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

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Abstract. Right after the Fukushima accident in 2011, KAERI immediately carried out necessary safety reconfirmation program in accordance with the government's safety reassurance policy. The Nuclear Safety and Security Commission (NSSC) of the Korean government formed a special nuclear safety inspection team with the participation of civilian experts. The team initiated an overall safety checkup program for all major nuclear facilities in the country including KAERI's HANARO. As a result of the safety mission, the NSSC requested KAERI to reassess the seismic qualification of the HANARO with particular emphasis on the reactor building and the stack.[1] The NSSC also recommended KAERI to develop necessary seismic reinforcement measures in order to reassure the safety of HANARO. The NSSC therefore, strongly recommended KAERI to reinforce an outer wall of the reactor building to protect the Reactor Concrete Island (RCI) more effectively from possible seismic issues. This paper is to report the completion of HANARO reactor building reinforcement project that began in 2015 as part of the HANARO safety reinforcing endeavors.

1. Introduction

The HANARO is the nation's largest research reactor in operation and it boasts its highly advanced technical features. The HANARO is also proud of the fact that it has been constructed totally by indigenous local technologies and it now ranks within the 10 top research reactors in the world. It is noted that the HANARO construction was a 10 year national project that began from 1985. At present, the HANARO is extensively used for neutron beam science, development of reactor materials and nuclear fuels, research and production of medical and industrial radioisotopes, production of high quality semi-conductors by neutron transmutation doping techniques, neutron activation analysis of trace elements and so on.

Not to mention, ensuring safety is always KAERI's top priority in HANARO operation. We believe the reinforcement is important, because it is directly related with the safety of the facility, and preventing harm to our employees and users, local communities and the environment. This paper summarizes the HANARO reactor building reinforcement project.

1.1 Structural Characteristics

HANARO reactor building is a box type reinforced-concrete structure and the roof of its reactor hall area is made from steel trusses. In the design stage of reactor building, it was seismically designed based on the design earthquake SSE 0.2g (horizontal).[2]

The height of reactor building is totally 33 m (depth 7 m, height 26 m) and its width and length is 43 x 43 m. Basement slab is 45 x 44.2 m and depth is 1~2 m. The wall thickness is 60 cm at underground and 40 cm at above ground level. *(see FIG.1.)*

Reactor building consists of reactor hall area (43 x 32.6 x 31 m) and service area (43 x 10.4 x 27 m). Service area is in the east side of the building.

In the outer wall of reactor hall, 1/2 of south side of outer wall and 1/4 of west side of outer wall is connected with RCI (Reactor Concrete Island) concrete structure. North side of outer wall is just connected with west wall and service area.

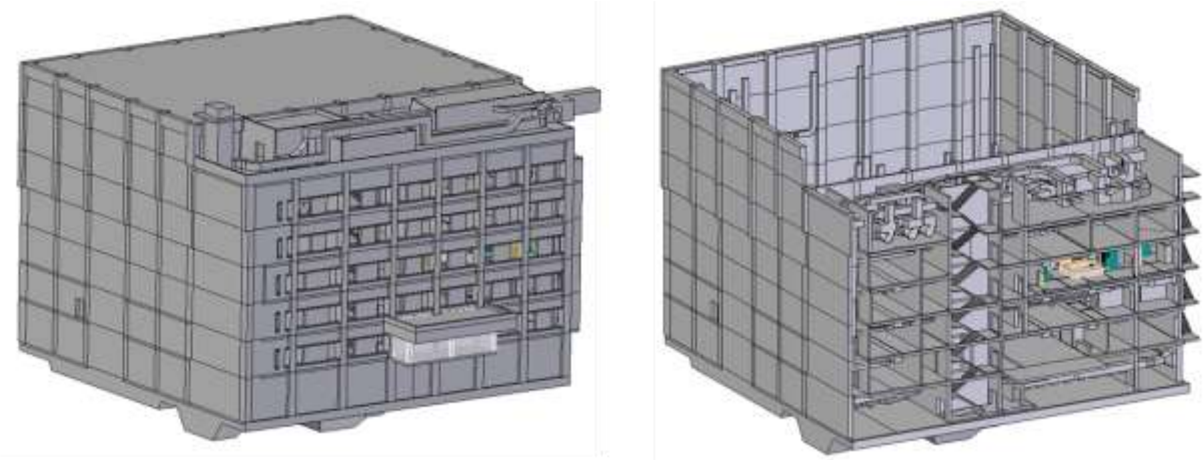

FIG. 1. Shape of Reactor building (left: exterior, right: without roof trusses)

1.2 Locational Features

Reactor building is located at reactor facility complex in KAERI site. *(see FIG.2.)* In the south side of reactor building, there is RIPF (Radio Isotope Product Facility) building and IMEF (Irradiated Material Examine Facility) building. And the CNL (Cold Neutron Laboratory) building is located at the west side of reactor building. Spaces between the reactor building and adjacent buildings are particularly narrow. The maximum space with adjacent buildings is 4.2 m at north side and there is a utility-pipe conduit at the underground.

