International Symposium on "Appropriate technology to ensure proper Development, Operation and Maintenance of Dams in Developing Countries", Johannesburg, South Africa, 18 May 2016
© SANCOLD, ISBN 978-0-620-71042-8

SUGGESTIONS FOR DAM CRISIS MANAGEMENT LEARNED THROUGH THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

H Okumura[1], T Matsumoto[1], and K Koyama[1]
1. Electric Power Development Co., Ltd., Tokyo, Japan

ABSTRACT

On 11th of March, 2011, the 2011 off the Pacific coast of Tohoku Earthquake, with a moment magnitude of 9.0, hit on Numappara dam. Immediately, more than 1,000 l/min of leakage increasing which was assumed to run through caused cracks on the asphaltic facing was detected. To avoid a possible serious failure, the water level was drawn down to the safe one. This paper describes the suggestions for dam crisis management learned through these responses taken for the Earthquake and also focuses on the importance of the usual dam monitoring.

1. NUMAPPARA DAM

1.1 Dam and Power Plant

Numappara dam has been operated as the upper reservoir of Numappara pumped storage power plant since 1973, which has 675 MW of the maximum output capacity and located in the northern part of Tokyo metropolitan area as shown in Figure 1.

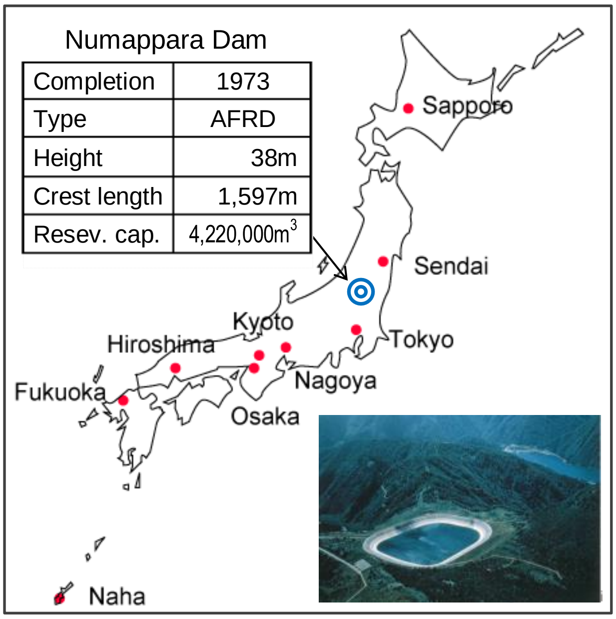


Figure 1. Location of the Dam

Numappara dam was constructed by excavating a top of hill, and depending on topographic conditions of cut-slopes, the embankments were placed on those. The dam is founded on well compacted volcanic deposits. The dam body was filled with muck excavated. As for the water proof function, all inside slopes and bottom were covered by asphaltic facing. The typical section of the dam is shown in Figure 2. The water proof surface is composed of the protection layer, upper and lower impermeable layers, and drain layer and the drain gallery is provided at the slope bottom. Total area of the facing is 197,000m^2. Since its start of operation, the dam has experienced no water leakage through the facing.

The surface of the facing has been periodically investigated at five-year intervals, and some maintenance works have been executed, when some deterioration were observed. Especially, the reservoir water surface is frozen during winter season due to ambient temperature which goes down beyond zero Celsius degree. Even if water surface is frozen, dam water level repeatedly moves up in off-peaking time and down in peaking time by the pumped storage operation; accordingly, the top layer, the protection layer, is likely to be scratched by the ice.

