Power house cavern stability monitoring using microseismics at Tala hydropower project, Bhutan

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Abstract

Underground power house of Tala Hydro Electric Project (THP) is constructed in Bhutan. During the construction of the power house cavern, unexpected incidents of roof instabilities were experienced and were overcome. In the machine hall cavern of THP, rock blot failures were observed since 2003 and failure is still continuing, mostly on the upstream wall. The cavern is situated in the highly deformed and stressed thrust zone known as Main Central Thrust (MCT) of Great Himalayan region. Since 2003, there were a number of incidents of rock bolt failures from the side walls of machine hall cavern and till today about 175 rock bolts were failed. In view of this there are great concern for cavern stability and safety of the workmen. It was felt the need of **long-term cavern stability monitoring in real time.** The micro seismic (acoustic Emission) technique was tried as it is the best solution for remote and real time monitoring of large cavern area with few sensors. This technique helps in identifying the zones of high stressed micro-cracking zone within the rock mass surrounding cavern/structure, which is in operation for the last five years, so that the identified vulnerable locations can be strengthened with additional support system (cable anchors).

To study the applicability, potential and suitability of micro seismic technique an advanced digital micro seismic instrumentation system using 12 geophone stations was installed and monitored the hydroelectric cavern from 10th June to 15th July 2009 for first time in the history of a commissioned Hydro power project. In total, 6 borehole geophones and 6 surface geophones were installed on the upstream wall and the downstream wall. Approximately 250,000 micro seismic counts were recorded during the 3-week uninterrupted recording period. Many clear signatures of brittle fracturing within the wall were recorded. During monitoring four prominent seismic events of fracturing in the rock mass that were large enough to compute the source parameters were recorded. Three of these events were located on the upstream wall, and the fourth event was located in the downstream side. The system responded well throughout the monitoring period. The micro cracking events were observed very close to the sensors. It was also observed that the rock mass around the cavern displays seismically high attenuation characteristics. Incidentally there was a rock bolt failure on 10th July 2009 on the downstream wall side has been correlated with the high stress zone identified from the recorded data. This paper discusses the results of successful demonstration of micro seismic monitoring during the experimental study.

1. Introduction:

The underground power house (IC 1020 MW) of Tala Hydro Electric Project is located on the right bank of Wangchu River, in Bhutan. Dr. P.C. Nawani, the then director of Geological Survey of India (GSI) during his inspection visit had pointed out, in June 2004 to the project authorities regarding underground power house caverns (Machine hall, transformer hall, penstocks) location within the thrust zone of MCT, which is considered as highly deformed and heavily stressed zone and expected some strata instability problem in future.

During the construction of the THP power house/transformer caverns many incidents of roof instabilities were experienced and were overcome. Since 2003, there had been a number of incidents of rock bolt failures from the side walls of machine hall cavern and till June 2009 about 168 rock bolts were failed. It was observed that this situation was very alarming and it may further deteriorate due to time dependent deformations in this heavily stressed MCT zone. The stability of the cavern and safety of the work force in the machine hall is of great concern. NIRM has carried out successfully micro seismic investigations in both hard rock mines and coal mines (Sivakumar, C. 1999) in assessing the stability of mine workings and identifying the high stress zones and prediction of roof falls in the underground coal mines (Sivakumar, C. et.al., 2005). During the inspection visit of the Director, NIRM in May 2009 this issue was discussed in detail with the Managing Director and Director (Projects), DGPCL. It was suggested that to carryout micro seismic (Acoustic Emission) monitoring, on long-term basis, to be carried out for identifying the zones of micro-cracking within the rock mass surrounding cavern. These vulnerable locations can be strengthened by installing additional support system (cable anchors) etc. It was decided, during the meeting, that NIRM will conduct an experiment for few weeks using micro seismic/ nanoseismic techniques to demonstrate its capability by detecting the events of micro-cracking and fracturing phenomena around the caverns to evaluate stress pattern in the surrounding rock mass. This micro seismic monitoring technology was used for the first time in the hydro power sector in the world for stability monitoring purpose by establishing a 12 geophones (sensor) network and interfaced to two 24 bit digital seismic data acquisition systems. It was considered most essential by Director, NIRM to address the serious cavern stability problem in view of large number of rock bolt failures from the walls of machine hall cavern

