Korea Atomic Energy Research Institute

Completion of Seismic Rehabilitation Project at HANARO after the Fukushima Daiichi Accident

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1. Introduction

History of HANARO seismic retrofitting project

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- Right after the Fukushima accident in 2011, the Nuclear Safety and Security Commission (NSSC) of the Korean government formed a special nuclear safety inspection team with the participation of civilian experts.
- As a result of the safety mission, the NSSC requested KAERI to reassess the seismic qualification of HANARO with particular emphasis on the reactor building and stack.
- KAERI carried out a seismic performance evaluation. However, it was identified that some part of the outer wall of HANARO should be reinforced.
- In the design stage of reactor building, it was seismically designed based on the design earthquake SSE 0.2g (horizontal)
- As a result of Seismic Margin Assessment, some parts of wall were found not meet the design criteria of 0.2g.
- In March 2015, the regulatory body formally asked to reinforce the confinement wall.

Structural Characteristics of HANARO reactor building

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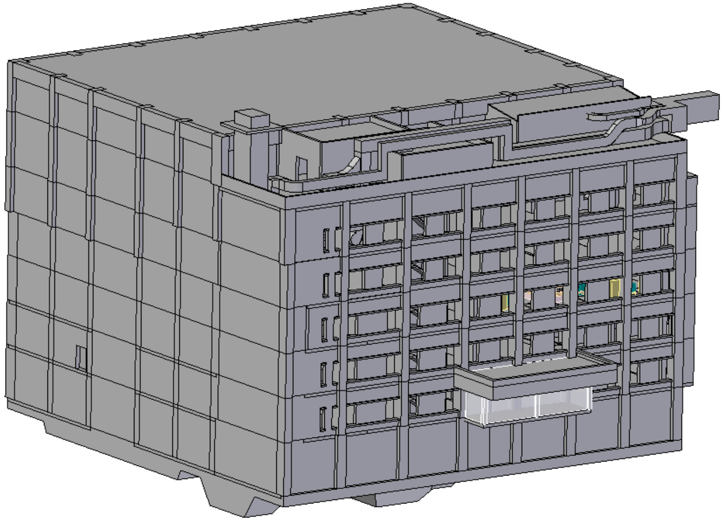
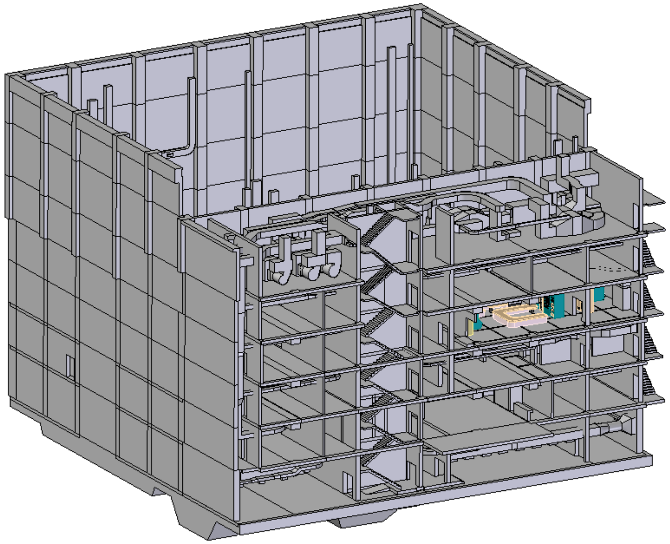
- Depth 7m, Height 26m (Total 33m)
- Seismic class box type reinforced-concrete structure
- Wall thickness : 60cm at underground & 40cm above ground level
- Reactor hall area : 43m × 32.6m × 31m
- Service area : 43m × 10.4m × 27m
- Basement : 45m × 44.2m, depth of mat slab is 1~2m



Shape of reactor building (exterior)



Shape of reactor building (interior)

Structural Characteristics of HANARO reactor building

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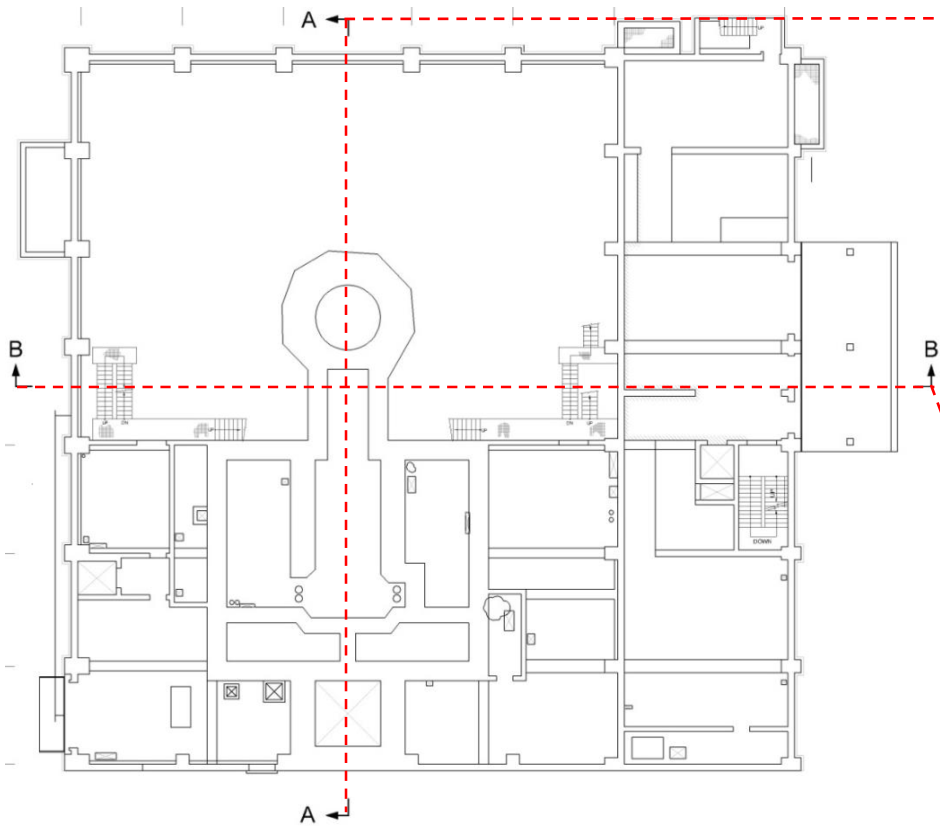
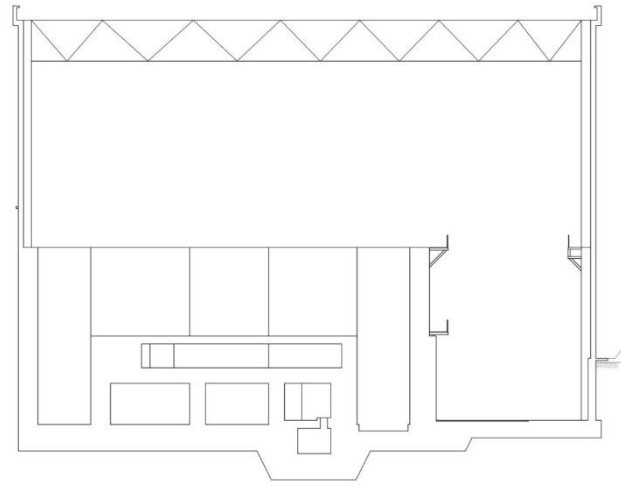
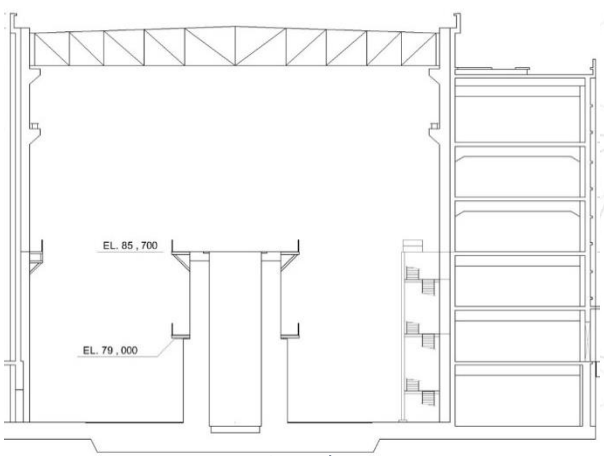
❍ **Asymmetric shape of reactor building**



