Role of geotechnical monitoring instrumentation in Tehri Pumped Storage Plant (1000 MW) – A case study

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Abstract

Instrumentation and monitoring are an essential part of current tunnelling practice. For safe and economical tunnelling in sensitive construction environments a continuous adaptation of excavation and support design is required so that input parameters can be revised when the predictions deviate from measured values. To understand the rock mass behaviour it is necessary to make a note of all parameters which needs to be measure in pre and post construction stages. Systematic monitoring results can provide valuable information pertaining to imminent collapse, thus making it possible to control the tunnel stability by providing proper counter measures. Excavation of any underground openings results in the release and readjustment of three dimensional stresses around the cavity. This results in displacements/deformations which are time dependent. Extensometer is used to measure deformation of a section of rock mass and adjacent surrounding strata with the help of anchors at different depths. The depth of anchors varies with type of rock strata and the location of fix point with respect to which deformation are to be measured. More importantly, it involves detailed planning to finalize the position of each monitoring instrument based on location and orientation of geological features. The present geotechnical monitoring practices for underground structures involve convergence monitoring with the help of optical targets and rock mass displacement with help of bore hole extensometers. In addition to this load cells are also used for recording and monitoring of loads in structural elements like rock bolts and cable anchors. This paper briefly describes about the deformation of rock mass in underground structure of Tehri Pumped Storage Plant for long term monitoring their results and conclusions.

Key Words: Underground Excavation, Geotechnical monitoring Instrumentation, Warning limits, MPBX, BRT and Load cells.

1. Introduction:

The geotechnical instrumentation has a vital role in evaluating the structural performance of an underground structure. The natural ground or rock mass tends to deform and de-stress when subjected to excavations, foundation and other loadings etc. Activities like squeezing, swelling and creep depend upon the mechanical characteristics of the material and are responsible for the disturbances inside the underground rock mass.

The long term performance of an underground structure is monitored by installing the structural instruments to predict and evaluate the safety of excavated openings. However, the question on number, type and locations of instruments can only be addressed by fortuitous combination of understanding of underground structural behaviour, experience and judgement. The instrumentation design therefore needs to be conceived with care and considerations of site specific conditions associated with the structures. (Kelllaway, M., Taylor, D. et.al.)

Various types of instruments are used for underground structures including system to record by key monitoring parameters listed as under:

1) Convergence – Deformations of excavated surface and surrounding rock mass
2) Load developed in rock bolts after installation and tensioning
3) Pore water pressure in the rock mass
4) Earth Pressure developed due to excavation

Multiple underground structures are under excavation at Tehri Pumped Storage Plant along with several adits, tunnels, shafts and cavern. The structural behaviour of these openings has been monitored by instruments installed at respective location along the length and cross section. Further, it is equally important to ensure proper recording of monitoring data in order to analyze and take immediate action in case of any adverse conditions observed.

2. Brief Description of Project:

As an integral part of Tehri Power House Complex located in the state of Uttarakhand in Northern India; an underground 4 X 250 MW Tehri Pumped Storage Plant is under construction based on the concept of upper and lower reservoir. The Tehri dam reservoir will function as the upper reservoir and Koteshwar reservoir as the lower balancing reservoir. On completion additional generating capacity 1000 MW (4 X 250 MW) peaking power will be added to Northern grid. During non-peak hours, water from lower reservoir would be pumped back to upper reservoir by utilizing the surplus available power in the grid.

Tehri Pumped Storage Plant comprises construction of Power House, two nos. of upstream Surge Shafts, Butterfly Valve Chamber, Penstock Assembly Chamber, two nos. of downstream Surge Shafts, four nos. of Penstocks, Bus bar Chamber, Ventilation tunnel, Drainage Galleries, two nos. Tail Race Tunnels and Outfall Structure located on the left bank of Bhagirathi River.