A demonstration of nanoseismic/micro seismic monitoring technology at the Tala Hydroelectric Project (THP), Bhutan was carried out by the National Institute of Rock Mechanics (NIRM), Kolar Gold Fields (KGF), India during June/July 2009 in order to evaluate the applicability of the advanced real time strata monitoring technology to address the stability problem of hydroelectric caverns. In the machine hall cavern of THP, rock bolt failures were observed since 2003 and the failure is still continuing, mostly on the upstream wall. NIRM had conducted experimental monitoring to study the strata condition using highly advanced digital micro seismic instrumentation. In total, 6 borehole geophones and 6 surface geophones were installed in the upstream wall (4 sensors) and the downstream wall (2 sensors). During the monitoring period the system detected approximately 250,000 micro seismic counts and recorded. While many of these records are buried in noise and were extracted using digital filtering techniques in offline. Many clear signatures of brittle fracturing within the wall were observed from these records. During the monitoring period four prominent micro seismic events of micro cracking in rock mass that were large enough to trigger four or more sensors were recorded. Three of these events were located on the upstream wall, and the fourth event was located in the transformer hall. This clearly indicates that there is clear evidence that displacement /deformations in the walls of Power House cavern is continuing even after the commissioning of structure about six years back.

The monitoring instrumentation was provided by Integrated Seismic Systems International (ISSI), South Africa. The system was used for recording the micro cracks information from cavern walls to study strata behaviour. Preliminary data analysis was carried out on day to day basis in offline by bringing the data in memory sticks and intensive batch data processing/analysis was done after obtaining the sensors survey co-ordinates, P-wave velocity model and noise characteristics. The results of micro seismic monitoring were presented to DGPCL management on 16th July 2009 with the clear information on strata behaviour during the monitoring period. The system responded well throughout the monitoring period for the micro cracking events and were recorded and observed that many of them were occurred very close to the sensors. It was also observed that the rock mass around the cavern displays seismically high attenuation characteristics due to fracturing in the immediate strata. Incidentally the rock bolt failure on 10th July 2009, on downstream wall (10RD, EL 519m) could also be detected from the recorded micro seismic data from the two sensors installed on the downstream wall. Based on the monitoring results, it was recommended to establish a full-fledged thirty six channels micro seismic/Acoustic emission network in the Power House cavern for long term monitoring to identify the high stress vulnerable (active) zones and to adopt suitable stabilizations measures at these locations.

2. Installation of nanoseismic/ micro seismic system:

The installation of micro seismic sensors network preparation work was started on 12th June 2009 by conducting survey for identifying ideal feasible locations to install the sensors. The locations for six drill holes of (49mm size) for installation of geophones were also decided. Single pair copper cable for extending Geophone's cable to reach GS stations after due estimation of distances from sensors to GS units(data acquisition units) were laid during 12-06-2009 to 19-6-2009. On 20-06-2009 six borehole geophones were installed in 49mm diameter and 1.3m long drilled boreholes on the upstream wall of machine hall and drainage gallery. The geophones were grouted with quick setting cement slurry in order to obtain better coupling with rockmass and given 24 hours for settling time. Figure -1 and Figure -2 show the borehole geophone and along with the borehole installation tool.

Figure 1 Borehole geophone

Figure 2 Borehole geophone with installation tool

On 21-06-2009 six surface geophones were installed by welding 100mmx100mm size of 6mm thick plate on selected 12m long rock bolts on the upstream and the downstream walls of machine hall as shown in Figure 3.

