TOKYO TECH Pursuing Excellence

国立大学法人 東京工業大学

Non-Destructive Evaluation (NDE)

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Purpose of Inspection

In-service structures

Safety or not → NDE is the only method to inspect without damage to structures.

Advantage of NDE

- Selection of appropriate repairing and retrofitting method
- Life prediction by fracture mechanics
- Periodic inspection schedule

Types of NDE Methods

2 main types for different types of cracks

Surface-breaking cracks

VT : Visual Testing
PT : Dye Penetrant Testing
MT : Magnetic Particle Testing
ET : Eddy Current Testing
UT : Ultrasonic Testing

Embedded cracks

difficulty in detection because they are invisible!!

UT : Ultrasonic Testing
RT : Radiographic Testing

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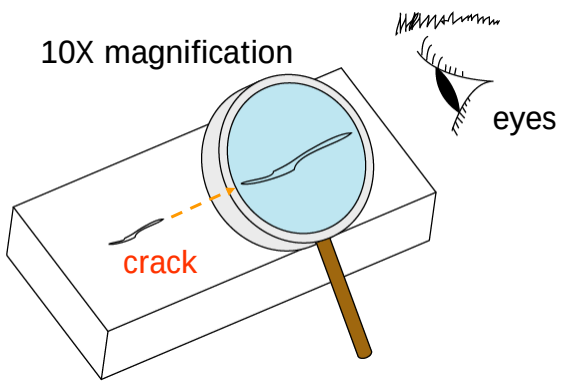
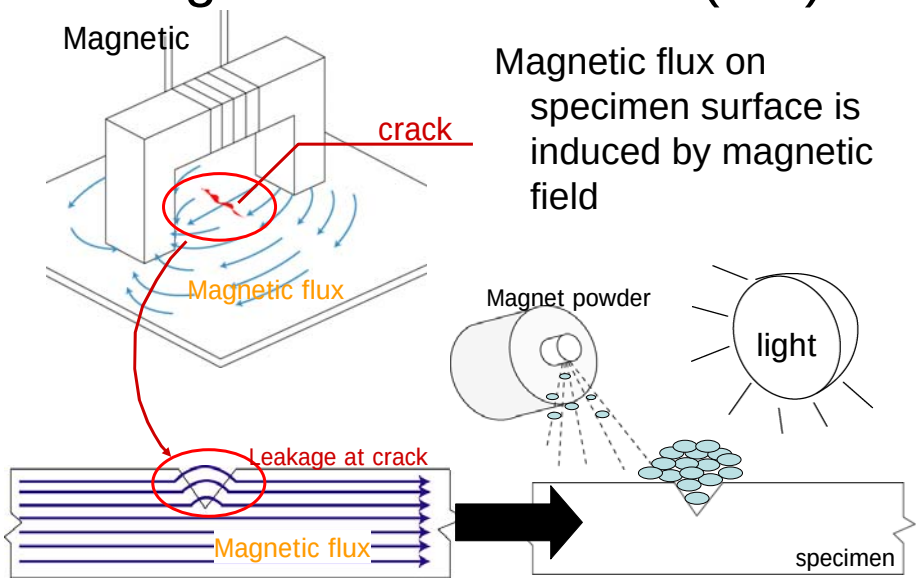
Visual Test (VT)

Preliminary inspection of structures

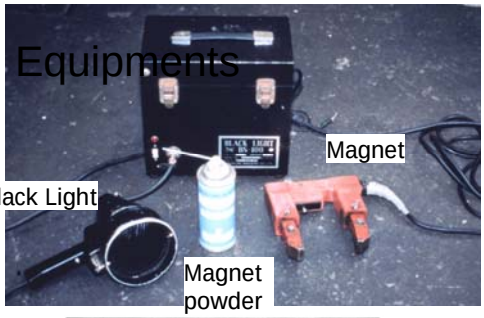


Magnetic Particle Test (MT)



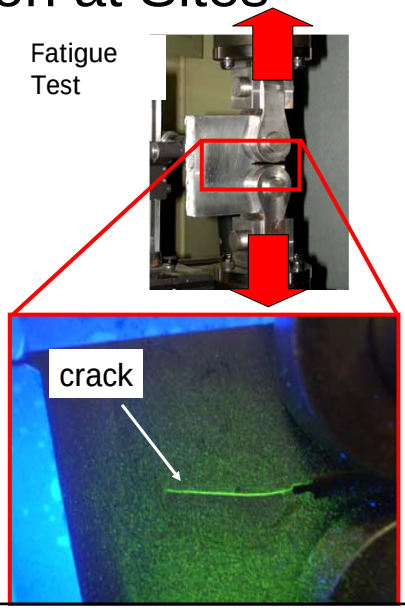
Magnetic flux on specimen surface is induced by magnetic field

MT – Application at Sites



Testing

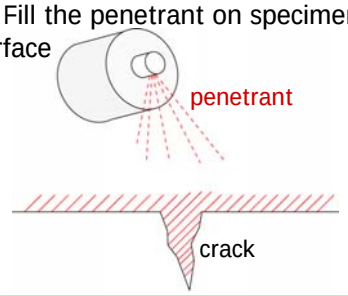
Fatigue Test



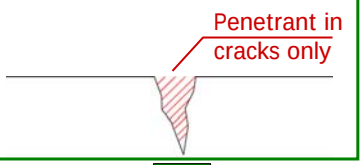
Dye Penetrant Test (PT)

Theory

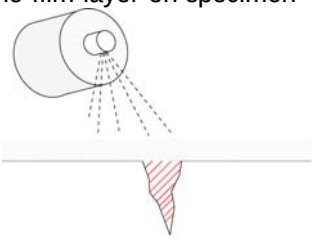
1. Fill the penetrant on specimen surface



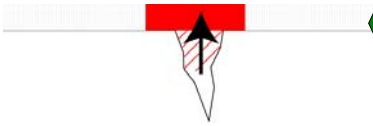
2. Clean specimen surface (eliminate excessive penetrant)



