ABSTRACT:

Dam monitoring is the key element for dam safety and risk mitigation. For many years, Switzerland has put into place a dam surveillance policy enabling dam owners, operators, engineering consultants and authorities (Governmental Dam Surveillance Authority) to interact and coming up with the state-of-art safety concepts. Switzerland thus plays a leading role for international dam safety recommendations and in technical committees such as the International Commission on Large Dams (ICOLD).

The Dam Safety Enhancement Program (DaSEP) favours cooperation between Switzerland and China allowing both countries to share their knowledge, standard practices, analysis and prediction methods, experience and safety concepts. Exchanging knowledge and information leads to better understanding, prediction of failure and, hence, risk mitigation. The DaSEP project, which is presented in this paper, has for aim to raise awareness among authorities, engineers, dam owners and operators. The importance of the proactive and systematic analysis of monitoring data will be pointed out as a necessary preventive measure regarding the behaviour of dams.

Keywords: Dam safety, regulatory framework, organization, knowledge transfer, surveillance

1. INTRODUCTION

The DaSEP is one of the cooperation projects within the framework of a Memorandum of Understanding signed between the Chinese and the Swiss governments in 2009. The Letter of Intent signed on June 1st, 2011, by the Chinese Ministry of Water Resources (MWR) and the Swiss Federal Offices for Environment (SFOEN) and for Energy (SFOE) gives the objectives of the DaSEP project as follows:

1. "to introduce Swiss best-practice solutions in dam safety management which are suitable to the Chinese situation, to assist the Ministry of Water Resources of China to implement dam safety management plan, to develop the capacity of professional engineers and technicians of dam safety, and to train the experts as trainers for subsequent widespread training for others, so as to meet the long-term needs for dam safety management in China;

2. through demonstrative projects, to improve reservoir management systems and to construct facilities related to dam monitoring, rainfall and runoff forecast, as well as warning systems so that experiences can be provided for the improvement of Chinese dam safety management and safety monitoring."

A first exploratory mission of Chinese dam safety governmental and provincial authorities has been organized in Switzerland in November 2010 in order to define the objectives above. In May 2011, a second mission of Swiss delegates from SFOE, ALPIQ and EOS Holding, dam owners, who co-sponsor the project and STUCKY visited the Nanjing Hydraulic Research Institute (NHRI), the Dam Safety Management Center (DSMC) and several large dams in Sichuan Province. The general situation regarding dam safety in both countries is described hereafter. A third mission of Chinese delegates was organised in September 2011 to discuss the details of the continuation of the program.

2. DAM SAFETY ENHANCEMENT PROGRAM OVERVIEW

2.1. Monitoring and Risk Mitigation

The risk management associated to water storage structures for energy, human consumption, irrigation or flood protection generally consists of three components explained here below:

1. The monitoring and the risk prevention aims at:
   - Early detection of anomalies of the structure’s behaviour;
• Identification of preventive and protection measures against potential dangers. It generally relies on adequate organization, monitoring and maintenance measures of the structure.

2. The analysis of the serviceability aims to identify and quantify risk in the presence of an identified anomaly or an extraordinary event affecting the structure such as an earthquake or an exceptional flood.

3. The improvement or repair measures aimed at reducing an identified and quantified risk and potential damages downstream of the dam.

The Dam Safety Enhancement Program (DaSEP) project addresses exclusively the component 1), i.e. the monitoring and the risk mitigation.

2.2. DaSEP Objectives

Exchanged information through the DaSEP programs encourages risk mitigation through dam surveillance and good maintenance of the structures, raise the awareness of the whole decision chain, from the Dam Surveillance Authority down to the dam operator’s staff on the importance of adequate surveillance, monitoring strategies and data analyses.

The project aims to train a limited amount of professionals dealing with dam surveillance and data analyses who will then share the knowledge and experience among other specialist in their country. The training includes a practical course at the Large Dam Laboratory ALIP, Switzerland. The Swiss experience will enable the Chinese Ministry of Water Resources (MWR) to integrate new concepts and thus gain in effectiveness.

3. DAM SURVEILLANCE WITHIN THE SWISS DAM SAFETY CONCEPT

The global monitoring and maintenance concept of Swiss structures is defined by the flow chart illustrated in the Fig. 1 hereafter.

The organisation of the dam surveillance in Switzerland calls for three different competence levels:

Level 1 The dam operator proceeds to periodical detailed visual inspection, measurements with the monitoring equipments and devices, tests and checks the monitoring and safety equipment and performs the maintenance works.