FIG. 2. Bird-eye view of Reactor facility complex (right: North direction)

2. Seismic Assessment before Seismic Rehabilitation Project

HANARO performed a seismic margin assessment and it was a part of follow-up after the Fukushima Daiichi Accident. As a result, it was founded that the seismic margin of reactor building was partially insufficient (about 4.8% of outer wall area). HANARO decided to reinforce the reactor building to meet the design criteria.
As we mentioned above, HANARO has narrow spaces near the building and it makes hard to rehabilitate. We investigated many kinds of a reinforcing construction methods.

2.1 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)) had been applied. It is one of the official seismic assessment methods which have been authorized by US NRC.[3]

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 Richter scale 7.7 which was more than qualified. However, it was found out that some area of the outer wall of the reactor building did not meet the seismic design criteria. The findings were reported to the NSSC in December 2014 and the Commission requested KAERI to reinforce those areas identified as dissatisfaction in March 2015.

2.2 Design Concept of Seismic Rehabilitation Project

Based on the evaluation, KAERI immediately began the HANARO outer wall reinforcement project. Fig. 3 shows the reinforcement concept. *(see FIG.3.)* Steel H-beams were used to support the reactor building both inside and outside. It was designed that the H-beams will share the seismic impact applied on outer wall of the reactor building. It was confirmed that the reinforcement concept will be effective based on the in-depth analysis as well as real scale test. Through the seismic reinforcement, both the axial and flexural strengths were greatly improved. Meanwhile, PS tendon was used for some part of the outer wall of the reactor building in order to improve specific seismic performance. The PS tendon is lighter than retrofit steel used at built-up sections but stronger.[4]

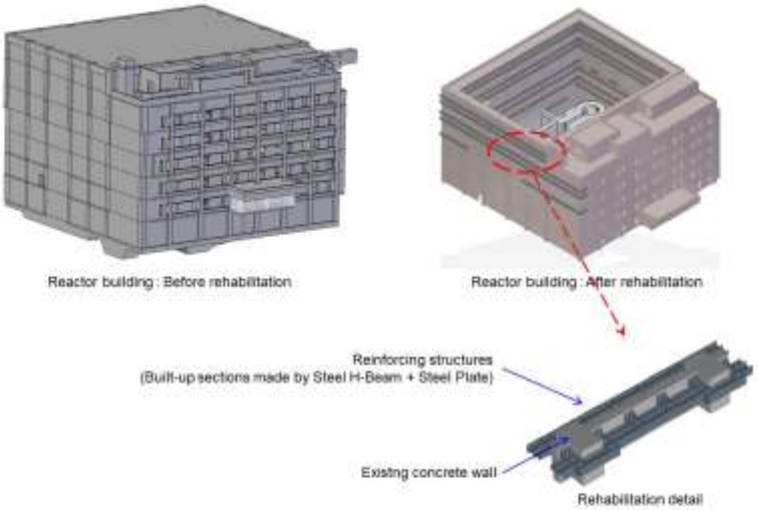

FIG. 3. Reinforcing Design Concept of Reactor Building

3. Seismic Rehabilitation Project

After finalizing the reinforcement design, KAERI submitted the design changes to Commission. KINS (Korea Institute of Nuclear Safety, TSO of NSSC) technically checked the design changes and asked KAERI questions about the reinforcing design concept. KINS also requested a verification test about reinforcing design. KAERI answered a series of questions and proceeded with the test. As the result, KAERI got the construction approval.

3.1 Structural Performance Verification Test

In approval process, KINS requested a structural performance verification test to confirm the reinforcing effect of built-up section in concrete outer wall. *(see FIG.4.)*

To check the reinforcing effect of built-up section, KAERI made 2 samples for the test. One was in original condition and the other was reinforced with built-up section. A part of the real wall was made as the sample at 1:1 scale, of which size was 6.2 x 2.45 x 3.0 m.

Static loading was given to check the reinforcing effect. *(see FIG.5~6.)* Test criteria was determined from the result of maximum value through an analysis of the whole reinforcing 3D-FE model.

