GeoWatch

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GeoSIG

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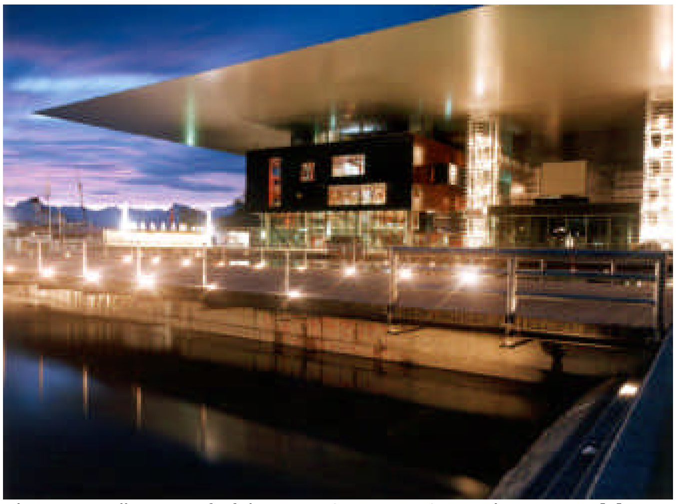
Foreword from the CEO

Within this issue of GeoWatch the need for strong motion instrumentation in dams is addressed. Dr. Martin Wieland, Chairman of the Committee on Seismic Aspects of Dam Design of the International Commission on Large Dams (ICOLD) describes in his paper "Why Do We Need Strong Motion Instruments in Large Dams?" the various aspects.

Strong motion instrumentation of large arch dam

The conclusions made and justifications given for the strong motion instrumentation of large dams are also applicable for the strong motion instrumentation of other major infrastructure projects such as nuclear power plants, offshore platforms, (petro)chemical plants, large bridges, telecommunication towers etc., and also for high-rise or extraordinary buildings.

An example is the roof monitoring system for the New Congress Center in Lucerne (KKL, Switzerland), which was provided by GeoSIG. For this astonishing building the designer and contractor were awarded the 1999 European Price for Steel Construction, and the building was selected as one of the 10 landmark buildings of the period 1990 to 2000 worldwide by Structural Engineering International, the journal of the International Association for Bridge and Structural Engineering. GeoSIG is proud to have provided the state-of-the-art roof monitoring system for this beautiful project.



The extraordinary roof of the New Congress Center in Lucerne [1]

Structural monitoring and damage detection are subjects of major international research. If a damage has been detected based on changes in the dynamic behavior of a structure, the location of the damage should be identified and the severity of the damage be quantified. Finally, based on this information, a reliable evaluation of the safety of the structure could be performed. Considerable research work is still needed before this information can be used for emergency planning.

GeoSIG contributes to this technological development as the basic requirement for all such new systems is a reliable and robust instrumentation.

Christoph Kündig

[1] Wieland, M., Malla, S., Wüthrich, W.: Lucerne Culture and Congress Centre, Structural Engineering International, No. 1, 2000, pp. 8-11.

Special Article by Dr. Martin Wieland; "Why Do We Need Strong Motion Instruments in Large Dams?"

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Background

Up to now no incidents have been reported in the literature, where people have been killed due to the failure of a well-engineered dam during an earthquake. This is very encouraging, indeed. However, this favorable performance of dams does not necessarily mean that dams are inherently safe against earthquakes. For example, during the Bhuj earthquake of January 26, 2001 in Gujarat Province in India, about 200 earth dams were damaged and need repair and/or strengthening. Because the reservoir levels were extremely low during the time of the earthquake, no water was released from the reservoirs of the severely damaged dams.

Despite the fact that these earth dams with a height of less than 30 m, which are often built by local communities, are different from the well-engineered dams for hydropower projects, we have to recognize that plenty of similar dams exist all over the world.

There is also the problem that the majority of the older dams were built using methods of seismic analysis and seismic design criteria, which, today, are considered as obsolete or outdated. Therefore, in many cases, it is not known if an old dam complies with the new seismic safety guidelines published by the International Commission on Large Dams (ICOLD).

None of the dams damaged by the Bhuj earthquake was instrumented with strong motion instruments. Therefore, it is not known what level of ground shaking has caused the observed damage. This would be essential information to judge the vulnerability of the many irrigation dams to strong ground shaking all over the world. A back analysis would also be based on numerous analysis assumptions and, therefore, a reliable estimate of the peak ground acceleration and the other characteristics of the ground motion at the sites of the damaged dams would be extremely difficult. At this time it is assumed that the peak ground acceleration (PGA) was of the order of 0.5g at the severely damaged dams. One could easily imagine that there would be serious safety concerns, if the PGA would have been less than half of that as the return period of an event that could produce such shaking levels would be quite short and thus the risk of dam failure may increase substantially.

