Application of a knowledge support system to dam safety: a user report

Application of a Knowledge Support System to Dam Safety: a User Report

Application d'un système expert pour la sécurité d'un barrage

Anwendungsbericht über ein wissensbasiertes Staumauerüberwachungssystem

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SUMMARY
The article describes the experience of the user in the automatic monitoring and risk assessment of the Ridracoli Dam, using a knowledge support system for the on-line interpretation of the dam's behaviour. Data collected by a complex monitoring system is continuously processed and interpreted by the knowledge support system in order to support the Safety Manager in the surveillance of the evolution of the behaviour of the structure and of its foundation.

RÉSUMÉ
L'article décrit l'expérience acquise par un utilisateur dans le domaine de la surveillance automatique et de l'évaluation des risques du barrage de Ridracoli. Il s'agit d'un système expert pour l'interprétation en temps réel du comportement du barrage. Le système exploite de façon continue les données récoltées par un système complexe afin d'aider le responsable de la sécurité dans la surveillance de l'évolution du comportement du barrage et de sa fondation.

ZUSAMMENFASSUNG
Der Beitrag beschreibt die Erfahrung in der Benutzung eines On-Line-Systems zur automatischen Ueberwachung und Gefährdungsbeurteilung der Ridracoli-Staumauer. Die vom komplexen Erfassungssystem gesammelten Daten werden kontinuierlich ausgewertet und durch ein wissensbasiertes System interpretiert, um den Sicherheitsbeauftragten bei der Ueberwachung des Verhaltens von Staumauer und Untergrund zu unterstützen.

1. INTRODUCTION

The collection, storage and analysis of information concerning a dam are a critical part of managing safety of the structure. An important part of the management of this information is the interpretation of data coming from the monitoring. In addition the use of automatic instrumentation and data storage in dam monitoring has resulted in large amounts of data requiring analysis and interpretation. The use of knowledge support system for the on-line check of dam's behaviour is useful to reduce human time consuming and to request timely human intervention and analysis.

2. DESCRIPTION OF RIDRACOLI DAM

The Ridracoli arch-gravity concrete dam (height 103.5 m and crest length 432 m) closes a very wide U-shaped valley in the Tuscan-Romagna Apennines in Italy. The storage reservoir is intended for water supply to 37 communities in the Forli' and Ravenna Provinces, including the main towns and the San Marino Republic.
Ridracoli dam was completed in 1982 and subsequently the experimental storages started following a program of water level steps with the aim of analyzing creep deformation, anelastic settlements and displacements of the dam and of the rock foundation due to water level and thermal variations. The reservoir was filled completely for the first time in 1986 and nowadays the dam is going to be commissioned for normal operation.

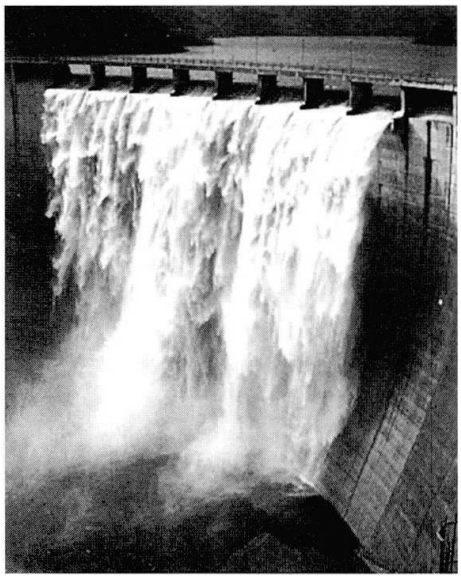


Fig.1 -View of the Ridracoli dam

3. THE AUTOMATIC MONITORING SYSTEM

To control the Ridracoli dam structure, the foundation, the reservoir banks and the slopes of the downstream rocky formation a large monitoring network has been installed during the construction. The reading, centralized in the warden house via cable, of most of the measurements (259 on a total of 971) is realized by an automatic monitoring system. Many instruments were installed for a detailed monitoring of the structure's behaviour during construction and first filling phase. In the current normal operation, the surveillance of dam performance is obviously based on a limited subset of measurements.
The instrumentation network makes it possible to acquire the most important "cause" quantities (water level, air, water and concrete temperatures, meteorological quantities) and "effect" quantities on the dam and its foundation (vertical and planimetric displacements, stresses and deformations, rotations, movements of the joints, seepage, uplift pressures in the foundation, fault control behaviour, water table in the abutment).

