MAINTENANCE PLAN FOR 100 YEARS OF THE SERVICE LIFE ON NEWLY CONSTRUCTED STRUCTURE

Koji TAKEWAKA

Associate Professor
Dept. of Ocean Civil Engineering
Kagoshima University

INTRODUCTION

- To keep durability of structures during their service life is very important, in the view points not only of keeping their require performance but also of economical and environmental conservation sides, such as reduce of construction wastes.

INTRODUCTION

On marine concrete structure

- it is difficult to keep its durability for 100 years or more only by protection ability of concrete itself.
- In some case, use of additional protection system is required in design
- Especially in the important structure. a preventive maintenance may need to be installed during the service life.

Contents of Presentation

Introduce a structure in which the preventive maintenance concept are installed in its design concept, and actual activity for maintenance will be started from the initial stage of the service, that is the first trial on the real structure in Japan.

- **Outline of Structure**
- **Durability Design**
- **Maintenance Program**
- **Monitoring System for Chloride Attack**
- **Conclusive Remarks**

Out Line of Structure

- Objective structure:

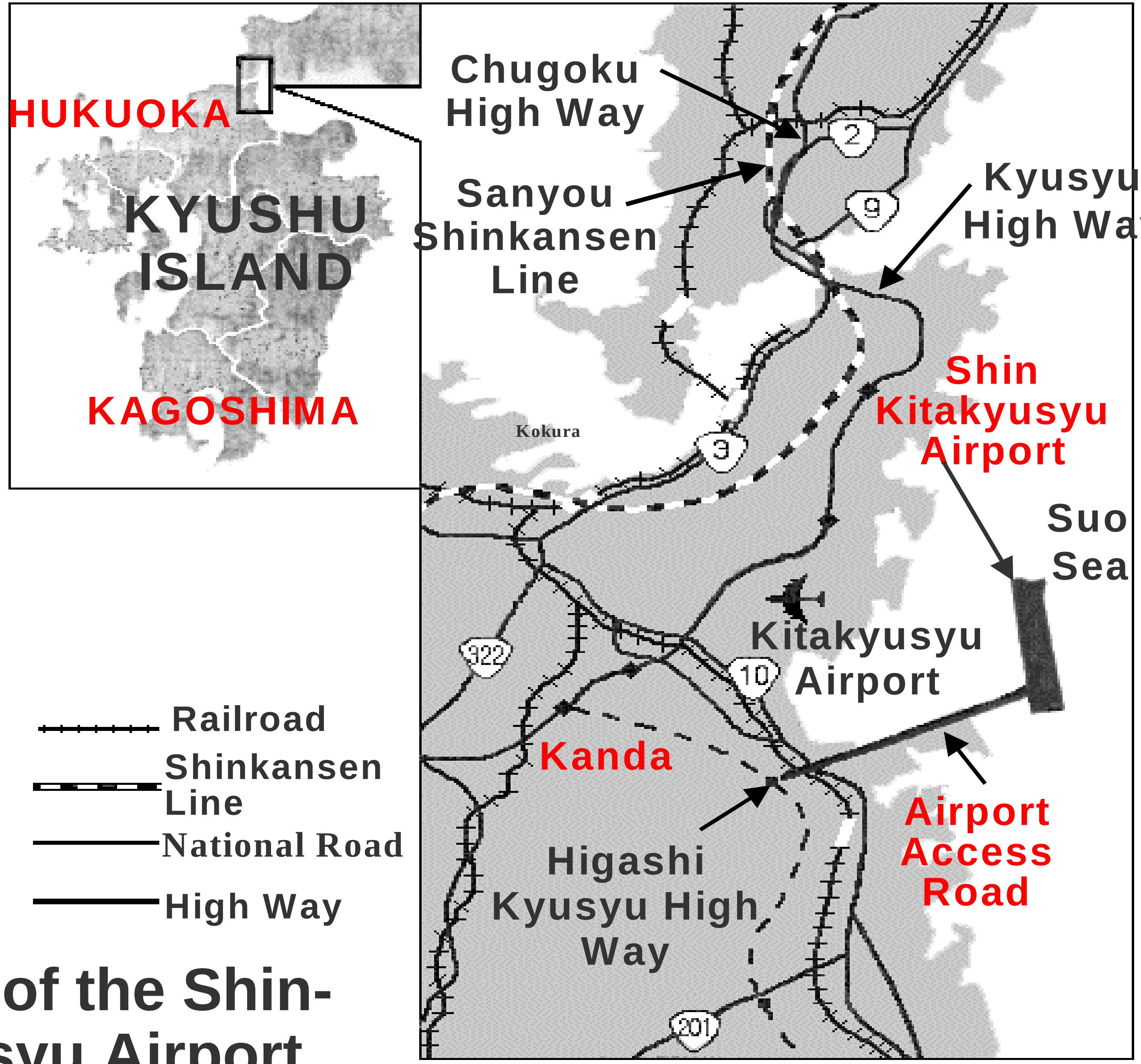
Concrete piers in a access bridge of

Shin-Kitakyusyu airport

Shin-Kitakyusyu Airport

- **Now under construction as a substitute for Kitakyusyu Airport which capacity have been overflowed for 2million residents in Kitakyusyu city and the surrounding regions.**

- **Being scheduled to open in March 2005**



Location of the Shin-Kitakyusyu Airport

Shin-Kitakyusyu Airport

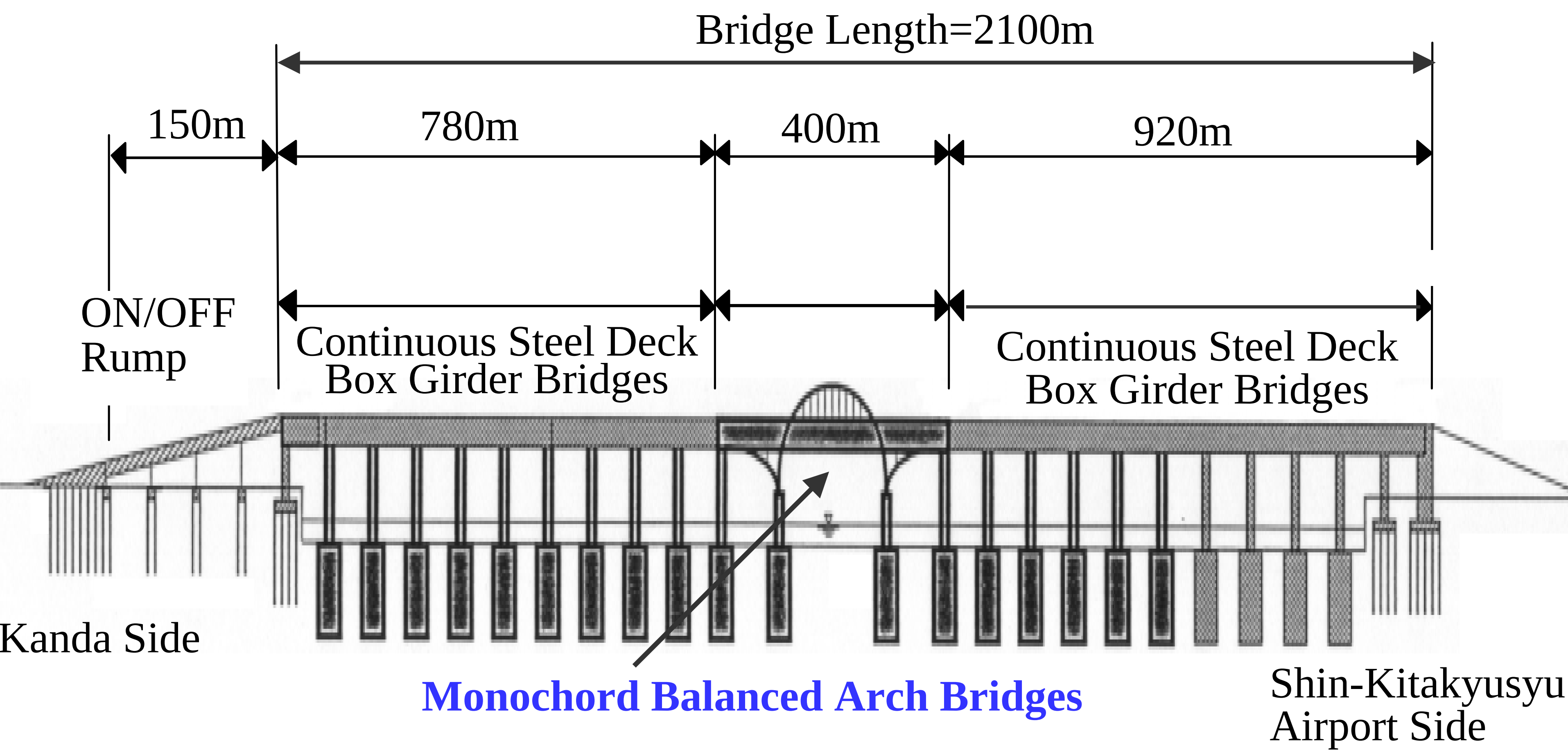
- Being constructed on 370 hectares of a reclaimed island in sea about 2km off the east coast of Kitakyusyu City

- Being connected with the land (coast) by an access bridge having 2.1 km of a total length

Shin-Kitakyusyu Airport

- The access bridge that is constructed across the sea is very important structure, because of the only way to access from the land to the airport

- High durability is required for the bridge structure to keep its required performances and functions during the service life



Outline of the Access bridge

Overview of Access Bridge

- Total length: 2,100m
- Superstructure:

Central bridge:

400-m length of steel monochord balanced arch bridge

Approach Bridge(at the land side):

780-m length of 10-span continuous steel slab box girder bridge

Approach Bridge(at airport island side):

920-m length of 11-span continuous steel slab box girder bridge

Main Bridge in the Access Bridge

Overview of Access Bridge

- **Substructure:**

  Total numbers of 24 of reinforced concrete piers (typical size of cross-section: 6m by 9m)

  / 22 RC piers in offshore

  / 2 RC piers on the land

  1 of reinforced concrete abutment

- **Foundations:**

  Open caisson type of foundation using steel pipe sheet pile

- **Design service life : 100years**

Piers of the Access Bridge

Overview of Access Bridge

"Committee on Design and Construction of the Access Bridge to Shin-Kitakyusyu Airport"

Established by Fukuoka Prefecture Office in 1996

"Sub Committee on Concrete Structure"
(Chairman: Prof. Matsushita, Kyushu Univ.)

