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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

TECHNICAL BRIEF

Water engineering

Structural health monitoring of arch dams

A completed Water Research Commission (WRC) project developed a holistic approach to structural safety assessment of concrete arch dams, while developing high level manpower in the field of dam safety.

Background

Dams constitute significant and critical discrete components of a water resource system. They are among the most expensive investment asset of any country's civil infrastructure. Dams also have a long service life compared with most commercial products and are rarely replaceable once they are built.

Dam failure often leads to both economic loss and loss of human life.Therefore, given these severe consequences of failure of any dam, it is imperative to maintain dams in such a way that they function reliably and efficiently throughout their service life.

Since the 1800s, many countries have introduced legislation on dam safety, primarily to ensure periodic safety evaluation of large dams. In South Africa, the Department of Water Affairs is responsible for dam safety as stipulated in the National Water Act, Section 123(1), 1998.

Dam safety monitoring

Dam safety evaluation includes structural assessment through dam surveillance and monitoring data and finite element analysis. Static surveillance and monitoring of dams, that is, continuous or periodic monitoring of static structural parameters such as strain and temperature, is now well established.

In recent years, it has been shown that monitoring of the dynamic behaviour of civil engineering infrastructures can provide essential information for determining their safety. While this technology has grown in many civil engineering applications, its viability in dam safety has not been fully investigated.

One of the reasons for the limited use of ambient vibration testing in arch dams is that early trials concluded that it was difficult to apply this approach to dams owing to their high stiffness. However, since that time, there have been substantial improvements in sensing technologies and data processing algorithms.

This has led to the development and maturity of a new discipline in structural health monitoring, now often referred to as operational modal analysis (OMA). This discipline deals with ambient vibration testing of structures and the analysis of resulting data.

Finite element analysis (FEA)

FEA plays an important role in safety evaluation of dams as it allows the application of various load combinations which are not always observed through surveillance and monitoring. The challenge in FEA is generating a finite element model that is representative of the as-built dam with respect to dynamic behaviour.

The most commonly adopted approach for dynamic analysis of dams is the so-called Westergaard approach. While this approach has been used successfully for investigating the dynamic performance of dams under seismic loading, it has not been applied in finite element model updating based on ambient vibration testing.

The essential difference between the two situations is the magnitude of accelerations induced on the structure by the

excitation force. In a seismic event, large accelerations are experienced compared to the normal operating environment. Thus, the applicability of the Westergaard approach in finite element model updating of arch dams based on ambient vibration testing needed to be established.

Modelling stresses

Cyclic seasonal temperature and associated thermally induced stresses have been found to contribute significantly to long-term degradation of strength and stiffness of concrete dams. Thus accurate modelling of thermally induced stresses is critical in dam safety evaluations. Also, thermal stresses may affect the dynamic behaviour of concrete arch dams. Consequently, this aspect needs to be investigated.

Key objectives

The project focused on three key objectives. The first focused on the applicability ambient vibration testing to concrete arch dams. A concrete arch dam (i.e. Roode Elsberg Dam) was monitored periodically over three years. A high-resolution, low noise vibration measuring system was used.

The second objective tested the applicability of the Westergaard approach in finite element model updating on arch dams based on ambient vibration testing. Another aspect of finite element modelling that strongly influences the behaviour of arch dams is the foundation-wall system. Here the challenge is generally what size of the foundation is necessary to model the system with minimal error.

Thirdly, the focus was on temperature modelling for arch dams, and the influence of seasonal temperature variations on dynamic properties of arch dams.

Findings

The following findings were obtained:

- Ambient vibration testing is a viable methodology for surveillance and monitoring of arch dams
- The Westergaard method tends to overestimate the added mass of water for divergent and/or skewed reservoirs. This method cannot be directly applied to dams with divergent and/or skewed reservoirs.
- In order to accurately model the effect of seasonal temperature variations on arch dam, the temperature model must include seasonal reservoir level variations. The results of the temperature analysis show that it is critical to include temperature effects for dynamic analysis of arch dams. However, once the initial thermal stresses have been introduced, the influence of seasonal temperature variations on dynamic characteristics is negligible.

Recommendations

Based on the findings of this research the following recommendations are made:

- Revise the Westergaard method to account for skew/divergent reservoirs in estimation of added mass
- Further investigate the effect of thermal stresses in concrete dams
- The current study confirmed the viability of the application of ambient vibration testing of dams. It is recommended to install permanent monitoring systems for dam surveillance based on ambient vibration testing.

Further reading:
To order the report, ***Structural health monitoring of arch dams using dynamic and static measurements*** (**Report No. 2025/1/13)** contact Publications at Tel: (012) 330-0340, Email: orders@wrc.org.za or Visit: www.wrc.org.za to download a free copy.