Also during the devastating earthquakes, which hit Turkey and Taiwan in 1999, very few earthquake records of dams that experienced strong ground shaking are available. It was reported that at the 181 m high Techi arch dam, where below the crest spillway a PGA of 0.87 g was recorded, power failure of some strong motion instruments at the dam site made them useless. Also the critically damaged Shih-Kang dam was not instrumented, despite the fact that Taiwan has one of the densest and most sophisticated strong motion networks. In a nearby town a PGA of 0.57g was recorded.

In 1994, during the Northridge earthquake near Los Angeles some of the important records obtained from the well-instrumented Pacoima arch dam, where PGA values exceeding 2g were recorded at the dam crest, could not be used as some of the older strong motion instruments could not accommodate that high accelerations. Therefore, it was not possible to perform a reliable back analysis, which would be needed, for example, to determine the damping of the dam during very strong ground shaking. A key problem in many seismic analyses of concrete dams, that has not yet been resolved.
Also the 106 m high Sefid Rud buttress dam in the Northwest of Iran, which was severely damaged during the 1990 Manjil earthquake and which is one of the most important reference cases for dam engineers, had no properly functioning seismic instruments. It was reported that at the time of the earthquake, the epicenter of this magnitude 7.5 earthquake was located within less than one kilometer of the dam site, the seismograph was being repaired in Tehran.

These examples show that there is a real need for the strong motion instrumentation of large dams. The following dam safety aspects have to be considered in the future:

- Appropriate site-specific instruments shall be in place to monitor a dam, both for ongoing behavior and safety of the dam, and for identifying changes in its performance after an earthquake or other unusual events; and
- Back-analysis of dams that were subjected to strong earthquake shaking would help provide calibration of analytical methods used in dam design and to develop new analysis tools.

Over the last decades it has also turned out that for dam safety considerations, the earthquake action has developed from an almost negligible action into the most important one. This fact has been true in the nuclear industry for quite some time. In the past, dams were designed for an earthquake acceleration of 0.1g. Today, according to current ICOLD guidelines, the dam safety must be guaranteed for the worst earthquake, i.e. the so-called maximum credible earthquake. This is an event, which up to now only a handful of the over 40'000 existing large dams have experienced.

The dynamic behaviour of dams under such severe motion is not known satisfactorily, therefore, data from strong motion instruments will eventually form the basis for a more reliable seismic safety assessment of the existing and future dams. Experimental investigations, which would be an alternative, would be too costly for most dams.

Therefore, in view of the ever-increasing safety concerns and rapidly increasing risks of large dam projects, low-cost seismic instrumentation is the future state-of-the-art in dam safety monitoring.

Overview

The conventional monitoring instruments installed in large dams are well suited for the control of the long-term and quasi-static behaviour of a dam. Accordingly, the frequency of most static readings is of the order of one measurement per week or month. However, processes such as cracking in concrete dams and actions like earthquakes cannot be recorded satisfactorily by these instruments.

The main dynamic actions are those caused by strong earthquakes in the vicinity of a dam, i.e. vibrations in the dam body causing cracks and settlements, faulting in the dam foundation and water waves in the reservoir. Other short-duration phenomena are impulsive waves caused by mass movements and avalanches into the reservoir, wind-induced water waves, terrorist attacks and military actions, and dynamic loads caused by faulty operation of hydro- and electro-mechanical equipments as well as accidents during repair and maintenance works. In addition, it is necessary to monitor fracture processes in concrete dams (formation and propagation of cracks in concrete dams), progressive failure of slopes in embankment dams, which may be triggered by sudden changes in the water level in the reservoir, effects due to very low temperatures, reservoir-triggered seismic phenomena, etc.

As some of these processes and actions may jeopardize the safety of a dam, it is important to monitor the response of the dam caused by such unpredictable phenomena.

Today, the strong motion accelerometers available on the market are highly reliable, are able to record both small amplitude vibrations as well as motions caused by strong earthquakes or even explosions. Moreover, during the last decade the cost of digital sensors and recorders have dropped and at the same time the performance of these instruments and the data analysis features built in these systems have improved dramatically.

Similar to other types of monitoring systems, strong motion instruments do not improve the structural safety of an existing dam. But dam monitoring forms a key element in the overall safety concept of a dam, which comprises the following:

(i) Structural safety (capability of a dam to resist water load, earthquake forces and other types of forces and actions);

(ii) Dam safety monitoring (evaluation of dam behaviour and safety based on visual and instrumentally recorded data);

(iii) Safe operation (safe operation of reservoir on the basis of reliable rule curves and well-trained staff); and

(iv) Emergency management (timely warning of the population in the case of an accident and preparation of evacuation plans, etc.).

