Support performance control in large underground caverns using instrumentation and field monitoring

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ABSTRACT: A careful monitoring program at Masjed Soleiman underground powerhouse enabled determination of hazardous areas around the main cavern and was used as a controlling tool to check the adequacy of a new support program. Preliminary support design in centerline and downstream side of the powerhouse cavern showed to be not enough to maintain the integrity and stability of the rock mass. The adequacy of the additional ground anchors was proved by recording a decreasing trend in rock mass displacements using monitoring instruments. The upstream side did not require further support according to the monitoring results but was additionally supported for higher safety factor. The powerhouse cavern and other peripheral excavations are now finished and final concrete structure is under execution. The installation of the power generator units will finish by the end of year 2004.

1 INTRODUCTION

Most of underground structures are built in grounds where without some means of improvement can not maintain their stability. These reinforcement operations range widely from compaction, drainage and grouting of soft soils to installation of fully grouted bolts and applying shotcrete in jointed and blocky rock masses. The amount of ground improvement measures which is really adequate for each job is a challenging question in front of the engineers. A heavy reinforcing system can assure safety but is often not economical. On the other hand, insufficient measures will not assure the safety of the structures therefore having an accurate ground improvement program always is a question to be answered.

In recent decades with advances in other branches of science and technology, specially electronics and mechanics, very accurate instruments are developed which are frequently used in geomechnical projects. These instruments have helped a lot to determine the exact performance of the surface and underground structures as well as the reinforcement and improvement aids. With continuous monitoring of the whole system, one can pin point the problematic locations and quantitatively determine the sufficient improvement measures to provide the required safety factor.

This paper has focused on an example of underground hydroelectric power plant project in Iran which has benefited from a careful monitoring program. This will show how a continuous interaction between obtained data from the monitoring team and prompt response by the engineering and contractor teams have helped to overcome some instability problems by applying an economical reinforcing program.

2 MASJED-SOLEIMAN HYDROELECTRIC POWER PLANT

Masjed-Soleiman Hydroelectric Power Plant (HEPP) is built in two phases with total capacity of 2000MW on Karun River in Iran. The rock mass consists of compact Conglomerates, Siltstone, Sandstone and Claystone layers crossed by widely spaced joints. The dimensions of the powerhouse cavern are 266m in length, 30m in width and 50m in height. Transformer cavern is located to the right side of the powerhouse cavern at a higher elevation as shown in figure 1. The layers dip at about 25 degrees towards the upstream side. Day lighting Claystone in the roof and the walls of the caverns with low frictional and mechanical properties has resulted in some instability problems.

3 GEOMECHANICAL PROPERTIES OF THE ROCK MASS

Based on laboratory and field tests performed the following parameters are reported by Stabel (2002).

Low mechanical properties of the Claystone rock especially when absorbing water results in further drop in the values and results in instability at the roof.

Table 1: Rock type and its mechanical properties.

	Conglomerate	Sandstone	Claystone
Young's Modulus (MPa)	15	7	6
Poisson's ratio	0.2	0.2	0.25
Cohesion (MPa)	2.28	1.67	0.73
Friction Angle (Degree)	43	38	30

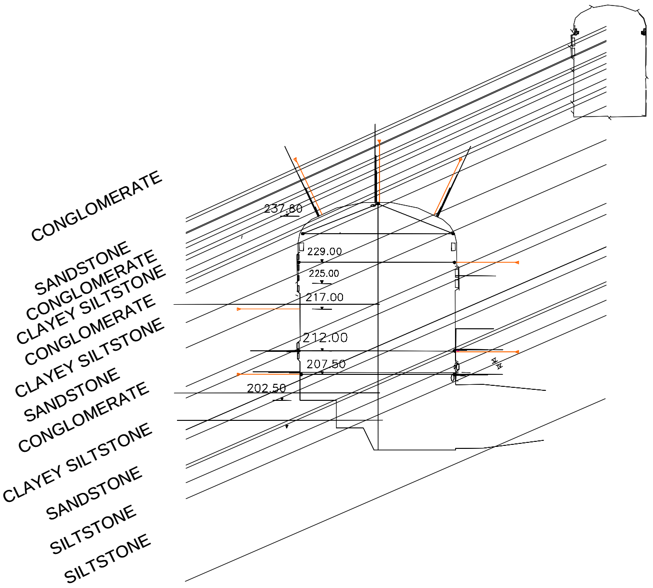

Figure 1. Underground power station scheme and rock mass structure.

