



ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL & ENVIRONMENTAL ENGINEERING

**A thesis proposal submitted to the School of Civil & Environmental Engineering
in the partial fulfillment of the degree of Master of Science in Railway Civil
Engineering**

**Evaluation of Different Seepage Treatment Methods in Railway
Tunnels**

Case Study: Addis Ababa Light Rail Transit System (LRT)

By

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March 2016

Declaration and Copy right

I, Dereje Tesfu, declare that this thesis is my original work and that it has not been presented and will not be presented by me to any other University for similar or any other degree award.

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Thesis Submitted to Addis Ababa Institute of Technology, School of Graduate Studies in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering with Railway Engineering.

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Abstract

This research investigated and evaluated water blocking techniques in tunnel sections present at the St. Georgis tunnel using 2D modelling by numerical simulation software namely GeoStudio. With the help of GeoStudio extension, GeoStudio SEEP/W, the tunnel geometry along with material property of the concrete and backfill material using readily available hydraulic property as an assumption was modelled. This together with simplifying assumptions such as material homogeneity and isotropy, maximum water flux or infiltration pressure was seen at tunnel bottom of the side wall and clearly seen much like the actual condition.

With this assumptions, the model showed that, the tunnel section exhibits maximum flux or infiltration in the bottom corner each side. The inner lining of the tunnel in particular have been studied and results show that the nodes exhibit water infiltration occurs in each node point with the maximum $9.75E^{-05}m^3/s$. Proper application of water proofing helps in preventing water infiltration throughout the tunnel lining. Even if exterior waterproofing is part of the solution, it is also necessary to implement a drain pipe at the bottom of the tunnel to remove the water that will accumulate near the tunnel bottom. One additional finding here would be that the protection of the waterproofing on the tunnel side linings will be greatly increased if a rock-fill can be implemented on the as a backfill material for a limited width so that the gravitational drainage of the rock-fill avoids any saturation to develop at the tunnel side lining. In both cases though, the implementation of a drain pipe is mandatory.

Furthermore the research has managed to deduce the applied water proofing material has malfunctioned or otherwise since it has been claimed that water proofing material has been implemented on all section of the tunnel, where there should have been less threat of leakage according to the research, the top slab of the tunnel, on actual ground it was seen to have had high leakage.

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1. Introduction

1.1. Railway in Ethiopia

The railway industry in Ethiopia goes back to 1897 in which the construction was undertaken by a foreign company. The operation of the railway stopped due to its primeval technology and high maintenance costs.

Out of understanding and wanting to push forward the growth of Ethiopia, the then leader of the empire King Menelik II came to an agreement to construct railway on the Entoto-Harar-Djibouti route on 1893 and construction began three years later together with the inauguration of the Imperial Railway Company of Ethiopia. Due to technical problems and bankruptcy it was terminated in 1907. It again resumed on 1909 to achieve a milestone in construction reaching Addis Ababa in 1917. Two years later it was official opened to the public. After the Italian invasion, the Italian authority considered new routes to pursue which was later left. As the treaty signed by both the then Ethiopian Government and Franco-Ethiopian Railway Company in 1959, it gave absolute freedom in using the railway route till 31 of December 2016. After becoming an independent country in 1977, Djibouti and Ethiopia came to have a composed management team for the railway infrastructure from the countries in 1981.

Modern railway infrastructure will support the national economy of Ethiopia through minimizing cost of passenger and freight transport. Even though cost of construction and maintenance is generally high for any railway scheme, it outweighs the losses by supporting majority of the population with lower income.

In Addis Ababa, the current railway project, namely the Addis Ababa Light Rail Transit construction has been underway for the past three years and has progressed to its final stages of the civil work including the construction of a tunnel. The St Georgis tunnel can be listed under one of the mega structures to be built with in course of the project.

As it has always been, seepage problem will and does threaten this underground structure. Seepage in concrete should be carefully dealt with because it weakens the reinforcement and lowers the structural strength. The St Georgis tunnel at the construction completion stage exhibited water leakage or seepage from the surrounding area.

This thesis research will evaluate seepage prevention techniques based on the St. Georgis tunnel as a reference using numerical simulation.



Figure 1 Status at the Time of Study

1.2. Study Area

St. Georgis tunnel is located at Piassa St. Georgis Church, which is the center of Addis Ababa. The area is densely populated. The tunnel is built under three roundabout, St Georgis roundabout, Minilik roundabout and Abune Petros roundabout.

Its surroundings is populated with government office building and residential houses towards the east and south section, residential buildings towards the north and St. Georgis Church towards the west.

In geographic projection, the tunnel start is located at Easting=472745 meters and Northing=998960 meters chainage 1+730 and the end is located at Easting=472362 meters and Northing=998551 meters chainage 2+390 spanning around 720 meters in length.

During the construction stage, the contractor used the cut and cover method to provide space for the tunnel. So the construction disturbed and demolished the existing road on top. In order to help keep the surrounding buildings intact during the construction, the contractor provided reinforced sheeting along the cut wall edge. Afterwards casting of the concrete floor, wall and top roof was performed. When the

tunnel was fully constructed, the contractor placed backfill material for the wall and top side of the tunnel. Afterwards a second contractor was engaged in the construction of the existing road route.

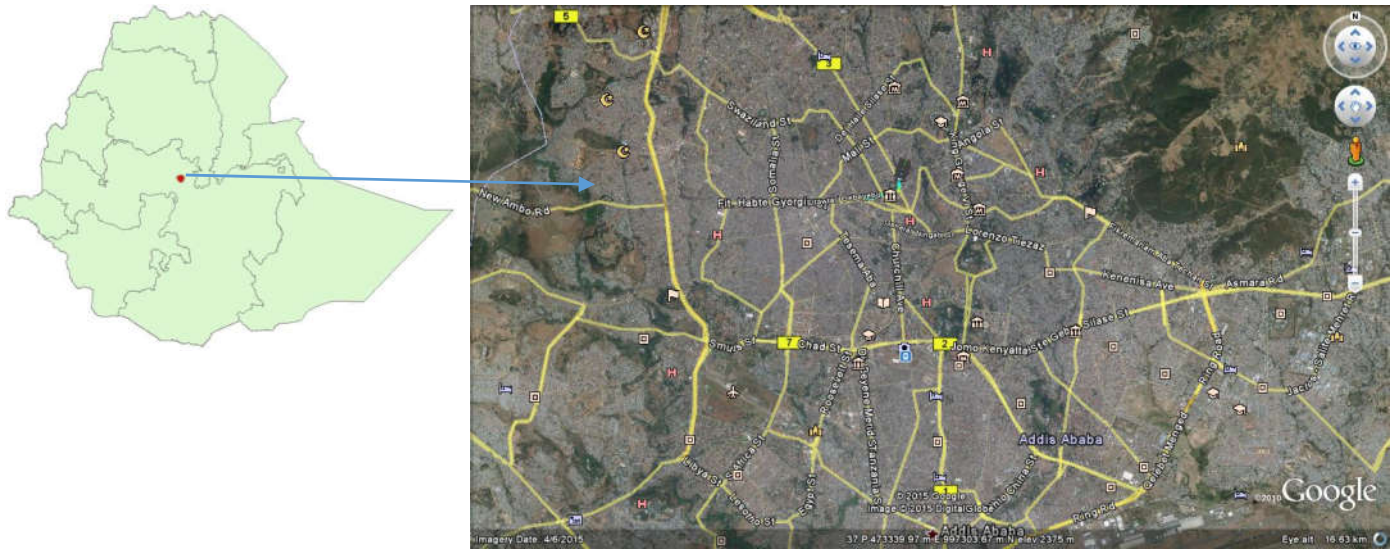


Figure 2 Ethiopia's Map (LEFT), Addis Ababa's Aerial Map (RIGHT)



Figure 3 Tunnel Start (Left), Tunnel End (Right)

A symmetrical turnout is located near 1+850m. The tunnel has two separate lane with maximum span of 7.94 m together with a 0.1*0.2 m open ditch for waterway.

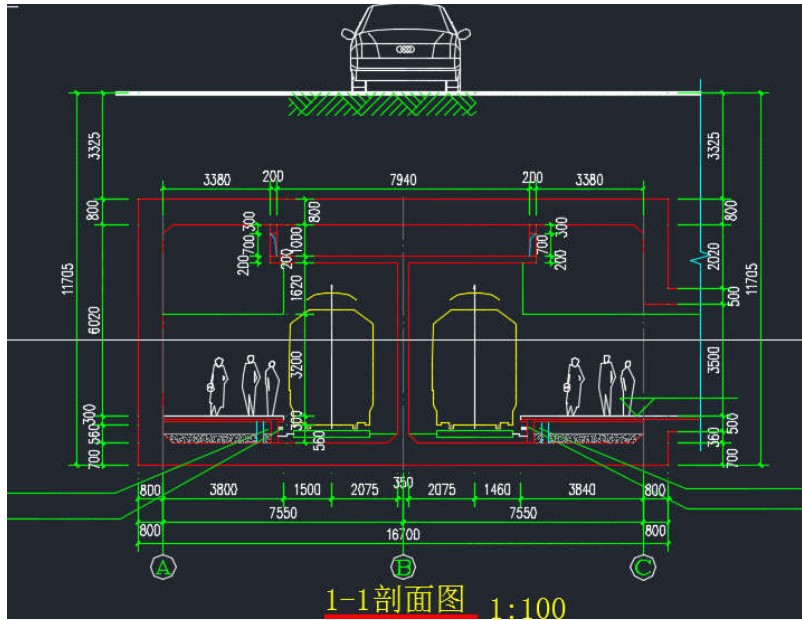


Figure 4 Tunnel Platform at station YDK 1+930

The start station located at 1+731 has an open ceiling in both lanes exposed to the above road surface and the profile grade falls back from the turn out station towards the start.

The platform located at 1+930 has access to the above road surface in three locations fully exposed. As can be seen in the picture below, the exposed section or tunnel portals are the two in the top section and one at the bottom. The tunnel portals are used by commuters as a passage way between the tunnel and the existing road above. It may have a stair case or an elevator.

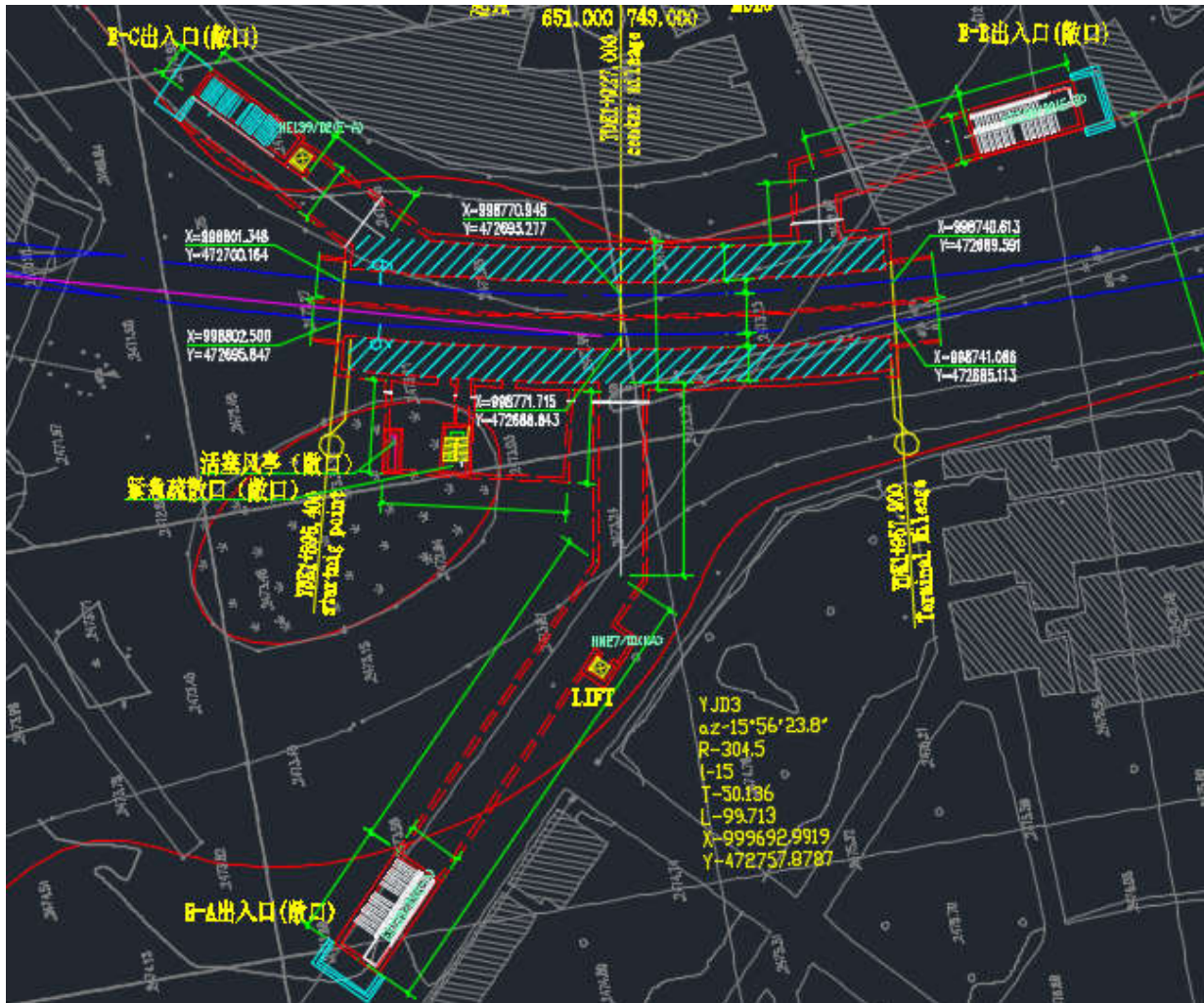


Figure 5 Tunnel Portals (two in top left and right corner and one in bottom center)

1.3. Geogis Tunnel Observation

On a field survey, it was observed that the tunnel lining was under heavy seeping pressure from the surrounding. At the time of observation, there neither was pipe burst from the water supply pipes of the municipality nor was any direct pressurized water exposure from the surround buildings or places. As has been explained before, the contractor implemented cut and cover method to place and construct the tunnel. So as part of the construction methodology, the width of excavation for the tunnel included ample space for working area and ease of machinery operation. On both ends of the cut wall, there was a reinforced sheathing. So any placement the municipality pipe lines had been placed outside this buffer region.

Some location along the tunnel wall had exhibited large area of water leakage approximately within 50 centimeter range from the tunnel finished floor level. It can clearly be seen in the picture below that the leakage is only zoned in that 50 centimeter range. And also, the water pressure is intense in that the water is not trickling but pressurized.

At other locations, heavy water gushing was seen at the underground platform section from the top slab. One other location was at the tunnel start. At that location, there was a septic tank provided for the tunnel toilet. At that location, water was pumping up to railway track line from the floor level and septic tank. Large volume of water used to accumulate at the finished floor level. As a counter mechanism, the contractor pumped the water outside to the roadway above every day.



Figure 6 Side wall leakage



Figure 7 Tunnel start water pumping

1.4. Statement of the Problem

In the underground concrete structures construction sector, the seepage problem has always been found to be serious case in any situations. In particular to the Addis Ababa LRT project, upon site visit, it has been seen that most sections of the tunnel has been experiencing leakage problem.

According to the design, the first stretch from the tunnel start up to the symmetrical turnout, the vertical grade or profile of the railway geometry falls back to the tunnel start. This in turn means that any water leakage, seepage or water gushing experienced, any drainage placed within this section will have nowhere to go. Not only this, any leakage problem within a concrete structure is fatal to the structure's life decreasing its life span.

For an underground structure, water pressure may arise at any time and may have a drastic effect on the structure. Water pressure together with poor workmanship in concreting or waterproofing stage may lead to water ingress or leakage. Possible methods of solving this type of problems lay between either implementing **water blocking techniques** to the exterior of the structure or implementing remedial measures to the interior of the structure after the problem is seen on problem specific locations.

1.5. Objective of the Research

It is well known that concrete is permeable in allowing certain gases such as CO_2 and SO_3 and liquids including rain and ground water to some extent but on a minimal amount. If in case the liquid or water movement within the concrete involves the transportation of chloride salt, it will be a means to corrosion of the reinforcing steel.

Therefore, instead of trying to achieve completely impermeable reinforced concrete mass, which is totally impossible under the current condition, permeability of concrete can be minimized to a certain level.

The St. Georgis tunnel during its construction stage, utilized concrete mixes premade in concrete mixing plants. Even though quality concrete made within a concrete mixing plant, which will be under controlled environment, is of high quality, yet again it was observed on a site survey within the tunnel that water seepage, leakage and water gushing on the tunnel lining to be present.

Therefore the objective of the study is to evaluate means of water blocking techniques in tunnel sections.

1.6. Limitations

Throughout the research, many obstacles had been faced including:

- Data shortage
- Time gap between actual site work and research
- No actual experiments on material property (assumptions on material property)
- Lack of software license
- Limitations on student version software license (interface or geomembrane material can be modelled in fully licensed version)

2. Literature Review

2.1. Tunnel Seepage History

Tunnel history tells us that frequent tunnel problems involves water ingress one way or another. It causes ongoing problems on the structure and its fittings. These problems usually will be treated once the tunnel has entered in to the operation stage. The problem causes effects on the external, structural and functional elements of the tunnel and its surrounding. Mainly in reinforced structures, past problem might either be caused by construction and design faults which often involves the misjudging the property of the concrete material. The littlest things as concrete cover design faults can be a means to concrete reinforcement bars to corrode hence providing ways for loss of structural capacity. Another kind of problem is water tightness in certain type of construction methods which can be crucial at times. In any cases, once water permeation is seen, in the long term the structure will lose its rigidity as it is exposed to dissolved salts. Some cases in the past also were a result of the head increase of ground water table after completion of construction. One to keep in mind is that concrete might only have a reduced or low permeability hence any exposure to ground water will eventually lead to the concrete being decomposed by the dissolved salt and further more corrosion of the reinforcement. (Haack, 1986)

In 1985 Germany, a 14.2 km double track light railway reinforced concrete tunnel with several layers of the waterproofing bitumen membrane constructed in the town center exhibited a measured 10 liter/day seepage. This seepage exhibited seen in number of locations along the tunnel length. No further effect to the structure and fittings was seen at the time. Afterwards, the management decided to seal and watertight the whole length of tunnel by re-grouting. (Haack, 1986)

In 1960 Germany, a 0.7 km double track underground railway reinforced concrete tunnel with external bitumen sealing constructed in the town center also exhibited seepage. As it was several types of chemicals were seeping through and destroyed the sealing. The seepage of the chemicals also created discomfort among whoever is using the tunnel due to its smell. (Haack, 1986)

Afterwards, the management decided to seal and watertight the whole length of tunnel by re-grouting. For the floor maintenance, they removed lower part of the tunnel and used foil-bitumen seal combination to create a waterproof layer under. As for the wall maintenance, the same method was

used but in order for it to stand vertical the joints between were soldered with steel section. (Haack, 1986)

In 1977 Germany, a 1.6 km double track light railway tram tunnel with internal and external water tight concrete and shotcrete shell exhibited leakage in between the joints. The seepage created wet spots and dripping water at various locations of the tunnel. This further had effect on the tunnel fittings and electrical installations. Wooden sleeper and electrical wirings were severely damaged. So the management decided to grout the interior side with foam. (Haack, 1986)

In 1980 China, a 10 km single track precast reinforced concrete metro railway tunnel which was part of Hong Kong mass transit railway exhibited ground water with dissolved salt. Due to the presence of the dissolved salt, the reinforcement bars corroded and chunk of the concrete were spalling off. Alongside this, the track flooring were destroyed by the current created by the faults in the electrical wirings caused by the water leakage. So the management decided to remove the concrete which was affected by the dissolved salt and rebuild the lining. (Nozawa, Goto, & Yoshida, 1980)

In 1944 Japan, a 3.6 km single track steel-reinforced railway tunnel in which a portion of the tunnel lies under sea section witnessed leakages at several locations along the tunnel. And since the tunnel lies under the sea, the leakages constituted of dissolved salt which had adverse effect. The concrete lining was destroyed and multiple cracks were exhibited on the concrete track slabs. Subsequently the electrical and track facilities were deteriorated such as the fastenings, wiring insulation, lightings and rail surfaces. Even though the repair work was expensive, with the help of the sealing coats which intern sealing voids of the concrete, the repair made a remarkable change. (Okada & Kawaguchi, 1980)

In 1970 Japan, a 1.4 km reinforced concrete railway tunnel with inner shotcrete exhibited acidic ground water flow seeping through. This condition has been witnessed even at the time of construction. Eventually severe corrosion on track facilities, coloring of the lining and deteriorated electrical facilities insulation were typically noticed along the tunnel. So to elevate the deterioration, with the help of chemical grouting the seepage was reduced. (Okada & Kawaguchi, 1980)

2.2. Flooding and Water Inrush in Tunnels

Flooding in general can be caused by three factors namely meteorological factors, hydrological factors and human factors. Climate changes, meteorological factor, affecting the frequencies and intensity of rainfall and storm. Hence, it is the main contributing factor for flood peak discharges. Antecedent soil moisture and ground water levels affecting the ground rate of infiltration can be grouped under hydrological factors. (World Meteorological Organization, 2008)

Amongst the human factors land use change influence runoff retention character of the ground. Different types of land usage including buildings, highways, factories, industries and real-estate. This means that any urbanization development will result in disruption of the normal water flow and hence being one of the contributing factors to flooding.

Such land coverage by concrete, asphalt and other impervious construction materials, contribute highly to the production of surface flooding in urban populated areas. In case of tunnel flooding, while the above mentioned factors contribute as an external source of flood, internal sources of flooding can also be mentioned additionally such as active firefighting systems, fire hydrant leakages, tunnel lining infiltrations and seepages and emergency exit leakages.



Figure 8 Leakages in tunnels

In tunnel construction, water inrush and mud gushing are the challenging issues. The surrounding strata undergo drastic changes due to the excavation, hence releasing energy stored in underground water carrying mud and sand that gush to the tunnel face. Water inrush in tunnels can be classified by location,

time delay of the process, quantity and inducing factors. The inducing factors include condition or status of surrounding rock, rain impact and construction induced disturbance. As it is, tunnel excavation disturbs the original strata formation. Treatment for such conditions can be grouped in to drainage oriented control, blocking oriented control and drainage-blocking oriented control. Energy relief and pressure reduction method, advanced grouting (for fractured rock) and advanced jet grouting (for deformation control) are the technologies mostly implemented. (Zhao, Li, & Tian, 2013)

2.3. Tunnel Drainage Recommendations

As tried to explain before, water egression or infiltration to the tunnel has many ways starting from the leakages in utility line up to tunnel lining leakage by itself. In rail transit system with the signaling, communication and other train power supply present and susceptible to this leakages may even lead to serious mishaps in the occupants and users as well as the tunnel structure itself. (US Department of Transportation, 2005)

Possible outcome water infiltration can include eroded concrete liners, corroded reinforcement steel due to inadequate concrete cover, soil pump between cracks, settlement problem as well as development of stresses. When this situation tend to create a serious problem, detailed study is required to investigate the source of the leakage and the material property of the tunnel lining so as to provide a reasonable solution. Most of the time, this leakage conditions may not have a permanent solution. As a general guide line, there are short and long term repairs to conditions like this. Short term repairs such as temporarily diverting the infiltrations up to installing pipes in to the tunnel lining so that, the pipe will act as weep hole at main leakage area. Long term repairs such as fitting insulation panels in rock tunnels to secure to the rock, providing water proofing membrane within the inner wall of the tunnel (which will affect and lower the tunnel clear height) and grouting repairs in cracks, joints and lining. (US Department of Transportation, 2005)

Any infiltration can be minimized either by treating the inner lining with sealants or by water proofing the outer section of the tunnel. The selection of the proper sealant chemical depends on the tunnel leakage. It is common in other countries to label the leakage type in descriptive manner such as the moist, past moisture, glistening surface, flowing or dry.

Groundwater seepage in the inner side of the tunnel can be temporarily controlled by using catchment troughs and interior composite liners. After evaluation of the tunnel liner for potential risk from soil pumping, settlement and clearance, this temporary solutions can be applied.

Tunnels usually have an initial liner (temporary support) and a final liner (permanent support). Initial support is typically provided by shotcrete and bolts for easing the construction progress in every aspects of tunneling methods. The final liner is usually the main tunnel support either cast in-situ concrete, precast concrete, steel or timber lining.

Concrete Liners and Shotcrete – Concrete liners are mostly recommended due to its low construction cost, ease in application of architectural effects and ease in maintenance. It can be of precast or cast in-situ concrete liners. A shotcrete is a pneumatically sprayed concrete which is commonly used for temporary support.



Figure 9 Precast (left) and Shotcrete and Cast in-situ liners (right)

Mostly in tunnels, the final liner is concrete liners. This being said, most mitigation plan regarding concrete structure with leakage problem is conducted through injection of grout. Grouting can be done using chemicals or cement.

Presented below are the variable ways that can be implemented to stop water leakage with in concrete tunnel lining with respect to the problem type. It should be noted that there is no particular best practice priority as to which method of repair should be. Election of a particular solution to follow bases upon constraints such as funding available for the repairs, overall schedule to complete the repairs, time of the year for making the repairs, operational constraints, recommendations from geologists and geotechnical/structural engineers, the severity of the problem, etc. The best practices presented below are various alternatives.

a) Elimination of Groundwater From Penetrating the Tunnel Liner

It is a best practice to eliminate this ground water from penetrating through the tunnel liner if at all possible. However, it is considered as a last option due to heavy construction cost. Before this method is selected, geotechnical investigation of the site and characterization of the material within should be known, ground water condition and its variation with time should be determined. Grouting methods for tunnel rehabilitation typically include permeation grouting, compaction grouting, and jet grouting (Gannett Fleming, 2010). These methods typically focus on cementitious grouting of pores in the soil and rock crack around the tunnel exterior as a restraint to the groundwater reaching the tunnel's exterior face.

b) Sealing of Cracks and Joints With Active Leakage

This repairing scheme is best taken as a solution on tunnel cracks and joint leakage problem. It seals off the infiltrating water by injection of materials in cracks and joints, the methods considered best practices are either conduction of water leakage or sealing of cracks.

Conduction of Water Leakage by channeling the water into an existing drainage system, the build-up of water can be avoided in the tunnel inner section and any tunnel operational items. These situations cause both operational and safety problems. This is a temporary and cost-effective measure to divert the flow of water without trying to use a more extensive methods. Advantages such as ease in constructability, less traffic destruction less expensive. Disadvantages such as its applicability being limited to tunnel lining cracks and material limitation on the type of troughs and pipes for fire events are the only noted disadvantages.

The types and sizes of trough systems (neoprene, steel, fiberglass, flexible or rigid polyvinyl chloride; toxic at the event of fire in tunnels) to be installed depend upon the severity of the water infiltration, the inclination of the cracks (typically used for transverse or radial cracks), and whether the materials are appropriate should a fire event occur in the tunnel.

Several systems in place are fairly simple, such as using neoprene troughs adhered by anchor bolts to the concrete liner and inserting pipes on the underside of a fairly straight crack as a temporary repair. For a more permanent solution by this method, a more robust fixation of the edges of the catchment is needed achieved by either chemical or mechanical fittings. At times, water relief holes may be drilled to decrease the surroundings water pressure, but it is not usually recommended. Common problem facing this type of repair comes from inadequacy of vehicle height clearance.

Troughs size will be determined by rate of infiltration. Troughs will installed on the inside of the liner to catch leaking water and convey it into the drainage system. Simple catchment systems are shown in Figures 3. More robust systems are simply sealed better to minimize the chances of water leaks.

Sometimes radial drainage holes are drilled into the tunnel liner to relieve the water pressure behind the liner; this water can be collected and conveyed into the drainage system.

Aside from the periodic maintenance for unclogging and fixing corrosion, it's a viable solution for joint leakage problem.

As far as construction goes, these systems are fairly easy to install. The necessary steps to follow will be,

- Clean the infected concrete area using water-jets or concrete chipping hammer
- Inject the crack with sealant and grout (optional)
- Drill the concrete liner for fixing bolts that supports the troughs or pipe
- Place sealing rubber around the edges
- Install and fix the pipe or trough

Sealing by chemicals and grouts this type of repair only deals with inhibiting water intrusion from the surrounding by waterproofing the inner face of the tunnel lining. An international study suggests that there are six types of water leakage rates that can be easily identified with the naked eye. (Gannett Fleming, 2010)

- Past moisture – staining arising from former moisture
- Damp patch – discoloration of part of the surface of a lining, moist to the touch
- Seep – visible movement of a film of water across the surface
- Standing drop – a drop of water, which does not fall within a period of one minute
- Drip – drops of water which fall at a rate of at least one drop per minute
- Continuous leak – a trickle or jet of water; also includes drops exceeding 300 drops/minute

Based on the above, the following best practices were implemented and recommended for common infiltration problems.

✓ **Installing a waterproofing membrane system over the interior surfaces of the tunnel liner.**

This system comprising of waterproofing membranes is typically suited for an aerial water leakage infected concrete structures. As compared to the previous method of containing the infiltration with in a catchment pipe, it has a better long term effect in arresting water leakage.

After the crack and joints are properly sealed, a composite liner will be implemented in between the tunnel liner and a shotcrete which can harden in short period of time and also protects the composite liner from fire (See Figure 3.14). Furthermore, a geotextile or geo-drain will be used to provide a path for drainage.

As far as construction goes, these systems require the tunnel operation to be halted for the time being and is difficult to install as compared to the previous method discussed.

✓ **Installing a sprayed cementitious waterproofing membrane over the interior surfaces of the tunnel liner.**

This technique minimizes water penetration through the inner tunnel concrete liner. This system is made of a blend of co-polymers and Portland cement (crystalline cementitious grouts) in which by reducing the pore size within the concrete, particle leakage will be greatly reduced. Other method involves the use of a thick cementitious coat applied to moist concrete surface.

Advantages of this method include;

- rapid installation

- less costly
- isolated area repair

Table 1 Grouting Materials Description (Gannett Fleming, 2010)

Description	Viscosity	Toxicity	Strength	Remarks
Particle Grout				
Flyash Type F;C	Med (50cps-2:1)	Low	High	Non flexible
Type I Cement	Med(50Cps-2-1)	Low	High	Non flexible
Type III Cement	Med (15cps-2:1)	Low	High	Non flexible
Microfine Cement	Low (8cps-2:1)	Low	High	Non flexible
Bentonite	Med (50 cps 2:1)	Low	Low	Semi flexible
Chemical Grout				
Acrylamides	Low (10 cps 2:1)	High	Low	Flexible
Acrylates	Low (10 cps)	Low	High	Semi flexible -No shrinkage: Good success record
Silicates	Low (6cps)	Low	High	Non flexible- High Shrinkage
Lignosulfates	Low (8 cps)	High	Low	Flexible not widely used
Polyurethane (MDI)	High (400 cps)	Med.	Low	Flexible: Good success record (Hydrophilic)
Polyurethane (TDI)	High (400 cps)	Med.	Low	Flexible : Good success Record(Hydrophobic)

✓ **Injecting leaking cracks with grouts to arrest water infiltration through the tunnel liner.**

This system involves the injection of grouts with in concrete cracks. Potential types of grouts that are used in cracks with active leakage include **particle** grouts and **chemical** grouts.

Particle grouts are referred to as fine cementitious grouts and can only be applied where no crack movement is anticipated, because of their rigidity.

Chemical grouts typically used in tunnel repairs consist of acrylate esters, polyurethanes, acrylamides (highly toxic) and sodium silicates. Acrylate esters form a gel when reacting to water which make its ideal for active leakage repair. Polyurethanes may be either hydrophilic or hydrophobic in which the hydrophilic grouts react in the presence of water without requiring a catalyst to initiate a reaction, whereas hydrophobic grouts do not react well with water and require a catalyst to initiate a reaction. This grout is well suited for permanent water table seepage condition or else with the absence of water, the bond with concrete will loosen. (Gannett Fleming, 2010)

In cases where the initial assessment suggests the presence of movement, it is recommended the use of flexible grout and if there is no mention of movement, then the inflexible ones can be applied.

In cases where the initial assessment suggest the presence of moisture, it is recommended the use of hydrophilic sealants.

✓ **Repairing Leaking Construction Joints.**

This particular problem arises from either the improper placement of the concrete (not consolidated or porous concrete) around construction joints or waterstops improperly placed due to poor workmanship.

It is recommended that injecting chemical grout into the interior of the construction joint with defective waterstops is the best practice for sealing the joint against further leakage. Similarly, keyed joints without waterstops should be chemical grouted in a manner that fills all sides of the keyed joint for maximum protection against further water leakage.

If the joint has experienced delamination and spalls near the surface, which is often the case, the deteriorated concrete should be removed with a chipping hammer or hydro demolition to remove intensively infected area. The edge of the joint can then be rebuilt with a polymer modified mortar that has similar characteristics as the concrete substrate.

An alternative method which has been employed where the concrete on either side of a vertical construction joint is in good condition is to install a flexible chemical grout, a drainage pipe, mastic, and mortar near the surface of the joint to prevent further leakage through the joint. The drain pipe serves as a dual backup system for water penetrating through the chemical grout and into the pipe before being discharged through the existing drainage system.

2.4. Seepage in depth

Darcy's law developed which was developed in the 1856, is commonly used to model the flow of water through an unsaturated soil (Buckingham, 1907). Hydraulic conductivity k , in Darcy's law is a hydraulic property. A similar hydraulic property was also introduced by Fick' law. (Hillel, 1982)

Material's percentage of void play important role in water flow. As per plotted hydraulic conductivity values of various materials, when the soil becomes unsaturated, voids will be filled by some of the water in the larger pores, and this causes the water to flow through the smaller pores in disarrayed flow path.

The hydraulic conductivity function of an unsaturated soil with respect to suction or water content can be determined using either direct techniques such as laboratory and field measurements (Klute, 1965), or indirect techniques. More attention is increasingly being directed to the accurate measurement of unsaturated soil hydraulic properties close to saturation (Leji & van Genuchten, 1999), i.e., moisture conditions that are strongly affected by the soil structure and macro-pores.

However, the measurement of unsaturated hydraulic conductivity in the laboratory is time-consuming and costly, as it requires special devices and generally the service of a skilled technical person.

Therefore, numerous theoretical (indirect) methods have been proposed by researchers to predict the hydraulic conductivity of unsaturated soils (Fredlund, Xing, & Huang, 1994); (van Genuchten, 1980); (Mualem, 1976); (Kunze, Uehara, & Graham, 1968)). Most of these predictive methods require saturated hydraulic conductivity and the soil– water characteristic curve as inputs. Soil– water characteristic curve can either be measured in the laboratory or predicted using a grain-size distribution curve taking into account such factors as dry density, porosity, and void ratio (Fredlund, Wilson, & Fredlund, 1997), (Tyler & Wheatcraft, 1989); (Gupta & Larson, 1979), (Aubertin, Mbonimpa, Bussiere, & Chapuis, 2003)).

2.4.1. Infiltration in soil

Seepage's simple definition is the flow of water through a porous media. Any porous media has a unique capacity in conducting water or any other fluid for that matter. (M.Shaw, 2005)

For soil media, seepage or infiltration, is the condition that arises from residual precipitation at the ground surface infiltrating into the top soil and further into any porous media layer, usually a sedimentary layer. As a soil material gets coarser, porosity increases.

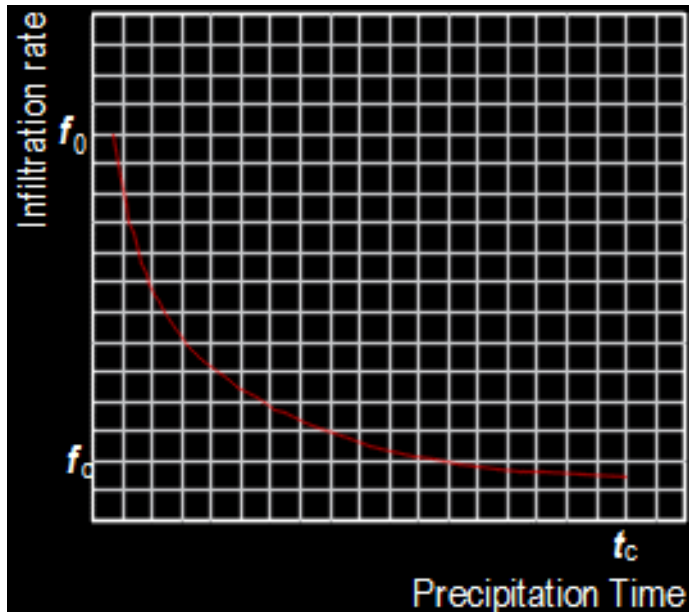


Figure 10 Infiltration in a porous media (Hydrology in Practice, 1994)

In order for infiltration within a soil media to occur, the initial condition of the soil should be below field capacity or typically unsaturated, usually denoted by f_0 . At saturation level, usually denoted by f_c , infiltration halts and reduces to a constant value.

