Numerical Analysis for Earthquake Response of Polar Crane

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Abstract. To evaluate seismic properties of polar crane in nuclear power station, the earthquake responses of polar crane are analyzed. The first order frequency of polar crane fixed on containment wall is 2.44 Hz. The first order mode shape of polar crane is transverse horizontal deformation of two horizontal parallel main girders. El Centro earthquake loading and Los Angeles earthquake loading are used as input loadings on bottom the containment wall. The maximum accelerations of time histories of earthquake loading are normalized. The numerical simulation investigation shows that the maximum Mises stress in mid-span of girder of polar crane under the action of El Centro earthquake loading and Los Angeles earthquake loading are 131 MPa and 133 MPa respectively, and they are less than permissible stress of material. The numerical simulations indicate that the wheels on polar crane don’t derail during earthquake process because the wheel pressure is always compressive state. Considering the El Centro earthquake loading, the maximum vertical acceleration on polar beam of containment wall is 3.3 m/s² and less than gravity acceleration (9.8 m/s²).

Keywords. Polar crane, seismic response, numerical simulation, nuclear power station, natural frequency.

1. Introduction

In the nuclear power plant, the polar crane is responsible for carrying various loads, equipment installation and maintenance, replacement of nuclear fuel and other important work. The main hoist and the auxiliary hoist work together to ensure that all positions are covered in the nuclear island. Therefore, there are high requirements for the reliability, safety and accuracy of the polar crane. Especially in the earthquake, the dynamic response characteristics of the polar crane are directly related to the safety of other adjacent equipment, nuclear reactor and pipeline components. Politopoulos [1] established a numerical model of a real nuclear power plant and carried out numerical analysis. The results show that the soil structure interaction can cause base rocking excitation, which can amplify the non-isolated modal response. Sytos [2] established a numerical model of containment structure. Soil and foundation were divided into solid elements, and nuclear power plant containment structure was divided into shell elements. This paper studies the phenomenon of soil and foundation separation under a group of earthquakes with different frequencies. Hoseyni [3] studied the effect of soil structure interaction (SSI) on earthquake vulnerability of power station containment. Based on the results, the earthquake vulnerability and corresponding vulnerability curves of the structure are obtained. The overall seismic risk caused by soil structure interaction is quantitatively analyzed. Kabanda [4] established the Hualian seismic model, and studied the SSI in nuclear power facilities with the nonlinear analysis method. Hashash [5] proposed a new formula to calculate viscous damping.
and the surface response results calculated by the new formula are more accurate. Based on the earthquake data of swr1000 reactor building Bielor [6] established the numerical model of the structure to study the effect of SSI on the dynamic response. Jaya [7] built a scaled containment model and conducted dynamic response analysis to research the seismic performance of containment under the design and the beyond design earthquake. Politopoulos [8] considers that the horizontal floor response spectrum will be amplified at higher modal frequencies because the coupling effect of the non-isolated modes. Tuñón-Sanjú [9] established a coarse shell visco finite element model for soil structure interaction, and used the ANSYS to conduct dynamic analysis of fixed foundation. Ostadan [10] summarized an approach known as the "Nei method," explained the steps of applicability for the standard plants considering the seismic data. Loading from earthquake is presented as a time history of acceleration record. The analysis is based on the use of an old acceleration record, suitably scaled to the design maximum acceleration. This paper will investigate the earthquake responses of polar crane, evaluate the bearing capacity of girder of polar crane, and determine if the separation between wheels of polar crane and circular rail beam fixed on containment wall occurs during earthquake process.

2. Natural Frequencies of Polar Crane Fixed on Steel Containment Shell

As shown in figure 1, the polar crane consists of two horizontal parallel main girders (bridge) and a crane hoist (Trolley). The two horizontal main girders move along the annular runway fixed on steel containment wall and rotate in 360°. The crane hoist moves straightly on the two horizontal parallel main girders, as shown in figure 1.

The polar crane and containment wall are made by steel Q345B. The diameter of containment wall is 43 m. The length of two horizontal main girders is 40 m. The level of the annular runway is 42 m. The self-weight of polar crane including trolley is greater than 700 t. The hoisting capability of polar crane is greater than 600 t, as shown in figure 2. Shell element is used to model containment wall. Tree-dimensional beam element is used to model two horizontal parallel main girders, annular runway and crane hoist. Lumped mass is used to model hoisting weight.