Plan drawing of RX



A Section



B Section

Locational Features of HANARO building

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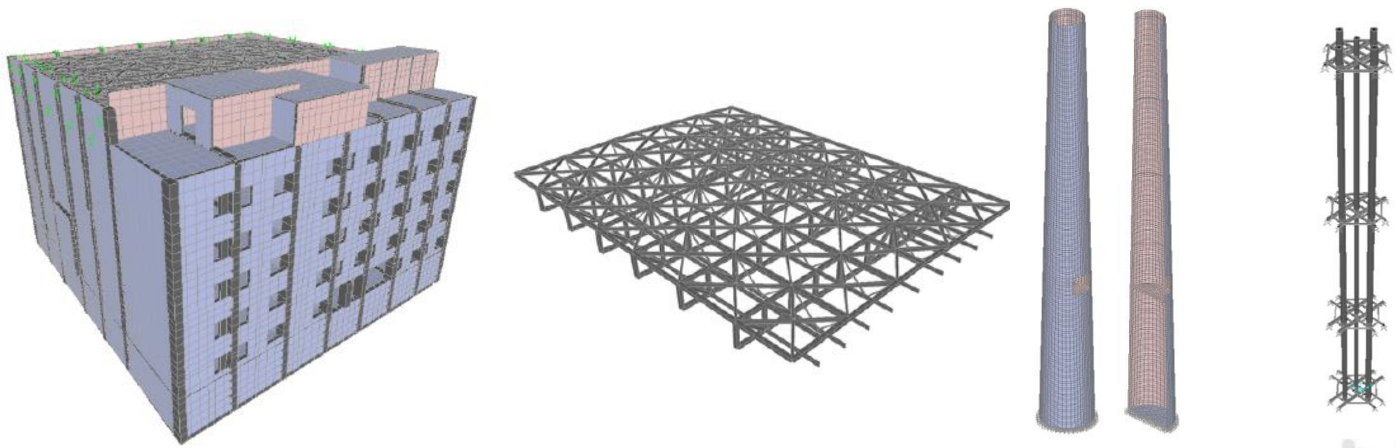
- In the south side of the reactor building, there is a RIPF (Radio Isotope Product Facility) building and an IMEF (Irradiated Material Examine Facility) building.
- the CNL (Cold Neutron Laboratory) building is located at the west side of the reactor building
- The spaces between the reactor building and adjacent buildings are particularly narrow. The maximum space with the adjacent buildings is 4.2 m at north side, and there is a utility-pipe conduit underground.

HANARO Reactor Complex

2. Previous Works

Seismic Margin Assessment

- For the seismic assessment of the reactor building, the EPRI-NP-6041-SL (A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Rev. 1)) has been applied.
- The outcomes of the assessment proved that the seismic margin of the reactor concrete island that accommodate the reactor structure and major reactor systems was 7.7 on the Richter scale, which makes it more than qualified.
- However, it was found out that some areas of the outer wall of the reactor building did not meet the seismic design criteria.



- Node : 17,471 EA
- Beam element : 3,045 EA
- Shell element : 17,075 EA

3D FE Model of Reactor building, Roof truss, Stack

Seismic Margin Assessment

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❑ Ground response spectrum

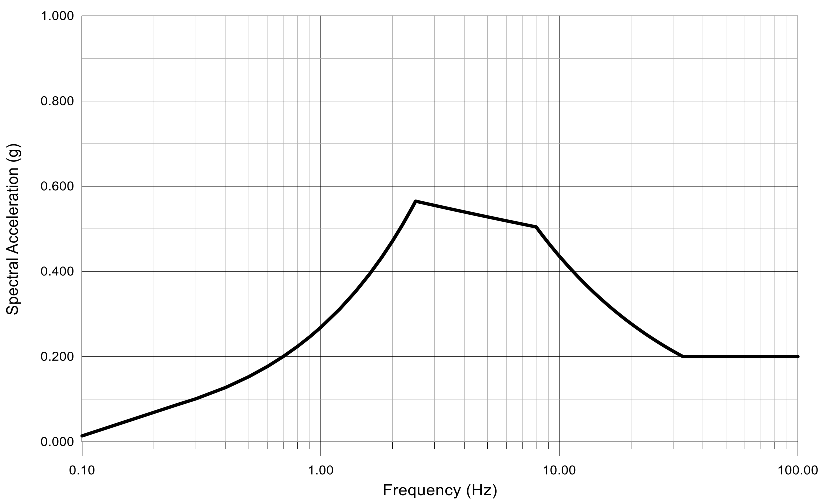
❍ DGRS in initial design(Horizontal PGA 0.2g) is applied.

