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Long-term impact on unlined tunnels of hydropower plants due to frequent start/stop sequences

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Objective

This research aims to contribute to fulfilling the knowledge gap between the state-of-the art design principle of unlined pressure tunnels and problems of block falls associated with the current and future operational regime of Norwegian power plants. The main objectives of this research are listed as follows:

1. Investigate the basic mechanism of pore pressure changes which occurs in the rock mass during pressure transients.
2. Analysis of inter-relation among rock mass property, hydraulic/operational factors, and destabilizing forces along unlined pressure tunnels subjected to pressure transients.
3. Identify the most critical parameters that can contribute to rock mass fatigue and block falls due to frequent pressure transients.

Background

It is seen that the operational regime of power plants in Norway has changed after the power market de-regulation in 1991. In the demand driven market, the power prices can vary on an hourly basis and the power plants can experience multiple load changes per day to benefit from the variable power prices, causing frequent pressure transients in the waterway. Further, an increasing share of unregulated energy from solar and wind power in the energy system as seen in the recent years will demand more operational changes from regulated hydropower systems which are used to maintain the balance between supply and demand. Such an operation will lead to frequent pressure pulsations and cyclic loading on the rock mass around unlined tunnels and may contribute to increased instances of block falls as a result of rock mass fatigue. Hence, this research is focused on understanding the effects of frequent pressure pulsations in the long-term stability of unlined water tunnels.

The results are primarily based on measured rock mass pore pressure and tunnel water pressure obtained from a tunnel instrumentation and monitoring carried out during this research. Prior to this work, only a theoretical understanding of the pore pressure response of the rock mass during pressure transients existed. Hence, a full-scale monitoring of an operational unlined pressure tunnel was crucial to understand both the rock mass response during pressure transients. The results from field instrumentation are further enhanced using numerical simulation using the distinct element code 3DEC.

In addition to this, supplementary information was collected from surface geological mapping and laboratory testing for acquiring relevant geological and rock-mechanical properties. Further, operational data from 10 power plants was collected to enhance the understanding of operational trend of Norwegian power plants in the recent years. Hence, field experiment, analysis of production data of various power plants and numerical simulation are the main methods used in this research.

Results/Findings

The main findings are as follows:

1. Results indicate that pressure transients can have significant influence on the pore pressure variation and rock joint displacement in the rock mass around unlined pressure tunnels as a result of the time-lag between the pressure transient in the tunnel and the rock mass pore pressure. It is the source of hydraulic stresses in the rock mass and is dependent on their hydro-mechanical properties.

2. Results confirm the previous knowledge that mass oscillations cause larger hydraulic stresses in the rock mass as compared to water hammer. However, exceptions are known, and the effect of water hammer may not be completely ignored.

3. It is seen that 200-400 start/stops and more than 1000 load changes of varying magnitudes occur every year per generating unit in Norwegian power plants, causing frequent pressure transients. It is envisaged that this trend will further increase in the future due to addition of larger share of unregulated power from wind and solar energy. This implies that rock mass fatigue in unlined pressure tunnels may occur at an accelerated rate.

4. The results indicate that an increased conservatism may be needed in rock support decisions in critical areas where the rock mass permeability permits significant pore pressure changes in the rock mass during pressure transient, especially for tunnels excavated in schistose rock mass, and power plants with multiple load changes within a day.

5. Power plant operation is seen to have a significant influence on the amount of hydraulic stress acting on the rock mass during pressure transients. The shutdown/opening duration is usually dependent on the individual operator due to lack of standard guidelines for speed of load changes. Especially for large load changes, the power is usually changed in smaller steps, where the size and number of these steps are decided by the individual power plant operator. Results show that the shutdown/opening duration during load changes directly affects the time-lag between pressure in the tunnel water and in the rock mass. It is seen that shorter shutdown/opening duration i.e., faster speed, can cause significantly high hydraulic stresses on the rock mass. Thus, slowing down the load change operation can provide significant benefit in slowing down the fatigue process. Hence, it is recommended that more emphasis should be given towards keeping the speed of load changes consistently slow.

Relevance/utilization

The results of this research could be relevant for the hydropower industry in the following aspects:

Realtime pore pressure monitoring

The instrumentation method developed in this research has proven to be useful in monitoring pore pressure changes over the real-time operation of the power plant. Readings from similar monitoring programs along with the proposed method of calculating hydraulic impact can thus be used to define the most suitable shutdown duration to delay the rock mass fatigue and prolong the serviceable lifetime of unlined pressure tunnels with serious block fall issues.

Operational changes

The recommendation to carry out slower load changes can be readily implemented in power plants to reduce the hydraulic impact caused by pressure transients. However, flexibility needs in the future may demand faster load changes which may be in contradiction to the recommendation to show down the load changes. A compromise between these two contradictory requirements may be needed in order to cater to the market needs as well as ensure the long-term stability of unlined pressure tunnels.

Assessment of block fall possibility

The knowledge of the observed mechanism and contributing factors can be used to assess the potential of block falls. This should be considered in power plants with significant block falls and concerns about the tunnel stability. However, its application in quantitative terms demands more data from similar instrumentation in different power plants such that a larger database is created in order to correlate the observed block fall events and the contributing parameters.

Conclusion

The main conclusions are as follows:

1. Experimental and numerical simulation results indicate that pressure transients can have significant influence on the pore pressure variation and joint displacement in the rock mass around unlined pressure tunnels of hydropower plants. This influence is dependent on the hydro-mechanical properties of the rock joint contributing to the transmission delay or time-lag between the pressure transient and rock mass pore pressure.
2. The analysis of operational data of some power plants for the last 19 years shows that already large number of start/stops and load changes occur every year in Norwegian power plants, causing frequent pressure transients. It is envisaged that this trend will further increase in the future due to addition of larger share of unregulated power from wind and solar energy. This implies that rock mass fatigue in unlined pressure tunnels can occur at an accelerated rate.
3. The result indicates that additional rock support may be needed in critical areas where the rock mass permeability permits significant pore pressure changes in the rock mass during pressure transient, especially for tunnels excavated in schistose rock mass, and power plants with large number of load changes (multiple load changes within a day).
4. Power plant operation is seen to have a significant influence on the amount of hydraulic stress acting on the rock mass during pressure transient. It is seen that the shutdown/opening duration during load changes directly affects the time-lag between pressures pulses. It is seen that shorter shutdown/opening duration can cause significantly high hydraulic stresses on the rock mass.

5. It is seen that slowing down the load change operation can provide significant benefit in slowing down the fatigue process. However, it is as a challenge that the shutdown/opening duration is usually dependent on the individual operator and lack of standard guidelines for speed of load changes. Hence, more emphasis should be given towards keeping the speed of load changes consistently slow.
6. A new method called "Hydraulic impact" has been developed to quantity the hydraulic stress on the rock mass caused by pressure transients in unlined hydropower tunnels. It can also be used to define a suitable shutdown duration of the power plant in order to help slow down the fatigue process.

References and links to publications and thesis

1. PhD Thesis: **Long-term impact on unlined tunnels of hydropower plants due to frequent start/stop sequences**
2. **Effect of Power Plant Operation on Pore Pressure in Jointed Rock Mass of an Unlined Hydropower Tunnel: An Experimental Study**, Rock Mechanics and Rock Engineering (2020) 53:3073–3092.
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5. Cyclic fatigue in unlined hydro tunnels caused by pressure transients.

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