Analyzing the role of Segmental lining in the tunnels with Tunnel Boring Machine (TBM) at Vishnugad Pipalkoti Hydroelectric project (4*111 MW). A case study

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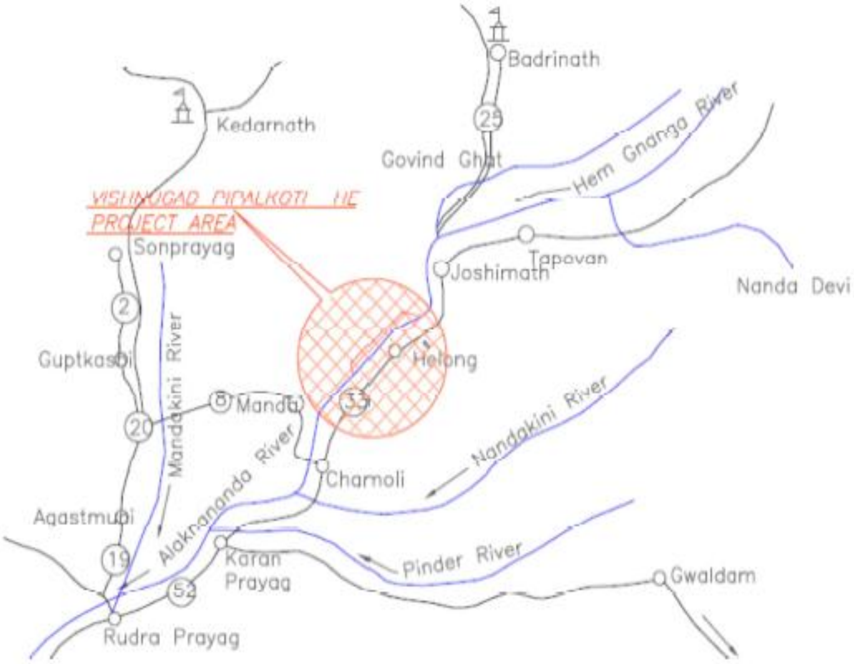
Abstract -*Segmental Lining in tunnels have the potential to play a significant role in managing & providing sufficient strength to the tunnels rather than time consuming concrete lining. The segmental lining or lining with precast segments is very fast process as various segments which are pre-constructed or pre-casted with required grade of concrete & reinforcement, categorized as per rocks classification and geological conditions of the tunnels gets installed with automatic Tunnel Boring Machine (TBM). The process of installation is a continuous process i.e., just needed pre-casted segments to install. Since direct cost of project is associated with time and hence studies and research are made to minimize the cost of construction and reducing project duration. Concrete lining has proved to be a time-consuming process since involvement of various necessary preparations viz. placing of reinforcement followed by shuttering that after concrete of necessary grade according to the design mix needs to be feed and ultimately curing. Construction of the project gets delayed therefore to avoid such issues concrete lining is now days replaced by the Segmental lining as this practice having various advantages when compared with Concrete lining. (Segmental method also have a better aesthetic view than lining since it can't be uniform).*

Key Words: **Concrete segments, Segmental Lining, Tunnel Boring Machine (TBM), Concrete Lining, rocks classification, rock formation, headrace tunnel, shear zone.**

1. INTRODUCTION

The project area of Vishnugad Pipalkoti Hydroelectric project is located at northern India in the province Uttarakhand at Alaknanda River. The hydro power plant is containing a reservoir beside the river with intake and desilter`, the headrace tunnel, surge shaft, underground powerhouse as well as the tailrace tunnel. The electric power of the plant is given with 4 x 111 MW. The report at hand is focusing at the segmental lining of the headrace tunnel, describing the geometrical design of the segmental lining and its erecting structural analysis.

