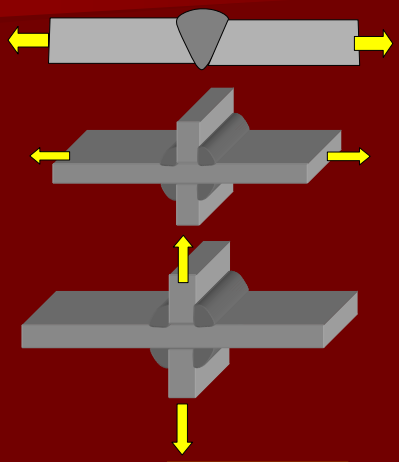
3. Local (Structural) Stress Based Fatigue Design

Contents

- Brief Review of Nominal Stress Based Fatigue Design
- Structural Stress Based Fatigue Design
  -Fatigue Assessment of Welded Joints-
    >Cope Hole Joints
    >High Strength Steel Steels
- Stress Analysis Method for Root Cracks
  -Effective Notch Stress-

Fatigue Design

- Nominal Stress Based Fatigue Design (Review)



Butt Welded Joints:
JSSC-Category D

Non-Load Carrying
Cruciform Joints:
JSSC-Category E

Load Carrying
Cruciform Joints:
JSSC-Category F(toe), H(root)

Joint Types

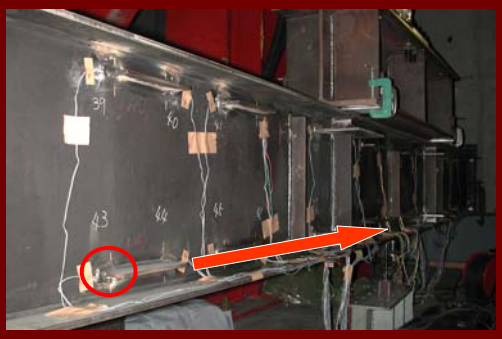
Strength
Category

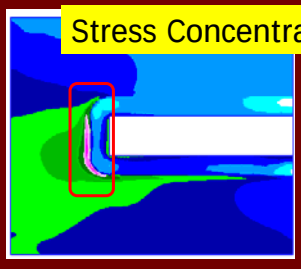
Fatigue Design

- **Structural Stress Based Fatigue Design**

Structural Hot-spot Stress Approach

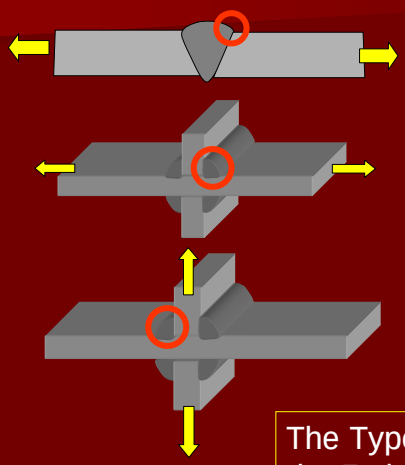
Define the fatigue strengths directly
By the local stress at crack initiation points

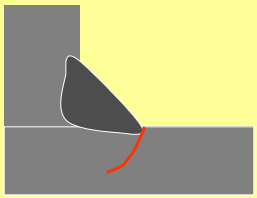




Stress Distribution

Structural Stress (Hot Spot Stress) approach





Local Stresses
control the fatigue phenomenon
in any types of joints.

The Types of Joints don't affect
the Fatigue Strengths Defined
by Structural Hot-Spot Stress Approach

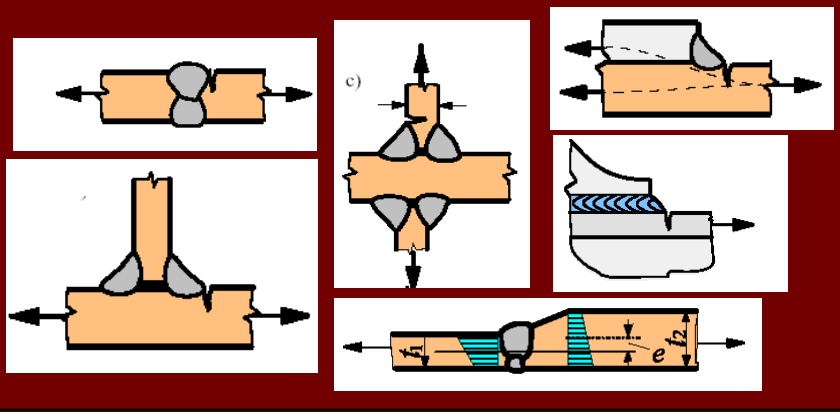
The Structural Hot-Spot Stress Approach

The Structural Hot-Spot Stress Approach is recommended for welded joints where there is no clearly defined nominal stress due to complicated geometric effects, and where the structural discontinuity is not comparable to a classified structural detail

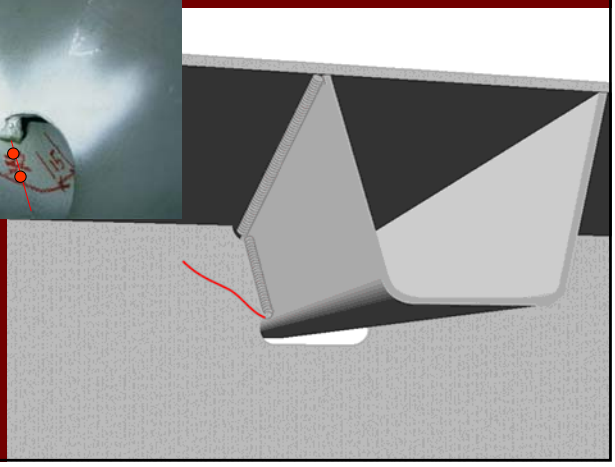
- due to complicated geometry
- due to structural discontinuities
- due to complicated plate deformation

applicability of the hot spot stress to the weld toe

- where there is no clearly defined nominal stress due to complicated geometric effects
- where the structural discontinuity is not comparable to a classified structural detail

