The Damaged Water Supply Facility for Repair or Reconstruction Evaluation Program – A Case Study of Nao-Guan Service Reservoir at Taichung, Taiwan

[1]Kuo-Ching Lin [2] Chang-Chou Chien

[1] Deputy Director, Central Region Engineering Office, Taiwan Water Corporation

[2] Engineer, Central Region Engineering Office, Taiwan Water Corporation

Abstract

Many water facilities in Taiwan suffered from structural damages during the strong earthquake striking Nantou Jiji on 21/09/1999, causing facility structures leaking or failure in storage function. However, water facilities require more water impermeability than constructions of other function facility. To avoid more damages, it is very important to decide whether to repair, reinforce, rebuild, or find new sites for the damaged water facilities.

For example, Nao-Guan storage tank (Taiwan Water Corporation's property), located in Taiping, Taichung, near Chelongpu Fault, was seriously damaged during the 21/9/1999 Jiji-earthquake. We have evaluated different projects to decide whether to repair, reinforce, rebuild on the same site, or find new sites. Our project evaluations aimed at several aspects of water facilities, such as structural safety, operations, geological features, regulation limits, and the future development. We will choose the most appropriate projects after full assessment.

Introduction

Taiwan is located in the hub of mutual collision between Eurasia continent plate and Philippines ocean plate. There are approximately 15,000 - 18,000 earthquakes of all sizes happened every year.

Many water facilities suffered from major damage during the strong earthquake striking Taiwan on 21/09/1999. For instance, Fongyuan water treatment plant and Nao-Guan

storage tank in Taichung were seriously damaged due to their locations in the vicinity of Che-long-pu Fault. For these water facilities which were damaged, whether to repair, reinforce, rebuild on the same site, or find a new site, it is necessary to proceed a detail evaluation procedure and choose the most appropriate projects.

Assessment items and methods

Our evaluations aimed mainly at three aspects of water facilities, structure safe, usability and restoration. Structure seismic-resistance evaluation guideline was applied as our blueprint. Following tasks were sequencing proceeded：

1. Collection of Basic architecture data

   Architecture design figures, structure design figures, calculation sheets of structure, material specifications and design methods of original water facility were collected and interpreted.

2. Structure condition and architecture damage investigation

   Tasks focus on major damage and secondary damage patterns, damage location and extent. Such as crack width and distribution of reservoir, damage situation of top slab, the damage condition of beam and column joint, water seepage, concrete swelling, rust and corrosion of steel reinforcement and investigation of steel reinforcement allocation.

3. Material testing

   Material testing include concrete strength test, neutralization test and chloride test of concrete.

4. Analysis of structure basic data

   To check whether the seismic-resistance design specification which used at that time is a new one from structure design drawing and calculation sheet, and compare it with current specification.

5. Seismic-resistance evaluation and analysis

   3D-model is established by using structure analysis software and then to analyze x、y、z three dimensions seismic resistance capability with 3D-model. 3D-model is also used to calculate axis-force, shear force, moment, displacement, the relationship of function target and requirement of seismic-resistance (A_P/A_T).

6. The choice of seismic-resistance reinforcing plan

   There are three categories for structure reinforce and of repair: strength

reinforcement、toughness reinforcement and combined method. Several structure reinforcement and repair methods are now used. Displacement method, thickness increasing method, lining method, truss increasing method, supporting method, steel plate sticking method, FRP sticking method, rolling steel plate cover method, pre-stress method, method of water proof material pouring into crake, seismic-resistance RC shear wall increasing method. Lining method, steel plate sticking method and method of water proof material pouring into crake are frequently used in water facilities structure depending on their structure type.

7. Engineering cost estimation of repair and reinforcement

   Engineering cost was estimated according to the selected repair method and area of repair. Investment benefit also must be carefully considered.

8. Relative ordinance

   Relative ordinance must be carefully evaluated to realize their effects on repair or reconstruction plan. Such as soil conservation law, environmental impact assessment law, building law, Geology law and ban on building.

9. The requirement of operation

   Inlet and outlet pipeline condition, space for pipe installation, space for construction, operation base size and hydraulic analysis are all needed be carefully considered.

10. Engineering geology evaluation

    To justify the property of stratum in planning site, the relative distance between active geological fault and planning site and the susceptive area of active geological fault, then the suitable area to be built water facilities can be scoped.