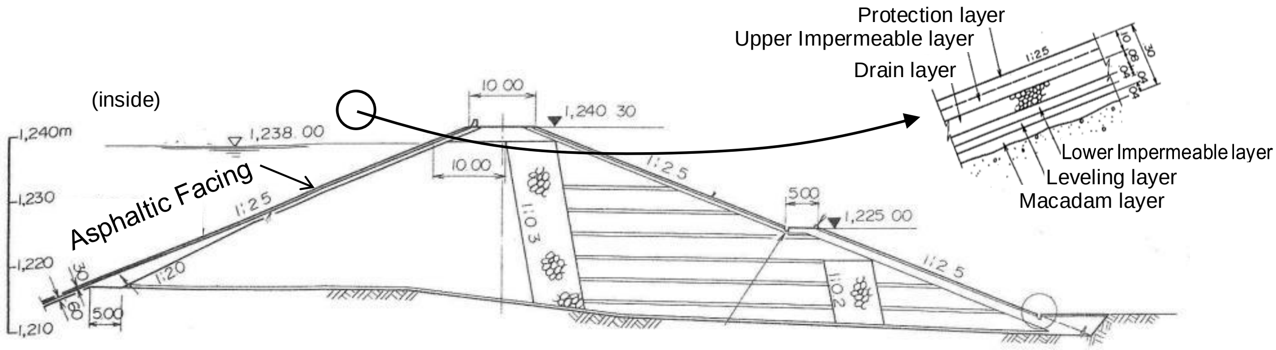


Figure 2. Cross Section (Asphaltic Facing Rockfill Dam)

1.2 Roles and Operation

Numappara pumped storage power plant has been operated as a peak-power station, the operation of which is as illustrated in Figure 3. Usually, in the daytime, the plant take a role for peak-power supply discharging water to the lower reservoir, and in the night time, it charges by pumping water up from the lower reservoir absorbing surplus energy on the power grid. Generally, pumped storage power plants also contribute to stabilizing the voltage and the frequency of the power grid.

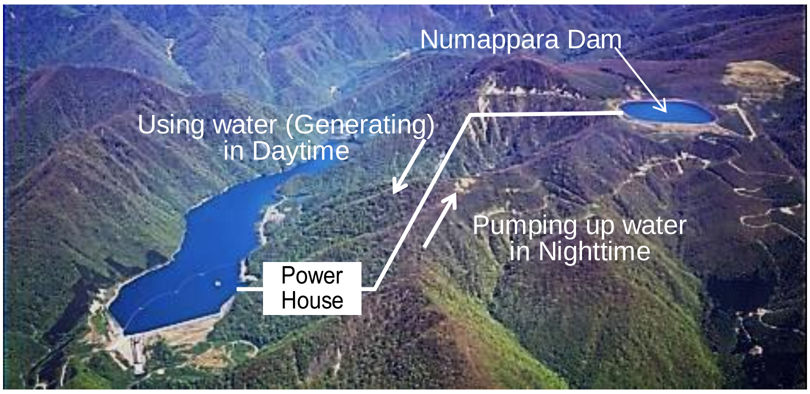


Figure 3. Roles and Operation of the Power Plant

2. THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

2.1 The Earthquake

On 11th of March, 2011, the 2011 off the Pacific coast of Tohoku Earthquake (hereafter The 2011 Tohoku Earthquake), with a moment magnitude of 9.0, hit on the Northeast area of Japan. It was approximately 280km from the epicenter to Numappara dam as shown in Figure 4. Moment magnitude of 9.0 is the largest in the record history in Japan. Causalities including disappeared totalled over 18 thousands and damaged buildings totalled over 1 million. It is said that caused damages were the largest in disasters happened after 20th century.

2.2 Influence on Numappara Dam

Monitoring items were as summarised in Table 1. The monitoring activities have been regularly conducted since initial impounding to detect any abnormal behaviour in term of the dam safety. Except cases of large disasters, the long-term trend of each item has been checked. However, just afte 2011 Tohoku Earthquake, those accumulated monitoring records were very helpful to evaluate dam safety at that time, so that decision making for the dam operation was smoothly done. The details are mentioned below.