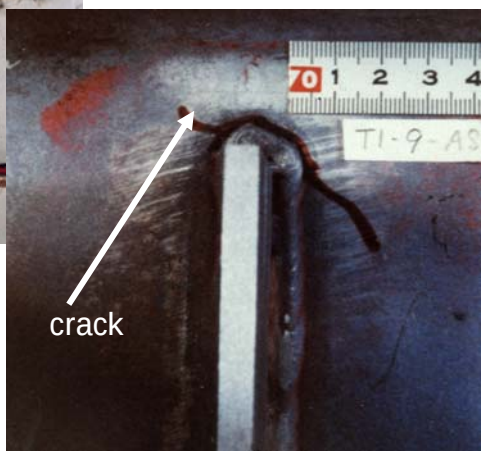
3. Fill the film layer on specimen



4. Penetrant leaks to film layer resulting in image of crack

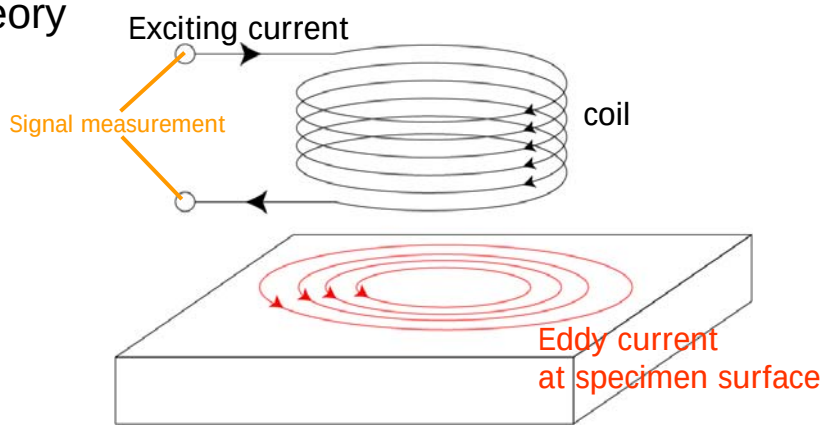


PT – Application at Sites



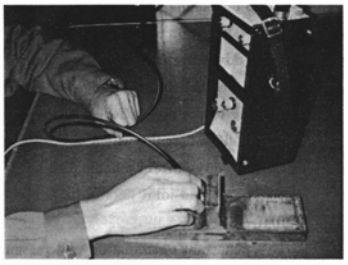
Eddy Current Test (ET)

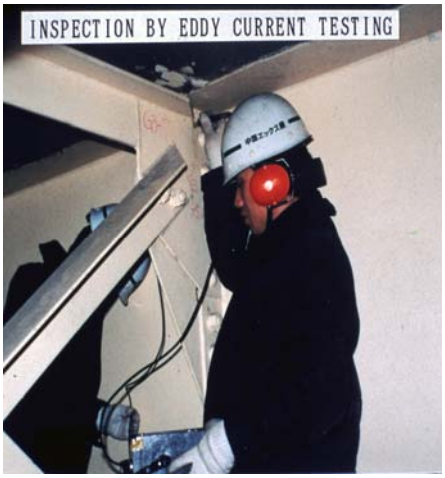
Theory



If there is cracks or defects, signals will change

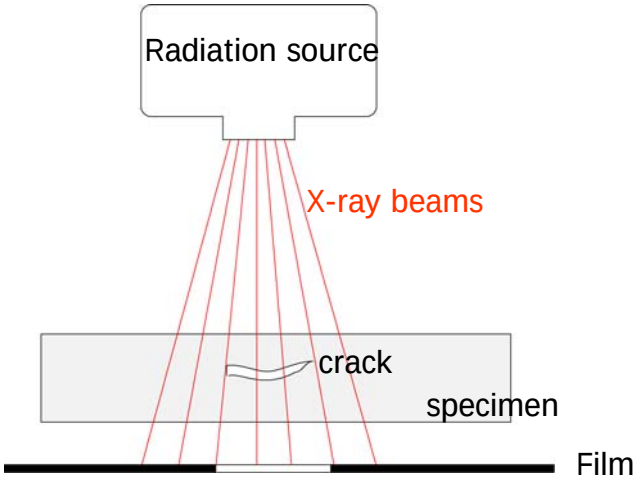
ET – Application at Sites



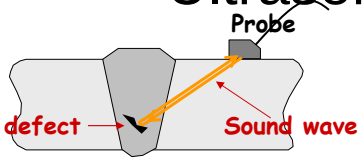


Radiographic Test (RT)

Transmit X-rays to a specimen and a film



Ultrasonic Test (UT)

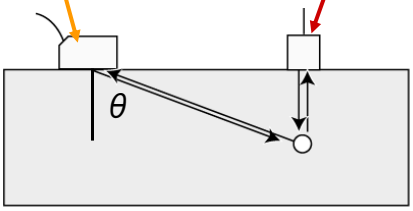


- Quality control of welds in shops
- Maintenance inspection in sites

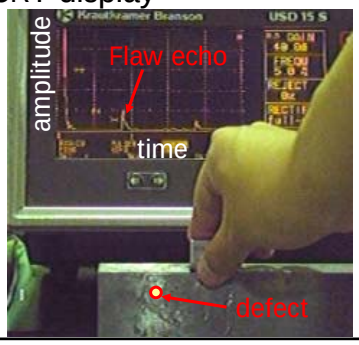
Types of probes

Normal-beam probe

Angle-beam probe:
45º, 60º, 65º, and 70º



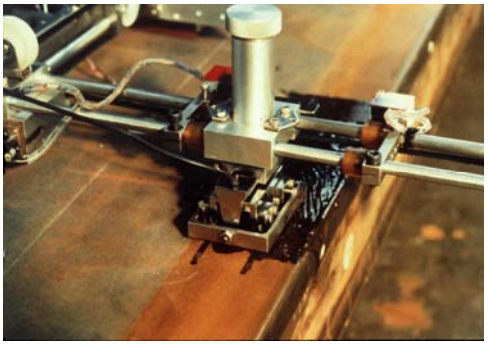
A-Scan:
Observe the flaw echo via CRT display



UT – Application at Sites

Manual UT (MUT)

Automatic UT (AUT)



Research Works on NDE

Topics

- Detection of surface-breaking fatigue cracks
  Chitoshi Miki, Makoto Fukazawa, Masahiko Katoh, and Hisao Ohune: Journal of Structural Eng./Earthquake Eng., JSCE, No.386/I-8, pp. 329-337, 1987.10. (in Japanese)

- Effects of paint films on detectability of cracks by NDI methods
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- Current development of ultrasonic testing systems (2001~2004)

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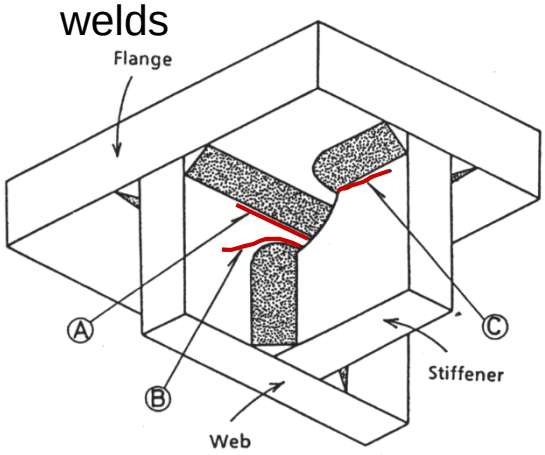
Surface-Breaking Fatigue Cracks

Fatigue cracks initiated at toes of fillet welds



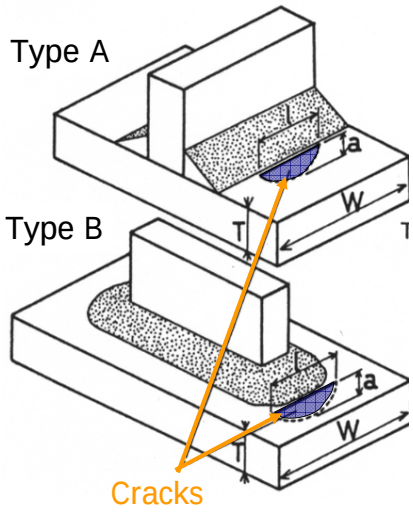
1. MT
2. PT
3. ET
4. RT
5. UT

Which is the most promising method ?