- Working from 1996 to 2002 -

To discuss mainly about the durability of RC piers in the offshore environment

Durability Design of RC Piers in Access Bridge

Characteristic of RC Pier

- Exposed to the severe marine environment
- Very important structure
- Design service life is 100 years

Basic Consideration of Durability Design of RC Piers

- **Piers are constructed in the severe maritime conditions:**

  ⇨ **Need to ensure the durability against chloride attack**

Durability Design of RC Piers

-- Examination in view point of durability against chloride attack --

Basically according with the JSCE Standard Specification (1996 version)

- **Mixture proportion of concrete**

f'_{ck}	Gmax	slump	Air	W/C	s/a	Unit weight (kg/m^3)				
N/mm^2	mm	cm	%	%	%	W	C	S	G	AE
27	20	8±1.5	4.5±1.5	45	40	149	330	717	1165	1.17

- **Execution-related measures**

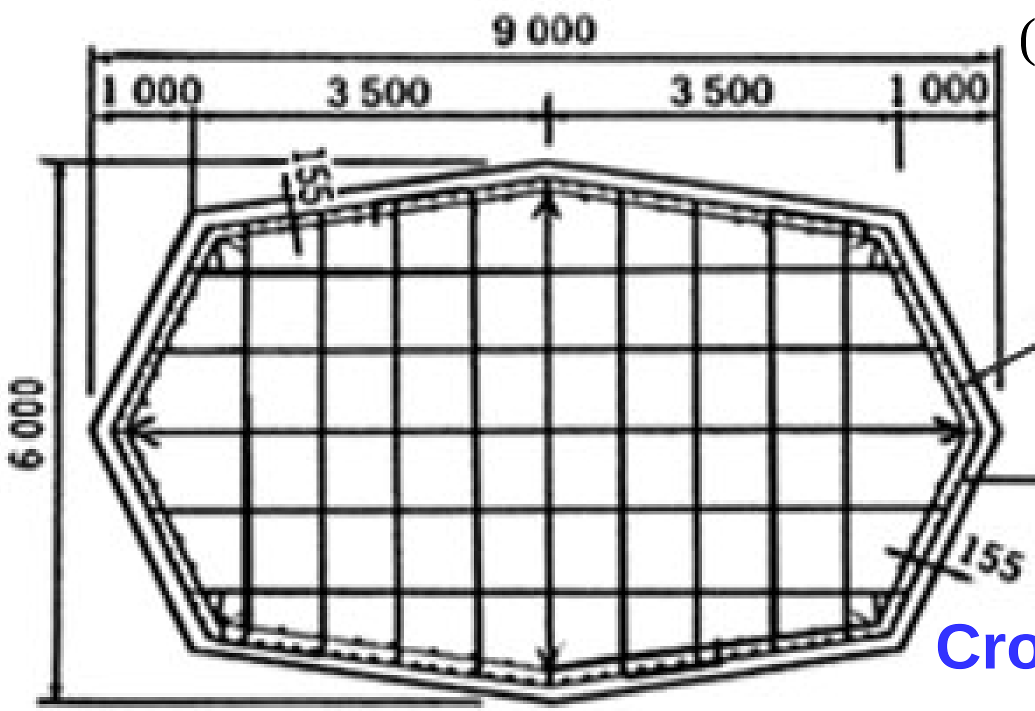
/ Use of permeable formworks

Durability Design of RC Piers

-- Examination in view point of durability against chloride attack --

Basically according with the JSCE Standard Specification (1996 version)

- **Concrete cover thickness : More than 10.5cm**



(Unit:mm)

Main rebar (D51)
(Cover thickness:164.5mm)

Tie hoop (D19)
(Cover thickness: 145.5mm)

Cross section of pier

Durability Design of RC Piers

JSCE Standard Specification (1996 version)
was not based on the performance-based design concept but on prescription–based design concept

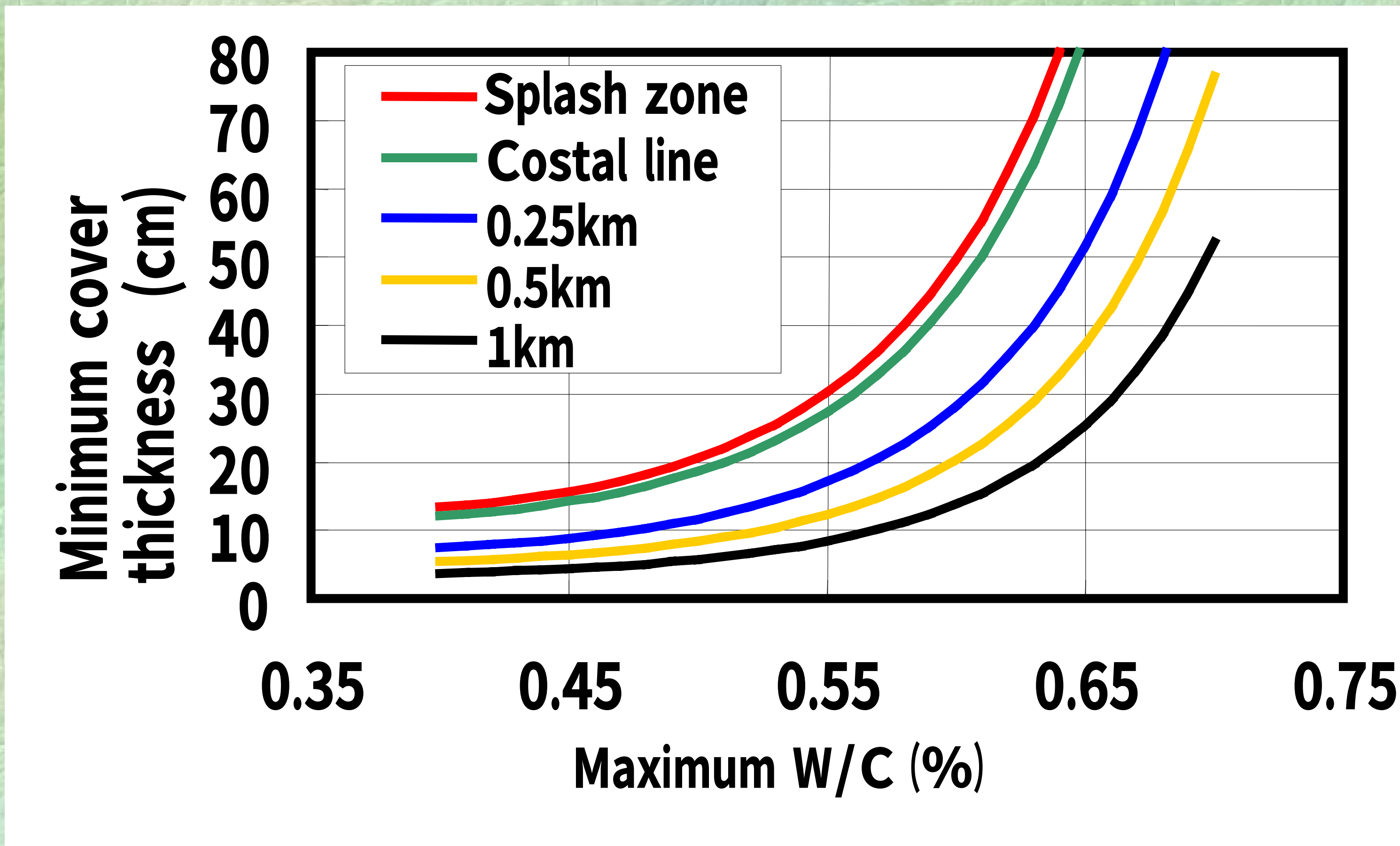
Durability of structure is decided only by structural detail and material performance prescribed in the specification

Design conditions were confirmed to satisfy JSCE Standard Specification (1999 version)
which is based on the performance-based design concept

Relationship between minimum cover thickness and maximum W/C required for durability satisfying JSCE Spcification(1999)

Design condition

Blast furnace slag: 50%, Design service life: 100 years



Arrangement Condition of Reinforcing Steel

Durability Design of RC Piers

-- Examination in view point of AAR --

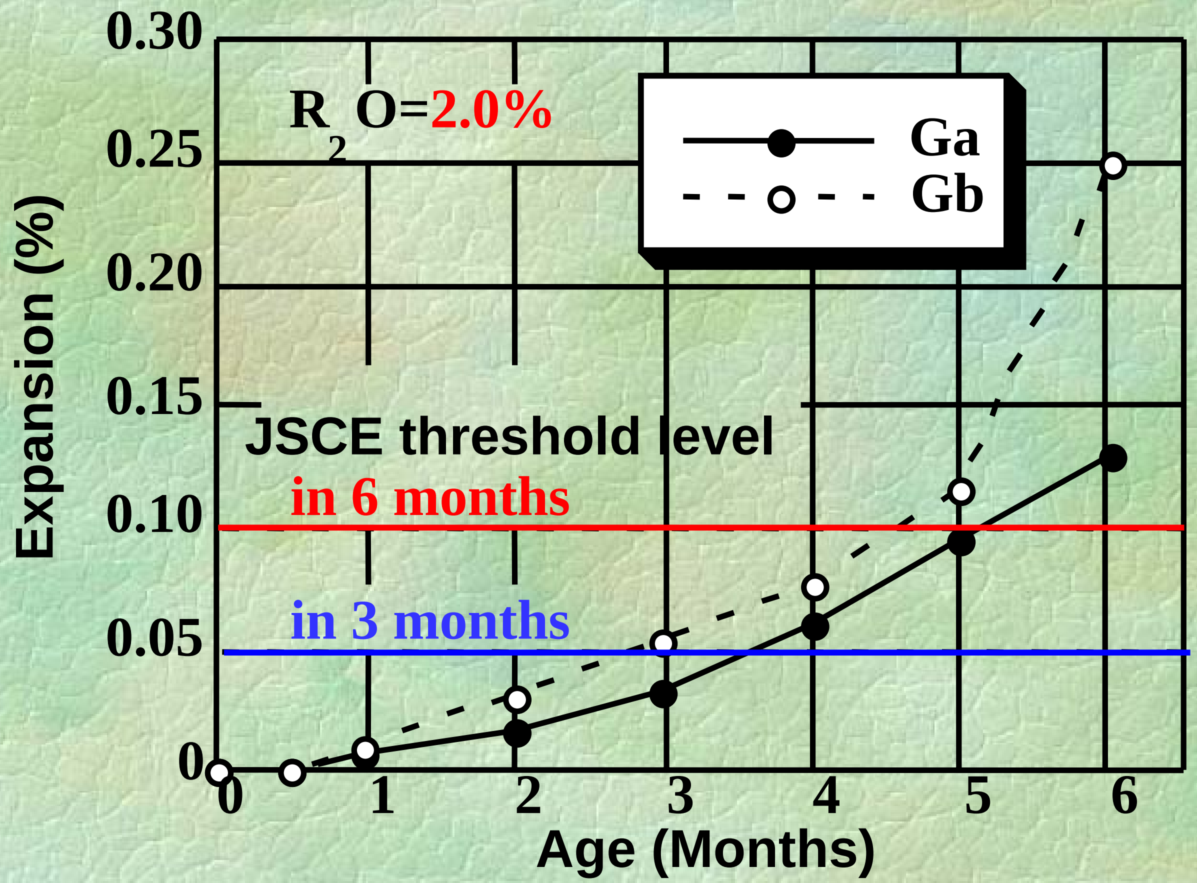
Preliminary survey

- **15 types of aggregate were sampled from concrete mixing plants near the construction site.**
- **All of aggregate was judged as innocuous under test condition of the chemical method or the mortar bar method specified by JIS**
- **Some of aggregate showed abnormal expansion under higher alkali concentration than the critical value in the JIS test method**

