Research on Concrete Durability: My experience and request for young researchers

濱田, 秀則
Kyushu University

Department of Civil Engineering
National Institute of Technology Karnataka (NITK), Surathkal, India.
organising
One Week International Workshop on
Durability of Concrete (IWODOC – 2020)
(Online)
Date: 26th Oct – 30th Oct, 2020

Research on Concrete Durability

My experience and
request for young researchers

H. Hamada
Kyushu University

Research Career (Hidenori Hamada)

April 1986 – March 2006 (20 years)

PHRI (Port and Harbour Research Institute)

PARI (Port and Airport Research Institute)

October 1992 – September 1993 (1 year)

University of Sheffield, England, U.K.

Prof. R. Narayan Swamy

April 2006 – September 2009 (3.5 years)

Kyushu University (Associate Professor)

October 2009 – August 2020 (almost 12 years)

Kyushu University (Professor)

Research Career (Hidenori Hamada)

April 1986 –

PHRI (P

PARI (P

October 1

Univers

April 2006 –

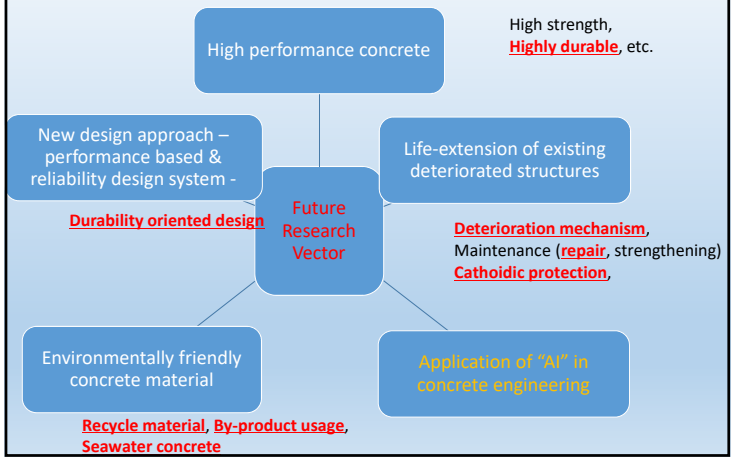
Kyushu

October 200

Kyushu University (Professor)

Prof. R. Narayan Swamy

Concrete research – present and future --



Development History of Concrete Material

1st Topic

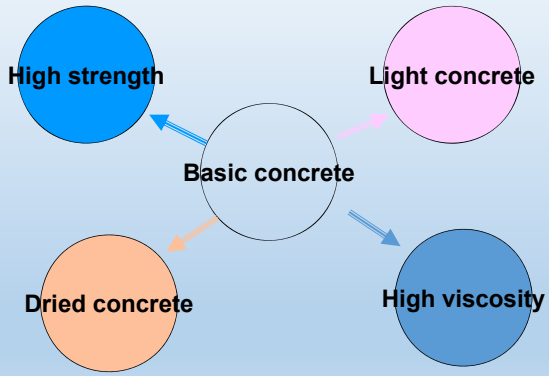
Three Key Orientation of Material Development

1) High performance material development
   → ex. High strength

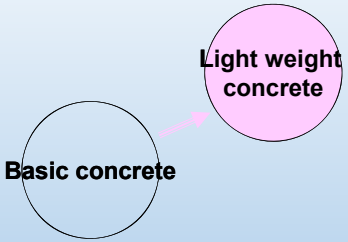
2) Double requirement for properties be inconsistence each other
   → ex. High strength and low weight

3) New material development
   → ex. Usage of by-products

Material development of concrete



Material development of concrete (1)



Method for light weight concrete

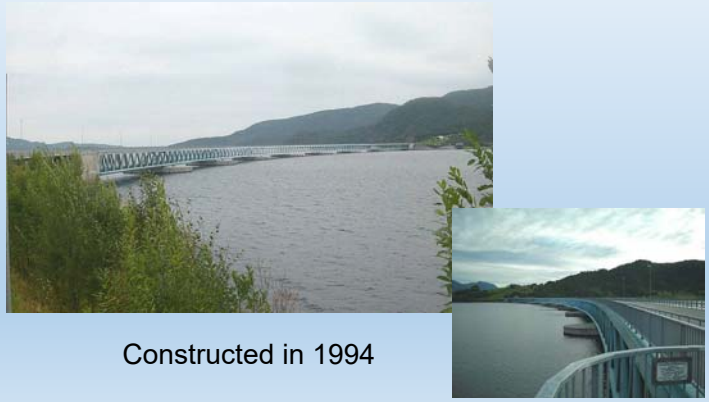
- Use light weight stone (aggregate)
- Density of light weight concrete.

  Normal concrete 2.3 [t/m^3]

  Light weight concrete (level 1) 1.85～1.90 [t/m^3]

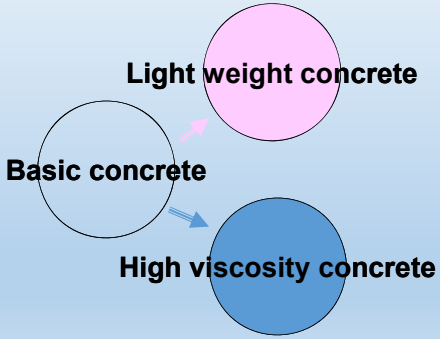
  Light weight concrete (level 2) 1.65～1.80 [t/m^3]

The Bergsoysund Floating Bridge
(Norway, North Europe)

