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Fracture Cotrol Design of Steel structures 2007

What is Fatigue and Fracture?

1

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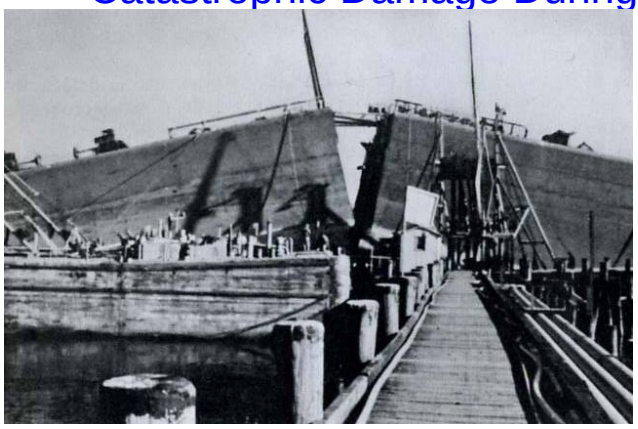
Catastrophic Damage During World War II



5000 ships built

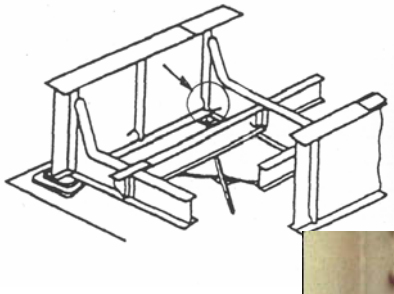
over 1000 ships: cracks by 1946

200 ships: serious damage

9 T-2 tankers

7 Liberty ships broken in two

2



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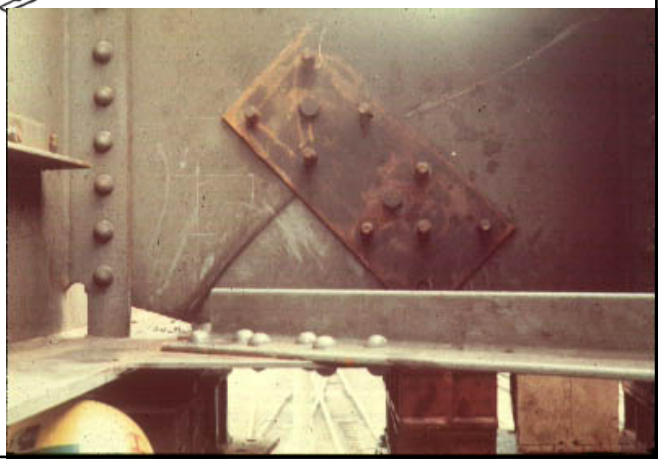
Brittle Fracture
Originated from Fatigue Crack

Shinkannsen in Japan



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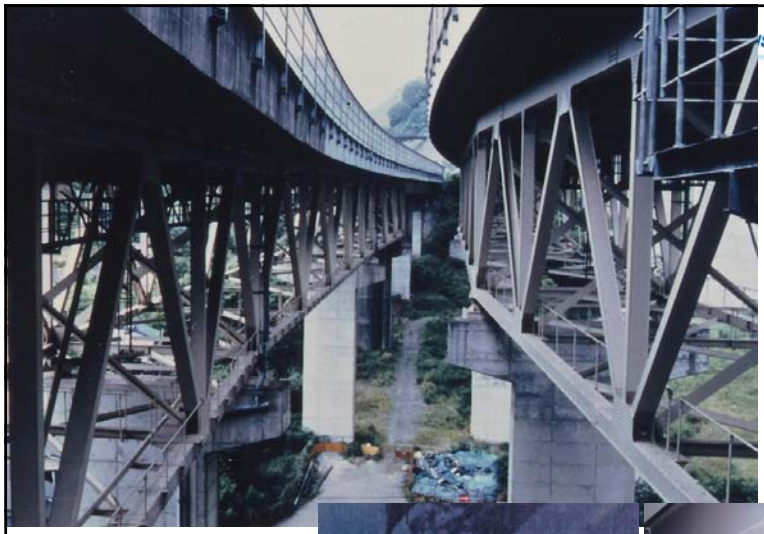
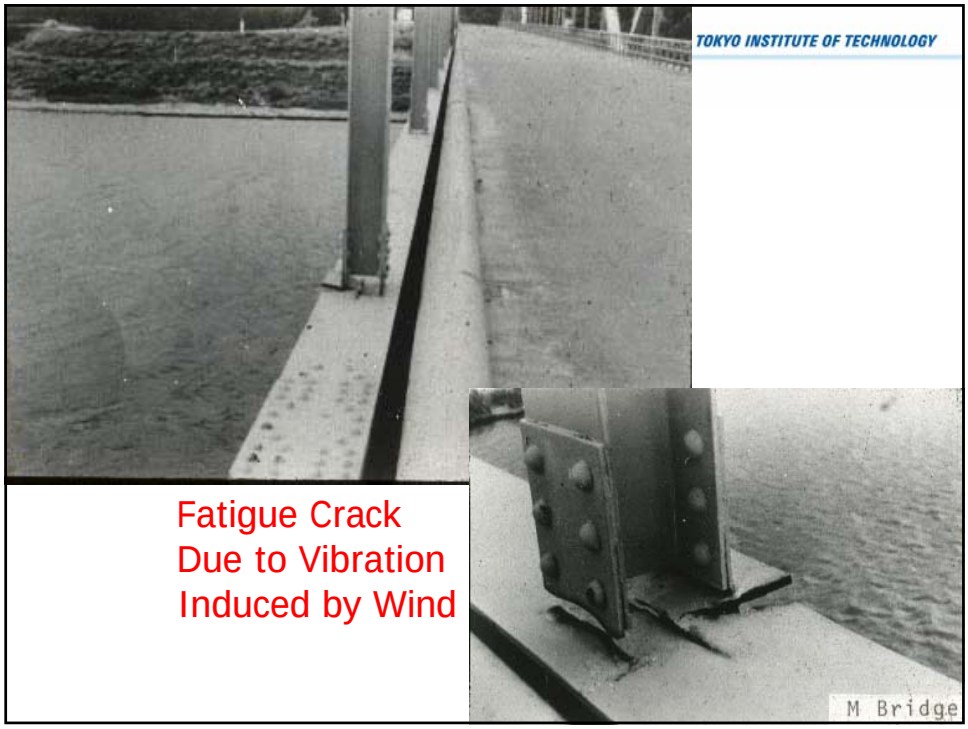
Brittle Fracture
In Hoan Bridge, 2000, USA

Fatigue Cracks in Joints between Longitudinal Girders and Transverse Girders (JR East, Chuo-Line)





Fatigue Crack
Due to Vibration
Induced by Wind

Fatigue Crack
Butt Welded Joints

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Brittle Fracture
Originated from Fatigue Crack