Infiltration in soil media can be modeled using Horton's equation (1940) which compares infiltration to decaying general exponential equation (M.Shaw, 2005)

$$f_t = f_c + (f_0 - f_c) \exp^{-kt}$$

Where, f_t is the infiltration rate at any time t

f_0 is the initial infiltration rate

f_c is the final infiltration rate (constant)

or using Philip's equation (1960) which gives analytical expression (M.Shaw, 2005)

$$f_t = \frac{1}{2} A t^{1/2} + B$$

Where, f_t is the infiltration rate at any time t

A & B Relate to soil property and physical condition

2.4.2. Ground Water Movement Modelling

According to Darcy's equation, water movement through a media is product of difference between water head between two points which is also known as the hydraulic gradient and the media's conductivity capacity;

$$V = k \cdot \frac{\Delta h}{\Delta x} \quad \text{Or} \quad V = k \cdot i$$

Where, V is the velocity of water under a media

i Is the hydraulic gradient and

Δh Is the

k Is the hydraulic conductivity.

The hydraulic conductivity depends on;

- Position in geologic formation layer
 - Homogenous: single layer
 - Heterogeneous: different layers
- Direction of measurement or flow,
 - Isotropic: same discharge in every direction
 - Anisotropic: increased discharge in a one direction

In particular concern, the concrete hydraulic conductivity needs to be determined. The saturated hydraulic conductivity for backfill and rock-fill can be taken as $3.00 \cdot 10^{-4}$ cm/s and 1.85 cm/s respectively, the saturated volumetric water content also can be taken as 0.371 and 0.518 respectively and as for the concrete saturated volumetric water content an estimation of 0.225 can be taken which are an average value (Rockhold, Fayer, & Heller, 1993). This average value was collected using Modified Constant head method which is particularly used for medium with low permeability.

Table 2 Experimental findings of hydraulic properties (Rockhold, Fayer, & Heller, 1993)

TABLE 4.1. Average Water Retention Parameters and Vertical Saturated Hydraulic Conductivity Values Used for Grout Vadose Zone Flow and Transport Modeling

Material Type	No. of Samples	Water Retention				Unsaturated Hydraulic Conductivity	
		θ_r	θ_r	α cm ⁻¹	n	No. of Samples	K_r cm s ⁻¹
Hanford Formation^(a)							
Sandy Sequence	57	0.4203	0.0234	0.1943	1.868	45	1.55 x 10 ⁻³
Lower Gravels	14	0.3584	0.0213	0.0290	1.613	13	2.73 x 10 ⁻⁴
Ringold Formation^(a) (undifferentiated)	5	0.4982	0.0283	0.0176	1.338	5	2.42 x 10 ⁻⁶
Backfill Soil ^(b)	2	0.3710	0.0450	0.0683	2.080	2	3.00 x 10 ⁻²
Gravel ^(b)	2	0.5180	0.0140	3.5366	2.661	1	1.85
Clay ^(b)	3	0.4480	0.0000	5.39 x 10 ⁻⁴	1.324	3	9.40 x 10 ⁻⁹
Asphalt ^(c)	0	0.162	0.0	1.00 x 10 ⁻⁷	2.0	0	1.0 x 10 ⁻²⁰
Concrete ^(d)	6	0.2258	0.0000	7.61 x 10 ⁻⁶	1.393	6	3.75 x 10 ⁻¹⁰
DSSF Grout ^(e)	9	0.5781	0.0000	1.08 x 10 ⁻⁵	1.650	3	1.47 x 10 ⁻⁸

^(a) Original data for well No. 299-E25-234 contained in laboratory record book BNW 52457; other data sources were Smoot et al. (1989), Connelly et al. (1992b), and Dames and Moore (1988).
^(b) Original data contained in laboratory record book BNW 53071.
^(c) Estimated parameters; no available data.
^(d) Original data contained in laboratory record books BNW 4042 and BNW 50881.
^(e) Original data contained in laboratory record book BNW 53294.

2.4.3. Ground Water Flow Equations

For a single cell one directional water flow movement, if we consider a non-steady state movement, it puts together Darcy’s equation with Continuity Principle to come up with a Laplacian equation;

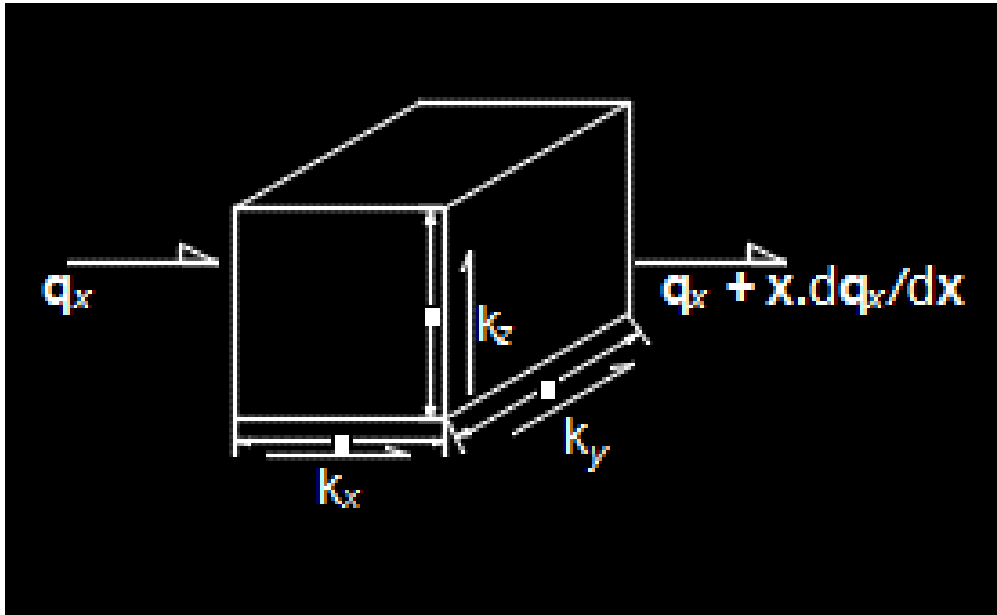


Figure 11 One Directional Flow in Elementary Soil

$$\text{Inflow} = \text{Outflow} + \text{Storage Change}$$

$$q_x = (q_x + x \frac{dq_x}{dx}) + (S_s x y z \frac{dh}{dt})$$

but $q_x = k_x \cdot y \cdot z \cdot \left(-\frac{dh}{dx}\right)$; Replacing...

$$\frac{k_x d^2 h}{dx^2} = S_s \frac{dh}{dt} \quad \text{For 1D flow}$$

$$\frac{k_x d^2 h}{dx^2} + \frac{k_y d^2 h}{dy^2} = S_s \frac{dh}{dt} \quad \text{For 2D flow}$$

$$\frac{k_x d^2 h}{dx^2} + \frac{k_y d^2 h}{dy^2} + \frac{k_z d^2 h}{dz^2} = S_s \frac{dh}{dt} \quad \text{For 3D flow}$$

For a condition where the flow is steady and the medium is homogenous and isotropic;

-steady state means that $\frac{dh}{dt}=0$

-homogenous material means that conductivity changes with in N layers of material,

$$K_1 \neq K_2 \neq \dots \neq K_N$$

-isotropic material means that conductivity in every direction will be constant,

$$K_x = K_y = K_z = K$$

in the case of the 3D flow; the equation changes to :

$$\frac{d^2h}{dx^2} + \frac{d^2h}{dy^2} + \frac{d^2h}{dz^2} = 0 \quad \text{For 3D flow}$$

2.4.4. Flow Nets

These are equipotential lines of flow or stream which represent ground water movement. Flow net can be presented using graphical solutions, electrical analogues solutions and most commonly numerical methods.

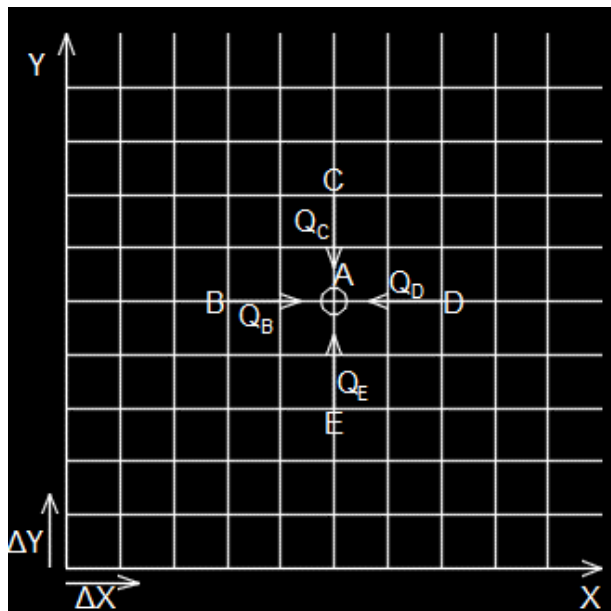


Figure 12 Finite Element Nodal Calculation

Finite element methods is the most commonly used numerical method technique involving a 2D plane with regularly subdivided grids or meshes.

For flow at point A from B, using Darcy’s principles for unit thickness;

$$V_{BA} = k_{BA} \cdot \frac{h_b - h_a}{\Delta x}$$

With unit thickness, the area will come to be;

$$A = \Delta y \cdot 1 = \Delta y$$

Therefore;

$$Q_{BA} = A \cdot V_{BA} = \Delta y \cdot k_{BA} \cdot \frac{h_b - h_a}{\Delta x}$$

Assumptions like material homogeneity and isotropy, equal divisions (i.e. $\Delta x = \Delta y$), and mass conservations in opposite directions (i.e. $Q_{EA} = -Q_{CA}$, and etc.) makes the summation at a node point (i.e. at point A) simplified to;

$$h_a = \frac{h_b + h_c + h_d + h_e}{4}$$

2.5. Permeability in Concrete

Concrete permeability is an important property of concrete in which it determines the durability of the concrete (Young, 1988). The movement of water through concrete might expose it to chemical agents such as;

- Aggressive gas agents (CO₂ and SO₃)
- Aggressive liquid agents (acid rain, salt water and etc.)

Estimation of seepage within concrete can be achieved through the following with better approximation using computer aided numerical analysis;

- Mathematical analysis
- Numerical analysis
- Physical modelling
- Semi experimental techniques

2.6. Methods of Hydraulic Conductivity Determination

Hydraulic conductivity determination of soils can be realized with correlations methods or with hydraulics methods. Hydraulic methods can be divided into laboratory methods or field (in-situ) methods.

Correlation methods come from predetermined relationship between soil property (e.g. grain size distribution, texture, etc.) which can be easily determined and K-value. The advantage of the correlation methods is a fast estimation of the K-value, than the direct measurement. A defect is a fact that the application of relationship can be incorrect and can be a reason of random errors.

Hydraulic methods come from supposed certain flow conditions, with boundary and initial conditions and with use of Darcy's Law (respectively Darcy-Buckingham Law in a case of unsteady

state flow in unsaturated zone) and with use of equation of continuity. Final formulas for direct calculations (approximation) of K-values were received by analytical solution of initial fundamental equations. The hydraulic laboratory methods, or laboratory methods, still fast and cheap, are used to core soil samples. They have similar deficiency as correlation methods and also the small sample area means the high possibility of a large random error. The hydraulic fields methods, or fields methods, based also on description of the water flow processes, can determine K-values around the hole made in the investigated soils (in a case of small-scale), but the external boundary line of the soil environment is very often not exactly known. The hydraulic field methods can be divided into small-scale and large-scale methods, where small-scale field methods serve for fast testing of many locations. They supposed allowable simplifications of groundwater (subsurface water) flow, so that measurements can be realized relatively cheaply and quickly. The large-scale field methods guarantee the representative K-values, where the problem of variation is eliminated as much as possible. But the large-scale field's methods are rather expensive and time-consuming, than the methods mentioned above. (Ritzema, 2006)

2.7. Numerically Simulated Modelling

A numerical model is a mathematical simulation of a real physical process. SEEP/W is a numerical model that can mathematically simulate the real physical process of water flowing through a particulate medium and in this sense rests the clear difference with physical or field modelling.

Numerical modeling has the following advantages over physical modeling:

- Numerical models can be very quickly set up rather than physical models which may take days to prepare
- Numerical models offer wide variety of different scenarios to be investigated as opposed to the narrow set of scenarios in physical models.
- Since gravity cannot be scaled, it is a limitation with laboratory modeling as opposed to numerical modelling.
- Numerical modeling provides information and results at any location within the cross-section as opposed to providing only visual response in physical modeling.
- Numerical models can accommodate a wide variety of boundary conditions, whereas physical models are often limited in the types of boundary conditions possible.

The soil behavior component includes laboratory tests, in situ tests and field measurements. The ground profile component basically involves site characterization: defining and describing the site conditions. Modeling may be conceptual, analytical or physical. Making measurements and characterizing site conditions is often time consuming and expensive. This is also true with modeling, if done correctly. The objective of modelling is to analyze the problem. The following points are some of the main reasons for modeling, from a broad, high level perspective. We model to make quantitative predictions, compare alternatives, identify governing parameters and understand processes and train our thinking.

A numerical model, SEEP/W is an extended tool of Geo Studio a geotechnical software, is a numerical model that can mathematically simulate the real physical process of water flowing through a medium. It is different than scaled physical modeling in the laboratory or full-scaled field modeling. (GEO-SLOPE International Ltd., 2013)

Generally, In order to know the seepage condition of rock mass for tunnels or underground structures in operation, to provide the designer with necessary supports for corresponding layout of seepage controlled countermeasures, and to protect the safety of underground structures, it is usually necessary to arrange monitoring instruments at some places where the rock mass is greatly affected by ground water flow, to measure the water pressure, and to monitor the seepage field of ground water. The commonly used pore water gauges are of double pipe, air pressure, resistance, vibrating etc. Among them, because it can transmit frequency signal, and has a great ability of resisting disturbance, the vibrating pore water gauge is often used (Zhongru, 1999)

With the rapid development of optical fiber technology, the new type of monitoring instrument based on optical fiber technology has been gradually applied to actual projects rather than in laboratory. (Xiong, 1999) Recently, in-situ monitoring tests and application research by applying the optical fiber technology have been carried out in many Chinese hydropower projects, such as Gezhouba Project (Keli, Zhaoming, & Shaojuan, 2005), Three Gorges Project, and Geheyan Project etc. it has been shown by testing results and research output that the optical fiber osmometer has some merits of small volume, high precision, wide range of measurement etc. It has an obvious advantage and a promising prospect compared to the conventional monitoring instruments.

By numerical simulation and stress coupling analysis for seepage field based on monitoring information obtained, we can predict the development pattern of seepage field, evaluating the effect of the seepage field on the stability of tunnels and other underground structures, and learning the effect of the seepage-controlled measures. Afterwards, it can provide scientific supports on designing schemes of seepage monitoring and seepage control, and optimizing the supporting design of tunnel.

The currently used seepage models of jointed rock mass include double medium model of jointed rock mass, discrete crack network model and equivalent continuous medium model (Priest, 1993).

Among them, by applying the theoretical basis of porous medium seepage theory and rich numerical simulation experience, the Equivalent continuous medium model can reflect the basic characteristics of jointed rock mass such as non-homogeneity and anisotropy. It has become the most commonly used model in numerical analysis of seepage field presently (Junrui, 2002).

Numerical method is often used for seepage analysis, and the finite element method is the most commonly used numerical simulation method today. As the problems of underground water are widely existed, much special computer software for this problem has been developed in China and other countries. The seepage analysis programs of STSE-2D and FAPD-3D based on the saturation condition have also been developed by IWHR. Since stress-strain analysis of Geotechnical engineering often involves the problem of ground water, the multi-field coupling model that can simulate seepage is usually included in some large FEM software, such as ANSYS, ABAQUS etc., and some special software for geotechnical engineering analysis, such as GeoStudio and FLAC3D.

Different numerical modelling packages have been produced and put in to use for seepage analysis in order to better approximate flow patterns, determine flux sections and obtain section seepage discharge, and this modelling packages include;

- Midas GTS NX
- Soil Vision flux
- MODFLOW
- GeoStudio SEEP/W
- Hydrus 1D with RETC for quantifying hydraulic properties of unsaturated models

Studies on seepage in the past has been based on physical modelling techniques which presented a rather inaccurate representation of the actual condition. These numerical modelling packages provide advantages such as:

- Quick and easy setup as opposed to physical modelling
- Simulates a variety set of variables
- Sectional values of flux rates and pore water pressure can be achieved
- Quantitative prediction can be made easily
- Comparisons between alternative scenarios can be done
- Visualization of the process is made easier.

The use of a simple 1D and 2D modelling software of the study area and other hydrological ,geotechnical and meteorological character of the area produced better results in defining important aspects of permeability concrete. (Karimi & Abrishami, 2015)

2.7.1. Midas GTS NX

Midas GTS NX uses 2D and 3D finite element analysis for modelling various civil works such as in tunneling, mining, foundations, excavations (construction stage analysis) and seepage analysis. It is different from the other modelling packages in that, it uses the same interface for modelling and analysis. It means that it has only one module that will be used before and after analysis hence improving modelling inputs even after the analysis is done in the same interface. (MIDAS Information Technology Co. Ltd., 1989)

2.7.2. Soil Vision SV FLUX

SV Flux uses 1D, 2D and 3D finite element analysis for modelling seepage. The medium under consideration can be in either saturated or unsaturated condition. Its unique features include:

- Soil models of various material property can be used from database
- Automatic mesh generation and refinement
- Model can coupled with other SVOoffice products to consider alternative dimension of the modelling such as with SV HEAT and SV AIRFLOW. (SVOFFICE 2009- 1D/2D/3D Finite Element Modeling Software, 2009)

2.7.3. GeoStudio SEEP/W

SEEP/W analyzes seepage pressure within any medium of either saturated or saturated/unsaturated condition. Here the saturated/unsaturated represents conditions where the saturation level is in varying state so that a separate function for the hydraulic conductivity property may need to be defined. Water flow conditions can be in steady or transient state.

GeoStudio SEEP/W can be applied in various range of civil structure modelling, hydrogeological and mining engineering projects. (GEO-SLOPE International Ltd., 2013)

3. GeoStudio SEEP/W Numerical Modelling

3.1. Introduction

Finite element numerical methods are based on the concept of subdividing a continuum into small pieces, describing the behavior or actions of the individual pieces and then reconnecting all the pieces to represent the behavior of the continuum as a whole. This process of subdividing the continuum into smaller pieces is known as discretization or meshing. The pieces are known as finite elements.

In GeoStudio, the geometry of a model is defined in its entirety prior to consideration of the discretization or meshing. This is an approach that is new in GeoStudio 2007. Furthermore, automatic mesh generation algorithms have now advanced sufficiently to enable a well behaved, numerically robust default discretization often with no additional effort required by the user. The user can also generate mesh and any required changes can easily be made by changing a single global element size parameter, by changing the number of mesh divisions along a geometry line object, or by setting a required mesh element edge size.

3.2. Material Models and Property Definition

There are four different material models to choose from when using SEEP/W.

1. None (used to removed part of a model in an analysis)
2. Saturated / Unsaturated model
3. Saturated only model
4. Interface model

If there is any doubt about which model to choose for a soil region (as opposed to an interface region), the Saturated / Unsaturated model is the first choice and starting from that, the other models can be selected when it is clearly understood.

The Saturated Only soil model is very useful for quickly defining a soil region that will always remain below the phreatic surface, but it should not be used for soils that will at some point during the analysis become partially saturated. If this happens, the model will continue to solve but you will be saying, in

effect, that the unsaturated zone can transmit the water at the same rate as for the saturated soil. This will result in an over estimate of flow quantity and can result in an unrealistic water table.

The Interface soil model is to be used in conjunction with “interface elements” that are added to the mesh to represent geo-membranes or such.

3.3. Boundary Condition Definition

Numerical models are boundary valued problems. This is to say that, the user controls the model condition by placing boundary values to parameters. Boundary conditions can be easy to place or may be iteratively determined. In transient model analysis, the boundary conditions can vary along with the time.

In finite element analysis, the fundamental seepage analysis equation is of the form, $\{Q\}=[K]\{H\}$, in which $\{Q\}$ is a vector of response or flow quantity of each nodes, $[K]$ is the matrix of known geometry-material properties and $\{H\}$ is vector of unknown variables or total hydraulic head at each node. The unknowns will be computed relative to the H values specified at some nodes and/or the specified Q values at some other nodes. In a steady-state analysis, at least one node in the entire mesh must have a specified H condition. The specified H or Q values are the boundary conditions.

For cases where the values of H or Q is to be determined, here we consider seepage face where the value of a seepage faces pore water pressure is zero. So using an iterative approach, it will be solved for the value of one of the two.

As has been noted before, the first type of boundary condition is head boundary condition in which the total head is defined or other terms the total of pressure and elevation head. In this regard, the primary unknown is the flow rate or flux. Solution for this type of problem can be given either by elevation head difference or by head gradient only. Constant pressure condition is when the pressure head is constant on an inclined ground while the total head varies. Far field head conditions is a condition in which the initial water conditions needs to be defined around the project extent in terms of elevation head.

The second type of boundary condition is to specify the rate of flux across or flux boundary. So for such type of conditions, the unit rate of flow will need to be defined across an element. The flow rate can be

made to vary along with time in transient analysis as stated before. SEEP/W integrates the what to solve from the given boundary conditions realizing what is given as a boundary condition and what needs to be solved at each node.

The third type of boundary condition is to specify a drain point, point of zero pore pressure known as sink condition. Here we are considering a drain pipe to be implemented so that at any time of the process the point pore water pressure value is zero.

The fourth type of boundary condition is to specify a seepage face as pointed above.

4. Methodology and Analysis

4.1. Input Data Collection

4.1.1. Tunnel Design (plan, profile and section)

The tunnel design, the plan, profile and tunnel section details was obtained from Project office. The tunnel plan design offers,

- The layout of the tunnel including the symmetrical turnout and the platform
- The location of start chainage of the tunnel
- The location in coordinate of the access portals
- The location in coordinate of the tunnel start

The tunnel profile design offers,

- Gradient of the alignment,
- Design elevation.

The section drawing offers,

- The tunnel dimensions at different locations
- The Platform design
- The tunnel drainage detail
- The tunnel wall thickness
- Any other necessary section views.

4.1.2. Material Property

As per the tunnel design acquired, the tunnel section has four materials to be considered for the water flow medium namely;

- The backfill material besides tunnel lining
- The waterproofing material on the tunnel lining
- The Reinforced Cement Concrete C-30 grade

- The Shotcrete concrete C-20 grade. (Messrs Swedish National Roads Consulting AB (SweRoad) Hifab International AB (Hifab), 2014)

Construction began with cut and cover method for the tunnel. After the excavation of the area, reinforcement mesh and Shotcrete concrete was applied to the adjacent side-cut for protection. Afterwards the reinforced cement concrete of the tunnel wall and slabs were casted. Towards the end of the casting, as per the agreement and conceptual design, water proofing work was to be implemented. At the end of all this works, back filling towards the tunnel wall and cover filling above the tunnel top slab of about 2.5meter in depth was conducted. (Messrs Swedish National Roads Consulting AB (SweRoad) Hifab International AB (Hifab), 2014)

So therefore, for the research modelling purpose, hydraulic material property of the reinforced cement concrete together with the backfilling material has been incorporated in the model. This values of the hydraulic material property was only estimated from literature findings since there was no test conducted or experiment performed on the actual material during the construction phase.

4.2. Research Conditions

The research tries to assess the actual condition of the tunnel in the case study in its original condition which was taken as Condition-1-which is the tunnel lining without waterproofing. It also assesses the same tunnel section under the protections of waterproofing material which was taken as Condition-2- which is the tunnel lining with waterproofing without drain pipe. Finally it investigates the tunnel section when under the protection of rock-fill with a potential for gravitational water drainage with in the backfill which was taken as Condition-3-which is the tunnel lining with rock-fill with drainpipe. So therefore an independent three models were developed using SEEP/W.

4.2.1. Scenario-1 Tunnel Section without Waterproofing

The tunnel section as it is, it is a reinforced concrete structure with C-30 MPa compressive strength. Normal construction procedure suggests that the Cut and Cover Tunneling technique involves the following construction steps:

- Excavate a trench up to the bottom of the level (including working space)
- Compact the tunnel base area to required strength and density

- Place the bottom slab and wall reinforcement
- Place the bottom slab and wall concrete
- Place the top slab reinforcement
- Place the top slab concrete
- Waterproof the outer face of the wall and top slab
- Backfill area left from the tunnel section.

Amongst these steps, the last two step is the primary focus of this research. This is because, if proper water blocking technique is implemented, water ingress can be totally prohibited. As explained earlier in chapter 2, waterproofing can be applied either on the inner wall or on the outer wall. The disadvantage of applying the waterproofing on the outer wall is that unless it is considered prior to backfilling the tunnel section, it is impractical to uncover and waterproof at a later stage.

Scenario-1 in particular focuses on avoiding waterproofing the outer wall and evaluate the response of the surrounding condition as well as the tunnel. Obviously pressure from water will be seen on the wall and water inrush can be expected.

So special attention on this scenario will be to focus on the water flow path and to determine which area of the tunnel section receives maximum water pressure.

4.2.2. Scenario-2 Tunnel Section with Waterproofing

Amongst the construction steps to be followed in typical Cut and Cover Tunneling, Scenario-2 presents an option where waterproofing is applied to the tunnel outer section. It evaluates the response of the surrounding condition as well as the tunnel. Obviously pressure from water will be seen on the wall and water inrush to the minimum can be expected. Primarily this focuses on, the difference in response from scenario-1 on the application of waterproofing, meaning the physical and visual changes seen.

So special attention on this scenario will be to focus on the water flow path and to determine which area of the tunnel section receives maximum water pressure.

4.2.3. Scenario-3 Tunnel Section with Rock-fill and Drainpipe

Amongst the construction steps to be followed in typical Cut and Cover Tunneling, Scenario-3 presents an option where instead of waterproofing application to the tunnel outer section, what if a drainage

layer is to be placed alongside of the tunnel wall with a draining point at the tunnel bottom. It evaluates the response of the surrounding condition as well as the tunnel. Obviously pressure from water will be seen on the wall and water inrush to the minimum can be expected. Primarily this focuses on, the difference in response from scenario-1 and scenario-2 on the application of rock-fill, meaning the physical and visual changes seen.

Basically a rock-fill instead of a backfill can be used as a drainage layer since the gradation of the rock-fill allows easy water flow with the help of gravity. So special attention on this scenario will be to focus on the water flow path and to determine which area of the tunnel section receives maximum water pressure.

4.3. Software Processing

GeoStudio 2012 student version is a free numerical model software with a capacity to model and analyze engineering aspects starting from stability, thermal, dynamic and seepage conditions in any geotechnical investigations. It is available in commercial and student version in which the student version is readily used in university teachings and researches.

GeoStudio 2012 provides a specialized tool, SEEP/W, for analyzing seepage models. Modelling in GeoStudio follows an ordinary modelling steps which can be summarized as follows,

1. Choose analysis type to be used
2. Defining the Geometry under investigation
3. Defining the material property associated
4. Defining the initial water table
5. Defining the boundary conditions
6. Running the model

4.3.1. Choose Analysis Type

Since the tunnel under consideration is being modelled for seepage condition from ground water, the chosen analysis type will be of Steady State flow of ground water. Underground flow conditions are mostly investigated under steady state condition for the fact that due to the ground soil condition does not allow any turbulent water flow.

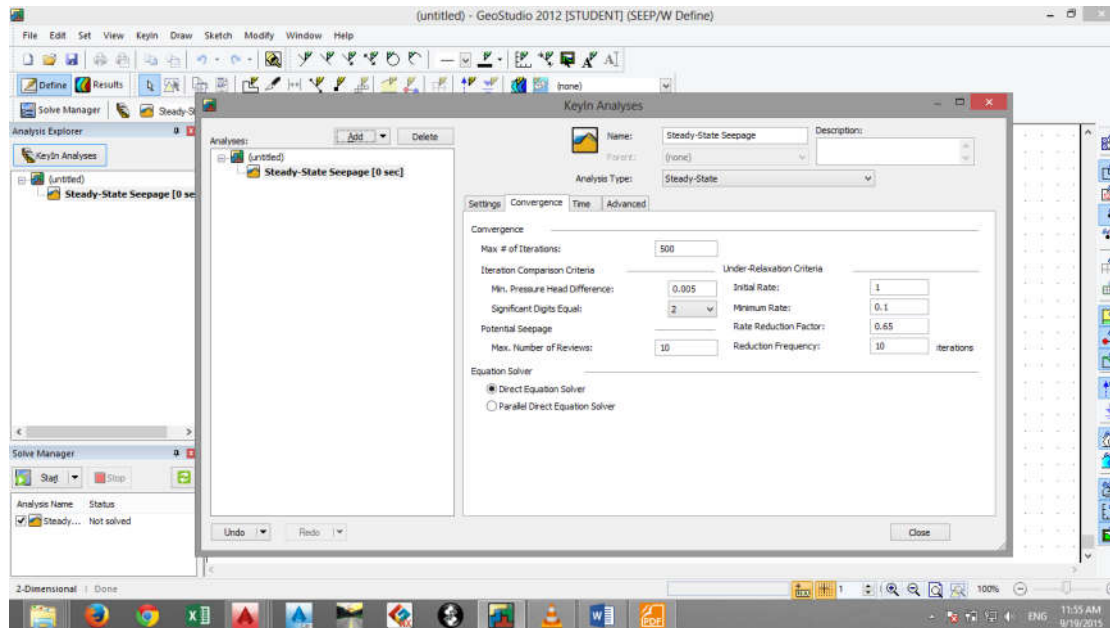


Figure 13 GeoStudio Analysis Configuration Tab

Under convergence tab, allowed maximum iteration for the numerical simulation, iteration comparison criteria and under relaxation criteria are present. Each of this items are determined by default and are limited for student version.

- Maximum iteration: determines the iteration repetition to minimize the result to a minimal acceptable error percent.
- Iteration comparison criteria: determines the differentiating values between the iterations of the minimum pressure head.
- Under relaxation criteria: limits and controls any solution divergence from progressive iterations using the materials property of conductivity.

4.3.2. Defining the Geometry

A simple geometry of the tunnel section outside the station platform was taken, a rectangular geometry with dimensions of 9.50m*6.58m with wall thickness 0.80m. The section differs in and out from the station platform section. Within the station platform, the wall thickness increases to 0.80m and the tunnel height increases to 8.38m.

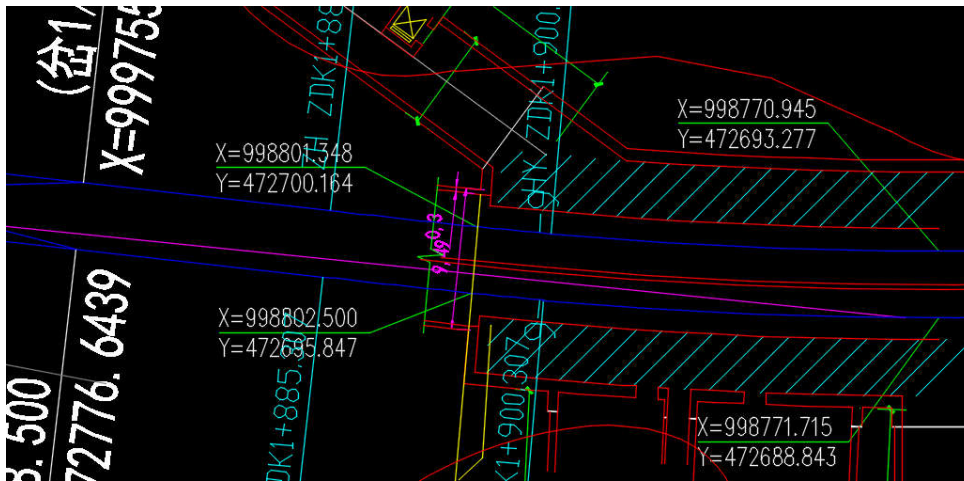


Figure 14 Plan of Tunnel at the Start of the Platform

4.3.3. Defining Material Property

As previously stated in Section 4.1.2, there are four materials which can be modelled namely;

- The Backfill material
- The water proofing material
- The rock-fill material (hypothetical)
- The wall concrete, C-30.

Any material can be defined using either saturated, saturated/unsaturated and interface model.

Amongst this, using the saturated model will be safer to consider since the exhibited condition suggests that the tunnel is always under the phreatic level.

The saturated model uses the following inputs to define the material:

- Hydraulic conductivity (Ks)
- Material Anisotropy coefficient

- Compressibility Coefficient (M_v) and,
- Saturated Volumetric Water Content (θ_s)

The software has also implemented the unsaturated material model. In this conditions, material property varies with varying water level. This material property can be modelled using value estimating function from popular theories like Van Genuchten-Mualem theory, Brook-Corey theory and Fredlund-Xing theory. For example, Van Genuchten estimation method estimates the volumetric water content of the material using a generic formula;

$$\theta_w = \theta_r + \frac{(\theta_s - \theta_r)}{(1 - (\alpha h)^n)^m}$$

Where θ_w : is the volumetric water content

θ_r : is the residual water content

θ_s : is the saturated water content

α, n and m : are curve fitting parameters used for curve fitting
in which $m = 1 - 1/n$,

and the hydraulic conductivity of the material using ;

$$k_w = k_s \frac{\left[1 - (a\Psi^{(n-1)}) \left(1 + (a\Psi^n)^{-m} \right) \right]^2}{\left((1 + a\Psi^n)^{\frac{m}{2}} \right)}$$

where:

k_s = saturated hydraulic conductivity,

a, n, m = curve fitting parameters,

n = $1/(1-m)$, and

ψ = required suction range.

Since the assumption is for when the tunnel is always under the phreatic level, there is no need to consider this theories. Only using the experimental findings which is tabulated in section 2.3.2, the modelling and analysis can proceed.

4.3.3.1. Concrete C30 Hydraulic Conductivity

In this aspect, the hydraulic conductivity of the concrete was synthesized according to site observation. At the time of inspection or site visit, the infiltration on tunnel lining had been estimated to be around 0.2lit/s. Accordingly, using the anticipated hydraulic head between the water table and the infiltration level inside the tunnel, the hydraulic conductivity was estimated using a simple excel calculation sheet (included in the appendix), which came out to be 1.5×10^{-5} m/s. This value has been utilized throughout the scope of the research.

4.3.3.2. Waterproofing Hydraulic Conductivity

In this aspect, the hydraulic conductivity of the waterproofing was taken as 0 m/s as it is a waterproofing material which repels or blocks water infiltration. This waterproofing for this modelling had been implemented on the exterior of the tunnel lining. This value has been utilized throughout the scope of the research.

4.3.3.3. Rock-fill Hydraulic Conductivity

In this aspect, the hydraulic conductivity of the rock-fill was taken as 0.018 m/s as it is a gravel material with enough porosity to let water seep through by gravitational effect. The rock-fill was taken as 1 m in width, on each side of the tunnel, to start the model. This value has been utilized throughout the scope of the research.

4.3.4. Defining Initial Water Table

An initial water table condition defines the water level which be present before the analysis. The water table controls the head calculations and the pore water calculations.

As an assumption, the water table was taken to be 1 meter below the road surface. This will insure the effect of the water table on the model as well as the effect of the pavement structure is well considered since the pavement structure usually drains water down.

4.3.5. Defining Boundary Conditions

A boundary condition is a control mechanism developed for numerical analysis. A numerical analysis by itself is an iterative process in which multiple variable with in a domain or condition gets to be solved by limiting some boundary values. For example, in case of a seepage flow, our first concern will be the cause so that we would fully understand the concept behind seepage flow. The cause, as stated above, is either head difference between points or flow with in a medium. In this case, limiting the head or the flow for some particular scenario will make up a boundary condition.

In SEEP/W, it is expected that the user specify either the total hydraulic head or flow at a node (H or Q) as a boundary condition. In cases where the user specifies the total hydraulic head (H) the solution will be provided in terms of the total flow (Q) and vice versa.

Type one boundary condition, Dirichlet boundary condition, involves the user specifying the hydraulic heads or otherwise known as the field variable or the primary unknown. Type two boundary condition, Neumann boundary condition, involves the user specifying the flow gradient. The Seepage analysis form:

$$\{Q\} = [k].\{H\}$$

Where $\{Q\}$ Flow vector

$\{H\}$ Hydraulic head vector

$[k]$ Material conductivity matrice

In this particular modelling however, the primary concern is to determine the physical space, size and value of flow or flux with in the tunnel inner face. In that case, both end of the above mentioned seepage form are totally unknown. SEEP/W in this case has one additional boundary condition, the potential seepage face.

