** The following is the outline and some figures of a paper drafted by Dr. Prof. Toyoaki Miyagawa, Department of Civil and Earth Resources Engineering, Kyoto University, Kyoto, Japan, who was Chairperson of Sub-committee on Countermeasures for Damage due to Alkali Silica Reaction, and Sub-committee related members. Major contents of this paper will be based on the JSCE research report. The full paper will be available at the symposium in honor of Dr. Prof. Kenji Sakata held during the 7th CANMET/ACI International Conference on Durability of Concrete, May 2006, Montreal, Canada.*

Fracture of Reinforcing Steels in Concrete Structures Damaged by ASR

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1. Introduction

Although only two to three incidences of Alkali-Silika Reaction (ASR) deterioration of concrete structures in Japan had been reported prior to 1970, this type of deterioration was discovered in bridge piers of Hanshin Super Highway in 1982 and thereafter cases have been confirmed with many types of structures (bridge piers, protective walls, levees, and etc.) using crushed andesite for concrete.

Then the Ministry of Construction and Japan Society of Concrete Engineering started to survey the nationwide status quo and to investigate the measure against such damages. Consequently, they suggested the ASR testing method of aggregate, the method of examining, diagnosing, and repairing of ASR deteriorated structures along with the measure to control ASR damages.

In 1986 testing method and ASR control measures against the use of blended cement, low alkali type cement, and the selection of aggregate were established, and since 1990 there has been little ASR cases reported in newly constructed structures.

On the other hand, ASR deteriorated structures constructed between 1970's and 1980's were actively repaired with the application of surface coat, stopping moisture seepage from outside. But it became clear, in some cases, stopping the moisture seepage could not completely cease the developing ASR. Consequently the difficulty of repairing and maintenance management of ASR deteriorated structures was re-confirmed.

In latter half of 1990's, fractures in reinforcing steels were found. **An ASR related Sub-committee (Chairperson: Prof. Toyoaki Miyakawa, Kyoto University) was established in Concrete Committee, Japan Society of Civil Engineering to investigate the repair and strengthening, the analytical qualitative evaluation of the safety of structures, and the understanding of current status and mechanism of steel failures.** Additionally, Highway-Bridge Maintenance Manual (Proposed) was delivered the Ministry of Land, Infrastructure and Transportation in relation to the problem of steel bar failures, and the nationwide investigation of ASR caused such failures is still going on.

Currently, there are about 30 structures, highway and railroad bridges, nationwide, confirmed to have reinforcing bar fractures in ASR deteriorating structures. Andesite type reactive aggregate that generates large expansions was used for concrete material at the locations where these steel bar failures occurred. Additionally, steel fractures occurred at many bent sections of steel bars in pier girders, and similar cases have been reported to occur at footings. These findings show that ASR deterioration is easily influenced by weather and tends to become reality at places where steel bars are relatively few. (Photo 1.1)

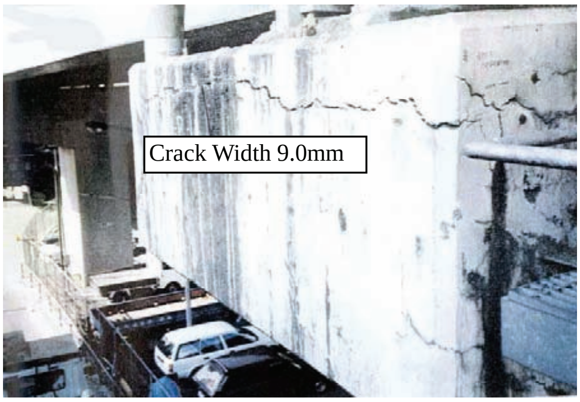


Photo 1.1 - The Damage Condition of a Pier

2. Fracture of Reinforcing Steels in Highway Bridges Damaged by ASR

2.1 An Example of Steel Bar Failure (The pier girder of a highway bridge)

Photo 2.1 - Pier Beam Chipping Inspection

Photo 2.2 - Failed Steel Bar

2.2 An Example of Follow-up Inspection of ASR Deteriorated Piers

3. Fracture Mechanism of Reinforcing Steels
3.1 Reinforcing Steel Material Testing
3.2 Bending Test
3.2.1 Fluorescent Magnetic Particle Test

