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ON-LINE STRUCTURAL HEALTH MONITORING OF REHABILITATED DAMS

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1. INTRODUCTION

Dams are critical components of civil infrastructure of any country. They provide a range of economic, environmental and social benefits like hydroelectric power, irrigation, water supply, flood control and recreation. However, like other assets, dams also age and deteriorate posing a potential threat to life, health, property and environment. The safe functioning of the dam is an important matter of economic benefit and public safety.

Aging dams need to be strengthened and rehabilitated. Improvement of dam instrumentation is an important structural aspect of dam rehabilitation program. This includes replacement of faulty instruments to the extent necessary and practicable. Additional instruments are installed depending on the feasibility and health of the dam.

Continuous monitoring to ensure early detection of failures and to enhance response times to prevent disasters. Changes in the behavioural characteristics of the structure may be indicative of impending dam failure and it is the primary goal of the monitoring system to detect such changes. This calls for online monitoring systems that are capable of near real-time monitoring of the installed instrumentation.

2. DAM INSTRUMENTATION & MONITORING SYSTEM

It is necessary to have a combination of instruments across different sensing technologies to give complete information about potential deformations in a dam. Ease and practicality of installation/replacement of the old instruments for the and communication setup are equally important, apart from proven sensor types and core-technologies to achieve an effective and long-term dam monitoring system. Various building blocks of the system are described in the following paragraphs:

2.1 FIELD INSTRUMENTS

Some surface and subsurface sensors that may be used are mentioned below. Subsurface monitoring gives important information on ground/soil movement which may affect the stability of the structure.

- Tiltmeter and plumb lines to monitor dam tilt/inclination
- Crack meter and joint meter to monitor cracks/joint openings in blocks
- Borehole extensometers to monitor subsurface settlement and deformation
- In-place inclinometers to monitor lateral movement
- Water level & barometric pressure sensors to monitor reservoir level
- Piezometer/uplift pressure sensors to monitor pore and uplift pressure variations
- Seepage/flow meter
- Temperature meter
- Weather station for rainfall, wind velocity, air temperature, humidity and solar radiation

2.2 AUTOMATIC 3-D DEFORMATION MONITORING SYSTEM (ATDMS)

The ATDMS measures movements of targets fixed at critical locations on the dam's structure in three dimensions (x, y & z). It comprises of the following major components:

- 3D prism targets
- Automatic total stations (ATS)
- Control box

- Monitoring database

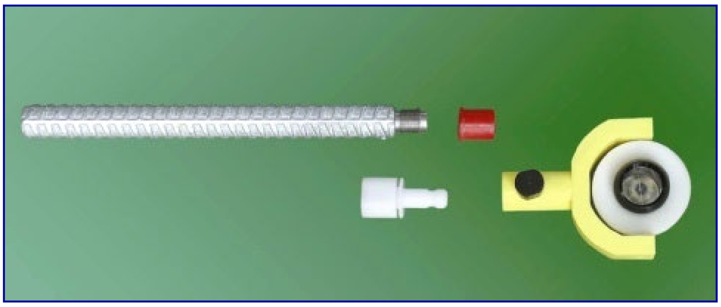
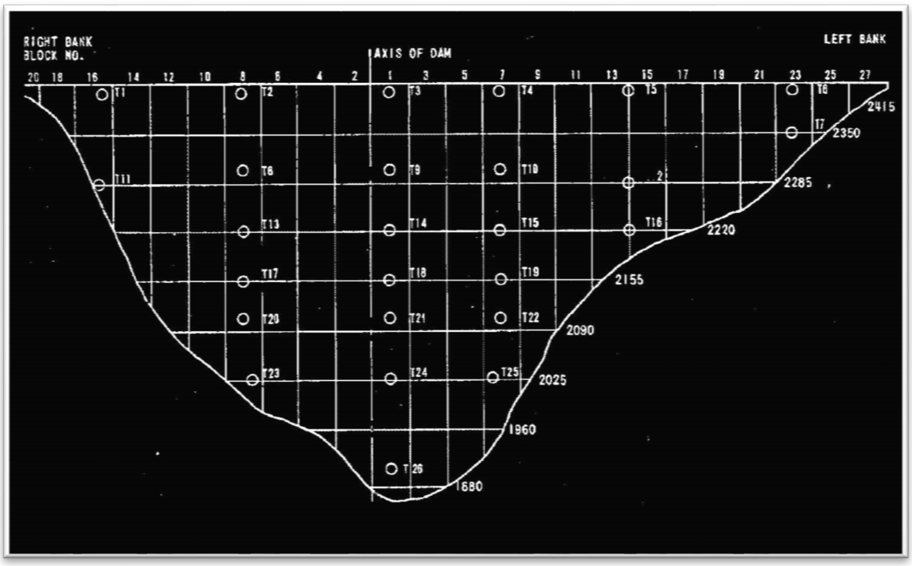
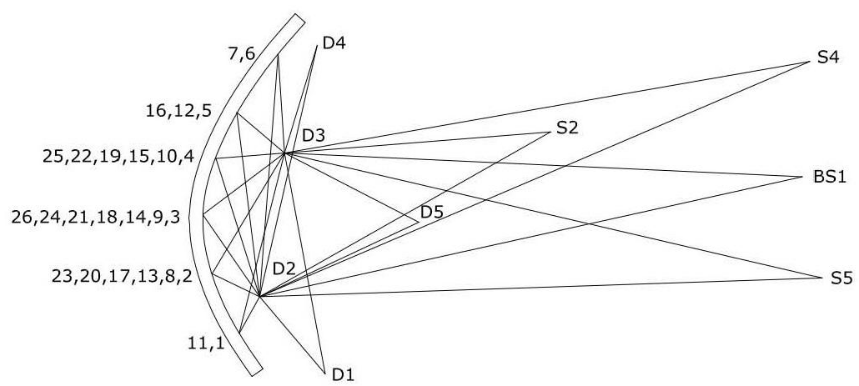


Fig. 1
Prism target components





Geodetic stations and target positions

Fig. 2 (Top & Bottom)
Typical locations of targets on the downstream side of an arch dam

3D prism targets (Fig. 1) are installed on the face of the downstream side of the dam in a grid form or at critical locations (Fig. 2)

One or more high precision servo driven, computer controlled ATS is installed at a suitable location on concrete/steel pillar with protective enclosure to automatically sight these points sequentially and record data. Reference prism targets at stable locations make the system complete. Refer to figure 3 for possible mounting arrangements of the ATS.

The ATS is controlled by a control box (Fig. 4) which is essentially rugged field computer. It is powered by 220 V, 50 Hz AC mains and in turn power up the ATS. Solar panels can be used where mains power supply is not available. The control box features GSM/GPRS modem with dual SIM slots for data transmission using the cellular network. Data is collected by the public cloud-based web data monitoring service described in section 3. Alarms can also be programmed in the database resulting in sending SMS/e-mail alerts automatically to the concerned personnel, in case deformation of any point breaches a predetermined trigger value.

Fig. 3

ATS with different mounting arrangements

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Fig. 4
ATS control box

2.3 Sensor communication & data transmission

2.3.1. Monitoring system with SDI-12 Interface sensors

The SDI-12 system is a bus communication system in which a wide array of dam monitoring sensors can be connected to a single 3-core cable. This is a great advantage and is possible as the electrical interface for the protocol involves three lines: a serial data line, a 12 V power line, and a ground line. The datalogger, featuring GSM/GPRS modem transmits the logged data over the cellular network to the web-based data monitoring service described in section 3. Refer to Fig. 5 for a block diagram of dam monitoring instruments network built on an SDI-12 bus.

Fig. 5
Dam monitoring instruments on an SDI-12 network

The datalogger can be powered either by Lithium or Alkaline cells or by a 12V SMF battery chargeable from AC mains or solar panel.