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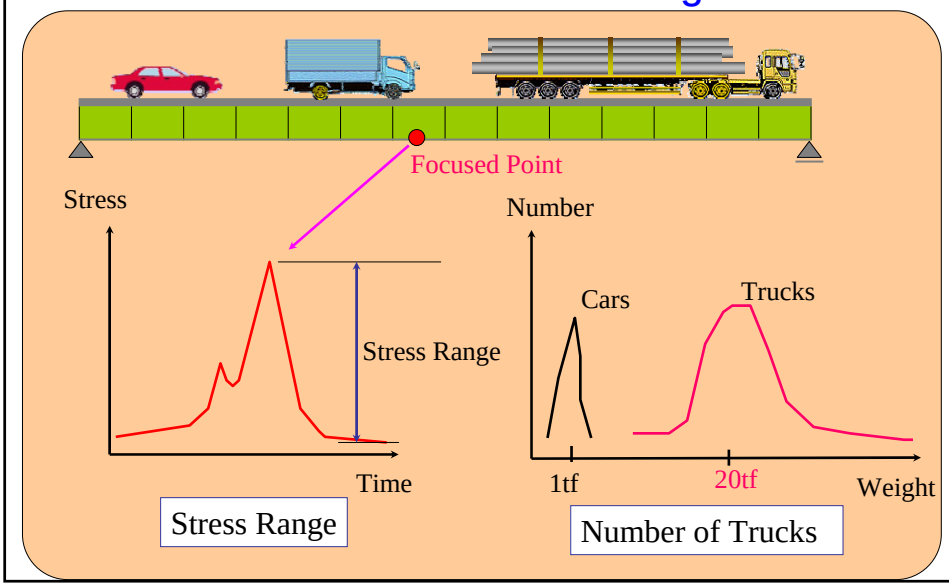
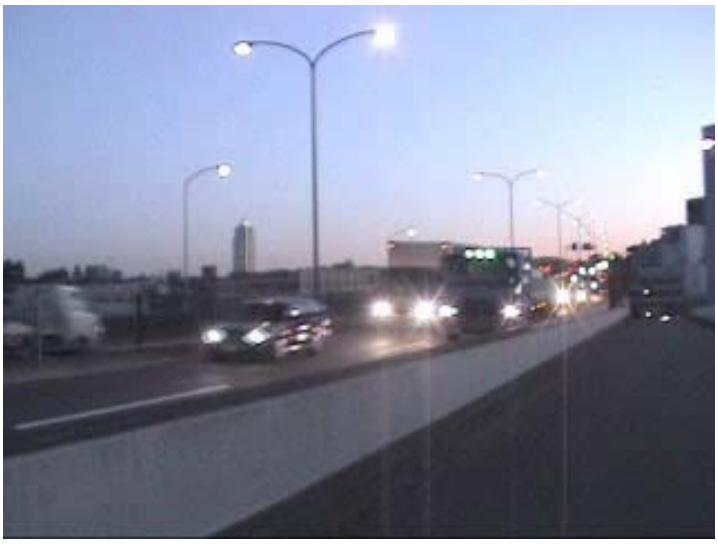
Dominant Factors on Fatigue



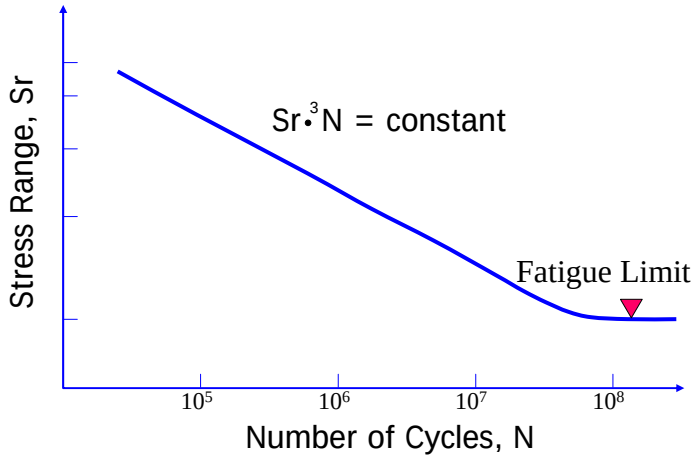
Traffic on M-Bridge (Tokyo, Japan)

Traffic Volume 80000/day

Traffic on Tamagawa Viaduct



Feature of Fatigue Phenomenon

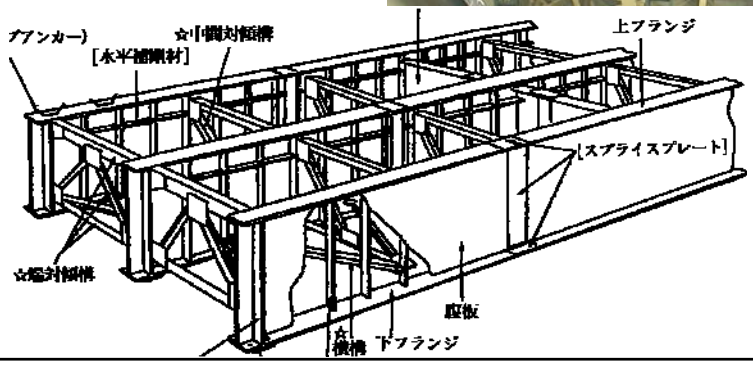


Steel Bridge Structures

Various Types of Joints

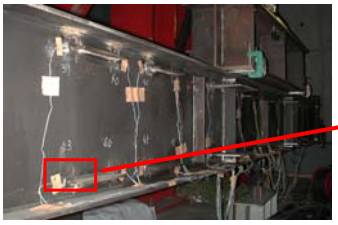
Bolted Joints | Welded Joints

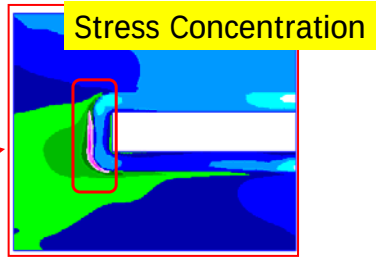
Fatigue Problem



Causes of Fatigue Damage in Welded Joints

- Stress Concentration





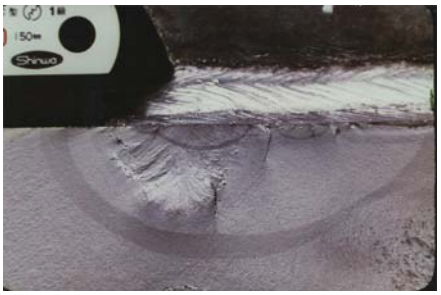
- Weld Defects

  Blow Hole
  Slag Inclusion
  Crack
  Lack of Fusion
  etc

Slag Inclusion

Fatigue Cracks from Slag Inclusion

Fatigue and Fracture



Initiation and Propagation

↓

Brittle Fracture

Brittle Fracture

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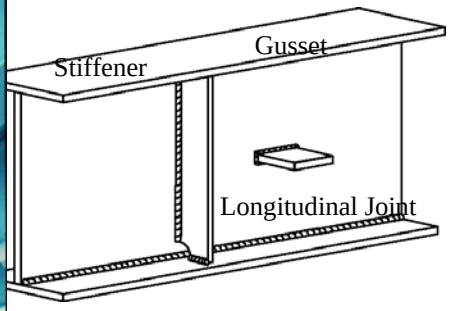
Influential Factors of Fatigue in Welded Joints

Types of Welded Joints, Configuration of Welding, Weld Residual Stress, Loading modes, ...



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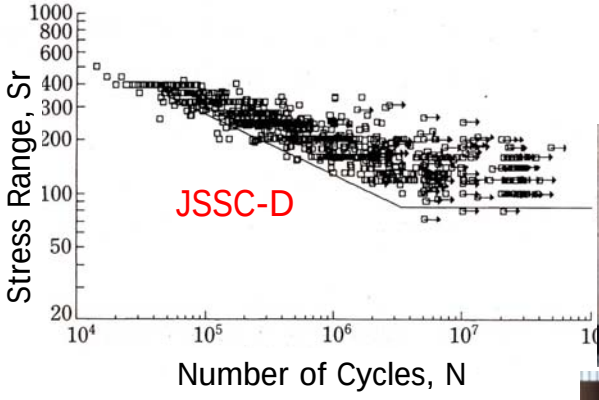
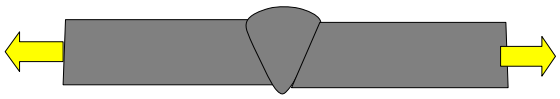
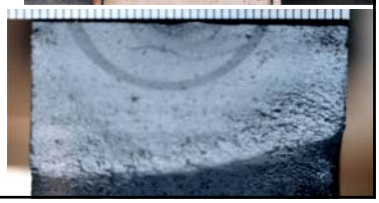
Butt-Welded Joints







