Application of risk management in the design and construction of deep circular excavation with 140 meters in diameter

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Abstract

Enormous deep excavations in the metropolitan district were always closed to the neighboring buildings and at the intersection with heavy traffic. Therefore, there had a high risk of excavation during the design and construction phase. It would be more suitable to conduct the construction which was based on risk management with risk recognition, evaluation, and reaction. In addition, with immediate feedback information and monitoring system, it would be able to reduce the uncertainty and risk of hazard during the construction phase.

Keywords: Deep circular excavation; Risk management; Diaphragm wall; MRT geotechnical engineering

1 Introduction of CR4 project and risk management

For the sake of integrating and expanding the existing traffic infrastructure and economic development for the future, KMRT (Kaohsiung Mass Rapid Transit), the second MRT system in Taiwan, was developed in 2002 and opened in 2008 in Kaohsiung, one of the biggest cities in Taiwan. Including the red and orange line, 「Formosa Boulevard Station」 is the only transfer station between two lines and is famous for its extraordinary design – 「Dome of Light」 which became the new landmark in Kaohsiung. Furthermore, it was voted online for one of the most beautiful stations all over the world.

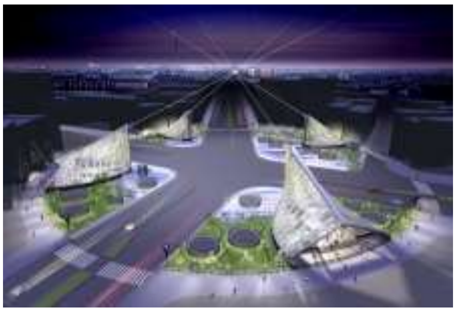

Figure. 1. Formosa Boulevard Station

This paper will take KMRT-Formosa Boulevard Station (CR4 project) for instance. In the early phase, with the awareness of the high risk, risk management was carried out to control the design and construction phase. This project was particular since it was conducted with deep circular excavation which was 140 meters in diameter and without any inner strut in this area. Risk management, in this case, included choosing a proper method for constructing the diaphragm wall, irregular displacement from diaphragm wall, arriving and starting of the shield machine, excavation area outside the circular area, traffic maintenance plan, and so on. By conducting systematic analysis, we get to take precaution to prevent any hazard during the design and construction phase. Additionally, with appropriate and timely auxiliary method, it would be safe and faultless during the design and construction phase whenever the crisis or hazard happened. This paper will introduce its process and success and expect it could be a reference to others.

2 Risk assessment during the design phase

At the beginning of the fundamental plan, the layout of diaphragm wall shown in Figure 2 was first designed along the road; however, the depth and area of excavation were enormous and the construction was close to surrounding buildings. Conducting the traditional method would need to divide the construction area into several sections which would be hard to install inner struts and maintain the traffic flow.

During the basic design phase, subcontractor, KAJIMA Corporation, took Japanese underground LNG holders which were constructed with circular diaphragm wall and without inner strut as the reference. At first, circular diaphragm wall shown in Figure 2 was then designed in 100 to 105 meters in diameter and was encompassed by the regular diaphragm wall. Therefore, this plan had two diaphragm walls. Nevertheless, the excavation between two diaphragm walls was likely to cause the discrepancy in soil pressure. Besides, the construction process and strut's efficiency were also affected and it would decline the efficiency of excavation and structure.

During the detail design phase, Sinotech Engineering Consultants and KAJIMA corporation reevaluated the method of basic design and proposed a new method containing all facilities into a circular diaphragm wall with 140 meters in diameter. As shown in Figure 2, this method promoted the benefit by not only retaining the concept of the basic design but also enhancing the efficiency of the excavation without inner struts.

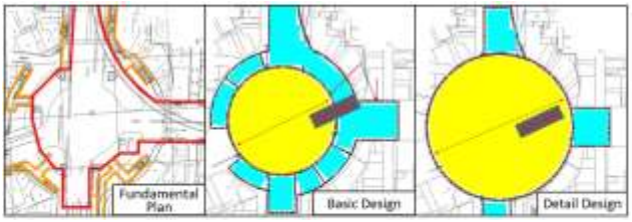

Figure. 2. Layout of diaphragm wall for the fundamental plan, basic design, and detail design

The concept of the circular diaphragm is like to oak barrel, that each unit of diaphragm wall is rectangular. As shown in Figure 3, the axial force along the circumference produced by the upper ring beam and external force constrains each unit of the diaphragm wall. With this enormous axial force and resistance force, the structure gets to stand and resist the soil pressure without any strut.

The construction of the circular diaphragm wall in the city must consider several issues such as traffic maintenance, the impact of surrounding buildings, the noise of the construction, and so forth. The excavator chose to conduct the construction must have the ability to deal with these problems. Thus EXM-150 shown in Figure 3 was adopted.

Concrete Cutting Joint was conducted during the construction phase. Cutting the former unit in the wake of the former unit, because of the large axial force along the circumference, this method was able to prevent leakage.

