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STUDY ON EFFECTS OF WATER DEPTH ON SEISMIC PERFORMANCE OF THE AQUEDUCT-WATER COUPLING STRUCTURE

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Abstract. *This paper uses finite element method to study how the change of water depth in tank affects the seismic performance of the aquedcut-water coupled structure. The results shows that sloshing amplitude of the water in U-shape aqueduct is very significant; the vribration frequency of the aqueduct structure is reduced due to the existence of the water body, and then the response wave shape of the aqueduct body is changed relatively. This explains that the effect of the water in the aqueduct structure has great relationship with the spectrum dynamic properties of the input earthquake wave. Water in the aqueduct plays TLD damping when the frequency scale of the input earthquake wave includes the basic frequency of the aqueduct structure and the vibration frequency of the water in the aqueduct is closed to the the basic frequency of the aqueduct structure. Finally an approximate criterion is also put forward to adjudge when the aqueduct water plays TLD damping through judging mass ratio and frequency ratio, and gives the discriminate.*

1 INTRODUCTION

The water weight on the top of the large aqueduct structures is generally heavier than structure self-weight, some reached 1.5 ~ 2.0 times as much[1]~[7]. Under the earthquake, the ground acceleration superpositons of the elastic vibration acceleration on the top of the aqueduct structure, that make fluid vibrate, which causes thus the bigger sloshing amplitude of the fluid and the sloshing of the fluid has impact on the vibration of the aqueduct structure relatively. Many scholars' research shows that[8]~[12], the role of the aqueduct water sloshing is not allowed to ignore under the earthquake, which has great threats on the security of the aqueduct structure; However in some reference[13]~[14] think the water in the aqueduct plays TLD damping on the bent-support aqueduct structural system, the sloshing of the water is stronger, and the TLD damping effect of the water on the structure is stronger.

Due to the dynamic response of the aqueduct - water coupling structure under the earthquake is complicated, involving many factors, whether the water is benefit or harm to the anti-seismic performance of the whole structure system, still remain to be further studied. In this paper, through changing the water depth in the aqueduct the anti-seismic performance of the aqueduct-water coupling structure is discussed by the analysis of many cases.

2 CALCULATION PARAMETERS AND CALCULATION CASES[15]

The aqueduct model analyzed in this paper is shown in Fig. 1 and Fig.2. The aqueduct has three spans with the length of 12.0m for each span. The U-type aqueduct body is supported with a bent via a basin-shaped rubber support. The bents of the aqueduct are H-shape with the height of 8.0m and fixed bottoms.

The U-type aqueduct section dimension: width is 8.0m, height is 6.9m, inner radius is 3.5m, out radius is 3.8m. The material parameters used in the calculation are: mass density of reinforced concrete is 2700kg/m^3, Poisson's ratio is 0.1667.

Considering the change of the water depth in the aqueduct, the calculation conditions includes that the depth of water in the aqueduct is 0m, 2.50m, 4.41m respectively.

