*Transactions of the 17th International Conference on Structural Mechanics in Reactor Technology (*SMiRT 17)
Prague, Czech Republic, August 17 –22, 2003
Paper # O04-5

Structural Integrity Assessment of the HANARO Reactor Pool Cover

Jeong-Soo Ryu[1)], Yeong-Garp Cho[1)], Doo-Byung Yoon[1)], Jong-Sup Wu[1)] , Cheol Park[1)] and Byung-Jin Jun[1)]

1) HANARO Management Division, KAERI, Korea

ABSTRACT

The basic design of the reactor pool cover for increasing HANARO applications has been carried out for supporting the driving devices which can load, unload and rotate the irradiation targets in the in-core and out-core vertical irradiation holes under on-power operation. The comments of a HANARO user's group related with irradiation tests have been optimally considered in the process of the design. The interference between fuel handling and control absorber units in the reactor pool and activities to load, unload and rotate the irradiation targets at the top of the reactor pool have been minimized. The pool cover can be moved for maintenance and can protect the reactor pool from unexpected drop of foreign materials. It provides the space for vertical access of the driving devices for NTD, CT/IR and OR4/OR5 under on-power operation. And the pool cover assembly must maintain its structural integrity under seismic load. Based on the basic design concept, the HANARO pool cover has been newly proposed as a supporting structure of the driving devices for NTD, fission moly and RI production under on-power operation. To evaluate the structural integrity on the pool cover, ANSYS finite element analysis model is developed and the dynamic characteristics are analyzed. The seismic response spectrum analyses of the HANARO pool cover under the design floor response spectrum loads of OBE and SSE were performed. The analysis results show that the stress values for the seismic loads are within the ASME Code limits. It is also confirmed that the fatigue usage factor is less than 1.0. Therefore any damage of structural integrity is not expected when the HANARO pool cover is installed in the upper part of the reactor pool.

KEY WORDS: HANARO, reactor pool, pool cover, irradiation holes, on-power operation, structural integrity, finite element modeling, response spectrum analysis, floor response spectrum, combined stress ratio, fatigue usage factor

INTRODUCTION

HANARO(Hi-flux Advanced Neutron Application Reactor) is an open-tank-in-pool type research reactor with a thermal power of 30MW. Research and utilization areas of HANARO include four main subjects; radioisotope production, fuel and material irradiation test, neutron beam application, and neutron activation analysis. Figure 1 represents the top view of the experimental holes for irradiation. HANARO has several vertical irradiation holes, CT, IR, OR in the core region and NTD, CNS, LH, IP, in the reflector region. These irradiation holes are being utilized for the production of the radioisotopes and for the irradiation of the capsules that contain nuclear fuel or other materials for R&D needs.

In proportion to the increase of need for utilizing of the irradiation holes, additional installation of irradiation target handling devices, which can easily handle the irradiation target in the irradiation holes, have been required. The basic design of the reactor pool cover for increasing HANARO applications has been carried out for supporting the driving devices which can load, unload and rotate the irradiation targets in the core and the reflector vertical irradiation holes under on-power operation.[1-2] The comments of a HANARO user's group related with irradiation tests have been optimally considered in the process of the design. The interference between fuel handling and control absorber units in the reactor pool and activities to load, unload and rotate the irradiation targets at the top of the reactor pool have been minimized.

The reactor pool cover can be moved for maintenance and can protect the reactor pool from unexpected drop of foreign materials. The designed pool cover can provide the operator with working space for handling the irradiation targets in the vertical irradiation holes such as CT/IR, IP, and OR holes. In addition, it provides space for the installation of the NTD driving devices that can load and unload the irradiation targets in NTD holes under the on-power condition of the reactor.

The pool cover assembly must maintain its structural integrity under seismic load. Based on the basic design concept, the HANARO pool cover has been newly proposed as a supporting structure of the driving devices for NTD, fission moly and RI production under on-power operation. To evaluate the structural integrity on the pool cover, ANSYS finite element analysis model is developed and the dynamic characteristics are analyzed. The seismic response spectrum analyses of the HANARO pool cover under the design floor response spectrum loads of OBE and SSE were performed.[3-4] The analysis results show that the stress values in HANARO pool cover for the seismic loads are within the ASME Code limits. Therefore any damage of structural integrity is not expected when the HANARO pool cover is installed in the upper part of the reactor pool.