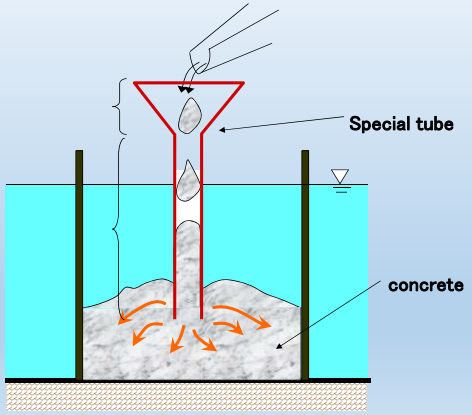


Constructed in 1994

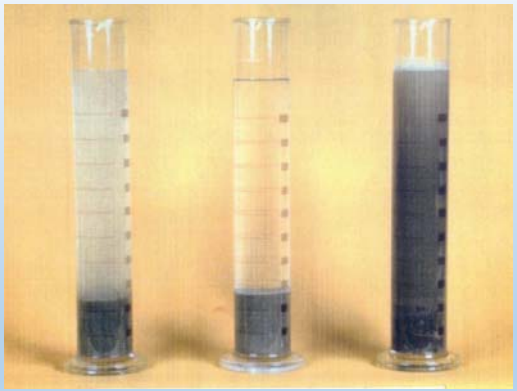
Material development of concrete



Method of concrete casting in water
In the case of normal concrete



High viscosity chemical agent



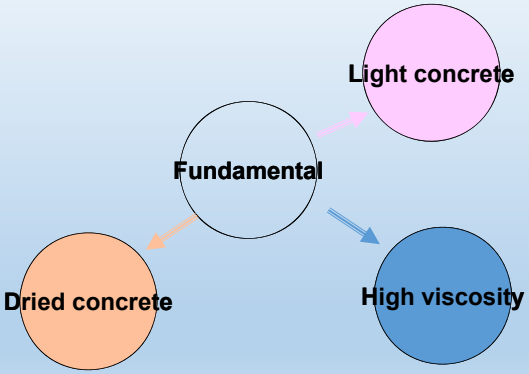
Agent: substance that can cause a reaction

Bridge of Kansai International Airport in 1991

"Sky Gate Bridge"

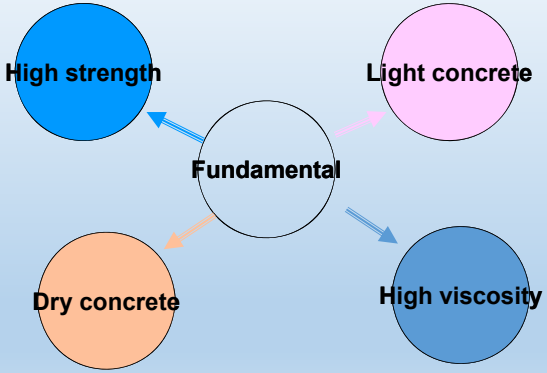
Ryogoku- bashi Bridge Tokyo metropolitan pref.

Material development of concrete

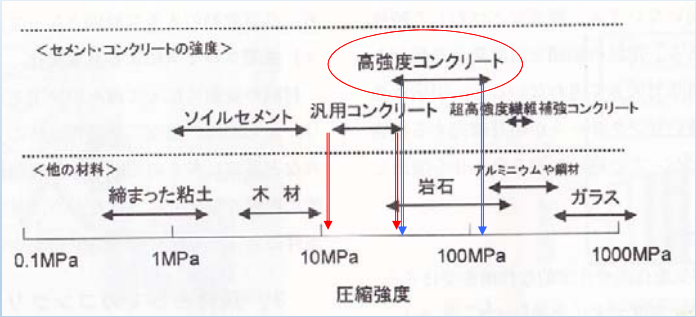


RCD (Roller Compacted Dam) with dried concrete (like sand)

Material development of concrete



Compressive strength of several materials



CEM'S (Taiheiyo Cement Technical Information) No.46 2010.7 より引用

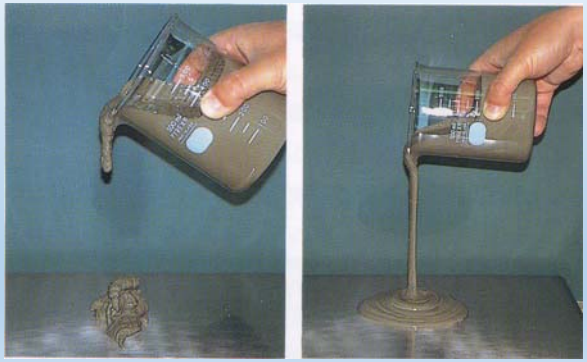
Step for high strength
"development of ultra fine particle"

図-3 DSPの機構[1)]

出展:同書

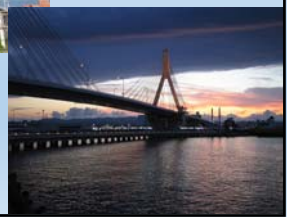
Step for high strength concrete

"Super plasticizer, chemical agent for high flow concrete "



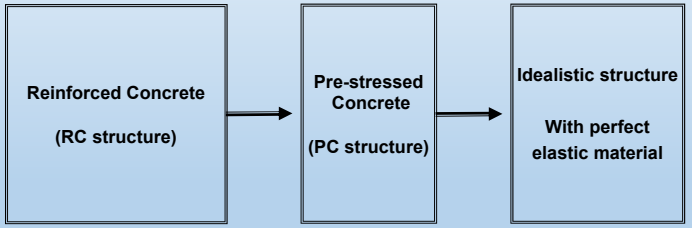
High (Tall) building

Aomori-bay Bridge in 1992



HSC（60N/mm²）was pumped
Up to high place.
With New type Super Plasticizer

From RC (Reinforced Concrete) to PC
(Pre-stressed Concrete),
moreover to "Idealistic Structure"



Prestressed Concrete

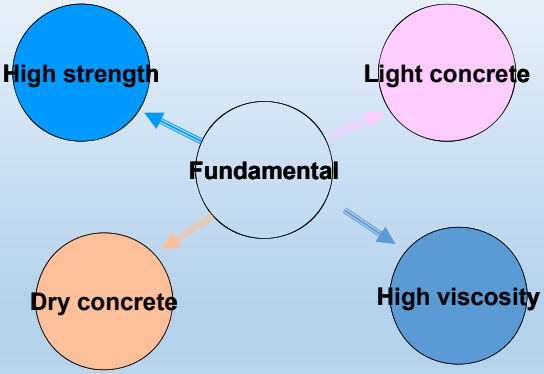
Chosei-bashi Bridge (Ishikawa pref.)　1951

Compressive strength　50N/mm² （500kgf/cm²）

Sakata-mirai Bashi Bridge, Yamagata pref. in 2002

Larger than 150N/mm²
in compressive strength

Material development of concrete

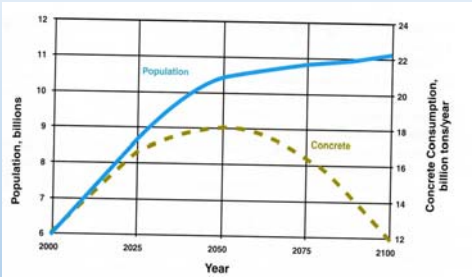


2nd Topic

Concrete Durability

Present and Future Consumption of Concrete

P. K. Mehta, Concrete International Vol. 24, July 2002



Year	Concrete Consumption	
2000	12 billion tons (two tons per person)	⇨ 14 billion tons of aggregate
2050	18 billion tons	

"Durability" and "Durable concrete"

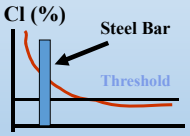
1. "Durability" is defined as the ability of concrete to resist weathering action, chemical attack, abrasion, and other conditions of service (ACI 116R-90).

