Uma Oya Project – First TBM Project in Sri Lanka – Focus on Allocation of Lining Types

D. Wenner
Amberg Engineering Ltd., Regensdorf, Switzerland

Z. Shahrokhi
Farab- Energy and Water Project Company, Tehran, Iran

A.K.D.N Atukorala
Ministry of Irrigation and Water Resources Management, Colombo, Sri Lanka

ABSTRACT: Uma Oya Hydropower Project in Sri Lanka has a 15 km long headrace tunnel. It is currently excavated by Tunnel Boring Machine (TBM), which is the first use of a TBM in Sri Lanka. In particularly good ground sections, only the invert segment is installed for the operation of the TBM. In the crown, no rock support or rock bolting is applied. In more jointed and worse ground sections, a conventional full ring segmental lining is used. The allocation of lining types is not only determined by the requirement of stability during excavation, but also by the nature of the tunnel as a pressure tunnel during operation. This paper describes the relevance and applicability of different lining types for TBM driven tunnels with special emphasis on geotechnical conditions seen in Central Highlands of Sri Lanka.

1 INTRODUCTION

1.1 *Project Description*

The Uma Oya Multipurpose Development Project is a water transfer, hydropower and irrigation project in the south-eastern part of the central highland region of Sri Lanka. It will transfer 145 MCM per year. The head difference of more than 700 m will be used for the production of electricity in a 120 MW power plant. Part of the waterway is a 15 km long headrace tunnel (HRT), which transfers water from a reservoir to the pressure shaft, followed by the powerhouse cavern. The headrace tunnel is currently being excavated by double shield TBM (excavation diameter 4,3 m), which represents the first use of a TBM in Sri Lanka.

2 LINING CONCEPTS

Normally, a double shield TBM installs full ring segmental lining. In this project, the geological conditions as well as the TBM allow for two different concepts of rock support and lining: In particularly good ground sections, only the invert segment is installed for the operation of the TBM. In the crown, no rock support or rock bolting is applied. In more jointed and worse ground sections, a conventional full ring segmental lining is used.

2.1 *Full Ring Segmental Lining*

In this project, the full ring segmental lining consists of four precast segments, which form a hexagonal or honey comb lining (Fig. 2). Invert and crown stone are installed together, the two side wall stones half an advance ahead. The inner diameter is 3.6 m. With 25 cm segment thickness, the outer diameter is 4.10 m. The remaining void of 7 to 13 cm is filled by pea gravel closely behind installation of the ring to provide ring bedding and stability. The invert segment has some consoles integrated to fix the rails required for the TBM backup system and for the rail logistics along the tunnel (supply of segments and material, mucking of excavation material). No screw connections and no gaskets are used in the segment joints. This allows quicker installation with higher tolerance, since the gasket is not required to be exactly positioned, as compared to conventional ring segments.

Finally, after excavation, the pea gravel will be injected by grout and also different rock mass grouting measures are to be applied.

2.2 *Open Rock Support*

From early project studies, it was clear that long sections of the HRT will not require a full ring segmental lining. Therefore the TBM was specified to also be able to apply conventional support (as in drill and blast tunnelling) with rock bolts, wire mesh, steel beams and even shotcrete. Two drill rigs are installed directly behind the TBM shield, which can install rock bolts at the entire circumference of the tunnel. Because of space restrictions, drill depth without extension of drill rod allows for rock bolts with 1.3 m length only. They may be applied locally as spot bolts to stabilize certain limited areas with single rock wedges or as systematic bolt pattern.

Mesh reinforcement is used in the crown for head fall protection of small stones during excavation and also to keep them in place where required during operation of the tunnel with internal water flow for power generation downstream. Therefore small mesh size (100x100 mm) has been selected.

Rock bolts and mesh will be exposed to the transferred water. Inspection of these elements and refurbishment is difficult and should be reduced as much as possible. Therefore, corrosion has to be prevented and long life time must be granted. Thus, bolts and mesh of glass fibre reinforced polymer were used. Conventional fully grouted rock bolts might have been possible as well, but they do not provide quick load bearing capacity, which is required with high TBM advance rates (more than 30 m/day were executed). Combination bolts, which have an expansion shell for immediate load bearing and a full grouting for long-term, would have been an alternative.

The highest conventional open rock support designed is a mesh at 120° and 4-5 bolts in the crown over 150° at 1.2 m axial spacing (see Fig. 1), which corresponds to one hub length of the TBM and to the segment length. Shotcrete and steel beams are not designed to be used systematically on the TBM.

