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Stability Analysis of the Underground Powerhouse in the Himalayan Region using Micro-seismic Monitoring

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ABSTRACT

The powerhouse of Tala Hydropower Plant (THP) of Druk Green Power Corporation (DGPC) Ltd. having installed capacity of 1020 MW is adjacent to the Main Central Thrust (MCT) and Main Boundary Thrust (MBT). The project area is located at 3.0 km south to Chukka city of Bhutan at an average depth of +500.0 m having adverse geological conditions and falls either in seismic zone IV or V if one extends the seismic zonation map of India. THP underground powerhouse cavern encounters a number of rock mechanics challenges. THP powerhouse has been experiencing many incidents of strata instabilities during and post-construction such as rock mass failures and rock bolt ejection. Three percent of rock bolts have been ejected till 2017 from various places in the transformer hall, machine hall and other locations in the powerhouse from the sidewall in a ferocious way. This paper discusses the application of micro-seismic monitoring technique after excavation in rock to analyse the stability issue and rock bolts ejection in the powerhouse. A thirty sensor micro-seismic network has been installed at powerhouse to study the strata condition and ejection of rock bolts. The real time online micro-seismic monitoring system consists of a three-dimensional array of sensors, data acquisition unit, cable layout and an underground laboratory equipped with communication equipment and various micro-seismic software. The study of the spatial and temporal variations of the micro-seismic events and its source parameters is correlated to understand the strata behaviour of the powerhouse and rock bolts failure mechanism.

Keywords: Micro-seismic monitoring; Micro-seismic software; Rock bolts ejection; Stability; THP; Underground powerhouse.

1. INTRODUCTION

Tala Hydropower Plant of Druk Green Power Corporation Ltd. (DGPC) located in Chukka, Bhutan is at a depth of about 500.0 m having capacity of 1020.0 MW. The project area falls in Seismic zone IV or V (Timothy et al., 2016) close to the Main Central Thrust (MCT) and Main Boundary Thrust (MBT). This project has encountered a number of rock engineering problems since its start to post-construction which has been continuing till now. There is always a threat to stability of any structure in the Himalayan region. The stress level generally increases with the start of construction in the rock mass that may concentrate around the openings of caverns that may result in numerous instabilities. Therefore, there is a need to continuously monitor and analyse the stress level in different areas, displacements at various depths and load on supporting structures to understand the mechanism of instabilities. National Institute of Rock Mechanics (NIRM) and DGPC installed a thirty-station micro-seismic monitoring system in the cavern of THP powerhouse manufactured by Institute of Mines Seismology (IMS), Australia to understand the powerhouse stability status.

The micro-seismic monitoring technique was applied to predict stability in the underground openings (Obert & Duvall, 1957) of mines in USA. This method has also been used in numerous hydropower projects in China for Rockburst predictions in tunnelling in China (Tang et al., 2010) and in Tapovan Vishnugad Hydroelectric power project, Joshimath, India for the stability analysis of underground powerhouse (Vikalp et al., 2016) post construction.

Micro-seismic monitoring system at the THP powerhouse was established in 2013 with the objective to study the strata behaviour in real time, address the strata stability around the powerhouse caverns and to find out the reason of rock bolts failure (Sivakumar et al., 2015). Waveforms have been continuously recorded on Central Desktop Runtime System (CDRS), auto processed and micro-seismic activity is displayed in real time in the powerhouse. Further, the offline data processing units at the NIRM, Bangalore, India access the data in near real time for detailed data processing, analysis and interpretation.

The system records waveforms mainly consisting of body and surface waves of various amplitudes and frequencies. These waveforms have been studied to find out the micro-seismic signals. The spatial and temporal variations of the micro-seismic events have been mapped on the powerhouse cavern to observe the rock mass conditions by studying the parameters like energy index, apparent stress, cumulative apparent volume, activity rate, displacement and various other parameters (Mendecki et al, 1999; Lynch and Mendecki, 2001). The present work has been used to study the strata behaviour using micro-seismic monitoring system of the underground powerhouse cavern. Micro-seismic events have been observed and attempted to correlate it with the rock bolt failures and the cavern stability.

2. MICRO-SEISMIC MONITORING SYSTEM AT THP

THP powerhouse consists of following major components: Machine Hall (206.4 m x 20.4 m x 44.6 m), Transformer Hall (191 m x 16 m x 26.5 m), three Bus Ducts, and Drainage Gallery at the top of the cavern as shown in Fig. 1.

Reconnaissance survey at the powerhouse site was conducted for sensor locations, media attenuation characteristics, wave velocities (P and S) and various noise sources (Sivakumar et al., 2011). Using this data, an optimal configuration of three dimensional network of sensors was designed to record all the micro-seismic events generated in and around the powerhouse.

The micro-seismic monitoring system installed into the powerhouse consists mainly of thirty geophones, eight data acquisition units, central communication hub and central data recording server (CDRS) with duplex communication (Fig. 2). The CDRS acquires and stores the micro-seismic events in triggered mode and displays the online processed data results in real time and the same provides the data to different laboratories using VPN connection.

Figure 3 demonstrates the 3D visualization of installed geophone at different locations in the powerhouse. The axes enable the user to get an idea of the orientation of objects in the 3D viewer: The red arrow points South, the green arrow West and the blue arrow downwards. All the micro-seismic events within the powerhouse and its surroundings have been recorded and processed to analyse the stability and rock bolt failure mechanism.

