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Construction of Sahar Crossover Cavern using Steel Fiber Reinforced Sprayed Concrete (SFRSC) lining at Mumbai Metro Line 3

by

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MUMBAI METRO RAIL CORPORATION

MMRC is the nodal agency responsible for the implementation of Mumbai Metro Line–3 project. It has been constituted as a JV of the Govt. of India(GOI) and the Government of Maharashtra(GOM) on 50:50 sharing basis.

MML-3 is fully underground line of 33.5 km having 26 UG stations and 1 at grade station at Aarey depot.

MUMBAI METRO LINE 3 PROJECT

METRO PHASE- 03

PACKAGE -06

SAHAR CROSSOVER

Sahar Crossover is part of Metro Line 3 project at Package 6. It is provided at North end of Sahar station.

Sahar Crossover is provided for the movement of metro train to switch between Upline and Downline and considering various operational requirements during operation.

This crossover is being constructed using combination of TBM tunnel and NATM philosophy for section enlargement to suit SOD requirements.

SALIENT FEATURES

- Length of Crossover- 227m (Approx.)
- Type of crossover- Scissor type
- Cavern Type- Stepped Profile Cavern
- NATM section largest depth and width- 10.39m and 16.20m
- Primary lining type- Shotcrete with SN/GFRP Rock bolts and mesh
- Permanent lining type- Fibre Reinforced Sprayed Concrete in Crown/side walls and RCC in Invert.
- Waterproofing- Sprayed Waterproofing in Overt and PVC Membrane in Invert section

PLANNING FOR CROSSOVER

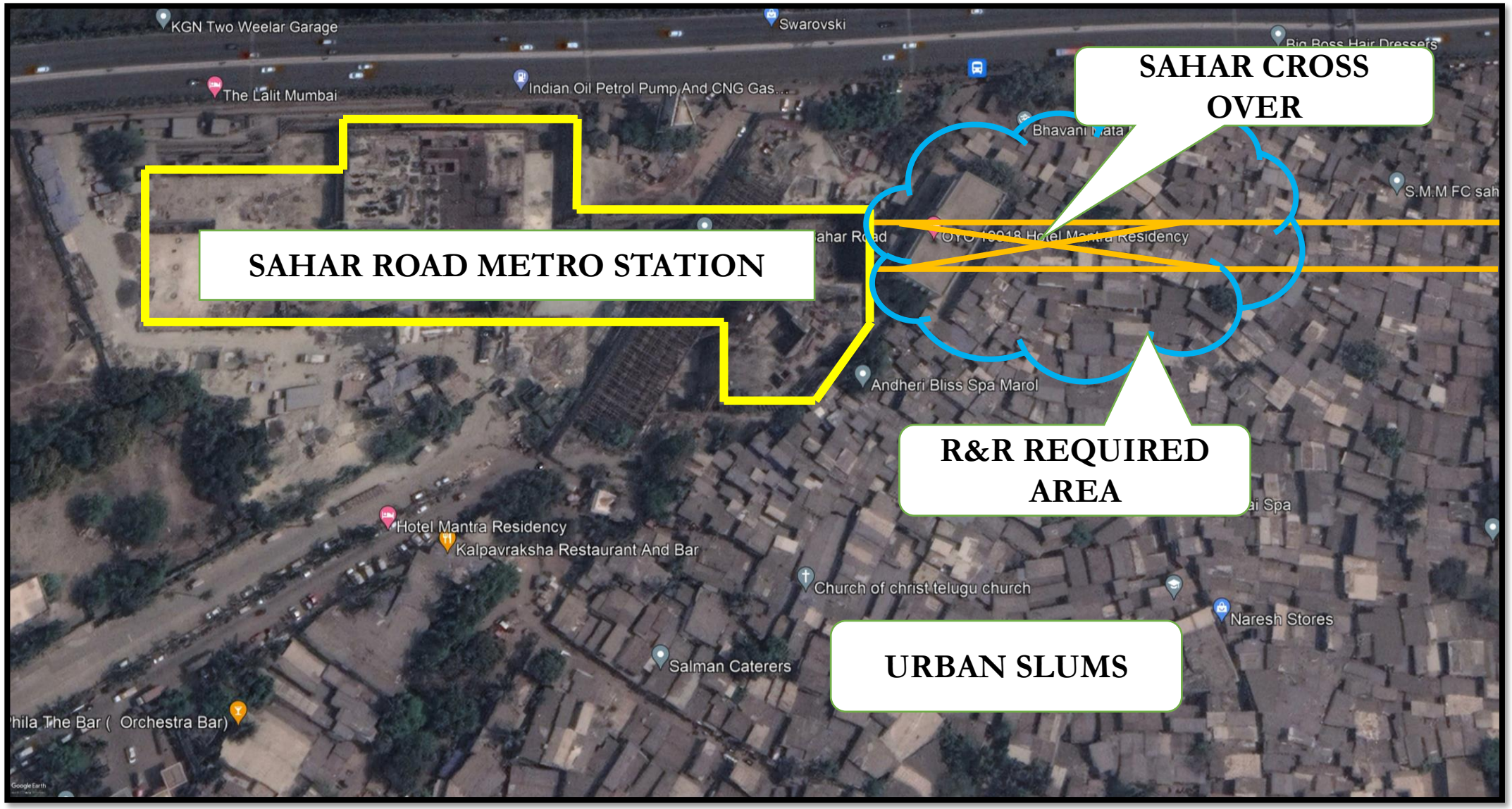
Crossover was contemplated after award of the contract for operational efficiency.