2. "Durable concrete" is quality concrete.
   A quality product is one that meets predetermined expectations. "Durable concretes" need not to be maintenance free concrete.

2. Different Forms of Deterioration

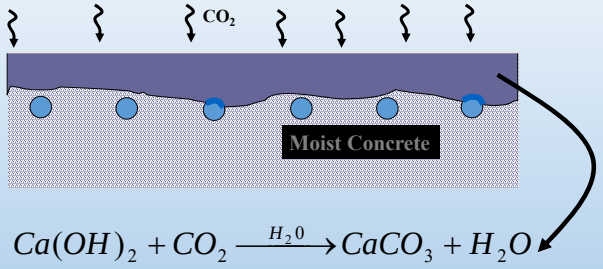
Chloride-Induced Corrosion

Example of a Wharf Structure



After 20 years in service

Carbonation-Induced Corrosion



$$Ca(OH)_2 + CO_2 \xrightarrow{H_2O} CaCO_3 + H_2O$$

The pH in concrete drops significantly. The passive film is lost. Corrosion continues depending on the moisture condition, oxygen permeability through the cover concrete, etc.

Example: Carbonation-Induced Corrosion

Generally, it is micro-cell type corrosion.
Produce more or less uniform rust over the steel bars.

Alkali Silica Reaction

1. Alkali-silica reaction (ASR) occurs between the reactive silica in the aggregate and the alkali in concrete (cement paste).

2. ASR is found in almost all over the world.

Examples

ASR related damage of Concrete Structures are recognized in around 1940.

Concrete Wall

Bridge Pier

Footing of a Bridge Pier

Map (net-work) cracking caused by ASR.

Alkali Silica Reaction – Cracking after Repair

Repair is not a easy task.

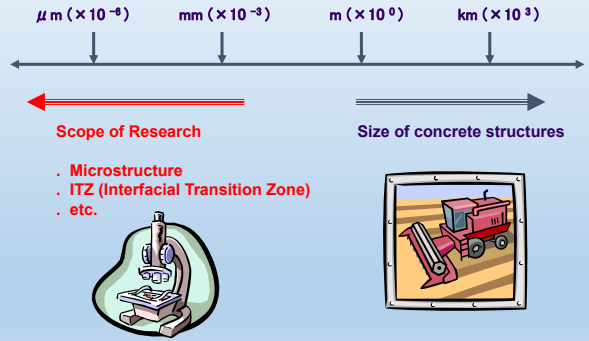
Others Forms of Deterioration

- Freezing / Thawing attack
- Sulfate attack (DEF)
- Seawater attack (Sulfate attack)
- Acid attack
- Expansion of aggregates (Laumontite)

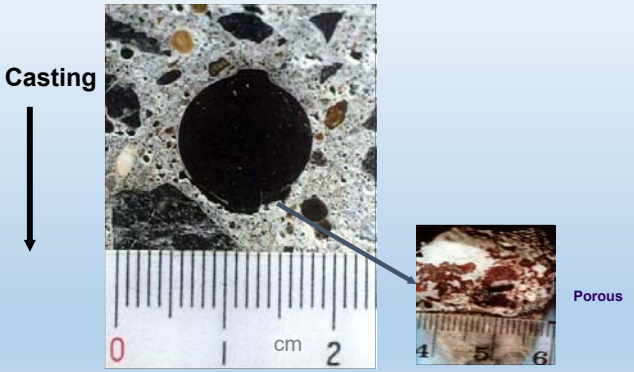
3. CORROSION

Steel-Concrete Interface

Research Scope

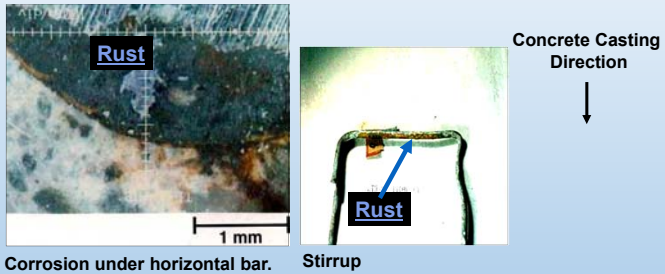


Gap/Void Under the Bar



Condition of the Steel Bars: 23 Years Exposure

W/C=0.7, WS Chloride = 1% of Cement Mass



Corrosion under horizontal bar. Stirrup

Corrosion under the bar….

Remarks

1. The entrapped micro air voids are easily formed at the steel-concrete interface, especially bottom surface.

2. Investigations are still necessary on the following issues:
   1) How to make a dense steel-concrete interface?
   2) How chloride threshold varies with the size of voids at the steel-concrete interface?

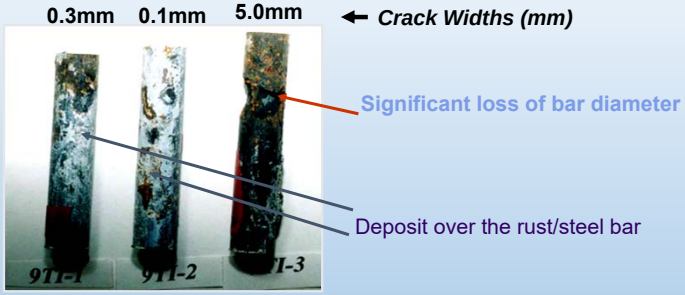
CORROSION

Cracks

Seawater Splashing

3-hour splashing twice a day

Steel Bars at Cracked Regions



SCB-T-45

Healing covers rust.

Severe loss at unhealed cracks.

Remarks

1. We cannot avoid the occurrence of cracks in concrete.
2. However, in the marine environment, if we can ensure earlier healing of the cracks, it is possible to reduce the corrosion rate significantly.

Followings are items requested to be investigated,

1. How to accelerate healing at the cracks in concrete?
2. How chloride threshold and corrosion rate varies with cracking?

Sustainability (High Durability)

Sustainability (High Durability)

- Design
- Construction
- Maintenance

Holistic Approach

Feedback

Lessons learned from
-- the laboratory,
-- long-term exposure tests,
-- actual structures, high and low durability.