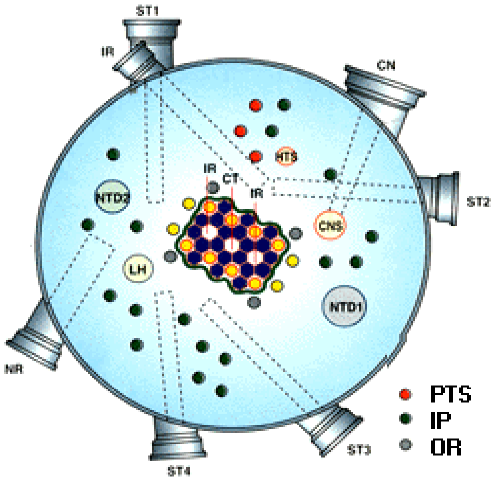


Figure 1 Experimental holes for HANARO irradiation (Top view)

DESIGN OF THE POOL COVER

Figure 2 represents the schematic of the newly designed pool cover assembly. In the design process of the pool cover, the review comments of a HANARO user's group have been fully considered. It consists of pool cover assemblies (PCA-A and PCA-B), sliding panels (SP-A, SP-B, and SP-C), and extension rails. To take sub-assembly of the pool cover up and down from the base, fixed boundary condition and connection parts have been designed with anchor bolts and stoppers. The outer boundary of the pool cover assembly PCA-A and PCA-B of semicircle-shape are fixed to the concrete foundation by three anchor bolts, respectively. It provides the space for vertical access of the driving devices for NTD, CT/IR and OR4/OR5 under on-power operation. And the pool cover assembly must maintain its structural integrity under seismic load.

For the neutron transmutation doping (NTD) of silicon, the NTD 1 and 2 driving devices, which can handle the silicon target in the NTD hole, are installed on the upside of the sliding panel SP-A. The sliding panels can slide on the extension rail in the north and south direction, as shown in Figure 3. In addition, the sliding panel SP-B and SP-C can be folded for maintenance and other works in the reactor pool. After the movement of the sliding panel toward the northern extension rail, the height of the pool cover assemblies PCA-A and PCA-B are limited within 100 mm to pass the HANARO man-bridge crane at the top of reactor pool. Fixing stoppers, frictional stoppers, locking pins and bolts are provided for preventing the movement of the sliding panel for normal operation and accidental events.

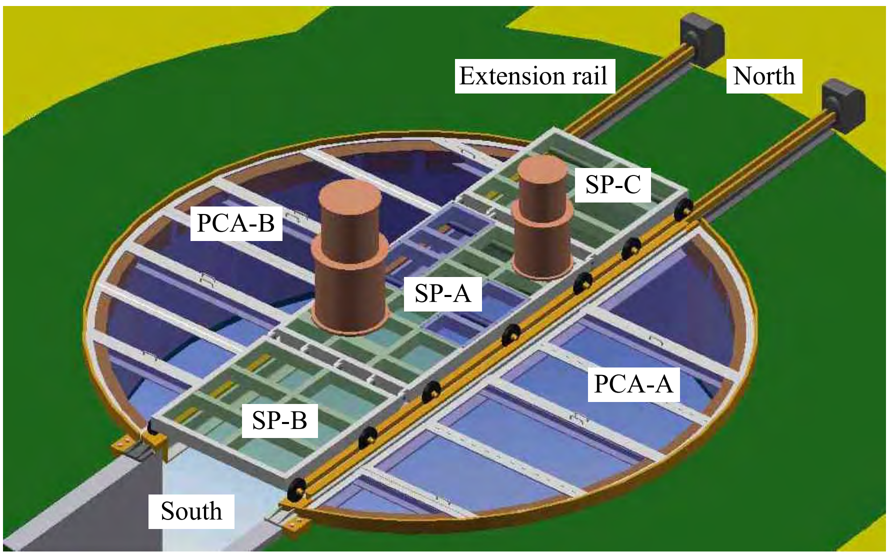


Figure 2 Unfolded pool cover during normal operation (Case I)

