Advances in Dam Safety Management
Research Activities on Dam Safety at K-water
Dam Safety Symposium

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Abstract

The main objective of this paper is to introduce recent research activities at K-water, Korea regarding advanced dam construction technology and safety management. Recent global warming and climate change causes extreme loading conditions in many dams in the world hence safety evaluation and management are one of great concerns from public and managing authorities. Various construction technology as well as information technology (IT) aimed solutions are utilized in dam safety management systems, and it provides valuable information about not only for the better understanding of the structural behavior but also preparing countermeasures. The research activities introduced in this paper may provide some idea about how the new technologies can help the management of dam safety.

Keywords: embankment dams, safety, rehabilitations, risk assessment

1. Foreword

The performance of dams subjected to various loading conditions is important not only to guarantee its safety but also prevent tragic consequences. For examples, one may see a large dam in China which withstood great seismic loading and caused minimized disaster even though there were severe damages in the dam (Zhang et al., 2015). One may also see unexpected breaches of dams due to earthquake (Matsumoto et al., 2011) or piping induced by internal erosion. Precise performance evaluation utilizing advanced technology is important in dam construction project as well as safety management to prevent unexpected disaster.

With evolution of science and technology, there have been great advances in field of dam engineering; including not only design and construction technology, but also information technology aimed safety evaluation and management programs.

In K-water, number of research programs in dam construction and safety managements have been conducted utilizing various new technology and some of recent research activities are introduced in this paper.

2. Large dam constructions in Korea

2.1 K-water

K-water, Korea Water Resources Corporation, was established in 1967 by Korean government with important missions of national water supply; construction of major multi-purpose dams to secure water resources and national/local water supply networks, hence over 20 largest dams in Korea was constructed and managed by K-water. It also has been making a great contribution toward the development of the national economy and improving the quality of life for local people.

K-water has constructed 15 large multi-purpose dams, and now it is in charge of operation and management of various 20+ major large dams in Korea which are multi-purpose, local water supply, hydro power, flood controls, etc, and the types are also diverse; rock-fill with impervious core, concrete faced rock fill dams, concrete dams, etc. The company has been playing an important role in dam construction technology in Korea by its own experiences in number of construction cases, and also by promoting domestic and international collaboration and networks. Leading the technology, it also has been working in development of various engineering and management technology by its research institute.

2.2 Research and development in dam construction engineering

K-water founded its own research institute, K-water Institute, which has goals of research and development for various water related technology and national/global policies.

At the beginning of dam construction projects in Korea, the institute supported these projects by carrying out various tests for construction materials, and it expended its role to research and development of various technologies regarding dam construction and safety management.
Main research areas for dam construction and safety managements are as follows; 1) advanced testing for construction materials and performance evaluation of large water-related infrastructures, 2) development of investigation and rehabilitation measures for aged deteriorated dams, 3) risk based approaches in dam safety management. The institute has been carrying out various research programs in these fields and these research activities are introduced in following sections.

3. Recent advances and research activities at K-water

3.1 Geotechnical engineering for advanced dam safety programs

In general, large infrastructures such as embankment dams are designed according to guidelines and engineers tend to adopt empirical methods in their design; e.g. assessment of engineering soil properties, structural performance. In early projects of K-water, embankment dams were designed with limited informations, especially for soil material with large grains due to lack of technology. Number of research projects for advanced dam design and constructions have been carried out and various testing systems have been developed at K-water Institute in order to support reliable design and assessment of large dams as well as develop new construction technologies.