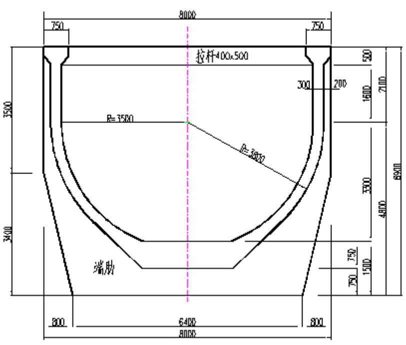


Fig. 1 Section of the aqueduct model

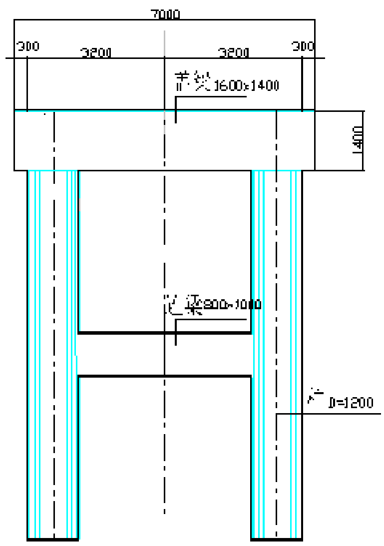
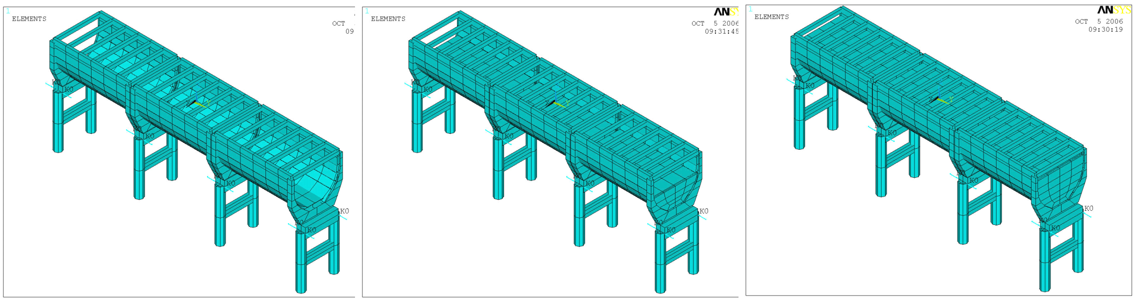


Fig. 2 Section of the bent model

3 DYNAMIC CHARACTERISTICS AND RESPONSE OF HEADINGS OF THE AQUEDUCT-WATER COUPLING STRUCTURE WHEN CHANGING THE DEPTH OF WATER IN AQUEDUCT

Figure 3 shows a three-dimensional calculation model of the bent-type aqueduct - water coupling structure, among which Figure 3 (a) is empty-aqueduct model (water depth $h = 0$m), Figure 3 (b) is half-aqueduct model(water depth $h = 3.50$m), and Figure 3 (c) is full-aqueduct model (water depth $h = 4.41$m).



(a) (b) (c)

Fig. 3 Three-dimensional calculation model of the bent-type aqueduct - water coupling structure

3.1 Dynamic characteristics

Table 2 is the first frequency in all direction of the aqueduct structure with different water depth.

Depth of water (m)	Horizontal (X direction)	Longitudinal (Y direction)	Vertical (Z direction)
h=0	2.41	1.24	13.58
h=3.50	2.07	0.99	10.93
h =4.41	1.75	0.86	9.19

Table 1: The first frequency in all direction of the aqueduct structure with different water depth.(Hz)

From the result shown in Table 2, the whole natural frequency of the aqueduct structure is reduced following the depth of water in aqueduct is increased, these indicates that the mass of the structure is larger and the frequency of the structure is lower due to the quality of water body in the aqueduct, which is consistent with experimental results obtained. As the water depth increases from 0m to 3.50m, the whole horizontal base frequency decreases 14.1%, the longitudinal base frequency decreases 20.2%, the vertical base frequency decreases 19.5%. As the water depth increases from 3.50m to 4.41m, the whole horizontal base frequency decreases 18.3%, the longitudinal base frequency decreases 13.1%, the vertical base frequency decreases 15.9%; When the water depth increases from 0m to 4.41m, the whole horizontal base frequency decreases 27.4%, the longitudinal base frequency decreases 30.7%, the vertical base frequency decreases 32.3%.

It indicates that the vibration characteristics of the aqueduct structure in every direction are greatly affected when the depth of water in aqueduct change greatly, especially for the vertical base frequency. Therefore, the effect of the water in aqueduct on the vibration characteristics and anti-seismic performance should be not ignored.

Figure 4 represents the mode schemes of the aqueduct prototype structure in all directions. Figure 4(a)~(b) represent the first order mode schemes of the aqueduct prototype structure without water and fulled with water in X direction respectively; Figure 4(c)~(d) represent the first order mode schemes of the aqueduct prototype structure without water and fulled with water in Y direction respectively; Figure 4(e)~(f) represent the first order mode schemes of the aqueduct prototype structure without water and fulled with water in Z direction respectively. The calculation result indicates that the local modes of water sloshing appears at first when there is water in the aqueduct.

