Session:

Hydropower safety
What is good practice?

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For more information:  www.hydropower.org/congress
Safe operation of the Sayano-Shushenskaya HPP.
The cause of the accident dated 2009/08/17 and lessons learned
based on the geophysical Survey of the Siberian Branch of
the Russian Academy of Sciences

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Short description of the Sayano-Shushenskaya Hydroelectric Power Plant (SSHPP) and conclusions of the Governmental Commission on the origins of the accident dated 2009/08/17

Sayano-Shushenskaya Hydroelectric Power Plant (SSHPP) is the largest HPP in Russia with total installed capacity of 6400 MW situated in Siberian part of Russia

The Governmental Commission was established to investigate the cause of the accident at the SSHPP dated 17/08/2009 when all machine hall equipment was destroyed or seriously impacted and 75 lives were lost.

The main conclusion is that “turbine cover bolts were destroyed due to ADDITIONAL dynamic forces”

The dam safety was provided.
The safe spillway operation in winter time was provided.
All machine hall equipment was replaced in accordance to the newly developed safety requirements.

On 2014/12/12 SSHPP returned to the full scale operations with 10 new units of the same capacity

But what was the source of the “…ADDITIONAL dynamic forces…”?
Seismic sensors (triangles) before the accident were established only in the body of the dam of Sayano-Shushenskaya HPP.

After the accident, additional recording equipment was installed in the machine hall of the HPP.

The waves propagating from the operating HPP and recorded by seismic stations, are similar to recordings of the sounds of the orchestra.
Example of relationships between SSHPP’s working regimes and registered seismic data

Oscillations (vibrations) caused by the operation of the hydraulic units are well recordable by seismic stations even at a distance of several kilometers.

Correlation between operating mode of the Unit#6 and oscillations amplitudes changes is clear and strong even in cases of idling, ramping up and down (curve #3).

1, 2 – Oscillations amplitudes changes at frequency of 38.1 Hz (vertical channel, dam body (um/s²) and CERR (1500*um/s²), accordingly). 3 – Change in produced power by Unit#6 (MW).
Water hummer, external impact, strong vibrations?

It was a lot of versions based on hypotheses of water hummer or other shock impact of “…the ADDITIONAL force…”

Seismological station data recorded at the time of the accident indicate that the cause of the accident is not associated with shock effects. No indication of impacts stronger than 10 kJ was detected.

Seismic sensor is very sensitive - 22 minutes before the accident the earthquake near Japan was clearly registered.
Data analyzed from instruments located in the dam of SSHPP

Data on the dam oscillations at the time of the accident helped to determine that the hydraulic unit#2 rose and fell slowly enough – approximately within 11 seconds.

(a) Recordings of modeled slow movement. (b) Real data from different locations within SSHPP body
Spectrogram of seismic recordings prior to the accident (registered at CERR)

In the records of the Seismic Station "Cheremushki" there is no indication that the amplitude of the oscillations of hydraulic units increased prior to the accident.
Oscillations spectra registered on turbine covers (generators under a load of 640 MW)

Oscillations analysis has detected high frequency vibrations for units of old design (Unit#3, curve #2).

The turbine cover and the studs have long been exposed to high frequency vibrations giving rise to fatigue defects (despite the fact that the amplitude of the vibrations was 236 times lower the established limits)

1, 2 – for Unit#9 (new design) and for Unit#3 (old design) accordingly
Conclusions

Analysis of seismic records obtained by Seismic Station "Cheryomushki" and stations installed in the dam body revealed that:
1. Cause of the accident was not a shock or hit (water hammer or “...ADDITIONAL force...”);
2. There was no degradation in vibration conditions of hydraulic units before the accident;
3. The most probable cause of the accident is the destruction of studs (bolts) of turbine cover due to the long term influence of high-frequency vibration (with amplitudes 236 times lower than safety limits) and accumulation of fatigue defects
4. Before the accident, the main priority was given for monitoring the safety parameters of the dam. After the accident, we came to the conclusion that we should not pay less attention to online monitoring of ALL hydraulic structures, ALL equipment and their mutual influence.
5. The methodology used for remote monitoring of the safety parameters of the HPP’s equipment can be recommended for use. It is desirable to formalize it as an industry safe operation standard
Thank you for your attention!
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