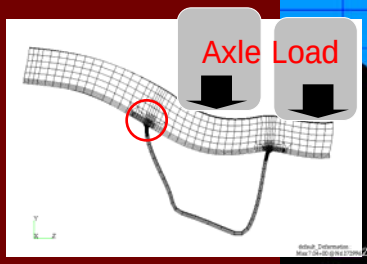


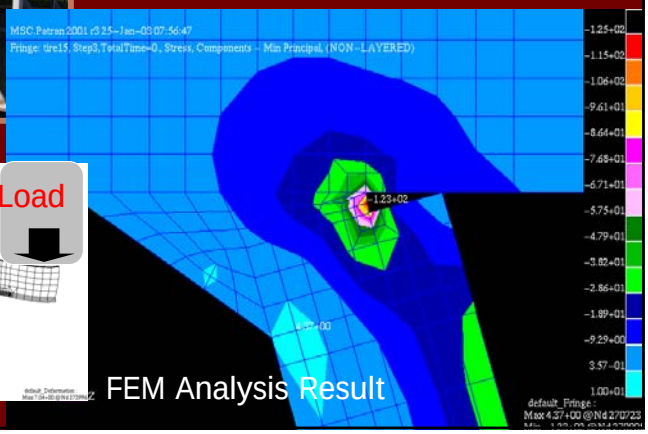
applicability of Hot Spot Stress



Complicated Geometry

In case of Orthotropic Steel Deck Bridges

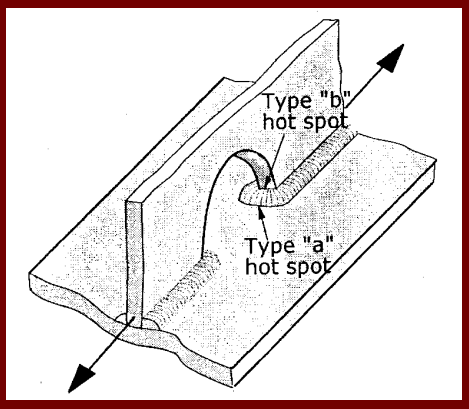




FEM Analysis Result

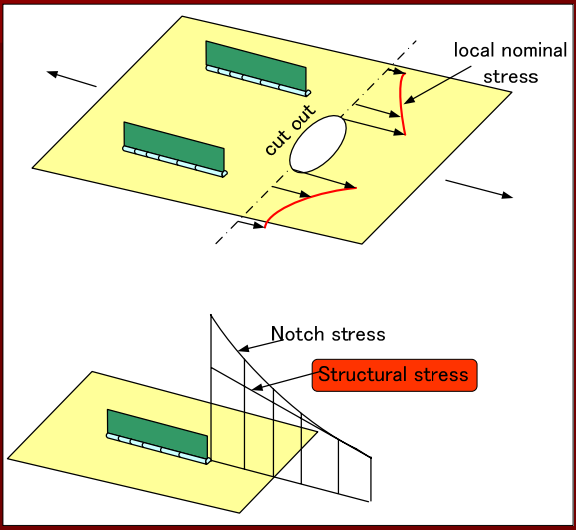
2 Types of Hot Spot

2 Types: “a” and “b”



a: structural hot spot stress (SHSS) transverse to weld toe on plate surface
b: SHSS transverse to weld toe at plate edge

Definition of The Structural Hot-Spot Stress



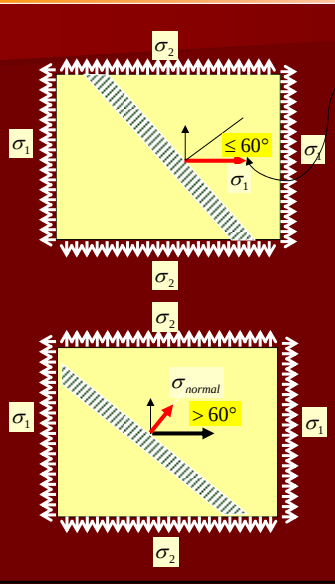
Local nominal stress includes

- The effects of macro-geometric features of the component
- stress fields in the vicinity of concentrated loads
- significant shell bending stress

Structural Hot Spot Stress

- includes all stress raising effects of a structural detail excluding all stress concentrations due to the local weld profile.
- non-linear peak stress caused by the local notch is excluded

Dependency on Angle : principal or normal

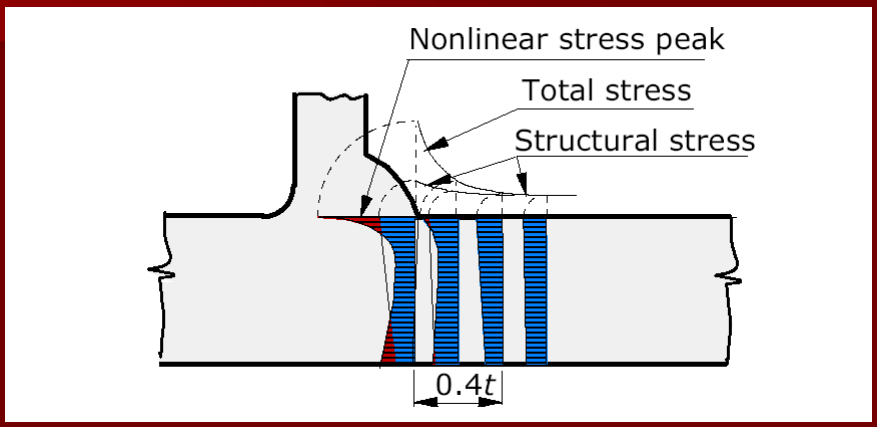


the principal stress which is approximately in line with the perpendicular to the weld toe

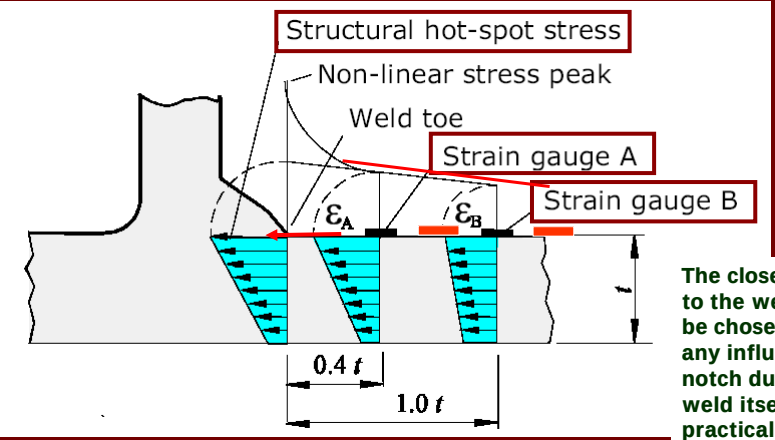
$$\sigma_{HotSpot} = \sigma_1$$

$$\sigma_{HotSpot} = \sigma_{normal}$$

Definition of The Structural Hot-Spot Stress



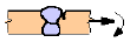
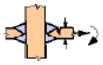
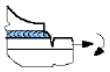
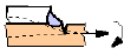
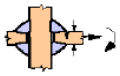
The Estimation Method of The Structural Hot-Spot Stress by Measuring Strain



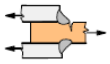
Linear Extrapolation

The closest position to the weld toe must be chosen to avoid any influence of the notch due to the weld itself. This is practically the case at a distance of 0.4t from the weld toe.

