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Research Article

Study on the Bearing Plate of Steel Clarification Tank under Earthquake

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The stress at the support structure of the clarification tank is large, which will have a certain impact on the whole clarification tank structure. The typical stress concentration phenomenon will cause structural damage and serious harm to the steel clarification tank itself. In order to study the influence of the bearing plate on the seismic response of steel clarification tank, this paper analyzes the dynamic response of the clarification tank by setting different thickness bearing plates at the connection between the steel column and the structure body of the steel clarification tank. Based on the displacement, stress, and liquid sloshing height of the steel clarification tank, the thickness of the bearing plate is obtained. The results show that the maximum stress of the steel clarification tank under different seismic waves decreases with the increase of the thickness of the bearing plate. The thickness of the bearing plate has a certain influence on the maximum displacement of the clarification tank structure, but the increase in the thickness of the bearing plate does not necessarily reduce the maximum displacement. Different bearing plate thicknesses have no effect on the position of displacement, and the maximum displacement occurs at the top of the outer wall.

1. Introduction

In recent years, China's economic development and industrialization continue to advance, and the use of tank structures has become more common. Clarification tank is a mechanically constructed sedimentation tank for coagulation of water and removal of suspended solids and colloids from water or liquid. Because of the particularity of its function, the steel clarification tank has a sudden change in the section of the bearing section of the steel column, which leads to a sudden increase in various stresses and adverse loads on the structure. The problems of structural seepage and cracking caused by stress concentration are often hidden and not easy to be found. Once this situation is found, it is not easy to deal with, and it is easy to cause major safety accidents. Therefore, it is necessary to avoid it as much as possible in the design. Therefore, it is necessary to optimize the bearing plate at the stress concentration.

Sun [1] analyzed the seismic response and parameter sensitivity of a vertical liquid storage tank. Feng et al. [2] analyzed the water tank's dynamic response under liquid-solid coupling. Zhang et al. [3] carried out seismic response analysis of rectangular and circular concrete liquid storage structures. Jie [4] calculated the control equation of dynamic response under a high sloshing state. By studying the dynamic changes of the composite isolation structure, Lin et al. [5] obtained the effect of this combined isolation of the liquid storage tank. Zhang et al. [6] studied the three-dimensional finite element model of the vertical dome-roof liquid storage tank. Deng et al. [7] studied the influence of different seismic waves on the peak sloshing of liquid. Yu [8] studied the reliability of liquid storage structures. Zhang et al. [9] explored the vibration characteristics of the outer tank of an LNG storage tank. Housner [10] analyzed the hydrodynamic pressure generated by the fluid container. Sharari et al. [11] carried out nonlinear dynamic analysis of LNG storage tanks under the 1994 Beiling and 1995 Kobe earthquakes. Subba and Gorla [12] coupled thermal profile and structural designs. Kim et al. [13] proposed two simplified seismic response analysis models. Cheng et al. [14] studied the reduced sloshing effect of steel rectangle tank and the seismic response of plate-shell integrated concrete tank. Gabbianelli et al. [15] used the OpenSees finite element program to establish an accurate numerical model and conducted a detailed parameter study on the influence of separation on the isolation tank.

In summary, there exist some studies on the seismic response of liquid storage tanks. In order to study the influence of the thickness of the bearing plate on the ground motion response of the steel clarification tank, the dynamic response analysis of the connection between the steel column of the clarification tank and the tank is carried out by adding different thicknesses of the bearing plate. The stress, displacement, and liquid sloshing of the clarification tank structure under each thickness of the bearing plate are analyzed, and a suitable support plate is found, which provides the corresponding reference data for engineering design and application.

2. Analysis Model and Parameters

The model analysis diagram is shown in Figure 1, and the parameter selection is shown in Table 1. The clarification tank is a steel structure. The diameter of the outer tank is 11.50 m, the diameter of the inner tank is 3.65 m, and the height is 10.50 m. The main components include a deflector, reaction cylinder, sump, fender, and other components such as steel plates. In the establishment of the model, the clarification tank is divided into many small elements by meshing the established geometry. The clarification tank's wall, inner bucket, cone, and bottom plate are divided into shell elements to obtain a three-dimensional finite element analysis model.

3. Seismic Waves

Due to the uncertainty of the occurrence of earthquakes and the randomness of the location, it is difficult to obtain actual seismic records that are consistent with the proposed site area. In order to ensure the accuracy of the calculation, the selection of seismic waves is very important in the process of dynamic response analysis. The selected seismic waves should not only reflect the maximum deformation effect of the structure under earthquake but also meet the actual seismic design requirements. Generally, seismic waves have three elements: the spectral characteristics of ground motion, the intensity of ground motion, and the duration of ground motion [16, 17]. The El Centro, Trinidad, and Chalfant Valley seismic wave are used in this paper.

4. Analysis of Steel Clarification Tank under Earthquake

4.1. Structural Stress

4.1.1. 10 mm Bearing Plate Thickness. Under the action of El Centro, Trinidad, and Chalfant Valley seismic waves, the dynamic response of a steel clarification tank with a 10 mm bearing plate is analyzed. The stress calculation results of the steel clarification tank are shown in Figure 2.

As can be seen from Figure 2, under El Centro seismic wave, the maximum stress of the 10 mm bearing plate thickness clarifying tank is 3.637×10^8 Pa, under Trinidad seismic wave, the maximum stress of the 10 mm bearing plate thickness clarifying tank is 4.002×10^8 Pa, under Chalfant Valley seismic wave, the maximum stress of the 10 mm bearing plate thickness clarifying tank is 3.627×10^8 Pa, and the maximum stress of the structure occurs at the connection between the outer wall panel and the tank support. Through the comparison of the stress program of the steel clarification tank with 10 mm bearing plate thickness under El Centro, Trinidad, and Chalfant Valley seismic waves, it can be found that the maximum stress of the steel clarification tank under different seismic waves is different. The maximum stress of the steel clarification tank under the Chalfant Valley seismic wave is the smallest, followed by the maximum stress of the El Centro seismic wave clarification tank, and the maximum stress of the Trinidad seismic wave clarification tank is the largest, which indicates that the seismic wave has a certain influence on the maximum stress of the structure. The maximum stress of the structure occurs at the connection between the outer wall plate and the tank support.