Level 2 An experienced engineer ordered by the dam owner analyses the results of the monitoring measurements and identifies the behaviour anomalies of the structure. He performs an annual inspection of the dam (visual controls of the condition and maintenance, control of the qualification of the dam operators) and prepares an annual report.

Level 3 Two confirmed independent experts, one civil engineer and one geologist, approved by the Authority, assess every five years the safety of the dam. The engineer makes a thorough inspection of the structure condition, analyses the behaviour of the dam and its foundations. In case of an anomaly, he advises on measures to take and on the serviceability. He checks the condition and the maintenance of the structure and attends the tests of the safety outlets (gates). He prepares a report to the Authority, in which he exposes his observations and recommendations. The geologist assesses the behaviour of the dam abutments and foundation, and of the reservoir banks.

The governmental surveillance authority (Level 4) controls the organisation of the three levels. It makes sure that the various procedures and documents are in line with the guidelines and prescriptions and delivers the clearance to operate. It orders, when necessary, complementary studies and analyses and approves the proposed rehabilitation or repair measures.

Fig. 2 summarises the four levels of the dam surveillance concept described hereinbefore.

The owner’s and operator’s experience demonstrates the critical importance of the Levels 1 and 2 in the organisation of the dam surveillance. The tasks of the levels 1 and 2 are locally carried out by auxiliary specialists.
Figure 2. Organization chart of the four dam safety levels (height > 40m or height > 10m and reservoir volume > 1 Mm³)

The premonitory signs of a disorder of the structure can generally be observed in situ before it evolves towards a critical or fateful situation on a safety standpoint.

The risk prevention thus relies primarily on:

1. The detection by the dam operator (Level 1) of premonitory signs of a disorder in the structure.
2. The preliminary analysis by the specialist (Level 2) of the observations and measurements made at level 1.

4. SWISS OWNER’S MANAGERIAL ORGANIZATION

4.1. Foreword

The Swiss legislation is based on the dam owner’s prime responsibility in meeting the safety goals. The dam owner’s managerial organization plays a major role in his capability of bearing this responsibility since he is usually facing constraints on technical competencies and financial resources.

4.2. Management of Physical Infrastructures

The management of a physical infrastructure such as a dam implies the existence of three actors:

1. The "Owner", a legal entity with rights of ownership on the dam, beneficiary of water rights and bearing obligations to water end-users.
2. The "Asset Manager", a technical and administrative entity in charge of maintaining the long term desired performances of the dam.
3. The "Operator", an operational entity in charge of the dam operation and maintenance activities.

The distinction of roles between "Owner", "Asset Manager" and "Operator" is a standard approach to modern management of large infrastructures. It corresponds actually to the natural chain of delegation of responsibility between the three actors.

4.3. Asset Management Mission

The key activities of an Asset Manager are:

1. Definition of a standard of serviceability (SoS) that is the normal performances of the asset fulfilling the owner’s requirements.
2. Assessment of the current condition of the infrastructure.
3. Identification of the minimum acceptable condition grade of the infrastructure (minimum serviceability grade).
4. Management of emergency measures to be taken if the minimum acceptable condition grade is reached.
5. Identification of the medium/long-term actions required to sustain the SoS.
6. Establishment of a forward looking cost-profile for operating and maintaining the infrastructure in a condition to sustain the SoS.

The Asset Manager is therefore a specialized professional dealing with complex tasks requiring technical, legal and financial knowledge.

Sufficient financial and human resources are in general available for efficient managerial organization of large dams. Unfortunately, it is usually not the case for smaller dams where resources remain limited. In this case, the Asset Management may be performed unsatisfactorily.

Pooling several small dams in an Asset Manager portfolio is a tangible solution to prevent gaps in managerial organization, promote knowledge transfer and sharing of experience and expertise as well as optimizing human resources and costs (Fig. 3).

Figure 3. Pooling of Asset Management

Each owner’s dam sub-contracts his Asset Management to a centralized Asset Management Organization through a Service Level Agreement.

Since identical tools and methodologies can be used on all dams in the portfolio, a significant gain in efficiency and an important reduction of costs is possible through standardization of technical and administrative processes.

On the other side, as the Asset Management deals with several dams, specialized professional skills can be mobilized in the organization without stretching the limited financial resources of small dam owners.
5. DAM SAFETY AS AN OWNER'S MANAGEMENT TOOL

For economical (and political reasons), the Owner has a major interest in the continuity of operation in order to guarantee an energy and water supply guaranty to end users. Any unplanned interruption of service must be avoided.

