Safety Reassessments and Actions Taken in HANARO since Fukushima Daiichi Accident

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Special Safety review of HANARO

A special safety review of HANARO

- Nuclear facilities in Korea were taken a special safety inspection after FDA by government, regulatory body and civilian experts
  - Nuclear power plants
  - HANARO research reactor
  - Nuclear fuel fabrication facility

- Safety review of HANARO taking into account the following events
  - Flooding
  - Earthquake
  - Fire
  - Station blackout

Recommendations from the review (1)

- Reassessment of the seismic capability of reactor building and stack
  - Review and reevaluation of the design basis earthquake
  - Reassessment of the seismic capability reflecting modification and design change during operation
    - Identifying vulnerable points and planning remediation actions
  - Evaluation of margin
    - Seismic margin assessment
    - Range of earthquake severity the plant can withstand with losing confinement integrity
    - Provisions to prevent the cliff edge effect and to increase robustness of the plant

Recommendations from the review (2)

- Implementation of protective measures for reactor operators in main control room at seismic events
  - Fix the console and operation desk
  - Seismic strengthening of lighting fixture for prevention of dropping
  - Fix all furniture for prevention of sliding

Recommendations from the review (3)

- Reassessment of inundation depth
  - Evaluation of PMP(Probable Maximum Precipitation)
  - Evaluation PMF(Probable Maximum Flood) reflecting PMP
    - Earthquake is considered, but tsunami is not taken into account
  - Evaluation of the margins
    - Evaluation of flood level and inundation depth

Recommendations from the review (4)

- Revision of emergency plan and emergency preparedness program
  - Review the effectiveness of emergency preparedness program

Reassessment of seismic capability of reactor building and stack

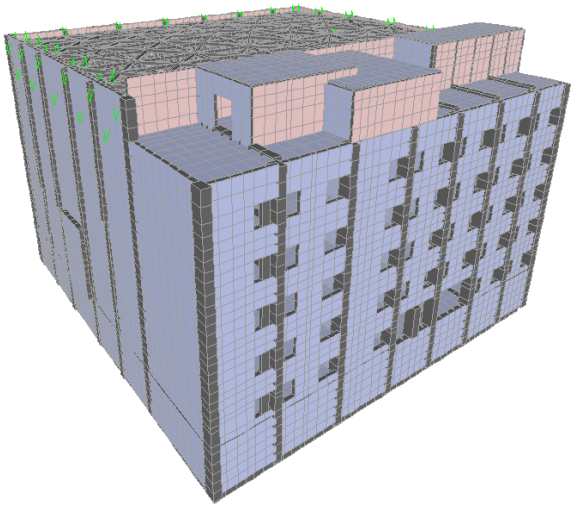
HANARO reactor building and stack

- Reactor building and Stack
  - Reactor building protects SSCs important to safety and is confinement against release of radioactive material
  - Stack is for the ventilation of the reactor building, RI building, and IMEF building
  - Safe Shutdown Earthquake(SSE) acceleration is 0.2g in horizontal direction
  - Need to reassess the reactor building and stack on design basis earthquake, and beyond design basis earthquake

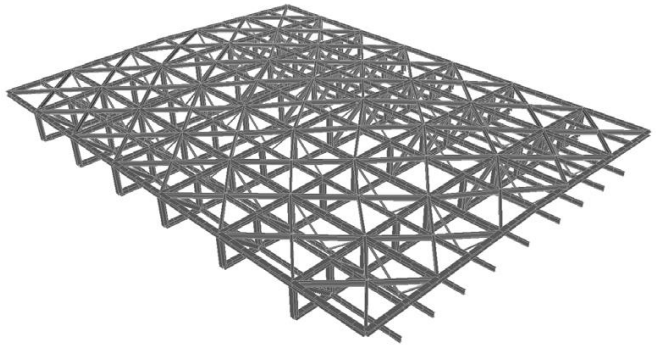
	Safety class	Seismic category	Quality class
Reactor building	**NA**	**I**	**Q**
Stack	**NA**	**II**	**T**

Seismic Margin Assessment

- EPRI-NP-6041-SLA : Methodology for Assessment of Nuclear Power Plant Seismic Margin (Rev. 1)
- The Seismic Margin Earthquake (SME) for SMA set to PGA 0.3g in horizontal direction
- 3D shell and beam model for a finite element analysis using SAP2000.



Reactor building

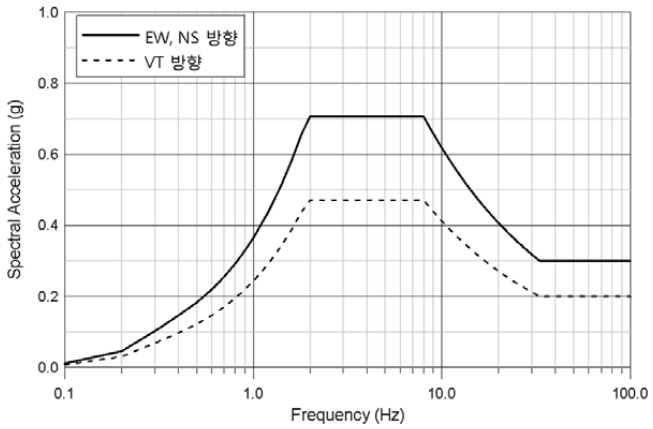


Roof Truss

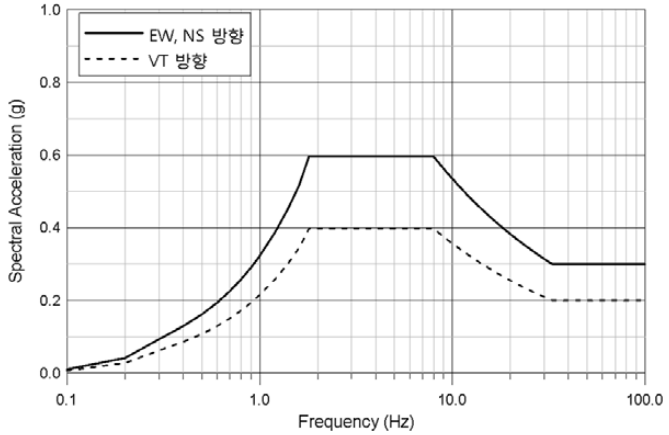
Exhaust Stack

Response Spectrum Analysis

- Mode shapes and natural frequencies of 3D model of the reactor building determined through a modal analysis
- NUREG/CR-0098 : Development of Criteria for Seismic Review of Selected Nuclear Power Plants
- Member forces under seismic loads were calculated through a response spectrum analysis



7% damping ratio



10% damping ratio

Ground response spectrum for SMA (PGA 0.3g)

The result of SMA

- Evaluated seismic capability
  - Reactor Concrete Island (RCI) : 1.71 g
  - Exhaust Stack: 0.57g
  - Outer wall of the reactor building
    - **4.8% of the reactor building wall didn't satisfy 0.2g(Safe shutdown earthquake)**

- Difference between the original design and the SMA
  - Beam-stick model for the original design
  - 3D detailed model for the SMA
  - Out of plane behavior of the building wall in horizontal direction was reevaluated.