Figure 3 Folded pool cover during reactor pool works (Case II)

The pool cover assembly PCA-A/B and sliding panel SP-A are covered with windows consisting of grating plates to provide the operator with working space. In addition, for the protection of the drop of a foreign substance and seeing inside the reactor pool, PCA-A/B and SP-A are covered with transparent polycarbonate panels and cover plates, respectively. In the southern end of the main frame of PCA-A/B, fixed hook and lugs are provided for hanging the various tools that are used for fuel handling. The movable hook is provided beneath the main frame of PCA-A/B for the transport of the container with the irradiation targets. Most parts of the pool cover are made of stainless steel 304(S.S 304). High strength stainless steel A564(type 630) is used as the material for the stoppers. The material of the anchor bolt is stainless steel A193.

DESIGN REQUIREMENTS OF THE POOL COVER

Design of the pool cover is classified as non-nuclear safety (NNS), seismic category II, and quality class T. [1-2] For the conservative assessment of the structural integrity of the pool cover, the response spectrum analysis for SSE and OBE, which is applied to the seismic category I, is performed.

Design Loads

The design loads consist of dead load, live load, and seismic loads. These are used as inputs for the structural integrity assessment by the seismic analysis.

(a) Dead load

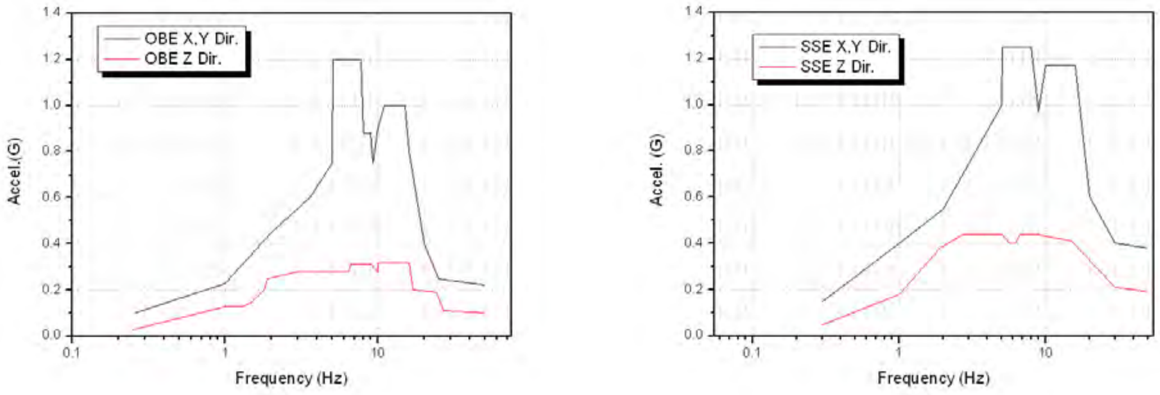
All sorts of weights for the pool cover including main frames, grating plates, cover plates of the sliding panels, NTD driving devices etc are considered for the calculation of the dead load. The weights of the driving devices including the targets for NTD1, NTD2, CT/IR, OR5, and OR6 are estimated as 100kg, respectively. The mass per unit area of the grating plate and polycarbonate panel is considered as 50kg/m^2 and 11.44kg/m^2, respectively. In addition, the concentration load of 100kg is respectively hung on 2 movable hooks, 1 fixed hook, and 4 fixed lugs. Therefore the total concentrated load on the pool cover becomes 1200kg for the conservative estimation of the dead loads.

(b) Live load

Since the design of the pool cover is similar with the case of a platform, it is assumed that the live load of the pool cover is 500kg/m^2.