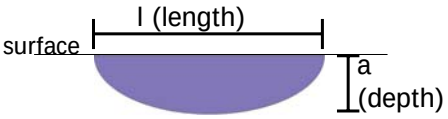
How is the resolution of the method?

Specimens and Inspection Methods

Specimens with fatigue cracks



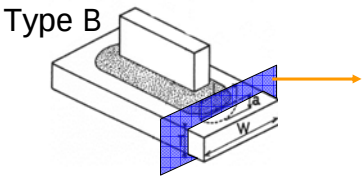
Fatigue cracks were introduced by 3-points bending test.

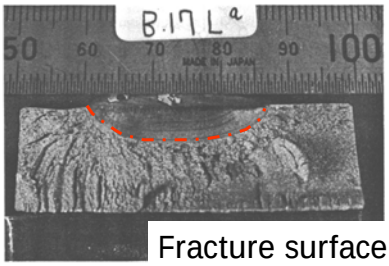


Inspection methods

- Length of cracks
  MT, PT, ET
- Depth of cracks
  UT

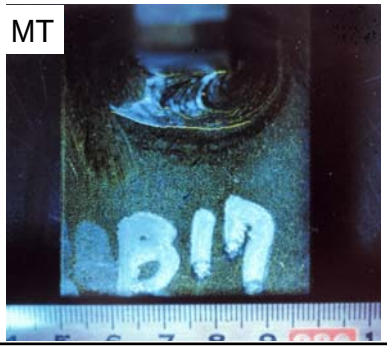
Fracture Surfaces and Results



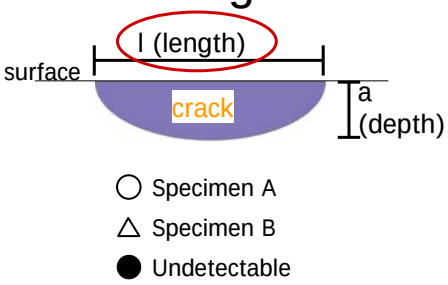


Fracture surface

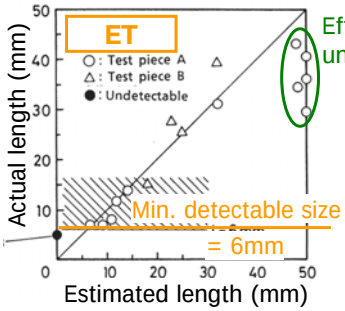
Results

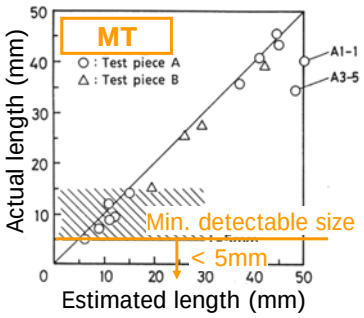


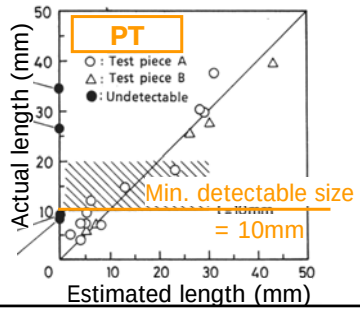
Length Estimation Results



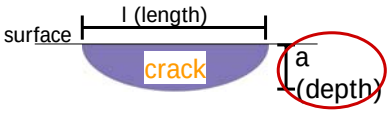
○ Specimen A
△ Specimen B
● Undetectable







