REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**287-8272**
SRP Section:	**09.01.02 – New and Spent Fuel Storage**
Application Section:	**9.1.2**
Date of RAI Issue:	**11/02/2015**

Question No. 09.01.02-30

1. The 10 CFR Part 50, Appendix A, General Design Criteria (GDC) 1, 2, 4, 5, 63, and 10CFR 52.80 (a) provide the regulatory requirements for the design of the new and spent fuel storage facilities. Standard Review Plan (SRP) Sections 9.1.2 and 3.8.4, Appendix D describes specific SRP acceptance criteria for the review of the fuel racks that are acceptable to meet the relevant requirements of the Commission's regulations identified above. SRP 3.8.4 Appendix D I (5) states that" Details of the mathematical model, including a description of how the important parameters are obtained, should be provided". In DCD Tier 2, Section 9.1.2.2.3, "New and Spent Fuel Storage Rack Design", the applicant stated that "The dynamic and stress analyses are performed as described in report APR1400-H-NNR-14012-P & NP". In the technical report APR1400-H-N-NR-14012-P, Rev 0, Subsection 3.1.2.2, "Details of Rack and Fuel Assembly" the staff finds that the information of the rack and fuel assembly mathematical model and the computer program used for the nonlinear seismic analysis is insufficient. The applicant is requested to provide the following additional information so that the staff can perform its safety evaluation of the seismic analysis of the rack and fuel assembly.

a. The applicant stated that "There are three nodes for rack cells and fuel assemblies". The applicant did not provide any technical basis to show that the three node model of the fuel assembly adequately represents the dynamic characteristics of the fuel assembly. The applicant is requested to provide the fuel frequencies of the three lumped mass fuel model along with a comparison with frequency of the fuel assuming the fuel assembly as a simply supported beam, and with any physical test measurements of a PWR fuel assembly.

b. The applicant stated that "All the fuel assemblies in each storage rack module are modeled as one beam of which the mass equals the sum of the masses of all the fuel assemblies in a rack". The applicant is requested to discuss and provide the details of how the stiffness properties of the beam that represents all the fuel assemblies in a rack are calculated to capture the dynamic characteristics of the free standing racks under seismic loading. The

applicant is also requested to provide the assumptions and computational details of the contact stiffness between the fuel and the rack's cell wall that is used to predict the maximum fuel-to-cell impact loads.

c. The applicant used ANSYS, Version 10 finite element program for the nonlinear dynamic analysis. The applicant is requested to provide reference to operating or new nuclear power plants free standing fuel racks that have been licensed using ANSYS Version 10. The applicant is also requested to provide the details of benchmarking, validation and verification of ANSYS commuter program for the specific application to the nonlinear seismic analysis of the free standing submerged fuel rack structures that includes nonlinear springs.

The applicant is requested to identify any proposed changes to and provide a mark-up of Subsections in the DCD Tier 2 and the report APR1400-H-N-NR-14012-P, Rev.0, as appropriate.

Response – (Rev. 1)

a. The mass (M) and the flexural rigidity (EI) values of a PWR fuel assembly are applied to the fuel assembly model for the fuel rack dynamic and stress analyses to reflect the dynamic characteristics of the PWR fuel assembly. These values are provided by the supplier of the PWR fuel assembly. Therefore, the dynamic analysis of rack do not use the frequencies of the three lumped mass fuel model. All the fuel assemblies in each storage rack are modeled as an individual distributed mass and beam elements. All fuel assemblies move simultaneously in one direction. The assumption included in this model brings about larger impact on the rack module than the actual case and results in the conservative loads to the storage rack.

b. The report APR1400-H-N-NR-14012-P, Section 3.2.1.4 (1), explains the contact stiffness between the fuel assembly and rack cell. A fuel assembly within the rack is modeled as three lumped masses equally spaced over the height of the rack. The node of the fuel assembly beam model and the node of rack beam model is connected using CONTAC52 element. The stiffness of the fuel assembly only is applied in consideration of conservatism.

c. The benchmarking of the ANSYS computer program for the specific application to the nonlinear seismic analysis is performed by comparing the ANSYS calculated results with the DYNARACK analysis tests. The rack seismic analysis of Shin-Kori Nuclear Power Plant Units 1 and 2 (SKN 1&2) was performed using the DYNARACK program. Benchmark test results for nonlinear seismic analysis using the ANSYS and the DYNARACK program are shown in attachment.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environment Report.