(c) Seismic load

The enveloped floor response spectrum for OBE and SSE at the top of the reactor pool, as shown in Figure 4, are used as the seismic load inputs. Damping values, 4% and 7%, are used for OBE and SSE respectively because the anchor bolts of the pool cover assembly are fixed on the concrete structure at the top of the reactor pool. [5]



(a) OBE (4% damping) (b) SSE (7% damping)

Figure 4 Floor response spectrum for OBE and SSE at the top of the reactor pool (EL 85.55)

Load Combination

For the conservative assessment of the seismic analysis, the dead load includes the weight of the pool cover, concentration load, and live load. These are used as inputs for the structural integrity assessment by the seismic analysis. According to the ASME code [6-7], load combination for the service level of the pool cover is shown in Table 1.

Table 1 Load combination for the service level of the pool cover

Service Level	Load combination
A	Dead load
B	Dead load + OBE
D	Dead load + SSE

Acceptance Criteria of the Structural Integrity

(a) Structural Members

For the estimation of the structural integrity of the beam members of the pool cover, the allowable stresses of ASME Section III, NF-3322 [6] are applied as follows;

- Allowable stress (F_t: tensile, F_v: shear, F_a: compression, F_b: bending)

$$F_t = 0.6S_y \quad (1)$$
$$F_v = 0.4S_y \quad (2)$$
$$F_a = S_y\,(0.47\text{-}kl/r/444), \quad kl/r < 120 \quad (3)$$
$$F_{b,major} = F_{b,minor} = 0.66S_y \quad (4)$$

- Combined stress ratio

$$(f_a/F_a)+(f_{bx}/F_{bx})+(f_{by}/F_{by}) < 1.0, \; f_a/F_a < 0.15, \quad (5)$$

where f_a denotes the computed compression stress, f_{bx} and f_{by} denote the computed bending stress in the x and y direction.

(b) Bolted Joints

There are many bolted joints and anchor bolts in the pool cover. Fixing stoppers, frictional stoppers, locking pins and bolts are provided for preventing the movement of the sliding panel for normal operation and seismic loadings. The allowable stresses of ASME Section III, NF-3324.6 [6] are applied for the structural evaluation of the bolted joints as follows;

- Allowable stress (F_{tb}: tensile, F_{vb}: shear)

$$F_{tb} = S_u/3.33 \tag{6}$$
$$F_{vb}= 0.62S_u/5 \tag{7}$$

- Combined stress ratio

$$(f_{tb}/F_{tb})^2+(f_{vb}/F_{vb})^2< 1.0, \tag{8}$$

where f_{tb} denotes the computed tensile stress, and f_{vb} denotes the computed shear stress of the bolt.

STRUCTURAL INTEGRITY ASSESSMENT OF THE POOL COVER

Finite-Element Modeling of the Pool Cover

The 3-D finite element models of the pool cover have been developed by utilizing ANSYS program [8-9]. All parts of the pool cover structures are modeled as beam elements and point masses. For the modeling of the beam structures of the pool cover, BEAM44 elements of ANSYS are used. BEAM44 is a uniaxial element with tension, compression, torsion, and bending capabilities. MASS21 element is used for the modeling of the point masses. The weights of the upper plates, grating plates, and concentrated loads are modeled as the point mass on the nodes of the beam elements.

Figures 5 and 6 represent developed finite element models of the pool cover with two cases; unfolded (Case I) and folded (Case II) pool cover. In the finite element models, as shown in Figures 5 and 6, fixed boundary conditions are applied at 6 points of the boundary of the pool cover assemblies (PCA-A/B), 2 points of SP-C for Case I, and 12 points of the extension rails. Table 2 represents the coupling conditions between the pool cover assemblies (PCA-A/B) and the sliding panels (SP-A/B/C).

