Rehabilitation and Preservation of Extremely Damaged World Heritage Concrete Structures

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Topics

- Target of Rehabilitation and Preservation
- Current Status of RC Buildings
- Investigation and Diagnosis of RC Buildings
- Repair and Retrofitting of RC Buildings
- Values and Preservation of RC Buildings

Target of Rehabilitation and Preservation

Hashima Island

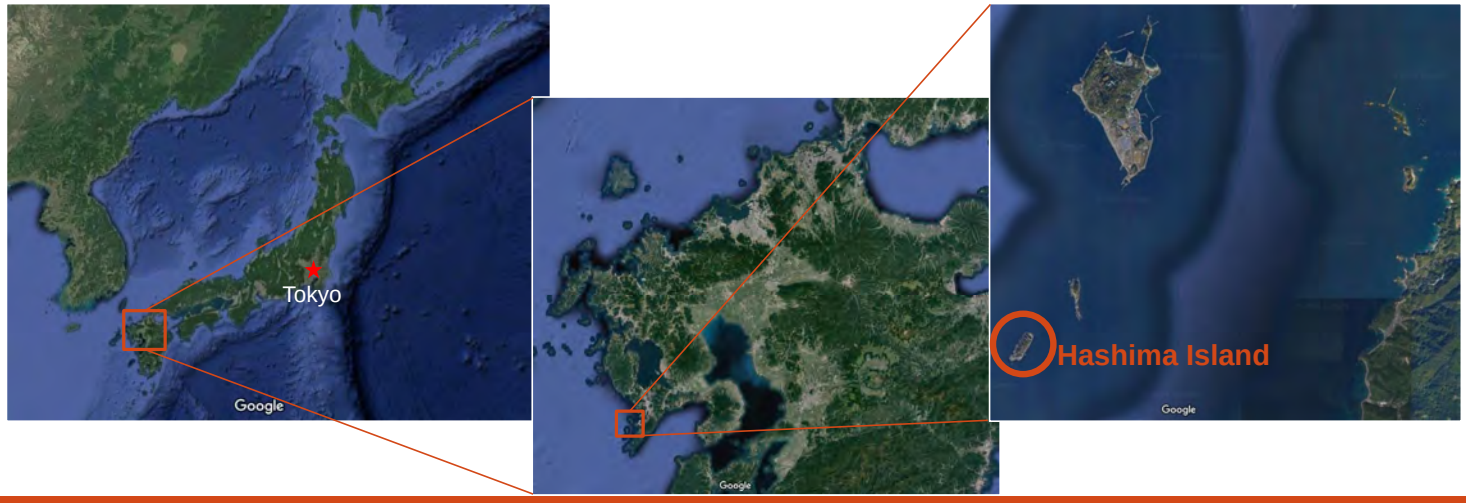
A ruin called “**Gunkanjima**”,
so called after its resemblance to the silhouette of a battleship

1810 Coal discovered
1886 The first vertical shaft completed
1916 The first RC building constructed
1974 The mine closed
2012 Motif of “007/SKYFALL”
2015 Registered as a World Cultural Heritage

Where is it located?

Hashima Coal Mine, Nagasaki-city

One of the **UNESCO World Cultural Heritage**,
"***Sites of Japan's Meiji Industrial Revolution: Iron and Steel, Shipbuilding and Coal Mining***"

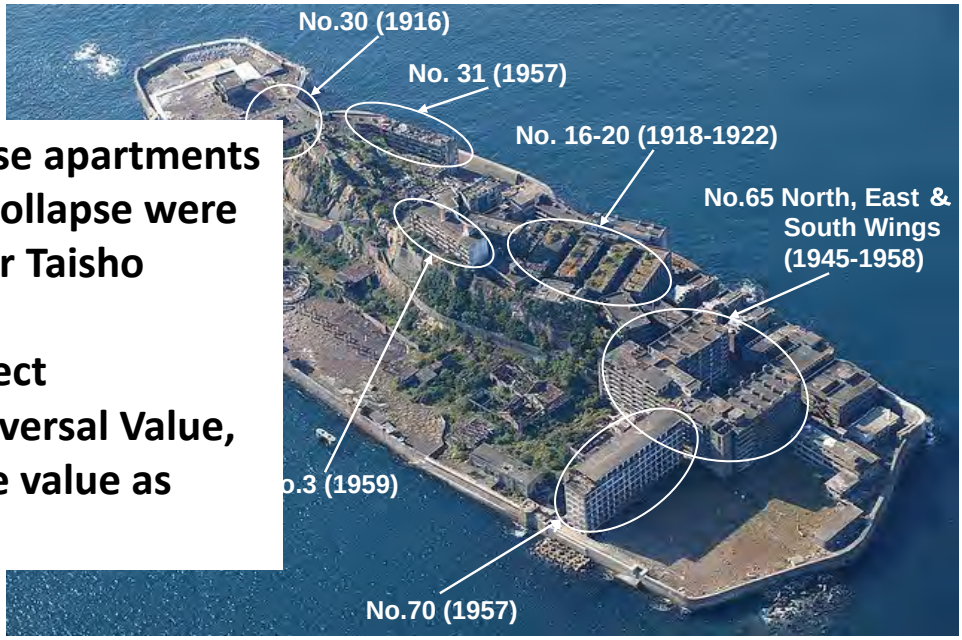


Current Status of RC Buildings

Chloride attack in typhoon season

Main buildings

Concrete high-rise apartments on the brink of collapse were constructed after Taisho Period.
They do not reflect Outstanding Universal Value, but they do have value as historic site.