- Accept regulatory-guideline in US and Canada (R.G 1.60 , CAN3-289.3-M81)
- SSE : Horizontal 0.2g, Vertical 0.133g
- GRS with 7% damping at Earthquake force calculation in RC material
- GRS with 4% damping at Earthquake force calculation in Roof-truss

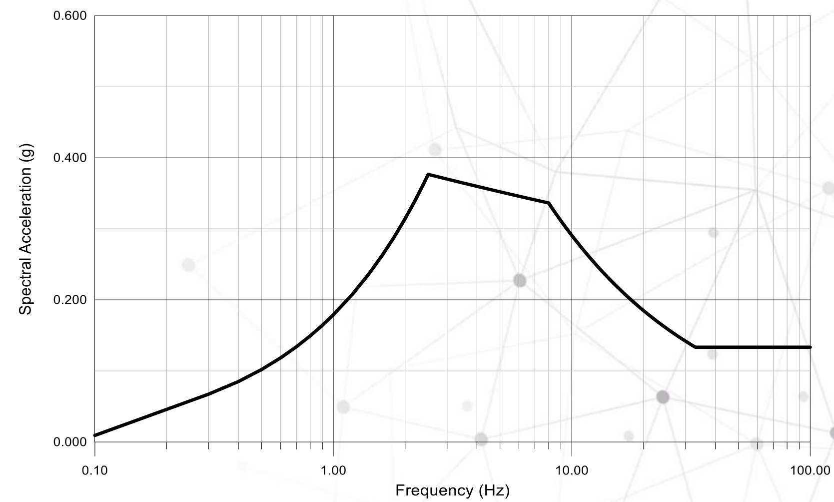
❑ Damping ratio

❍ R.G 1.61, "Damping Values for Seismic Design of Nuclear Power Plants”

- RC structure : 7%
- Roof-truss : 4% (Steel with friction connections)



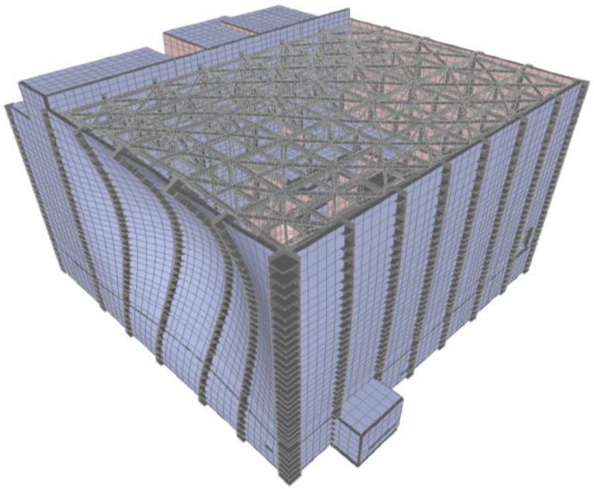
Horizontal EW,NS (PGA 0.2g), 7% damping



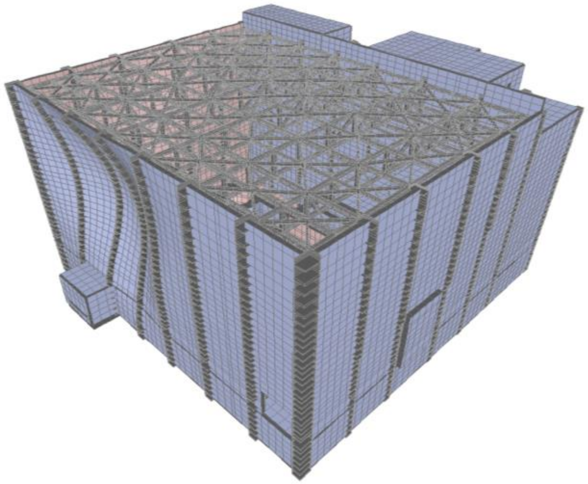
Vertical VT (PGA 0.133g), 7% damping

Seismic Margin Assessment

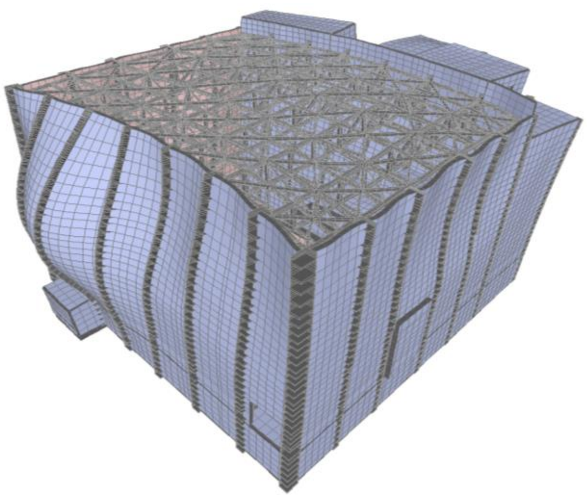
❑ Mode Shape



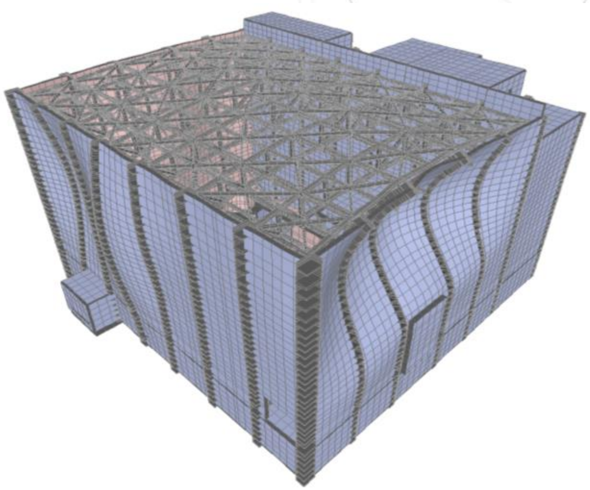
Mode No.1 (North wall) (f : 2.25Hz)



Mode No.1 (West wall) (f : 2.91Hz)



Mode No.1 (building overall, EW direction) (f : 4.16Hz)



Mode No.1 (building overall, NS direction) (f : 4.16Hz)

Seismic Margin Assessment

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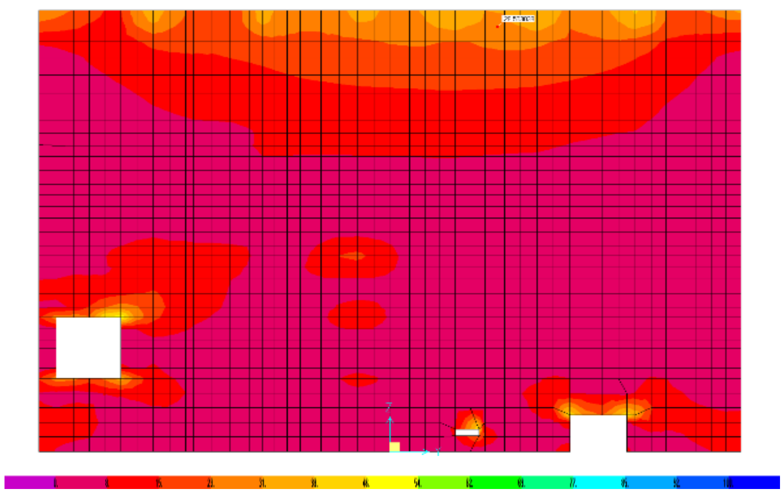
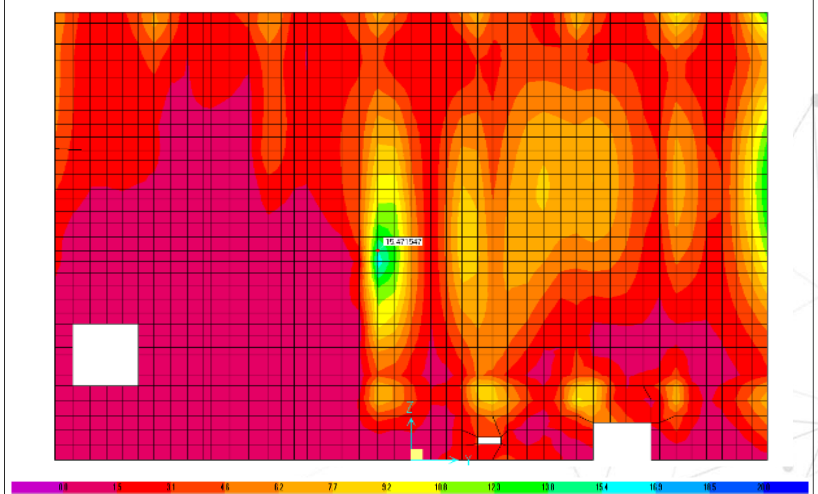
- When the draft SMA report was presented, we suspected some error occurred at SMA procedure.
- We checked modeling, assessment procedure and actual field condition.
- As a result of evaluation, some part of the outer wall (about 4.8%) is not satisfied the design criteria(SSE 0.2g).

