1

# Fatigue Strength of Welded Joints

Chitoshi Miki

Department of Civil Engineering
Tokyo Institute of Technology



2

## Contents

- Effects of Residual Welding Stresses on Fatigue Crack Growth Rate
- Effects of Weld Defects on Fatigue Strengths
  - Longitudinal Welded Joints Containing Blowholes
  - Butt-Welded Joints Containing Various Embedded Defects
- High Strength Steels
  Fatigue Strength of Large-Size Gusset Joints of 800MPa Class Steels
- Size Effects
  Full Size Fatigue Tests of Truss Chords

3

Topic 1

## Effects of Residual Welding Stresses on Fatigue Crack Growth Rate

4

## Fatigue Crack Propagation Rate, da/dN

Fatigue Life { Crack Initiation Life, Ni
Crack Propagation Life, Np

Evaluation of Np

ΔK—da/dN Relationship

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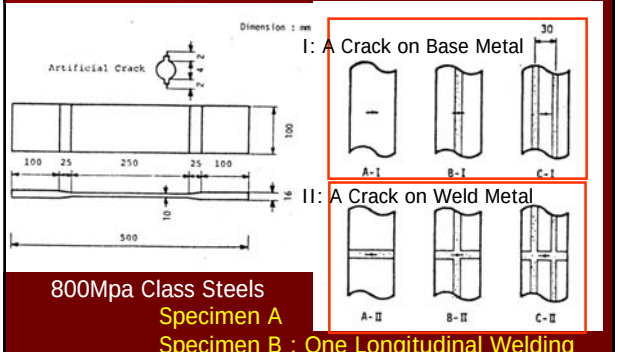
Affected by Residual Welding Stresses?

Experimental Investigations

5

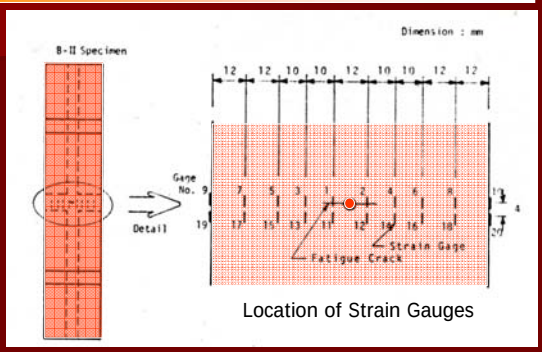
## Specimens




800Mpa Class Steels
Specimen A
Specimen B : One Longitudinal Welding
Specimen C : Two Longitudinal Welding

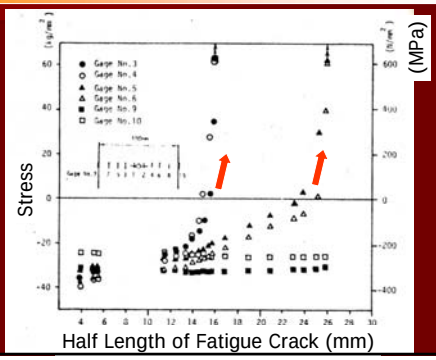
6

## Measurements of Residual Stress

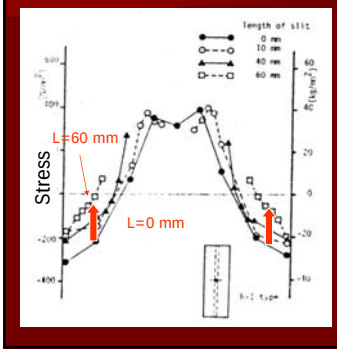


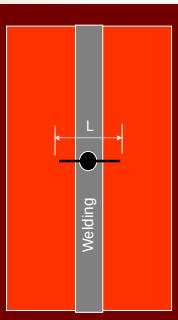

Location of Strain Gauges

## Change of Residual Stress Due to Crack Propagation



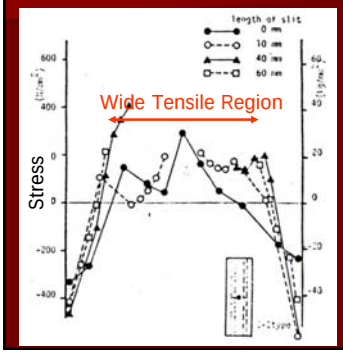

## Change of Residual Stress Distribution Due to Crack Propagation

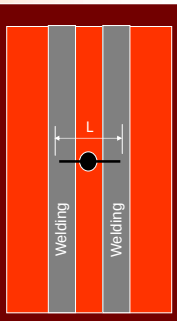



B-I Type Specimen

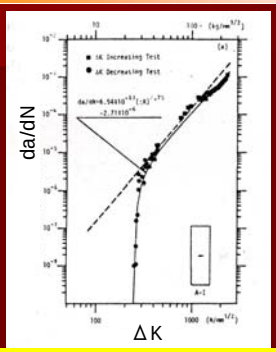
## Change of Residual Stress Distribution Due to Crack Propagation