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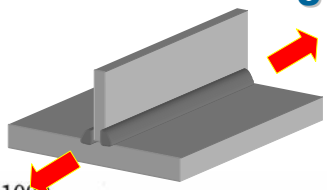
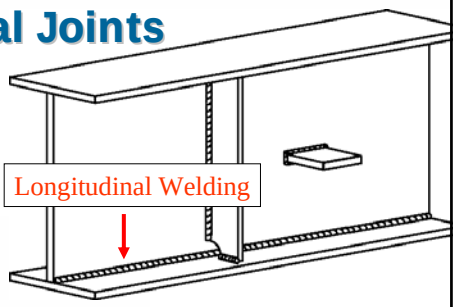
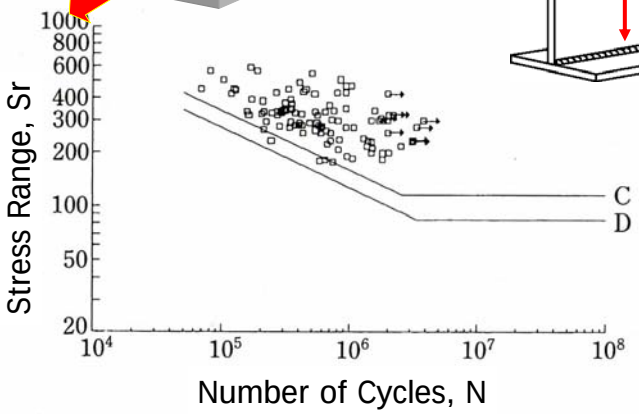
Longitudinal Joints







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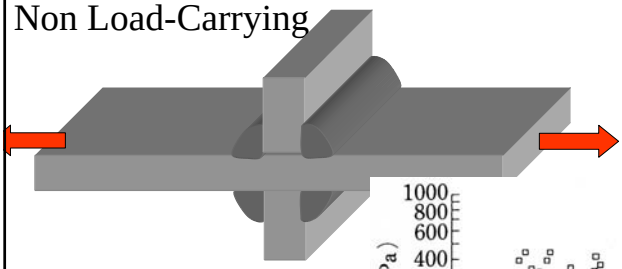
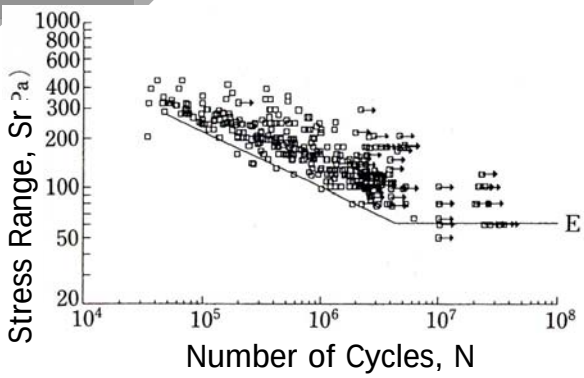
Cruciform Joints

Non Load-Carrying





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Social Infrastructure

Constructed in the Order of Demand(1960s-1970s)

The Greater the Importance
The More Severe the Service Condition
The Earlier the Used Technology

Fix it？

or

Scrap it？

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The Metropolitan Expressway (40 Years Ago)

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Welded structures ----Sensitive to fatigue

Welded bridges : positively adopted since 1960

Main highways and railways in Japan
Tomei, Metropolitan Exwy,
Shinkansen, ...

Fatigue damage in Japan

1970- Shinkansen bridges
1980- Highway bridges

Fatigue Cases and Retrofit Works in Steel Bridges

Causes of fatigue damage

1. Weld-defects
2. Inappropriate structural details
3. Unforeseen stresses and displacements
4. Unexpected structural behavior, such as vibration

Repair and/or Retrofit methods Immediate measure?

Remove the causes of damage
Increase fatigue resistance
Lower applied stress range

Explanations of the causes of damage is indispensable

Cause-1: Existence of weld-defects

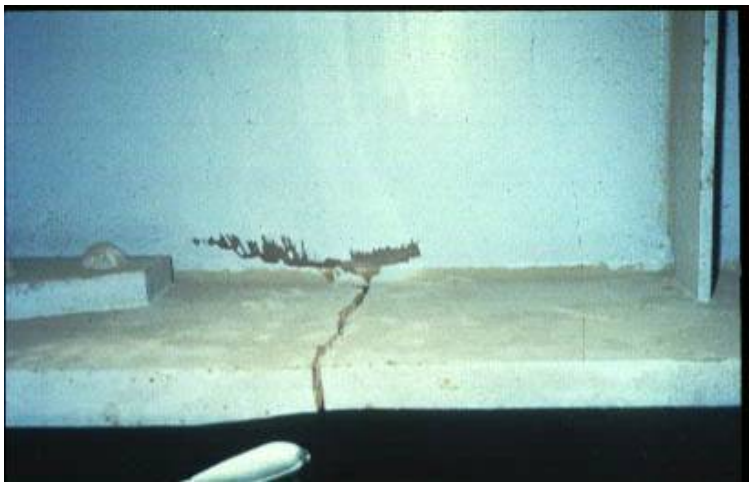
Butt welds--------NDE

Various types of defects and flaws
- Cracks
- Incomplete penetrations --→fatigue
- Slag inclusions
- Porosities
- Lack of fusions

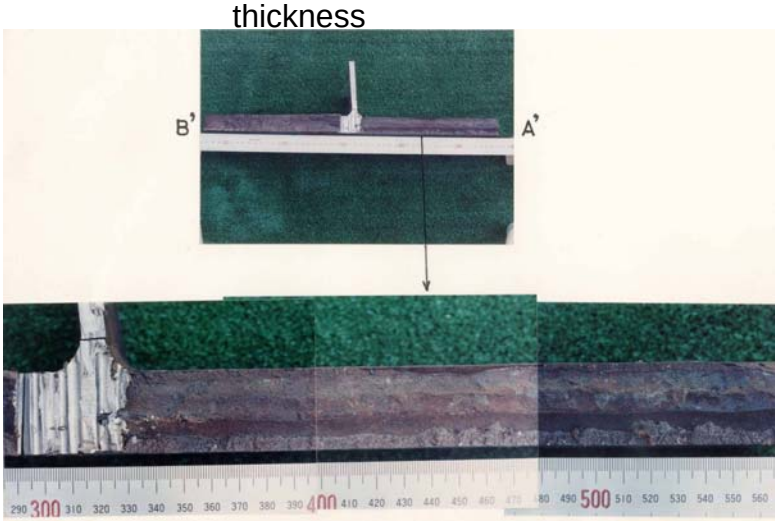
Case study : Plate girder bridge

Fatigue crack propagated through girder flange

Incomplete penetration in butt-welds of bottom flanges

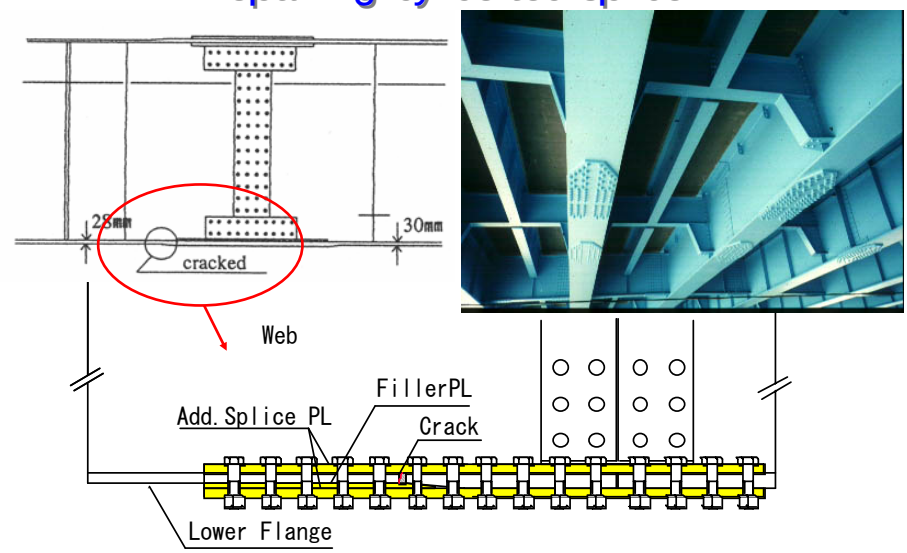


Fracture Surface: Unwelded Zone reaches 60-80% of plate thickness



All welded joints of same detail were inspected and several defects with fatigue cracks were found.