In-plane horizontal tension (F11)	Out-of-plane horizontal moment (M11)
	

This picture shows member force of the reactor building (west side of outer wall).

Maximum in-plane horizontal tension (F11) is 30 ton and maximum out-of-plane horizontal moment (M11) is 16 ton.m. It means that the performance of minimum allowable seismic load for horizontal moment is only 0.09g.

Design Concept of Seismic Rehabilitation Project

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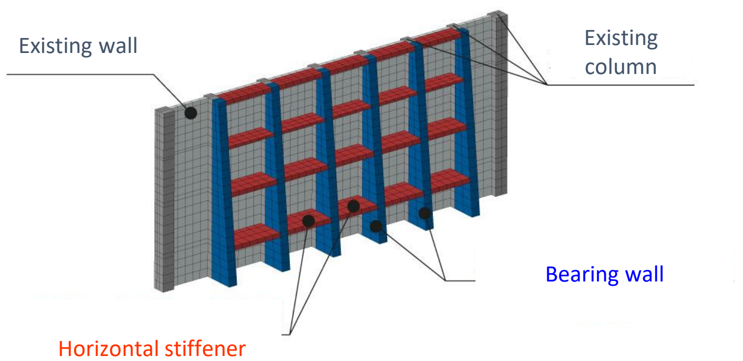
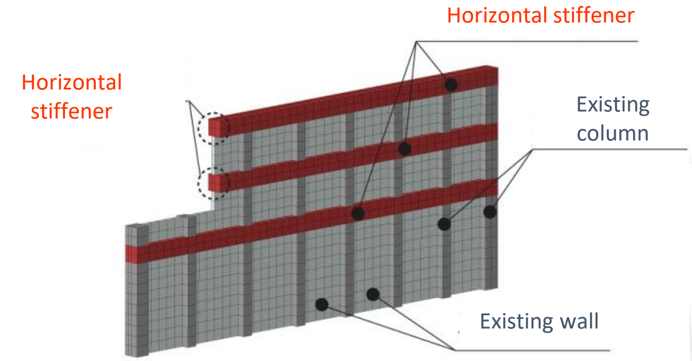
❑ Check the universal reinforcement

❍ Bearing wall

- Bearing walls & horizontal stiffeners on the North and West wall
- Horizontal stiffeners on the South wall

North and West wall	South wall
	

- According to preliminary calculation, it is likely expected that there is a limited reinforcing effect within allowable work space.
- And, in order to install the reinforcement, it is required to relocate the existing facilities around the reactor building such as underground structures that containing piping and cable. So, it could not be attainable.

Design Concept of Seismic Rehabilitation Project

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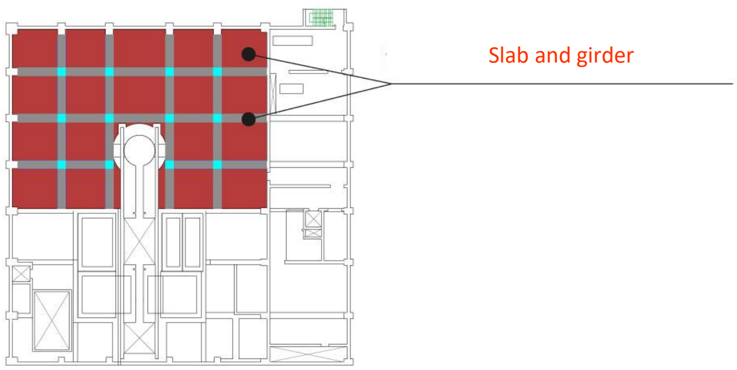
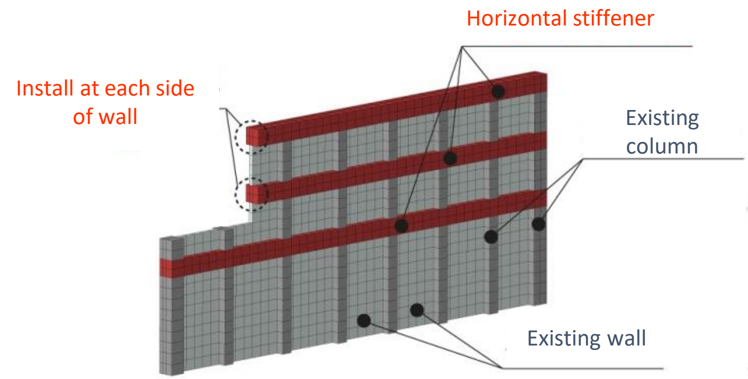
❍ Slab on 3rd floor

- Slab and girders at level of 3rd floor
- Horizontal stiffener on each side on North, West and South wall

3rd floor of reactor hall	North, West and South wall
	

- It is likely expected to enhance the reinforcing effect for the out-of-moment(M11), but there will be a limited effect for in-plane tension(F11).
- It is required to do mass concrete works inside the reactor building that is being controlled in radiation area. So, actually it could not be implementable.