Durability Design of RC Piers

-- Examination in view point of AAR --

Preliminary survey



Test result of mortar-bar method under higher alkali concentration

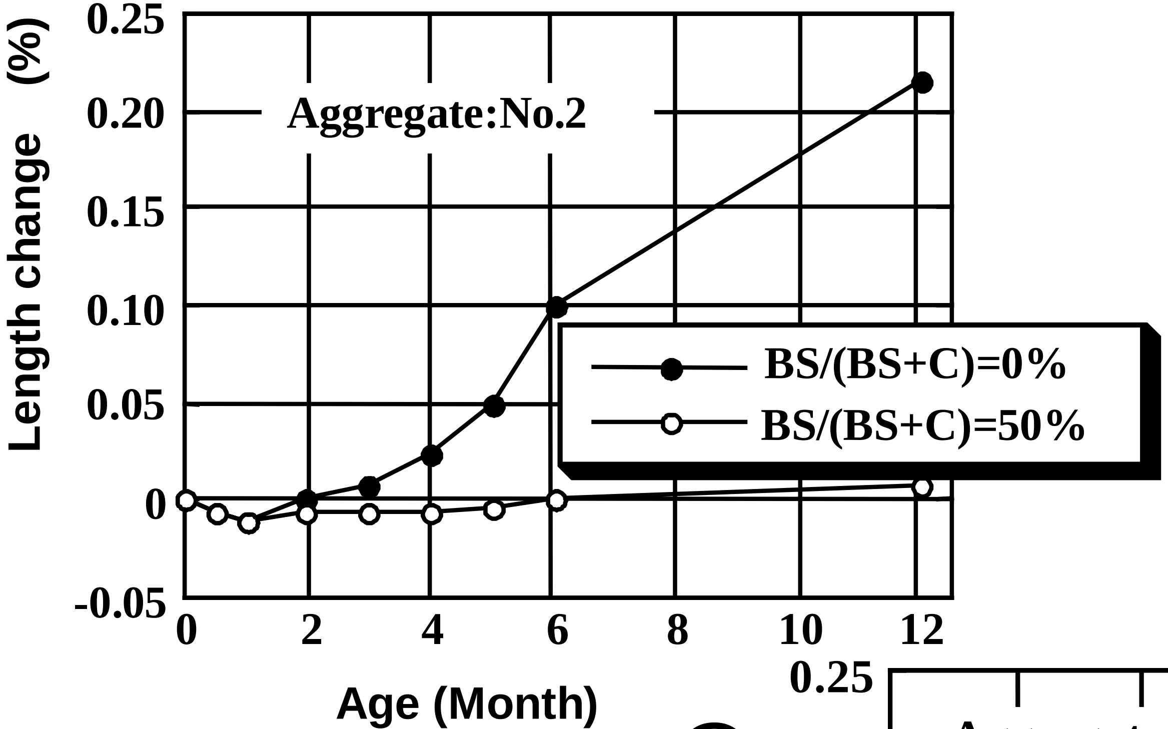
Durability Design of RC Piers

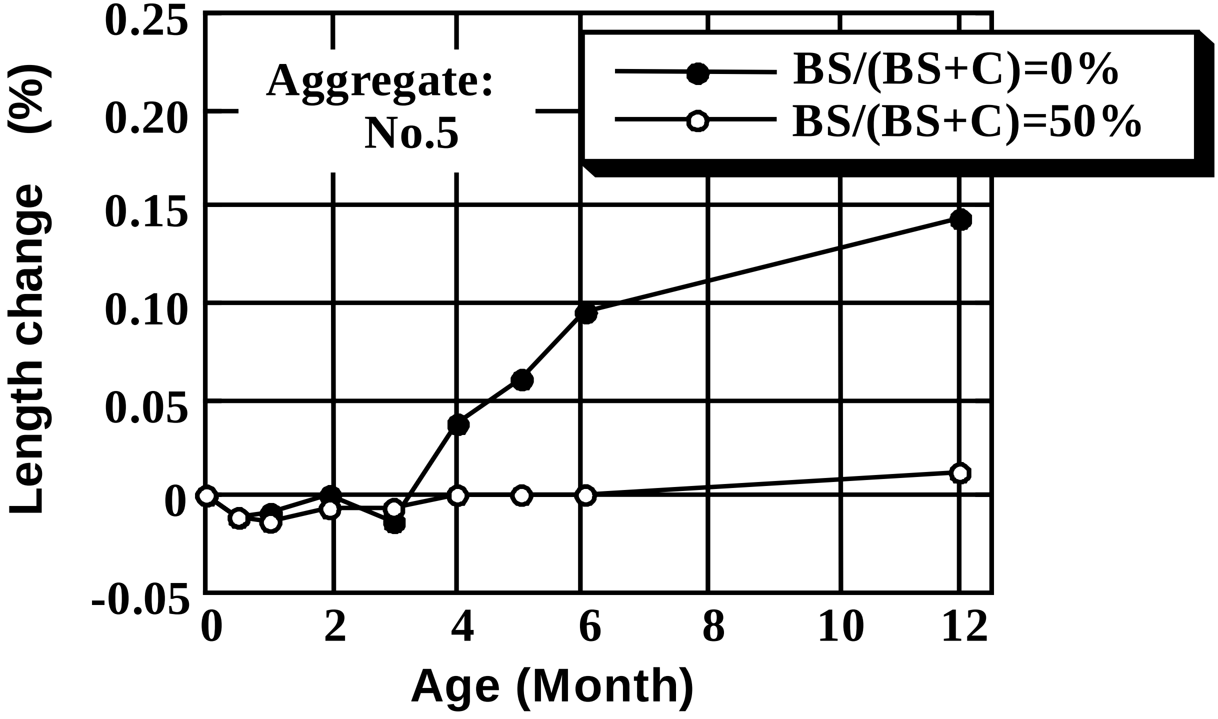
-- Examination in view point of AAR --

- In marine environment, a lot of alkali ions such as Na^+ and K^+ penetrates and concentrates in concrete
- It is difficult to select only the innocuous aggregate using for the pier, because the marketing system of aggregate is very complex.

Countermeasure

Use of Ground granulated blast-furnace slag in replace of 50% or more of cement





Inhibiting effect of GGBF slag on AAR

Durability Design of RC Piers

-- Examination in view point of thermal crack --

Result of thermal stress analysis

- **The size of the pier makes it difficult to eliminate thermal cracking completely**

Realistic countermeasure

- **To control the crack width within its threshold value in consideration of the durability of pier.**

Durability Design of RC Piers

-- Examination in view point of thermal crack --

Countermeasure for the thermal crack (1)

Use of low-heat Portland cement with GGBF slag at replacement ratio of 60 %

Additional Measure for thermal crack

Use of heat insulation formwork made of 5mm thickness of foamed polystyrene

Heat Insulation Formwork

Appearance of Thermal Crack on the Pier

Durability Design of RC Piers

-- Examination in view point of thermal crack --

Countermeasure for the thermal crack

If thermal cracks occur during the execution, they should be repaired in accordance with the following manners;

In the case of 0.2mm or more of crack width:

⇨ Repair by both epoxy resin injection in the crack and epoxy coating on the concrete surface

In the case of less than 0.2mm of crack width:

⇨ No repair

Maintenance Program for RC Piers in Access Bridge

-- Preventive Maintenance Concept --

Maintenance Program for the Pier

Risk of deterioration in the durability design

- **It is difficult to control generation of the AAR crack and thermal crack perfectly**
- **Difficulty of repair after deterioration occurs during service**

"Preventive Maintenance Concept"
is Required

Characteristic of the pier

- **Very important structure**
- **Design service life is 100 years**

Maintenance Program for the Pier

-- Sub-Committee's Conclusion --

A scheme of durability design of RC piers should be established in consideration of preventive maintenance activity performed continuously during its design service life

Such intentional maintenance of newly constructed RC structures is the first case in Japan

Maintenance Program for the Pier

-- Preventive Maintenance Concept --

Preventive Maintenance Concept

To keep required performances of the pier during it service life without any loss due to deterioration

- **Maintenance activity should be started from the initial stage of the service**
- **Monitoring system should be introduced to detect the sign of deterioration**

Maintenance Program for the Pier

-- Preventive Maintenance Concept --

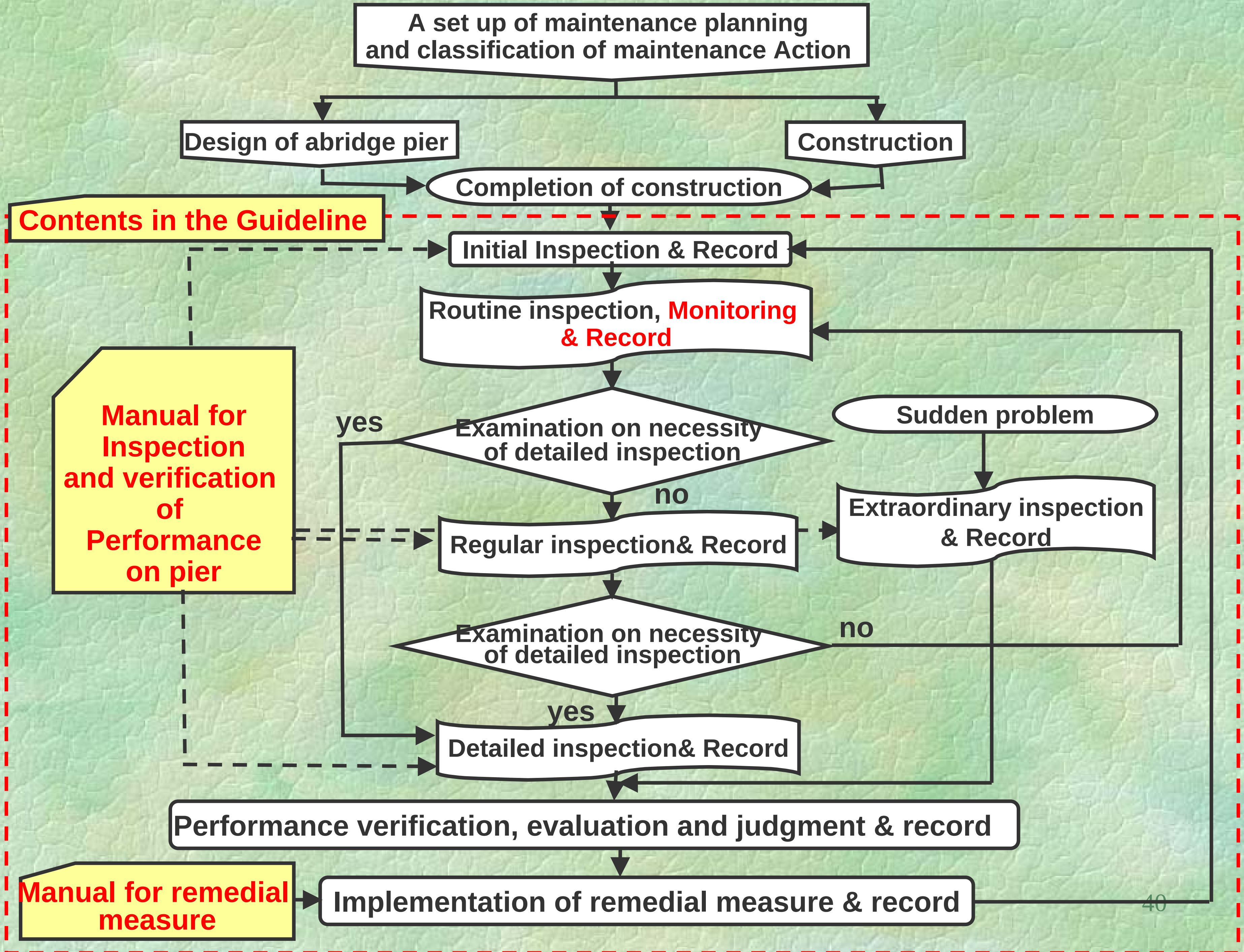
In order to carry out preventive maintenance systematically on the pier during its service life