Repairing by bolted splice



Cause-2:Adoption of low fatigue resistance detail

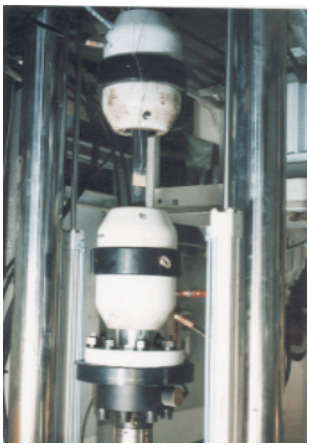
Case-1: Bridges were not designed against fatigue
many cases of poor structural detail

Case-2: Allowable stresses were inappropriate:
appeared as the differences between old code and new code
old codes based on fatigue test results of coupon type small specifications
Most of cases, size effects of fatigue strength

Full size and large size fatigue tests
in U.S.A. 1970-
in Japan 1975-

Importance of Size Effects

Welded joint specimen



Full scale floor beam

Results of Fatigue Tests S-N Curve

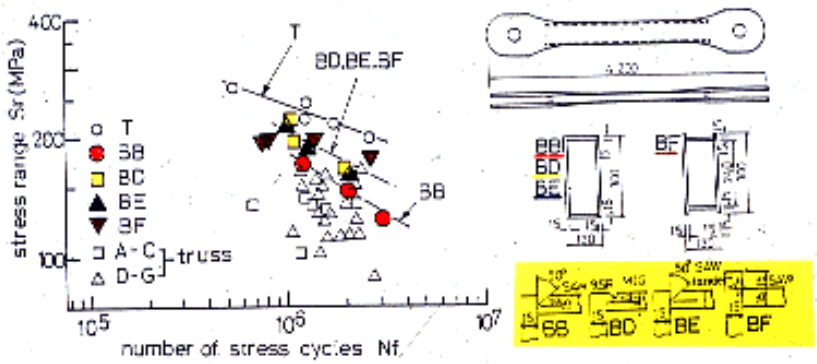


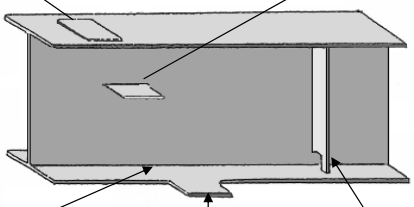
Fig. The fatigue strengths of corner joint

Wide difference of fatigue strength

Change of allowable fatigue stresses from ’60 code to ’92 code

Joint Type	Sleeper pad	
Code	Class	Fatigue strength at 2 million cycles (MPa)
Old code '60	$\overline{D}$	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



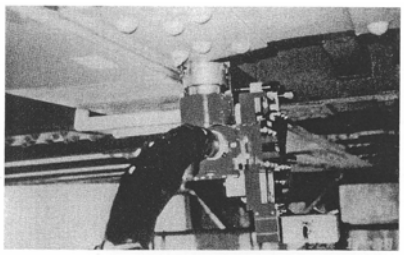
Joint Type	Longitudinal welding	
Code	Class	Fatigue strength at 2 million cycles (MPa)
Old code '60	B	150
Current code '92	C	125

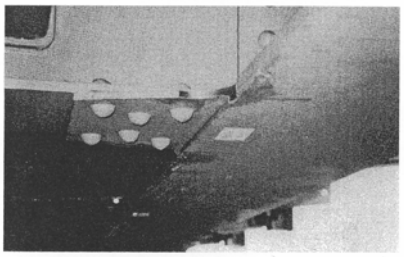
Joint Type	Cruciform weld	
Code	Class	Fatigue strength at 2 million cycles (MPa)
Old code '60	D	100
Current code '92	E	80

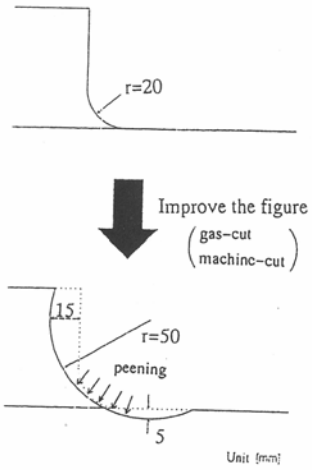
Joint Type	In-plane gusset (t=20mm)	
Code	Class	Fatigue strength at 2 million cycles (MPa)
Old code '60	C	126
Current code '92	F	65

Improving works of flange gusset detail

Lower stress concentration



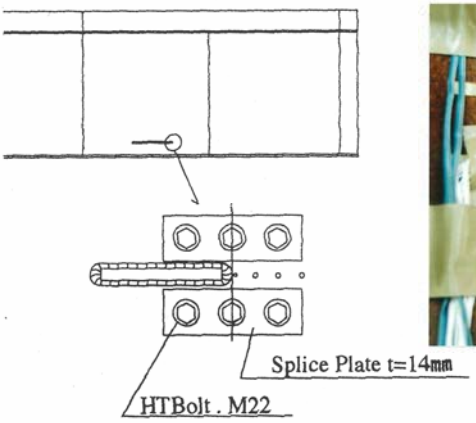




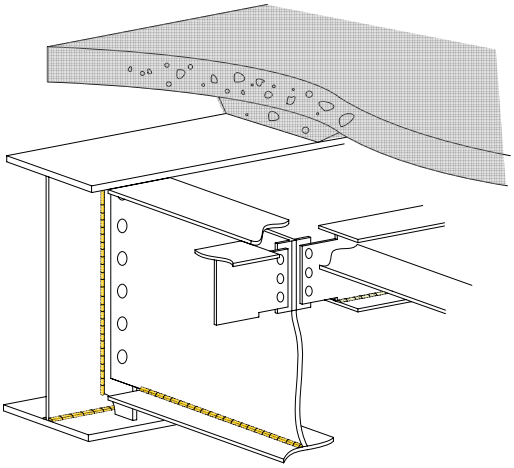
Fatigue improvement methods: , Peening, UIT

Improving works of flange gusset detail

Lower applied stress range



Cause3: Unforseen Stresses and Displacements



In design:
Connection between
Main girders – floor beam
Floor beams – stringers
Stringers –deck

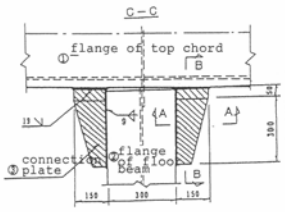
Simple support

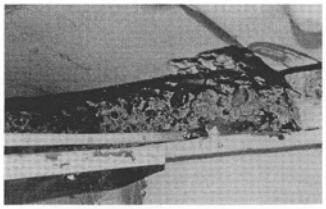
Courtesy of NHK Kofu

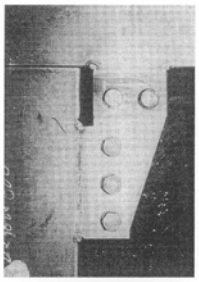
Fatigue Cracks in Joints between stringers and floor beam
(JR East, Chuo-Line)

Truss girder in Tokaido Shinkansen
Floor beam - stringer

Retrofitting works: Floor beam and the flange of truss top chord was connected directly using a connection plate