Design Concept of Seismic Rehabilitation Project

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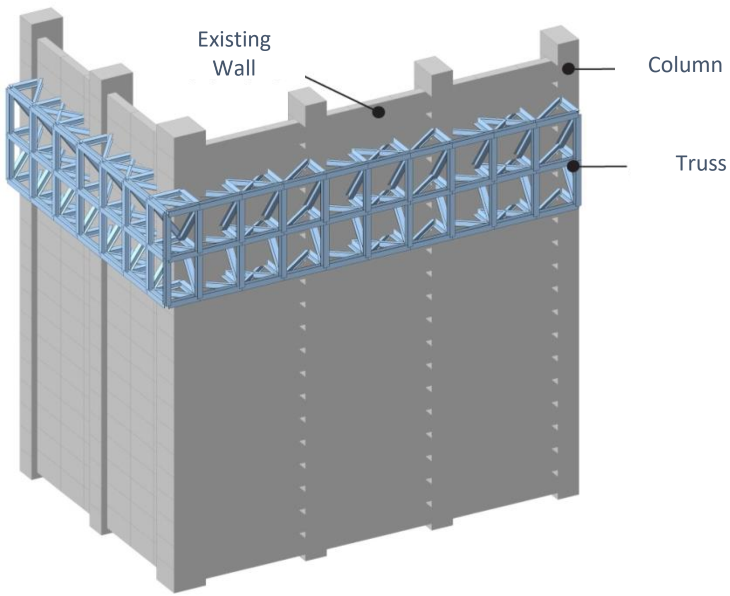
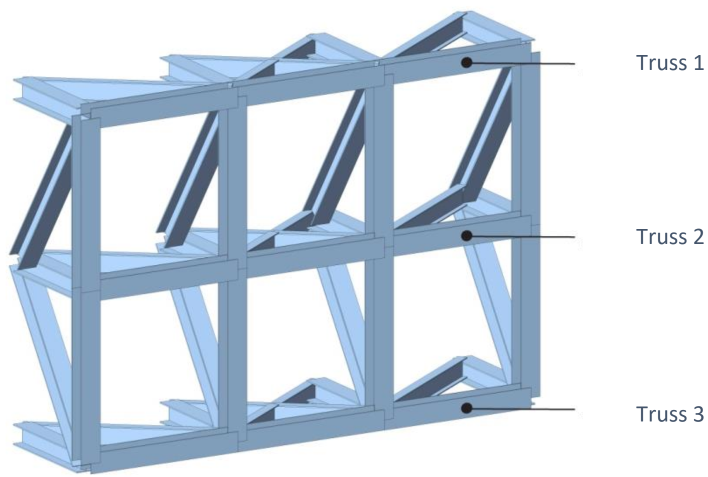
❍ Truss Reinforcement

- Truss reinforcement on all the walls

Outer wall



Truss details



Increase and decrease of truss quantity is set by analytical result

- It is expected to enhance the reinforcing effect for the out-of-moment(M11), but there will be no effect for in-plane tension(F11).
- So, it could not be acceptable. But, it may be used to enhance the out-of-moment, combining with reinforcements for in-plane tension.

Design Concept of Seismic Rehabilitation Project

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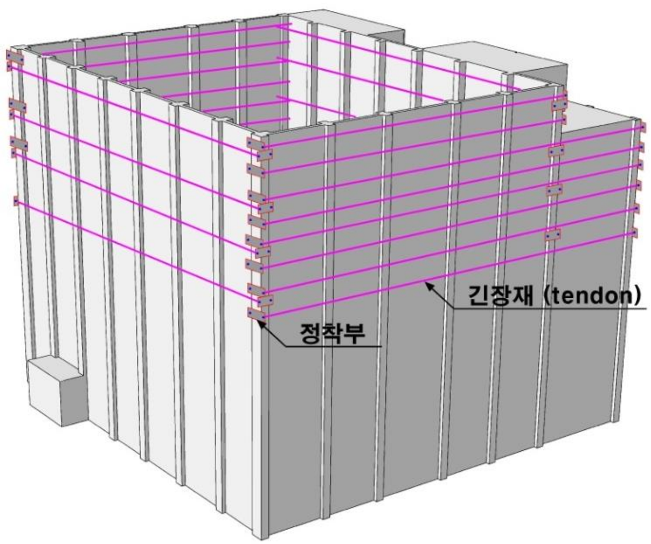
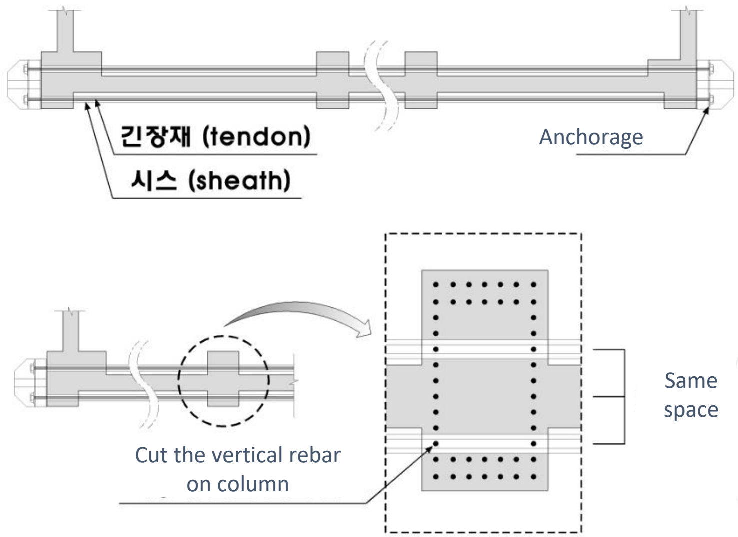
❍ Post-Tension Reinforcement

- Tendon on walls

Reactor building	Tendon install detail
	

- It is expected to enhance the reinforcing effect for only the in-plane tension(F11). To withstand the out-of-moment(M11) at once, the tensioning force should be applied to much higher than the structural capacity of the reactor building. It could not be able to accommodate.
- It is expected that there will be a loss of structural integrity by means of penetrations into columns. It could not be acceptable.

Design Concept of Seismic Rehabilitation Project

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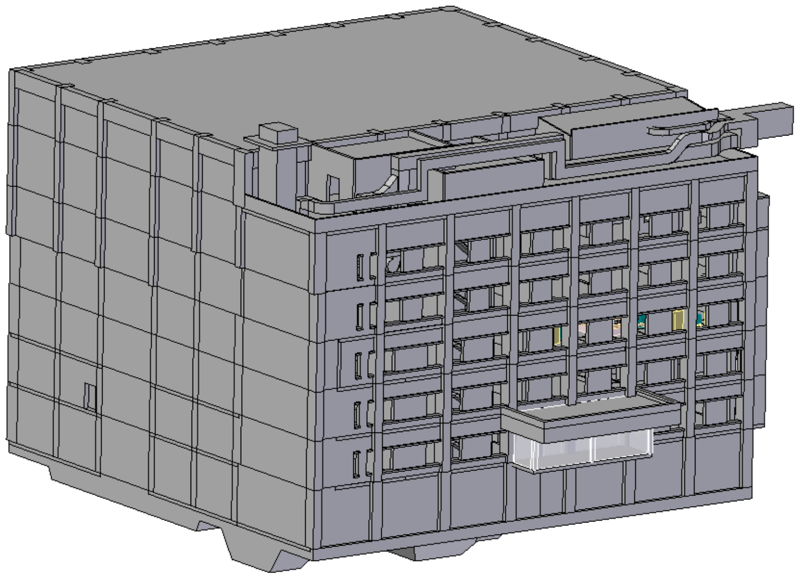
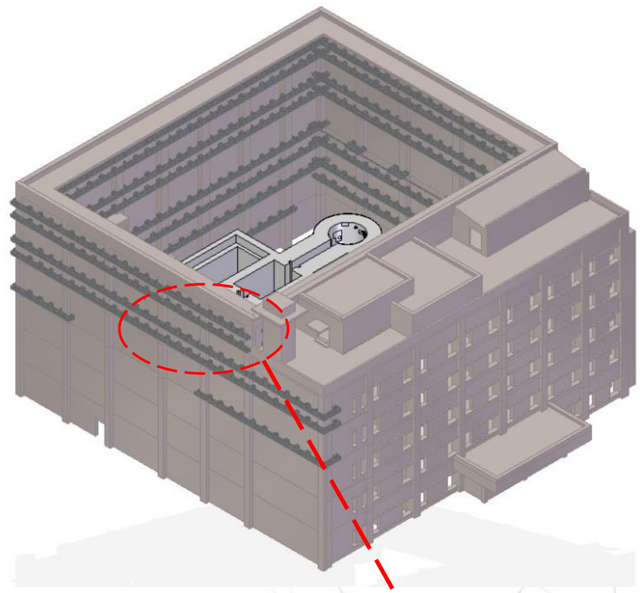
❑ Reinforcement concept (final)



