2019 Asia-Pacific Conference on Emerging Technologies and Engineering (ACETE 2019)

# Influence of Ground Motion Input Method on Seismic Response of AP1000 Nuclear Island Containment Building in Non-basic Rock Site

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**Keywords:** containment building; concentrated mass system; input method

**Abstract:** Based on the AP1000 nuclear power unit project which is under construction, based on the ABAQUS finite element software platform, the multi-site concentrated mass system is used to simplify the nuclear island containment building, and the viscoelastic artificial boundary simulation site semi-infinite domain is set. The effect of the difference in input mode on the seismic response of the structure under the action of seismic waves has obvious differences in characteristics. The research shows that the vertical seismic response of the containment building is far less than the horizontal change, and the simplified horizontal one-way input method is reasonable and reliable.

## 1. Introduction

Nuclear power generation is developing rapidly. The number of traditionally excellent coastal lithologic nuclear power plants is limited. It is an inevitable trend to develop nuclear power plants on soft soil foundations in inland areas[1]. It is well known that multi-directional seismic response analysis of nuclear island structures has been the focus of seismic research.

The pile foundation treatment for the selection of inland non-basic soft soil foundation is a practical and feasible solution. Li Weixin[2] and other scholars based on CPR1000 nuclear reactor buildings are the research objects, and the nuclear island structure on the undisturbed foundation and pile treatment foundation is compared. The floor response spectrum and the difference between the interlayer displacement and the interlaminar shear force show that the pile treatment method has obvious effect on improving the seismic level of the nuclear island structure, but the seismic wave is selected single and the seismic wave input mode is single. Hou Chunlin[3] compared the seismic response of the foundations of different nuclear island structures under the action of ground motion, but the soil parameters of the foundation are still based on the equivalent linear method, and the computational model is effective in simulating the nonlinear characteristics of the soil foundation. There is a lack of effects.

In order to solve the above problems, this paper takes an AP1000 nuclear power project as the research object, and uses the finite element software ABAQUS as the computing platform to establish the overall numerical model of the non-basic rock foundation combined with the containment building. Exploring the earthquake-resistant requirements of the nuclear island containment structure on the non-basic rock site after the change of the ground motion input mode, the earthquake with its nonlinear effect and the pile-soil-structure interaction effect is significant. Respond to changes that occur.

## 2. Establishment of calculation model

### 2.1 Nonlinear constitutive model of site soil

The stress-strain relationship of soil is described by Davidenkov constitutive model with irregular loading and unloading correction proposed by Zhao Dingfeng et al.[4]. The expression of the initial skeleton curve is specifically expressed by formulas (1) and (2). Gmax and maximum r are initial shear modulus and reference shear strain respectively; A and B are the experimental parameters of soil; yc represents the strain at the unloading point; the symbol "plus or minus" takes "-" when loaded and "+" when unloaded.

DOI: 10.25236/acete.2019.118

$$\tau = G \cdot \gamma = G_{\max} \cdot \gamma \cdot \left[1 - H(\gamma)\right] \quad (1)$$

$$H(\gamma) = \left\{ \frac{(\gamma / \gamma_r)^{2B}}{1 + (\gamma / \gamma_r)^{2B}} \right\}^{A} \quad (2)$$

$$\tau - \tau_c = G_{\max} \cdot (\gamma - \gamma_c) \cdot \left[1 - H\left(\frac{|\gamma - \gamma_c|}{2n}\right)\right] \quad (3)$$

$$(2n\gamma_{\mathrm{r}})^{2B} = (\gamma_{\mathrm{ex}} \pm \gamma_{\mathrm{c}})^{2B} \cdot \left(\frac{1-R}{R}\right) \quad (4)$$

$$R = \left(1 - \frac{\tau_{ex} \pm \tau_c}{G_{\max} \cdot (\gamma_{ex} \pm \gamma_c)}\right)^{\frac{1}{A}} \quad (5)$$

The dynamic constitutive model parameters of soil for calculation are shown in table 1. The relation between the dynamic shear modulus ratio G/Gmax and the damping ratio of each soil sample λ with the dynamic shear strain γ is shown in figure 1.

