Information System for Dam Safety Management

Nikola Milivojevic*, Nenad Grujovic**, Dejan Divac*, Vladimir Milivojevic*, Rastko Martac*
* Jaroslav Černi Institute, Belgrade, Serbia
** Faculty of Engineering, University of Kragujevac, Serbia
nikola.milivojevic@gmail.com, gruja@kg.ac.rs, ddivac@eunet.rs, vladimir.milivojevic@gmail.com, mrastko@gmail.com

Abstract—Dams must be permanently maintained in a proper way because of extremely grave consequences that may occur in case of a failure. Maintenance refers to monitoring the condition of a dam and its belonging facilities, that is to identification and undertaking of all necessary measures for ensuring safety and functionality of the facilities in a timely manner. Maintenance involves various factors concerning the facilities as structures: natural factors, environmental factors and human activities. With such complex issues, the question of optimality and use of available resources arises. This paper presents an information system for the support of implementation of regulatory frameworks for the safety of dams, which serves to improve the maintenance system, safety and functionality of the existing dams and provide the protection of local communities. An integrated approach to all aspects of dam maintenance is essential for solving this issue. The development of the system involves comprehension of measurable indicators that are relevant for the decision-making process, modernization and extension of the system for monitoring relevant values and development of physically-based mathematical models with the aim of analysing and predicting of dam behaviour. The system is developed and implemented on Prvonek dam (a 90 m rock-fill, water supply, latest facility of this kind that is constructed in Serbia). Some details on implementation and initial results are also presented.

I. INTRODUCTION

Regarding dam maintenance, in all countries that have large dams on their territory, the executive state authorities are obliged to monitor behaviour of all facilities in use and coordinate all activities that need to be taken in order to maintain the security of these facilities at a satisfactory level[1]. Recognizing the importance of dams and reservoirs which belong to the category of facilities of special social interest, as well as importance and impact of their maintenance on the service life and functionality, and safety of the facilities, and having in mind the level of actualization of legislation which deals with this field, it is extremely important to create technical conditions for implementation of strategy for maintenance of the existing dams, that is to define the proper way of maintaining large dams, so that their security and functionality is improved in a feasible and rational way[2].

Many tools for dam safety management provide owners and experts with procedures and methods for assessment of certain dam parameters[3,4], or periodic, more complex analysis[5,6,7]. Usually this means tight workflows and diverse and detailed data on safety management for specific use[8]. There are also examples of advanced monitoring systems [9] that provide valuable information on embankments’ stability, landslide risks, etc.

An efficient system for dam safety management should manage not only information on safety-related activities, monitoring and analysis, but also their correlation and provide feedback information on all interactions when required.

II. DAM SAFETY IN SERBIA

There are 69 large dams in use in Serbia with total volume of 6 billion cubic meters. According to their purpose, they can be generally classified in two categories – electrical energy production (23 dams within Electric Power Industry of Serbia) and water resources management (water supply, irrigation, and protection from floods – 46 dams). Dams, as well as other construction facilities, have limited working life. Over time, there is growing need to monitor their condition, and respond if necessary in order to reduce the probability of damage, failure and uncontrolled discharge of water. The average age of the large dams in Serbia is 36 years, and more than half of these dams (37 precisely) is over 30 years.

There is a consensus in Serbia over importance of dam maintenance, but the regulations in this area are not completely defined. Fortunately, no severe hazards happened to this day, mostly due to good design and quality construction works.

However, despite the fact that no serious incidents occurred, which would have jeopardized the safety and stability of dams, or lessen their usability, one must have in mind that, especially with ageing of dam constructions, emergence of various kinds of problems can be expected in future.

