Structural Analysis of Advanced Refueling Machine of APR1400

J.R. Cho[a], Y.H. Kim[a], B.T. Park[b], J.B. Park[b], J.H. Jung[b]
a Korea Maritime University, School of Mechanical and Information Eng., cjr@hhu.ac.kr
b Doosan Heavy Industries & Construction Co., Ltd, Nuclear Power Plant Reactor Design Team

1. Introduction

The Refueling Machine (RM) consists of two structural parts of bridge and trolley. The bridge structure is approximately 8.5 m long and 5m wide and is primarily composed of two deep wide flange sections spanning the rector area at the operating level. The trolley is mounted on wheels that roll on the rails of the bridge. Vertical movements of trolley and bridge are restricted by guide rollers.

In this paper, dynamic and structural analyses based on the earthquake spectrum are carried out to verify the structural integrity of advanced refueling machine. It is done by 3-dimmensional finite element analysis using ANSYS software [1].

2. Seismic Analysis

2.1 FE Modeling

The refueling machine was idealized as a finite element model consisting of 51303 nodal points with 1549 elastic beam elements, and 48574 elastic shell elements.

Material and section properties for 14 basic beam section types were determined. These properties were derived from combined shapes or built-up sections.

The analysis used to obtain the seismic response of the mathematical model is based on the standard equations of motion for damped linear systems. The matrix equations were used to find the natural frequencies, the corresponding mode shapes of the system and the response spectrum analysis.

The FE model is shown in considerable detail on Figure 1.

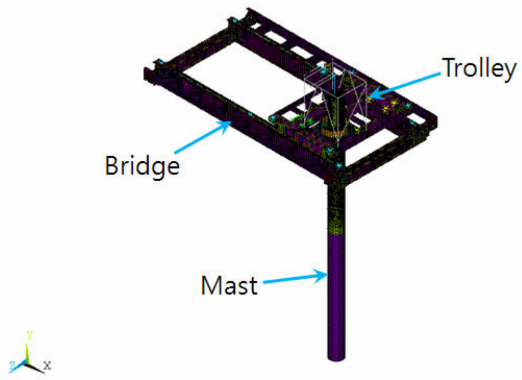

Figure 1. Mesh shape of 3D model

2.2 Loading Condition

The loading condition considered the machine with the hoist box in the full up position with fuel. A trolley is parked at the end of the bridge.

ANSYS calculates the maximum responses in each of the modes based on the spectra (accelerations) in the X, Y, and Z directions. The total response for displacements and stress resultants is calculated as the square root of the sum of the squares (SRSS) of the modal maximum responses for the vertical and two horizontal directions.

A response spectra of SHIN-KORI used in calculation are shown in Figure 2.

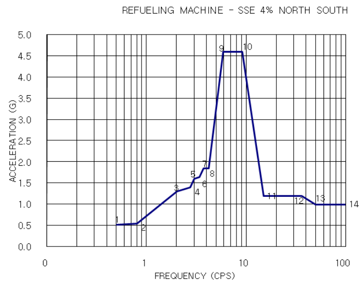

Figure 2. Reference response spectra

The water drag force is defined as:

$$F_{drag} = 1/2 C_{drag} A_p \rho V^2$$

where C_{drag} is drag coefficient for circular shape, C_p is area and V is velocity.

The drag force of 35N is ignored due to small value compared with total weight of 200 kN.

2.3 Seismic Evaluation

To perform seismic analysis, modal analysis was carried out in first step. The first ten modal frequencies for the refueling machine in cycles per second are listed in Table 1. The modal modes include effective mass ratio more than 90% of total mass.

Figure 3 shows first two mode shapes.