Exhaust Stack

Measures for the SMA result

- The reactor building has safely been maintained for over 20 years without any concerns.
- New findings were derived from the assessment based on the recent technologies
- The result of the SMA was reported to the regulatory body (NSSC) on 19th Dec. 2014.
- NSSC officially ordered KAERI to reinforce the reactor building wall that didn’t satisfy the seismic requirements on 19th Mar. 2015.

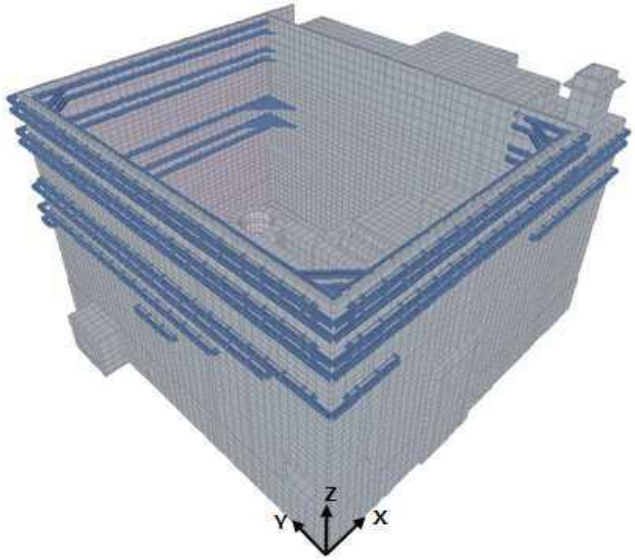
Design of the seismic reinforcement (1)

- A lot of building structures and reactor-related systems are complicatedly interconnected around and adjacent to the HANARO building
- A special task force team surveyed every possible reinforcement methods
- Steel H-beams and PS tendon were adopted for the reinforcement design
- H-beams can effectively reduce the bending moments that can be induced on the wall of the reactor building under seismic loads.
- PS tendon was used for some part of the wall of the reactor building to control the in-plane tensile stress

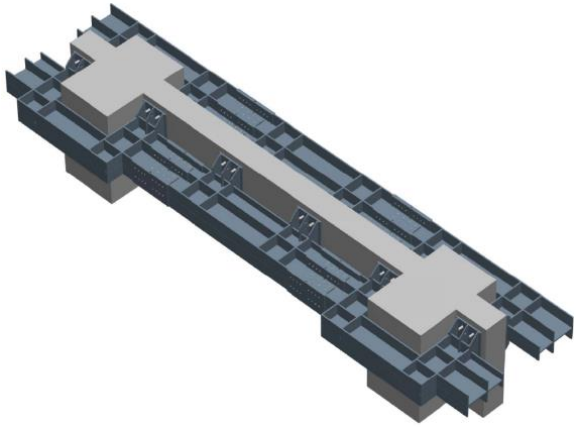
Exhaust Stack

Design of the seismic reinforcement (2)

- It was confirmed that the reinforcement concept would be effective based on a dynamic analysis as well as a real scale static test
- The reinforcement concept not only satisfy the required seismic criteria, but also have enough margins to withstand beyond design basis earthquake (PGA 0.3g).



Reinforced reactor building



Reinforcement concept

Implementation of the reinforcement of the reactor building (1)

- Installation of protection covers for the service pool and spent fuel storage pool
- Installation of scaffolds and safety nets
- Removal of interfering fixtures on the wall
- Measuring the level and coordinates of the wall
- Scanning the positions of re-bars inside the concrete walls
- Drilling the wall to make through-bolt holes
- Installation of through-bolts(filling with non-shrink grout)
- Attaching steel H-beams on the wall using through-bolts
- Reinstallation of detached fixtures
- Installation of exterior finish materials
- Dismantling scaffolds and safety nets
- Removal of protection covers for the pools

Implementation of the reinforcement of the reactor building (2)

Exterior wall

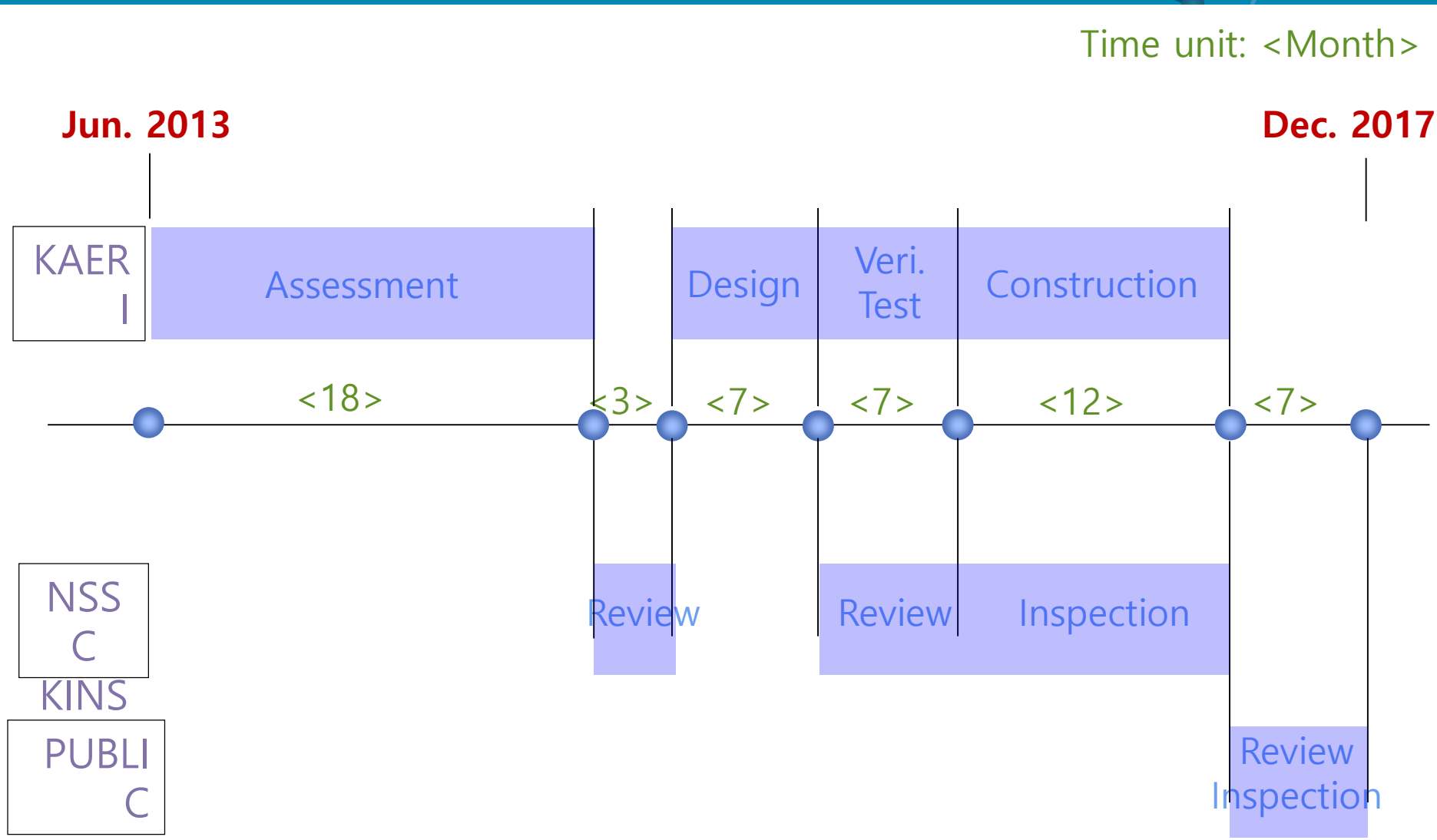
Exterior finish

Implementation of the reinforcement of the reactor building (3)