This provides information about the rock mass stability of the powerhouse and its surroundings over space and time. This high resolution micro-seismic network provides estimation of seismic parameters like stiffness, viscosity, relaxation time etc. for the precursory behaviour of any instabilities of the strata.

Figure 4 shows an example of the typical micro-seismic signal recorded by the THP system. This micro-seismic event is recorded by twelve stations. Figures 5 and 6 show the source location and source parameters of the same micro-seismic event respectively.

3. DATA PROCESSING AND ANALYSIS (JAN-DEC 2016)

The present work discusses the signals recorded during the year 2016. A large number of induced triggering have been recorded in 2016 (1 Jan-31 Dec). The chief source of coherent noise at the THP site are local earthquakes, compressor signal, noise from electric circuit breaker and source of incoherent noises include vehicular movement and human activity at the site. The pattern of coherent noises has been evaluated periodically and such waveforms have been eliminated during data processing where only 257 triggers have high signal to noise ratio (S/N). These 257 events have been mapped on the 3D diagram of the THP powerhouse (Fig. 7).The cluster of events have been encircled. These events have been processed in detail and analysed further for the spatial and temporal variations.

The recorded micro-seismic events have the local magnitudes ranging from -3.4 to -0.4. The moment magnitude log N_m of the micro-seismic events are in the range 6.9 to 10.5. Similarly, the radiated energy of the micro-seismic events during this period are ranging between 0.02 J and 3150.0 J. Figures 8 and 9 illustrate the temporal variations of activity with energy index (EI) and cumulative apparent volume (CAV) with EI respectively. In Fig. 8, as the log (EI) drops down, it has been encircled and data was further investigated to observe the changes in the cumulative apparent volume. Rock mass failure (large seismic event) may occur as log EI decreases and CAV increases (Mendecki et al., 2010). But, there is no significant increase/change in CAV. So, no rock mass failure results in the powerhouse.

4. STRATA CONDITION OF THP POWERHOUSE CAVERN

The acquired data has been validated, processed and analysed for the instability indicators of the powerhouse strata by the temporal and spatial analysis of the source parameters of the events. The apparent stress and displacement contour have been plotted as shown in Figs. 10 and 11 respectively. The area around bus ducts 2 and 3 may have potential stress pockets as demonstrated.

Figure 12 shows the cumulative frequency of events-magnitude graph which states that the hazard probability of any big event is not expected. The probable chance of estimated seismic hazard is 1.30 and probability of event of magnitude of 0.1 is one in a year.

Relative displacement of order 1.00 mm has been found from the 3rd bus duct to machine hall end. The stress drop and stress changes are in negligible range. Minor stress was observed between bus ducts 2 to transformer hall as depicted in Fig. 10. Micro-seismic activity concentrated in following four locations in the powerhouse with minor clusters: (i) at the cable tunnel and transformer hall junction (Feb-Mar), (ii) GIS chamber end close to sensor number GIS2 (Apr-May), (iii) at the bottom of bus duct 3 (July) and (iv) in bus duct 1 towards connecting tunnel (Sept-Oct). But none of these clusters converted into the rock failure. Thus, the cavern strata appears to be stable.

5. CORRELATING ROCK BOLTS FAILURE WITH MICRO-SEISMIC ACTIVITY

Table 1 gives the details of rock bolt failure occurrences during the micro-seismic monitoring period of the powerhouse in 2016. Every failure of rock bolt produces waveform signature.

Table 1 - Details of the rock bolts ejected

Date	Time (Hr. Min)	Ejected Rock bolt length (mm)	Rock bolt location
04.01.2016	05.06	1000	IT store room EMU/AMU
20.04.2016	11.45	2500	Incoming bay III & IV, above EOT crane GIS
04.06.2016	03.30	1500	Between RD 164-175m upstream wall of the machine hall
17.07.2016	11.30	1000	Near UAB panel unit no 01 at 509.m E.L
06.08.2016	16.11	6400	Above turbine pit unit no 02 at EL 523.5m,RD 97.3m
12.09.2016	17.10	3620	Upstream wall of machine hall at EL 531.95 above the crane rail
19.10.2016	10.59	670	Downstream wall of Machine hall EL 523m,RD 97.65m
31.12.2016	11.13	1400	Machine hall upstream wall EL 520m,RD 65.65m

The Powerhouse has been facing the problem of rock bolts ejection before operation. The exact cause of this problem is yet to be identified. The micro-seismic monitoring method has attempted to find out the correlation between rock bolts ejection and strata instability using accumulation of micro-seismic events. More than 200 rock bolts have failed till now in different areas of the powerhouse. Eight rock bolts have been ejected in 2016 and these rock bolts failure have been correlated with micro-seismic activity. There is no precursory information in the form of micro-seismic event rate (Sivkumar and Vikalp, 2017).

Figure 13 shows the waveform of one rock bolt failure on 4 June 2016, which ejected about 1.5 m from the upstream wall of the machine hall. Figures 14 and 15 show the location of the rock bolt failure and source parameters respectively.

6. RESULTS AND CONCLUSIONS

Out of all the waveforms recorded, only 257 waveforms have high S/N. There are accumulations of micro-seismic events at few places but that have not been converted into rock mass failures as the rate of events and number of micro-seismic events are not high. The strata of the powerhouse appears to be stable on the basis of micro-seismic source parameters evaluation and no prior information is generating before the rock bolt failure.