Records of strong motion instruments could actually be used to contribute to al four of the above safety elements of a large dam project. But dam safety monitoring is the most obvious application for accelerometers. However, these state-of-the-art instruments can easily be used to issue an alarm, if critical acceleration or spectrum intensity values etc. are exceeded. Therefore, strong motion instruments installed within the dam are important components of an alarm and rapid response system and allow

(i) the timely warning of the population living in the downstream valley (water alarm),

(ii) to operate safety devices such as valves in penstocks, and

(iii) to shut down the turbines and generators etc.

Despite the fact that it may take some time to safely close valves and to shut down turbines without causing large dynamic effects in the pressure system, the consequences of earthquake damage to these devices would be greatly reduced.

Therefore, today, strong motion instruments and a rapid alarm system should belong to the standard instruments for the safety monitoring of large dams. To complement the standard static instruments with dynamic strong motion instruments allows the comprehensive monitoring of a dam under the whole spectrum of actions affecting the safety of a dam. In view of the large damage potential of most large dams, it is in the interest of the dam owners, the dam safety agencies and in particular of the people affected by a possible dam incident to reduce the earthquake risk of a dam as far as possible.

As the prediction of the time, location and magnitude of strong earthquakes, which may affect the safety of a dam, will not be possible in the foreseeable future, the aspect of pre-warning of the population living downstream of a dam is an important issue.

In addition, today's strong motion instruments have a large dynamic range, i.e. they can be used for recording small and high amplitude vibrations ranging from a few micro g's to over ten g (acceleration due to gravity: g = 9.81 m/s^2). The records of continuous monitoring of small amplitude vibrations of a dam caused by ground motions, wind, water waves in the reservoir, operation of equipment in the dam etc. can be used for the health monitoring of the dam and for the calibration of numerical dam models. Real time health monitoring on the basis of monitoring changes in the fundamental frequencies of the dam, can easily be implemented in these instruments.

Moreover, the data collected from strong motion instruments can be used

(i) to check and to improve the seismic design criteria of the dam, and

(ii) to locate micro-earthquakes in the vicinity of the dam.

Because of these unique features and advantages, it is highly recommended to install strong motion instruments in all large dams, which are already equipped with pendulums for deflection measurement. Three instruments would be the absolute minimum for a large dam as it has to be assumed based on the past experience that one or the other instrument may not be working properly at the time of a strong earthquake due to maintenance problems as experienced in the past.
The number of large dams equipped with strong motion devices is steadily increasing. Because of the long return period of strong earthquakes in many parts of the world, the owners lack proper justification for this additional investment, which may be of the order of USD 50’000 for a minimum set up. The annual operation and maintenance costs including the costs for routine data interpretation should not exceed 20% of the initial investment.

We hope that this paper provides sufficient arguments for the dam owners and dam safety agencies to recommend and also to justify the installation of strong motion instruments in large dams.

Any new dam with a large damage potential should have at least a few strong motion instruments and the monitoring systems of the existing dams should eventually be upgraded as well.

Moreover, the damage caused to a considerable number of irrigation dams during the 2001 Bhuj earthquake in India has shown, that there is also a need for strong motion instrumentation of smaller dams, which are vulnerable to strong ground shaking.

Technical Aspects

The development in the field of electronics and sensor technology is proceeding very rapidly. Automatic recording of measured data and applications of data communication techniques are widely used. Strong motion instruments have gained a lot from this recent development.

The earthquake motions to be recorded and which are of greatest interest from the dam engineering point of view are ground accelerations with frequencies up to 20 Hz. For traditional dam monitoring instruments relatively long measuring intervals of say one to four weeks are sufficient under normal operation. Some parameters like water level in the reservoir and ambient temperatures are measured continuously. Due to this fact man-operated measuring is widely used in the field of dam monitoring.

In the meanwhile the technology of strong motion instruments was developing to a stable level and thousands of instruments have been installed and are operating world-wide. The resolution capability has improved over the last ten years by a factor of 4000, allowing now the accurate measurement of very small ground movements. The measuring range is actually only limited by the noise level of the sensor. Since the sensor noise level is far below the natural ground acceleration at the measuring site, therefore, with a sensor fixed to a dam the eigenfrequencies of the structure can be calculated easily based on power spectra of the recorded accelerations. Due to the high dynamic range of modern strong motion instruments and due to the fact that all the recordings are in digital form, the following goals can be reached:

(i) Alerting in the case that a pre-defined peak acceleration is exceeded and the event is identified by a suitable software to be of seismic source.