3. Geology of the area:

Tehri Project area lies within the Main Himalayan Block (MHB), in the midlands of Lesser Himalayas, bounded to the north and south by regional tectonic lineaments – the Main Central Thrust (MCT) and Main Boundary Fault (MBF) respectively. The former, to the north separates the meta-sedimentary sequence of Lesser Himalaya from the crystalline rocks of Higher Himalaya and the latter marks boundary between lesser Himalaya and tertiary sequence of Frontal Foothill Belt (FFB), in the south. The rock stratigraphy of lesser Himalaya exposed around the Tehri Project area are broadly classified into Garhwal, Shimla, Jaunsar, Bailana, Krol and Tal groups. The folded meta-sedimentary rocks exposed around the project site form an uninterrupted sequence of Chandpur Phyllites having a variable proportion of argillaceous and arenaceous constituents. Considering the rhythmicity of intercalated bands and varied the degree of tectonic effects in them, the Phyllites at project side have been classified into mainly four lithological variants as described below.

Phyllitic Quartzite Massive (PQM)
Phyllitic Quartzite Thinly Bedded (PQT)
Quartzite Phyllite (QP)
Sheared/Schistose Phyllite (SP)

PQM and PQT are more quartzite (arenaceous) and rarely micaceous in composition and are coarser in grain size. These rocks are grey, dark grey, brownish grey, greenish grey, greyish grey and green in colour. It is mainly comprised of quartz, feldspar and oriented leths of micaceous minerals. QP is more areno-argillaceous in composition, fine-grained and dark coloured. SP comprises of argillaceous and deformed variants of PQM and PQT rock, formed in sheared zone area which has weak rock mass characterististics.

4. Instrumentation and Monitoring:

The main objective of instrumentation and monitoring are very important for any underground structure. Observations recorded through instruments installed at various underground structures serves as guide for taking proactive remedial actions. If the underground excavation encounters known or unexpected major geological features such as fault, shear zone or a highly weathered rock mass, instrumentation can be used to monitor its behaviour. The use of proper instrument at appropriate time can give very valuable information, which can help to prevent a likely major mishap. This can provide early warning of many conditions that could contribute any failure mechanism.

Type and selection of monitoring instruments based on geotechnical aspects and surrounding rock mass. Various monitoring instruments installed in multiple adits, tunnels, shafts and chambers at different cross sections as per approved drawings and in consultation with designers.

1.1 Instrument Installed:

The monitoring instruments installed at various locations in the underground openings are listed in Table 1 along with general specifications.

Table 1
Specifications of Monitoring Instruments installed at Tehri Pumped Storage Plant

S No.	Instrument	Type	Parameter	Unit	Range	Resolution	Sign Convention
1	Bi-reflex targets	Optical	Deformation of Excavated Surface	mm	-	2.omm	"+ve" displacement indicate Divergence in cavern "-ve" displacement indicate Convergence in cavern
2	MPBX (2m, 5m, 10m & 15m or 20m)	Vibrating wire	Deformations of rock mass	mm	0.0 – 50 or ±25m	0.01 mm for sensors	"+ve" displacement indicate separation of anchors from wall "-ve" displacement indicate convergence of anchors towards wall
3	Load cells (in rock bolts)	Vibrating wire	Load developed in rock bolts	tons	30m	Accuracy 1%	"+ve" value indicates increase in rock bolt load (Due to convergence) "-ve" value indicates decrease in rock bolt load (due to loosening or far field convergence)
4	Load cells (in cable anchors)		Load developed in cable anchors		200m		

The technical aspects of monitoring instruments installed at various components of project are briefly described as follows:

a) Bi-Reflex Targets :

Bi-Reflex Targets consists of reflector plate mounted on a robust frame. The target has reflectors on both sides and is mounted on a universal joint such that it can be oriented in any direction as required. The target has cross mark to allow precise targeting. It is used along with the convergence bolt and break off point as shown in Figure1 below:

Figure 1 A Bi-Reflex Target

The targets are generally installed in cross sections of underground openings at required locations and monitor the absolute position of point on the excavated surface. For monitoring the displacements in different type of roc class five, three and one bi-reflex target installed at a given cross section of tunnel profile. Targets are designated as T1, T2, T3, T4 and T5. The absolute displacement of each target is determined as displacement vector in terms of its magnitude and direction. As the direction of all the appropriate coordinates (i.e. Northing and Easting) are selected to determine the displacement vectors. The magnitude of displacement vector between two consecutives date is plotted with respect to time or date to analyze the behaviour of target. The continuous vector diagram in plane of tunnel cross section is superimposed on the cross section of the opening to analyze the movement of tunnel boundary.