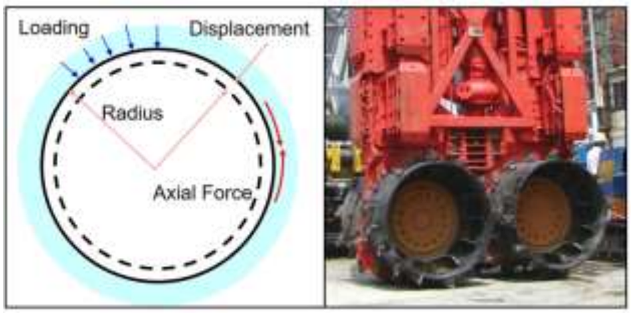

Figure. 3. The concept of circular diaphragm wall and photo of EMX-150

3 The application of risk management

Formosa Boulevard Station was the first project whose method of deep circular excavation without inner struts was adopted in Taiwan. Comparing to commonly tradition methods, this method would encounter lots of challenges, identify its representation, and therefore, have the highly demand for risk management.

According to systematic risk management, managing risk identification and risk evaluation to build up each risk item during construction. In the design phase, strategies would be proposed to cope with high risk items and difficult construction items. In the wake of strategies, risk evaluation report including strategies during the design and construction phase should be submitted for the subsequent work of risk management during the construction phase to refer. Risk management must be strictly conducted before, during, and after the construction phase for the sake of preventing from hazard and immediate protective measure while hazard happens.

3.1 Process of risk management

Risk management is the process of systematic identification, assessment, confirmation, analysis, and the respond of the risk of a project. The whole process of the risk management is illustrated in Figure 4 and the evaluation score of risk matrix and its extent are shown in Table 1. At the beginning of the project, risk evaluation norm will be built up. After the risk evaluation and confirmation of the risk item during the design phase, analyzing the risk item and proposing risk handling to reduce or remove the risk. In the meantime, proposing the risk managing plan to oversee the situation during every phase.

Table 1. Risk matrix

Likelihood Score	Severity				
	1.Insignificant	2.Minor	3.Moderate	4.Major	5.Catastrophic
5.Certain					High
4.Likely					
3.Possible			Medium		
2.Unlikely					
1.Rare	Low				

Fig. 4. Process of risk management

3.2 Strategies during each step of the construction

During the construction phase, many unexpected and inevitable challenges would show up. Therefore, an exceptional design must be paired with strictly risk construction management, especially for this project which was the first one carrying out the deep circular excavation without inner struts in Taiwan. In the following essay, this construction would be divided into eight steps and risk identification, evaluation score, and strategies of each step would also be shown to conduct the risk management.

Table 2. Step1: Constructing the diaphragm wall

Risk Identification	1. According to the geological uncertainty and existing unit of the diaphragm wall, the error of the construction and excavation led to the crack and excess deformation and stress of the unit of diaphragm wall. 2. Inner excess water inrush, settlement of ground surface and the surrounding, and settlement or inclination of surrounding buildings caused insufficient excavation depth.
Evaluation score: Medium	
Strategies	1. In the design phase, accurate measurement, hypothetical error, and the detailed geological survey were conducted. 2. In the construction phase, using ultrasonic to confirm the verticality of excavation. Tide staff was carrying out to measure the depth. If the depth was not sufficient, re-excavate to the proposed depth. Using the monitoring system during the excavation.
Evaluation score after strategies: Low	

Table 3. Step2: The construction by the EMX

Risk Identification	1. Because of the poor quality of stabilizing solution and decreased elevation, the ground surface surrounding the guide wall collapsed and led to the fall and inclination of EMX and surrounding builds. 2. The delay of diaphragm wall construction as a result of obstacles that EMX was unable to excavate such large rock or woods. 3. The collapse of guide wall and workbench owing to the poor quality of concrete and insufficient flexibility of the steel.
Evaluation score: Medium	
Strategies	1. In the design phase, comprehensive building protection was conducted to prevent from collapsing. Make sure that investigation was conducted and that obstacles were removed. 2. In the construction phase, the automatic monitoring system was adopted to monitor the water table, surrounding settlements on the ground surface and buildings. When the water table arose, the elevation of stabilizing solution must be reset. While there was an obstacle unable to eliminate EMX was removed and another boring machine was conducted to remove the obstacle.
Evaluation score after strategies: Low	

Table 4. Step3: Behavior of diaphragm wall during the inner excavation phase.

Risk Identification	1. Because of variability and incomplete geological drilling data, the underestimation of design led to unusual soil pressure and safety concern about the diaphragm wall. 2. The elevation of water table fluctuated along with the season, tide or underwater flow owing to the construction of diaphragm wall cause unusual water pressure.
Evaluation score: High	
Strategies	1. In the design phase, the detailed geological survey were conducted. Because of the variable soil layer and according to the past experience and monitoring data, unusual soil pressure was approximately 20% of soil pressure followed by the norm. 2. In the construction phase, using the automatic monitoring system to monitor the ground water level.
Evaluation score after strategies: Low	