Grooving by applying water jet

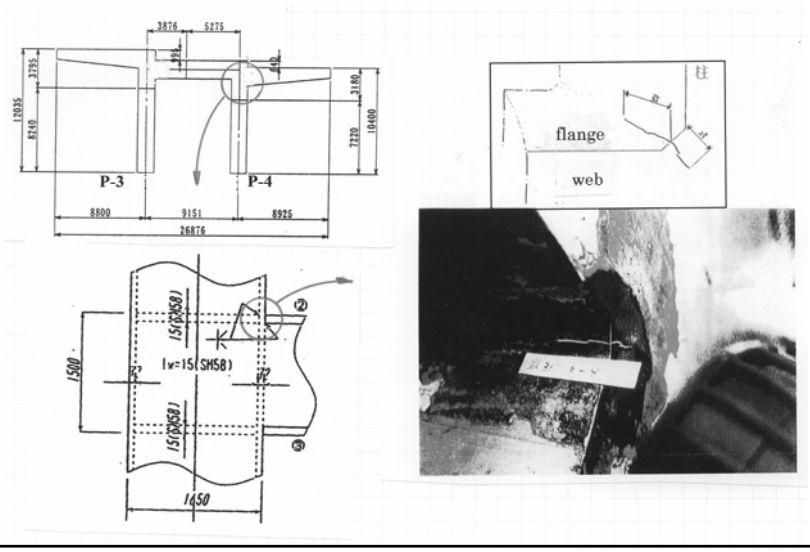
Retrofitting Work to Steel Bridge Bents in MEX

more than 2000 steel bents in MEX way

No consideration on fatigue
Because of highway structures and bents

Poor structural details
Weld defects

Damage Case MEX Ikejiri



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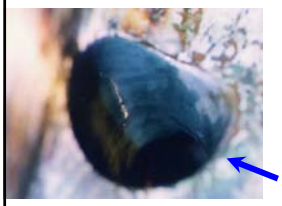
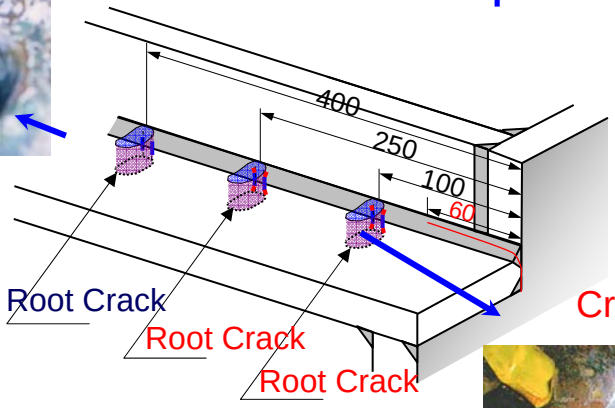
Drilling as Stop Holes
Observation of weld-penetration





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Typical Plate Assembling Methods

WW

WF

FW

FF

SWW

SFF

Remaining of weld defects is inevitable from these joint details
Welders can not access to welding spots!!

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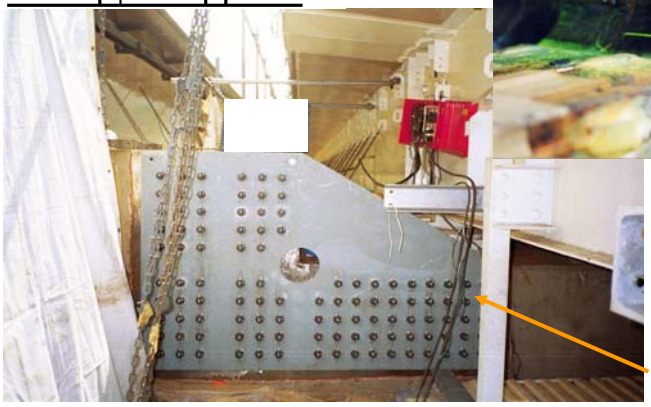
As a Temporary Measurer, Splicing by Bolts

Fatigue Damage



Lower applied stress range

Splice Plate

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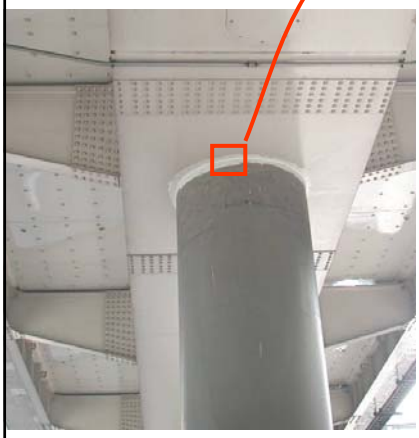
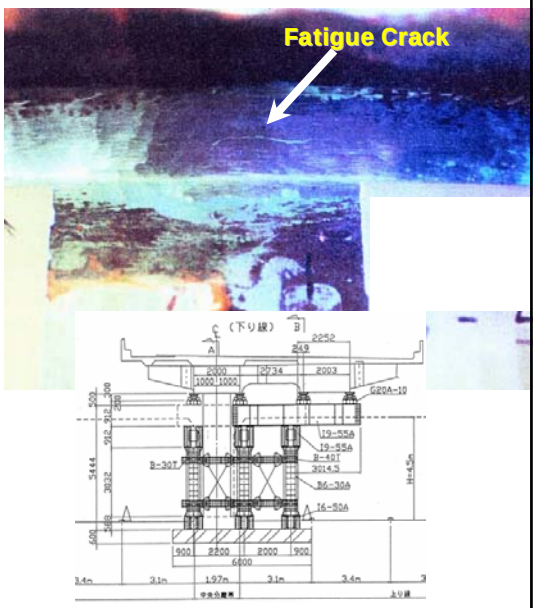
Remove weld defects with fatigue cracks by large hole drilling method

MEX Hirakawa-Cho

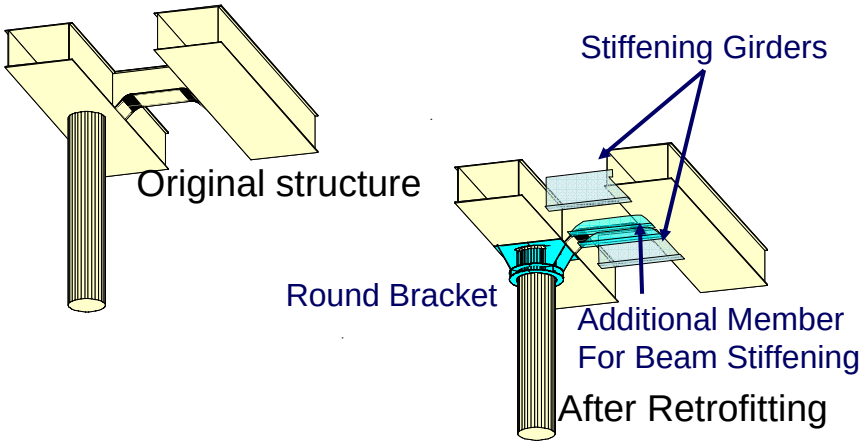
Single column of circular section support two box section girders



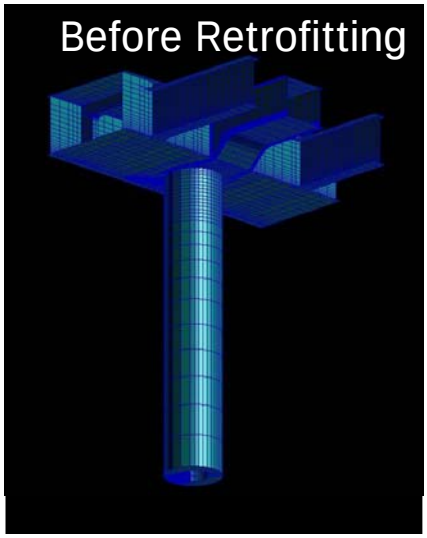


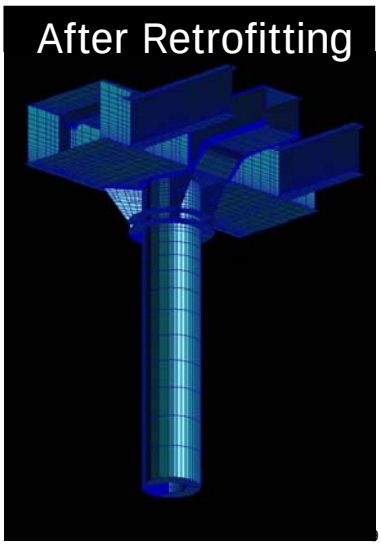
Retrofitting work

Lower applied stress range by changing load carrying pass



FEM Model





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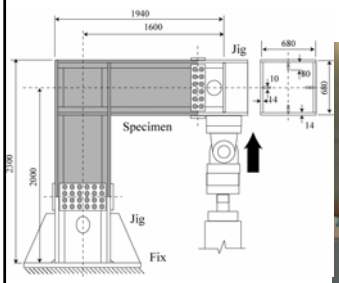
Large Scale Loading Tests (1/3 scaled)