All the rock bolts failure instances have been correlated and back analysis with micro-seismic data has been done to study the precursory phenomenon and to identify seismic source parameter variations. There are signatures of metallic failure of the order of KHz but those signatures are not in the range of micro-seismic emission. So, micro-seismic method may not evaluate it. There may be presence of local faults close to the powerhouse. So, a detailed investigation comprising a team of geophysicist, geologist and civil engineers is further required in the powerhouse region to study the reasons behind the rock bolts failure.

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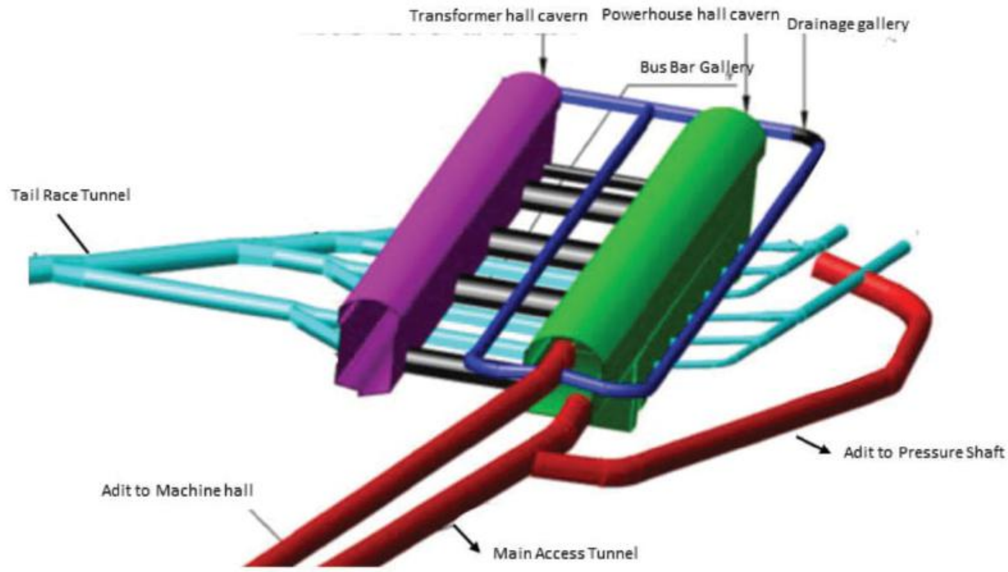