Benchmarking Test for Spent Fuel Storage Rack Using ANSYS Program

Non-Proprietary

April 2016

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1 ABSTRACT

Nonlinear dynamic analysis is performed to characterize the nonlinear seismic behavior of a spent fuel storage rack (SFSR). A free standing spent fuel storage rack (SFSR) is submerged in water in a spent fuel pool (SFP) of a nuclear power plant. The seismic analysis of the free standing SFSR requires careful considerations of several nonlinear phenomena. The response of a free-standing rack module to seismic inputs is highly nonlinear and involves a complex combination of motions such as sliding, rocking, twisting, and turning by impacts and friction effects.

In order to evaluate adequacy for the response of nonlinear dynamic analysis using the ANSYS computer program (Version 10), the benchmark test of ANSYS computer program is performed for the whole pool multi-rack (WPMR) analysis model of Shin-Kori Nuclear Power Plant Units 1 and 2 project (Reference 1) in Korea.

The rack seismic analysis of Shin-Kori Nuclear Power Plant Units 1 and 2 (SKN 1&2) was performed using the DYNARACK program which is a code based on the component element method.
The benchmarking of the ANSYS computer program for the specific application to the nonlinear seismic analysis is performed by comparing the ANSYS calculated results with the DYNARACK analysis tests. Comparison tables for the analysis results using the ANSYS and the DYNARACK program are included in section 6.0.

2 DESCRIPTION OF THE BENCHMARK TEST

The module layouts of the spent fuel pool (SFP) for benchmarking test are shown in Figure 3-1. The dynamic simulations using the ANSYS program are preformed to provide the results for the nonlinear seismic analysis of the free standing submerged fuel rack structures that includes nonlinear springs. The composite dynamic simulation wherein all racks in the pool are modeled, is utilized to determine reaction loads and displacements for each spent fuel rack in the pool.

3 METHODOLOGY

3.1 Method Using "ANSYS" program

3.1.1 Modeling

3.1.1.1 General Considerations

(1) Coefficient of Friction

Because the spent fuel storage rack is placed but not fixed on pool, sliding occurs between the rack and bottom of pool. Coefficient of friction (COF) values are applied at each interface, which reflect the realities of wetted stainless steel-to-stainless steel contact in a wet environment. The applied coefficient of friction values for benchmarking test are 0.2 and 0.8 which are based on experimental data (Reference 2).

(2) Impact Phenomena

Compression-only spring elements, with gap capability, are used to provide opening and closing of interfaces for the pedestal-to-bearing pad interface, the fuel assembly-to-cell wall interface, and the rack-to- rack and rack-to-pool wall potential contact.

(3) Fuel Loading

The dynamic analyses for benchmarking test are performed for the condition that all fuel assemblies are fully loaded in the racks.

(4) Fluid Coupling

The formula for a hydrodynamic effect of the adjacent storage racks due to a storage rack in the spent fuel pool (Reference 3) is adopted. This formula is based on the potential flow theory of Fritz (Reference 4) and calculates the values of hydrodynamic mass of two objects in the fluid.

Fritz's classical two-body fluid coupling model (Reference 4) is extended to multiple bodies and used to perform a three-dimensional multi-rack analysis. This technology is incorporated in the whole pool multi rack (WPMR) analysis. In its simplest form, fluid coupling effect can be explained by considering the proximate motion of two bodies (for example, a rack and a wall) under water. If one body (mass M_1) vibrates adjacent to a second body (mass M_2), and both bodies are submerged in frictionless fluid, Newton's equations of motion for the two bodies are as follows:

$-M_H \cdot A_1 + (M_1 + M_H) \cdot A_2$ = Fluid reaction forces on mass M_1, and
$(M_1 + M_H) \cdot A_1 - (M_1 + M_2 + M_H) \cdot A_2$ = Fluid reaction forces on mass M_2,

where,
M_1 = Mass of fluid displaced by the inner body,
M_2 = Mass of fluid inside the outer body in the absence of the inner body,
A_1, A_2 = Absolute accelerations of masses M_1 and M_2, respectively, and
M_H = Hydrodynamic mass that depends on the fluid flow when the two bodies move relative to each other.

The fluid adds mass to the body (M_H to mass M_1), and is considered an inertial force proportional to acceleration of the adjacent body (mass M_2). Thus, acceleration of one body affects the force on another. This force is a function of a gap between bodies. Lateral motion of a fuel assembly inside a storage location is subject to this effect. Generally, the fluid coupling is always present when a series of closely spaced bodies (for example, fuel racks) undergo transient motion in a submerged environment of SFP. Therefore, the kinematics phenomenon of the storage rack in the spent fuel pool is indicated by analysis which includes a hydrodynamic effect.