Table 1 Constitutive mode parameters of the site

| Layer no. | Soil viscosity | Severe (KN/m$^4$) | $G_{max}$(GPa) | $u$ | $A$ | $B$ | $\gamma_r$ |
|---|---|---|---|---|---|---|---|
| 1 | Silty clay ① | 18.1 | 0.020 | 0.49 | 1.2 | 0.48 | 0.0008768 |
| 2 | Silty clay ② | 19.0 | 0.020 | 0.49 | 1.2 | 0.48 | 0.0008768 |
| 3 | Silt① | 19.3 | 0.110 | 0.49 | 1.8 | 0.32 | 0.0008124 |
| 4 | Silty clay ③ | 18.9 | 0.106 | 0.49 | 1.36 | 0.38 | 0.0008894 |
| 5 | Silty clay ④ | 19.4 | 0.125 | 0.48 | 1.2 | 0.4 | 0.0008078 |
| 6 | Silty clay ⑤ | 19.6 | 0.207 | 0.47 | 1.6 | 0.4 | 0.0008578 |
| 7 | Silt② | 20.1 | 0.240 | 0.32 | 1.6 | 0.33 | 0.0008132 |

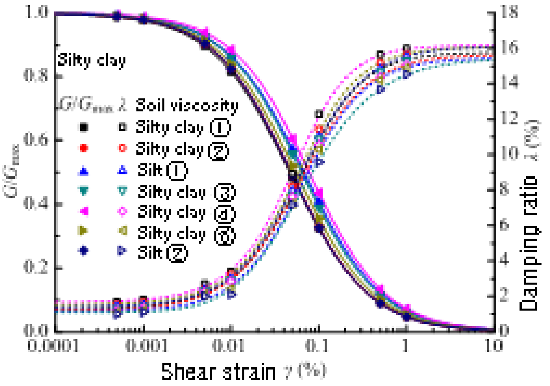


Fig. 1 Curves of *G-r* and *D-r* of soils

## 2.2 Model parameters of nuclear island containment building model and group-pile foundation model

In the two-dimensional overall finite element calculation model, the pile foundation is divided into bearing platform and group piles. The group pile foundation is composed of 240 bored cast-in-place piles with diameter of 1.5m and pile length of 37.6m. The 240 solid group piles in the actual project are simplified into 20 equivalent piles. Table 2 shows the calculation parameters of pile beam element. Beam element was selected for simulation. The planar dimension of bearing platform was 78m x 46m and 3m thick.The centralized mass bar system was used to simplify the containment building of an AP1000 nuclear island, and the detailed overall finite element calculation model is shown in Figure 2. The mass and rotational inertia of the two structures are concentrated on each node, and the simulation of geometrical moment of inertia and shear area, which are used to resist torque and shear deformation, is carried out by the beam element between the two nodes. The two-dimensional viscoelastic artificial boundary proposed by Zhang Xiaolong et al.[5] is adopted to simulate the semi-infinite domain of non-bedrock site.