"Maintenance Guideline for Reinforced Concrete Piers of Access Bridge to Shin-Kitakyusyu Airport"

was published by the Sub-Committee in 2002

“Maintenance Guideline for Reinforced Concrete Piers of Access Bridge to Shin-Kitakyusyu Airport”

Maintenance Guideline for Reinforced Concrete Piers of Access Bridge to Shin-Kitakyusyu Airport
--Contents--


A set up of maintenance planning and classification of maintenance Action
Design of abridge pier
Construction
Completion of construction
Contents in the Guideline
Initial Inspection & Record
Routine inspection, Monitoring & Record
Manual for Inspection and verification of Performance on pier
yes
Examination on necessity of detailed inspection
Sudden problem
no
Regular inspection& Record
Extraordinary inspection & Record
Examination on necessity of detailed inspection
no
yes
Detailed inspection& Record
Performance verification, evaluation and judgment & record
Manual for remedial measure
Implementation of remedial measure & record

Maintenance Program for the Pier

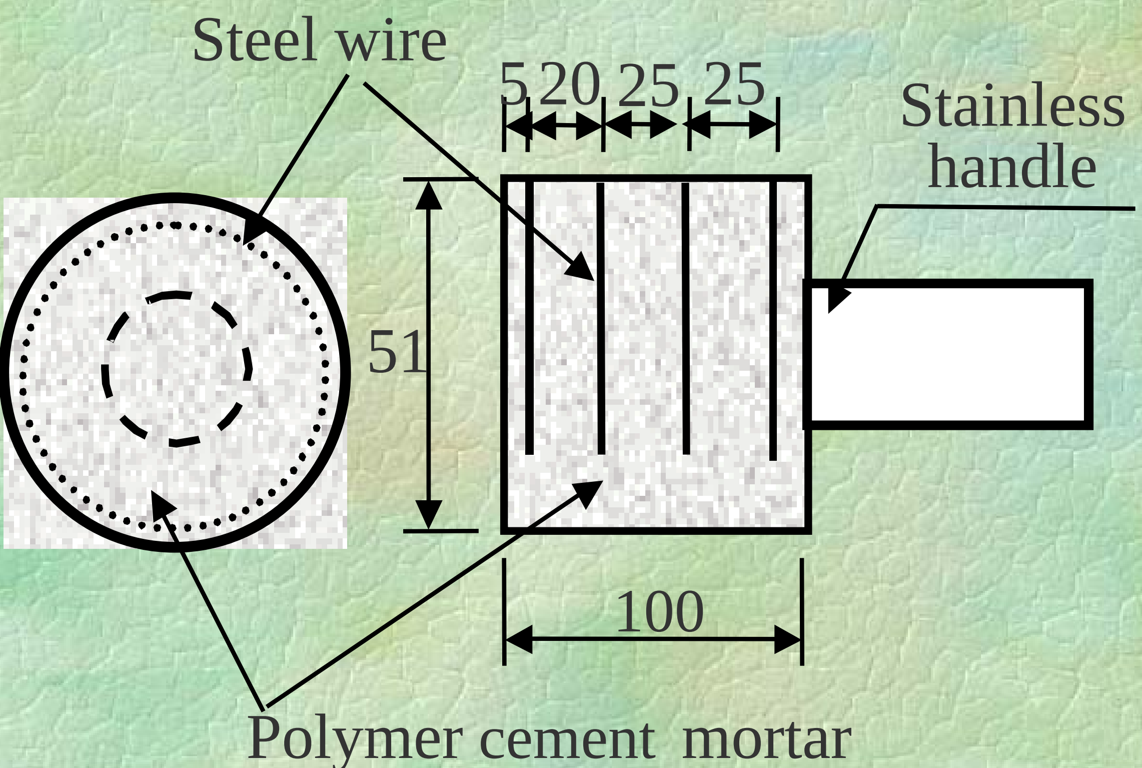
-- Monitoring System --

Two types of monitoring system have been installed in the piers constructed in the offshore environment

- **Newly developed monitoring sensor to detect chloride penetration depth into concrete non-destructively**
- **Embedded type reference electrode for monitoring natural potential of rebar in concrete to detect the initiation of reinforcement corrosion**

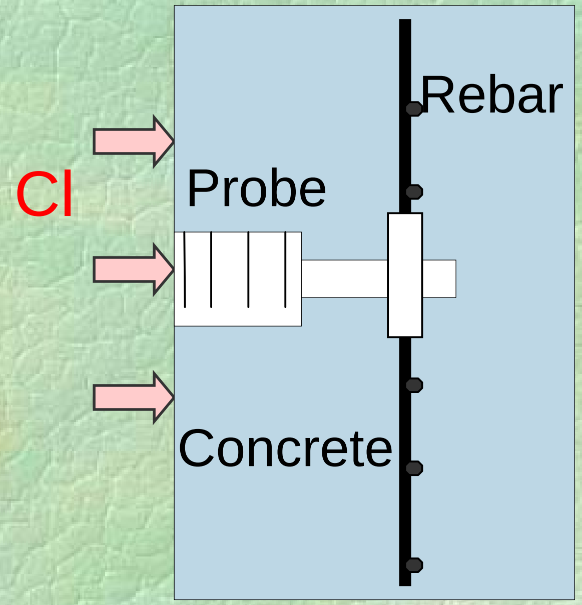
Chloride Penetration Monitoring Sensor

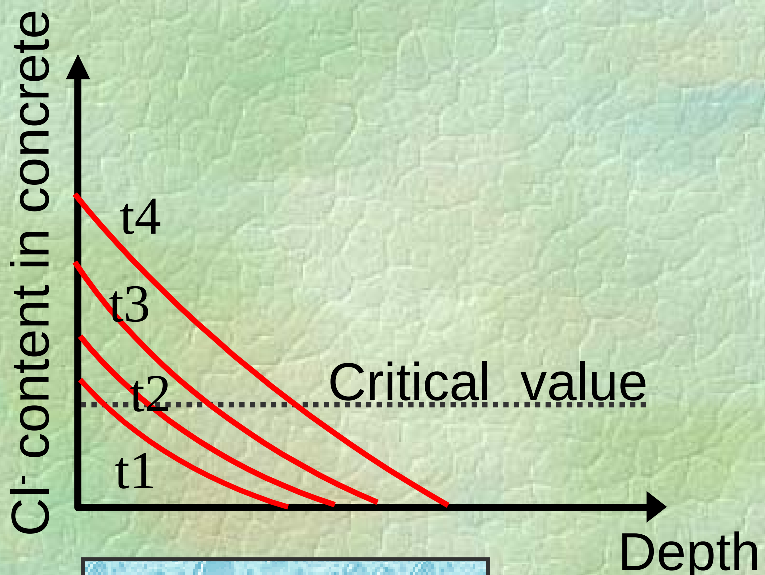
New sensor system detecting the depth where chloride content is critical level for initiating rebar corrosion

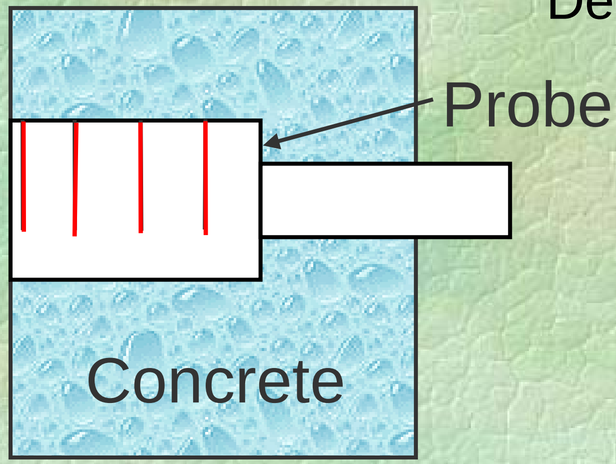


- Four steel wires having 0.1 mm of diameter are set in ditches along the circumference, at distances 5, 25, 50 and 75 mm from the top surface.

