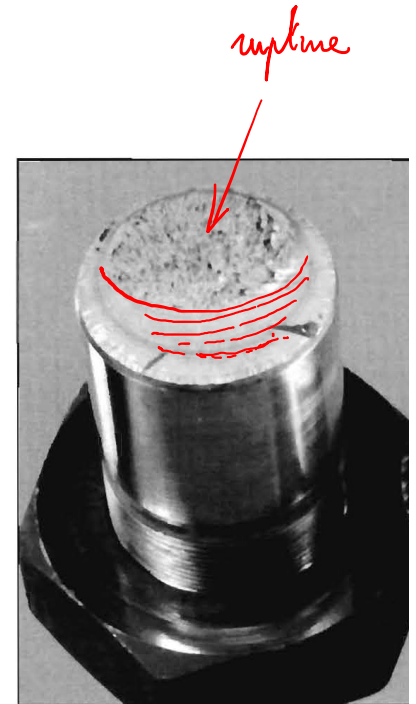


Bolted connections.

Relationship e.g. tensile force - external force



Réf.: J. Maljaars, TNO



Réf.: Caterpillar,
analyzing fractures part1

Platines: best solution for bolted assembly?



Supports de structures panneaux de signalisation

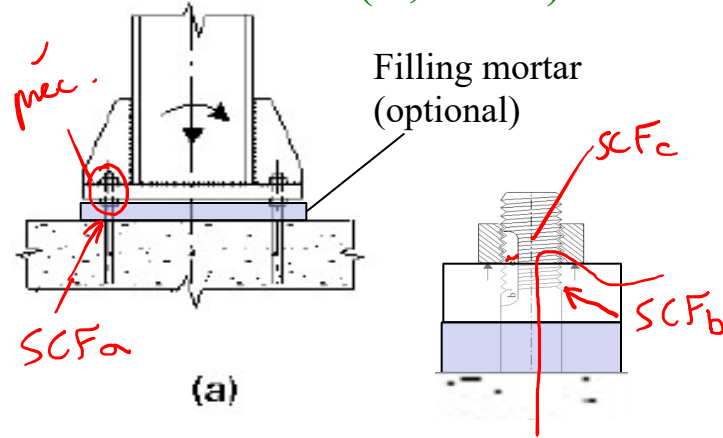


Platines: Best Solution for Bolted Assembly ?

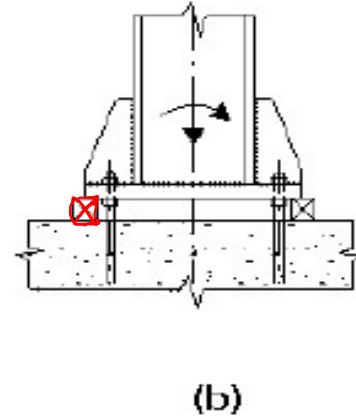


On the platform, Bern station

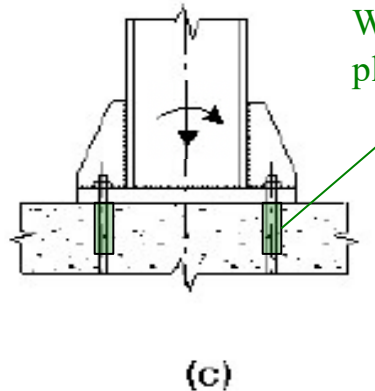
Recommended (N,M low)



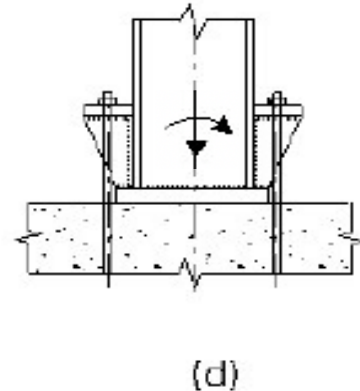
Not recommended



To be avoided Recommended:
With enlarged holes in
plate and plast. sleeves.