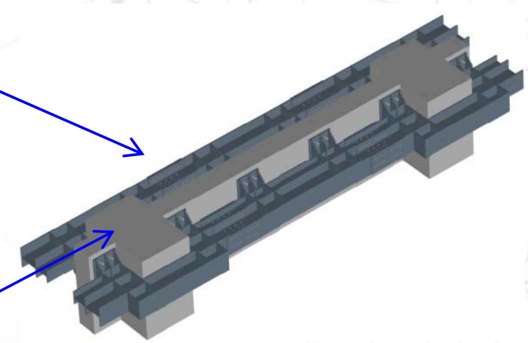
Reactor building : Before rehabilitation



Reactor building : After rehabilitation

Reinforcing structures
(Built-up sections made by Steel H-Beam + Steel Plate)

Existing concrete wall

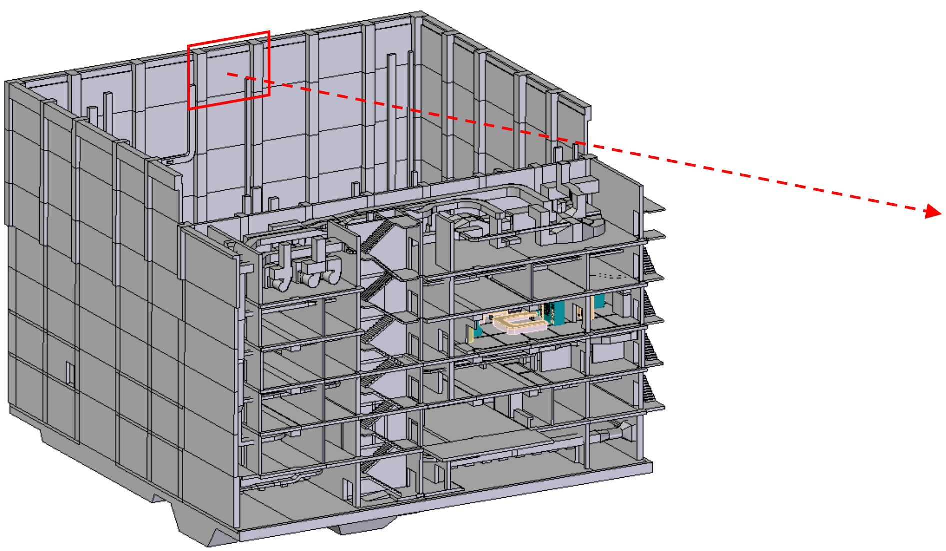


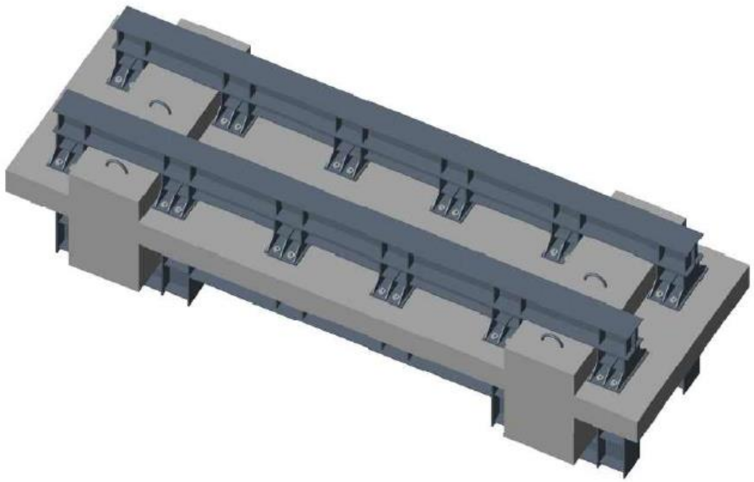
Rehabilitation detail

3. Seismic Rehabilitation Project

Structural Performance Verification Test

- In the approval process, KINS(Korea Institute of Nuclear Safety, TSO of NSSC) requested a structural performance verification test to confirm the reinforcing effect of a built-up section in a concrete outer wall.
- A part of the real wall was made as the sample at a 1:1 scale, of which the size was 6.2 × 2.45 × 3.0 m.
- To check the reinforcing effect of the built-up section, KAERI made two samples for the test. One was in the original condition and the other was reinforced with the built-up section.





Structural Performance Verification Test

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- A course of making specimen, we regard it as a rehearsal of real reinforcement construction.
- We check the whole process following quality management plan.

Formwork and rebar arrange, Concrete casting, Form removal, Core drilling

Arrange anchor bolt using template, Size inspection of built-up section, Assembling of built-up section, Relocate the specimen