3.1.1.2 Details for Rack and Fuel Assembly

Figure 3-1 shows the storage layout of the spent fuel storage rack in the spent fuel pool for Shin-Kori units 1 and 2. The spent fuel pool is made up of Region I and Region II. Figure 3-2 is whole pool multi-rack analysis model of spent fuel storage rack using ANSYS program. It is overall dynamic analysis model of spent fuel storage rack created by combining the model shown in the Figure 3-3 for Region I and Region II.

Figures 3-3 and 3-5 shows the sketch of nodes and elements of a dynamic analysis model for the SFSR of ANSYS and DYNARACK, respectively. The racks and fuel assemblies are modeled as 3-D elastic beam (BEAM4) and lumped mass (MASS21) of ANSYS finite element analysis program (Reference 5). The BEAM4 element indicates the dynamic characteristics of storage racks using the effective structural property. Effective structural properties for the dynamic model are determined from the natural frequencies and mode shapes of the detailed model.

There are five nodes for rack cells and fuel assemblies, respectively. Five nodes are located at the rack baseplate, 1/4H, 1/2H, 3/4H, and H (where H is the rack height measured above the baseplate), respectively. Each node of the elements for racks has a displacement and rotation degree of freedom in each direction and a lumped mass with it. The nodes for the rack and the fuel assembly are connected with impact spring elements in the horizontal direction to consider impact by a relative motion of the storage rack and the fuel assembly.

Lumped masses of rack and fuel assemblies are distributed among the five nodes for rack cells and fuel assemblies as shown in the table below:

No	Location	Total Mass Distribution
1	Top of Rack	12.5 %
2	3/4 Height	25 %
3	1/2 Height	25 %
4	1/4 Height	25 %
5	Bottom (Baseplate) of Rack	12.5 %

All the fuel assemblies in each storage rack module are modeled as one beam of which the mass equals the sum of the masses of all the fuel assemblies in a rack module. Because the fuel assemblies in a rack module are modeled together, all fuel assemblies move simultaneously in one direction. The assumption included in this model brings about larger impact on the rack module than the actual case, and results in the conservative loads to the storage rack.

Figures 3-4 and 3-6 shows a two-dimensional elevation schematic depicting the five masses of fuel and rack cells, and their associated fuel assembly/rack cell spring elements, the support pedestal spring elements, and adjacent rack impact spring elements used on the programs of ANSYS and DYNARACK. Nonlinear gap element and linear friction spring element are used to represent the vertical and horizontal motions of support pedestals, respectively. A directional stiffness value of pedestals is assigned to linear friction spring element. In order to represent an impact of rack-to-rack and rack-to-pool wall, compression

impact spring elements between the lumped masses are used. Impact spring element of horizontal direction between racks is assigned to upper and lower of storage rack.

The hydrodynamic masses on rack-to-fuel, rack-to-rack, and rack-to-pool wall are modeled as mass MATRIX27 element of ANSYS program. This element connects two nodes for the rack-to-fuel, rack-to-rack, and rack-to-pool wall.

3.1.1.3 Hydrodynamic Mass

In addition to the structural mass of racks and fuel assemblies, hydrodynamic masses of rack-to-rack and rack-to-fuel assembly for the SFSRs are included in the total mass to consider the fluid coupling effect. Details for the hydrodynamic mass are described in the followings:

(1) Between Cell and Fuel Assembly

Fuel assembly consists of several fuel rods and guide tubes, and is supported by spacer grid. A hydrodynamic mass is calculated assuming the structure as of long cylinders whose centers match with the center of the structure. A hydrodynamic mass acting at the centers of the two rigid bodies and liquid filled therein is represented using following formula of Reference 3.

$$M_H = \left[\frac{R_2^2 + R_1^2}{R_2^2 - R_1^2} \right] \pi \rho R_1^2 h$$

where,
M_H = Hydrodynamic mass that depends on the fluid flow when the two bodies move relative to each other,
R_2 = Equivalent radius of storage cell, converting cell width into radius,
R_1 = Equivalent radius of fuel assembly, converting distance between fuel rods of outermost into radius,
h = Length of fuel assembly, and
ρ = Density of fluid.

(2) Rack-to-Rack and Rack-to-Pool Wall

Hydrodynamic masses between rack-to-rack and rack-to-pool wall are calculated based on height of rack, density of fluid and gap of adjacent racks, assuming that the fluid is filled between two objects.

