

# The earthquake damage and reinforced method of combined water tank

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## ABSTRACT

Because Taiwan is located in between the Eurasian Plate and the Philippine Sea Plate, there are 33 fault zones existing in the island of Taiwan. The high frequency of earthquake activity, such as the famous 921 Jiji Earthquake, has been causing different extent of damages of running water tanks. This makes the concern of insufficient earthquake resistance ability more outstanding.

Because the design code in early years didn't attach the importance of earthquake resistance ability. That caused the inexact contents of code or requirements of the detail of construction which was more inexact than nowadays. The running water facilities designed in early years was damaged during the serious earthquake. Especially the structure of combined water tanks is easier to occur such as the sort of structure damage such like cracking, even dislocation, of the bottom board or the wall of water tank. That would really affect the steady water supplying.

The research principally analyses the damage of combined water tank caused by earthquake, and try to propose a method to reinforce the earthquake resistance ability. Then, according to the "The Guide of Seismic Design of Water-Supplying Facility", we try to estimate the earthquake resistance ability after reinforced whether to be enough. Eventually, make sure the steady water-supplying ability after earthquake.

## 1. Introduction

Combined pools are common in T.W.C. earlier reservoirs, and the key feature is to combine several individual pools with expansion joints. Although each pool has the independent structure system and is able to bear the dead load of stored water, this design has not considered the frequency of earthquake in Taiwan, which probably leads to the distortion between each subarea and the damage of expansion joints (as shown in Fig. 1). The research will investigate the damage to combined pools, then propose the method of repairing storage function and reinforcing the earthquake resistance ability



Figure 1 The roof of water tank – the failure of extension joint by expansion

## 2. Analysis of the damage of combined pools

At present, the reservoir is located nearby the forth public cemetery and Providence University in Shalu Dist., Taichung City. It is away from the Tuntzuchio fault approximately 2.623 KM, which was constructed in 1990 (The project of water distribution center in the specific district of Taichung Harbor). The overall sizes are 108M of length, 64M of width, 6.4M of height, about 0.8M of foundation depth, and the storage capacity is about 40,000 tons. The structure got slightly deformation and leakage, showing as figure 2.



Figure 2 the nearby of water tank

The water tank is reinforced concrete structure. There are several part divided by extension joint, showing as figure 1. Each part of tank is an independent structure, bearing self-weight and external forces by itself. And then all independent water tank combined to one complete large water tank, connecting by extensive for preventing leakage.

### 2.1 impairment of storing function

The common usage impairment is the crack of walls and plate that is caused by interactional collision, or tear impairment of extension joint caused by large displacement, showing by figure 3, figure 4 and figure 5. Moreover the combined water tank was built in early years. And the early building code which is lenient on the capacity of earthquake resistance, the joints of beam and column usually got cracking after the earthquake, showing by figure 6.



Figure 3 The crack caused by interactional bump of base plate of water tank



Figure 4 The expansion of the extension joint



Figure 5 the crack of wall



Figure 6 the crack of the joint of beam and column

## 2.2 Lack of capability of earthquake resistance of whole water tank

The water tank was built in 1990, the water tank combined by 16 rectangular water tank and 4 irregular water tank. Each water tank was connected by extension joint. There is a similar water tank which is located at Taichung. The water tank had got extremely severe damaged by the over expansion of extension joints in earthquake duration. It caused the fundamental losing and storage function losing, showing by figure 7. Therefore this tank we discuss here didn't apply connection of improving earthquake capability. It may also face the same situation which the large expansion displacement causes the storage capability losing after a massive earthquake.



Figure 7 The severe expansion of extension joint

### 3. The program of improve and repair

#### 3.1 Repair of the storage function

Because of the combined feature of these combined water tank, every independent structure system of unit water tank will vibrate separately during the earthquake. The corner, side and internal part was damaged by strike of the interactional displacement. That causes the severe damage of extension joints.

The damaged extension joints can be dealt by removing the exterior of 60 cm, re-placing the waterproof material, re-smearing silicon that is elastic and waterproof, placing three layers of glass fabrics, smearing silicon again, placing the rubber mat, placing stainless steel plate and then fixing the stainless steel plates with expansion screws.