Chloride Penetration Monitoring Sensor







Critical chloride content

↓

Corrosion of steel wire

↓

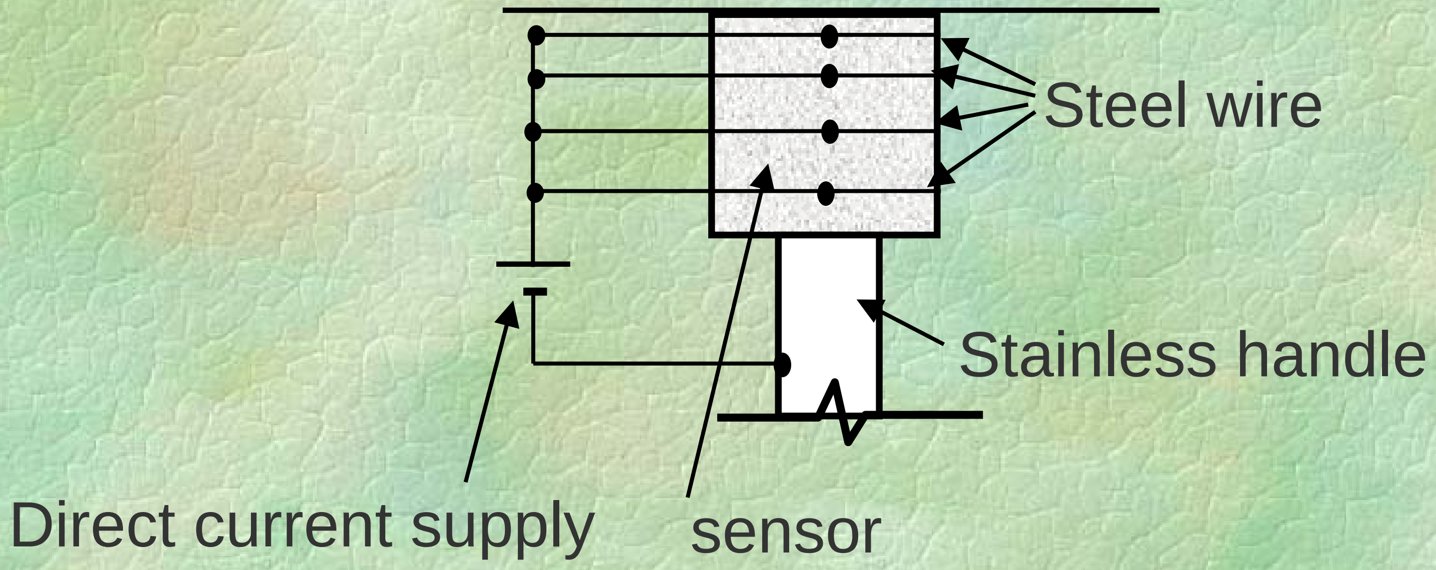
The wire breaks

↓

Sharp increment of electric resistance of wire

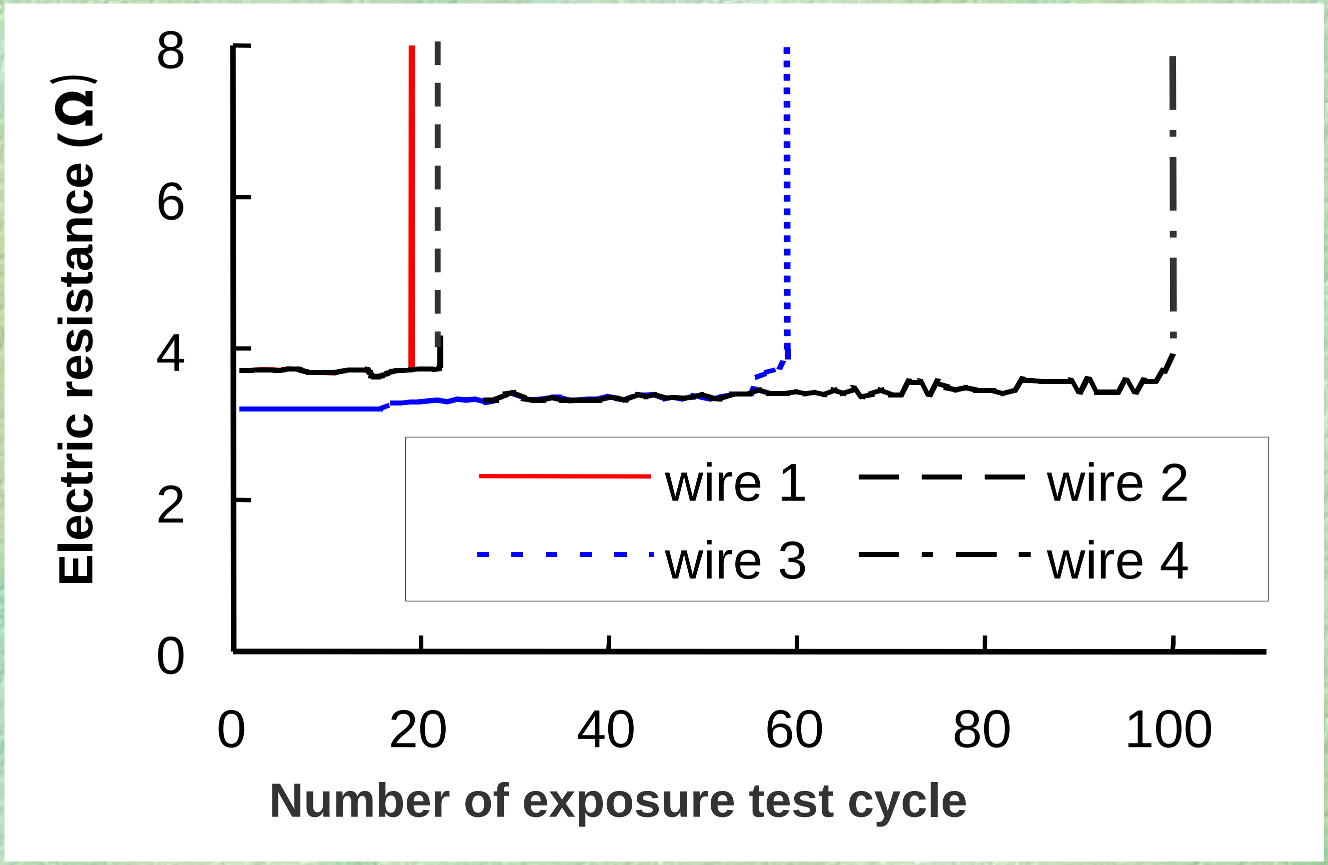
Chloride Penetration Monitoring Sensor

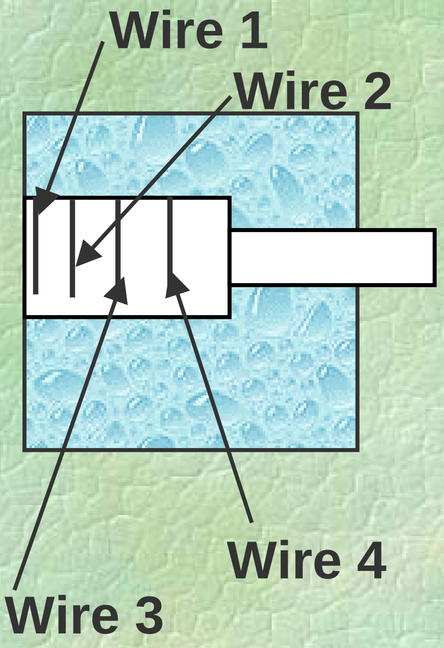
For improvement on sensitivity of sensor, small current supply to wires in sensor and potentials of wires are polarized 400 - 450 mV in positive direction



Chloride Penetration Monitoring Sensor

An Example of indoor experiment for examining sensitivity of the sensor

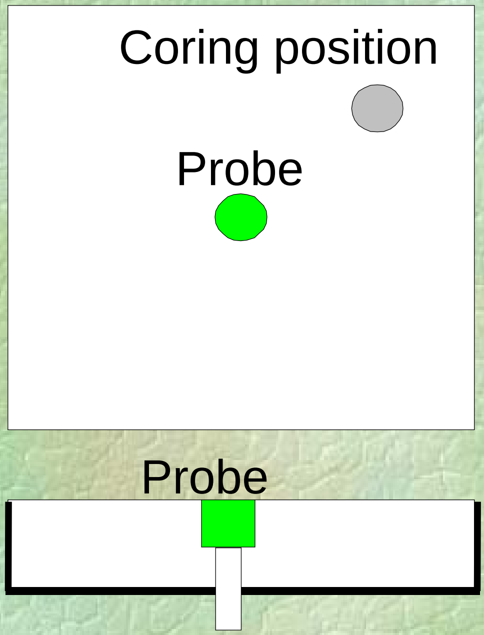


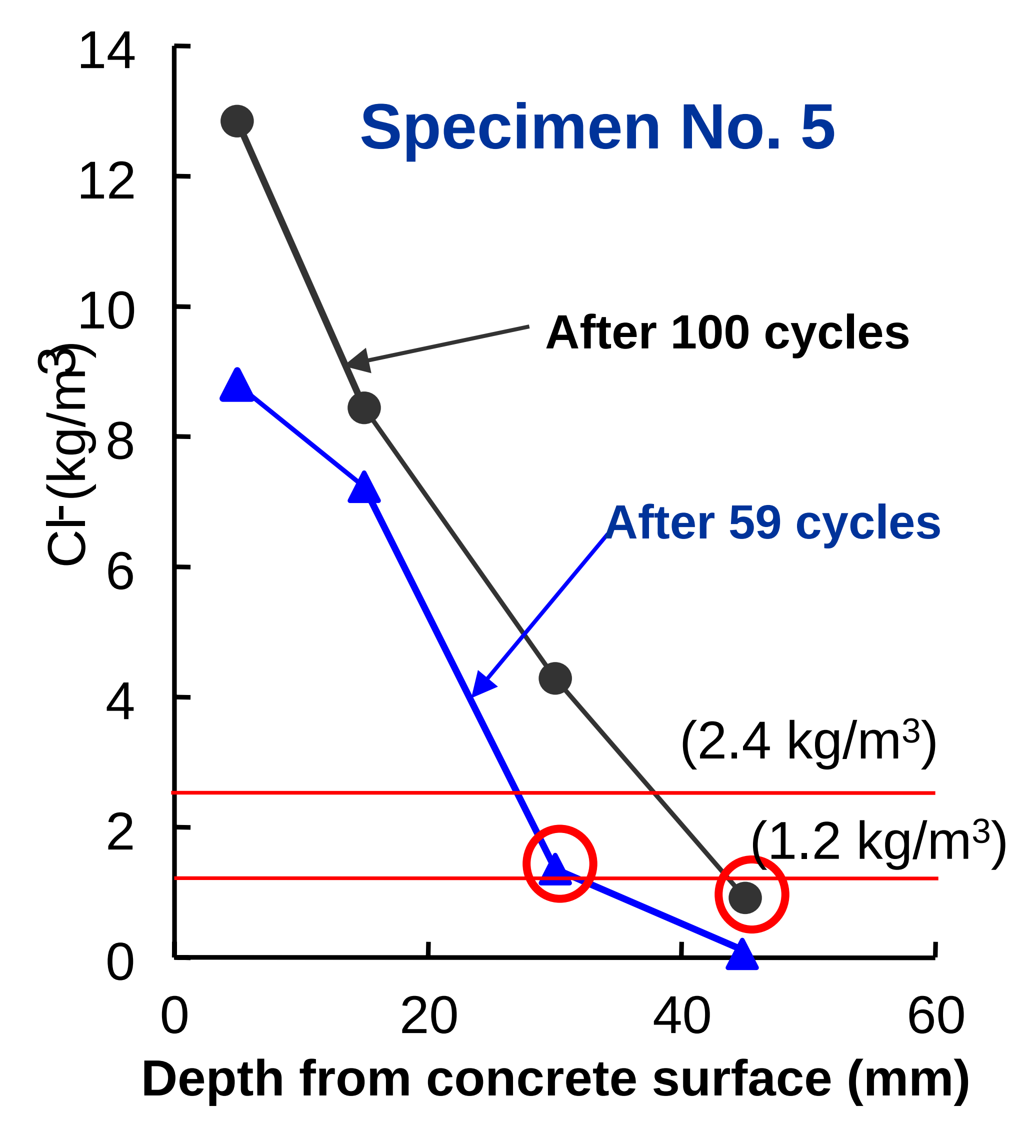


It can be confirmed that electric resistance of the wire set in sensor shows sudden increment at the certain time in order of the depth from the surface.