3.1.1.4 Stiffness of Model

The spring element for the dynamic analysis is used to calculate the loads in horizontal direction by friction between the pedestal of storage rack and bottom of the pool and impact loads of cell-to-fuel assembly and rack-to-rack, and rack-to-pool wall. Impact phenomena can be represented with a contact element (CONTAC52) of ANSYS (Reference 5). This element is capable of supporting only the compression in the direction normal to the surfaces and the shear (coulomb friction) in the tangential direction. The element has three degrees of freedom for a displacement at each node. A specified stiffness acts in the normal and tangential directions when the gap is closed and not sliding. The impact stiffness values of rack-to-rack and pedestal-to-pool floor used in the ANSYS and DYNARACK are same as shown in Table 3-1.

Table 3-1 Stiffness Values

Location	Rack	Stiffness Value (lbf/in)	
		DYNARACK	ANSYS
Rack-to-Rack	Region I (A1 & A2)	1.624E+06	1.624E+06
	Region I (J)	1.624E+06	1.624E+06
	Region II	1.624E+06	1.624E+06
Pedestal-to-Pool Floor	Region I (A1 & A2)	1.682E+06	1.682E+06
	Region I (J)	1.462E+06	1.462E+06
	Region II	1.281E+06	1.281E+06

3.1.2 Simulation and Solution Methodology

The WPMR analysis using the ANSYS program is performed to evaluate the displacement and the reaction loads of each rack in the pool. The analysis of the fuel storage rack is performed in the procedure of modeling and analysis as follows:

(1) Prepare a three dimensional (3-D) analysis model of all rack modules in the pool for a time-history analysis using ANSYS program. This model includes hydrodynamic effects and nonlinear elements of rack-to-rack and rack-to-fuel to performing an accurate nonlinear simulation and is combined with a spent fuel pool.

(2) Perform a WPMR dynamic analysis of a friction coefficient, 0.2 and 0.8. Displacements and loads of the storage rack are calculated by ANSYS post-processing.

3.1.3 Assumptions

The following assumptions are used in the WPMR dynamic analysis using ANSYS program:

(1) Fluid damping is conservatively neglected, since it yields larger rack displacement.

(2) Fuel assembly is considered as 3-D elastic beam with concentrated masses at five point of the rack.

(3) When earthquake occurs, the rack is affected by irregular movement of every single fuel assembly. For conservative evaluation, all the fuel assemblies within the rack rattle in unison throughout the seismic event, which obviously exaggerates the contribution of impact against the cell wall.

3.2 Method Using "DYNARACK" program

3.2.1 General Considerations

The 3-D rack model dynamic simulation for DYNARACK, handles the coefficient of friction, impact phenomena, fuel loading, and fluid coupling. Details are referred on the analysis report of Reference 9.

3.2.2 Simulation and Solution Methodology

The solver contained within the Holtec In-house Code MR2 (a.k.a. DYNARACK) was used to determine displacement and loads within the rack and also serves to establish the presence or absence of specific rack-to-wall and rack-to-rack impacts during the seismic event. The sequence of model development and analysis steps that are undertaken are summarized in the following:

(1) Prepare 3-D dynamic models of the rack module. Include all fluid coupling interactions and mechanical couplings appropriate to performing an accurate non-linear simulation.

(2) Identify bounding scenarios for seismic evaluation and perform the associated 3-D non-linear rack transient analyses. Archive, for post-processing, the appropriate displacement and load outputs from the dynamic model.

By using the 22-DOF rack structural model (Refer to Figure 3-5) in each DYNARACK simulation, equations of motion corresponding to each degree-of-freedom are obtained using Lagrange's formulation of the dynamical equations of motion. The system kinetic energy includes contributions from solid structures and from trapped and surrounding fluid. The final system of equations has the matrix form:

$$[M]\,\{d^2q/dt^2\} = \{Q\} + \{G\}$$

where:

[M] - Total mass matrix (including structural and fluid mass contributions). The size of this matrix will be 22 X 22 for the single rack analyses performed for this project.
{q} - The nodal displacement vector relative to the pool slab displacement.
{G} - A vector dependent on the given ground acceleration.
{Q} - A vector dependent on the spring forces (linear and nonlinear) and the coupling between degrees-of-freedom.

The above column vectors have length 22. The equations can be rewritten as follows:

$$\{d^2q/dt^2\} = [M]^{-1}\,\{Q\} + [M]^{-1}\,\{G\}$$

This equation set is mass uncoupled, displacement coupled at each instant in time. The numerical solution uses a central difference scheme built into MR2.

The mass of the model is comprised primarily of the fuel assemblies, which rattle within the storage cells during the seismic event.

3.2.3 Assumptions

The following assumptions are taken from Reference 9 and used on the simulation of DYNARACK program for SKN 1&2.

