Rationalization of Emergency Inspection for Hydraulic Structure by combining Earthquake Early Warning and 3D Dynamic Analysis

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SUMMARY:
Confirmation and securing of seismic safety of existing structures is very important in earthquake countries. Especially at the time of severe earthquake, quick and efficient inspection will be strongly required. Therefore, we studied about the rational method for confirming seismic safety of existing structures. The method proposed in this study is devised by combining 3D dynamic analysis and the Earthquake Early Warning (EEW). The applicability of the method was examined by the case study for existing spillway by using the earthquake motions recorded during the 2008 Iwate-Miyagi-Nairiku Earthquake. By applying this method, the workers at the site who are unfamiliar with the earthquake engineering can easily recognize the important parts which should be inspected urgently. Then, it becomes possible to execute the emergency inspection effectively.

Keywords: Earthquake Early Warning, seismic safety, 3D dynamic analysis, emergency inspection, spillway

1. INTRODUCTION

On one hand, seismological observation networks such as the Hi-net/ KiK-net, the K-NET by the National Research Institute for Earth Science and Disaster Prevention (NIED), and the seismological observation network by the Japan Meteorological Agency (JMA) have been densely realized in Japan. Magnitude of earthquake and the location of epicenter are estimated in a few seconds based on the observed data of P-waves. And, arrival time and seismic intensity of main shock are estimated and informed before the attack of main shock. This earthquake information before the arrival of main shock is defined as the Earthquake Early Warning (EEW). JMA started issuing EEW for the public through TV and radio from October 1, 2007.

On the other hand, we have developed 3D dynamic analysis technique for a coupled structure - foundation - reservoir water system, and it has become possible to evaluate the seismic safety of structures with high accuracy.

With these points as background, we have developed a method for evaluating the earthquake damage of existing hydraulic structures immediately by combining 3D dynamic analysis, EEW and strong earthquake motions observed at the site in order to rationalize the emergency inspection just after large earthquake. It is needless to say that EEW is to be utilized for evacuation just before the arrival of earthquake motion.

2. PURPOSE OF STUDY

In regard to the infrastructures of great social importance, such as dam, spillway, electric power station, highway, railway, and so forth, it is necessary to grasp the earthquake damages accurately, and to confirm the seismic safety effectively. At the time of severe earthquake, quick and efficient inspection will be strongly required. Furthermore, the reliable information in regard to safety and security should be dispatched to the parties concerned and the public in the vicinity of the site as soon as possible.

But, the following problems can be pointed out from the earthquake experiences in the past.

- It takes much time to recognize what has happened, or what earthquake has occurred.
- It takes much time to grasp the actual state of earthquake damage, the quality and the quantity of damage.
- Usually, there is no engineer who is familiar with the earthquake engineering at the site.
- Decision making becomes more difficult as the earthquake damages become great.
- A flood of inquiries for safety of structures rushes to the site and the parties concerned. Consequently, it becomes difficult to cope well with these inquiries, and the social trust will be lost finally.

Taking such matters into consideration, we studied the efficient method for confirming the seismic safety of dam and spillway by combining 3D dynamic analyses, EEW, from the viewpoint of facility management and earthquake disaster prevention and mitigation.

3. EFFICIENT CONFIRMATION METHOD FOR SEISMIC SAFETY

3.1. Flow of the Method

The fundamental concept for rationalization of seismic safety confirmation is shown in Fig. 3.1. It is considered that the combination between 3D dynamic analysis and earthquake information can produce new useful information for earthquake disaster prevention and mitigation.