Excessive rock mass displacement which causes shotcrete cracking and bolt failure could be seen in some parts of the roof especially in the centerline and downstream side of the powerhouse cavern.

4 MONITORING PROGRAM IN THE PROJECT

To control the stability of the structure while excavating the caverns in stages, a comprehensive instrumentation program was proposed and implemented for the caverns which consisted of 200 instruments including borehole extensometers, load cells and pressure cells distributed in the caverns according to tables 2 and 3.

Some of the monitoring results are depicted in figures 2-4. The upper graph is rock mass displacement recorded by borehole extensometer, the lower graph is the corresponding load cell results with time. As shown in figure 2, which corresponds to monitoring station at chainage 21 at downstream, the rock mass has kept moving although the reinforcement program had fully been applied according to the initial design. This is also the case for chainage 71, centerline as shown in figure 3. As noted in figure 1, this extra amount of rock movement in downstream is due to the presence of soft Claystone layer with potential of swelling. However, at the upstream side and to some extends, at the centerline, the rock mass movement is much less and in many cases the rock has stopped moving after a while. Such an example is depicted in figure 4 for chainage 71, upstream side.

Table 2: Monitoring stations at phase 2 of the powerhouse and transformer caverns.

Chainage of the monitoring stations (measured from the beginning of the cavern)						
Powerhouse cavern	8	25	43	75	93	107
Transformer cavern	0	28	58	78	100	110

Table 3: Type of instruments in the powerhouse and transformer caverns.

Instrument type
4 point, 30m/15m long borehole extensometers, 50 t and 200 t load cells and 2 MPa pressure cells
4 point, 15m long borehole extensometers, 50 t load cells and 2 MPa pressure cells

Increasing trend of the rock movement has resulted in an increasing trend of load in the load cells. At a stage, the load in the bolts had increased to a level very close to the yield capacity of the bolts. The bolt containing this load cell was unloaded and the load cell was installed again to be able to detect further increase in bolt load. This increasing trend of displacement and load in centerline and downstream side together with a local rock fall alarmed the engineer that more support pressure than what was anticipated earlier is required to assure long term stability of the cavern.

The additional support program consisted of 15 and 20 meters long tendons (Double Corrosion Protected, DCP) with 60 ton working capacity. This system was gradually applied to the whole roof of the powerhouse cavern as shown in figure 5.

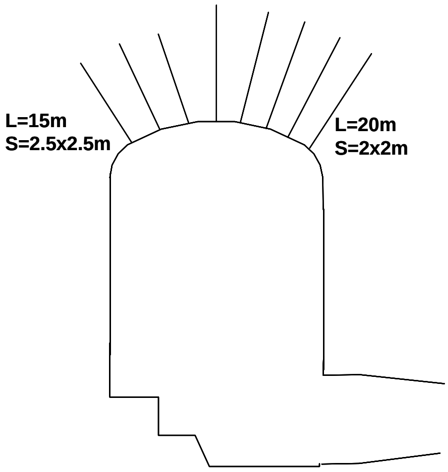

Figure 5: Additional support scheme.

