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Engineering Geological Investigations and Assessments of Support System of Delivery Mains of Package-6 of Kaleshwaram Lift Irrigation Scheme, Telangana State, India

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Abstract Detailed engineering geological and geotechnical investigations were carried out for the delivery mains for assessment of rock mass properties and to provide a sound support system. Seven numbers of delivery mains are constructed which are an important component of the pump house complex for lifting water from the pump house to the delivery cistern. Regionally the rock types belong to Karimnagar Granulite Terrain (KGT) and Peninsular Gneissic Complex (PGC) of Archean age. The main rock types of delivery mains are medium to coarse grained grey granite and charnockite traversed by dykes/basics enclaves. The rock mass was classified on the basis of rock mass rating (RMR) and tunnelling quality index (Q) classifications. The calculated classes of rock masses range between very poor to good. Geo-mechanical properties of the rock samples were tested as per IS codes. Delivery mains were constructed as per the Norwegian method of tunnelling (NMT) and support design as per the Q- system chart. Rock support in the form of rock bolts, steel fibre reinforced shotcrete and grouting arrangement were applied. The main challenge for the construction of seven delivery mains was the less rock ledges in between these delivery mains and presence of nearby live reservoir. So, before excavation, data was collected from adits and pump house heading portion to classify the rock masses of delivery mains. In this paper engineering geological investigations, challenges and design of rock support system is described in detail for seven delivery mains.

Keywords*:* Delivery mains, Rock mass rating (RMR), Tunnelling quality index (Q), Norwegian method of tunnelling (NMT).

1. Introduction

Kaleshwarm lift irrigation is an interlinked scheme of Telangana State and the world's largest multi-stage, multi-purpose lift irrigation project has been constructed on the Godavari River. The scheme is formulated to irrigate 7,38,835 hectares in thirteen districts of the state. Water is being lifted from 100 m elevation to higher elevation up to 630 m with the help of a multi-stage lifting mechanism. The total demand of water is 225 thousand million cubic feet (TMC), out of which 169 TMC for irrigation, 40 TMC for drinking purposes and 16 TMC for industrial utility in the state. A total 20 reservoirs (17 live reservoirs) with the capacity of 147.71 TMC and 20 lifts have been constructed to lift water from the River Godavari. The electric power required to operate the entire lift will be 4627 MW. The project is expected to bring a major boost in the socio-economic status of the people in the command area with assured irrigation facilities. The major components of the scheme are barrages, water conveyer system consisting of gravity canals, tunnels, lift systems, reservoirs and distributary network systems. The total length of the scheme is 500 km from the source (Medigadda barrage on the river Godavari) to the destination point (Narketpally village). Mechanical motors capacity of ranging from 40 MW to 139 MW each have been installed for lifting of water as per the site topography and volume of water.

Kaleshwaram lift irrigation scheme is divided into seven links and 28 packages to complete the project as per the given schedule. Package-6 of KLIS is one of the leading package of the scheme and which was operated for wet run of the first pump among the entire 28 packages in April 2017. An underground pump house complex has been constructed which has many advantages like less land occupation, higher security, economic, and more environmentally friendly.

he package-6 is design to lift 146.24 TMC water for 90 days in monsoonal period. The important components of package-6 are shown in (**Fig.1.**&**2.**). The underground pump house complex is having a surge pool, transformer cavern, draft tubes, pump house and delivery mains. Underground surge pool structure will be feed water by twin tunnels of 9.534 km long. The salient features of the KLIS package-6 are given in **Table 1**. All underground components were excavated with drill and blasting methods. Surge pool, pump house and transformer caverns were excavated with heading and multistage benching method. The maximum height of heading and benching were maintained 8 m. Delivery mains are important components of the pump house complex in any lift irrigation system and need to excavate and support with the appropriate techniques. The salient features of the delivery mains are given in **Table 2**.