Rectangular Column

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Full Scale Loading Tests

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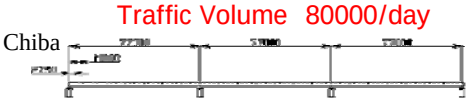
Case study:Orthotropic Steel Bridge Deck

- Poor structural details
- Heavy trucks, over weight

Retrofitting works
Preventive Works against Fatigue Damage

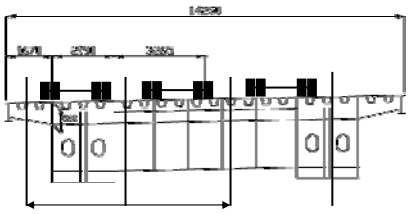
Fatigue Damage Case - M-Bridge -

25 years Old
Traffic Volume 80000/day

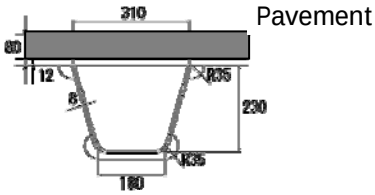


Three-Span Continuous Bridge

Interval of Transverse Ribs: 2.75m
Interval of Cross Girders : 11m



Passing Lane Driving Lane



Conventional Detail

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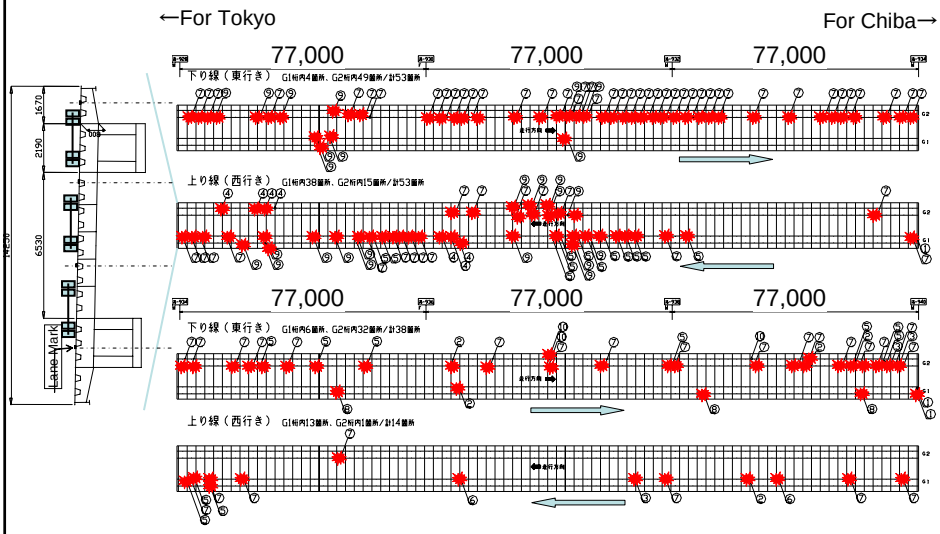
Map of fatigue cracks



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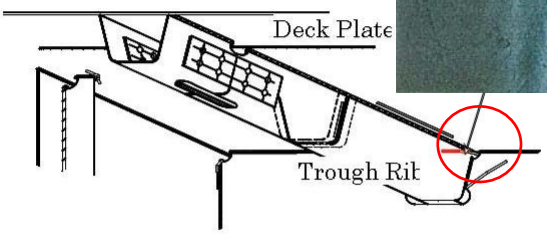
Type-1 Fatigue Cracks

Trough Rib to Deck Plate Connection



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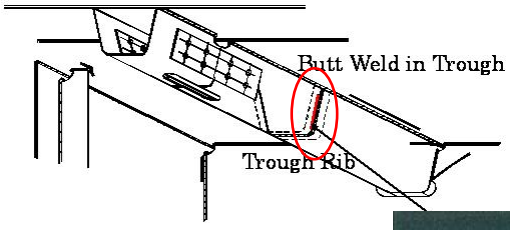
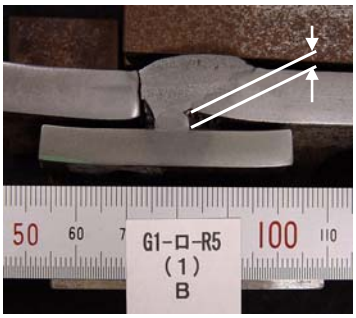
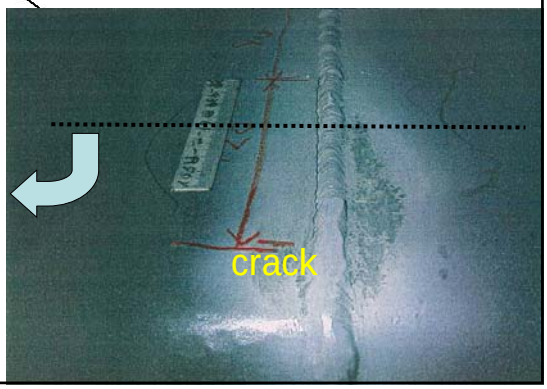
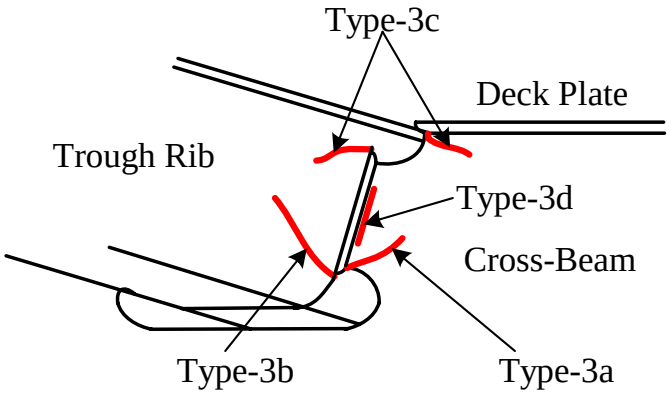
Type-2 Fatigue Cracks



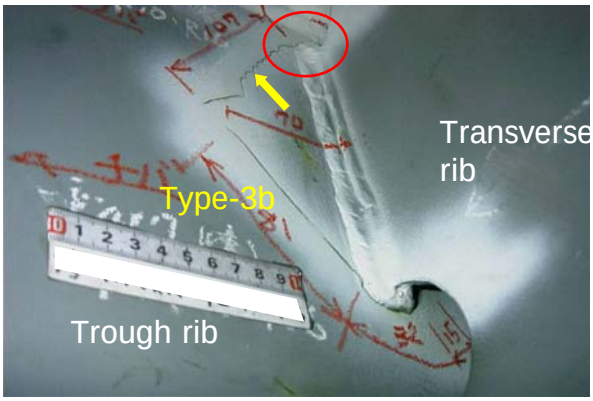




Crack Modes of the Intersection of Trough Rib and Cross-Beam (Type-3)



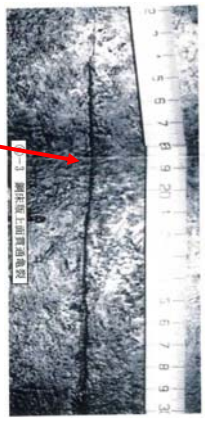
Type-3b,c Fatigue Cracks



Type-3c;occurs from the web side toe of the trough rib in the boxing weld

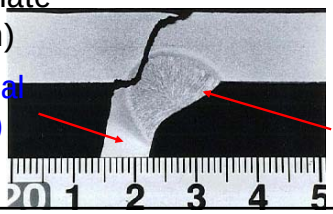
Fatigue Cracks in The Deck Plate

After Removal of Pavement



Deck Plate (12mm)

