# BRIDGE MAINTENANCE

## - Application to Steel Bridges in Subtropics -

**Tetsuya Yabuki**

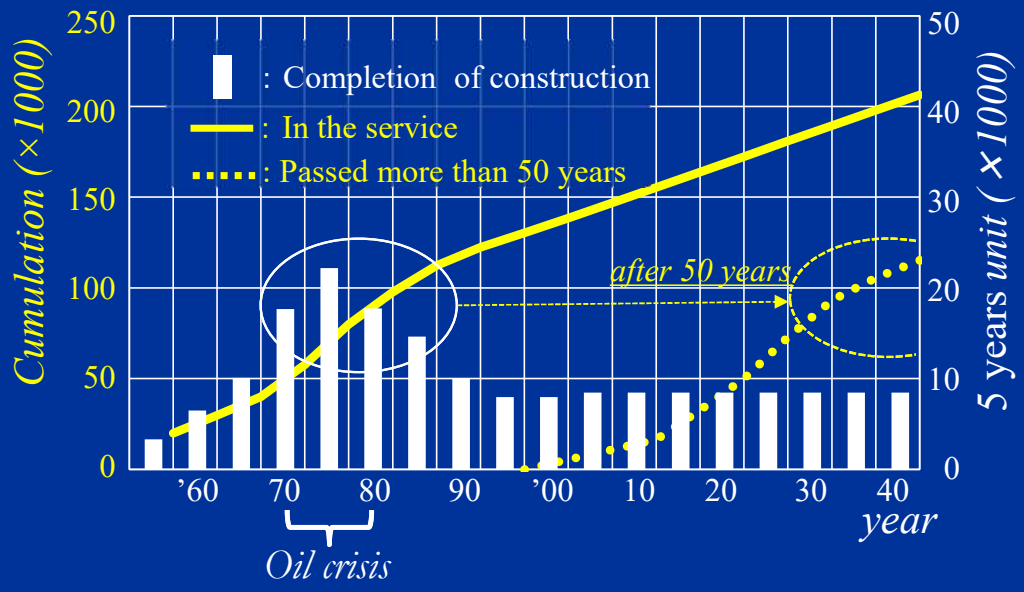
**Doctor of Engineering**
**Emeritus Professor, University of Ryukyu**
**Fellow of the Japan Society of Civil Engineers**

# CONTENTS

# 1. INTRODUCTION

## Current Situation of Bridges

- Increase in Aging Bridges -Case of All Japan -



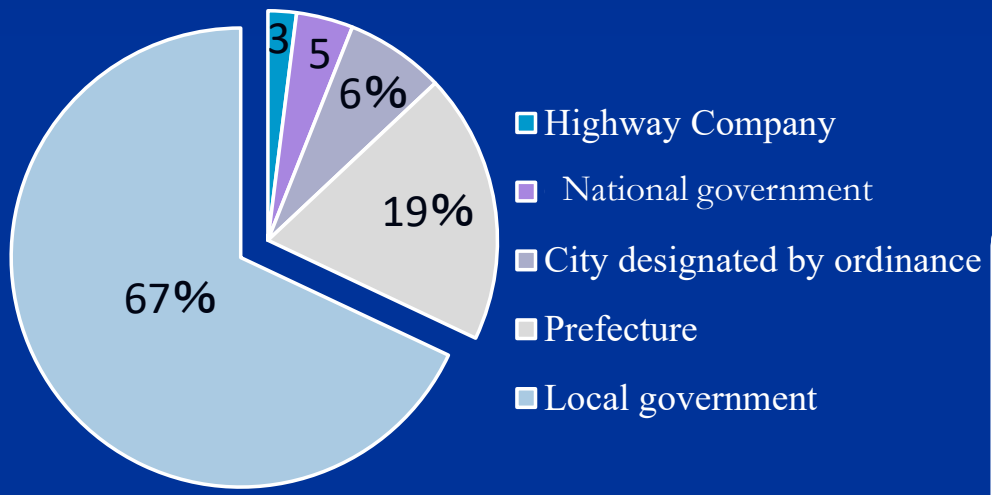

Number of bridges in each year in Japan


**The number of aging bridges to need the advanced maintenance**

→ *Increase after 50 years in response to the increase of Bridge Constructions.*

# The situation is severe in local areas!!

- Serious Problems in Local Areas




Administrators of steel bridges used in Japan

*Serious problems in local areas*

Lacks of maintenance budget and skill

- Roads are the key to national land strength.
- Bridges are the cornerstones of roads.

→ **<u>The national government should help for the maintenance of bridges (67%) in local government.</u>**

*Important policy!*

# Bridge Performance Requirements

## Essential Requirements for Bridge Performance

- ✓ **Load carrying capacity** : *Most basic requirement*
  → *Strength required by the bridge.*
- ✓ **Service performance** : *Comfort provision*
  → *Not only be practical, but also have a design that harmonizes with its surroundings.*
- ✓ **Durability** : ***Directly linked to the maintenance***
  → *Essential factor that determines the bridge's sustained performance over 100 years life cycle.*

- Design Considerations for Durability

✓ **When in designing, high quality elements having 100-year sustained performance under suitable maintenance should be considered.**

→ ***High quality elements : Materials, Structural details (Ex. Girder ends)***

→ ***Suitable maintenance : Examination, Treatment***

*In advance, the suitable maintenance should be considered in designing stage!!*

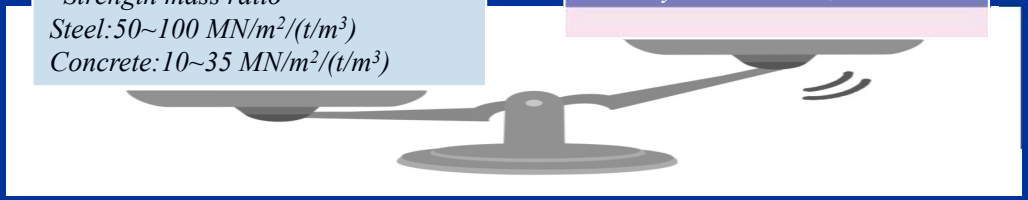
# Advanced Performance of Steel Bridges

| *Merits* | |
|---|---|
| *Weight** | *Lighter* |
| *Strength** | *Stronger* |
| *Construction period* | *Faster* |
| *Quality level* | *Higher* |
| *Repair period & accuracy* | *Faster & Higher* |
| *Material quality* | *Higher* |

**Strength mass ratio*
*Steel:50~100 MN/m²/(t/m³)*
*Concrete:10~35 MN/m²/(t/m³)*

| *Demerits* | |
|---|---|
| *Material cost* | Higher* |
| *Construction technology* | Need higher |
| *Deterioration* | Prone to rust |

**Only material cost, not total.*



*Balance merits against demerits of steel material*

Steel is a reasonable material in constructing advanced bridges because of its merits.

*Once rust causing deterioration is overcome, the future of steel bridges is always in victory!*

# 2. MAINTENANCE CONCEPT

## Management Cycle

- **Examination and Treatment**

**Most important matter**

→ *Make the total cost reduce by achieving healthy long life to the bridges.*

**Mandatory items for achieving**

→ *Sustainable and appropriate maintenance*

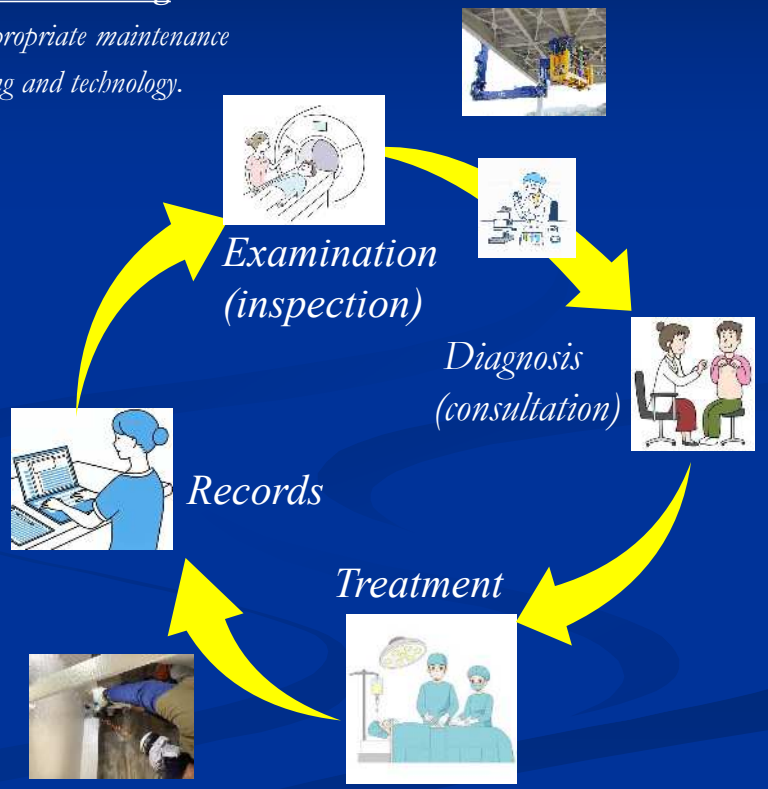
→ *Advanced engineering and technology.*

**Bridge maintenance is like human health care.**

→ *Detection by periodic examination (inspection) is an important first step in maintenance management.*

→ *Next is to promote systematic and efficient consultation and treatment based on regular examinations.*

→ *The final step is to record the results.*




Health care management cycle

- Assessment of **Soundness**

**The degree of damage revealed by periodic inspections**

→ *Evaluated at four classifications of "Soundness"*

| Classification | | Impaired Level of Function |
|---|---|---|
| I | Sound | Not be impaired. |
| II | Preventive Maintenance | Not be impaired but desirable to take measures from the viewpoint of preventive maintenance. |
| III | Early Action | May be impaired and measures should be taken as soon as possible. |
| IV | Emergency Action | Being impaired or highly likely impaired and urgent action should be taken. |