2. Project site location

Kaleshwaram lift irrigation scheme package-6 is located in the Peddapalli district in Telangana state. The inlet portal of the twin pressure tunnels is near Kukkalagudur village (18°47’19”N: 79°18’16”E) and the cistern near Medaram village (18°43’33”N: 79°13”06”E) is falling in Survey of India Toposheet No.56 N (1,2,5,6) and shown on google map (**Fig.1.**). Both sites are well connected with Panchayat roads. The project site is approximately 45 km from Karimnagar District headquarters, which is 165 km from Hyderabad.

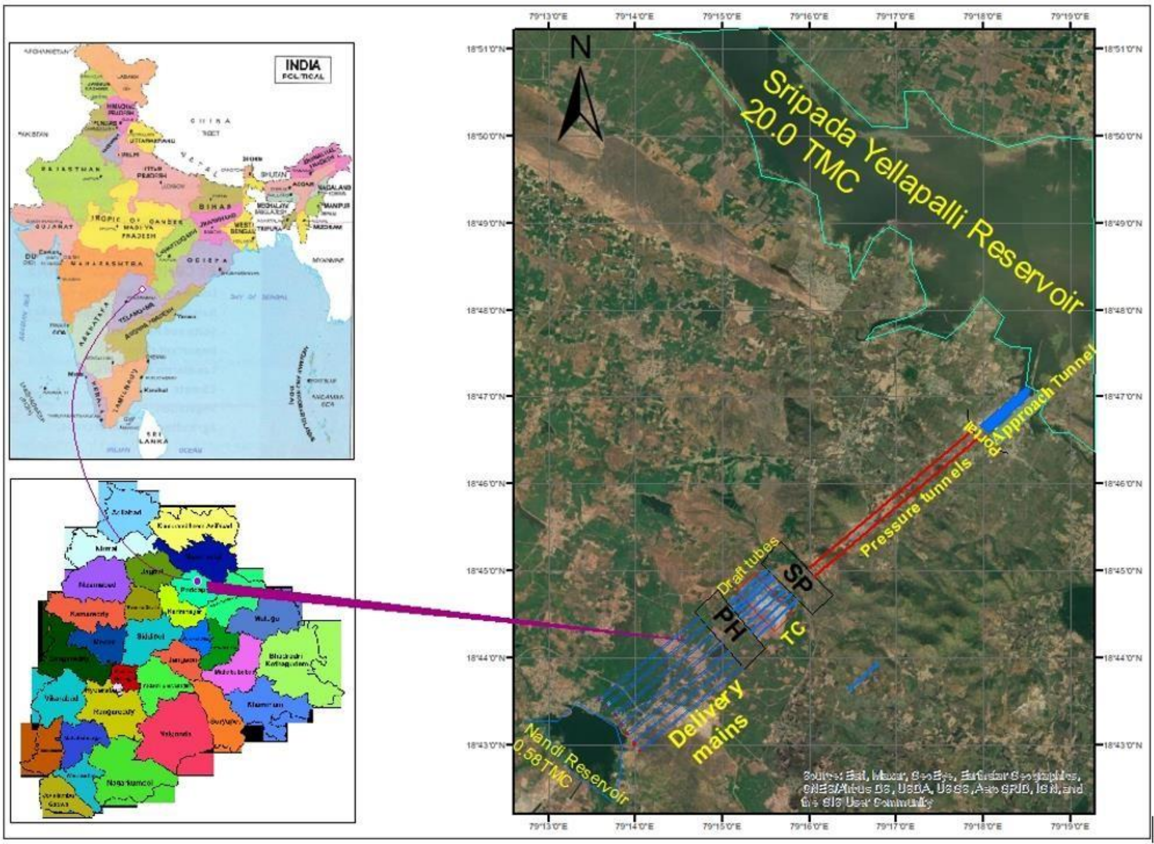

Fig. 1. Location map of the KLIS-P6 project site.