(1) No fluid damping is assumed to be present.
(2) All fuel rattling mass at each level is assumed to move as a unit thus maximizing the impact forces and rack response.
(3) Fluid gaps used in formulation of hydrodynamic effects are maintained at their nominal initial value. No credit is taken for the fact that the resistive fluid effects increase considerably as the inter-body gaps close.
(4) Spring rates are computed in a conservative manner to employ maximum values in the analyses. This tends to conservatively overestimate peak impact forces.

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Figure 3-1 Layout of Spent Fuel Storage Rack

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Figure 3-2 Dynamic Analysis Model for Whole Pool Multi-Rack of ANSYS

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Figure 3-3 Dynamic Analysis Model of ANSYS

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Figure 3-4 Schematic of Spring Elements used for ANSYS

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Figure 3-5 Schematic of the Dynamic Model for DYNARACK

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Figure 3-6 Two Dimensional View of the Spring-Mass Simulation for DYNARACK

4 INPUT DATA

The used ANSYS input data for the rack and fuel assembly weight, and rack material properties are as follows:

4.1 Rack and Fuel Assembly

Rack dimensions, weight of the spent fuel storage rack and the fuel assembly used on dynamic analysis of ANSYS and DYNARACK are summarized in the Tables 4-1 and 4-2.

Table 4-1 Dimensions of SFSR

<table>
<tr><th>No.</th><th colspan="3">Description</th><th>Dimensions (in)</th></tr>
<tr><td>1</td><td colspan="3">Cell Height from Baseplate Top to Rack Top</td><td>180</td></tr>
<tr><td>2</td><td colspan="3">Cell Thickness</td><td>0.09</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Cell Inside Dimension(Width)</td><td rowspan="2">Region I</td><td>A1 & A2</td><td>8.5</td></tr>
<tr><td>J</td><td>9.5</td></tr>
<tr><td colspan="2">Region II</td><td>8.5</td></tr>
<tr><td rowspan="3">5</td><td rowspan="3">Cell Pitch</td><td rowspan="2">Region I</td><td>A1 & A2</td><td>10.716 (N-S & E-W)</td></tr>
<tr><td>J</td><td>14.694 (N-S) & 11.605 (E-W)</td></tr>
<tr><td colspan="2">Region II</td><td>8.736</td></tr>
<tr><td>6</td><td colspan="3">Baseplate Thickness</td><td>0.75</td></tr>
<tr><td>7</td><td colspan="3">Baseplate Hole Diameter</td><td>4.5</td></tr>
<tr><td>8</td><td colspan="3">Distance from Baseplate to Liner</td><td>5.11</td></tr>
<tr><td>9</td><td colspan="3">Male Pedestal Dia.</td><td>5</td></tr>
</table>

Table 4-2 Rack and Fuel Assembly Weight

Rack Modules(*)		Array Size	Rack Weight (lbf)	Total Fuel Assembly Weight (lbf)
SFSR	A1	10 x 9	26,740	133,632
	A2	10 x 9	26,740	133,632
	J	10 x 7	23,580	103,936
	C1	10 x 12	21,130	178,176
	C2	10 x 12	21,030	178,176
	D1	10 x 11	19,460	163,328
	D2	10 x 11	18,530	163,328
	E1	10 x 10	18,220	148,480
	E2	10 x 10	17,780	148,480
	F	8 x 12	16,710	142,541
	G	8 x 11	15,400	130,662
	H	8 x 10	14,430	118,784

(*) Refer to Figure 3-1

4.2 Structural Damping

Rayleigh damping is used to specify mass (M) and stiffness (K) proportional damping (C):

$$C = \alpha \times M + \beta \times K$$

The constants α and β are calculated in the range of the lowest and highest frequencies of interest in the dynamic analysis. M corresponds to real mass of the real-fuel system and does not include any hydrodynamic mass. Only material damping for the fuel and rack is used in calculating the damping matrix C. Structural damping is taken to be 3% for SSE based on project specification (Reference 1).

4.3 Material Properties

Material properties of spent fuel storage rack and fuel assembly are as shown in the Table 4-3. In addition, those of rack are obtained from ASME Code, Section II, Part D (Reference 8). The values listed correspond to a design temperature of 200 ^{o}F.