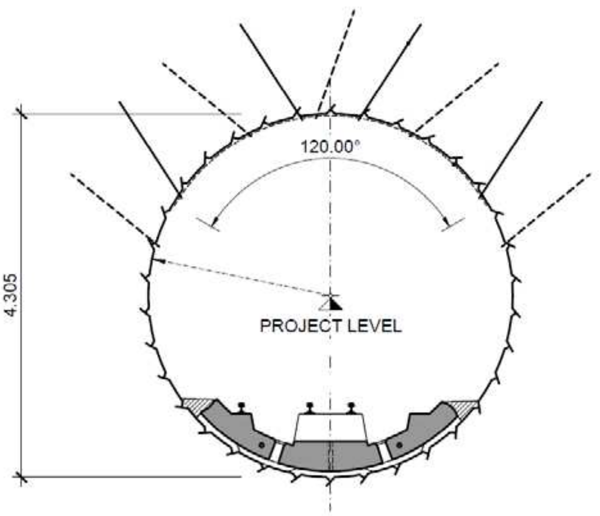

Fig. 1 Maximum conventional rock support

If more than this support is required for some length of tunnel for stabilization of the ground, then the support is changed to full ring segmental lining, see Fig. 2.

In any case, the invert segment is also required with open rock support to facilitate the rail logistics. For use with open rock support, it has been modified from hexagonal to rectangular shape, which later has less hydraulic friction and head lost.

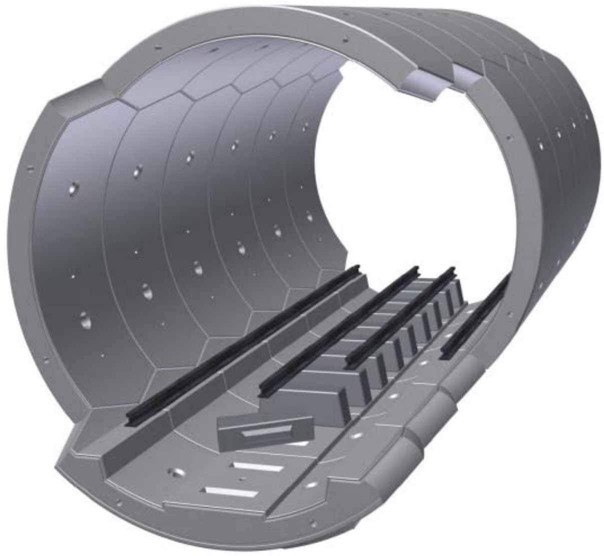

Fig. 2 Layout of full ring hexagonal lining

2.3 *Pros and Cons*

The use of open rock support saves money for the crown and side wall segments, but also for related pea gravel, joint closing and contact grouting. Since a double shield TBM is used, there should not be a time delay from the full ring building, since it can be executed in parallel with advance in good ground conditions. In fact, if many rock bolts have to be installed, then this operation can become time critical and slow down the excavation. Also, the schedule of train journeys remains unchanged between full ring and open rock support lining.

The change of lining type along the tunnel during excavation requires some special measures for stabilization of the ends of the segmentally lined sections. If the transition from open rock support to full ring segmental lining has been decided later than finally required, then some section of shotcrete or cast in place lining is required for long term support of this transition zone. Also, for long term support of the end of the full ring segment sections and to provide a hydraulically smooth transition into the unlined tunnel profiles, a transition zone is constructed by shotcrete lining.

The construction of transition zones between full ring segments and open rock support as well as the support of these transitions during construction is an additional investment in time and cost, which needs to be compared with the savings of not installing full ring segments in sections, where this is technically possible. The change in lining type only pays off, if there is a good chance that the conditions will not change again in the upcoming 50 to 100 m. For this purpose, Tunnel Seismic Prediction (TSP) is used to investigate the ground ahead of the TBM cutter head for as long as 150 m.

3 SELECTION OF LINING TYPE

The selection of lining types is not only determined by the requirement of stability during excavation, but also by the nature of the tunnel as a pressure tunnel during operation: in situ stress, water losses, long term erosion, jointing in combination with changing internal water pressure, the rock mass permeability, head lost and maintenance provisions also dictate the lining requirements.

3.1 *In Situ Stress*

Water pressure in the tunnel during operation is increasing, when the turbine valves are suddenly closed. The surge shaft controls this pressure burst, but some maximum dynamic pressure head still develops. Under worst case conditions, this head may be as high as 1008 m above sea level (asl) at the downstream end of the HRT (the intersection with the surge shaft). The HRT is at level 859 m asl here, corresponding to 159 m internal water head. The minimum in situ stress in the rock mass must be smaller than this pressure. Otherwise joints would be progressively opened by the water pressure (hydraulic jacking). If this criterion is not fulfilled, then a load sharing lining (steel, cast reinforced concrete, pre-stressed, etc.) is required, which takes the tensile stress of the internal pressure.

Up to the surge shaft, this criterion is fulfilled and no load sharing final lining is required.