Improvement on Sensitivity of Probe

Chloride content in Concrete

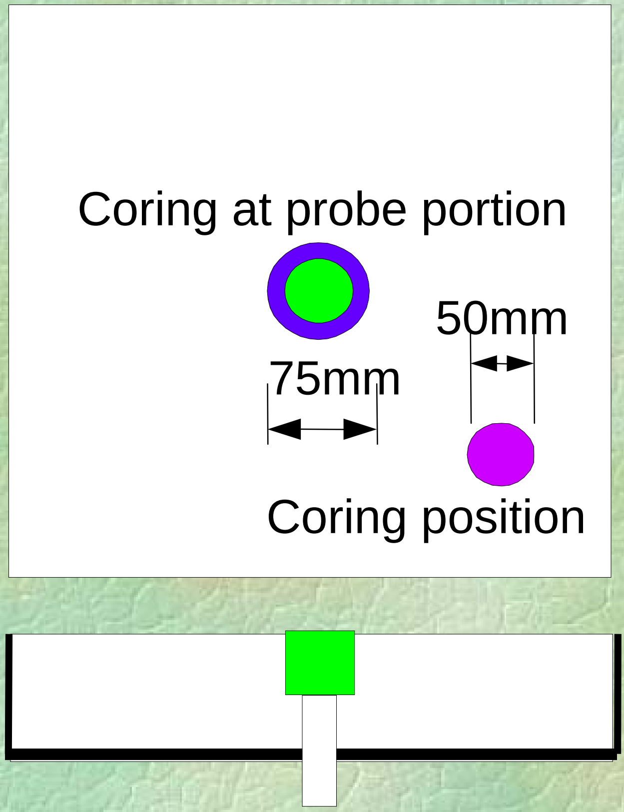


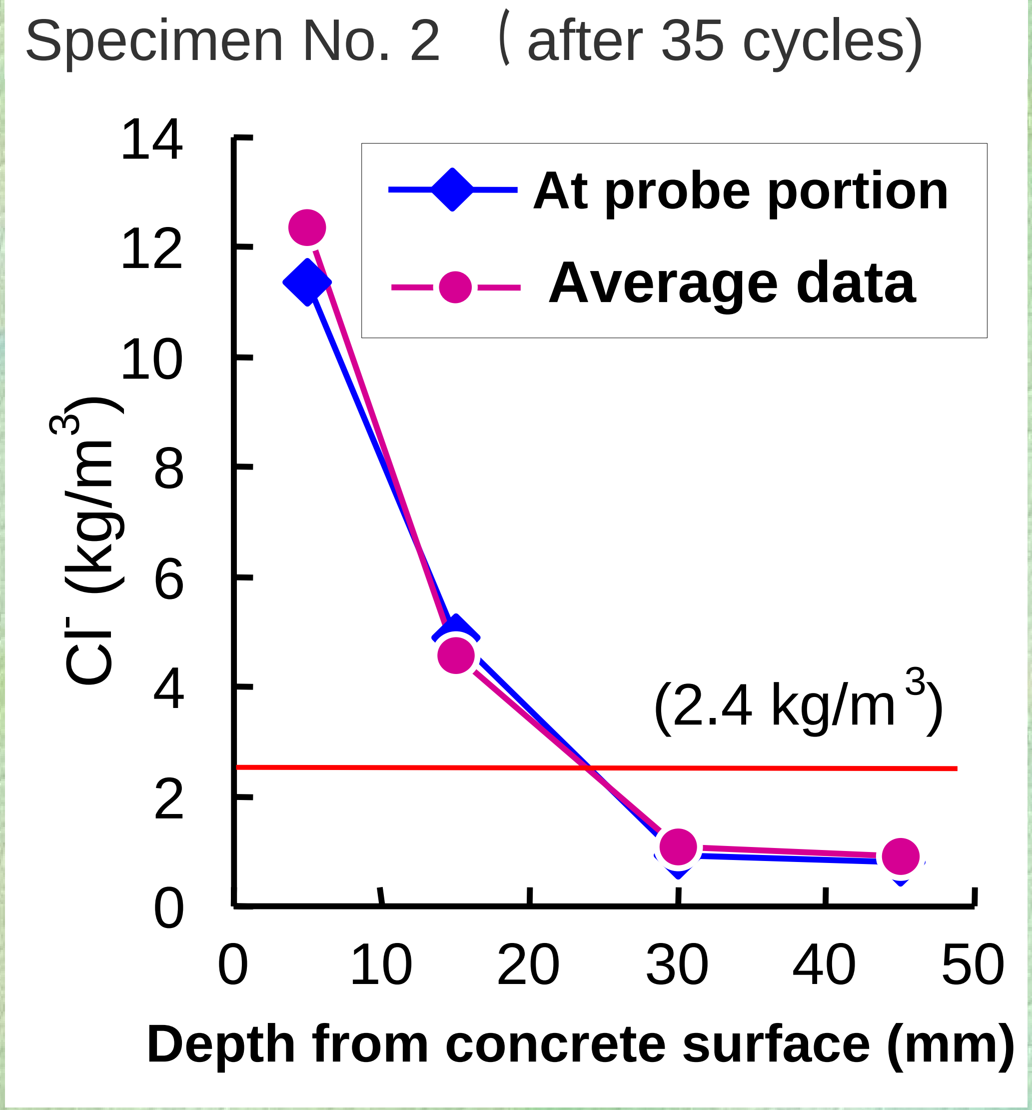


/ The wires broke whenever the chloride content reached abut 1.0 kg/m^3 in surrounding concrete.

Improvement on Sensitivity of Probe

Chloride content in Concrete





/ **Presence of the probe did not disturb chloride penetration process at concrete near to probe in the specimen No.2, to which any current was not supplied.**

ESTIMATION OF CORROSION START TIME ON REBAR BY USING MONITORING DATA

- Chloride diffusion into concrete can be analyzed macroscopically in accordance with the Fick's second low

$$\frac{\partial C(x,t)}{\partial t} = D\frac{\partial^2 C(x,t)}{\partial x^2}$$

(Assumption)

Diffusion coefficient (D) and chloride concentration at concrete surface (C_0) are constant respectively.

$$C_{(c,t)} = C_0\left[1 - erf\left(\frac{x}{2\sqrt{D\cdot t}}\right)\right]$$

When assuming that critical chloride content for initiating steel corrosion is constant,

$$C_0\left[1-erf\left(\frac{x_i}{2\sqrt{D\cdot t_i}}\right)\right]=C_0\left[1-erf\left(\frac{x_R}{2\sqrt{D\cdot t_R}}\right)\right]=C_c$$

Corrosion start time (t_R) on rebar having x_R of concrete cover thickness can be estimated by a following equation using the monitoring data of corrosion initiation time (t_i) and depth (x_i) of wire (*i*) .

$$t_R=\left(\frac{x_R}{x_i}\right)^2 t_i$$

x_R : **Cover thickness of rebar**

x_i : **Depth of wire (*i*) corroded**

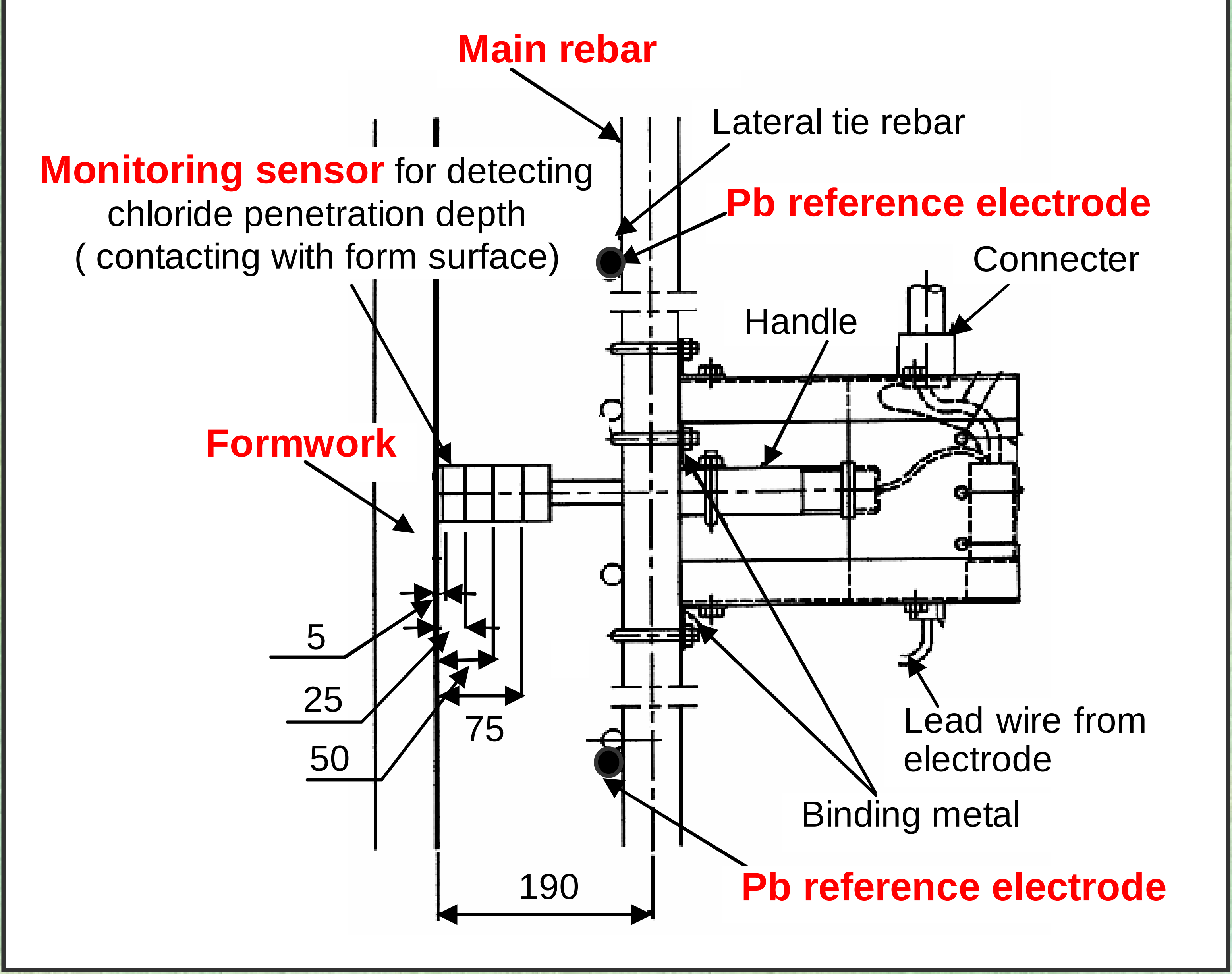
t_i : **Corrosion start time of wire (*i*)**

