International Dam Safety Conference - 2018
23-24 January 2018, Thiruvananthapuram

REAL TIME DAM STABILITY MONITORING

TON PETERS[1], FRANS VAN DEN BERG[1], MARIA LUISA TACCARI[1]

[1]*Geo-Engineering unit, Deltares, Delft, the Netherlands,*
Corresponding e-mail: ton.peters@deltares.nl

ABSTRACT

A pilot project, called DAMSAFE, is currently being carried out, in which a number of innovative monitoring and forecasting technologies are implemented and demonstrated at the Bhadra dam and reservoir, located in Karnataka. The overarching goal of the pilot project is to contribute to enhancing dam safety and water management in India.
The innovative technologies that will be integrated in DAMSAFE are: PS-InSAR satellite measurements, online monitoring systems, risk-informed dam safety assessment and Delft-FEWS forecasting of reservoir inflow and dam safety response. In this paper the focus is on real time dam stability assessment using an online monitoring system in combination with the Delft-FEWS software platform.

1 BACKGROUND

1.1 Introduction

Demand for water is steadily increasing throughout the world and conflicting interests generate a complex and delicate field of work. Multi-purpose water reservoirs and dams play a major role for water supply, irrigation and flood protection in India. The dams are aging, but are also facing different circumstances than when designed, often decades or more ago. This is due to changes in land use, socio-economic developments and climate change. In order to ensure long-term operation and safety of the dams, continuing investments have to be made in adaptation planning and actions including monitoring, maintenance, repair and retrofitting (Peters and Giri, 2017). The on-going Dam Rehabilitation and Improvement Project (DRIP) in India is one of the major endeavors targeting at improving the existing situation of the large dams in India (Pillai and Giraud, 2014).

In cooperation with the Karnataka Water Resources Department (KaWRD), a pilot project, called DAMSAFE, is currently being carried out in which a number of innovative technologies on dam safety assessment and water reservoir performance are demonstrated at the Bhadra dam and water reservoir in Karnataka.

1.2 Goal DAMSAFE project

The Deltares led DAMSAFE consortium consists of the Dutch companies SkyGeo and Royal Eijkelkamp and the Spanish company iPresas. These companies provide high tech, specialist technologies on PS-InSAR satellite measurements, online monitoring systems and risk-informed dam safety assessment. The role of Deltares as a research organisation is to provide the needed integrating, enabling software technologies (Delft-FEWS, RTC-Tool, DAM etc.). The ambition of the consortium partners is to use this pilot project for building a long-term cooperation with end-users in this sector and to offer integral solutions.

The overarching goal of the pilot project is to contribute to enhancing dam safety and water management in India. This goal is achieved by delivery of the following set of actions:

- To demonstrate tools that forecast reservoir inflow and outflow, increase reservoir performance and allow for a more controlled release of water in the environment.
- To demonstrate innovative tools for assessment of the dam condition resulting in optimization of Operation and Maintenance (O&M).
- To demonstrate innovative tools for rapid and risk based assessment of dam safety in order to provide information for emergency response.
- To organize open sessions during the project with stakeholders, end-users and the wider water and dam safety community in order to discuss plans and to actively disseminate project results.

2 BHADRA DAM AND RESERVOIR

2.1 Pilot case description

The Bhadra Dam is located across the Bhadra River near Lakkavalli village, Tarikere Taluk, Chikkamagalore District of Karnataka State at an elevation of 601.00 m above Mean Sea Level (MSL). This is a multi-purpose dam, including irrigation, water supply and hydropower generation.

Fig.1 Masonry dam, Bhadra dam-reservoir system.

The dam was finished in 1962. It includes a main masonry dam (Fig. 1) and two saddle (earthen) dams. The main dam includes a spillway with four gates and a total length of 76.8 m. The reservoir capacity is 2026 hm^3. The maximum height is 76.8 m for the masonry dam (main dam). The maximum height is 49.4 m for saddle dam 1 and 32.3 m for saddle dam 2. The base level is located at 583.39 m [1914 ft] in the masonry dam (main dam), and at 612.95 m [2011 ft] and 630.02 m [2067 ft] for saddle dams 1 and 2, respectively. The maximum water level in normal operation is established at 657.76 m [2158 ft], being 657.15 m [2156 ft] during the monsoon season. The spillway has a maximum discharge of 3012 m^3/s [106700 cusecs]. The maximum spillway opening height is 7.16 m [23.5 ft].