Table no.1 Major geotechnical testing systems at K-water Institute

<table>
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<tr>
<th>Equipment</th>
<th>Specifications</th>
<th>Applications</th>
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<tr>
<td>Large triaxial test apparatus</td>
<td>D=300mm, H=600mm</td>
<td>Static &amp; cyclic loading</td>
</tr>
<tr>
<td>Large true triaxial test apparatus</td>
<td>26cm×26cm×26cm</td>
<td>Anisotropic triaxial test</td>
</tr>
<tr>
<td>Large oedometer test apparatus</td>
<td>D=1m, H=0.6m</td>
<td>Consolidation tests</td>
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<tr>
<td>Large direct shear test apparatus</td>
<td>1m×1m, H=0.6m</td>
<td>Shear test for rockfill materials</td>
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<tr>
<td>Large resonant column test apparatus</td>
<td>D=20cm, H=40cm</td>
<td>Deformation parameters of gravels for seismic design</td>
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Table no. 1 lists major large geotechnical testing apparatus developed at K-water Institute and Figures no. 1 to 2 shows large scale triaxial and resonant column testing apparatuses. Most of embankment dams designed by K-water are constructed using rockfill materials hence the strength and deformation characteristics must be precisely evaluated to be utilized in design and performance evaluations. Various research projects have been carried out using these large scale testing systems to investigate general behaviour of rockfill materials in terms of critical state strength parameters as well as dynamic deformation characteristics for seismic design.

Various technologies to investigate in-situ material characteristics such as shear wave velocity (or deformation modulus) and electrical resistivities have been also utilized. Optimized technologies to apply in dam design and safety management have been investigate as well.

Performance evaluation based on precise material characteristics utilizing advanced engineering solutions is also an important issue in design and safety management of embankment dams. K-water has evaluated safety and performances of dams in Korea subjected to extreme loading conditions such as floods and earthquakes, and also investigate effective way to simulate realistic behaviour of the embankments.

For example, the interaction between the embankment and foundation, or between embankment...
and abutments affects the amplification of earthquake motions in dams hence should be evaluated in some cases. K-water has investigated this “valley” effect in seismic response by three dimensional numerical analysis and could confirm its validity by comparing with in-situ data which measured the earthquake responses.

More recently, physical modelling using geotechnical centrifuge is actively utilized in performance evaluation and investigation of failure modes of embankment dams subjected to extreme loading conditions. Since it is difficult to simulate progressive failure and/or large deformation by numerical modelling, physical modelling is widely used in many geotechnical engineering problems. At K-water, geotechnical centrifuge have been actively used to simulate in-situ structural behaviour of various water-related systems, especially for important projects. Recently, it has played a key role to evaluate seismic performance and safety of an existing dam.

3.2 Investigations in aged dams and rehabilitations

There are more than 20,000 dams in Korea, which are mostly operated and managed by local governments, and most of dams have been built before 1970s. Since the first construction of a multi-purpose dam in 1973, number of large dams have been constructed in Korea. With recent cases regarding breaches of old dams due to heavy rainfalls or pippings, the deterioration of embankment dams is an important issue in Korea and there are great interests and requests for research on in-situ investigation and/or diagnosis, and rehabilitation measure.

Various nondestructive technologies have been applied to distinguish deteriorated zone in embankment dams. Nondestructive seismic methods such as SASW, MASW, seismic reflection methods have been applied to find localized defect in dam and the results have been compared with various in-situ testing to evaluate their applicabilities (Figure no. 4).

2-dimensional visualization of electrical resistivities in the embankment is widely applied in dam safety programs in the world due to its convenience, performance and verified applicability. This method is widely applied to most of designate inspection programs for irrigational dams in Korea, but the result can be highly affected by transient condition of dam body so it is sometimes difficult to analyze the results. K-water has developed a real-time resistivity monitoring system for embankment dams (Figure no. 5). The system can carry out automated in-situ resistivity testing at a certain period and the results can be sent to the office server system via wireless communication systems. The measurement and analyzed data of each event can be compared in the server system to verify variation of resistivity, which may mean progressive deterioration of embankment. Hence the management office can have quantitative information regarding the dam safety.

Figure no.3 800g-ton geotechnical centrifuge with earthquake simulator

Figure no.4 Applications of rayleigh wave based seismic testing and electrical resistivity tomography; measurement from creast of ECRD dam in Korea

Figure no.5 Applications of rayleigh wave based seismic testing and electrical resistivity tomography; measurement from creast of ECRD dam in Korea
The deterioration of embankment dams results in leakage through the dam body or presence of a softened zone in the impermeable core. Cement grouting is mostly used as a rehabilitation measure for embankment dams, however, this application will be highly limited when locating the weakened zone or seepage path is not precise, or the injection pressure is not appropriately controlled.