Outdoor change of No.30 building (1916)

March 2020
Rooftop slab/wall collapse on south side

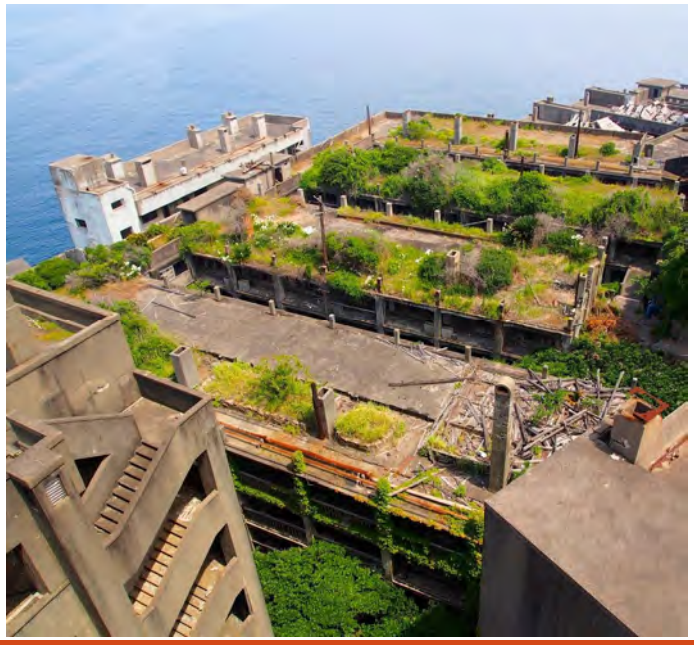
June 2020
Rooftop slab/wall collapse on west side

November 2021 - June 2023
South rooftop slab collapse (different location)

October 2024 - November 2024
East rooftop slab collapse

Indoor of No.30 building (1916)

Outdoor of No.16-20 buildings (1918-1922)

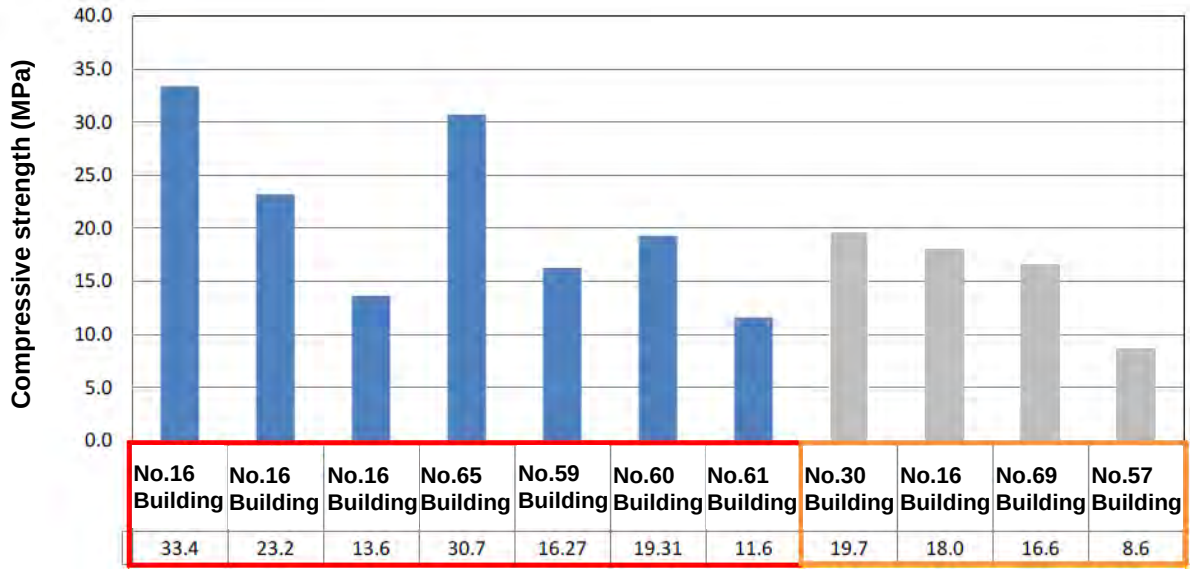


Indoor of No.16-20 buildings (1918-1922)

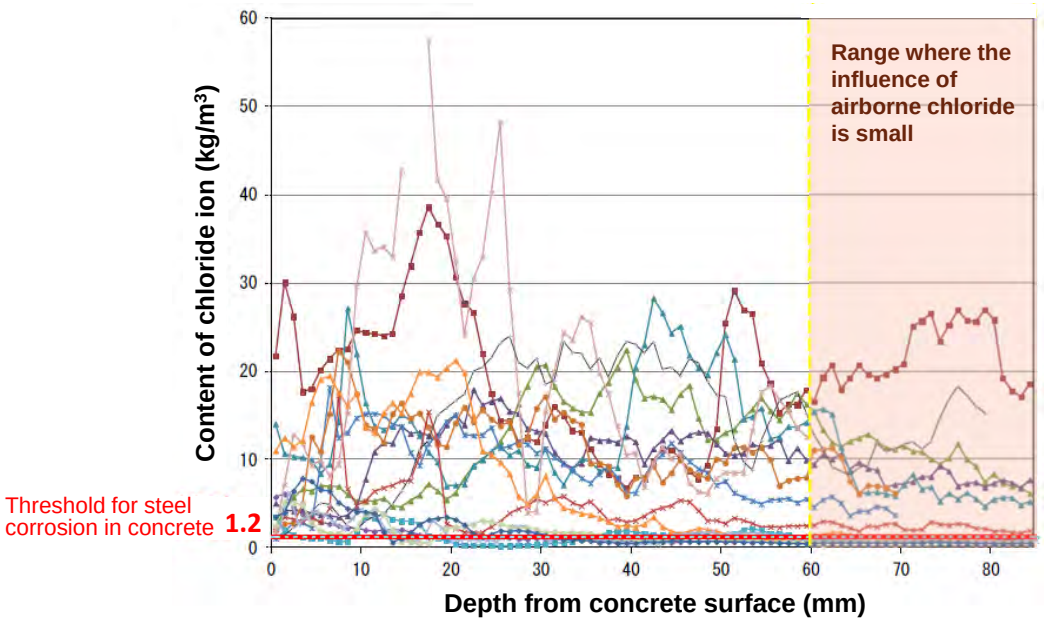
Outdoor of No.65 building (1949)