Rate of movement is calculated as ratio of displacement magnitude in mm and number of days elapsed since last date of measurement. All three layouts of installed BRT's are shown in Figure 2a, 2b and 2c respectively along with indicative displacement vectors.

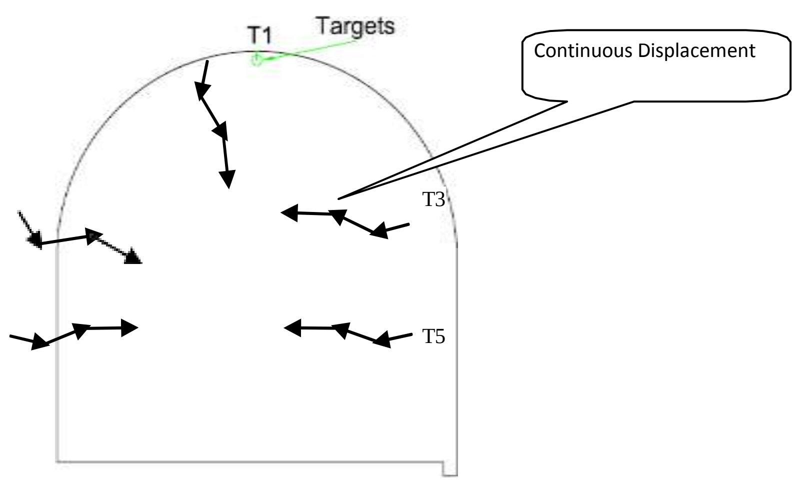

Figure 2a Five Target Section

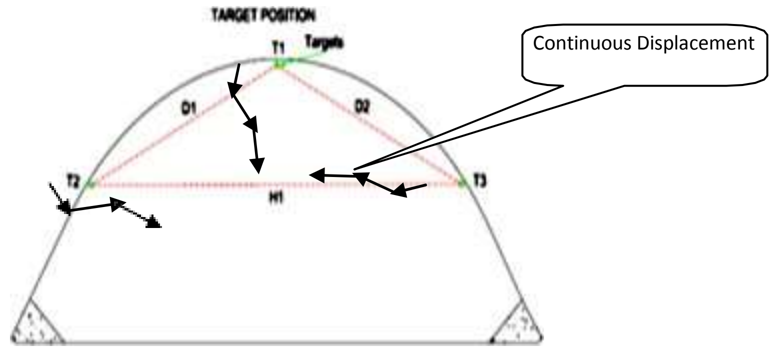

Figure 2b Three Target Section

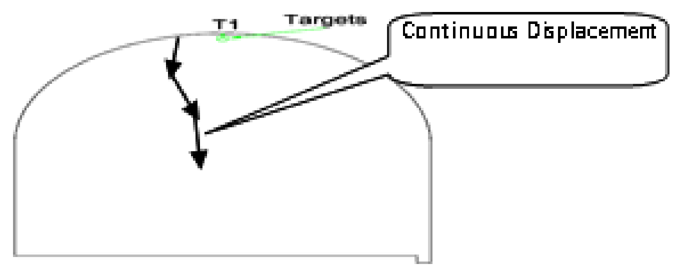

Figure 2c Single target section

b) MPBX-Multiple Point Bore hole Extensometer:

Multiple Point Bore hole Extensometer is used to measure the deformation of a section of rock mass with respect to deep anchor. MPBX can be either single point or multiple point consists of sliding rod, anchored at selected points within bore hole and fitted with vibrating wire sensors(Figure 3).The movement of the rock mass around bore hole is transferred to the attached anchors and same is recorded by transducers placed on the top of bore hole.