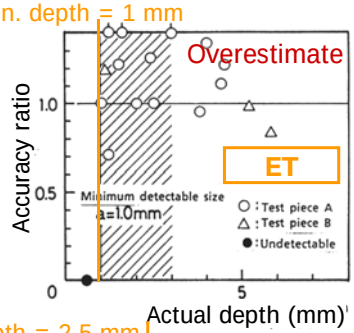
Minimum Detectable Crack Depths



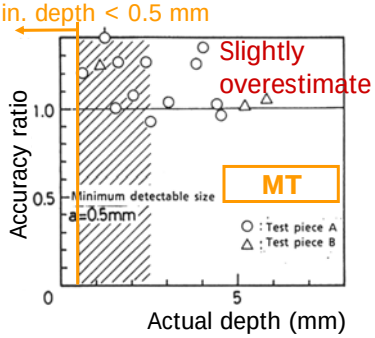
Accuracy ratio = Estimated / Actual

Ratio > 1 → Overestimate
< 1 → Underestimate

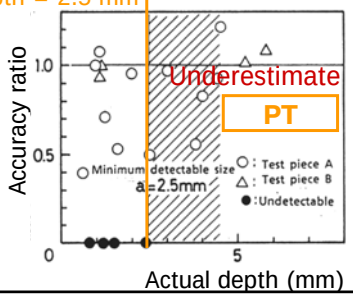
Min. depth = 1 mm



Min. depth < 0.5 mm

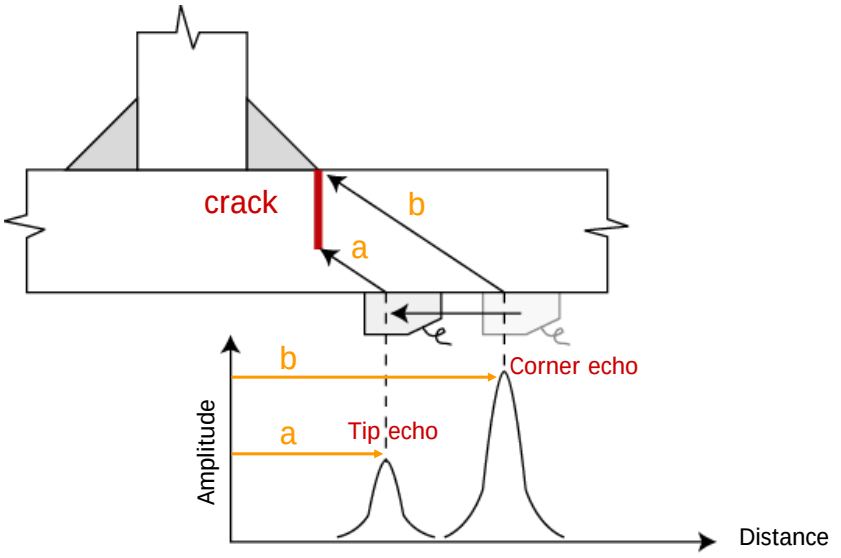


Min. depth = 2.5 mm

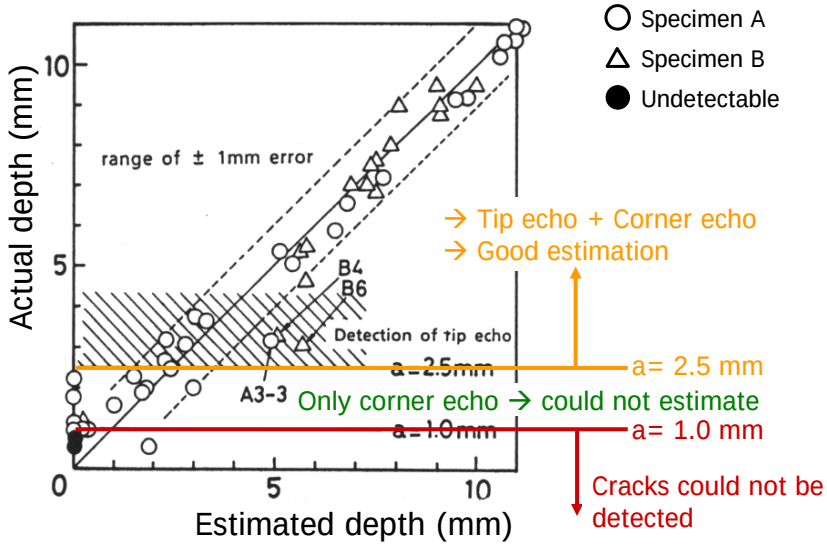


Estimation of Crack Depths by UT

Tip-echo method



Results of UT



Summary

Minimum detectable sizes of defects by NDI methods

For MT, ET, PT

	Size		Detection of crack(a ≧ 5mm)
	ℓ	a	
MT	<5mm	<0.5mm	Overestimated
ECT	6mm	1.0mm	Overestimated
PT	10mm	2.5mm	Underestimated

For UT

	Minimum Detectable Depth	Accuracy
Corner Echo	1mm	-----
Tip Echo	2.5mm	± 1mm

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- Current development of ultrasonic testing systems (2001~2004)

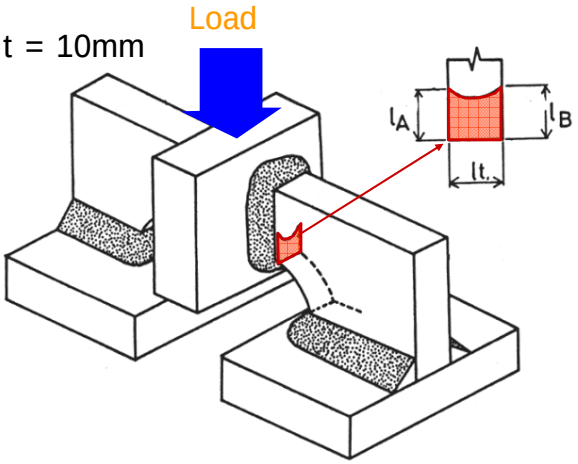
Paint Films

Most of steel bridge members are coated with paint.

Paint films prevent steel bridges from weathering corrosion.

How does it affect the inspection ?

Specimens with Paint Films



→ **Before** removal of paint

→ **After** removal of paint

VT, ET, MT, PT, UT

Painting Process

Process		Painting Material	Standard amount used (g/cm²)	Painting Interval (20°C)
Work Shop	1st layer	Etching Primer	Spray 130	12H-3M
	2nd layer	Rust Resisting Paint	Spray 170	2D-1M
	3rd layer	Rust Resisting Paint	Spray 170	2D-6M
Field	4th layer	Phthalic Resin Coating	Brush 110	24H-15D
	5th layer	Phthalic Resin Coating	Brush 105	

Total Thickness =100 μm

5 Layers

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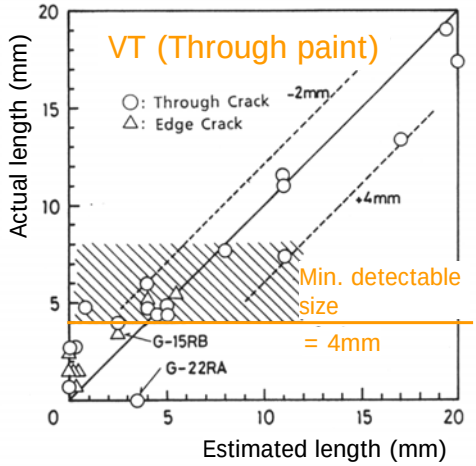
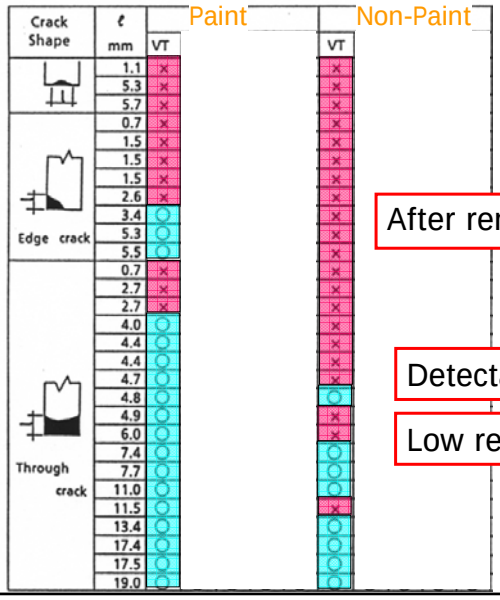
Inspection Results – VT (I)



Discontinuities of paint films are the **sign of presence of cracks** → Easy to detect

Inspection Results – VT (II)