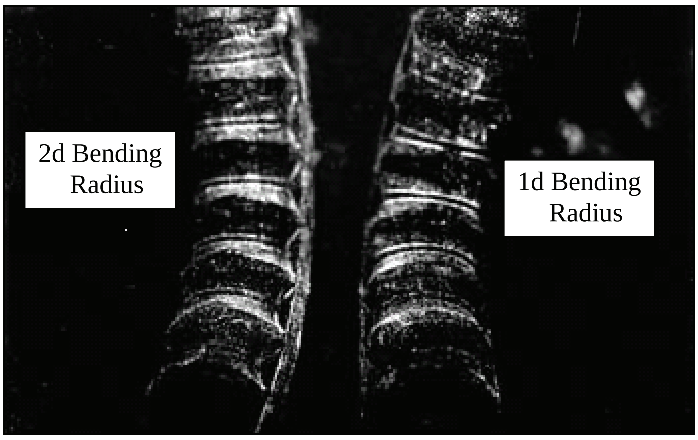


Photo 3.1 - Condition of Crack (Fluorescent Magnetic Particle Inspection)

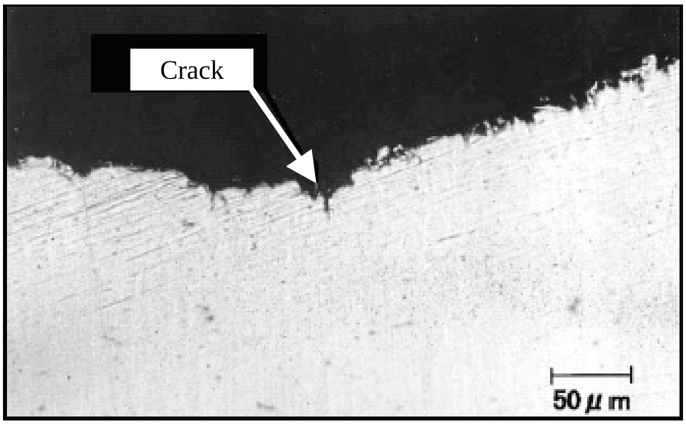


Photo 3.2 - Vertical Section of Inner Part of Bend (1d Bending Radius)

3.2.2 Tensile Test

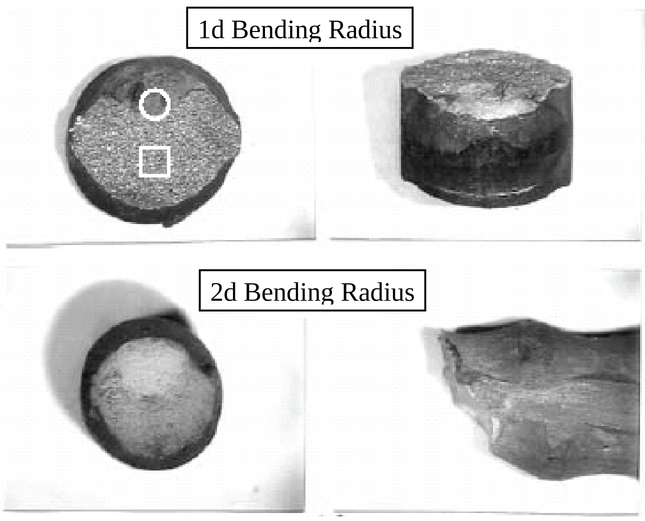
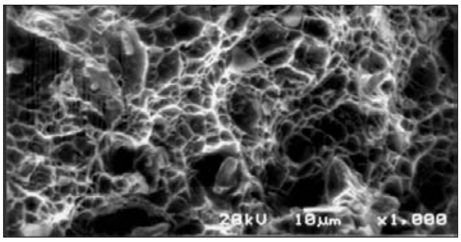