4. OFF-LINE MANAGEMENT AND BEHAVIOUR ANALYSIS

Measurements, automatically or manually recorded, have been periodically stored into the historical data bank and processed to analyze the dam's behaviour. During the design phase a three dimensional F.E. model has been set up in order to predict the theoretical behaviour caused by water level and thermal variations (Fig.2). Starting from the beginning of the first filling of the reservoir the theoretical model has been used as reference to check in time the behaviour of the dam.

The behaviour analysis carried out has pointed out the occurrence of cyclic phenomena, with seasonal period mainly linked to water level and temperature variations, and anelastic phenomena correlated to the first fillings. Dam displacements fully comply with the forecasted theoretical displacements. This analysis also made it possible to check the logical consistency of the information provided by different instruments affected by the same phenomena.

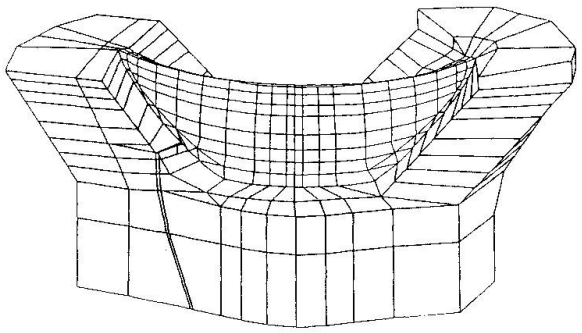


Fig.2 - 3D F.E. model of the dam

5. ON-LINE CONTROL

During the off-line activity, the parameters used for the on-line check have been determined (1987), and they are periodical verified. The theoretical model has been calibrated with reference to the measured behaviour and it is periodically used for in depth analysis of dam's behaviour.
The on-line surveillance during operation is mainly based on 32 measured quantities.
Since 1987 the most important measurements are tested against threshold values and theoretical behaviour predicted by the reference model. For each measurement that is not consistent with the reference values a warning message is generated.
A knowledge support system (named **Mistral**) has been installed in 1992 on a personal computer connected to the automatic monitoring system in the acquisition center located in the warden house near the dam. Mistral is a knowledge based system for evaluating, explaining and filtering the information collected by the most important instruments connected to the automatic monitoring system, providing on-line interpretation of the behaviour of the structure in order to support the activity of the personnel responsible of the safety surveillance.
The on-line system makes it possible to verify the state of each measurement with respect to threshold levels (physical threshold, measure rate of variation and reference structural model - Fig.3), using knowledge about significance and reliability of each instruments, and evaluates the current state of the dam and of any elementary structural part, identifying any anomalous process and verifying the reliability of the measurements by congruency checks.