Option of Cut and Cover was dropped to avoid extensive R&R and land acquisition issues.

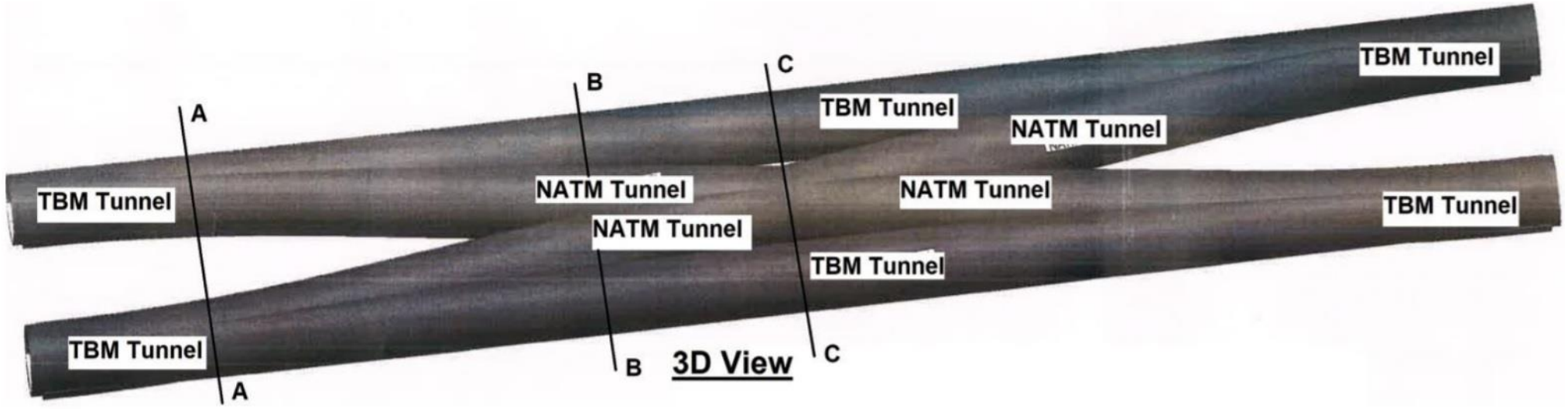
Crossover kept at North end of Sahar station to avoid construction beneath MIAL's land.

Crossover planned to be constructed by NATM through enlarging TBM tunnels.

PLANNING FOR CROSSOVER



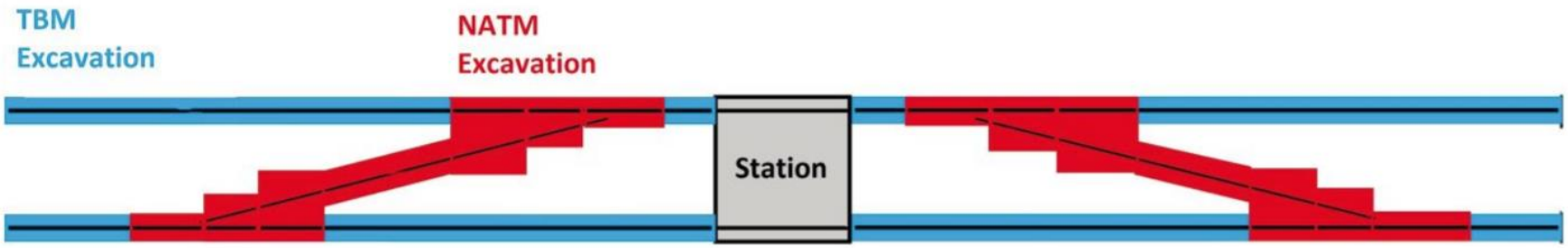
CONCEPT PROPOSAL



Alternative Proposals

- Concept plan was difficult to construct with such wide sections and little overburden which could have jeopardise safety of the residents above.