4.1.2. 12 mm Bearing Plate Thickness. Under the action of El Centro, Trinidad, and Chalfant Valley seismic waves, the dynamic response of a steel clarification tank with 12 mm bearing plate is analyzed. The stress calculation results of the steel clarification tank are shown in Figure 3.

As can be seen from Figure 3, the maximum stress of the 12 mm bearing plate thickness clearing tank under the El Centro seismic wave is 3.637×10^8 Pa, the maximum stress of the 12 mm bearing plate thickness clearing tank under the Trinidad seismic wave is 4.002×10^8 Pa, and the maximum stress of the 12 mm bearing plate thickness clearing tank under the Chalfant Valley seismic wave is 3.627×10^8 Pa. By comparing the stress nephogram of the steel clarification tank under El Centro, Trinidad, and Chalfant Valley seismic waves with the thickness of 12 mm bearing plate, it can be found that the maximum stress of the steel clarification tank under different seismic waves is different. The maximum stress of steel clarification tank under El Centro seismic wave is the smallest, followed by the maximum stress of steel clarification tank under the Chalfant Valley seismic wave, and the maximum stress of the steel clarification tank under the Trinidad seismic wave is the largest, which indicates that seismic wave has a certain influence on the maximum stress of structure.

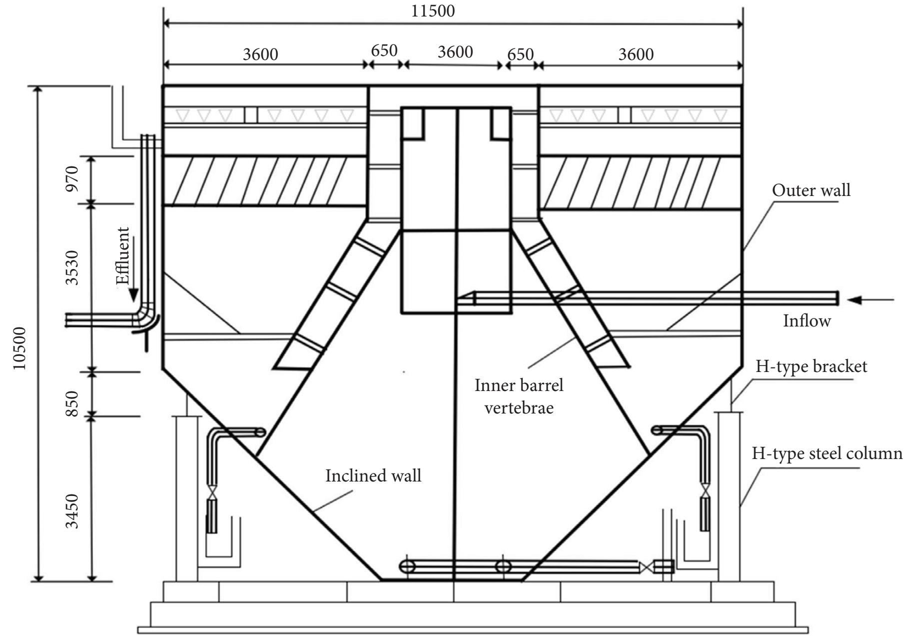
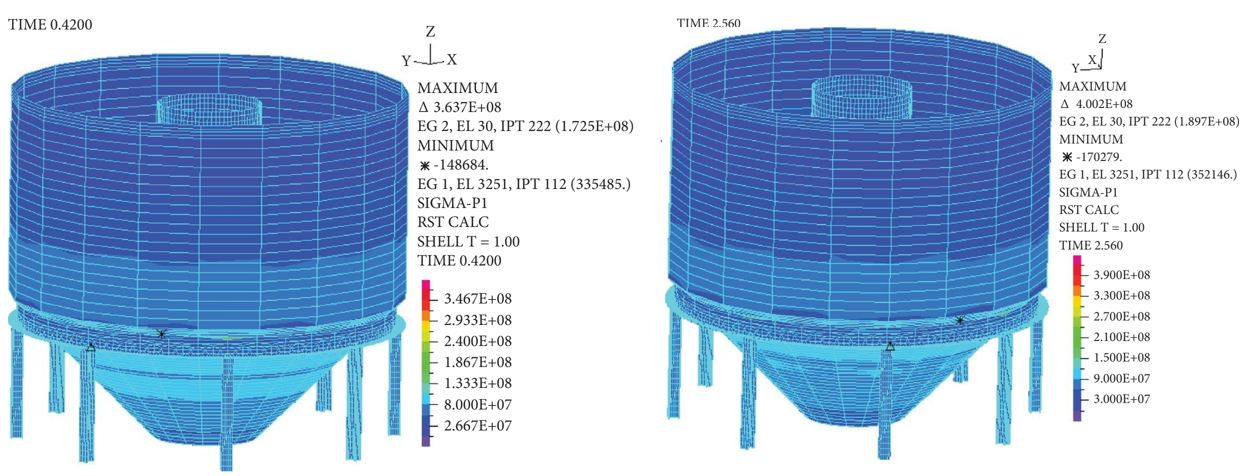


Figure 1: Clarification tank (unit: mm).

