Structural/Seismic Analysis of High Density Storage Rack for Fresh Fuel Assemblies

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1. Introduction

Fresh fuel assembly storage racks, owned and operated by Korea Nuclear Fuel(KNF), are the structures to store manufactured PWR fresh fuel assemblies until delivered to nuclear power plants. The KNF intends to increase the storage capacity of the storage pit by replacing the existing storage cylinders with new High Density Storage Rack (HDSR). This paper provides a description of structural/seismic evaluation of the HDSR, and demonstration of structural integrity of the HDSR under seismic loading.

The Storage pit where 12 new HDSR modules are supposed to be installed is 8.64m wide and 5.00m deep to accommodate 780 fresh fuel assemblies. The rack modules are installed with self-standing on the storage pit and steel frames are installed for work-corridor between the rack modules at 1st floor level. In normal operation the fresh fuel assemblies are suspending on basket cell lid. The overall facility consists of four types of rack modules, 4 x 13, 4 x 14, 4 x 16 and 4 x 17 modules. The analyses are performed only for 4 x 17 module, whose structural behavior is expected to be critical case. The analyzed rack module is shown in Fig. 1, and the material properties of the rack module components are presented in Table 1.

2. Methods and Results

2.1 Considerations

Considered loads are dead load including fresh fuel assembly weight in service level A and safe shutdown earthquake (SSE) condition in service level D. Stress evaluation follows KEPIC MNF for Class 3 Shell-Type Supports [1].

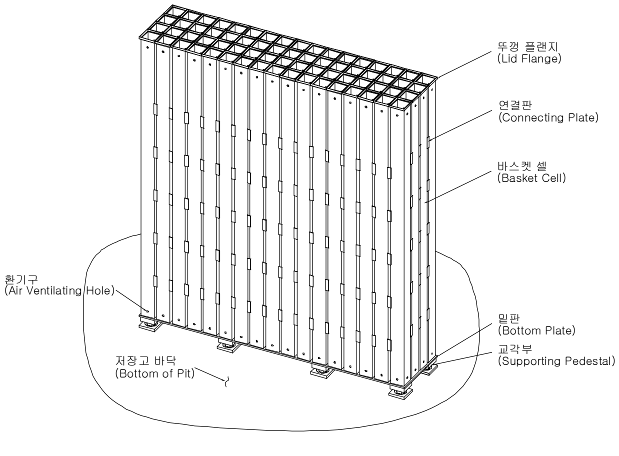

Fig. 1. High density storage rack (HDSR)

The response of a freestanding rack module in seismic condition is highly nonlinear and involves a complex combination of motions (sliding, rocking, twisting, and turning), resulting in impacts and frictional effects. Linear methods, such as modal analysis and response spectrum techniques, cannot accurately describe the response of such a highly nonlinear structure to seismic excitation. In this study, dynamic analyses of direct integration method are performed to obtain accurate nonlinear response of the rack module.

Table 1: Material properties

No.	Material	Density [kg/m^3]	Young's modulus [MPa]	Poisson's ratio
#1	A887 Type B6 (S30460)	8,304	195,121	0.3
#2	A240 Type 304L (S30403)	8,304	195,121	0.3
#3	A564 Type 630 H1100 (S17400)	8,304	201,326	0.3

* Notes : Components
#1 : Basket cell
#2 : Lid, Lid flange, Connecting plate, Top plate, Bottom plate, Supporting nut, Bearing plate
#3 : Supporting bolt

2.2 Seismic response of storage pit

Artificial acceleration time histories in three orthogonal directions (N-S, E-W, and vertical) are generated in accordance with the provisions of SRP section 3.7.1 [2]. The input motion for seismic analyses is safe shutdown earthquake (SSE) with peak ground acceleration 0.2g in horizontal and vertical directions. The computer code SIMQKE is utilized in order to prepare an acceptable set of acceleration time histories. Seismic response analyses of soil and soil-structure interaction (SSI) analyses are performed to evaluate the acceleration response on bottom slab of storage pit where the storage modules are installed. Soil properties for analyses input are taken from Licensing Report for Design and Construction of Korea Nuclear Fuel Fabrication Plant [3]. The evaluated acceleration time history, as shown in Fig. 2, is applied as an input for further seismic analysis of the rack module.