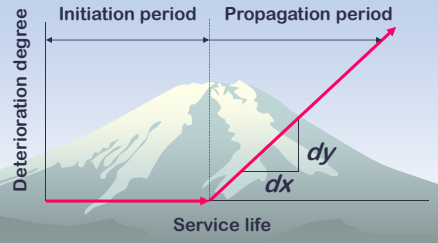
Discussion on Deterioration Rate of Concrete and Steel Structures Especially under Marine Condition

-- My small contribution to research field on durability of civil infra structure --

Contents in this Topic

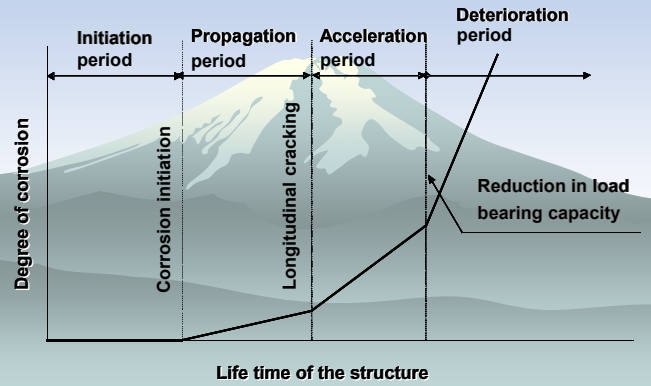
1. *Long-term Exposure* Test of Concrete Materials under Marine Environments.
2. Conceptual model of RC deterioration in the *Acceleration stage*.
3. *Markov Chain* Representation of Deterioration Progress of RC Wharves Damaged by Chloride Attack.

Deterioration Progress *(by K. Tutti)*



"*dy / dx*" is quite small
in case of steel corrosion even under marine condition
→ 0.4mm / year → 0.04mm / month → 1μm / day
→ it is impossible to measure a dairy change

Deterioration Progress Due to Chloride Attack by Prof. T. Miyagawa (Japan)



Part 1

Long-term Exposure Test of Concrete Materials under Marine Environments

Exposure-site Operated by PARI (PHRI)

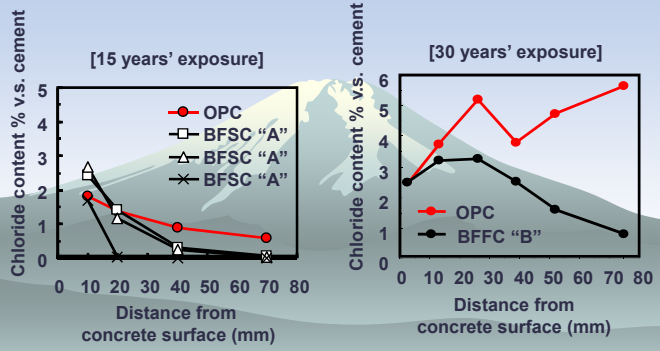
Sakata port

Kagoshima port

Shimizu port

PARI

Chloride Distribution in the Specimen Exposed under Marine Tidal Condition



Chloride Diffusion Coefficient Obtained from "Long-term Exposure Test"

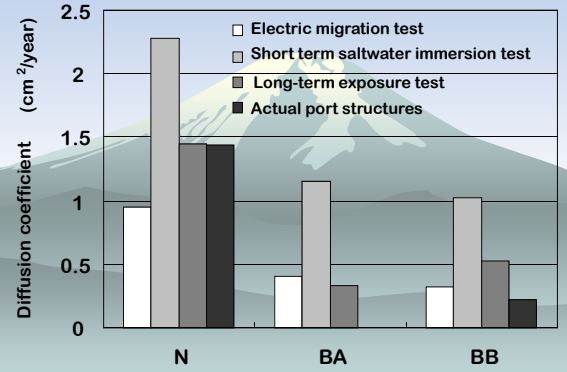
$$\frac{\partial C}{\partial t} = D_C \frac{\partial^2 C}{\partial x^2}$$

Cement type	Diffusion Coefficient (mm^2 / year)
OPC	145
BFSC type "A"	33
BFSC type "B"	22
BFSC type "C"	10

Estimated Length of "Initiation Period"

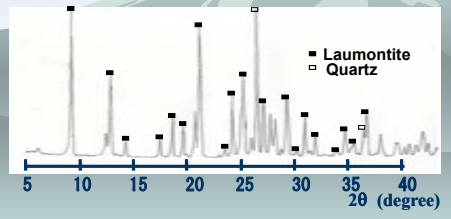
Specimen No.	W/C	Estimated Initiation Period (years)	
		Cover depth = 35mm	Cover depth = 55mm
OPC	0.45	3.9 year	Over 21 years
OPC	0.60	1.8 year	5.1 year
OPC	0.75	0.6 year	2.4 year
Blast Furnace Slag	0.60	Over 12 years	Over 21 years
Fly Ash	0.60	3.7 year	Over 21 years
Silica Fume	0.60	Over 12 years	Over 21 years
Blast Furnace Slag	0.75	2.4 year	19.6 year

Various Diffusion Coefficients Obtained by Different Method



Unexpected Expansion of Concrete

15 years exposure.



Laumontite Mineral : ($CaO.Al_2O_3.4SiO_2.4H_2O$)

Similar Experience in Kyushu University

Deterioration due to cyclic sulfate attack (master thesis)

Deterioration found in PARI, in marine tidal condition

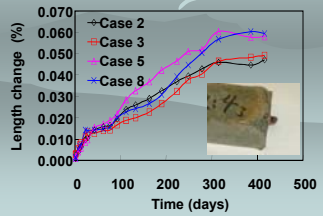
Verification of Expansion Mechanism

[Expansively destructed concrete specimen]

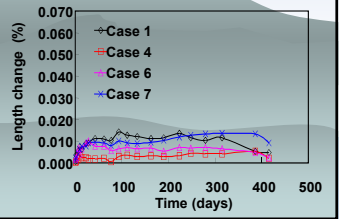
[Re-made mortar specimen]

Fine aggregate were re-made from coarse aggregate

Sea water immersion



Tap water immersion



Deterioration in Actual Port Concrete

Only ASR ? or Combined ?