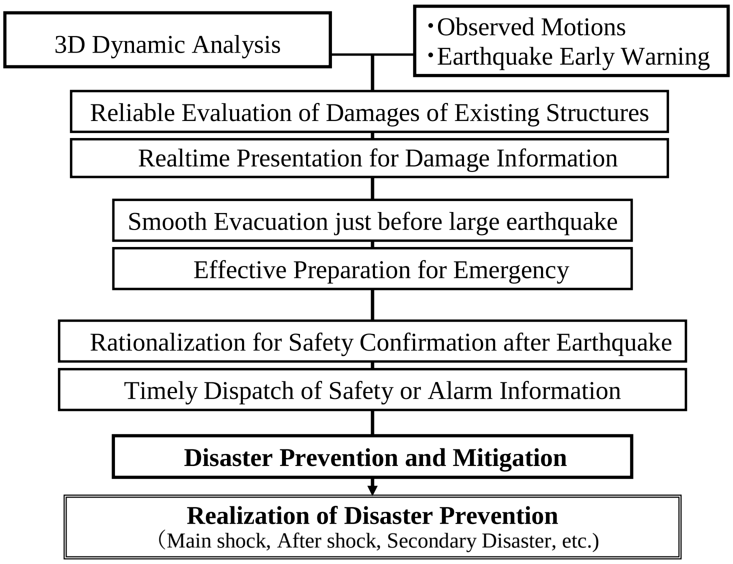

Figure 3.1. Flow of rational confirmation method for seismic safety of existing structures

3.2. Combination between 3D Dynamic Analysis and EEW

Procedure of efficient confirmation method for earthquake damage of dam and spillway is shown in Fig. 3.2. And the relationship between advance evaluation in ordinary time and immediate evaluation in earthquake time is shown in Fig. 3.3. Specialty of this study is a organic combination among 3D dynamic analysis, EEW and actual strong earthquake motion observed at the site. As shown in Fig. 3.2, the method is composed of three stages.

The first stage is an advance evaluation in peace time. The advance evaluation consists of the arrangement of earthquake damages of existing dams and spillways, the 3D dynamic analyses under various conditions, and the arrangement of the analyzed results concerning earthquake damage. The 3D dynamic analyses are made in order to evaluate the dynamic stress and strain within the structures under various conditions, such as input earthquake motions, dynamic properties of structures and foundation, depth of reservoir water, and so forth.

The second stage is an immediate evaluation just before the arrival of earthquake motion. The immediate evaluation consists of the receipt of EEW, the estimation of earthquake motion at the object site based on EEW, the immediate evaluation of earthquake damage, search of the most adequate results about earthquake damage, the transmission of selected information to the site, and so forth. The procedure from the receipt of EEW to the transmission of information can be executed within several second.

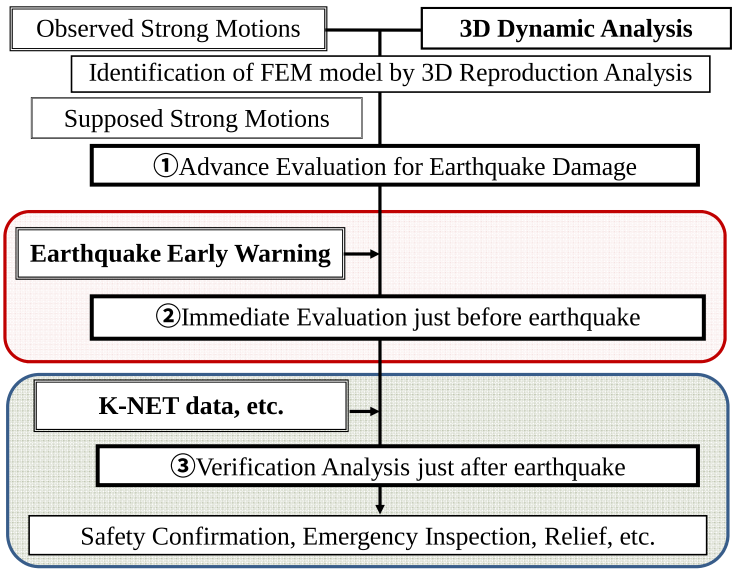

Figure 3.2. Procedure for efficient confirmation of earthquake damage and seismic safety