Recommended



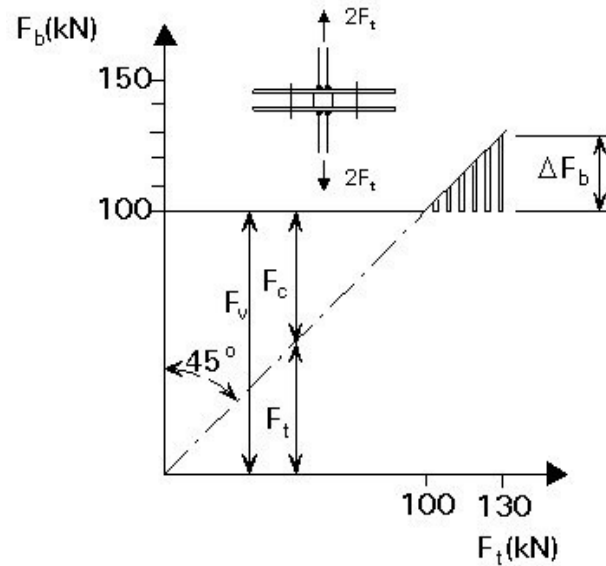
Riveted connections, FAT 71 (not in SIA 263 or Eurocode 3)

- In SIA 269/3 (existing structures)