Investigation and Diagnosis of RC Buildings

Compressive strength of concrete



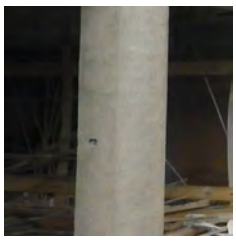
Chloride ion content



Classification of members based on deterioration level

Grade	Deterioration state	
I	Concrete	No crack, or minor cracks not due to rebar corrosion
	Rebars	No corrosion, or minor corrosion (3% or less mass reduction)
II	Concrete	Cracks, rust stain and partial spalling due to rebar corrosion
	Rebars	Clearly corroded (3 to 10% mass reduction), and bonding to concrete slightly reduced
III	Concrete	Partial spalling or completely separation from rebars due to rebar corrosion
	Rebars	Advanced corrosion (about 10% mass reduction)
IV	Concrete	Cover concrete continuous spalling, and rebars largely exposed
	Rebars	Significant corrosion (10 to 30% mass reduction), but no breakage
V	Concrete	Cover concrete totally spalled off and concrete behind rebars also damaged
	Rebars	Terrible corrosion (30% or more mass reduction) or broken

Structural performance according to deterioration level

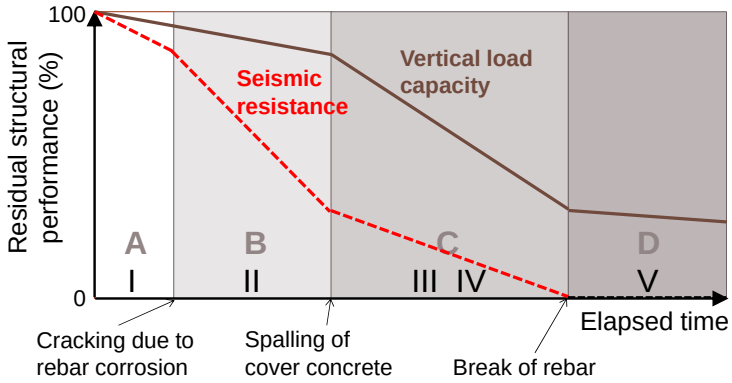


A) **No cracks in concrete due to rebar corrosion**

B) **Concrete cracked or detached due to rebar corrosion**

C) **Cover concrete spalled off and rebars exposed**

D) **Rebars of which cross-sectional area decreased broken or disappeared**



Structural performance (Deterioration)	Progress of deterioration	Residual capacity of vertical load	Residual seismic resistance
A (I)	Slow	1.0	1.0
B (II)	Rapid	0.95	0.8～0.95
C (III, IV)	Extremely rapid	0.8～0.9	0.1～0.65
D (V)	—	0.3	0