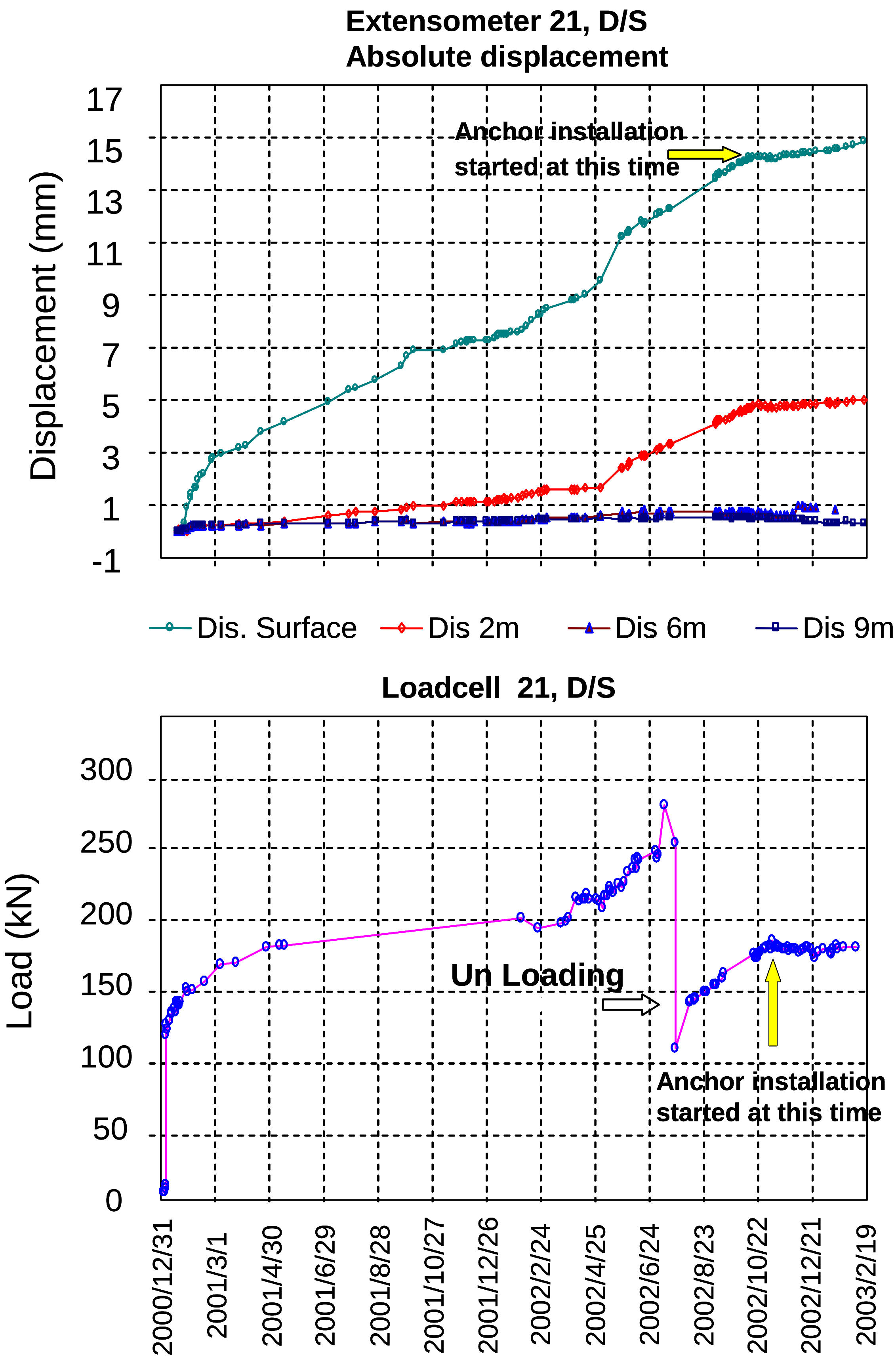

Figure 2. Displacement (upper) and load increase (lower) at chainage 21m, downstream.