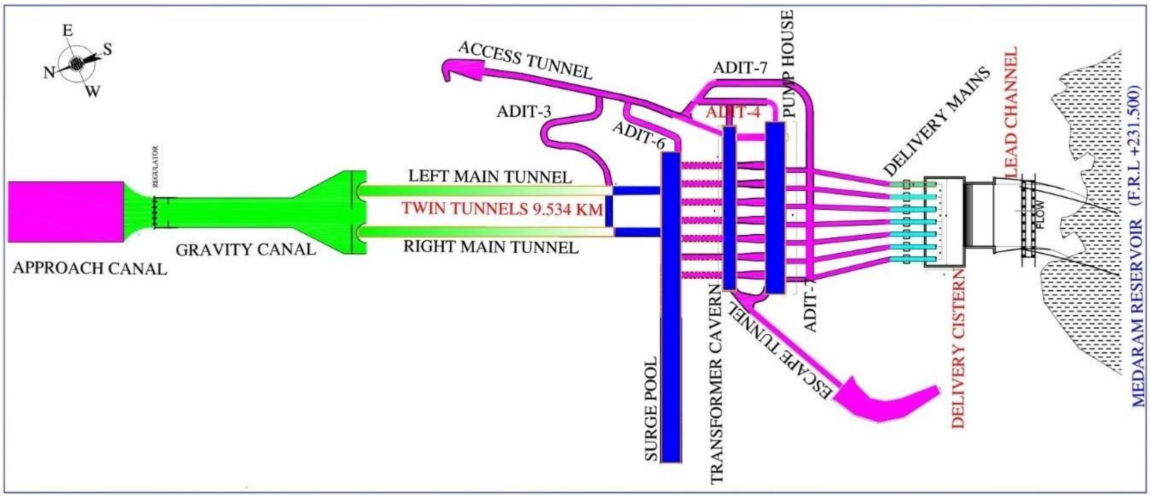

Fig. 2. General layout map of the KLIS-P6 project site.

Table 1. Salient features of the Kaleshwram lift irrigation scheme package-6.

Components	Description	FRL/Length /shape/Dimension (m/km)
Source water level	The Godavari River	100.0 m (elevation)
Twin Tunnels	Length	9.534 km
	Excavated diameter	11.0 m
	Finished diameter	10.0 m
Surge Pool	Location (chainage)	Ch. 10.675 to 10.700 km
	Dimension (m)	25 (W) x 375 (L) x 67.6 (H)
	Crown Level	EL+ 172.63 m
	Maximum Water Level in Surge Pool	+159.70 m
	Minimum Water Level in Surge Pool	+132.268 m
Draft tube tunnels	Orientation of draft tube tunnels	222º
	Total length	101m
	Total numbers	07
	Excavated diameter of draft tube tunnels	6.0 m, to 10.50 m as per design requirement
Transformer cavern	Dimension (m)	16 (W) x 210 (L) x 27.0 (H)
Pump House	Dimension (m)	25 (W) x 210.6 (L) x 50.3 (H)
	Crown Level	148.00 m
	Foundation Level	97.7 m
Escape tunnel	Length	158.65 m
	Diameter	8.0 m (D-Shaped)

Table 2. Salient features of delivery mains (horizontal) tunnels of KLIS-P6.

1.	Orientation of delivery mains	222º
2.	Total number of delivery mains	Seven
3.	Shape of delivery mains	D-shape
4.	Rock ledge between delivery mains	16 m
5.	Slope gradient of delivery main tunnels delivery mains	No gradient up-to 50 m than 1 in 7 up-to 255 m
6.	Excavated diameter of delivery mains	6.0 m
7.	Finished diameter of delivery mains	5.0 m
8.	Ground level above delivery mains	230 m
9.	Overburden above crown delivery mains	156 m

3. Regional and project site geology

The regional lithological units belong to NW-SE trending Karimnagar Granulite Terrane (KGT), supracrustal rocks of Peninsular Gneissic Complex (PGC) of Archean age [Ramam & Murthy, 2012, Prakash & Sharma, 2011]. The selected location for the underground pump house complex was no influence of any active or regional fault but many weak zones were encountered in twin tunnels area. Dykes/basic enclaves and unfavourable joints were encountered of few centimetres to many meters almost in all components. The bedrock at the project site belongs to the Archean age and the main rock types are medium to coarse-grained grey granite and charnockite intersected by dykes and basic enclaves. The physical and mechanical properties of the granitic rock were determined from laboratory tests of core samples of NX size as per ISRM [1981] and BIS standard and results are shown in **Table 3.**

Table 3. Physico-mechanical properties of rock cores.