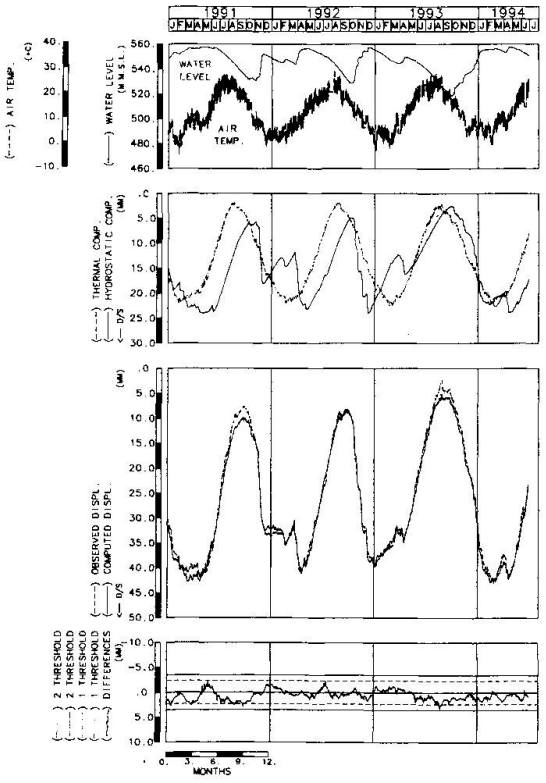
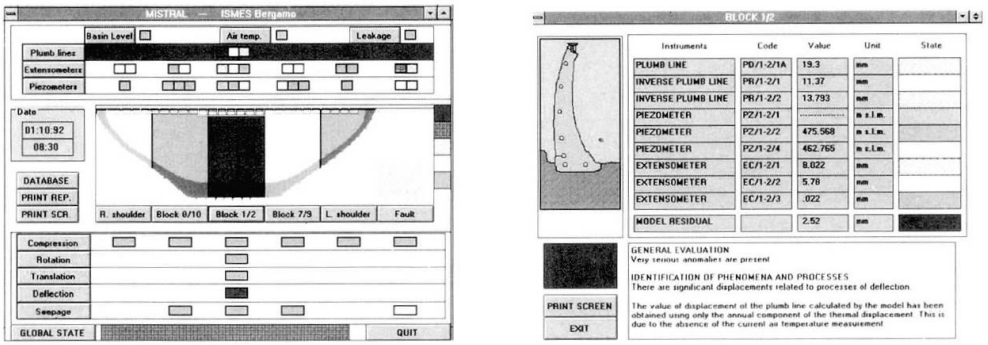


Fig.3 - Measured-Computed displacements

6. MISTRAL USE AND RESULTS

Mistral provides on-line interpretation of the behaviour of Ridracoli dam, evaluating, filtering and explaining the data collected by the automatic monitoring system in order to support the Safety Manager during the surveillance of the dam and requiring his intervention for anomalous situation.
As scheduled in the surveillance activities, the technicians working at the warden house check daily

the information provided by Mistral verifying the state of the sensors and the results obtained by the analysis of the dam's behaviour, displayed through the colour-based graphical interface that represents the state of the measurements, of the processes, of each section and of the entire structure under evaluation and relevant explanation (Figg.4,5).
Mistral is a friendly program and obtained a very rapid acceptance by the user (1 day training).
If necessary the technicians use its functionalities to get more detailed information and enter to the local data base to compare the evolution of the dam state in time.
If any signalling or warning is reported on the display, the technicians have to verify the proper functioning of the signalled instrumentations and perform a visual inspection of the zone pointed out and in case of anomalous situation request the Safety Manager intervention for in depth analysis.



Figg 4,5 - Mistral Interfaces (general state of the dam and the expansion for the main section)

Mistral performs on-line check every hour and from its installation till now has analyzed more than 15000 situations (about 580000 instrument data). From 1992, running Mistral the following issues were pointed out:

- Wrong data are properly filtered by congruency checks avoiding incorrect signalling. The validation data process recognized errors in data due to wrong signals for about 0.5 percent of the examined measurements.
- Instrumentation problems due to anomalous functioning of some sensors, such as piezometers in rock foundation and one potenziometric transducer installed on the rockmeter installation. Mistral gives the possibility to request and perform prompt maintenance interventions to the sensors, with no delay in time.
- The basic parameters implemented in Mistral (threshold values, parameters of the reference model, parameters synthesizing the significance and reliability of each instrument) have been confirmed and did not need any update.
- The behaviour of the structure complies with the forecasted values computed by the theoretical reference model, without identification of any anomalous process, confirming that the dam and its foundation behave in elastic manner.

The two years of experience in the use of the knowledge support system have provided valuable verification of its effectiveness within the safety surveillance activities.

7. CONCLUSIONS

Monitoring and observation are fundamental parts for managing the safety of structures. At Ridracoli dam a knowledge support system enables decision support to assist Safety Manager in the surveillance management of the dam. The Mistral system is used as a control panel that shows the current state of the dam and of its structural parts analyzing the evolution of the measured behaviour without time delay. The system obtained very rapid acceptance by the user. It reduced the effort required for the management of warnings and improved the quality of the safety management procedures.