(ii) Recording of all the events exceeding a pre-defined peak acceleration with appropriate pre- and post-event time series. Based on the recorded acceleration time histories the velocity and displacement time histories can be calculated.

(iii) Continuous recording of the complete time series during a period of several days before having them deleted or overwritten. This allows the analysis of the history of an event.

The continuous recording may also be used for ‘health monitoring‘ by continuously checking any short-term or long-term changes in the dominant eigenfrequencies of the dam.

Conclusions

Modern strong motion instruments, having been ignored for some time, have been developed with the latest sensor and communications technologies. In the meanwhile very user friendly and versatile instruments are available. These instruments can contribute significantly to the safety monitoring of dams. Therefore, strong motion instruments are expected to become useful additions to the standard instrumentation of dams.

Moreover, the recorded data will be retrievable from centralised recording units through the Internet, thus instantaneous data access can easily be provided for all parties involved in the dam safety evaluation process.

Fig.1: Sefid Rud buttress dam in Iran, damaged by the June 21, 1990 Manjil earthquake

Fig. 3: Earth dam damaged by the January 26, 2001 Bhuj earthquake, Gujarat, India

Fig. 2: Shih-Kang weir in Taiwan, destroyed by fault movement during the September 21, 1999 Chi-Chi earthquake

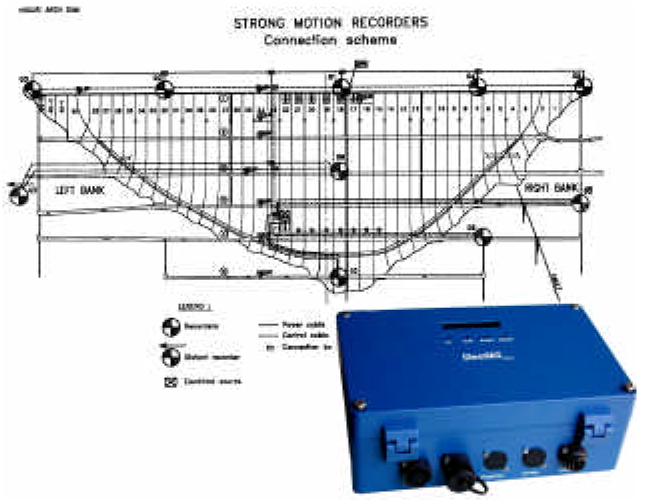


Fig. 4: Layout of strong motion instruments in a major arch dam and picture of a strong motion instrument

Istanbul Earthquake Early Warning and Rapid Response System has been shipped

Components of the Istanbul Earthquake Early Warning and Rapid Response System have been delivered to Kandilli Observatory and Earthquake Research Institute (KOERI) by mid-February 2002.

The project is being conducted by the Swiss Joint-Venture Electrowatt Ekono – GeoSIG.

Products loaded for shipment to Turkey

The system was completely developed by GeoSIG and is scheduled be fully operational by mid-June 2002. The project consists of many newly developed state of the art digitizing and communication technologies as well as revolutionary data acquisition, analysis and damage assessment software GeoDAS. Currently installation activities are being performed at more than 100 locations in the city of Istanbul with an immense population of more than 12 million. It is estimated that a magnitude 7.5 earthquake may hit the greater Istanbul region with a probability of 62% in the next 30 years.

By the second half of March GeoSIG will perform a second telemetry test, after the preliminary tests one year ago, to make sure that all final radio links for the online Early Warning portion of the project are rational.

GeoSIG has become the official reseller of IKONOS Satellite Imagery

Starting on January 2002, GeoSIG is now a reseller for Space Imaging Eurasia for the IKONOS satellite imagery. CARTERRA™ - IKONOS line of imagery products is derived from IKONOS satellite, the world's first commercial high-resolution imaging satellite.

Satellite imagery has a wide variety of implementation areas. Many, if not all, Geographical Information Systems (GIS) users take benefits of these high resolution images with select properties tailored for their individual needs. This top of the line products serve