Specific gravity	2.76-2.81
Hardness	6-7
Universal compressive strength (UCS)	115 (38)- 130 (135)
Tensile strength (MPa)	16-10
Cohesion value (MPa)	5
Friction value	59º
Modulus of elasticity (GPa)	7.5-6.9

The drainage patterns are dendritic, radial, and parallel in nature. The dendritic and radial patterns are characteristics of granite terrain. The terrain is mostly covered with alluvial soil. The range of the soil cover is 1 to 2 m followed by 3-4 m thick highly to moderately weathered rock and further underlain by slightly weathered to fresh granitic/ granitic gneiss.

4. Engineering geological investigations of delivery mains

Detail engineering geological investigations of any excavated structures are very important for predicting geologic conditions and planning of support system as per rock mass qualities and site geological conditions at the various levels of the excavation and to following designed drawing support. Engineering geological mapping of the face were carried out on a 1:100 scale to predict any adverse geological condition in the form of weak zones or sudden ingress of water and to suggest the rock class to design the blasting pattern for proper shape with maximum face pull. 3D geological mapping of the delivery mains were carried out on 1:200 scale for a permanent record of the exposed discontinuities from the excavated underground structures, calculation of the rock quality classes and for providing design and additional rock support system. Delivery main tunnels (horizontal and vertical) were excavated through the dry, damp, and dripping tunnelling media of medium to coarse-grained grey granite and charnockite. Occasional traverses of dykes/basic enclaves were observed at different chainages with a thickness of 25 cm to 3.7 m. Whenever dykes/basic enclaves were encountered during the excavation of delivery mains, additional care was taken in the form of controlled blasting and rock support in the form of sealing shotcrete and spot rock bolts. The details of joint sets mapped are given in **Table 4.** The general trends of dykes were skew and vertical.

Table 4. Joint sets recorded in medium to coarse grained granite and dyke/basic enclaves of delivery mains (01 to 07).

Joint sets	Azimuth / Dip Amount	Spacing (cm)	Strike length (m)	Roughness	Aperture (mm)	Infilling	GW
J1	200-225/V	35-120	5-10	Rough irregular planar	Tight-2	None	Dry
J2	300-320/15-25	20-250	>25	Rough irregular planar to smooth undulating	Tight-2	Coated/Non softening	Dry-damp
J3	325-330/V	20-110	5-15	Rough irregular planar	Tight-2	Coated/Non softening	Dry-damp
J4	270-280/V	50-200	>10	Rough irregular planar	Tight-3	Coated/Non softening	Dry
J5	220-240/30	30-300	15-20	Rough irregular planar	Tight-2	Coated/Non softening	Dry-dripping
J6	025-035/60-65	35-120	5-10	Rough irregular planar	Tight-2	None	Dry
J7	360-010/15-25	20-300	>15	Rough irregular planar	Tight-2	Non softening material	Dry-Damp
J8	120-130/60-70	30-100	5-15	Smooth planar	Tight-1	None	Dry
Dyke	275/V	-	10-15	Smooth planar	Tight-1	None	Dry
R1	205/35	-	5-10	Smooth undulating	Tight	None	Dry
R2	065/70	-	5-15	Smooth undulating	Tight	None	Dry
R3	215/25	-	5-7	Smooth undulating	Tight	None	Dry

Fig. 3. View of full excavated delivery main tunnel-4, junction point of horizontal and vertical portion is also shown

Fig. 4. Steel lining work of delivery main tunnel-2 horizontal portion under progress.

Fig. 5. Excavation of delivery main vertical shaft-01 under progress.

Fig. 6. View of delivery main vertical shaft 01 after full excavation.

