Title: Evaluation of soundness and seismic behavior of long-term-use irrigation dams

Author(s): Hayashida, Yoichi

Citation: Kyoto University (京都大学)

Issue Date: 2018-03-26

URL: https://doi.org/10.14989/doctor.r13183

Rights: 学位規則第9条第2項により要約公開; 許諾条件により要約は2019-03-25に公開; 許諾条件により本文は2019-02-05に公開

Type: Thesis or Dissertation

Textversion: ETD

Kyoto University
Evaluation of soundness and seismic behavior of long-term-use irrigation dams

-Abstract version-

Yoichi HAYASHIDA

2018
Abstract

Historically speaking, earthquakes have caused significant damage to few dams. On a worldwide basis, only several dams are known to have failed completely as a result of an earthquake. Hence, if one considers the total number of existing large dams around the world, the current performance record appears to be outstanding, based on the limited number of failures that have occurred. From this fact, it is confirmed that modern design and construction methods can guarantee the seismic performance of dams.

Many dams in Japan have been used for long periods of time. In 2010, it was reported that 50% of the dams constructed after 1900 were still in good working condition over 50 years after their construction, and this number is expected to rise to 58% by 2020. Thus, it is important to manage the safety of these dams and to maintain their healthy condition. In Japan, huge earthquakes have been occurring frequently since the 1995 Hyogoken-Nanbu Earthquake; they include the 2004 Niigataken-Chuetsu Earthquake, the 2008 Iwate-Miyagi Nairiku Earthquake, the 2011 off the Pacific coast of Tohoku Earthquake, and the 2016 Kumamoto Earthquake.

Under such circumstances, social awareness of earthquakes has increased; and thus, checks of the seismic performance of existing dams are being carried out nowadays to evaluate the safety of the dams and to assess their stability against large earthquakes.

In this thesis, the mechanisms of the possible failures of fill dams induced by earthquakes have been revealed, and a countermeasure to moderate these harmful effects on the dams has been proposed. Moreover, a new measuring system to evaluate the health of fill dams has been developed and improved, and its performance has been verified for some real dams over the long term.

In Chapter 2, the seismic damage to dams during past massive earthquakes was reviewed and the features of the damage were summarized. Moreover, reviews of both the seismic design of fill dams and studies on the possible failures of fill dams due to earthquakes were given. In summary, it is obvious that the seismic performance of rock-fill dams is excellent, and that concrete dams are superior to embankment dams in seismic performance, while earth-fill dams have suffered more serious damage during earthquakes than other types of dams. Most of the damage was due to settlement at the crest, longitudinal and transverse cracking on the crest, transverse cracking, and a difference at the connecting part between the abutment and the embankment, and sliding, cracking, and a difference parallel to the dam-axis at the downstream or upstream slope. Their effects were mainly concentrated in the upper part and the crest of the embankment, and such portions were found to be the most vulnerable to earthquakes. Earth-fill dams composed of low-density sandy or silty materials are vulnerable to massive earthquakes; and thus, it is essential to assess the harmful effects of such earthquakes on dams and to take measures to reduce them.

In Chapter 3, the performance of the new measuring system installed within embankment dams
was verified. This system can improve the efficiency of dam construction and the stability of pore water pressure measurements for the safety evaluation of fill dams. This system is called the “wireless pore water pressure transducer (WPT)”. From the results of tests conducted at real dams, it was confirmed that WPTs can measure data as well as conventional sensors with cables. The validity of WPTs is obvious from the ease of their installation and their measurement performance. However, the test models for the WPTs installed in real dams became inoperative and unable to perform data communication after only five and a half years. This was a much shorter lifetime than the expected and specified one of ten years. It was clarified by capacity tests on their batteries and a look at the voltage data of the batteries measured on site that the reason for this phenomenon was not due to a lack of battery capacity, but to a drop in voltage during the communication mode induced by the increase in the internal resistance of the batteries. Thus, the batteries were set in parallel to moderate the effect of the drop in voltage. Improved ones were installed in a real dam. The results of the improved WPTs showed that the effect of the drop in voltage induced by internal resistance can be modified compared with the test models, and that the long-term performance of WPTs can be advanced.