Interior wall

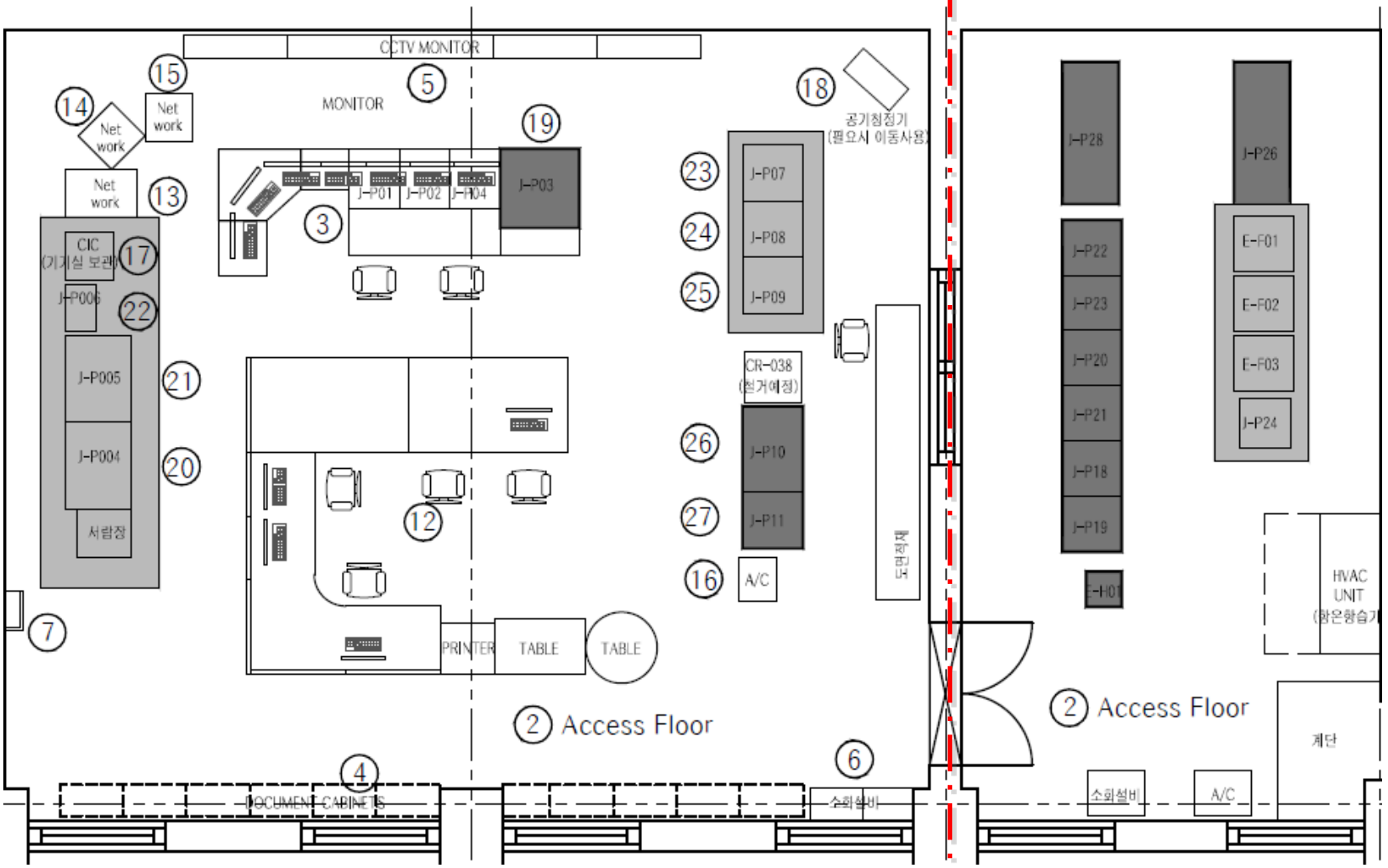
Interior reinforcement

Brief history of the seismic reinforcement



Implementation of protective measures for reactor operators in main control room

Layout of main control room



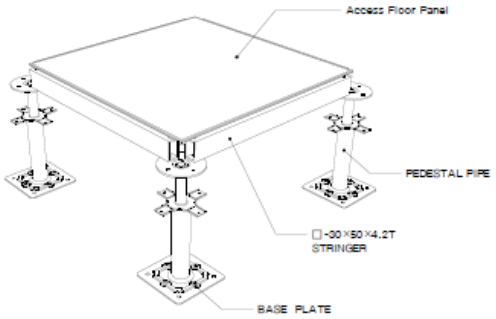
Review of items to be seismically considered

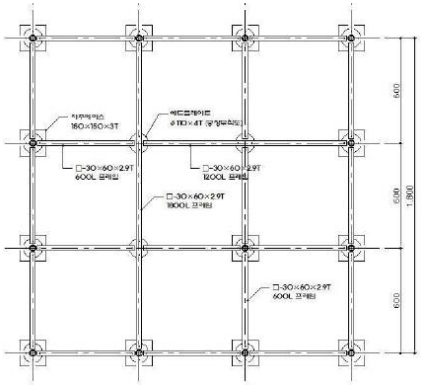
To be reinforced or replaced	Movable to instrument room	Seismically installed
Access Floor	OWS Rack	Main control desk
Console desk	CCTV Rack	RPS Panel A
Wall cabinet	RMS Rack	RPS Panel B
Surveillance Monitor	CIC	RPS Panel C
Fire extinguisher cabinet	Air Conditioner	Utility Panel
Lighting fixture		RRS Panel
		FTL Control Panel 1
		FTL Control Panel 2
		FTL Indicator Panel

Seismic design and analysis (1)