Hot Spot S-N Curves

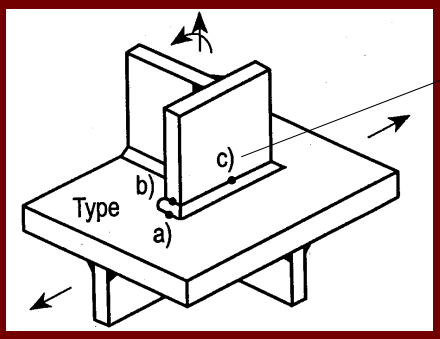
No.	Structural detail	Description	Requirements	FAT Steel	FAT Alu.
1		Butt joint	As welded, NDT	100	40
2		Cruciform or T-joint with full penetration K-butt welds	K-butt welds, no lamellar tearing	100	40
3		Non load-carrying fillet welds	Transverse non-load carrying attachment, not thicker than main plate, as welded	100	40
4		Bracket ends, ends of longitudinal stiffeners	Fillet welds welded around or not, as welded	100	40
5		Cover plate ends and similar joints	As welded	100	40
6		Cruciform joints with load-carrying fillet welds	Fillet welds, as welded	90	36

Hot Spot S-N Curves

No.	Structural detail	Description	Requirements	FAT Steel	FAT Alu.
7		Lap joint with load carrying fillt welds	Fillet welds, as welded	90	36
8		Type "b" joint with short attachment	Fillet or full penetration weld, as welded	100	40
9		Type "b" joint with long attachment	Fillet or full penetration weld, as welded	90	36

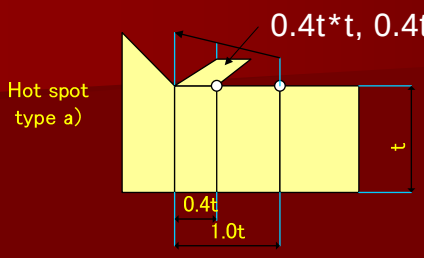
Hot Spot Stresses in Complex Welded Structures

Types of Weld Toes



Type a) : On the Plate Surface at the End of an Attachment
Type b) : At the Plate Edge at the End of an Attachment
Type c) : Along the Weld of an Attachment

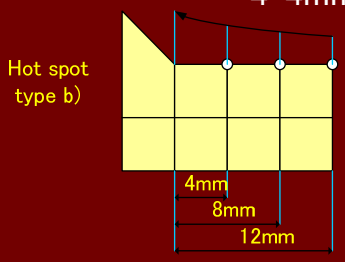
Calculation of SHS Stress 1



a) Fine mesh not more than 0.4t at the hot spot,

$$\sigma_{hs} = 1.67\sigma_{0.4t} - 0.67\sigma_{1.0t}$$

4*4mm



b) The stress distribution is not dependent of plate thickness. Ref. points are given at absolute distances

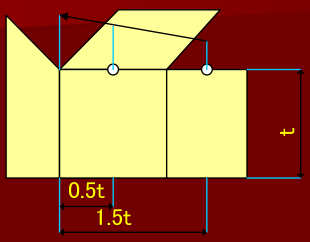
$$\sigma_{hs} = 3\sigma_{4mm} - 3\sigma_{8mm} + \sigma_{12mm}$$

quadratic extrapolation

Calculation of SHS Stress 2

t*t, t*w/2

Hot spot type a)

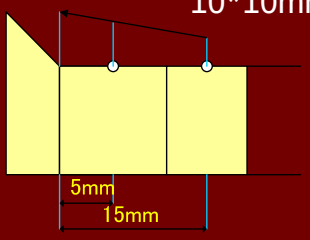


a) 0.5t,1.5t for corse mesh with higher-order elements having length equal to plate thickness,

$$\sigma_{hs} = 1.5\sigma_{0.5t} - 0.5\sigma_{1.5t}$$

10*10mm

Hot spot type b)

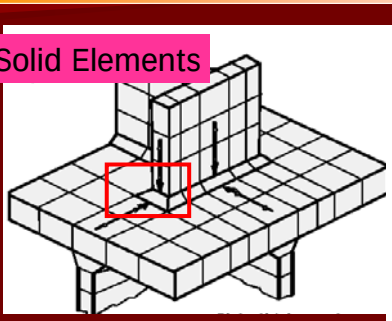


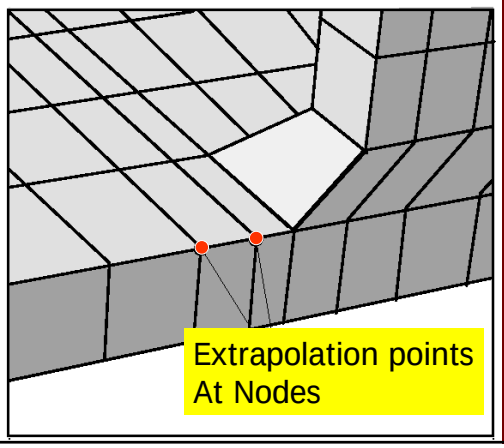
b) Ref. points are given at absolute distances

$$\sigma_{hs} = 1.5\sigma_{5mm} - 0.5\sigma_{15mm}$$

FEM Modeling for Structural Hot-Spot Stress Evaluation(1)

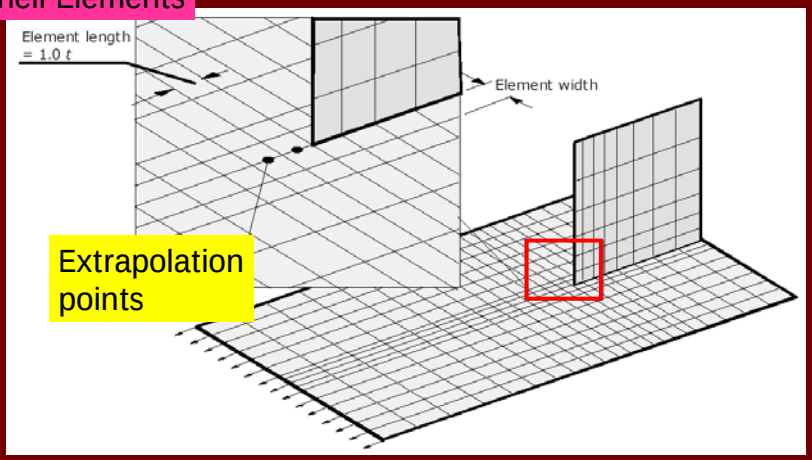
Solid Elements



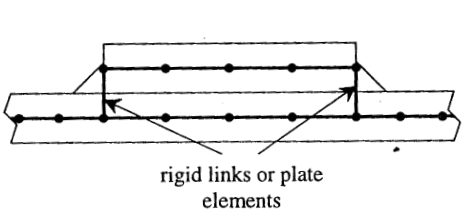


FEM Modeling for Structural Hot-Spot Stress Evaluation(2)