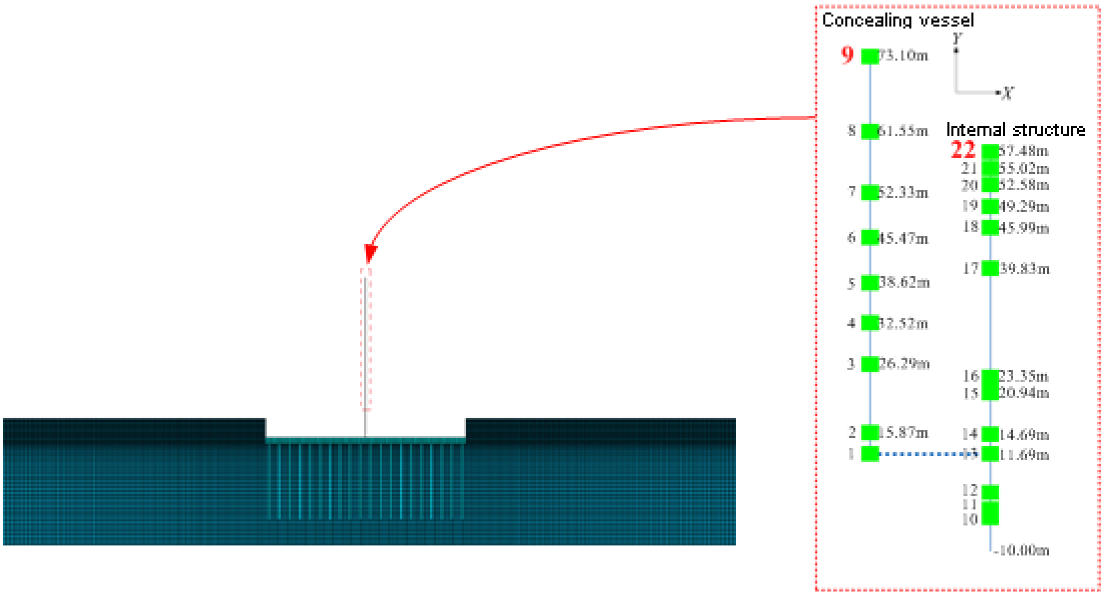


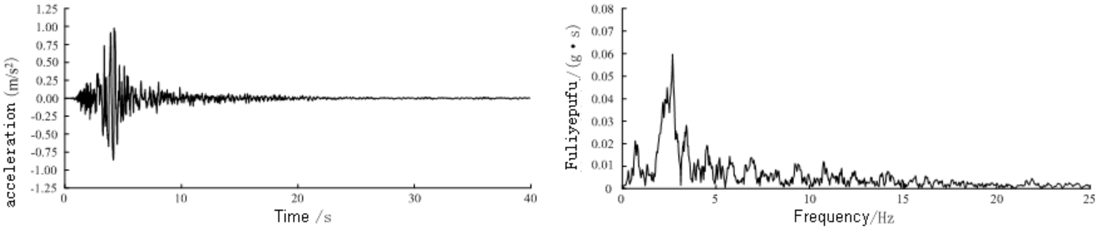
Figure 2 Overall finite element calculation model local grid diagram and safety shell building enlargement diagram

Table 2Beam element parameters of the modelpile

| Parameter category | Elastic Modulus /kPa | Shear modulus /kPa | Severity /kN·m$^{-3}$ | Cross-sectional area /m$^2$ | Effective shear area factor | Moment of inertia /m$^4$ |
|---|---|---|---|---|---|---|
| Parameter value | $3.26\times10^7$ | $1.30\times10^7$ | 25 | 1.7671 | 0.9 | 0.2485 |

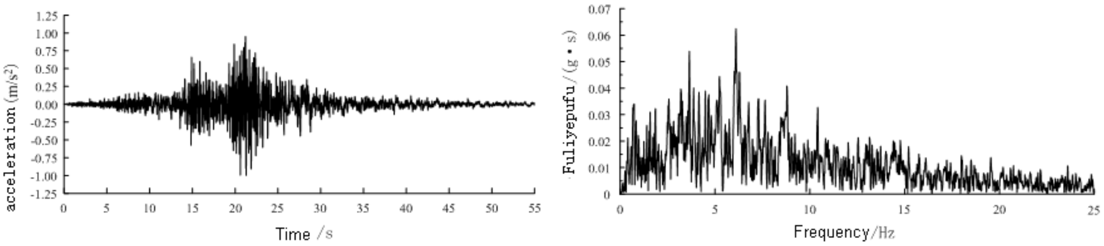
## 3. Input ground motion

The low-frequency rich near-field Loma Prieta wave and the medium-high frequency relatively rich mid-field Aizuruo-song wave (hereinafter referred to as AIZU wave) are selected as the calculation model for the bedrock input seismic wave, and the corresponding acceleration time history and response input ground motion spectrum characteristics of Fuli The leaf spectrum is shown in Figure 3.