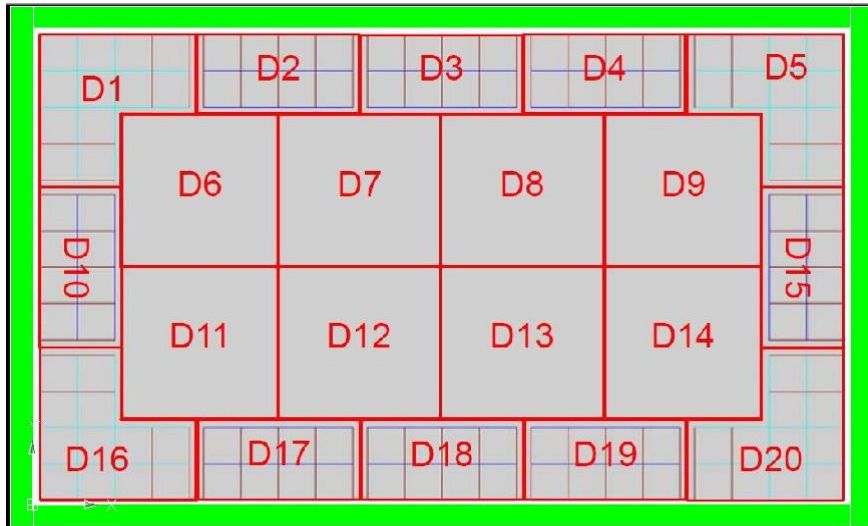
About the respect of corrosion of concrete reinforcing bars, after cleaning up the damaged part of concrete and corrosion of concrete reinforcing bars, the concrete cover repairing method is smear Anti rust ester and Epoxy resin interface, and then smear epoxy resin. But the repairing way can only prevent the corrosion going on, not recover the capability of earthquake resistance. If another earthquake strike, the damaged part will get more severe damaged, and the lower capability of earthquake resistance will cause more numbers and damaged degree of extension joints.

#### 3.2 The improve method for earthquake resistance

Reinforcing program will forcing on the horizontal stiffness, avoiding the large interactional displacement of each separate water tank during massive earthquake. Using the proper internal or external space builds new wall to undertake the earthquake affect and reduce the interactional displacement between each separate unit water tank.

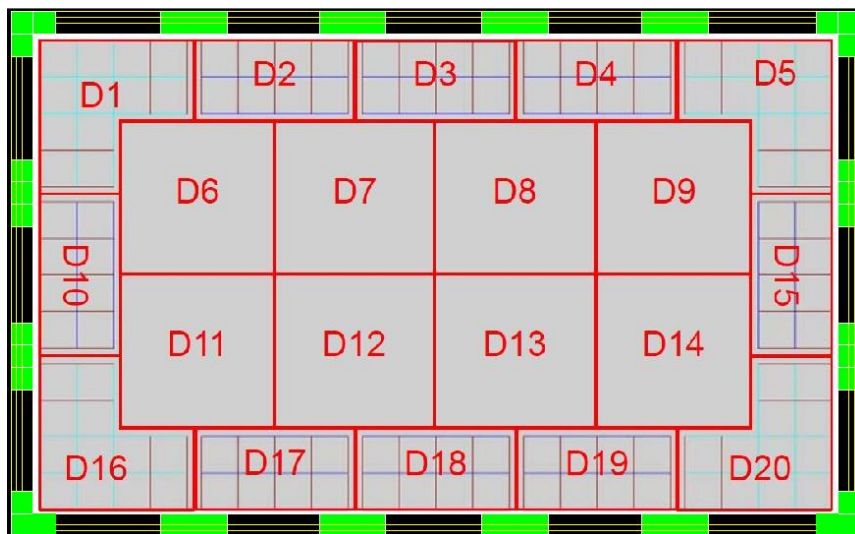
##### Program1:

Considering the water tank is still using, for maintaining the water supply, applying the external space to build new walls. The horizontal stiffness and confining effect are provided by the new wall to confine the internal displacement.



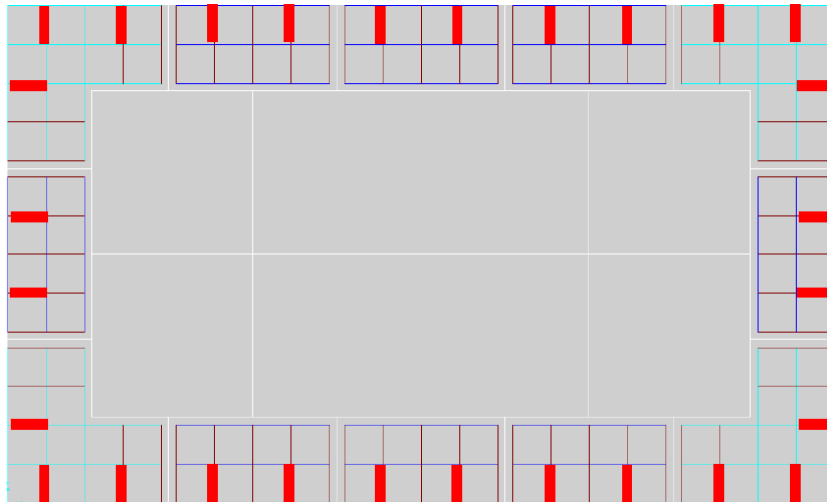
Program2

Installing prestressed steel strand, using the external force confines water tanks. Besides providing the resistance of horizontal earthquake force, it also can confine the displacement during earthquake. Otherwise this program can maintain steady water supply because of building outside of water tank.