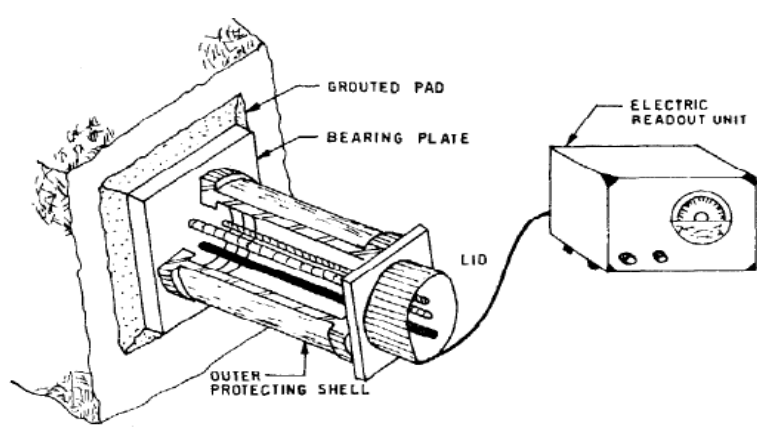

Figure 3 Collar Head at the Excavated Surface

The maximum number of anchors possible to install in a bore hole depends on diameter of bore hole and type of anchor used. The anchors can be attached to the surrounding rock mass in two ways; either by grouting the bore hole or by mechanical attaching with hydraulic anchors. For measurements of displacements the vibrating wire type sensors are used for long term measurements of relative displacements at four anchor points.

MPBX installed at Tehri Pumped Storage Plant has four anchor points (2m, 5m, 10m, 15m and 20m) are grouted type in which the anchors are grouted in to bore hole while keeping the movements transferring elements free with PVC pipe. Photograph of MPBX before and after installation shown in Figure 4 below:

Figure 4a Anchors

Figure 4b Rods with PVC Pipe

Figure 4c Collar Head

c) Load Cell in Rock bolts:

Vibrating wire load cells are used for recording and monitoring of loads in structural elements like rock bolts, tie backs, foundation anchors tunnel supports and in prestressing. It is installed at the time of the structural elements. A pretension force induced in the rock bolt recorded in the load cell. The distressing of the rock mass takes place due to any excavation or loading activity and the rock load is transferred to the rock bolts. The axial load which is developed in rock bolts is reflected in load cells as an increment to the initial installed load.

The vibrating wire load cell comprises of a set of three or six vibrating wire gauges, mounted parallel to each other, equally spaced in a ring in an alloy steel cylinder. The method of construction results in a very robust instrument suitable for use where high performance, longevity and mechanical strength are important. Typical arrangement of load cell installed along with rock bolt is shown in Figure 5.

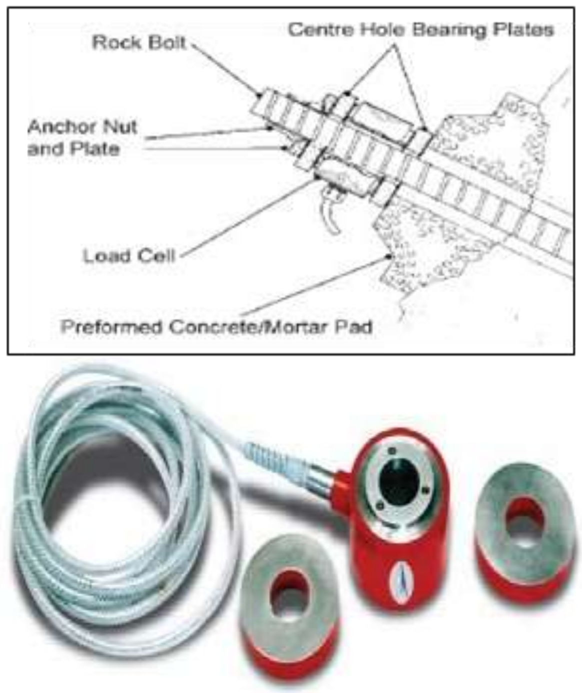

Figure 5 Load Cells and its typical arrangement with rock bolts

The monitoring of load cell data is also carried out periodically and the data obtained is analyzed with warning limits provided by designers. Generally the increase in rock bolt loads indicates the convergence in openings and vice versa.