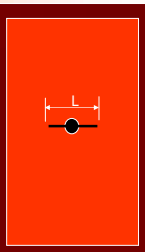



C-I Type Specimen

## ΔK—da/dN Relationship (1)



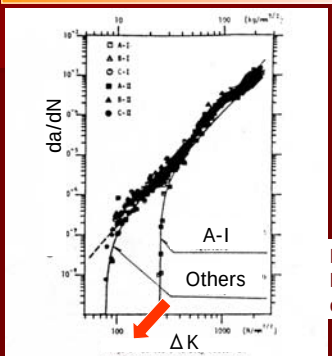




A-I Type Specimen
No Weld-Beads

Equation 1

$$\frac{da}{dN}[mm/cycle] = 6.54\times10^{-13}\left(\Delta K[N/mm^{1.5}]\right)^{2.75} - 2.71\times10^{-6}$$

## ΔK—da/dN Relationship (2)




No Significant Differences Between The Other Types of Specimens

Equation 2

$$\frac{da}{dN}[mm/cycle] = 3.82\times10^{-13}\left(\Delta K[N/mm^{1.5}]\right)^{2.95} - 9.37\times10^{-8}$$

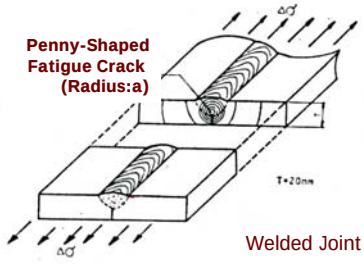
## Estimation of Fatigue Crack Propagation Life, Np

$$\frac{da}{dN}[mm/cycle] = 6.54\times10^{-13}\left(\Delta K[N/mm^{1.5}]\right)^{2.75} - 2.71\times10^{-6}$$

Equation 1

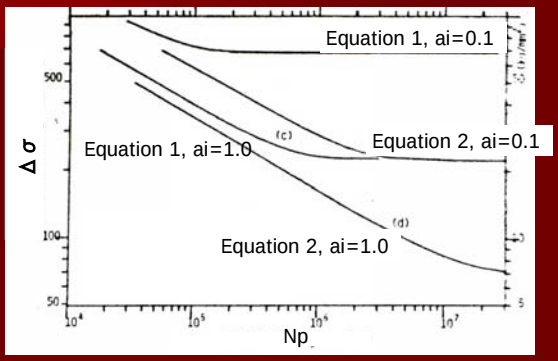
$$\frac{da}{dN}[mm/cycle] = 3.82\times10^{-13}\left(\Delta K[N/mm^{1.5}]\right)^{2.95} - 9.37\times10^{-8}$$

Equation 2




Welded Joint Model

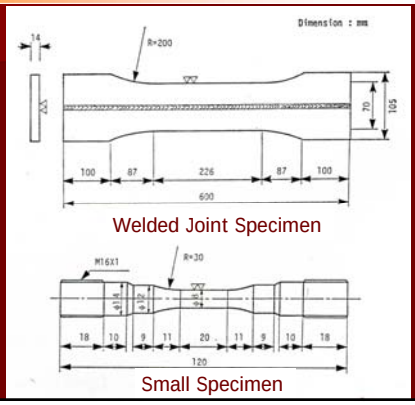
## Estimation of Fatigue Crack Propagation Life, Np



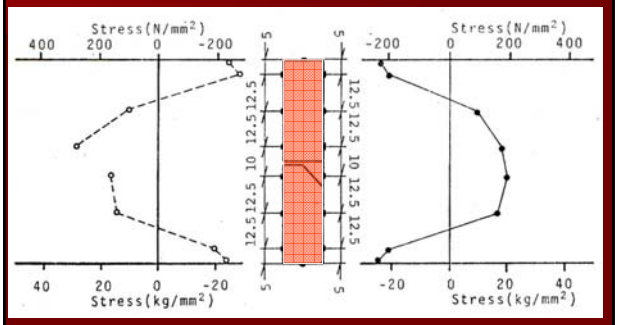

Topic 2

**Effects of Weld Defects on Fatigue Strengths**
Longitudinal Welded Joints
Containing Blowholes

## Specimens




## Residual Stress Distribution in The Welded Joint Specimen



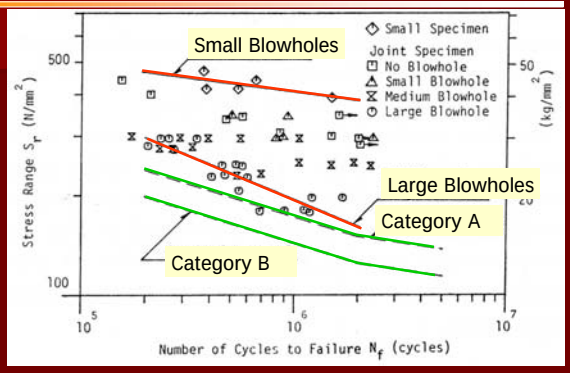

## Classification of Blowhole Sizes

Base on Radiographic Examination

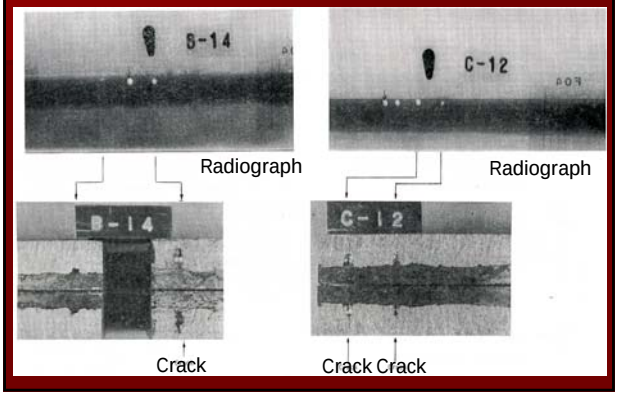
- No Blowholes
- Small Blowholes b < 1mm
- Medium Blowholes 1 mm < b < 2mm
- Large Blowholes b > 2mm