Structural performance of the building

Residual capacity of vertical load

Total number of members

Number of members surveyed

Degree of deterioration

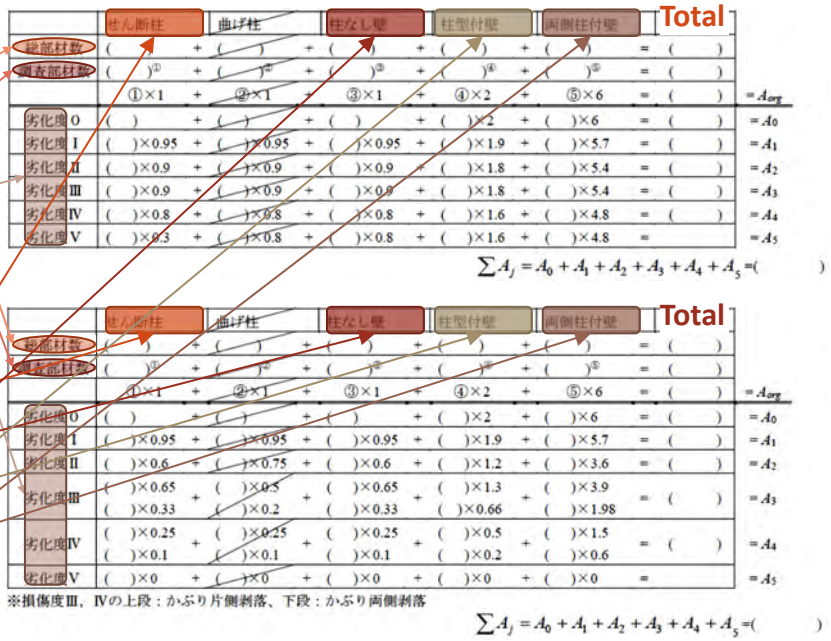
Residual seismic resistance

Shear resistant column

Wall without column

Wall with column on one side

Wall with column on both sides



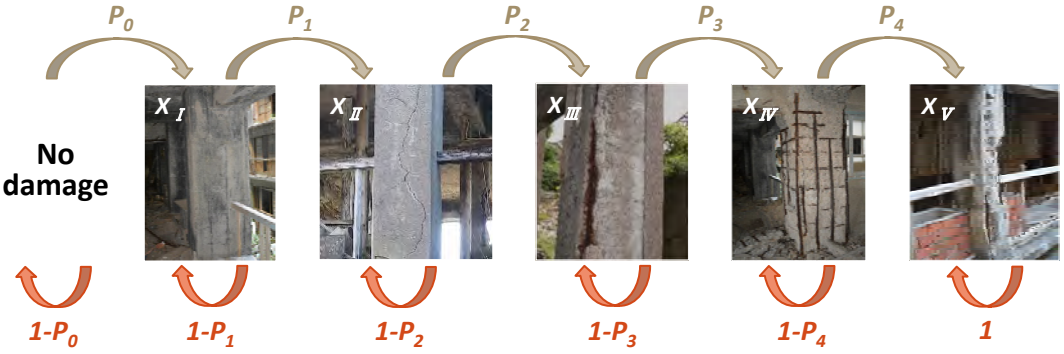
Residual structural performance of buildings

Residual capacity of vertical load

Residual seismic resistance

- In all buildings, the decrease in vertical load carrying capacity is relatively small.
- Some buildings have a large decrease in seismic resistance.

Prediction of future deterioration state by Markov chain model



区分・部材種			Transition probability				
			P_0	P_1	P_2	P_3	P_4
Outdoor	Sea level	H	C	0.619	0.217	0.180	0.106	0.031
			B	0.641	0.487	0.256	0.108	0.053
			W	0.627	0.347	0.122	0.199	0.028
		M	C	0.333	0.086	0.065	0.068	0.042
			B	0.428	0.117	0.163	0.062	0.063
			W	0.514	0.232	0.059	0.014	0.040
		L	C	0.369	0.026	0.048	0.062	0.034
			B	0.469	0.073	0.054	0.055	0.048
			W	0.571	0.016	0.034	0.029	0.096
Indoor			C	0.309	0.018	0.025	0.128	0.039
			B	0.431	0.056	0.031	0.081	0.032
			W	0.271	0.013	0.023	0.022	0.026

$$\begin{pmatrix} X_0 \\ X_I \\ X_{II} \\ X_{III} \\ X_{IV} \\ X_V \end{pmatrix} = \begin{pmatrix} 1-P_0 & 0 & 0 & 0 & 0 & 0 \\ P_0 & 1-P_1 & 0 & 0 & 0 & 0 \\ 0 & P_1 & 1-P_2 & 0 & 0 & 0 \\ 0 & 0 & P_2 & 1-P_3 & 0 & 0 \\ 0 & 0 & 0 & P_3 & 1-P_4 & 0 \\ 0 & 0 & 0 & 0 & P_4 & 1 \end{pmatrix}^t \begin{pmatrix} X_0' \\ X_I' \\ X_{II}' \\ X_{III}' \\ X_{IV}' \\ X_V' \end{pmatrix}$$

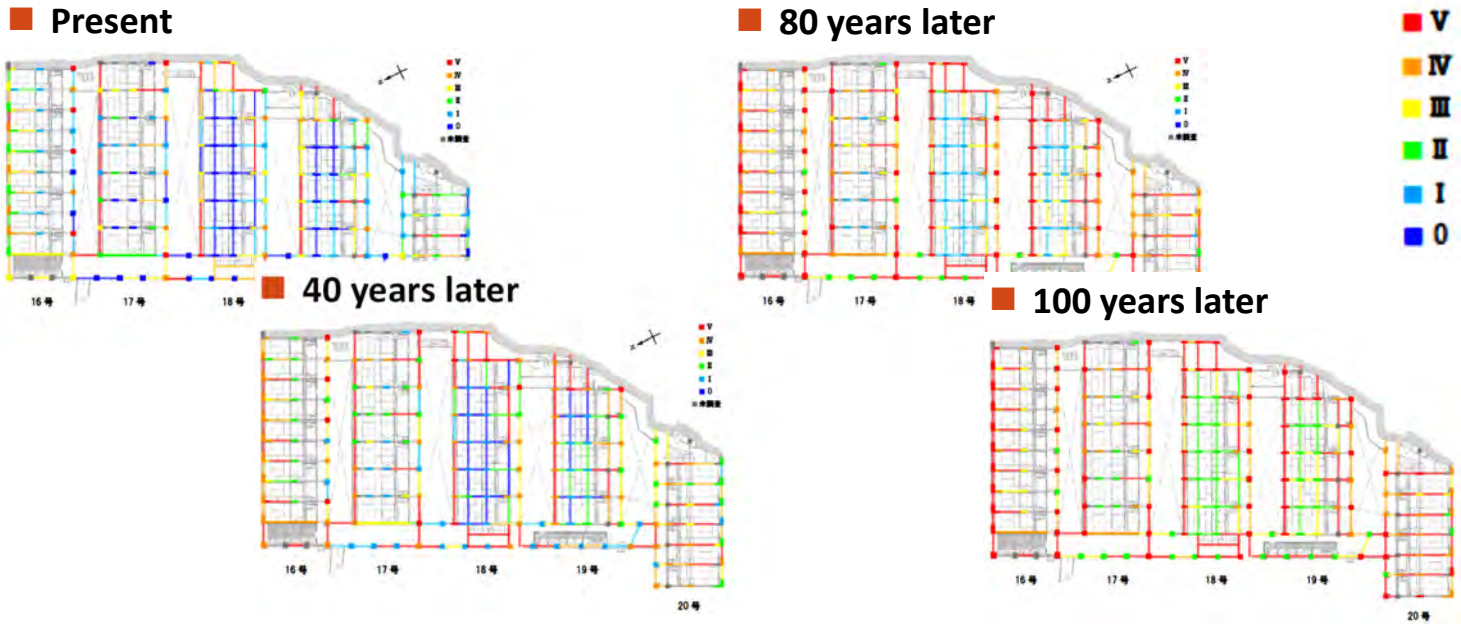
$X_{0\sim V}$: Percentage of current deterioration