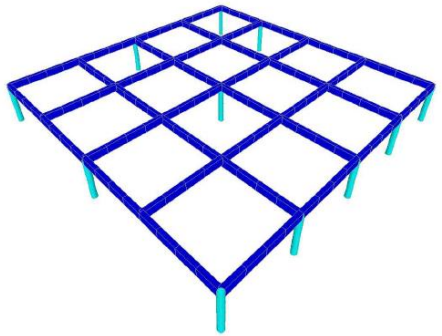
Access floor

Design

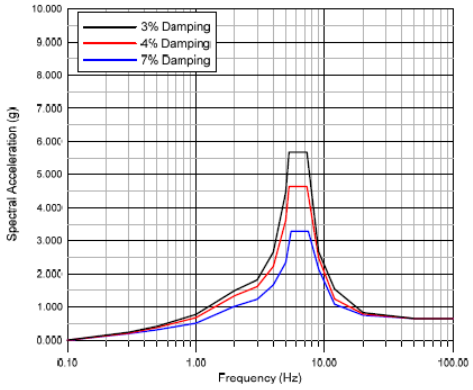




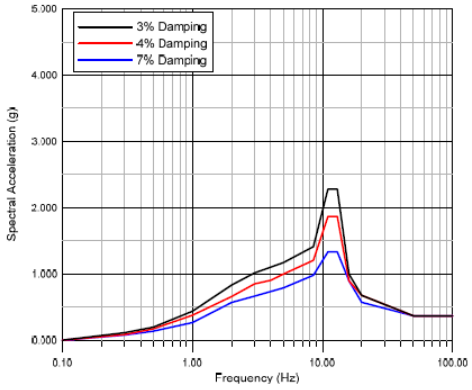
Modeling



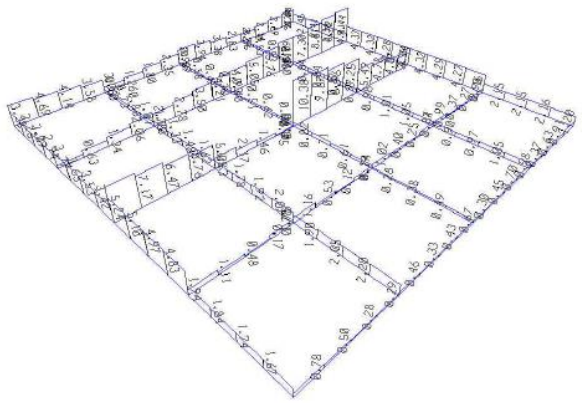
Seismic analysis(PGA 0.3g)



(a) 수평방향



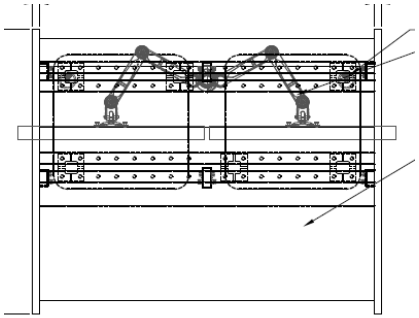
(b) 수직방향

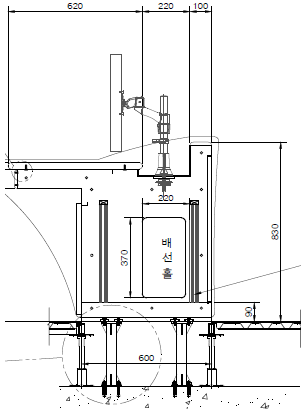


Seismic design and analysis (2)

Console desk

Design





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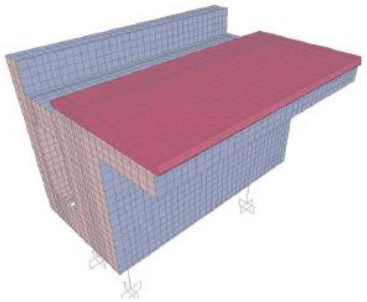

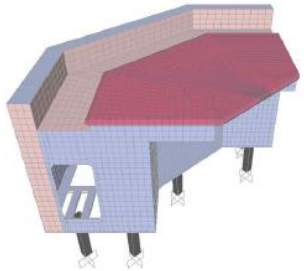

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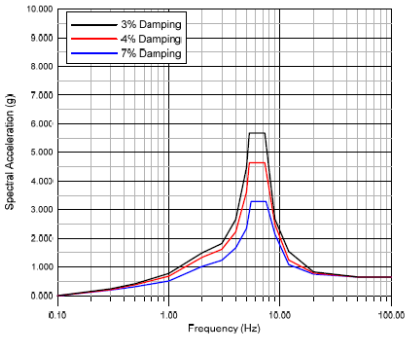

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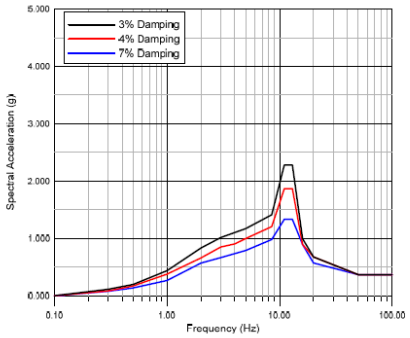
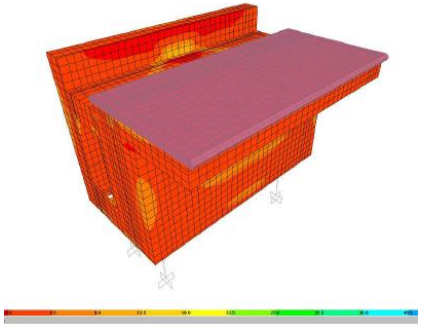
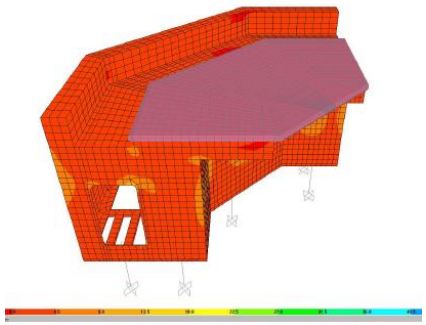


(b) 수직방향

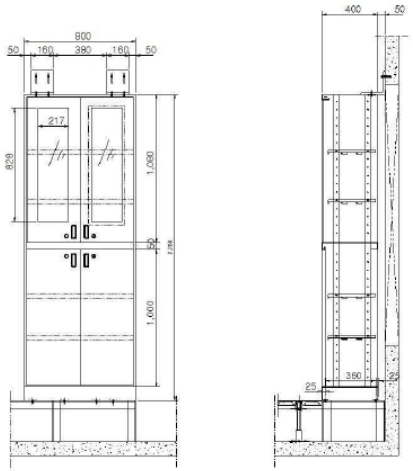




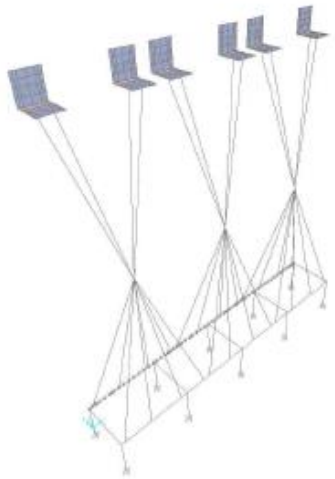
Seismic design and analysis (3)

Wall cabinet

Design



Modeling



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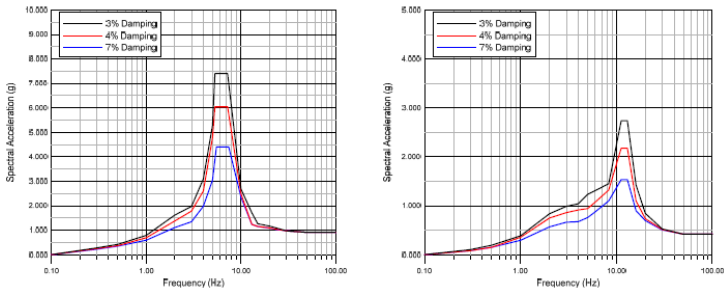
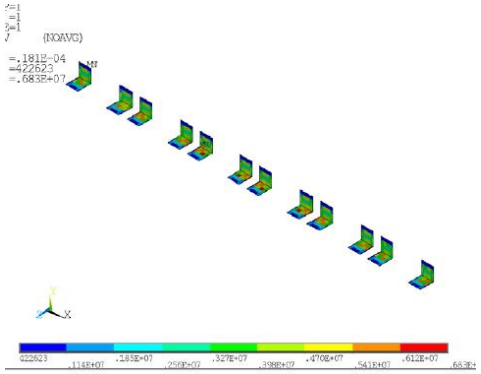
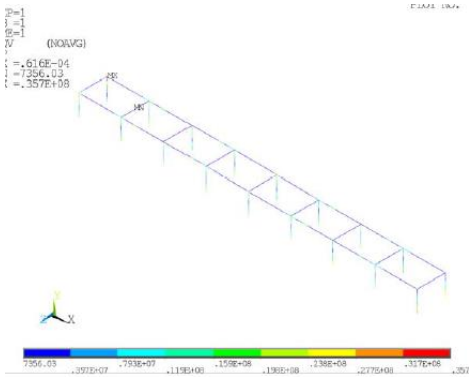


