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Modal Analysis of a Super-large FRP Combined Tank System with Floating Roof Considering the Coupled Effect of Tank Fluid

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Abstract. The modal analysis of the super-large FRP combined tank structure system with floating roof is carried out. Firstly, the finite element model of the super-large FRP combined tank structure system with floating roof is established. Then, the modal analysis of the super-large FRP combined tank structure system with floating roof is carried out. The results show that when the storage height is less than or equal to 50% of the total storage height, the first-order frequency of the FRP combined tank fluid coupling vibration is very small. When the storage height is large, the vibration frequency of the FRP combined storage tank liquid coupling is larger than that when the water storage state is less than or equal to 50%. The vibration frequency of the tank fluid coupling also decreases with the increase of the tank radius. The larger the tank radius is, the more significant the tank fluid coupling effect is.

1. Introduction

Since the reform and opening up, the demand for petroleum energy at home and abroad has been increasing, and the volume requirements for temporary storage equipment are increasing. Therefore, an innovative research on large-sized new storage tanks is urgent. In the early 1960s, Western countries and other places began to build 100,000 cubic meters of floating roof storage tanks. By the end of the 1960s, Venezuela took the lead in building a floating roof storage tank with a volume of 150,000 cubic meters[1]. The establishment of large domestic storage tanks began in the 1970s. In 1975, the construction of the first 50,000 cubic meters of floating roof storage tanks was completed at Chenshan Terminal in Shanghai, dozens of 50,000 cubic meters of floating roof tanks had been built in ports, oil fields, chemical systems[2]. However, the large-scale development of storage tanks poses a major challenge to current design and construction technologies. The use of large-volume storage tanks is extremely demanded, and the corrosion resistance and impermeability of the tank walls must be ensured, and the loss of the tank under external fire and external impact is minimized, and the structure is guaranteed to have good airtightness. The floating roof in the conventional storage tank is exposed to the outside for a long time, and in the low temperature area, it is impossible to effectively solve the problems such as snow melting and melting, so that the floating roof can not fully exert its function, so it is imperative to develop a new type of super large storage tank system. This paper proposes an ultra-large FRP combined tank structure system with floating roof. The combined tank structure includes tank top, tank wall and tank bottom. The tank top adopts FRP net shell structure; the



tank wall is sandwiched between two inner and outer FRP plates, (RPC) which are consisted of active powder concrete. The inner FRP plate and the outer FRP plate are connected by FRP splice plate through tongue and groove. The floating roof is installed in the tank wall[3]-[8]. This structural system can solve the problem, which the existing conventional steel storage tanks have not been able to meet the development needs well.

2. Finite element model of a super-large FRP combined tank structure with floating roof

2.1 Structural System Simplified Mechanical Model

The FRP combined tank structure system tank adopts a fully symmetrical cylindrical vertical tank structure. The basic parameters of the tank are: the tank volume is $160,000 \text{ m}^3$, the tank inner diameter D is 100 m, the tank height H is 21.7 m, the liquid storage height H_w is 20.18 m, and the inner and outer layers of the tank wall are FRP plates. The double wall thickness t_f is taken as 0.1 m. The intermediate layer of the tank wall and the bottom are made of reactive powder concrete (RPC100) with excellent performance. The wall thickness t_c of the tank wall is taken as 2 m, and the bottom plate t_b is taken as 5 m. The outer diameter is 104.4 m. The floating roof of the tank is a FRP plate, and the thickness t_f is taken as 0.1 m. The simplified mechanical model of the super large FRP combined storage tank is shown in figure 1. The main parameters of the FRP composite tank structural materials are shown in table 1.

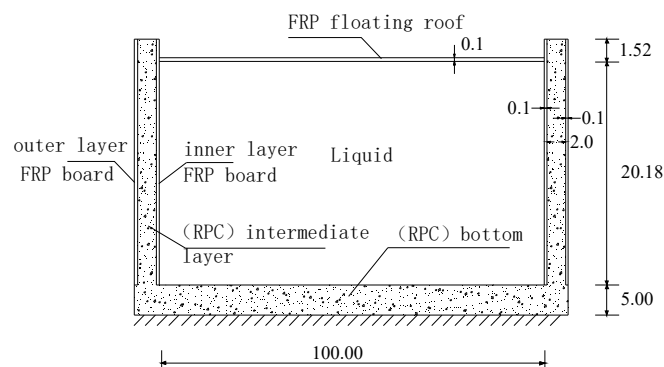


Figure 1. Simplified mechanical model (unit: m).

In practical applications, the storage material of the storage tank is generally crude oil, but since the density of the crude oil is less than water and the viscosity of the crude oil is greater than that of water, during the earthquake the hydrodynamic pressure of the water on the tank wall is greater than the hydrodynamic pressure generated by the crude oil. From the perspective of safety, the medium in the tank is safe to choose water.

Table 1. Main parameters of materials.