- 1st Alternative (At both end of station)

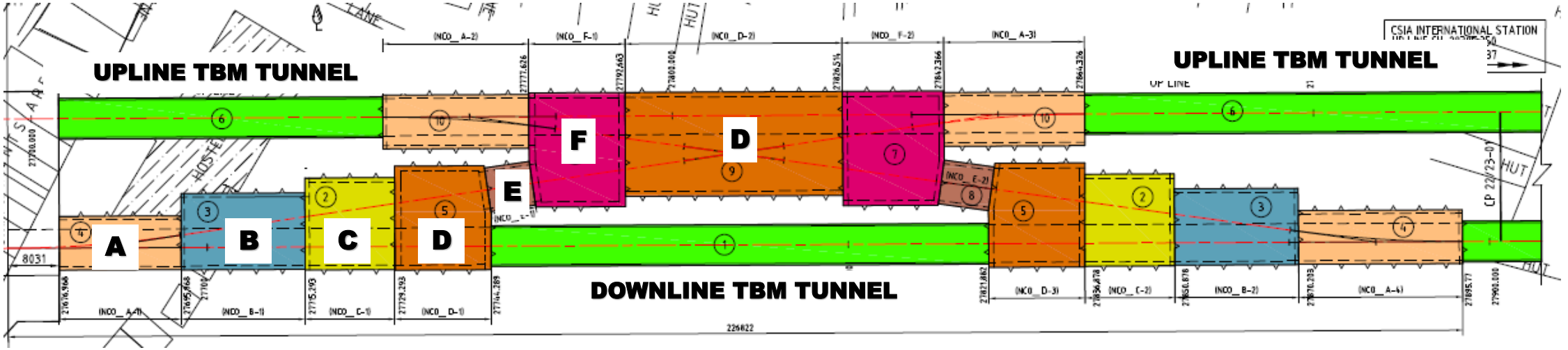


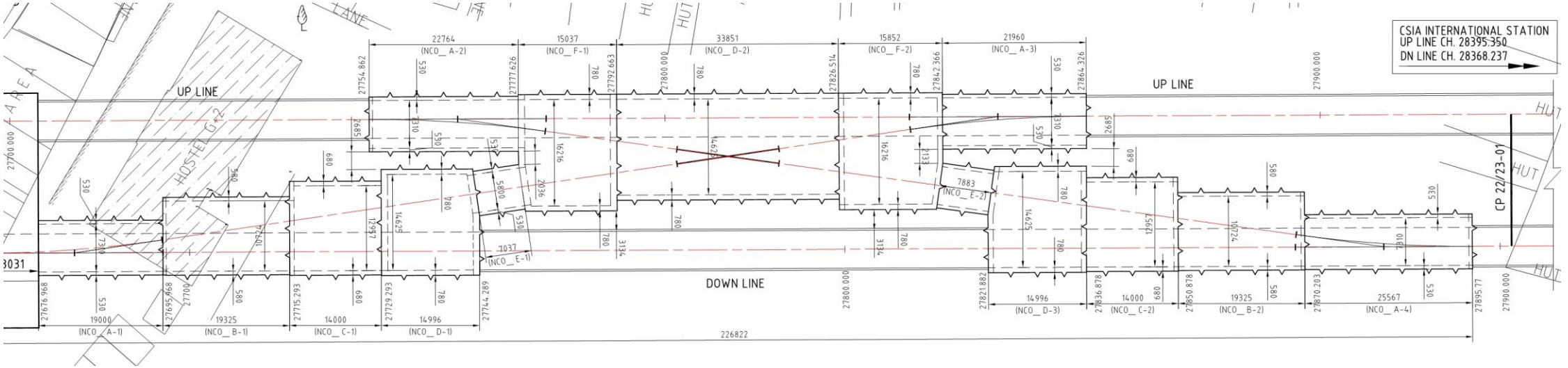
Alternative Proposals

- 2nd Alternative (Symmetric Profile, Uniform width)

- 3rd Alternative (Asymmetric Stepped Cavern Profile)