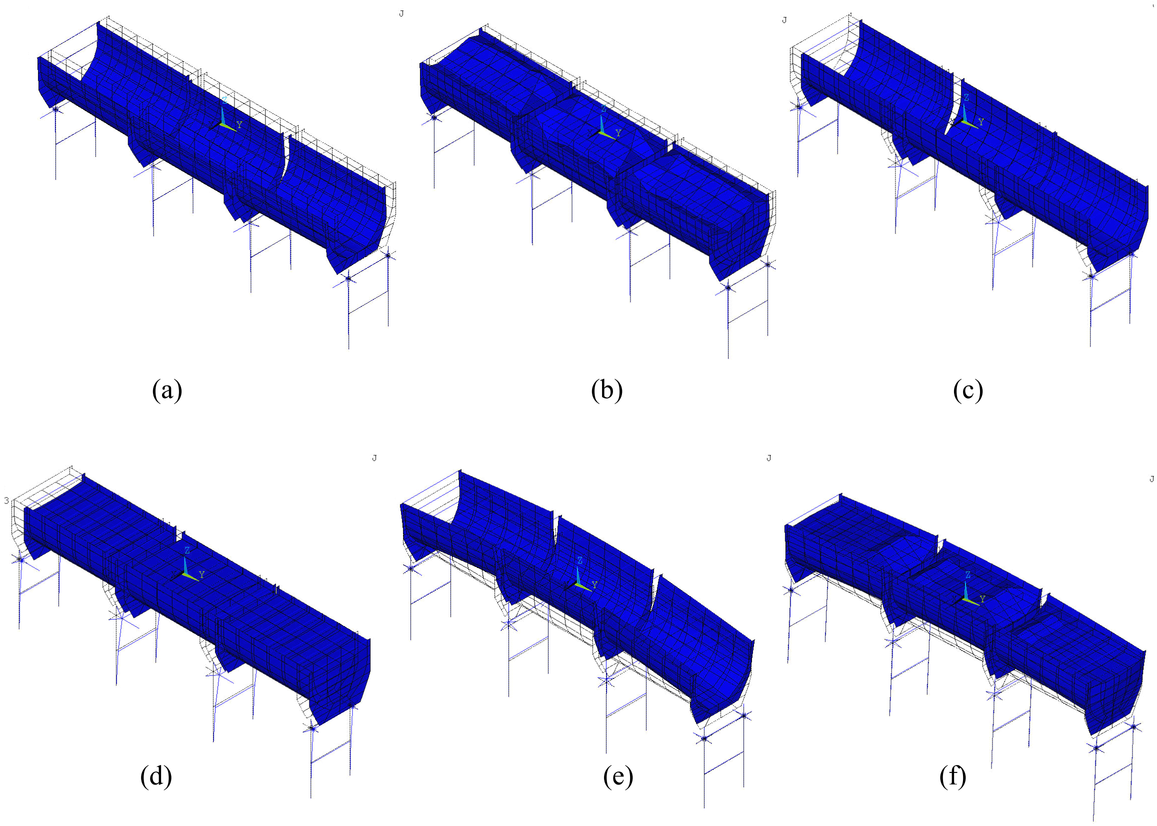
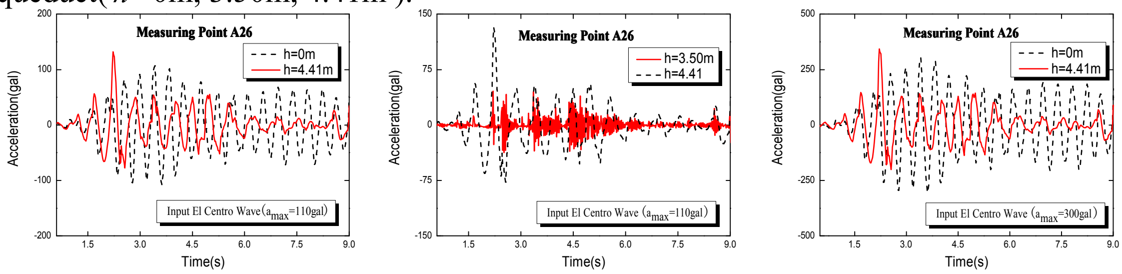