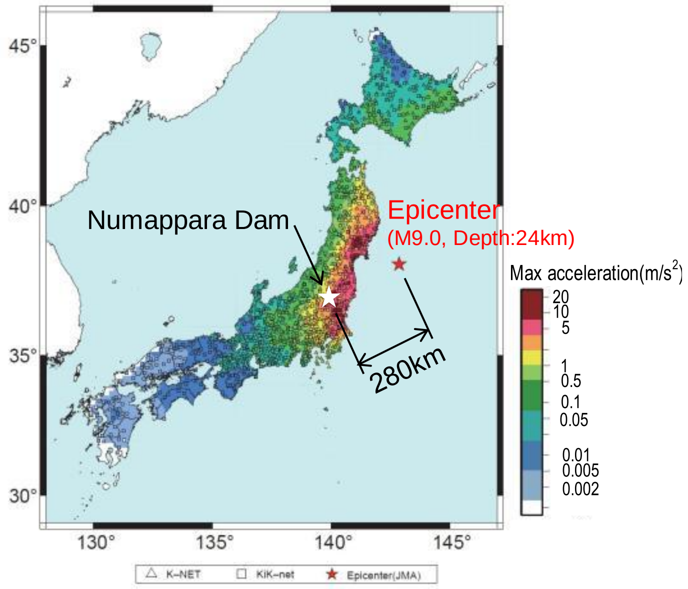


Figure 4. Epicenter of the 2011 off the Pacific coast of Tohoku Earthquake

Table 1. Menu of the Dam Monitoring

Object	Contents	Remarks
Displacement	On the dam crown 7 points in perpendicular direction and 27 points in vertical.	Monitoring by GPS was added in 2007.
Water leakage	Measured in the gallery once a hour.	Data is transmitted to the site office on real time.
Seismic acceleration	3 seismometers installed on the crown and in the foundation.	
External appearance of facing	Visual inspection, in every 5 years with emptying the reservoir.	
Site view	TV camera installed on the crown.	Picture is transmitted to the office on real time.
Downstream slope	Visual inspection and weed control on the downstream slope.	

2.2.1 Monitoring Record

Maximum accelerations measured during The 2011 Tohoku Earthquake are summarized in Table 2. Maximum 3.82 m/s^2 on the crown and 2.10 m/s^2 in the foundation were recorded respectively, either of which were in perpendicular direction to the dam axis. They were the largest record in ever experienced ones at the dam. As for displacement, maximum 3mm in horizontal direction and maximum 11mm in vertical direction were detected as shown in Figure 5.

Table 2. Record of Max Acceleration Measured at the Dam Body

Position	Dam axis	Horizontal*	Vertical
Southern bank crown	3.16 m/s^2	3.47 m/s^2	1.68 m/s^2
Western bank crown	3.16 m/s^2	3.82 m/s^2	1.95 m/s^2
Foundation (gallery)	1.35 m/s^2	2.10 m/s^2	0.97 m/s^2