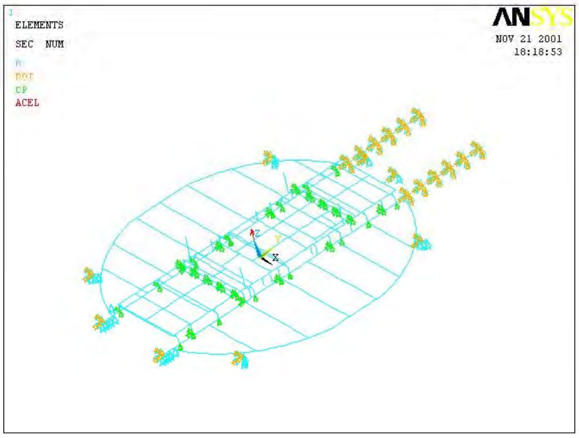


Figure 5 Finite element model of the unfolded pool cover (Case I)

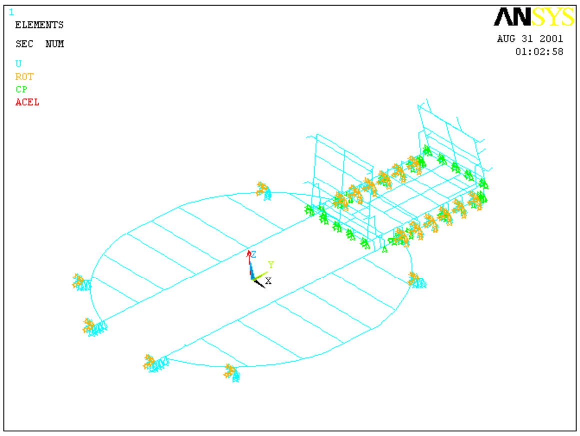


Figure 6 Finite element model of the folded pool cover (Case II)

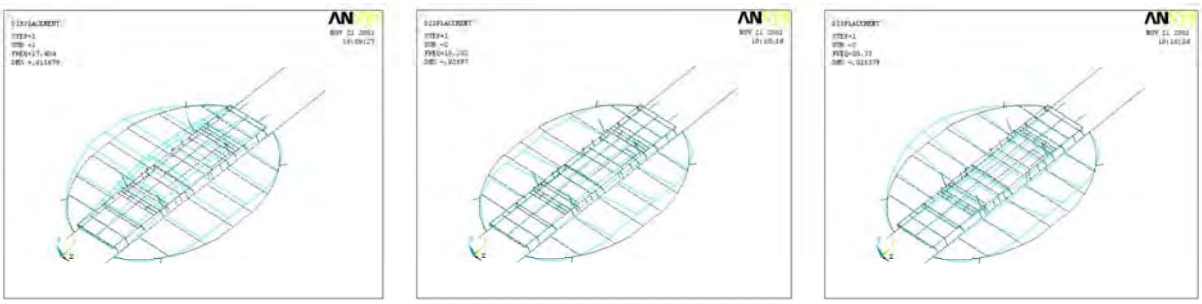
Table 2 Coupling conditions between the pool cover assemblies and the sliding panels (×: fixed, O: free)

Case	Components	Translation			Rotation		
		U_x	U_y	U_z	R_x	R_y	R_z
Case I	Wheel	×(W)	O	×(W/E)	O	O	O
	Fixing stopper	×	×	O	×	×	O
	Frictional stopper	×	O	×	×	×	O
	Hinge between SP-A, SP-B, and SP-C	×	×	×	O	×	×
	Locking pin of SP-B and SP-C	×	×	×	O	O	O
Case II	Wheel	×(W)	O	×(W/E)	O	O	O
	Frictional stopper	×	O	×	O	O	O
	Hinge between SP-A, SP-B, and SP-C	×	×	×	O	×	×
	Locking bolt	×	×	×	×	×	×

Modal Analysis

In order to investigate the vibration characteristics of the pool cover, modal analysis of the developed finite element models is performed. The typical measure of vibration characteristics, natural frequencies and mode shapes, are obtained by utilizing the ANSYS 5.7 program [8].