b: Blowhole Length

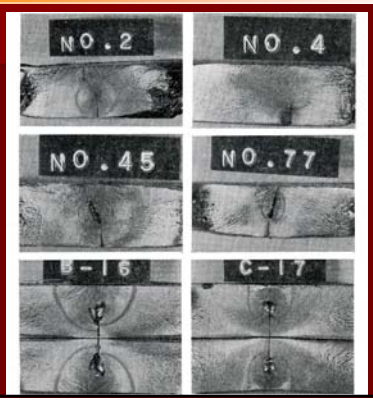
## Fatigue Test Results



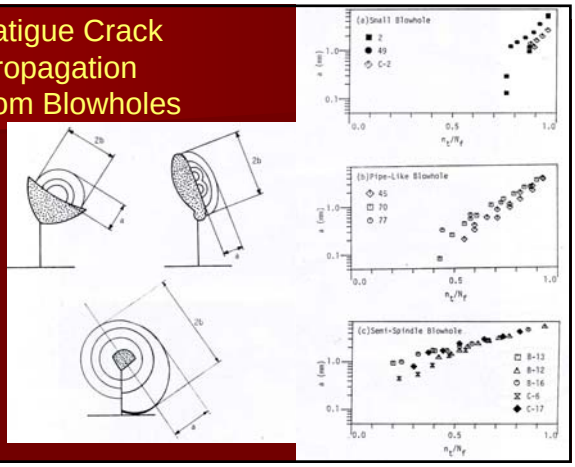
## Fatigue Cracks Originated From Blowholes




## Fracture Surfaces with Beach Marks




## Fatigue Crack Propagation from Blowholes

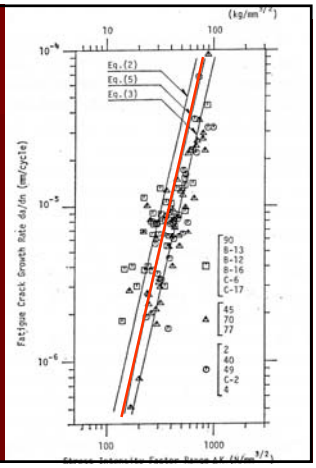


## Fatigue Crack Propagation Rate from Blowholes

$$\frac{da}{dN} = 2.97\times10^{-13}(\Delta K)^{3.0}$$

$$\frac{da}{dN} = 0.90\times10^{-13}(\Delta K)^{3.0}$$

$$\frac{da}{dN} = 1.73\times10^{-13}(\Delta K)^{3.0} - 8.34\times10^{-8}$$

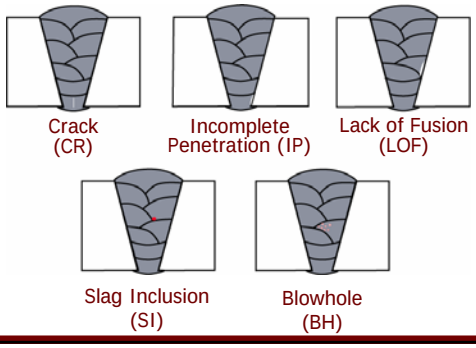


Topic 2

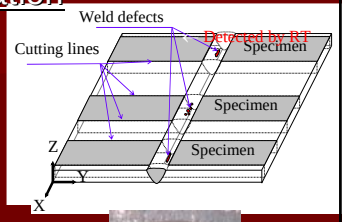
Effects of Weld Defects on Fatigue Strengths
Butt-Welded Joints
Containing Various Embedded Defects