1.2 Instrumentation Scheme:

Adequate instrumentation scheme has been specified by the design consultant, in particular the monitoring plan, frequency of readings, definition of threshold limits adopted in case of ground movements exceeding prescribed conservative ‘trigger’ limits are indicated. The general procedure for the implementation of countermeasures should be the movement exceeds the limit of displacement/stress established from design calculation for the structural integrity and safety of workers during excavation. Geotechnical monitoring instrument installed at various structure of project along with their excavated width listed in Table 2.

Table2
List of Underground Structure monitored by Geotechnical Instrument

S. No.	Structure Name	Structure ID	Orientation of opening w.r.t. North	Maximum excavated of opening (m)
1	Adit	AA-6	N30°	7.0
		AA-10	N08°	
		AA-11	N30°	
2	Butterfly Valve Chamber	BVC	N303°	10
3	Upper Penstock Assembly	PAC	N303°	13
4	Lower Penstock Assembly	LPAC	N71°	11.6
5	Tail Race Tunnel-3	TRT-3 D/S	N185°	11.0
6	Tail Race Tunnel-4	TRT-4 D/S	N185°	11.0
7	Ventilation Tunnel	VT	N102°	4.6
8	Bus Bar Chamber	BBC	N213°	10.0
9	Drainage Gallery	DG around BVC	N303°	4.4
10	D/S surge Shaft Chamber-3	D/S SSChamber-3	N30°	19.8
11	D/S Surge Shaft Chamber-4	D/S SSChamber-4	N30°	19.8
12	Link tunnel between D/S Surge Shaft Chamber-3&4	D/S SSChamber-3 & 4	N30°	11.5
13	Lower Bus bar Tunnel-5	LBB-5	N300-335°	7.9
14	Lower Bus bar Tunnel-6	LBB-6	N300-335°	7.9
15	Lower Bus bar Tunnel-7	LBB-7	N300-335°	7.9
16	Lower Bus bar Tunnel-8	LBB-8	N300-325°	7.9
17	Upper Bus bar Tunnel-5	UBB-5	N120°	7.9
18	Upper Bus bar Tunnel-6	UBB-6	N120°	7.9
19	Adit	AA-1	N54°-90°	7.0
		AA-2	N303°	7.0
		AA-3	N303°	7.0
20	U/S Surge Shaft Chamber-3	U/S SSChamber-3	Vertical Direction	15.0
21	U/S Surge Shaft Chamber-4	U/S SSChamber-4	Vertical Direction	15.0
22	U/S Surge Shaft-3	U/S Shaft-3	Vertical Direction	20.8
23	U/S Surge Shaft-4	U/S Shaft-4	Vertical Direction	20.8
24	Drainage Gallery around upstream Surge Shaft	DGUSSS	N325°	4.4
25	Power House	Service Bay	N30°	24.6
26		Crane Beam	N30°	24.6
27		Pipe Gallery	N210°	3.6

The type number and interval of readings are being finalized by the designer based on evaluation of previous monitoring results, trend and warning limits. The tunnel convergence monitoring is the predominant measure adopted for the all foreseen/ unforeseen roc mass condition. As earlier stated, the convergence readings are the main parameter for evaluating the stability of any underground structure, while other measures can be considered additional tool to know the behavior of rock mass.

1.3 Frequency of monitoring and warning limit:

The frequency of monitoring data is depended upon the warning limit of individual structure provided by designers in approved instrumentation drawing for individual project component. A pre determined or rate of change of a key indicator parameter that is considered to indicate a potential problem, but not of sufficient severity to require cessation of the works. Exceeding this trigger level will generally require a check on instrument function, visual inspection of structure being monitored, increase in monitoring frequency, review of the design and modification of construction process. The warning limit of different engineering parameters obtained from monitoring data to check the health of structure as under.

A) Deformation measurements:

Alarming limits for benching and heading activities for different structures obtained from approved instrumentation drawing and readings are taken in same reference line as mentioned in Table 3a and 3b respectively.