The potential seepage face or seepage face is an area where pore water pressure is either negligible or equal to zero. In this condition, the physical space and size are also unknown. However in SEEP/W, a potential seepage face can be set or defined so that the software, at the end of each iteration, would review the criteria and estimate the head or flux condition.

After taking the aforementioned steps, was modelled under the following preconditions,

1. Tunnel lining without waterproofing
2. Tunnel lining with water proofing
3. Tunnel lining with a hypothetical implementation of rock fill drain

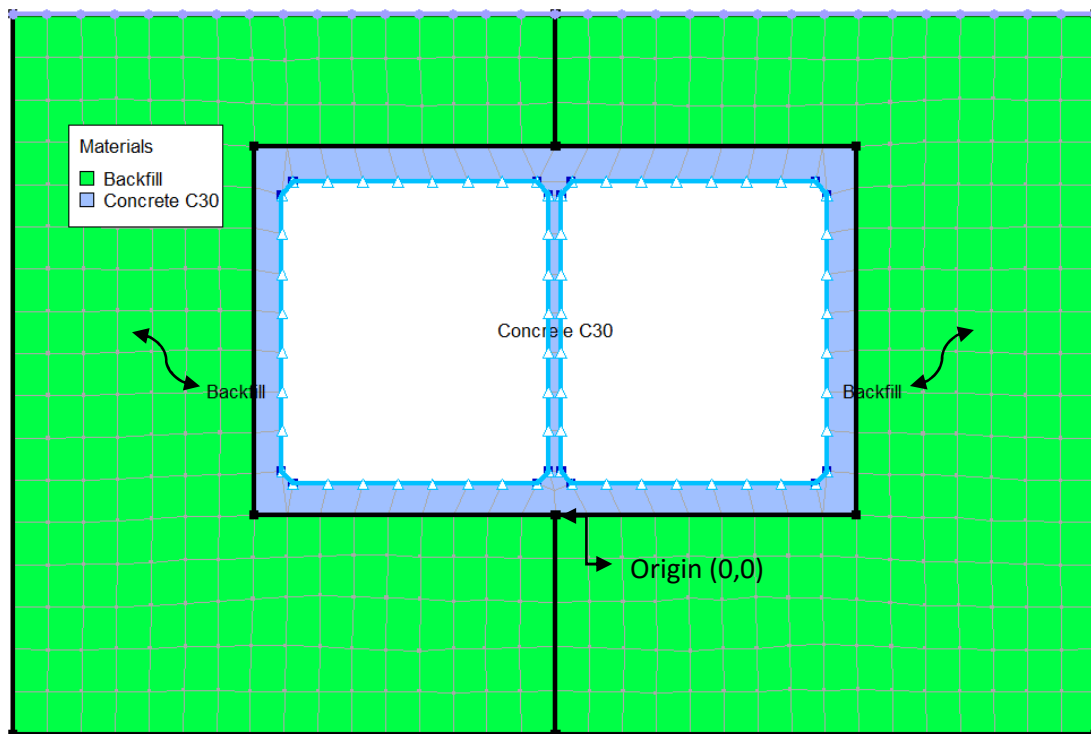


Figure 15 Condition-1 without Waterproofing

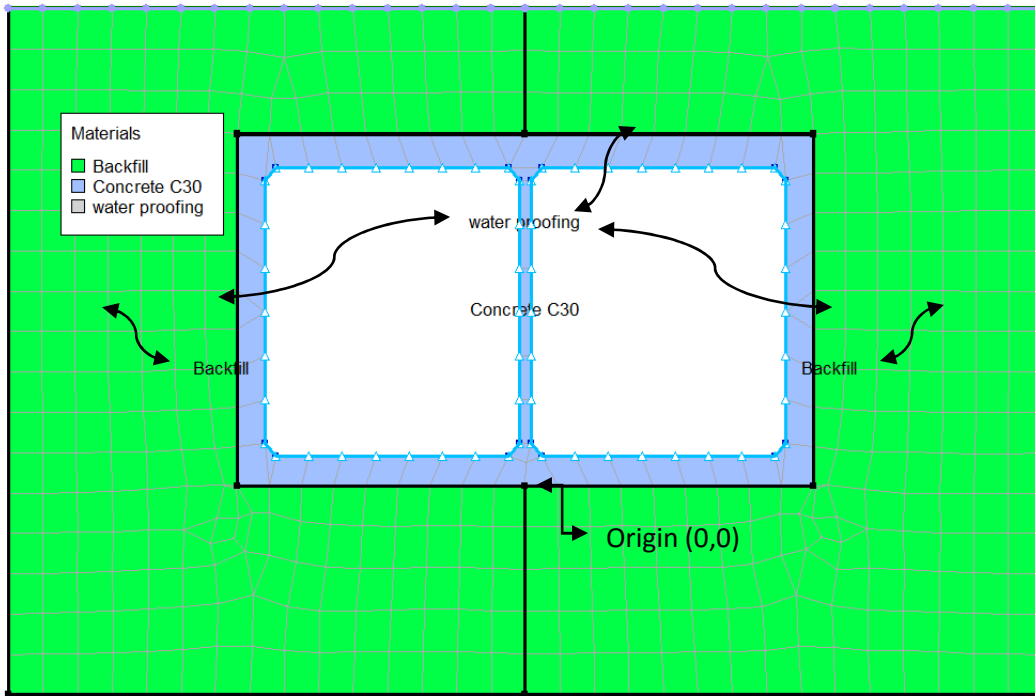


Figure 16 Condition-2 with waterproofing (applied on external surface of the tunnel)

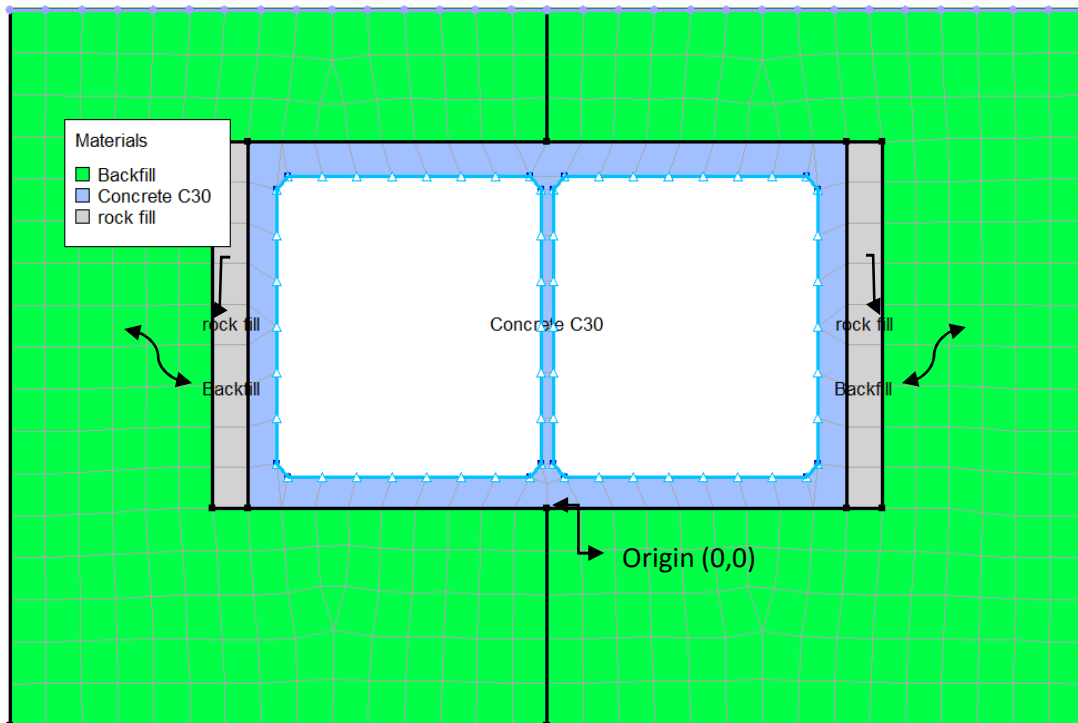


Figure 17 Condition-3 Rock- fill (1 meter width) on each side with drain point at toe

5. Result Discussion

5.1. Visual Output

Output from SEEP/W are in terms of visual and report form. The visual outputs are all the 2D representation the tunnel in regards to material property, total pressure and flow paths. Whereas the nodal report is the quantitative report, as opposed to the visual outputs, of each node under consideration.

SEEP/W finally outputs the result with in three categories;

1. Pore Pressure
2. Water flow
3. Flow Paths

5.1.1. Pore Pressure

In this category the total head, pressure head and pore water pressure can be presented. The total head which is the sum of the pressure head and the elevation head. As per the legend we have six measurement zones with 2 meter interval. Color blue for total head zone ranging from 0-2 meter, color cyan for total head zone ranging from 2-4 meter, color green for total head zone ranging from 4-6 meter, color light green for total head zone ranging from 6-8 meter, color yellow for total head zone ranging from 8-10 meter and color orange for total head zone greater than 10 meter. Here it is seen that the maximum total head being greater than 10meter whilst the minimum total head being 0 meter.

Condition-1

Four actual zones are depicted in the backfill area with values ranging from 4-6meter, 6-8meter, 8-10meter and greater than 10meter. The top 3meters of the backfill has the maximum head of value greater than 10meters. Further down on both side, total head decreases down to 8-10meter and again

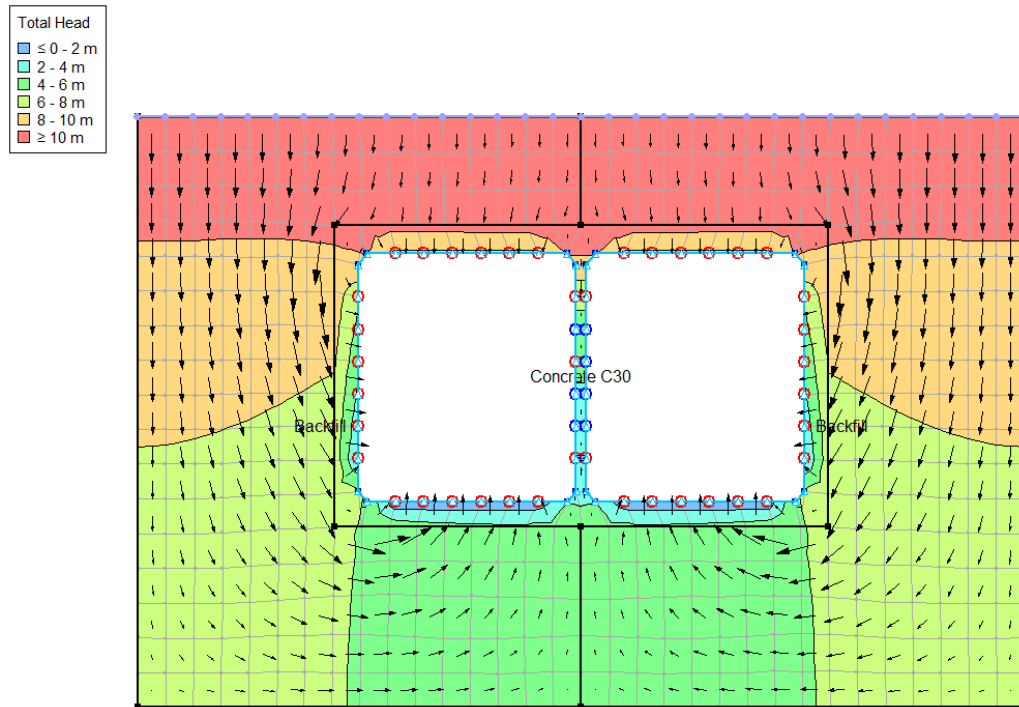


Figure 18 Total Head Condition-1

towards the bottom corner, it reduces to 6-8meter. Finally the ground at the bottom of the tunnel, it will have a minimum of 2-4meter total head.

As for the tunnel section, top tunnel lining total head value ranges between greater than 10meter towards the top surface an 8-10meter towards the bottom of top slab and top corner of the tunnel side tunnel lining. As we go further down to the bottom of the side lining, total head value reduces to 2-4meter. The bottom slab of the tunnel value ranges from 4-6meter at the bottom surface till 0-2meter at the top surface.

In summary, the backfill total head variation and tunnel lining total head variation is more or less similar but since the conductivity of the tunnel lining is radically lower than the backfill, minimum zone head is only seen in the tunnel section only.

Condition-2

Four actual zones are depicted in the backfill area with values ranging from 4-6meter, 6-8meter, 8-10meter and greater than 10meter. The top 7meters of the backfill has the maximum head of value greater than 10meters. Further down on both side upto the bottom slab corner, total head decreases down to 8-10meter and again

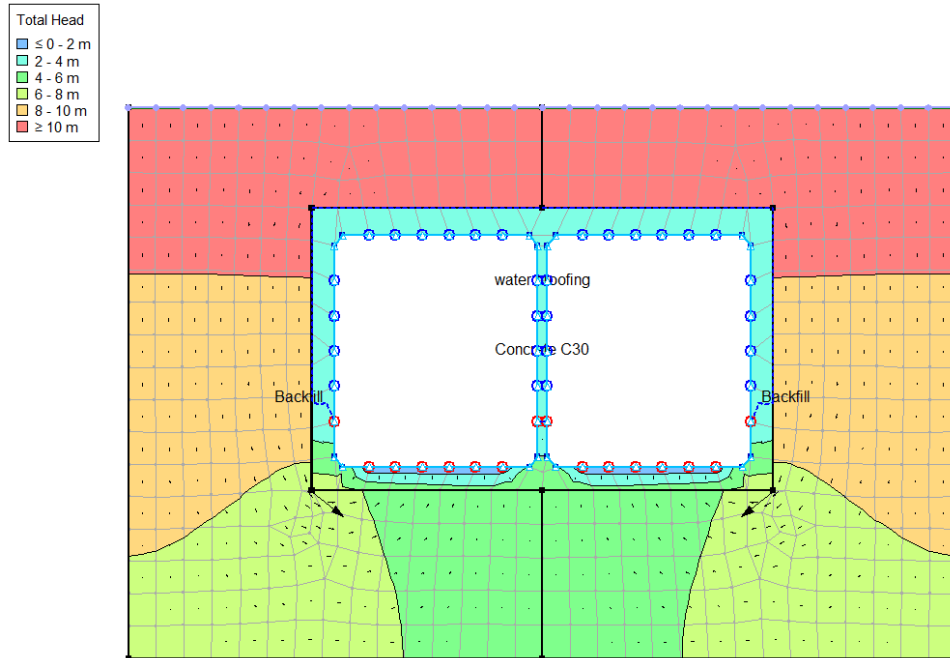


Figure 19 Total Head Condition-2

towards the bottom corner, it reduces to 6-8meter. Finally the ground at the bottom of the tunnel, it will have a minimum of 2-4meter total head.

As for the tunnel section, top tunnel lining and side wall total head value ranges between 2-4meter. The bottom slab of the tunnel value ranges from 6-8meter at the bottom surface till 0-2meter at the top surface.

In summary, the backfill total head variation and tunnel lining total head is radically changed due to the consideration of the waterproofing. As for the bottom slab, due to absence of waterproofing, it shows relatively similar response as the backfill.

Condition-3

All zones are depicted in the backfill area with values ranging from 0-2meter up to greater than 10meter. The top 4meters of the backfill shows maximum variation, ranging from 4-6meter up to greater than 10meter, as compared to the rest of the backfill area. Further down on both side including the tunnel bottom area, total head drastically decreases down to 0-2meter.

As for the tunnel section, top tunnel lining total head value ranges between greater than 10meter towards the top surface of tunnel middle section and 4-6meter towards the corner of top slab.

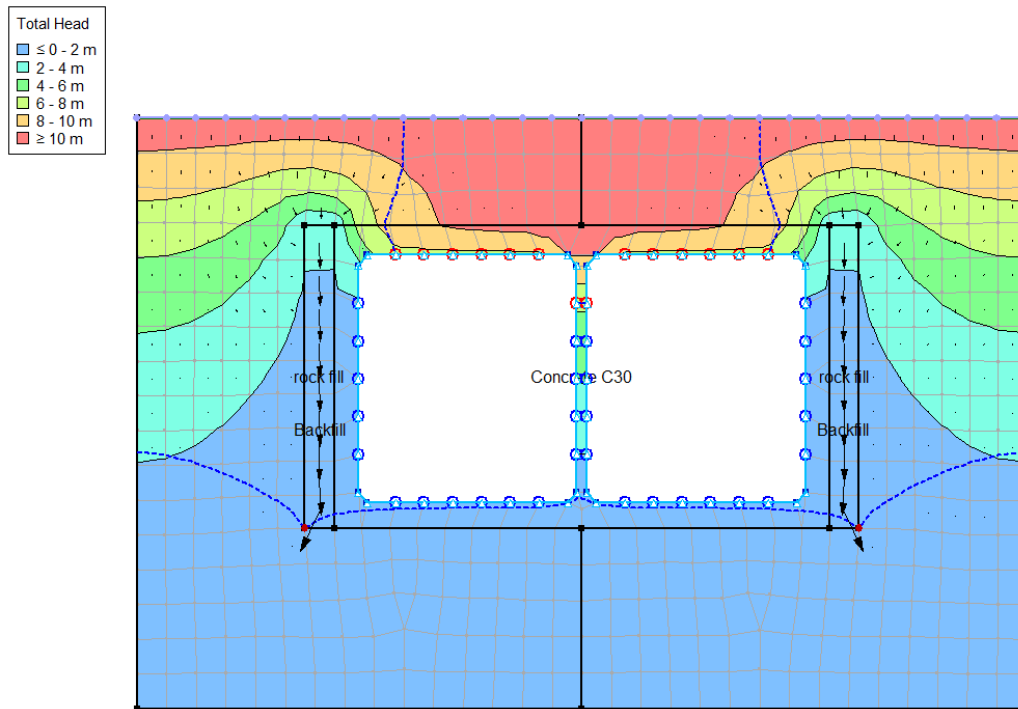


Figure 20 Total Head Condition-3

In summary, the backfill total head variation and tunnel lining total head is radically changed due to the consideration of the rockfill on the tunnel side. The rockfill greatly minimized the total head around the tunnel side and bottom. As for the top slab, due to absence of waterproofing, it shows relatively higher head response as the backfill.

5.1.2. Water flow

In this category the software determines the water flow velocity and gradient in the X and Y direction with vector. As per the legend, here we have eight measurement zones eight 2*E⁻⁰⁵m/sec interval. Color blue for XY velocity zone ranging from 0-2*E⁻⁰⁵m/sec, color cyan for XY velocity zone ranging from 2*E⁻⁰⁵m/sec -4*E⁻⁰⁵m/sec, color dark green for XY velocity zone ranging from 4*E⁻⁰⁵m/sec -6*E⁻⁰⁵m/sec, color green for XY velocity zone ranging from 6*E⁻⁰⁵m/sec -8*E⁻⁰⁵m/sec, color light green for XY velocity zone ranging from 8*E⁻⁰⁵m/sec -1*E⁻⁰⁴m/sec, color yellow for XY velocity zone ranging from 1*E⁻⁰⁴m/sec -1.2*E⁻⁰⁴m/sec, color orange for XY velocity zone ranging from 1.2*E⁻⁰⁴m/sec -1.4*E⁻⁰⁴m/sec and color

red for XY velocity zone greater than 1.4×10^{-4} m/sec. Here it is seen that the maximum XY velocity being greater than 1.4×10^{-4} m/sec whilst the minimum total head being 0 m/sec.

Condition-1

All eight zones are identified in the backfill area while only six zones starting from 0m/sec up to 1.2×10^{-4} m/sec are depicted in the tunnel lining section. As for the backfill area, in general, areas covering the tunnel top and greater than 5 meter below the tunnel bottom level have values ranging from $0-6 \times 10^{-5}$ m/sec. Areas covering the tunnel side up to 3 meter below the tunnel bottom level have intense

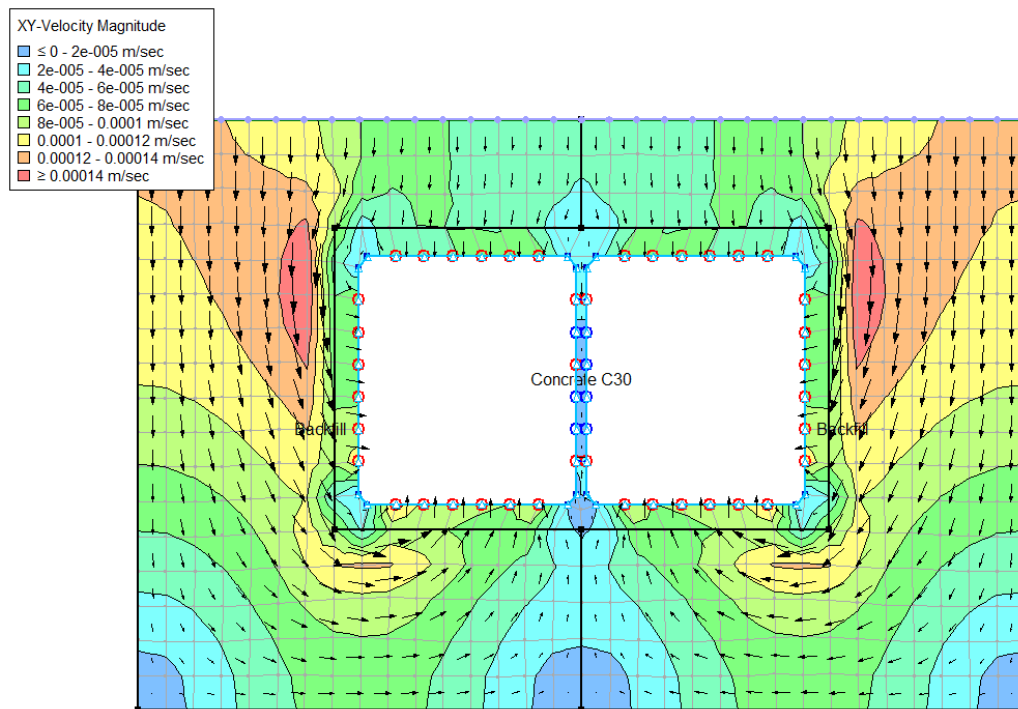


Figure 21 XY-Velocity Magnitude Condition-1

water velocity ranging from 8×10^{-5} - 1.4×10^{-4} m/sec.

As for the tunnel lining section, the tunnel top lining up to the side wall half way through from the top, the value ranges from 2×10^{-5} - 6×10^{-5} m/sec. The value changes from 2×10^{-5} - 1.2×10^{-4} m/sec in the remaining sections of the tunnel sidewall and bottom slab. Here it is clear that at corner of the tunnel section, there lays concrete chamfer. This intern increases the thickness hence reduced the value of the XY velocity of water flow to a minimum range of $0-4 \times 10^{-5}$ m/sec. specifically near the corner section in the sidewall and bottom slab, value rises to 1×10^{-4} - 1.2×10^{-4} m/sec and hence making water flow through the tunnel.

Condition-2

Here additional eight zones are identified in the backfill area making in total sixteen zones while only six zones starting from 0m/sec up to 1.2×10^{-4} m/sec are depicted in the tunnel lining section. As for the backfill area, in general, areas covering the tunnel top and greater than 5 meter below the tunnel top level have values ranging from

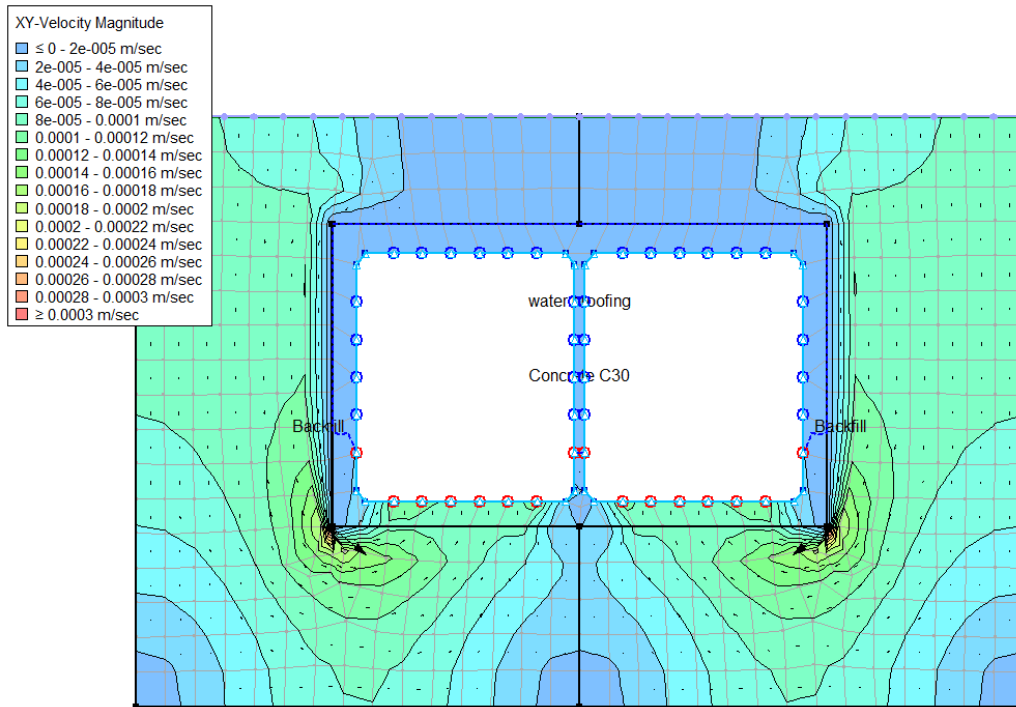


Figure 22 XY-Velocity Magnitude Condition-2

$0 - 1 \times 10^{-4}$ m/sec. Areas covering the tunnel side up to 3 meter below the tunnel bottom level have intense water velocity ranging from 8×10^{-5} - 1.8×10^{-4} m/sec.

As for the tunnel lining section, the tunnel top lining up to the side wall, the value ranges from $0 - 2 \times 10^{-5}$ m/sec. The value changes from 2×10^{-5} - 1.2×10^{-4} m/sec in the remaining sections of the tunnel bottom slab. Here it is clear the tunnel bottom slab experiences water flow through the tunnel.

Condition-3

Here the zone measurement interval, differs from the above two conditions, is in $2 \cdot 10^{-4}$ m/sec. As for the backfill area, all six zones are identified while only three zones starting from $0 - 6 \cdot 10^{-4}$ m/sec are depicted in the tunnel lining section. As for the backfill area, in general, areas covering the tunnel top and the side wall starting from halfway through from the top until the ground under the tunnel, values ranges from

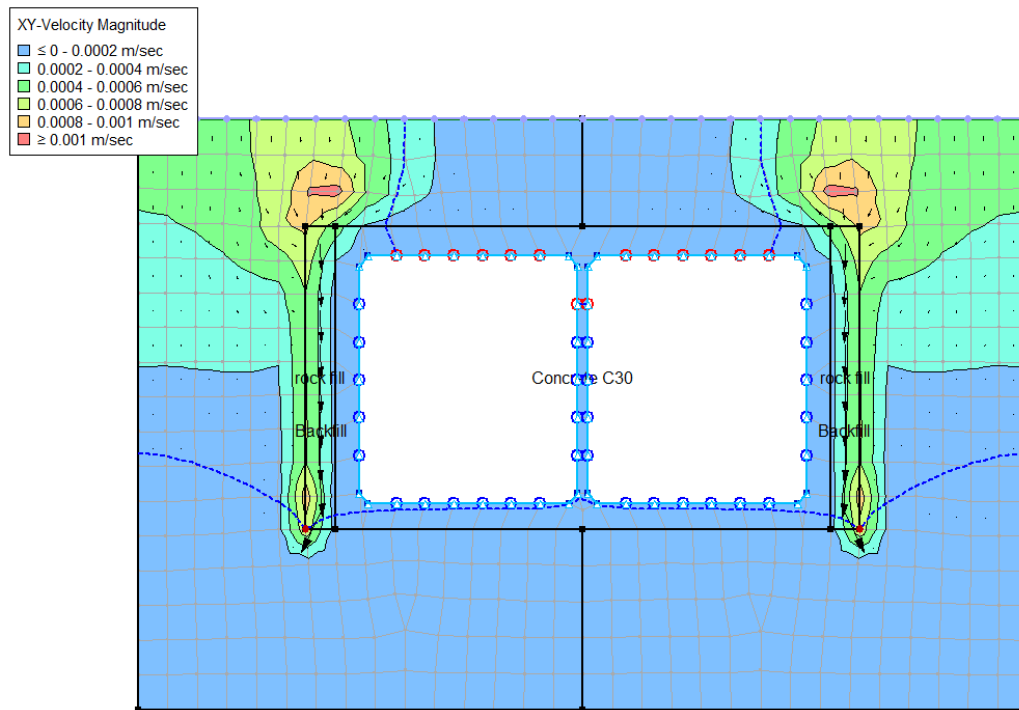


Figure 23 XY-Velocity Magnitude Condition-3

$0 - 2 \cdot 10^{-4}$ m/sec. Areas covering the tunnel side up to 3 meter below the tunnel top slab (towards the top of the rock fill serving as collecting and conduction medium) have intense water velocity ranging from $2 \cdot 10^{-4} - 1 \cdot 10^{-3}$ m/sec.

As for the tunnel lining section, apart from the tunnel top lining, the remaining sections value ranges from $0 - 2 \cdot 10^{-4}$ m/sec. The value with in the tunnel top is a little over null which ranges from $0 - 4 \cdot 10^{-5}$ m/sec.

5.1.3. Flow paths

The flow path out puts the path where an individual water drop or unit will take though out the course of time provided the conditions are met.

The software determines each node in iteration for all of the previously discussed parameters as well as the water flow direction of each cell surrounded by each nodes. Therefore all of these individual water flow direction can be interpolated and hence determining any points water flow path with in the considered area.

Condition-1

The water flow path shows that water particles tends to penetrate the tunnel from every direction but rather intensified towards the tunnel sidewall bottom corner and bottom slab.

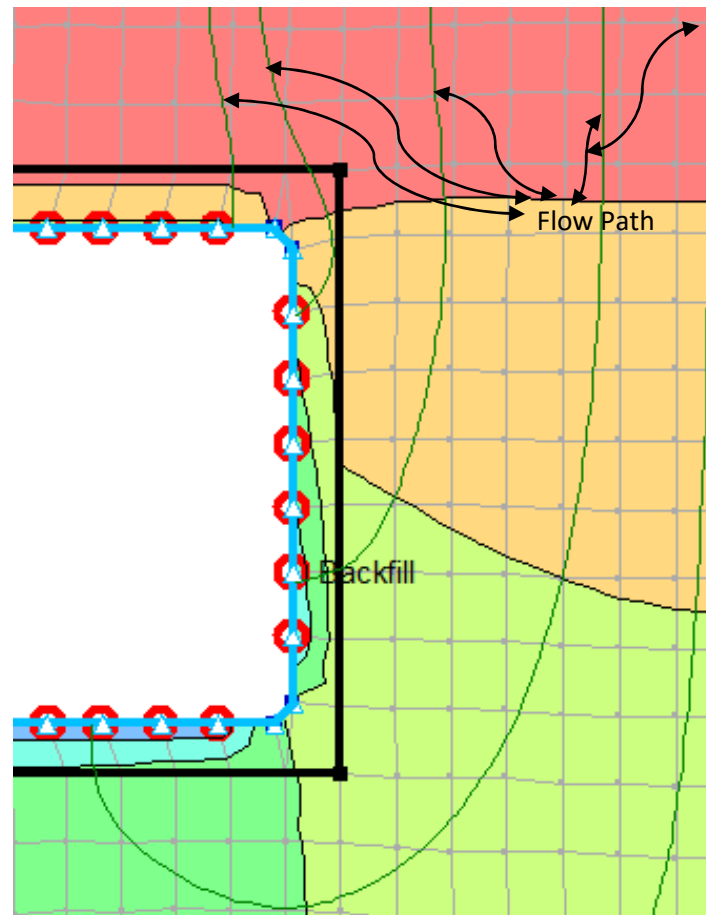


Figure 24 Flow path Condition-1

Condition-2

The water flow path shows that water particles tends to fall back from the tunnel waterproofed lining and move to the non-waterproofed bottom slab.

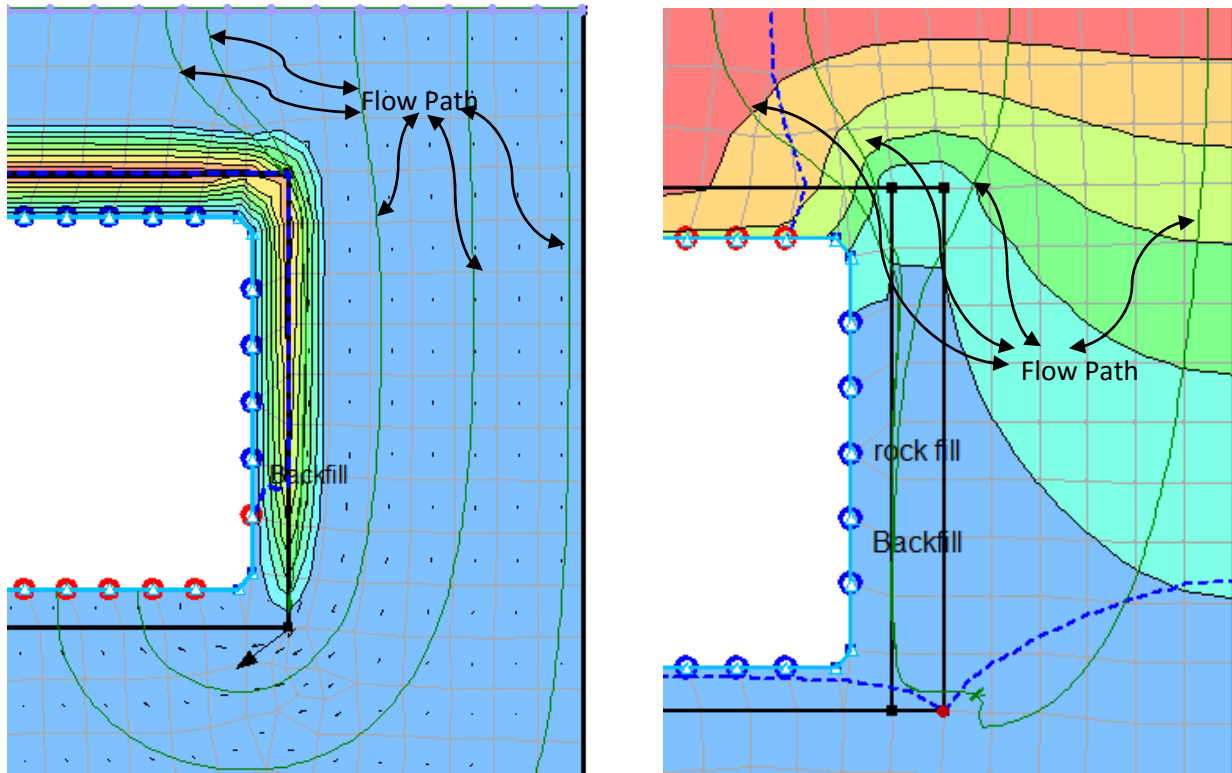


Figure 25 Flow path Condition-2 (left) and Condition-3 (right)

Condition-3

The water flow path, figure shown above in Figure 27, shows that water particles tends to penetrate the tunnel from every direction but rather intensified towards the tunnel sidewall bottom corner and bottom slab.

5.2. Nodal Reports

Nodal points are points created by meshing in finite element numerical analysis. It discretizes the object under consideration in to lesser units of sub regions as described in chapter 2.