*) perpendicular direction to dam axis

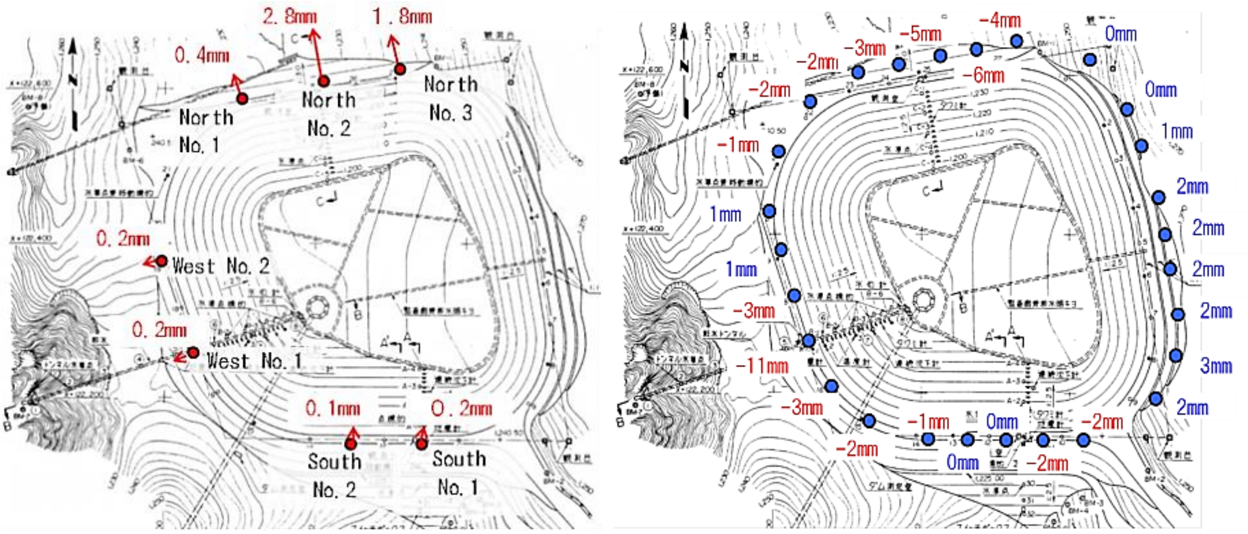


Figure 5. Displacement (Left : in Horizontal Direction, Right : in Vertical Direction)

More than 1,000 l/min of water leakage through the cracks was detected in spite that almost zero leakage had continuously been observed until the earthquake occurred. To avoid a possible serious failure, the water level was drawn down to the safe one. Detail is described in the following section 2.3.

Furthermore, in the field investigation conducted afterwards, many cracks on the facing surface were found as shown in Figure 6. They were concentrated near the boundary between embankment and cut slope. Widths of the cracks were within 1mm in the daytime, nevertheless, it expanded to 3mm depending on the ambient temperature, and total length of the crack reached to 1,547m. Causes of the cracks were assumed as follows; in general, mechanistic characters of the asphalt material depend on its temperature, and in low temperature circumstance, it tends to lose its resilience. When the earthquake occurred, ambient temperature was recorded around minus 10 degrees Celsius which was low enough for the asphalt material to lose its resilience Furthermore, there seemed to be considerable difference of displacement caused between on the cut-slope and on the embankment. These are assumed as reasons why cracks were intensively induced near the boundary.

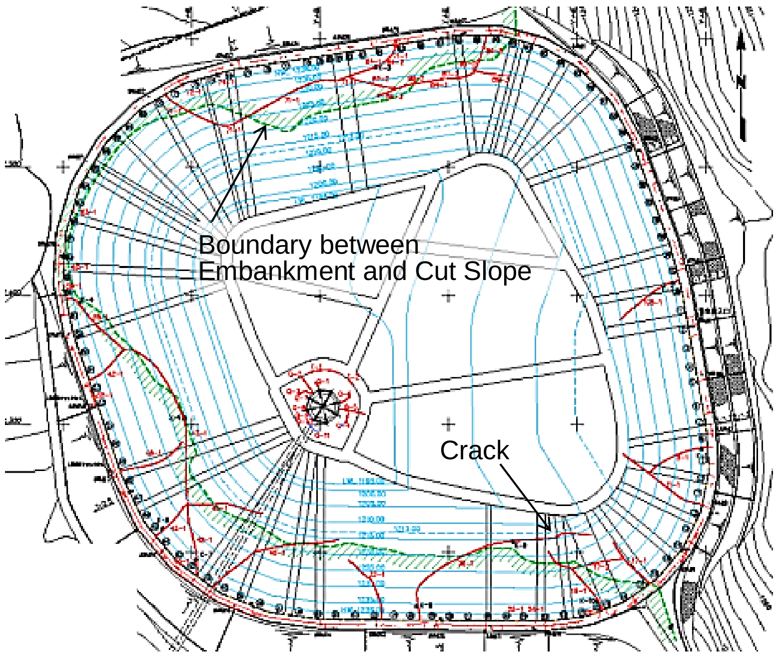


Figure 6. Cracks on the Asphaltic Facing

2.2.2 Dam Safety

Safety of the dam body itself was also evaluated just after The 2011 Tohoku Earthquake from the displacement data and seismic response characteristics. Displacements were not so large considering records of the past. Seismic response characteristics were not changed during the earthquakes including aftershocks shown in Figure 7. In the field investigation conducted afterwards, any damages. such as slope sliding, were not founded on the dam body and limb ground. Consequently, it was judged that the dam body was still kept in safe condition and damage occurred only on the asphalt facing.