<그림 1.4> 내진보강 설계용 제어실 상부(천정) 층응답스펙트럼 (PGA 0.3g)

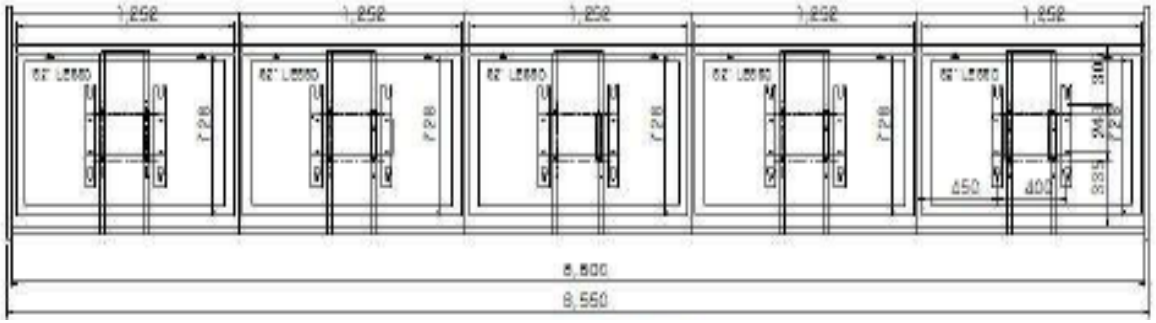


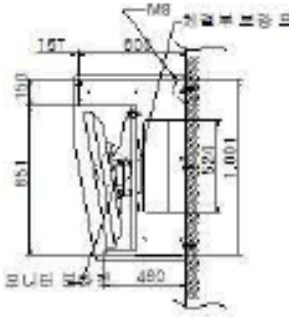


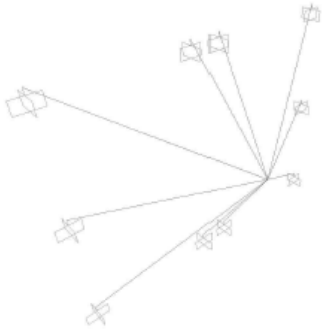
Seismic design and analysis (4)

- **Surveillance monitor**

  Design and Seismic analysis (PGA 0.3g)

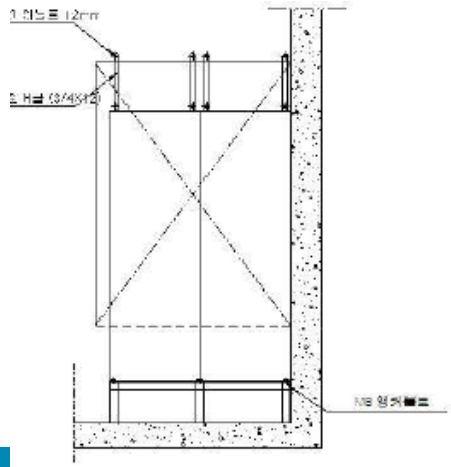


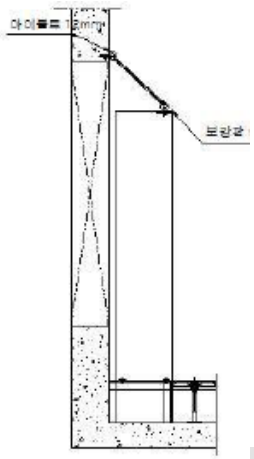


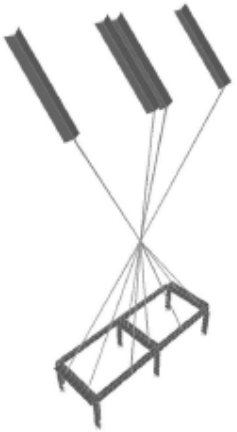


- **Fire extinguisher cabinet**

  Design and Seismic analysis (PGA 0.3g)



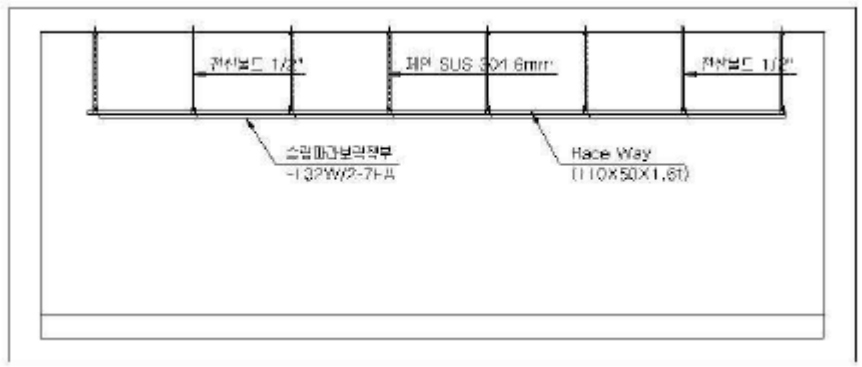




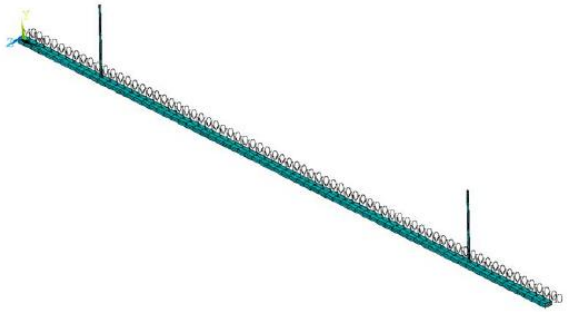
Seismic design and analysis (5)