## Various Embedded Weld Defects

- Butt welded joint with V-groove



## Specimen Preparation

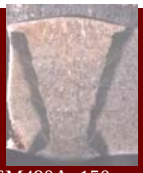



JIS SM490A

| | YP(MPa) | TS(MPa) |
|---|---|---|
| SM490 | 343 | 532 |
| DW-Z100 | 497 | 567 |

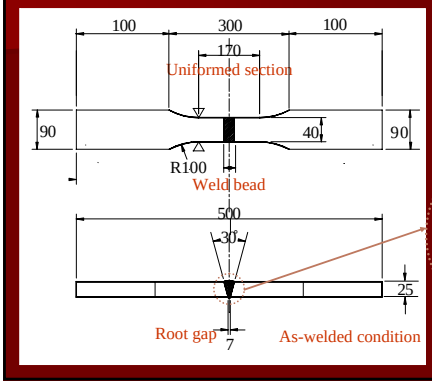
JIS SM570Q

| | YP(MPa) | TS(MPa) |
|---|---|---|
| SM570-Q | 588 | 660 |
| DW-60 | 534 | 614 |

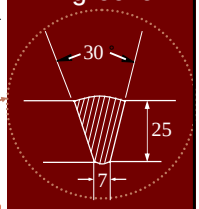


JIS SM490A: 150 specimens
JIS SM570Q: 27 specimens

## Specimen Configuration

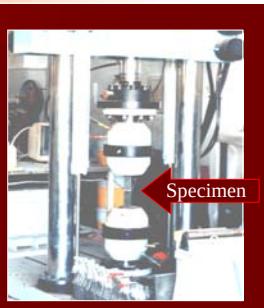



Weld detail, V-groove



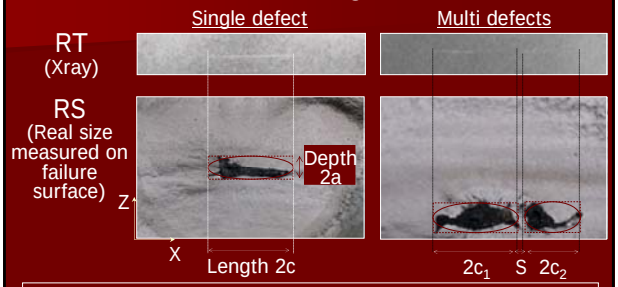

## Fatigue Test

- Testing machine
  - Capacity: 300 kN
- Testing conditions
  - Constant amplitude
  - Stress ratio R=0
  - Maximum stress: 100 - 350 MPa




## Fatigue Test Results

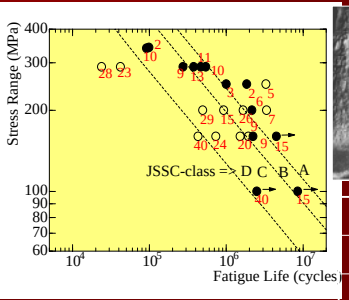
Evaluation : defect length "2c" is used.




WES 2805
Real Size

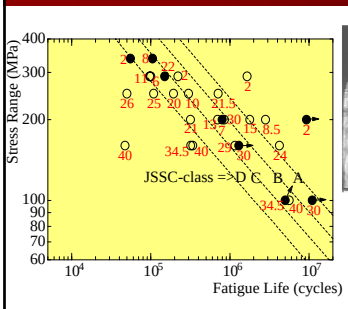
$S_0 = 0.25 \times \min(c_1, c_2)$
$S \le S_0 \rightarrow 2c = 2c_1 + 2c_2 + S$
$S > S_0 \rightarrow$ cracks are isolated

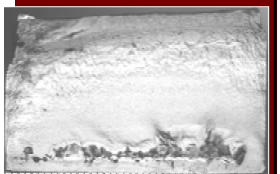
## Fatigue Test Result, CR Type Defect (SM490A)




| | initiation | length |
|---|---|---|
| ○ | Defect | RS |
| ● | Toe | RT |

## Fatigue Test Result, IP Type Defect (SM490A)

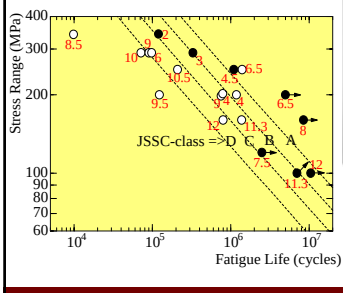


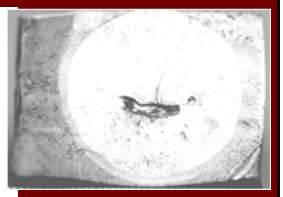



| | initiation | length |
|---|---|---|
| ○ | Defect | RS |
| ● | Toe | RT |

31

## Fatigue Test Result, LOF Type Defect (SM490A)

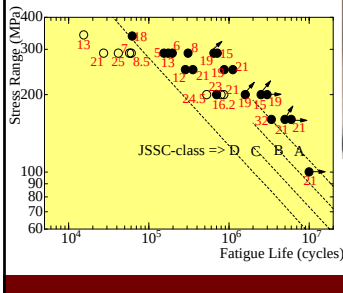


| | initiation | length |
|---|---|---|
| ○ | Defect | RS |
| ● | Toe | RT |

32

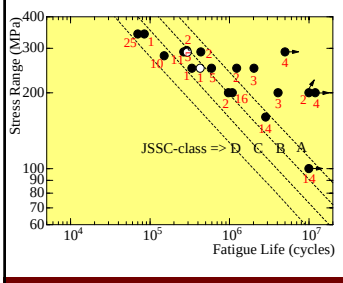
## Fatigue Test Result, SI Type Defect (SM490A)