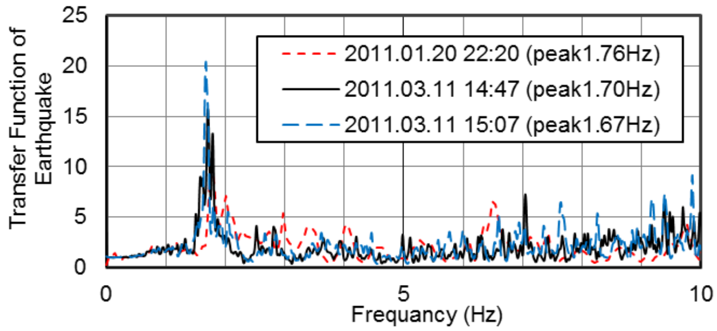


Figure 7. Transfer Function of Earthquake

2.3 Responses against Water Leakage

Even just after The 2011 Tohoku Earthquake, water leakage data showing rapid increase was available because those were to be transmitted to the site office automatically. However, due to heavy snow, site personnel could not access to the dam and industrial television camera installed on the crown did not work well due to heavy snowfall.

As a countermeasure against the water leakage, the draw-down operation was executed immediately by remote control to the safety level to avoid a possible serious failure as shown in Figure 8. With first draw-down operation after the earthquake occurrence (14:47), amount of leakage water could be reduced successfully. Fortunately, the telephone lines were available even just after the earthquake; therefore, we could had discussions between the site office, and the main office including the branch office and external organizations. Although the site office had the authority of decision making for the dam operation, cautious technical considerations were required for it because there were not enough information showing factual state. In this sense, technical discussions by available telephone lines taken between responsible personnel at the site and experts in the head office were very helpful.