2.3.2. Wireless monitoring system using radio frequency (RF)

Dam monitoring sensors network with radio frequency (RF) communication does not require any cabling. It essentially comprises of sensors connected to RF dataloggers and gateways (Fig. 6) and features long-range communication on ISM frequency range of permitted in the country of use, of up to 15 km in open field conditions. The low power consumption of the system results in datalogger batteries lasting up to 5 years. Refer to Fig. 7 for a block diagram of a dam monitoring instruments network built on RF data communication technology.

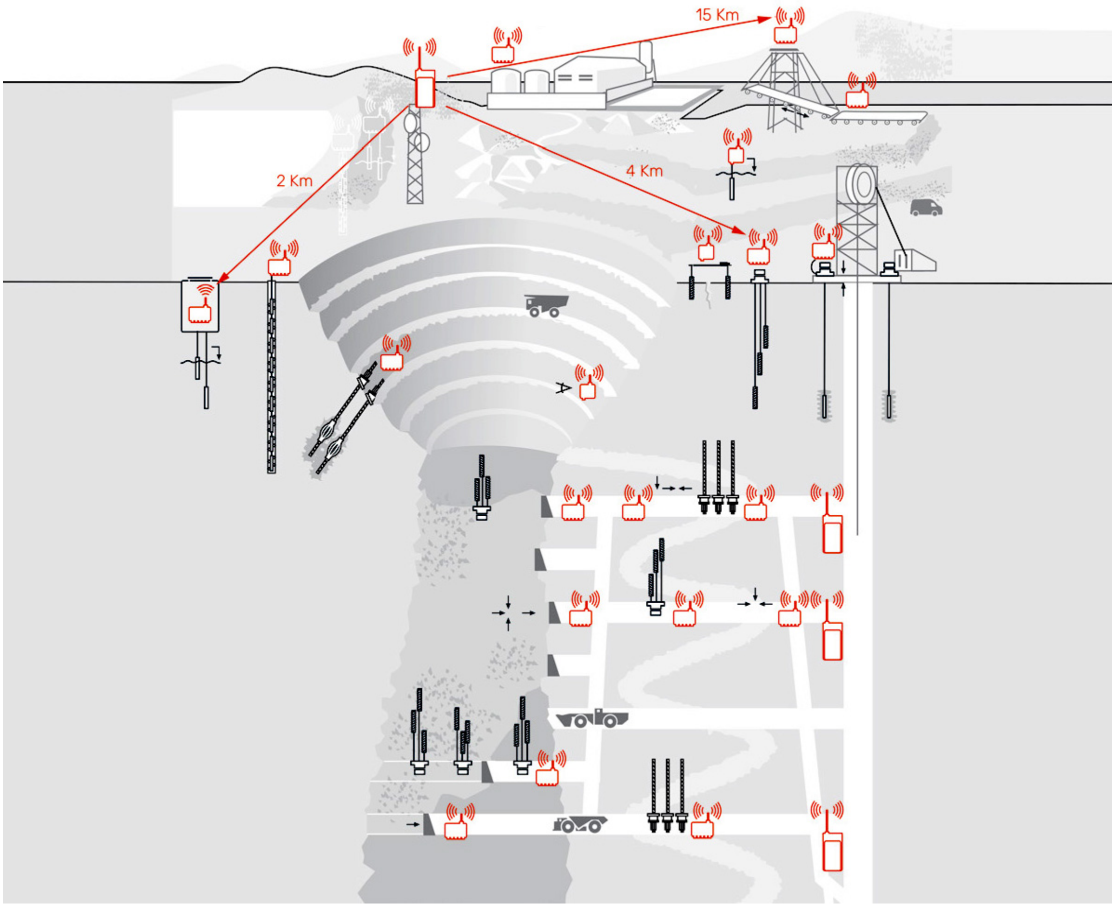

Fig. 6
Typical RF sensor network at field

The RF dataloggers, often called the ‘nodes’ of the wireless network, can be easily configured in the field using the smartphone Android app provided. These are available in single and multichannel configurations suitable for receiving the vibrating wire and analogue inputs and automatically collect, store and transmit data from the connected sensors. The RF gateway (Fig. 8) controls the network and is the aggregator of all data collected by the