FINAL PROPOSAL

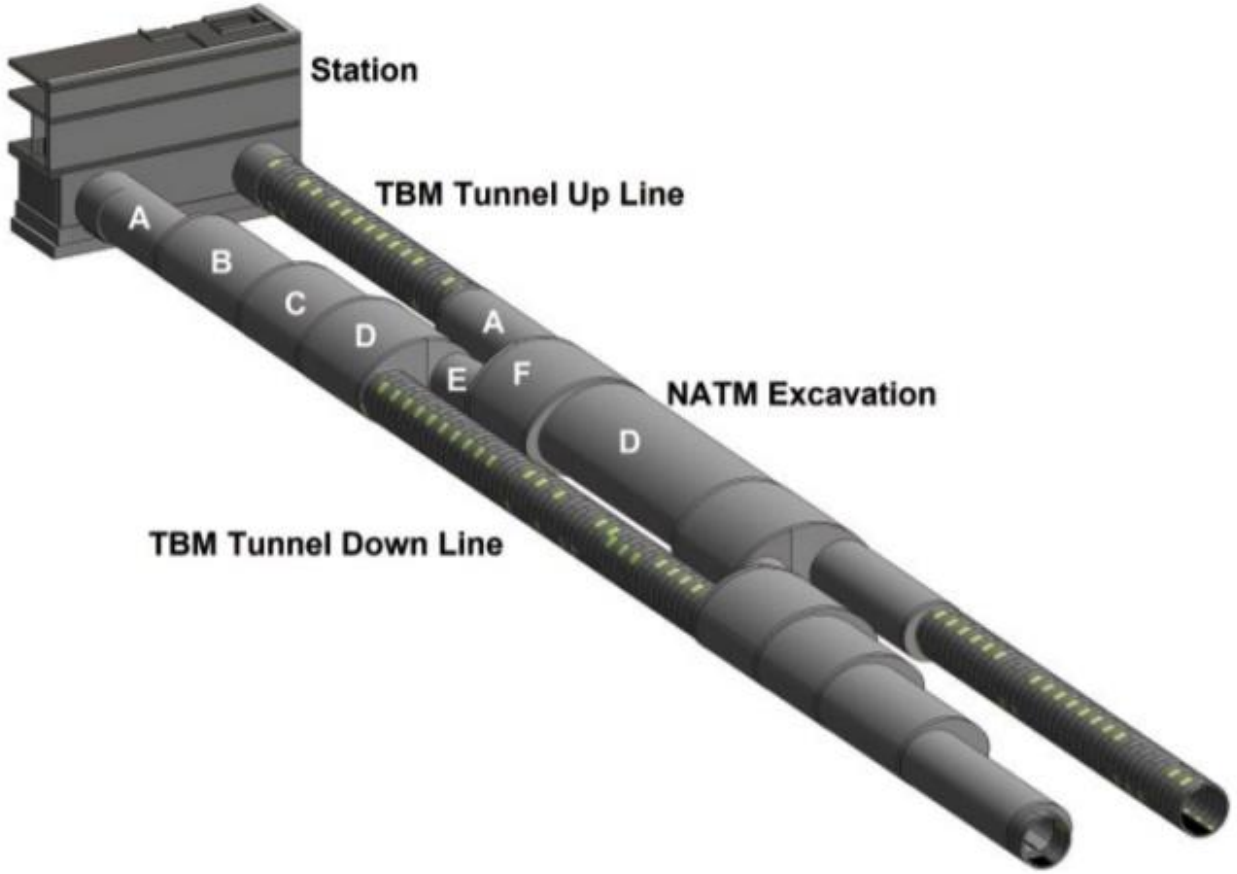




FINAL PROPOSAL

Proposal was finalised by keeping six standard sections to optimize the requirements of the shutters.

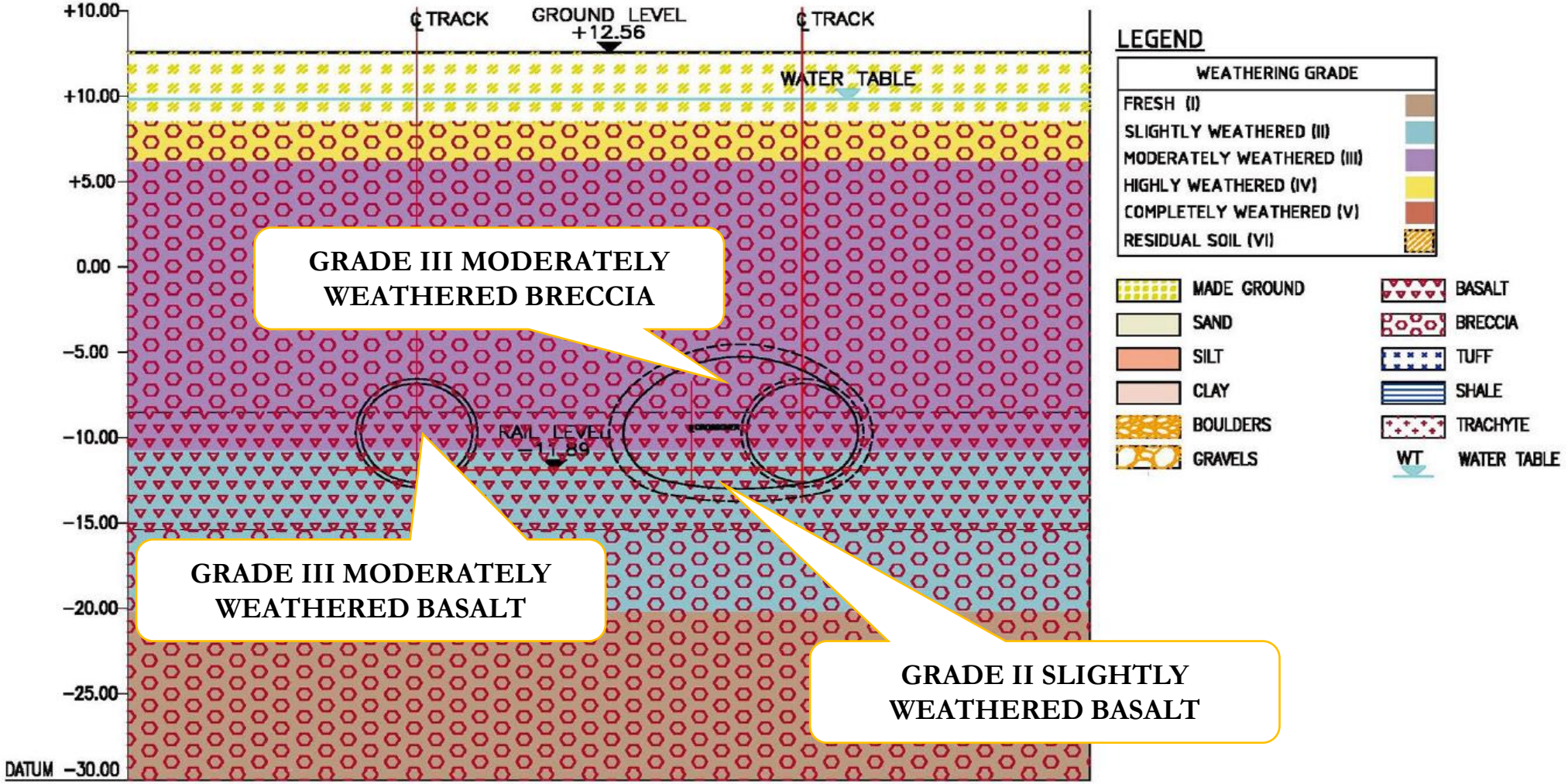
This proposal allows to open up multiple excavation faces to minimize construction time..