3.2 *Water Lost*

Water losses are possible, if the groundwater table is lower than the hydrostatic water pressure in the tunnel. As long as the groundwater table is above the maximum operation level at the upstream reservoir (Dyraaba Dam), water losses are not possible. Some pressure deficit was identified close to the downstream surge shaft end, where the pressure surface even exceeds the ground surface. If permeability is high, then seepage flow through the lining and bedrock can reach the terrain surface and induce, due to the water flow, instabilities in the loose overburden material or even in the bedrock surface area. Such instabilities can result in landslides and endangering settlements. Thus in this section, a technical water tight lining is required. This can be achieved by a cast in place concrete lining or by an intense grouting campaign to control the leakage of a segmental lining tunnel. Full ring segmental lining has been installed in the TBM part of the HRT here to avoid water loss and seepage flow up to terrain surface.

3.3 *Rock Mass Permeability / Conductivity*

In weak or fault and shear zones sealing grouting is mandatory in order to minimize water movement near the tunnel, control leakage and to prevent fine materials form being washed out. Also in other zones with increased conductivity or rock mass permeability, this has to be controlled.

The condition for sealing grouting is defined by the rock mass permeability, which has to be low ($\leq$ 5 Lu) or by the rock mass conductivity ($k_{rm} \leq 1E^{-6}$ m/s). The values are project specific. The conductivity may be assessed from the quantity and pressure of water flowing into the tunnel.

For an effective application of sealing grouting with sufficient grouting pressure, a final lining (e.g. cast-in-place concrete, segments) has to be installed.

3.4 *Rock Mass Structure*

The internal water pressure will act as a mechanical and hydraulic action on the excavation boundary. The mechanical action leads to an expansion of the excavation circumference and opens existing discontinuities. Due to the opening of discontinuities, small pieces of rock (which cannot be secured with bolts) could lose their clamping and fall down.

Typical conditions for loosening of rock mass due to internal water pressure are shear and fault zones or fractured and fragmented rock mass zones. The condition for consolidation grouting is defined by the rock mass structure. The rock mass structure is defined by using the jointing intensity of the Geological Strength Index: If the rock mass structure is disintegrated to very blocky (with joint spacing less than 30 cm), loosening of rock mass due to internal water pressure is relevant. In this case, consolidation grouting is required. Again, for an effective application of consolidation grouting, a final lining (e.g. cast-in-place concrete, segments) has to be installed.

3.5 *Long-term Stability of Excavation*

Long-term stability of excavation is satisfied, if the following requirements are fulfilled:

- Guarantee the stability of the tunnel during operation.
- Guarantee the chemical integrity of rock mass (weathering).

The stability of the tunnel during operation is fulfilled in massive non-jointed rock. Otherwise, a permanent rock support (bolts) or a final lining is required, depending on the ground behavior.

Chemical integrity of rock mass (weathering) has been investigated in preliminary studies by slake durability tests. Most rocks are classified in these studies as having very high durability. In some sections of the HRT, weathering may reach down to tunnel level. When feldspar gneiss is exposed to this weathering, clay minerals may exist or could develop over time. Weathered material can be washed out, which could result in problems with long term stability of the excavation.

During tunnel excavation, the degree of weathering is continuously mapped. If material fragments or block corners can be chipped by hand or any weak material like stiff clay joint coating, then a final lining (cast in place concrete, full ring segments) is required to prevent washout.

4 PRACTICAL CONSIDERATIONS OF LINING TYPE SELECTION

In this size of TBM with 4,3 m diameter, space for technical installations is quite limited. The section behind the shield, where a lot of work takes place, becomes congested by the segment erector and the rock bolt drill rigs at the same place. Therefore, drill rigs were often disassembled and not mounted to the TBM, because they hinder full ring segment installation or even normal works in the small diameter TBM.

A shotcrete platform had been foreseen but has never been mounted and used because of practical limitations. The space for shotcreting from a dedicated platform with protected inner segment crane tunnel does not allow for reasonable shotcreting.

Until Dec 2014, ~3.1 km have excavated, 25% by full ring segmental lining and 75% by invert only segments. It is expected that on the remaining HRT tunnel section by TBM (~11.2 km), the percentage of full ring segmental lining support will stay like this or further decrease.

5 CONCLUSIONS

A first TBM tunneling excavation is under way in Sri Lanka for a hydropower scheme. TBM tunneling may also be useful for other hydro schemes with long tunnels involved.

The concept of applying full ring segmental lining in some parts of a tunnel and lighter open rock support with invert segment only has, for the first time, been practically applied in the same tunnel by the same TBM of this size.

The different criteria dictating the type of tunnel lining, like internal water and ground water pressure, in situ stress, tunnel water lost, permeability, rock mass jointing and long term stability have been discussed.

ACKNOWLEDGMENT

The authors thank the client for permission to publish the paper and the reviewers for their valuable input.