Table 3a

Max^{m} allowable and warning limit of deformation in underground openings of Tehri PSP

Structure	**Warning limit (MM)**			
	Heading		**Benching**	
	I level	**II level**	**I level**	**II level**
BVC (1st bench)	1% of the underground opening		50mm to 75mm	More Than 75mm
UPAC			50mm to 75mm	More Than 75mm
LPAC	1% of the underground opening			
PH	1% of the underground opening			
DSSS-3	50mm to 100mm	More than 100mm	150mm to 200mm	More than 200mm
DSSS-4	50mm to 100mm	More than 100mm	150mm to 200mm	More than 200mm
USSS-3	20mm to 40mm	More than 40mm	50mm to 60mm	More than 60mm
USSS-4	20mm to 40mm	More than 40mm	50mm to 60mm	More than 60mm
LINK TUNNEL	15	30	50mm to 100mm	More than 100
ADITS	1% of the underground opening			
DRAINAGE GALLERY	1% of the underground opening			
TRT-3	1% of the underground opening			
TRT-4	1% of the underground opening			
VENTELATION TUNNEL	1% of the underground opening			
TRT outfall	1% of the underground opening		30	40
DS SS	Rock Type- PQM + PQT PQT + QP QP + SP SP		 50 120 150 200	 100 150 200 250
US SS	Rock Type- Type-2 Type-3 Type-4		 50 100 200	 75 150 250

LOWER BUS BAR TUNNEL			100	150
UPPER HORIZONTAL PENSTOCK	Rock class II III IV V		30 50 100 200	
VERTICAL SHAFT	Rock class II III IV V		30 50 100 200	

Table 3b
Warning limit for rock bolt loads in UG Openings at PH Cavern of Tehri PSP

S. No.	Rock bolt dia. (mm)	Design load, D (Tons)	Warning limit W = 80 % of D (Tons)
1	25	20.0	16.0
2	32	35.0	28.0

B) Rock Load Measurements:

The warning limits for the rock bolt loads monitored by load cells installed in the rock bolts are suggested by 80% of the design capacity of the rock bolt. The design capacity of rock bolts are different for different size of bolts installed and so shall be the warning level for the rock load observed and recorded by instrument as shown in Table 3.

120 ton capacity of cable anchors locked at 80 ton installed in Power House, Butterfly Valve Chamber, Penstock Assembly Chamber and presently installation is in progress at the benches of Tail Race Tunnel outfall beyond El: 623.0m.

Regular monitoring data is taken based on the above warning limit considered for different instruments and the behavior of underground openings observed from the analysis of monitoring data in terms of correlation with major construction activities.

2. Regular Monitoring data processing and interpretation:

As stated earlier also monitoring data is regularly taken at site in consideration with their warning limits and frequencies for individual structures. The deformation occurred after the instrumentations are monitored regularly and interpretation work carried out accordingly on monthly basis. Maximum rate of displacement observed by Bi-reflex targets, MPBX and increment in load on rock bolts/cable anchors by load cells are summarized in Table 4, 5 and 6 respectively.

Table 4
Maximum Rate of displacement observed by Bi-reflex target

SNo.	Component	RD (m)	Class of Rock	Target ID	Maximum movement w.r.t. initial (mm)	Maximum Rate of Movement in last month (mm/month)
1	Adit AA-1	160	IV	T-3	34.60	0.00
2	AA-2 Drainage Gallery	25	IV	T-2	37.68	1.19
3	U/S Surge Shaft Chamber 3	16.3	IV	T-5	17.63	2.07
4	Chamber-3 Cracking	23.32	IV	Lower Left	12.17	0.00
5	USSS-3	EL: 802.80	III	OP-4	36.77	0.00
6	U/S Surge Shaft Chamber 4	2.2	IV	T-6	45.89	0.0
7	USSS-4	EL:802	III	OP-8	67.82	12.38
8	BVC	35.6m	VA	T-4	133.5	0.00
9	DG-USS	82.00	IV	T-2	40.59	0.00
10	PAC	30.32	IV	T-2	49.75	0.00
1	PH	41.5	IV	T-2	34.4	0.00
2	UDG-PH	0.00	III	T-1	40.51	0.00
3	PH Service Bay	16.34	IV	Left OP-1	15.5	0.00
4	LBB-5	10	III	OP-1	17.09	0.00
5	LBB-6	15	III	T-3	25.67	0.00
6	LBB-7	35	III	T-3	10.8	Target damaged in Jan'17
7	LBB-8	18	III	T-1	10.4	Target damaged in August'17
8	UBB-5	7.5	III	T-2	41.7	0.00
9	UBB-6	7.5	III	T-2	7.5	0.00
10	Adit 3	15.9	IV	T-4	15.3	2.01
11	AA-10	195.54	III	T-1	17.54	2.00
12	AA-11	160	IV	T-5	33.49	2.69
13	AA-8R	112.5	III	T-2	30.27	0.00
14	Pipe gallery	22	III	T 3	2.2	0.00
15	VT	310	IV	T-4	38.64	0.00
16	BBC	81	III	T-2	25.09	0.00
17	D/S Surge Shaft Chamber 3	17.3	IV	T-4	33.86	0.00
18	DSSS-3	EL:580	III	OP-2	36.04	0.00