2.2 Online monitoring system

A system has been designed for monitoring of the water reservoir and identified dam failure mechanism. While this is a pilot project to demonstrate effectiveness of the approach, not all failure mechanisms were taken into account. The focus was determined on the uplift/sliding mechanism of the main dam and macro instability of both saddle dams. The online monitoring system was installed by Royal Eijkelkamp with local assistance from the district in which the Bhadra dam and reservoir are located. Figure 2 shows an installed measurement station at the river inlet into the reservoir to determine the water inflow from the main river. It is equipped with a battery and solar panel for energy supply and a wireless connection for data transmission.

Fig.2 Measurement station at the river inlet into the reservoir

The focus of the monitoring system is on weather, water flow and level and dam behavior. Therefore, the online monitoring system includes:

- weather stations in the catchment area to measure rainfall, temperature, wind and sun radiation,
- devices for measuring surface water levels at the dam and at the rivers flowing into the reservoir,
- (pore) water pressures in the dam body and foundation, and
- outflow of water from the dam drainage systems.

The acquired data in combination with other historical data from the pilot dam are the input for the numerical computations of dam safety. The measurements are fully automated and real-time available on a secured internet platform accessible worldwide for stakeholders and project partners. Monitoring activities will also include a dashboard within the Bhadra dam control room to present the results to the dam operator and maintenance staff.

2.3 Delft-FEWS platform

Delft-FEWS is a platform developed by Deltares that is used to integrate data from different sources and to perform computations automatically using different numerical models, e.g. SOBEK and DAM. SOBEK is a powerful modelling suite for hydraulic and morphological simulations including inundation, dam-break, dam/weir operation integrated with a Real-Time-Control (RTC) tool.

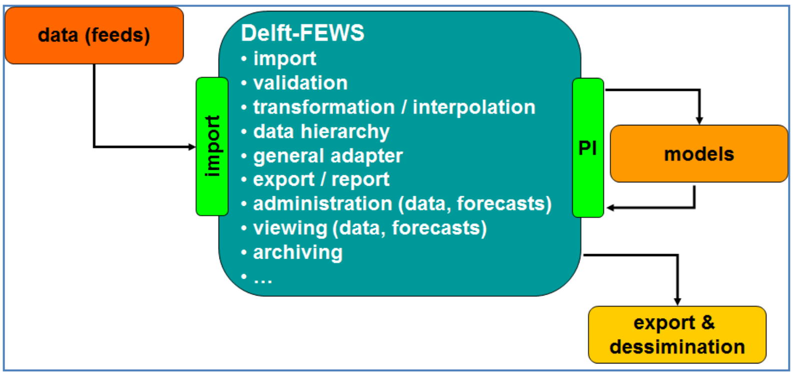

Fig.3 Overview Delft-FEWS software platform.

DAM is a software tool that determines the strength of a dam or dike based on certain failure mechanisms (Peters and Van den Berg 2016). The DAM tool is designed to routinely integrate data from different sources in a GIS environment, to perform automated, high density calculations of dam safety and to present the results in a GIS environment. Uncertainties in subsoil properties and loading on the dam can be dealt with, thus enabling scenario analyses, e.g. by using various stochastic subsoil models. This approach has been widely accepted in the Netherlands as a standard for dike and levee safety assessment, in accordance with Dutch law. (Knoeff and Vastenburg 2011). Other projects have for instance been performed in Belgium, South-Korea, São Paulo state (Brazil), Yellow River basin China (Van den Berg et al. 2012) and Louisiana USA (Van et al. 2015).