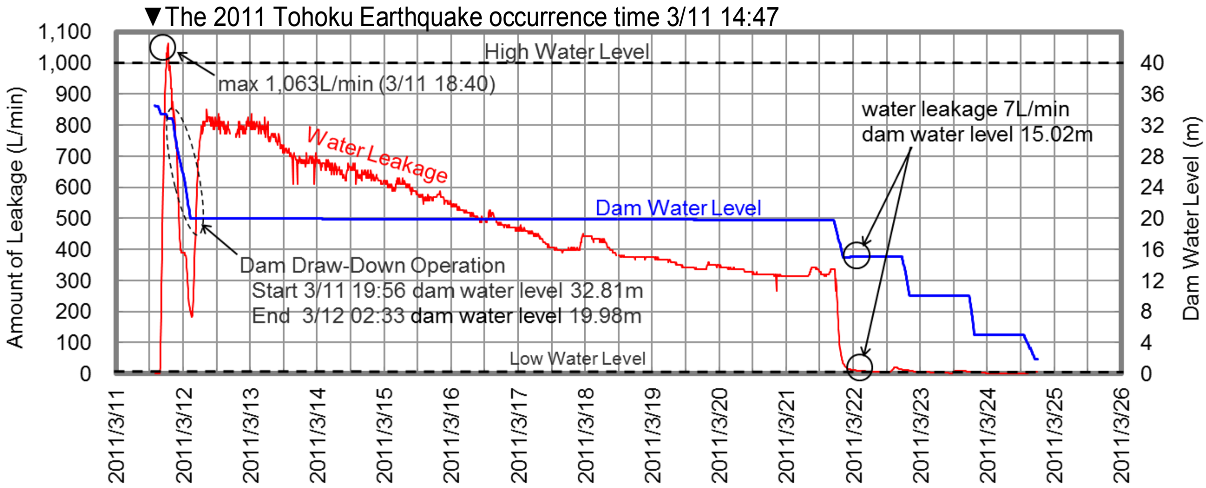
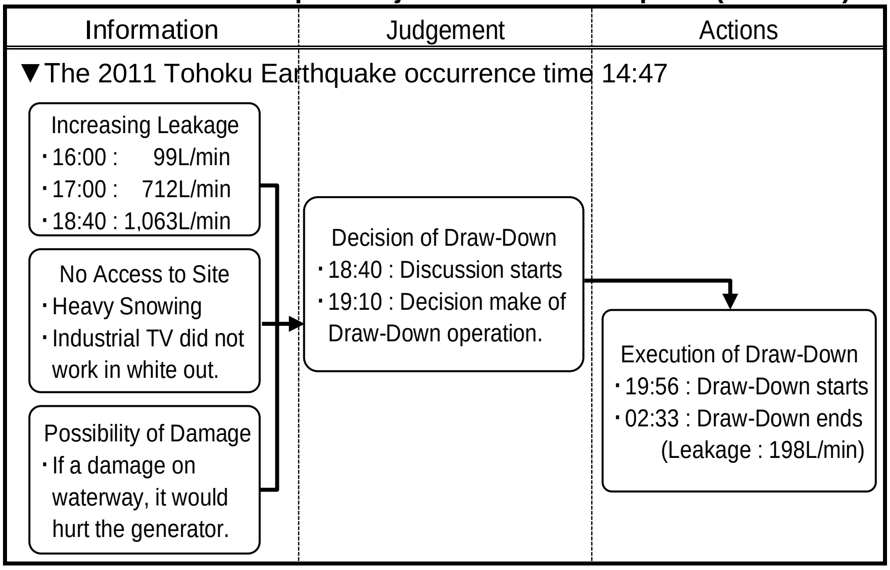


Figure 8. Water Leakage and Dam Water level after the Earthquake

Flow of responses including information taken at that time just after the earthquake is shown in Table 3. As a purpose of the preparation for a possible disaster in the future, all responses were recorded. What kinds of information we had, what kinds of decision we made, what kinds of action we executed, and etc. are described in the record.

Table 3. Flow of Responses just after the Earthquake (2011.3.11)



3. REPAIR WORKS FOR CRACKS ON THE ASPHALTIC FACING

3.1 Requirements and Design

For repair works on the cracks caused by The 2011 Tohoku Earthquake, there were two requirements as follows;

1) Repair works were to be completed earlier than the summer power heavy demand in consideration of severe power situation after the earthquake.

2) The repair method is to be designed to have some level of durability because of no prospection for next maintenance.

Typical section of the repair works is shown in Figure 9. In this design, impermeability of the facing is satisfied by three elements, which are the asphalt overlay, the (water-proof?) sheet impregnating with asphalt and the asphaltic rubber plugging.