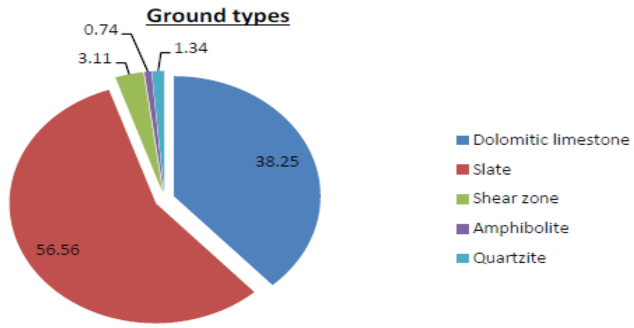
Salient features of VPHEP	
Dam/ water level at dams:	Type Concrete Gravity Dam, Length 89.55 m., Height 65 m., Top El-1270 m., Foundation El-1205, FRL-1267 m.
Headrace tunnel:	Length 13.4 Km, Dia. 8.8 m. (finish), Design flow: 228.86 m^3/s and circular shaped
Surge Shaft	Restricted Orifice Type, Dia. 15 m./22 m., Height 140 m.
Pressure shaft	Nos 02/04, Type Circular, Dia. 5.2m/3.65 Length 310m/35m
Powerhouse	Type U/G, Size 146x20.3x50, Unit 04 nos. (each 111 MW), Turbine types: Francis
Surge tank	Type U/G, Size 150x16x35, Max. Surge Level 1040m, Min. 1026.5m
Tailrace tunnel	Size 8.8 m. dia. (Horse shoe shaped), Length 3070 m.



Plan view

1.1 Case study-Geology

(Pipalkoti and Gulabkoti formations are present along the headrace tunnel. Both rock formations are composed of Dolomitic Limestone, Slates, Amphibolite, Quartzite and shear zones the percentage of Dolomitic Limestone is given with 38.25% while Slates are present with 56.56%. The amount of shear zones is given with 3.11%. Amphibolite is proposed with a percentage of 0.74% while Quartzite is predicted for 1.34% of the total length.), the use of segments has the potential to greatly improve the efficiency and sustainability of tunnel.



1.2 Plan view

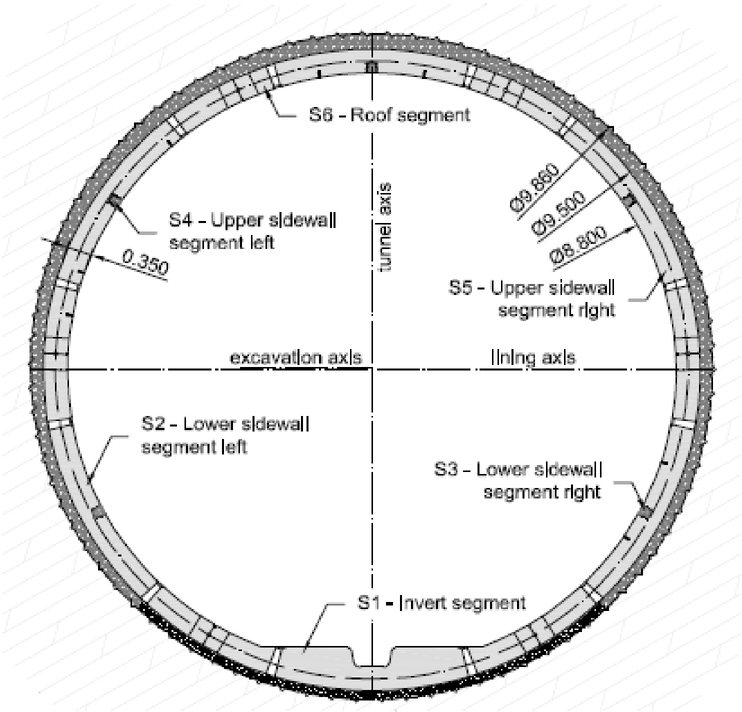
The headrace tunnel of Vishnugad Pipalkoti H.E Project will be excavated by drill and blast method as well as by TBM (Tunnel Boring Method). Tunnel alignment is composed of the following geometric elements the total length of the headrace tunnel is 13'430.37m, where 12km are excavated by TBM and lined with segmental lining. The current report is only focusing on the approximately 12.0km long head race tunnel excavated by TBM. This tunnel stretch will be designated further as Vishnugad HRT.

1.3 Lining Segment's dimensions

Irjet The following salient features have been defined to serve as a basis within the lining design

- Internal tunnel diameter: Di =8'800mm (as per requirement)

- Segment thickness: st =350mm
- Excavation diameter: Dexc =9'860mm
- Segment width (nominal): sw =1'500mm
- Annular gap (nominally): a: =180mm (geometrically derived)
- Segment system: left / right ring system



Typical Section

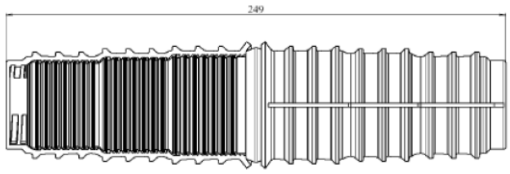
1.4 Methodology- Facilities for TBM operation

- In order to start actual excavation of HRT by TBM there are various initial facilities are to be developed which supports various functions such activities are listed below.
- Development of TBM Platform for assembly of TBM
- Development of Casting & Initial curing Yard
- Development of normal curing yard
- Development and installation of high-capacity power Plant
- Installation of Assembly support equipment's.