Table 3 Condition-1 Inner Tunnel Lining Flux Values

Node	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
145	-7.550	1.000	6.177	50.771	5.177	None
146	-7.550	1.897	1.897	0	0	-9.67E-05
147	-7.550	2.794	2.794	0	0	-7.77E-05
148	-7.550	3.691	3.691	0	0	-6.82E-05
149	-7.550	4.589	4.589	0	0	-5.98E-05
150	-7.550	5.486	5.486	0	0	-5.23E-05
151	-7.550	6.383	6.383	0	0	-4.98E-05
152	-7.550	7.280	9.671	23.452	2.391	None
163	-7.250	0.700	5.863	50.631	5.163	None
164	-7.250	7.580	10.096	24.678	2.516	None
175	-6.282	0.700	0.7	0	0	-9.75E-05
176	-6.282	7.580	7.58	0	0	-6.12E-05
187	-5.314	0.700	0.7	0	0	-8.72E-05
188	-5.314	7.580	7.58	0	0	-5.79E-05
199	-4.346	0.700	0.7	0	0	-8.21E-05
200	-4.346	7.580	7.58	0	0	-5.81E-05
211	-3.379	0.700	0.7	0	0	-7.87E-05
212	-3.379	7.580	7.58	0	0	-5.85E-05
223	-2.411	0.700	0.7	0	0	-7.69E-05
224	-2.411	7.580	7.58	0	0	-5.90E-05
235	-1.443	0.700	0.7	0	0	-8.21E-05
236	-1.443	7.580	7.58	0	0	-6.59E-05
247	-0.475	0.700	3.98	32.168	3.28	None
248	-0.475	7.580	10.094	24.65	2.514	None
249	-0.175	1.000	3.619	25.684	2.619	None
250	-0.175	1.897	1.897	0	0	-7.60E-06
251	-0.175	2.794	2.794	0	0	0
252	-0.175	3.691	3.691	0	0	0
253	-0.175	4.589	4.589	0	0	-3.39E-21
254	-0.175	5.486	5.486	0	0	0
255	-0.175	6.383	6.383	0	0	-6.58E-06
256	-0.175	7.280	9.53	22.062	2.25	None

Node	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
257	-0.022	0.548	4.034	34.189	3.486	None
268	0.175	1	3.61	25.6	2.61	None
269	0.175	1.897	1.897	0	0	-7.70E-06
270	0.175	2.794	2.794	0	0	0
271	0.175	3.691	3.691	0	0	0
272	0.175	4.589	4.589	0	0	0
273	0.175	5.486	5.486	0	0	0
274	0.175	6.383	6.383	0	0	-6.58E-06
275	0.175	7.28	9.53	22.065	2.25	None
276	0.475	0.7	3.984	32.203	3.284	None
277	0.475	7.58	10.099	24.707	2.519	None
288	1.443	0.7	0.7	0	0	-8.21E-05
289	1.443	7.58	7.58	0	0	-6.59E-05
300	2.411	0.7	0.7	0	0	-7.69E-05
301	2.411	7.58	7.58	0	0	-5.90E-05
312	3.379	0.7	0.7	0	0	-7.87E-05
313	3.379	7.58	7.58	0	0	-5.85E-05
324	4.346	0.7	0.7	0	0	-8.21E-05
325	4.346	7.58	7.58	0	0	-5.81E-05
336	5.314	0.7	0.7	0	0	-8.72E-05
337	5.314	7.58	7.58	0	0	-5.79E-05
348	6.282	0.7	0.7	0	0	-9.75E-05
349	6.282	7.58	7.58	0	0	-6.12E-05
360	7.25	0.7	5.863	50.63	5.163	None
361	7.25	7.58	10.096	24.677	2.516	None
372	7.55	1	6.177	50.772	5.177	None
373	7.55	1.897	1.897	0	0	-9.67E-05
374	7.55	2.794	2.794	0	0	-7.77E-05
375	7.55	3.691	3.691	0	0	-6.82E-05
376	7.55	4.589	4.589	0	0	-5.98E-05
377	7.55	5.486	5.486	0	0	-5.23E-05
378	7.55	6.383	6.383	0	0	-4.98E-05
379	7.55	7.28	9.671	23.452	2.391	None

Table 4 Condition-2 Inner Tunnel Lining Flux Values

Node	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
159	-7.55	1	5.267	41.844	4.267	None
160	-7.55	2.047	2.047	0	0	-2.84E-05
161	-7.55	3.093	2.602	-4.823	-0.492	0
162	-7.55	4.14	2.532	-15.765	-1.608	0
163	-7.55	5.187	2.521	-26.143	-2.666	0
164	-7.55	6.233	2.506	-36.55	-3.727	0
165	-7.55	7.28	2.49	-46.971	-4.79	None
172	-7.25	0.7	5.781	49.831	5.081	None
173	-7.25	7.58	2.485	-49.971	-5.095	None
185	-6.282	0.7	0.7	0	0	-0.00011014
186	-6.282	7.58	2.469	-50.121	-5.111	0
198	-5.314	0.7	0.7	0	0	-9.91E-05
199	-5.314	7.58	2.456	-50.25	-5.124	0
211	-4.346	0.7	0.7	0	0	-9.33E-05
212	-4.346	7.58	2.443	-50.381	-5.137	0
224	-3.379	0.7	0.7	0	0	-8.95E-05
225	-3.379	7.58	2.429	-50.512	-5.151	0
237	-2.411	0.7	0.7	0	0	-8.75E-05
238	-2.411	7.58	2.416	-50.644	-5.164	0
250	-1.443	0.7	0.7	0	0	-9.35E-05
251	-1.443	7.58	2.403	-50.774	-5.177	0
263	-0.475	0.7	4.458	36.853	3.758	None
264	-0.475	7.58	2.387	-50.924	-5.193	None
265	-0.175	1	4.086	30.268	3.086	None
266	-0.175	2.047	2.047	0	0	-5.34E-06
267	-0.175	3.093	2.113	-9.617	-0.981	0
268	-0.175	4.14	2.179	-19.234	-1.961	0
269	-0.175	5.187	2.245	-28.851	-2.942	0
270	-0.175	6.233	2.311	-38.468	-3.922	0
271	-0.175	7.28	2.377	-48.084	-4.903	None

Node	X (m)	Y (m)	Z (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
283	0.01	0.545	0	4.527	39.059	3.983	None
284	0.175	1	0	4.094	30.34	3.094	None
285	0.175	2.047	0	2.047	0	0	-5.24E-06
286	0.175	3.093	0	2.113	-9.617	-0.981	0
287	0.175	4.14	0	2.179	-19.234	-1.961	0
288	0.175	5.187	0	2.245	-28.851	-2.942	0
289	0.175	6.233	0	2.311	-38.468	-3.922	0
290	0.175	7.28	0	2.377	-48.085	-4.903	None
291	0.475	0.7	0	4.454	36.815	3.754	None
292	0.475	7.58	0	2.387	-50.929	-5.193	None
304	1.443	0.7	0	0.7	0	0	-9.35E-05
305	1.443	7.58	0	2.403	-50.772	-5.177	0
317	2.411	0.7	0	0.7	0	0	-8.75E-05
318	2.411	7.58	0	2.416	-50.643	-5.164	0
330	3.379	0.7	0	0.7	0	0	-8.95E-05
331	3.379	7.58	0	2.429	-50.512	-5.151	0
343	4.346	0.7	0	0.7	0	0	-9.33E-05
344	4.346	7.58	0	2.443	-50.381	-5.137	0
356	5.314	0.7	0	0.7	0	0	-9.91E-05
357	5.314	7.58	0	2.456	-50.25	-5.124	0
369	6.282	0.7	0	0.7	0	0	-0.00011013
370	6.282	7.58	0	2.469	-50.121	-5.111	0
382	7.25	0.7	0	5.781	49.827	5.081	None
383	7.25	7.58	0	2.485	-49.971	-5.095	None
390	7.55	1	0	5.266	41.841	4.266	None
391	7.55	2.047	0	2.047	0	0	-2.84E-05
392	7.55	3.093	0	2.601	-4.823	-0.492	0
393	7.55	4.14	0	2.532	-15.765	-1.608	0
394	7.55	5.187	0	2.521	-26.143	-2.666	0
395	7.55	6.233	0	2.506	-36.549	-3.727	0
396	7.55	7.28	0	2.49	-46.971	-4.79	None

Table 5 Condition-3 Inner Tunnel Lining Flux Values

Node	X (m)	Y (m)	Z (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
145	-7.55	1	0	0.503	-4.871	-0.497	None
146	-7.55	2.047	0	0.739	-12.821	-1.307	0
147	-7.55	3.093	0	1.018	-20.356	-2.076	0
148	-7.55	4.14	0	1.287	-27.984	-2.853	0
149	-7.55	5.187	0	1.55	-35.67	-3.637	0
150	-7.55	6.233	0	1.856	-42.925	-4.377	0
151	-7.55	7.28	0	3.483	-37.242	-3.797	None
156	-7.25	0.7	0	0.5	-1.965	-0.2	None
157	-7.25	7.58	0	5.532	-20.087	-2.048	None
169	-6.282	0.7	0	0.526	-1.702	-0.174	0
170	-6.282	7.58	0	7.58	0	0	-1.84E-05
181	-5.314	0.7	0	0.549	-1.485	-0.151	0
182	-5.314	7.58	0	7.58	0	0	-3.74E-05
193	-4.346	0.7	0	0.561	-1.365	-0.139	0
194	-4.346	7.58	0	7.58	0	0	-4.63E-05
205	-3.379	0.7	0	0.568	-1.291	-0.132	0
206	-3.379	7.58	0	7.58	0	0	-5.15E-05
217	-2.411	0.7	0	0.574	-1.232	-0.126	0
218	-2.411	7.58	0	7.58	0	0	-5.49E-05
229	-1.443	0.7	0	0.586	-1.117	-0.114	0
230	-1.443	7.58	0	7.58	0	0	-6.31E-05
241	-0.475	0.7	0	0.685	-0.146	-0.015	None
242	-0.475	7.58	0	10.038	24.103	2.458	None
243	-0.175	1	0	0.911	-0.875	-0.089	None
244	-0.175	2.047	0	1.981	-0.644	-0.066	0
245	-0.175	3.093	0	3.043	-0.496	-0.051	0
246	-0.175	4.14	0	4.107	-0.328	-0.033	0
247	-0.175	5.187	0	5.17	-0.164	-0.017	0
248	-0.175	6.233	0	6.233	0	0	-5.61E-06
249	-0.175	7.28	0	9.532	22.085	2.252	None

Node	X (m)	Y (m)	Z (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
250	-0.01	0.545	0	0.724	1.765	0.18	None
261	0.175	1	0	0.922	-0.768	-0.078	None
262	0.175	2.047	0	1.978	-0.67	-0.068	0
263	0.175	3.093	0	3.043	-0.49	-0.05	0
264	0.175	4.14	0	4.106	-0.329	-0.034	0
265	0.175	5.187	0	5.17	-0.164	-0.017	0
266	0.175	6.233	0	6.233	0	0	-5.60E-06
267	0.175	7.28	0	9.532	22.088	2.252	None
268	0.475	0.7	0	0.68	-0.198	-0.02	None
269	0.475	7.58	0	10.045	24.171	2.465	None
280	1.443	0.7	0	0.586	-1.122	-0.114	0
281	1.443	7.58	0	7.58	0	0	-6.31E-05
292	2.411	0.7	0	0.574	-1.234	-0.126	0
293	2.411	7.58	0	7.58	0	0	-5.49E-05
304	3.379	0.7	0	0.568	-1.292	-0.132	0
305	3.379	7.58	0	7.58	0	0	-5.15E-05
316	4.346	0.7	0	0.561	-1.367	-0.139	0
317	4.346	7.58	0	7.58	0	0	-4.63E-05
328	5.314	0.7	0	0.548	-1.488	-0.152	0
329	5.314	7.58	0	7.58	0	0	-3.74E-05
340	6.282	0.7	0	0.526	-1.707	-0.174	0
341	6.282	7.58	0	7.58	0	0	-1.84E-05
352	7.25	0.7	0	0.499	-1.97	-0.201	None
353	7.25	7.58	0	5.532	-20.087	-2.048	None
359	7.55	1	0	0.503	-4.873	-0.497	None
360	7.55	2.047	0	0.739	-12.822	-1.307	0
361	7.55	3.093	0	1.017	-20.358	-2.076	0
362	7.55	4.14	0	1.286	-27.987	-2.854	0
363	7.55	5.187	0	1.549	-35.674	-3.638	0
364	7.55	6.233	0	1.856	-42.93	-4.377	0
365	7.55	7.28	0	3.482	-37.246	-3.798	None

The inner lining of the tunnel in particular have been studied and results show that the nodes exhibits water infiltration in each node point with the maximum $9.75E^{-05}m^3/s$ at nodes 175 and 348 which are the inner bottom left and right corner nodal points for Condition-1. Also for Condition-2, a maximum of

1.10E⁻⁰⁴ m³/s at nodes 185 and 369 is exhibited at the tunnel bottom slab or floor. And finally for Condition-3, a maximum of 6.31E⁻⁰⁵ m³/s at nodes 230 and 281 is exhibited at the tunnel top slab or roof.

This suggests that in Condition-1, the bottom corner area on both side of the lining are strongly affected by water infiltration as opposed to other lining sections. In Condition-2, the effect of the waterproofing would have sufficed the situation at hand but the fact that there is no draining pipe at the bottom of the tunnel side increases seepage in the bottom slab of the tunnel. And finally in Condition-3, the effect of the rock-fill would also have sufficed the seepage problem but the fact that there is no waterproofing on the top slab of the tunnel increased the seepage pressure at top of the tunnel lining.

5.3. Comparison of the Scenarios

Comparison was made on 10 nodal point evaluating the performance of water proofing in condition 2 against condition 1 and the performance of rock fill drain in condition 3 against condition 1. The 10 nodal points were chosen based there exhibition of high flux or rate of seepage on the different conditions studied. Of the 10 nodal points considered, 5 nodal points are located on the left half of the tunnel and the other 5 on the right half of the tunnel in which the nodal points can be located symmetrical from the tunnel centerline.

It was found out that the rock drain has a better performance on avoiding seepage from the bottom slab and the wall while the water proofing performed well on avoiding seepage from the top slab.

Table 6 Comparison of each condition (by percent)

Condition-1					Condition-2		Condition-3		Percentile Variation Condition 2 vs Condition 1	Percentile Variation Condition 3 vs Condition 1
Node	Location	X (m)	Y (m)	Water Flux (m ³ /sec)	Node	Water Flux (m ³ /sec)	Node	Water Flux (m ³ /sec)		
146	Left wall near floor level	-7.550	1.897	9.67E-05	160	2.84E-05	146	0.00E+00	Seepage Decreased to 29.37%	Seepage fully removed
175	Bottom slab on left extreme	-6.282	0.700	9.75E-05	185	1.10E-04	169	0.00E+00	Seepage Increased to 112.92%	Seepage fully removed
176	Top slab on left extreme	-6.282	7.580	6.12E-05	186	0.00E+00	170	1.84E-05	Seepage fully removed	Seepage Decreased to 30.07%
235	Bottom slab near middle wall just to the left	-1.443	0.700	8.21E-05	250	9.35E-05	229	0.00E+00	Seepage Increased to 113.89%	Seepage fully removed
236	Top slab near middle wall just to the left	-1.443	7.580	6.59E-05	251	0.00E+00	230	6.31E-05	Seepage fully removed	Seepage Decreased to 95.75%
288	Bottom slab near middle wall just to the right	1.443	0.700	8.21E-05	304	9.35E-05	280	0.00E+00	Seepage Increased to 113.89%	Seepage fully removed
289	Top slab near middle wall just to the right	1.443	7.580	6.59E-05	305	0.00E+00	281	6.31E-05	Seepage fully removed	Seepage Decreased to 95.75%
348	Bottom slab on right extreme	6.282	0.700	9.75E-05	369	1.10E-04	340	0.00E+00	Seepage Increased to 112.92%	Seepage fully removed
349	Top slab on right extreme	6.282	7.580	6.12E-05	370	0.00E+00	341	1.84E-05	Seepage fully removed	Seepage Decreased to 30.07%
373	Right wall near floor level	7.550	1.897	9.67E-05	391	2.84E-05	360	0.00E+00	Seepage Decreased to 29.37%	Seepage fully removed

For nodal point 146 and 373, located near floor level of each wall, the seepage was **decreased** to 29 percent with the implementation of waterproofing and **completely removed** with the implementation of rock fill drain.

For nodal point 175 and 348, located on bottom slab on both left and right ends, the seepage was **increased** to 113 percent with the implementation of waterproofing and **completely removed** with the implementation of rock fill drain.

For nodal point 176 and 349, located on top slab on both left and right ends, the seepage was **completely removed** with the implementation of waterproofing and **decreased** to 30 percent with the implementation of rock fill drain.

For nodal point 235 and 288, located on bottom slab just to left and right of the middle wall, the seepage was **increased** to 114 percent with the implementation of waterproofing and **completely removed** with the implementation of rock fill drain.

For nodal point 236 and 289, located on top slab just to left and right of the middle wall, the seepage was **completely removed** with the implementation of waterproofing and **decreased only** to 95 percent with the implementation of rock fill drain.

6. Conclusion and Recommendations

6.1. Conclusion

With this research, it is made possible to find out performance of waterproofing and rock-fill construction using simple assumptions and numerical modelling.

The research was developed using the following assumptions,

- The wall concrete has an average permeability of $1.50 \times 10^{-05} \text{m/s}$
- The backfill soil has an average permeability of $3.00 \times 10^{-04} \text{m/s}$
- The backfill soil is homogenous and isotropic material
- The water proofing material has zero permeability
- The rock-fill has 0.018 m/s permeability
- Water table is above the tunnel located at 0.5 meter below the road surface
- Water table is continuous and remains constant

With this assumptions, the model showed that, the tunnel section exhibits maximum flux or infiltration in the bottom corner each side. Proper application of water proofing helps in prevents water infiltration throughout the tunnel lining. Even if exterior waterproofing is part of the solution, it is also necessary to implement a drain pipe at the bottom of the tunnel to remove the water that will accumulate near the tunnel bottom. One additional finding here would be that the protection of the waterproofing on the tunnel side linings will be greatly increased if a rock-fill can be implemented on the as a backfill material for a limited width so that the gravitational drainage of the rock-fill avoids any saturation to develop at the tunnel side lining and bottom slab. In both cases though, the implementation of a drain pipe is mandatory.

In actual conditions, it has been noted that even with the application of the water proofing material in all the tunnel outer lining section regardless, leakages had been seen in the bottom corner and top roof section. This intern deduces to either:

- the application of the water proofing material is negligible
- the applied water proofing material is below expected

6.2. Recommendation

Accordingly the following recommendations is given:

1. Divert the water from ever reaching the tunnel lining
 - a. Reconditioning the backfill material to minimize the porosity (using cementitious material with the backfill)
 - b. Regrading the backfill material so that porosity would be minimized
 - c. Implementation of rock-fill material for a limited width
 - d. Installation of drain pipe at the tunnel bottom to go with the rock-fill
 - e. Using the proper water proofing material with drain pipe at the tunnel bottom
2. For any cases, installation of a freely draining (gravitationally draining) perforated drain pipe is a must since any application of the external waterproofing will eventually create an accumulation of water at the tunnel bottom.
3. Use chemical injection or sealants such as hydrophobic Polyurethanes in which these active water leakage condition will be used to catalyze the chemicals and hence reducing the water leakage in the inner lining.
4. Consideration of enough clearance height for the future which can accommodate the addition of post seepage tunnel linings which might have multiple layer hence reducing the tunnel clear height.

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Annexes

Appendix A: Research Input Report

Condition-1: Tunnel Lining Without Waterproofing

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/1/tunnel redefined 1...

Steady-State Seepage

Report generated using GeoStudio 2012. Copyright © 1991-2015 GEO-SLOPE International Ltd.

File Information

File Version: 8.15
Created By: Ddy
Last Edited By: Ddy
Revision Number: 46
Date: 11/12/2015
Time: 11:18:54 PM
Tool Version: 8.15.4.11512
File Name: tunnel redefined 1.gsz
Directory: C:\Users\user1\Documents\Seepage\GeoStudio\
Last Solved Date: 11/12/2015
Last Solved Time: 11:18:58 PM

Project Settings

Length(L) Units: Meters
Time(t) Units: Seconds
Force(F) Units: Kilonewtons
Pressure(p) Units: kPa
Mass(M) Units: Grams
Mass Flux Units: g/sec
Unit Weight of Water: 9.807 kN/m³
View: 2D
Element Thickness: 1

Analysis Settings

Steady-State Seepage

Kind: SEEP/W
Method: Steady-State
Settings
Include Air Flow: No
Control
Apply Runoff: Yes
Convergence
Maximum Number of Iterations: 500
Minimum Pressure Head Difference: 0.005
Significant Digits: 2
Max # of Reviews: 10
Hydraulic Under-Relaxation Criteria
Under-Relaxation Initial Rate: 1
Under-Relaxation Min. Rate: 0.1
Under-Relaxation Reduction Rate: 0.65
Under-Relaxation Iterations: 10

1 of 4

11/13/2015 1:35 PM

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/1/tunnel redefined 1...

Equation Solver: Direct
Time
Starting Time: 0 sec
Duration: 0 sec
Ending Time: 0 sec

Materials

Backfill

Model: Saturated Only
Hydraulic
Sat Kx: 0.0003 m/sec
Ky'/Kx' Ratio: 1
Rotation: 0 °
Volumetric Water Content: 0.371 m³/m³
Mv: 0 /kPa

Concrete C30

Model: Saturated Only
Hydraulic
Sat Kx: 1.5e-005 m/sec
Ky'/Kx' Ratio: 1
Rotation: 0 °
Volumetric Water Content: 0.225 m³/m³
Mv: 0 /kPa

Boundary Conditions

Potential Seepage Face

Type: Total Flux (Q) 0
Review: Yes

water table

Type: Head (H) 11.38
Review: No

Flux Sections

Flux Section 1

Coordinates
Coordinate: (-7.55, 7.28) m
Coordinate: (-7.55, 1) m

Flux Section 2

Coordinates
Coordinate: (7.55, 7.28) m
Coordinate: (7.55, 1) m

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/1/tunnel redefined 1...

Points

	X (m)	Y (m)
Point 1	-8.35	8.38
Point 2	-8.35	0
Point 3	0	0
Point 4	8.35	0
Point 5	8.35	8.38
Point 6	0	8.38
Point 7	-0.475	7.58
Point 8	-0.175	7.28
Point 9	-0.175	1
Point 10	-0.475	0.7
Point 11	-7.25	0.7
Point 12	-7.55	1
Point 13	-7.55	7.28
Point 14	-7.25	7.58
Point 15	0.175	7.28
Point 16	0.475	7.58
Point 17	7.25	7.58
Point 18	7.55	7.28
Point 19	7.55	1
Point 20	7.25	0.7
Point 21	0.475	0.7
Point 22	0.175	1
Point 23	-15	11.38
Point 24	0	11.38
Point 25	15	11.38
Point 26	15	-5
Point 27	0	-5
Point 28	-15	-5
Point 29	-7.25	7.58
Point 30	-7.55	7.28
Point 31	-7.55	1
Point 32	-7.25	0.7
Point 33	-0.475	0.7
Point 34	-0.175	1
Point 35	-0.175	7.28
Point 36	-0.475	7.58
Point 37	0.475	7.58
Point 38	0.175	7.28
Point 39	0.175	1
Point 40	0.475	0.7
Point 41	7.25	0.7
Point 42	7.55	1
Point 43	7.55	7.28
Point 44	7.25	7.58

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/1/tunnel redefined 1...

Lines

	Start Point	End Point	Length (m)	Angle (°)	Hydraulic Boundary
Line 1	1	2	8.38	90	
Line 2	4	5	8.38	90	
Line 3	29	30	0.42426	45	Potential Seepage Face
Line 4	30	31	6.28	90	Potential Seepage Face
Line 5	31	32	0.42426	-45	Potential Seepage Face
Line 6	32	33	6.775	0	Potential Seepage Face
Line 7	33	34	0.42426	45	Potential Seepage Face
Line 8	34	35	6.28	90	Potential Seepage Face
Line 9	35	36	0.42426	-45	Potential Seepage Face
Line 10	36	29	6.775	0	Potential Seepage Face
Line 11	37	38	0.42426	45	Potential Seepage Face
Line 12	38	39	6.28	90	Potential Seepage Face
Line 13	39	40	0.42426	-45	Potential Seepage Face
Line 14	40	41	6.775	0	Potential Seepage Face
Line 15	41	42	0.42426	45	Potential Seepage Face
Line 16	42	43	6.28	90	Potential Seepage Face
Line 17	43	44	0.42426	-45	Potential Seepage Face
Line 18	44	37	6.775	0	Potential Seepage Face
Line 19	2	3	8.35	0	
Line 20	3	4	8.35	0	
Line 21	5	6	8.35	0	
Line 22	6	1	8.35	0	
Line 23	24	23	15	0	water table
Line 24	23	28	16.38	90	
Line 25	28	27	15	0	
Line 26	27	3	5	90	
Line 27	6	24	3	90	
Line 28	25	24	15	0	water table
Line 29	27	26	15	0	
Line 30	26	25	16.38	90	

Regions

	Material	Points	Area (m ²)
Region 1	Concrete C30	1,2,3,4,5,6	139.95
Region 2		29,30,31,32,33,34,35,36	50.56
Region 3		37,38,39,40,41,42,43,44	50.56
Region 4	Backfill	24,23,28,27,3,2,1,6	175.73
Region 5	Backfill	25,24,6,5,4,3,27,26	175.73

Condition-2 Tunnel Lining With Waterproofing

Steady-State Seepage

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Steady-State Seepage

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File Information

File Version: 8.15
Created By: Ddy
Last Edited By: Ddy
Revision Number: 12
Date: 11/12/2015
Time: 11:26:13 AM
Tool Version: 8.15.4.11512
File Name: tunnel redefined 2.gsz
Directory: C:\Users\user1\Documents\Seepage\GeoStudio\
Last Solved Date: 11/12/2015
Last Solved Time: 11:33:46 AM

Project Settings

Length(L) Units: Meters
Time(t) Units: Seconds
Force(F) Units: Kilonewtons
Pressure(p) Units: kPa
Mass(M) Units: Grams
Mass Flux Units: g/sec
Unit Weight of Water: 9.807 kN/m³
View: 2D
Element Thickness: 1

Analysis Settings

Steady-State Seepage

Kind: SEEP/W
Method: Steady-State
Settings
Include Air Flow: No
Control
Apply Runoff: Yes
Convergence
Maximum Number of Iterations: 500
Minimum Pressure Head Difference: 0.005
Significant Digits: 2
Max # of Reviews: 10
Hydraulic Under-Relaxation Criteria
Under-Relaxation Initial Rate: 1
Under-Relaxation Min. Rate: 0.1
Under-Relaxation Reduction Rate: 0.65
Under-Relaxation Iterations: 10

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/2/tunnel redefined 2...

Equation Solver: Direct
 Time
 Starting Time: 0 sec
 Duration: 0 sec
 Ending Time: 0 sec

Materials

Backfill

Model: Saturated Only
 Hydraulic
 Sat Kx: 0.0003 m/sec
 Ky'/Kx' Ratio: 1
 Rotation: 0 °
 Volumetric Water Content: 0.371 m³/m³
 Mv: 0 /kPa

Concrete C30

Model: Saturated Only
 Hydraulic
 Sat Kx: 1.5e-005 m/sec
 Ky'/Kx' Ratio: 1
 Rotation: 0 °
 Volumetric Water Content: 0.225 m³/m³
 Mv: 0 /kPa

water proofing

Model: Saturated Only
 Hydraulic
 Sat Kx: 1e-100 m/sec
 Ky'/Kx' Ratio: 1
 Rotation: 0 °
 Volumetric Water Content: 0 m³/m³
 Mv: 0 /kPa

Boundary Conditions

Potential Seepage Face

Type: Total Flux (Q) 0
 Review: Yes

water table

Type: Head (H) 11.38
 Review: No

Points

	X (m)	Y (m)
Point 1	-8.35	8.38

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/2/tunnel redefined 2...

Point 2	-8.35	0
Point 3	0	0
Point 4	8.35	0
Point 5	8.35	8.38
Point 6	0	8.38
Point 7	-0.475	7.58
Point 8	-0.175	7.28
Point 9	-0.175	1
Point 10	-0.475	0.7
Point 11	-7.25	0.7
Point 12	-7.55	1
Point 13	-7.55	7.28
Point 14	-7.25	7.58
Point 15	0.175	7.28
Point 16	0.475	7.58
Point 17	7.25	7.58
Point 18	7.55	7.28
Point 19	7.55	1
Point 20	7.25	0.7
Point 21	0.475	0.7
Point 22	0.175	1
Point 23	-15	11.38
Point 24	0	11.38
Point 25	15	11.38
Point 26	15	-5
Point 27	0	-5
Point 28	-15	-5
Point 29	-7.25	7.58
Point 30	-7.55	7.28
Point 31	-7.55	1
Point 32	-7.25	0.7
Point 33	-0.475	0.7
Point 34	-0.175	1
Point 35	-0.175	7.28
Point 36	-0.475	7.58
Point 37	0.475	7.58
Point 38	0.175	7.28
Point 39	0.175	1
Point 40	0.475	0.7
Point 41	7.25	0.7
Point 42	7.55	1
Point 43	7.55	7.28
Point 44	7.25	7.58
Point 45	8.36	0
Point 46	8.36	8.39
Point 47	0	8.39
Point 48	-8.36	8.39
Point 49	-8.36	0

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/2/tunnel redefined 2...

Lines

	Start Point	End Point	Length (m)	Angle (°)	Hydraulic Boundary
Line 1	1	2	8.38	90	
Line 2	4	5	8.38	90	
Line 3	29	30	0.42426	45	Potential Seepage Face
Line 4	30	31	6.28	90	Potential Seepage Face
Line 5	31	32	0.42426	-45	Potential Seepage Face
Line 6	32	33	6.775	0	Potential Seepage Face
Line 7	33	34	0.42426	45	Potential Seepage Face
Line 8	34	35	6.28	90	Potential Seepage Face
Line 9	35	36	0.42426	-45	Potential Seepage Face
Line 10	36	29	6.775	0	Potential Seepage Face
Line 11	37	38	0.42426	45	Potential Seepage Face
Line 12	38	39	6.28	90	Potential Seepage Face
Line 13	39	40	0.42426	-45	Potential Seepage Face
Line 14	40	41	6.775	0	Potential Seepage Face
Line 15	41	42	0.42426	45	Potential Seepage Face
Line 16	42	43	6.28	90	Potential Seepage Face
Line 17	43	44	0.42426	-45	Potential Seepage Face
Line 18	44	37	6.775	0	Potential Seepage Face
Line 19	2	3	8.35	0	
Line 20	3	4	8.35	0	
Line 21	5	6	8.35	0	
Line 22	6	1	8.35	0	
Line 23	24	23	15	0	water table
Line 24	23	28	16.38	90	
Line 25	28	27	15	0	
Line 26	27	3	5	90	
Line 27	25	24	15	0	water table
Line 28	27	26	15	0	
Line 29	26	25	16.38	90	
Line 30	2	49	0.01	0	
Line 31	49	48	8.39	90	
Line 32	48	47	8.36	0	
Line 33	47	24	2.99	90	
Line 34	47	46	8.36	0	
Line 35	46	45	8.39	90	
Line 36	45	4	0.01	0	

Regions

	Material	Points	Area (m²)
Region 1	Concrete C30	1,2,3,4,5,6	139.95
Region 2		29,30,31,32,33,34,35,36	50.56
Region 3		37,38,39,40,41,42,43,44	50.56
Region 4	Backfill	24,23,28,27,3,2,49,48,47	175.56
Region 5	Backfill	25,24,47,46,45,4,3,27,26	175.56

Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/2/tunnel redefined 2...

Region 6	water proofing	2,1,6,5,4,45,46,47,48,49	0.3348
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Condition-3 Tunnel Lining With Rock-Fill

Steady-State Seepage

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Steady-State Seepage

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File Information

File Version: 8.15
Created By: Ddy
Last Edited By: Ddy
Revision Number: 16
Date: 11/12/2015
Time: 11:47:24 AM
Tool Version: 8.15.4.11512
File Name: tunnel redefined 3.gsz
Directory: C:\Users\user1\Documents\Seepage\GeoStudio\
Last Solved Date: 11/12/2015
Last Solved Time: 11:47:28 AM

Project Settings

Length(L) Units: Meters
Time(t) Units: Seconds
Force(F) Units: Kilonewtons
Pressure(p) Units: kPa
Mass(M) Units: Grams
Mass Flux Units: g/sec
Unit Weight of Water: 9.807 kN/m³
View: 2D
Element Thickness: 1

Analysis Settings

Steady-State Seepage

Kind: SEEP/W
Method: Steady-State
Settings
Include Air Flow: No
Control
Apply Runoff: Yes
Convergence
Maximum Number of Iterations: 500
Minimum Pressure Head Difference: 0.005
Significant Digits: 2
Max # of Reviews: 10
Hydraulic Under-Relaxation Criteria
Under-Relaxation Initial Rate: 1
Under-Relaxation Min. Rate: 0.1
Under-Relaxation Reduction Rate: 0.65
Under-Relaxation Iterations: 10

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Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/3/tunnel redefined 3...

Equation Solver: Direct

Time

Starting Time: 0 sec

Duration: 0 sec

Ending Time: 0 sec

Materials

Backfill

Model: Saturated Only

Hydraulic

Sat Kx: 0.0003 m/sec

Ky'/Kx' Ratio: 1

Rotation: 0 °

Volumetric Water Content: 0.371 m³/m³

Mv: 0 /kPa

Concrete C30

Model: Saturated Only

Hydraulic

Sat Kx: 1.5e-005 m/sec

Ky'/Kx' Ratio: 1

Rotation: 0 °

Volumetric Water Content: 0.225 m³/m³

Mv: 0 /kPa

rock fill

Model: Saturated Only

Hydraulic

Sat Kx: 0.018 m/sec

Ky'/Kx' Ratio: 1

Rotation: 0 °

Volumetric Water Content: 0.518 m³/m³

Mv: 0 /kPa

Boundary Conditions

Zero Pressure

Type: Pressure Head 0

Review: No

Potential Seepage Face

Type: Total Flux (Q) 0

Review: Yes

water table

Type: Head (H) 11.38

Review: No

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Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/3/tunnel redefined 3...

Points

	X (m)	Y (m)	Hydraulic Boundary
Point 1	-8.35	8.38	
Point 2	-8.35	0	
Point 3	0	0	
Point 4	8.35	0	
Point 5	8.35	8.38	
Point 6	0	8.38	
Point 7	-0.475	7.58	
Point 8	-0.175	7.28	
Point 9	-0.175	1	
Point 10	-0.475	0.7	
Point 11	-7.25	0.7	
Point 12	-7.55	1	
Point 13	-7.55	7.28	
Point 14	-7.25	7.58	
Point 15	0.175	7.28	
Point 16	0.475	7.58	
Point 17	7.25	7.58	
Point 18	7.55	7.28	
Point 19	7.55	1	
Point 20	7.25	0.7	
Point 21	0.475	0.7	
Point 22	0.175	1	
Point 23	-15	11.38	
Point 24	0	11.38	
Point 25	15	11.38	
Point 26	15	-5	
Point 27	0	-5	
Point 28	-15	-5	
Point 29	9.35	0	Zero Pressure
Point 30	9.35	8.38	
Point 31	-9.35	8.38	
Point 32	-9.35	0	Zero Pressure
Point 33	-7.55	7.28	
Point 34	-7.55	1	
Point 35	-7.25	0.7	
Point 36	-0.475	0.7	
Point 37	-0.175	1	
Point 38	-0.175	7.28	
Point 39	-0.475	7.58	
Point 40	-7.25	7.58	
Point 41	0.475	7.58	
Point 42	0.175	7.28	
Point 43	0.175	1	
Point 44	0.475	0.7	
Point 45	7.25	0.7	

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Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/3/tunnel redefined 3...

Point 46	7.55	1	
Point 47	7.55	7.28	
Point 48	7.25	7.58	

Lines

	Start Point	End Point	Length (m)	Angle (°)	Hydraulic Boundary
Line 1	31	32	8.38	90	
Line 2	32	2	1	0	
Line 3	2	1	8.38	90	
Line 4	1	31	1	0	
Line 5	5	4	8.38	90	
Line 6	4	29	1	0	
Line 7	29	30	8.38	90	
Line 8	30	5	1	0	
Line 9	2	3	8.35	0	
Line 10	3	4	8.35	0	
Line 11	5	6	8.35	0	
Line 12	6	1	8.35	0	
Line 13	33	34	6.28	90	Potential Seepage Face
Line 14	34	35	0.42426	-45	Potential Seepage Face
Line 15	35	36	6.775	0	Potential Seepage Face
Line 16	36	37	0.42426	45	Potential Seepage Face
Line 17	37	38	6.28	90	Potential Seepage Face
Line 18	38	39	0.42426	-45	Potential Seepage Face
Line 19	39	40	6.775	0	Potential Seepage Face
Line 20	40	33	0.42426	45	Potential Seepage Face
Line 21	41	42	0.42426	45	Potential Seepage Face
Line 22	42	43	6.28	90	Potential Seepage Face
Line 23	43	44	0.42426	-45	Potential Seepage Face
Line 24	44	45	6.775	0	Potential Seepage Face
Line 25	45	46	0.42426	45	Potential Seepage Face
Line 26	46	47	6.28	90	Potential Seepage Face
Line 27	47	48	0.42426	-45	Potential Seepage Face
Line 28	48	41	6.775	0	Potential Seepage Face
Line 29	24	23	15	0	water table
Line 30	23	28	16.38	90	
Line 31	28	27	15	0	
Line 32	27	3	5	90	
Line 33	6	24	3	90	
Line 34	27	26	15	0	
Line 35	26	25	16.38	90	
Line 36	25	24	15	0	water table

Regions

	Material	Points	Area (m²)
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Steady-State Seepage

file:///C:/Users/user1/Documents/Seepage/redefined/3/tunnel redefined 3...