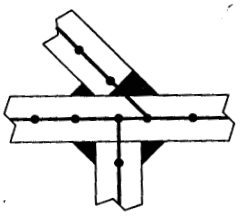
Shell Elements



Modeling of Offsets in Shell Models



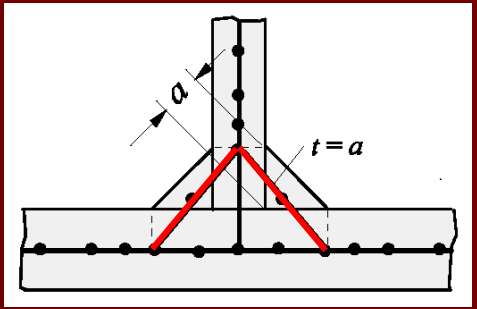
Doubling Plates

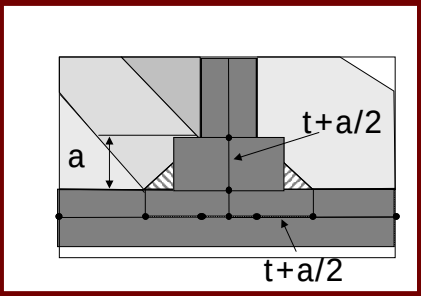


Hopper Corner

Recommended Techniques for Modeling of Welds

Shell Elements



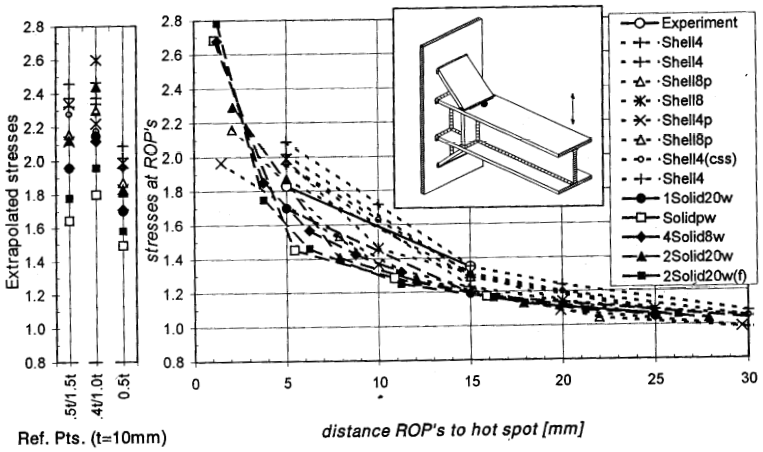


Method I:
Inclined Shell Elements

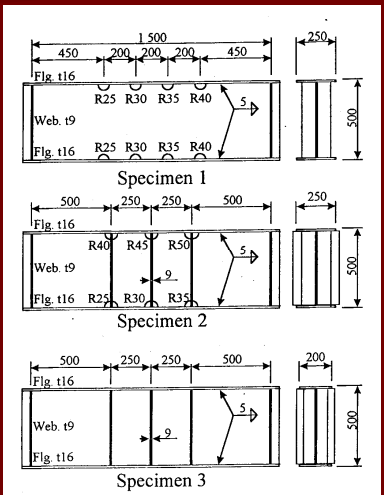
Method II:
Thickness Changes

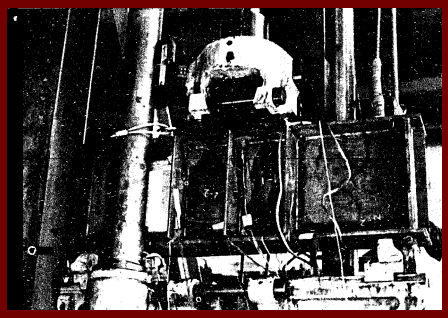
International Institute of Welding (IIW)

Round Robin Study for Hopper Corner Model

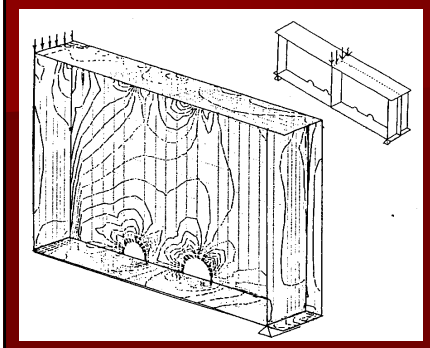


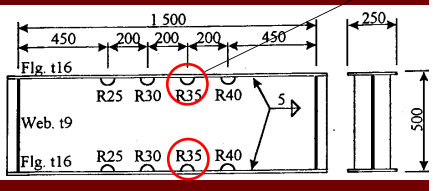
Fatigue Assessment of Cope Hole Details in Steel Bridges



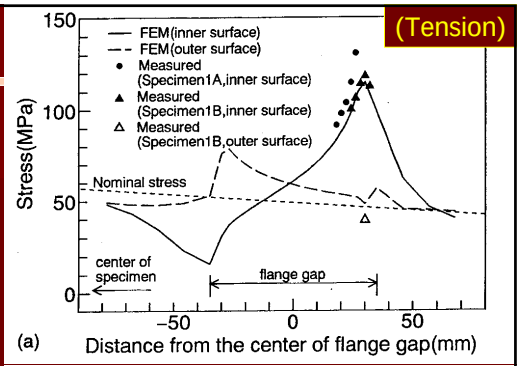


FEM Analysis Results

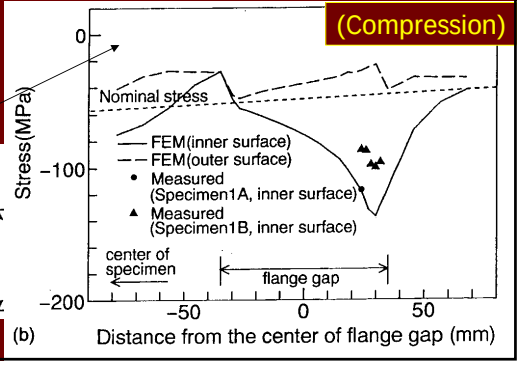




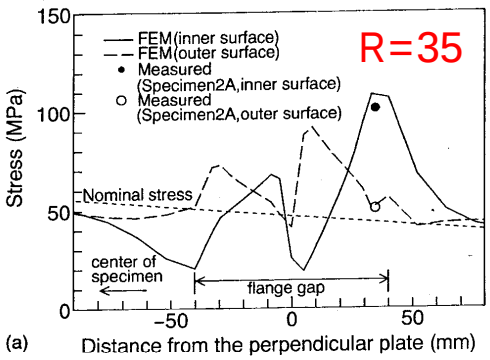
(Tension)

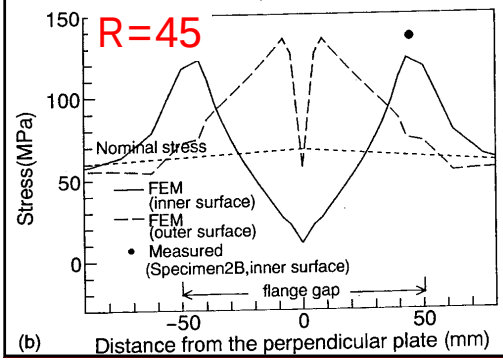


(Compression)