= Correct Judgment

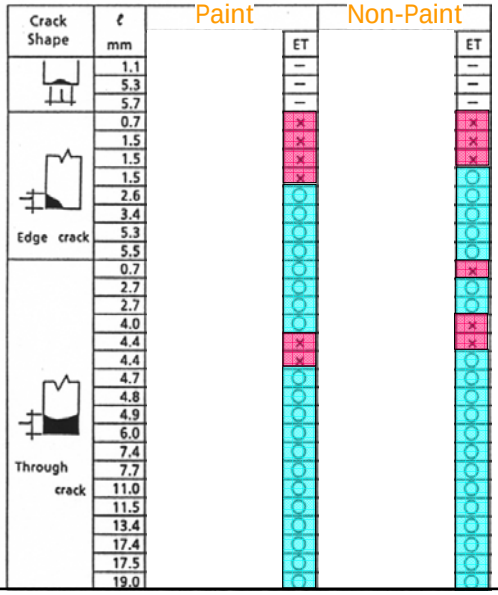
= Misjudgment

After removal ⟶ No sign of cracks

Detectability largely decreases

Low reliability

Inspection Results – ET

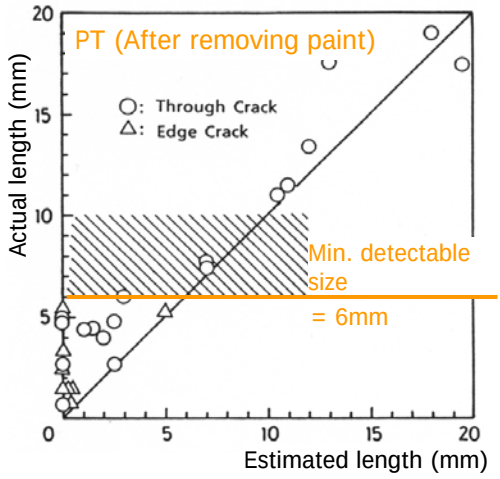


= Correct Judgment

= Misjudgment

Almost no effects

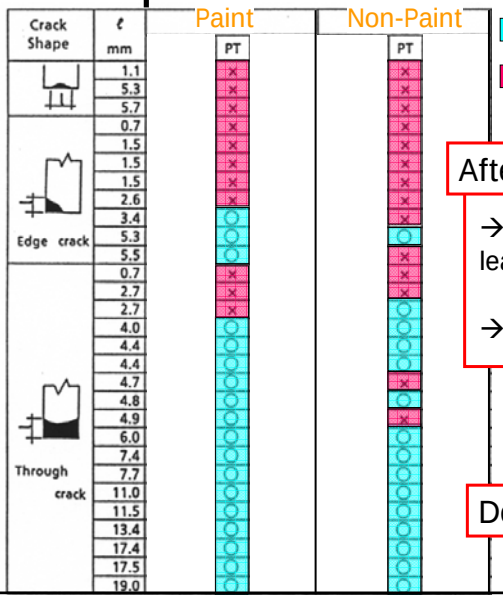
Inspection Results – PT (I)



Underestimate the length of cracks

Min. size = 6 mm

Inspection Results – PT (II)



= Correct Judgment

= Misjudgment

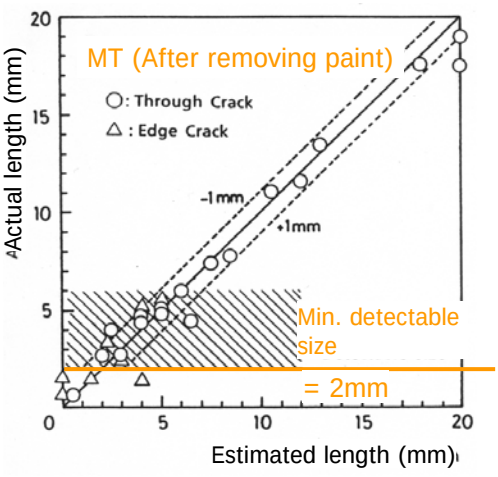
After removal of paint films

→ Slight amount of penetrant leaks into the cracks

→ Low color contrast

Detectability decreases

Inspection Results – MT (I)

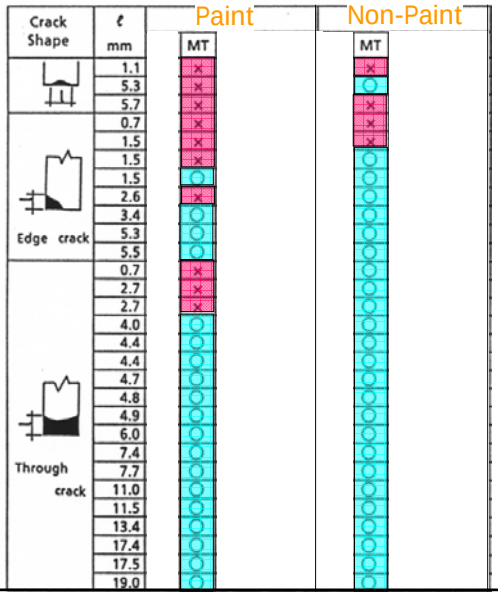


Min. size = 2 mm

Error = ±1 mm

The most reliable methods

Inspection Results – MT (II)



= Correct Judgment

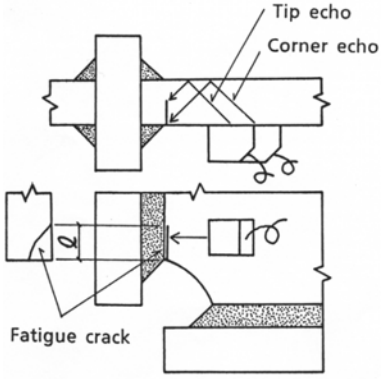
= Misjudgment

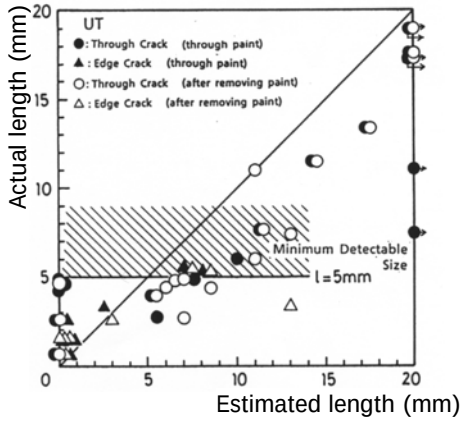
After the removal

Detectability increases

Inspection Results – UT (I)

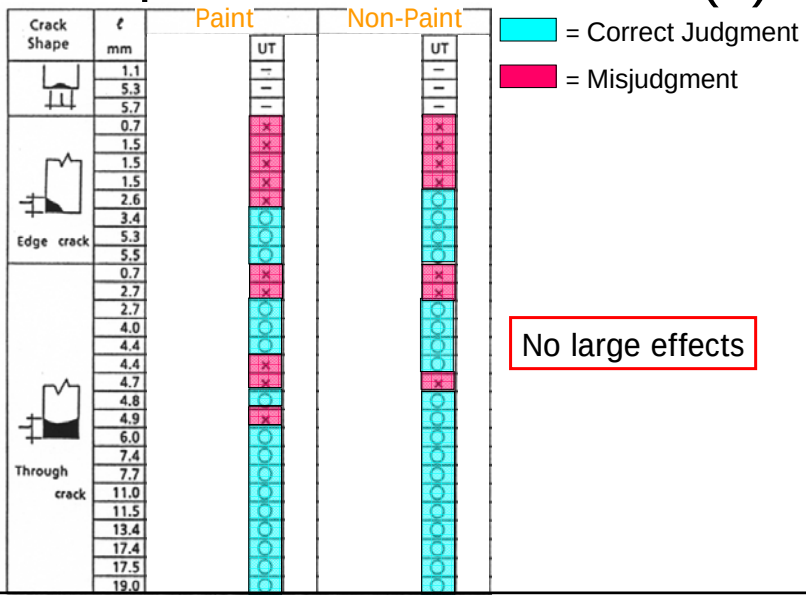
Inspection procedure





Overestimate the length of cracks

Inspection Results – UT (II)



= Correct Judgment

= Misjudgment

No large effects

Summary

Detectable crack length limit

NDT	Minimum Detectable Length, mm		Accuracy
	Paint	Nonpaint	
VT	4.0	8.0	Poor accuracy(varied widely)
MT	(4.0)	2.0	Appropriate
PT	(4.0)	8.0	Underestimated
UT	5.0	6.0	Overestimated
ECT	5.0	5.0	None

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Topics

- Detection of surface-breaking fatigue cracks
  Chitoshi Miki, Makoto Fukazawa, Masahiko Katoh, and Hisao Ohune: Journal of Structural Eng./Earthquake Eng., JSCE, No.386/I-8, pp. 329-337, 1987.10. (in Japanese)