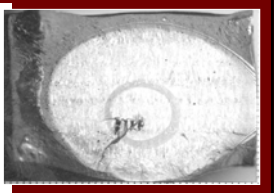



| | initiation | length |
|---|---|---|
| ○ | Defect | RS |
| ● | Toe | RT |

33

## Fatigue Test Result, BH Type Defect(SM490A)



| | initiation | length |
|---|---|---|
| ○ | Defect | RS |
| ● | Toe | RT |

34

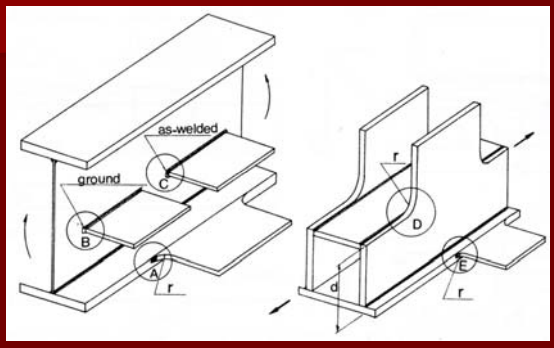
Topic 3

**High Strength Steels**

**Fatigue Strength of Large-Size Gusset Joints of 800MPa Class Steels**

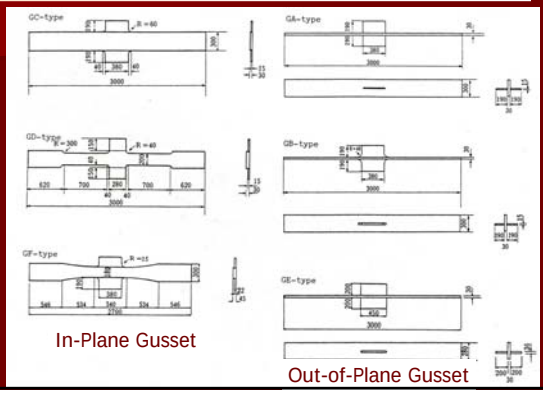
35

## Types of Gusset Joints




36

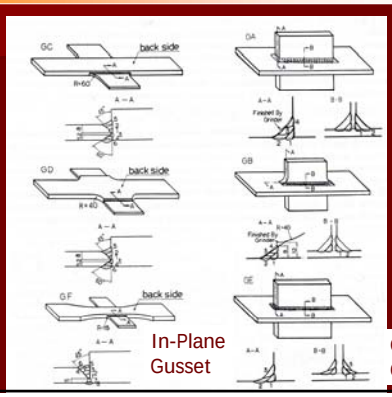
## Specimens




In-Plane Gusset

Out-of-Plane Gusset

## Welding Details of Specimens

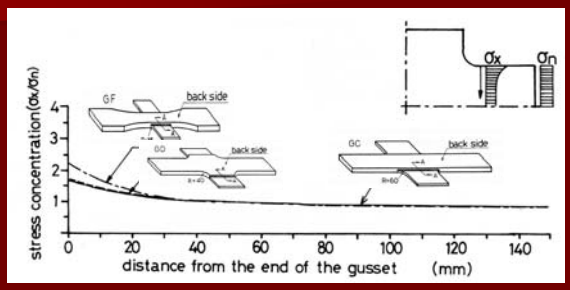



## The Used Steels

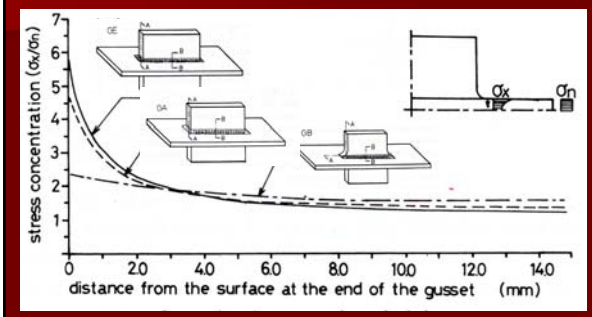
HT80, SM570Q

| Steel | Mechanical Properties | | | | | Chemical compositions % | | | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | t | Y.P. | T.S. | El | VE | C | Si | Mn | P | S | Cu | Ni | Cr | Mo | B | V | Ceq | |
| | mm | MPa | MPa | % | N.m | ×100 | | | ×1000 | | | ×100 | | | ×1000 | | ×100 | |
| HT80 | 30 | 833 | 882 | 22 | 80 | 11 | 25 | 97 | 18 | 8 | 250 | 83 | 51 | 38 | 10 | 44 | 50 | Main Pl. GA~GE |
| HT80 | 22 | 764 | 823 | 24 | 201 | 10 | 27 | 97 | 15 | 5 | — | 104 | 59 | 33 | 2 | — | 50 | Main Pl. GF |
| SM58Q | 15 | 568 | 657 | 36 | 186 | 14 | 34 | 133 | 17 | 6 | — | 1 | 2 | 3 | — | 37 | 39 | Gusset Pl. GA~GD |

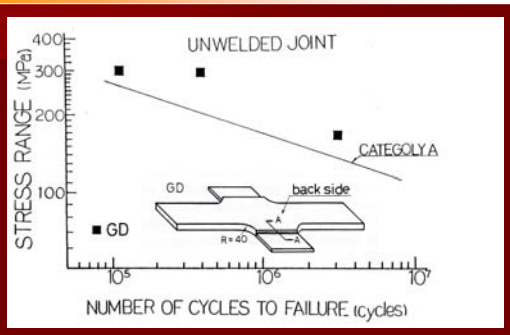
## Stress Distribution at the End of the In-Plane Gussets