Structural Performance Verification Test

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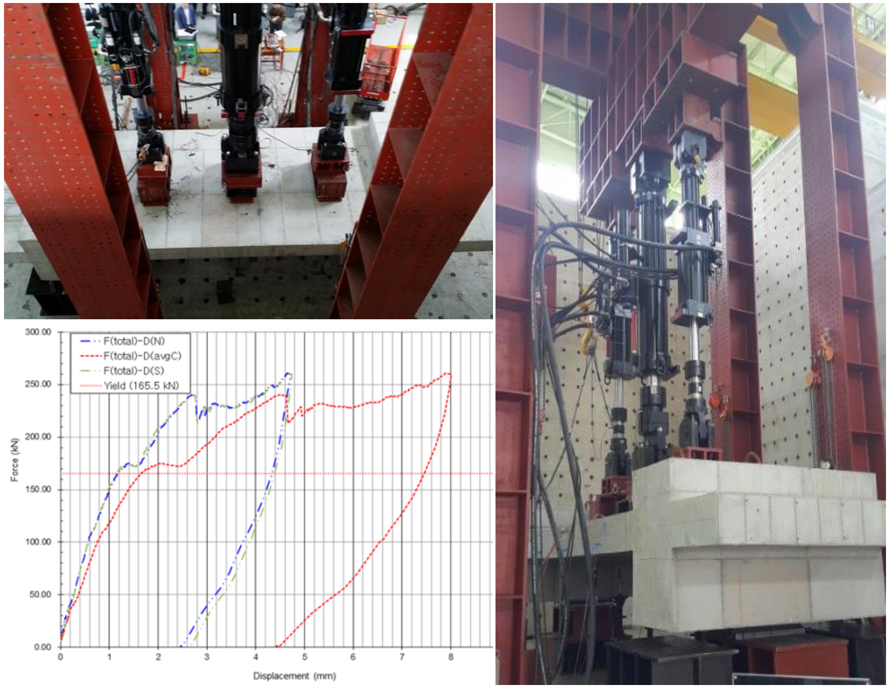
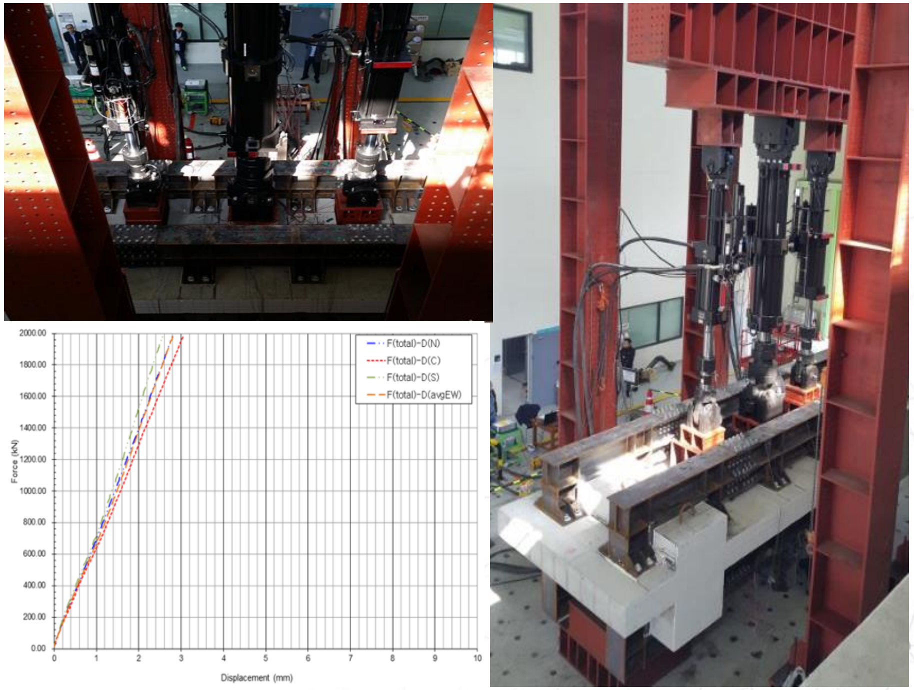
- The test result showed that the static loading capacity of the reinforced specimen was stronger than the one in the original condition.
- The built-up section showed an increase in the structural strength capacity.
- Original wall specimen yields at (about) 170kN and reinforced specimen is not yields until 2000kN. It was not able to check. (Limited capacity of actuator)





Static loading test (Left : Original wall, Right : Reinforcing with built-up section)

Main Construction Progress

- Measuring and recording the points of installation
  - To determine the positions of built-up sections, KAERI made a precision survey.
  - After that, rebar scanning was conducted to avoid cutting the existing rebar in the wall.
  - When rebar existed in the installation position, the installation position was changed to maintain the existing rebar.

Rebar scanning to avoid cutting existing rebar

Main Construction Progress

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❍ Drilling the outer wall by using core drill

- As a result of precision survey, KAERI determined suitable coring point.
- To locate the through-bolt through the wall, we made holes using a core drill machine at the installation points

- To check the cutting of the existing rebar, we carried out the total inspection about the core remainder.
- In case an unexpected rebar cutting is detected, we stopped drilling and checked the design calculation.
- If the design margin was sufficient, we made the report with ‘use as is’. And if not, we applied additional reinforcement.

- The HANARO building adopted a confinement concept for the reactor hall, which isolates the air, but allows a small leakage.
- To keep its own function in the construction period, we used a rubber plug.
- Right after the wall was penetrated, we stopped up the holes with rubber plugs. It functions as a physical shield between the reactor hall and outside

- To hang the built-up sections on the wall, a through-bolt was used.

Main Construction Progress

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❍ Locate the through-bolt in the core hole and put the non-shrink grout in the core hole

- To make the through bolt centered in the hole, we made a special template to locate the through bolt. After that, we injected non-shrink grout between the through bolt and the wall of reactor building
- After the injection, we checked all of the holes to keep the confinement function of the reactor building. To check the individual leak, we made a leak test box and attached the box at the inspection point. After that, we made a -0.5 bar vacuum condition inside the box and checked if it is maintained over 20 seconds at the inspection position. The results showed that all holes are filled with non-shrink grout well and have airtightness.

Inject non-shrink grout into hole to fix the through bolt in the hole

Leak test box

Main Construction Progress

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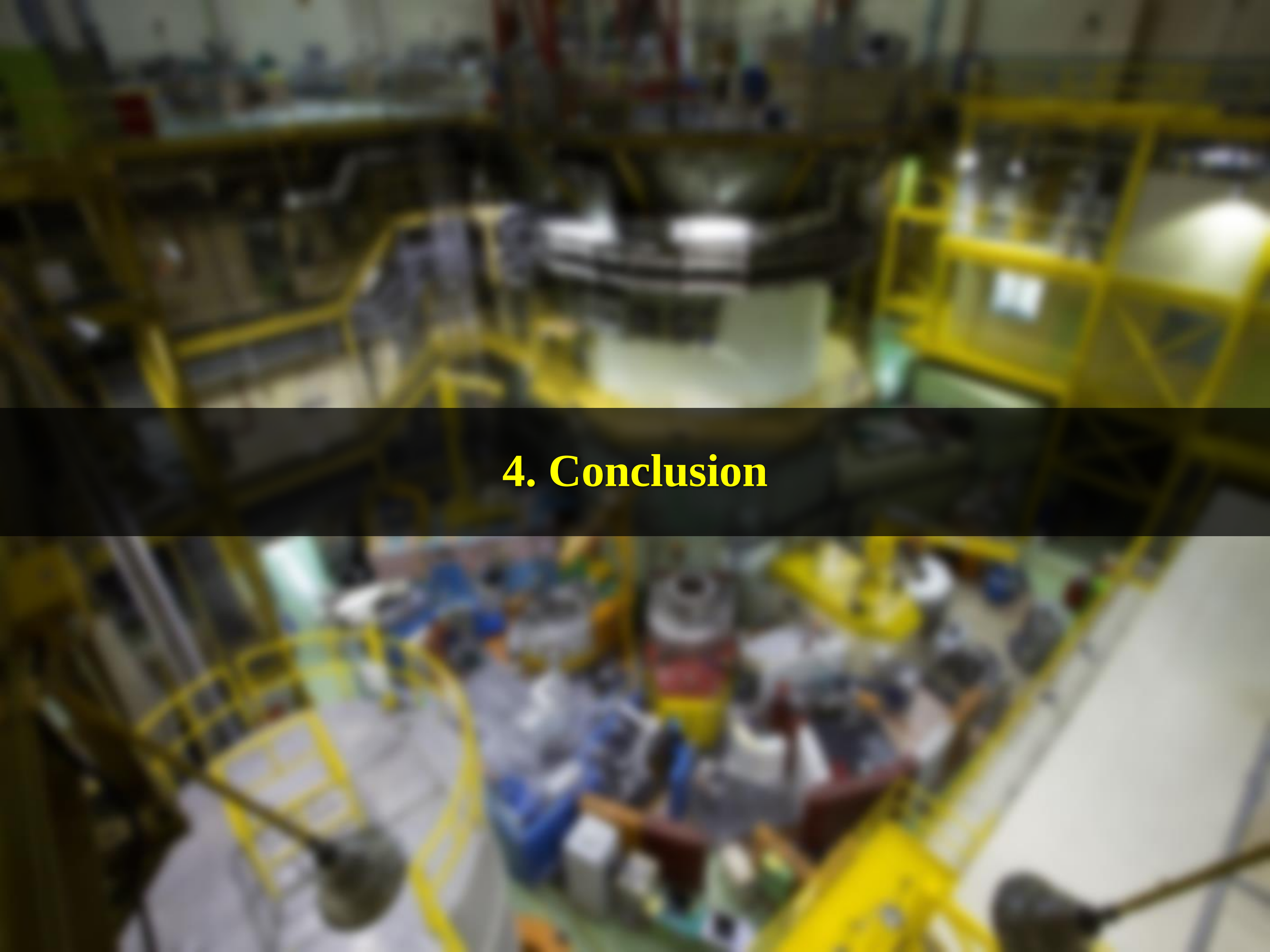
❍ Install the built-up section on the wall by using through bolt