Program3

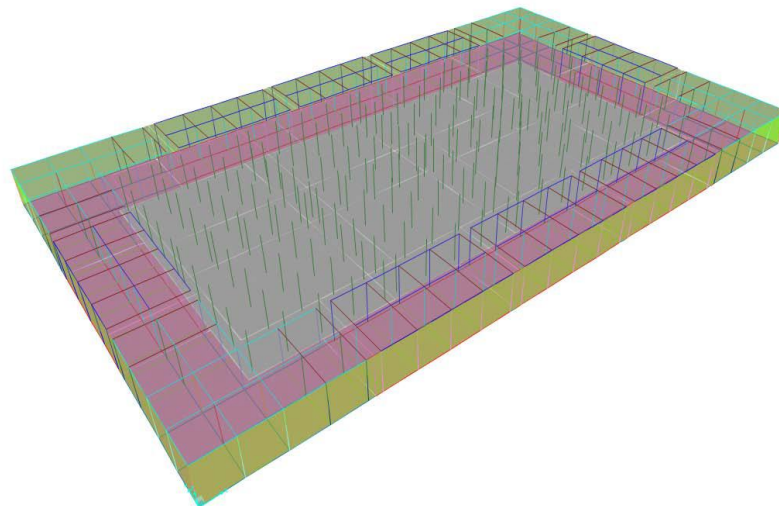
This program has built some walls inside of the water tank. The horizontal and vertical reinforcing bars connect with original beam and column by planting. On the length side, we plan to build 8 walls totally, 4 walls at each side, distributing evenly. On the width side, the program is to build 20 walls totally, 10 walls at each side, distributing evenly.



#### 4. The structure analysis and the estimate of earthquake resistance

##### 4.1 The structure analysis

Using SAP2000 analysis software analyzes the whole building model, including beam, column and plate...etc. all structure element and span base on the real size or distance for simulating as the real situation. Each plate and wall is divided by extended joint as well. Every divided part would not interact by each other. The vibration barycenter will depend on the setting of combined water tank. Totally 20 pieces of vibration barycenter was set. The earthquake forces applied on water tank calculate and applied separately, according to the real weight of structure.



3D analysis model

According to the degree of importance and waterproofness of this water tank, it should take the first rank of earthquake resistance and RANK A1. And the design should take the second rank of earthquake force to ensure the stress would not surpass

the limitation of elasticity.

#### 4.1.1 The calculation of site class

There is no drilling report to represent the site class data. So it introduces the drilling Reports “Engineering drilling report of land NO.741, Shalu Dist., Taichung City 433”. That site is in the distance of 1.7Km. The calculation of site natural vibration period is as fallow.

H	N	Vs	H/Vs
2	10	99.65	0.0201
4.5	39	132.79	0.0339
10	50	235.14	0.0425

※Vs suggests of  $61.8 \times N^{(-0.211)}$

After calculation,  $T_G$  is 0.4976. The site class is the second kind.

#### 4.1.2 Calculation of dynamic water pressure

Because the water tank includes overflow pile, the water in tank is of the property of free water surface. So according to the design code, the dynamic water pressure applying on the wall in X and Y direction is as follow:

$$\begin{aligned}
 P(Z) &= \beta \times \frac{7}{8} \times \gamma_0 \times K_h \times \sqrt{h \times z} \\
 &= 1 \times \frac{7}{8} \times 0.3048 \times 0.52 \times \sqrt{z}
 \end{aligned}$$

In which  $\beta$  is the modified coefficient is the ratio of B and H. The ratio is bigger than 4 regardless of the X and Y direction of the tank. Conservatively, we take 1.0 for it. According to the formula, it is associated with Z which is height.

#### 4.2 The estimate of capacity of earthquake resistance

In general, the estimate of capacity of earthquake resistance is divided into three stages, which is preliminary estimate, detailed estimate and then the final stage of improving design. The method of estimating earthquake resistance capacity which is accepted by the administration of Taiwan is TS-RC, SERCB (Seismic Evaluation of RC Building) and TEASPA (Taiwan Earthquake Assessment for Structures by Pushover Analysis). And TS-RC belong elastic analysis. Using the estimate ductility as the capacity of earthquake resistance might not response the real capacity. The outcome is too conservative and then causes the higher improvement budget. It is not commonly used. While the pushover analysis is the non-linear statics analysis method, the estimate result is more close to the real action. It also is common method to analyze.



So far, this tank is still at preliminary estimate stage. We would like to use the normal non-linear business software, like ETABS, SAP2000 etc. Though they can run the analysis of Pushover Analysis, they still can not provide the non-linear joint on the shell element, and the earthquake resistance capacity most is provided by the shell element. Therefore this paper still needs further detailed estimate of earthquake resistance capacity.

## 5. Conclusion

Tap water is the necessity of life, even the most important goods during the severe disaster. Therefore the water supply system needs the serious earthquake resistant design, avoiding the shutdown. Although, the earthquake resistant capacity of this water tank is not sufficient, but the economic benefit that repair the tank is still considerable. So it suit to do further detailed improve analysis of earthquake resistance, or it should be rebuilt. In addition, if water tank is the important facility for modification, and the improve design should enhance the capacity by applying several equipment of earthquake resistance and damping.

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