1.5 Ring Installation

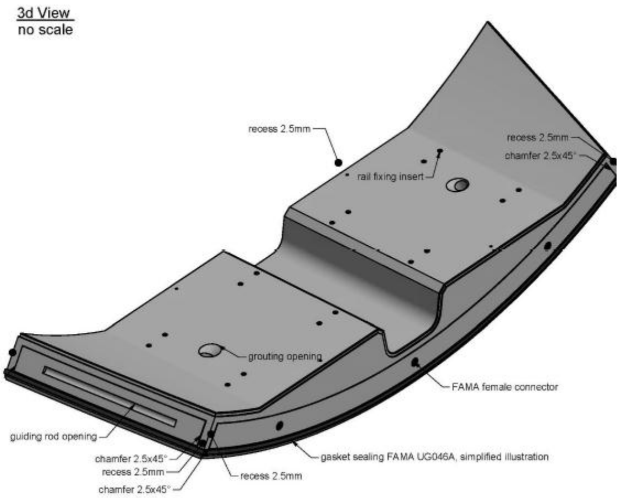
For assembling of the segment ring, the invert segment will be installed first, being put on the dowels of the circumferential joint and resting on the invert pads, but in addition being held in position by means of the auxiliary thrust cylinders of the TBM. Within the next steps the both left and right bottom and top sidewall segments will be installed and kept in position by means of the auxiliary thrust cylinders. As last element of the ring, the key segment will be placed in position by means of the auxiliary thrust cylinders. Now the complete ring is assembled.

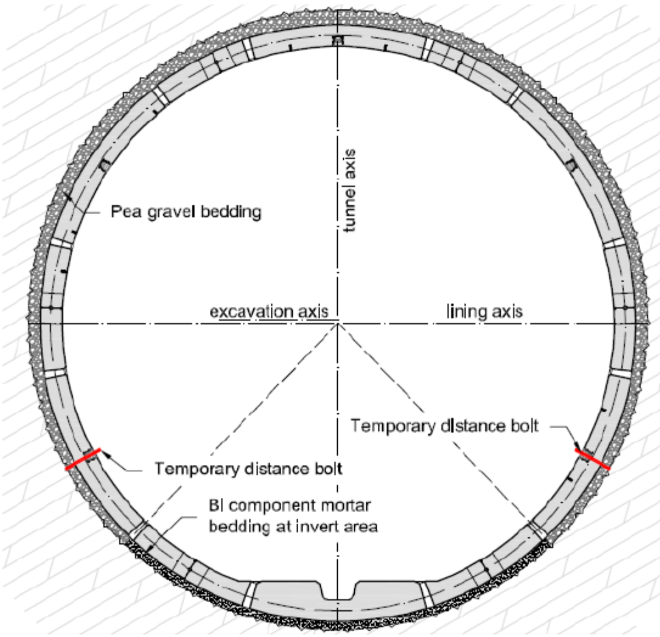
Dowel connectors (three for each segment) have the function to facilitate the proper placement of the concrete segment during the ring assembly and to guarantee the alignment when concrete segments come into contact with each other. They feature a strong extraction force, that allows to withstand the gap pressure exerted on concrete segments from rubber sealing gaskets and by the weight of the segment itself. They are made by extruded polyetilene (P6).



Dowel connector

Within the next step re-gripping takes place, meaning that the tail shield of the TBM is pulled towards the front shield, thereby releasing the last ring from its protection. During this procedure the auxiliary thrust cylinders are still under pressure providing full support for the new ring. When the new ring has left the tail shield the segment lining immediately is filled with pea-gravel on top and bi-component grout.





The maximum size of the pea-gravel is 16mm (range of 8-16 mm) and to be dimensioned and shaped to allow its injection by using air pumps (concrete pump for dry mixture) mounted on the back-up gantry. pea-gravel is injected behind the second-last completely assembled ring. Pea-gravel is injected using the holes presents on each ring, both higher holes on both side segments and in the central and transverse hole at the crown segment. Bi component mortar is a mix of cement, bentonite, water accelerated with silicate. Immediately after injection the grouting holes will be plugged with suitable wooden plugs to prevent the pea gravel/bi-component mortar from escaping.