**Deterioration is the most significant factor disturbing bridge function!!.**

# Pre- and Post-Measures in Maintenance

✓ **Pre-measures : Preventive maintenance**

→ *Minor restorations while still in classification II small scale damage.*

→ *Reduced maintenance cost*

✓ **Post-measures : Corrective maintenance**

→ *Major repairs after serious damage in classification III or IV.*

→ *Increased maintenance cost*

**The key concept is that "Early detection, early treatment"!!**

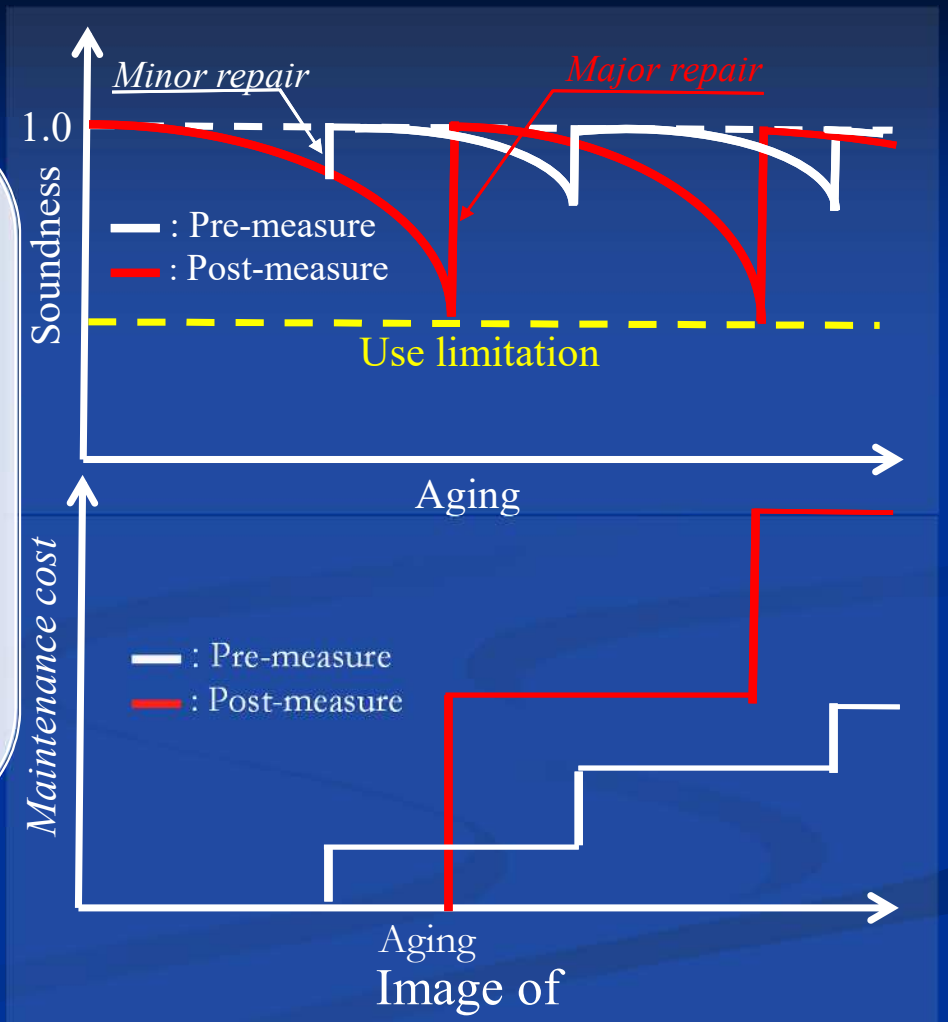
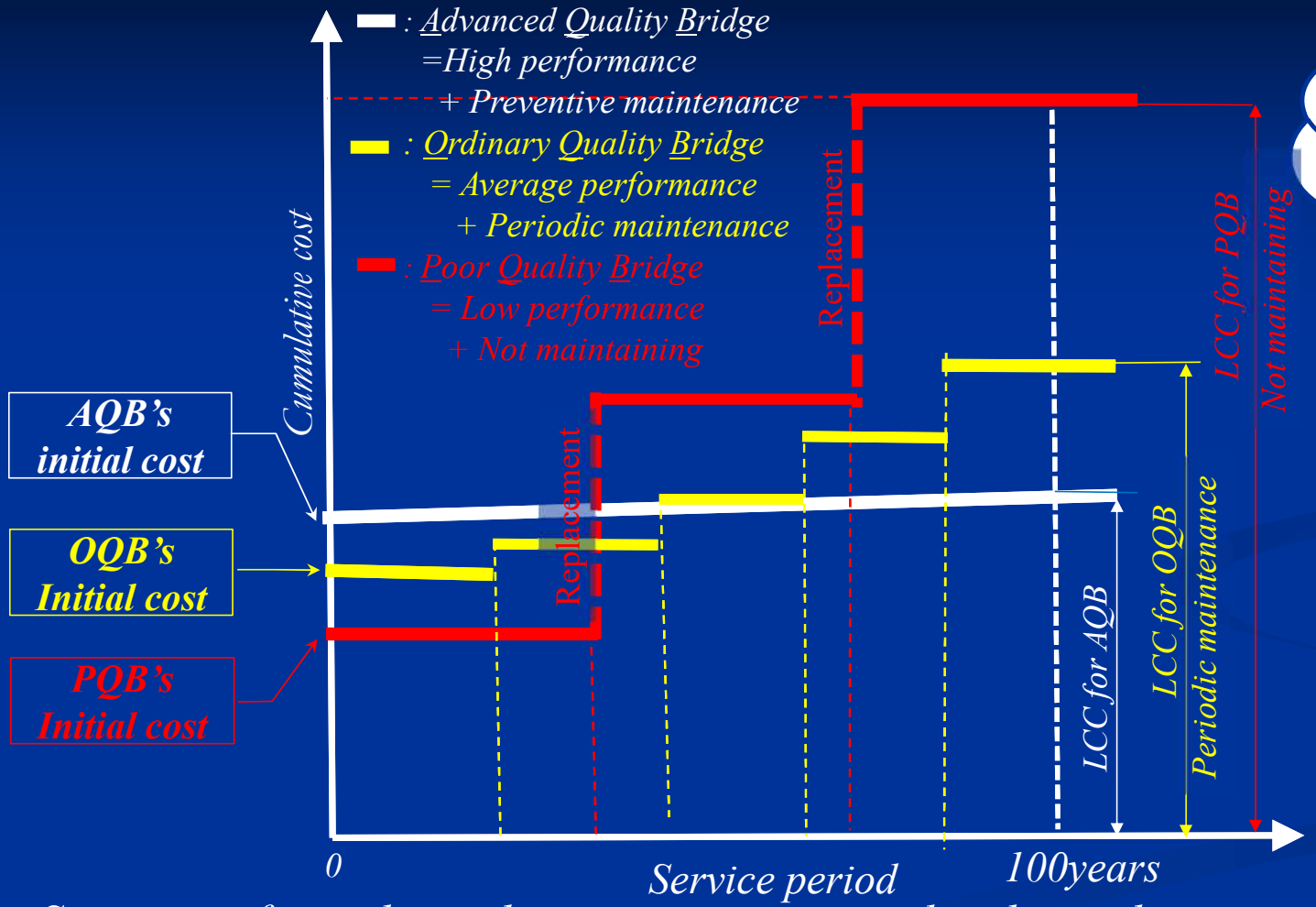



Image of longer service life and reduced life cycle costs

# Bridge Quality, Maintenance Management and Life-Cycle-Cost




*Summary of correlation between service period and cumulative cost*


**Advanced performance**
**+ Preventive maintenance**
**→ *Extend the life***
***and reduce the LCC.***

# 3. UNDERSTANDING DETERIORATION

## Cause of Steel Bridge Deterioration

*There are two kinds of phenomena.*

✓**Physical phenomenon**

→ *Cracks due to fatigue*

✓**Chemical phenomenon**

→ *Corrosions under wet condition*

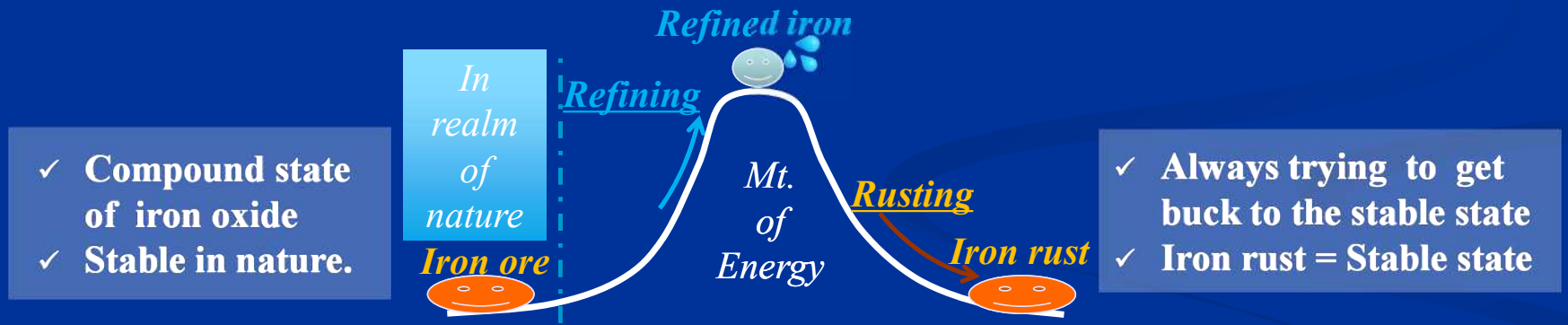
In subtropical areas, the major deterioration is ***steel corrosion***.

# Steel Corrosion Phenomenon

## The true nature of iron rust

About 90% of steel is refined iron.

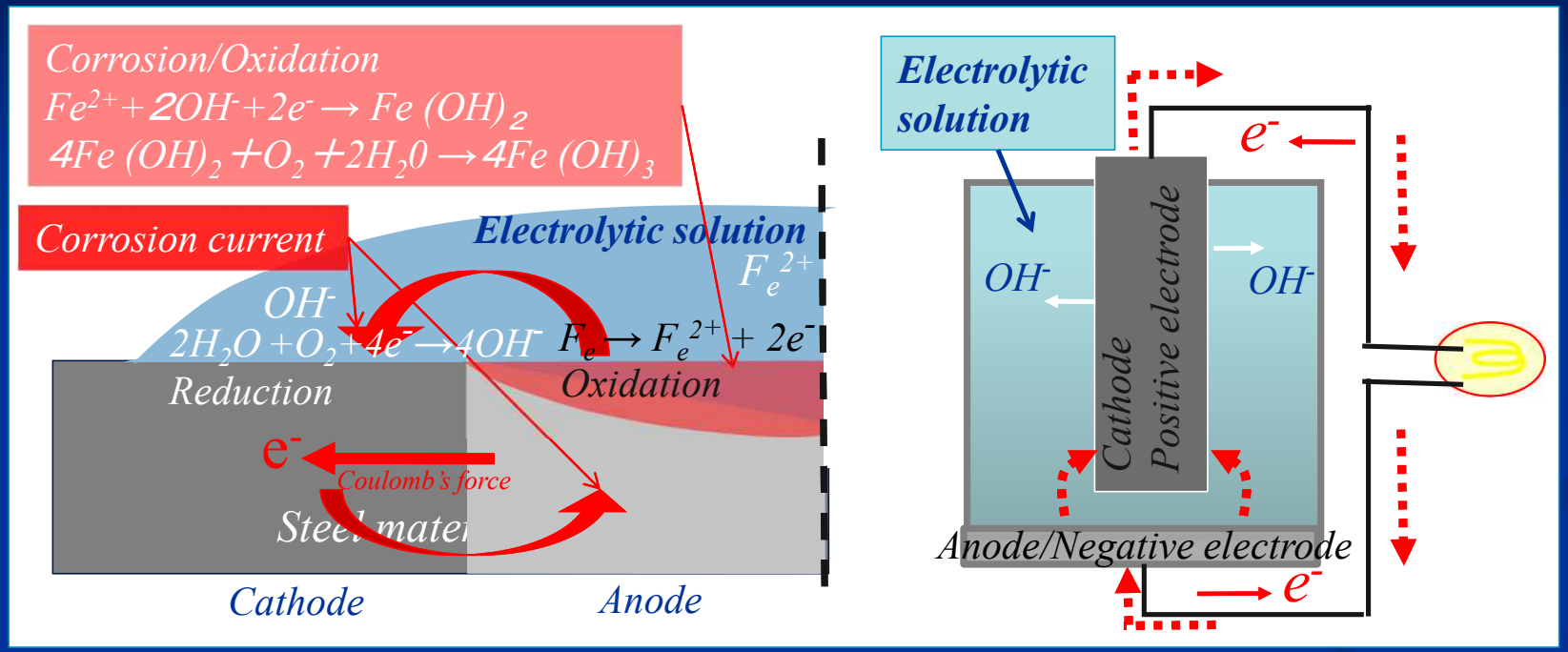
- ✓ Pouring large amount of heat energy into the iron ores.
- ✓ Separating oxygen from the iron ores.
- ✓ Refined iron by the separating.
- ✓ Unstable in nature.




*The change of iron-ore to refined iron and iron-rust*

An iron refined is unstable equilibrium state, in the realm of nature.
→ **Steel is always trying to get buck to the stable state = Corrosion state.**

# Mechanism of Rust Generation




Mechanism of the corrosion cell

Mechanism of an electric cell

**Mechanism of rust generation is mechanism forming corrosion cell !!.**

## ● Factors of Corrosion Promotion (Assist and Accelerate)

**- Assist Factors -**

→ Assist factors work directly to make the corrosion cell activate.