FEM Analysis Results

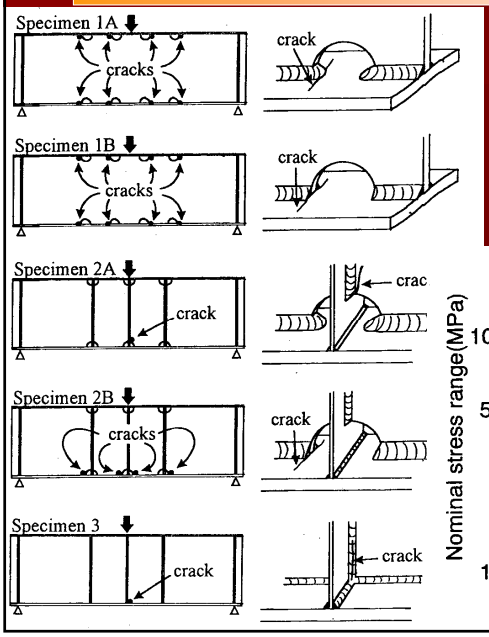


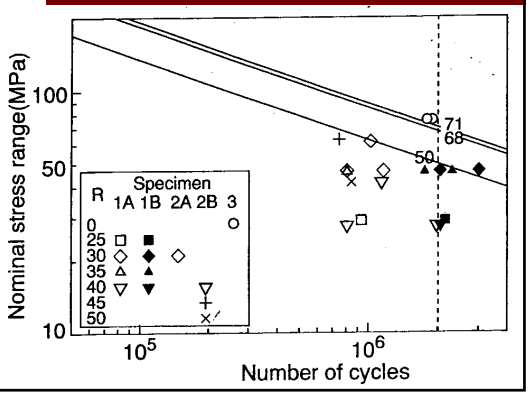


Cope Hole Located 250mm away from the Loading Point

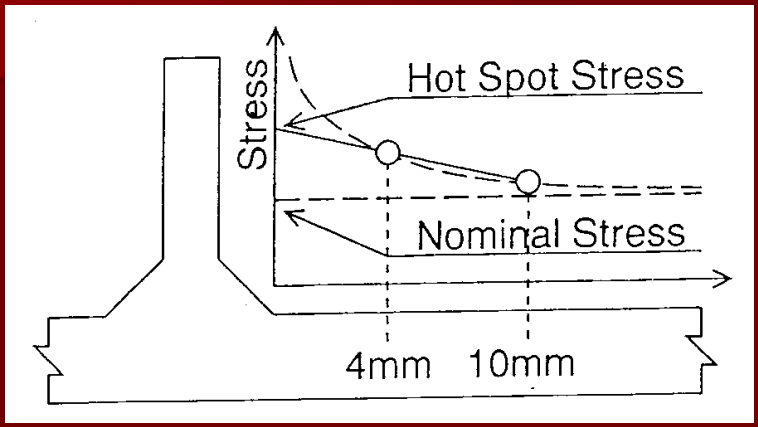
Cope Hole Located directly below the Loading Point

Fatigue Test Results

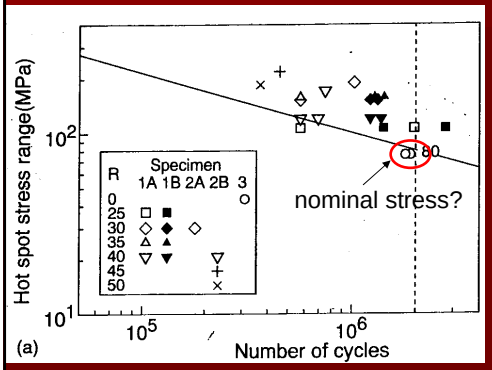


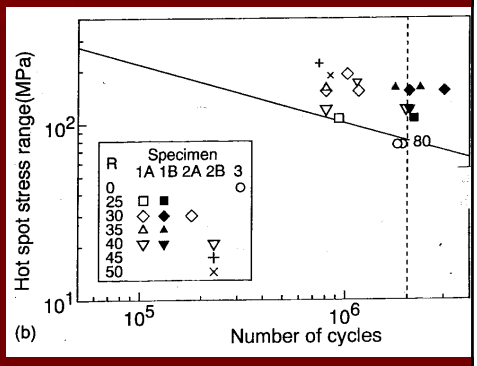


Definition of Hot Spot Stress



S-N Diagram Arranged on Hot Spot Stress Range



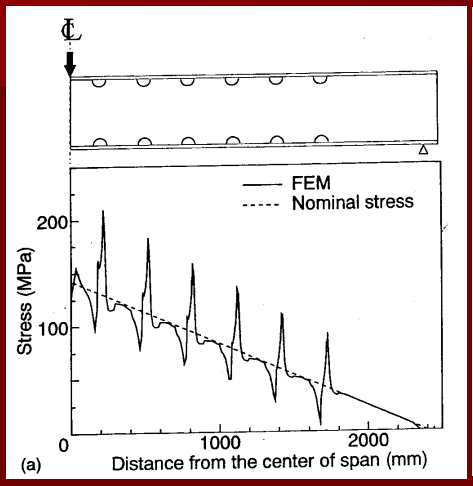


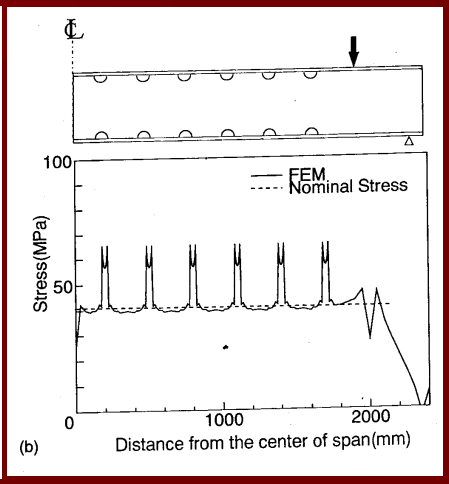
Crack Length: 10mm

Crack Length: 20mm

Fatigue strengths of longitudinal weld with cope hole lie on FAT 80 line with hot spot stress range arrangement.

Influence of Shear Force (1)



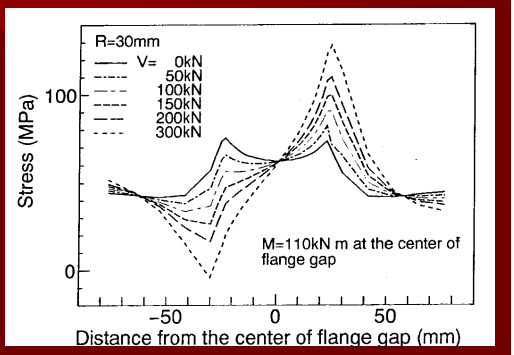


V=const, M=linear

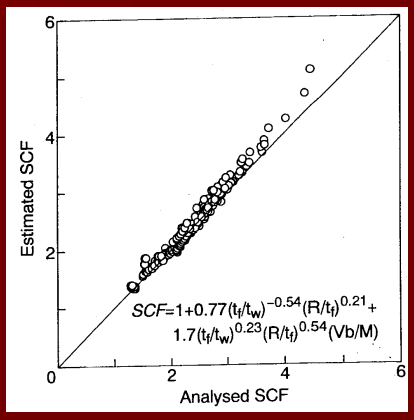
V=0, M=const.