Fig. 1 - Three dimensional view of abutments of powerhouse

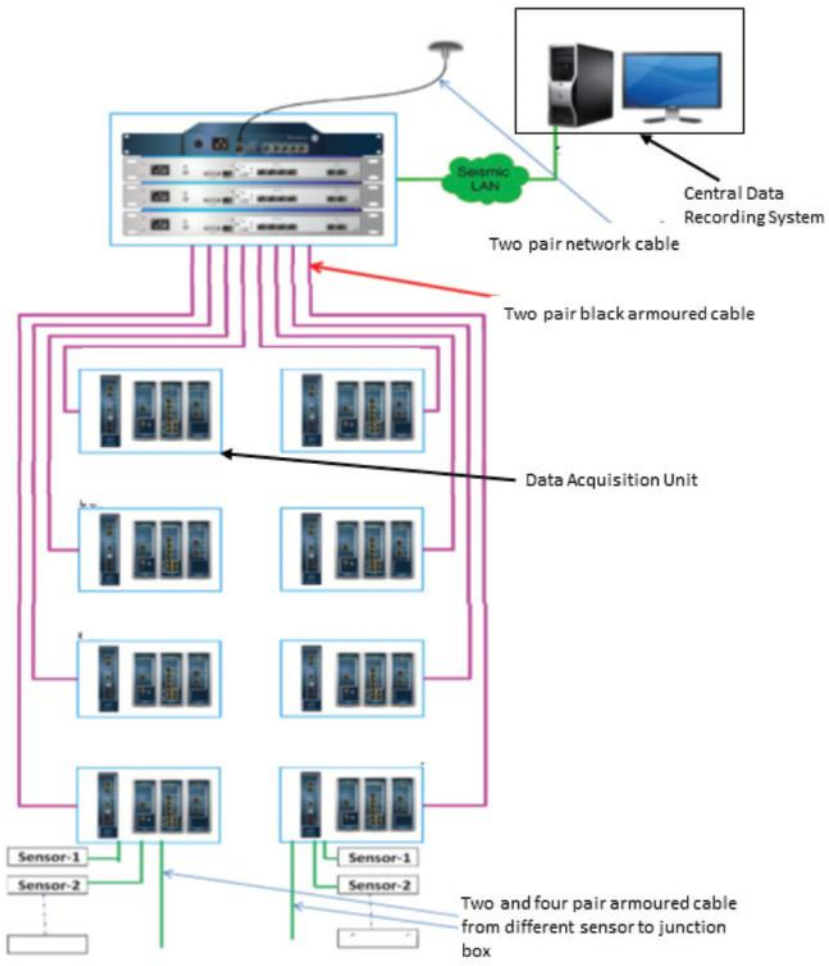

Fig. 2 - Micro-seismic Monitoring system layout at THP

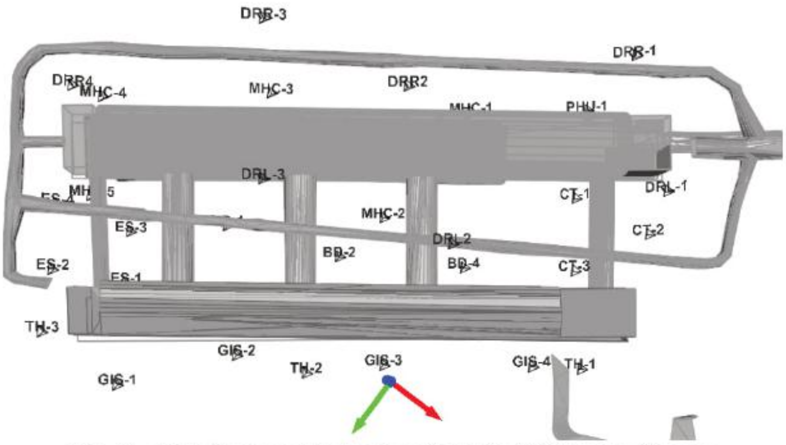

Fig. 3 - Installed geophone locations in THP powerhouse