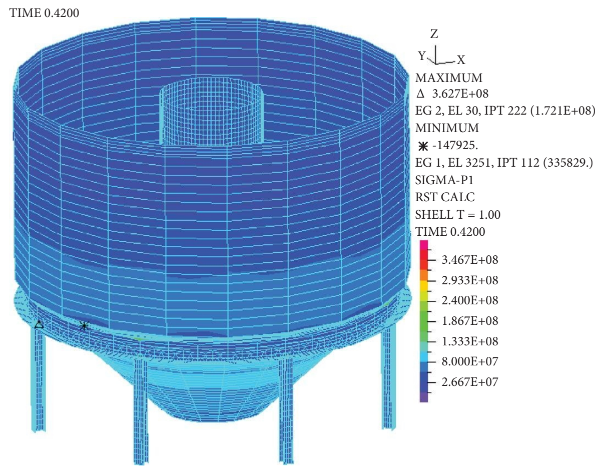
Table 1: Model parameters.

Parameter	Value
Elastic modulus E (Pa)	2.1×10^{11}
Poisson's ratio μ	0.3
Density ρ (kg/m^3)	7800
Acceleration of gravity g (m/s^2)	9.8



(a) (b)

Figure 2: Continued.



(c)

Figure 2: The stress nephogram of clarification tank with 10 mm thickness bearing plate. (a) El Centro seismic wave. (b) Trinidad seismic wave. (c) Chalfant Valley seismic wave.

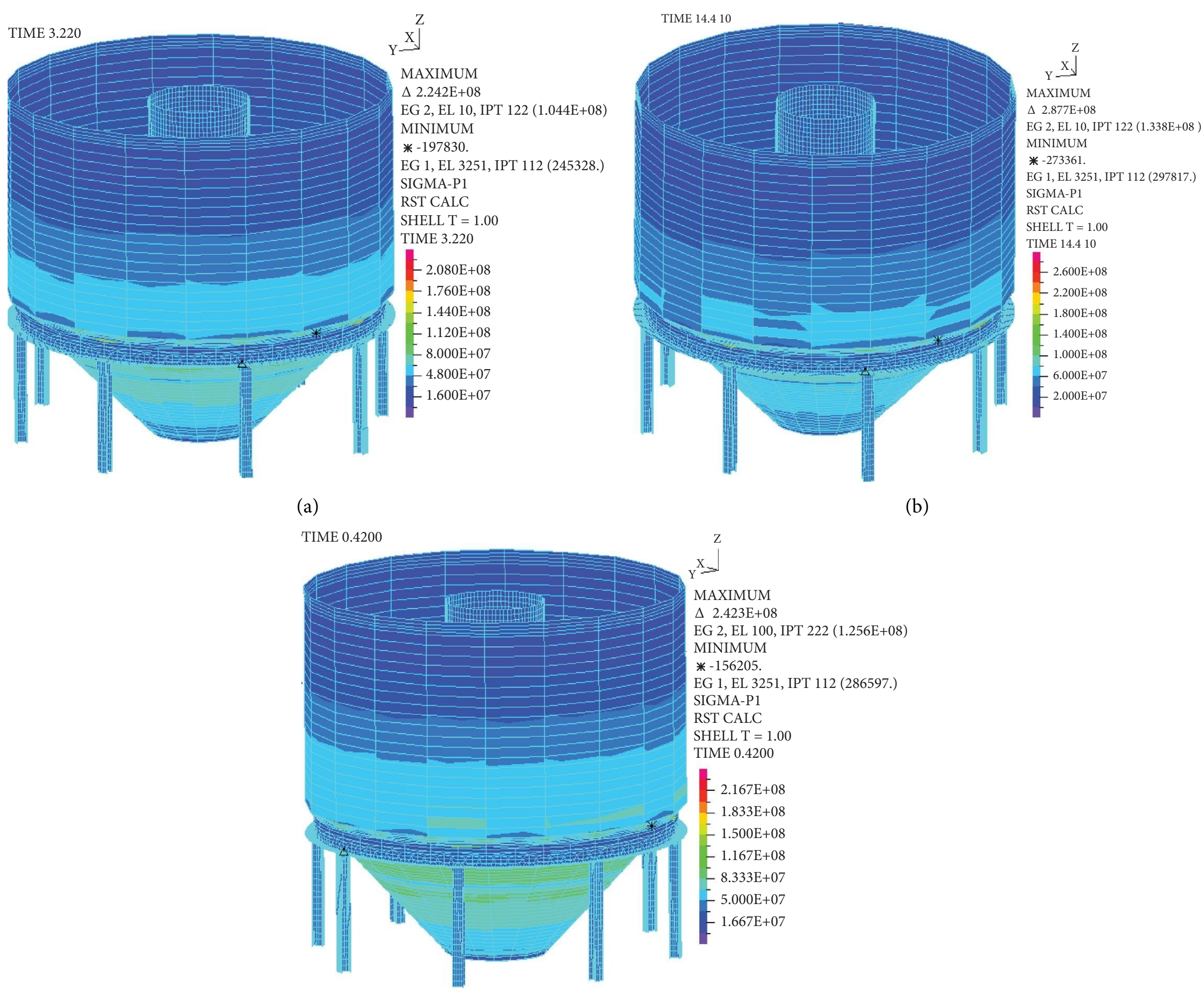


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Figure 3: The stress nephogram of clarification tank with 12 mm thickness bearing plate. (a) El Centro seismic wave. (b) Trinidad seismic wave. (c) Chalfant Valley seismic wave.