    After aforementioned information are collected and surveyed, and then taking account of regulation, structure safety, operation requirement and investment benefit. Finally a most appropriate program can be determined.

Case study：The renovation proposal of Nao-Guan storage tank.

1. Basic data collection

   Nao-Guan storage tank is located in Taichung, Taiwan. It is a 10,000 m^3 RC tank with beam-column system and single footing foundation, and built in 1987. It was

seriously damaged during the 21/9/1999 Jiji big earthquake and completely lost the function of service take due to its location near che-long-pu fault.

2. Structure current situation and building damage investigation

   The main damage patterns of Nao-Guan reservoir are relative displacement damage produced from expansion joint and stress damage of beam-column joint, as shown picture 1-4. It can be seen that there is an obvious crack and disturbance near ground. This is because reservoir is located near geological fault zone. The maximum crack width from basin wall relative displacement is around 1 m, it can be passed through by one man. Many foundations displacement happened and then resulted in base slab rupture when there is an earthquake due to the single footing foundation was used in the tank structure. The service tank was seriously damaged and completely lost it function.

3. Material testing

   Because the service reservoir was seriously damaged and can't be repaired, the material tests didn't be run.

4. Structure basic data analysis

   Nao-Guan storage tank was constructed in 1987. After 9/21/1999 strong earthquake, the seismic-resistance design rules has been revised three times in 1999, 2005 and 2011. Thus the original design seismic-resistance capability of the tank can't comply with the current rules.

5. Seismic-resistance evaluation and analysis

   Because the service reservoir was seriously damaged, three dimension seismic-resistance capability analyses using 3D model was not carried out.

6. Choice of seismic-resistance reinforcement plan

   Beam-column system structure of reservoir were partly damaged due to extra shear force and moment produced by foundation displacement. To remove and reconstruct a new reservoir is more possible choice because the structure was seriously damaged and the function was completely lost.

7. Cost for reservoir repair and reinforcement

   The capacity of Nao-Guan storage tank is 10,000 m^3. NTD100,000,000 was estimated for rebuild, not including the cost of land which has already been obtained.

8. Relative ordinance

   - Soil conservation

Nao-Guan storage tank is located in Nei-Hu section, Tai-Ping district, Taichung. It belongs to the scope of soil conservation limitation after mapping the extent of hillside issued by Committee of Agriculture, and a soil conservation plan should be provided if the area is exploited.

- Environmental impact assessment

  No matter repair or reconstruction plan be proposed. It is not necessary to execute environmental impact assessment according to the law of environmental impact assessment.

- Building law

  This service reservoir is not a structure for person or public use. So it doesn't belong to the building defined by building law. In this case, it is not necessary to apply for a building permit.

- Geological law

  According to geological law, a site geological investigation and safety evaluation should be executed before land exploitation if the site is totally or partly located in a geological sensitive area.

  The site of Nao-Guan storage tank is located in the susceptive area of active geological fault after mapping the latest active geological fault data. Site geological investigation and geological safety evaluation should be executed.

- Regulation about banning of building

  According to the No.762 meeting record of urban planning committee, both sides within a 15 m limit Che-Long-Pu geological fault line is banned for building.

  The distance after mapping is only 10 m between Nao-Guan storage tank site and Che-Long-Pu geological fault limit region. as shown in figure 5.

To summarize the results of evaluation, if choose to rebuild Nao-Guan reservoir at original site, it is needed to propose soil conservation plan and execute site geological investigation and safety evaluation, although environmental impact assessment is not necessary to implement. On the other hand, it is only 15 m distance between Nao-Guan reservoir and Che-Long-Pu geological fault limit region, although not within the limit region.

According to building technique rule, both sides within 100 m limit of geological

fault region, it is not suitable to have any exploitation. So it is also not suitable to construct water facilities near geological fault region.

Again, from picture 6 and 7, it is shown that there is an obvious exposed stratum and ground rupture in the surrounding surface of reservoir. It can be forecasted that if reconstruct reservoir at the original site, it is very possible to have a serious damage when there is an another earthquake happened.