Photo 3.3 - Fracture sections after Tensile Test



○ Portion of Photo

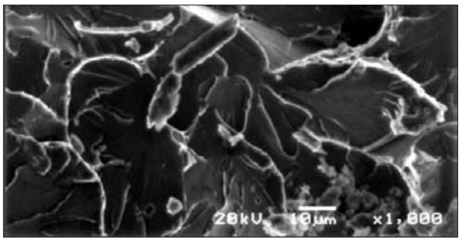


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Photo 3.4 - Fracture after Tensile Test (SEM)

3.3 Bending Analysis

3.3.1 Bending Test

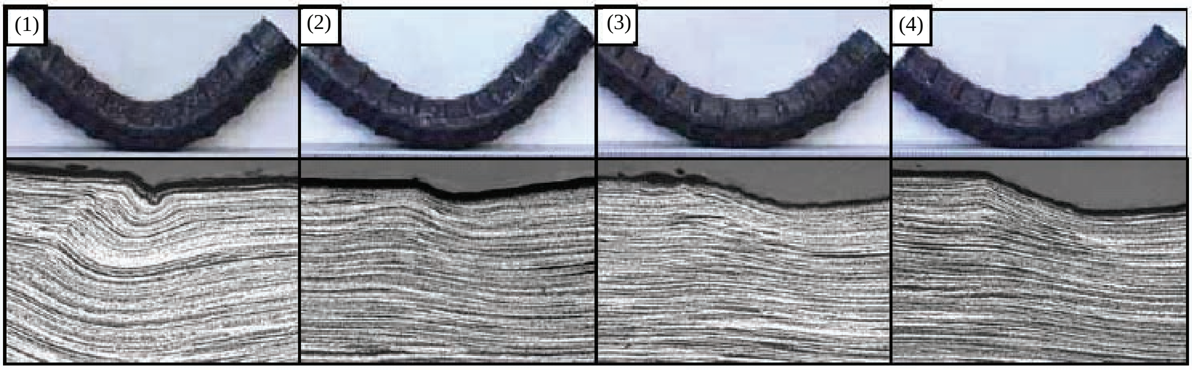
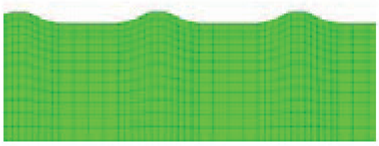


Photo 3.5 – Steel Bars after Bending
and observation of Metal Flow around Knot Base
[(1) r=16, (2) r=24, (3) r=30, (4) r=40]

3.3.2 FEM Analysis of Bent Section

a) Model for Current Shape
Knot Spacing : 9.8mm
Knot Height : 0.9mm
Knot Base : r=4.5



b) Model for Old Shape
Knot Spacing : 10.9mm
Knot Height : 1.1mm
Knot Base : r=0.6, 0.9

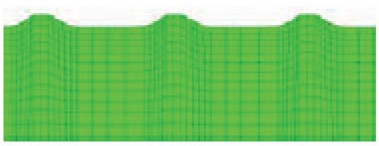


Fig 3.3 – FEM Analysis Model for Steel Bar Shape

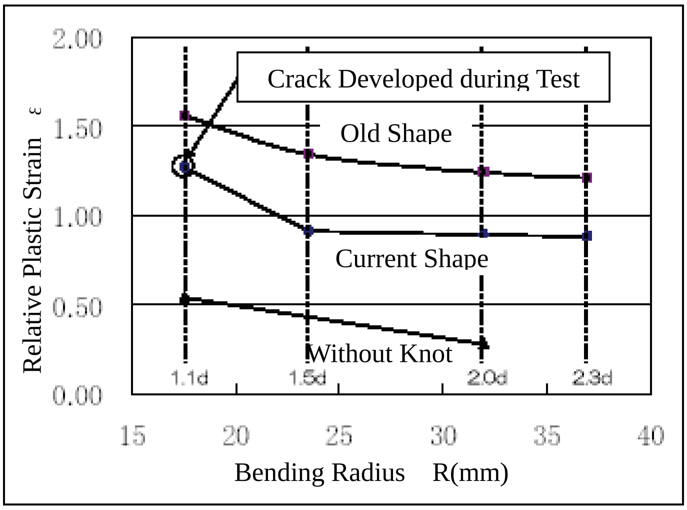


Fig 3.4 - Relationship between Maximum Relative Plastic Strain and Bending Radius