Figure 3 Surface Sensors mounted on 12m long rock bolts

On 21st June 2009 two data acquisition units (GS Units) were commissioned by interfacing the 12 geophones to two portable GS units (24 bit, 6 channel, >115 dynamic range, 10KHz sampling rate and flash drive data storage) and GPS timing unit for time synchronization. System was in observation for about 24 hours for setting optimum threshold levels to detect the micro seismic events/cracks from rockmass. Six short (1.3m) boreholes were drilled into this wall, four from the machine hall itself and two from the drainage gallery behind this wall. Into each of these holes a uni-axial Omni directional 14Hz geophone was permanently grouted. This method provides the best coupling between the rock and the sensors as seen in Figure 2. In addition to borehole geophones six surface-mount 14Hz uni-axial geophones were also used in this experiment. These sensors can be recovered, but do not have as good coupling to the rock. The sensor, as installed for this project, coupled to the rock mass beneath the 100mm shotcrete layer. Though not optimal in terms of resonance effects, this provided the maximum sensitivity to local signals. Two of the surface-mounted sensors were installed on the downstream wall of the machine hall to provide the micro seismic event release rate (ERR) only. Four surface sensors were installed on the upstream wall. The 14Hz geophones have a linear response to vibrations between 14 Hz and 2000 Hz, and were sampled at 6000 Hz by 2 GS seismic stations. This sampling rate provides a 2700 Hz bandwidth, which matches the sensor response. The two seismic stations were synchronized in time by a copper cable link and central time generator. Seismogram data was stored on USB memory disks for later retrieval and analysis. Figure 4 shows the locations of the geophones marked on the cavern 2D cross section and seismic stations.

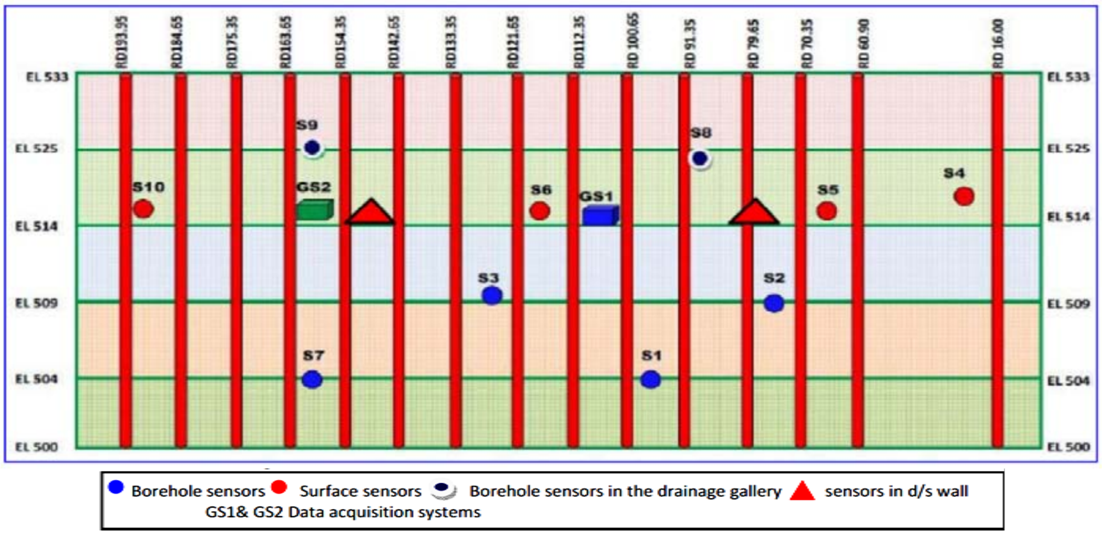

Figure 4 Sensors locations marked on the cross section of cavern

1.1 Signals Calibration and Velocity modeling:

After commissioning the 12 channel microseismic monitoring system, vibration signals were recorded by giving sledge hammer stampings on the upstream wall of the cavern. Based on observation of these recorded signals by hammer stampings needful improvements were incorporated in the instrumentation to ensure a good quality of data recording from all the 12 sensors. The same signals were also used to deduce the micro seismic signals velocity in the rock media. The seismic velocities were obtained as P-wave velocity V_P = 4500 m/s and S-wave velocity V_S = 2600 m/s. Figure-5 show the signatures of hammer stampings on the rock.