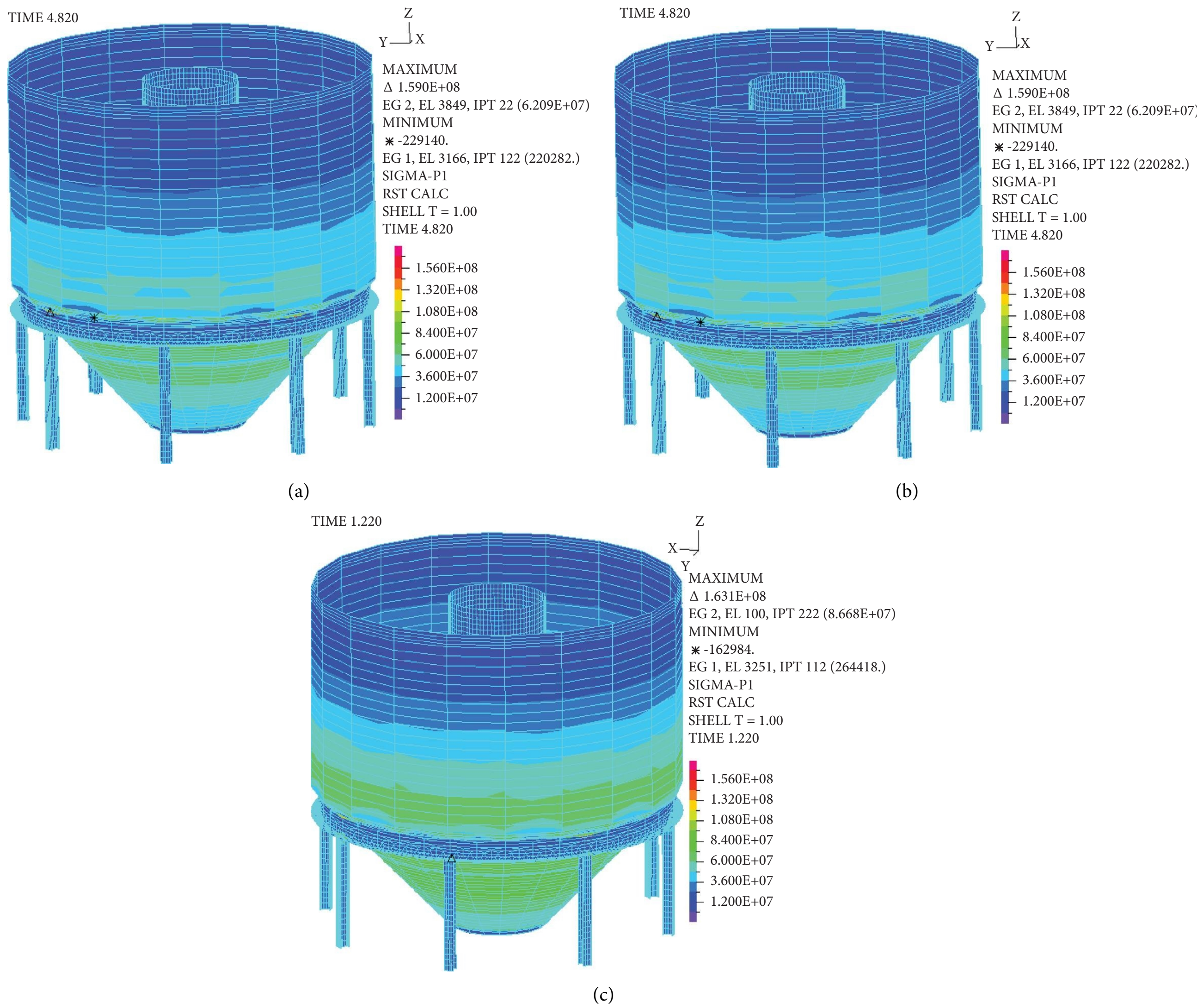


Figure 4: The stress nephogram of the steel clarification tank with 15 mm thickness bearing plate. (a) El Centro seismic wave. (b) Trinidad seismic wave. (c) Chalfant Valley seismic wave.