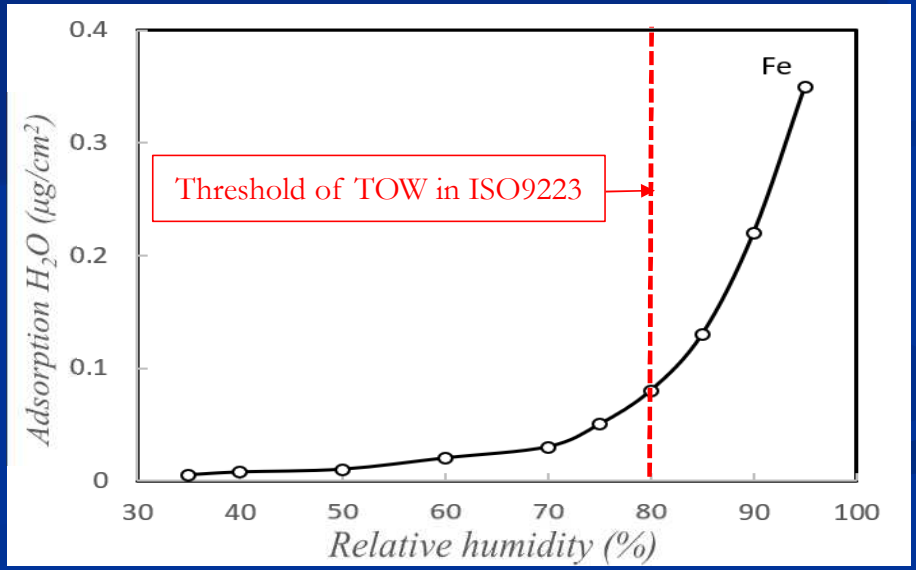
✓ *High temperature : to assist chemical reaction active.*

*A 10° C (Celsius) increase in temperature doubles the rate of chemical reactions.*

✓ *High humidity : to assist electrolytic solution abundantly*

*Water adsorption increases rapidly when humidity exceeds around 80%.*

*The time of wetness (TOW) in ISO 9223 is defined as the time during which the relative humidity exceeds 80%.*

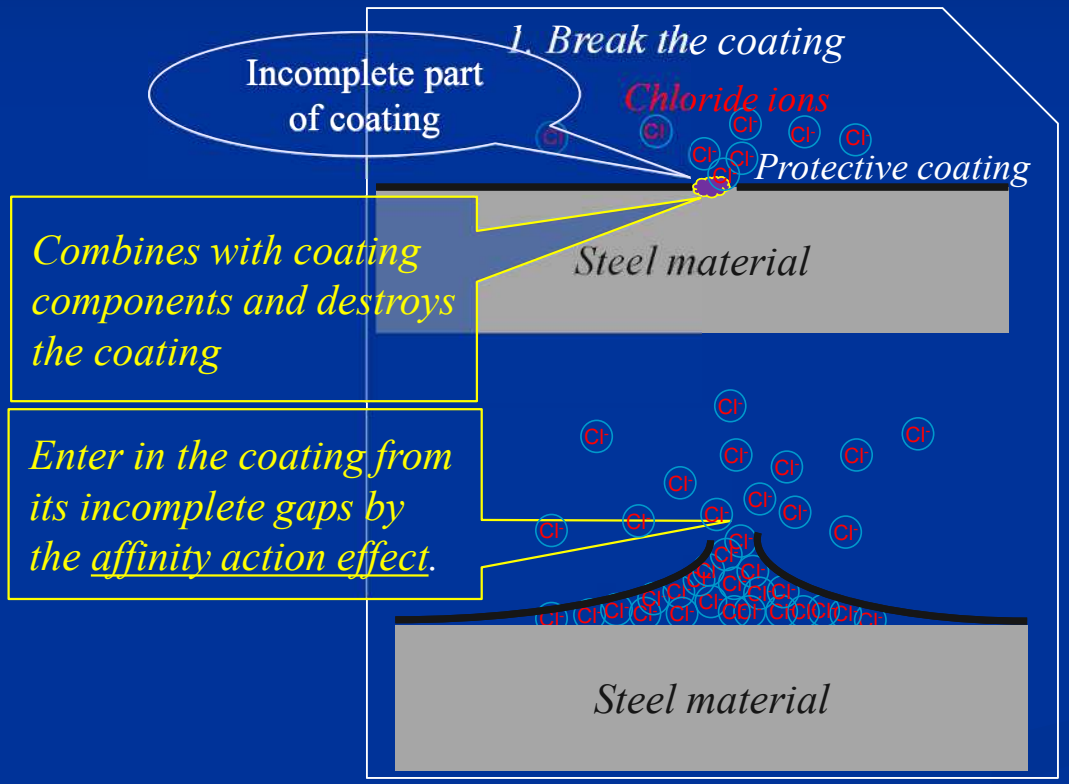


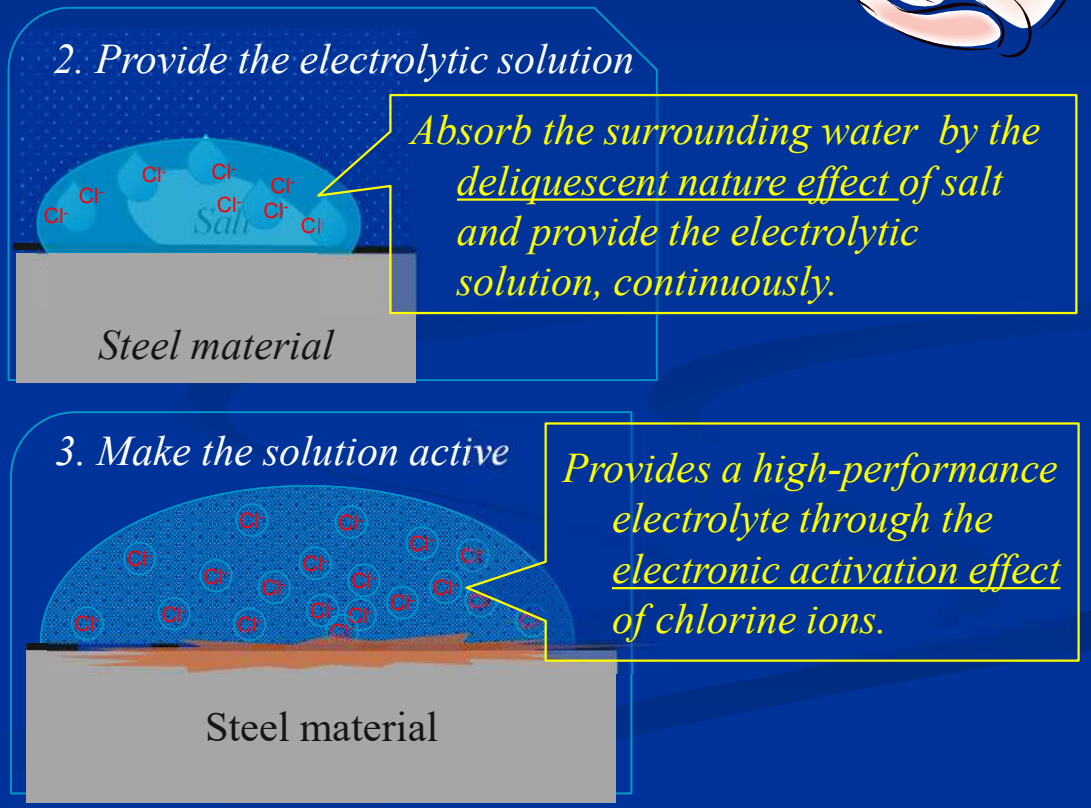

*Relation between water adsorption and relative humidity*

## - Accelerate Factor -

→ Chloride : *to accelerate strongly the function of the corrosion cell from the side.*

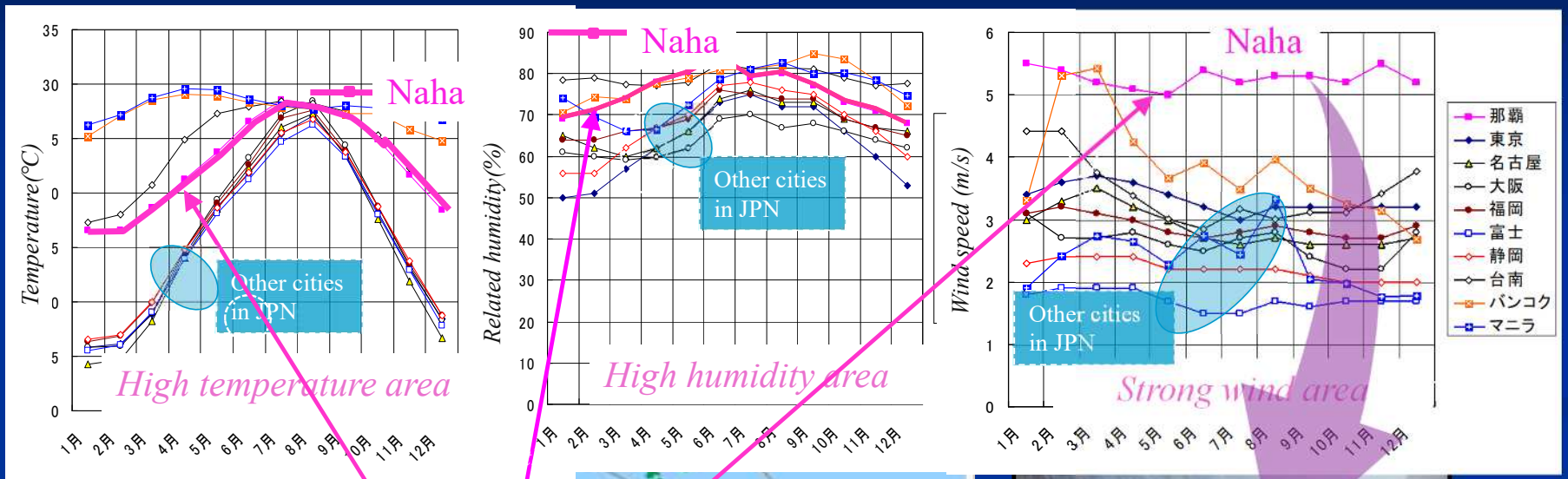
*Chlorides are the most powerful corrosion accelerators, although they are not involved in corrosion chemistry at all.*

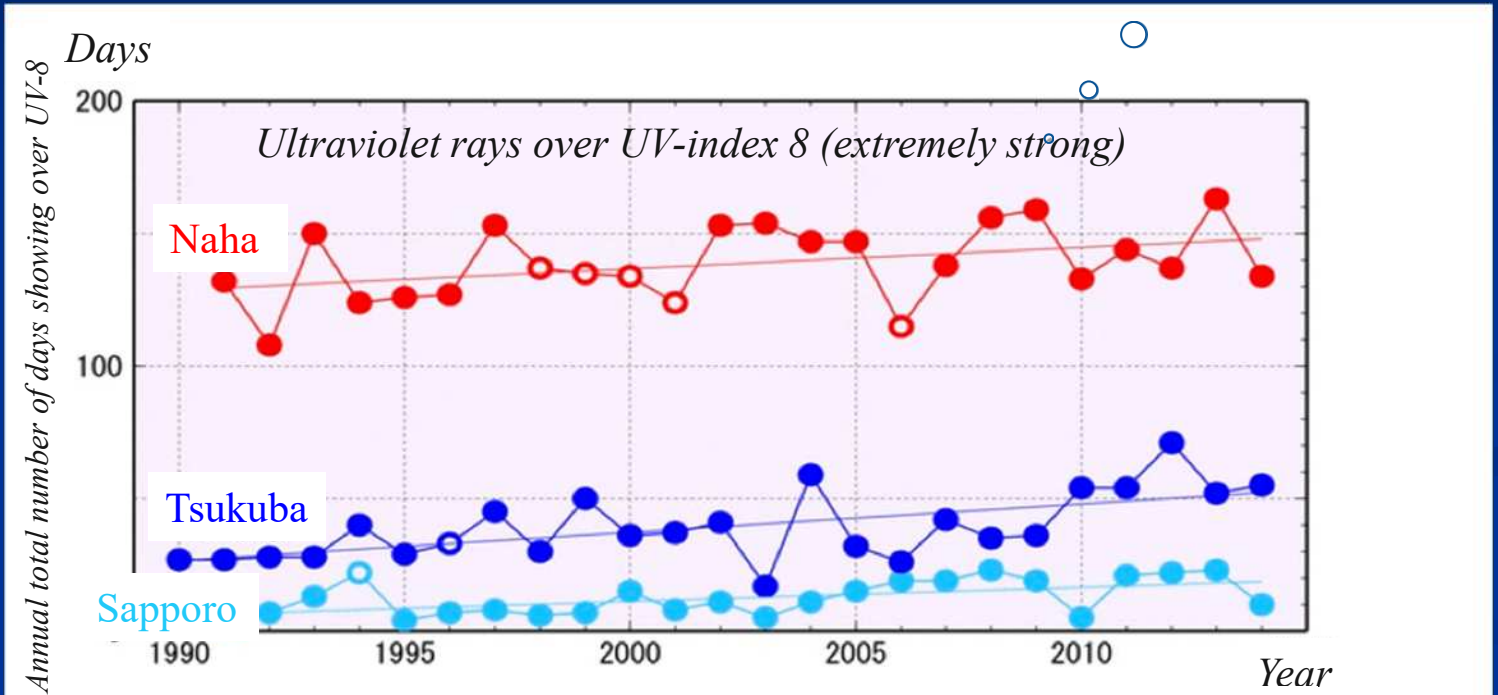
# Subtropical Meteorology and Corrosive Environment

## Meteorology Observation Results





By global warming?