K-water Institute has investigated the appropriate methodology of grouting in rehabilitation of earth core. Recently, it is carrying out a research program to develop a smart grouting system. The system utilizes ambient noise-based MASW methods to precisely locate the deteriorated zone as well as to locate the area where cement grout penetrated inside the dam. The low pressure to inject cement grouting is controlled by the pressure and flow rate inside the dam, hence it can significantly reduce the risk of damage during injection.

More recently, K-water has initiated a research program for rehabilitation of embankment dam by bio-clogging, which utilizes biofilms produced by microorganisms in the soil. The method may utilize the microorganisms which exist in the dam and act for self-healing processes once they are activated by injecting nutrients into the soil. This method is expected to be utilized in many embankments as an eco-friendly measure.

### 3.3 Dam safety & risk management

The state-of-the-art concept of safety management for dams and facility structures is changing from factor of safety based criteria to evaluation of vulnerability and risk management. In the United States, Australia, and the Netherlands for examples, risk analysis and assessment is adopted as new safety management paradigm considering engineering or economic aspects. It is also a good issue which is actively discussed in major expert groups such as ICOLD or other international societies and the cases of risk analysis and assessment around the world are frequently adopted. Awareness of risk analysis and assessment in dam safety has also spread in Korea and systematic tools for risk-based assessment, which is named as D-SMART, have been developed for advanced safety management of dams.
Since the first risk assessment trial for K-water’s large dams in 2011 and very first development of D-SMART version in 2013, risk analyses and assessments for large multi-purpose dams in Korea were carried out. Currently, D-SMART provides total solution for the risk analysis and assessment of dam safety. This system is being updated to accommodate advanced risk analysis modules for floods and earthquakes, and will be applied for more general cases in near future.

The same methodology and system is now adopted in a nationwide project for risk assessment of irrigational dams in Korea. With increased number of dam breaches in last 5 years, Korean government has designated 256 dams as disaster hazard structures in 2014 and currently the number is increasing as inspections for each system are conducted. In this circumstances, there are requests from the government to support decision making process for the order and priority of rehabilitations among these dams based on sound engineering background. Finally, the risk based method has been adopted in 2015.

The characteristics of small irrigational dams are much simpler than multi-purpose dams which are dealt in D-SMART; small sized, less appurtenant structures, less damage and social/economic effect expected in general. Detailed information regarding the construction and management records or site investigation results are not sufficiently provided for these types of dams, hence simple and site-specifically optimized applications of risk based method had to be considered.

In this program, risk assessment of dams considering hydrological and geotechnical risk analysis methods are carried out and K-water is mainly developing simplified risk assessment program for geotechnical risk analysis; focusing on both internal erosion and earthquake hazard related scenarios. The geotechnical assessment can be realized using general information of the structures, basic soil properties of the embankment, and on-site visual inspection results which describes and indicates critical safety condition or clues for defects. The detailed results which are given as value of total risk is expected to support the decision making process and the entire process will be introduced later.

4. Concluding remarks

Various research activities at K-water Institute and their application in dam safety management and performance evaluations are introduced in this paper.

The evaluation of engineering properties of the materials as well as in-situ characterization technologies to assess the structural conditions are important to evaluate the performance or safety of dams, especially in management of aged deteriorated embankment dams. Advanced monitoring and visualization techniques as well as state-of-the-art rehabilitation method are introduced and application of these new technology will greatly contribute the safety of embankment dams.

Risk based safety management philosophy is introduced with recent solution developed by K-water, D-SMART. The system can aid the management authorities to make safety management policies and decide priorities and orders of rehabilitation plan for number of dams.

Finally, K-water Institute is looking forward to exchange of its knowledge and experiences with international partners, as well as collaborations for dam safety managements and construction projects.

Reference