In Chapter 4, the influence of the regions of the modeled area and the material properties of the bedrock on the seismic behavior of the dam were investigated by numerical experiments. From the results, it was clarified that the acceleration amplitude ratio, the Fourier spectrum ratio, and the 1st predominant frequency of the dam mainly depend on the material properties of the dam’s bedrock. Moreover, the modeled area of the bedrock was found to have a lesser effect on them. These phenomena can be caused by the deformation modes of the dam based on the interaction between the dam and its bedrock. The deformation modes of the dam mainly depend on the material properties of the bedrock, and the regions of the modeled area have a lesser effect on the deformation modes of the dam. The seismic characteristics of the bedrock are affected by the predominant frequency of the dam body. Thus, it is important to determine the modeled area of the dam’s bedrock in seismic response analyses such that the predominant frequencies of the dam do not approach those of its bedrock.

In Chapter 5, the fracturing mechanism of the dam body developed by the interaction among the liquefiable foundation, the dam body, and the reserved water were examined by centrifugal liquefaction experiments in view of the liquefaction of the foundation which is one of the principal factors inducing large deformations of the dam body during an earthquake. From the results of the experiments, it was clarified that fractures in the dam body develop progressively according to the interaction between the liquefiable foundation and the dam body. It is also supposed that the deformation of the upstream slope of the dam body is the dominant factor in inducing the catastrophic destruction of the dam body. It was clarified that the retrofit at the toe of the downstream slope can moderate such deformation and, even when the dam body has been damaged
severally, catastrophic destruction inducing overtopping can be prevented. Deformation behaviors of earth-fill dams due to the liquefaction of foundation grounds were examined by an effective stress analysis method, in which the zoning type, the dynamic properties of the liquefiable foundation ground, the reserved water condition, and the input wave were changed. It was clarified that the zoning type and the reserved water condition will remarkably affect the tendency of the dam to deform. The settlement of a dam with inclined core zoning will be larger than that with other types of zoning under the reserved water condition.

In Chapter 6, the characteristics of the seismic behavior of fill-type dams were examined by shaking table tests, in which three dam models with different shapes were shaken separately in the stream direction and in the dam-axis direction, and then the effects of the dam shape and the direction of the input wave on the seismic response behavior were examined. From the test results, it was concluded that the points at which the maximum acceleration values were recorded during the shaking in the stream and the dam-axis directions are right above the deepest part of the dam’s valley. It was clarified that the response orthogonal to the shaking direction could arise depending on the shape of the dam body, and the direction and the dominant frequency of the input wave. In particular, when the shaking direction is dam-axis, the dam body shows complicated three-dimensional behavior, and the point at which no response can be incited appears on the crest of the dam. Thus, it is important to pay attention to the relation between the seismic modes of a dam body and the dominant frequency of the input wave when the data recorded by seismometers installed in real dams are analyzed and the cause of the damage to the dam is examined.

Therefore, fill dams show very complicated behavior during earthquakes based on the interaction among the foundation, the reserved water, and the dam body. Moreover, such behaviors largely depends on the nature of the earthquake motion. However, it is technically very difficult to accurately predict the earthquake motion at a dam site. To check the seismic performance of a fill dam, the slope stability is mainly taken into account. However, it is also important to determine the possible failures under each condition of the dam and to assess its seismic performance by a comparison with the already well-known “defensive design”. Creating countermeasures for the purpose of protecting existing dams, that do not satisfy the “defensive design”, is important from the viewpoint of dam management, and it is expected that such countermeasures will be developed along with useful evaluation procedures for the safety of dams, if such dams must be utilized in the future.