Table 4-3 Material Properties

Part	Material	Young's Modulus (E) (psi)	Yield Strength (S_y) (psi)	Ultimate Strength (S_u) (psi)
Rack	SA-240 Type 304L	27.6E+06	21,300	66,200
Support Pedestal (Upper Part)	SA-240 Type 304L	27.6E+06	21,300	66,200
Pedestal Bolt Part	SA-564 Grade 630 (Hardened at 1100 °F)	27.6E+06	106,300	140,000

4.4 Seismic Loads

Figures 4-1 through 4-3 show the design input of the time history accelerograms for dynamic analysis of SKN 1&2.

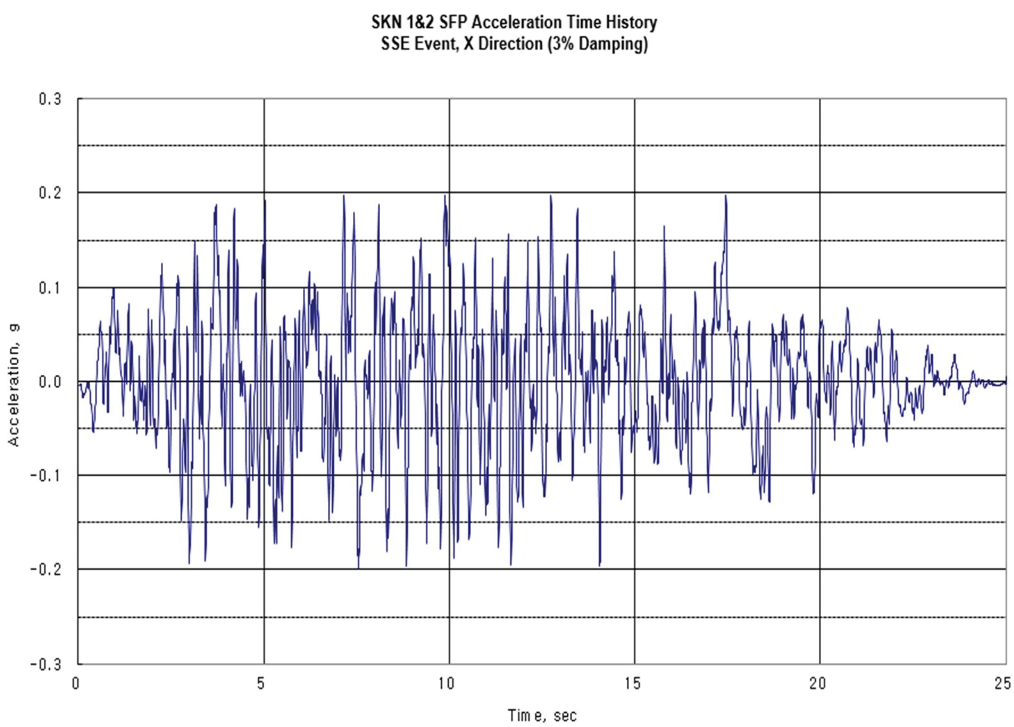

Figure 4-1 Acceleration-Time History (3% Damping, N-S Direction)