$X_{0\sim V}'$: Percentage of deterioration t years ago

$P_{0\sim 4}$: Transition probability

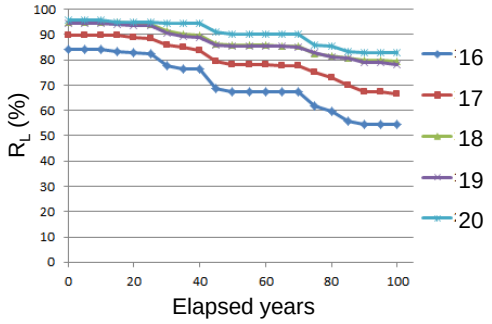
t : Years elapsed

Change in degree of deterioration (Nos. 16-20 Buildings)

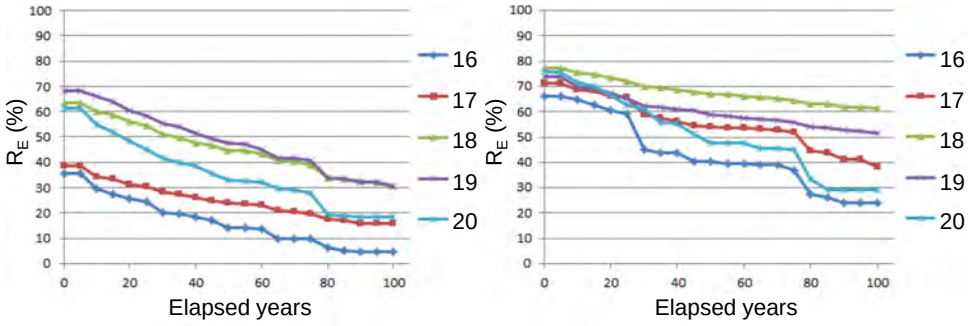


Change in residual structural performance (Nos. 16-20 Buildings)

Residual capacity of vertical load

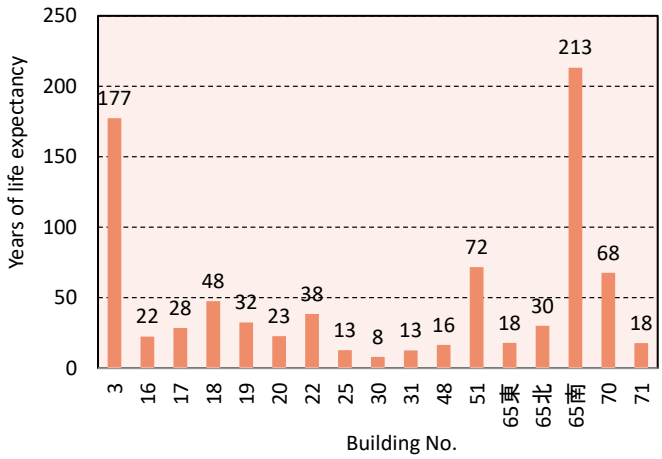


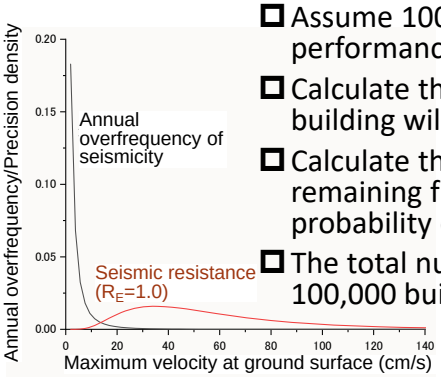
Residual seismic resistance



(a) X direction (b) Y direction

Years of life expectancy (starting in September 2015)





- Buildings collapse only by earthquakes
- Assume 100,000 buildings of the same performance
- Calculate the probability $\alpha_t(R_E)$ that a building will collapse over time
- Calculate the number of buildings remaining from the collapse probability $\alpha_t(R_E)$ at each year
- The total number remaining divided by 100,000 buildings is the life

Calculation of life expectancy of a building
≒ Calculation of average life expectancy of a person

- P (bearing capacity < seismic force) = Probability of collapse
- How many out of 100,000 buildings will collapse and when?
- The average value is the life expectancy

Repair and Retrofitting of RC Buildings

Concept of repair, retrofitting and preservation

Securing authenticity

- **Ruined aesthetics**
  - A feeling of ruins and momentum aesthetically created
    - ✓ A symbol of Japan's modernization process
    - ✓ Abandoned at the end of the period of high economic growth
    - ✓ Left in a state of excessive deterioration
  - Repair, retrofitting and preservation
    - ✓ Maintain the current deterioration state as much as possible
    - ✓ Avoid new damage caused by natural disasters

Securing reversibility

- **Corresponding to future development and innovation of repair and retrofitting technologies**
  - More authenticity secured
  - Advances expected in durability (inhibition of deterioration) and structural safety (earthquake resistance, vertical load support)
- **Repair and retrofitting method**
  - Replaced as easily as possible in the future

Criteria for preservation priorities for members

Historical value, landscape value, economic efficiency

- **High priority as preservation target**
- **Relatively low priority as preservation target**
  - High value recognized, however, technically and economically preservation extremely difficult
  - Relatively low value

Visibility

- **Visually recognized by tourists**
  - The whole members
  - Part of the member
- **Visually unrecognized by tourists**