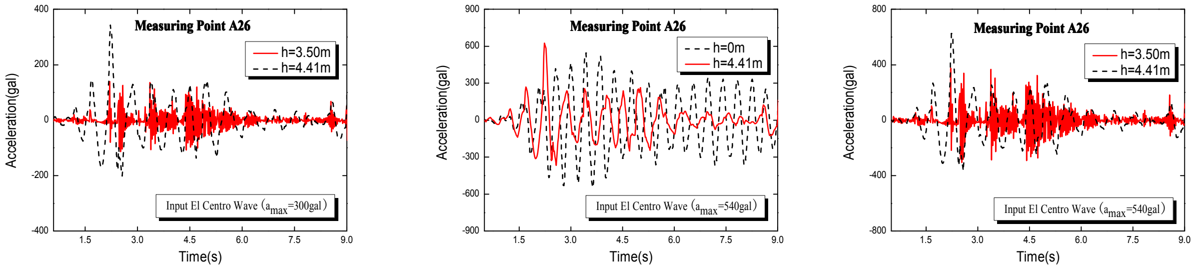
Fig. 4 Mode schemes of the bent-type aqueduct prototype structure in all directions

3.2 Acceleration response characteristics

The top point in the middle of the middle span aqueduct body is selected as research object for better descripting the effect of the water in aqueduct on the earthquake response of the aqueduct-water coupling structure. Figure 5 ~ Figure 6 show that the acceleration time-history curves of the measuring point 26 on the top of the aqueduct body under the action of EI Centro wave and ANPING wave repectively, when there is different water depth in aqueduct(h=0m, 3.50m, 4.41m).

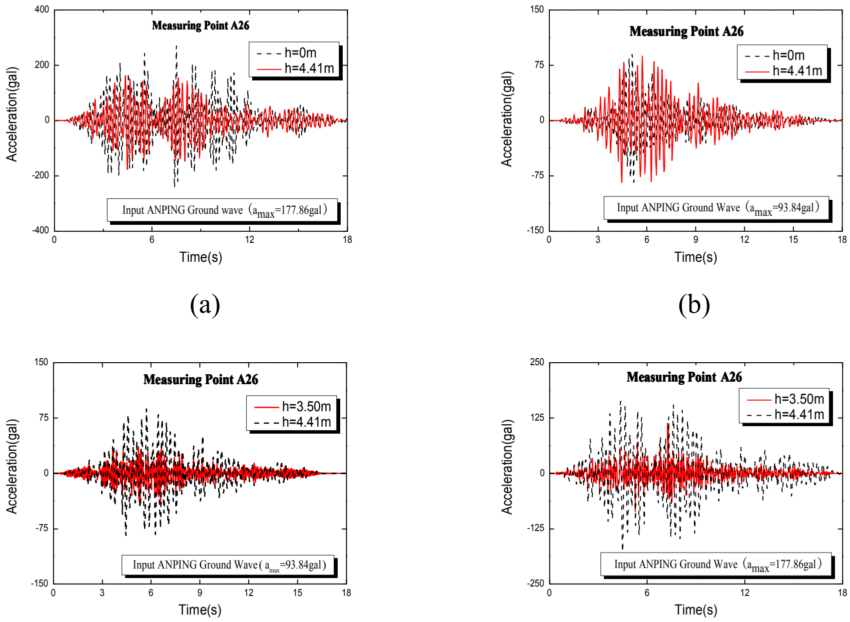


(a) (b) (c)



(d) (e) (f)

Fig. 5 Earthquake esponse of the aqueduct body with different water depth under El Centro wave



(a) (b)

(c) (d)

Fig. 5 Earthquake esponse of the aqueduct body with different water depth under ANPING wave