Final Proposal - Sectional details

SECTIONAL DETAILS					
SR. No.	SECTION NAME	HEIGHT (m)	WIDTH (m)	PRIMARY SPRAYED CONCRETE THICKNESS (mm)	SECONDARY PERMANENT LINING THICKNESS (mm)
1	NCO A1 TO A4	6.167	7.31	200	300
2	NCO B1 TO B2	7.374	10.724	200	350
3	NCO C1 TO C2	8.276	12.957	250	400
4	NCO D1 TO D3	9.334	14.625	300	450
5	NCO E1 TO E2	5.372	5.80	200	300
6	NCO F1 TO F2	10.389	16.216	300	450

GEOLOGY


+10.00
+10.00
+5.00
0.00
−5.00
−10.00
−15.00
−20.00
−25.00
DATUM −30.00
℄ TRACK
GROUND LEVEL
+12.56
℄ TRACK
WATER TABLE
RAIL LEVEL
−11.89
GRADE III MODERATELY WEATHERED BRECCIA
GRADE III MODERATELY WEATHERED BASALT
GRADE II SLIGHTLY WEATHERED BASALT
LEGEND
WEATHERING GRADE
FRESH (I)
SLIGHTLY WEATHERED (II)
MODERATELY WEATHERED (III)
HIGHLY WEATHERED (IV)
COMPLETELY WEATHERED (V)
RESIDUAL SOIL (VI)
MADE GROUND
SAND
SILT
CLAY
BOULDERS
GRAVELS
BASALT
BRECCIA
TUFF
SHALE
TRACHYTE
WT
WATER TABLE

GEOLOGY

The strata comprised moderately weathered (Grade-III) Breccia with slightly weathered (Grade-II) Basalt in the invert.

Fractured Rock mass with high permeability and high water table were potential threat for significant water inflow.