Long-tem exposure test is a message…

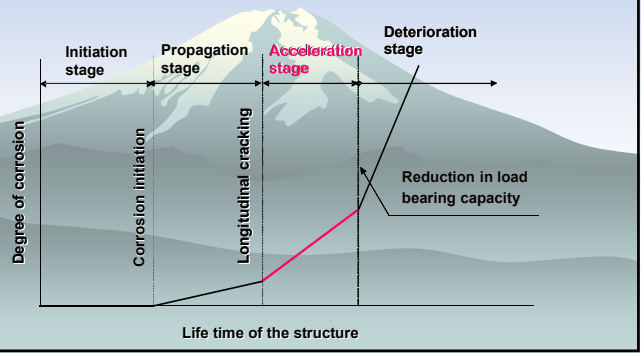
(1) From senior to junior over several generations.

(2) Conversation with natural environments through the language of specimen, or response from environments to us.

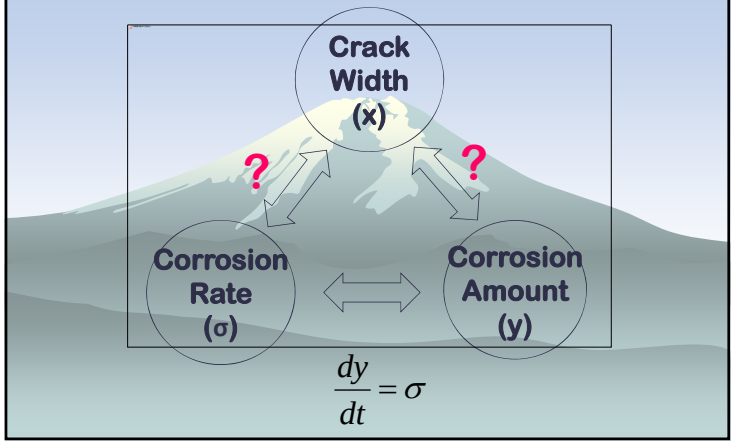
I express sincere and many thanks to old members of PHRI and PARI for their effort to start this precious long-term exposure test.

Part 2

Conceptual Model of RC Deterioration in The Acceleration Stage



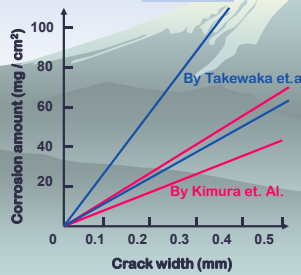
Triangle Relationship in The Acceleration Period



$$\frac{dy}{dt} = \sigma$$

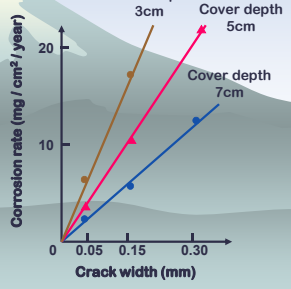
Crack width and Corrosion Amount Relationship

$$y = a \cdot x$$

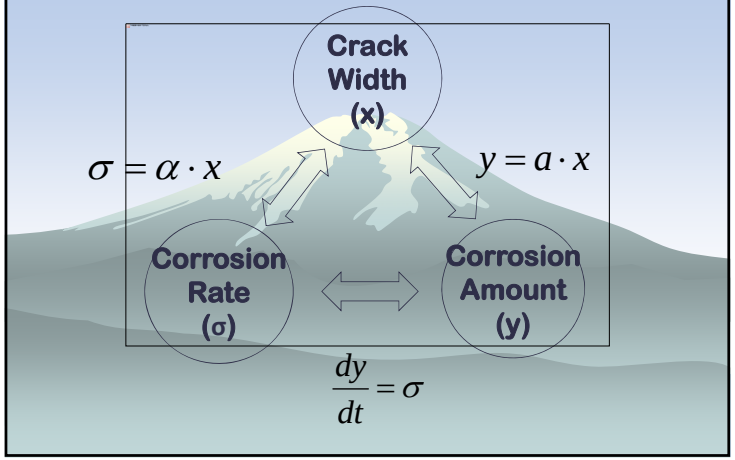


Crack width and Corrosion Rate Relationship

$$\sigma = \alpha \cdot x$$



Triangle Relationship in The Acceleration Period



$$\frac{dy}{dt} = \sigma$$

Deformation and Solving Process

$y = a \cdot x \rightarrow \frac{dy}{dt} = a \cdot \frac{dx}{dt}$

$\sigma = \alpha \cdot x$

$\frac{dy}{dt} = \sigma \rightarrow \sigma = a \cdot \frac{dx}{dt} \rightarrow \frac{\alpha}{a} \cdot dt = \frac{dx}{x}$

$\ln(x) = \frac{\alpha}{a} t + C \rightarrow x = C \cdot e^{\frac{\alpha}{a} t}$

Theoretical Corrosion Rate of Rebar

$x = C \cdot e^{\frac{\alpha}{a} t} \Rightarrow V_{red} = \frac{4ac}{\phi \gamma_{Fe}} e^{\frac{\alpha}{a} t}$

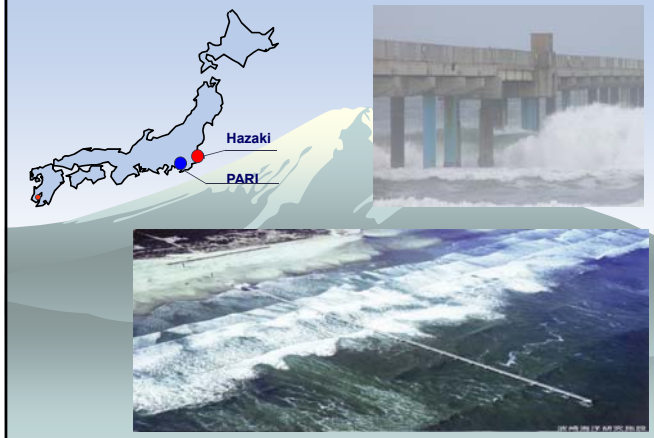
$y = a \cdot C \cdot e^{\frac{\alpha}{a} t}$

$\sigma = \alpha \cdot C \cdot e^{\frac{\alpha}{a} t}$

V_{red} : Volume reduction due to corrosion
γ_{Fe} : Density of rebar
a : Coefficient relating to V_{red} and crack width (=1500mg/cm^2)
c : Initial crack width formed by rebar corrosion (=0.005cm)
ϕ : Diameter of rebar
α : Coefficient relating to the rate of corrosion and crack width (=220mg/cm^3/y)
t : Elapsed time

Introduction of Exposure Test for Protected Steel Structures in Real Marine Wave Environment

Exposure Facility in Hazaki, Ibaragi-pref.