1.6 Lining type

The segmental lining system for Vishnugad HRT is specified as follows:

- Rhomboidal left/ right ring segment geometry

- Composed of 5 segments and one key segment per ring

- Two trapezoidal segments (S1 – Invert segment & S6 – Roof segment) and 4 rhomboidal segments (S2 to S4 – left/right, upper and lower sidewall segments)

- Caulked grooves at segment intrados at longitudinal and circumferential joints

- Guiding rods in longitudinal joints for increasing segment installation accuracy

- Connectors at circumferential joint for increasing segment installation accuracy

- Gasket sealing at circumferential and longitudinal joint.

- Central water ditch respectively walking area.

The rhomboidal segment system has already proved to work sufficient at similar projects with large tunnel diameter. Guiding rods in the longitudinal joints and connectors in the circumferential joints will help to achieve accuracy during installation and backfilling of the segments.

The nomenclature of segments is designated with their installation sequence, beginning with S1 – Invert segment at first and ending with S6 – roof segment, which has the function as key segment. Furthermore, the segment designation indicates the type of ring. The suffix "L" stands for "left ring", while the suffix "R" stands for "right ring".

As example:

- S1**L** – Invert segment, **left ring**

- S4**R** – Lower sidewall segment left, **right ring**

Segment designation without suffix is describing segment features for right ring as well as for left ring.

S1 – Invert segment

The trapezoidal invert segment with its designation "S1" is the first segment to be installed within the tail shield. The segment has two grouting openings located in the flat invert area, where also rail fixing inserts are located. Contact area is defined with a width of 190mm at longitudinal joint and circumferential joint. At corners between circumferential joint and longitudinal joint recesses are foreseen to avoid segment damage. The circumferential joint offers 3 connector openings at leading side and 5 connector openings (3 standard connector + 2 openings for Anixter Bi-Cone) at trailing side.

S1-Invert segment

S2 – Lower sidewall segment left,

S2 – Lower sidewall segment left

The lower sidewall segment at left side (in heading direction) is called "S2" and will be installed after invert segment "S1". The segment has two grouting openings for pea gravel application respectively for grouting purpose. The circumferential joint is offering 4 connector openings (3 openings for standard connector + 1 opening for Anixter Bi-Cone) at trailing as well as at leading joint. For centring purpose, the segment has a safety pin insert, fitted with plastic insert for proper final closure.

S3 – Lower sidewall segment right

The lower sidewall segment is showing the same characteristics than segment S2, with additional fixing inserts to mount some cable and pipe holder.

S3 – Lower sidewall segment right

S4 - Upper sidewall segment left

S4 – Upper sidewall segment left

The upper sidewall segment left, designated as S4 is showing the same characteristics than segment S2, with additional fixing inserts to mount the conveyor belt.

S5 – Upper sidewall segment right

Upper sidewall segment right is showing the same characteristics than segment S2.

S5 – Upper sidewall segment right

S6– Roof segment,

S6 – roof segment

The roof segment, designated as S6 is the key stone of the segmental lining system. Beside the two radially located grouting openings, in the top an additional inclined grouting opening is foreseen right in the centre line to increase the effectivity of pea gravel application in the roof area. Corners between circumferential joint and longitudinal joint are fitted with a recess to avoid segment damage. The leading circumferential joint is containing in total 5 connector openings, 3 for standard connector and 2 for Bi-Cone connector, while on trailing circumferential joint the 3 standard connector openings are foreseen.

1.7 SEGMENT JOINTS SEALING & SEGMENT REPAIR WORKS

SEALING

The next step during the normal activities (excavation and re-gripping), in the range of the Back-Up decks, the caulking grooves will be closed with mortar and all repair works is done. Within the same step the major number of grouting holes (about ¾) is filled with a repair mortar prior to contact grouting. The remain grouting holes later are fitted with packers for grouting.

SEGMENT REPAIR

Segments can be damaged in one of the three following phases:

1- Fabrication

2- Transport to the tunnel

3- Erection

Scope of this report is to define the principle of the repair procedure of damages held during the erection.

Two different types of damages can happen:

1- Edge broken

2- Crack appeared

To repair breaking the following procedure may be used:

1. Concrete surface cleaning and broken concrete parts removing. By using chisel, concrete surface will have new roughness.

2. Washing by water with pressure.

3. Removing of water excess keeping wet the part to be repaired

4. Applying of admixture as per supplier technical sheet

5. Applying more than one layer considering that each layer has a thick of maximum 20 mm. the subsequent layers can be applied when the previous is dried out.