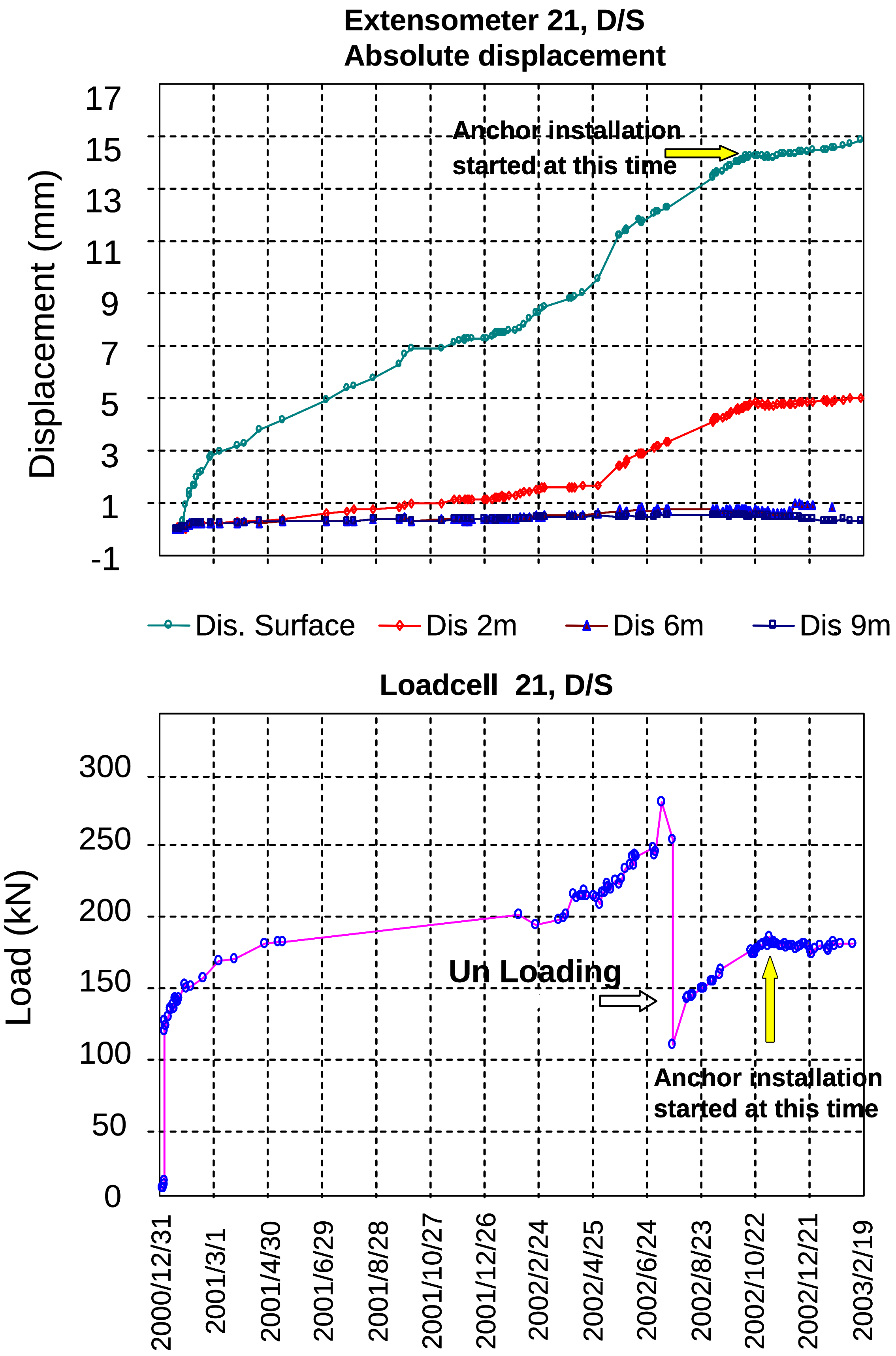

Figure 3. Displacement (upper) and load increase (lower) at chainage 71m, centerline.