Longitudinal Rib (8mm)



welding

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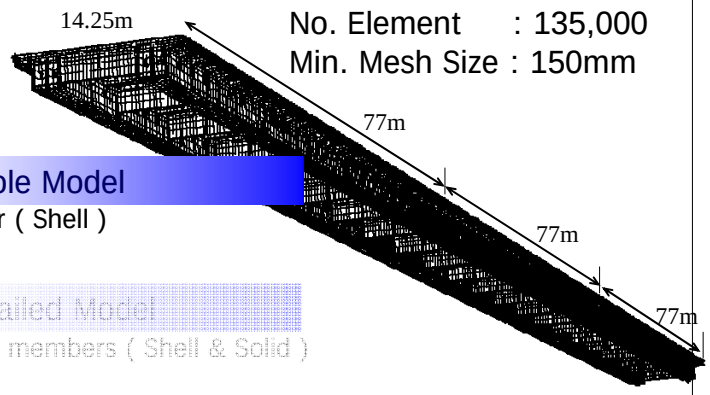
FEA Model

Models : Necessary to evaluate local behavior



No. Element : 135,000
Min. Mesh Size : 150mm

Step1 : Whole Model
Whole behavior (Shell)
Zooming

Step2 : Detailed Model
Deformation of members (Shell & Solid)
Zooming

Step3 : Zoomed Model
Stress behavior around connections (Solid)

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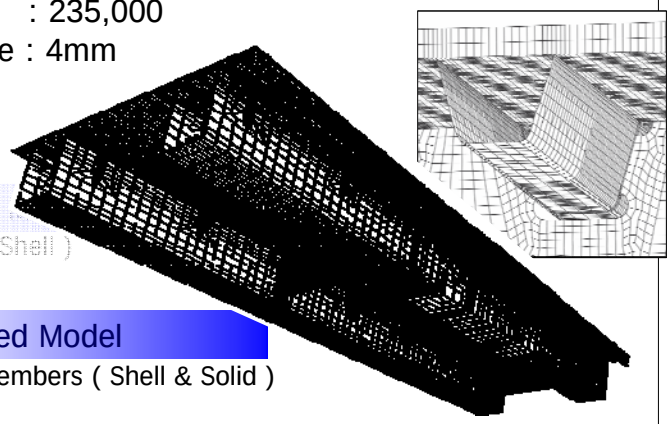
FEA Model

No. Element : 235,000
Min. Mesh Size : 4mm

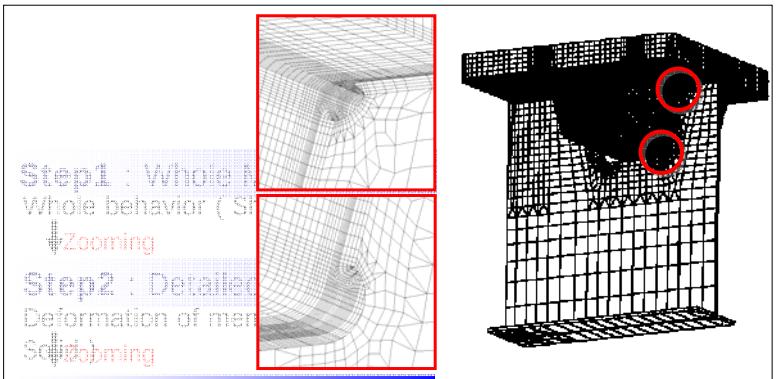


Step1 : Whole Model
Whole behavior (Shell)
Zooming

Step2 : Detailed Model
Deformation of members (Shell & Solid)
Zooming

Step3 : Zoomed Model
Stress behavior around connections (Solid)

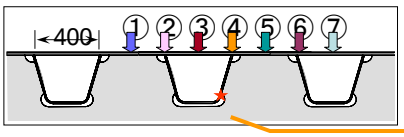
FEA Model

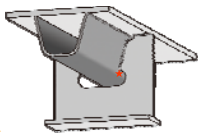


Step3 : Zoomed Model
Stress behavior around connections
(Solid)

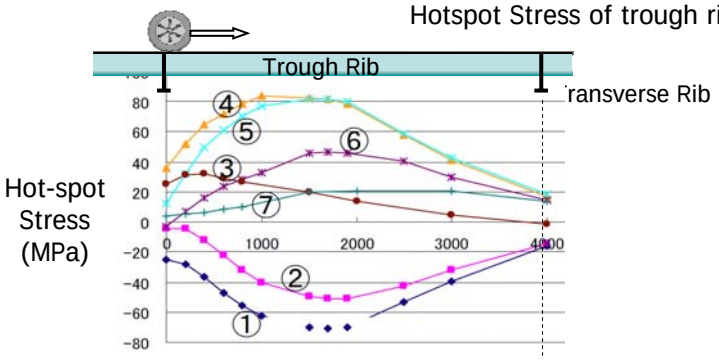
No. Element : 130,000
Min. Mesh Size : 0.4mm

Stress Changes with the location of Axle Loads





Hotspot Stress of trough rib



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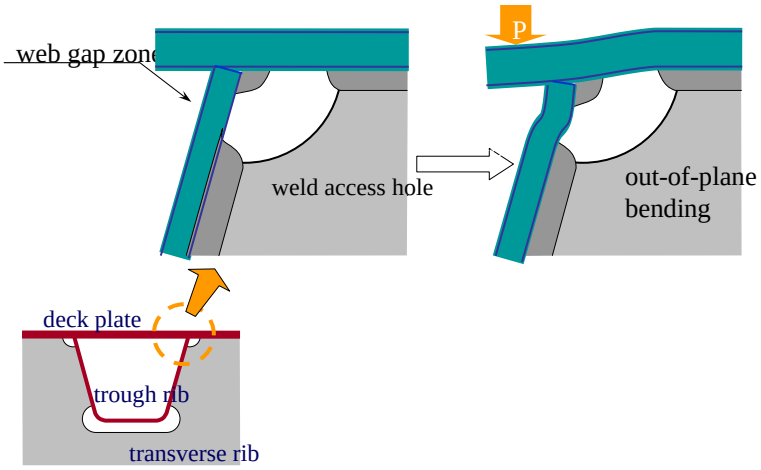
Out of plane bending at web gap zone



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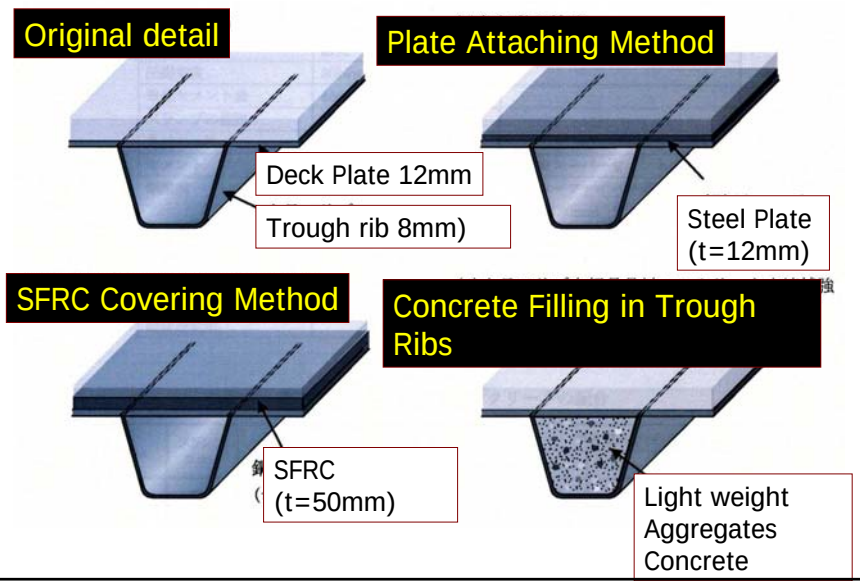
Candidates of Retrofitting works