*Secular variation of annual total number of days showing over UV-8*

- **Meteorology Characteristics**
  → High temperature, High humidity, Strong wind
  → Extremely strong ultraviolet

Impacts on corrosion


- ✓ **High temperature** : *to make a chemical reaction active*
- ✓ **High humidity :** *to supply the electrolytic solution abundantly*

} *Assist factors*

- ✓ **Strong wind** : *to create salinity environment (flying salinity)*
- ✓ **Extremely strong ultraviolet light**: *to break the paint film*

} *Accelerate factors*

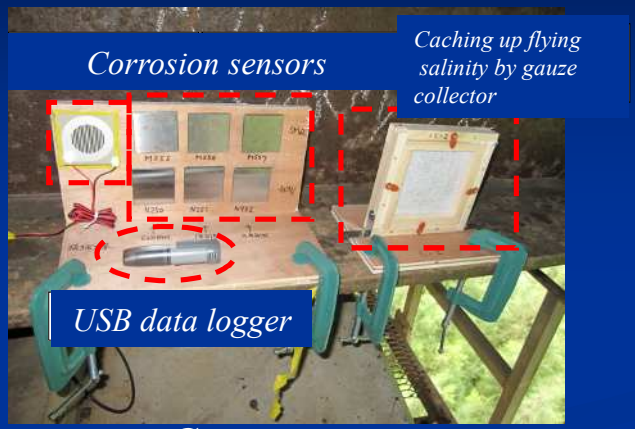
Okinawa is a typical corrosion environment area in subtropics - **Treasure Island of Corrosion Information!!**

# Survey for Corrosion Environment

## Exposure Fields for Monitoring Corrosion Environment in OKINAWA

# Survey Items for Corrosion Environment

- ✓ Flying salinity amount
- ✓ Moisture and temperature
- ✓ Wind velocity and direction
- ✓ Corrosion property




*Censer set up*

*Anemometer*

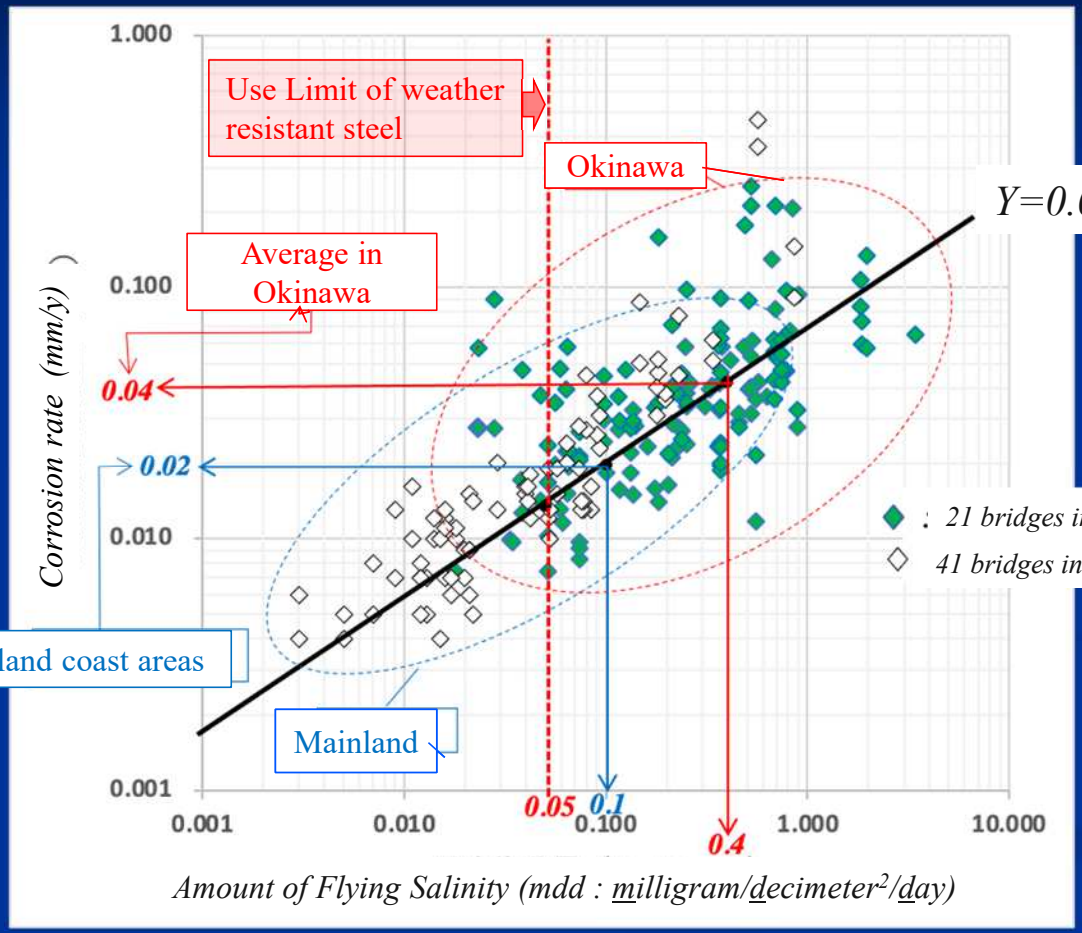
*Thermo-hygrometer (USB data logger)*

*ACM Censer*

*Gauze collector (for flying salinity)*

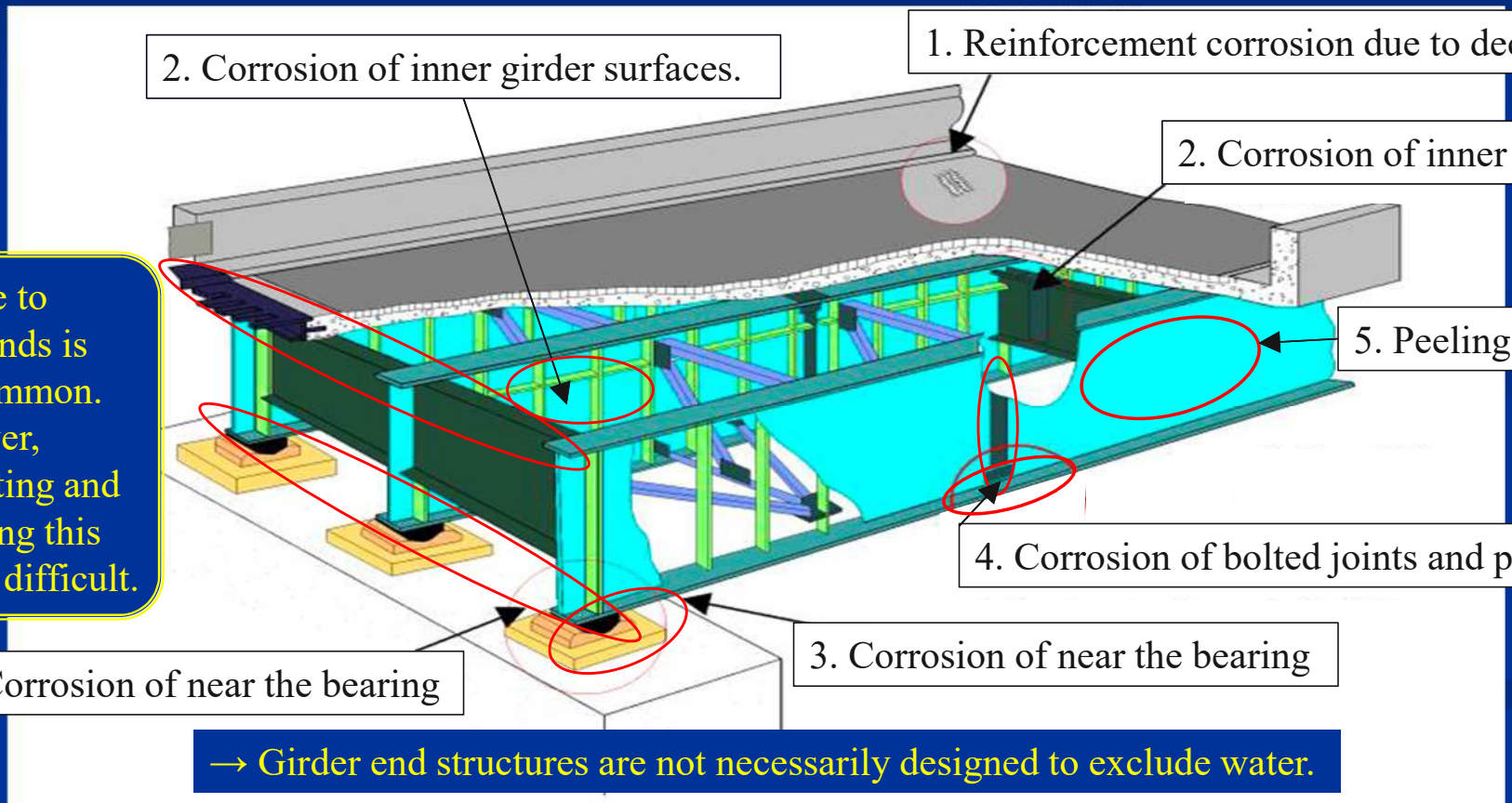
*Corrosion censer (bare metal specimen)*

# Relationship between Corrosion Rate and Amount of Flying Salinity




# 4. STEEL BRIDGE CONSIDERATIONS

## Damage Diagram of Major Steel Bridge Corrosions




- Damage to girder ends is very common.
→However, inspecting and checking this area is difficult.

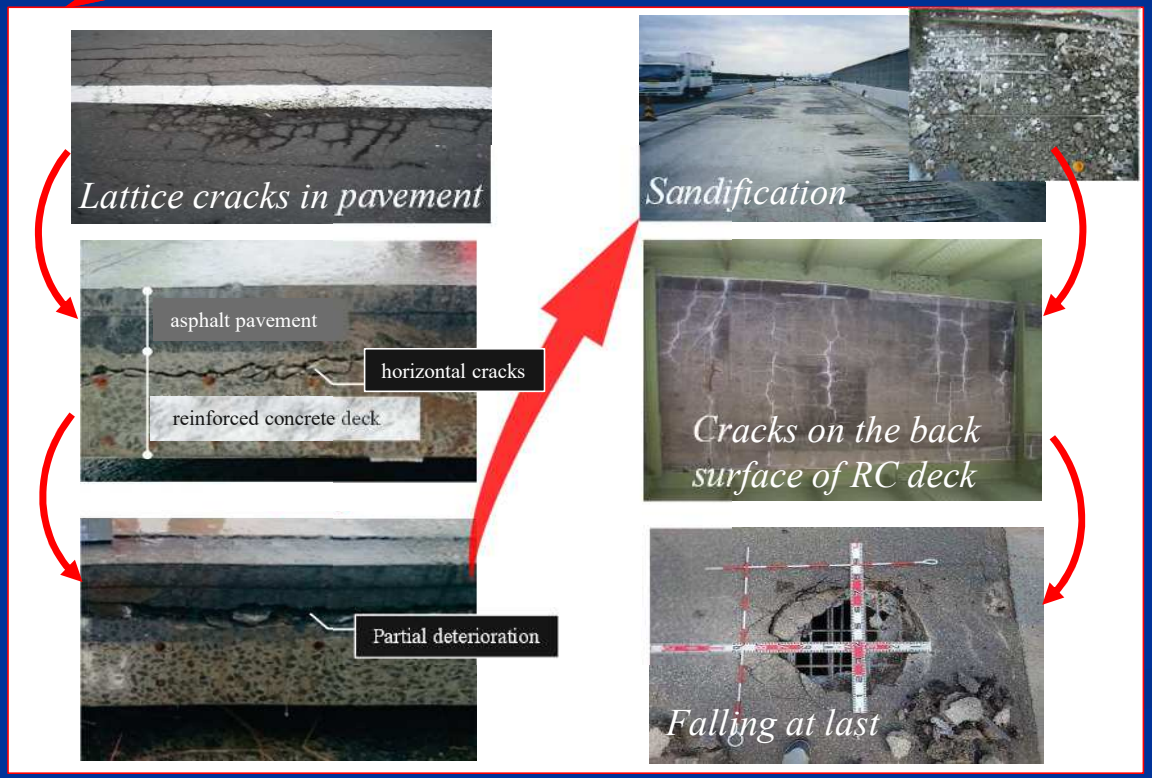
→ Girder end structures are not necessarily designed to exclude water.