Table 5. Step4: Irregular transformations of diaphragm wall

Risk Identification	1. Irregular transformation of the circular diaphragm wall caused buckling and thus led to the collapse of the surrounding, settlement and inclination of surrounding buildings. 2. Broken diaphragm wall, the collapse of the surrounding, and settlement of buildings due to the earthquake. 3. Uneven excavation due to poor design and construction caused unusual stress affecting the diaphragm wall.
Evaluation score: High	
Strategies	1. In the design phase, after the bottom slab construction, X-JET method was adopted to prevent from declining of groundwater level before the excavation of the surrounding. 2. In the construction phase, joint of circular and straight part of diaphragm wall was conducted accurately.
Evaluation score after strategies: Medium	

Table 6. Step5: The construction of the structure

Risk Identification	1. In the construction of station or rail, due to the insufficient strength of concrete and leakage at joint of diaphragm wall, diaphragm wall suffered excess displacement and caused the insufficient inner size of the structure and excess leakage.
Evaluation score: Medium	
Strategies	1. In the design phase, considering the transformation and error. The diaphragm wall retreated 75 mm for enough structure space. 2. In the construction phase, monitor the concrete quality and groundwater level. With proper waterproofing method, leakage and unusual soil pressure could be avoided. Using the automatic monitoring system to monitor the measurement of the inclinometer, strain gauge and water pressure within and without the construction area.
Evaluation score after strategies: Low	

Figure. 5. The proceeding of shield machine.

Table 7. Step6: The proceeding of shield machine

Risk Identification	1. During the proceeding, the shield machine cut and broke the diaphragm wall. The stress of structure and circumference was uneven because of the cutting effect. 2. With the irregular displacement of diaphragm wall, leakage at breaking point of diaphragm wall, or poor quality of ground improvement, it was likely to cause the settlement of the road or surrounding buildings.
Evaluation score: High	
Strategies	1. In the design phase, ground improvement and waterproofing grouting method were conducted outside the mirror face breaking point. FRP(Fiberglass Reinforced Plastics) was conducted at the mirror face breaking point for the proceeding of the shield machine. 2. In the construction phase, the installation of the steel cage and FRP must be accurate and high quality. The automatic monitoring system was used during the proceeding to monitor the displacement of the diaphragm wall.
Evaluation score after strategies: Low	

Table 8. Step7: Transformations of the excavation outside the circular diaphragm wall

Risk Identification	1. If the construction outside the circular diaphragm wall was conducted before the finish of the bottom slab, it was likely to cause the leakage of the joint, unusual stress from the circumference, damage of the diaphragm wall or ring beam, settlement or inclination of surrounding buildings, and aberrant monitoring data.
Evaluation score: High	
Strategies	1. In the design phase, the schedule of the excavation outside the circular diaphragm wall must be evaluated accurately. 2. In the construction phase, follow the schedule and make sure that the excavation was conducted after the finish of the bottom slab.
Evaluation score after strategies: Low	

Table 9. Step8: Traffic maintenance plan

Risk Identification	1. The traffic flow was likely to transfer into S route because of the incoming excavation machine and relevant equipment before the construction of diaphragm wall. 2. The damage of the road deck due to the insufficient strength of road deck or earthquake caused traffic jam, traffic accidents, road closed, and even other issues that might affect the schedule of the construction.
Evaluation score: Medium	
Strategies	1. Increase the width of a temporary road. With appropriate construction and traffic maintenance plan, arrange traffic guide and signals and adjust the incoming time of equipment to save time. 2. The overload and earthquake must be included in the capacity of road deck's, and construction equipment near the construction platform must be controlled at the same time to maintain the safety of construction site.
Evaluation score after strategies: Low	

Figure. 6. Traffic maintenance plan.

4. Conclusion

Formosa Boulevard Station(CR4 project) was the deep circular excavation with 140 meters in diameter. By rigorous evaluation of risk management including the designed alignment, method of diaphragm wall, method of excavation, and design of monitoring system.

Risk management was conducted before the construction to consider and adopt an appropriately auxiliary method to get rid of or cope with risk problems. By pre-evaluation, identification, and suitable strategies with automatic monitoring system and synchronous feedback, uncertain factors and risk of hazard was controlled during the construction ph.

KMRT was operated in 2008, 「Formosa Boulevard Station」, the only transfer station, has become the new landmark in Kaohsiung because of its exceptional design and construction. Risk management also played an important role in this construction during the design and construction phase. By this essay, we hope to introduce the successful example of risk management so that it could be a reference to others and make the design and construction complete.

5. Reference

Sinotech Engineering Consultants, LTD. (2003). Build Operate and Transfer The Kaohsiung Metropolitan Mass Rapid Transit System Red and Orange Lines, calculation report of circular diaphragm wall.

Lee, C.C. (2009). The Design of Deep Excavation and Retaining Wall with Enormous Circular Structure in KMRT-CR4, Difficult Cases in MRT Geotechnical Engineering, Sino-Geotechnics(vol.8), Taipei, pp.7-16.

Cheng, J.L., Hung, C.F., Cheng, C.T., Tada, Y., and Lee, C.C. (2009). The Construction of Deep Excavation and Retaining Wall with Enormous Circular Structure in KMRT-CR4, Difficult Cases in MRT Geotechnical Engineering, Sino-Geotechnics(vol.8), Taipei, pp.17-22.