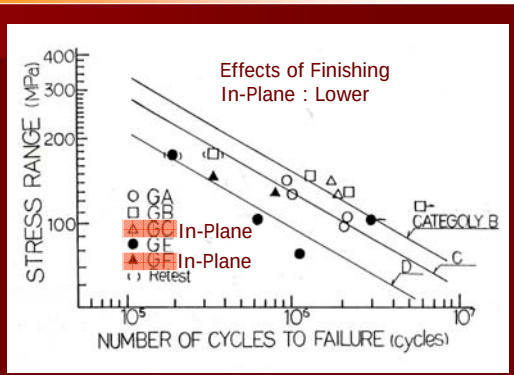

## Stress Distribution at the End of the Out-of-Plane Gussets



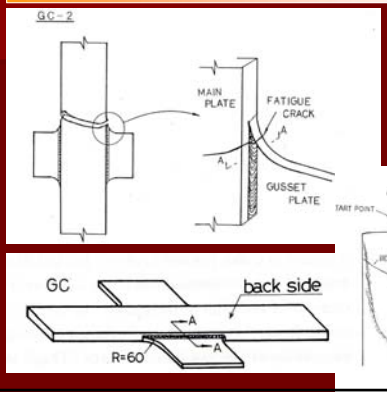

## Fatigue Test Results




## Fatigue Test Results

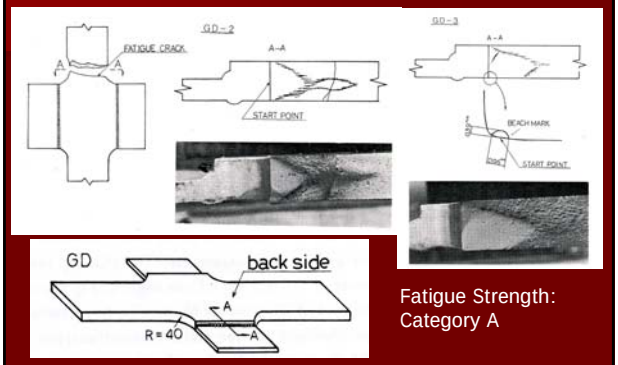


## Fatigue Crack in In-Plane Gusset Joints



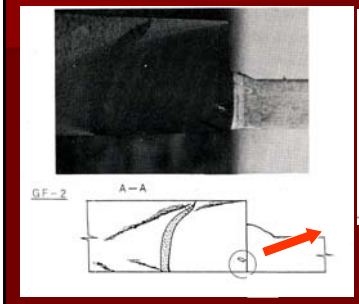

Fatigue Strength:
Category B

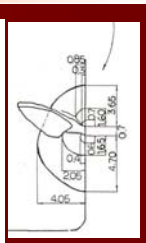
## Fatigue Crack in In-Plane Gusset Joints




Fatigue Strength:
Category A

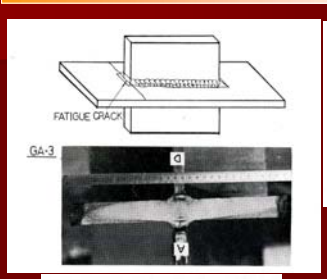
## Fatigue Crack in In-Plane Gusset Joints

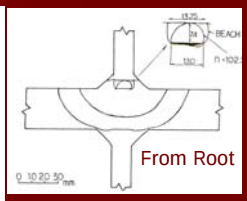


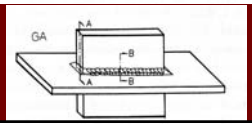
Fatigue Strength:
Category C and D

## Fatigue Crack in Out-of-Plane Gusset Joints

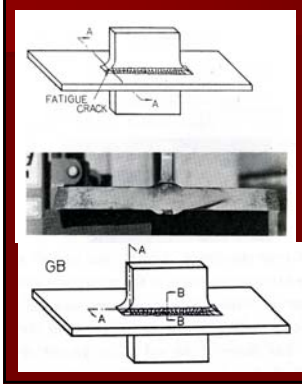


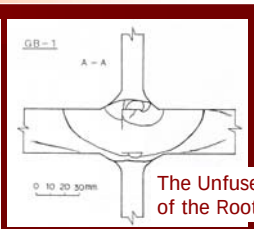




Fatigue Strength:
Category D



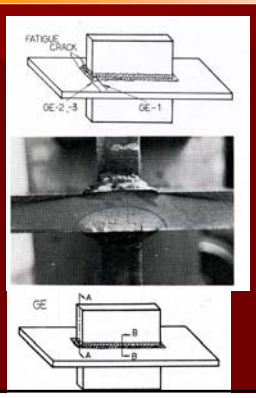

## Fatigue Crack in Out-of-Plane Gusset Joints

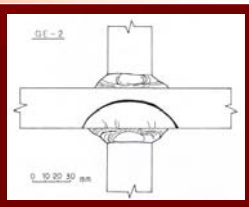



Fatigue Strength:
Category C

## Fatigue Crack in Out-of-Plane Gusset Joints




Fatigue Strength:
Category E

This Type was not used in the Honshu-Shikoku Bridge Project

49

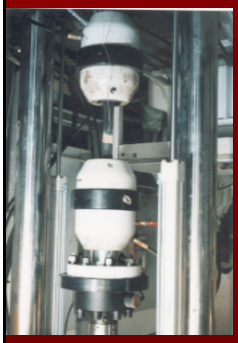
Topic 4

Size Effects

Full Size Fatigue Tests of Truss Chords

50

## Importance of Size Effects



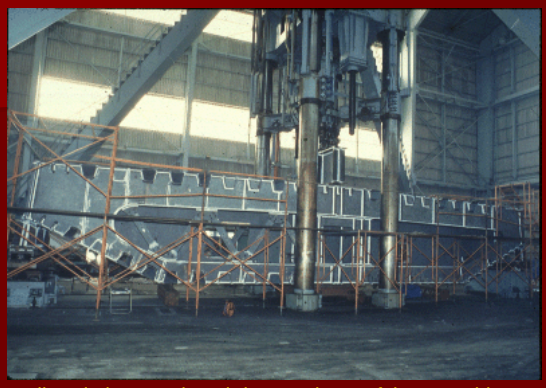
Welded joint specimen

Real scale floor beam of the Seto Bridge

51

Girder specimen at Lehigh University in the US

52



Full scale box section girder specimen of the Kurushima Bridge

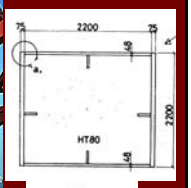
53

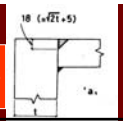
## Full Size Fatigue Tests of Truss Chords