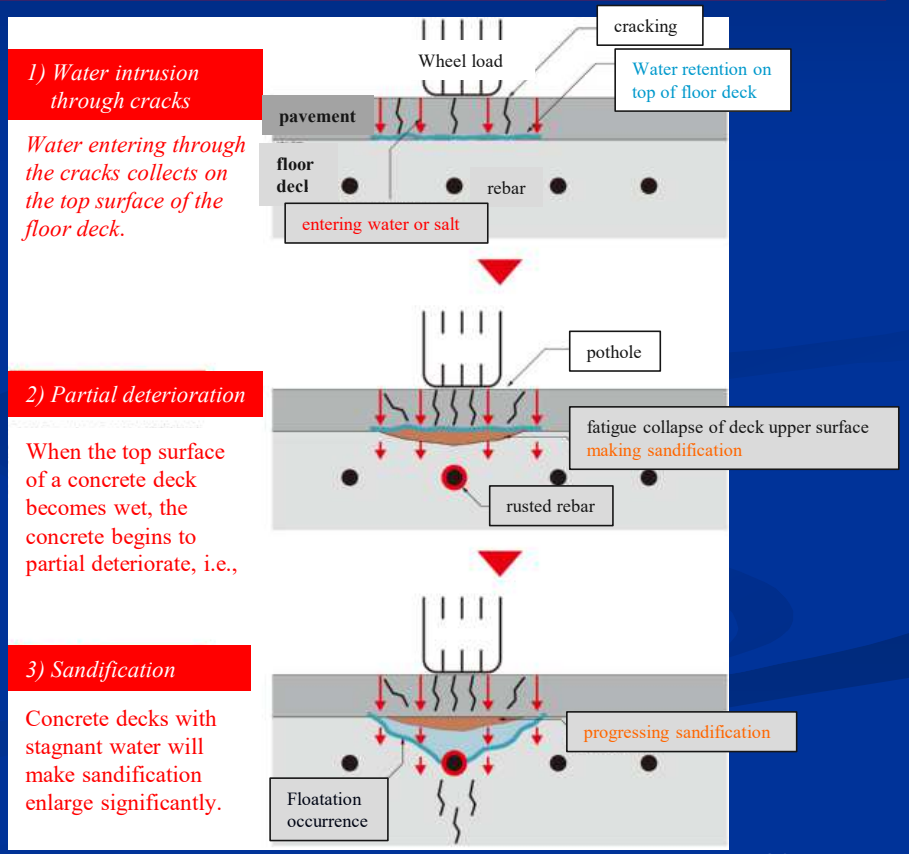
# Challenges and Solutions

## Challenge 1 : Floor Deck Damage

**The primary cause of floor deck damage is cracking of the concrete deck.**

Attention!!
When the moisture content of concrete becomes saturated, its compressive fatigue strength decreases markedly to about 60% of its dry state.



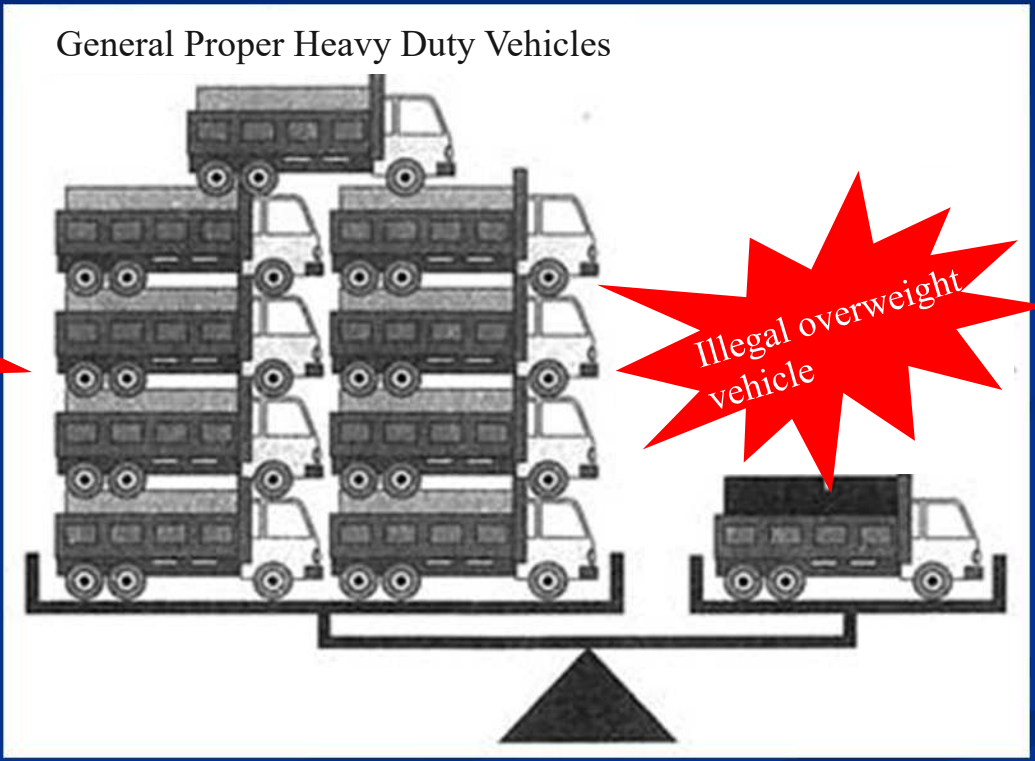
## Solution 1 : Example

*- Elimination of overweight vehicles-*

✓ The effect on the deterioration of the slab is proportional to the twelfth power of its weight.

If the axle weight of one large vehicle exceeds 10 tons by 2 tons, the effect on the slab is equivalent to that of about 9 vehicles.

✓ Some offending vehicles are the main cause of road deterioration

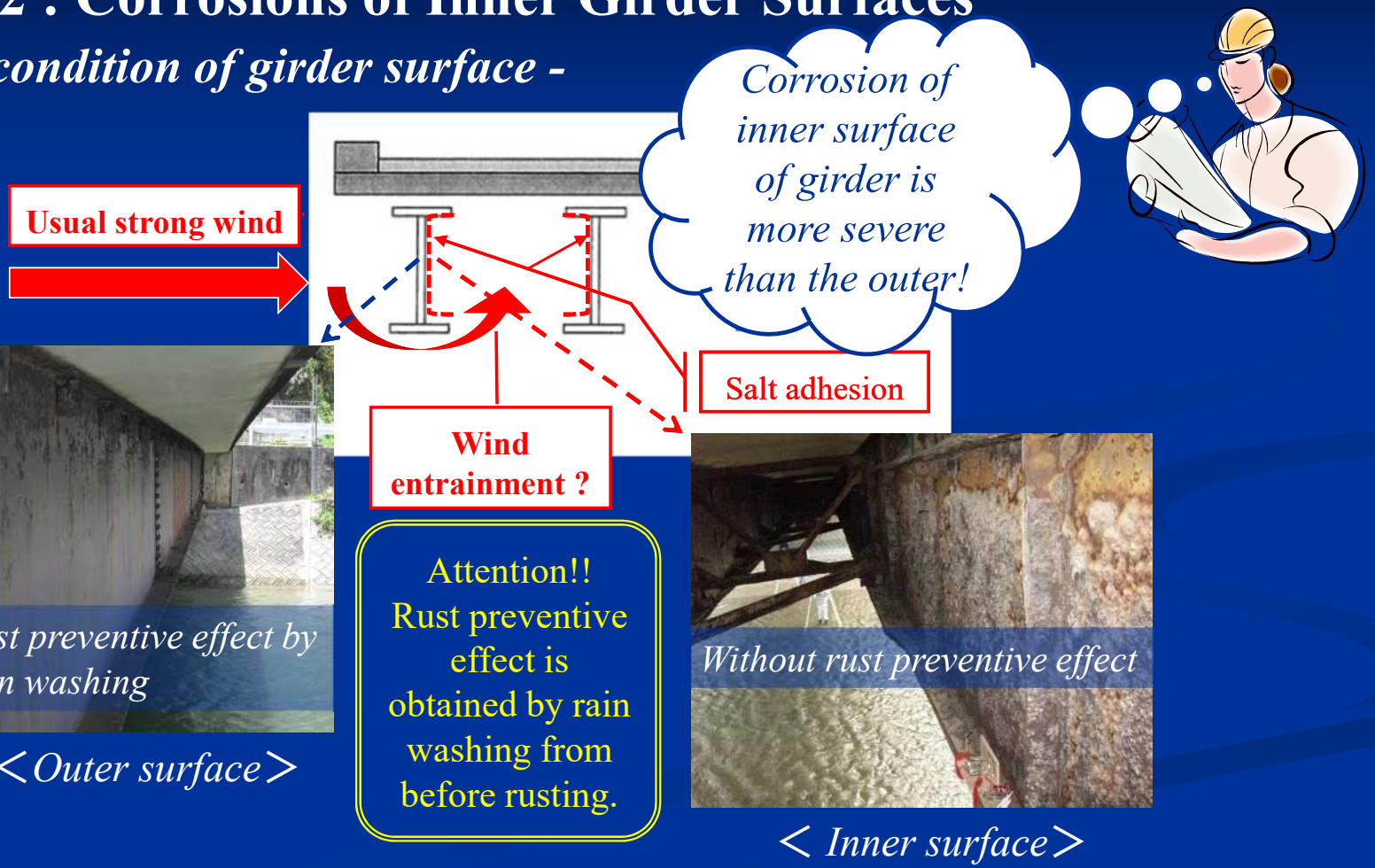



Eliminating overweight vehicles is key to preventing floor slab deterioration!!

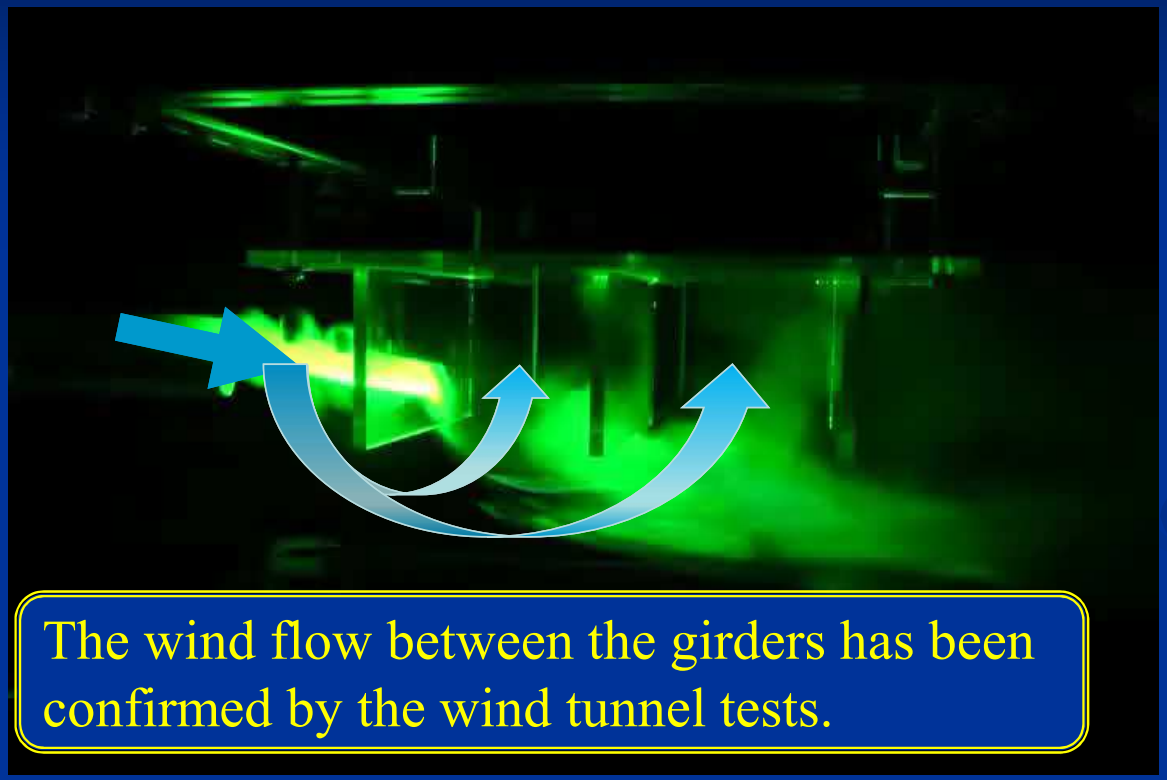
# Challenges and Solutions

## Challenge 2 : Corrosions of Inner Girder Surfaces

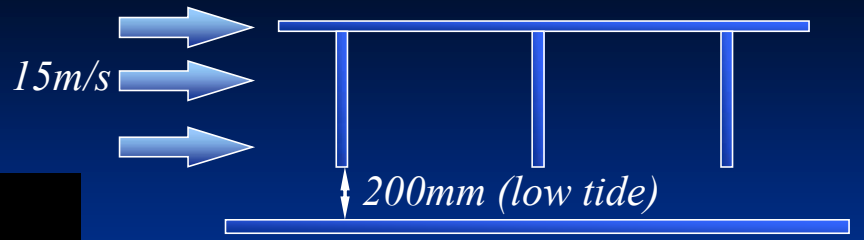
*- Corrosion condition of girder surface -*

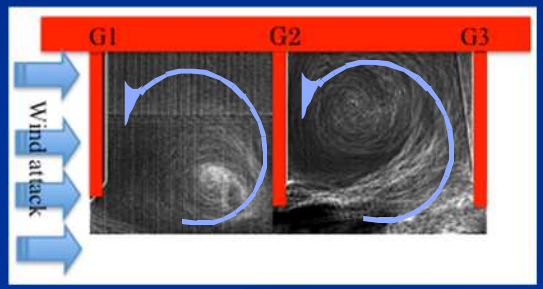


## *- Confirmation by experiment -*



The wind flow between the girders has been confirmed by the wind tunnel tests.