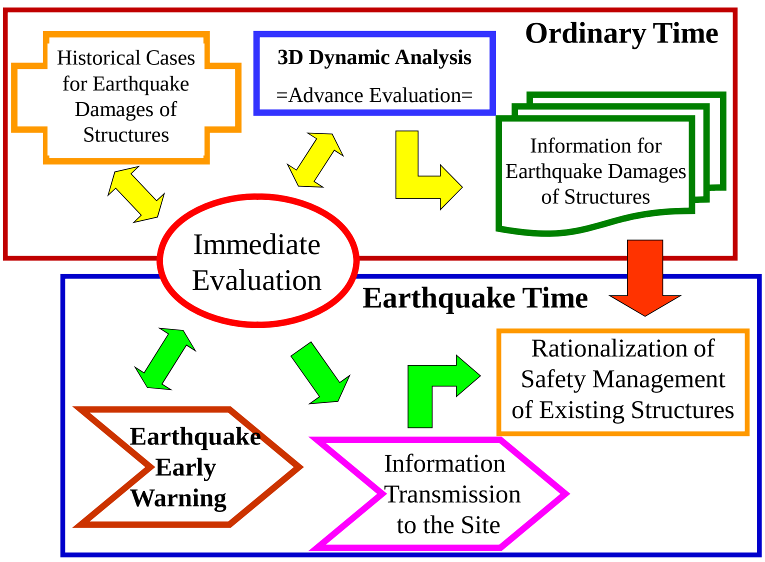

Figure 3.3. Coordination between 3D dynamic analysis and earthquake information

And the third stage is a proof evaluation just after the earthquake. The verification analyses by using the actual earthquake motions are made in this stage. The information necessary for rational emergency inspection, such as the contour map for dynamic stress distribution and so forth will be send to the site automatically when earthquake occurs.

3.3. Effective Evaluation Method just before and after Earthquake

The earthquake damage of dam and spillway is evaluated by the 3D dynamic analysis. The leeway time before the attack of main shock will be expected to be several to several ten seconds. At present time, it is difficult to execute 3D dynamic analysis within several seconds. And the engineer who is familiar with the earthquake engineering is not necessarily working at the dam site.

Taking these matters into consideration, we devised the information transmission system which works automatically at the same time of receipt of EEW. The fundamental flow of the immediate evaluation before earthquake and verification analysis after earthquake is shown in Fig. 3.4.

The damage of structure by strong earthquake motion will be affected by the shape and the size of structure, the dynamic property of structure and foundation, the condition of reservoir water, the amplitude and frequency characteristics of input motion. These affects should be examined by the 3D dynamic analysis. The 3D dynamic analyses are made by assuming various conditions in regard to the maximum acceleration of input motions, the water level of reservoir, the dynamic property values of foundation.

The charts for urgent judgment of earthquake damage of dams are made based on the results of the 3D dynamic analyses which are made under the plenty of analytical conditions. The charts are arranged as the function of maximum acceleration and predominant frequency of input earthquake motions.

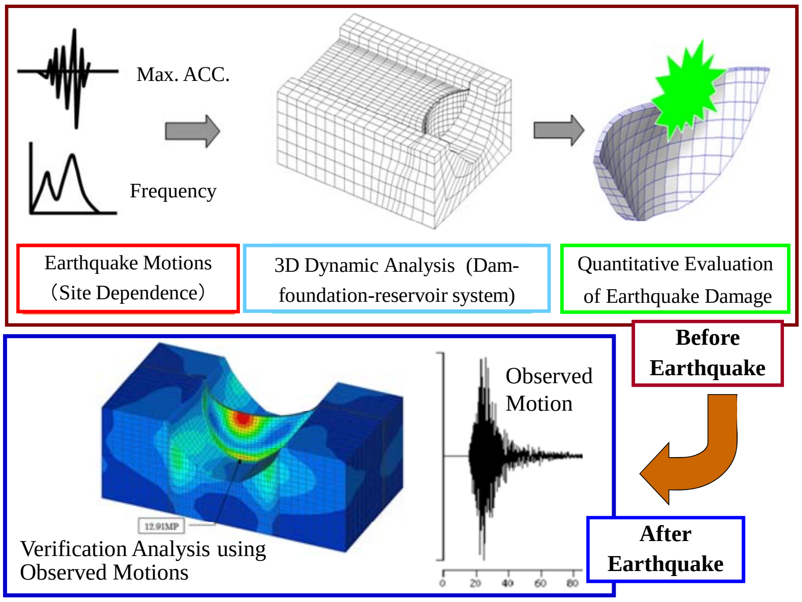

Figure 3.4. Advance evaluation before earthquake and verification analysis after earthquake

4. CASE STUDY FOR EXISTING SPILLWAY

4.1. Outline

The method proposed in this study is contrived as the organic fusion of 3D dynamic analysis and EEW and seismological observation. This method is devised based on the idea that the organic fusion of earthquake observation data and 3D dynamic analysis enables to produce new information necessary for the earthquake disaster prevention and mitigation.