9. Operation requirement

- Current pipeline situation

  The network hydraulic analysis of average daily demand in Tai-Ping in 2021 is shown in Figure 8, hydraulic analysis of Nao-Guan reservoir is shown in Figure 9. Nao-Guan reservoir elevation is 128 m, the high water level and low water level of design is 129 m and 122.5 m respectively. There is a 1000 mm distribution pipe between pressure-reducing value and this service reservoir, and its distance is 250 m long. The operation head is 140 m before pressure-reducing value, and the operation head is 139.7 m in reservoir inlet.

10. Geology evaluation

Nao-Guan reservoir is located at hillside, its elevation is 128 m. There is a 3 m pebble and gravel lay on the top of soil (Figure 10), rock characteristic is siltstone intersperse with thin shale strata (Figure 11). This rock stratum is mild to middle weathering, and stratification of stratum is still clear to be identified. The relative position of Che-Long-Pu geological fault and Nao-Guan reservoir is shown in Figure 7. From the point of geological condition view, the site of original Nao-Guan reservoir is located in active geological fault susceptible region, and it is not suitable to reconstruct reservoir in the original site.

Conclusion

It has been almost 27 years since Nao-Guan reservoir completed in 1987. During this period of time, it encountered 21/09/1999 strong earthquake, and it is one of few water facilities that haven't been repaired after 21/9/1999 earthquake. The reason is that Nao-Guan reservoir was seriously damaged at that time. Several alternatives are proposed including repair, reconstructing at the same place and finding a new site to construct new reservoir, and many aspects must be considered including location, structure safety,

future operation requirement, geological feature, regulation limits and economics. After detail evaluation, repairing the damaged reservoir or reconstructing reservoir at the original site is not suitable. Finding a site to construct a new reservoir is a better proposal.

Reference

1. Site evaluation for Nao-Guan reservoir, Taiwan Water Corporation (2012)
2. Seismic-resistance evaluation guideline for senior and junior high school building, Ministry of Education (2013)
3. Repair and reinforcement technique handbook of concrete structure, Civil and Hydraulic Engineering Association, ROC (2005)
4. Repair and enforcement technique handbook of reinforced concrete structure, Structure Engineering Association, ROC