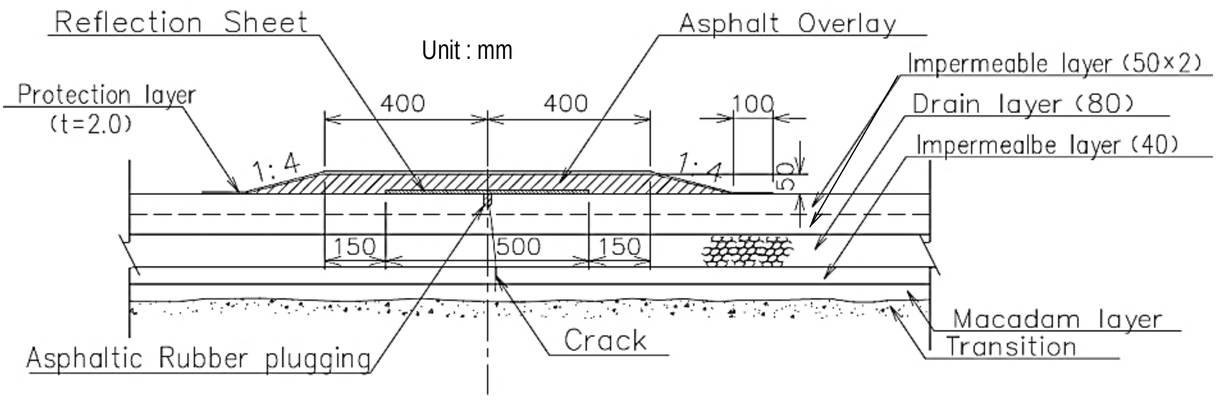


Figure 9. Typical Section of Repair works for Cracks on the Asphaltic facing

3.2 Execution

It took two months from the end of April to the end of June in 2011 until the all repair works were completed. It was just in time to resume the operation before the summer power heavy demand. Since cracks were dispersed and not straight, repair works were to be done by manual. Execution of manual paving of asphalt overlay and coating the protection layer are shown in Figure 10. A panorama view of the repair works completion is shown in Figure 11.

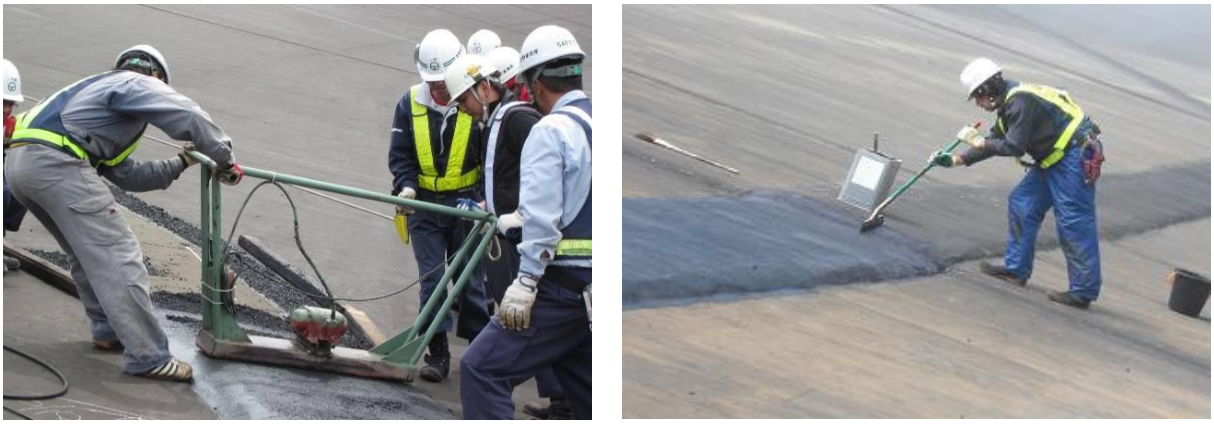


Figure 10. Paving of Asphalt Overlay and Coating the Protection Layer

Figure 11. Panorama View of Repair Works Completion (2011.6)

3.3 Effect

It has been 4 years since the repair works completed, however, no leakage has been found. It is considered that the repair works have worked well in terms of impermeability and durability.

4. SUGGESTIONS

Review of the responses in Numappara dam for The 2011 Tohoku Earthquake, following three suggestions are given for a similar situation in the future.

1) It is important to prepare have a definite action plan for crisis management.

2) Proper usual dam monitoring system is quite effective to carry out safety evaluation of the dam after a disaster.

3) Tough communication facilities should be established and the site office should be given more wide discretion in case that the communication facilities is spoiled.

4.1 Crisis Management

Although an action plan for risk management was prepared in definite manner, there was no definite action plan for crisis management at the earthquake. Difference of conceptual definition between those shown in Table 4. We managed to take adequate responses for The 2011 Tohoku Earthquake on 11th March in 2011as a result, however, more smooth and precise actions should have been done, if a definite action plan were prepared for possible disasters. It is important to prepare a definite action plan for Crisis Management, consequently, it will related to enhance dam safety..