19	D/S Surge Shaft UP Chamber 4	15	IV	T-6	40.72	0.00
20	DSSS-4	EL:611	III	OP-8	36.76	9.32
21	AA-6 (Link Adit)	6	IV	T-4	31.64	0.00
22	TRT-3 D/s	500	III	T-1	25.27	0.00
23	TRT-3 U/s	146	VA	T-2	4.5	0.00
24	TRT-4 D/s	612	VA	T-3	18.18	1.99
25	TRT-4 U/s	110	VA	T-3	4.5	0.00
26	TRT Out Fall	70.00	IV	SM-3	34.98	1.38
27	Vertical Penstock-5	EL: 704.167		M-3	9.6	0.0
28	Vertical Penstock-7	EL: 704.355		M-3	8.9	0.00

Table 5
Maximum displacement observed by MPBX

SNo.	**Component**	**Maximum sensor displacement w.r.t. initial @ sensor depth , RD**		
		Crown	**U/S wall**	**D/S wall**
1	U/S surge shaft Chamber-3	1.51mm @ 10m, RD 16.6m Cable Damaged Since Nov'18	-6.80mm @ 15m, RD 16.6m, EL: 873m	11.01 mm @ 5m, RD 16.6m,EL 862m
2	U/s Surge Shaft-3	**Gallery Side EL: 857m**	**Adit Side EL: 856m**	**Adit Side, R/s EL: 856m D/s Wall**
		-5.00mm @ 2m	3.55mm @ 10m	4.65mm @ 2m
		Adit Side , L/s EL: 856.00m, U/s Wall		
		-0.98mm@5m Cable damaged since April'19		
3	U/S surge shaft Chamber-4	2.65 **mm** @ 2m, RD 21m	2.21**mm** @ 2m, RD 21m, EL: 873m	**-4.13mm** @ 2m, RD 21m
4	U/s Surge Shaft-4	**Adit Side Wall, EL: 857m**	**Gallery Side Wall EL: 856m**	**Adit L/s EL: 855m, U/s Wall**
		3.94mm @ 10m	4.56mm @ 10m	**2.04mm @ 5m**
		Adit Side Wall, EL: 790m	**U/s Wall EL: 790m**	**D/s Wall, EL: 790m**
		-2.79mm @2m	-1.60mm @ 10m	-0.74mm @2m
5	BVC	-22.66mm @ 2m, RD 72.13m	-7.57mm @ 15m, RD 35.605m, El:722m	19.93mm @ 15 m, RD 35.60 m, El:722m
6	PAC	-4.96mm @ 10m, RD 80.69m	-5.62mm @10m, RD 6.18 m	-9.66mm @ 10m, RD 6.18m
7	PH	-0.60mm* @ 5m, RD 87m	0.79mm @ 20m, RD 12m	5.32 mm @ 5m, RD 37m
8	PH-UDG	**-5.59mm** @ **10**m, RD 41m		
9	D/S surge shaft Chamber-3	-1.96 mm @ 10m, RD 13.8m	-2.44mm @ 5m, RD 13.8m	16.72mm @ 2m, RD 13.8m, EL 644.50m
		Adit Side EL: 613.393	**Link Tunnel Wall EL: 613.393m**	
		1.58mm @ 5m	0.51mm@m	