Material category	Density ρ (kgm^{-3})	Elastic modulus E (Nm^{-2})	Poisson's ratio	Bulk modulus (Nm^{-2})
RPC100	2500	4×10^{10}	0.2	---
FRP board	1800	1.5×10^{10}	0.2	---
Water	1000	---	---	2×10^9

2.2 Establishment of finite element model of a super-large FRP combined storage tank structure with floating roof

The tank wall RPC concrete, the inner and outer FRP plates, the base floor and the floating roof are all entities with a large thickness, so 8-D solid elements are used, but due to different thicknesses, three unit groups are set; The liquid adopts 8-node three-dimensional unit. When the tank liquid is coupled, the liquid surface is set as the fluid-solid coupling fluid unit; the sliding contact between the floating roof and the tank wall contact surface is provided. In this paper, 3-D single-sided rigid contact is selected. The finite element model of the completed FRP combined storage tank with floating roof is shown in figure 2.

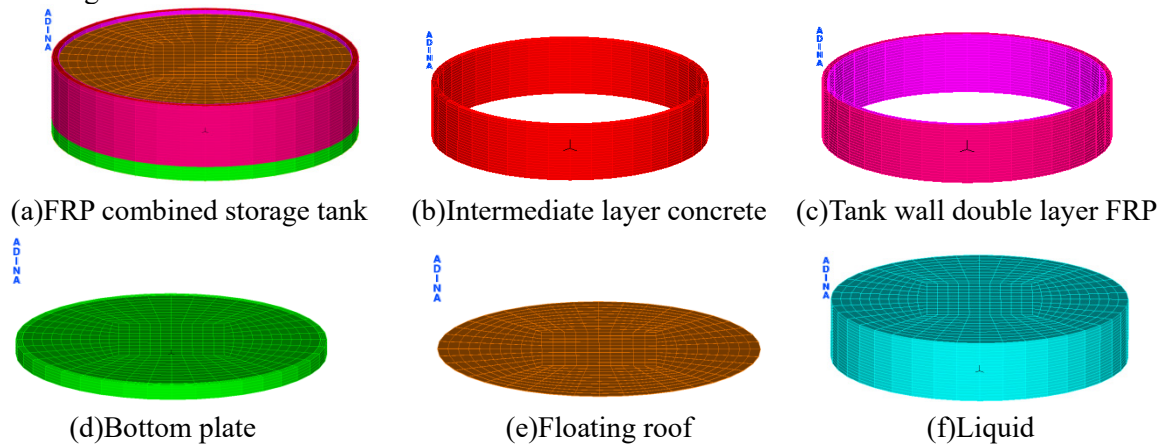
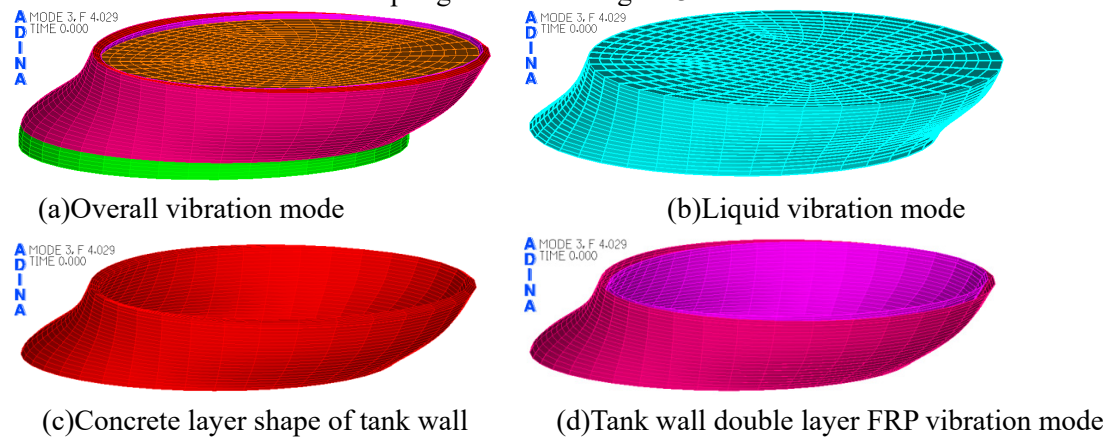


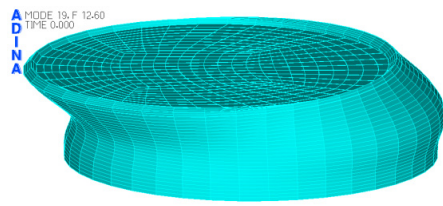
Figure 2. Finite element model of FRP combined tank structure system with floating roof.

3. Vibration mode analysis of liquid coupling of FRP combined tanks with floating roof

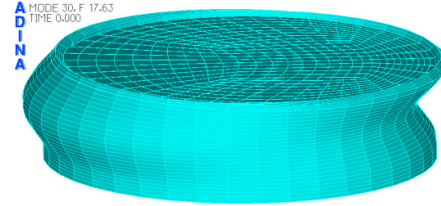
Considering the liquid coupling vibration analysis of the tank with floating roof, the displacement of the liquid surface and the floating roof contact surface is constrained in the Z direction, that is, the floating of the floating roof and the liquid surface Z direction is controlled, and the inherent vibration of the tank fluid is coupled. The frequency is much larger than the frequency of the reservoir sloshing. The first three modes of the tank fluid coupling is shown in figure 3.