Table 4. Risk and Crisis Management

Items	Definition
Risk Management	Mainly to take some measures for preventing from Crisis
Crisis Management	Mainly to take some measures against an occurred Crisis

For example, the aseismic performance evaluation done before the earthquake implicated that some cracks may have been induced on the asphaltic facing in the coldest period. Therefore, it was adequately conjectured that cause of water leakage was cracks induced on the facing; however, there were no preparations for what to do against caused water leakage, no idea for repair works of cracks along with serious amount of water leakage.

4.2 Usual Dam monitoring

In Numappara Dam, the improvement activities for usual dam control had been continuously conducted since 2007. Some of those, as shown in Table 5, were quite effective to carry out safety evaluation of the dam smoothly after The 2011 Tohoku Earthquake. Proper usual dam monitoring makes dam safety evaluation rapidly and correctly in case of disaster.

Table 5. Safety Evaluation based on Dam Monitoring at Numappara Dam

Monitoring Items	Safety Evaluation
Dam Displacement Monitoring	Displacements of dam crown are measured once a month. After the earthquake, we found no hazardous displacements of the dam crown.
Leakage Monitoring	Result of leakage monitoring is transmitted to the office every hour. After the earthquake, we did not have access to the dam site, But we found Increasing leakage by the data transmitting system and made a decision of draw-down operation rapidly.
Television monitoring	Installed on the crown, pictures are transmitted to the office on real time. Because of snowstorm, TV monitoring did not work on the day.
Aseismic Performance Evaluation	It implicated that some cracks may have been induced on the asphaltic facing in the coldest period, We adequately conjectured that cause of leakage was cracks induced on the facing.
Maintenance Works for Downstream Slope	It had been carried out to avoid influence of tree roots on the dam body and to make it easier to check dam deformation. After the earthquake, this maintenance made it easy to check the shape of the Dam.
Periodical Investigation of Asphaltic Facing	Visual investigation of the asphaltic facing is executed in every five years. After the earthquake, it was easy to recognize the caused change of the asphaltic facing.

4.3 Communication Facilities

Direct discussions between responsible personnel in site office and experts in the head office could be done because the communication system was available even just after The 2011 Tohoku Earthquake. And the earthquake occurred in the working time.

In this regard, tough communication facilities should be established. It would especially be a big advantage when initial responses are taken without sufficient information. Furthermore, the site office should be given more wide discretion in case that the communication facilities are spoiled.

5. FOR A POSSIBLE DISASTER

As above-mentioned, Numappara dam was damaged by the 2011 Tohoku Earthquake. Our experiences through a series of actions and measures taken place to damages by the earthquake are very valuable for a possible disaster in the future. In this sense, it is also important to make technical succession effectively to the younger generation based on not only successful experiences but rather failing ones. It should be keep in mind even in usual dam monitoring activities those secondary disasters which cause damages to the public shall be absolutely avoided as a responsible dam owner.

6. ACKNOWLEDGEMENTS

Thanks go to Tatsuo Omach, an emeritus professor of Tokyo Institute of Technology, and Norihisa Matsumoto, an executive director of Japan Commission on Large Dams, they supported us to make the record of responses in The 2011 Tohoku Earthquake for a possible disaster. And thanks go to Atsushi Kasahara, an emeritus professor of Hokkaido University of Science, he gave us valuable advices in designing of repair works and has been supporting us to maintain the repair parts..

7. REFERENCES

Okumura, HIROFUMI (2012). *Influence of the 2011 off the Pacific coast of Tohoku Earthquake on Numappara Dam and Repair Works*. Electric Power Civil Engineering No.362: pp 30-34. in Japanese

Okumura, HIROFUMI (2015). *Record and Technique Succession of Crisis Response for Numappara Dam Water Leakage on the 2011 Tohoku Earthquake.* Journal of Japan Society of Dam Engineers, Nol.25 No.2, pp 99-104. in Japanese

oOOo