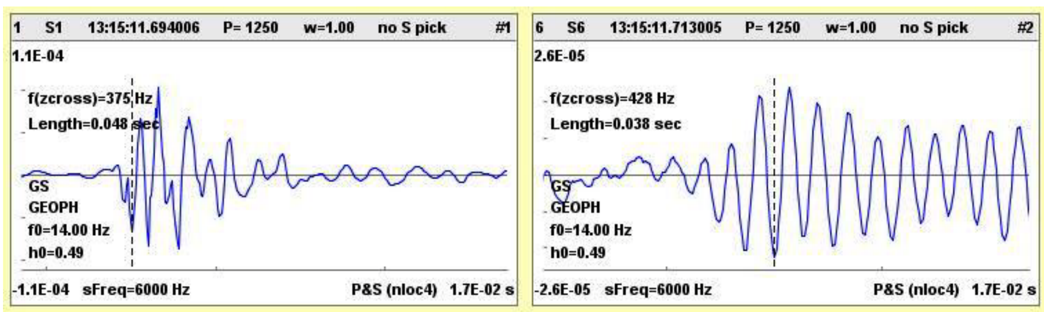

Figure 5 Seismograms of hammer strike recorded by Sensors S1 & S6

3. Data acquisition and data processing:

After the micro seismic monitoring system commissioned on 20th June 2009, the data recording was started from 21st June 2009 and continued up to 15th July 2009 almost without any interruption. Aapproximately 250,000 seismograms were recorded during the monitoring period. The majority of these events were found to be near to the noise levels and few were buried in noise, but there are quite good signatures of brittle fracturing recorded by two and more channels. A typical seismic signature of brittle fracture of strata is shown in Figure 6.

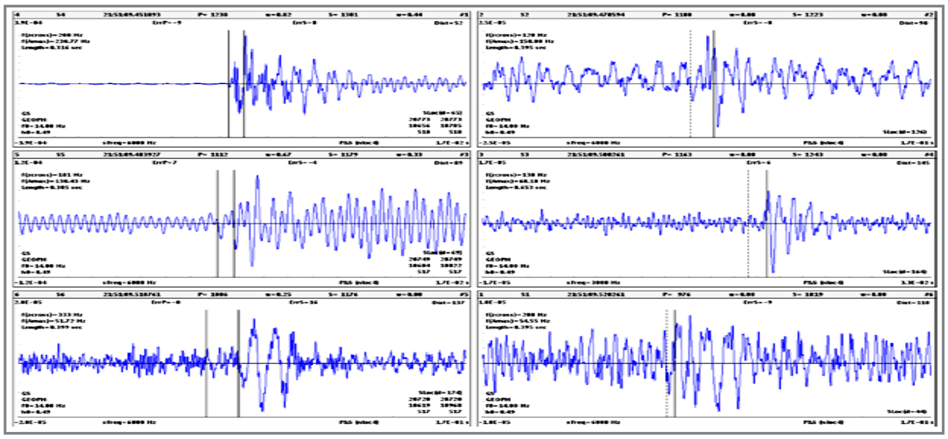

Figure 6 Micro seismic event recorded by S1.S2 &S3sensors

The environment around the power house was found to be rather noisy, with large amounts of electrical interference and machinery vibrations. This is expected in a large power generating stations. Figure-7 and figure-7a show the effectiveness of noise filters used to obtain the better signatures of micro seismic events.

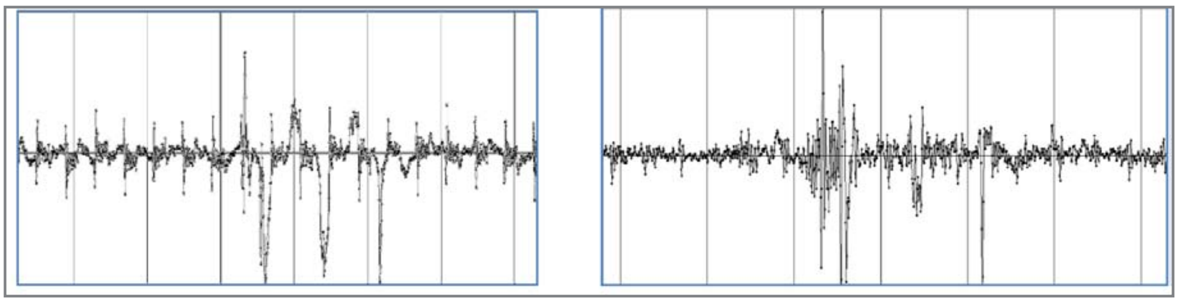

Figure 7 Micro seismic event buried in the noise Figure 7a the signal after filtering