Stress Distribution (FEM)

Influence of Shear Force (2)

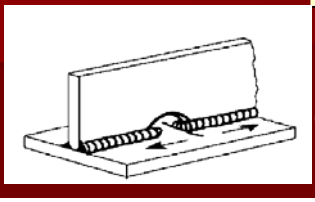


FEM Results



Comparison between Analyzed and Estimated SCF Values

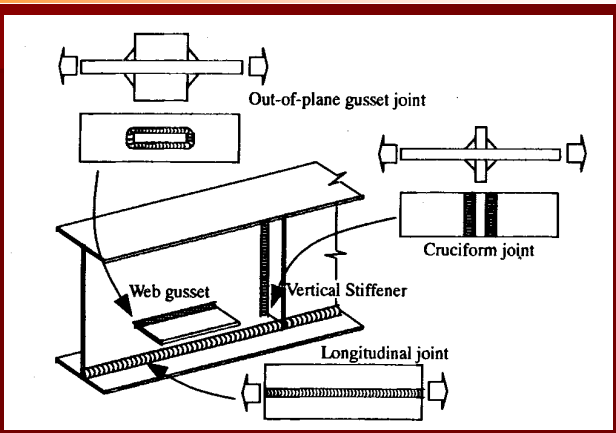
Effect of shear on weld with cope holes in IIW



τ : shear stress in web at weld end
σ : nominal stress in flange at weld end

Description (St.= steel; Al.= aluminium)	FAT St.	FAT Al.	Requirements and Remarks
Longitudinal butt weld, fillet weld or intermittent weld with cope holes (based on normal stress in flange σ and shear stress in web τ at weld ends), cope holes not higher than 40% of web.			Analysis based on normal stress in flange and shear stress in web at weld ends. representation by formula??
τ/σ = 0	71	28	steel $80 \cdot (1 - \frac{\Delta\tau}{\Delta\sigma})$ but >=36
0.0 - 0.2	63	25	
0.2 - 0.3	56	22	
0.3 - 0.4	50	20	
0.4 - 0.5	45	18	alum. $36 \cdot (1 - \frac{\Delta\tau}{\Delta\sigma})$ but >=14
0.5 - 0.6	40	16	
> 0.6	36	14	

Fatigue Assessment of Welded Joints made of High Strength Steels

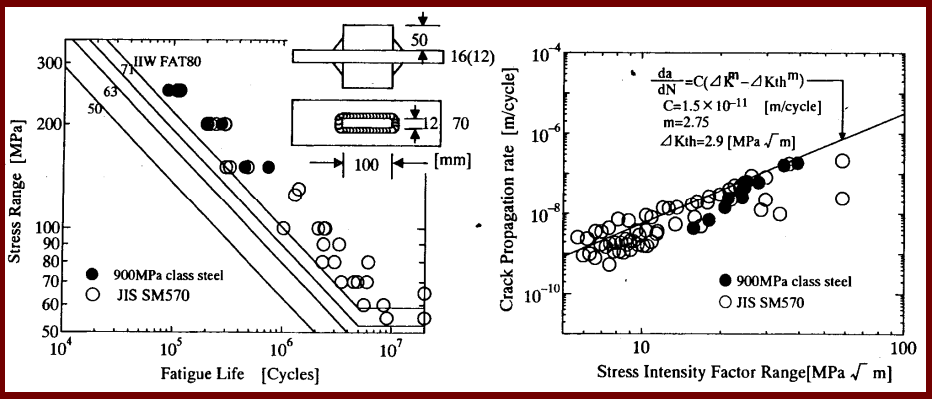


Out-of-Plane Gussets
Cruciform Joints
Longitudinal Joints

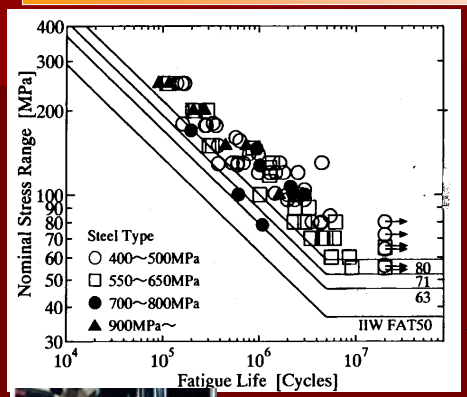
Fatigue Test Data
-Out-of-Plane Gusset Joints-

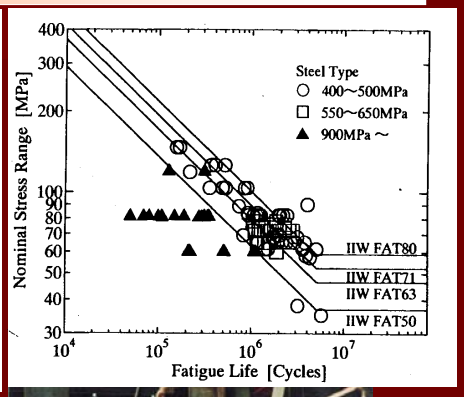
Effects of Strength of Steels
900MPa Class Steel
JIS SM570

In JSSC spec., fatigue class E(80 toe grounded) or F (65 as-weld) is given to gusset (L<100mm).



Fatigue Test Data
-Out-of-Plane Gusset Joints-



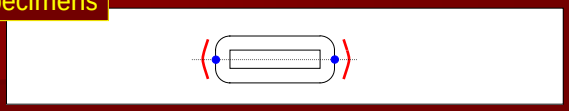


Joint Specimens

Girder Specimens

Principal Stress Distribution around the Gussets

Joint Specimens



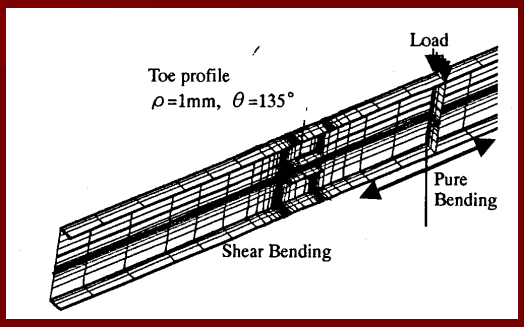
Location of Maximum Principal Stress

Stress Distribution

Crack Initiated from the toe located in the front

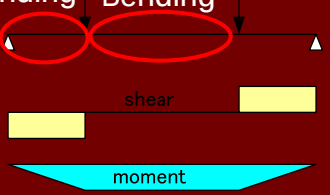
Principal Stress Distribution around the Gussets