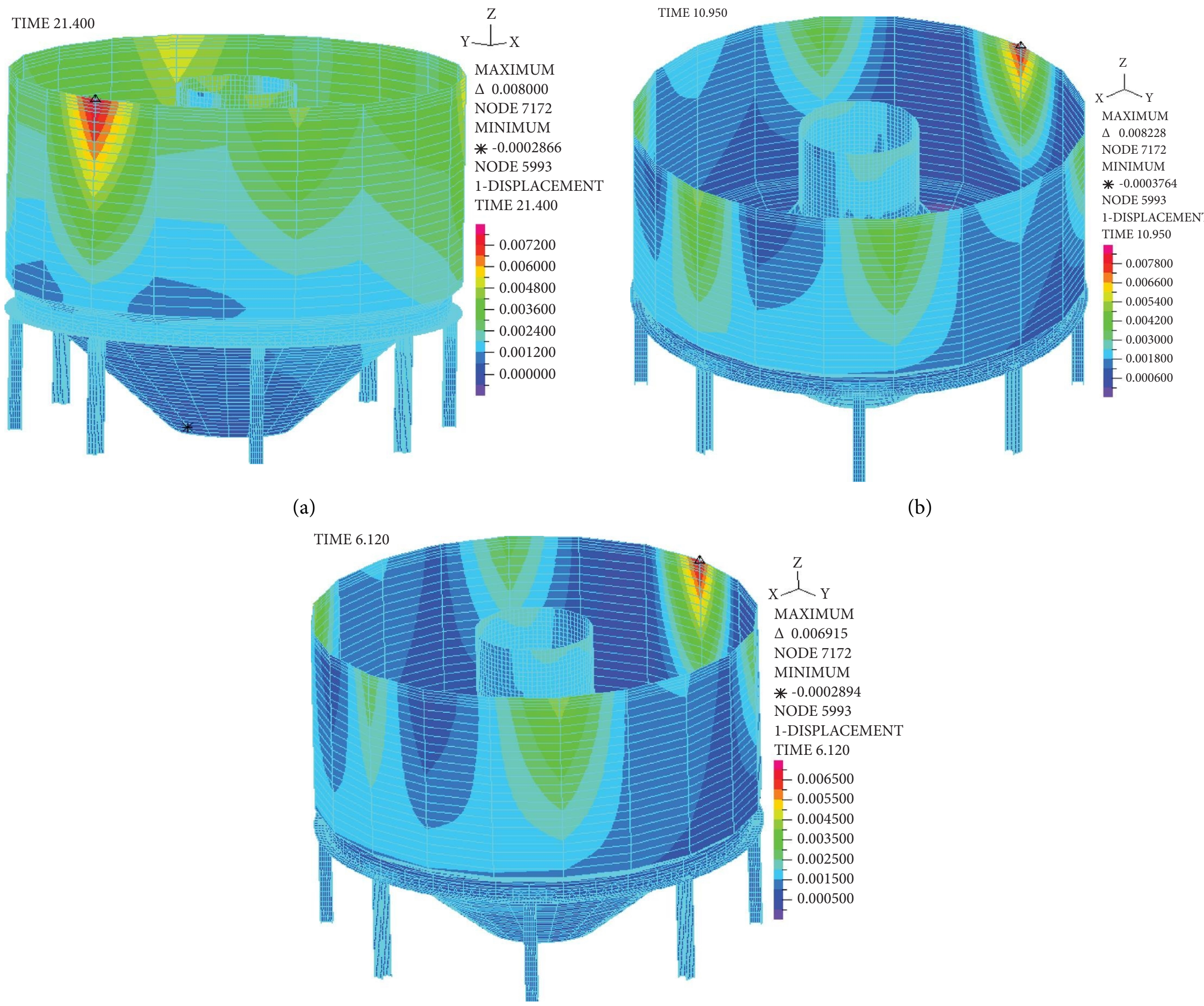
4.1.3. 15 mm Bearing Plate Thickness. Under the action of El Centro, Trinidad, and Chalfant Valley seismic waves, the dynamic response of a steel clarification tank with 15 mm bearing plate is analyzed. The stress calculation results of the steel clarification tank are shown in Figure 4.

As can be seen from Figure 4, under El Centro seismic wave, the maximum stress of 15 mm bearing plate thickness clarification tank structure is 1.590×10^8 Pa, under Trinidad seismic wave, the maximum stress of 15 mm bearing plate thickness clarification tank structure is 1.892×10^8 Pa, and under Chalfant Valley seismic wave, the maximum stress of 15 mm bearing plate thickness clarification tank structure is 1.631×10^8 Pa. By comparing the stress nephograms of the steel clarification tank with 15 mm plate bearing thickness under El Centro, Trinidad, and Chalfant Valley seismic waves, it can be found that the maximum stress of the steel clarification tank under different seismic waves is different. The maximum stress of the steel clarification tank under El Centro seismic wave is the smallest, followed by the maximum stress of the steel clarification tank under the Chalfant Valley seismic wave, and the maximum stress of the steel clarification tank under the Trinidad seismic wave is the largest, which indicates that the seismic wave has a certain influence on the maximum stress of the structure. The maximum stress of the structure occurs at the connection between the outer panel and the support.

4.2. Structural Displacement

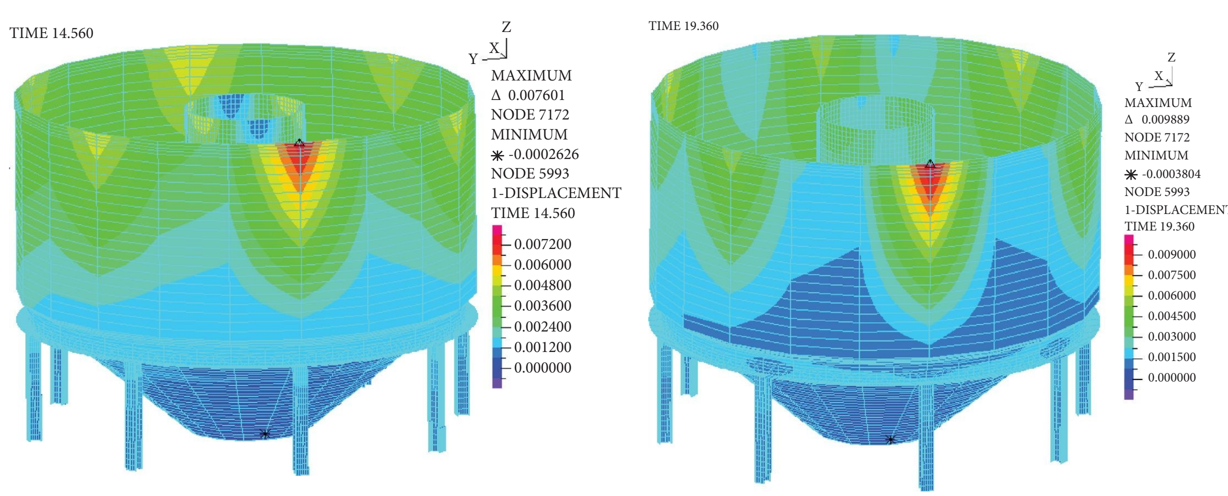
4.2.1. 10 mm Bearing Plate Thickness. Under the action of El Centro, Trinidad, and Chalfant Valley seismic waves, the dynamic response of a steel clarification tank with 10 mm bearing plate is analyzed. The displacement calculation results of the steel clarification tank are shown in Figure 5.