Repair method and appearance change according to recovery level

Grade	Target	Recovery level		
		Suppression of deterioration	Stop of deterioration	Restoration
I	Concrete	Crack filling or impregnation	Crack filling or impregnation	Crack filling
	Rebars	Impregnation (Lithium nitrite)	Desalination or electrolytic protection	Electrolytic protection
II III	Concrete	Crack filling and concrete restoration	Crack filling and concrete restoration	Crack filling and concrete restoration
	Rebars	Electrolytic protection	Electrolytic protection	Electrolytic protection
IV V	Concrete	Concrete restoration	Concrete restoration	Concrete restoration
	Rebars	Retrofitting (Additional rebars)	Retrofitting (Additional rebars)	Retrofitting (Additional rebars)

Repair method	Appearance change
Crack filling	Small
Impregnation	No
Concrete restoration	Large
desalination	No
Electrolytic protection	No to large
Retrofitting (Additional rebars)	Large

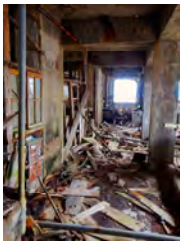
Retrofitting strategy

- **Goal of seismic retrofitting**
  - Seismic performance possessed at the time of building construction
- **Securing authenticity**
  - Never install seismic retrofitting materials as much as possible in a position that can be seen from the street outside the building
- **Securing reversibility**
  - Retrofitting materials be removed as much as possible in order to respond to future technological innovation in the retrofitting method
- **How to join retrofitting materials**
  - Doubt about the effectiveness of anchor considering the deterioration state
  - Precast concrete crimping method with tendon through holes (easy to remove retrofitting materials)
- **Securing durability of retrofitting materials**
  - Use of glass fiber material (corrosion resistance, high strength, light weight, easy manufacturing, maintenance-free)

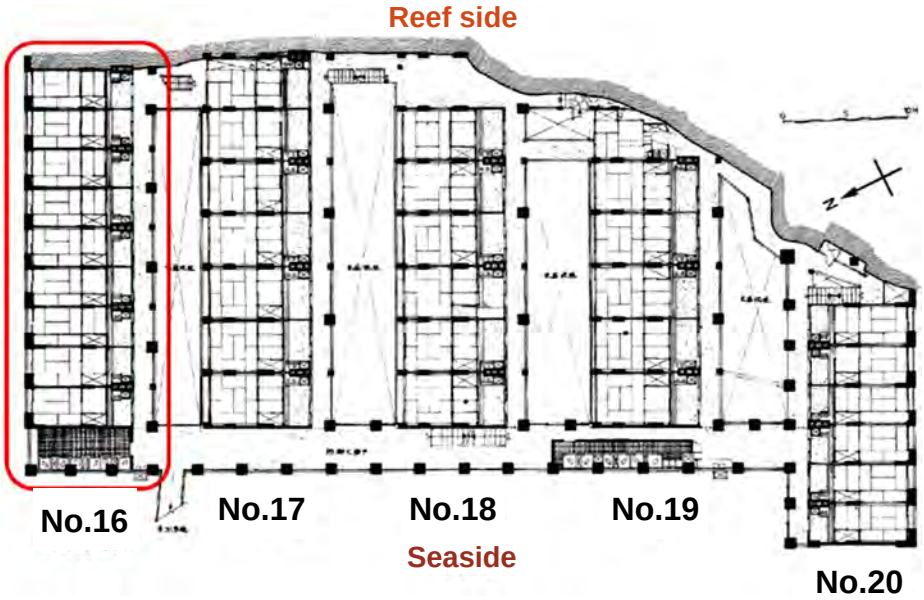
Construction strategy

- **Preservation of ruins (consideration for authenticity)**
  - Conservation of rubble scattered indoors and outdoors
  - Conservation of falling dangerous concrete
- **Securing reversibility (consideration for cultural properties)**
  - Consideration for how to attach repair materials and retrofitting materials to the frame
- **Securing workers' safety**
  - Caution of rubble scattered indoors and outdoors
  - Caution of falling dangerous concrete
- **Pursuit of economic efficiency**
- **Consideration for weather and environmental conditions**





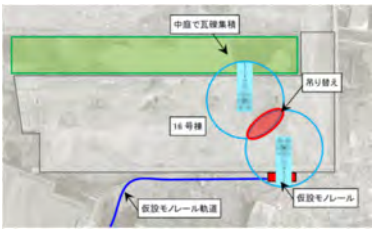
No.16 Building (completed in 1918)



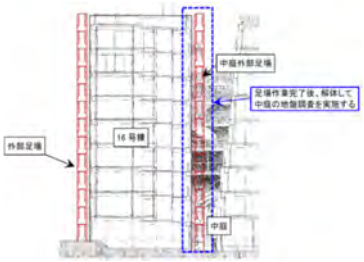
Rubble removal work and scaffolding installation work for No.16 Building