Fig. 4 - Typical micro-seismic event recorded

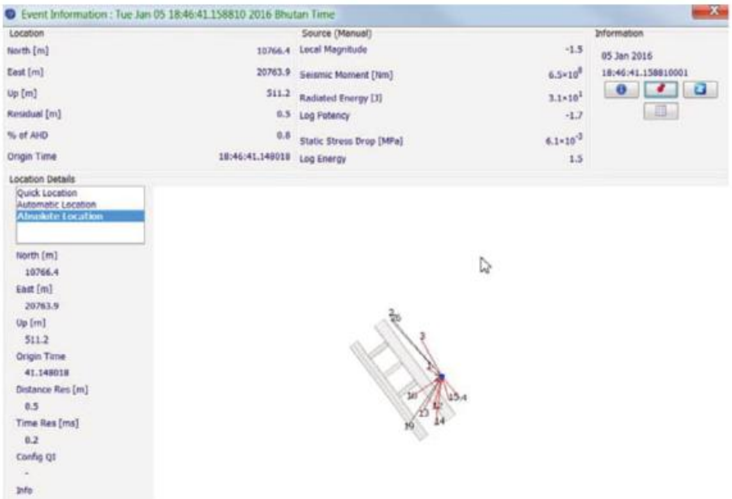

Fig. 5 - Source location of the micro-seismic event

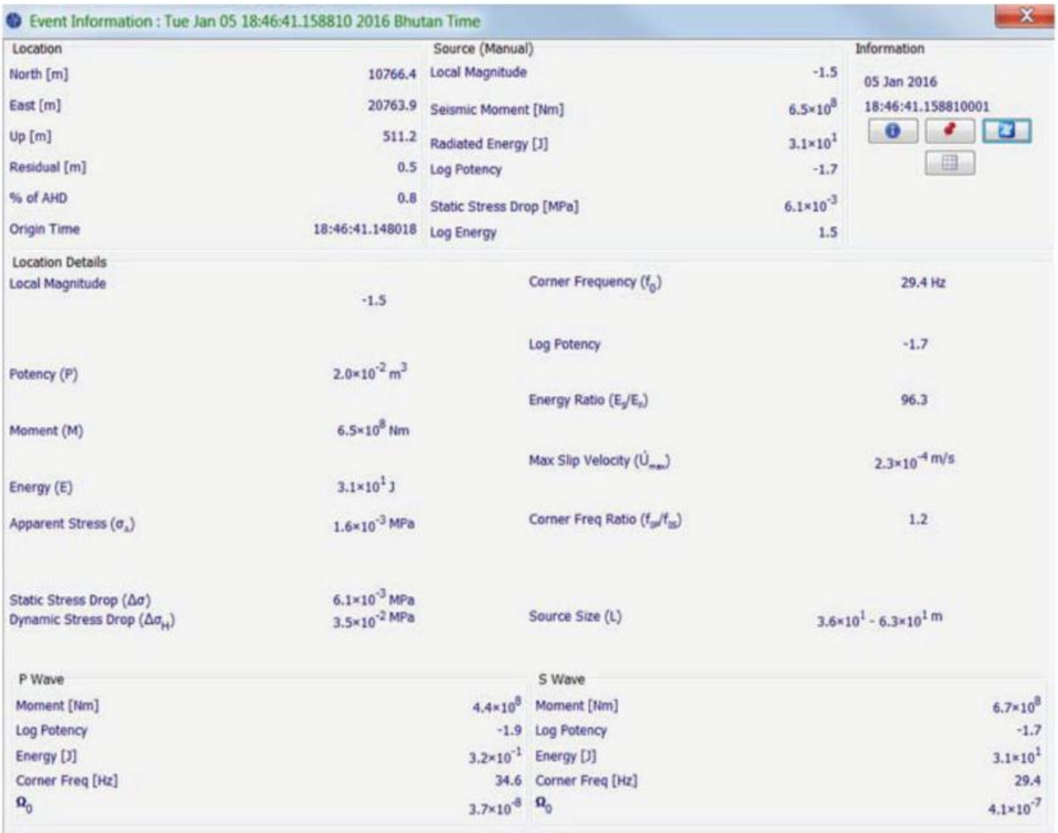

Fig. 6 - Source parameters of the micro-seismic event