5. Excavation methodology and challenges

Stabilities of delivery mains were additionally taken care of in view of the very high-water pressure generates at the time of the operational stage on these structures. Delivery mains were excavated with the full-face drilling and blasting methodology. Excavations of delivery mains were challenging in view of the nearby existing Nandi Medaram reservoir with its 0.58 TMC capacity and limited rock ledges between these structures. The distance of Nandi Medaram reservoir from the vertical shafts is approximately 300 m (**Fig.1.**) The rock ledge between the two delivery mains is also less which is 16 m. Due to the conventional excavation method, the damage zone of the rock mass increases when repeated blasting were taken at similar chainages in these delivery mains. In this case, rock masses were disturbed seven times (parallelly) at a similar chainage and necessary precautions were taken because of parallel excavation, poor ventilation was there and the temperature was high and difficult to identify newly developed cracks or loose portions (**Fig.7.).** The construction cycle of each face of these delivery mains were getting delayed in respect of increasing mucking time. Muck was taken up to the junction of the connection tunnel (adit-7) from the various construction faces by the loader and the distance were increasing with the progress of these delivery mains. There was no option to make any pocket structures in the middle part of these delivery mains for providing turning facilities for operational vehicles due to limited rock ledges. Two prominent unfavourable horizontal joints (N300-325°/15-20° and 360-010°/15-25°) were encountered in delivery mains 1, 2, 3, and 4 which were tackled by providing longer rock bolts. It was assumed that high ingress of water may come from the nearby reservoir in case of separation of persistence joints due to uncontrolled blasting, so only 2.0 to 2.5 m deep blast holes with proper periphery holes on the crown portion were followed strictly. Horizontal joints cause slab conditions on the crown portions of the delivery mains and create tunnel unstable and the falling of rock chunks. The falling of rock chunks after the face blasting/drilling were observed at many tunnels reaches from the unsupported span. As per the site geological conditions, a minimum of 25 to 30 m tunnel face difference in alternate delivery mains were maintained and timely rock bolts and shotcrete were provided on a mandatory basis to ensure the safety of the crew and machineries. Air blast were a common problem in these delivery mains and mostly reported in the good rock types due to very tight joints nature (**Fig. 8.**).

Fig. 7. Rock damage portion on the right crown of delivery main-1and treated with shotcrete.

Fig.8. Hanging rock chunk at the crown portion in delivery main-2.

Three numbers of pressure release holes were provided at the centre of the crown and left and right crown portions. To complete delivery mains within scheduled time, a connection tunnel (adit-7) with 8.0 m dia was excavated which was perpendicular to delivery mains at 30 m from the downstream wall of the pump house cavern. The crown portion of the connection tunnel and 6 m on either side, all delivery mains were supported as per intersection area. Adit-7 was helpful in speedy excavations of delivery mains. By following controlled blasting, pressure release holes, timely rock support, and grouting provisions were the key tools to tackle the situation which were followed strictly till the last blast of the delivery mains.

6. Rock mass classification systems

For preliminary rock support design of the delivery mains, rock mass properties were determined and rock mass was classified using rock mass rating (RMR) and Tunnelling Quality Index (Q) classifications. Rock mass rating (RMR) was introduced by [Bieniawski] in 1973 based on case studies in various shallow depth sedimentary rocks. Further, this system was modified in the years 1979 and 1989. At present, the latest 1989 version of RMR [Bieniawski 1989] is being world widely used in tunnels, chambers, mines, slopes and foundations studies. Before excavation of delivery mains, data was collected from adit-4, adit-7 and pump house for assessment of rock mass and details are given in Table 4 & 5.

Table 5. RMR-values determined from nearby tunnels i.e. adit-4, 7 & pump house heading.