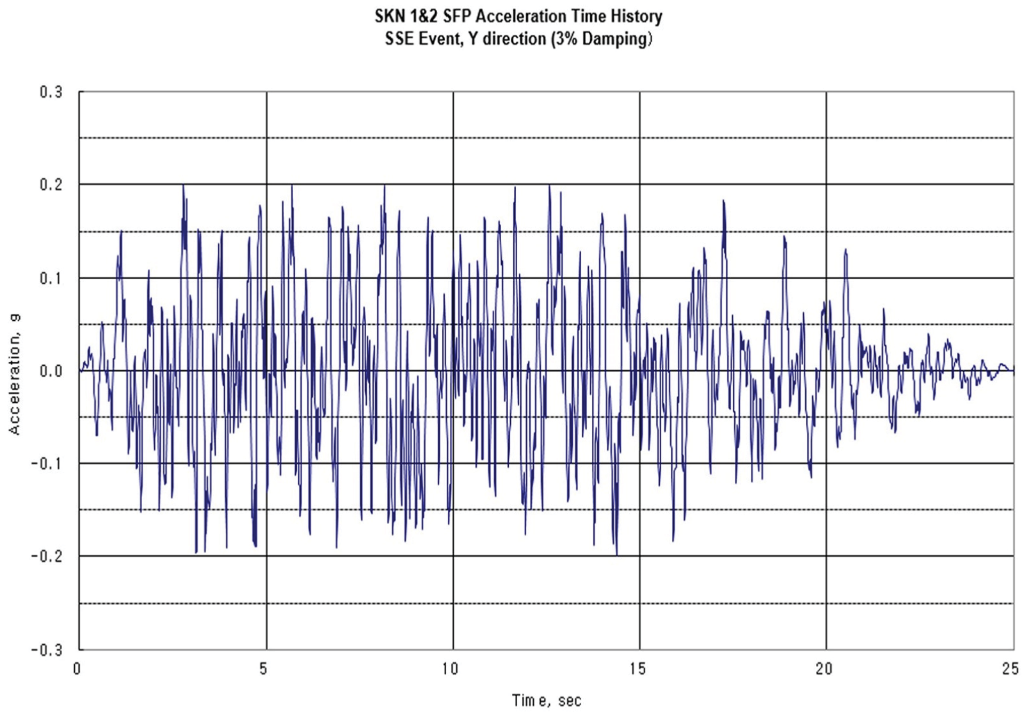

Figure 4-2 Acceleration-Time History (3% Damping, E-W Direction)

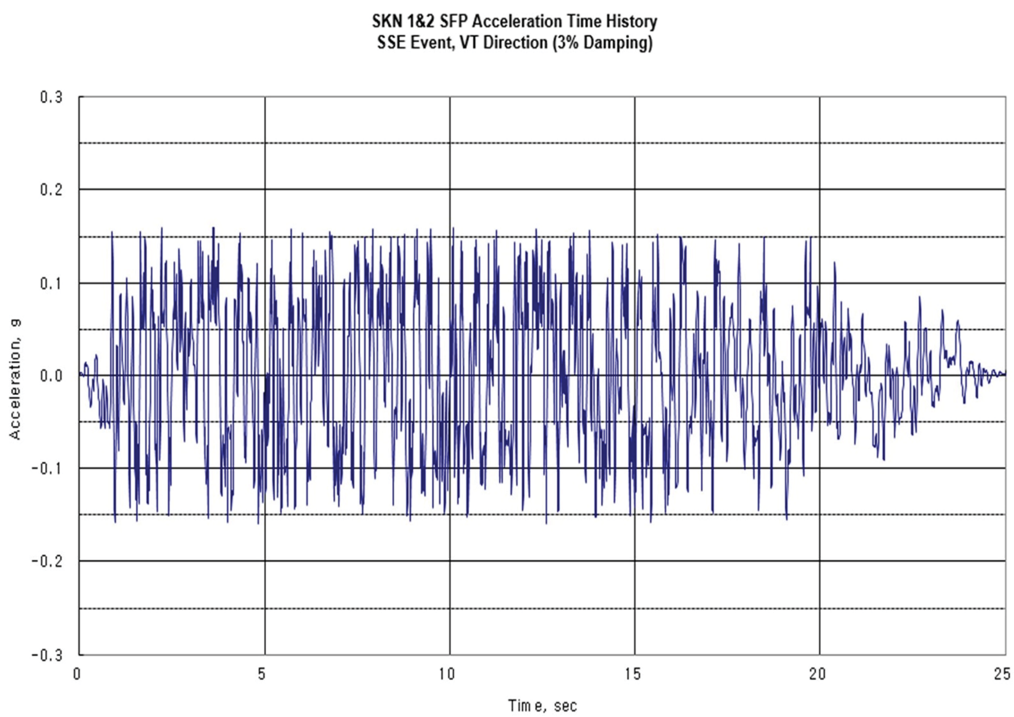

Figure 4-3 Acceleration-Time History (3% Damping, Vertical Direction)

5 BENCHMARK SIMULATIONS

Two simulations shown in Table 5-1 are performed for the spent fuel pool racks to investigate displacements and reaction loads calculated on each rack module. The storage rack configurations at the full loading are considered in the dynamic simulations. To consider the effort of the friction coefficient between pedestal and liner plate as discussed in subsection 3.1 of this report, simulations are performed by varying the friction coefficient with upper and lower bound values. Nonlinear dynamic analyses for dynamic simulations of the SFSRs are performed using the ANSYS finite element program.

Table 5-1 List of Simulations

Test Case	Rack	Fuel Storage Condition	Seismic Load	COF
1	SFSR	Fully Loaded	SSE	0.8
2		Fully Loaded	SSE	0.2

6 RESULTS OF NONLINEAR SEISMIC ANALYSIS

The analysis results from ANSYS are compared with those of DYNARACK.

6.1 Displacements of Rack

The horizontal displacements at rack top calculated from ANSYS and DYNARACK for individual rack are shown in Table 6-1.

For test cases 1 and 2, the range of gap difference between the horizontal displacements at rack top calculated from ANSYS and DYNARACK is within ±0.16 in (4 mm).