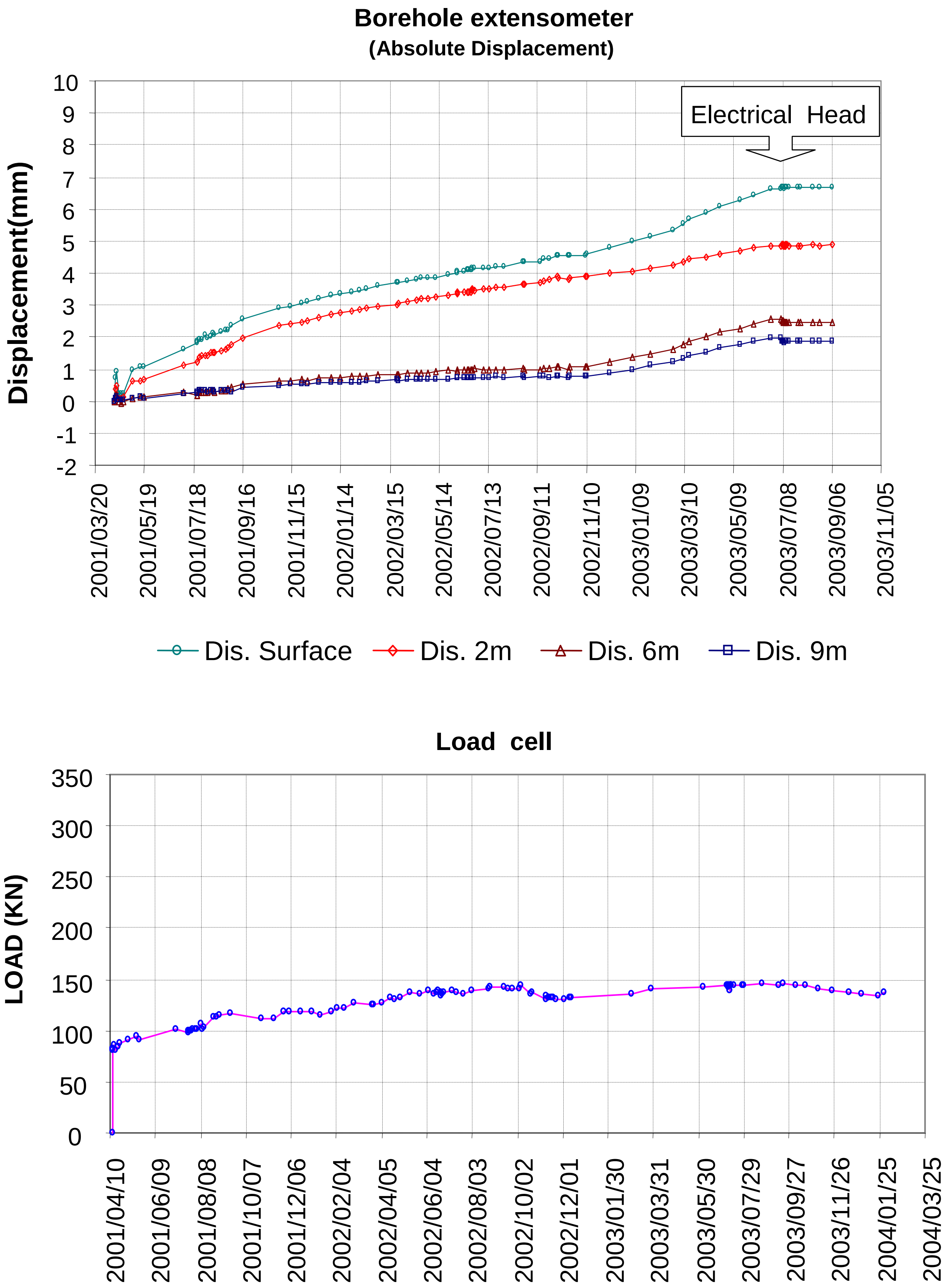

Figure 4. Displacement (upper) and load increase (lower) at chainage 71m, upstream.

Start and the end of ground anchor installation in the vicinity of the extensometer at chainages 21m and 71m are shown by arrows on the previous figures. This remedial work stopped the increasing trend of rock movement gradually according to these figures. What happened at the roof in terms of rock pressure and reinforcement pressure is summarized in table 4. To calculate the roof and support pressure, the suggestions of Barton (1974) and Hoek (1999) are used respectively.

Table 4: Summary of the roof and support pressure before and after additional reinforcement.

Reinforcement system in the powerhouse cavern		Roof pressure (by Q)	Reinforcement pressure (MPa)	
			Before additional support	After additional support
Powerhouse cavern	**D/S-** ϕ 28mm, L=6 &12 m, spacing 1.75x1.75, Tendon ϕ 40mm, L=20m and 2x2m spacing	0.225	0.192	0.288
	C/L- ϕ 28mm, L=6 &12 m, spacing 1.75x1.75, Tendon ϕ 40mm, L=20m and 2x2m spacing	0.225	0.192	0.288
	U/S- ϕ 28mm, L=6 &12 m, spacing 1.75x1.75, Tendon ϕ 40mm, L=15m and 2.5x2.5m spacing	0.05	0.192	0.253
Transformer	ϕ 28mm, L=6 &12 m, spacing 1.75x1.75m	0.05	0.073	

As can be seen from table 4, the support pressure from reinforcements before adding complementary reinforcement (0.192 MPa) is less than what is applied by the roof at centerline and downstream side (0.225 MPa) which explains increasing trend of the recorded rock mass displacements by the instruments. After applying extra pressure by additional support, the reinforcement pressure becomes more than the roof pressure (0.288 MPa) and results in the roof stability. The initial support pressure in upstream side was originally more than the roof pressure which explains the decreasing trend of rock movements in these sides. The applied additional support proved to be not necessary for upstream.

The above mentioned example illustrates how we can make advantage of a reliable monitoring program to control the rock mass stability and to feed the required information to the design team for an optimal final ground support design.

To summarize the rock movement profile of the cavern roof and the depth of the movements and corresponding load increase in load cells, table 5 is presented.

Table 5: Rock movement profile of the powerhouse cavern roof

Location	**Displacement (mm)**	**Depth of the rock movement (m)**	**Load increase in the load cells (kN)**
Downstream	24	9-12	230
Center line	10	6-7	120
Upstream	4.6	5-6	50

To get a general idea about the situation of this cavern with respect to the other cases around the world, the rock displacement is overlaid in the graph presented by Barton (1999) for cavern displacement around the world (figure 6).