nodes. It has an integrated 3G modem with antenna supporting HSDPA, EDGE & GPRS, and a high sensitivity GPS-GNSS module. The gateways transmit the data over the cellular network to web data monitoring service described in section 3.

The system offer benefits by means of hassle-free installation- as cable runs-often long and tedious at the dam sites are not involved, cost & time savings, remote monitoring of hard to access locations, easy expansion of the system, if required in future, and easy maintenance.

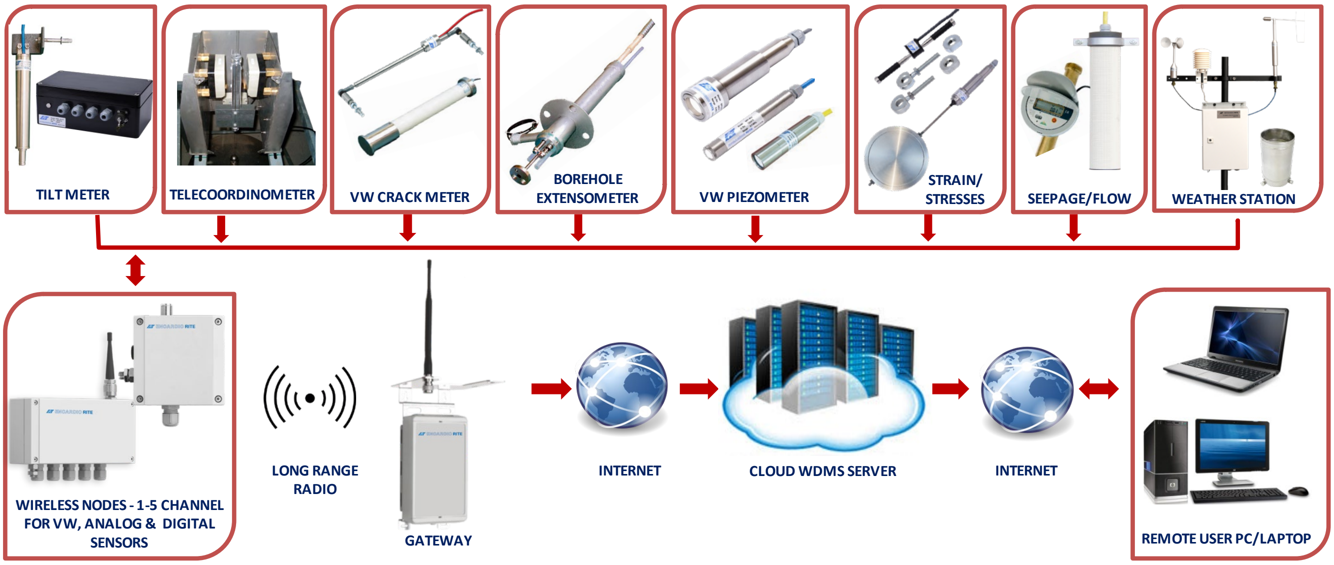

Fig. 7
Dam monitoring sensors connected to an RF network

Fig. 8
RF gateway

3. WEB BASED DATABASE MANAGEMENT SYSTEM

Cloud-based web data monitoring service is available with major geotechnical instrumentation service providers for retrieving data from the dataloggers, archiving retrieved data in a SQL database, processing data and presenting the processed data in tabular and most suitable graphical forms (Fig. 9) for easy interpretation of logged data. This is a highly flexible online monitoring system that can combine data from structural, geodetic and environmental sensors.