- **Lighting fixture**

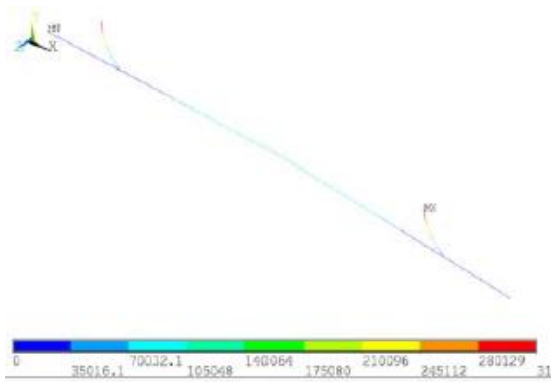
Design

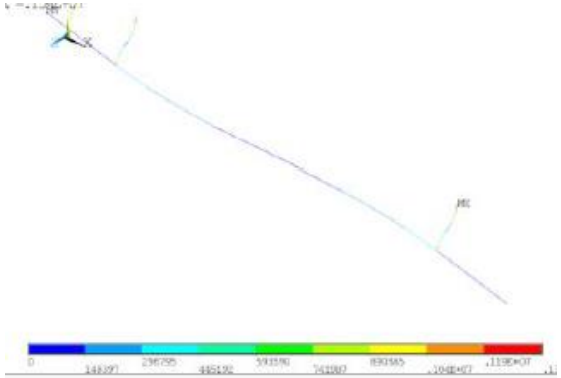


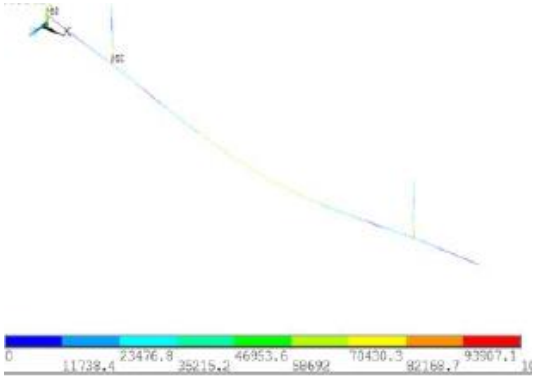
Modeling



Seismic analysis(PGA 0.3g)







Implementation of the reinforcement (1)

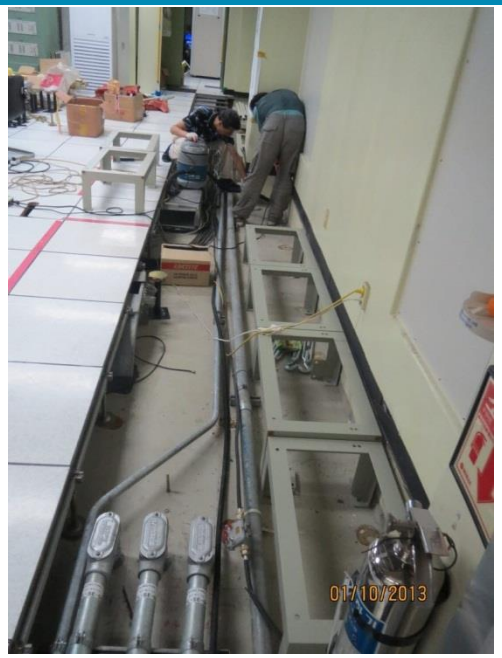
- **Console desk**

Implementation of the reinforcement (2)

- **Access floor**

Implementation of the reinforcement (3)

- **Wall cabinet**



Implementation of the reinforcement (4)

- **Surveillance monitor**

Implementation of the reinforcement (5)

- **Fire extinguisher cabinet**

Implementation of the reinforcement (6)

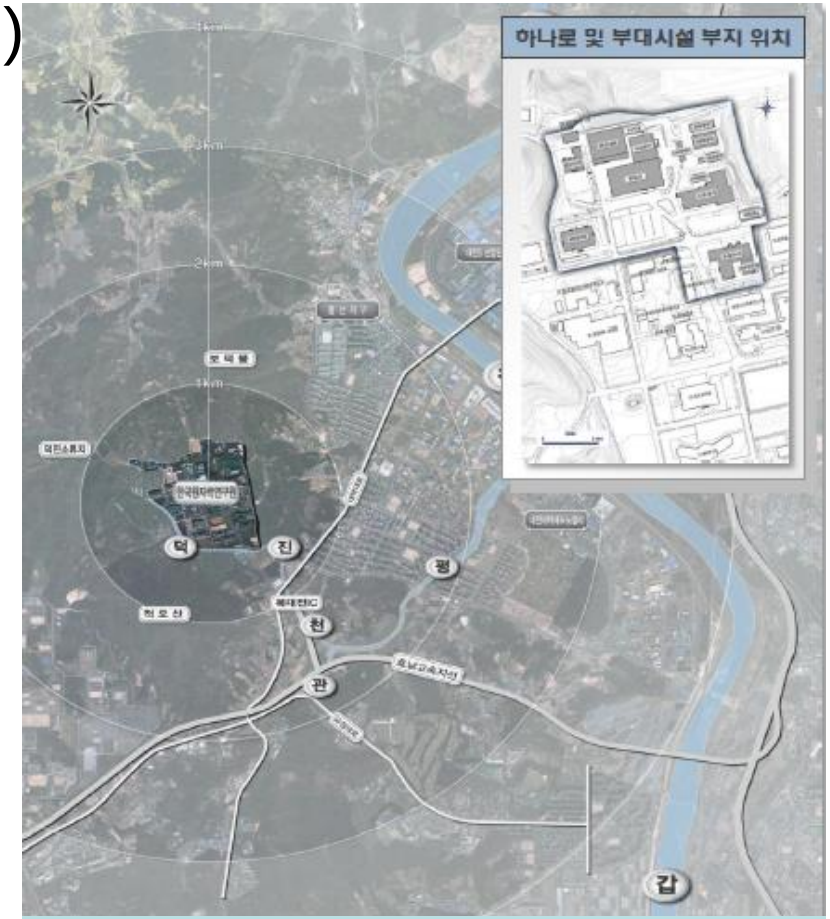
- **Lighting fixture**

Main Control Room in HANARO

Reassessment of inundation depth

Purpose

- Evaluation of flood level and inundation depth of HANARO site when PMP (Probable Maximum Precipitation)



Location of HANARO site

Procedure

- Investigation of the site considering hydrometeorology
  - Site location
  - Historical records of temperature, humidity, wind velocity, and precipitation
  - Geometry, altitude, and inclination of the river
  - Drain system of the site
- Evaluation of PMP(Probable Maximum Precipitation)
- Evaluation PMF(Probable Maximum Flood) reflecting PMP
- Evaluation of the margins
  - Flood level and inundation depth

Evaluation of PMP(Probable Maximum Precipitation)