6. At the end of the operation the surface will be smoothed out by spatula

7. Keeping wet the surface for the next 24 hours

Segment details

In the following sub chapters segment details will be described further in terms of:

- Longitudinal joint

- Circumferential joint

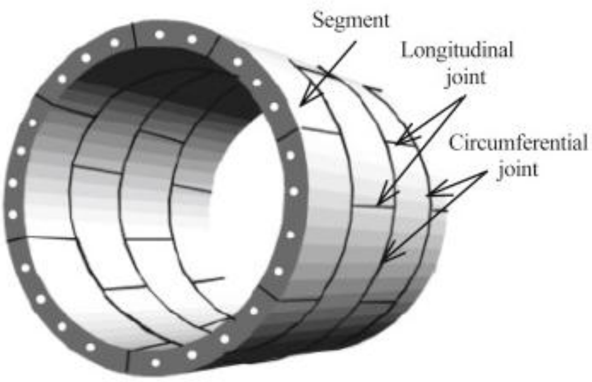
- Gasket sealing

- Grouting openings

- Inserts

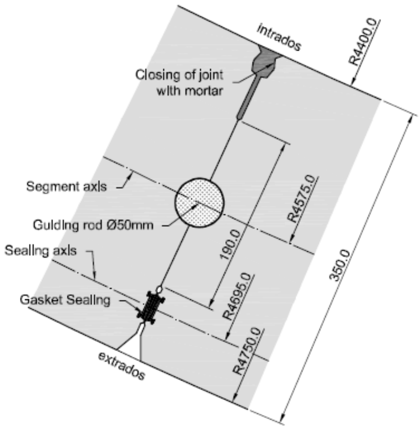
- Safety pin openings

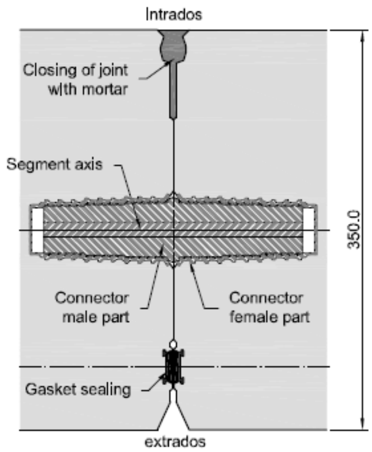
- Segment markings



Longitudinal joint

The longitudinal joint is showing a flat contact area between two segments, where forces will be transmitted. Inside the symmetric contact area a guiding rod opening is located. Guiding rod opening radius is slightly bigger than the guiding rod itself, avoiding load transmission over guiding rod. The intrados joint will be closed with mortar to improve the hydraulic friction behaviour. The intrados joint is design in a self- locking principle, to avoid that mortar will fall into turbine water. At extrados side of contact area a gasket sealing is located.





Longitudinal joint **Circumferential joint with standard connector**

Circumferential joint

Circumferential joint is showing a flat contact area between two segments, where piston forces will be transmitted. The intrados joint will be closed with mortar to improve the hydraulic friction behaviour. The intrados joint is design in a self-locking principle, to avoid that mortar will fall into turbine water. At extrados side of contact area a gasket sealing is located.

Gasket sealing

Due to tender requirements a gasket sealing is required to withstand against a water pressure of 8.0bars. For achieving the requirements gasket sealing "FAMA U.G.046A" will be used. Considering the systematic gap referring to the technical specification shown in Annex 1, the required pressure of p=8.0bar can be reached with the following gaps:

- 5.3mm at offset 0mm

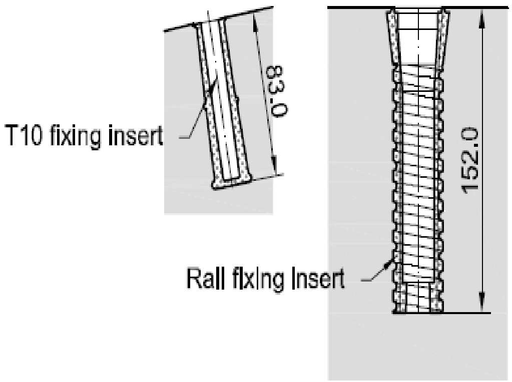
- 4.2mm at offset of 5mm

- 2.75mm at offset of 10mm

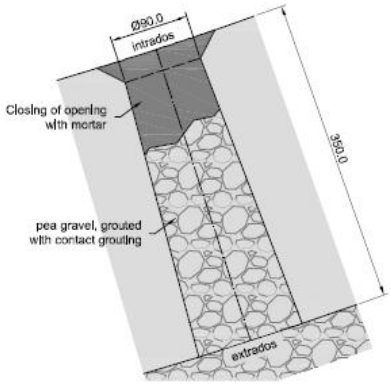
Grouting openings

Grouting openings are required for the filling in process of pea gravel as well as for grouting purpose. Due to hydraulic reasons all grouting openings must be closed with mortar. Due to the shape of the grouting openings a self- locking effect of the mortar plug is present, preventing the mortar from falling into turbine water.