Cloud-based WDMS usually work on a rental model. The user has to pay a small setup fee for the first time and then a monthly rental has to be paid for accessing the data over the cloud as long as required.

Web data monitoring service's database management software acts as a data collection agent, a database server and a web server and is hosted on a high-reliability server computer. Choice of the software depends on the measurement technologies deployed.

A master plan of the project is incorporated into the database with locations of each monitoring sensor. From this master plan, the user can get data in the graphical form of any sensor with just a mouse click.

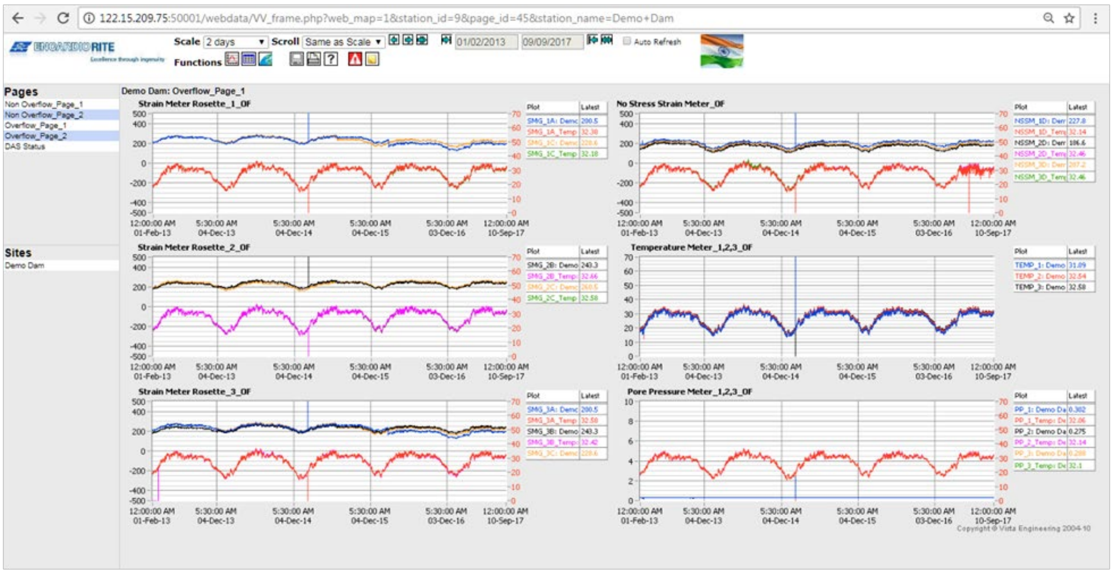

Fig. 9
Graphical data presentation on WDMS

Multiple authorized users at different locations assigned with an individual password are allowed to view any data or report from the structure simultaneously. Graphs & reports can be viewed using popular web browsers like Microsoft Internet Explorer or Mozilla Firefox amongst others.

Details like sensor identification tag, last recorded sensor reading and values of programmed alert levels can generally be viewed on the master plan of the project. If any of the alarm levels of any sensor exceeds, the colour of the marker representing the sensor location changes. Clicking the pop-up table brings up an associated data window where the sensor data can be seen either as a table or as a graph.

Site administrators can set alarm limits, which are generally considered as "alert level" and "evacuate level". WDMS can also be programmed to send SMS alert messages or e-mail to selected users as soon as any sensor data crosses its predefined alarm levels, either while going above or going below the alarm level.