(1) FRP combined storage tank with liquid storage height of 20.18m is coupled with first-order vibration mode.



(2)The second-order vibration mode.



(3)The third-order vibration mode.

Figure 3. The first three modes of the FRP combined tank fluid coupling vibration with floating roof.

4. Influence of water storage height on liquid coupling mode of FRP combined storage tank with floating roof

In order to study the effect of water storage height on the vibration coupling frequency of FRP combined storage tank with floating roof, we list the first three-order frequencies of liquid coupling vibration of FRP combined storage tank with different storage heights in table 2. Figure 4 shows the first three-order frequency curve of the fluid coupling vibration of the FRP combined storage tank with different floating heights.

Table 2. Tank fluid coupling vibration frequency at different water storage heights.

H_w (m)	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)
2.018	7.790	11.34	18.41
4.036	7.661	11.42	17.84
6.054	7.184	11.55	17.27
8.072	6.581	11.75	17.01
10.090	6.003	12.02	17.15
12.108	5.506	12.33	17.65
14.126	5.086	12.64	18.51
16.144	4.717	12.85	18.69
18.162	4.370	12.88	18.22
20.180	4.029	12.60	17.63

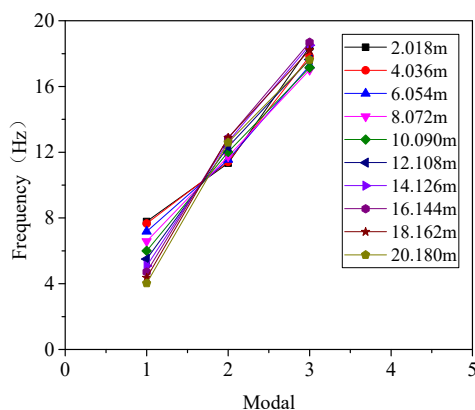


Figure 4. Comparison of the first three-order frequencies of the FRP combined storage tank with different floating heights.

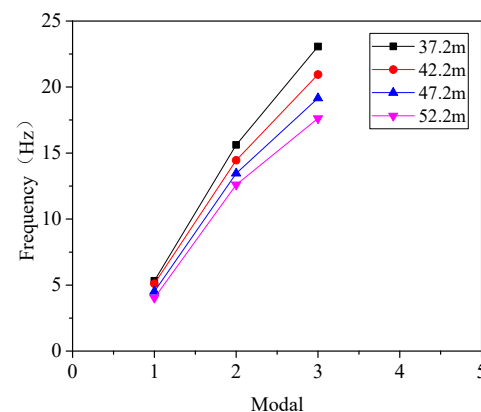


Figure 5. The first three-order frequencies of the FRP combined storage tank at different tank radius.

It can be seen from table 2 and figure 4 that the FRP combination tank fluid coupling vibration first-order frequency has a small difference when the water storage height is less than or equal to 50% of the total water storage height. When the storage height is large, there is a large increase in the

vibration frequency when the water storage state is less than or equal to 50%. Compared with the vibration frequency coupled without the floating roof tank, the first-order frequency decreases when the floating roof is considered, and the second and third order vibration frequency changes are not obvious, but the overall trend is gradually increasing.

5. Influence of water storage radius on liquid coupling mode of FRP combined tank with floating roof

In order to compare the influence of different tank radius on the liquid coupling vibration mode of floating tank, this paper still selects the modal analysis of the storage tank radius of 37.2m, 42.2m, 47.2m and 52.2m. The height is 20.18m. Table 3 lists the first three-order frequencies of the FRP combined tank system tank fluid coupling corresponding to different tank radius. Figure 5 shows the first three-order frequency curves of the FRP combined tank system tank fluid coupling for different tank radius.

Table 3. Tank fluid coupling vibration frequency at different tank radius.

R(m)	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)
37.2	5.328	15.62	23.07
42.2	5.100	14.45	20.95
47.2	4.511	13.46	19.16
52.2	4.029	12.60	17.63

It can be seen from table 3 and figure 5 that the vibration frequency of the tank fluid coupling also decreases with the increase of the tank radius. The larger the tank radius is, the more significant the tank fluid coupling effect is. Compared with the vibration frequency of the liquid coupling mode of FRP combined tank without the floating roof, the first-order frequency of the FRP combined tank system with floating roof is reduced, the decrease is not large, and the second-order and third-order vibration frequency increase trend is obviously larger than the first-order increase degree.

6. Conclusion

In this paper, the first three modes and their variation rules are given for the tank fluid coupling mode of FRP combined tank system with floating roof. The conclusion is as follows: the vibration frequency of the same-stage tank fluid coupling increases with the increase of the water storage height, indicating that the larger the water storage height is, the more obvious the liquid-solid coupling effect is; the tank-liquid coupling self-vibration frequency decreases with the increase of the tank radius, and it is a great influence on the coupling mode of the tank liquid; the vibration frequency of the FRP combined tank system with floating roof is lower than that of the unset floating roof, but the amplitude change is not obvious.

Acknowledgments

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