3.4 Stress Corrosion Cracking and Hydrogen Brittleness Test

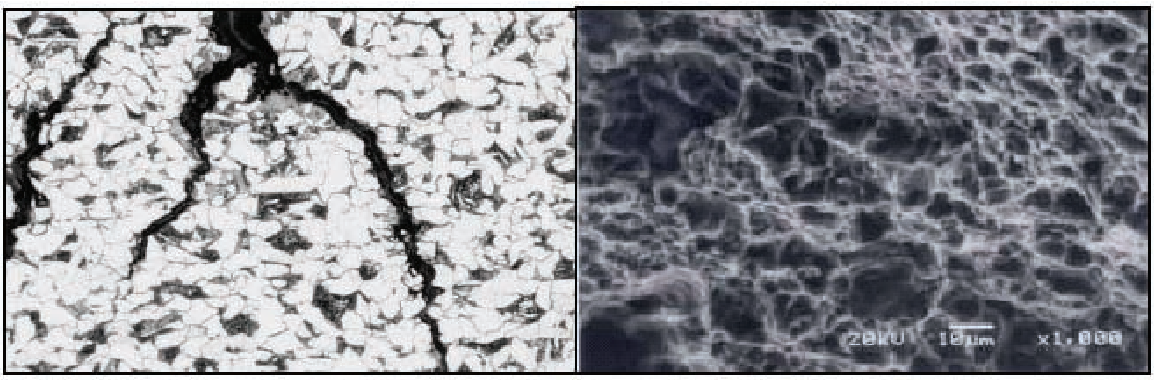


Photo 3.6 - Vertical Section through Cracks after Stress Corrosion Cracking Test

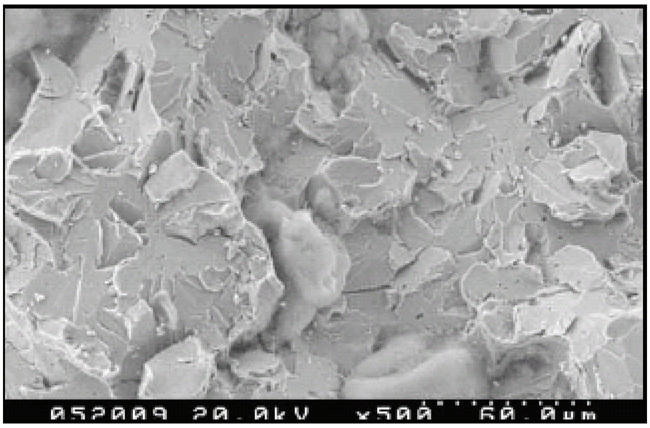


Photo 3.7 - Fracture caused by Hydrogen Brittleness Test (1d)