ESTIMATION OF CORROSION START TIME ON REBAR BY USING MONITORING DATA

- Comparison between actual breaking time of wire(i+1) and its estimation result by using the breaking time data of wire (i)

Cover thickness	Corrosion start time of wire (day)	Corrosion start time estimated by using the result at shallower portion (day)	Ratio between estimation and actual result
15mm	65	-----	---
30mm	177	260	1.47
45mm	366	398	1.09

Relatively accurate corrosion time can be estimated



Outline of Installed Condition of Monitoring Equipment in the Pier

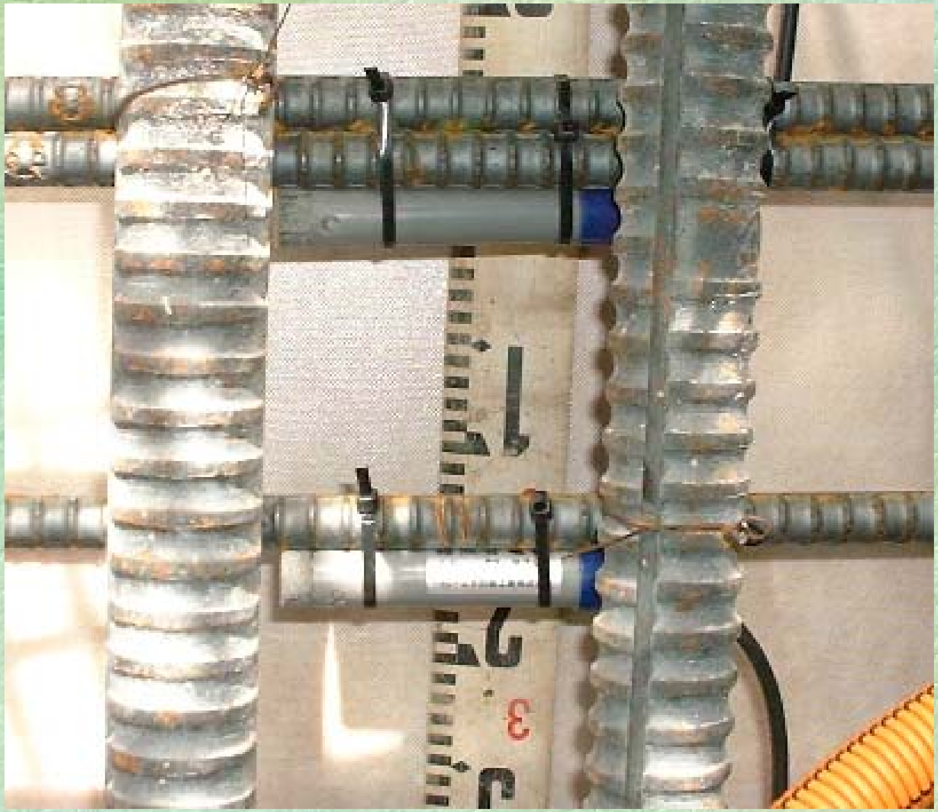

W-3

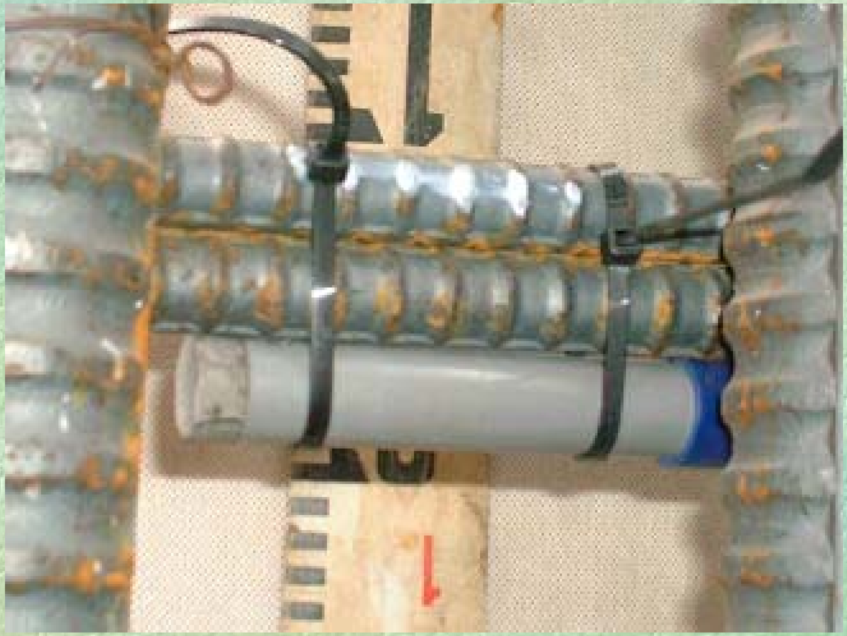

2001

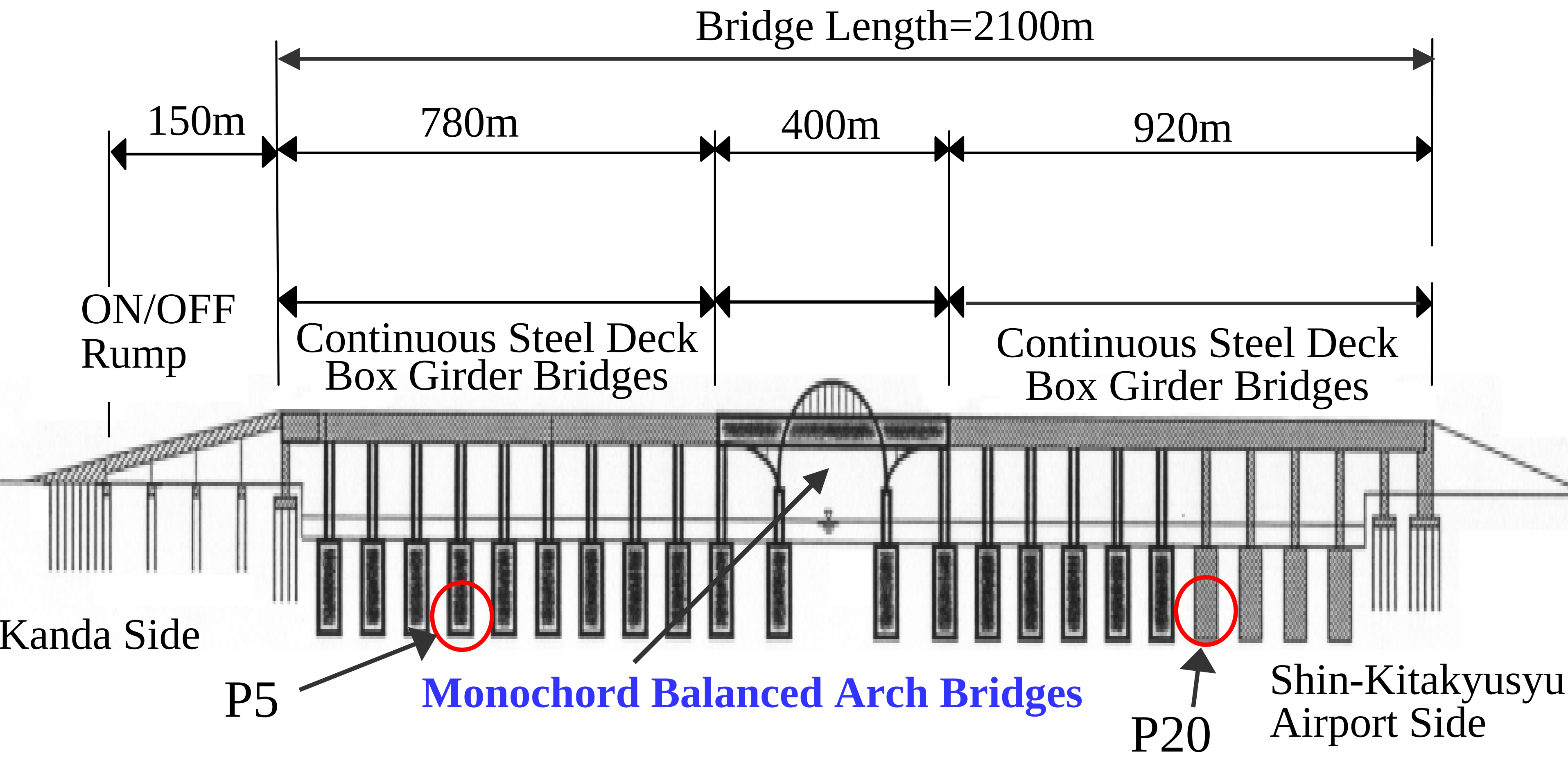
Monitoring Natural Potential of Rebar by Embedded Type Reference electrode

Some number of reference electrodes have arranged in concrete;

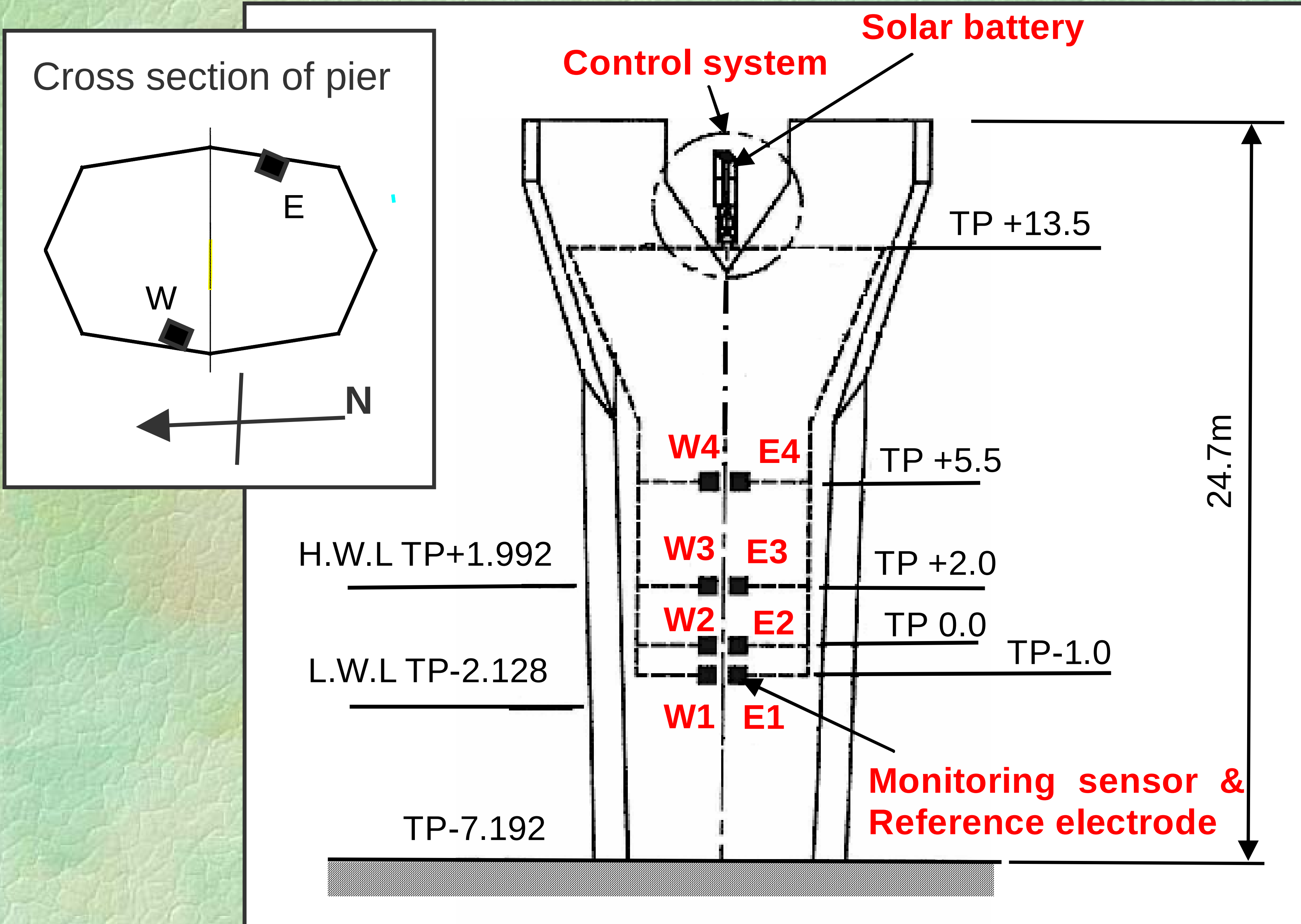
- To predict the initiation in the rebar corrosion
- To estimate the macro-cell corrosion formation