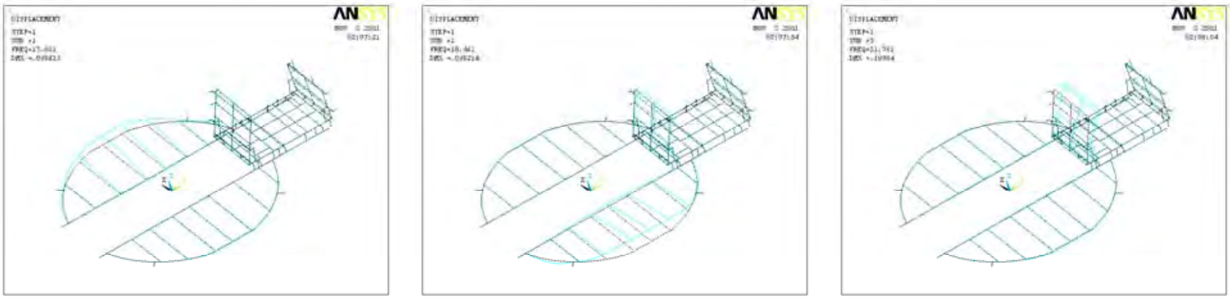
Figure 7 represents the mode shapes and natural frequencies of the unfolded pool cover (Case I). From Figure 7(a), we can observe that the fundamental vibration mode for Case I is bending mode of the pool cover assemblies with corresponding natural frequencies of 17.4 Hz. In addition, from Figure 7(b) and 7(c), one can see that bending of the PCA-A and PCA-B is dominant in the second and third vibration modes.



(a) 1st mode(17.4Hz) (b) 2nd mode(18.2Hz) (3) 3rd mode(20.3Hz)

Figure 7 Natural frequencies and mode shapes of the unfolded pool cover (Case I)

Figure 8 represents the mode shapes and natural frequencies of the folded pool cover (Case II). Similarly with the Case I, we can observe that the bending of the pool cover assemblies is dominant in the first and second vibration modes. In addition, one can see that the third mode is a bending mode of sliding panel SP-B with natural frequency of 21.8Hz. Table 3 summarizes the natural frequencies of the pool cover for Case I and Case II.



(a) 1st mode(17.6Hz) (b) 2nd mode(18.5Hz) (3) 3rd mode(21.8Hz)

Figure 8 Natural frequencies and mode shapes of the folded pool cover (Case II)

Table 3 Natural frequencies of the pool cover

Boundary Condition	Natural frequency (Hz)		
	1st	2nd	3rd
Case I	17.4	18.2	20.3
Case II	17.6	18.5	21.8

Seismic Response Spectrum Analysis

For the structural integrity assessment of the pool cover, the response spectrum analysis for developed finite element models, unfolded (Case I) and folded (Case II), were carried out. [4,9] As the seismic load inputs, the enveloped floor response spectrum for OBE (4% damping) and SSE (7% damping) as shown in Figure 4 were used. The maximum value of the response combination of modes and 3 spatial directions was obtained by the square root of the sum of the squares (SRSS). The used modes were selected to bring the effective mass to about 90% of the total mass.

In the response spectrum analysis, tensile, shear, and bending stresses of each element of the pool cover are estimated. Then, the combined stress ratios of it are obtained. The results of the seismic response spectrum analysis show that the highest stress point is the southern end of the main frame with bending stress of 129.8MPa for the service level D. Table 4 summarizes the maximum stresses of the pool cover under service levels. The maximum combined stress ratios of the pool cover are shown in Table 5.

Table 4 Maximum stresses of the pool cover

Case	Maximum stress (Mpa)								
	Service level A			Service level B			Service level D		
	Tensile	Shear	Bending	Tensile	Shear	Bending	Tensile	Shear	Bending
Case I	4.68	4.92	94.7	5.79	5.74	114.6	6.65	6.36	129.8
Case II	3.11	3.49	53.0	3.65	3.88	82.0	4.02	4.71	86.0

Table 5 Maximum combined stress ratios of the pool cover

Case	Maximum combined stress ratio		
	Service level A	Service level B	Service level D
Case I	0.701	0.638	0.423
Case II	0.392	0.333	0.212

These analysis results show that the maximum stress values of the pool cover structures for the seismic loads are within the ASME code limits.[6-7] In addition, the maximum combined stress ratios are less than 1.0. Also the results of structural integrity assessments for fixing stoppers, frictional stoppers, locking pins, and bolts satisfied the ASME code. Thus, we can confirm that any damage on the structural integrity of the pool cover is not expected when the pool cover is installed at the top of the reactor pool.