Barton has gathered the information of a number of the caverns around the world in terms of the recorded rock mass movement and the quality of the media and has come up with the following empirical relation.

$$\Delta(mm) = \frac{span(m)}{Q}$$

in which Q is rock quality index (NGI system), span is the width of the cavern in meters and Δ in millimeters is the rock movement. Plotting the recorded rock mass displacements in figure 6 by Barton shows that the displacements at this cavern conform to the range of what have been recorded in other projects around the world.

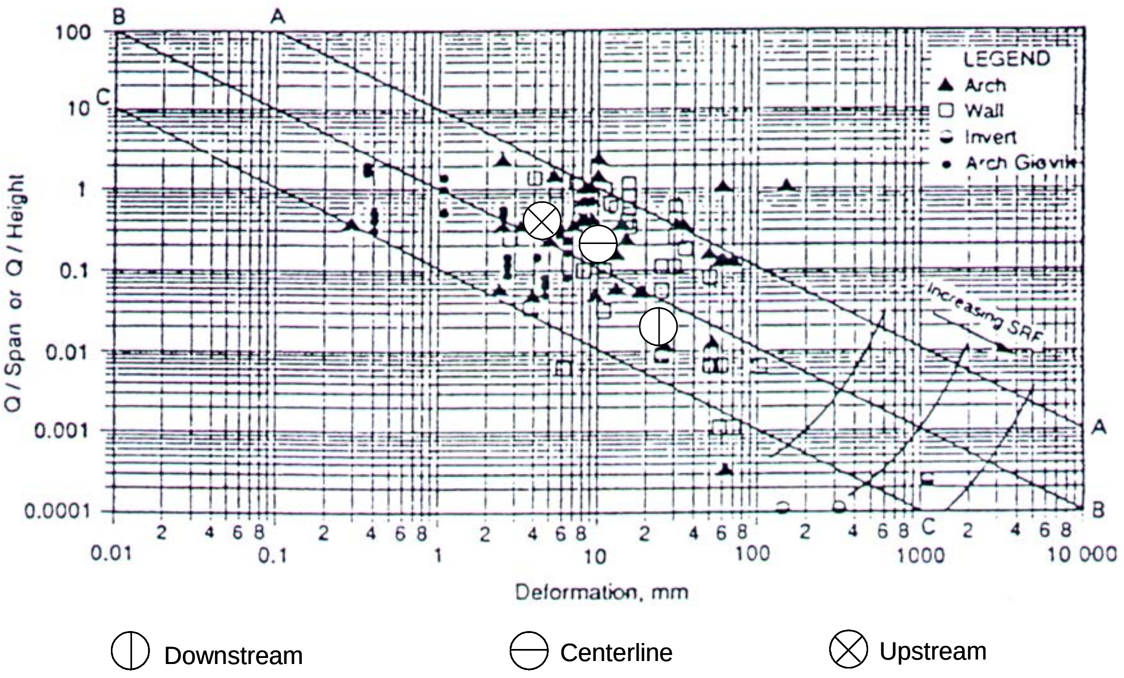

Figure 6. Comparison of the recorded rock movement with other cases in the world

5 CONCLUSIONS

Monitoring program at extension phase of Masjed-Soleiman underground power plant is a typical example of a reliable monitoring program to control the amount and performance of a ground improvement technique to assure stability requirements for an underground structure. The continuous rock mass movement results recorded from borehole extensometers necessitated additional support installation at the downstream side which later on by installation of more reinforcement proved to be adequate by observing a decreasing trend in movements. On the other hand, the rock movement trend in upstream side of the cavern indicated no further support requirement, the fact that was also confirmed through experimental load calculations for the roof and the supports.

6 ACKNOWLEDGMENTS

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7. REFERENCES

Stabel B. Bauckage, 2002. Report on Godar-E-Landar HEPP Extension Cavern Support.

Barton, N.,1999. General report concerning some 20th century lessons and 21st century challenges in applied rock mechanics, safety and control of the environment. *9th international congress on rock mechanics,* Paris, France.

Barton, N., Lien, R. & Lunde, J., 1974. Engineering classification of rock masses for the design of tunnel support. Rock Mechanics, 6 (4): 189-236.

Hoek, E., 1999. Support for very weak rock associated with faults and shear zones. *Proceedings of the Rock Support and Reinforcement Practice in Mining Conference, Rotterdam. Balkema.*