Long term planning of dam maintenance and rehabilitation measures is of utmost importance for the Owner.

The permanent assessment of the current condition of the dam in terms of structural integrity allows forecasting the state of the dam. If a disorder appears, the knowledge of the past and present conditions provides a scientific basis for a diagnosis based on sound engineering judgment. If this diagnosis is done early enough, the Owner has an adequate time to plan the mitigation measures and to find a source of financing to execute them.

If an Owner possesses several dams, a priority list of mitigation measures can be set and Owners' resources (engineering, financing) can be used optimally.

In this context, dam safety management is not only a regulatory obligation but also an essential management tool for the Owner.

There are indeed many similarities between Asset Management and Dam Safety Management, as illustrated in Fig. 4.

- Organizing and controlling the dam inspection, measurements and functional tests performed by operator's Level 1.
- Assessing the current condition and behaviour of the dam (annual inspection and safety report) based on the dam initial design as well as on results provided on-site dam surveillance by Operator's Level 1.

and also (according to the Owner's specification) of:

- Coordinating (as information provider) the contract with experts Level 3 and following its execution.
- Identifying the necessary dam rehabilitation measures, defining the scope of corresponding special studies to be performed by Experts Level 3 and controlling their execution.
- Providing the Owner with a long term planning and with a forward looking cost-profile for operating and maintaining the dam according to the safety requirements.
- Organizing the dam rehabilitation works, when needed.

The experienced engineer responsible of Level 2 has an activity at the intersection of regulatory duties and Asset Owner tasks. In short, the experienced engineer Level 2 is the Owner's warrant of the continuity of services and the Owner's warrant of the safety of the dam, a very important role indeed.

6. DAM SAFETY CONCEPT IN CHINA

6.1. Dams in China

China counts some 87,151 dams including 544 large dams (Volume of the reservoir > 100 Mm³), 3,259 medium importance (10 Mm³ < V < 100 Mm³) and 83,348 small dams. Most of these last ones have been built between 1950 and 1970 with no real engineering design or technical supervision. Many of them present hazardous safety conditions.

<table>
<thead>
<tr>
<th>Categories of dams</th>
<th>Large</th>
<th>Medium</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to the Chinese classification</td>
<td>V &gt; 100 Mm³</td>
<td>10 Mm³ &lt; V &lt; 100 Mm³</td>
<td>V &lt; 10 Mm³</td>
</tr>
<tr>
<td>According to the Swiss regulations (seismic assessment)</td>
<td>H &gt; 40 m or H &gt; 10m and V &gt; 1 Mm³</td>
<td>H &gt; 25 m or H &gt; 15 m + V &gt; 0.05 Mm³</td>
<td>others</td>
</tr>
</tbody>
</table>

Figure 4. Dam Safety Management as a special task of Asset Management

In the Owner's Asset Management organization, the experienced engineer responsible of Level 2 plays a key role. According to 1998 Swiss legislation, he is in charge of:

- Defining the instrumentation and monitoring concept in collaboration with the experts (level 3).
6.2. Dam Safety Organization

The organization of dam safety in China depends not only on the dimension of the reservoir, rather than the dam itself, but also on the purpose of the dam. Hence, dams dedicated to flood control, irrigation and water supply have distinct administrative procedures from those dedicated to hydropower. Nevertheless, the Ministry of Water Resources (MWR) is responsible for the safety of all dams in China.

Dam safety is supported by comprehensive regulatory framework defining in particular responsibilities, design standards, reservoir management and emergency preparedness plans. Technical specifications for monitoring are also defined.

6.3. Non-hydropower Dams

In general, large dams are under the responsibility of the Provincial Water Resources Dpt., medium size dams under the responsibility of the Prefectures or Cities and the small ones under the responsibility of the districts or townships.

The reservoir management in terms of operation, inspection and monitoring is assumed by Reservoir Management Units (RMU) who report to either the Provincial Water Resources Dpt., the Provincial Flood Control HQ, to the equivalent at the district or city level depending on the ownership (and importance). The RMU's must produce a yearly planning report describing the forecasted operation and regulation schedules.

If some abnormality is detected through visual inspections, a report is sent to the above administrative level. The report contains the monitoring data collected if any. No systematic analysis of these data is performed prior to the identification of the abnormality.