Fatigue Analysis

The fatigue analysis of the pool cover is conducted to investigate the possibility of the fatigue failure due to seismic load of OBE. Then, the fatigue usage factor, which is a typical measure of fatigue life prediction, is estimated.

First of all, the highest stress point that has the largest possibility of the fatigue failure is determined from the stress analysis of the pool cover (Table 4, service level B). For the conservative prediction of the fatigue failure, the peak stress intensity is calculated as the multiplication of the maximum stress due to seismic load (OBE) and the stress concentration factor. After calculating the peak stress intensity, its allowable operating cycle is obtained from the *S-N* curve of ASME, Sec.III, Appendix Fig. I-9.2.1.[10] As the predicted number of operating cycles (n) during the designed life of the HANARO, the expected cycles of the maximum stress loading due to five OBE, 200, is used. Then, the fatigue usage factor is calculated as the ratio of operating cycles to allowable operating cycles. Table 6 summarizes the fatigue analysis results.

Table 6 Fatigue usage factor of the pool cover

Maximum stress intensity (S_{max})	Stress concentration factor	Peak stress intensity (S_p)	Operating cycle (n)	Allowable operating cycle (N)	Fatigue usage factor (n/N)
114.6MPa	4	458.4Mpa	200	9,000	0.022

The fatigue analysis results show that the fatigue usage factor of the pool cover is to be 0.022. Since the fatigue usage factor is less than 1.0, we can confirm that the possibility of fatigue failure for the pool cover subjected to seismic loads is negligible during the designed life of the HANARO.

CONCLUSIONS

The structural integrity of the newly designed reactor pool cover under seismic load has been investigated. For this purpose, 3-D finite element models of the pool cover were developed. Then, seismic response spectrum analysis and fatigue analysis of the pool cover were carried out. The seismic analysis results show that the maximum stresses due to seismic loads are within the allowable stresses of the ASME code, and the maximum combined stress ratios are less than 1.0. The modal analysis results show that the fundamental vibration modes for Case I and Case II are bending modes of PCA-A and PCA-B with corresponding natural frequencies of 17.4Hz and 17.6Hz, respectively. In addition, the fatigue analysis demonstrates the possibility of fatigue failure for the pool cover is negligible. Finally, the newly developed pool cover have been successfully installed at the top of the reactor pool and is being used for the neutron transmutation doping of silicon under on-power operation.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by the Ministry of Science and Technology of Korea.

REFERENCES

1. Ryu, J.S., Kim, S.W., Wu, S.I., Wu, J.S., and Jun, B.J., "Design of Pool cover for Increasing HANARO Application," *Proc. of 2001 Spring KNS*, 2001.
2. Ryu, J.S., "Technical Specification for Fabrication of HANARO Pool Cover," HAN-RS-DD-SP-402-01-001, Rev.0, HANARO Center, KAERI, 2001.
3. Ryu, J.S., "Technical Specification for Seismic Analysis of HANARO Pool Cover," HAN-RS-DD-SP-402-01-002, Rev.0, HANARO Center, KAERI, 2001.
4. Ryu, J.S., Cho, Y.G., Wu, S.I., Wu, J.S., and Jun, B.J., "Seismic Analysis of Pool cover for Increasing HANARO Application," *Proc. of 2002 Fall KNS*, 2002.
5. U.S. Nuclear Regulatory Commision, *Damping Values for Seismic Design of Nuclear Power Plants*, Regulatory Guide 1.61, Revision 1, 1973.
6. ASME Boiler and Pressure Vessel Code Section III, Division 1, Subsection NF, *Component Supports*, 1989.
7. ASME Boiler and Pressure Vessel Code Section III, Division 1, Appendix F, *Rules for Evaluation of Service Loadings with Level D Service Limits*, 1989.
8. ANSYS 5.7, User's Manual, ANSYS Inc., 2000.
9. Ryu, J.S., "Structural Integrity Assessment of HANARO Pool Cover," KAERI/TR-1954/2001, KAERI, 2001.
10. ASME Boiler and Pressure Vessel Code Section III, Division 1, Appendix I, *Fatigue Design Curves*, 1989.