Sea Water Utilization in Concrete Production in Future Water Stressed World

-- From the View Point of Corrosion Prevention of Steel in Concrete --

Why now! we need to use seawater for concrete production ?

- Our world is now facing :
  - Water scarcity !
  - Water stress !!
  - Water crisis !!!
- However, it is difficult to realize it in modern city, in developed country.

Water scarcity ?

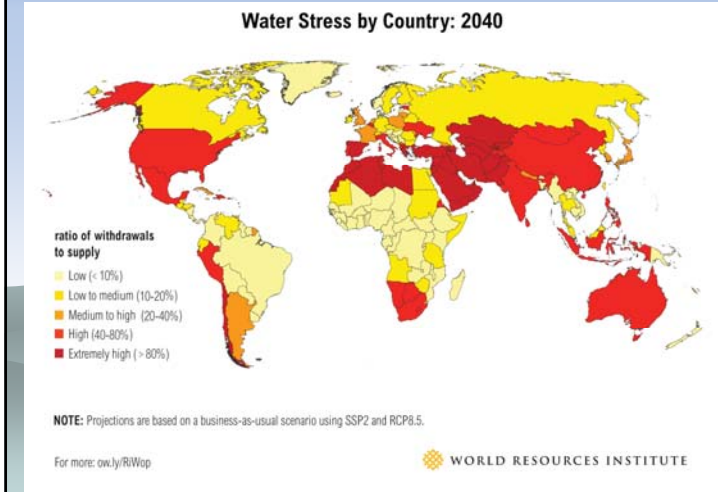
- The lack of fresh water resources to meet water demand.
- A mere **0.014%** of all water on Earth is both fresh and easily accessible. Of the remaining, **97%** is saline and a little less than **3%** is hard to access.
- The essence of global water scarcity is the geographic and temporal mismatch between freshwater demand and availability.

Water stress ?

- More than **one in every six people** in the world is water stressed, meaning that they do not have sufficient access to potable water.
- Those that are water stressed make up **1.1 billion people** in the world and are living in developing countries.

Water crisis ?

- When there is **not enough potable water for a given population**, the threat of a water crisis is realized.
- In 2025, **2/3 of world population** will be suffered from water shortage, even drinking water.



Water : The new oil ! In 21st Century

Goldman Sachs estimates that global water consumption is doubling every 20 years, and *United Nations* expects that demand for pure water will outstrip the supply by more than 30% by 2040.

Water : The new oil !

In Australia ,

brokers in urban areas are buying up water rights from farmers.

Water : The new oil !

Rural residents *around the US* are trying to sell their land and water to multinational water bottlers.

Present situation of Seawater usage in concrete production

JCI (JAPAN CONCRETE INSTITUTE) TECHNICAL COMMITTEE ON THE USE OF SEAWATER IN CONCRETE 2012 -

- In the field of concrete, **billions tons of freshwater** is consumed annually for mixing, curing and washing.
- Seawater is presently not permitted to be used for these purposes. Active use of seawater in the field would help more effective use of freshwater resources.

Committee report

- Chapter 1 Objectives and activities of the Committee
- Chapter 2 **Case studies** of concrete structures
- Chapter 3 Evaluation of the material properties of concrete
- Chapter 4 **Durability** of concrete mixed with seawater
- Chapter 5 Higher performance of concrete mixed with seawater and appropriate reinforcement
- Chapter 6 Investigation of manufacturing and casting methods for concrete
- Chapter 7 Overall summary and future outlook

- HOW TO ORDER
- Please ask us how to order by e-mail address as below.
- **jci-books@jci-net.or.jp**

Seawater for Concrete Production ?

Negative aspect:

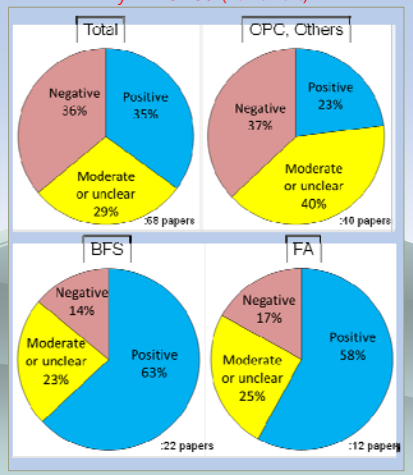
* All the standards in the world inhibit using seawater as mixing water for RC.
* Almost all the authorities in the world are against.

Positive aspect:

* Some researchers reported "not so bad" to use seawater with mineral admixtures.

Literature review on seawater mixed concrete

By T Nishida (P. A. R. I.)



Then !

What is problem of seawater use for concrete production ??

Physical property ?
Long term durability ?
(Chemical property ?)

Is seawater harmful for cement hydration ??

not harmful !!

Is seawater harmful on fresh concrete property ??

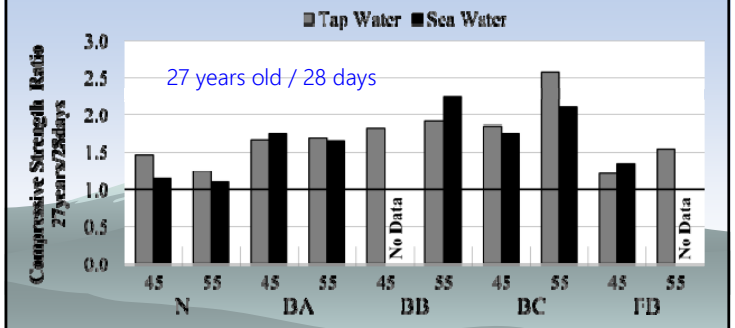
Slightly !!

Is sea water harmful for

initial strength development ??
long term strength development ??

Not harmful !!

27 years' Compressive strength of seawater mixed concrete



From PARI & Kyushu University Collaboration,
By Adiwijaya, in his doctoral thesis of Kyushu Univ..

Is seawater harmful for durability ??

Carbonation ?? *May be "no" !!*

Chloride attack ?? *Sure "yes" !!*

Alkali silica reaction ?? *May be "yes" !!*

Chemical attack ?? *May be "no" !!*

Conceptual model of RC deterioration due to the chloride attack.