From figure 5~figure 6, it can be observed that the acceleration response of the measuring point A26 increases with the increasement of the peak values of the input earthquake wave. When input El centro wave, the acceleration response of the measuring point A26 with empty-aqueduct is larger than full with water, but its' response is not decrease as the water depth increase. When the water depth is 3.50m, also called half-aqueduct, the acceleration response of the measuring point A26 is smaller than full-aqueduct. When input El Centro wave of the peak accleration 110gal, the ratio of the empty-aqueduct to full-aqueduct is 1.50, the ratio of the full-aqueduct to the empty-aqueduct is 3.43; When input El Centro wave of the peak accleration 300gal, the ratio of the empty-aqueduct to full-aqueduct is 1.34, the ratio of the full-aqueduct to the empty-aqueduct is 2.88; When input El Centro wave of the peak accleration 540gal, the ratio of the empty-aqueduct to full-aqueduct is 1.06, the ratio of the full-aqueduct to the empty-aqueduct is 2.91. When input ANNPING wave of the peak accleration 93.84 gal, the acceleration response of the measuring point A26 without water is little smaller than that full of water except at 3.9~5.5 second. The acceleration response of A26 is larger that the half-aqueduct, and both peak values of the half-aqueduct and the full-aqueduct.The ratio of both peak acceleration is 4.06; When input ANNPING wave of the peak accleration 177.86 gal, the acceleration response of the measuring point A26 at full-aqueduct is much larger than that at half-aqueduct. The ratio of the peak value acceleration at the full-aqueduct to half-aqueduct is 3.27. In addition, it can be seen from the figures obviously, that the waveforms of the acceleration response of the measuring point A26 are different when the aqueduct with water and without water.

This shows that the water sloshing in aqueduct changes the dynamic characteristics of the aqueduct structure, and the water plays a TLD damping role to a certain extend, however, TLD effect is not stronger fllowing the more water sloshing more powerful. In this model, inputting El Centro wave horizontally, TLD effect reaches the strongest when the water volume is a half of the whole tank($h = 3.50$ m); The acceleration response of the aqueduct-water coupling structure increases when the aqueduct is full with water($h = 4.41$ m), but that still smaller than that when the aqueduct is empty. Because the natural frequency of the water is 1.38 Hz when the water depth is 3.50m, the natural frequency of the water is 1.09 Hz when the water depth is 4.41m, the fundamental frequency of the aqueduct structure(2.41 Hz) is closer to the natural frequency of aqueduct when the water depth is 3.50m, and then the main frequency range of El Centro wave aross the fundamental frequency of the aqueduct structure. Inputting ANPING ground wave, the water in tank does not play a similar damping effect of TLD, because of the greater difference between the main frequency range of ANPPING wave and the fundamental frequency of the aqueduct structure. In additon, the presence of water makes the vibration frequency of the aqueduct structure reduce, thus chaning the aqueduct body's response waveform. This indicates that the effect of the water in tank on the aqueduct structure has great relationship to the spectrum dynamic properties of the input earthquake wave. When the main frequency range of the input earthquake wave across the fundamental frequency of the aqueduct structure, the virbation frequency of the water in tank and the fundamental frequency of the aqueduct structure is similar, the water in tank can play TLD damping on the aqueduct structure, but the effect at the initial stage of time-history is not significant, as the water sloshing needs a process for starting.

4 CONCLUSIONS

Numerical calculations results shows that the water in tank play a TLD damping on the aqeudcut-water coupling to some extent. The water in the aqueduct can be seen as deep TLD. Based on the hypothesis of the aqueduct-water coupling structure dynamic interaction, the water in aqueduct is ideal incompressible irrotational fluid, that the space size properties and the damping characteristics of the fluid are determined, therefore the main factors which decide when the water in aqueduct play TLD damping effect is the mass ratio(μ) and frequency ratio(β).

According to the curves of the water damping effect(η) following changes of the mass ratio and frequency under all kinds of cases, drawing the fitting curve, the discriminant of the water TLD damping is obtained as fllows:

$$\eta = 296.89\mu^2 + 329.87\mu - 48.17 \qquad (0 < \mu < 1) \qquad (1)$$

$$\eta = -3085.64\beta^2 + 3491.82\beta - 945.43 \qquad (0 < \beta < 1) \qquad (2)$$

From the discriminant (1) or (2), it can judge when the water in tank play TLD damping effect on the aqueduct structure.

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