4. Data analysis and interpretation:

The micro seismic data recorded was stored in the flash drive of data acquisition systems (GS Units). These flash drives have the capacity to record about one week data. These drives were brought to surface and analyzed using the JMTS, seismological processing software in offline. If the micro seismic signal is strong enough it will be picked up by more geophones in the network. Minimum four geophones are required to pick up the signal for computing its source parameters such as the source location, size of fracture, energy and stress drop etc. By continuous monitoring and recording of more number of micro seismic events, it is possible to get an idea of the high stress zone. In the present experiment the numbers of micro seismic events were not sufficient to compute the high stress zones precisely. With continuous and long time monitoring it is possible to identify the high stress zone on daily basis and thus it will help to correlate with roof bolt failure and take action in advance. Accordingly, suitable place for taking the safety measures in a phased manner (installing cable anchors etc.,) will be decided. Further remedial measures can be incorporated by redesigning the roof bolts length in the vicinity of high stress zone.

During the monitoring period, the network recorded four significant micro seismic events generated by fractures in the rock strata. For these events, source parameters were calculated. There are many clear micro seismic event signatures recorded by two or three sensors for which the source parameters were not calculated.

1.2 Significant micro seismic events:

During the monitoring period, four significant seismic events were recorded one on the 25thJune, 2009, two on the 30thJune 2009 and one on the 13thJuly 2009. These events were recorded by four or more geophones, and they could be located in 3-D space. All of the events were in the -0.4 to -0.1 magnitude range, with approximate source sizes of 12–30 m. Table-1 gives the details of the computed source parameters of four significant events recorded during the above monitoring.

Table1
Details of source parameters of significant events recorded

Sl No	Date & Time	Location (X;Y;Z) [m]	Local magnitude	Source Size[m]	Stress Drop [mpa]
1	25-06-09 21:51:51	20796;10682,490	-0.3	15-26	0.6
2	30-06-09 01:18:15	20683;10839;500	-0.1	--	--
3	30-06-09 13:11:26	20762;10738;548	-0.4	12-22	2.4
4	*13-07-09 23:52:01*	*20636;10765;438*	*-0.2*	*17-30*	*0.1*

The locations of the seismic events relative to the machine hall are shown in Figure-8. For this demonstration project, a homogeneous seismic velocity model was assumed and the location algorithm does not take the caverns themselves into account, and all seismic rays are assumed to be straight. In reality, seismic waves will not travel through the caverns, but will rather bend around them. This can be taken into account by constructing a 3D velocity model, setting the grid points within the cavern to velocities of air rather than rock. Seismic ray-tracing then provides more reliable locations for seismic events, and thus should be used for any future routine seismic monitoring at THP.

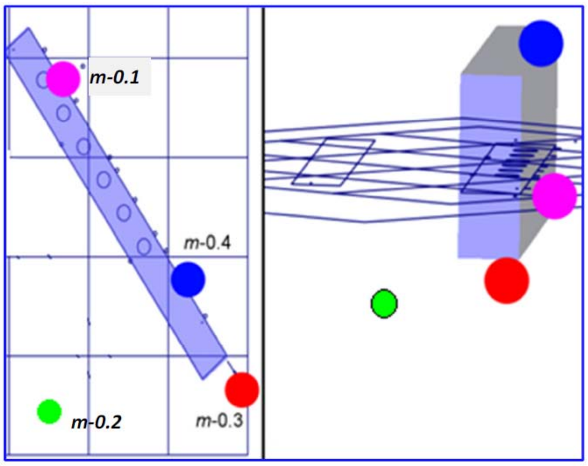

Figure- 8 Plan view (left) and oblique view from the direction of the tunnel entrance (right) showing the location of the four micro seismic events (colored dots) relative to the machine hall (blue block)