Table 6-1 Horizontal Displacements for Individual Rack

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6.2 Reaction Load on Single Pedestal

The maximum reaction loads on single pedestal calculated from ANSYS and DYNARACK are shown in Table 6-2. Figures 6-1 through 6-3 show the plot of reaction load of single pedestal on seismic event.

For test case 1, the range of ratio for the reaction loads on single pedestal calculated from ANSYS and DYNARACK are 1.05 ~ 3.83 for X (N-S) direction, 1.67 ~ 3.58 for Y (E-W) direction, and 0.95 ~ 1.51 for Z (Vertical) direction, respectively. For test case 2, the range of ratio for the reaction loads on single pedestal calculated from ANSYS and DYNARACK are 0.78 ~ 1.21 for X (N-S) direction, 0.79 ~ 1.36 for Y (E-W) direction, and 0.79 ~ 1.27 for Z (Vertical) direction, respectively.

Table 6-2 Maximum Reaction Loads on Single Pedestal

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Figure 6-1 Reaction Load on Single Pedestal of Rack Module A2 in X (N-S) Direction

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Figure 6-2 Reaction Load on Single Pedestal of Rack Module A2 in Y (E-W) Direction

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Figure 6-3 Reaction Load on Single Pedestal of Rack Module A1 in Z (Vertical) Direction

6.3 Fuel Assembly-to-Cell Wall Impact Loads

The maximum fuel assembly-to-cell wall impact loads calculated from ANSYS and DYNARACK are shown in Table 6-3.

The results of maximum fuel assembly-to-cell wall impact load calculated from ANSYS are about 55% and 30% larger than DYNARACK for the test cases 1 and 2, respectively.

Table 6-3 Maximum Fuel Assembly-to-Cell Wall Impact Loads

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7 CONCLUSIONS

The benchmark test for the nonlinear seismic analysis of SFSR was performed using the ANSYS program version 10 with acceleration time histories. The analysis results from ANSYS program are compared with the DYNARACK program results those are rack displacements, pedestal reaction loads of each rack, and the maximum impact loads of fuel assembly-to-cell wall. As a comparison results, the difference of rack displacement is within ±0.16 in (4 mm). And pedestal reaction loads calculated by ANSYS program is similar or larger than those of DYNARACK program in general.

Therefore, the benchmark tests show that using the ANSYS program version 10 for nonlinear seismic analysis of SFSR is adequate.

8 REFERENCES

1. Korea Power Engineering Company, Inc. KOPEC Job No. 1J032, Project Technical Specification 9-423-N224, “New and Spent Fuel Storage Racks”, Revision 1, dated December 09, 2003.

2. Rabinowicz, E., "Friction Coefficients of Water Lubricated Stainless Steels for a Spent Fuel Rack Facility," MIT, a report for Boston Edison Company, 1976.

3. S. Singh, et. Al., “Structural Evaluation of Onsite Spent Fuel Storage: Recent Developments,” Proceedings of the Third Symposium, Orlando, Florida, December 1990, North Carolina State University, Raleigh, NC 27695, pp V/4-1 through V/4-18.

4. Fritz, R.J., "The Effects of Liquids on the Dynamic Motions of Immersed Solids," Journal of Engineering for Industry, Trans. of the ASME, February 1972, pp. 167-172.

5. Computer code, ANSYS Version 10.0; Installed on IBM P6 570 24Core, Verification Document No. DAVM100, Rev.0, December 2010.

6. Levy, S., and Wilkinson, John, "The Component Element Method in Dynamics", McGraw Hill, 1976.

7. ASME Boiler & Pressure Vessel Code Section III, Subsection NF, Component Supports, 1995 Edition with 1995, 1996 and 1997 Addenda.

8. ASME Boiler & Pressure Vessel Code Section II, Materials, Part D, 1995 Edition with 1995, 1996 and 1997 Addenda.

9. Structural and Seismic Analysis Report for New and Spent Fuel Storage Racks of Shin-Kori Nuclear Power Plant Units 1 and 2, HA-950S-003, Rev.2, October 2010. (Doosan Proprietary)

10. DOOSAN Drawings. (Doosan Proprietary)

    C-HA-95200-D01, Rev. 1, Spent Fuel Pool Layout for Unit 1

    C-HA-95200-D03, Rev. 1, Spent Fuel Pool Layout for Unit 2

    C-HA-95210-D01, Rev. 2, Region I Racks “A1” & “A2” Construction

    C-HA-95210-D02, Rev. 1, Region I Racks “A1” & “A2” Construction Details

    C-HA-95210-D03, Rev. 2, Region II Rack Construction

    C-HA-95210-D04, Rev. 1, Region II Rack Construction Details