*Flying salinity is drawn always in the girder by the wind entrainment!!*

## Solution 2 : Example

*- Washing girder -*

- ✓ **Inner surface of the girder**
  → Salt adhered sustainably
  → No-washed by rain.
- ✓ **Corrosion of inner girder surfaces**
  → extremely sever.


**Standard Solution**

→ To wash off salt to be adhered to the inner surface **before rusting** and to **continue cleaning regularly**.

Attention!!

Rust preventive effect is obtained by rain washing from before rusting

## *- Washing situations -*

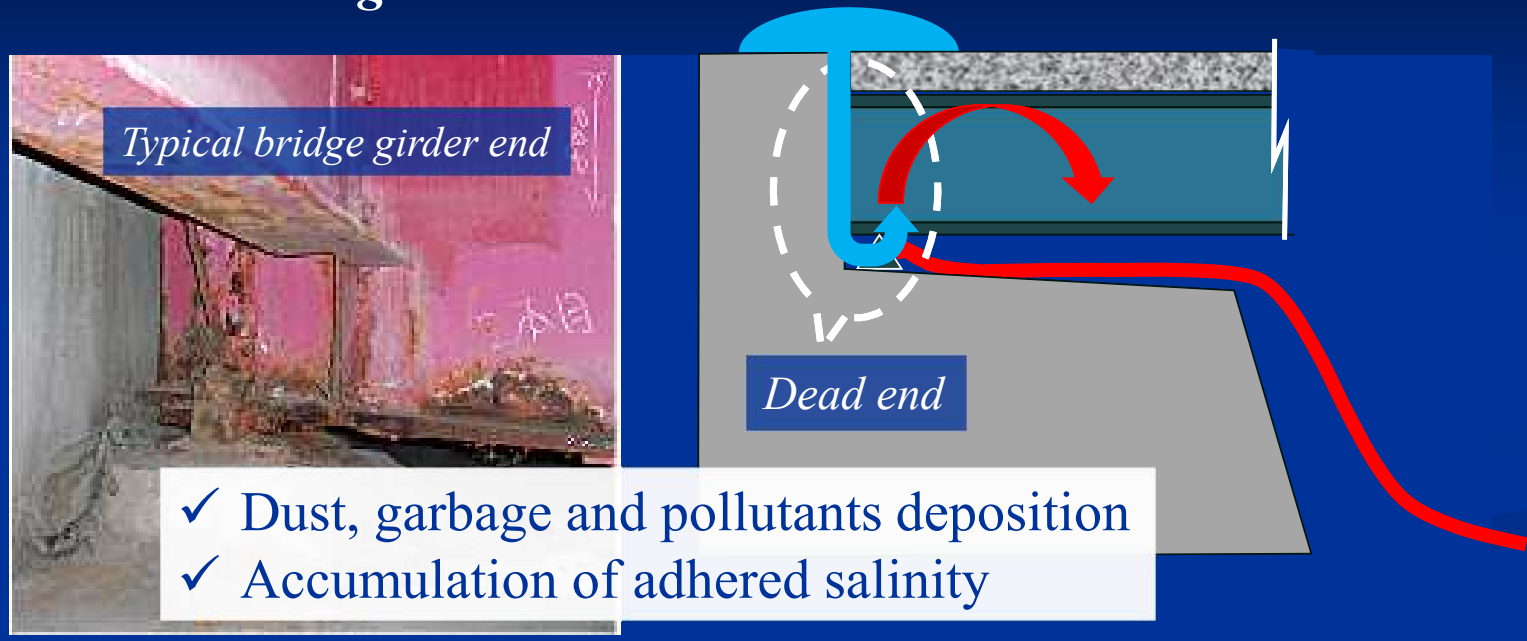
*by using cage of inspection vehicle*

*by using inspection passage*

Washing must start immediately after construction
i.e., **before rusting** !!

- **Challenge 3 : Corrosions of Bridge Girder Ends**

  *- Wind flow around bridge end -*




→ Girder end structures are not necessarily designed to exclude water.
→ A girder end is the most severe deterioration spot in a bridge structure.

## *- Corrosion damages around bridge end-*


✓ → No inspection and no maintenance for a long time.
✓ → Too late to apply preventive maintenance.

Cases where the responsibility of the administrator is questioned!!

## Solution 3 : Example

***- Deterioration factor removal -***


*by using a water gun device set up in road cleaning truck.*


→ Clean and remove girder deterioration factors such as adhered salinity and accumulated dust, garbage and pollutants.

## *- Use of anti-corrosion specification-*

Fluoric-resin coating

Zn-Al compound plating + Nylon 12 powder coating -OKINAWA Spec.-

Zn-Al compound plating

Hot-dip galvanizing

*A variety of anticorrosion specification*

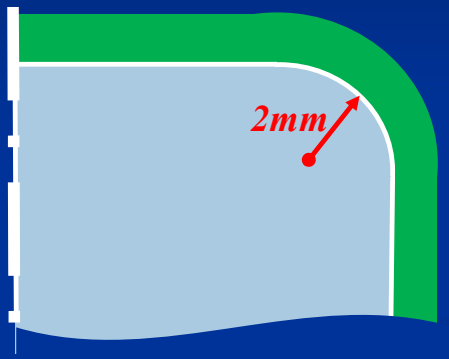
→ Use the anti-corrosion support bearing apparatus.

# Challenge 4 : Corrosion of Corners

*- Corrosion of bottom flange corners-*



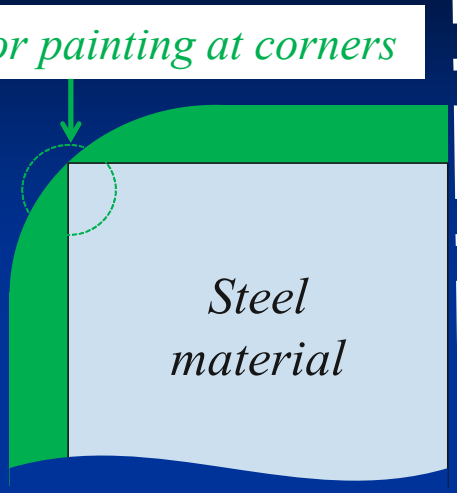
*- Solution example for plate conner corrosion -*




*Curved surface processing*

→ Curved surface processing of **2 mm Radius** or more for main members.

## - Corrosion of bolted joints -




✓ Complete anti-corrosion of bolt corners is impossible by painting.

**Remarkable corrosion only on bolts in joint**

→ Poor paint thickness at corners
→ Scratches by torque wrench during construction
→ Uneven parts where salt easily adheres

## - Solution example for bolt corrosion -

✓ Often rust-proof bolts are used.
✓ Its anti-corrosion effect is about 2,3 months.

*Salt spray test*


*Wash primer*


*Zinc alloy*

→ Need the anticorrosion measures after construction.

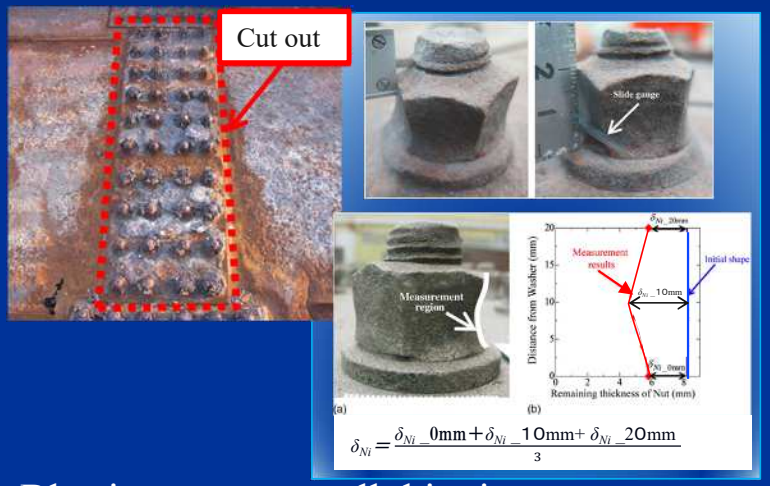
*Shut water, salt, dust, pollutants out.*

*Visibility bolt cap*

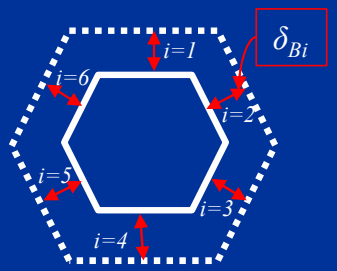
Install visibility bolt caps after construction.

## *- Residual axial force of corroded bolts -*

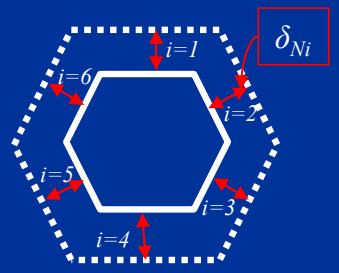
**The residual axial force of corroded high strength bolts can be evaluated from the following correlation chart between residual axial force and amount of wall thinning, which was obtained through research in Okinawa ※.**




Blasting process wall thinning measurement




Bolt head

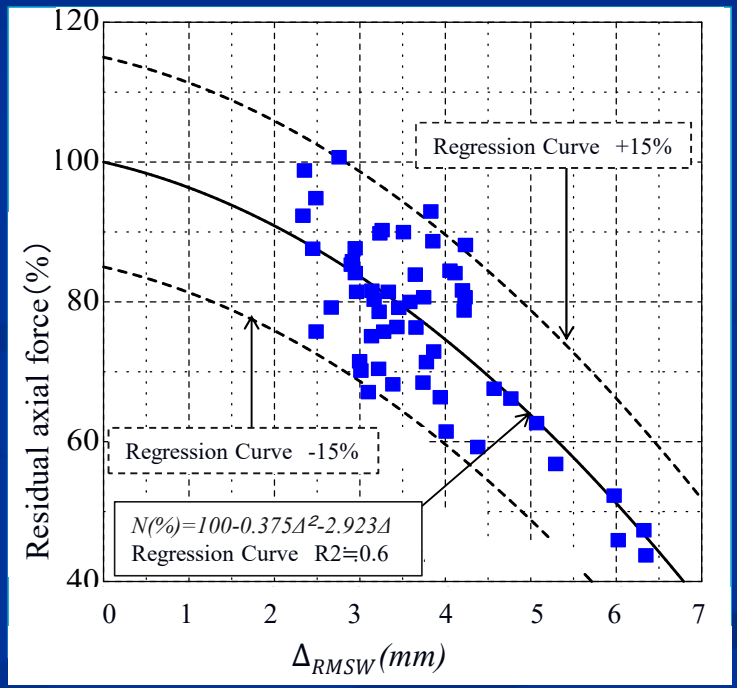



Nut

*Amount of corrosion thinning*

$$\underline{\delta}_{Bi}=\frac{\sum_1^6 \delta_{Bi}}{6},\ \underline{\delta}_{Ni}=\frac{\sum_1^6 \delta_{Ni}}{6}$$