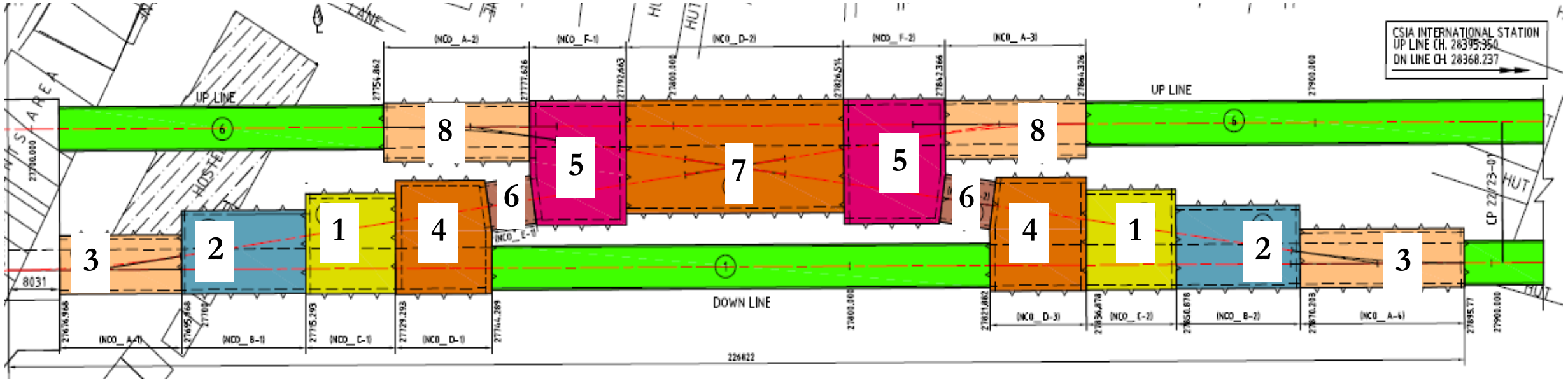
PRIMARY SUPPORT ELEMENTS USED

Sr. No	Section Name	Height (m)	Width (m)	Sprayed Concrete Thickness (mm)	Permanent Lining Thickness (mm)	Support Class	Wire mesh	SN Bolts	Pre-Support (Forepoling)	Round Length
1	NCO_A1 to A4	6.167	7.31	200	300	I	1 Layer, 150x150x6mm	4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						II	2 Layer, 150x150x6mm	6m/4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						III	2 Layer, 150x150x6mm	6m/4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
2	NCO_B1 to B2	7.374	10.724	200	350	I	1 Layer, 150x150x6mm	4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						II	2 Layer, 150x150x6mm	6m/4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						III	2 Layer, 150x150x6mm	6m/4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
3	NCO_C1 to C2	8.276	12.957	250	400	I	1 Layer, 150x150x6mm	4m Long	-	1.4m
						II	2 Layer, 150x150x6mm	6m/4m Long	-	1.4m
						III	2 Layer, 150x150x6mm	6m/4m Long	-	1.4m
4	NCO_D1 to D3	8.276	14.625	300	450	I	1 Layer, 150x150x6mm	4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						II	2 Layer, 150x150x6mm	6m/4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						III	2 Layer, 150x150x6mm	6m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
5	NCO_E1 to E2	5.372	5.8	200	300	I	1 Layer, 150x150x6mm	4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						II	2 Layer, 150x150x6mm	6m/4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						III	2 Layer, 150x150x6mm	6m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
6	NCO_F1 to F2	10.389	16.216	300	450	I	1 Layer, 150x150x6mm	4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m
						II	2 Layer, 150x150x6mm	6m/4m Long	SN Bolts Dia 32mm, 4m & 400mm c/c	1.4m

CONSTRUCTION METHODLOGY PRIMARY SUPPORT SYSTEM

CONSTRUCTION METHODLOGY

EXCAVATION SEQUENCE



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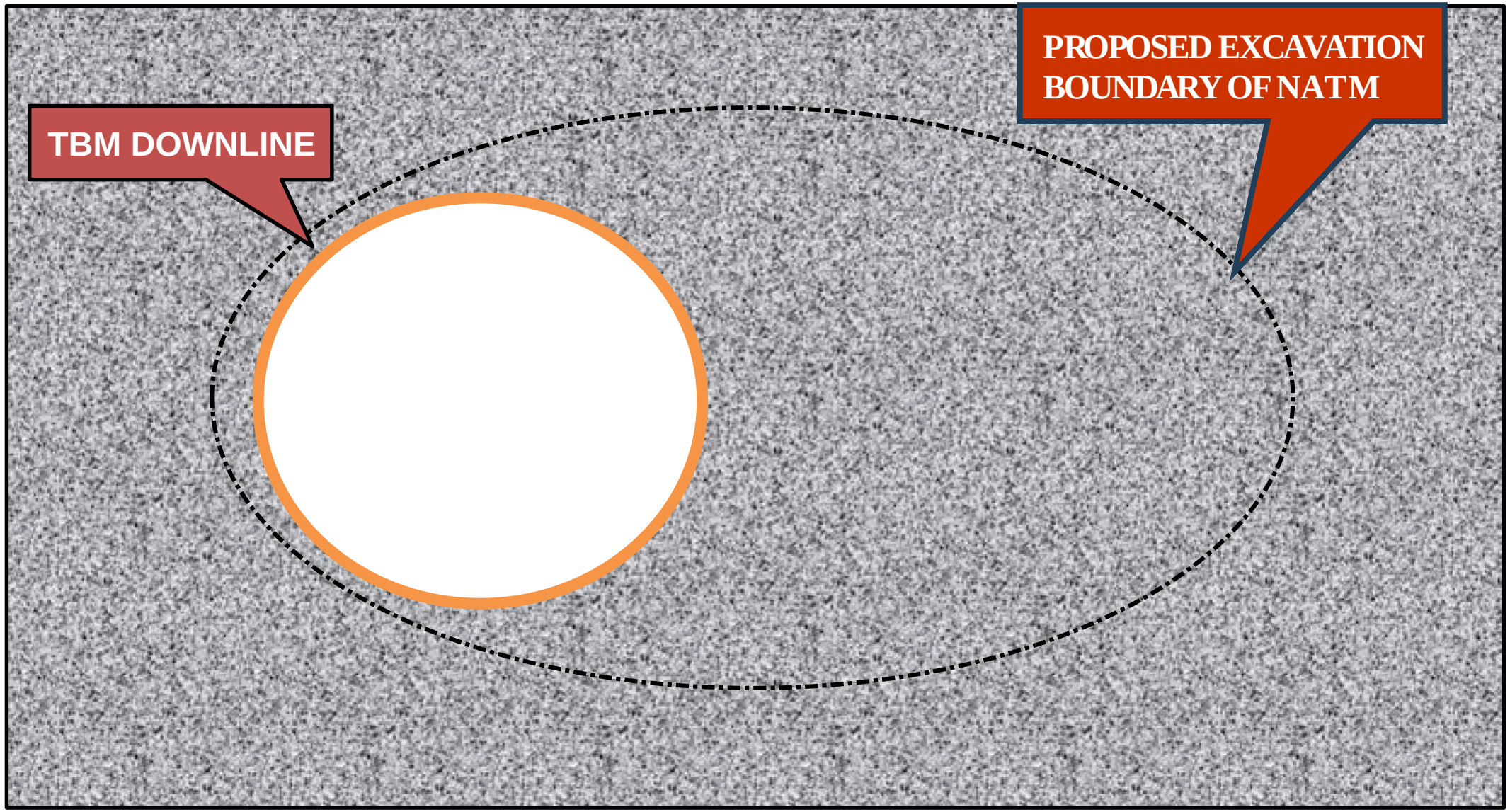