Structure/sites		UCS	RQD	Spacing (cm)	Condition of discontinuity					Ground water	Orientation	RMR	
					Persistence (m)	Aperture (mm)	Roughness	Infilling	Weathering			Value	Class
Adit-4	P	123	98.5	60-100	10-20	1-5	Rough	Soft filling <5	W-II	Dry	Unfavourable	66	Good
	R	12	20	15	1	1	5	2	5	15	-10		
Adit-7	P	123	95.2	30-60	10-20	1-5	Slightly rough	Hard filling <5	W-I	Dry	Unfavourable	62	Good
	R	12	20	10	1	1	3	4	6	15	-10		
Pump house (heading)	P	123	88.6	20-60	>20	1-3	Smooth	Soft filling <5	W-II to WIII	Dry	Unfavourable	51	Fair
	R	12	17	10	0	1	1	2	3	15	-10		

Based on more than 200 case histories, Barton et al. developed the Q-system in 1974. The Q-system was further updated by [Grimstad and Barton in 1993]. [Nick Barton 2002] compiled the system again and made some changing in support recommendations. The Q-system is based on the information available with the joints. The assessment of Q-values for the granitic rock mass of the delivery mains based on the information available with the rock joints and their nature and 3D geological mapping is tabulated in (**Table 5.**). The rock mass quality (Q) is related to the ultimate support pressure requirement. The Q-values varying from 7.3 to 31.7, and it is categorized under fair to good rock mass categories and the average Q-value calculated is 17.10.

Table 6. Q-values recorded from adit-4,7 & pump house heading portion

Structures/sites	Rock Type	RQD (%)	Jn		Jr	Ja	Jw	SRF	Q	
									Value	Class
Adit-4	Coarse grained grey granite	98.5	P	2+R	Rough irregular planar	Slightly altered	Minor inflow	Medium stress	12.31	Good
			R	6	1.5	2	1	1		

Adit-7	Coarse grained grey granite	95.2	P	2+R	Rough undulating	Fresh	Minor inflow	Medium stress	31.73	Good
			R	6	2	1	1	1		
Pump house (Heading)	Coarse grained grey granite	88.6	P	2+R	Smooth planner	Slightly altered	Minor inflow	Medium stress	7.3	Fair
			R	6	1	2	1	1		

7. Assessment of rock support design using RMR and Q systems

The estimated support categories based on the Q-system for each class has been shown in **Table 7.** The dimension which is the factor of the size and degree of the excavation is obtained by the De+ Excavation span (diameter or length)/Excavation support ratio by Barton et al. 1974. The ESR is ranges between 0.8 to 5 and suggested values as per [Barton 1974]. The rock bolt length can be estimated terms of excavation with B or height H for crown and wall

$$Lb\ 2+0.15*B \text{ or } H/ESR$$

The rock bolt length for crown and wall can be calculated by applying a 6 m span. The calculated rock bolt length for delivery mains was 2.9 m and was taken to 3.0 m length for the better utility of the iron bars. The ground level of shafts of an initial 10.0 m area was supported with the RCC ring beam as per site geological condition or approved design drawing. The initial 10.0 m area was considered as poor to very poor classes in view of low-stress zones. The thickness of the RCC ring beam was maintained 500 mm thick. Remaining poor and very poor areas were supported with rock bolts 3.0 m in length and 25 mm in diameter at 1.5 m to 1.0 m c/c. Delivery mains were finally lined with MS plates of 32 mm and 25 mm thick sheets for the entire portion (horizontal & vertical) with 5.0 m finish diameter. The gap between the iron sheet and rock masses was filled up with the M30 grade concrete and grouting at 3 m c/c the entire tunnels. The purpose of the tunnel lining was to smooth the flow of water and minimize the abrasion on rock masses.

The rock classes for the excavated length of delivery mains (horizontal and vertical) vs total length are calculated and illustrated in (**Fig. 9.**)