The test result showed that the static loading capacity of the reinforced specimen was stronger than the one in original condition. The built-up section showed that the increase of structural strength capacity.

We tried to check the ultimate strength of reinforced specimen. But it was impossible to check. Its strength was too high to test with a prepared loading machine. It exceeded its expected yielding strength and it was hard to exactly expect the failure.

FIG. 4. Relocate the test specimen (original condition)

FIG. 5. Static loading test (original condition)

FIG. 6. Static loading test (reinforcing with built-up section)

3.2 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. *(see FIG.7.)* If rebar existed in the installation position, the installation position was changed for maintaining the existing rebar.

FIG. 7. Rebar scanning to avoid cutting existing rebar

Drilling the outer wall by using core drill: To hang built-up sections on the wall, through-bolt was used *(see FIG. 8 (b).)*. And to locate the through-bolt through the wall, we made holes using core drill machine at the installation points. *(see FIG. 8 (a).)*
HANARO building adopted a confinement concept for the reactor hall, which isolates the air, but allows the small leakage. To keep its own function in 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.
Also, to check the cutting of the existing rebar, we carried out the total inspection about core remainder (*see FIG.8(c)).* In case unexpected rebar cutting is detected, we stopped drilling and check the design calculation. If the design margin was sufficient, we made the report with 'use as is'. And if not, we did the additional reinforcement.

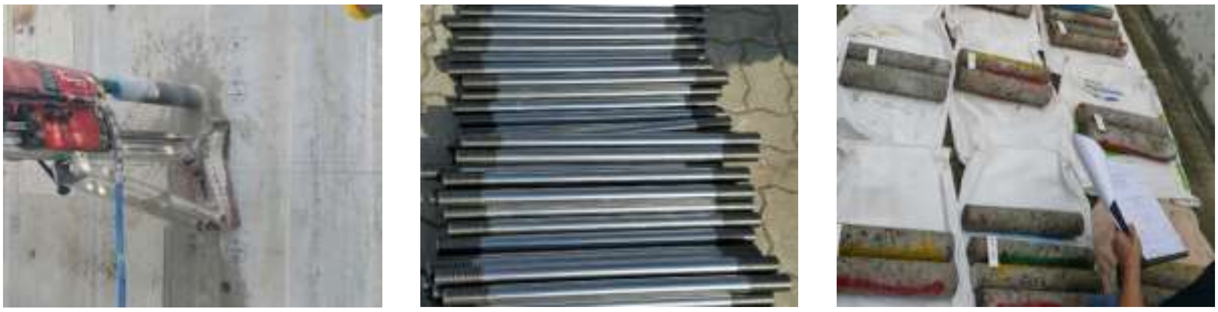
(a) *(b)* *(c)*

FIG. 8. (a): Drilling the outer wall by using core-drill (b): Through bolt
(c): Check the core remainder procedure

Locate the through-bolt in the core hole and put the non-shrink grout in the core hole: Non-shrink grout is a special construction material for its high strength and fast curing. It is used for emergency repair in damaged infrastructure. It was very useful and has many strong points. But we should take care of its feature when use this material.
In the construction field, it was generally recommended that non-shrink grout should have its own thickness to keep the structural strength. And the recommended thickness is about 1 in. (2.54 cm). To keep this advice, we set up the size of hole (Ø=89 mm) and through bolt diameter (Ø=36 mm).
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. *(see FIG.9.)*
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 the leak test box and attached the box at the inspection point. *(see FIG.10.)* After that, we made a -0.5 bar vacuum condition inside the box and checked if it is maintained over the 20 seconds at the inspection position. The result showed that all holes are filled with non-shrink grout well and have airtightness.

FIG. 9. Inject non-shrink grout into hole to fix the through bolt in the hole.

FIG. 10. Leak test box

Install the built-up section on the wall by using through bolt: The built-up sections were lifted by using a crane and integrated on the through-bolt installed at the wall of the reactor building. *(see FIG.11.)* A snug tightening was applied when connecting the built-up sections with through-bolts according to the design concept. 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. *(see FIG.12.)*

Finally, an epoxy was injected into the gap between the baseplate of built-up sections and the wall of reactor building, which works as a filler and also helps airtightness.

FIG. 11. Crane is lifting the built-up section to install with through bolt at the wall

FIG. 12. Workers are tightening the high-tension bolt with regulated torque.

4. Conclusion

KAERI will re-operate the HANARO with the regulatory authority's approval. An extensive leak test has been successfully done for the whole reactor building and the result was satisfied with the design criteria. KAERI will also welcome additional verification by 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 the 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.

5. References

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