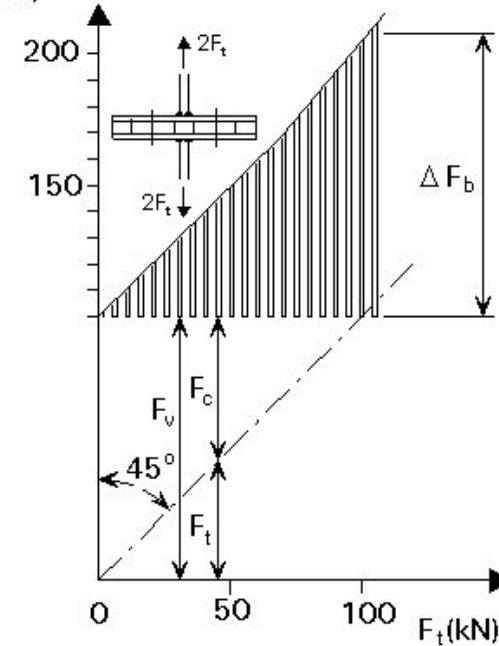


Alternative Explanation Tensile Cycle in Bolts

- Prestressed
- Depending on contact position $F_b(\text{kN})$



(a) Contact force in centre

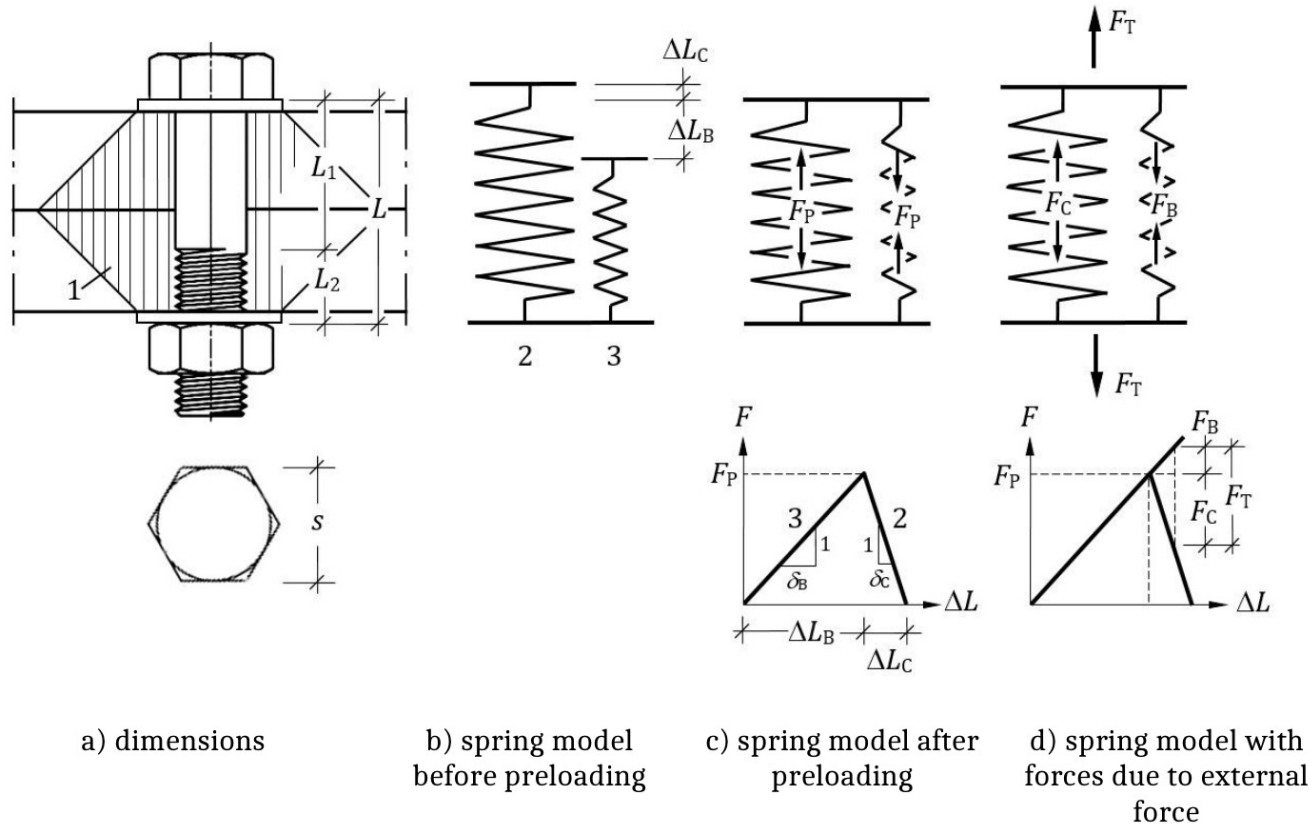


(b) Contact forces located at flange edges.

Réf.: cours Esdep

Prestressed bolted connections, computation of force range

- EN 1993-1-9 : draft 2022. Annex D



Additional tensile force F_B on bolt, reduction compressive force F_C

$$F_B = \frac{\delta_c}{\delta_b + \delta_c} F_T$$

$$F_C = \frac{\delta_b}{\delta_b + \delta_c} F_T$$

Flexibility of bolt δ_b and of clamped components δ_c

$$\delta_b = \frac{L_1}{E (1,1 A_s)} + \frac{L_2}{E A}$$

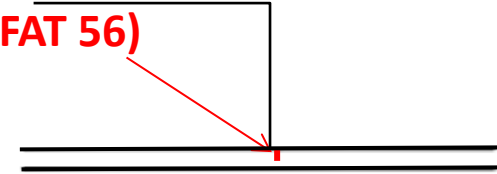
$$\delta_c = \frac{L}{A_p E}$$

Appendix: Example of a design improvement study: Longitudinal Fastener Ends (FAT 56)



DETAIL RAIDISSEUR LONG.

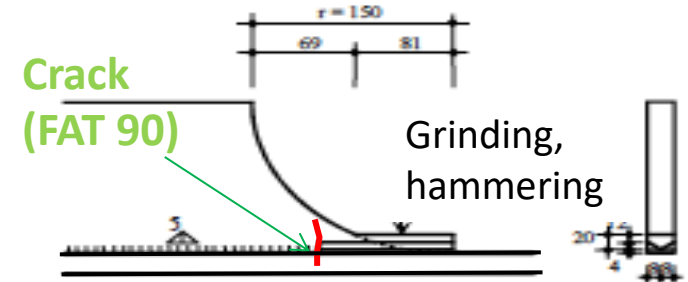
Crack
(FAT 56)



Appendix: Example of a design improvement study: Longitudinal fastener ends (FAT 56 -> 80 -> 112)