- The built-up sections were lifted using a crane and integrated on the through-bolt installed at the wall of the reactor building. The built-up sections were connected with each other by tightening high strength bolts using an electric impact wrench. A specific torque was applied to the connecting bolts and the full inspection was fulfilled to check it using a torque wrench.
- Finally, an epoxy was injected into the gap between the baseplate of the built-up sections and the wall of reactor building, which works as a filler and also helps with airtightness.

Crane lifting the built-up section to install with through bolt at the wall

Workers are tightening the high-tension bolt with regulated torque.



4. Conclusion

Conclusion

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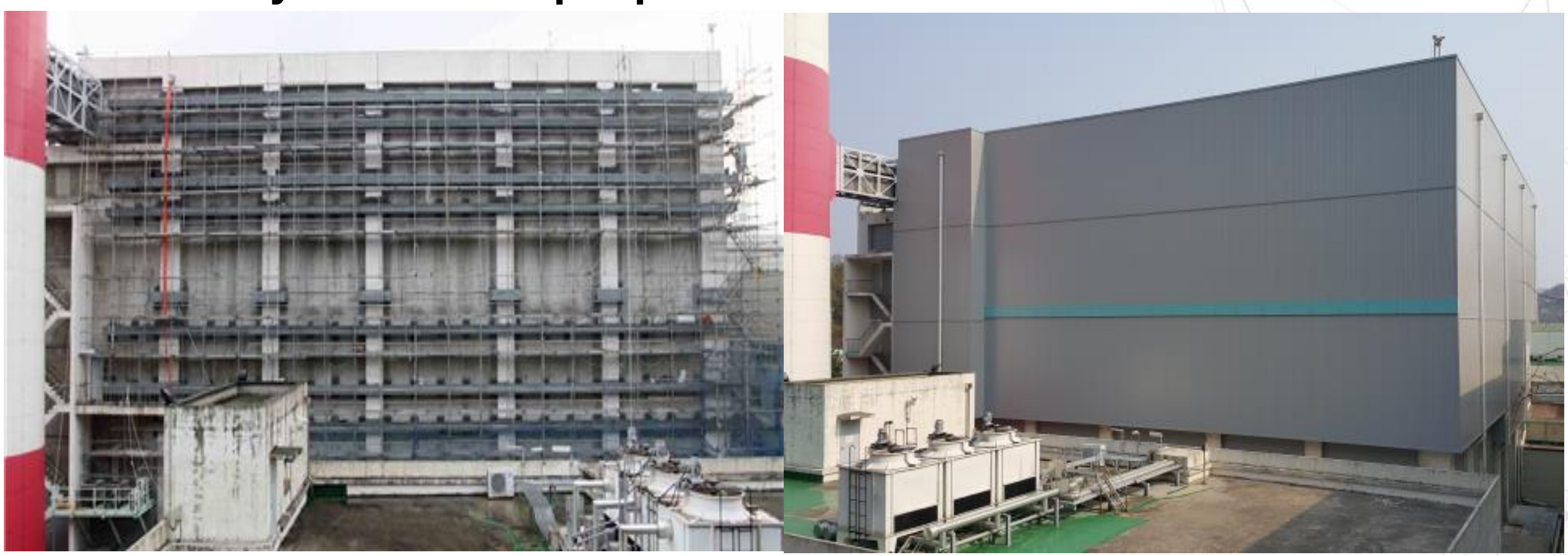
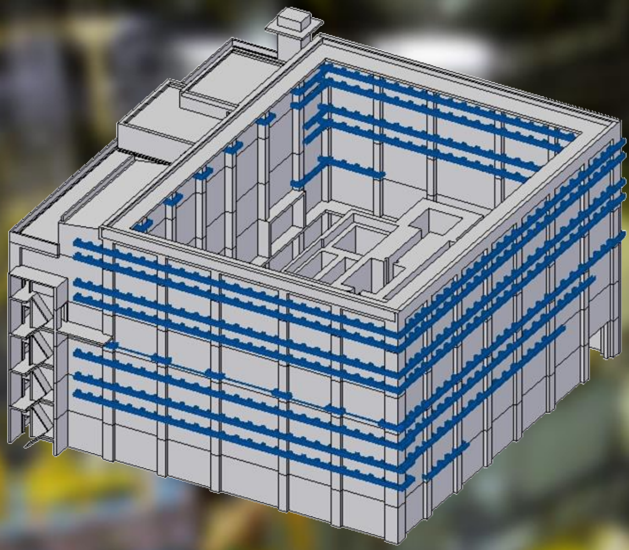
- ❍ **KAERI will re-operate HANARO with the regulatory authority's approval.**
  - An extensive leak test was successfully conducted for the whole reactor building and the result was satisfied with the design criteria.
  - KAERI will also welcome additional verification by a citizen's verification team that will be organized by the local government. It is expected that the citizen's additional verification will eventually exhibit the improved safety of HANARO.
- ❍ **With the completion of the HANARO safety reinforcement and rehabilitation project, KAERI truly hopes that it will once again clearly demonstrate its unsparing effort to secure safety for the country and for the people.**



Rehabilitation project finished (Left : on installing procedure, Right : finishing with insulation panel)



Thanks for your attention!

HANARO Together!