3.5 Hydrogen Absorption Test

3.6 Presumed Mechanism of Fracture of Steel Bars

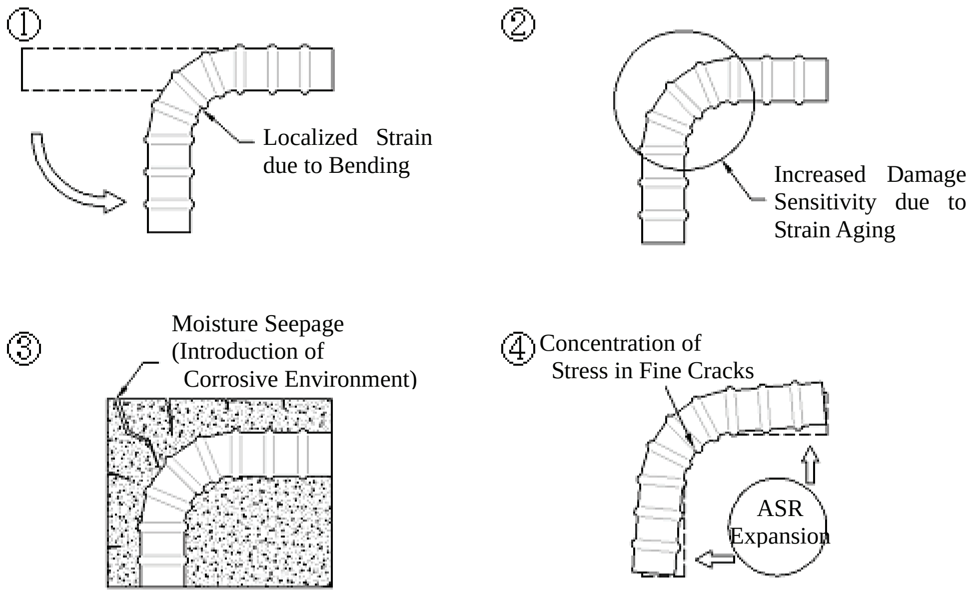


Fig 3.8 - Presumed Mechanism of Fracture of Steel Bars

4. Non-destructive Testing of Structures Deteriorated by ASR

4.1 Ultrasonic Wave Method

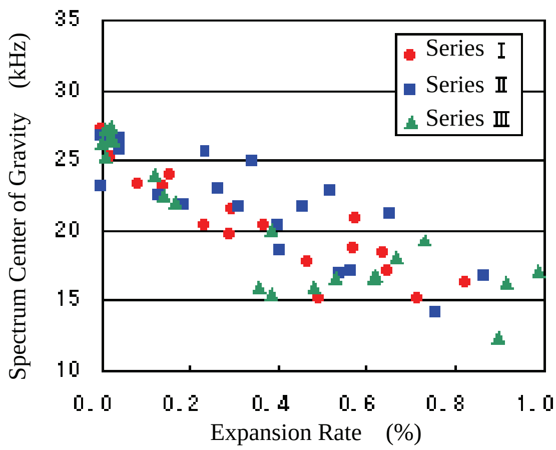


Fig 4.3 - Ultrasonic Wave Spectrum Center of Gravity and Expansion Rate

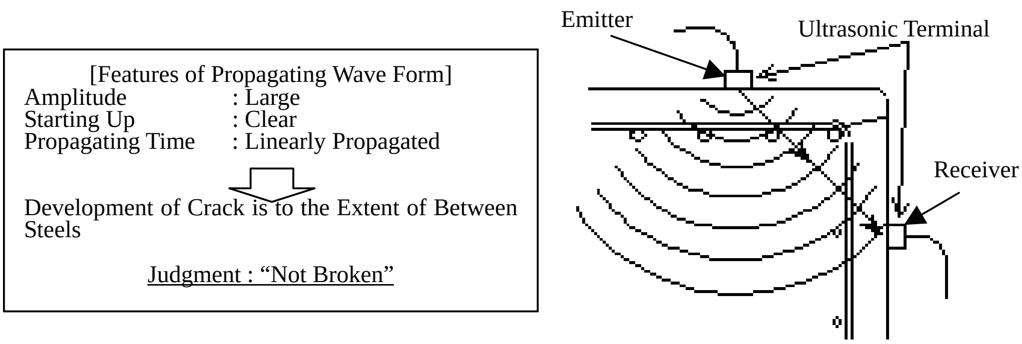


Fig 4.4 - Trend of Propagating Wave Form (Not Broken Case)

[Features of Propagating Wave Form]
Amplitude : Small
Starting Up : Unclear
Propagating Time : Detour Propagation

Cracks are Extended Deep into the Section

Judgment : “Broken”

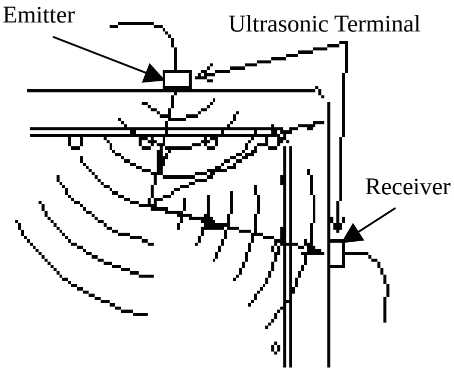


Fig 4.5 - Trend of Propagating Wave Form (Broken Case)