3 FIRST RESULTS BHADRA CASE

A study has been conducted for several critical failure mechanisms at the Bhadra reservoir's dams. The study focused on both the saddle dams as well as the main dam. From this study two failure mechanisms have been prioritized and chosen for monitoring. The Delft-FEWS platform is in the implementation stage for both the reservoir and the dams. The DAM module will be used for automated calculations of macro-instability of the saddle dams and sliding at the dam-foundation contact for the masonry dam.

3.1 Integrating data with FEWS

The real time monitoring of the failure mechanisms give an insight in the real time safety of the dam. Monitoring data is the input for the stability calculations and will give the dam's owner an indication of the actual status and if additional actions (e.g. visual inspections, checks on monitoring instrumentations or more detailed analyses) are needed, especially from a forecasting point of view. For the failure mechanisms analyses, the phreatic line inside the dams' body and the water pressures in the foundations are inputs needed for determination of the pore water pressures inside the dams and the uplift pressures acting on the base of dams. The latter destabilizes and directly influences the safety of the dam. The analyses of these failure mechanisms and the evaluation of their safety are therefore linked to a monitoring system for evaluating interstitial pressures in dams' body and foundations. In particular, the monitoring system gathers data from the reservoir water level sensor and water pressure sensors for each dam studied. In case of the saddle dam one piezometer is placed in the dam's body in order to get information about the phreatic line inside the dam while the second sensor is placed beneath the dam, in the foundation, for detecting the uplift force acting on the dam base. Regarding the masonry dam piezometers are located in the foundation near the drains' line to accurately detect the behaviour of uplift force in correspondence with the drainage system. The monitoring system is also composed of sensors for the measurement of water discharge trough the drainage system of the saddle dams and the main dam. Information deriving from these sensors will be useful for detecting anomalies of the drainage system or in the impervious zones inside the dams' body.

Macro-instability phenomena can lead to sliding of portions of the dam's body and a progressive overall instability for the entire dam. Analyses on this mechanism are performed by FEWS through the DAM software. This module automatically finds the slip surface associated to the minor safety factor and gives a detailed result on the stability of the dams for this kind of failure mode. The software splits the dam's volume in slices whose base is a segment of the slip surface and for each of them the software evaluate forces acting on the slice, both resisting and destabilizing. From the monitoring system it's possible to get information about the pressures acting on the dam's base and about the phreatic line inside dam's body and its degree of saturation. In this way the software can calculate the stability of dam's body taking into account also the presence of water in the soil.

3.1 Discussion results

At the writing of this paper the real data from the monitoring system is not yet available. That is why data is used from another project to illustrate the Bhadra case. The Dam safety is only calculated for a few calculation steps.