Region 1	rock fill	31,32,2,1	8.38
Region 2	rock fill	5,4,29,30	8.38
Region 3	Concrete C30	1,2,3,4,5,6	139.95
Region 4		33,34,35,36,37,38,39,40	50.56
Region 5		41,42,43,44,45,46,47,48	50.56
Region 6	Backfill	24,23,28,27,3,2,32,31,1,6	167.35
Region 7	Backfill	24,6,5,30,29,4,3,27,26,25	167.35

Concrete Hydraulic Conductivity Estimation Sheet

Estimating K-Hydraulic conductivity Using Excel

**Basic formula to consider is:

$$\Rightarrow Q = A.V$$

$$\Rightarrow Q = A.K.\frac{\Delta h}{\Delta x}$$

$$\Rightarrow Q \frac{\Delta x}{\Delta h} = K \text{ for a unit area in consideration}$$

As per site visit, the wall infiltration was approximately **0.20 Lit/s=2E-04 m³/s. Therefore **Q=2E-04 m³/s**



**As per site visit, infiltration mid-level was around 0.25 m above Finished Floor Level.

**As an estimation for the exterior water table, 2.50 m above the top of the tunnel slab or 0.50m below the typical road asphalt level was taken. Also this water table can be taken variable from 2.50 m until 0.50 m above the top of the slab.

**Finally, the thickness of the tunnel concrete lining, was taken to be 0.3m from the typical section drawing from the project file

Hydraulic Gradient-*i*-Data Table

$$i = \frac{\Delta h}{\Delta x}$$

h_1	0.95
h_2	11.38
x	0.80

<i>bottom head</i>
<i>top water table head</i>
<i>tunnel wall thickness</i>

h1 Data Row

i	13.0375	0.70	0.75	0.80	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20
h_2	6.00	6.625	6.562	6.500	6.437	6.375	6.312	6.250	6.187	6.125	6.062	6.000

6.30	7.000	6.937	6.875	6.812	6.750	6.687	6.625	6.562	6.500	6.437	6.375
6.60	7.375	7.312	7.250	7.187	7.125	7.062	7.000	6.937	6.875	6.812	6.750
6.90	7.750	7.687	7.625	7.562	7.500	7.437	7.375	7.312	7.250	7.187	7.125
7.20	8.125	8.062	8.000	7.937	7.875	7.812	7.750	7.687	7.625	7.562	7.500
7.50	8.500	8.437	8.375	8.312	8.250	8.187	8.125	8.062	8.000	7.937	7.875
7.80	8.875	8.812	8.750	8.687	8.625	8.562	8.500	8.437	8.375	8.312	8.250
8.10	9.250	9.187	9.125	9.062	9.000	8.937	8.875	8.812	8.750	8.687	8.625
8.40	9.625	9.563	9.500	9.438	9.375	9.313	9.250	9.188	9.125	9.063	9.000
8.70	10.000	9.938	9.875	9.813	9.750	9.688	9.625	9.563	9.500	9.438	9.375
9.00	10.375	10.313	10.250	10.188	10.125	10.063	10.000	9.938	9.875	9.813	9.750
9.30	10.750	10.688	10.625	10.563	10.500	10.438	10.375	10.313	10.250	10.188	10.125
9.60	11.125	11.063	11.000	10.938	10.875	10.813	10.750	10.688	10.625	10.563	10.500
9.90	11.500	11.438	11.375	11.313	11.250	11.188	11.125	11.063	11.000	10.938	10.875
10.20	11.875	11.813	11.750	11.688	11.625	11.563	11.500	11.438	11.375	11.313	11.250
10.50	12.250	12.188	12.125	12.063	12.000	11.938	11.875	11.813	11.750	11.688	11.625
10.80	12.625	12.563	12.500	12.438	12.375	12.313	12.250	12.188	12.125	12.063	12.000
11.10	13.000	12.938	12.875	12.813	12.750	12.688	12.625	12.563	12.500	12.438	12.375

11.40	13.375	13.313	13.250	13.188	13.125	13.063	13.000	12.938	12.875	12.813	12.750
11.70	13.750	13.688	13.625	13.563	13.500	13.438	13.375	13.313	13.250	13.188	13.125
12.00	14.125	14.063	14.000	13.938	13.875	13.813	13.750	13.688	13.625	13.563	13.500
12.30	14.500	14.438	14.375	14.313	14.250	14.188	14.125	14.063	14.000	13.938	13.875

2017

**Therefore, the hydraulic gradient,

$$i = \frac{\Delta h}{\Delta x} = \mathbf{13.063}$$

$$1/i = \frac{\Delta x}{\Delta h} = \mathbf{0.0766}$$

**Therefore, the hydraulic conductivity can be estimated to be,

$$\Rightarrow K = Q \frac{\Delta x}{\Delta h} = \underline{\underline{\mathbf{1.531E-05}}}$$

Appendix B: Nodal Report

Condition-1 Tunnel Lining Without Waterproofing-Nodal Report

Table 7 Condition-1 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-I

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
115	Backfill	-9.326	9.404	10.665	12.359	1.26	None
116	Backfill	-9.324	-1.031	6.576	74.596	7.606	None
117	Backfill	-9.312	8.434	10.24	17.72	1.807	None
118	Backfill	-9.305	7.486	9.769	22.389	2.283	None
119	Backfill	-9.303	-0.046	6.783	66.971	6.829	None
120	Backfill	-9.298	6.54	9.262	26.69	2.721	None
121	Backfill	-9.296	0.899	7.036	60.189	6.137	None
122	Backfill	-9.29	5.598	8.785	31.253	3.187	None
123	Backfill	-9.281	1.862	7.322	53.545	5.46	None
124	Backfill	-9.281	2.793	7.616	47.292	4.822	None
125	Backfill	-9.281	3.724	7.955	41.487	4.23	None
126	Backfill	-9.281	4.656	8.344	36.173	3.689	None
132	Backfill	-8.373	-0.986	6.267	71.13	7.253	None
133	Backfill	-8.371	9.36	10.749	13.631	1.39	None
135	Interface bn Concrete n Backfill	-8.35	0	6.487	63.621	6.487	None
136	Interface bn Concrete n Ground	-8.35	0.931	6.905	58.59	5.974	None
137	Interface bn Concrete n Ground	-8.35	1.862	7.123	51.595	5.261	None
138	Interface bn Concrete n Ground	-8.35	2.793	7.382	45	4.589	None
139	Interface bn Concrete n Ground	-8.35	3.724	7.746	39.443	4.022	None
140	Interface bn Concrete n Ground	-8.35	4.656	8.163	34.395	3.507	None
141	Interface bn Concrete n Ground	-8.35	5.587	8.626	29.806	3.039	None
142	Interface bn Concrete n Ground	-8.35	6.518	9.162	25.933	2.644	None
143	Interface bn Concrete n Ground	-8.35	7.449	9.731	22.376	2.282	None
144	Interface bn Concrete n Backfill	-8.35	8.38	10.394	19.752	2.014	None
145	Concrete	-7.55	1	6.177	50.771	5.177	None
146	Concrete	-7.55	1.897	1.897	0	0	-9.67E-05
147	Concrete	-7.55	2.794	2.794	0	0	-7.77E-05
148	Concrete	-7.55	3.691	3.691	0	0	-6.82E-05
149	Concrete	-7.55	4.589	4.589	0	0	-5.98E-05
150	Concrete	-7.55	5.486	5.486	0	0	-5.23E-05
151	Concrete	-7.55	6.383	6.383	0	0	-4.98E-05
152	Concrete	-7.55	7.28	9.671	23.452	2.391	None
158	Backfill	-7.435	-0.962	5.898	67.283	6.861	None
159	Backfill	-7.428	9.324	10.847	14.927	1.522	None
161	Interface bn Concrete n Backfill	-7.422	0	5.868	57.55	5.868	None
162	Interface bn Concrete n Backfill	-7.422	8.38	10.718	22.924	2.338	None
163	Concrete	-7.25	0.7	5.863	50.631	5.163	None
164	Concrete	-7.25	7.58	10.096	24.678	2.516	None
170	Backfill	-6.502	-0.948	5.508	63.318	6.456	None
171	Backfill	-6.499	9.323	10.924	15.701	1.601	None
172	Interface bn Concrete n Ground	-6.494	0	5.36	52.563	5.36	None
173	Interface bn Concrete n Ground	-6.494	8.38	10.769	23.428	2.389	None
175	Concrete	-6.282	0.7	0.7	0	0	-9.75E-05
176	Concrete	-6.282	7.58	7.58	0	0	-6.12E-05
182	Backfill	-5.57	9.322	10.952	15.985	1.63	None
184	Backfill	-5.567	-0.928	5.177	59.872	6.105	None
185	Interface bn Concrete n Ground	-5.567	0	4.948	48.525	4.948	None
186	Interface bn Concrete n Ground	-5.567	8.38	10.764	23.377	2.384	None
187	Concrete	-5.314	0.7	0.7	0	0	-8.72E-05
188	Concrete	-5.314	7.58	7.58	0	0	-5.79E-05
195	Backfill	-4.641	9.319	10.966	16.152	1.647	None
196	Backfill	-4.639	-0.928	4.927	57.417	5.855	None
197	Interface bn Concrete n Ground	-4.639	0	4.699	46.084	4.699	None
198	Interface bn Concrete n Ground	-4.639	8.38	10.778	23.522	2.398	None

199	Concrete	-4.346	0.7	0.7	0	0	-8.21E-05
200	Concrete	-4.346	7.58	7.58	0	0	-5.81E-05
207	Backfill	-3.715	-0.956	4.757	56.027	5.713	None
208	Interface bn Concrete n Ground	-3.711	0	4.528	44.404	4.528	None
209	Interface bn Concrete n Ground	-3.711	8.38	10.794	23.674	2.414	None
210	Backfill	-3.711	9.308	10.978	16.382	1.67	None
211	Concrete	-3.379	0.7	0.7	0	0	-7.87E-05
212	Concrete	-3.379	7.58	7.58	0	0	-5.85E-05
219	Backfill	-2.803	-0.975	4.647	55.129	5.621	None
220	Backfill	-2.789	9.34	11.003	16.308	1.663	None
221	Interface bn Concrete n Ground	-2.783	0	4.42	43.342	4.42	None

Table 8 Condition-1 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-II

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
222	Interface bn Concrete n Ground	-2.783	8.38	10.814	23.874	2.434	None
223	Concrete	-2.411	0.7	0.7	0	0	-7.69E-05
224	Concrete	-2.411	7.58	7.58	0	0	-5.90E-05
228	Backfill	-1.886	-0.965	4.585	54.433	5.55	None
232	Backfill	-1.868	9.352	11.029	16.454	1.678	None
233	Interface bn Concrete n Ground	-1.856	0	4.379	42.945	4.379	None
234	Interface bn Concrete n Ground	-1.856	8.38	10.852	24.243	2.472	None
235	Concrete	-1.443	0.7	0.7	0	0	-8.21E-05
236	Concrete	-1.443	7.58	7.58	0	0	-6.59E-05
241	Backfill	-0.958	9.354	11.057	16.703	1.703	None
242	Backfill	-0.948	-0.981	4.573	54.474	5.555	None
245	Interface bn Concrete n Ground	-0.928	0	4.429	43.431	4.429	None
246	Interface bn Concrete n Ground	-0.928	8.38	10.916	24.871	2.536	None
247	Concrete	-0.475	0.7	3.98	32.168	3.28	None
248	Concrete	-0.475	7.58	10.094	24.65	2.514	None
249	Concrete	-0.175	1	3.619	25.684	2.619	None
250	Concrete	-0.175	1.897	1.897	0	0	-7.60E-06
251	Concrete	-0.175	2.794	2.794	0	0	0
252	Concrete	-0.175	3.691	3.691	0	0	0
253	Concrete	-0.175	4.589	4.589	0	0	-3.39E-21
254	Concrete	-0.175	5.486	5.486	0	0	0
255	Concrete	-0.175	6.383	6.383	0	0	-6.58E-06
256	Concrete	-0.175	7.28	9.53	22.062	2.25	None
257	Concrete	-0.022	0.548	4.034	34.189	3.486	None
262	Backfill	0	-1	4.574	54.66	5.574	None
263	Interface bn Concrete n Ground	0	0	4.503	44.162	4.503	None
264	Interface bn Concrete n Ground	0	8.38	10.979	25.492	2.599	None
265	Backfill	0	9.38	11.072	16.59	1.692	None
268	Concrete	0.175	1	3.61	25.6	2.61	None
269	Concrete	0.175	1.897	1.897	0	0	-7.70E-06
270	Concrete	0.175	2.794	2.794	0	0	0
271	Concrete	0.175	3.691	3.691	0	0	0
272	Concrete	0.175	4.589	4.589	0	0	0
273	Concrete	0.175	5.486	5.486	0	0	0
274	Concrete	0.175	6.383	6.383	0	0	-6.58E-06
275	Concrete	0.175	7.28	9.53	22.065	2.25	None
276	Concrete	0.475	0.7	3.984	32.203	3.284	None
277	Concrete	0.475	7.58	10.099	24.707	2.519	None
278	Interface bn Concrete n Ground	0.928	0	4.429	43.432	4.429	None
279	Interface bn Concrete n Ground	0.928	8.38	10.916	24.87	2.536	None
282	Backfill	0.947	-0.982	4.573	54.483	5.556	None
283	Backfill	0.952	9.357	11.057	16.675	1.7	None
288	Concrete	1.443	0.7	0.7	0	0	-8.21E-05
289	Concrete	1.443	7.58	7.58	0	0	-6.59E-05
290	Interface bn Concrete n Ground	1.856	0	4.379	42.948	4.379	None
291	Interface bn Concrete n Ground	1.856	8.38	10.852	24.243	2.472	None
292	Backfill	1.866	9.357	11.03	16.414	1.674	None
296	Backfill	1.877	-0.978	4.588	54.583	5.566	None
300	Concrete	2.411	0.7	0.7	0	0	-7.69E-05
301	Concrete	2.411	7.58	7.58	0	0	-5.90E-05
302	Interface bn Concrete n Ground	2.783	0	4.419	43.341	4.419	None
303	Interface bn Concrete n Ground	2.783	8.38	10.814	23.874	2.434	None
304	Backfill	2.79	9.348	11.004	16.24	1.656	None

305	Backfill	2.797	-0.968	4.645	55.042	5.613	None
312	Concrete	3.379	0.7	0.7	0	0	-7.87E-05
313	Concrete	3.379	7.58	7.58	0	0	-5.85E-05
314	Interface bn Concrete n Ground	3.711	0	4.528	44.401	4.528	None
315	Interface bn Concrete n Ground	3.711	8.38	10.794	23.674	2.414	None
316	Backfill	3.711	9.308	10.978	16.382	1.67	None
317	Backfill	3.716	-0.951	4.756	55.963	5.706	None
324	Concrete	4.346	0.7	0.7	0	0	-8.21E-05
325	Concrete	4.346	7.58	7.58	0	0	-5.81E-05
326	Interface bn Concrete n Ground	4.639	0	4.7	46.09	4.7	None
327	Interface bn Concrete n Ground	4.639	8.38	10.779	23.522	2.399	None
328	Backfill	4.639	9.308	10.964	16.24	1.656	None

Table 9 Condition-1 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-III

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
329	Backfill	4.642	-0.964	4.935	57.853	5.899	None
336	Concrete	5.314	0.7	0.7	0	0	-8.72E-05
337	Concrete	5.314	7.58	7.58	0	0	-5.79E-05
338	Backfill	5.566	-0.937	5.179	59.976	6.116	None
339	Interface bn Concrete n Ground	5.567	0	4.948	48.525	4.948	None
340	Interface bn Concrete n Ground	5.567	8.38	10.764	23.377	2.384	None
341	Backfill	5.567	9.308	10.95	16.101	1.642	None
348	Concrete	6.282	0.7	0.7	0	0	-9.75E-05
349	Concrete	6.282	7.58	7.58	0	0	-6.12E-05
350	Interface bn Concrete n Ground	6.494	0	5.36	52.561	5.36	None
351	Interface bn Concrete n Ground	6.494	8.38	10.769	23.43	2.389	None
352	Backfill	6.494	9.308	10.921	15.821	1.613	None
353	Backfill	6.498	-0.946	5.507	63.284	6.453	None
360	Concrete	7.25	0.7	5.863	50.63	5.163	None
361	Concrete	7.25	7.58	10.096	24.677	2.516	None
362	Interface bn Concrete n Backfill	7.422	0	5.868	57.547	5.868	None
363	Interface bn Concrete n Backfill	7.422	8.38	10.717	22.922	2.337	None
364	Backfill	7.428	-0.952	5.895	67.143	6.846	None
365	Backfill	7.428	9.328	10.847	14.902	1.52	None
372	Concrete	7.55	1	6.177	50.772	5.177	None
373	Concrete	7.55	1.897	1.897	0	0	-9.67E-05
374	Concrete	7.55	2.794	2.794	0	0	-7.77E-05
375	Concrete	7.55	3.691	3.691	0	0	-6.82E-05
376	Concrete	7.55	4.589	4.589	0	0	-5.98E-05
377	Concrete	7.55	5.486	5.486	0	0	-5.23E-05
378	Concrete	7.55	6.383	6.383	0	0	-4.98E-05
379	Concrete	7.55	7.28	9.671	23.452	2.391	None
380	Interface bn Concrete n Backfill	8.35	0	6.488	63.626	6.488	None
381	Interface bn Concrete n Ground	8.35	0.931	6.906	58.591	5.974	None
382	Interface bn Concrete n Ground	8.35	1.862	7.123	51.596	5.261	None
383	Interface bn Concrete n Ground	8.35	2.793	7.382	45	4.589	None
384	Interface bn Concrete n Ground	8.35	3.724	7.746	39.443	4.022	None
385	Interface bn Concrete n Ground	8.35	4.656	8.163	34.395	3.507	None
386	Interface bn Concrete n Ground	8.35	5.587	8.626	29.806	3.039	None
387	Interface bn Concrete n Ground	8.35	6.518	9.162	25.932	2.644	None
388	Interface bn Concrete n Ground	8.35	7.449	9.731	22.377	2.282	None
389	Interface bn Concrete n Backfill	8.35	8.38	10.394	19.753	2.014	None
390	Backfill	8.363	-0.966	6.266	70.929	7.232	None
392	Backfill	8.367	9.35	10.747	13.698	1.397	None
398	Backfill	9.281	1.862	7.322	53.544	5.46	None
399	Backfill	9.281	2.793	7.616	47.291	4.822	None
400	Backfill	9.281	3.724	7.955	41.487	4.23	None
401	Backfill	9.281	4.656	8.344	36.173	3.689	None
402	Backfill	9.292	5.6	8.786	31.245	3.186	None
403	Backfill	9.297	0.907	7.039	60.135	6.132	None
404	Backfill	9.3	6.541	9.262	26.687	2.721	None
405	Backfill	9.303	-0.044	6.784	66.956	6.827	None
406	Backfill	9.304	-1.025	6.571	74.491	7.596	None
407	Backfill	9.307	8.427	10.238	17.758	1.811	None
408	Backfill	9.308	7.486	9.769	22.388	2.283	None
410	Backfill	9.322	9.396	10.662	12.41	1.265	None

Table 10 Condition-1 Nodal Report on X and Y Velocity, X and Y Gradient -Part-I

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
115	Backfill	-9.326	9.404	2.40E-05	0.000121501	0.000123845	-0.082	-0.406	0.414
116	Backfill	-9.324	-1.031	8.50E-05	5.18E-05	9.96E-05	0.287	-0.177	0.337
117	Backfill	-9.312	8.434	3.23E-05	0.000140754	0.000144405	-0.116	-0.468	0.483
118	Backfill	-9.305	7.486	3.35E-06	0.000155482	0.000155518	0.008	-0.517	0.517
119	Backfill	-9.303	-0.046	8.13E-05	7.30E-05	0.000109227	0.273	-0.243	0.365
120	Backfill	-9.298	6.54	2.65E-05	0.000156297	0.000158522	0.079	-0.521	0.526
121	Backfill	-9.296	0.899	5.25E-05	8.59E-05	0.000100645	0.174	-0.284	0.333
122	Backfill	-9.29	5.598	4.13E-05	0.00014568	0.000151425	0.138	-0.486	0.505
123	Backfill	-9.281	1.862	5.93E-05	9.24E-05	0.000109803	0.198	-0.308	0.366
124	Backfill	-9.281	2.793	6.45E-05	0.000101715	0.000120467	0.218	-0.34	0.403
125	Backfill	-9.281	3.724	5.93E-05	0.000117117	0.000131273	0.199	-0.391	0.439
126	Backfill	-9.281	4.656	5.14E-05	0.000132435	0.000142075	0.172	-0.442	0.474
132	Backfill	-8.373	-0.986	0.000109731	4.92E-05	0.000120276	0.364	-0.16	0.398
133	Backfill	-8.371	9.36	3.52E-05	0.000103472	0.000109282	-0.11	-0.34	0.358
135	Interface bn Concrete n Backfill	-8.35	0	6.72E-05	5.10E-05	8.43E-05	0.495	-0.341	0.602
136	Interface bn Concrete n Ground	-8.35	0.931	2.90E-05	2.60E-05	3.90E-05	0.544	-0.348	0.646
137	Interface bn Concrete n Ground	-8.35	1.862	8.24E-05	2.11E-05	8.50E-05	3.379	-0.262	3.389
138	Interface bn Concrete n Ground	-8.35	2.793	8.06E-05	2.36E-05	8.40E-05	2.993	-0.333	3.011
139	Interface bn Concrete n Ground	-8.35	3.724	7.14E-05	2.91E-05	7.72E-05	2.638	-0.418	2.671
140	Interface bn Concrete n Ground	-8.35	4.656	6.24E-05	3.25E-05	7.04E-05	2.312	-0.471	2.359
141	Interface bn Concrete n Ground	-8.35	5.587	5.35E-05	3.65E-05	6.48E-05	2.01	-0.535	2.08
142	Interface bn Concrete n Ground	-8.35	6.518	4.06E-05	4.41E-05	5.99E-05	1.733	-0.588	1.83
143	Interface bn Concrete n Ground	-8.35	7.449	4.73E-06	4.90E-05	4.92E-05	-0.027	-0.659	0.659
144	Interface bn Concrete n Backfill	-8.35	8.38	4.15E-05	7.42E-05	8.50E-05	-0.271	-0.542	0.606
145	Concrete	-7.55	1	1.46E-05	9.62E-06	1.75E-05	0.757	1.45	1.636
146	Concrete	-7.55	1.897	0.000105797	3.97E-05	0.000112983	6.451	1.872	6.717
147	Concrete	-7.55	2.794	8.62E-05	1.60E-05	8.76E-05	5.736	-0.996	5.822
148	Concrete	-7.55	3.691	7.55E-05	1.56E-05	7.71E-05	5.028	-0.996	5.125
149	Concrete	-7.55	4.589	6.59E-05	1.55E-05	6.77E-05	4.384	-0.997	4.496
150	Concrete	-7.55	5.486	5.71E-05	1.54E-05	5.91E-05	3.799	-0.997	3.928
151	Concrete	-7.55	6.383	6.66E-05	3.08E-05	7.34E-05	3.083	-2.322	3.859
152	Concrete	-7.55	7.28	2.26E-06	2.28E-05	2.29E-05	-0.451	-1.826	1.881
158	Backfill	-7.435	-0.962	0.000122829	4.69E-06	0.000122918	0.405	0.008	0.405
159	Backfill	-7.428	9.324	3.06E-05	5.77E-05	6.53E-05	-0.097	-0.196	0.218
161	Interface bn Concrete n Backfill	-7.422	0	3.72E-05	6.28E-06	3.77E-05	0.661	-0.103	0.669
162	Interface bn Concrete n Backfill	-7.422	8.38	1.32E-05	2.26E-05	2.62E-05	-0.264	-0.573	0.631
163	Concrete	-7.25	0.7	3.46E-05	1.66E-06	3.47E-05	3.107	-0.757	3.198
164	Concrete	-7.25	7.58	2.00E-05	1.09E-05	2.28E-05	1.046	-0.551	1.182
170	Backfill	-6.502	-0.948	0.000115254	4.00E-05	0.000121986	0.384	0.12	0.402
171	Backfill	-6.499	9.323	1.79E-05	5.61E-05	5.88E-05	-0.057	-0.188	0.196
172	Interface bn Concrete n Ground	-6.494	0	4.20E-05	7.30E-05	8.42E-05	0.504	3.327	3.365
173	Interface bn Concrete n Ground	-6.494	8.38	1.24E-06	5.59E-05	5.59E-05	-0.02	-2.077	2.077
175	Concrete	-6.282	0.7	8.87E-06	0.000129695	0.000129998	2.682	5.843	6.429
176	Concrete	-6.282	7.58	7.31E-07	5.96E-05	5.96E-05	1.309	-3.639	3.867
182	Backfill	-5.57	9.322	7.59E-06	6.06E-05	6.11E-05	-0.023	-0.202	0.203
184	Backfill	-5.567	-0.928	9.24E-05	5.71E-05	0.000108585	0.31	0.195	0.366
185	Interface bn Concrete n Ground	-5.567	0	2.62E-05	8.16E-05	8.57E-05	0.355	3.094	3.114
186	Interface bn Concrete n Ground	-5.567	8.38	4.54E-07	5.99E-05	5.99E-05	-0.005	-2.091	2.091
187	Concrete	-5.314	0.7	6.47E-07	9.11E-05	9.11E-05	-0.002	6.07	6.07
188	Concrete	-5.314	7.58	1.77E-08	5.97E-05	5.97E-05	0	-3.98	3.98
195	Backfill	-4.641	9.319	4.67E-06	6.00E-05	6.02E-05	-0.015	-0.2	0.201
196	Backfill	-4.639	-0.928	6.81E-05	6.13E-05	9.16E-05	0.23	0.208	0.31
197	Interface bn Concrete n Ground	-4.639	0	1.69E-05	7.88E-05	8.06E-05	0.226	2.932	2.941

198	Interface bn Concrete n Ground	-4.639	8.38	1.24E-06	6.00E-05	6.00E-05	-0.016	-2.102	2.102
199	Concrete	-4.346	0.7	4.18E-07	8.57E-05	8.57E-05	-0.002	5.714	5.714
200	Concrete	-4.346	7.58	3.06E-08	6.00E-05	6.00E-05	0	-3.998	3.998
207	Backfill	-3.715	-0.956	4.63E-05	6.11E-05	7.67E-05	0.158	0.206	0.26
208	Interface bn Concrete n Ground	-3.711	0	1.11E-05	7.62E-05	7.70E-05	0.15	2.818	2.822
209	Interface bn Concrete n Ground	-3.711	8.38	1.45E-06	6.00E-05	6.00E-05	-0.019	-2.112	2.112
210	Backfill	-3.711	9.308	5.31E-06	5.90E-05	5.93E-05	-0.018	-0.197	0.198
211	Concrete	-3.379	0.7	2.75E-07	8.20E-05	8.20E-05	-0.001	5.469	5.469
212	Concrete	-3.379	7.58	3.60E-08	6.03E-05	6.03E-05	0	-4.017	4.017
219	Backfill	-2.803	-0.975	2.70E-05	5.88E-05	6.47E-05	0.095	0.198	0.22
220	Backfill	-2.789	9.34	7.05E-06	5.74E-05	5.79E-05	-0.023	-0.191	0.193
221	Interface bn Concrete n Ground	-2.783	0	5.43E-06	7.41E-05	7.43E-05	0.08	2.751	2.752

Table 11 Condition-1 Nodal Report on X and Y Velocity, X and Y Gradient -Part-II

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
222	Interface bn Concrete n Ground	-2.783	8.38	2.27E-06	5.99E-05	5.99E-05	-0.031	-2.127	2.127
223	Concrete	-2.411	0.7	1.34E-07	7.97E-05	7.97E-05	-0.001	5.314	5.314
224	Concrete	-2.411	7.58	5.61E-08	6.06E-05	6.06E-05	0	-4.043	4.043
228	Backfill	-1.886	-0.965	4.54E-06	5.39E-05	5.41E-05	0.04	0.182	0.186
232	Backfill	-1.868	9.352	8.93E-06	5.35E-05	5.42E-05	-0.028	-0.178	0.18
233	Interface bn Concrete n Ground	-1.856	0	7.28E-06	7.39E-05	7.43E-05	-0.011	2.74	2.74
234	Interface bn Concrete n Ground	-1.856	8.38	5.93E-06	5.97E-05	6.00E-05	-0.059	-2.153	2.154
235	Concrete	-1.443	0.7	2.29E-06	9.51E-05	9.51E-05	-1.706	6.262	6.49
236	Concrete	-1.443	7.58	1.92E-06	7.21E-05	7.22E-05	-1.307	-4.764	4.94
241	Backfill	-0.958	9.354	6.40E-06	4.53E-05	4.58E-05	-0.021	-0.15	0.152
242	Backfill	-0.948	-0.981	1.04E-06	4.09E-05	4.10E-05	0.009	0.135	0.136
245	Interface bn Concrete n Ground	-0.928	0	1.03E-05	2.55E-05	2.75E-05	-0.075	0.421	0.427
246	Interface bn Concrete n Ground	-0.928	8.38	7.44E-06	2.85E-05	2.94E-05	-0.073	-0.609	0.614
247	Concrete	-0.475	0.7	4.22E-06	1.87E-05	1.92E-05	-1.046	1.474	1.808
248	Concrete	-0.475	7.58	7.91E-07	2.36E-05	2.36E-05	-0.674	-1.641	1.774
249	Concrete	-0.175	1	7.41E-07	1.80E-05	1.80E-05	0.082	1.271	1.273
250	Concrete	-0.175	1.897	1.28E-14	2.08E-05	2.08E-05	0	0.46	0.46
251	Concrete	-0.175	2.794	5.88E-21	1.50E-05	1.50E-05	0	-1	1
252	Concrete	-0.175	3.691	2.35E-20	1.50E-05	1.50E-05	0	-1	1
253	Concrete	-0.175	4.589	6.35E-20	1.50E-05	1.50E-05	0	-1	1
254	Concrete	-0.175	5.486	5.31E-161	1.50E-05	1.50E-05	0	-1	1
255	Concrete	-0.175	6.383	3.89E-155	2.81E-05	2.81E-05	0	-2.254	2.254
256	Concrete	-0.175	7.28	2.31E-08	3.85E-05	3.85E-05	-0.001	-2.695	2.695
257	Concrete	-0.022	0.548	2.21E-06	1.32E-05	1.34E-05	0.011	0.879	0.879
262	Backfill	0	-1	1.63E-06	2.75E-05	2.75E-05	0	0.092	0.092
263	Interface bn Concrete n Ground	0	0	4.48E-06	1.69E-05	1.75E-05	-0.001	0.46	0.46
264	Interface bn Concrete n Ground	0	8.38	5.31E-06	2.16E-05	2.23E-05	0	-0.6	0.6
265	Backfill	0	9.38	4.42E-06	3.55E-05	3.58E-05	0	-0.12	0.12
268	Concrete	0.175	1	4.96E-07	2.29E-05	2.29E-05	0.009	1.561	1.561
269	Concrete	0.175	1.897	1.28E-14	2.07E-05	2.07E-05	0	0.455	0.455
270	Concrete	0.175	2.794	9.50E-21	1.50E-05	1.50E-05	0	-1	1
271	Concrete	0.175	3.691	2.35E-20	1.50E-05	1.50E-05	0	-1	1
272	Concrete	0.175	4.589	1.39E-20	1.50E-05	1.50E-05	0	-1	1
273	Concrete	0.175	5.486	7.00E-161	1.50E-05	1.50E-05	0	-1	1
274	Concrete	0.175	6.383	3.89E-155	2.81E-05	2.81E-05	0	-2.254	2.254
275	Concrete	0.175	7.28	2.31E-08	3.87E-05	3.87E-05	-0.001	-2.702	2.702
276	Concrete	0.475	0.7	4.77E-06	1.88E-05	1.94E-05	1.042	1.478	1.808
277	Concrete	0.475	7.58	7.27E-07	2.61E-05	2.61E-05	0.869	-1.804	2.003
278	Interface bn Concrete n Ground	0.928	0	9.99E-06	2.54E-05	2.73E-05	0.075	0.418	0.424
279	Interface bn Concrete n Ground	0.928	8.38	8.16E-06	2.84E-05	2.95E-05	0.073	-0.606	0.61
282	Backfill	0.947	-0.982	1.12E-06	4.09E-05	4.09E-05	-0.009	0.135	0.135
283	Backfill	0.952	9.357	6.37E-06	4.53E-05	4.58E-05	0.02	-0.15	0.152
288	Concrete	1.443	0.7	2.28E-06	9.51E-05	9.51E-05	1.708	6.263	6.492
289	Concrete	1.443	7.58	1.92E-06	7.22E-05	7.22E-05	1.31	-4.766	4.943
290	Interface bn Concrete n Ground	1.856	0	7.42E-06	7.38E-05	7.41E-05	0.011	2.74	2.74
291	Interface bn Concrete n Ground	1.856	8.38	5.93E-06	5.97E-05	6.00E-05	0.059	-2.153	2.154
292	Backfill	1.866	9.357	8.88E-06	5.35E-05	5.42E-05	0.028	-0.178	0.18
296	Backfill	1.877	-0.978	4.14E-06	5.36E-05	5.38E-05	-0.04	0.181	0.185
300	Concrete	2.411	0.7	1.33E-07	7.97E-05	7.97E-05	0.001	5.314	5.314
301	Concrete	2.411	7.58	5.61E-08	6.06E-05	6.06E-05	0	-4.043	4.043
302	Interface bn Concrete n Ground	2.783	0	5.40E-06	7.41E-05	7.43E-05	-0.08	2.751	2.752
303	Interface bn Concrete n Ground	2.783	8.38	2.27E-06	5.98E-05	5.99E-05	0.031	-2.127	2.127
304	Backfill	2.79	9.348	7.03E-06	5.74E-05	5.78E-05	0.023	-0.191	0.193

305	Backfill	2.797	-0.968	2.69E-05	5.89E-05	6.47E-05	-0.094	0.199	0.22
312	Concrete	3.379	0.7	2.76E-07	8.20E-05	8.20E-05	0.001	5.468	5.468
313	Concrete	3.379	7.58	3.60E-08	6.03E-05	6.03E-05	0	-4.017	4.017
314	Interface bn Concrete n Ground	3.711	0	1.11E-05	7.62E-05	7.70E-05	-0.15	2.818	2.822
315	Interface bn Concrete n Ground	3.711	8.38	1.45E-06	6.00E-05	6.00E-05	0.019	-2.112	2.112
316	Backfill	3.711	9.308	5.30E-06	5.90E-05	5.93E-05	0.018	-0.197	0.198
317	Backfill	3.716	-0.951	4.63E-05	6.13E-05	7.68E-05	-0.158	0.207	0.26
324	Concrete	4.346	0.7	4.18E-07	8.57E-05	8.57E-05	0.002	5.714	5.714
325	Concrete	4.346	7.58	3.06E-08	6.00E-05	6.00E-05	0	-3.998	3.998
326	Interface bn Concrete n Ground	4.639	0	1.69E-05	7.85E-05	8.03E-05	-0.226	2.932	2.94
327	Interface bn Concrete n Ground	4.639	8.38	1.24E-06	6.00E-05	6.00E-05	0.016	-2.102	2.102
328	Backfill	4.639	9.308	4.67E-06	6.00E-05	6.02E-05	0.015	-0.2	0.201

Table 12 Condition-1 Nodal Report on X and Y Velocity, X and Y Gradient -Part-III