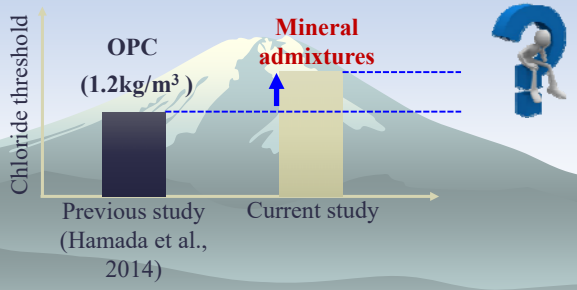
Initial chloride content in fresh concrete

normal concrete : 0 – 0.6 kg/m^3

"sea water" mixed concrete : 3.0 kg/m^3

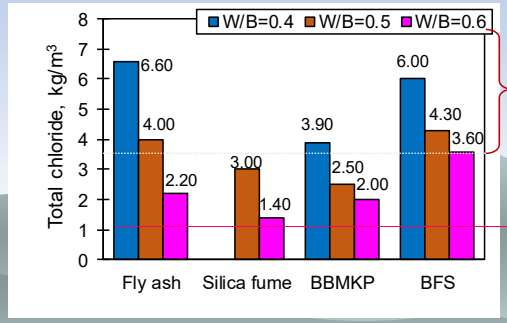
"sea water" + "unwashed sea sand" : 4.8 g/m^3

How is "the chloride threshold value" for corrosion initiation of steel in concrete ?



By Dahlia Patah, in her doctoral thesis, Kyushu University, 2019.

Chloride Threshold Value for various kinds of cement (binder)



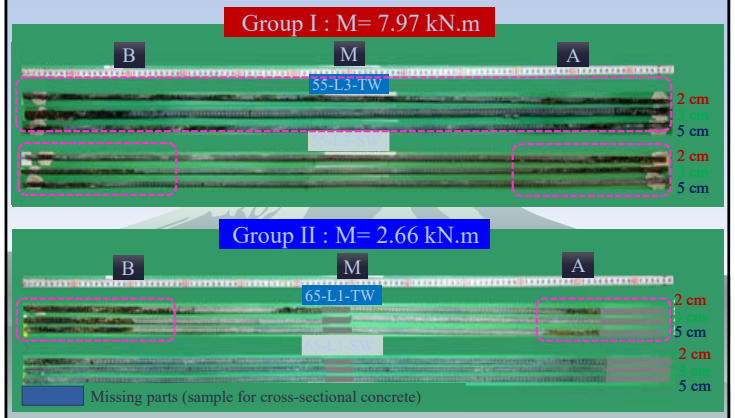
By Dahlia Patah, in her doctoral thesis, Kyushu University, 2019.

Performance of Seawater-mixed Concrete in Natural Corrosion Environments

By Dahlia Patah,
Kyushu University, in her doctoral thesis, 2019.

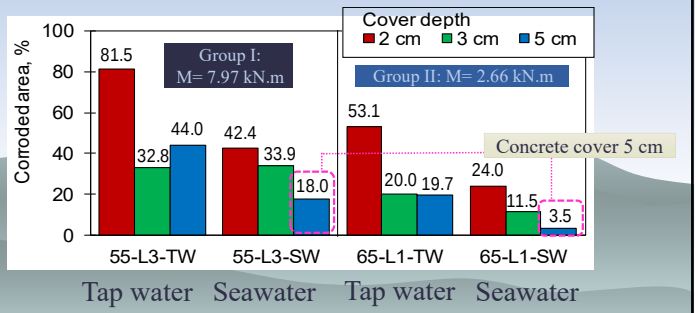
History of RC Beam

Appearance of Steel Bar



◆ Most damage zone (close to position at maximum crack width and depth)

Total Corroded Area



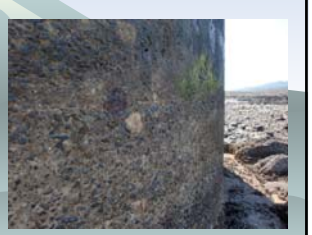
Can we use seawater for concrete production safely ?

What countermeasure is necessary for corrosion prevention of steel in seawater mixed concrete ?

Several experiences of sea water mixed real concrete structures in Japan.

Light house in Nagasaki Pref.

Light house in Nagasaki Pref.



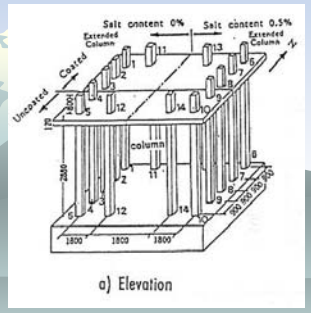
From old research

By Prof. Oshiro & Dr. Tanikawa

Effectiveness of surface coating

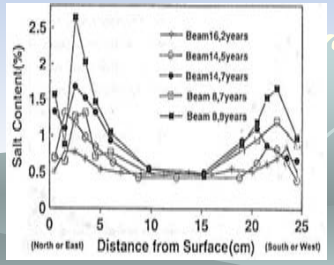
Marine Exposure test by Prof. Oshiro and

Dr. Tanikawa, in Okinawa Island

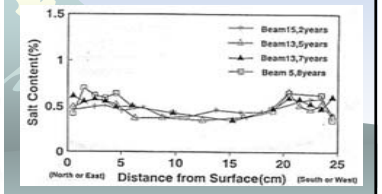


Chloride content in concrete

--- with initially added chloride ---

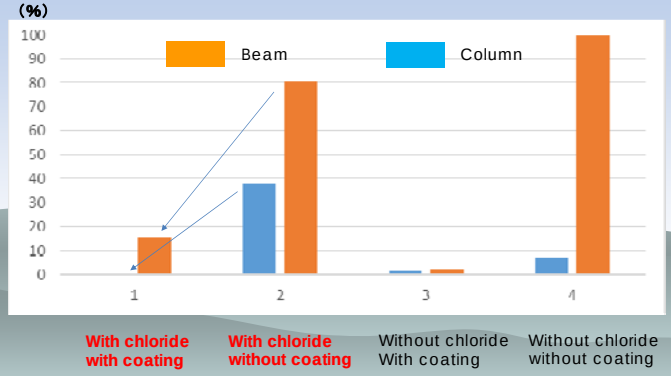


Without coating



With coating

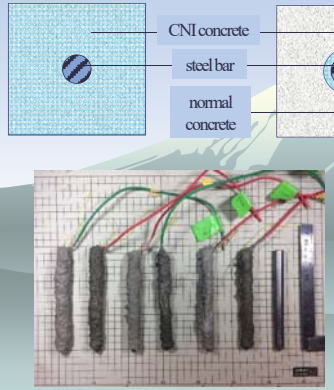
Corroded area（4 years' Exposure）



An application of corrosion prevention, Calcium Nitrite-based corrosion Inhibitor (CNI)

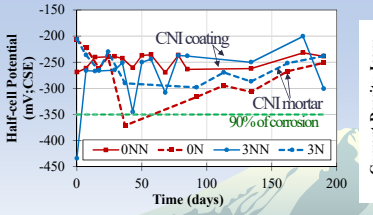
By Sabrina Harahap,
in her Master thesis, Kyushu University, 2019.