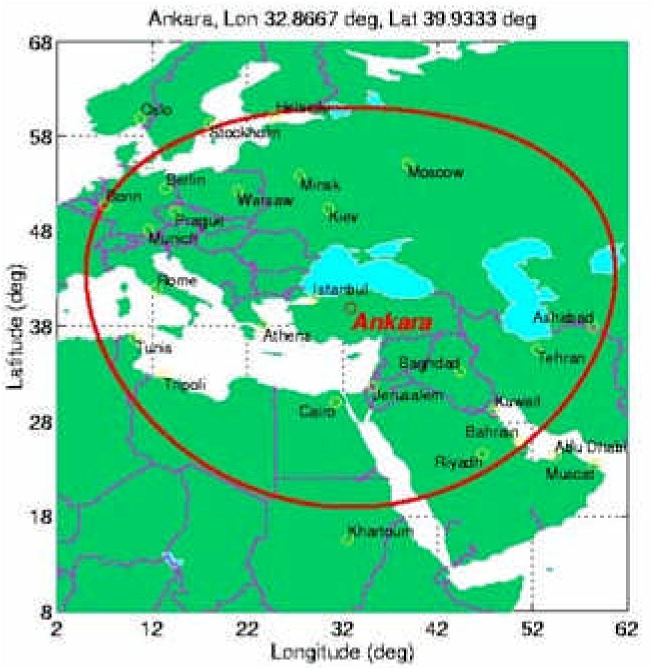
many industries and organizations ranging from insurance/reinsurance companies which perform **asset and risk analyses**, to government or commercial organizations which perform **investment, resource, transportation and logistics planning**, as well as **land use and policy development**. Educational or research organizations which conduct complicated **regional analyses on especially earth sciences** also utilize such products frequently. **Cartography and telecommunications** are just a few of other countless industries that benefit from space imagery.
The CARTERRA™ product line of imagery offers diversity and flexibility to support a variety of applications. Launched in September 1999, IKONOS is owned and operated by Space Imaging.

IKONOS 1-meter resolution Panchromatic, 1-meter resolution Pan-sharpened Multispectral and 4-meter resolution Multispectral (color) products can be used for a wide variety of applications and represent the highest resolution satellite imagery currently commercially available. The satellite carries a state-of-the-art sensor and is the most advanced commercial imaging system currently in orbit. IKONOS began commercial operations in 2000, collecting data of client-specified Areas of Interest (AOIs).

IKONOS has two parameters superior to the other satellites. These are:

- **The maneuvering speed of the satellite**. The quicker the satellite can maneuver (or rotate) the more images it can capture of separate areas that lie off the nadir track (nadir = vertically beneath the satellite). Also for the collection of in-track stereo imagery, the maneuvering speed is critical. An in-track stereo image pair is collected by capturing in one pass a forward-looking and backward-looking image. Because of the very small time difference between the 2 images, specialists often prefer in-track stereo rather than multi-pass stereo.

- **Revisit frequency**. Due to its high orbit altitude (680 km), it can look further off the nadir track, which enables IKONOS to revisit areas more frequently. This is critical, as often multiple collections are required to have an image with acceptable cloud coverage.



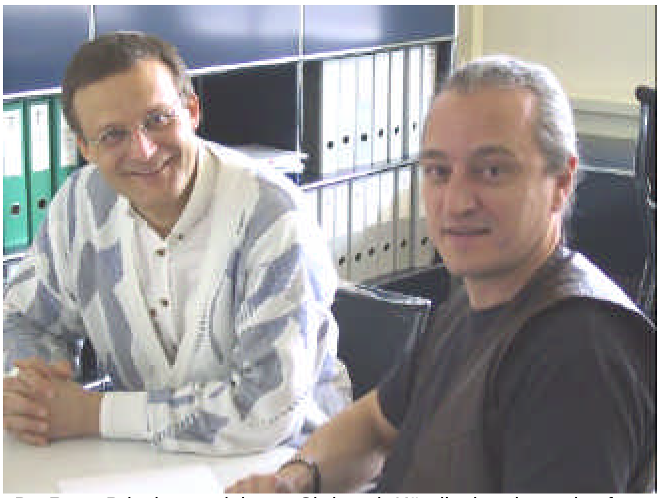
The coverage cone of Space Imaging Eurasia extends from Middle East to Central Europe.

Technology Seminar Scheduled in Zurich area on ARTeMIS Software

Dr. Rune Brincker, from SVS Structural Vibration Solutions ApS, Denmark visited GeoSIG Ltd. on his trip to Italy. He reported on the technology seminar on the ARTeMIS modal analysis software hold in Rome with more than 20 participants.

With the revolutionary ARTeMIS Extractor software modal analysis and mode shape identification of the structures can be performed in an easy way. ARTeMIS comes in three versions, the Light, Handy and Professional. For universities attractive discounts are offered. During Dr. Brincker's visit in Switzerland a technology seminar was planned to be hold in Zurich area on May 16 and 17.

GeoSIG is an official distributor for the ARTeMIS software.



Dr. Rune Brincker explains to Christoph Kündig the planned software package supporting ARTeMIS Extractor.

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