Girder Specimens



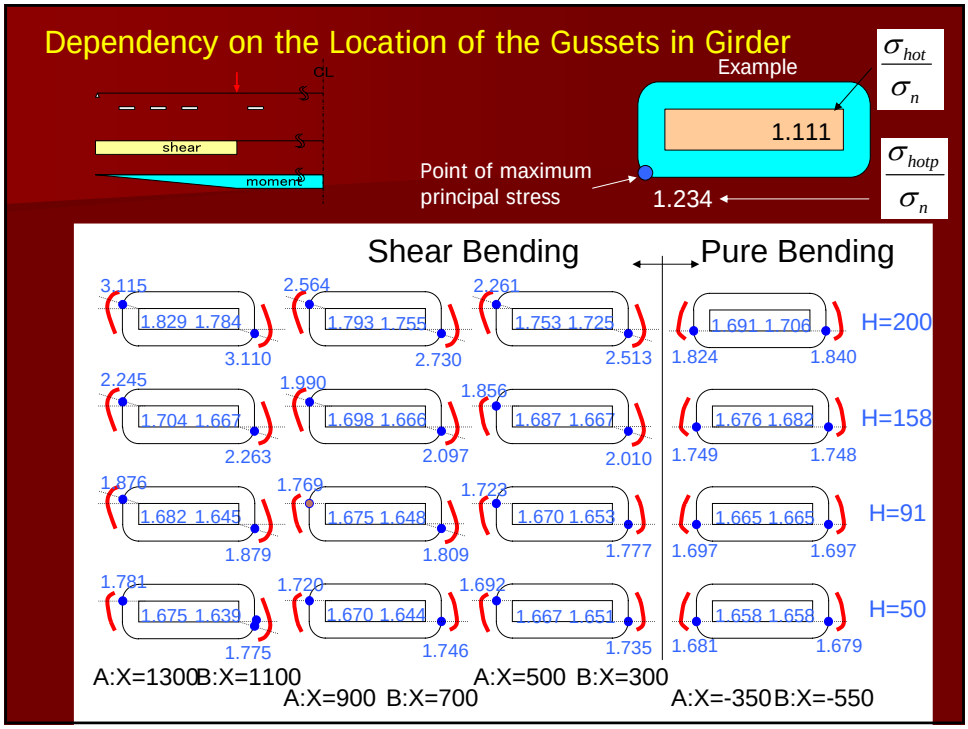
4 Point Bending Tests

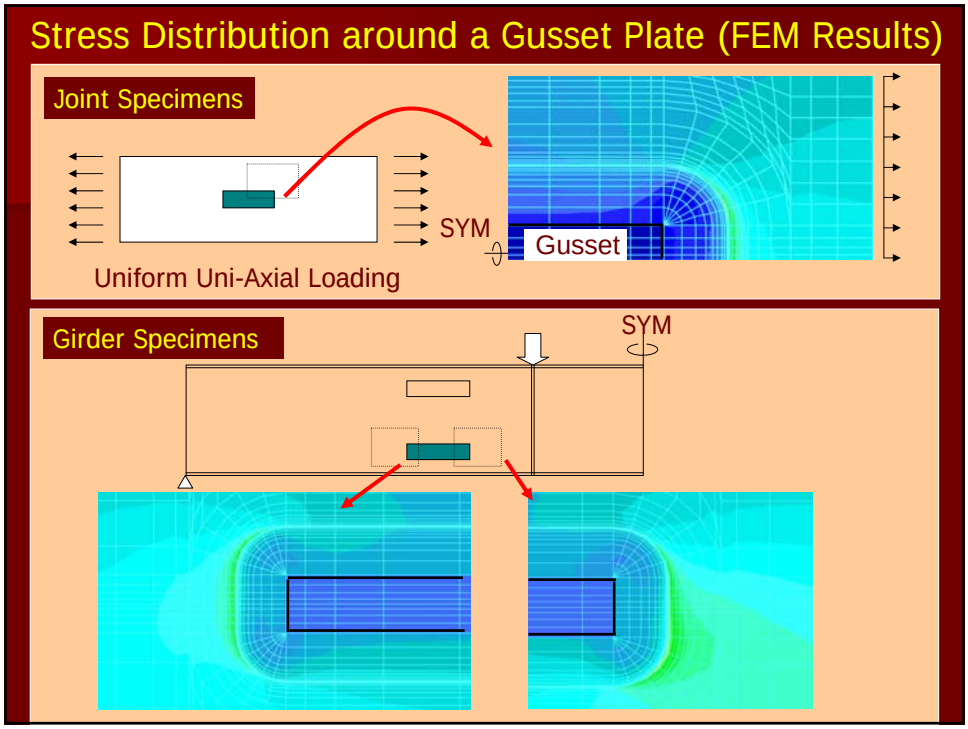
Shear Bending | Pure Bending



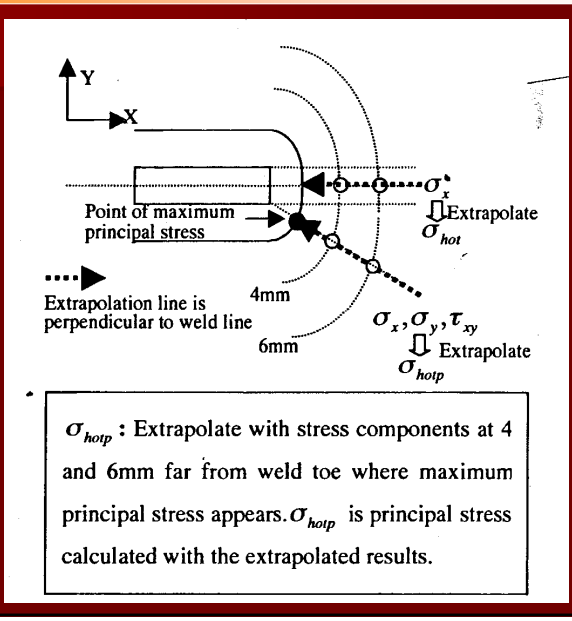
existence of shear → crack initiation points and principal stress range

Nominal stress range →underestimation of the fatigue strength


Dependency on the Location of the Gussets in Girder
CL
shear
moment
Example
1.111
Point of maximum
principal stress
1.234
$\frac{\sigma_{hot}}{\sigma_n}$
$\frac{\sigma_{hotp}}{\sigma_n}$
Shear Bending
Pure Bending
3.115
1.829 1.784
3.110
2.564
1.793 1.755
2.730
2.261
1.753 1.725
2.513
1.691 1.706
1.824
1.840
H=200
2.245
1.704 1.667
2.263
1.990
1.698 1.666
2.097
1.856
1.687 1.667
2.010
1.676 1.682
1.749
1.748
H=158
1.876
1.682 1.645
1.879
1.769
1.675 1.648
1.809
1.722
1.670 1.653
1.777
1.665 1.665
1.697
1.697
H=91
1.781
1.675 1.639
1.775
1.720
1.670 1.644
1.746
1.692
1.667 1.651
1.735
1.658 1.658
1.681
1.679
H=50
A:X=1300 B:X=1100
A:X=900 B:X=700
A:X=500 B:X=300
A:X=-350 B:X=-550


Stress Distribution around a Gusset Plate (FEM Results)
Joint Specimens
SYM
Gusset
Uniform Uni-Axial Loading
Girder Specimens
SYM

A Proposed Definition of Hot Spot Stress

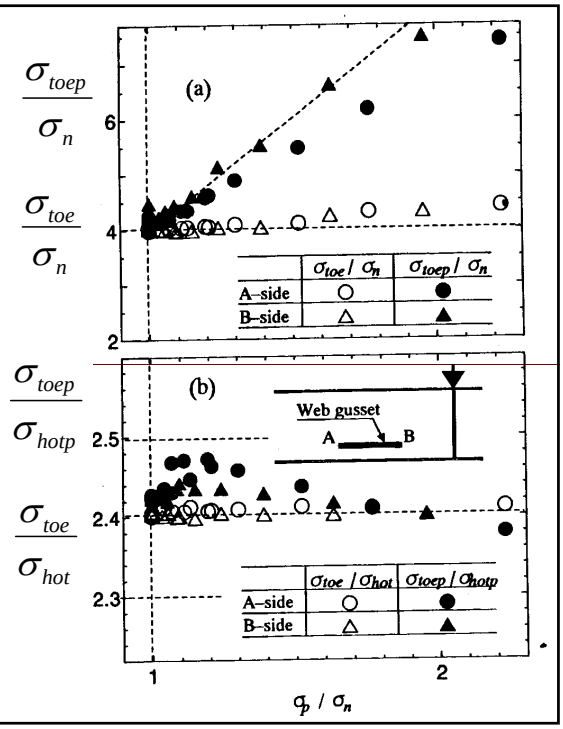


σ_{hotp} : Extrapolate with stress components at 4 and 6mm far from weld toe where maximum principal stress appears. σ_{hotp} is principal stress calculated with the extrapolated results.