SPECIMEN DESIGN

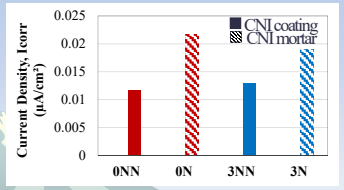


How's CNI working in seawater-mixed concrete?
Can CNI coating prevent corrosion?

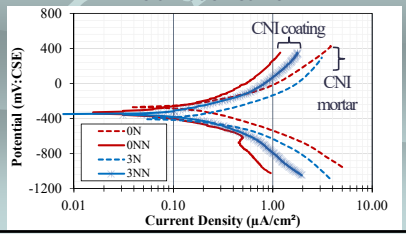
- Half-Cell Potential



- Maximum current density



- Polarization curve



My bitter memory in Viet Nam in 2001

- In near future, seawater mixing will be inevitable technique in concrete engineering almost all over the world under collaboration of **concrete engineer** and **corrosion engineer**.

What is Innovation ? Originality ? in Concrete Engineering / Research

Innovation

- **Innovation** in its modern meaning is "a new idea, creative thoughts, new imaginations in form of device or method".
- Innovation is related to, but not the same as, invention.
- Innovation is a "**New combination or new connection**" which create new idea, unknown results.

What is "originality" in research ?

Professor of Kyoto University

Novel Prize Winner in Chemistry

Dr. Kenichi Fukui

Originality is ··· to look at or think a "fact", "phenomenon", etc. by new way, which nobody did nor nobody could find···

An Example : from Lia-sans' research

Department of Civil and Structural Engineering
Graduate School of Engineering
KYUSHU UNIVERSITY

A STUDY ON CORROSION EVALUATION OF STEEL REINFORCEMENT IN CONCRETE DURING INITIATION AND PROPAGATION STAGE DUE TO CHLORIDE ATTACK

[A Presentation for Doctoral Degree – August 6, 2019]

Prepared by: **DAHLIA PATAH**

Supervisor: Prof. Hidenori HAMADA

Concrete Engineering Laboratory

Chapter 4

The Effectiveness of Mineral Admixture on Corrosion Resistance of Steel Bar in Mortar

(Initiation Period)

Chapter 4

The Effec
Admi
Resistance of

Chloride Threshold Value (CTV)

Actual structure & service life estimation

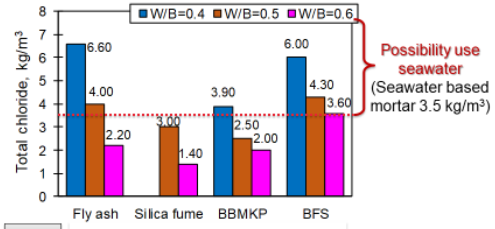
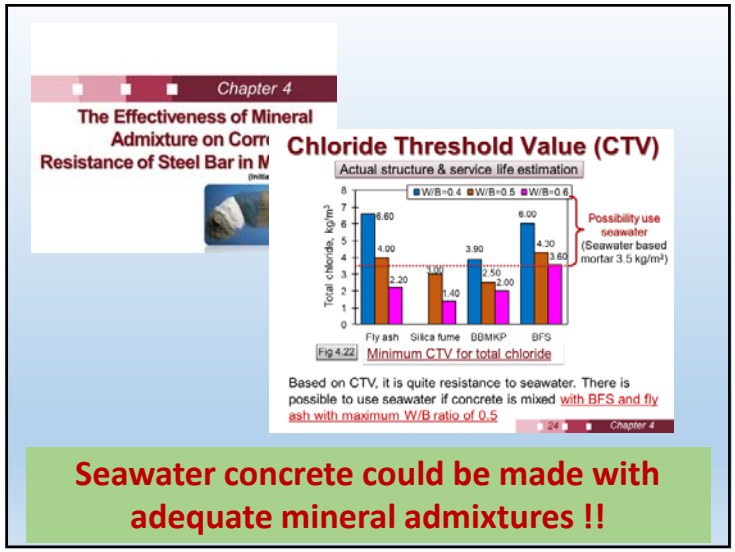


Fig 4.22 Minimum CTV for total chloride

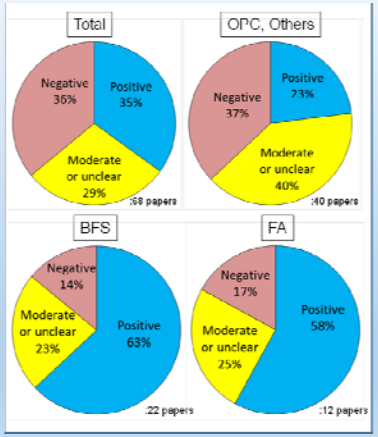
Based on CTV, it is quite resistance to seawater. There is possible to use seawater if concrete is mixed with BFS and fly ash with maximum W/B ratio of 0.5



Seawater concrete could be made with adequate mineral admixtures !!

Literature review on seawater mixed concrete

By T Nishida (P. A. R. I.)



New connection ! Innovation !!

Lia-sans' experiment

Nishida-sans' research (Literature survey)

Seawater concrete (material design)

CONCLUDING REMARKS

-- Message to Young Engineers --

1. **Young students** are requested to perform innovative and excellent research works to solve the problems related to the durability of concrete.
2. If we can make long-term durable concrete, our future generation will certainly construct **sustainable social system (society)** all over the world.
3. We can also save our **planet's environment** as well as it's limited resources.

As Acknowledgement !!

- ***Present faculty member of Concrete Labo. of Kyushu University***.

- Dr. Hidenori HAMADA (Prof.)
- Dr. Yasutaka SAGAWA (Associate Prof.)
- Dr. Takayuki FUKUNAGA (Assistant Prof.) ***new member***
- Dr. Daisuke YAMAMOTO (Technical Officer)

Hope to see you again directly !!
after present disaster/pandemic.

Thank you very much for your kind attention.

2020 October

Research on Concrete Durability

My experience and request for young researchers

Hidenori Hamada
濵田　秀則