The case study was made in order to examine the applicability of the method. A spillway was selected as the object for the case study. And, the strong earthquake motions observed during the Iwate-Miyagi Nairiku Earthquake in 2008 (M7.2) were used for input motion.

4.2. Analytical Model

3D FEM model of spillway is shown in Fig. 4.1. The spillway is composed of four concrete piers and 3 steel fixed-wheel gates. The total height of spillway is 34m. The piers and the training walls are made with reinforced concrete. The fixed-wheel gates were missing in this model, because the fixed-wheel gates are structurally separated from the piers.

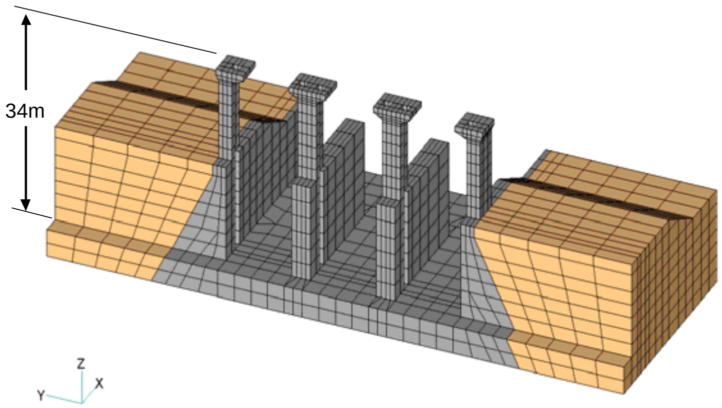

Figure 4.1. 3D dynamic analysis model of spillway

Table 4.1. Dynamic Property Values of Spillway

Item	Dynamic Shear Modulus (N/mm^2)	Density (g/cm^3)	Poison's ratio	Damping Factor (%)
Concrete Pier	9,375	2.40	0.20	3
Embankment	119	1.76	0.30	8

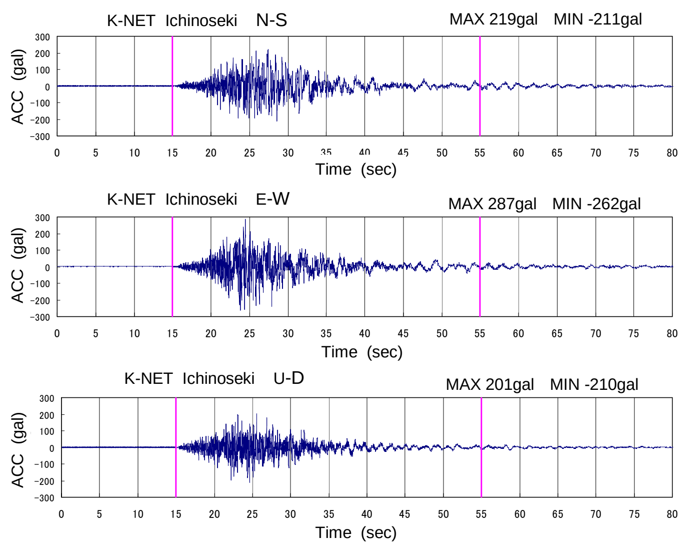

Figure 4.2. Earthquake motions recorded at Ichinoseki point during the 2008 Iwate-Miyagi-Nairiku Earthquake

The reservoir water was also missing in this model, because the reservoir water will not have significant influence on the displacement behavior of spillway especially in the dam-axis direction. The spillway and the embankment were meshed with the solid elements. As for the boundary conditions, the rigid boundary is applied for the bottom boundary, and the viscous boundary for the right and left lateral boundaries.