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
329	Backfill	4.642	-0.964	6.81E-05	6.05E-05	9.11E-05	-0.23	0.205	0.308
336	Concrete	5.314	0.7	6.46E-07	9.11E-05	9.11E-05	0.002	6.069	6.069
337	Concrete	5.314	7.58	1.81E-08	5.97E-05	5.97E-05	0	-3.98	3.98
338	Backfill	5.566	-0.937	9.23E-05	5.69E-05	0.000108428	-0.31	0.195	0.366
339	Interface bn Concrete n Ground	5.567	0	2.61E-05	8.15E-05	8.56E-05	-0.354	3.094	3.114
340	Interface bn Concrete n Ground	5.567	8.38	4.41E-07	6.00E-05	6.00E-05	0.005	-2.091	2.091
341	Backfill	5.567	9.308	7.62E-06	6.06E-05	6.11E-05	0.023	-0.202	0.203
348	Concrete	6.282	0.7	8.86E-06	0.000129713	0.000130016	-2.682	5.843	6.429
349	Concrete	6.282	7.58	7.46E-07	5.96E-05	5.96E-05	-1.309	-3.639	3.867
350	Interface bn Concrete n Ground	6.494	0	4.20E-05	7.31E-05	8.43E-05	-0.504	3.328	3.365
351	Interface bn Concrete n Ground	6.494	8.38	1.20E-06	5.58E-05	5.59E-05	0.02	-2.077	2.077
352	Backfill	6.494	9.308	1.80E-05	5.59E-05	5.87E-05	0.057	-0.188	0.196
353	Backfill	6.498	-0.946	0.000115279	3.96E-05	0.000121893	-0.384	0.12	0.402
360	Concrete	7.25	0.7	3.46E-05	1.66E-06	3.47E-05	-3.107	-0.757	3.198
361	Concrete	7.25	7.58	2.01E-05	1.09E-05	2.28E-05	-1.046	-0.551	1.182
362	Interface bn Concrete n Backfill	7.422	0	3.72E-05	6.21E-06	3.77E-05	-0.662	-0.102	0.669
363	Interface bn Concrete n Backfill	7.422	8.38	1.32E-05	2.26E-05	2.62E-05	0.264	-0.573	0.631
364	Backfill	7.428	-0.952	0.000123363	4.66E-06	0.000123451	-0.407	0.008	0.407
365	Backfill	7.428	9.328	3.07E-05	5.78E-05	6.55E-05	0.097	-0.196	0.219
372	Concrete	7.55	1	1.46E-05	9.63E-06	1.75E-05	-0.757	1.45	1.636
373	Concrete	7.55	1.897	0.000105798	3.97E-05	0.000112984	-6.451	1.872	6.717
374	Concrete	7.55	2.794	8.62E-05	1.60E-05	8.76E-05	-5.736	-0.996	5.822
375	Concrete	7.55	3.691	7.55E-05	1.56E-05	7.71E-05	-5.027	-0.996	5.125
376	Concrete	7.55	4.589	6.59E-05	1.55E-05	6.77E-05	-4.384	-0.997	4.496
377	Concrete	7.55	5.486	5.71E-05	1.54E-05	5.91E-05	-3.799	-0.997	3.928
378	Concrete	7.55	6.383	6.66E-05	3.08E-05	7.34E-05	-3.082	-2.322	3.859
379	Concrete	7.55	7.28	2.26E-06	2.28E-05	2.29E-05	0.451	-1.826	1.881
380	Interface bn Concrete n Backfill	8.35	0	6.71E-05	5.13E-05	8.45E-05	-0.495	-0.342	0.602
381	Interface bn Concrete n Ground	8.35	0.931	2.89E-05	2.60E-05	3.89E-05	-0.543	-0.348	0.645
382	Interface bn Concrete n Ground	8.35	1.862	8.23E-05	2.11E-05	8.50E-05	-3.379	-0.262	3.389
383	Interface bn Concrete n Ground	8.35	2.793	8.06E-05	2.36E-05	8.40E-05	-2.993	-0.333	3.011
384	Interface bn Concrete n Ground	8.35	3.724	7.14E-05	2.91E-05	7.72E-05	-2.638	-0.418	2.671
385	Interface bn Concrete n Ground	8.35	4.656	6.24E-05	3.25E-05	7.04E-05	-2.312	-0.471	2.359
386	Interface bn Concrete n Ground	8.35	5.587	5.34E-05	3.65E-05	6.47E-05	-2.01	-0.535	2.08
387	Interface bn Concrete n Ground	8.35	6.518	4.06E-05	4.41E-05	5.99E-05	-1.733	-0.588	1.83
388	Interface bn Concrete n Ground	8.35	7.449	4.70E-06	4.90E-05	4.92E-05	0.027	-0.659	0.659
389	Interface bn Concrete n Backfill	8.35	8.38	4.15E-05	7.42E-05	8.50E-05	0.271	-0.542	0.606
390	Backfill	8.363	-0.966	0.000110397	4.97E-05	0.000121064	-0.367	-0.161	0.4
392	Backfill	8.367	9.35	3.52E-05	0.000103492	0.000109329	0.11	-0.341	0.358
398	Backfill	9.281	1.862	5.93E-05	9.24E-05	0.000109788	-0.198	-0.308	0.366
399	Backfill	9.281	2.793	6.46E-05	0.000101715	0.000120469	-0.218	-0.34	0.403
400	Backfill	9.281	3.724	5.93E-05	0.000117123	0.000131277	-0.199	-0.391	0.439
401	Backfill	9.281	4.656	5.14E-05	0.000132427	0.000142054	-0.172	-0.442	0.474
402	Backfill	9.292	5.6	4.13E-05	0.000145672	0.000151414	-0.138	-0.486	0.505
403	Backfill	9.297	0.907	5.25E-05	8.59E-05	0.000100625	-0.173	-0.284	0.333
404	Backfill	9.3	6.541	2.64E-05	0.000156244	0.000158463	-0.079	-0.52	0.526
405	Backfill	9.303	-0.044	8.12E-05	7.31E-05	0.000109227	-0.272	-0.243	0.365
406	Backfill	9.304	-1.025	8.55E-05	5.14E-05	9.98E-05	-0.289	-0.176	0.338
407	Backfill	9.307	8.427	3.24E-05	0.000140866	0.000144544	0.117	-0.469	0.483
408	Backfill	9.308	7.486	3.36E-06	0.000155583	0.000155619	-0.008	-0.517	0.517
410	Backfill	9.322	9.396	2.42E-05	0.000121579	0.000123964	0.083	-0.406	0.414

Condition-2 Tunnel Lining With Waterproofing-Nodal Report

Table 13 Condition-2 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-I

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
109	Backfill	-9.292	3.729	9.139	53.056	5.41	None
110	Backfill	-9.292	4.661	9.448	46.946	4.787	None
111	Backfill	-9.292	5.593	9.753	40.794	4.16	None
112	Backfill	-9.292	6.526	10.059	34.65	3.533	None
113	Backfill	-9.27	7.477	10.383	28.499	2.906	None
114	Backfill	-9.237	2.761	8.805	59.277	6.044	None
115	Backfill	-9.231	8.438	10.693	22.121	2.256	None
116	Backfill	-9.165	9.412	10.965	15.236	1.554	None
117	Backfill	-9.146	1.809	8.452	65.154	6.644	None
121	Backfill	-9.002	0.881	8.043	70.244	7.163	None
125	Backfill	-8.944	-0.79	7.345	79.775	8.134	None
127	Backfill	-8.738	0.003	7.545	73.97	7.543	None
129	Backfill	-8.415	-0.093	7.323	72.734	7.417	None
130	Interface bn Concrete n Backfill	-8.36	0	7.339	71.969	7.339	None
131	Interface bn Concrete n Backfill	-8.36	0.932	8.06	69.897	7.127	None
132	Interface bn Concrete n Backfill	-8.36	1.864	8.454	64.619	6.589	None
133	Interface bn Concrete n Backfill	-8.36	2.797	8.807	58.945	6.011	None
134	Interface bn Concrete n Backfill	-8.36	3.729	9.133	52.997	5.404	None
135	Interface bn Concrete n Backfill	-8.36	4.661	9.446	46.924	4.785	None
136	Interface bn Concrete n Backfill	-8.36	5.593	9.754	40.801	4.16	None
137	Interface bn Concrete n Backfill	-8.36	6.526	10.064	34.706	3.539	None
138	Interface bn Concrete n Backfill	-8.36	7.458	10.386	28.721	2.929	None
139	Interface bn Concrete n Backfill	-8.36	8.39	10.82	23.83	2.43	None
140	Interface bn Concrete n Backfill	-8.35	0	7.304	71.632	7.304	None
141	Interface bn Concrete n Backfill	-8.35	0.931	4.992	39.823	4.061	None
142	Interface bn Concrete n Backfill	-8.35	1.862	3.358	14.67	1.496	None
143	Interface bn Concrete n Backfill	-8.35	2.793	2.45	-3.368	-0.343	None
144	Interface bn Concrete n Backfill	-8.35	3.724	2.55	-11.515	-1.174	None
145	Interface bn Concrete n Backfill	-8.35	4.656	2.529	-20.856	-2.127	None
146	Interface bn Concrete n Backfill	-8.35	5.587	2.515	-30.122	-3.071	None
147	Interface bn Concrete n Backfill	-8.35	6.518	2.502	-39.382	-4.016	None
148	Interface bn Concrete n Backfill	-8.35	7.449	2.492	-48.616	-4.957	None
149	Interface bn Concrete n Backfill	-8.35	8.38	2.488	-57.783	-5.892	None
150	Backfill	-8.325	-0.774	7.081	77.039	7.856	None
151	Backfill	-8.255	9.356	11.053	16.634	1.696	None
157	Backfill	-7.947	-0.659	6.886	73.993	7.545	None
159	Concrete	-7.55	1	5.267	41.844	4.267	None
160	Concrete	-7.55	2.047	2.047	0	0	-2.84E-05
161	Concrete	-7.55	3.093	2.602	-4.823	-0.492	0
162	Concrete	-7.55	4.14	2.532	-15.765	-1.608	0
163	Concrete	-7.55	5.187	2.521	-26.143	-2.666	0
164	Concrete	-7.55	6.233	2.506	-36.55	-3.727	0
165	Concrete	-7.55	7.28	2.49	-46.971	-4.79	None
166	Backfill	-7.44	-0.658	6.602	71.196	7.26	None
168	Interface bn Concrete n Backfill	-7.431	8.39	11.11	26.677	2.72	None
169	Interface bn Concrete n Backfill	-7.422	0	6.537	64.107	6.537	None
170	Interface bn Concrete n Backfill	-7.422	8.38	2.483	-57.836	-5.897	None
171	Backfill	-7.37	9.231	11.145	18.767	1.914	None
172	Concrete	-7.25	0.7	5.781	49.831	5.081	None
173	Concrete	-7.25	7.58	2.485	-49.971	-5.095	None
180	Backfill	-6.653	9.254	11.219	19.277	1.966	None
181	Backfill	-6.538	-0.864	6.164	68.92	7.028	None
182	Interface bn Concrete n Backfill	-6.502	8.39	11.217	27.724	2.827	None

183	Interface bn Concrete n Ground	-6.494	0	5.978	58.627	5.978	None
184	Interface bn Concrete n Backfill	-6.494	8.38	2.473	-57.933	-5.907	None
185	Concrete	-6.282	0.7	0.7	0	0	-0.000110137
186	Concrete	-6.282	7.58	2.469	-50.121	-5.111	0
193	Backfill	-5.725	9.365	11.286	18.838	1.921	None
194	Backfill	-5.665	-0.928	5.822	66.203	6.751	None
195	Interface bn Concrete n Backfill	-5.573	8.39	11.279	28.337	2.889	None
196	Interface bn Concrete n Ground	-5.567	0	5.525	54.187	5.525	None
197	Interface bn Concrete n Backfill	-5.567	8.38	2.46	-58.062	-5.92	None
198	Concrete	-5.314	0.7	0.7	0	0	-9.91E-05
199	Concrete	-5.314	7.58	2.456	-50.25	-5.124	0
206	Backfill	-4.767	9.368	11.324	19.178	1.956	None

Table 14 Condition-2 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-II

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
207	Backfill	-4.717	-0.97	5.534	63.783	6.504	None
208	Interface bn Concrete n Backfill	-4.644	8.39	11.319	28.725	2.929	None
209	Interface bn Concrete n Ground	-4.639	0	5.246	51.45	5.246	None
210	Interface bn Concrete n Backfill	-4.639	8.38	2.447	-58.187	-5.933	None
211	Concrete	-4.346	0.7	0.7	0	0	-9.33E-05
212	Concrete	-4.346	7.58	2.443	-50.381	-5.137	0
219	Backfill	-3.812	9.375	11.346	19.326	1.971	None
220	Backfill	-3.77	-0.976	5.326	61.806	6.302	None
221	Interface bn Concrete n Backfill	-3.716	8.39	11.343	28.957	2.953	None
222	Interface bn Concrete n Ground	-3.711	0	5.052	49.547	5.052	None
223	Interface bn Concrete n Backfill	-3.711	8.38	2.434	-58.313	-5.946	None
224	Concrete	-3.379	0.7	0.7	0	0	-8.95E-05
225	Concrete	-3.379	7.58	2.429	-50.512	-5.151	0
232	Backfill	-2.858	9.377	11.359	19.437	1.982	None
233	Backfill	-2.821	-0.969	5.188	60.385	6.157	None
234	Interface bn Concrete n Backfill	-2.787	8.39	11.357	29.094	2.967	None
235	Interface bn Concrete n Ground	-2.783	0	4.93	48.346	4.93	None
236	Interface bn Concrete n Backfill	-2.783	8.38	2.421	-58.439	-5.959	None
237	Concrete	-2.411	0.7	0.7	0	0	-8.75E-05
238	Concrete	-2.411	7.58	2.416	-50.644	-5.164	0
245	Backfill	-1.901	9.382	11.367	19.465	1.985	None
246	Backfill	-1.883	-0.971	5.12	59.739	6.091	None
247	Interface bn Concrete n Backfill	-1.858	8.39	11.365	29.173	2.975	None
248	Interface bn Concrete n Ground	-1.856	0	4.885	47.904	4.885	None
249	Interface bn Concrete n Backfill	-1.856	8.38	2.408	-58.565	-5.972	None
250	Concrete	-1.443	0.7	0.7	0	0	-9.35E-05
251	Concrete	-1.443	7.58	2.403	-50.774	-5.177	0
258	Backfill	-0.956	9.383	11.37	19.485	1.987	None
259	Backfill	-0.95	-0.981	5.106	59.689	6.086	None
260	Interface bn Concrete n Backfill	-0.929	8.39	11.369	29.213	2.979	None
261	Interface bn Concrete n Ground	-0.928	0	4.942	48.466	4.942	None
262	Interface bn Concrete n Backfill	-0.928	8.38	2.396	-58.683	-5.984	None
263	Concrete	-0.475	0.7	4.458	36.853	3.758	None
264	Concrete	-0.475	7.58	2.387	-50.924	-5.193	None
265	Concrete	-0.175	1	4.086	30.268	3.086	None
266	Concrete	-0.175	2.047	2.047	0	0	-5.34E-06
267	Concrete	-0.175	3.093	2.113	-9.617	-0.981	0
268	Concrete	-0.175	4.14	2.179	-19.234	-1.961	0
269	Concrete	-0.175	5.187	2.245	-28.851	-2.942	0
270	Concrete	-0.175	6.233	2.311	-38.468	-3.922	0

271	Concrete	-0.175	7.28	2.377	-48.084	-4.903	None
276	Backfill	0	-1	5.106	59.885	6.106	None
277	Interface bn Concrete n Ground	0	0	5.028	49.305	5.028	None
278	Interface bn Concrete n Backfill	0	8.38	2.39	-58.746	-5.99	None
279	Interface bn Concrete n Backfill	0	8.39	11.37	29.226	2.98	None
280	Backfill	0	9.387	11.371	19.464	1.985	None
283	Concrete	0.01	0.545	4.527	39.059	3.983	None
284	Concrete	0.175	1	4.094	30.34	3.094	None
285	Concrete	0.175	2.047	2.047	0	0	-5.24E-06
286	Concrete	0.175	3.093	2.113	-9.617	-0.981	0
287	Concrete	0.175	4.14	2.179	-19.234	-1.961	0
288	Concrete	0.175	5.187	2.245	-28.851	-2.942	0
289	Concrete	0.175	6.233	2.311	-38.468	-3.922	0
290	Concrete	0.175	7.28	2.377	-48.085	-4.903	None
291	Concrete	0.475	0.7	4.454	36.815	3.754	None
292	Concrete	0.475	7.58	2.387	-50.929	-5.193	None
293	Interface bn Concrete n Ground	0.928	0	4.942	48.466	4.942	None
294	Interface bn Concrete n Backfill	0.928	8.38	2.397	-58.68	-5.983	None
295	Interface bn Concrete n Backfill	0.929	8.39	11.369	29.213	2.979	None
296	Backfill	0.947	-0.984	5.106	59.731	6.091	None
297	Backfill	0.949	9.376	11.37	19.557	1.994	None
304	Concrete	1.443	0.7	0.7	0	0	-9.35E-05
305	Concrete	1.443	7.58	2.403	-50.772	-5.177	0
306	Interface bn Concrete n Ground	1.856	0	4.885	47.903	4.885	None
307	Interface bn Concrete n Backfill	1.856	8.38	2.408	-58.564	-5.972	None

Table 15 Condition-2 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-III

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
308	Interface bn Concrete n Backfill	1.858	8.39	11.365	29.173	2.975	None
309	Backfill	1.883	-0.974	5.121	59.767	6.094	None
310	Backfill	1.897	9.374	11.367	19.54	1.992	None
317	Concrete	2.411	0.7	0.7	0	0	-8.75E-05
318	Concrete	2.411	7.58	2.416	-50.643	-5.164	0
319	Interface bn Concrete n Ground	2.783	0	4.93	48.344	4.93	None
320	Interface bn Concrete n Backfill	2.783	8.38	2.421	-58.438	-5.959	None
321	Interface bn Concrete n Backfill	2.787	8.39	11.357	29.094	2.967	None
322	Backfill	2.816	-0.97	5.187	60.382	6.157	None
323	Backfill	2.848	9.373	11.359	19.477	1.986	None
330	Concrete	3.379	0.7	0.7	0	0	-8.95E-05
331	Concrete	3.379	7.58	2.429	-50.512	-5.151	0
332	Interface bn Concrete n Ground	3.711	0	5.052	49.544	5.052	None
333	Interface bn Concrete n Backfill	3.711	8.38	2.434	-58.312	-5.946	None
334	Interface bn Concrete n Backfill	3.716	8.39	11.343	28.957	2.953	None
335	Backfill	3.759	-0.972	5.323	61.739	6.295	None
336	Backfill	3.796	9.371	11.346	19.368	1.975	None
343	Concrete	4.346	0.7	0.7	0	0	-9.33E-05
344	Concrete	4.346	7.58	2.443	-50.381	-5.137	0
345	Interface bn Concrete n Ground	4.639	0	5.246	51.445	5.246	None
346	Interface bn Concrete n Backfill	4.639	8.38	2.447	-58.187	-5.933	None
347	Interface bn Concrete n Backfill	4.644	8.39	11.319	28.725	2.929	None
348	Backfill	4.702	-0.97	5.53	63.742	6.5	None
349	Backfill	4.752	9.371	11.324	19.159	1.954	None
356	Concrete	5.314	0.7	0.7	0	0	-9.91E-05
357	Concrete	5.314	7.58	2.456	-50.25	-5.124	0
358	Interface bn Concrete n Ground	5.567	0	5.525	54.188	5.525	None
359	Interface bn Concrete n Backfill	5.567	8.38	2.46	-58.062	-5.92	None
360	Interface bn Concrete n Backfill	5.573	8.39	11.279	28.337	2.889	None
361	Backfill	5.625	-0.935	5.809	66.132	6.743	None
363	Backfill	5.746	9.363	11.285	18.85	1.922	None
369	Concrete	6.282	0.7	0.7	0	0	-0.000110131
370	Concrete	6.282	7.58	2.469	-50.121	-5.111	0
371	Interface bn Concrete n Ground	6.494	0	5.977	58.621	5.977	None
372	Interface bn Concrete n Backfill	6.494	8.38	2.473	-57.932	-5.907	None
373	Interface bn Concrete n Backfill	6.502	8.39	11.216	27.717	2.826	None
374	Backfill	6.523	-0.842	6.154	68.609	6.996	None
376	Backfill	6.677	9.285	11.219	18.966	1.934	None
382	Concrete	7.25	0.7	5.781	49.827	5.081	None
383	Concrete	7.25	7.58	2.485	-49.971	-5.095	None

384	Backfill	7.411	-0.671	6.587	71.178	7.258	None
385	Backfill	7.415	9.22	11.138	18.813	1.918	None
387	Interface bn Concrete n Backfill	7.422	0	6.536	64.102	6.536	None
388	Interface bn Concrete n Backfill	7.422	8.38	2.483	-57.835	-5.897	None
389	Interface bn Concrete n Backfill	7.431	8.39	11.11	26.677	2.72	None
390	Concrete	7.55	1	5.266	41.841	4.266	None
391	Concrete	7.55	2.047	2.047	0	0	-2.84E-05
392	Concrete	7.55	3.093	2.601	-4.823	-0.492	0
393	Concrete	7.55	4.14	2.532	-15.765	-1.608	0
394	Concrete	7.55	5.187	2.521	-26.143	-2.666	0
395	Concrete	7.55	6.233	2.506	-36.549	-3.727	0
396	Concrete	7.55	7.28	2.49	-46.971	-4.79	None
399	Backfill	7.966	-0.671	6.895	74.197	7.566	None
404	Backfill	8.264	9.347	11.05	16.699	1.703	None
405	Backfill	8.325	-0.774	7.082	77.05	7.857	None
406	Interface bn Concrete n Backfill	8.35	0	7.304	71.63	7.304	None
407	Interface bn Concrete n Backfill	8.35	0.931	4.992	39.82	4.06	None
408	Interface bn Concrete n Backfill	8.35	1.862	3.358	14.668	1.496	None
409	Interface bn Concrete n Backfill	8.35	2.793	2.45	-3.368	-0.343	None
410	Interface bn Concrete n Backfill	8.35	3.724	2.55	-11.515	-1.174	None
411	Interface bn Concrete n Backfill	8.35	4.656	2.529	-20.856	-2.127	None
412	Interface bn Concrete n Backfill	8.35	5.587	2.515	-30.122	-3.071	None
413	Interface bn Concrete n Backfill	8.35	6.518	2.502	-39.381	-4.016	None
414	Interface bn Concrete n Backfill	8.35	7.449	2.492	-48.616	-4.957	None
415	Interface bn Concrete n Backfill	8.35	8.38	2.488	-57.783	-5.892	None

Table 16 Condition-2 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-IV

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ² /sec)
416	Interface bn Concrete n Backfill	8.36	0	7.339	71.971	7.339	None
417	Interface bn Concrete n Backfill	8.36	0.932	8.059	69.889	7.126	None
418	Interface bn Concrete n Backfill	8.36	1.864	8.454	64.624	6.59	None
419	Interface bn Concrete n Backfill	8.36	2.797	8.808	58.952	6.011	None
420	Interface bn Concrete n Backfill	8.36	3.729	9.133	53.002	5.405	None
421	Interface bn Concrete n Backfill	8.36	4.661	9.446	46.927	4.785	None
422	Interface bn Concrete n Backfill	8.36	5.593	9.754	40.804	4.161	None
423	Interface bn Concrete n Backfill	8.36	6.526	10.065	34.709	3.539	None
424	Interface bn Concrete n Backfill	8.36	7.458	10.387	28.725	2.929	None
425	Interface bn Concrete n Backfill	8.36	8.39	10.82	23.83	2.43	None
426	Backfill	8.414	-0.092	7.322	72.708	7.414	None
428	Backfill	8.775	0.009	7.563	74.085	7.554	None
434	Backfill	9.038	-0.746	7.39	79.791	8.136	None
435	Backfill	9.047	0.853	8.036	70.44	7.183	None
438	Backfill	9.192	9.413	10.963	15.203	1.55	None
439	Backfill	9.201	1.819	8.46	65.127	6.641	None
440	Backfill	9.245	8.429	10.69	22.167	2.26	None
441	Backfill	9.269	2.778	8.812	59.182	6.035	None
442	Backfill	9.281	7.467	10.379	28.561	2.912	None
443	Backfill	9.292	3.729	9.139	53.06	5.41	None
444	Backfill	9.292	4.661	9.448	46.949	4.787	None
445	Backfill	9.292	5.593	9.753	40.797	4.16	None
446	Backfill	9.292	6.526	10.059	34.653	3.534	None

Table 17 Condition-2 Nodal Report on X and Y Velocity, X and Y Gradient -Part-I

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
109	Backfill	-9.292	3.729	3.27E-06	0.000101345	0.000101398	0.012	-0.338	0.338
110	Backfill	-9.292	4.661	2.03E-06	9.88E-05	9.88E-05	0.005	-0.329	0.329
111	Backfill	-9.292	5.593	6.99E-08	9.83E-05	9.83E-05	-0.001	-0.328	0.328
112	Backfill	-9.292	6.526	2.93E-06	0.000100266	0.000100309	-0.009	-0.334	0.334
113	Backfill	-9.27	7.477	8.20E-06	9.96E-05	9.99E-05	-0.025	-0.331	0.332
114	Backfill	-9.237	2.761	6.13E-06	0.000106733	0.000106909	0.022	-0.356	0.357
115	Backfill	-9.231	8.438	3.20E-05	8.86E-05	9.42E-05	-0.112	-0.295	0.315
116	Backfill	-9.165	9.412	2.58E-05	7.28E-05	7.72E-05	-0.087	-0.244	0.259
117	Backfill	-9.146	1.809	1.25E-05	0.000119719	0.000120369	0.043	-0.4	0.402
121	Backfill	-9.002	0.881	1.79E-05	0.000146879	0.000147961	0.065	-0.49	0.494
125	Backfill	-8.944	-0.79	0.000110661	8.34E-05	0.000138569	0.372	-0.285	0.469
127	Backfill	-8.738	0.003	0.000130852	0.000127342	0.000182587	0.428	-0.423	0.602
129	Backfill	-8.415	-0.093	0.000274337	0.000160591	0.000317884	1.301	-0.808	1.531
130	Interface bn Concrete n Backfill	-8.36	0	6.02E-28	8.96E-29	6.08E-28	1.976	-1.058	2.242
131	Interface bn Concrete n Backfill	-8.36	0.932	5.32E-52	1.70E-53	5.33E-52	153.357	-0.599	153.358
132	Interface bn Concrete n Backfill	-8.36	1.864	6.62E-52	1.60E-53	6.62E-52	254.743	-0.401	254.743
133	Interface bn Concrete n Backfill	-8.36	2.797	4.95E-52	3.77E-53	4.96E-52	317.808	-0.364	317.809
134	Interface bn Concrete n Backfill	-8.36	3.729	3.64E-52	6.55E-53	3.70E-52	329.057	-0.343	329.057
135	Interface bn Concrete n Backfill	-8.36	4.661	2.70E-52	6.74E-53	2.79E-52	345.751	-0.333	345.752
136	Interface bn Concrete n Backfill	-8.36	5.593	7.26E-53	6.66E-53	9.85E-53	361.814	-0.332	361.814
137	Interface bn Concrete n Backfill	-8.36	6.526	3.91E-52	6.78E-53	3.97E-52	377.983	-0.339	377.983
138	Interface bn Concrete n Backfill	-8.36	7.458	6.64E-52	7.95E-53	6.69E-52	394.553	-0.405	394.553
139	Interface bn Concrete n Backfill	-8.36	8.39	9.93E-43	1.29E-42	1.62E-42	166.354	-166.973	235.698
140	Interface bn Concrete n Backfill	-8.35	0	1.90E-23	8.09E-24	2.07E-23	1.842	0.478	1.903
141	Interface bn Concrete n Backfill	-8.35	0.931	2.40E-52	1.29E-52	2.72E-52	153.25	2.121	153.265
142	Interface bn Concrete n Backfill	-8.35	1.862	1.59E-51	7.07E-53	1.59E-51	255.588	1.364	255.592
143	Interface bn Concrete n Backfill	-8.35	2.793	1.32E-52	1.34E-53	1.33E-52	317.762	0.427	317.762
144	Interface bn Concrete n Backfill	-8.35	3.724	7.01E-53	2.03E-54	7.01E-53	329.142	-0.042	329.142
145	Interface bn Concrete n Backfill	-8.35	4.656	9.19E-53	9.34E-55	9.19E-53	345.852	0.019	345.852
146	Interface bn Concrete n Backfill	-8.35	5.587	1.72E-53	8.60E-55	1.72E-53	361.93	0.014	361.93
147	Interface bn Concrete n Backfill	-8.35	6.518	2.59E-54	8.31E-55	2.72E-54	378.122	0.013	378.122
148	Interface bn Concrete n Backfill	-8.35	7.449	1.13E-52	6.94E-55	1.13E-52	394.743	0.008	394.743
149	Interface bn Concrete n Backfill	-8.35	8.38	3.06E-69	3.08E-69	4.35E-69	277.734	-277.724	392.768
150	Backfill	-8.325	-0.774	0.000150475	6.91E-05	0.000165602	0.505	-0.234	0.557
151	Backfill	-8.255	9.356	3.69E-05	5.86E-05	6.93E-05	-0.119	-0.191	0.225
157	Backfill	-7.947	-0.659	0.00017248	6.97E-05	0.000186033	0.572	-0.186	0.601
159	Concrete	-7.55	1	3.30E-06	2.54E-05	2.56E-05	-0.512	1.835	1.905
160	Concrete	-7.55	2.047	1.78E-05	1.10E-05	2.09E-05	1.346	1.272	1.852
161	Concrete	-7.55	3.093	5.88E-06	9.74E-07	5.96E-06	-0.098	-0.244	0.263
162	Concrete	-7.55	4.14	1.91E-07	2.77E-07	3.37E-07	0	0.034	0.034
163	Concrete	-7.55	5.187	1.80E-09	1.85E-07	1.85E-07	-0.001	0.012	0.012
164	Concrete	-7.55	6.233	2.30E-08	2.19E-07	2.20E-07	0	0.015	0.015
165	Concrete	-7.55	7.28	8.05E-08	1.26E-07	1.50E-07	0.007	0.009	0.012
166	Backfill	-7.44	-0.658	0.000161181	4.12E-06	0.000161234	0.535	0.05	0.538
168	Interface bn Concrete n Backfill	-7.431	8.39	3.91E-53	9.94E-52	9.94E-52	-0.214	-431.49	431.49
169	Interface bn Concrete n Backfill	-7.422	0	3.87E-05	1.89E-05	4.31E-05	0.486	0.732	0.878
170	Interface bn Concrete n Backfill	-7.422	8.38	1.58E-45	1.07E-43	1.07E-43	0.009	-345.098	345.098
171	Backfill	-7.37	9.231	3.35E-05	1.83E-05	3.82E-05	-0.107	-0.059	0.122
172	Concrete	-7.25	0.7	2.66E-05	1.36E-05	2.99E-05	2.386	0.492	2.436
173	Concrete	-7.25	7.58	2.26E-07	8.98E-08	2.43E-07	0.015	0.006	0.016
180	Backfill	-6.653	9.254	2.48E-05	1.12E-05	2.72E-05	-0.085	-0.048	0.097
181	Backfill	-6.538	-0.864	0.000137573	4.34E-05	0.000144268	0.461	0.146	0.484
182	Interface bn Concrete n Backfill	-6.502	8.39	2.01E-53	6.95E-52	6.95E-52	-0.091	-437.256	437.256

183	Interface bn Concrete n Ground	-6.494	0	4.53E-05	8.33E-05	9.48E-05	0.553	3.78	3.82
184	Interface bn Concrete n Backfill	-6.494	8.38	2.38E-55	1.68E-53	1.68E-53	0.012	-437.207	437.207
185	Concrete	-6.282	0.7	9.19E-06	0.000115067	0.000115433	2.639	6.74	7.238
186	Concrete	-6.282	7.58	2.21E-07	1.37E-08	2.22E-07	0.015	0	0.015
193	Backfill	-5.725	9.365	1.55E-05	7.98E-06	1.75E-05	-0.053	-0.03	0.062
194	Backfill	-5.665	-0.928	0.000107369	6.28E-05	0.000124381	0.361	0.218	0.421
195	Interface bn Concrete n Backfill	-5.573	8.39	1.33E-53	6.40E-52	6.41E-52	-0.055	-441.024	441.024
196	Interface bn Concrete n Ground	-5.567	0	2.91E-05	9.22E-05	9.67E-05	0.393	3.515	3.537
197	Interface bn Concrete n Backfill	-5.567	8.38	1.33E-55	2.67E-54	2.68E-54	0.014	-440.993	440.993
198	Concrete	-5.314	0.7	7.19E-07	0.000103469	0.000103471	-0.003	6.894	6.894
199	Concrete	-5.314	7.58	2.06E-07	2.49E-09	2.06E-07	0.014	0	0.014
206	Backfill	-4.767	9.368	9.10E-06	4.56E-06	1.02E-05	-0.031	-0.017	0.036

Table 18 Condition-2 Nodal Report on X and Y Velocity, X and Y Gradient -Part-II

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
207	Backfill	-4.717	-0.97	7.90E-05	6.80E-05	0.000104257	0.267	0.231	0.353
208	Interface bn Concrete n Backfill	-4.644	8.39	6.83E-54	4.93E-52	4.93E-52	-0.034	-443.63	443.63
209	Interface bn Concrete n Ground	-4.639	0	1.90E-05	8.91E-05	9.11E-05	0.254	3.333	3.342
210	Interface bn Concrete n Backfill	-4.639	8.38	1.79E-55	9.15E-55	9.32E-55	0.014	-443.612	443.612
211	Concrete	-4.346	0.7	4.71E-07	9.75E-05	9.75E-05	-0.002	6.495	6.495
212	Concrete	-4.346	7.58	2.07E-07	2.89E-10	2.07E-07	0.014	0	0.014
219	Backfill	-3.812	9.375	5.38E-06	2.72E-06	6.03E-06	-0.018	-0.01	0.021
220	Backfill	-3.77	-0.976	5.36E-05	6.88E-05	8.72E-05	0.183	0.232	0.296
221	Interface bn Concrete n Backfill	-3.716	8.39	3.03E-54	3.83E-52	3.83E-52	-0.02	-445.443	445.443
222	Interface bn Concrete n Ground	-3.711	0	1.26E-05	8.65E-05	8.74E-05	0.17	3.204	3.208
223	Interface bn Concrete n Backfill	-3.711	8.38	3.27E-55	8.92E-55	9.50E-55	0.014	-445.433	445.433
224	Concrete	-3.379	0.7	3.12E-07	9.33E-05	9.33E-05	-0.001	6.218	6.218
225	Concrete	-3.379	7.58	2.07E-07	6.43E-12	2.07E-07	0.014	0	0.014
232	Backfill	-2.858	9.377	3.10E-06	1.66E-06	3.52E-06	-0.011	-0.006	0.012
233	Backfill	-2.821	-0.969	3.09E-05	6.70E-05	7.38E-05	0.109	0.226	0.251
234	Interface bn Concrete n Backfill	-2.787	8.39	1.34E-54	3.00E-52	3.00E-52	-0.012	-446.78	446.78
235	Interface bn Concrete n Ground	-2.783	0	6.10E-06	8.42E-05	8.45E-05	0.09	3.129	3.13
236	Interface bn Concrete n Backfill	-2.783	8.38	4.44E-55	5.55E-54	5.56E-54	0.014	-446.774	446.774
237	Concrete	-2.411	0.7	1.50E-07	9.06E-05	9.06E-05	-0.001	6.043	6.043
238	Concrete	-2.411	7.58	2.06E-07	5.86E-11	2.06E-07	0.014	0	0.014
245	Backfill	-1.901	9.382	1.67E-06	1.06E-06	1.98E-06	-0.006	-0.004	0.007
246	Backfill	-1.883	-0.971	4.21E-06	6.10E-05	6.12E-05	0.045	0.206	0.211
247	Interface bn Concrete n Backfill	-1.858	8.39	4.13E-55	2.41E-52	2.41E-52	-0.007	-447.822	447.822
248	Interface bn Concrete n Ground	-1.856	0	8.71E-06	8.40E-05	8.45E-05	-0.014	3.116	3.116
249	Interface bn Concrete n Backfill	-1.856	8.38	5.88E-55	2.22E-53	2.22E-53	0.013	-447.819	447.819
250	Concrete	-1.443	0.7	2.59E-06	0.00010828	0.000108311	-1.955	7.13	7.394
251	Concrete	-1.443	7.58	2.22E-07	1.63E-09	2.22E-07	0.015	0.001	0.015
258	Backfill	-0.956	9.383	6.60E-07	7.59E-07	1.01E-06	-0.003	-0.003	0.004
259	Backfill	-0.95	-0.981	9.57E-07	4.64E-05	4.64E-05	0.01	0.153	0.154
260	Interface bn Concrete n Backfill	-0.929	8.39	1.25E-55	2.04E-52	2.04E-52	-0.003	-448.632	448.632
261	Interface bn Concrete n Ground	-0.928	0	1.34E-05	2.85E-05	3.14E-05	-0.086	0.46	0.467
262	Interface bn Concrete n Backfill	-0.928	8.38	5.03E-55	8.77E-53	8.77E-53	0.01	-448.633	448.633
263	Concrete	-0.475	0.7	3.75E-06	2.04E-05	2.07E-05	-1.219	1.63	2.036
264	Concrete	-0.475	7.58	3.81E-08	1.20E-07	1.26E-07	0.006	-0.012	0.013
265	Concrete	-0.175	1	4.34E-07	2.31E-05	2.31E-05	-0.008	1.58	1.58
266	Concrete	-0.175	2.047	1.35E-10	5.26E-06	5.26E-06	0	0.943	0.943
267	Concrete	-0.175	3.093	7.79E-13	9.47E-07	9.47E-07	0	-0.063	0.063
268	Concrete	-0.175	4.14	3.42E-12	9.47E-07	9.47E-07	0	-0.063	0.063
269	Concrete	-0.175	5.187	1.49E-11	9.47E-07	9.47E-07	0	-0.063	0.063
270	Concrete	-0.175	6.233	6.13E-11	9.47E-07	9.47E-07	0	-0.063	0.063