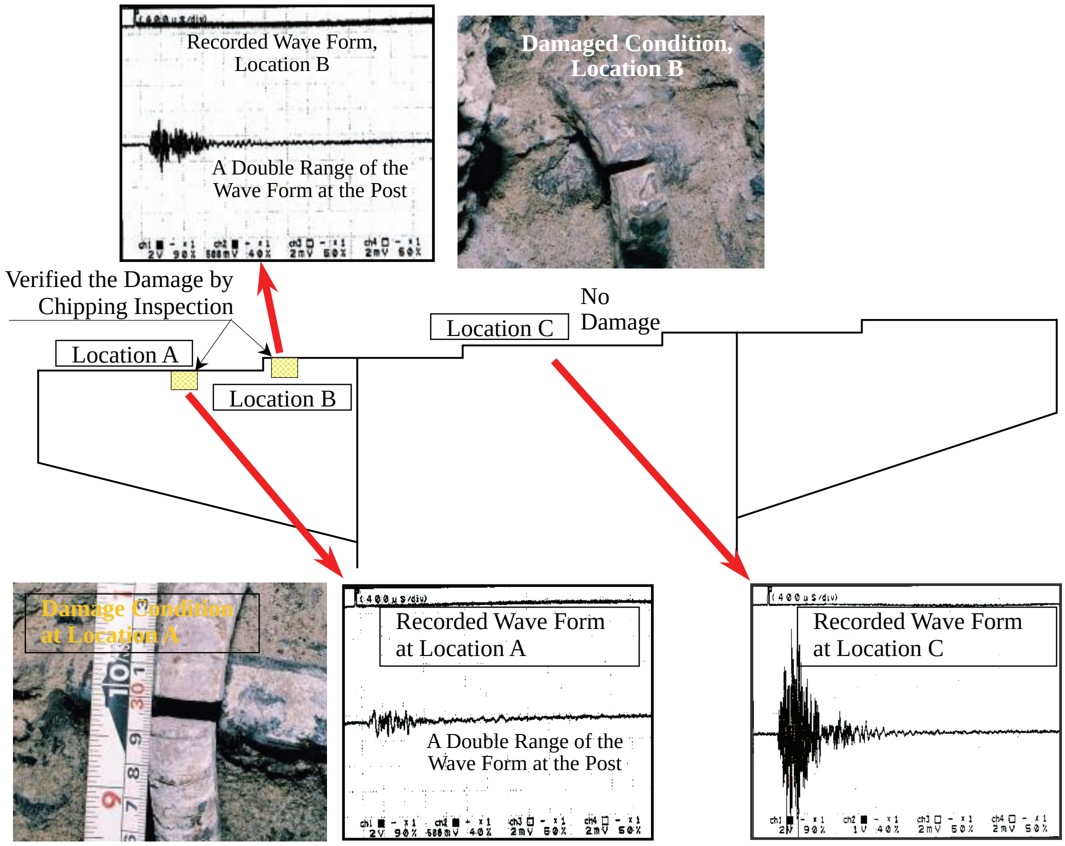


Fig 4.6 - Examples of Recorded Wave Forms from Existing Bridge Pier

4.2 Electromagnetic Testing Method

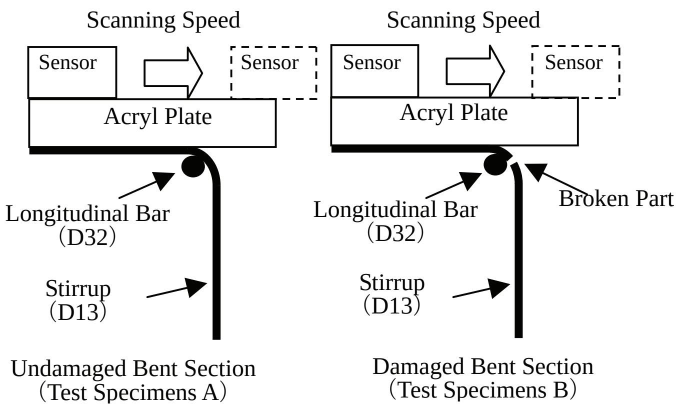


Fig 4.9 - Electromagnetic Testing Method (Bent Section)