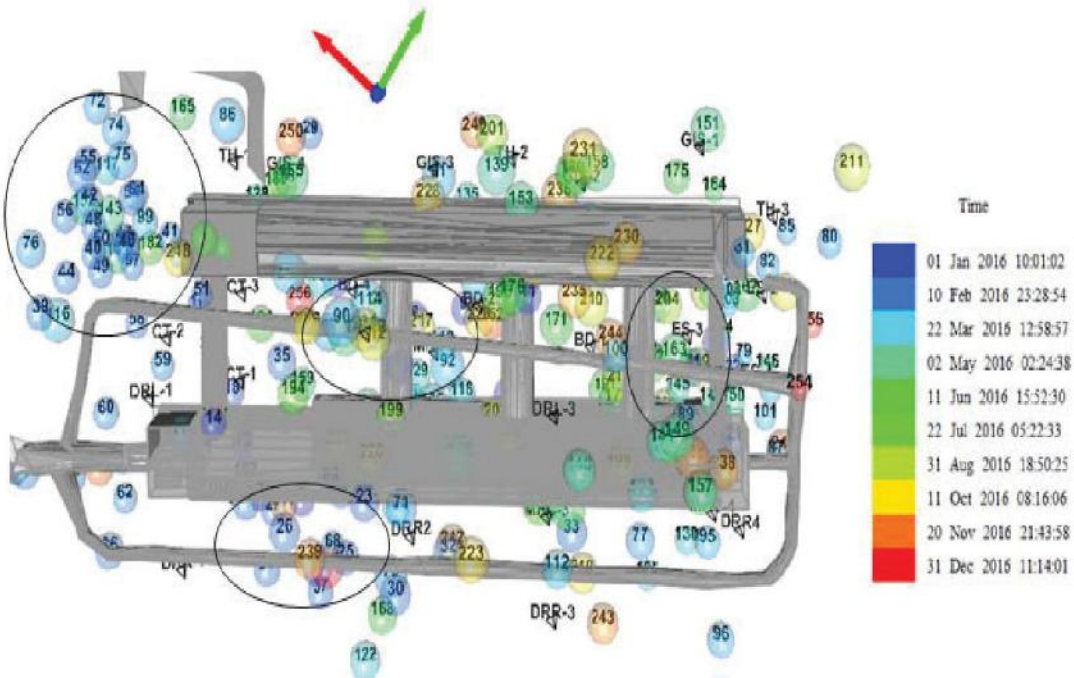

Fig. 7 - Mapped micro-seismic events on 3D powerhouse cavern

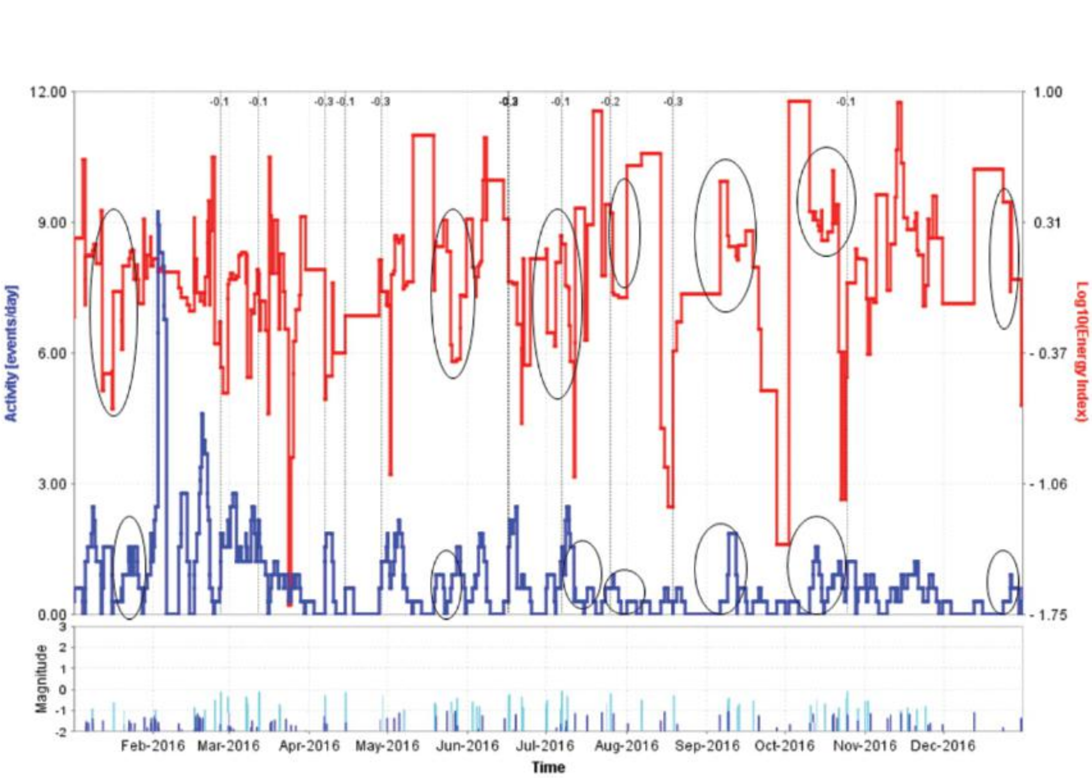

Fig. 8 - Temporal variation of activity vs log energy index

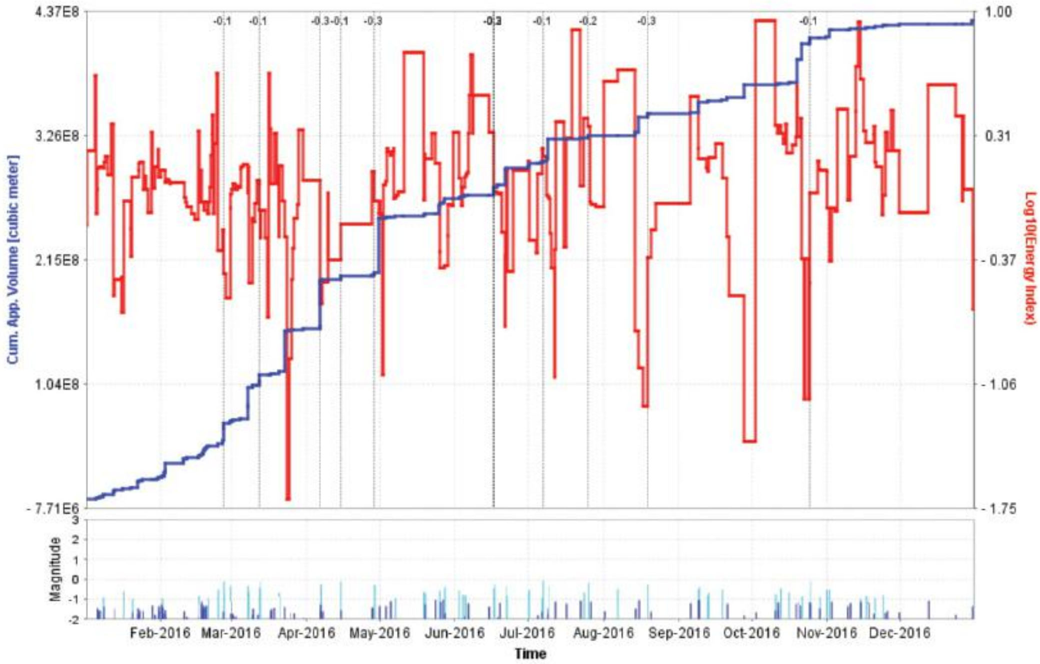