Minato Ohashi

Constructed in 1974

(235m+510m+235m)



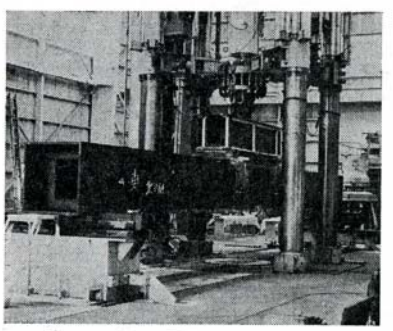
The Corner Joints of Truss Chords

Outside: Partially Penetrated Groove Welds

Inside: Fillet Welds

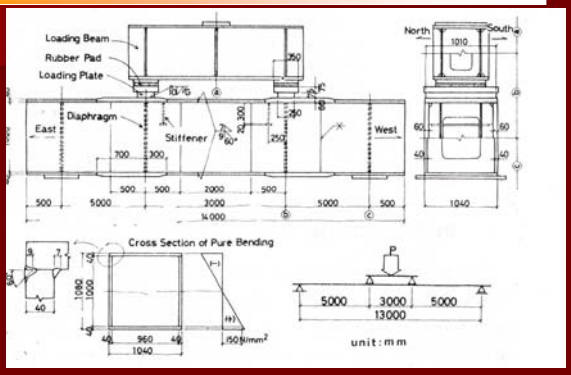
54

## The Full Size Specimen of Truss Chords



4 Point Bending Tests

## The Full Size Specimen of Truss Chords




## The Used Steels

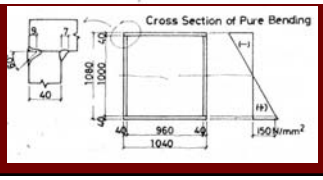
| | Mechanical Properties | | | Chemical Composition (%) | | | | | | | | | | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yield Point N/mm² | Tensile Strength N/mm² | Elongation % | C X100 | Si X100 | Mn X100 | P X10000 | S X10000 | Mo X100 | Cu X100 | Cr X100 | Ni X100 | V X10000 | B X10000 | |
| SM58Q, t=40 | 588 | 667 | 26 | 14 | 32 | 135 | 18 | 4 | 10 | 10 | – | 14 | 42 | 1 | Flange |
| SM58Q, t=40 | 539 | 637 | 29 | 14 | 32 | 135 | 18 | 4 | 10 | 10 | – | 14 | 42 | 1 | Web |
| SM58Q, t=60 | 618 | 696 | 24 | 43 | 28 | 131 | 13 | 3 | 15 | – | 13 | – | 39 | 1 | Flange Web |

600MPa Class Steels
Thickness = 40, 60mm

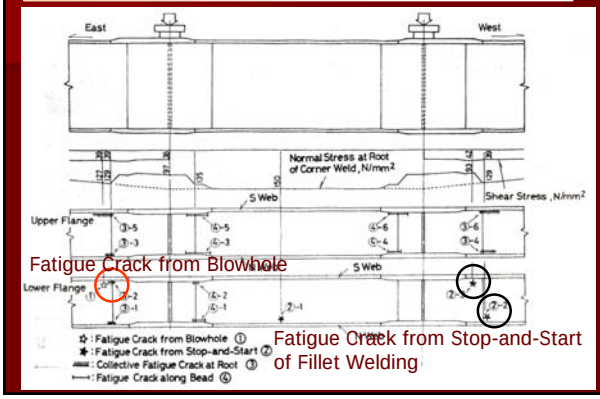
## The Welding Condition of The Corner Joints

| Joint | Wleding Sequence | Pass | Wleding Process | Wleding Materials | Preheat |
|---|---|---|---|---|---|
| Partial Penetrated Groove Weld | | 1 | Tandem SAW | Y-DM (4φ) | 50°C(t=40) |
| | | 2 | | YF15 (20×200) | 100°C(t=60) |
| Fillet Weld Type-1 S Web | | 1 | MAW | L-60 (4φ) *1 | 100°C |
| | | 2 | MAW | LBF62A (6φ) *2 | |
| Fillet Weld Type-2 N Web | | 1 | GMA | YM-60 (1.2φ) | 50°C(t=40) |
| | | 2 | MAW | LBF62A (6φ) | 100°C(t=60) |