Loma Price wave acceleration time map

Loma Price wave acceleration Fu spectrum



AIZU wave acceleration time map

AIZU wave acceleration Fu spectrum

Fig. 3 Time-histories of acceleration and Fourier spectra used as the input motion

## 4 Influence of ground motion input method on seismic response at the top of the structure

### 4.1 Influence of multi-directional input ground motion on seismic response at the top position of the structure

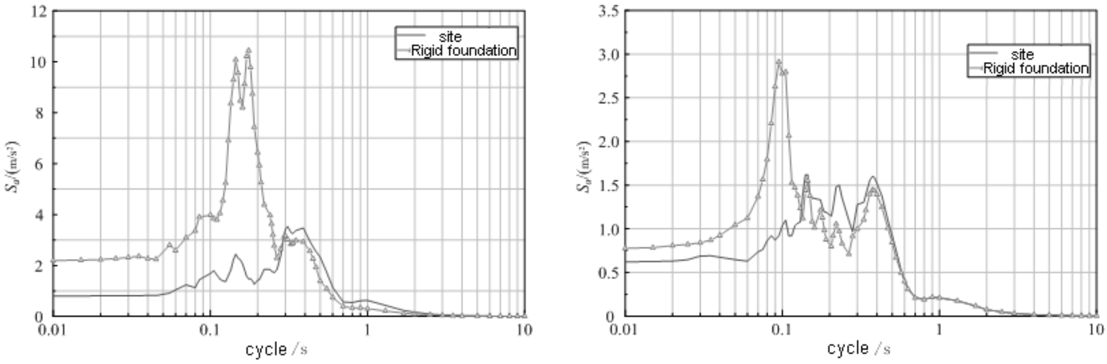
The input ground motions with obvious difference in spectral characteristics are amplitude-modulated to 0.3g, and the calculation models are input simultaneously in the X-direction and Y-direction at the bedrock position. The calculation results of inputting two kinds of ground motions are shown in Fig. 4 and Fig. 5. . It can be seen from the calculation results that when the Loma Prieta wave is input, the amplitude of the response spectrum of the node 9 in the X direction is about 16.6% higher than that of the node 22 under the rigid ground condition, and the amplitude of the response spectrum of the former is higher than that of the latter. About 0.31%, the gap is almost negligible. The amplitude of the response spectrum of node 9 in the X direction is also about 14.3% higher than that of node 22 under non-bedrock site conditions. Also in the Y direction, the response spectrum of node 9. The amplitude is about 0.28% higher than node 22. When the AIZU wave is input, the amplitude of the response spectrum of the upper node 9 is 11% higher than that of the upper node 9 under the rigid ground condition, and the upper node 9 is only 0.33% higher. Similarly, under the actual site conditions, the node 9 is in the X direction. It is also 10% higher and 0.29% higher in Y. It is not difficult to see that the difference in amplitude between the amplitudes of the acceleration response spectra at the two vertices of the structure in the same degree of freedom is small, and is hardly affected by the difference in the overall stiffness of the soil layer where the nuclear island is located and the two vertices are in the X direction. The amplitude difference of the response spectrum is much larger than the difference between the two Y-directions.

In addition, the ground motion input with obvious difference between the two spectral characteristics is calculated. Under the same working condition, the amplitudes of the Y-direction response spectra of the nodes 9 and 22 are almost equal, so it can be found that the top position of the structure is sensitive to the X-direction seismic excitation, but is insensitive to the Y-direction.