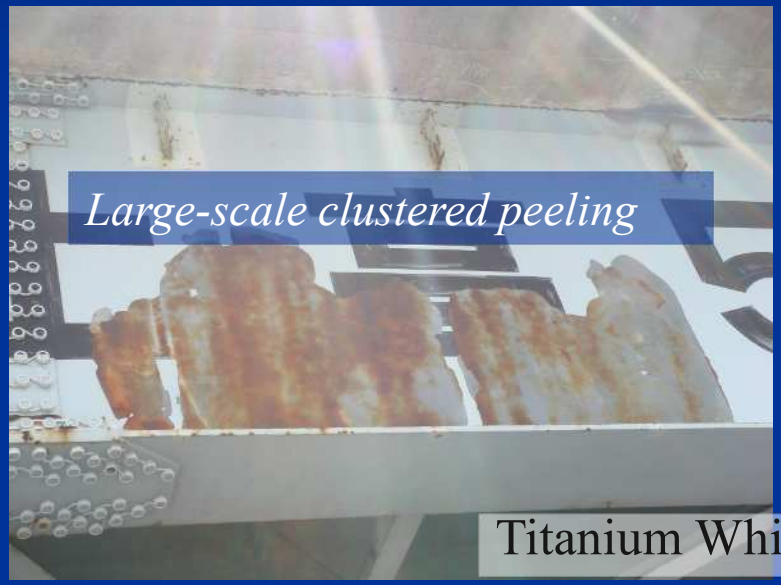
$$\Delta_{RMSW}=\frac{\sqrt{(\underline{\delta}_{Bi})^2+(\underline{\delta}_{Bi})^2}}{2}$$




※*Masayuki TAI, Tetsuhiro SHIMOZATO, Yoshitomo NAGAMINE, Yasunori ARIZUMI, Tetsuya YABUKI: Dependence of Residual Axial Force on Thickness and Shape in Corroded High-Strength Bolts, Journal of Structural Engineering, Vol.144, Issue 7, ASCE, 2018.*

- **Challenge 5 : Peeling of Paint Coating**

  ***- Clustered peeling of surface coating on girders -***





**Cause** → Collapse of the adhesion mechanism of coating.

**Feature** → Clustered peeling and its size.

# Solution 5: Example

*- Careful surface preparation -*

✓ Cause of clustered peeling
→ Discarding of the close contact between material surface and painting by destruction factors.
✓ **Destruction factors**
→ **Water-Membrain* and Substances (salt, corrosion**, pollutants, etc.)

***Formed by water absorption.**
→ Rapidly increasing when the relative humidity exceeds 80%.
→ Forming a local cluster-membrane.

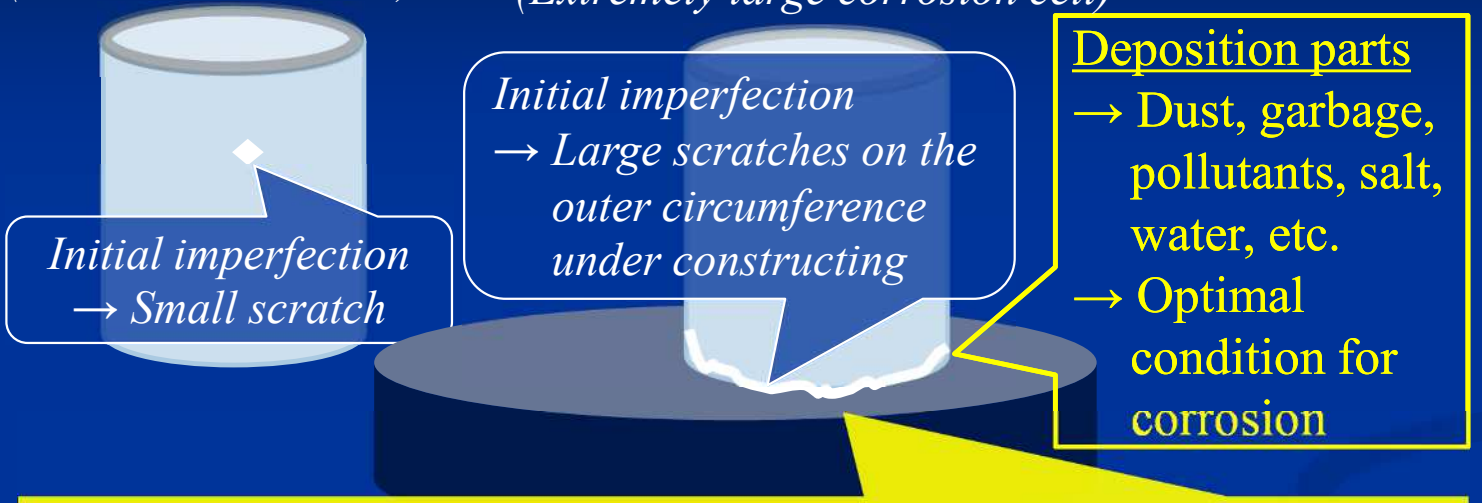
**Remove destructive factors:**
→ by **wet abrasive blasting** before repainting


**Repaint:**
→ when the relative humidity is less than 80%.
→ after when the careful surface preparation and the entire surface to allow dry.

# Challenge 6 : Other Sever Corrosion – Macro-Cell Corrosion –

*Ordinary corrosion*
*(Small corrosion cell)*

*Macro cell corrosion*
*(Extremely large corrosion cell)*




**Potential different boundary**
→ High electric potential different at boundary between steel and concrete

*Rupture of truss diagonal member*

*Ring corrosion with through-hole*

**Cause** → The extremely large corrosion cell is formed around at the boundary between the concrete and steel.

**Feature** → Its corrosion rate becomes extremely faster.

# Lack in understanding!!


**Macro cell corrosion around boundary between steel and concrete**
→ Ring corrosion with though-hole.

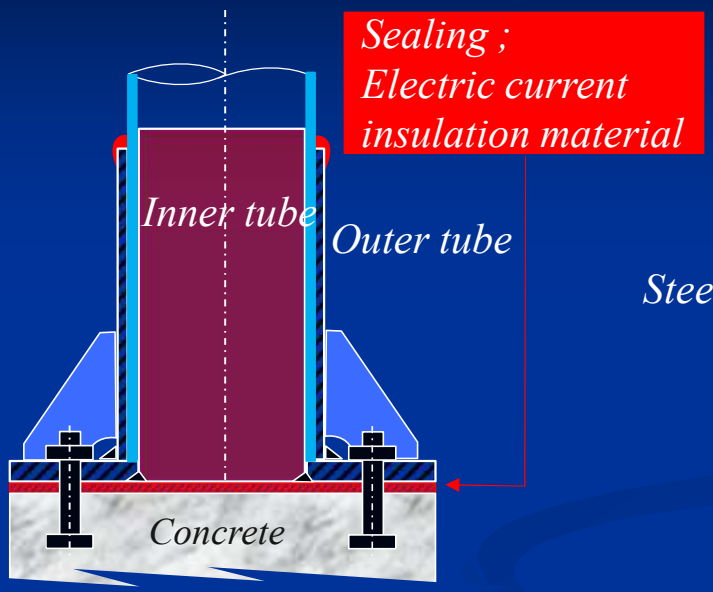

**Meaningless concrete block**
→ Make construction method by no-damage the paint ineffective.

*Strive to understand the essential of things!!*

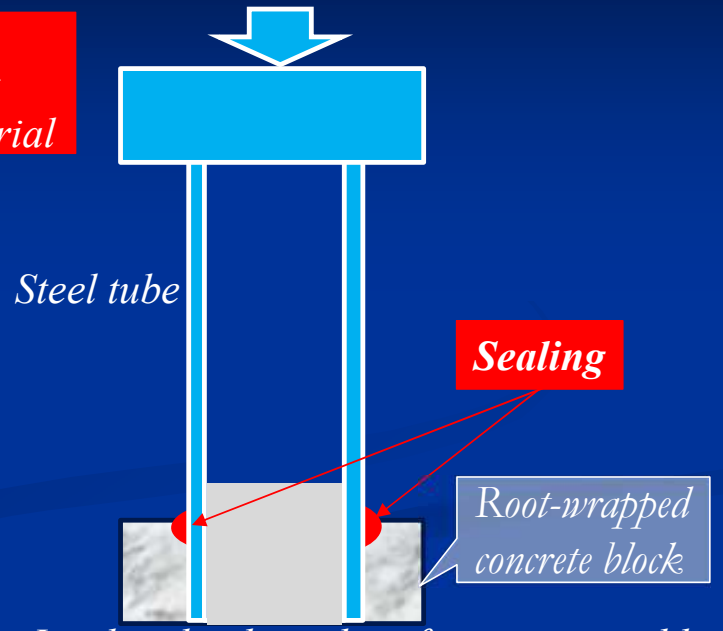
**Concrete block for covering the pier base is structurally useless.**
→ Lack in understanding on structural mechanism and engineering.

## Solution 6: Example

*- Insulate steel and concrete in corrosion surrounding environment -*




*Insulated at base plate*




*Insulated at boundary from concrete block*

**Take construction measure to insulate steel and concrete by sealing material in the corrosion surrounding environment.**

→ No initial impaction at the boundary.

→ Electrically isolate between steel and concreate.

# Challenge 7 : Chalking Phenomenon

- ✓ Chalking phenomenon→ hydrolysis phenomenon of titanium oxide in fluorine paint brought by photo-oxidation phenomenon of **ultraviolet rays**.
- ✓ Photo-oxidation phenomenon → Activated by dissolution of salt in moistures.

*Attention!!*
*The titanium oxide is used as white pigment.*



→ **Ultraviolet rays** make deterioration of undercoating (epoxy resin) faster.

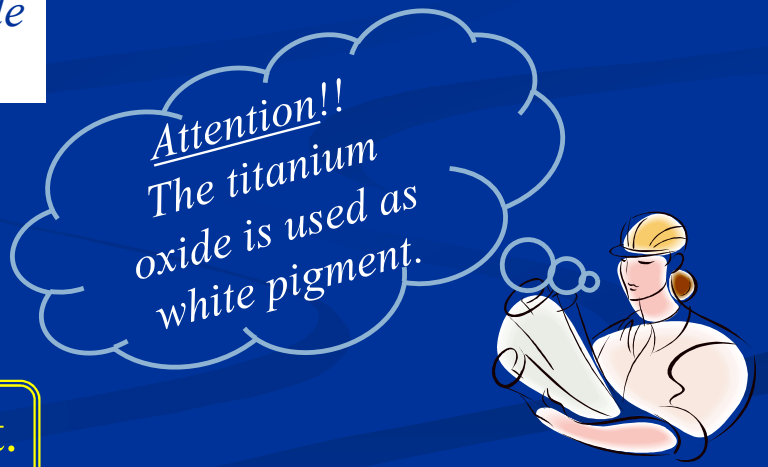
# Solution 7 : Example

✓ Surface resins with the irregulars i.e., uneven coating thickness and pinholes brought by water, oil, dust, salt, pollutants, etc.
→ Causing rapid chalking

→ Remove the irregulars perfectly by **wet abrasive blasting** before repairing.

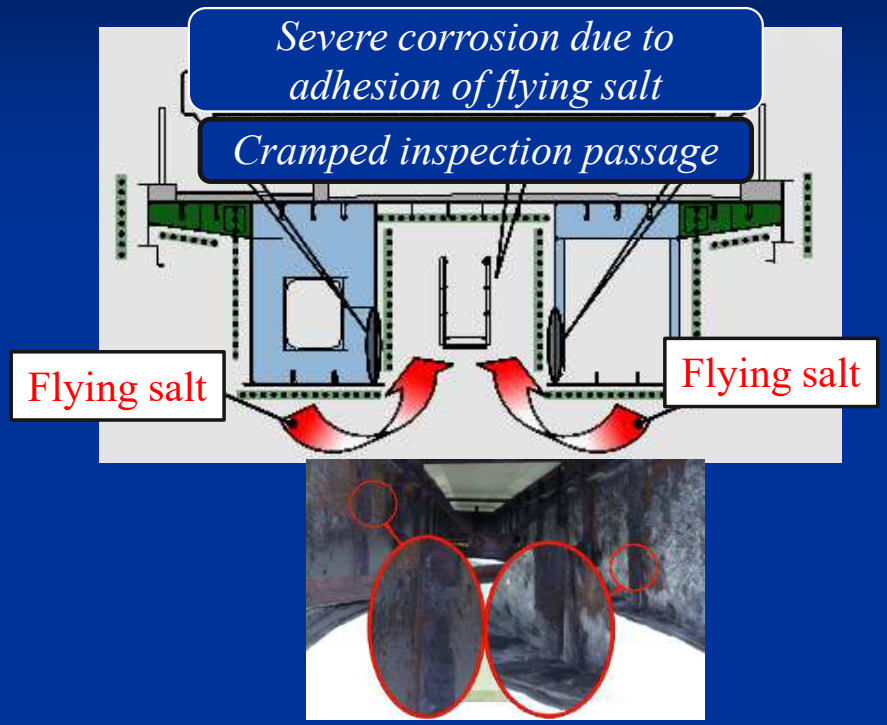
*Chalking phenomenon by hydrolysis phenomenon of titanium oxide*
→ The titanium oxide is used as white pigment.