10	D/s Surge Shaft-3	**Link Tunnel Side Wall EL: 580M**	**D/s Wall EL: 580M**	**U/s Wall EL: 580M**
		4.21mm @ 15m	-1.13mm @15m	-2.53mm @ 15m
11	D/S surge shaft Chamber.4	**1.77mm** @ 10m, RD 13.8m Cable Damaged since July'17	**-3.42mm** @ 15m, RD 13.8m EL 649 m	**-6.78mm** @ 5m, RD 13.8m, EL: 649.50 m Cable Damaged since Jan'18
12	D/S surge shaft-4	**U/S wall EL:613.6m**	**EL: 613.711m End wall**	**EL: 613.650m D/S wall**
		-0.12mm @ 10m	1.77mm @ 5m	0.48mm @5m Cable Damaged since March'20
		Link Tunnel wall EL:613.603 m,		
		-2.00mm @15m		
13	Link Tunnel	7.16mm @ 15m RD: 21.50m	1.37mm @ 10m RD: 21.50m	-9.25mm @ 2m RD: 21.50m

Note: (-ve reading) Internal Convergence dominates, (+ve reading) Wall Convergence Dominates

Table 6
Rock bolt load increment w.r.t initial installed load

Component	**Maximum rock bolt load increments w.r.t. initial installed load (Tons)**		
	Crown	**U/S wall**	**D/S wall**
U/S SURGE SHAFT-3		1.10 Tons @ EL: 812.25	1.60Tons @ EL:812.25
U/S SURGE SHAFT- 4, EL: - 806.25		2.90 Tons @ EL:803.25	3.23 Tons @ EL:806.25m
		EL: 790.650m Gallery Side Wall	
		2.33 @ EL:790.65m	
BVC Load cell on Rock Bolt		3.07 Tons @ RD: 18.93	1.07 Tons @ RD: 23.42
BVC Load cell on Cable Anchor		47.65 Tons @ RD 74 m	67.99Tons @ RD 43 m
Rock Bolt Load Cell PH	9.55 Tons @ RD 138m	11.94 Tons @ RD 138m	9.33 Tons @ RD 38m
Cable Anchor Load Cell PH Gallery		41.13Tons @ RD 3.15 m	16.79 Tons @ RD 135.5m
D/S SURGE SHAFT-3, EL: 593.50m			3.40Tons @ EL: 593.50m
D/S SURGE SHAFT-4, EL:602.60m			9.90@ EL: 602.60m
Cable Anchor Load Cell Link Tunnel Between DSSS Chamber 3 & 4			3.37@ RD: 10m, EL: 645.5m
Cable Anchor Load Cell Out Let		5.10Tons @ RD -5 m EL: 620m	20.01Tons @ RD -50 m EL: 622m

Note:(-ve) reading indicates relaxation of load, (+ve) reading indicates accumulation of load

3. Conclusions:

The most important aspect of the interpretation part is the calculation of the expected value of the parameters being monitored. The recorded values of various parameters are being compared with the expected values to ensure collection of meaningful data. Another effective way to validate instrument reading is through routine visual observation. Observation of the monitored area can provide early warning signals, such as tension crack or evident seepage, which may not be picked up by nearby field monitoring instruments and can also guide remedial actions. The following conclusions can be drawn from analyzing the instrumentation and monitoring records till date.

Based on the instrumentation work carried out in Tehri Pumped Storage Plant, significant movements are being observed in BVC, PAC, Downstream Surge Shaft and Chambers. These movements may be due to adverse geology encountered during excavation. Considering the case of BVC and PAC which is very critical component of project wherein at some locations first warning limit has been breached. Special precaution has been taken during further excavation in this area by control blasting in various steps to avoid any mishap. Additional rock supports is also suggested by designers and implemented at site immediately. The monitoring data of other project components lies within warning limit and considered to be safe. Further, it has also been proposed that the monitoring shall be continued as per present frequency and if found any change in data in terms of increment immediately frequency of reading should be increase and counter measures to be taken without any delay for the safety of project component.

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