271	Concrete	-0.175	7.28	3.07E-09	7.01E-07	7.01E-07	0	-0.049	0.049
276	Backfill	0	-1	1.81E-06	3.10E-05	3.10E-05	0	0.103	0.103
277	Interface bn Concrete n Ground	0	0	5.72E-06	1.85E-05	1.94E-05	0	0.495	0.495
278	Interface bn Concrete n Backfill	0	8.38	4.11E-55	5.28E-53	5.28E-53	0	-449.017	449.017
279	Interface bn Concrete n Backfill	0	8.39	8.38E-56	1.91E-52	1.91E-52	0	-449.016	449.016
280	Backfill	0	9.387	3.65E-07	6.69E-07	7.62E-07	0	-0.003	0.003
283	Concrete	0.01	0.545	1.78E-06	1.39E-05	1.40E-05	-0.007	0.926	0.926
284	Concrete	0.175	1	6.43E-07	1.85E-05	1.85E-05	-0.07	1.304	1.306
285	Concrete	0.175	2.047	1.35E-10	5.27E-06	5.27E-06	0	0.946	0.946
286	Concrete	0.175	3.093	7.79E-13	9.47E-07	9.47E-07	0	-0.063	0.063
287	Concrete	0.175	4.14	3.42E-12	9.47E-07	9.47E-07	0	-0.063	0.063
288	Concrete	0.175	5.187	1.49E-11	9.47E-07	9.47E-07	0	-0.063	0.063
289	Concrete	0.175	6.233	6.13E-11	9.46E-07	9.46E-07	0	-0.063	0.063
290	Concrete	0.175	7.28	3.07E-09	6.88E-07	6.88E-07	0	-0.048	0.048
291	Concrete	0.475	0.7	3.11E-06	2.04E-05	2.06E-05	1.227	1.631	2.041
292	Concrete	0.475	7.58	2.77E-08	1.90E-07	1.92E-07	-0.005	-0.016	0.017
293	Interface bn Concrete n Ground	0.928	0	1.34E-05	2.85E-05	3.15E-05	0.086	0.462	0.47
294	Interface bn Concrete n Backfill	0.928	8.38	5.45E-55	1.07E-52	1.07E-52	-0.01	-448.617	448.617
295	Interface bn Concrete n Backfill	0.929	8.39	1.36E-55	2.03E-52	2.03E-52	0.003	-448.615	448.615
296	Backfill	0.947	-0.984	1.02E-06	4.64E-05	4.64E-05	-0.01	0.153	0.154
297	Backfill	0.949	9.376	6.58E-07	7.53E-07	1.00E-06	0.003	-0.003	0.004
304	Concrete	1.443	0.7	2.58E-06	0.000108259	0.00010829	1.953	7.129	7.392
305	Concrete	1.443	7.58	2.26E-07	2.18E-09	2.26E-07	-0.015	0.001	0.015
306	Interface bn Concrete n Ground	1.856	0	8.58E-06	8.40E-05	8.45E-05	0.014	3.116	3.116
307	Interface bn Concrete n Backfill	1.856	8.38	5.77E-55	2.56E-53	2.56E-53	-0.013	-447.815	447.815

Table 19 Condition-2 Nodal Report on X and Y Velocity, X and Y Gradient -Part-III

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
308	Interface bn Concrete n Backfill	1.858	8.39	4.24E-55	2.39E-52	2.39E-52	0.007	-447.818	447.818
309	Backfill	1.883	-0.974	4.43E-06	6.10E-05	6.12E-05	-0.045	0.206	0.211
310	Backfill	1.897	9.374	1.67E-06	1.05E-06	1.97E-06	0.006	-0.004	0.007
317	Concrete	2.411	0.7	1.50E-07	9.06E-05	9.06E-05	0.001	6.043	6.043
318	Concrete	2.411	7.58	2.06E-07	8.25E-11	2.06E-07	-0.014	0	0.014
319	Interface bn Concrete n Ground	2.783	0	6.09E-06	8.42E-05	8.45E-05	-0.09	3.129	3.13
320	Interface bn Concrete n Backfill	2.783	8.38	4.44E-55	6.31E-54	6.33E-54	-0.014	-446.77	446.77
321	Interface bn Concrete n Backfill	2.787	8.39	1.33E-54	2.98E-52	2.98E-52	0.012	-446.776	446.776
322	Backfill	2.816	-0.97	3.08E-05	6.70E-05	7.38E-05	-0.108	0.226	0.251
323	Backfill	2.848	9.373	3.09E-06	1.64E-06	3.50E-06	0.011	-0.006	0.012
330	Concrete	3.379	0.7	3.11E-07	9.33E-05	9.33E-05	0.001	6.218	6.218
331	Concrete	3.379	7.58	2.07E-07	5.04E-12	2.07E-07	-0.014	0	0.014
332	Interface bn Concrete n Ground	3.711	0	1.26E-05	8.65E-05	8.74E-05	-0.17	3.204	3.208
333	Interface bn Concrete n Backfill	3.711	8.38	3.26E-55	1.15E-54	1.19E-54	-0.014	-445.43	445.43
334	Interface bn Concrete n Backfill	3.716	8.39	3.04E-54	3.80E-52	3.80E-52	0.02	-445.441	445.441
335	Backfill	3.759	-0.972	5.33E-05	6.90E-05	8.72E-05	-0.182	0.233	0.295
336	Backfill	3.796	9.371	5.33E-06	2.66E-06	5.96E-06	0.018	-0.01	0.021
343	Concrete	4.346	0.7	4.71E-07	9.74E-05	9.74E-05	0.002	6.495	6.495
344	Concrete	4.346	7.58	2.07E-07	3.05E-10	2.07E-07	-0.014	0	0.014
345	Interface bn Concrete n Ground	4.639	0	1.90E-05	8.92E-05	9.12E-05	-0.254	3.332	3.342
346	Interface bn Concrete n Backfill	4.639	8.38	1.78E-55	8.89E-55	9.07E-55	-0.014	-443.606	443.606
347	Interface bn Concrete n Backfill	4.644	8.39	6.84E-54	4.95E-52	4.95E-52	0.034	-443.624	443.624
348	Backfill	4.702	-0.97	7.84E-05	6.84E-05	0.000104038	-0.265	0.232	0.352
349	Backfill	4.752	9.371	9.06E-06	4.54E-06	1.01E-05	0.031	-0.017	0.035
356	Concrete	5.314	0.7	7.19E-07	0.000103471	0.000103473	0.003	6.894	6.894
357	Concrete	5.314	7.58	2.05E-07	2.49E-09	2.05E-07	-0.014	0	0.014
358	Interface bn Concrete n Ground	5.567	0	2.91E-05	9.23E-05	9.68E-05	-0.393	3.516	3.538
359	Interface bn Concrete n Backfill	5.567	8.38	1.35E-55	2.66E-54	2.67E-54	-0.014	-440.99	440.99
360	Interface bn Concrete n Backfill	5.573	8.39	1.33E-53	6.44E-52	6.45E-52	0.055	-441.021	441.021
361	Backfill	5.625	-0.935	0.000106732	6.33E-05	0.000124101	-0.359	0.219	0.42
363	Backfill	5.746	9.363	1.56E-05	7.96E-06	1.75E-05	0.054	-0.03	0.062
369	Concrete	6.282	0.7	9.18E-06	0.000115054	0.00011542	-2.639	6.739	7.237
370	Concrete	6.282	7.58	2.21E-07	1.37E-08	2.22E-07	-0.015	0	0.015
371	Interface bn Concrete n Ground	6.494	0	4.53E-05	8.41E-05	9.55E-05	-0.553	3.782	3.822
372	Interface bn Concrete n Backfill	6.494	8.38	2.41E-55	1.68E-53	1.68E-53	-0.012	-437.171	437.171
373	Interface bn Concrete n Backfill	6.502	8.39	2.00E-53	7.23E-52	7.23E-52	0.091	-437.221	437.221
374	Backfill	6.523	-0.842	0.00013681	4.49E-05	0.000143978	-0.459	0.15	0.482
376	Backfill	6.677	9.285	2.53E-05	1.19E-05	2.79E-05	0.086	-0.05	0.099
382	Concrete	7.25	0.7	2.66E-05	1.36E-05	2.98E-05	-2.386	0.492	2.436
383	Concrete	7.25	7.58	2.26E-07	8.97E-08	2.43E-07	-0.015	0.006	0.016

384	Backfill	7.411	-0.671	0.000160348	4.35E-06	0.000160407	-0.532	0.051	0.535
385	Backfill	7.415	9.22	3.39E-05	1.79E-05	3.83E-05	0.109	-0.059	0.123
387	Interface bn Concrete n Backfill	7.422	0	3.87E-05	2.01E-05	4.36E-05	-0.486	0.735	0.881
388	Interface bn Concrete n Backfill	7.422	8.38	1.58E-45	1.07E-43	1.07E-43	-0.009	-345.097	345.097
389	Interface bn Concrete n Backfill	7.431	8.39	3.90E-53	1.01E-51	1.01E-51	0.214	-431.49	431.49
390	Concrete	7.55	1	3.30E-06	2.54E-05	2.56E-05	0.512	1.835	1.905
391	Concrete	7.55	2.047	1.78E-05	1.10E-05	2.09E-05	-1.346	1.271	1.851
392	Concrete	7.55	3.093	5.88E-06	9.74E-07	5.96E-06	0.098	-0.244	0.263
393	Concrete	7.55	4.14	1.91E-07	2.77E-07	3.37E-07	0	0.034	0.034
394	Concrete	7.55	5.187	1.79E-09	1.85E-07	1.85E-07	0.001	0.012	0.012
395	Concrete	7.55	6.233	2.30E-08	2.19E-07	2.20E-07	0	0.015	0.015
396	Concrete	7.55	7.28	8.05E-08	1.26E-07	1.50E-07	-0.007	0.009	0.012
399	Backfill	7.966	-0.671	0.000171179	6.97E-05	0.000184825	-0.567	-0.186	0.597
404	Backfill	8.264	9.347	3.69E-05	5.78E-05	6.85E-05	0.119	-0.189	0.223
405	Backfill	8.325	-0.774	0.000148558	7.49E-05	0.000166371	-0.499	-0.248	0.557
406	Interface bn Concrete n Backfill	8.35	0	1.90E-23	8.09E-24	2.07E-23	-1.859	0.469	1.917
407	Interface bn Concrete n Backfill	8.35	0.931	2.40E-52	1.29E-52	2.72E-52	-153.221	2.121	153.236
408	Interface bn Concrete n Backfill	8.35	1.862	1.59E-51	7.09E-53	1.59E-51	-255.619	1.364	255.623
409	Interface bn Concrete n Backfill	8.35	2.793	1.32E-52	1.34E-53	1.33E-52	-317.798	0.427	317.798
410	Interface bn Concrete n Backfill	8.35	3.724	7.01E-53	2.03E-54	7.01E-53	-329.171	-0.042	329.171
411	Interface bn Concrete n Backfill	8.35	4.656	9.19E-53	9.33E-55	9.19E-53	-345.871	0.019	345.871
412	Interface bn Concrete n Backfill	8.35	5.587	1.72E-53	8.60E-55	1.72E-53	-361.946	0.014	361.946
413	Interface bn Concrete n Backfill	8.35	6.518	2.59E-54	8.31E-55	2.72E-54	-378.134	0.013	378.134
414	Interface bn Concrete n Backfill	8.35	7.449	1.13E-52	6.94E-55	1.13E-52	-394.765	0.008	394.765
415	Interface bn Concrete n Backfill	8.35	8.38	3.06E-69	3.08E-69	4.34E-69	-277.734	-277.724	392.768

Table 20 Condition-2 Nodal Report on X and Y Velocity, X and Y Gradient -Part-IV

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
416	Interface bn Concrete n Backfill	8.36	0	5.91E-28	9.01E-29	5.97E-28	-1.993	-1.068	2.261
417	Interface bn Concrete n Backfill	8.36	0.932	6.19E-52	1.68E-53	6.19E-52	-153.335	-0.599	153.336
418	Interface bn Concrete n Backfill	8.36	1.864	6.74E-52	1.58E-53	6.75E-52	-254.775	-0.402	254.775
419	Interface bn Concrete n Backfill	8.36	2.797	4.96E-52	3.77E-53	4.97E-52	-317.845	-0.364	317.845
420	Interface bn Concrete n Backfill	8.36	3.729	3.60E-52	6.55E-53	3.66E-52	-329.086	-0.342	329.086
421	Interface bn Concrete n Backfill	8.36	4.661	2.64E-52	6.73E-53	2.72E-52	-345.77	-0.333	345.771
422	Interface bn Concrete n Backfill	8.36	5.593	7.77E-53	6.65E-53	1.02E-52	-361.83	-0.332	361.83
423	Interface bn Concrete n Backfill	8.36	6.526	3.89E-52	6.78E-53	3.94E-52	-377.995	-0.339	377.995
424	Interface bn Concrete n Backfill	8.36	7.458	6.66E-52	7.95E-53	6.71E-52	-394.574	-0.405	394.574
425	Interface bn Concrete n Backfill	8.36	8.39	9.90E-43	1.28E-42	1.62E-42	-166.354	-166.973	235.699
426	Backfill	8.414	-0.092	0.00027085	0.000161657	0.000315425	-1.303	-0.818	1.538
428	Backfill	8.775	0.009	0.000127771	0.000127426	0.000180451	-0.419	-0.423	0.595
434	Backfill	9.038	-0.746	0.00010856	8.54E-05	0.000138099	-0.365	-0.291	0.467
435	Backfill	9.047	0.853	2.09E-05	0.000144673	0.000146174	-0.074	-0.482	0.488
438	Backfill	9.192	9.413	2.56E-05	7.31E-05	7.74E-05	0.087	-0.245	0.259
439	Backfill	9.201	1.819	1.29E-05	0.000119116	0.000119814	-0.045	-0.398	0.401
440	Backfill	9.245	8.429	3.16E-05	8.86E-05	9.41E-05	0.111	-0.295	0.315
441	Backfill	9.269	2.778	6.20E-06	0.000106361	0.000106542	-0.022	-0.355	0.355
442	Backfill	9.281	7.467	8.27E-06	9.95E-05	9.98E-05	0.025	-0.331	0.332
443	Backfill	9.292	3.729	3.21E-06	0.000101252	0.000101303	-0.011	-0.338	0.338
444	Backfill	9.292	4.661	2.15E-06	9.88E-05	9.88E-05	-0.005	-0.329	0.329
445	Backfill	9.292	5.593	5.31E-08	9.83E-05	9.83E-05	0.001	-0.328	0.328
446	Backfill	9.292	6.526	2.92E-06	0.000100219	0.000100261	0.009	-0.334	0.334

Condition-3 Tunnel Lining With Rock-Fill-Nodal Report

Table 21 Condition-3 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-I

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
91	Interface bn Concrete n Rockfill	-10.283	0.931	0.796	-1.327	-0.135	None
92	Interface bn Concrete n Rockfill	-10.281	2.793	1.323	-14.417	-1.47	None
93	Interface bn Concrete n Rockfill	-10.281	3.724	1.627	-20.569	-2.097	None
94	Interface bn Concrete n Rockfill	-10.281	4.656	1.964	-26.392	-2.691	None
95	Interface bn Concrete n Rockfill	-10.281	5.587	2.35	-31.744	-3.237	None
96	Interface bn Concrete n Rockfill	-10.281	6.518	2.817	-36.295	-3.701	None
97	Interface bn Concrete n Rockfill	-10.281	1.858	1.049	-7.941	-0.81	None
98	Interface bn Concrete n Rockfill	-10.28	7.45	3.456	-39.177	-3.995	None
99	Interface bn Concrete n Rockfill	-10.277	-0.006	0.673	6.663	0.679	None
100	Interface bn Concrete n Rockfill	-10.27	8.386	4.732	-35.833	-3.654	None
101	Interface bn Concrete n Rockfill	-10.186	-1.001	0.637	16.061	1.638	None
102	Interface bn Concrete n Rockfill	-10.125	9.383	6.628	-27.018	-2.755	None
109	Interface bn Rockfill n Backfill	-9.35	0	0	0	0	-0.005409408
110	Interface bn Rockfill n Backfill	-9.35	0.931	0.456	-4.661	-0.475	None
111	Interface bn Rockfill n Backfill	-9.35	1.862	0.694	-11.455	-1.168	None
112	Interface bn Rockfill n Backfill	-9.35	2.793	0.944	-18.132	-1.849	None
113	Interface bn Rockfill n Backfill	-9.35	3.724	1.187	-24.881	-2.537	None
114	Interface bn Rockfill n Backfill	-9.35	4.656	1.424	-31.694	-3.232	None
115	Interface bn Rockfill n Backfill	-9.35	5.587	1.652	-38.59	-3.935	None
116	Interface bn Rockfill n Backfill	-9.35	6.518	1.869	-45.594	-4.649	None
117	Interface bn Rockfill n Backfill	-9.35	7.449	2.072	-52.733	-5.377	None
118	Interface bn Rockfill n Backfill	-9.35	8.38	2.235	-60.263	-6.145	None
119	Interface bn Concrete n Rockfill	-9.242	-0.992	0.508	14.712	1.5	None
120	Interface bn Concrete n Rockfill	-9.211	9.372	6.23	-30.811	-3.142	None
127	Interface bn Rockfill n Backfill	-8.35	0	0.359	3.517	0.359	None
128	Interface bn Rockfill n Backfill	-8.35	0.931	0.423	-4.984	-0.508	None
129	Interface bn Rockfill n Backfill	-8.35	1.862	0.693	-11.462	-1.169	None
130	Interface bn Rockfill n Backfill	-8.35	2.793	0.941	-18.168	-1.853	None
131	Interface bn Rockfill n Backfill	-8.35	3.724	1.183	-24.92	-2.541	None
132	Interface bn Rockfill n Backfill	-8.35	4.656	1.419	-31.743	-3.237	None
133	Interface bn Rockfill n Backfill	-8.35	5.587	1.645	-38.653	-3.941	None
134	Interface bn Rockfill n Backfill	-8.35	6.518	1.86	-45.676	-4.657	None
135	Interface bn Rockfill n Backfill	-8.35	7.449	2.057	-52.88	-5.392	None
136	Interface bn Rockfill n Backfill	-8.35	8.38	2.24	-60.219	-6.14	None
137	Interface bn Concrete n Rockfill	-8.308	-0.977	0.456	14.059	1.434	None
138	Interface bn Concrete n Rockfill	-8.24	9.37	6.876	-24.464	-2.495	None
145	Concrete	-7.55	1	0.503	-4.871	-0.497	None
146	Concrete	-7.55	2.047	0.739	-12.821	-1.307	0
147	Concrete	-7.55	3.093	1.018	-20.356	-2.076	0
148	Concrete	-7.55	4.14	1.287	-27.984	-2.853	0
149	Concrete	-7.55	5.187	1.55	-35.67	-3.637	0
150	Concrete	-7.55	6.233	1.856	-42.925	-4.377	0
151	Concrete	-7.55	7.28	3.483	-37.242	-3.797	None
152	Interface bn Rockfill n Backfill	-7.422	0	0.481	4.713	0.481	None
153	Interface bn Rockfill n Backfill	-7.422	8.38	7.071	-12.837	-1.309	None
154	Interface bn Concrete n Rockfill	-7.328	-0.964	0.507	14.425	1.471	None
155	Interface bn Concrete n Rockfill	-7.257	9.347	8.07	-12.52	-1.277	None
156	Concrete	-7.25	0.7	0.5	-1.965	-0.2	None
157	Concrete	-7.25	7.58	5.532	-20.087	-2.048	None
164	Interface bn Concrete n Ground	-6.494	0	0.525	5.151	0.525	None
165	Interface bn Concrete n Ground	-6.494	8.38	8.69	3.04	0.31	None
166	Interface bn Concrete n Rockfill	-6.419	-0.873	0.535	13.809	1.408	None
168	Interface bn Concrete n Rockfill	-6.347	9.252	9.211	-0.403	-0.041	None
169	Concrete	-6.282	0.7	0.526	-1.702	-0.174	0
170	Concrete	-6.282	7.58	7.58	0	0	-1.84E-05
176	Interface bn Concrete n Rockfill	-5.661	9.25	9.746	4.87	0.497	None
178	Interface bn Concrete n Ground	-5.567	0	0.547	5.364	0.547	None

179	Interface bn Concrete n Ground	-5.567	8.38	9.579	11.761	1.199	None
180	Interface bn Concrete n Rockfill	-5.549	-0.867	0.551	13.903	1.418	None
181	Concrete	-5.314	0.7	0.549	-1.485	-0.151	0
182	Concrete	-5.314	7.58	7.58	0	0	-3.74E-05
188	Interface bn Concrete n Rockfill	-4.77	9.352	10.276	9.065	0.924	None
190	Interface bn Concrete n Rockfill	-4.657	-0.92	0.561	14.528	1.481	None
191	Interface bn Concrete n Ground	-4.639	0	0.559	5.484	0.559	None
192	Interface bn Concrete n Ground	-4.639	8.38	10.065	16.52	1.685	None

Table 22 Condition-3 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-II

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m ³ /sec)
193	Concrete	-4.346	0.7	0.561	-1.365	-0.139	0
194	Concrete	-4.346	7.58	7.58	0	0	-4.63E-05
200	Interface bn Concrete n Rockfill	-3.803	9.363	10.587	11.999	1.224	None
202	Interface bn Concrete n Rockfill	-3.74	-0.952	0.568	14.903	1.52	None
203	Interface bn Concrete n Ground	-3.711	0	0.567	5.559	0.567	None
204	Interface bn Concrete n Ground	-3.711	8.38	10.37	19.521	1.99	None
205	Concrete	-3.379	0.7	0.568	-1.291	-0.132	0
206	Concrete	-3.379	7.58	7.58	0	0	-5.15E-05
212	Interface bn Concrete n Rockfill	-2.851	9.36	10.766	13.789	1.406	None
214	Interface bn Concrete n Rockfill	-2.803	-0.947	0.572	14.902	1.52	None
215	Interface bn Concrete n Ground	-2.783	0	0.572	5.611	0.572	None
216	Interface bn Concrete n Ground	-2.783	8.38	10.559	21.37	2.179	None
217	Concrete	-2.411	0.7	0.574	-1.232	-0.126	0
218	Concrete	-2.411	7.58	7.58	0	0	-5.49E-05
225	Interface bn Concrete n Rockfill	-1.899	9.361	10.88	14.904	1.52	None
226	Interface bn Concrete n Rockfill	-1.877	-0.962	0.576	15.081	1.538	None
227	Interface bn Concrete n Ground	-1.856	0	0.577	5.657	0.577	None
228	Interface bn Concrete n Ground	-1.856	8.38	10.69	22.651	2.31	None
229	Concrete	-1.443	0.7	0.586	-1.117	-0.114	0
230	Concrete	-1.443	7.58	7.58	0	0	-6.31E-05
235	Interface bn Concrete n Rockfill	-0.954	9.358	10.952	15.635	1.594	None
238	Interface bn Concrete n Rockfill	-0.946	-0.981	0.579	15.3	1.56	None
239	Interface bn Concrete n Ground	-0.928	0	0.582	5.711	0.582	None
240	Interface bn Concrete n Ground	-0.928	8.38	10.8	23.73	2.42	None
241	Concrete	-0.475	0.7	0.685	-0.146	-0.015	None
242	Concrete	-0.475	7.58	10.038	24.103	2.458	None
243	Concrete	-0.175	1	0.911	-0.875	-0.089	None
244	Concrete	-0.175	2.047	1.981	-0.644	-0.066	0
245	Concrete	-0.175	3.093	3.043	-0.496	-0.051	0
246	Concrete	-0.175	4.14	4.107	-0.328	-0.033	0
247	Concrete	-0.175	5.187	5.17	-0.164	-0.017	0
248	Concrete	-0.175	6.233	6.233	0	0	-5.61E-06
249	Concrete	-0.175	7.28	9.532	22.085	2.252	None
250	Concrete	-0.01	0.545	0.724	1.765	0.18	None
255	Interface bn Concrete n Rockfill	0	-1	0.58	15.495	1.58	None
256	Interface bn Concrete n Ground	0	0	0.586	5.748	0.586	None
257	Interface bn Concrete n Ground	0	8.38	10.876	24.474	2.496	None
258	Interface bn Concrete n Rockfill	0	9.38	10.98	15.694	1.6	None
261	Concrete	0.175	1	0.922	-0.768	-0.078	None
262	Concrete	0.175	2.047	1.978	-0.67	-0.068	0

263	Concrete	0.175	3.093	3.043	-0.49	-0.05	0
264	Concrete	0.175	4.14	4.106	-0.329	-0.034	0
265	Concrete	0.175	5.187	5.17	-0.164	-0.017	0
266	Concrete	0.175	6.233	6.233	0	0	-5.60E-06
267	Concrete	0.175	7.28	9.532	22.088	2.252	None
268	Concrete	0.475	0.7	0.68	-0.198	-0.02	None
269	Concrete	0.475	7.58	10.045	24.171	2.465	None
270	Interface bn Concrete n Ground	0.928	0	0.582	5.709	0.582	None
271	Interface bn Concrete n Ground	0.928	8.38	10.8	23.728	2.42	None
272	Interface bn Concrete n Rockfill	0.949	-0.98	0.579	15.29	1.559	None
273	Interface bn Concrete n Rockfill	0.95	9.361	10.953	15.612	1.592	None
280	Concrete	1.443	0.7	0.586	-1.122	-0.114	0
281	Concrete	1.443	7.58	7.58	0	0	-6.31E-05
282	Interface bn Concrete n Ground	1.856	0	0.577	5.655	0.577	None
283	Interface bn Concrete n Ground	1.856	8.38	10.69	22.651	2.31	None
284	Interface bn Concrete n Rockfill	1.877	9.363	10.883	14.904	1.52	None
285	Interface bn Concrete n Rockfill	1.883	-0.963	0.576	15.098	1.539	None
292	Concrete	2.411	0.7	0.574	-1.234	-0.126	0
293	Concrete	2.411	7.58	7.58	0	0	-5.49E-05
294	Interface bn Concrete n Ground	2.783	0	0.572	5.61	0.572	None
295	Interface bn Concrete n Ground	2.783	8.38	10.559	21.37	2.179	None
296	Interface bn Concrete n Rockfill	2.79	-0.935	0.572	14.781	1.507	None
297	Interface bn Concrete n Rockfill	2.838	9.358	10.767	13.822	1.409	None
304	Concrete	3.379	0.7	0.568	-1.292	-0.132	0
305	Concrete	3.379	7.58	7.58	0	0	-5.15E-05

Table 23 Condition-3 Nodal Report on Total Head, PW.Pressure, Pressure Head and Flux rate-Part-III

Node	Material	X (m)	Y (m)	Total Head (m)	Pore-Water Pressure (kPa)	Pressure Head (m)	Water Flux (m³/sec)
306	Interface bn Concrete n Ground	3.711	0	0.567	5.557	0.567	None
307	Interface bn Concrete n Ground	3.711	8.38	10.371	19.528	1.991	None
308	Interface bn Concrete n Rockfill	3.745	-0.953	0.568	14.916	1.521	None
309	Interface bn Concrete n Rockfill	3.794	9.363	10.589	12.02	1.226	None
316	Concrete	4.346	0.7	0.561	-1.367	-0.139	0
317	Concrete	4.346	7.58	7.58	0	0	-4.63E-05
318	Interface bn Concrete n Ground	4.639	0	0.559	5.481	0.559	None
319	Interface bn Concrete n Ground	4.639	8.38	10.064	16.517	1.684	None
320	Interface bn Concrete n Rockfill	4.671	-0.936	0.561	14.683	1.497	None
321	Interface bn Concrete n Rockfill	4.729	9.358	10.295	9.188	0.937	None
328	Concrete	5.314	0.7	0.548	-1.488	-0.152	0
329	Concrete	5.314	7.58	7.58	0	0	-3.74E-05
330	Interface bn Concrete n Ground	5.567	0	0.547	5.361	0.547	None
331	Interface bn Concrete n Ground	5.567	8.38	9.581	11.775	1.201	None
332	Interface bn Concrete n Rockfill	5.573	-0.891	0.551	14.138	1.442	None
334	Interface bn Concrete n Rockfill	5.633	9.232	9.757	5.154	0.526	None
340	Concrete	6.282	0.7	0.526	-1.707	-0.174	0
341	Concrete	6.282	7.58	7.58	0	0	-1.84E-05
342	Interface bn Concrete n Rockfill	6.347	9.252	9.214	-0.377	-0.038	None
344	Interface bn Concrete n Rockfill	6.467	-0.924	0.534	14.297	1.458	None
345	Interface bn Concrete n Ground	6.494	0	0.525	5.144	0.525	None
346	Interface bn Concrete n Ground	6.494	8.38	8.691	3.045	0.311	None
352	Concrete	7.25	0.7	0.499	-1.97	-0.201	None
353	Concrete	7.25	7.58	5.532	-20.087	-2.048	None
354	Interface bn Concrete n Rockfill	7.258	9.352	8.078	-12.497	-1.274	None
356	Interface bn Concrete n Rockfill	7.374	-0.955	0.504	14.309	1.459	None
357	Interface bn Rockfill n Backfill	7.422	0	0.48	4.707	0.48	None
358	Interface bn Rockfill n Backfill	7.422	8.38	7.071	-12.835	-1.309	None
359	Concrete	7.55	1	0.503	-4.873	-0.497	None
360	Concrete	7.55	2.047	0.739	-12.822	-1.307	0
361	Concrete	7.55	3.093	1.017	-20.358	-2.076	0
362	Concrete	7.55	4.14	1.286	-27.987	-2.854	0
363	Concrete	7.55	5.187	1.549	-35.674	-3.638	0
364	Concrete	7.55	6.233	1.856	-42.93	-4.377	0
365	Concrete	7.55	7.28	3.482	-37.246	-3.798	None
372	Interface bn Concrete n Rockfill	8.241	9.369	6.874	-24.474	-2.496	None
373	Interface bn Concrete n Rockfill	8.321	-0.973	0.453	13.984	1.426	None
374	Interface bn Rockfill n Backfill	8.35	0	0.359	3.517	0.359	None
375	Interface bn Rockfill n Backfill	8.35	0.931	0.423	-4.985	-0.508	None
376	Interface bn Rockfill n Backfill	8.35	1.862	0.693	-11.464	-1.169	None

377	Interface bn Rockfill n Backfill	8.35	2.793	0.941	-18.17	-1.853	None
378	Interface bn Rockfill n Backfill	8.35	3.724	1.183	-24.922	-2.541	None
379	Interface bn Rockfill n Backfill	8.35	4.656	1.418	-31.746	-3.237	None
380	Interface bn Rockfill n Backfill	8.35	5.587	1.645	-38.658	-3.942	None
381	Interface bn Rockfill n Backfill	8.35	6.518	1.86	-45.681	-4.658	None
382	Interface bn Rockfill n Backfill	8.35	7.449	2.056	-52.887	-5.393	None
383	Interface bn Rockfill n Backfill	8.35	8.38	2.239	-60.226	-6.141	None
390	Interface bn Concrete n Rockfill	9.203	9.379	6.258	-30.608	-3.121	None
391	Interface bn Concrete n Rockfill	9.288	-0.991	0.512	14.735	1.502	None
392	Interface bn Rockfill n Backfill	9.35	0	0	0	0	-0.005408024
393	Interface bn Rockfill n Backfill	9.35	0.931	0.456	-4.662	-0.475	None
394	Interface bn Rockfill n Backfill	9.35	1.862	0.694	-11.456	-1.168	None
395	Interface bn Rockfill n Backfill	9.35	2.793	0.944	-18.134	-1.849	None
396	Interface bn Rockfill n Backfill	9.35	3.724	1.187	-24.883	-2.537	None
397	Interface bn Rockfill n Backfill	9.35	4.656	1.423	-31.698	-3.232	None
398	Interface bn Rockfill n Backfill	9.35	5.587	1.651	-38.595	-3.935	None
399	Interface bn Rockfill n Backfill	9.35	6.518	1.868	-45.6	-4.65	None
400	Interface bn Rockfill n Backfill	9.35	7.449	2.071	-52.739	-5.378	None
401	Interface bn Rockfill n Backfill	9.35	8.38	2.234	-60.273	-6.146	None
407	Interface bn Concrete n Rockfill	10.142	9.407	6.703	-26.518	-2.704	None
409	Interface bn Concrete n Rockfill	10.244	8.397	4.713	-36.131	-3.684	None
410	Interface bn Concrete n Rockfill	10.246	-1.008	0.654	16.294	1.661	None
411	Interface bn Concrete n Rockfill	10.277	-0.019	0.673	6.787	0.692	None
412	Interface bn Concrete n Rockfill	10.281	1.862	1.05	-7.969	-0.813	None
413	Interface bn Concrete n Rockfill	10.281	2.793	1.323	-14.418	-1.47	None
414	Interface bn Concrete n Rockfill	10.281	3.724	1.627	-20.572	-2.098	None
415	Interface bn Concrete n Rockfill	10.281	4.656	1.964	-26.395	-2.691	None
416	Interface bn Concrete n Rockfill	10.281	5.587	2.35	-31.746	-3.237	None
417	Interface bn Concrete n Rockfill	10.281	6.518	2.817	-36.298	-3.701	None
418	Interface bn Concrete n Rockfill	10.282	0.927	0.794	-1.304	-0.133	None
419	Interface bn Concrete n Rockfill	10.283	7.449	3.46	-39.121	-3.989	None