As can be seen from Figure 6, under the El Centro seismic wave, the maximum displacement of the 10 mm bearing plate thickness clarification tank structure is 8.000 mm, under the Trinidad seismic wave, the maximum



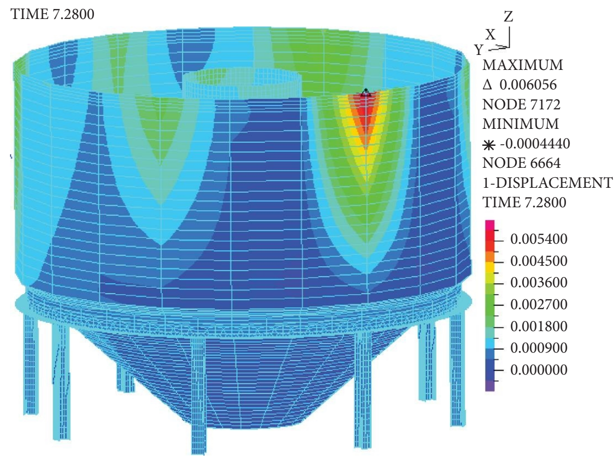
(a) (b) (c)

Figure 5: Displacement nephogram of clarification tank with 10 mm thickness bearing plate. (a) El Centro seismic wave. (b) Trinidad seismic wave. (c) Chalfant Valley seismic wave.



(a) (b)

Figure 6: Continued.



(c)

Figure 6: Displacement nephogram of clarification tank with 12 mm thickness bearing plate. (a) El Centro seismic wave. (b) Trinidad seismic wave. (c) Chalfant Valley seismic wave.

displacement of the 10 mm bearing plate thickness clarification tank structure is 8.228 mm, and under the Chalfant Valley seismic wave, the maximum displacement of the 10 mm bearing plate thickness clarification tank structure is 6.915 mm. By comparing the displacement of steel clarification tank structures under El Centro, Trinidad, and Chalfant Valley seismic waves with 10 mm wall thickness, it can be seen that the maximum displacement of steel clarification tank structures under different earthquakes is different. The maximum displacement of steel clarification tank structure under the Chalfant Valley seismic wave is the smallest of the three seismic waves. The maximum displacement of the clarification tank structure under the El Centro seismic wave is relatively small, and the maximum displacement of clarification tank structure under the Trinidad seismic wave is the largest. The maximum displacement of the steel clarification tank structure under three kinds of seismic waves occurs at the top of the outer wall, and the location is in the direction of seismic wave input.

4.2.2. 12 mm Bearing Plate Thickness. Under the action of El Centro, Trinidad, and Chalfant Valley seismic waves, the dynamic response of a steel clarification tank with 12 mm bearing plate is analyzed. The displacement calculation results of the steel clarification tank are shown in Figure 6.

As can be seen from Figure 6, under the El Centro seismic wave, the maximum displacement of the 12 mm bearing plate thickness clarification tank structure is 7.601 mm. Under the Trinidad seismic wave, the maximum displacement of the 12 mm bearing plate thickness clarification tank structure is 9.889 mm. Under the Chalfant Valley seismic wave, the maximum displacement of the 12 mm bearing plate thickness clarification tank is 6.056 mm. By comparing the displacement of steel clarification tank structures under El Centro, Trinidad, and Chalfant Valley seismic waves with 12 mm bearing plate thickness, it can be seen that the maximum displacement of steel clarification tank structures under different earthquakes is different. The maximum displacement of steel clarification tank structure under Chalfant Valley seismic wave is the smallest of the three seismic waves. The maximum displacement of clarification tank structure under El Centro seismic wave is relatively small, and the maximum displacement of clarification tank structure under Trinidad seismic wave is the largest. The maximum displacement of steel clarification tank structure under three kinds of seismic waves occurs at the top of the outer wall.

4.2.3. 15 mm Bearing Plate Thickness. Under the action of El Centro, Trinidad, and Chalfant Valley seismic waves, the dynamic response of steel clarification tank with 15 mm bearing plate is analyzed. The displacement calculation results of steel clarification tank are shown in Figure 7.

As can be seen from Figure 7, the maximum displacement of the 15 mm bearing plate thickness clarification tank structure under the El Centro seismic wave is 5.966 mm, the maximum displacement of the 15 mm bearing plate thickness clarification tank structure under the Trinidad seismic wave is 7.447 mm, and the maximum displacement of the 15 mm bearing plate thickness clarification tank structure under the Chalfant Valley seismic wave is 6.671 mm. By comparing the displacement of steel clarification tank structure with 15 mm bearing plate thickness under El Centro, Trinidad, and Chalfant Valley seismic waves, it can be seen that the maximum displacement of steel clarification tank structure is different under different seismic waves. The maximum displacement of steel clarification tank structure under Chalfant Valley seismic wave is the smallest among the three seismic waves. The maximum displacement of clarification tank structure under El Centro seismic wave is relatively small, and the maximum displacement of clarification tank structure under Trinidad seismic wave is the largest. The maximum displacement of steel clarification tank structure under three kinds of seismic waves occurs at the top of the outer wall.