It can be seen from Fig. 4 that when the Loma Prieta wave is being imported, the short-cycle attenuation of the response spectrum of the node 9 and the node 22 in the X-direction can be as high as 85.9% and 85.8%, when both appear at 0.175 s, by contrast, the maximum attenuation of the short-cycle attenuation of the acceleration response spectrum in the Y direction is also equal, up to 68.4%, so that the maximum reduction in the short-period of the X-direction acceleration response spectrum at both top positions is 1.25 times the Y direction, and node 9. The response spectrum pattern in the same degree of freedom as that of node 22 does not change, and the high-frequency attenuation period of the two-node acceleration response spectrum is shortened from 0.295 s in the X direction to 0.135 s in the Y direction. When the AIZU wave is input, the short-cycle attenuation amplitude of the X-direction acceleration response spectrum at the same two positions is 85.4% and 86.1%, respectively, which is 1.07 times and 1.08 times of the corresponding maximum reduction of 79.5%. Compared with the Loma Prieta wave, the high-frequency decay period of the two-node response spectrum is reduced from 0.5 s in the X direction to 0.16 s in the Y direction. Therefore, it is not difficult to see the influence of the difference in the nonlinear effect of the soil layer caused by the difference in the overall stiffness of the site on the difference of the seismic response at the top position of the structure, and the non-base rock site soil in terms of the high frequency attenuation of the acceleration response spectrum. The significant nonlinear effect and the interaction effect between pile and soil structure have a significantly higher impact on the seismic response of the X-direction at the top of the structure than the seismic response to the Y-direction. From the perspective of long-period amplification of the acceleration response spectrum, the position of the node 9 is higher than that of the node 22, but the input of any selected ground motion, the long-term amplification characteristics of the acceleration response spectrum in the Y direction there is hardly any change. Summarizing the results of the above three sections, it is not difficult to find out from the unfolded multi-directional input ground motion that the difference in seismic response between the two top positions of the structure in the Y direction is small. For this reason, the input of ground motion is changed from the perspective of improving computational efficiency. In this way, only the X-direction input calculation is performed on the overall calculation model, and the feasibility of simplifying the input ground motion mode is further explored.

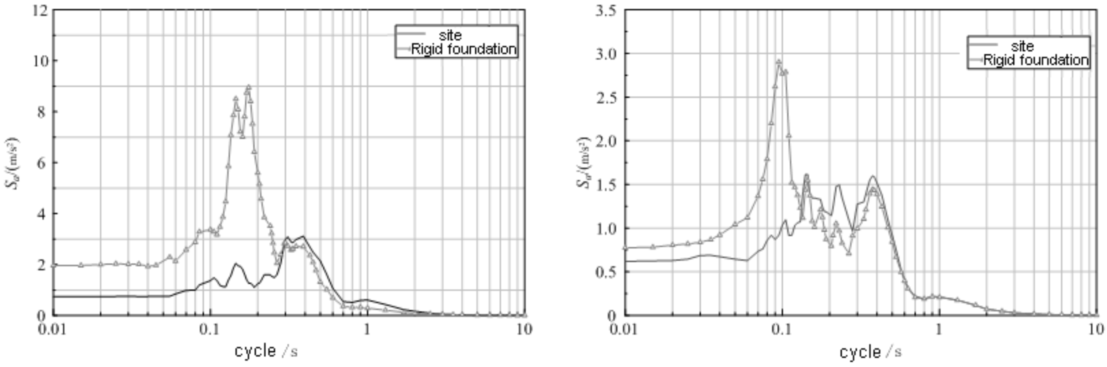
### 4.2 Impact of one-way input ground motion on the seismic response at the top of the structure and comparative analysis of the results with multi-direction input

Combining Figure 4, Figure 5 and Figure 6, the characteristic period and peak acceleration of x-direction acceleration response spectrum in multi-direction and unidirectional ground motion input mode were summarized,the results are shown in table 3When input Loma Prieta wave, the characteristic cycles of nodes 9 and 22 in the one-way input mode were extended by 0.21s and 0.22s respectively, and the characteristic cycles at the corresponding multi-direction input mode were extended by 0.135s, which was about 35.7% and 38.6% lower than the extension time of the basic cycle of response spectrum in the one-way input mode. When input AIZU wave, Node 9 and 22 in a unidirectional input mode acceleration response spectrum characteristics of the cycle extended respectively 0.13 s and 0.14 s and corresponding multidirectional input mode instead of the characteristics of the two cycles are shortened 0.03 s, this explains the contrast observation figure 5 and figure 6 reflects with the decrease of the foundation soil stiffness of one-way input mode of the structure of the acceleration response spectrum segment showed significantly enlarge trend for a long period of time. Contrast the differences of two spectrum characteristic obvious input fields, whether it is a multidirectional input mode or one-way input fields vibration way, under the condition of rigid foundation Loma Prieta and AIZU wave differences between the calculation results of acceleration response spectrum peak, obviously, this is because the stiffness of the nuclear structure itself is very big, so the overall calculation model of total stiffness level will be very high, the high frequency of earthquake ground motion of the relative abundance of assembly obviously better than the low frequency amplification of ground motion. The calculation results of the two types of ground motion were further observed. Under the condition of non-bedrock site, the characteristic periods of the response spectrum of Loma Prieta waves in different input modes were significantly longer than those of AIZU waves in different input modes. Regardless of the input mode difference under the condition of the former Loma Prieta wave input peak acceleration response spectrum of the acceleration are also lower than the latter corresponding calculation results of AIZU wave, which further shows that nuclear containment building combining with the calculation model of the whole rock sites in stiffness levels increase, its structure is always on the high frequency is relatively rich in the earthquake response of ground motion is more significant.