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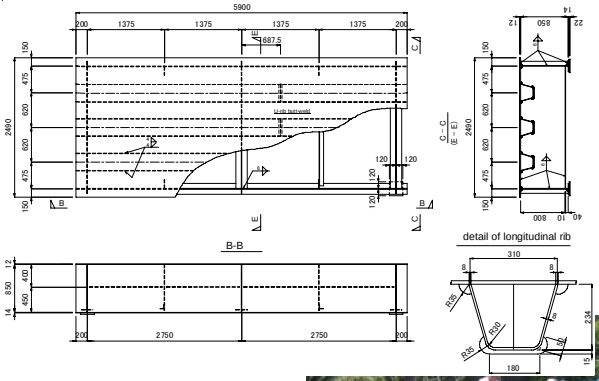
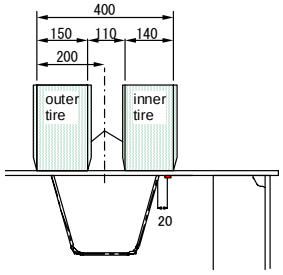
Effects of Retrofitting Works (Experiments)





Specimen

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Effectiveness of retrofitting works is examined by truck loading Test, first

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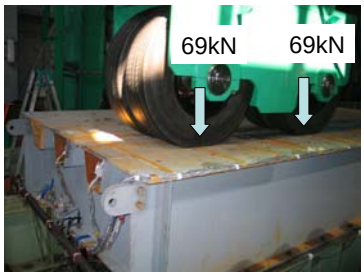
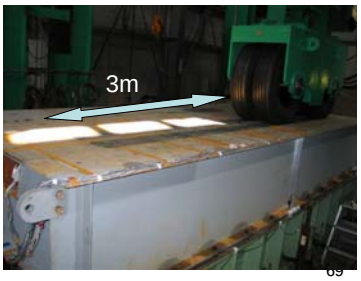
Fatigue performances are examined by Wheel Running Fatigue Test

Loading system:

actual double rubber tire tandem axle

Corresponding to the rear wheels of 350kN class truck





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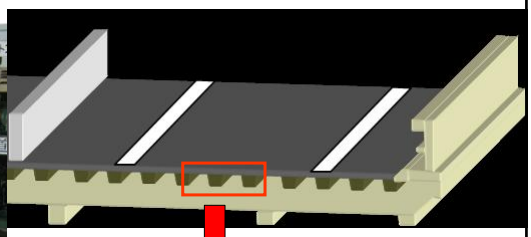
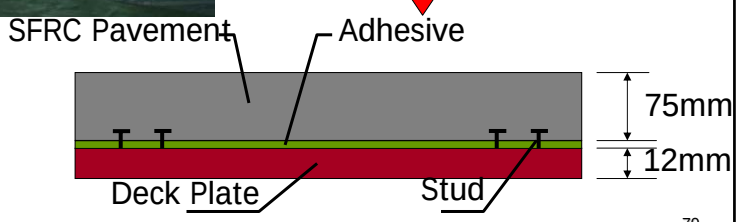
As a preventive work, orthotropic steel deck is changed to Composite Orthotropic Steel Deck





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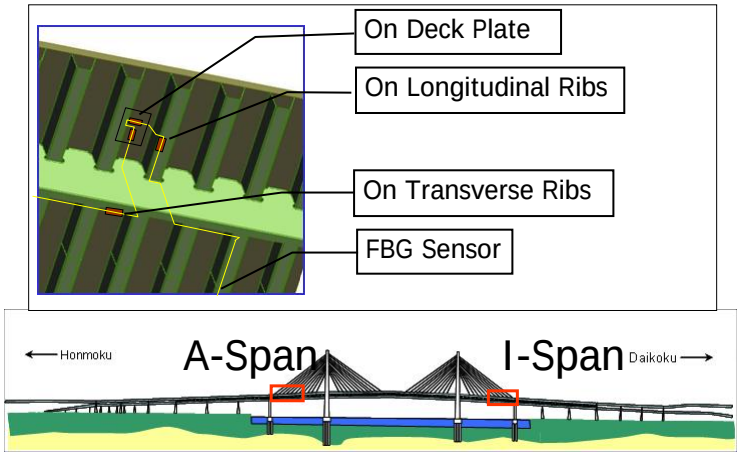
Long-range performance monitoring

Effectiveness of this preventive work of long-range has been monitoring by using FBG sensors and Weigh-in-Motion results



Future works

- **Early detection and appropriate measure**

  real time monitoring and data manage system

  how to judge, damage type and appropriate measure

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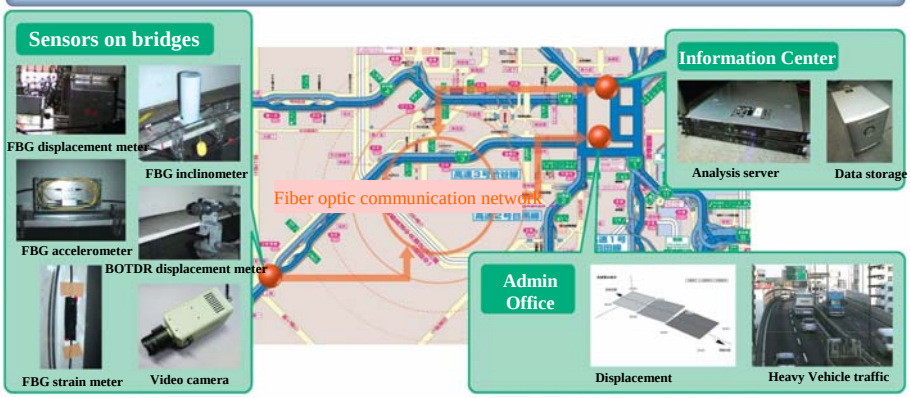
~ Real-time Bridge Health Monitoring System ~ System Overview

■OBJECTIVES

- Quick detection of damages on bridges in a earthquake
- Early detection of damages on bridges in a daily use
- Continuous traffic detection for fatigue damages caused by heavy vehicles

■ADVANTAGES

- "time-serial", "automatic", "remote" and "real time" data collection
- Statistic information is also available



Road map (c) Metropolitan Expressway Company Limited 73

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Output Information

~ Real-time Bridge Health Monitoring System ~

Disaster Management	Maintenance Management	Fatigue Estimation
Quick damage detection	Early damage detection	Continuous traffic detection
inclinometer, accelerometer: main girders and piers angularity, vibration; displacement meter: main girders distance	inclinometer, accelerometer: main girders and piers angularity, vibration; displacement meter: main girders distance	video camera: vehicle images; strain meter: main girders stress
Damage level	Statistical data change	Accumulative traffic

Geographical Representation

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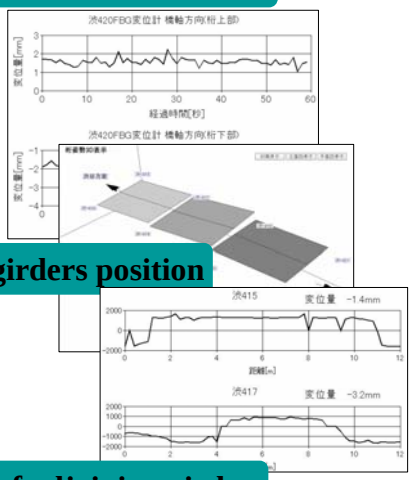
Administration Support System

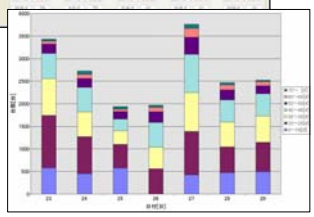
Real-time Measurement



Main girders position

Gap of adjoining girders

Heavy vehicle detection



Heavy vehicle traffic (statistics)

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