Fig. 9. Rock classes vs total length of delivery mains

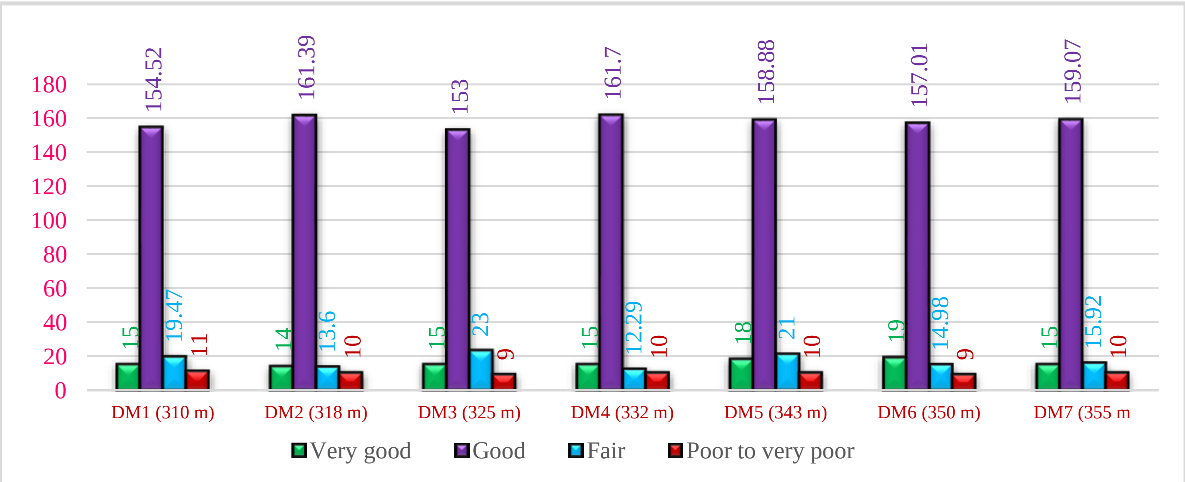

Table 7. Details of rock support arrangement for delivery mains (horizontal and vertical) of KLIS P-6 site

Q values	Rock bolt (25 mm diameter of Fe415)	Below SPL	Spacing (m)	SRF (mm)	Grouting 32-45 mm dia	Un span (m)
40-100	3.0 m long, resin end anchored cement grouted rock bolts	Spot rock bolts at the crown only		-	-	50
10-40	3.0 m long, resin end anchored cement grouted rock bolts	Spot rock bolts at the crown only		-	-	35
4-10	3.0 m long, resin end anchored cement grouted rock bolts	-	2.5 m c/c at crown	50	-	25
1-4	3.0 m long, resin end anchored cement grouted rock bolts	1.5 m c/c Crown to invert levels		50	4 m c/c spacing up-to 4.5 m deep	10
<1	3.0 m long. resin end anchored cement grouted rock bolts	1.0 m c/c Crown to invert levels		100	4 m c/c spacing up-to 4.5 m deep	5
Un span=Unsupported span						

Conclusion

The rock support system for delivery mains was provided as per estimated support categories based on the updated Q support chart. A typical rock support system can be obtained based on empirical rock mass classification. The empirical support system is capable to support the rock masses up to some extent and is easy to use for engineers but difficult to ensure the stability of blasting damage tunnel areas, sudden changes in geology or hidden weak zones. In view of blasting damage probability due to limited rock ledges, a rock mass support system was recommended based on site geological conditions and real-time monitoring. Additional longer rock bolts of 4.0 m and 50 mm thick shotcrete were applied in the dyke/basic enclave and unfavourable joints tunnel reaches. Controlled blasting with 2.5 to 2.0 m pulls in the good and fair rock and only 1.5 to 1.0 m in poor and very poor tunnel reaches was allowed. Timely rock support in the form of sealing shotcrete and spot rock bolts played a key role to avoid any type of overbreak from the critical tunnel reaches. Rock support was provided as per the stand-up time of the rock masses. Grouting was provided in view of the persistence horizontal joints. The total excavated length of these delivery mains is 2333 m and most of the tunnel reaches were supported with design rock bolts and shotcrete while vertical shaft at cistern or ground levels areas were strengthened up-to 7-11m deep with the RCC ring beams. Excavation of these delivery mains which are close to the existing cavern and the reservoir were challenging for Designers, Engineers, and Geologists. With the adoption of modern tunnelling methods all the delivery mains are safely constructed. Safe and stable delivery mains are the output of controlled blasting, real-time monitoring, and timely rock support at KLIS package -6 site even though with limited rock ledges.

Fig. 10. Panoramic view of delivery mains in the operational stage (lifting of water)

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