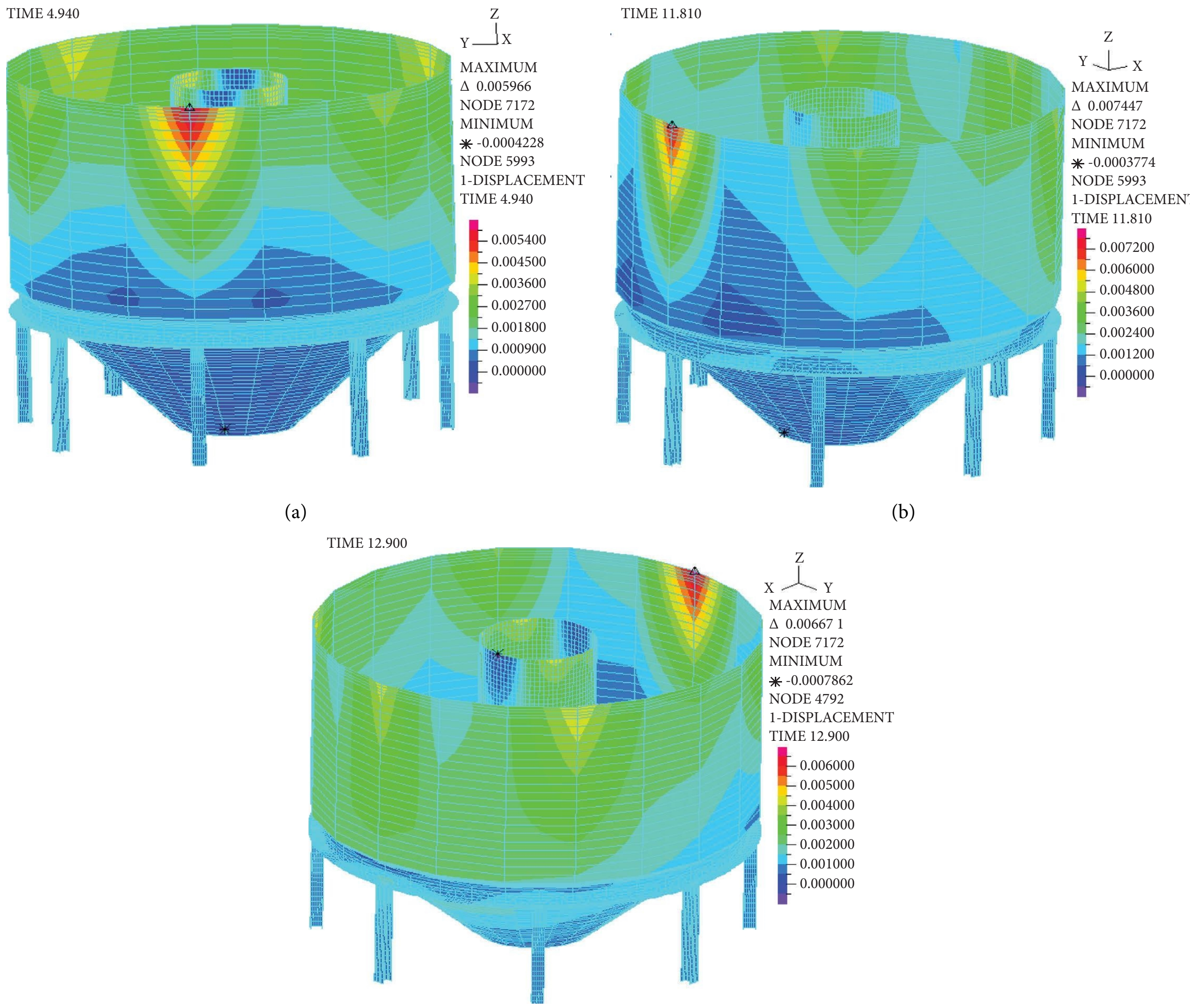


FIGURE 7: Displacement nephogram of clarification tank with 15 mm thickness bearing plate. (a) El Centro seismic wave. (b) Trinidad seismic wave. (c) Chalfant Valley seismic wave.

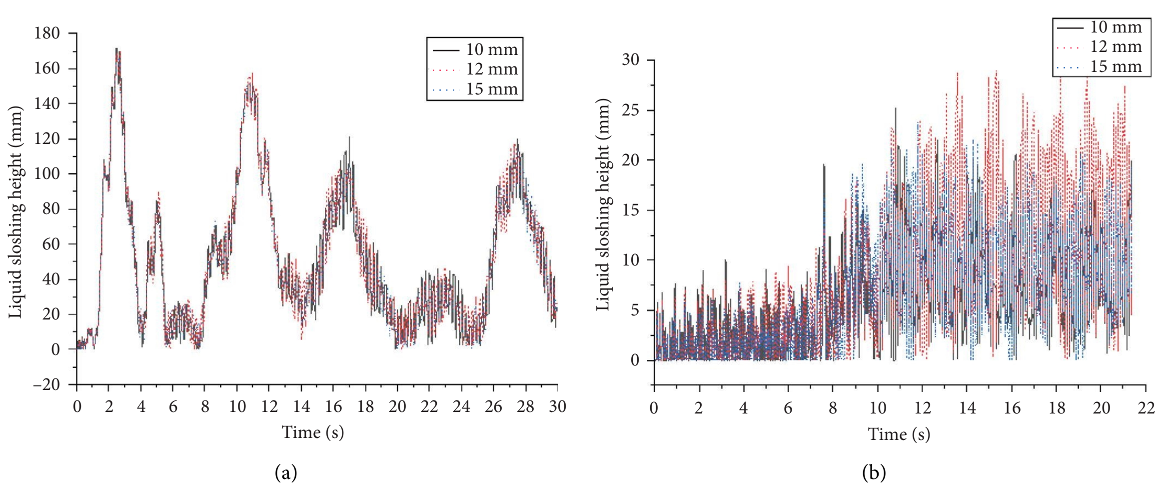
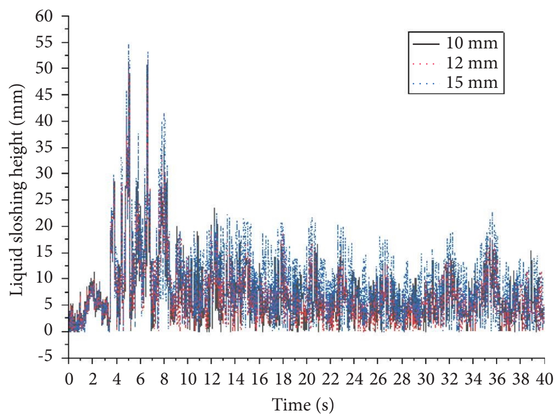


FIGURE 8: Continued.