Figure 1 Split of top slab from expansion joint

Figure 2 Break in the joint of beam-column joint

Figure 3 Split of basin from expansion joint

Figure 4 split of bottom slab

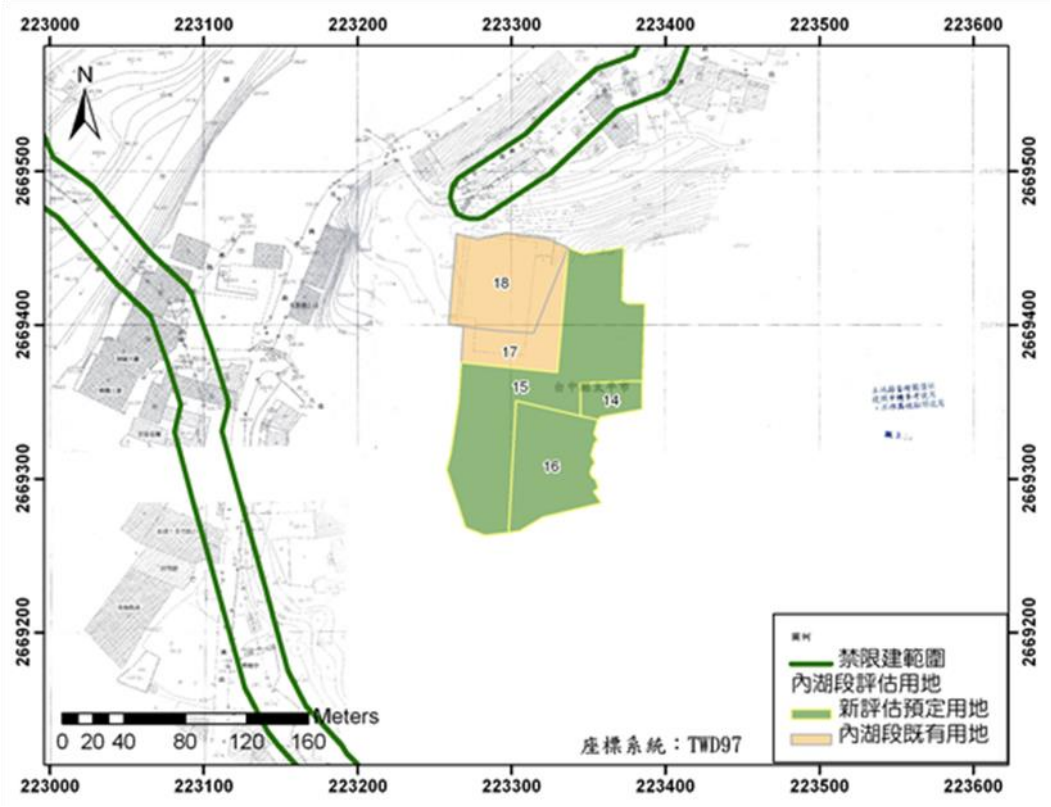

Figure 5　Relative location of reservoir site and region of Chelongpu fault

Figure 6　Rupture of ground in the surrounding surface of reservoir.

Figure 7　Obvious exposed stratum in the surrounding surface of reservoir.

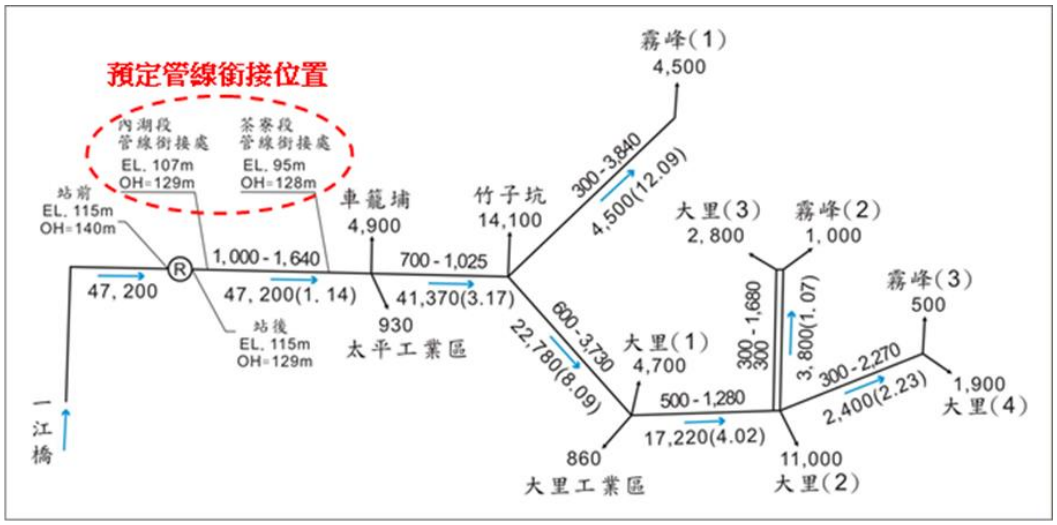

Figure 8　Network hydraulic analysis of average daily demand in Tai-Ping in 2021

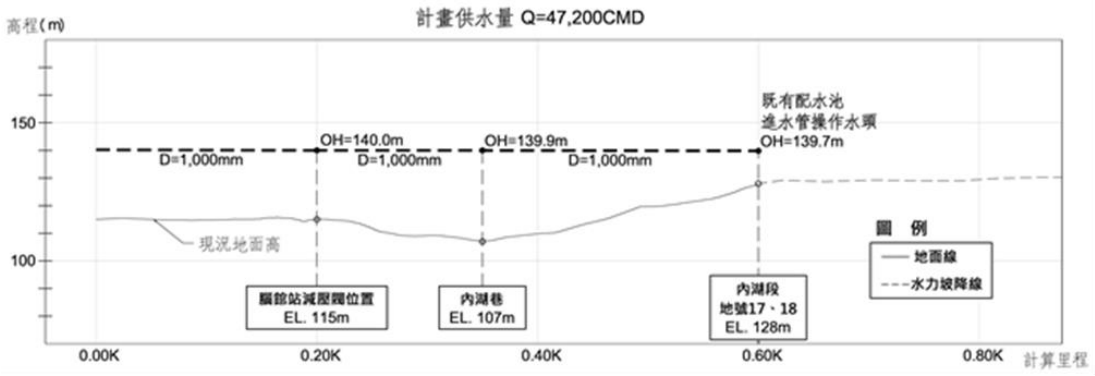

Figure 9 Hydraulic analysis of Nao-Guan reservoir

Figure 10 A 3 m pebble and gravel lay on the top of soil

Figure 11 Siltstone intersperse with thin shale strata in the vicinity of reservoir