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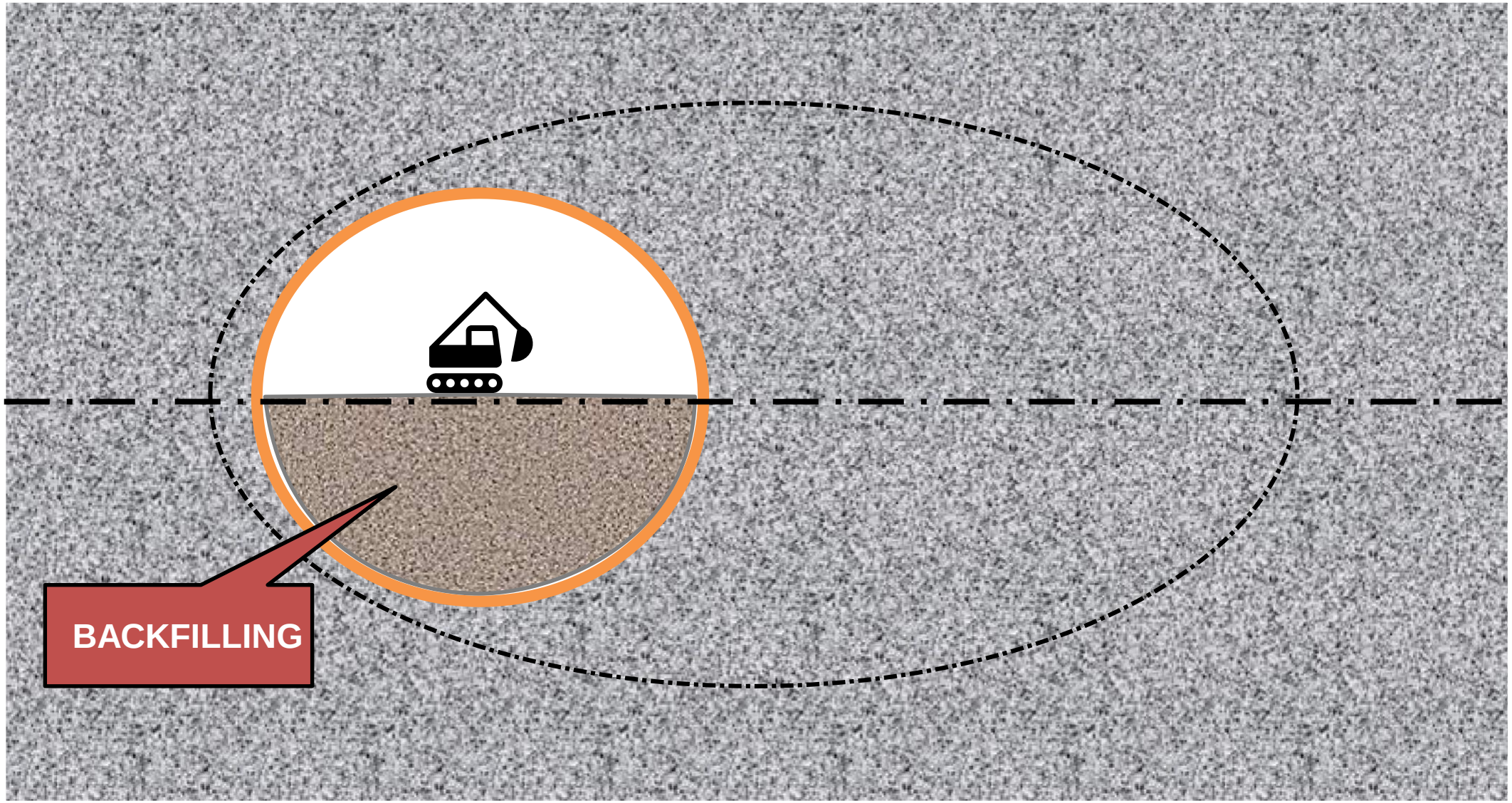