Features of the data management software can be summarized as follows:

- Data from multiple sensor types are converted into meaningful information in graphical as well as numerical format
- Results available on a wide variety of fixed and mobile devices
- Access to all sensors on one screen
- Instant alerts via SMS or e-mail to authorized personnel
- Combined charts in one report
- Create graphs from any combination of parameters and time period
- Variety of visualization and analysis tools to identify potential failure scenarios
- No special software required for accessing the user sites as information can be viewed using most standard and popular web browsers

4. CONCLUSIONS

While rehabilitation and improvement of dams and its operations and regular maintenance result in restoring their full operational capacity, a balanced and well-executed instrumentation system can provide data for greater understanding triggering mechanisms and deformation behaviour of a dam in great detail. It ensures improved performance on a long-term basis with reduced risk of failure/safety incidents. By monitoring a dam, corrective action may become possible earlier than the occurrence of any failure. The solution for setting up a dam safety instrumentation & on-line monitoring system is not expensive with the advent of new technologies in this field. Considering holistically, the cost of instrumentation and monitoring is a small fraction of what is spent later on in repair and rehabilitation operations.

REFERENCES

[1] Dunnicliff, John (1988). Geotechnical Instrumentation for monitoring field performance, A Wiley-Interscience publication, USA, pp 199-292; 417-435.
[2] Website of Dam Rehabilitation and Improvement Project: https://www.damsafety.in

SUMMARY

For control and mitigation of disastrous consequences caused by the failure of an ageing dam, it is essential not only to take preemptive corrective action at the site by strengthening and rehabilitating it but also by implementing a good monitoring and forewarning system. The latter is vital for identification of hazardous conditions or developments well before a catastrophic failure takes place and alert personnel with authority to take remedial measures as early as possible. This paper describes advanced instrumentation for dam safety monitoring comprising of field-proven and rugged geotechnical instruments, advanced automatic surveying techniques and public cloud-based web database management system. The field sensors for measuring parameters such as surface and subsurface deformations, porewater pressure, anchor load, rainfall etc. are connected to the field dataloggers either through an SDI-12 bus or through RF signals thus minimizing the cabling costs and increasing system's reliability. Deployment of the robotic total station to automatically monitor 3D prisms at critical locations adds to the comprehensiveness of the data collected and system's integrity. The data collected by the field instruments and sensors, transmitted using GSM/GPRS network, is readily available in real time to the different stakeholders, who may be located in any part of the world. Automatic notification of alarm conditions through e-mail or SMS is realized by the system. The dam safety monitoring network is cost-effective and value-wise is just a small fraction of what is spent later on in repair and rehabilitation.

RÉSUMÉ

Pour maîtriser et atténuer les conséquences désastreuses de la défaillance d'un barrage vieillissant, il est essentiel non seulement de prendre des mesures préventives préventives sur le site en le renforçant et en le réhabilitant, mais aussi en mettant en place un bon système de surveillance et d'alerte. Ce dernier est vital pour l'identification des conditions ou des développements dangereux bien avant qu'une défaillance catastrophique se produise et alerte le personnel avec l'autorité de prendre des mesures correctives le plus tôt possible. Cet article décrit une instrumentation avancée pour la surveillance de la sécurité des

barrages comprenant des instruments géotechniques éprouvés et robustes, des techniques de levés automatiques avancés et un système de gestion de base de données web basé sur le cloud public. Les capteurs de terrain pour mesurer les paramètres tels que les déformations de surface et souterraines, la pression d'eau interstitielle, la charge d'ancrage, les précipitations, etc. sont connectés aux dataloggers sur un bus SDI-12 ou par RF, minimisant ainsi les coûts de câblage. Le déploiement de la station totale robotisée pour surveiller automatiquement les prismes 3D à des emplacements critiques ajoute à l'exhaustivité des données collectées et à l'intégrité du système. Les données collectées par les instruments de terrain et les capteurs, transmises via un réseau GSM / GPRS, sont facilement accessibles en temps réel aux différents acteurs, qui peuvent être situés dans n'importe quelle partie du monde. La notification automatique des conditions d'alarme par e-mail ou par SMS est réalisée par le système. Le réseau de surveillance de la sécurité des barrages est rentable et la valeur n'est qu'une petite fraction de ce qui est dépensé plus tard dans la réparation et la réhabilitation.

KEYWORDS: MONITORING, REHABILITATION, TELEMETERING SYSTEM