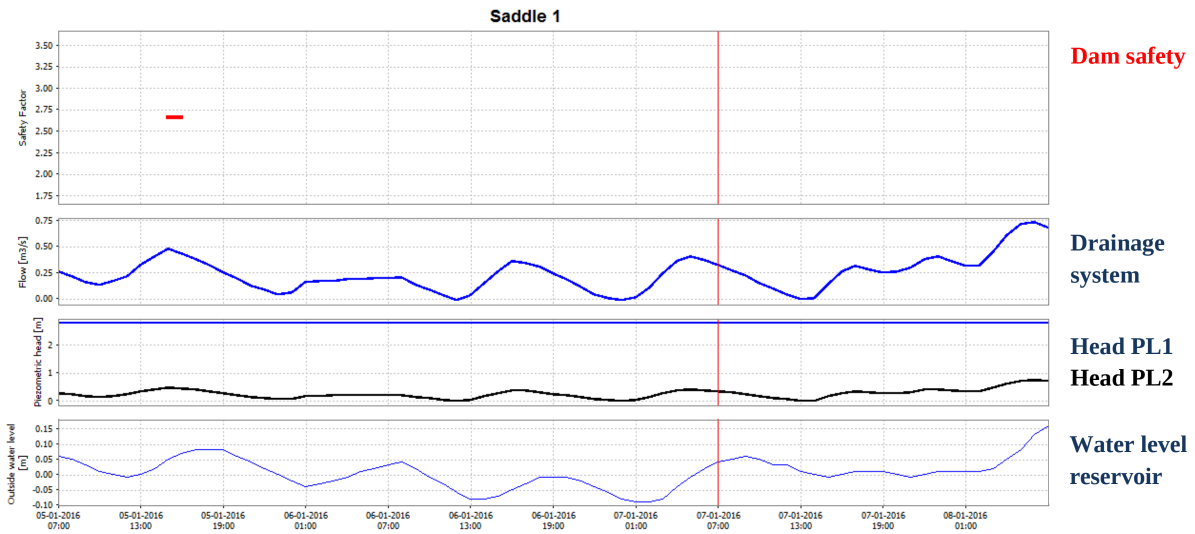

Fig.4 Information from monitoring system and results of stability analyses on saddle no. 1

The FEWS interface has been set up for each location studied. In this case two locations for the saddle dams and three locations for the main dam have been considered. Each section contains all the information related to the same location, included data coming from the monitoring system and results of stability calculations performed for each failure mechanism. In figure 4 an example of FEWS results' interface is reported. All the presented information is a function of time; starting from the bottom trend of reservoir' water level is shown accordingly to data coming from the sensor of water level placed in the reservoir near the dam. The second graph shows the piezometric lines related to two different depths, indeed the first one (PL1) refers to the interstitial pressure and phreatic line inside the dam body while the second one (PL2) refers to water pressures in dam's foundation and these are responsible of uplift force acting on dam's base. The third graph shows the trend of discharge trough the dam's drainage system. The graph on the top reports safety factors for each failure mechanism considered, that for the saddle dam are macro-instability phenomena and sliding at dam-foundation contact.

4 CONCLUSION

In the case Bhadra dam a practical application has been presented on innovative tools to support a rapid assessment of dam safety. Delft-FEWS and the DAM platform allow for an integral approach to the complete system for water reservoir management and flood protection. Initially, this systematic approach requires a substantial effort, but once completed numerical calculation become efficient. Already with limited information, different scenarios can be analyzed and used to assess the effects of mitigating measures (repair, retrofitting, etc.) and cost-benefit assessment.

A next step (DAM-live) is forecasting of dam safety based on the weather forecasting upstream, river run-off and reservoir behavior. It involves the use of monitoring (PSInSAR, in-situ instrumentation) and inverse analysis to back calculate system parameters. This will provide information for emergency response planning.

ACKNOWLEDGEMENT

The DAMSAFE project is supported by the Partners for Water program of the Dutch government. The authors wish to thank CWC, KaWRD and the Netherlands Enterprise Agency (RVO) for their support.

REFERENCES

Knoeff, J. and Vastenburg, E (2011) *Automated Engineering in Levee Risk Management*, ISGSR 2011 - Vogt, Schuppener, Straub & Bräu (eds) - ISBN 978-3-939230-01-4, http://www.smartlevee.nl/en/

Berg, van den, F., Heaton, J. and Moen, W. (2012) *Real time Monitoring of Levees through Sensor Technology along the Yellow River*, 5th International Yellow River Forum, Zhenghzhou, China, September 24-28 pp 235

Pillai, B.R.K. and Giraud, S. (2014) *Dam Rehabilitation and Improvement Project (Drip - India): 270 Dams To Be Rehabilitated*. Proceedings of First National Dam Safety Conference, 24-25 March, Chennai, India.

Van, M., Sharp, M. and Vastenburg, E. (2015) *Rapid Assessment Method for Stability and Piping of Mississippi Levees*, Proceedings of the 15th Pan-American Conference on Soil Mechanics and Geotechnical Engineering IOS Press pp 2295 – 2302

Peters, T., and Berg, van den , F (2016), *Rapid Assessment Tools for Dam Safety*, 2nd National Dam Safety Conference, Bengaluru, India.

Peters, T. and Giri, S (2017), “The DAMDAFE project in Karnataka”, 3rd National Dam Safety Conference, Roorkee, India.