1.3 Rock bolt failure on 10th July 2009:

Incidentally there was a rock bolt failure on 10th July, 2009 on the downstream wall side. As can be seen during monitoring, the sensors S11 and S12 which were installed on the downstream wall side have recorded high micro seismic activity compared to the other sensors on the upstream wall side. The sensors S4, S1, S3 and S11 have recorded continuous constant fracturing due to their close proximity to highly stressed area of the cavern. The fracturing took place in the vicinity of the two sensors S11 and S12 was a clear indication of precursory signals recorded before the rock bolt failure. From the beginning of monitoring till 5th July, 2009 the high activity trend was observed around the sensors S11 and S12. After the high fracturing there is a sudden decrease in the activity from sensors S11 and S12 and it was attributed to relaxation of stress in the downstream wall from 6th July2009 to 10th July2009. This observed trend of increased ERR followed by lull period is a common phenomenon in underground structures before any instability condition. Hence the rock bolt failure on the downstream wall side on 10th July, 2009 has given a clear indication well in advance. This high activity in the close proximity of the two sensors clearly provided the precursory information of impending instability on the downstream wall side.

Overall high micro seismic activity that was observed during monitoring period by the sensors S11 and S12, also S10 (on upstream wall) showed active brittle fracturing in the downstream wall and in the extreme end of power house. The micro seismic experiment was discontinued on 15th July, 2009. It is expected from the analysis of the recorded data, that the fracturing trend will be continued further in the downstream wall, This may result as some more rock bolt failures in future in the bottom of downstream wall side in the vicinity of sensors S12 and S10. This has been confirmed from the information received from the Project authority of THP that there was one more rock bolt failure on the extreme end of cavern recently.

5. Conclusions:

In view of the rock bolts failure taking place on the upstream wall side of the Power House, NIRM was asked to demonstrate the application of micro seismic technique to understand the deformability process of strata. Accordingly 12 geophones (sensors) were installed on the upstream wall side (10 sensors) and two sensors on the downstream wall side. Majority of the micro seismic counts were picked up by one, two and three sensors of the network. Even in the noisy environment good quality micro cracking signals were recorded. Four significant micro seismic events were picked up by more than four sensors. Out of these four events, three events were from upstream wall side and one event was from the downstream wall side. For these four events the source parameters such as source location, magnitude, source size and stress drop were computed. With more number of such events in a course of time it is possible to identify precisely the high stress zone locations. In the present case the majority of the micro seismic events were picked up by less than four sensors, hence these signals are considered for computing the microseismic event release rate (ERR) only, which enabled to know the fracturing trend in the close vicinity of sensors. The number of such micro seismic counts was plotted against the sensor. It was found that starting from the beginning of monitoring the sensors S11 and S12 from the downstream wall side, showed increasing trend compared to other sensors on the upstream wall side, indicating high activity or fracturing taking place on the downstream wall side. Thus the high stress zone was identified in the downstream wall side and incidentally there was a rock bolt failure on 10^{th} July 2009 on the downstream wall side which has been correlated. From the micro seismic monitoring setup it was found that the high micro seismic activity trend upto 5^{th} July 2009 indicating fracturing process taken place in the vicinity of sensors S11 and S12 and relaxation of stress has taken place from the 6^{th} July,2009.

Despite with only two sensors installed on the downstream wall, the micro seismic monitoring system for a short period has successfully recorded and detected the high stress zone, which ultimately resulted in rock bolt failure. More vital and detailed information is certainly possible with more number of sensors (Dense network) in the full pledged continuous real time micro seismic monitoring system.

The micro seismic experiment carried out from 10^{th} June to 16^{th} July 2009 at the THP power house cavern has successfully demonstrated the capability of micro seismic technology by detecting the micro cracking/fracturing and evaluated stress pattern surrounding rock mass in addressing the stability of underground structures. Thus, the micro seismic technology experimented for short period has fulfilled its objectives and certainly has many advantages for long term cavern monitoring.

Micro seismic monitoring would answer the following questions:

1. Is the rock cracking close to the surface of the cavern or deep in the wall?
2. How does this change with time? Is the rate of fracturing increasing, or decreasing?
3. Where are the high and low stress zones? Are they changing in time?

Advantages and Benefits micro seismic monitoring system:

1. Overall continuous strata stability surveillance of the structure for its life time in real time
2. Any movements from deep strata (ie. 30-50 m outside of walls) can be ascertained in advance
3. Localised stress zones information and changes can be obtained in real time to adopt phased manner extra support system at right location and at right time
4. Performance of safety measures taken can be studied

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