Table 24 Condition-3 Nodal Report on X and Y Velocity, X and Y Gradient -Part-I

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
91	Interface bn Concrete n Rockfill	-10.283	0.931	0.000110989	5.94E-05	0.000125866	0.365	-0.201	0.417
92	Interface bn Concrete n Rockfill	-10.281	2.793	0.00011767	9.30E-05	0.000150005	0.392	-0.31	0.5
93	Interface bn Concrete n Rockfill	-10.281	3.724	0.000136532	0.000103682	0.000171438	0.454	-0.344	0.57
94	Interface bn Concrete n Rockfill	-10.281	4.656	0.000167489	0.000117404	0.00020454	0.556	-0.388	0.678
95	Interface bn Concrete n Rockfill	-10.281	5.587	0.000214656	0.000139298	0.000255892	0.712	-0.458	0.847
96	Interface bn Concrete n Rockfill	-10.281	6.518	0.000285872	0.000181751	0.000338757	0.948	-0.594	1.118
97	Interface bn Concrete n Rockfill	-10.281	1.858	0.000109185	8.51E-05	0.000138403	0.364	-0.284	0.462
98	Interface bn Concrete n Rockfill	-10.28	7.45	0.000397772	0.000309108	0.000503756	1.319	-1.033	1.675
99	Interface bn Concrete n Rockfill	-10.277	-0.006	0.000150844	2.21E-05	0.000152461	0.524	-0.058	0.527
100	Interface bn Concrete n Rockfill	-10.27	8.386	0.000537375	0.000546734	0.000766609	1.897	-1.781	2.602
101	Interface bn Concrete n Rockfill	-10.186	-1.001	6.06E-05	1.72E-05	6.30E-05	0.192	0.037	0.196
102	Interface bn Concrete n Rockfill	-10.125	9.383	0.000201596	0.000680735	0.000709958	0.588	-2.248	2.323
109	Interface bn Rockfill n Backfill	-9.35	0	0.000538192	0.000487026	0.000725841	0.182	0.021	0.183
110	Interface bn Rockfill n Backfill	-9.35	0.931	0.000258332	0.00087117	0.000908666	0.199	-0.373	0.422
111	Interface bn Rockfill n Backfill	-9.35	1.862	6.79E-05	0.000609959	0.00061373	0.191	-0.262	0.325
112	Interface bn Rockfill n Backfill	-9.35	2.793	9.20E-05	0.000616213	0.000623049	0.205	-0.265	0.335
113	Interface bn Rockfill n Backfill	-9.35	3.724	0.000101042	0.000600454	0.000608896	0.238	-0.257	0.351
114	Interface bn Rockfill n Backfill	-9.35	4.656	0.000124973	0.000584894	0.000598096	0.293	-0.249	0.385
115	Interface bn Rockfill n Backfill	-9.35	5.587	0.00016242	0.000567325	0.000590117	0.378	-0.239	0.447
116	Interface bn Rockfill n Backfill	-9.35	6.518	0.000216972	0.000552138	0.00059324	0.513	-0.226	0.561
117	Interface bn Rockfill n Backfill	-9.35	7.449	0.000445207	0.000541272	0.000700846	0.751	-0.197	0.776
118	Interface bn Rockfill n Backfill	-9.35	8.38	7.85E-05	0.000830705	0.000834407	1.348	-2.196	2.577
119	Interface bn Concrete n Rockfill	-9.242	-0.992	2.22E-05	8.16E-05	8.45E-05	0.09	0.319	0.331
120	Interface bn Concrete n Rockfill	-9.211	9.372	0.000195273	0.001013375	0.001032018	-0.138	-3.4	3.403
127	Interface bn Rockfill n Backfill	-8.35	0	0.00010692	3.99E-05	0.000114123	-0.246	0.011	0.246
128	Interface bn Rockfill n Backfill	-8.35	0.931	3.05E-05	8.36E-05	8.90E-05	-0.026	-0.179	0.181
129	Interface bn Rockfill n Backfill	-8.35	1.862	1.62E-06	0.000144433	0.000144442	0.004	-0.278	0.278
130	Interface bn Rockfill n Backfill	-8.35	2.793	1.69E-06	0.000136716	0.000136726	0.003	-0.263	0.263
131	Interface bn Rockfill n Backfill	-8.35	3.724	2.12E-06	0.000133351	0.000133368	0.004	-0.257	0.257
132	Interface bn Rockfill n Backfill	-8.35	4.656	3.06E-06	0.000128864	0.0001289	0.005	-0.248	0.248
133	Interface bn Rockfill n Backfill	-8.35	5.587	1.41E-06	0.000123501	0.000123509	0.004	-0.237	0.237
134	Interface bn Rockfill n Backfill	-8.35	6.518	2.01E-05	0.000132713	0.000134229	-0.035	-0.228	0.231
135	Interface bn Rockfill n Backfill	-8.35	7.449	0.000119545	0.000161415	0.000200863	-0.934	-0.235	0.963
136	Interface bn Rockfill n Backfill	-8.35	8.38	5.15E-05	0.000497045	0.000499703	-2.614	-2.317	3.493
137	Interface bn Concrete n Rockfill	-8.308	-0.977	1.45E-05	3.57E-05	3.85E-05	-0.001	0.106	0.106
138	Interface bn Concrete n Rockfill	-8.24	9.37	0.000318092	0.001006948	0.001055995	-0.971	-3.443	3.577
145	Concrete	-7.55	1	7.26E-07	8.77E-07	1.14E-06	-0.064	-0.094	0.114
146	Concrete	-7.55	2.047	1.16E-07	3.67E-06	3.68E-06	-0.001	-0.245	0.245
147	Concrete	-7.55	3.093	2.58E-08	3.92E-06	3.92E-06	0.002	-0.261	0.261
148	Concrete	-7.55	4.14	3.79E-08	3.80E-06	3.81E-06	0.003	-0.254	0.254
149	Concrete	-7.55	5.187	2.60E-07	4.09E-06	4.10E-06	-0.017	-0.273	0.273
150	Concrete	-7.55	6.233	4.14E-06	1.10E-05	1.17E-05	-0.328	-0.936	0.992
151	Concrete	-7.55	7.28	4.36E-05	3.95E-05	5.88E-05	-2.881	-2.475	3.798
152	Interface bn Rockfill n Backfill	-7.422	0	2.75E-06	1.11E-06	2.97E-06	-0.074	-0.008	0.075
153	Interface bn Rockfill n Backfill	-7.422	8.38	0.000163594	7.99E-05	0.000182062	-3.591	-1.743	3.992
154	Interface bn Concrete n Rockfill	-7.328	-0.964	1.77E-05	1.08E-05	2.07E-05	-0.043	0.034	0.055
155	Interface bn Concrete n Rockfill	-7.257	9.347	0.000423149	0.000376792	0.000566593	-1.292	-1.167	1.741
156	Concrete	-7.25	0.7	2.76E-07	4.30E-07	5.10E-07	-0.02	-0.022	0.03
157	Concrete	-7.25	7.58	4.39E-05	3.87E-05	5.86E-05	-3.078	-2.587	4.021
164	Interface bn Concrete n Ground	-6.494	0	2.27E-06	4.94E-07	2.32E-06	-0.036	0.008	0.037
165	Interface bn Concrete n Ground	-6.494	8.38	9.27E-05	5.55E-05	0.000108063	-1.353	-1.059	1.718
166	Interface bn Concrete n Rockfill	-6.419	-0.873	7.79E-06	4.29E-06	8.90E-06	-0.026	0.015	0.029
168	Interface bn Concrete n Rockfill	-6.347	9.252	0.000308018	0.000167753	0.000350737	-1.04	-0.553	1.178
169	Concrete	-6.282	0.7	3.83E-07	2.87E-08	3.84E-07	-0.025	0.006	0.026
170	Concrete	-6.282	7.58	7.57E-06	2.52E-05	2.63E-05	-1.056	-1.668	1.974
176	Interface bn Concrete n Rockfill	-5.661	9.25	0.00019578	0.000132364	0.000236326	-0.663	-0.494	0.827
178	Interface bn Concrete n Ground	-5.567	0	1.18E-06	2.71E-07	1.21E-06	-0.018	0.004	0.019

179	Interface bn Concrete n Ground	-5.567	8.38	5.38E-05	5.85E-05	7.95E-05	-0.74	-1.502	1.675
180	Interface bn Concrete n Rockfill	-5.549	-0.867	4.42E-06	2.13E-06	4.91E-06	-0.015	0.008	0.017
181	Concrete	-5.314	0.7	2.55E-07	5.31E-08	2.60E-07	-0.018	0.004	0.018
182	Concrete	-5.314	7.58	1.33E-06	3.80E-05	3.80E-05	0.005	-2.497	2.498
188	Interface bn Concrete n Rockfill	-4.77	9.352	0.000125055	0.000114868	0.000169803	-0.43	-0.402	0.589
190	Interface bn Concrete n Rockfill	-4.657	-0.92	2.72E-06	1.20E-06	2.97E-06	-0.009	0.004	0.01
191	Interface bn Concrete n Ground	-4.639	0	7.00E-07	1.42E-07	7.14E-07	-0.011	0.002	0.011
192	Interface bn Concrete n Ground	-4.639	8.38	3.15E-05	6.36E-05	7.10E-05	-0.425	-1.768	1.818

Table 25 Condition-3 Nodal Report on X and Y Velocity, X and Y Gradient -Part-II

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
193	Concrete	-4.346	0.7	1.49E-07	2.45E-08	1.51E-07	-0.01	0.002	0.01
194	Concrete	-4.346	7.58	7.79E-07	4.67E-05	4.67E-05	0.003	-3.105	3.105
200	Interface bn Concrete n Rockfill	-3.803	9.363	7.41E-05	9.10E-05	0.000117333	-0.253	-0.31	0.4
202	Interface bn Concrete n Rockfill	-3.74	-0.952	1.82E-06	6.53E-07	1.93E-06	-0.006	0.002	0.007
203	Interface bn Concrete n Ground	-3.711	0	4.64E-07	7.91E-08	4.70E-07	-0.007	0.001	0.007
204	Interface bn Concrete n Ground	-3.711	8.38	1.96E-05	6.30E-05	6.60E-05	-0.265	-1.921	1.94
205	Concrete	-3.379	0.7	1.04E-07	1.49E-08	1.05E-07	-0.007	0.001	0.007
206	Concrete	-3.379	7.58	4.86E-07	5.24E-05	5.24E-05	0.002	-3.487	3.487
212	Interface bn Concrete n Rockfill	-2.851	9.36	4.56E-05	7.61E-05	8.88E-05	-0.154	-0.255	0.298
214	Interface bn Concrete n Rockfill	-2.803	-0.947	1.35E-06	2.20E-07	1.36E-06	-0.004	0.001	0.005
215	Interface bn Concrete n Ground	-2.783	0	3.71E-07	1.97E-08	3.71E-07	-0.005	0	0.005
216	Interface bn Concrete n Ground	-2.783	8.38	1.28E-05	6.18E-05	6.31E-05	-0.171	-2.013	2.021
217	Concrete	-2.411	0.7	1.33E-07	2.63E-09	1.33E-07	-0.009	0.002	0.009
218	Concrete	-2.411	7.58	3.17E-07	5.59E-05	5.59E-05	0.001	-3.723	3.723
225	Interface bn Concrete n Rockfill	-1.899	9.361	2.92E-05	6.53E-05	7.16E-05	-0.098	-0.218	0.239
226	Interface bn Concrete n Rockfill	-1.877	-0.962	1.07E-06	9.48E-08	1.07E-06	-0.003	0	0.004
227	Interface bn Concrete n Ground	-1.856	0	4.99E-07	2.16E-07	5.44E-07	-0.006	-0.005	0.008
228	Interface bn Concrete n Ground	-1.856	8.38	1.27E-05	6.12E-05	6.25E-05	-0.134	-2.079	2.084
229	Concrete	-1.443	0.7	5.98E-07	7.43E-08	6.03E-07	-0.058	0.021	0.061
230	Concrete	-1.443	7.58	3.51E-06	6.88E-05	6.89E-05	-1.278	-4.546	4.722
235	Interface bn Concrete n Rockfill	-0.954	9.358	1.39E-05	5.32E-05	5.50E-05	-0.051	-0.178	0.185
238	Interface bn Concrete n Rockfill	-0.946	-0.981	5.87E-07	7.67E-07	9.66E-07	-0.002	-0.003	0.003
239	Interface bn Concrete n Ground	-0.928	0	5.76E-07	1.65E-06	1.74E-06	-0.004	-0.074	0.074
240	Interface bn Concrete n Ground	-0.928	8.38	9.28E-06	2.88E-05	3.03E-05	-0.104	-0.586	0.596
241	Concrete	-0.475	0.7	2.39E-06	2.71E-06	3.61E-06	-0.151	-0.218	0.265
242	Concrete	-0.475	7.58	8.99E-07	2.20E-05	2.20E-05	-0.663	-1.534	1.671
243	Concrete	-0.175	1	1.16E-06	8.93E-06	9.00E-06	-0.098	-0.639	0.646
244	Concrete	-0.175	2.047	2.75E-08	1.53E-05	1.53E-05	0.008	-1.018	1.018
245	Concrete	-0.175	3.093	6.66E-09	1.52E-05	1.52E-05	-0.002	-1.015	1.015
246	Concrete	-0.175	4.14	1.54E-09	1.52E-05	1.52E-05	0	-1.016	1.016
247	Concrete	-0.175	5.187	3.49E-10	1.52E-05	1.52E-05	0	-1.016	1.016
248	Concrete	-0.175	6.233	5.76E-10	2.68E-05	2.68E-05	0	-2.084	2.084
249	Concrete	-0.175	7.28	2.63E-08	3.46E-05	3.46E-05	-0.002	-2.42	2.42
250	Concrete	-0.01	0.545	3.45E-06	4.87E-06	5.97E-06	-0.009	-0.326	0.327
255	Interface bn Concrete n Rockfill	0	-1	3.83E-07	1.10E-06	1.17E-06	0	-0.004	0.004
256	Interface bn Concrete n Ground	0	0	5.27E-07	2.69E-06	2.74E-06	0	-0.128	0.128
257	Interface bn Concrete n Ground	0	8.38	6.21E-06	2.24E-05	2.32E-05	0	-0.576	0.576
258	Interface bn Concrete n Rockfill	0	9.38	8.42E-06	4.23E-05	4.31E-05	0	-0.146	0.146
261	Concrete	0.175	1	9.03E-07	1.35E-05	1.35E-05	-0.013	-0.889	0.889
262	Concrete	0.175	2.047	2.75E-08	1.52E-05	1.52E-05	0.008	-1.014	1.014

263	Concrete	0.175	3.093	6.66E-09	1.52E-05	1.52E-05	-0.002	-1.017	1.017
264	Concrete	0.175	4.14	1.54E-09	1.52E-05	1.52E-05	0	-1.016	1.016
265	Concrete	0.175	5.187	3.49E-10	1.52E-05	1.52E-05	0	-1.016	1.016
266	Concrete	0.175	6.233	5.76E-10	2.68E-05	2.68E-05	0	-2.084	2.084
267	Concrete	0.175	7.28	2.63E-08	3.48E-05	3.48E-05	-0.002	-2.429	2.429
268	Concrete	0.475	0.7	2.66E-06	2.62E-06	3.73E-06	0.16	-0.217	0.27
269	Concrete	0.475	7.58	8.11E-07	2.42E-05	2.42E-05	0.849	-1.678	1.881
270	Interface bn Concrete n Ground	0.928	0	5.85E-07	1.58E-06	1.69E-06	0.004	-0.07	0.07
271	Interface bn Concrete n Ground	0.928	8.38	1.02E-05	2.87E-05	3.05E-05	0.104	-0.582	0.591
272	Interface bn Concrete n Rockfill	0.949	-0.98	6.13E-07	7.50E-07	9.68E-07	0.002	-0.002	0.003
273	Interface bn Concrete n Rockfill	0.95	9.361	1.38E-05	5.33E-05	5.50E-05	0.05	-0.178	0.185
280	Concrete	1.443	0.7	5.74E-07	7.00E-08	5.78E-07	0.055	0.02	0.058
281	Concrete	1.443	7.58	3.52E-06	6.88E-05	6.89E-05	1.281	-4.548	4.725
282	Interface bn Concrete n Ground	1.856	0	4.93E-07	2.01E-07	5.32E-07	0.006	-0.005	0.008
283	Interface bn Concrete n Ground	1.856	8.38	1.27E-05	6.10E-05	6.24E-05	0.134	-2.079	2.083
284	Interface bn Concrete n Rockfill	1.877	9.363	2.90E-05	6.51E-05	7.13E-05	0.097	-0.217	0.238
285	Interface bn Concrete n Rockfill	1.883	-0.963	1.08E-06	9.59E-08	1.09E-06	0.004	0	0.004
292	Concrete	2.411	0.7	1.31E-07	2.73E-09	1.31E-07	0.009	0.002	0.009
293	Concrete	2.411	7.58	3.17E-07	5.59E-05	5.59E-05	-0.001	-3.723	3.723
294	Interface bn Concrete n Ground	2.783	0	3.71E-07	2.23E-08	3.72E-07	0.005	0	0.005
295	Interface bn Concrete n Ground	2.783	8.38	1.28E-05	6.18E-05	6.31E-05	0.171	-2.013	2.02
296	Interface bn Concrete n Rockfill	2.79	-0.935	1.35E-06	2.22E-07	1.37E-06	0.004	0.001	0.005
297	Interface bn Concrete n Rockfill	2.838	9.358	4.53E-05	7.60E-05	8.85E-05	0.153	-0.255	0.298
304	Concrete	3.379	0.7	1.04E-07	1.46E-08	1.05E-07	0.007	0.001	0.007
305	Concrete	3.379	7.58	4.86E-07	5.24E-05	5.24E-05	-0.002	-3.488	3.488

Table 26 Condition-3 Nodal Report on X and Y Velocity, X and Y Gradient -Part-III

Node	Material	X (m)	Y (m)	X-Velocity Magnitude (m/sec)	Y-Velocity Magnitude (m/sec)	XY-Velocity Magnitude (m/sec)	X-Gradient	Y-Gradient	XY-Gradient
306	Interface bn Concrete n Ground	3.711	0	4.66E-07	7.75E-08	4.72E-07	0.007	0.001	0.007
307	Interface bn Concrete n Ground	3.711	8.38	1.96E-05	6.29E-05	6.58E-05	0.266	-1.921	1.94
308	Interface bn Concrete n Rockfill	3.745	-0.953	1.83E-06	6.63E-07	1.95E-06	0.006	0.002	0.007
309	Interface bn Concrete n Rockfill	3.794	9.363	7.33E-05	9.03E-05	0.000116341	0.25	-0.307	0.396
316	Concrete	4.346	0.7	1.50E-07	2.48E-08	1.52E-07	0.01	0.002	0.01
317	Concrete	4.346	7.58	7.79E-07	4.67E-05	4.67E-05	-0.003	-3.104	3.104
318	Interface bn Concrete n Ground	4.639	0	7.03E-07	1.45E-07	7.18E-07	0.011	0.002	0.011
319	Interface bn Concrete n Ground	4.639	8.38	3.15E-05	6.37E-05	7.10E-05	0.424	-1.768	1.818
320	Interface bn Concrete n Rockfill	4.671	-0.936	2.73E-06	1.23E-06	3.00E-06	0.009	0.005	0.01
321	Interface bn Concrete n Rockfill	4.729	9.358	0.000123105	0.000113785	0.000167636	0.423	-0.397	0.581
328	Concrete	5.314	0.7	2.57E-07	5.48E-08	2.63E-07	0.018	0.004	0.018
329	Concrete	5.314	7.58	1.33E-06	3.80E-05	3.81E-05	-0.005	-2.499	2.499
330	Interface bn Concrete n Ground	5.567	0	1.19E-06	2.87E-07	1.23E-06	0.019	0.004	0.019
331	Interface bn Concrete n Ground	5.567	8.38	5.38E-05	5.77E-05	7.89E-05	0.739	-1.499	1.672
332	Interface bn Concrete n Rockfill	5.573	-0.891	4.47E-06	2.17E-06	4.97E-06	0.015	0.008	0.017
334	Interface bn Concrete n Rockfill	5.633	9.232	0.000193079	0.000130072	0.000232805	0.655	-0.486	0.815
340	Concrete	6.282	0.7	3.84E-07	2.50E-08	3.85E-07	0.025	0.006	0.026
341	Concrete	6.282	7.58	7.57E-06	2.52E-05	2.63E-05	1.056	-1.668	1.975
342	Interface bn Concrete n Rockfill	6.347	9.252	0.000306731	0.000167877	0.000349667	1.035	-0.551	1.173
344	Interface bn Concrete n Rockfill	6.467	-0.924	8.03E-06	4.49E-06	9.20E-06	0.026	0.015	0.031
345	Interface bn Concrete n Ground	6.494	0	2.29E-06	5.21E-07	2.35E-06	0.036	0.009	0.037
346	Interface bn Concrete n Ground	6.494	8.38	9.28E-05	5.57E-05	0.000108239	1.353	-1.061	1.72
352	Concrete	7.25	0.7	2.70E-07	4.51E-07	5.26E-07	0.019	-0.023	0.03
353	Concrete	7.25	7.58	4.39E-05	3.87E-05	5.86E-05	3.079	-2.587	4.021
354	Interface bn Concrete n Rockfill	7.258	9.352	0.000423253	0.000376916	0.000566753	1.292	-1.166	1.74
356	Interface bn Concrete n Rockfill	7.374	-0.955	1.79E-05	1.08E-05	2.09E-05	0.044	0.034	0.056
357	Interface bn Rockfill n Backfill	7.422	0	2.72E-06	1.15E-06	2.96E-06	0.074	-0.008	0.074
358	Interface bn Rockfill n Backfill	7.422	8.38	0.000163619	8.01E-05	0.000182193	3.592	-1.745	3.994
359	Concrete	7.55	1	7.16E-07	8.84E-07	1.14E-06	0.064	-0.095	0.114
360	Concrete	7.55	2.047	1.16E-07	3.67E-06	3.68E-06	0.001	-0.245	0.245
361	Concrete	7.55	3.093	2.58E-08	3.92E-06	3.92E-06	-0.002	-0.261	0.261
362	Concrete	7.55	4.14	3.79E-08	3.80E-06	3.80E-06	-0.003	-0.254	0.254
363	Concrete	7.55	5.187	2.60E-07	4.09E-06	4.10E-06	0.017	-0.273	0.273
364	Concrete	7.55	6.233	4.14E-06	1.10E-05	1.17E-05	0.328	-0.936	0.992
365	Concrete	7.55	7.28	4.36E-05	3.95E-05	5.88E-05	2.881	-2.476	3.799
372	Interface bn Concrete n Rockfill	8.241	9.369	0.000318466	0.001007551	0.001056683	0.967	-3.444	3.578
373	Interface bn Concrete n Rockfill	8.321	-0.973	1.45E-05	3.59E-05	3.87E-05	-0.001	0.107	0.107
374	Interface bn Rockfill n Backfill	8.35	0	0.000107872	3.99E-05	0.000115031	0.245	0.011	0.246
375	Interface bn Rockfill n Backfill	8.35	0.931	3.04E-05	8.35E-05	8.89E-05	0.026	-0.179	0.181
376	Interface bn Rockfill n Backfill	8.35	1.862	1.62E-06	0.000144393	0.000144402	-0.004	-0.278	0.278

377	Interface bn Rockfill n Backfill	8.35	2.793	1.69E-06	0.000136675	0.000136685	-0.003	-0.263	0.263
378	Interface bn Rockfill n Backfill	8.35	3.724	2.12E-06	0.000133309	0.000133326	-0.004	-0.257	0.257
379	Interface bn Rockfill n Backfill	8.35	4.656	3.07E-06	0.000128821	0.000128858	-0.005	-0.248	0.248
380	Interface bn Rockfill n Backfill	8.35	5.587	1.41E-06	0.000123458	0.000123466	-0.004	-0.237	0.237
381	Interface bn Rockfill n Backfill	8.35	6.518	2.01E-05	0.000132652	0.000134168	0.035	-0.228	0.231
382	Interface bn Rockfill n Backfill	8.35	7.449	0.000115008	0.000161364	0.000198155	0.934	-0.235	0.963
383	Interface bn Rockfill n Backfill	8.35	8.38	6.07E-05	0.000497194	0.000500881	2.614	-2.32	3.495
390	Interface bn Concrete n Rockfill	9.203	9.379	0.0001911	0.001010125	0.001028042	0.155	-3.391	3.395
391	Interface bn Concrete n Rockfill	9.288	-0.991	2.23E-05	8.21E-05	8.51E-05	-0.097	0.32	0.334
392	Interface bn Rockfill n Backfill	9.35	0	0.000541153	0.000491436	0.000730997	-0.182	0.019	0.183
393	Interface bn Rockfill n Backfill	9.35	0.931	0.000258519	0.000871206	0.000908753	-0.199	-0.372	0.422
394	Interface bn Rockfill n Backfill	9.35	1.862	6.79E-05	0.000609779	0.000613551	-0.191	-0.262	0.325
395	Interface bn Rockfill n Backfill	9.35	2.793	9.21E-05	0.000616021	0.000622861	-0.205	-0.265	0.335
396	Interface bn Rockfill n Backfill	9.35	3.724	0.000101051	0.000600271	0.000608717	-0.238	-0.257	0.351
397	Interface bn Rockfill n Backfill	9.35	4.656	0.000124996	0.000584718	0.000597929	-0.293	-0.249	0.385
398	Interface bn Rockfill n Backfill	9.35	5.587	0.000162479	0.000567137	0.000589952	-0.378	-0.239	0.447
399	Interface bn Rockfill n Backfill	9.35	6.518	0.000217031	0.000552121	0.000593246	-0.514	-0.226	0.561
400	Interface bn Rockfill n Backfill	9.35	7.449	0.000428258	0.000541767	0.000690591	-0.75	-0.197	0.775
401	Interface bn Rockfill n Backfill	9.35	8.38	9.28E-05	0.000835795	0.00084093	-1.355	-2.2	2.584
407	Interface bn Concrete n Rockfill	10.142	9.407	0.000198733	0.000685175	0.000713414	-0.577	-2.262	2.334
409	Interface bn Concrete n Rockfill	10.244	8.397	0.000543019	0.000548936	0.00077214	-1.913	-1.783	2.615
410	Interface bn Concrete n Rockfill	10.246	-1.008	6.21E-05	2.34E-05	6.63E-05	-0.196	0.036	0.199
411	Interface bn Concrete n Rockfill	10.277	-0.019	0.000150515	2.14E-05	0.000152024	-0.524	-0.064	0.528
412	Interface bn Concrete n Rockfill	10.281	1.862	0.000109229	8.51E-05	0.000138452	-0.364	-0.284	0.462
413	Interface bn Concrete n Rockfill	10.281	2.793	0.000117831	9.30E-05	0.000150127	-0.393	-0.31	0.5
414	Interface bn Concrete n Rockfill	10.281	3.724	0.000136772	0.000103645	0.000171607	-0.455	-0.344	0.571
415	Interface bn Concrete n Rockfill	10.281	4.656	0.000167626	0.000117405	0.000204652	-0.557	-0.388	0.679
416	Interface bn Concrete n Rockfill	10.281	5.587	0.000214787	0.000139311	0.000256009	-0.713	-0.458	0.847
417	Interface bn Concrete n Rockfill	10.281	6.518	0.000286255	0.000182161	0.0003393	-0.949	-0.595	1.12
418	Interface bn Concrete n Rockfill	10.282	0.927	0.000111064	5.89E-05	0.000125699	-0.366	-0.2	0.416
419	Interface bn Concrete n Rockfill	10.283	7.449	0.000397312	0.000309212	0.000503456	-1.317	-1.033	1.674

Appendix C: Visual Report

Condition-1 Tunnel Lining Without Waterproofing-Nodes and Gauss Region

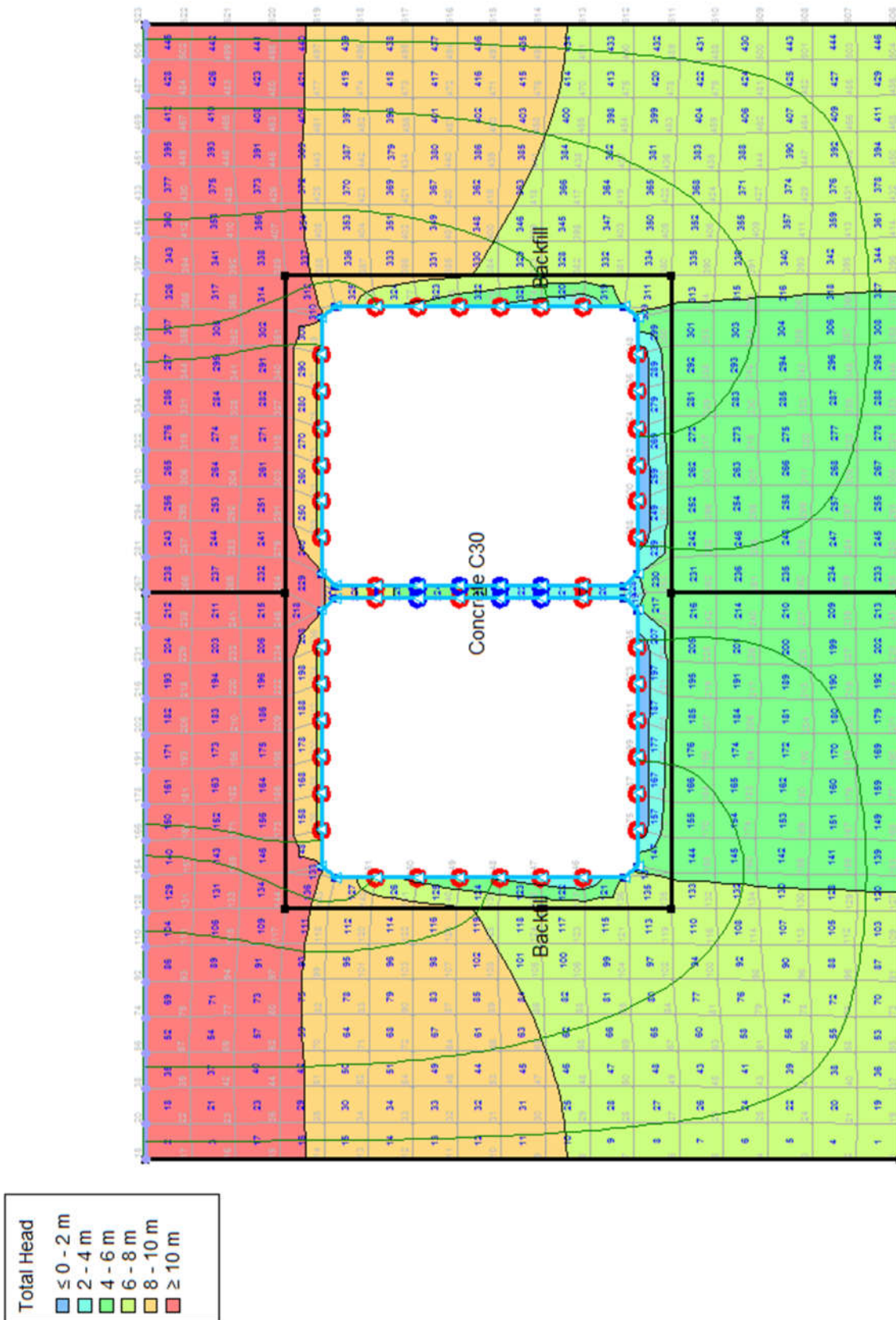


Figure 26 Condition-1 Nodal and gauss region

Condition-2 Tunnel Lining With Waterproofing-Nodes and Gauss Region

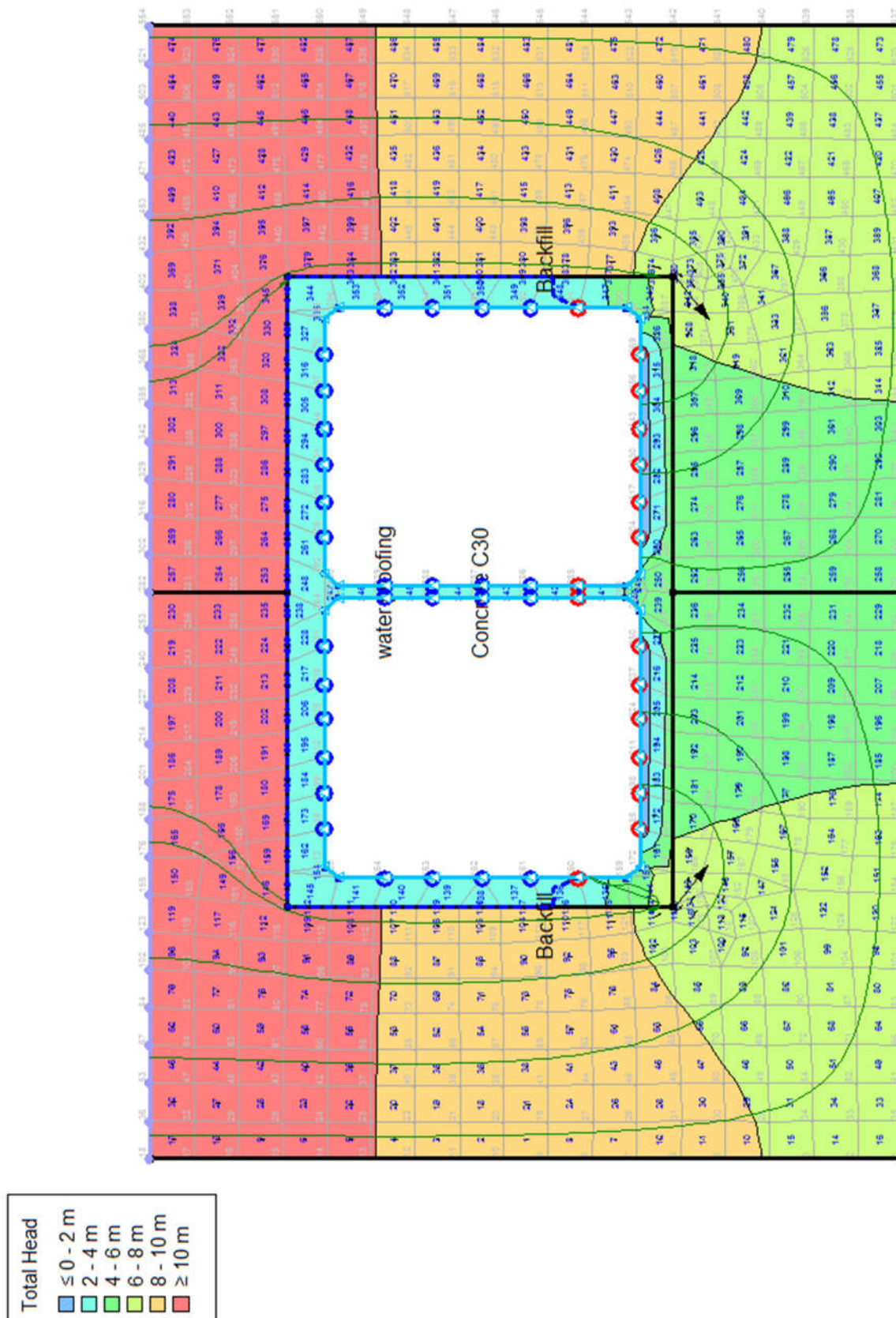


Figure 27 Condition-2 Nodal and gauss region

Condition-3 Tunnel Lining with Rock fill-Nodes and Gauss Region

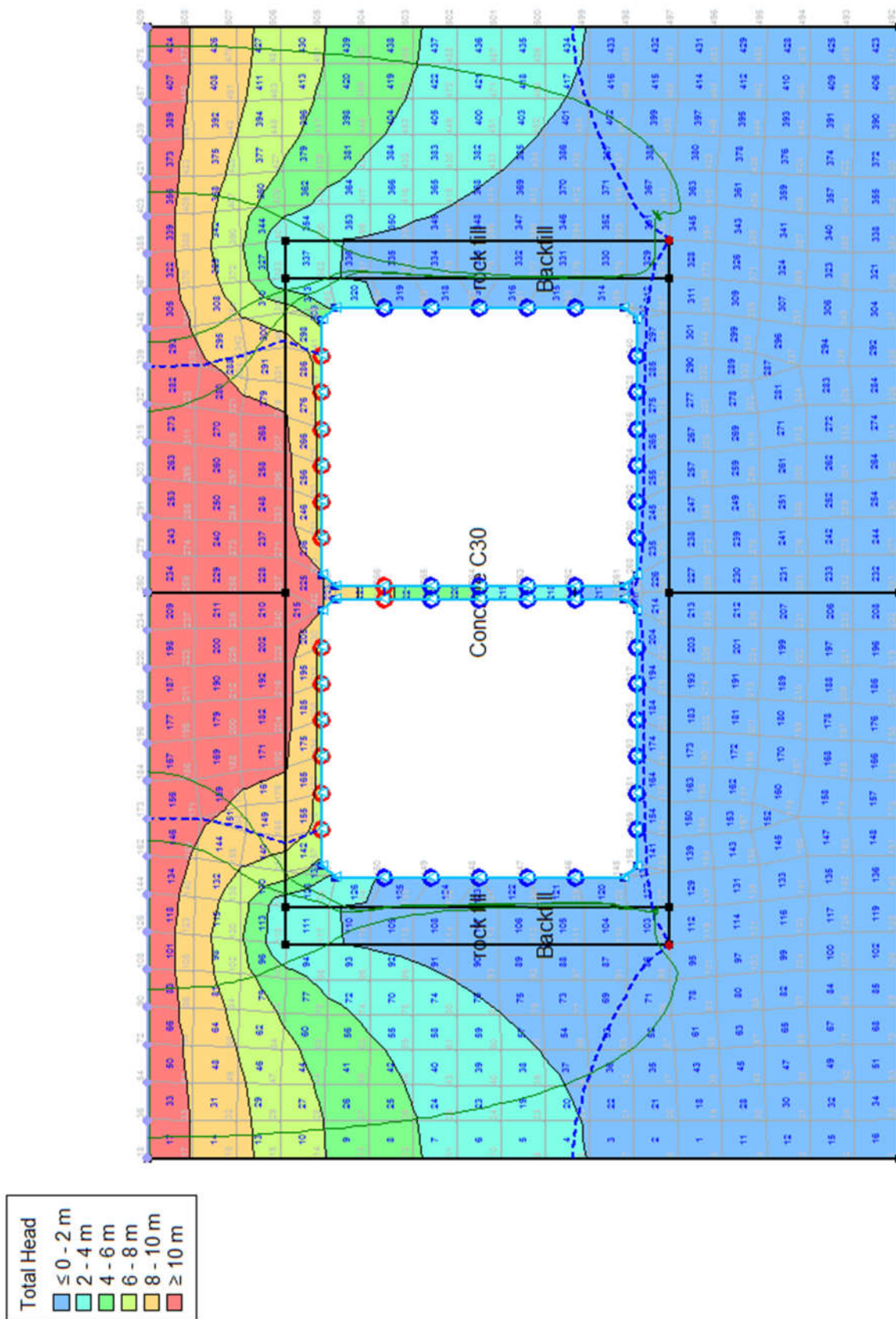


Figure 28 Condition-3 Nodal and gauss region