1) Carrying out rooftop greenery

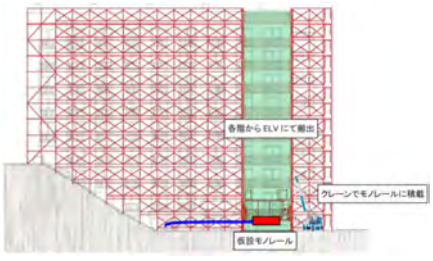
2) Removal of rubble from the courtyard



3) Installation of scaffolding

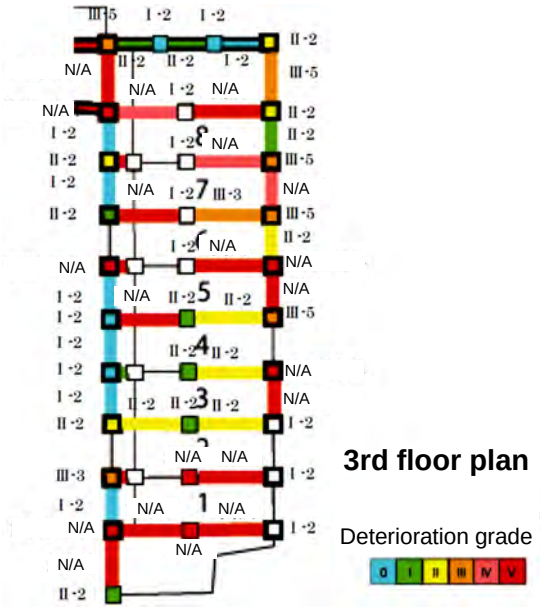


4) Removal of rubble from the room



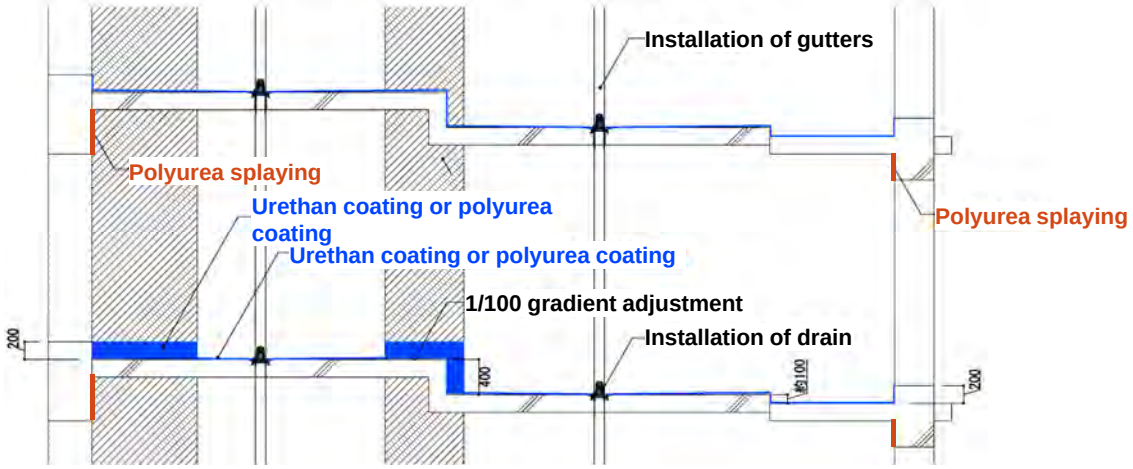
Deterioration states and repair methods for No.16 Building

Grade	Repair method	Column	Beam
I	Application of silicate-based impregnant	13	7
II	Restoration using polymer modified cement mortar	9	7
III	Electrolytic protection	4	1
III	Application of special paint	1	1
Not subject to repair		7	13
Total		36	29



Indoor waterproofing and spalling prevention of No.16 Building

- Drain installed on floors
- Polyurea splaying for spalling prevention and waterproof on walls and floors
- Urethane coating for waterproof on walls and floors



Structural performance of No.16 Building

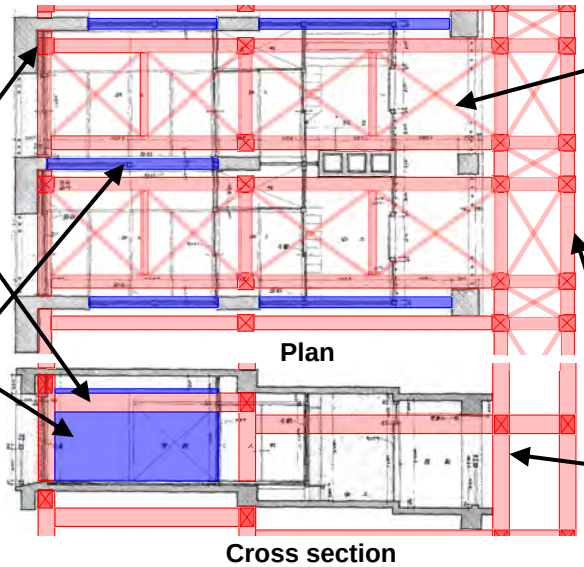
Residual performance

Vertical load carrying capacity	Seismic resistance	
	X-direction (long)	Y-direction (short)
73%	24%	30%

Retrofitting method for No.16 Building (to be continued)

Support of vertical load
Column: ☐-200x200x12mm
Beam: H-200x200x8x12mm

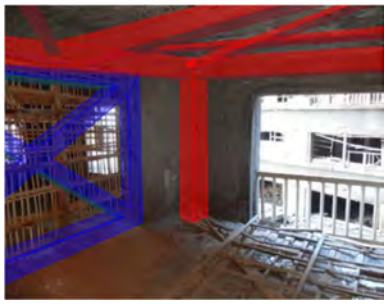
Bearing wall between beams (vertical brace)
: H-175x175x7.5x11mm