Dam maintenance and safety management in Serbia have recently come into general practice, based on existing legal framework for dam monitoring[10]. In order to provide basis for future regulations and tools for application of these regulations, a research is being carried out on information systems for dam safety management for dams in Serbia. Such system integrates monitoring on dam with numerical procedures and safety parameters. The architecture of this system will be presented in this paper along with an example of application on Prvonek dam.
III. DAM SAFETY MANAGEMENT INFORMATION SYSTEM

Information system for dam safety management is complex service-oriented system which allows the use of near real-time data in dam safety analysis. The data and services are standardized, making it possible to use this architecture with various monitoring systems and numerical techniques. The system is scalable and robust by design, and capable for future expansion and application of new tools and numerical procedures. Standard technologies such as SQL server database, .NET framework and Web services are used. Most of the applications are desktop applications built with rich and intuitive UI.

Dam safety management software consists of following components: interface to technical monitoring system, numerical module for statistical analysis, numerical module for groundwater seepage simulation, numerical module for stress/strain simulation, numerical module for data assimilation, and applications. The architecture of this system is illustrated on Fig. 1.

A. Interface to technical monitoring information system

To use data stored in technical monitoring information system it was necessary to develop adequate interface. Using this interface, numerical modules and user applications are able to request data at real-time. A web service implements this interface, so that various clients may request and receive the data. Missing data is common in monitoring of complex objects. Therefore, the interface to technical monitoring information system uses techniques for estimation of missing data[11].

B. Numerical module for statistical analysis

When sufficient amount of data from dam monitoring is available, it is possible to form statistical model of dam behaviour, using regression and numerical procedures[12]. As part of presented information system, numerical module for statistical analysis provides statistical modelling and analysis features, which can be used for estimation of dam behaviour, as well as adaption of previously designed statistical models. The module is designed with scalability and robustness in mind, so that future measurements can be easily included in modelling.

C. Numerical module for groundwater seepage simulation

This numerical module consists of pre-processor and FEM solver for groundwater seepage simulation. The pre-processor prepares input data for FEM solver. It also

![Interface to Monitoring Information System](image-url)
serves as communication layer between FEM solver and numerical model for data assimilation. Load cases and stress tests in user interface of FEM model are applied to FEM model through pre-processor. Model updated states obtained from data assimilation module are applied to FEM model through pre-processor, and FEM solver is then used to calculate resulting states of FEM model for specific load case (potentials, velocities, gradients, seepage forces, etc.) The results are presented to the user through graphical interface and printed reports.

D. Numerical module for stress-strain simulation

Similar to numerical module for groundwater seepage simulation, numerical module for stress/strain simulation consists of pre-processor and FEM solver for simulation of stress/strain processes. Pre-processor is designed to provide FEM solver with up-to-date FEM model (seepage forces, elastic modulus, etc.) and input data (load cases, stress tests). FEM solver performs calculation with provided data and outputs following results: stress fields, elastic and plastic deformation, safety factors, fracture modes, etc.) The results are presented to the user through interactive graphical interface and printed reports.

E. Numerical module for data assimilation

In order to perform consistent dam safety analysis calculations should be performed upon up-to-date state of model. State updating algorithms are implemented in numerical module for data assimilation[13]. Using data from monitoring information system this module performs data assimilation upon FEM model. Data assimilation is achieved using optimization algorithms and stochastic methods. This module functions automatically by communicating with other numerical modules.

F. Applications

Applications within information system for dam safety management are designed to provide users with visualisation of real-time measurement data and estimations of dam status. According to level of expertise required from users applications are grouped as: expert-oriented, as shown in Fig. 2 (for periodic assessments) and staff-oriented, as shown in Fig. 3, for day-to-day use.

Most of the applications are desktop applications, built with rich and intuitive UI. These applications enable the users of the system to interact with statistical and FEM models and processes within system. Web applications are also used for better communication with other interested parties.

Interaction with FEM model within dam safety management system requires expert knowledge and the application for model calibration and standard tests is the most complex in terms of UI. The expert is provided with tools for parameter control of FEM model, seamless data assimilation with measured data, and advanced visualisation of results. A report on dam safety parameters is also generated from this application. Dam safety criteria is defined according to shear strength reduction method, as given in [14].