*1 JIS D 5816
*2 JIS D 5826



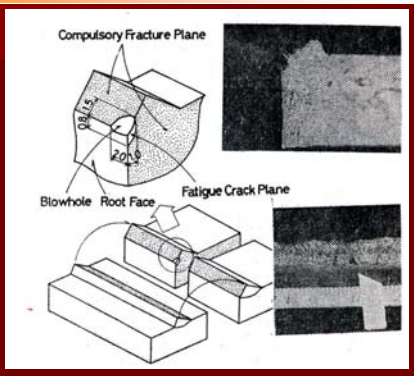

## Fatigue Cracks in The Corner Joints (4 Types)




Fatigue Crack from Blowhole

Fatigue Crack from Stop-and-Start of Fillet Welding

## Type 1 Fatigue Crack Originated from a Blowhole

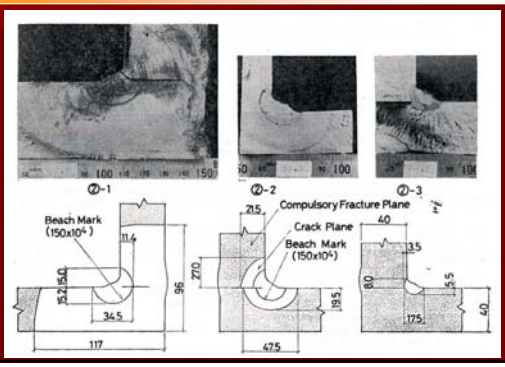



## Type 2 The Fatigue Crack Originated from Stop-and-Start Positions


A Stop-and-Start Position

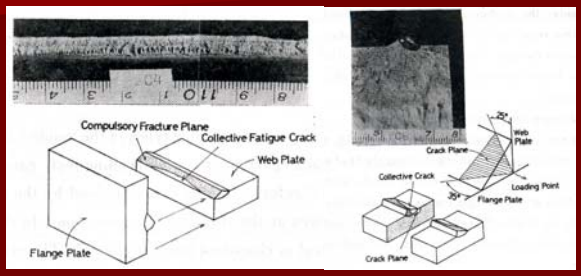
61

## Type 2 The Fatigue Crack Originated from Stop-and-Start Positions



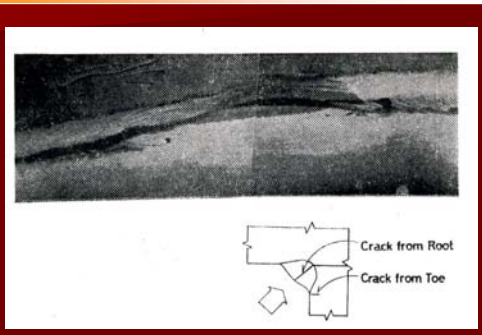

62

## Type 3 Collective Fatigue Cracks At the Roots of Fillet Welds



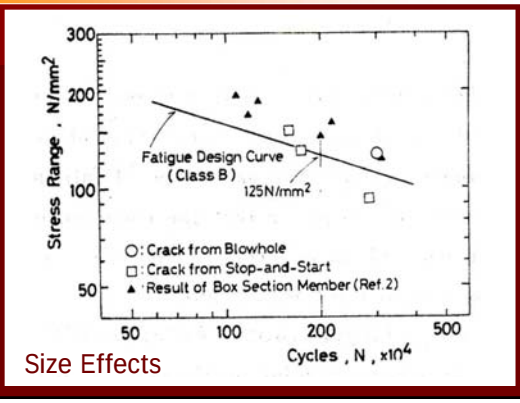

63

## Type 4 Fatigue Cracks Along the Fillet Weld-Beads




64

## Fatigue Test Results




Size Effects

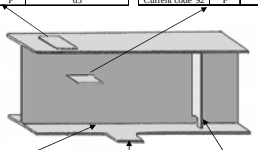
65

## Consideration of Size Effects

### Change of Fatigue Design Code

| Joint Type | Sleeper pad | |
|---|---|---|
| Code | Class | Fatigue strength at 2 million cycles (MPa) |
| Old code '60 | D | 120 |
| Current code '92 | F | 65 |

| Joint Type | Out-plane gusset (t=20mm) | |
|---|---|---|
| Code | Class | Fatigue strength at 2 million cycles (MPa) |
| Old code '60 | D | 100 |
| Current code '92 | F | 65 |



| Joint Type | Longitudinal welding | |
|---|---|---|
| Code | Class | Fatigue strength at 2 million cycles (MPa) |
| Old code '60 | B | 150 |
| Current code '92 | C | 125 |

| Joint Type | Cruciform weld | |
|---|---|---|
| Code | Class | Fatigue strength at 2 million cycles (MPa) |
| Old code '60 | D | 100 |
| Current code '92 | E | 80 |

| Joint Type | In-plane gusset (t=20mm) | |
|---|---|---|
| Code | Class | Fatigue strength at 2 million cycles (MPa) |
| Old code '60 | C | 126 |
| Current code '92 | F | 65 |

66

## References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4. Hirosuke Shimokawa, Koei Takena, Fumio Itoh, Chitoshi Miki: Fatigue Strength of Large Gusset Joints of 800MPa Class Steels, Proc. of JSCE, Vol.2, No.1, 1985.4.
5. Hirosuke Shimokawa, Koei Takena, Makoto Fukazawa, Chitoshi Miki: A Fatigue Test on the Full-Size Truss Chord, Proc. of JSCE, No.344/I-1, 1984.4.