To study the seismic properties of polar crane fixed on steel containment shell, seismic performance of structure are calculated using ABAQUS. The natural frequencies of polar crane fixed on steel containment shell are listed in table 1. It can be observed from table 1 that the distribution of frequencies of system is very dense.
Table 1. Natural frequencies of polar crane fixed on steel containment shell.

| No. of mode | Frequencies/Hz |
|-------------|---------------|
| 1           | 2.4401        |
| 2           | 3.4325        |
| 3           | 3.4327        |
| 4           | 3.4901        |
| 5           | 3.4902        |
| 6           | 3.6444        |
| 7           | 3.6446        |
| 8           | 3.8538        |
| 9           | 3.8540        |
| 10          | 3.9652        |

Figure 3 - figure 5 show the mode shapes of polar crane. The first order mode shape of polar crane is transverse horizontal deformation of two horizontal parallel main girders. The second order mode shape of polar crane is vertical deformation of crane hoist.

Figure 3. The first order mode shape of polar crane.

Figure 4. The second order mode shape of polar crane.

Figure 5. The third order mode shape of polar crane.
3. Numerical Analysis for Seismic Responses of Polar Crane

The wheels of two horizontal parallel main girders are fixed in the vertical direction and in the direction perpendicular to the rails, and are free to move with the containment wall. The trolley wheels are tied to the corresponding rail nodes at the top of the main girders.

The earthquake time histories are set to the bottom of containment wall. The El Centro, Las Angeles and Taft earthquake loadings are selected as input at the bottom of containment wall. The maximum accelerations of time histories of are normalized to 0.3 g (horizontal direction) and 0.2 g (vertical direction). A three-dimensional simulating model is created to study the structural static and coupled dynamic response of the polar crane by using finite element method.

Figures 6 and 7 show that the maximum Mises stresses in mid-span of girder of polar crane under the El Centro earthquake loading and Los Angeles earthquake loading are 131 Mpa and 133 Mpa respectively, and they are less than permissible stress of material. So, the girder of polar crane is safety under the action of El Centro earthquake loading and Los Angeles earthquake loading.

![Figure 6](image1.png)

*Figure 6. Variation of Mises stress in mid-span of girder of polar crane versus time under the El Centro earthquake loading.*

![Figure 7](image2.png)

*Figure 7. Variation of Mises stress in mid-span of girder of polar crane versus time under the action of Los Angeles earthquake loading.*
Table 2. Strength performances of girder of polar crane under the action of different earthquake loading.

| Loading cases                  | Maximum Mises stress/MPa | Safety Evaluation |
|--------------------------------|--------------------------|-------------------|
| Static loading                 | 72.0                     | $<\sigma_s/3=115\text{MPa}$ |
| El Centro earthquake loading   | 131.1                    | $<\sigma_s/3=171\text{MPa}$ |
| Las Angeles earthquake loading | 133.3                    | $<\sigma_s/3=171\text{MPa}$ |
| Taft earthquake loading       | 142.0                    | $<\sigma_s/3=171\text{MPa}$ |

Strength performances of girder of polar crane under the action of different earthquake loading are listed in table 2. In table 2, $\sigma_s$ is yielding strength of material, $\sigma_b$ is ultimate strength of material. For Q345B steel material, $\sigma_s=345\text{ MPa}$, $\sigma_b=513\text{ MPa}$.

Under the El Centro earthquake loading, the maximum vertical acceleration on polar beam of containment wall is $3.3\text{ m/s}^2$ and less than gravity acceleration ($9.8\text{ m/s}^2$), as shown in figure 8. So, derailing problem that means rails of crane girder separating from polar beam can not occur during earthquake period. The numerical simulations indicate that the wheels on polar crane don’t derail during earthquake process because the wheel pressure is always compressive state. The response properties of containment wall with supporting polar crane may modify the earthquake characteristics of polar crane. The containment wall will tend to response at its own fundamental frequency, changing the frequency distribution of the ground accelerations.

![Figure 8](image_url) Variation of vertical acceleration on polar beam of containment wall versus time under the El Centro earthquake loading.

4. Conclusions

1) Under the action of static loading, the safety property of main girders of polar crane meets the requirement of standards, and the maximum Von Mises stress on main girders of polar crane is less than one third of yielding limit of applied material.

2) Under the action of three typical earthquakes that the maximum accelerations of time histories of earthquake loading are normalized to $0.3\text{ g}$ (horizontal direction) and $0.2\text{ g}$ (vertical direction), the safety property of main girders of polar crane meets the requirement of standards, and the maximum Von Mises stress on main girders of polar crane is less than one third of ultimate limit of applied material.

3) The frequency characteristics of three typical earthquake loadings affect the seismic responses of polar crane. The seismic responses of polar crane will be strong while the preeminent frequency of earthquake wave approaches to the first order natural frequency of polar crane fixed on steel containment shell.

4) Under the action of El Centro earthquake loading, the maximum vertical acceleration on polar
beam of containment wall is 3.3 m/s² and less than gravity acceleration (9.8 m/s²). So, derailing problem that means rails of crane girder separating from polar beam can not occur during earthquake period.

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