IV. PRVONEK INFORMATION SYSTEM FOR DAM SAFETY MANAGEMENT

Prvonek dam is located in Southern Serbia, near the city of Vranje, on the river of Banjska, 9 km upstream from confluence with South Morava. Construction of this facility was completed in 2006. The dam (shown in Fig. 4) is rock-fill, 93 m in height, and is the latest multi-purpose facility of that kind constructed in Serbia. Main purposes of this facility are water supply of city of Vranje, flood protection downstream of the dam, as well as electrical energy production.

Dam safety implies such state of dam that required functionalities can be fulfilled without adverse effects to the environment, population, or other facilities. Existing Prvonek dam safety has been achieved by criteria defined in the design phase as well as by application of standards during the construction phase. Nevertheless, facility operational conditions are quite different in regard to design conditions, but also there are changes in dam material properties during the time. Because of that, there is necessity of permanent assessment of the most important indicators of dam safety. Information system for dam safety management has been implemented at Prvonek.
dam with goal of constant dam safety assessment in mind.

Use of dam safety management system consists of two main tasks:

- **Everyday use**
- **Periodic assessment**

Everyday use is performed by dam staff through web portal for dam assessment and real time monitoring dashboard. The main task is to verify if there exist some unexpected values in data, failure in measurement units or other problems. Significant help in performing this task to the staff is statistical model service. Statistical model service compares real time value to estimated value the staff is statistical model service. Statistical model service compares real time value to estimated value obtained from statistical model, and a warning is raised if there is deviation larger than one defined within model. If the warning occurs, there is well-defined procedure that must be completed in order to verify anomaly.

Unlike everyday use, periodic assessment can only be done by experts from accredited institution. The expert performs two main tasks:

- **Generating dam safety report**
- **Updating statistical models.**

Dam safety report is the output of the information system for dam safety management and is created semi-automatically through guided steps. Firstly, FEM model of dam must be updated according to available measurements using FEM model user interface and numerical module for data assimilation. After that, a set of predefined tests (groundwater seepage and stress/strain) of the updated model must be performed.

Set of groundwater seepage tests consists of two load cases:

- **Steady state seepage**
- **Emergency reservoir evacuation**

Each test generates large set of data that can be divided into several categories in order to simplify further analysis. Some of these categories are:

- **Surface plot of potential in whole dam**
- **Surface plot of pore pressure in whole dam**
- **Surface plot of groundwater seepage velocity**

Set of stress/strain tests consists of following cases:

- **Steady state seepage**
- **Emergency reservoir evacuation**
- **Typical earthquake (according to seismic data)**

Results of each test are fields of total displacement, plastic deformation and global safety coefficient.

Results obtained from all of the tests have to be analysed by experts in order to make conclusions about dam safety and overall dam state. Finally, dam safety report can be generated. Because of complexity of results, the generation of report is semi-automated process, which is based on report template. The expert is given choices in generating report, so that each generated plot is verified and adjusted if required. Upon confirmation of report elements, the application generates the report in Microsoft Word document format. This document is intended for use in obtaining dam permits and, if necessary, justifying investments in rehabilitation and maintenance.

V. CONCLUSION

Presented information system for dam safety management enables owners of dams to easily monitor safety parameters of a dam using intuitive software tools. The use case presented in this paper demonstrates an application of such system on rock-fill dam. However, the same architecture is applicable on various sorts of dams (gravity dam, arch dam, etc.) with specifically designed numerical modules for FEM simulation.

The main benefit of presented information system is seamless integration of monitoring data with numerical modules and applications. The use of web services and standard data formats provides sound base for further development.

With the development of legal framework for dam maintenance and safety management, the presented information system will provide efficient tools for owners of dams for application of regulations. On the other hand, by applying such systems to all high dams in one country, a real opportunity could be created for executive state authorities to standardize procedures and create a network of dam safety management systems.

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REFERENCES