2.3 Seismic analysis

The computer program ABAQUS/Explicit is utilized to analyze nonlinear seismic response of the rack module. The 4-node shell elements are used for

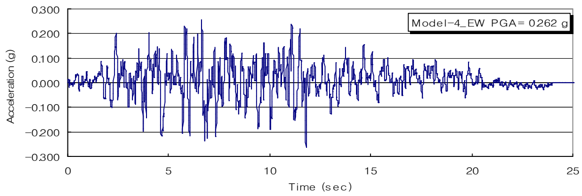

Fig. 2. Acceleration time history (E-W direction)

modeling the basket cell, connecting plate and bottom plate, and 8-node solid elements for the supporting bolt/nut and bearing plate. Contact constraints are defined on interface between fuel assembly and cell wall, cell wall and side support, and bearing plate and pit concrete slab respectively. Using those conditions the momentum transfers due to the rattling of fuel assemblies inside storage cells, the lift-off of the module and the subsequent impact of the support leg on the pit concrete slab can be correctly simulated. According to NUREG/CR-6865[4], coefficients of friction at steel /concrete interface show normal probability distribution with a mean of 0.484, a standard deviation of 0.12, the lowest value of 0.2, and the highest value of 0.72 from experimental studies. Values of 0.2, 0.8, and 0.5, which are the extreme lower bound, extreme upper bound, and best estimated value respectively, are selected for the coefficient of friction between bearing plate and pit concrete slab for a parametric study. FE model of the rack module is shown in Fig. 3.

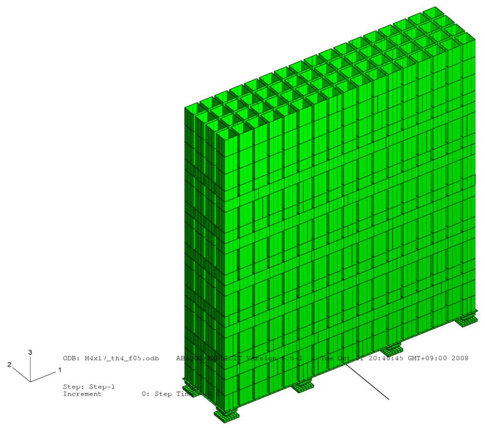

Fig. 3. FE model of HDSR

2.4 Analysis results

The maximum stresses of each component are occurred in case of coefficient of friction μ=0.8, and not greater than stress limits as listed in Table 2. Weld stresses are determined through the use of a simple conversion factor applied to the corresponding stress in the adjacent rack material. They do not exceed the stress limits too.

The maximum impact force between supporting leg and concrete slab amounts to 173kN at 3.8sec in case of coefficient of friction μ=0.8 as shown in Fig. 4. Average stress of pit concrete under the bearing plate reaches 2.2MPa, and it is smaller than the allowable bearing stress of 19MPa (Compressive strength of pit concrete is fck=28MPa).

Table 2: Stress evaluation of components
(Service level D, Seismic condition, friction μ=0.8)

Component	Stress intensity	Stress intensity limit	Stress ratios
	Pm+Pb (MPa)	S_{lmt_Pm} (MPa)	Pm / S_{lmt_Pm}
Basket cell	86	246	0.35
Connecting plate	82	204	0.40
Bottom plate	50	204	0.25
Supporting nut	48	204	0.24
Supporting bolt	69	676	0.10
Bearing plate	194	204	0.95

* Notes : Stress intensity is compared with membrane stress intensity limit for conservatism.

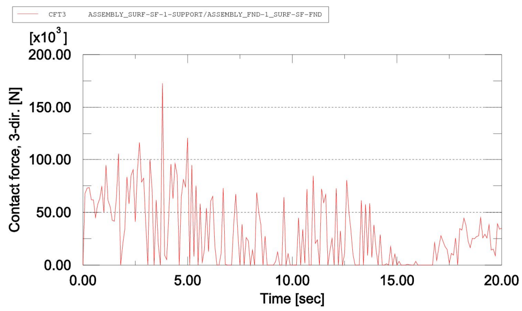

Fig. 4. Impact force time history in supporting leg
(Coefficient of friction μ=0.8)

3. Conclusions

Structural/seismic analyses of the new HDSR module are performed in this study. Nonlinear time history analyses based on direct integration method for SSE event have substantially estimated the dynamic behavior of the rack module, which consists of the complex motions such as sliding, rocking, twisting and turning. All the component- and weld stresses of the rack module are smaller than stress limits defined in KEPIC MNF for Class 3 Shell-Type Supports. The pit concrete slab stress due to the impact force induced by dynamic behavior of the rack module during SSE event is also proved to be smaller than the stress limit.

REFERENCES

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[4] USNRC NUREG/CR-6865, Parametric Evaluation of Seismic Behavior of Freestanding Spent Fuel Dry Cask Storage Systems