Evaluation of PMP

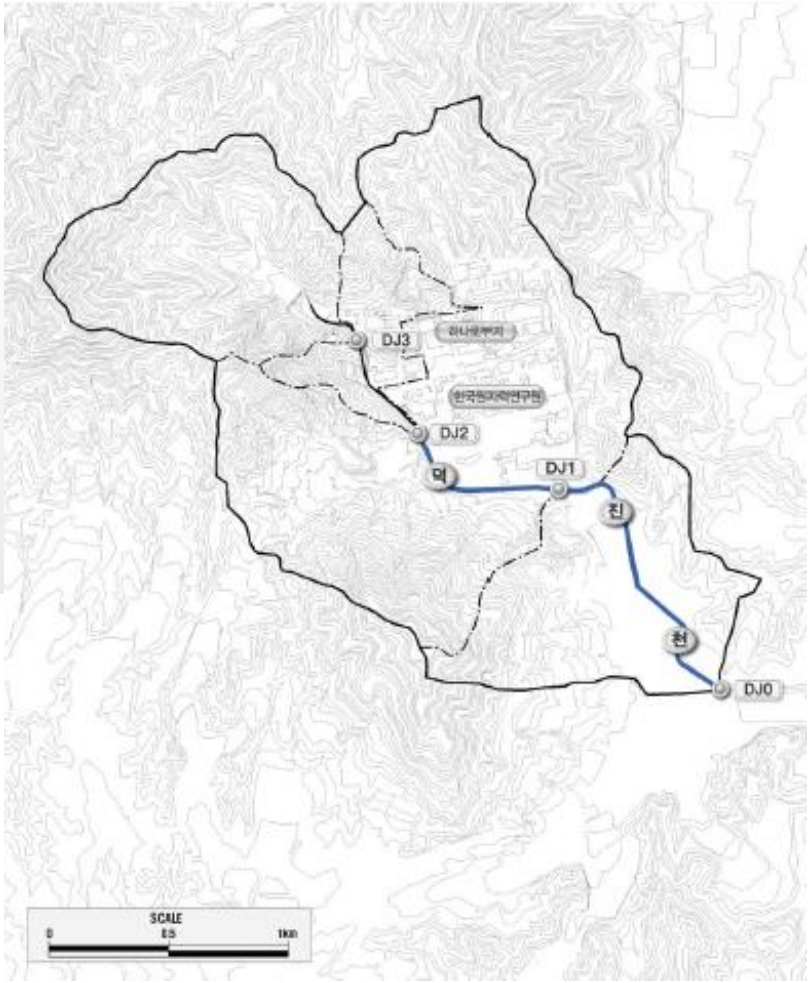
(Unit:mm)

Method	1hr	2hr	4hr	6hr	8hr	12hr	18hr	24hr	48hr	72hr
Hydrometeorology #1	138	242	421	524	605	722	1,007	1,099	1,141	1,136
Hydrometeorology #2	158	226	363	490	602	781	954	1,050	1,146	1,151
PMP Map #1	156	233	348	462	534	677	779	881	992	1,016
PMP Map #2	156	231	354	455	538	665	793	873	993	1,016

Evaluation PMF(Probable Maximum Flood) reflecting PMP

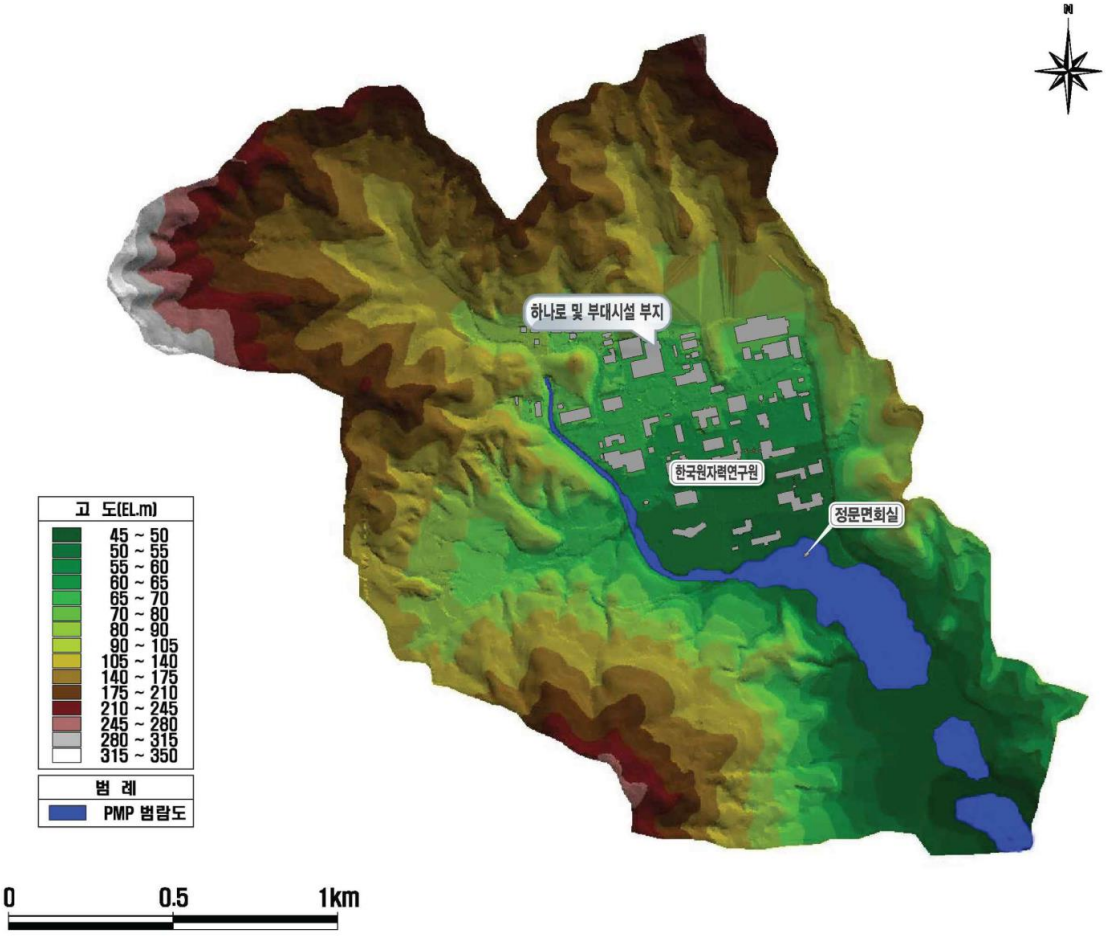
- Evaluation of PMF by Clark watershed routing method

산정 지점	빈도별 첨두홍수량 (㎥/s, 분)							
	20년	30년	50년	80년	100년	200년	500년	PMF
DJ0	62.73	69.01	77.13	84.53	88.04	98.99	113.56	212.69
DJ1	53.78	59.07	65.82	72.12	75.09	84.33	97.27	176.53
DJ2	16.15	17.99	20.32	22.48	23.51	26.72	31.18	60.98
DJ3	12.65	14.13	16.02	17.77	18.60	21.21	24.70	46.22