Table 1. Modal frequencies

Mode sequence number	Modal frequency	Mode sequence number	Modal frequency
1	0.616	6	16.922
2	9.562	7	17.508
3	11.658	8	19.273

4	14.270	9	20.480
5	14.629	10	21.035

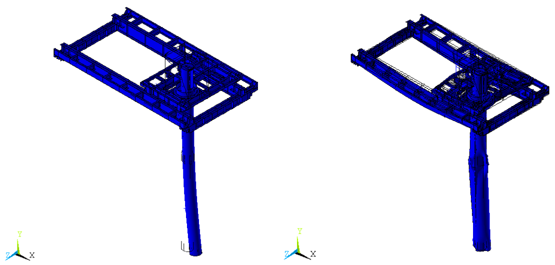

Figure 3. Mode shapes

The seismic analysis is performed in all cases of parking and operation. The result of seismic analysis is shown in distribution of the von Mises stress on Figure 4. The value of the stress is lower than allowable stress.

Table 2. Maximum stress summary of operating plus SSE condition (Unit : MPa)

Location	Maximum principal stress			Allowable
	σ_1	σ_2	σ_3	
Bridge	199.0	80.9	-22.3	223.2
Trolley	65.9	4.1	0.0	223.2
Mast	190.6	96.3	0.0	223.2

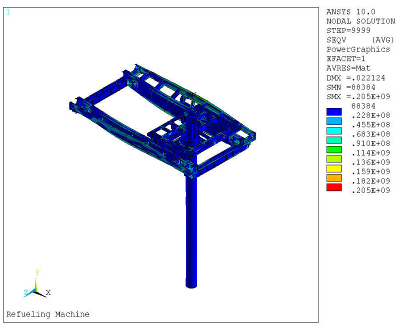

Figure 4. Distribution of the von Mises stress on refueling machine

3. Detail Stress Analysis

3.1 Weld Analysis

The weld joint is investigated for safety. The allowable stresses for fillet welds are based on the KEPIC SWS and MCN 2314[3]. Allowable stress for fillet welds in shear is defined as:

$$\sigma_{aw} = 0.3\sigma_t \times 1.5(\text{seismic factor})$$

The weld analysis considers the stress which is combination of shear and tensile stress at the most thin section of weld. The combination of shear and tensile stress is expressed as

$$fn = \sqrt{fwsy^2 + fwsz^2 + fwt^2}$$

where fn denotes combination of shear and tensile stress; fwsy and fwsz, shear stress in each direction; fwt, tensile stress.

3.2 Bolt Analysis

The bolt joint is investigated for safety. The allowable stresses for bolts are based on the MCN 2315 and 2323. Tensile allowable stress is defined as the lower values of following two equations:

$$\sigma_{at} = 0.33\sigma_t$$
$$\sigma_{at} = 0.6\sigma_t R - 1.6\tau$$

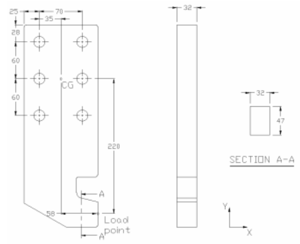

Figure 5. Bolt joint

The bolt analysis considers both shear stress and tensile stress. The sum of shear stress is expressed as

$$fv = \sqrt{(fvx + fst \cdot \cos(\theta))^2 + (fvy + fst \cdot \sin(\theta))^2}$$

where fv denotes sum of shear stress; fvx and fvy, shear stress in each direction; fst, shear stress due to torsion.
The tensile stress is generated from the axial force.

4. Results and Discussion

The structural analysis of refueling machine was carried out. The modal analysis is performed for seismic analysis. The modal modes include effective mass ratio more than 90% of total mass.
The results of seismic analysis show distribution of the von Mises stress that is lower than allowable stress.
In the detail stress analysis, bolt and weld joint were investigated for safety. They are satisfied with allow able stress.

References

[1] ANSYS Finite Element Computer Code & Manual.
[2] Specification of Structural Analysis of Fuel Handling Equipment.
[3] Korea Electric Power Industry Code (KEPIC) MCN, 2000