(c)

Figure 8: The influence on liquid sloshing with different bearing plate thicknesses under different seismic waves. (a) El Centro. (b) Trinidad. (c) Chalfant Valley.

Table 2: Economic analysis of bearing plates with different thicknesses.

Bearing plate specification	Unit price (Yuan)	Total price (Yuan)	Growth rate (%)
350 mm × 350 mm × 10 mm	131.31	1050.48	—
350 mm × 350 mm × 12 mm	157.57	1260.56	20
350 mm × 350 mm × 15 mm	183.85	1470.80	40

4.3. Liquid Sloshing Peak. Under the action of El Centro seismic wave, the dynamic response of the steel clarification tank with the bearing plate thickness of 10 mm, 12 mm, and 15 mm is analyzed. The sloshing of the liquid in the clarification tank is shown in Figure 8(a). Under the action of Trinidad seismic wave, the dynamic response of the steel clarification tank with the bearing plate thickness of 10 mm, 12 mm, and 15 mm is analyzed. The sloshing of the liquid in the clarification tank is shown in Figure 8(b). Under the action of Trinidad seismic wave, the dynamic response of the steel clarification tank with the bearing plate thickness of 10 mm, 12 mm, and 15 mm is analyzed. The sloshing of the liquid in the clarification tank is shown in Figure 8(c).

In Figure 8(a), through the analysis of the liquid sloshing in the clarification tank under the thickness of 10 mm, 12 mm, and 15 mm, the sloshing of the clarification tank under the El Centro seismic wave with different thicknesses of the plate is the same, and the thickness of the plate has little effect on the sloshing of the liquid in the clarification tank. Under El Centro seismic wave, the maximum height of liquid sloshing of 10 mm thickness bearing plate is 172.5 mm, the maximum height of liquid sloshing of 12 mm thickness bearing plate is 168.6 mm, and the maximum height of liquid sloshing of 15 mm thickness bearing plate is 166.9 mm.

It can be seen from Figure 8(b) that the sloshing of the clarification tank under the Trinidad seismic wave is basically the same for different pads. The thickness of the bearing plate has little effect on the sloshing of the liquid in the clarification tank, and the splash of the liquid in the clarification tank is more obvious under the bearing plate thickness of 12 mm. The maximum height of liquid sloshing in the clarification tank with 10 mm bearing plate thickness under Trinidad seismic wave is 25.22 mm. The maximum height of liquid sloshing in the clarification tank with 12 mm bearing plate thickness under the Trinidad seismic wave is 29.00 mm.

In Figure 8(c), the liquid sloshing heights of the clarification tank with the bearing plate thickness of 10 mm, 12 mm, and 15 mm are analyzed. The sloshing of the clarification tank with different bearing plate thicknesses under the Chalfant Valley seismic wave is basically the same, and the thickness of the plate has little effect on the sloshing of the liquid in the clarification tank. The maximum height of liquid sloshing in the clarification tank with 10 mm bearing plate thickness under the Chalfant Valley seismic wave is 51.85 mm. The maximum height of liquid sloshing in the clarification tank with 12 mm bearing plate thickness under the Chalfant Valley seismic wave is 50.83 mm.

In summary, through the analysis of the clarification tank with the bearing plate thickness of 10 mm, 12 mm, and 15 mm under three kinds of seismic waves, it can be seen that except for the splash phenomenon under individual seismic waves, the sloshing of the liquid in the clarification tank is almost the same under the same seismic wave. The maximum height is also basically close, and the time of occurrence is almost the same, indicating that the sloshing of the liquid is not related to the thickness of the pad but related to the seismic wave.

5. Economic Analysis

According to the above analysis, the plane size of the bearing plate is 350 mm × 350 mm, and the thickness of the bearing plate is 10 mm, 12 mm, and 15 mm, respectively. There are 8 pieces in total. The price of the bearing plate with different thicknesses is shown in Table 2.

As can be seen from Table 2, the cost increases with the increase in the thickness of the bearing plate. Through the economic analysis of the thickness of 10 mm, 12 mm, and 15 mm bearing plates, if the bearing plates with thickness of 12 mm and 15 mm are used, the cost of bearing plate increases by 20% and 40%, respectively, but the total price is small compared with the whole structure, that is, only 210.08 yuan and 420.32 yuan, respectively. Therefore, the increased cost of bearing plates is small. Therefore, in the structural design, a relatively thick plate should be chosen.

6. Conclusions

Through the analysis of the maximum stress of El Centro, Trinidad, and Chalfant Valley seismic waves in 10 mm, 12 mm, and 15 mm bearing plate thickness clarification tank, the maximum stress of steel clarification tank under three kinds of seismic waves decreases with the increase of the thickness of the plate, which indicates that increasing the thickness of the plate can reduce the maximum stress.

The thickness of the bearing plate has a certain influence on the maximum displacement of the tank structure, but the increase in the thickness of the bearing plate does not necessarily reduce the maximum displacement. The thickness of the bearing plate does not affect the position of the displacement, and the position of the maximum displacement is at the top of the outer wall.

By applying three different seismic waves to the steel clarification tank with the bearing plate thickness of 10 mm, 12 mm, and 15 mm, it can be seen that the liquid sloshing is almost the same under the same seismic wave, the maximum height is also basically close, and the time of occurrence is also similar, indicating that the liquid sloshing is less affected by the thickness of the bearing plate and the liquid splashes under the action of the Trinidad seismic wave.

Under the condition that the structural members meet the ground motion stress, the thickness of the bearing plate should be increased appropriately.

Results in this paper are only limited to the clarification tank shown in Figure 1. For steel clarification tanks of other types, similar analysis should be performed again.

Data Availability

All data, models, and codes generated or used during the study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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