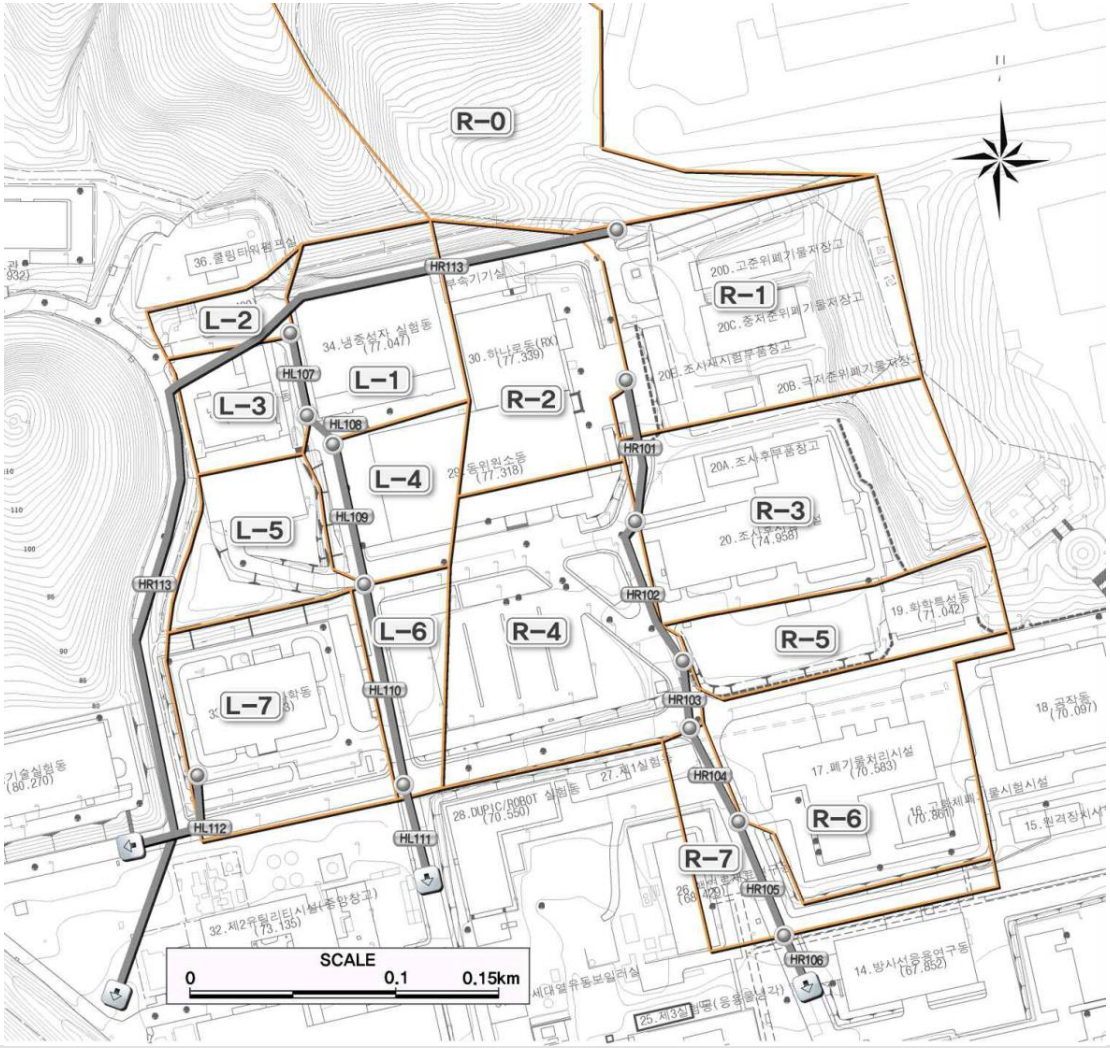
Assessment of inundation depth from external flooding

- The external flooding from the river doesn't affect HANARO site when PMP occurs.



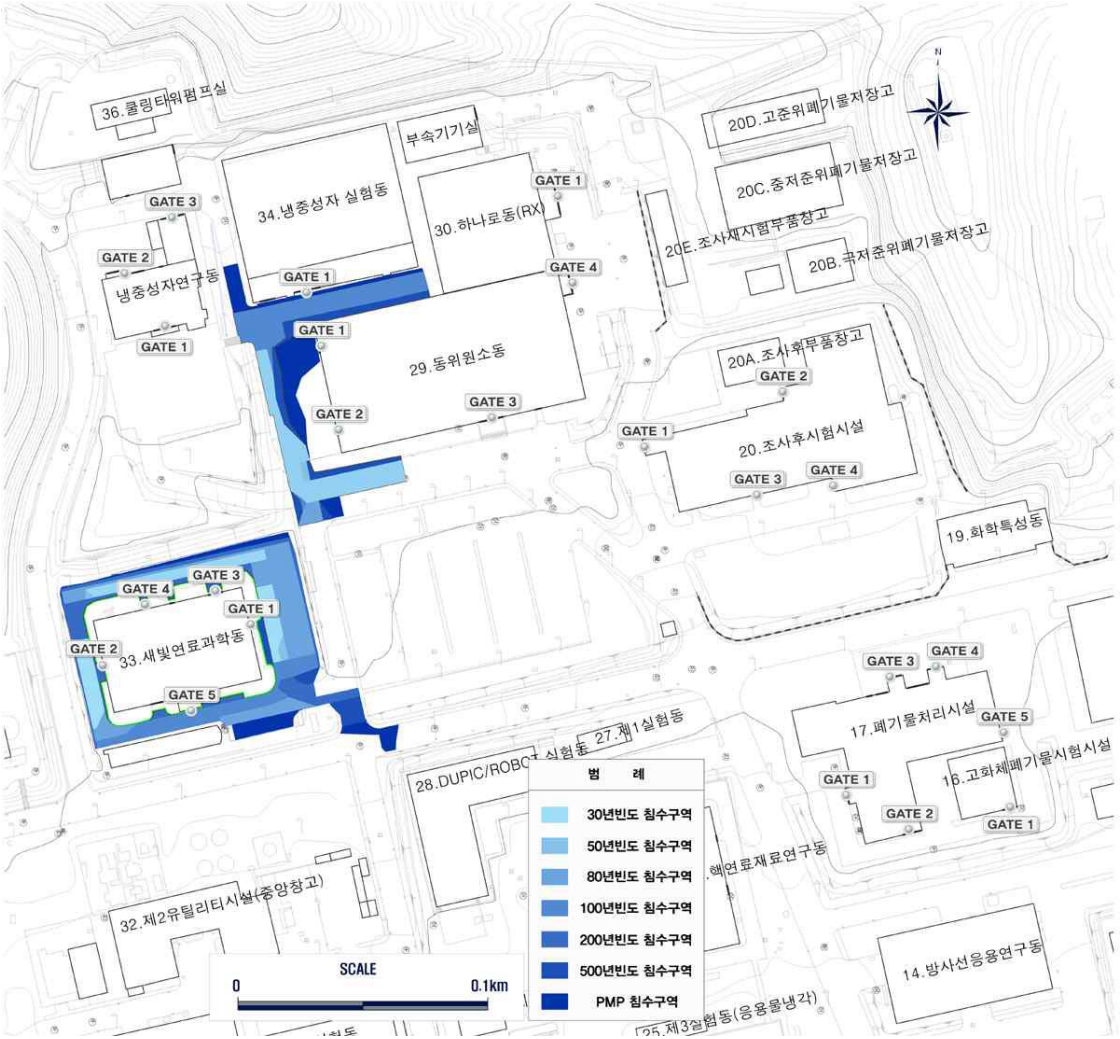
Assessment of inundation depth from internal flooding (1)

- Layout of drain pipes in HANARO site



Assessment of inundation depth from internal flooding (2)

- Inundation area of HANARO site when PMP occurs



Revision of emergency plan and emergency preparedness program

Revision of emergency plan and emergency preparedness program

- Considered simultaneous occurrence of emergency in KAERI nuclear facilities due to a natural event.
- The procedures related to teaming and the operation procedures of emergency response facilities were amended
- Public request to enlarge the EPZ boundaries of nuclear facilities was reflected in the National Law
- EPZ boundaries of HANARO changed from 800m to 1,500m in radius from the reactor.

Conclusions

- KAERI implemented all recommendations from the special safety review after the FDA.
- The seismic reassessment and the reinforcement of the HANARO reactor building were significant issues.
- The regulatory body has inspected the entire process of the reinforcement design and implementation.
- The citizen’s verification team has also inspected the results after the completion of the reinforcement.
- Finally, HANARO got the regulatory authority’s approval for the re-operation.


Thank you