Grouting openings



Fixing inserts



Inserts

Two types of inserts are used in the current segmental lining.

- T10 insert
- Railway fixing insert

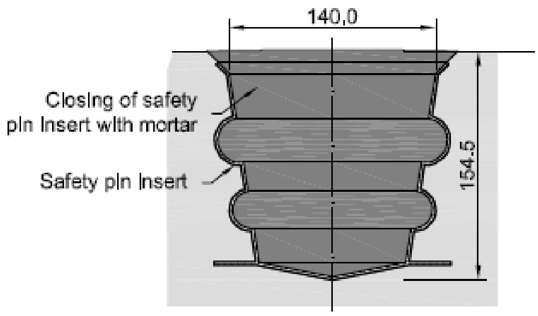
Railway fixing inserts are only used at S1- Invert segment, while T10 fixing insert is used for

all other fixing purpose as ventilation, conveyor- belt and pipe holders.

Safety pin opening

Due to the use of vacuum erector, safety pins openings are required to transmit shear forces

(self- weight during rotation) along vacuum plate.



Safety pin opening

1.8 SEGMENT JOINTS SEALING & SEGMENT REPAIR WORKS SEALING

Within a next step and during the normal activities (excavation and re-gripping), in the range of the Back-Up decks, the caulking grooves will be closed with mortar and all repair works is done. Within the same step the major number of grouting holes (about ¾) is filled with a repair mortar prior to contact grouting. The remain grouting holes later are fitted with packers for grouting.

The material used to seal the joints between segment and rings are: Premixed mortar with Sika Monotop-622 and/or Sika Latex (mix design has to be studied in the job site); In special cases could be used SIKA Igas Nero or similar the mortar is used to fill-up the grooves along the perimeter at the intrados. Grooves are shaped to capture mortar, avoiding any escaping toward tunnel. In a certain case, when water can flow from the bottom, along the perimeter of the invert Segment, is applied a cord of special product (IGAS NERO SIKA) bituminous elastoplastic sealing agent.

1.9 Summary and final statement

The 13.40km long HRT (head race tunnel) of hydroelectric project Vishnugad Pipalkoti shall be excavated by a Double Shield TBM and lined with a segmental lining. The design discharge is about $Q=228m^3/s$, therefore an internal diameter of øi=8.80m is foreseen. The foreseen rhomboidal gasket sealed segment system is composed of two trapezoidal segments (Invert segment and roof segment) together with 4 rhomboidal segments. The 350mm thick segments will be bedded with bi component mortar in the invert and pea gravel in the remaining circumference, which will be modified with contact grouting in a separate step. Temporary distance bolts are foreseen for securing the segmental lining until the full bedding is available. To achieve quite a smooth hydraulic behaviour all joints and large diameter openings have to be closed with mortar. Guiding rods in longitudinal joints and connectors in circumferential joints are helping to achieve an accurate segmental lining installation. An essential part of the segmental lining of VPHEP HRT is the grouting procedure. Over the entire tunnel systematic contact grouting on cement basis will be applied. In special stretches borehole grouting for consolidation, sealing or intervention purpose will be applied on cement basis. For intervention grouting also chemical grouting material are common. The proposed method is considered to be most economic and has proved to work in practice.

1.10. CONCLUSIONS

In this research paper, we analysed the role of Segments in tunnel management.

- We found that such technologies, such as segmental lining with the help of TBM have the potential to significantly improve project completion timing while maintaining the quality standards.
- These systems use a range of technologies, including sensors in tunnels which are used for monitoring the movement of hill, communication systems, and data analysis tools, to gather and the data and provide timely information to the agencies.
- This work focuses on the crucial features that should be incorporated into the numerical model when examining the response of a segmental liner which is generally employed in guard- driven tunnelling.
- The invariant ring model has been extensively used in design practice of shield- driven round tunnel in soft ground due to its simplicity.
- Specialised TBM is equipped to construct tunnel in highly abrasive ground without impacting the grounds nearby.

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