5. Strengthening Methods for Damaged Concrete Structures

5.1 Repair and Strengthening Procedure

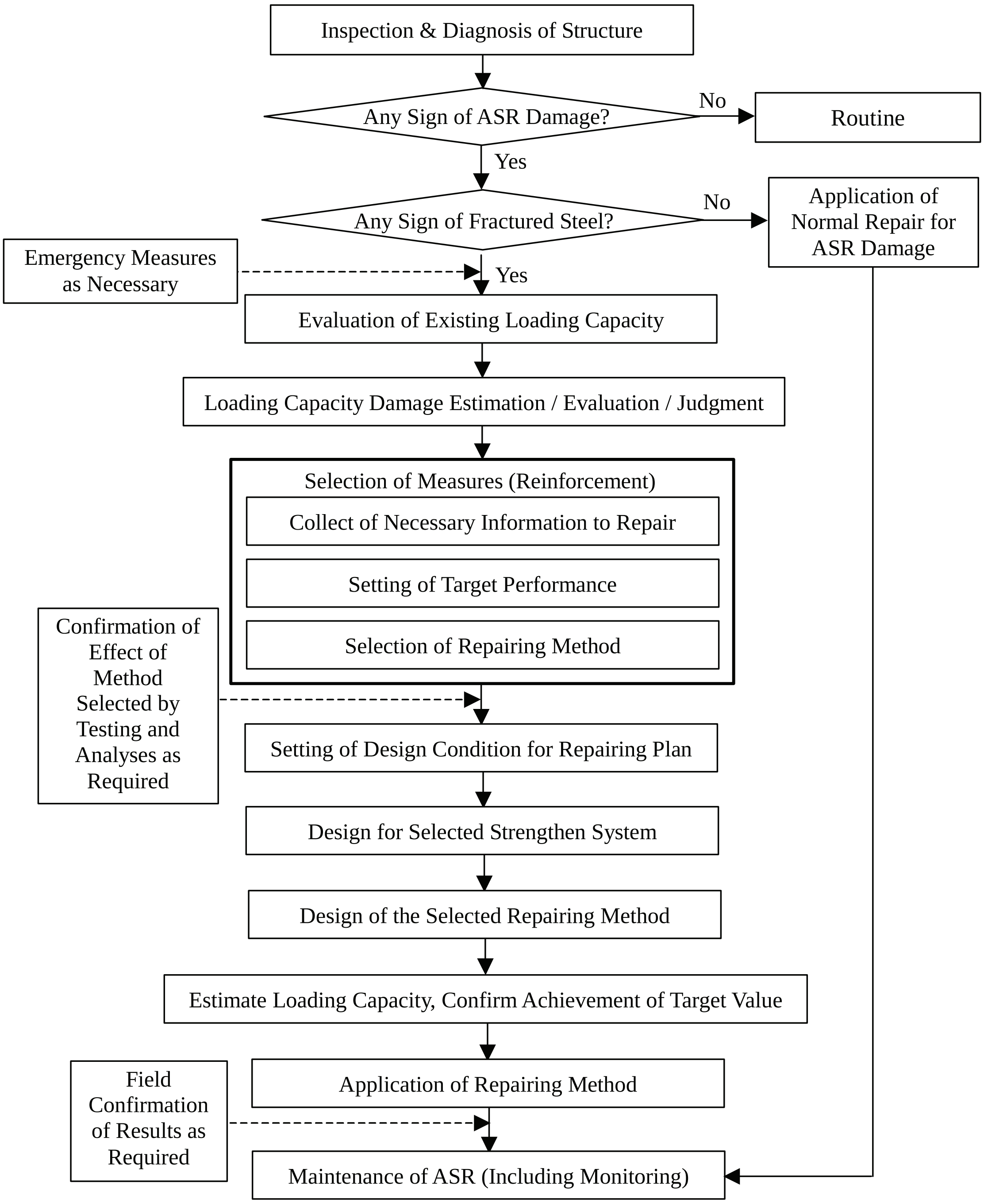


Fig 5.1 - Repair and Strengthening Procedure

5.2 Confirming Test of a Strengthening Method

5.2.1 The Outline of Experiment

5.2.2 Results and Discussions

6. Conclusion