Plan

Cross section

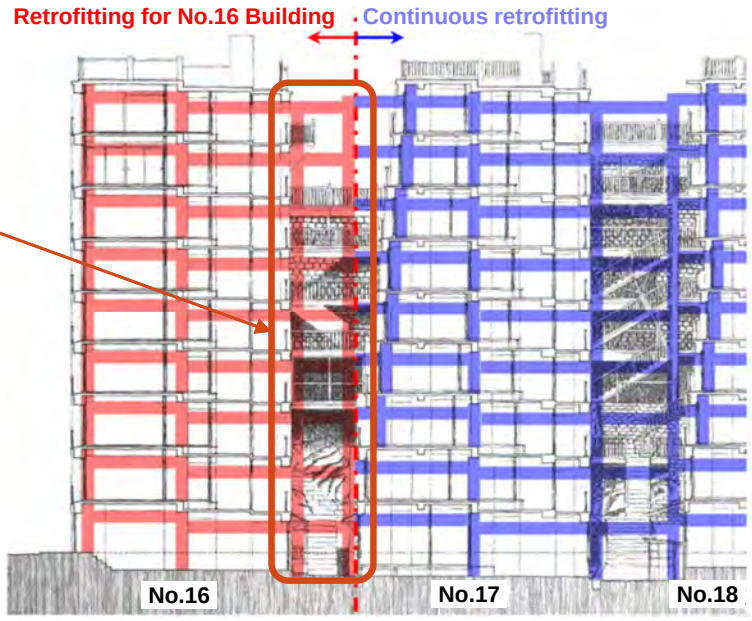
Horizontal brace
: 2Ls-90x90x10mm



Expansion frame (vertical brace)
: H-200x200x8x12mm

Retrofitting method for No.16 Building (continued)

Seismic frames added between the buildings and connected continuously to reinforce the entire buildings



Work schedule and cost estimation of repair and retrofitting for No.16 Building

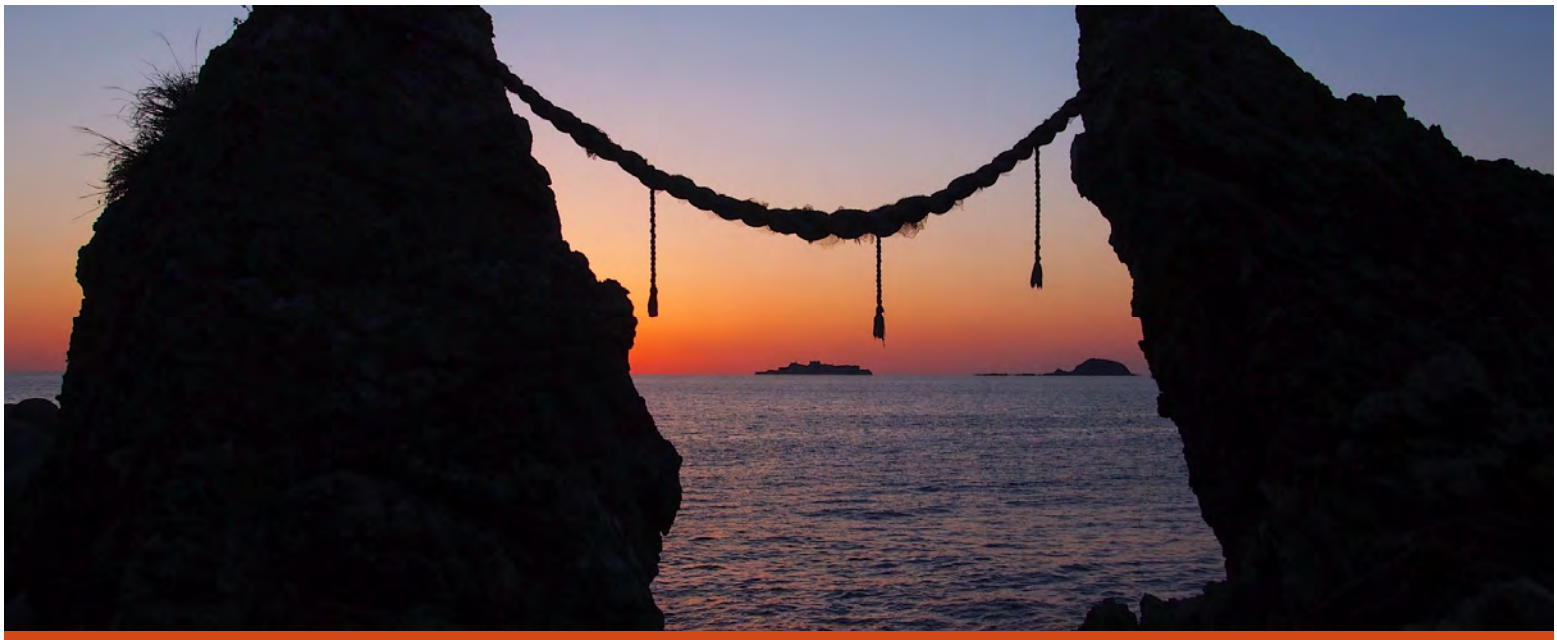
No.	Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	33	35	36
1	Preparatory work																																		
2	Scaffolding installation work																																		
3	Rubble removal work																																		
4	Waterproofing work																																		
5	Repair / retrofitting work																																		
6	Scaffolding removal work																																		

Estimated total cost for rehabilitation of No.16 Building (around 3,000m^2)
JPY 2,657,489,048 = USD 18,371,221 (More than 4 times the new construction)

Values and Preservation of RC Buildings

Values and preservation of RC buildings in Hashima Island

- **Cultural value of historic concrete structures**
  - Social capital that supported Japan's modern industrial revolution
- **Research value of historic concrete structures**
  - Concrete structures that have reached the end of their life and are in a state close to natural collapse are extremely rare and irreplaceable for the development of concrete engineering
  - An excellent teaching material for those who study and research deterioration phenomena, performance evaluation, repair techniques, etc. of concrete structures
  - A place where researchers and engineers can demonstrate their accumulated knowledge and research results
- **How historic concrete structures should be conserved and utilized**
  - It is necessary to rank the implementation of repairs in consideration of life expectancy.
  - Securing financial resources is an important issue, and it is necessary to consider tourism, entertainment, donation, and endowment based on multifaceted management perspectives.



Thank you for your kind attention!