Fig. 9 - Temporal variation of CAV vs Log EI

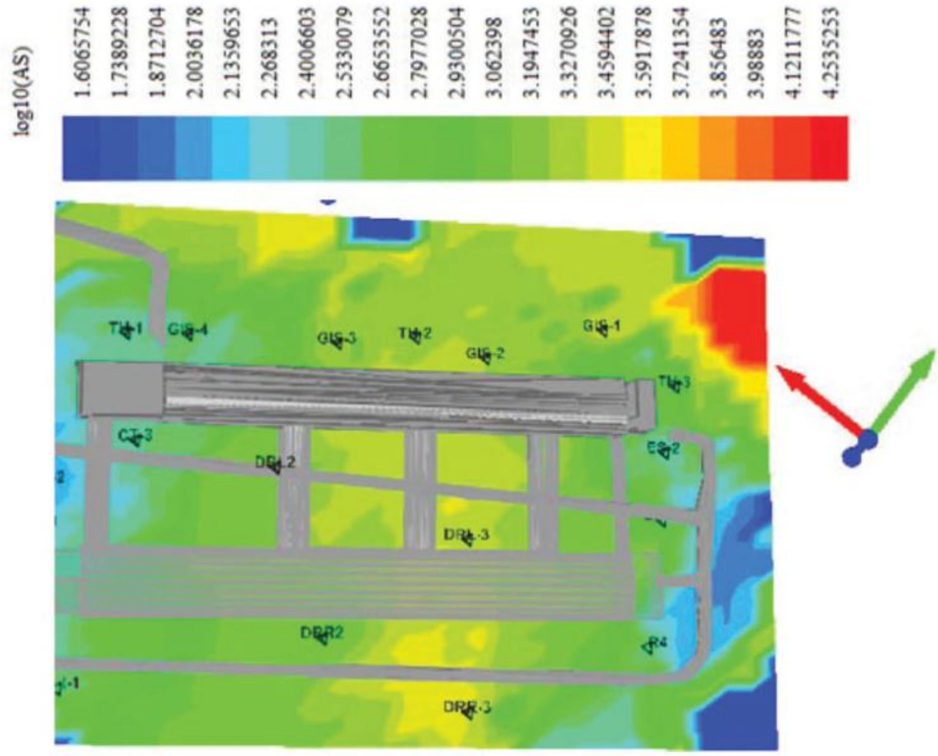

Fig. 10 - Apparent stress contour

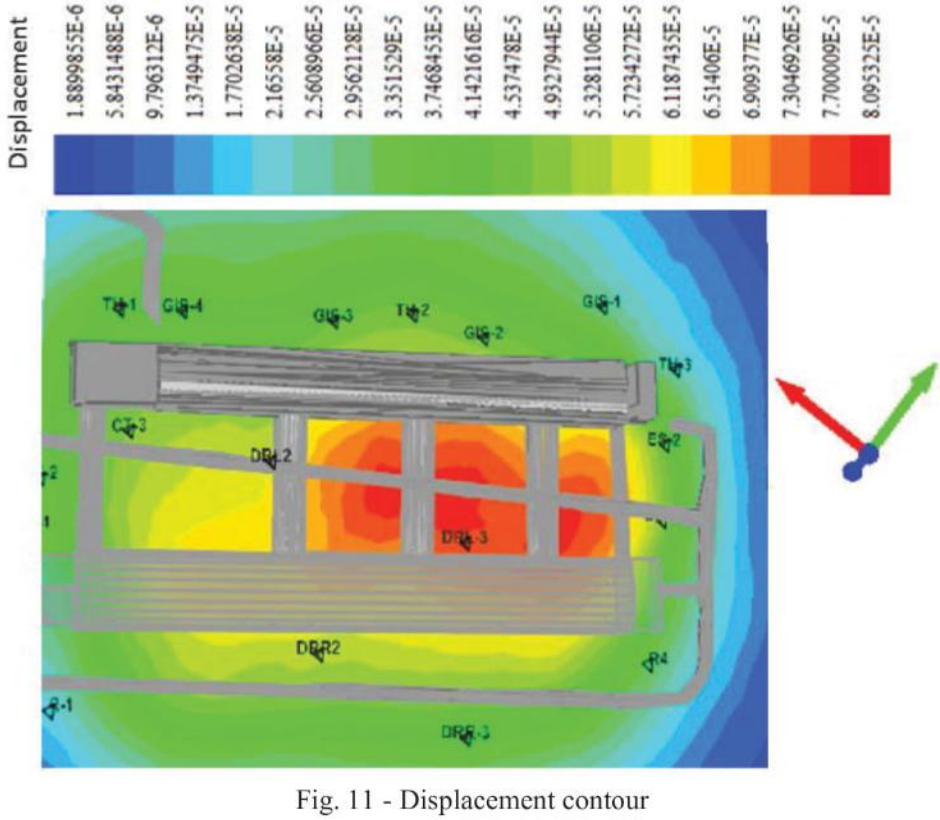

Fig. 11 - Displacement contour

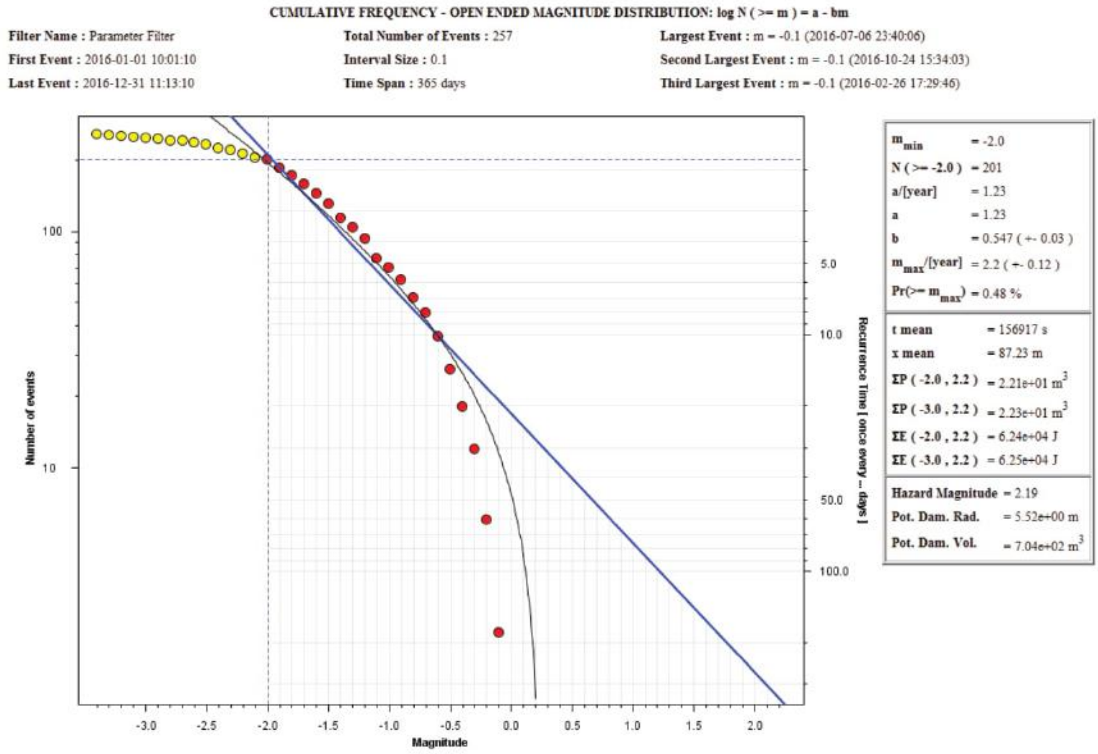

Fig. 12 - Gutenberg Richter relationship