- Effects of paint films on detectability of cracks by NDI methods
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- Detection of embedded fatigue cracks
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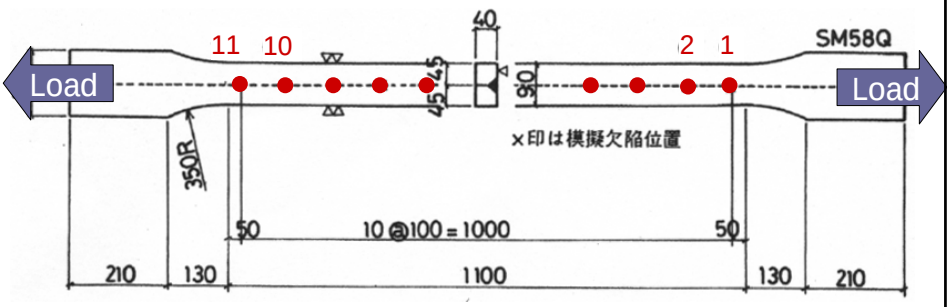
- Current development of ultrasonic testing systems (2001~2004)

Specimens with Artificial Defects

JIS-SM58Q

Totally 11 defects

● locations of defects

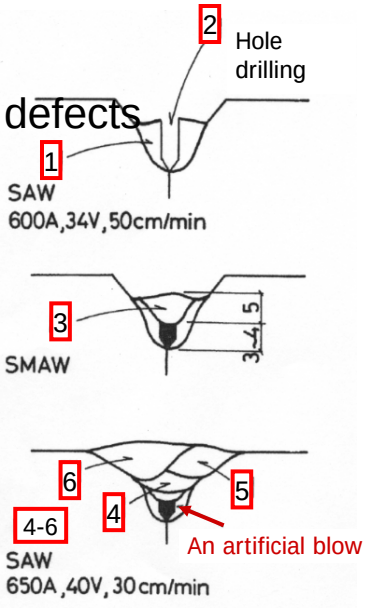


Apply fatigue test to this specimen until cracks reach surface

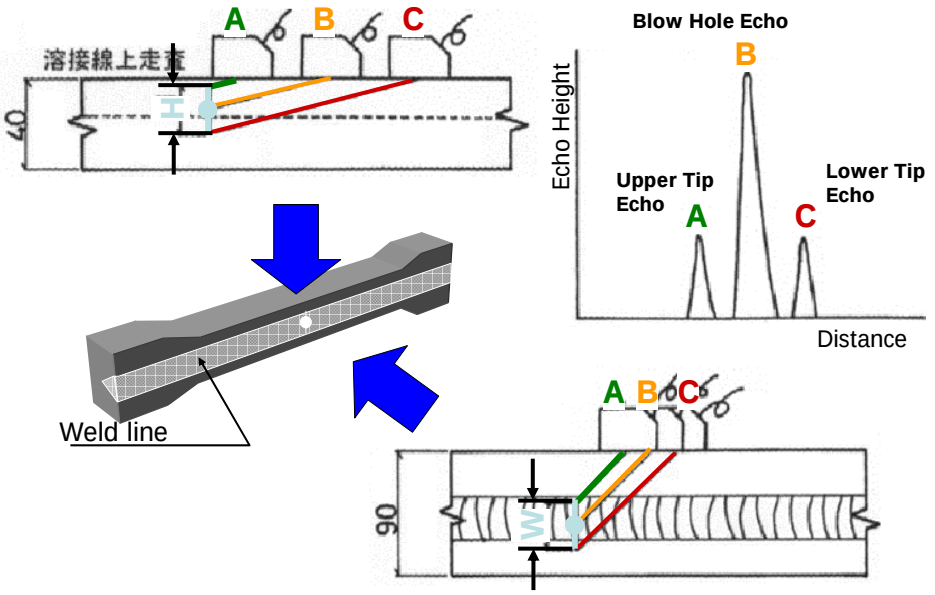
→ Apply **UT** and **RT**

Procedure for Introducing Defects

Blowhole-like defects



Testing Procedure – UT



Inspection Results

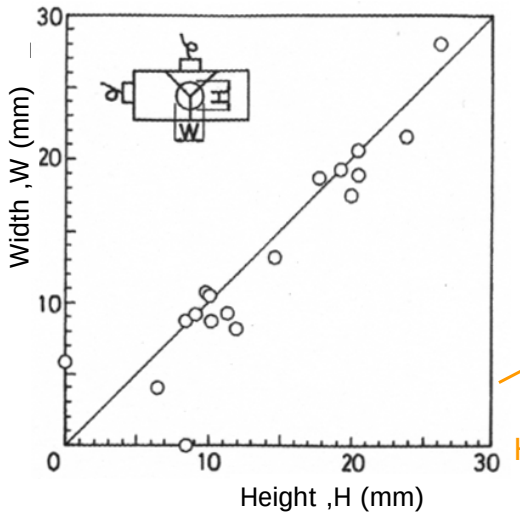
Compare with actual size

Crack	Estimated size by UT [mm]	Actual Size [mm]
C-5	19.3	19.1
C-6	6.2	6.3
A-9	5.9	5.9

Good agreement

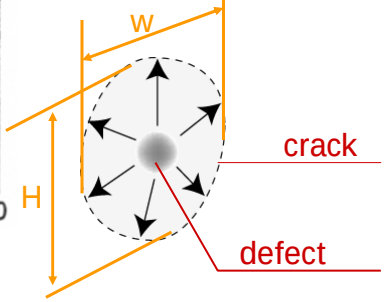
High accuracy of crack size estimation

Relation of Crack Width and Height

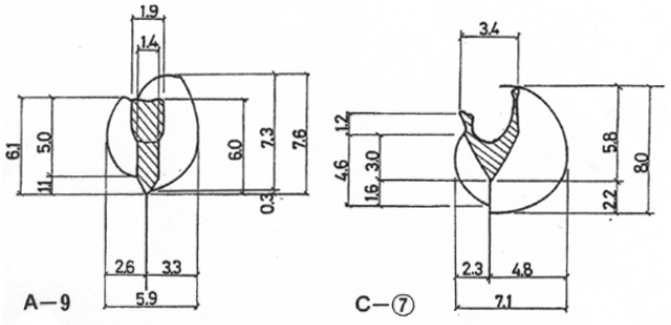


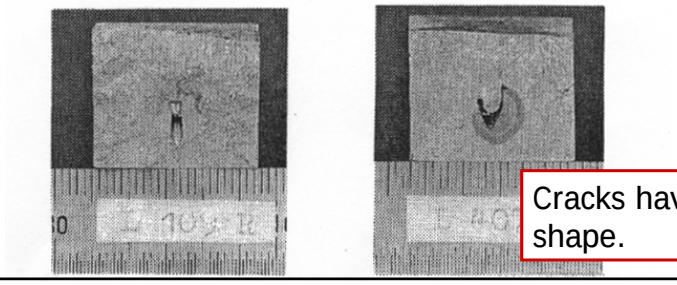
Width and height are almost the same

Cracks propagate with circular shape



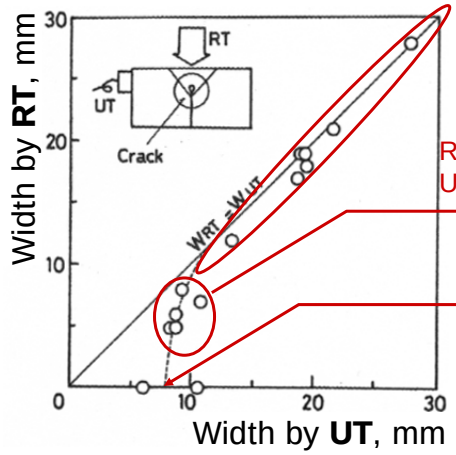
Fracture Surfaces





Cracks have circular shape.