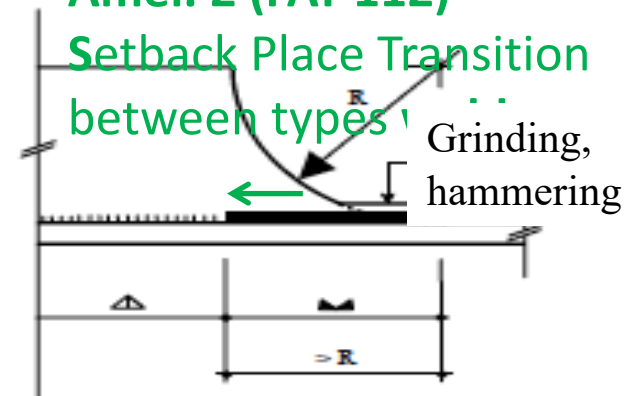


Amél. 1, Rounded, chgt critical place

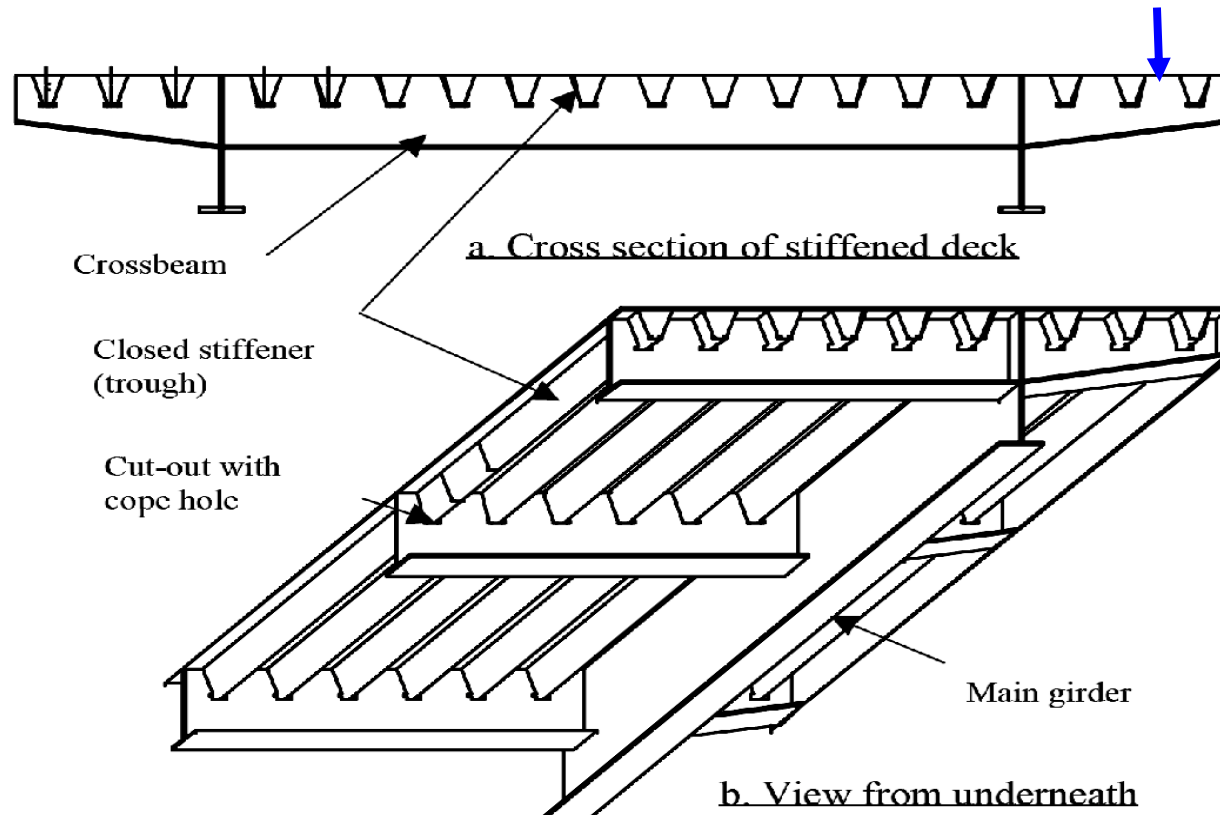


Amél. 2 (FAT 112)

Setback Place Transition
between types



Annex: orthotropic slabs, components and features, fct in 3D



Behavior:

1. Transv. flexion decking
2. Long flexion. bucket + decking, rotations at supports
3. Transv. bending, shear spacer + decking
4. Loads in main beams

=> Strut core subjected to stress in and out of its plane

Orthotropic slabs, 2 "optimal" design solutions

1. USA design: Low spacing between struts (2 to 3 m), therefore reduced height of the buckets and struts. Bucket height = width, spacing 300 to 600 mm. For good fatigue behavior, cuts as small as possible, addition of reinforcement plates in the buckets (improves spacer behavior in its plane, reduces shear deformations.) Rotations imposed by the buckets remain small (spans, height), limited out-of-plane deformations.
2. EU design: widely spaced spacers (3 to 5 m), therefore a minimum of high spacers. We need more buckets, higher too. The troughs are higher than they are wide, spaced 600 to 900 mm apart. Detailed recommendations in EN 1993-2, Annex C. For good fatigue behaviour, wide cut-outs to accommodate the large rotations imposed by the buckets (out-of-plane behaviour). Behavior in the spacer plane ok because of the great height, so limited shear deformations.

Orthotropic slabs, cracking areas to be checked