Before the flood season, an inspection or a coordination meeting is organised by the above administrative level to make sure that the dam will function correctly.

If improvements are required, the above administrative level is informed and NHRI or DSMC expertise is requested for State funding allocation.

General instructions for dam safety are prepared by the DSMC and imposed by the State Council. Some provinces have sub-DSMC and specific dam safety instructions.

DSMC and NHRI are technical consultants and have no enforcement power for instance to reduce the water level in case of hazardous conditions. They prepare recommendations which are transmitted to the Provincial Water Resources Dpt. or the entity who requested them. Only the above administrative level, the Provincial Water Resources Dpt., MWR or State Flood Control HQ can order to reduce the reservoir level.

A similar organization exists for hydropower dams. The Large Dams Supervision Center located in Hanzhou plays the role of the DSMC.

7. EMERGENCY DAM SAFETY MANAGEMENT EXAMPLES IN CHINA

In May 2008 a magnitude 8 earthquake hit the Sichuan Province and several dams were severely damaged. The Sichuan Province immediately developed emergency measures to face the problem and in a few weeks a complete inventory of the dams, their level of damage and risk was evaluated in order to prioritize the operational measures and rehabilitation works.

7.1. Zipingpu Dam

Located 17 km from the epicenter, the 156 m high Zipingpu CFRD was severely damaged as illustrated in Figure 6.

![Figure 6. Upstream and downstream face of the Zipingpu dam after the earthquake and at present](image)

Two years after the quake, the dam and its appurtenant structure are fully repaired and reinforced showing the high responsiveness of the Chinese authorities regarding the safety of the dam. The monitoring system has also been reinforced.

7.2. Bayi Dam

The first Bayi dam was built in 1956 with two stages of heightening in 1973 and 1986. The dam is dedicated to irrigation and water supply as well as flood control. It is a 30 m high homogeneous earthfill dam with concrete slabs protection U/S and grid concrete stabilizing structure D/S. The U/S foot is stabilized by gravel load. The D/S foot is made of non-cemented masonry for drainage and stabilization purposes.
During the 2008 earthquake, the dam experienced heavy damages with a 70 m long, 3 m deep and 5 cm wide crack along the crest. Rehabilitation has been performed with partial excavation and filling of the cracked zone, concreting of the crest road and grid stabilizing concrete structure on the D/S face.

No monitoring instruments were installed before the earthquake. Since then, 9 piezometers have been installed as well as 9 settlement marks. The piezometric measurements are intended to be automatically transmitted to the Jiangyou City Water Dpt.

For Bayi dam, daily sheets where the water level and the seepage discharge are reported are monthly sent to the Jiangyou City Water Dpt.

8. CONCLUSIONS REGARDING DAM SAFETY EVOLUTION ISSUES

It appears that the most addressing points identified by the Chinese delegates are the following:

- the Swiss Dam Safety Regulatory Framework is unique for all dams and every procedures regarding dam safety are well defined:
  - only the Federal State issues regulations
  - all actors have a certain degree of freedom within a clear framework
  - the responsibilities and tasks are clearly defined
  - various reports are requested and their frequency is defined
  - these reports are systematically transmitted for agreement and follow-up
  - flows of information and approval procedures are defined
- all the delegates are aware of the importance of Level 1 and 2
- the role of Level 2 implies skills, training and responsibilities
- organization for dam safety is efficient and adaptable to various conditions (e.g. pooling for managing a portfolio of dams or adopting simple and robust monitoring equipment adapted to each dam is important, in particular for small dams)
- Due to the evolution of ownership, the dam organization management has evolved. The roles and responsibilities issues are also to be revised. There is a need for a more clear definition of the roles and responsibilities taking into account ownership, not only structural issues but also in operational organization and safety management responsibilities at various levels, including the role of supervision of Governmental organizations and the necessary flow of information and approval
- Financial support from the administration is also a problem since there is a majority of small dams which implies limited financial resources (a difference between Eastern and Western areas is pointed out)
- Pooling the management of dams is a good track for operation, maintenance and dam safety issues. Some examples exist already in China but can be extended taking example on the Swiss experience
- Dam rehabilitation program must be based on prioritisation procedures
- Climate change, earthquake and extreme events impose also an evolution of the dam safety regulatory framework, not only on the structural point of view but also operational.

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The Swiss Federal Office for Energy (SFOE), through Dr Georges Darbre, Head of the Dam safety Division, gave a complete overview of the Swiss dam safety policy and procedures and clear indications on the philosophy behind.

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