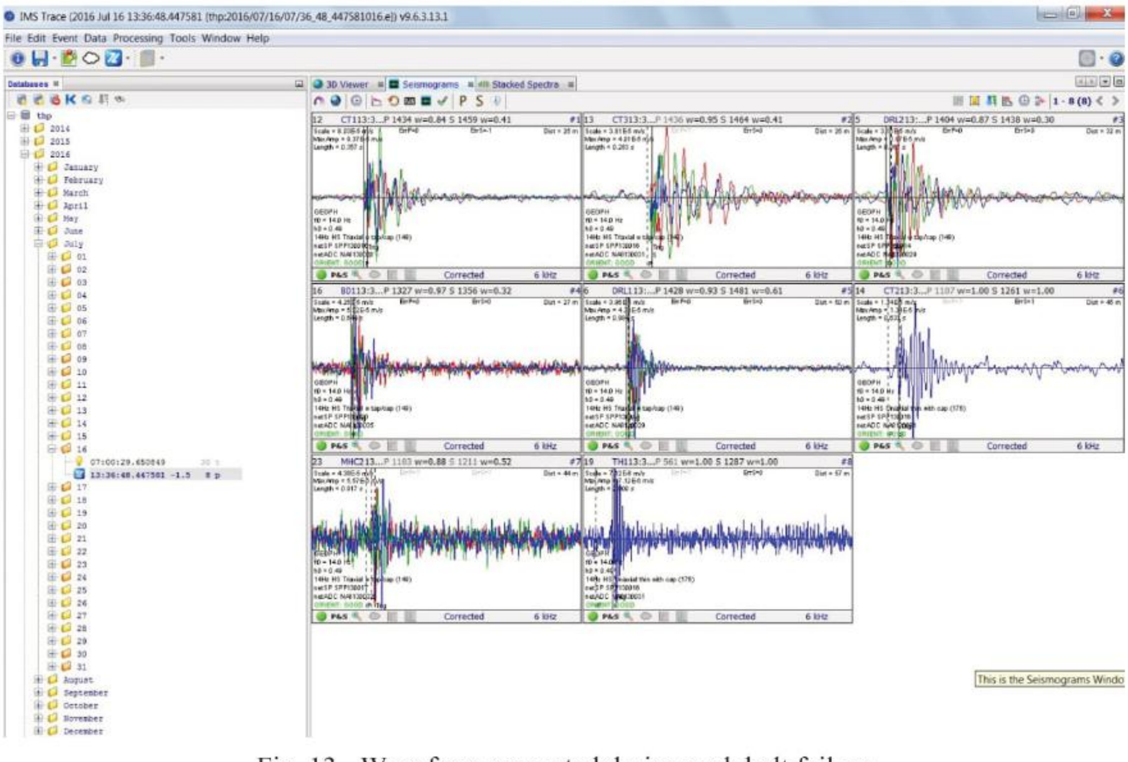

Fig. 13 - Waveform generated during rock bolt failure

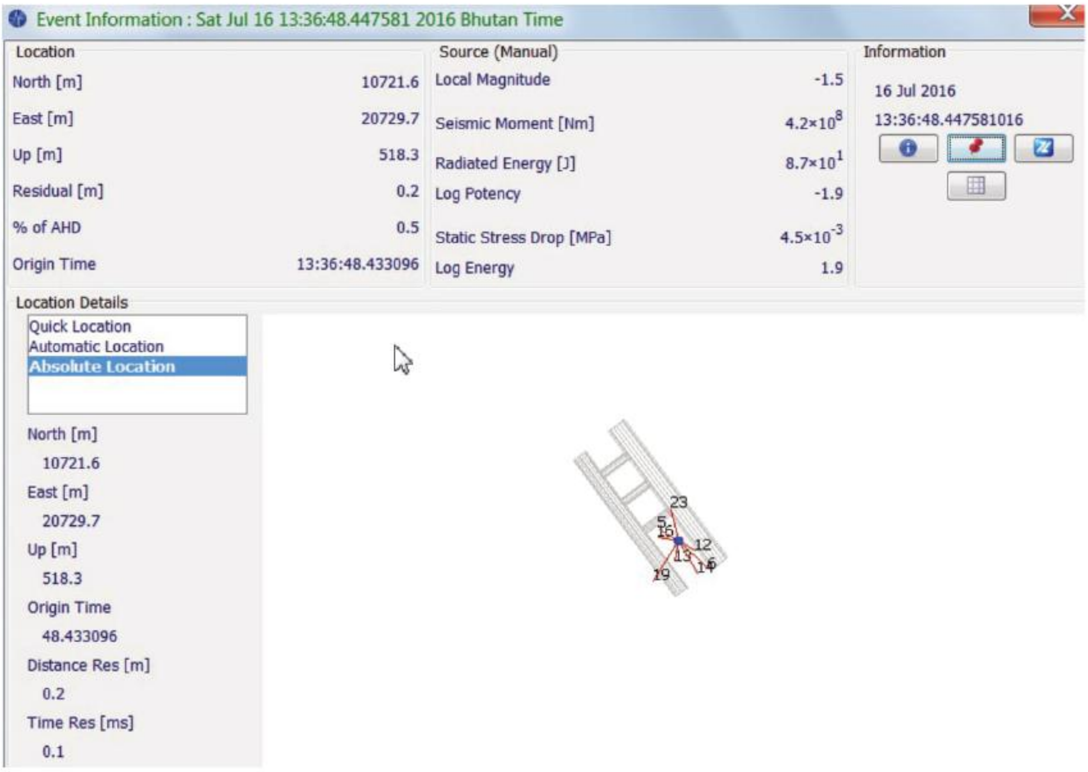

Fig. 14 - Source location of the rock bolt failure

Fig. 15 - Source parameter of the rock bolt failure