Width of Cracks by RT and UT



Good agreement with crack size >= 12mm

RT:
Underestimate cracks with size 8-12 mm

RT:
Cracks with size less than 8mm could not be detected.

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Summary

UT is better than RT in terms of accurate estimation of crack sizes.

Recently UT become the most used method for inspection.

- Not dangerous to human
- Faster than RT
- Cheaper than RT

Research Works on NDE

Topics

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- Current development of ultrasonic testing systems (2001~2004)

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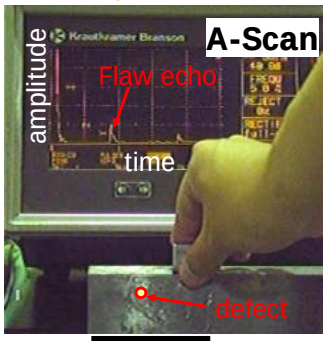
Drawbacks of UT

1. Presentation of results

UT lacks reliability and objectivity in the result presentation.

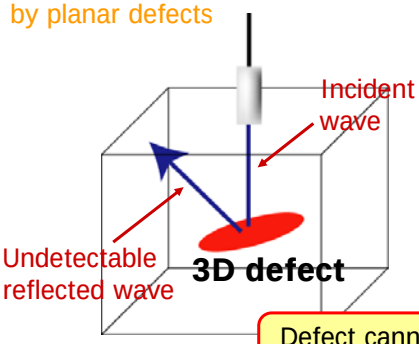


To improve

Visualization of defects

2. Detection of 3D defects

Difficult to detect waves reflected by planar defects



Defect cannot be detected !!

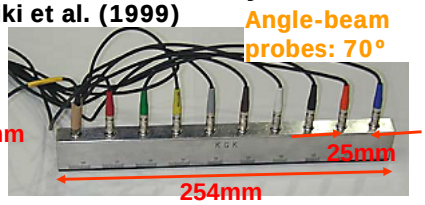
To improve

New type of probes

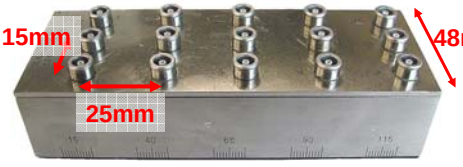
Recent Development of UT

Multi-channel array probes

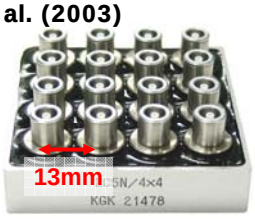
Linear Tandem Array Probe
Miki et al. (1999)



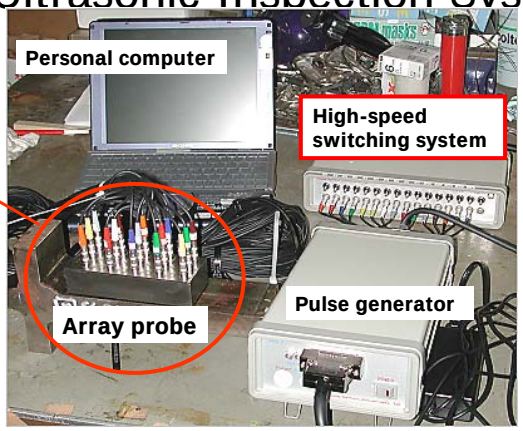
Planar Tandem Array Probe
Miki et al. (2002)



Planar Pitch-Catch Array Probe
Miki et al. (2003)



Ultrasonic Inspection System

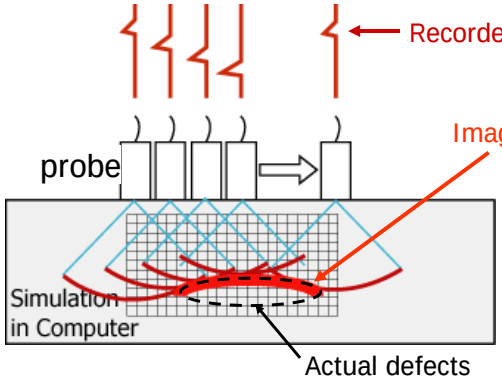


Advantages of this system

- Compact and portable ➔ appropriate for in-service inspection
- Very fast ➔ All wave signals are recorded within 5 seconds
- All wave signal can be recorded at sampling frequency of 60 MHz, which is large enough for defect evaluation.

Visualization System

Synthetic Aperture Focusing Technique (SAFT)