The dynamic property values of concrete piers and embankment are set as shown in Table 4.1. The values of dynamic shear modulus and damping factor were supposed according to the 3-D reproduction analysis for actual earthquake behaviour of existing spillway (Ariga, 2008).

4.3. Input Motion

Fig. 4.2 shows the acceleration time histories recorded at the Ichinoseki Point (Epicentral distance 23km) of K-NET during the Iwate-Miyagi-Nairiku Earthquake (M7.2) used for input motions. Three components of motions are input simultaneously in the analysis.

4.4. Result of Analysis

Fig.4.3 shows the distribution of calculated maximum acceleration. The maximum acceleration at the top of pier was 2167gal in this case. Fig.4.4 shows the distribution of calculated maximum tensile stress through all the time. The maximum tensile stress was 8.89N/mm^2 at the lower part of pier. In such a case, it will be necessary to suppose some earthquake damage and to make emergency inspection quickly and smoothly.

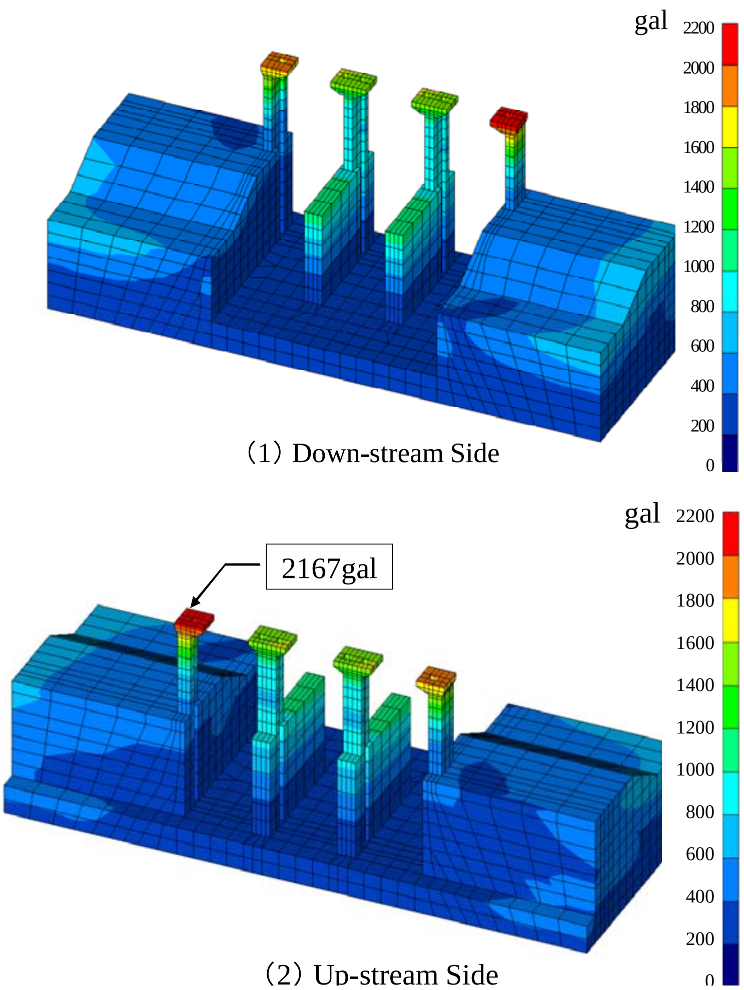

Figure 4.3. Distribution of calculated maximum acceleration

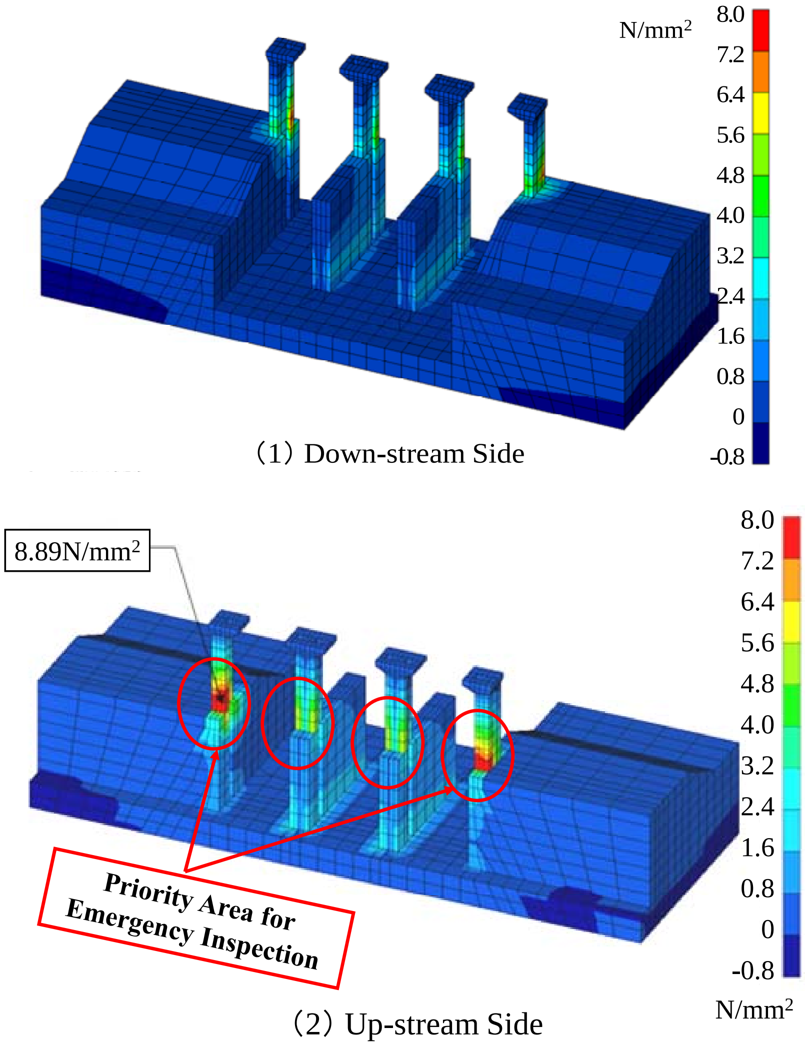

Figure 4.4. Distribution of calculated maximum tensile stress during earthquake

5. CONCLUSIONS

We studied the efficient method for confirming the seismic safety of hydraulic structures by combining EEW, the earthquake observation at the site, and 3D dynamic analysis in order to rationalize the emergency inspection just after large earthquake.

The rational emergency inspection and the efficient confirmation for seismic safety of hydraulic structures can be realized by applying the method proposed. This method will be useful for preventing and mitigating the human, physical and economical damage for the hydraulic structures by the large earthquakes.

The information necessary for emergency inspection, such as the distribution of dynamic tensile stresses evaluated by 3D dynamic analysis, can be sent to the site within 1~2 seconds. It becomes possible to execute emergency inspection within 24 hours smoothly by utilizing this information, which is also useful for enlightening and education for inexperienced young engineers.

If no earthquake damage is predicted and confirmed, the safety and security information can be sent immediately after earthquake to the site and the interested divisions. If any earthquake damage is predicted, the urgent inspection should be made by referring the 3D dynamic analysis results. The priority parts which should be inspected can be referred on the computer screen, and the worker at the site can make the emergency inspection effectively. The immediate evaluation method for earthquake damage proposed in this study can be also applied for the seismic safety evaluation of many kinds of structures.

This method can be broadly utilized for preventing not only the direct disaster but also the secondary disaster, and improving the earthquake disaster prevention performance. This method can be broadly applied to not only hydraulic structures but also social infra-structures such as highway, railway, high buildings, urban structures, and so forth.

The possibility for utilizing the information about frequency characteristics of earthquake motions, the improvement of reliability of earthquake damage evaluation, the development of supporting system for decision making at the time of emergency, the promotion of enlightening and education for earthquake disaster prevention, and so forth can be mentioned as the subjects for future study.

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