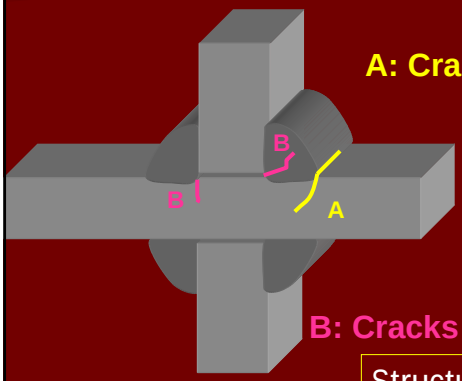
Change of Stress

With Increase of the Ratio Between Principal Stress and Nominal Stress

Principal stress at toe can be represented by principal hot spot stress with HSS concentration factor of 2.4



The Target Cracks of Structural Hot-Spot Stress Approach



A: Cracks Initiated from the Weld Toe

Structural Stress Approach
Can be Applied

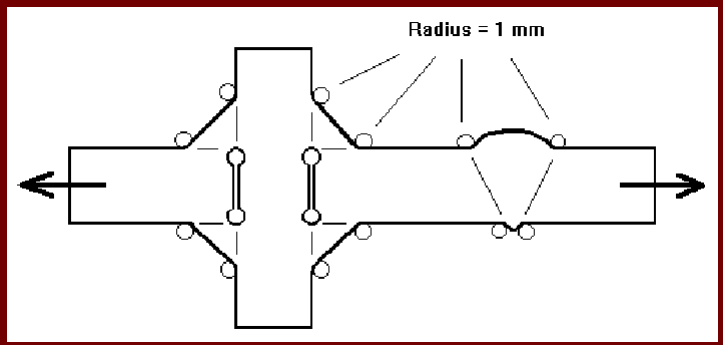
B: Cracks Initiated from the Roots

Structural Stress Approach
Cannot be Applied

⇨ Different Approach is Needed

Stress Evaluation by the Effective Notch Stress

Effective notch stress is the total stress at the root of a notch, obtained assuming linear-elastic material behavior. The real weld outline is replaced by an effective one. Effective notch root radius of r=1mm has been verified to give consistent results.



If the Toe is Finished, the radius = 2mm

Effective Notch Fatigue Resistance

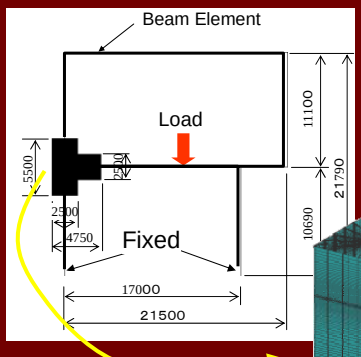
- The method is restricted to assessment of naturally formed weld toes and roots.
- The method is well suited to the comparison of alternative weld geometries.
- In case where a mean geometrical notch root radius can be defined, this radius plus 1mm may be used in the effective notch stress analysis.

Tab. {3.4}-1: Effective notch fatigue resistance for steel

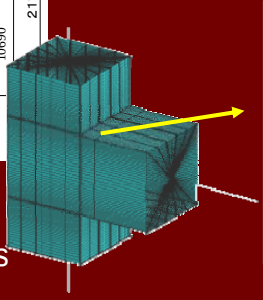
No.	Quality of weld notch	Description	FAT
1	Effective notch radius equalling **1 mm** replacing weld toe and weld root notch	Notch as-welded, normal welding quality m=3	225

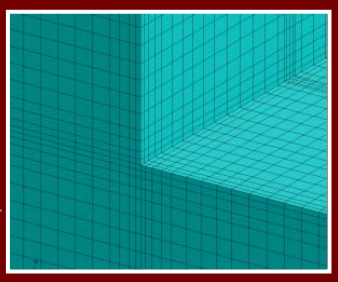
IIW fatigue recommendation

An Example of Application of the Effective Notch Stress –Beam-to-Column Connections-



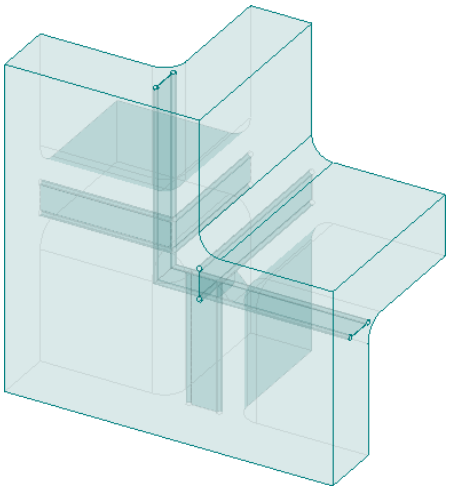
- Analysis Code: ABAQUS
- Min Element Size: 11.5mm (T/2)
- Number of Nodes: 91,278
- Number of Element: 90,200

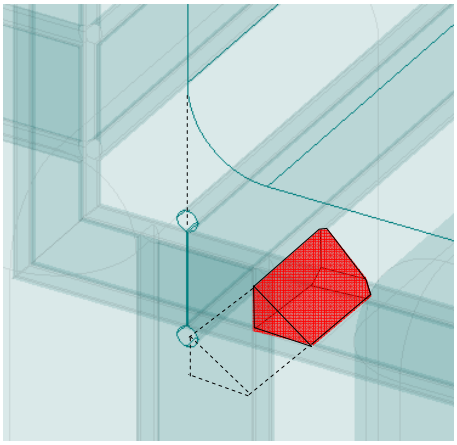




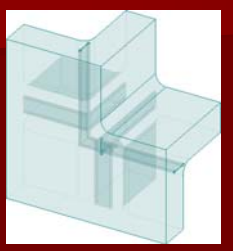
Full Scaled Structures

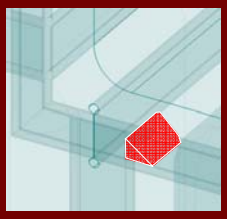
Model of Delta zone

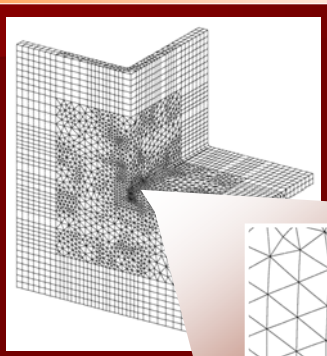




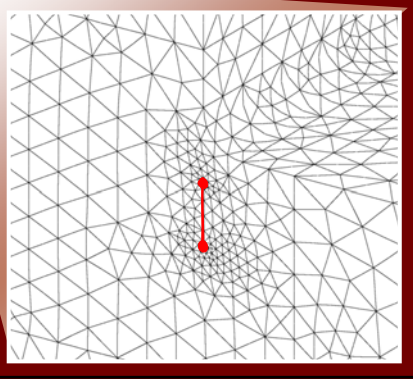
Detailed Solid Models







No. of Nodes: 294966
No. of Elements: 191382



FEM Mesh

The Analysis Result