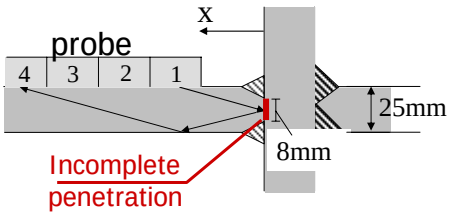
Reliability increased

Our target

- Three dimensions
- Multi-channel array probes

Detection by Linear Tandem Array Probe

Cruciform joint



Linear tandem array probe

Image result

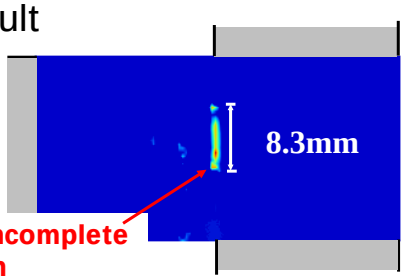


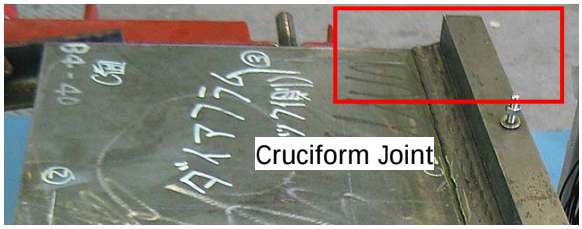
Image of incomplete penetration

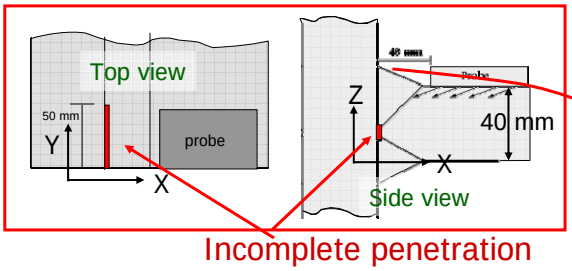
High objectivity

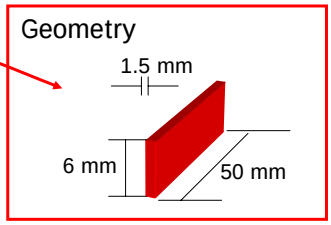
Very accurate results

Detection by Planar Tandem Array Probe

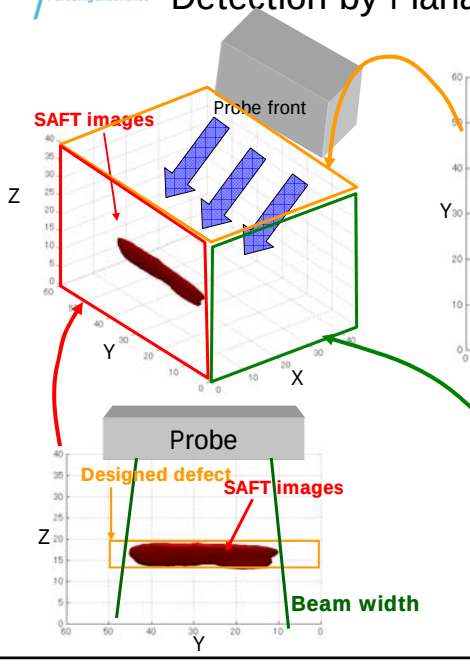
Weld defect in cruciform joint

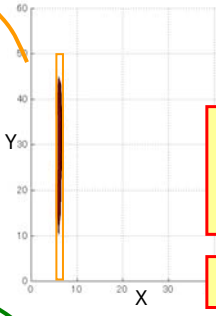


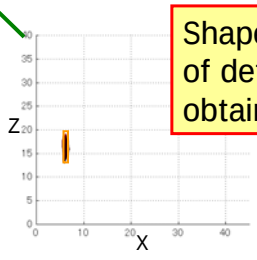




Detection by Planar Tandem Array Probe







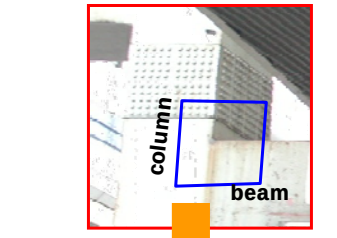
Accurate information in 3D

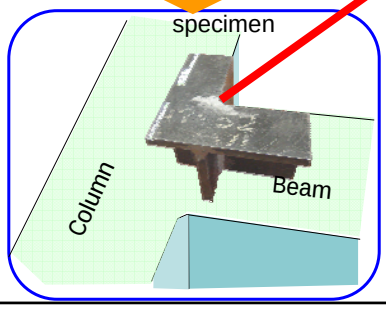
High objectivity

Shape and size of defect can be obtained

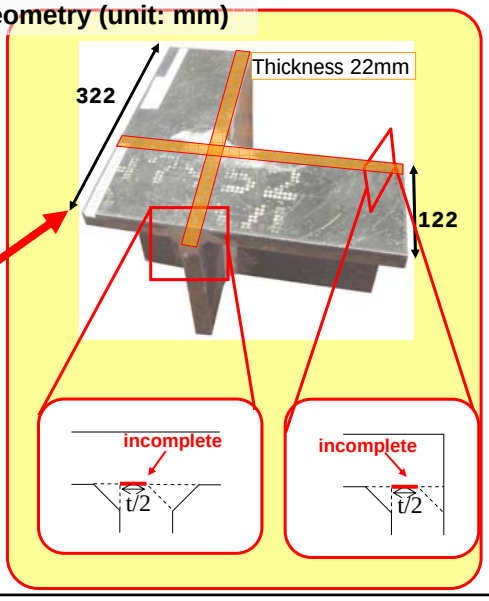
Detection by Planar Pitch-Catch Array Probe

Steel bridge frame pier

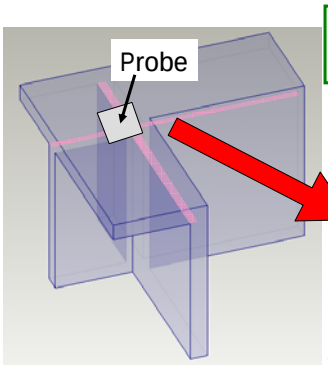




Geometry (unit: mm)



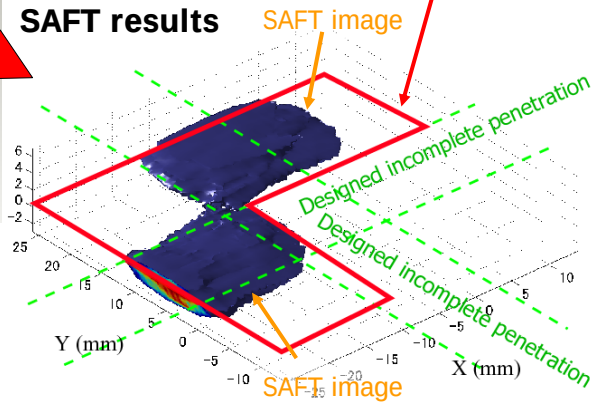
Detection by Planar Pitch-Catch Array Probe



Inspection at intersection of incomplete penetrations

Inspection area

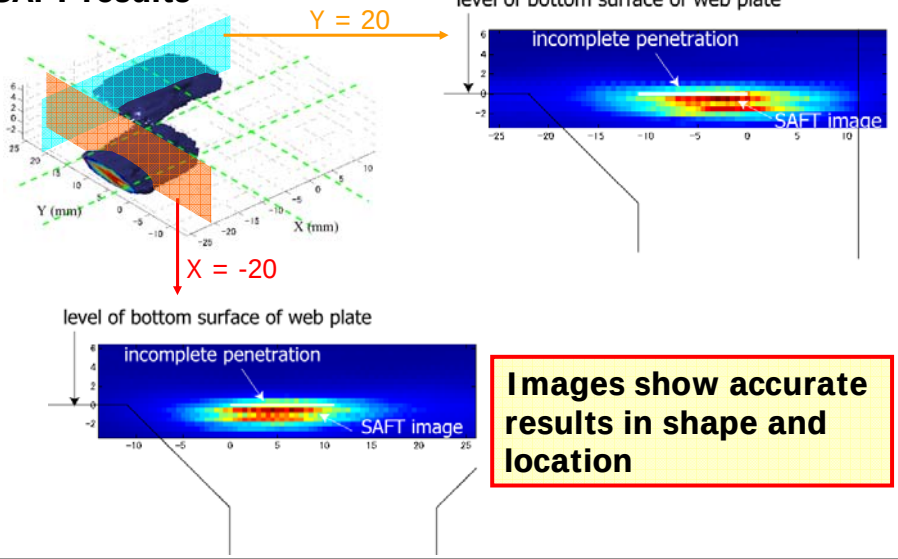
SAFT results



SAFT images present at location of incomplete penetrations.

Detection by Planar Pitch-Catch Array Probe

SAFT results



Images show accurate results in shape and location