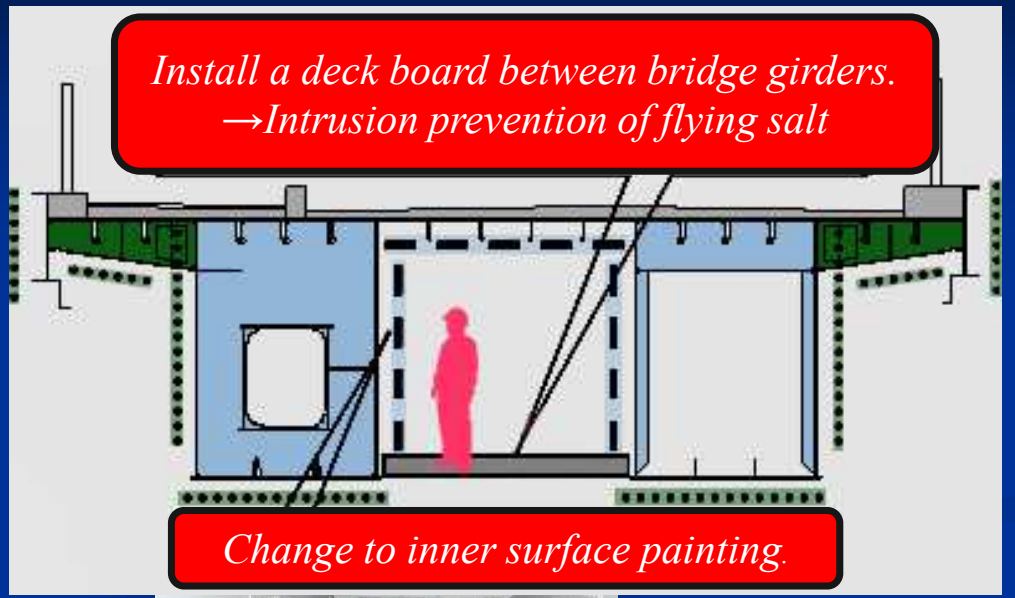
→ Avoid the usage of white and/or light color pigment.



# Advanced Measures

## Example 1 : Multi-Functional Anticorrosion Deck



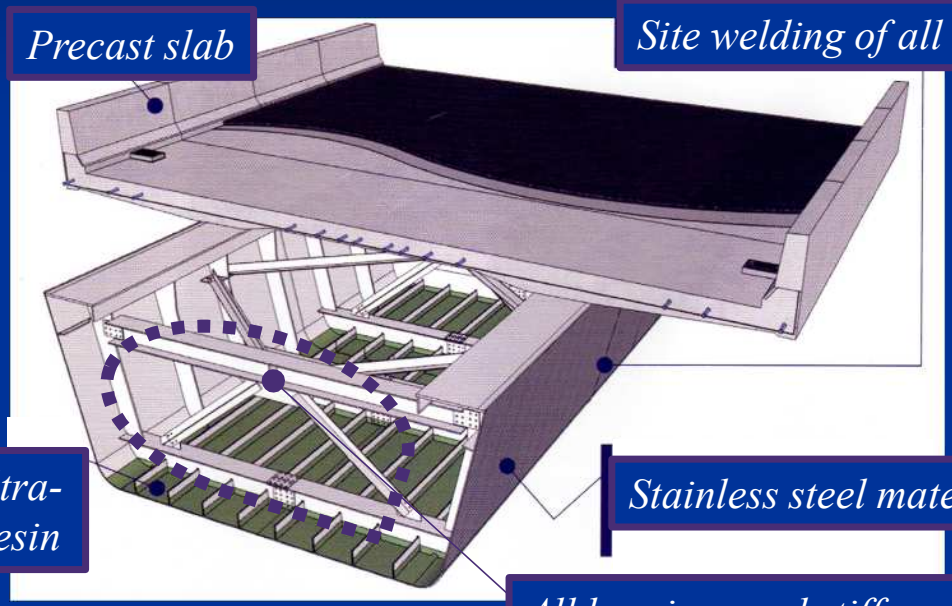


→ Block salt flying between girders by fiber-reinforced plate (FRP) deck board.

→ Significantly reduced LCC of painting & also be used as an inspection pass.

## Example 2 : Stainless Steel Applications

***- Application to outer members : Hybrid stainless-carbon steel bridge girder -***

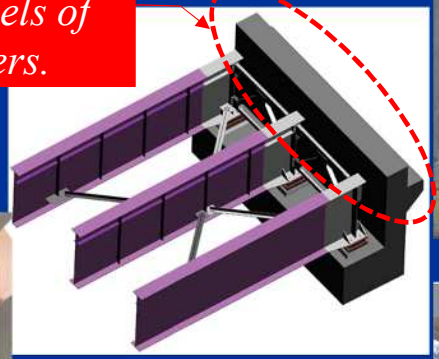



→ Stainless steel material is applied only to the outer material exposed to the corrosive environment of one-box girder to reduce costs.

## *- Application to end panels -*

✓ Girder ends are the most severe deterioration parts of bridge structures but not necessarily designed to exclude water.
→ Apply stainless steel only to the end panels of bridges to reduce costs.

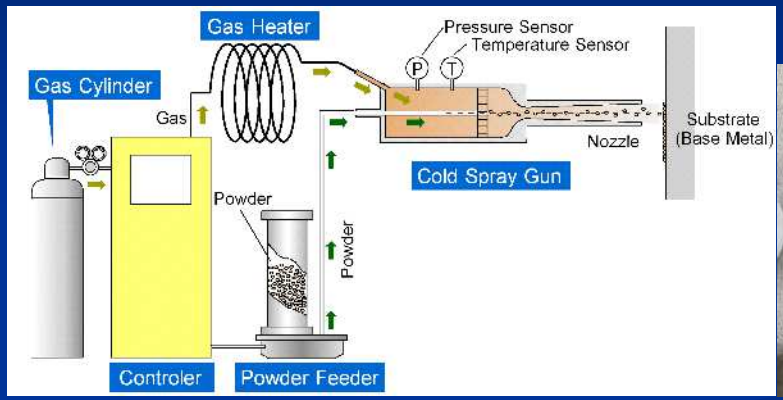
*Apply stainless steel to the end panels of bridge girders.*



- **Example 3 : Impact Coating**

***- Cold impact coating system-***

Smart ZIC Equipment




*Conceptual Diagram of Smart ZIC Construction Method*

*Zinc powder*

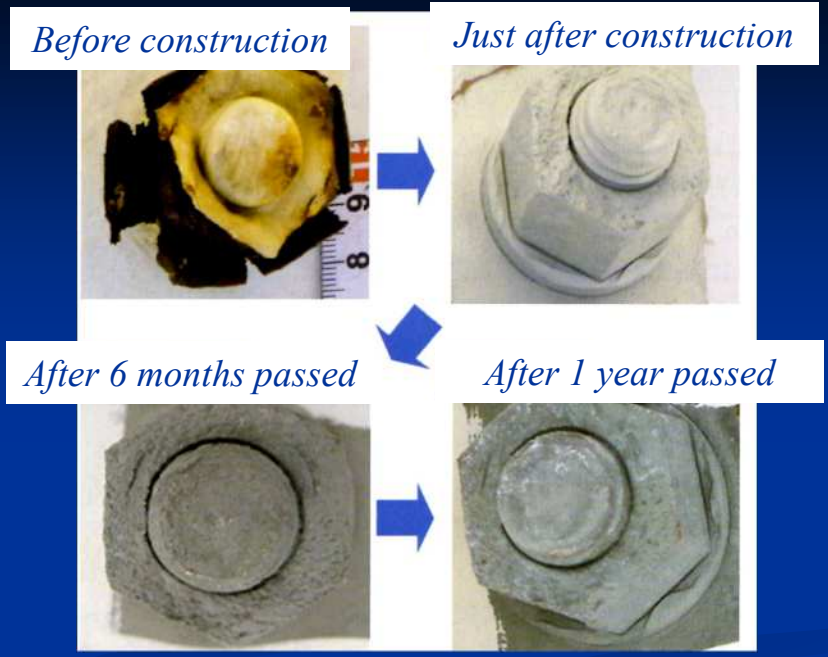
**The mixed powder(zinc +alumina) is impacted onto a substrate surface at supersonic speed to bite in and stack on the surface.**

→ Bring a blast effect by the mixed alumina.

→ Form membranes at bolt threads and corners by making zinc powder bite into.

## - *Results of Progressive Observation* -

Under construction




After construction

→ Proposed to be used as an undercoat with very easy adjustment of the base treatment

**Great sacrificial anticorrosion effect!!**

# 5. BEFORE CLOSING

## Application of Major Repairs

✓ Too late
→ Too late to apply preventive maintenance.


**Maximum advantage of steel material.**

→ Easy to cut and join; → Fast and accurate to repair in Stage IV* (p.8)
* Urgent action can be taken.








# Adoption of Manual

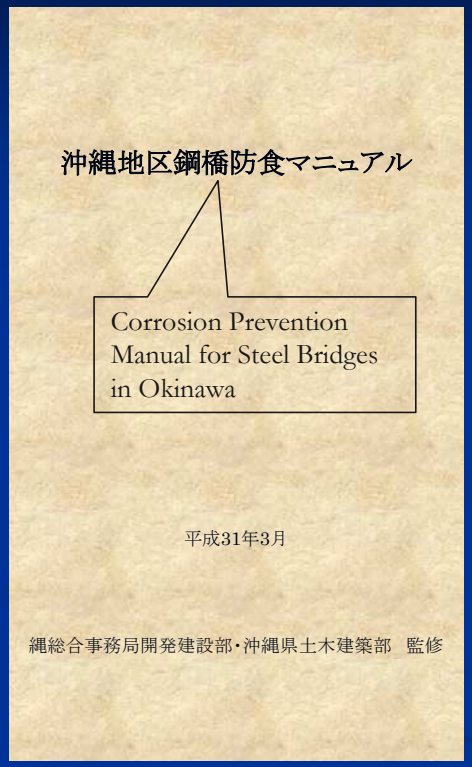
**Bridge maintenance engineers are the doctors of bridges.**

The Performance Requirements (p.4) is to be realized:

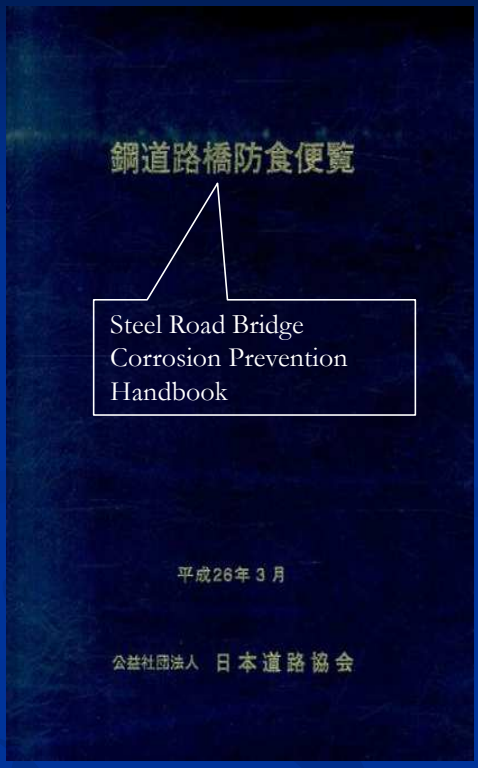
→ High level of expertise,

→ Sound judgment ability regarding maintenance.

**Use of manuals is strongly encouraged ! !**




*OKINAWA Specific Manual*




*ALL JAPAN Manual*

# Perspective on Future Prospect

**Long-term assurance of high B/C under corrosion characteristics is possible through controlled performance strategies such as those proposed in this lecture.**

***Even if it is too late to apply preventive maintenance, it is perfectly possible to repair the damage.***

**Once rust is overcome,**
**the future of steel bridges is always in victory!!**

Thank you for focusing your awareness on my job!!