X direction of node 9

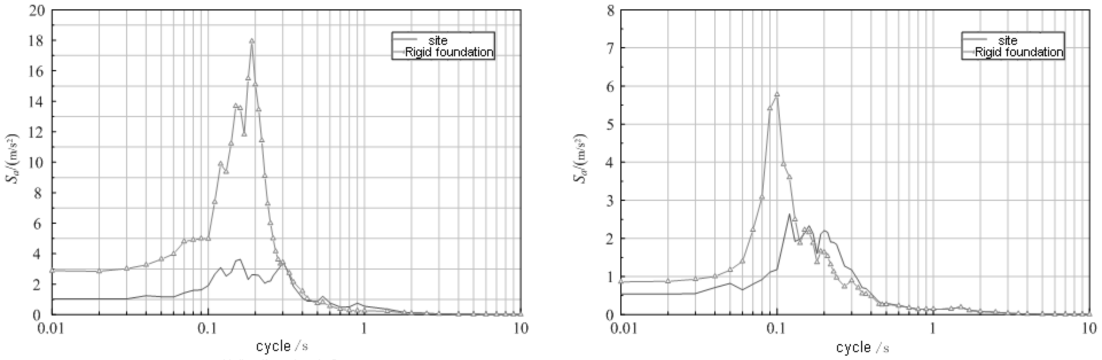
Y direction of node 9



X direction of node 22

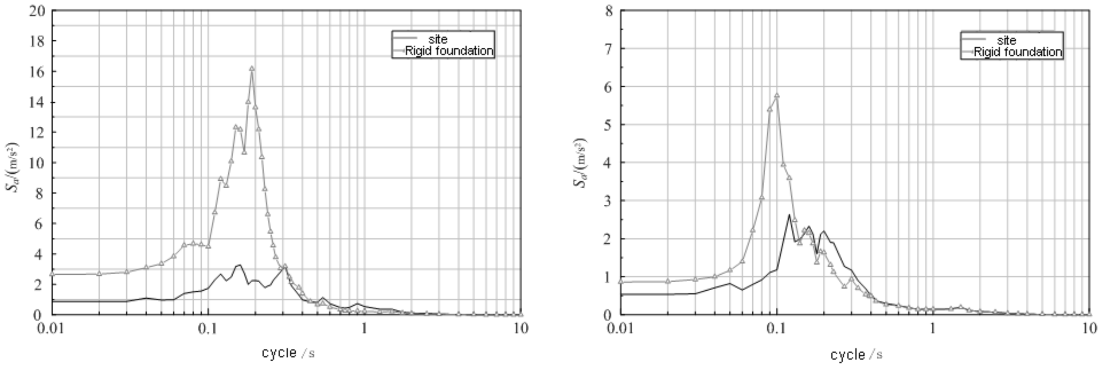
Y direction of node 22

Fig. 4 Acceleration response spectra used as LP motion of top locations



X direction of node 9

Y direction of node 9



X direction of node 22

Y direction of node 22

Fig. 5 Acceleration response spectra used asAIZU motion of top locations

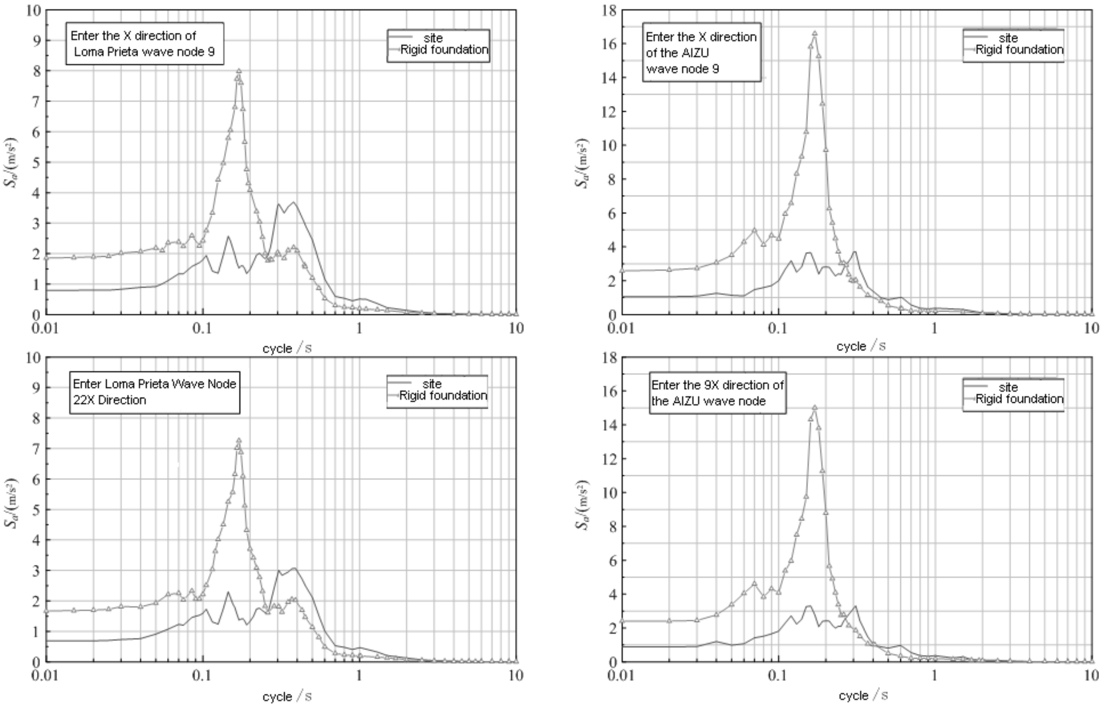


Fig. 6 Acceleration response spectra in X direction of top locations

Table 3 Comparisons of peak value and period of acceleration response spectra in Direction X

| Input mode | Loma Prieta wave | | AIZU wave | |
|---|---|---|---|---|
| | rigid foundation (period/s)/(crest value/m·s$^{-2}$) | Site(period/s)/(crest value/m·s$^{-2}$) | rigid foundation (period/s)/(crest value/m·s$^{-2}$) | Site (period/s)/(crest value/m·s$^{-2}$) |
| Multi-way (Node 9) | 0.175/10.43 | 0.31/3.53 | 0.19/17.93 | 0.16/3.62 |
| One-way (Node 9) | 0.17/7.98 | 0.38/3.68 | 0.17/16.58 | 0.30/3.69 |
| Multi-way (Node 22) | 0.175/8.95 | 0.31/3.11 | 0.19/16.16 | 0.16/3.28 |
| One-way (Node 22) | 0.17/7.25 | 0.39/3.17 | 0.17/15.01 | 0.31/3.31 |

## 5. Conclusion

1) According to the AP1000 standard design specification, the multi-input Seismic calculation was carried out for the total model. The calculation results showed that there were significant differences in the horizontal X-axis acceleration response spectra between the core mass points at the top of the containment and the internal structure with significant differences in elevation, while the differences in the vertical Y-axis response spectra of the two structures were almost negligible. It verifies the rationality and feasibility of the single horizontal X input Seismic calculation.

2) Comparing the calculation results under the two input modes, under the condition of non-bedrock site, the change in the seismic response of the upper structure caused by the soil dynamic nonlinearity under the unidirectional input mode and the pile-soil-structure interaction effect was higher than that under the multi-direction input mode. The seismic response at the top of the structure in the multi-input mode is significantly higher than that in the one-way input mode, because the coupling effect of the multi-input seismic wave intensifies the energy of ground motion.

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