Location of piers having monitoring systems

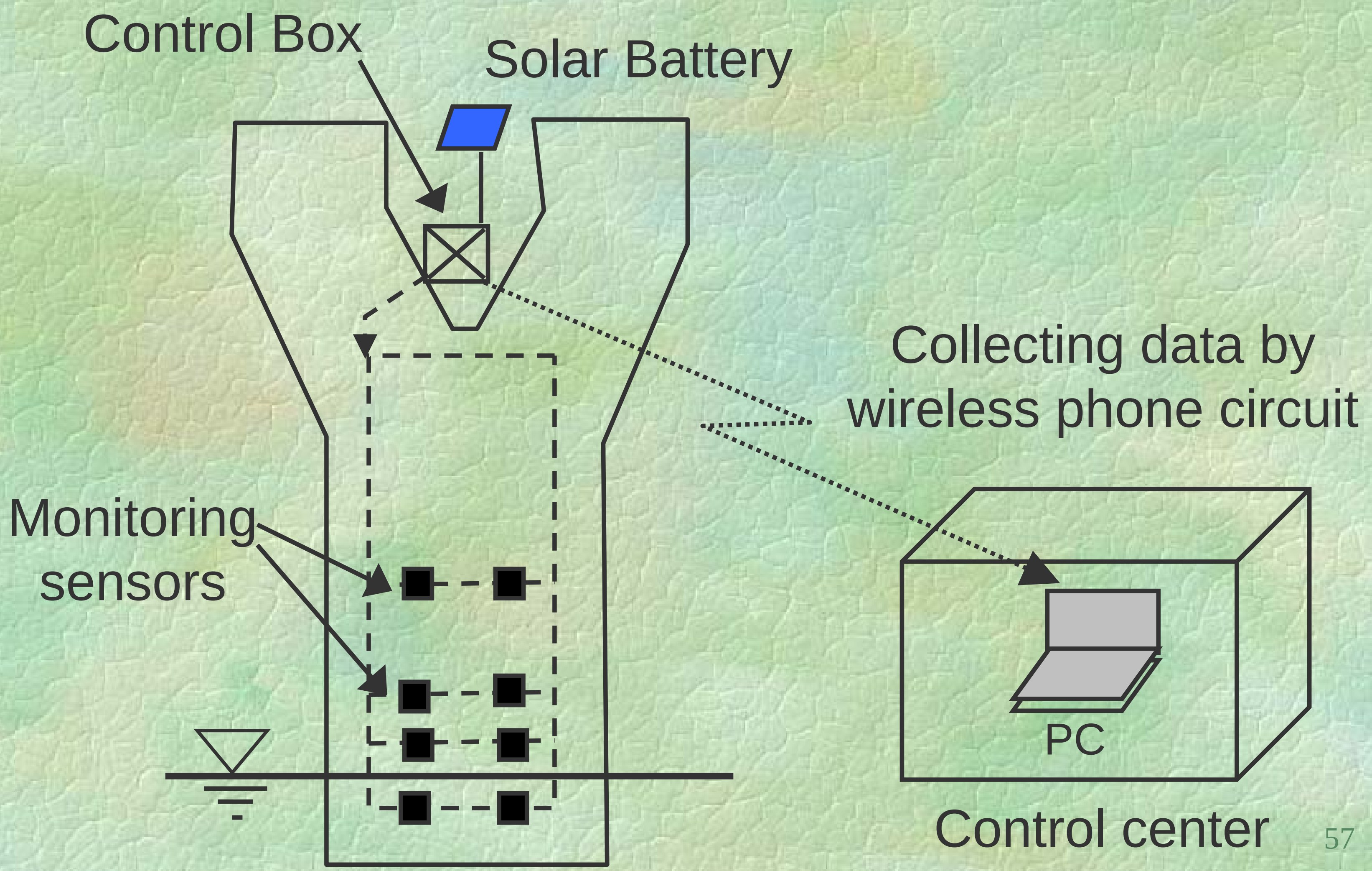


Positions of the Monitoring System Arranged in Pier

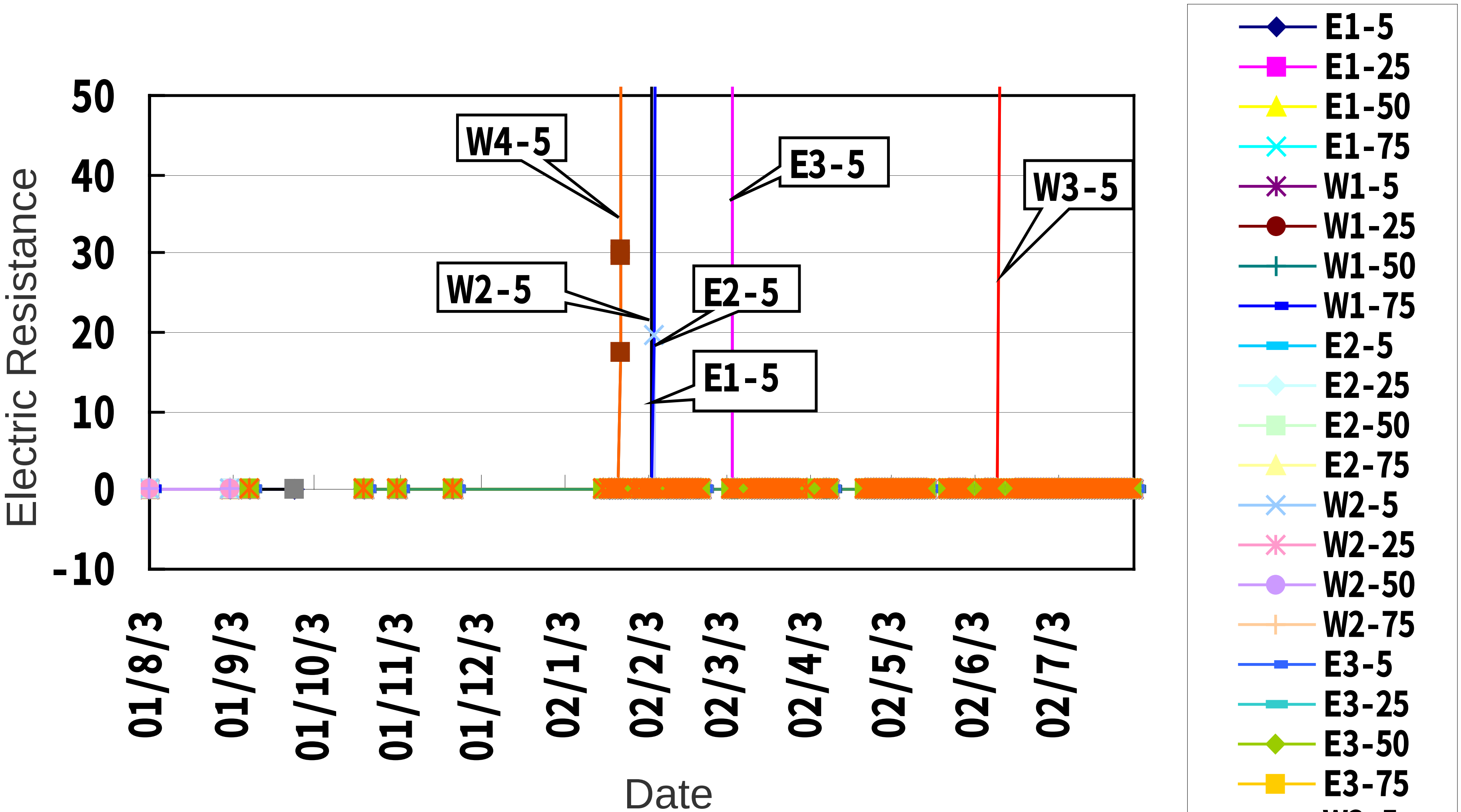
Control Box

Solar panel

All of monitoring data can be sent to PC in control center by using wireless phone circuit



Indication data form chloride penetration monitoring sensors



Monitoring data of electric resistance on wires having concrete cover thickness (x_R)

Expected corrosion initiation time on rebar

$$\left(\frac{145.5}{5}\right) \cdot 0.55 = 465.7 \text{ 年}$$

Objects of inspection by using monitoring

Type of system	Measurement	Object of Judgment	Threshold value
Embedded type of reference electrode	Natural potential of rebars	Initiation of corrosion	-180 mV vs Ag/AgCl
		Formation of macro cell	50mV of potential difference
Monitoring sensor detecting chloride penetration depth	Depth where chloride content is critical level for initiating rebar corrosion	Chloride penetration depth	75mm
		Alkali Contents in cover concrete	3.0kg/m^3

Conclusive Remarks

- In the construction of the access bridge to Shin-Kitakyusyu Airport, a lot of new trial to keep the durability of structure has been conducted.

- In the viewpoint of a preventive maintenance concept, maintenance activity will be performed on the piers from the beginning of the service.

Conclusive Remarks

- **The Guideline for the preventive maintenance on the piers has been published. It is the first one in Japan for maintenance of newly constructed structures.**

- **The monitoring system has been installed in the pier for collecting data concerning not only with rebar corrosion but also with chloride penetration depth into concrete, which is detected by using the newest technology developed.**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