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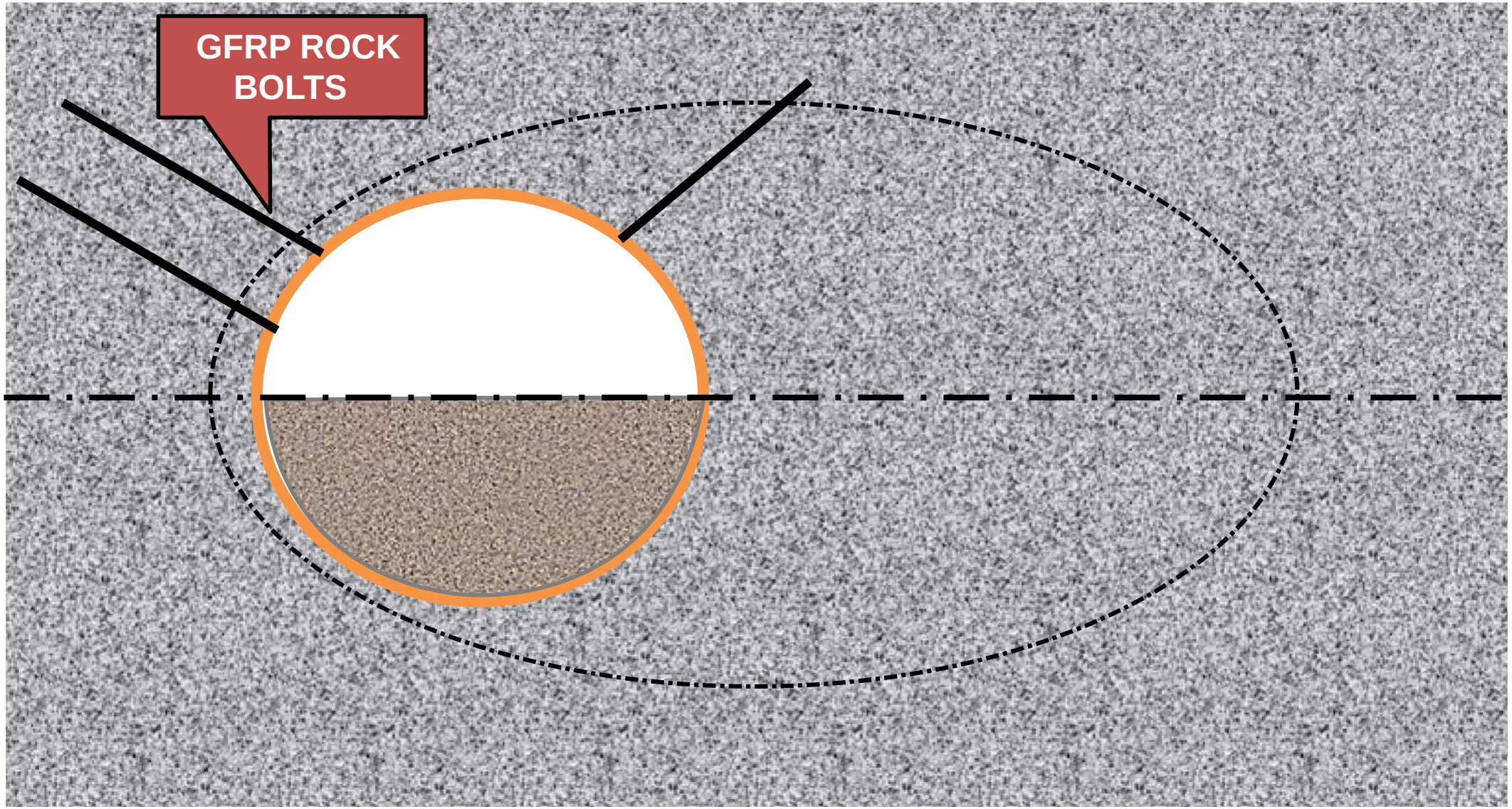

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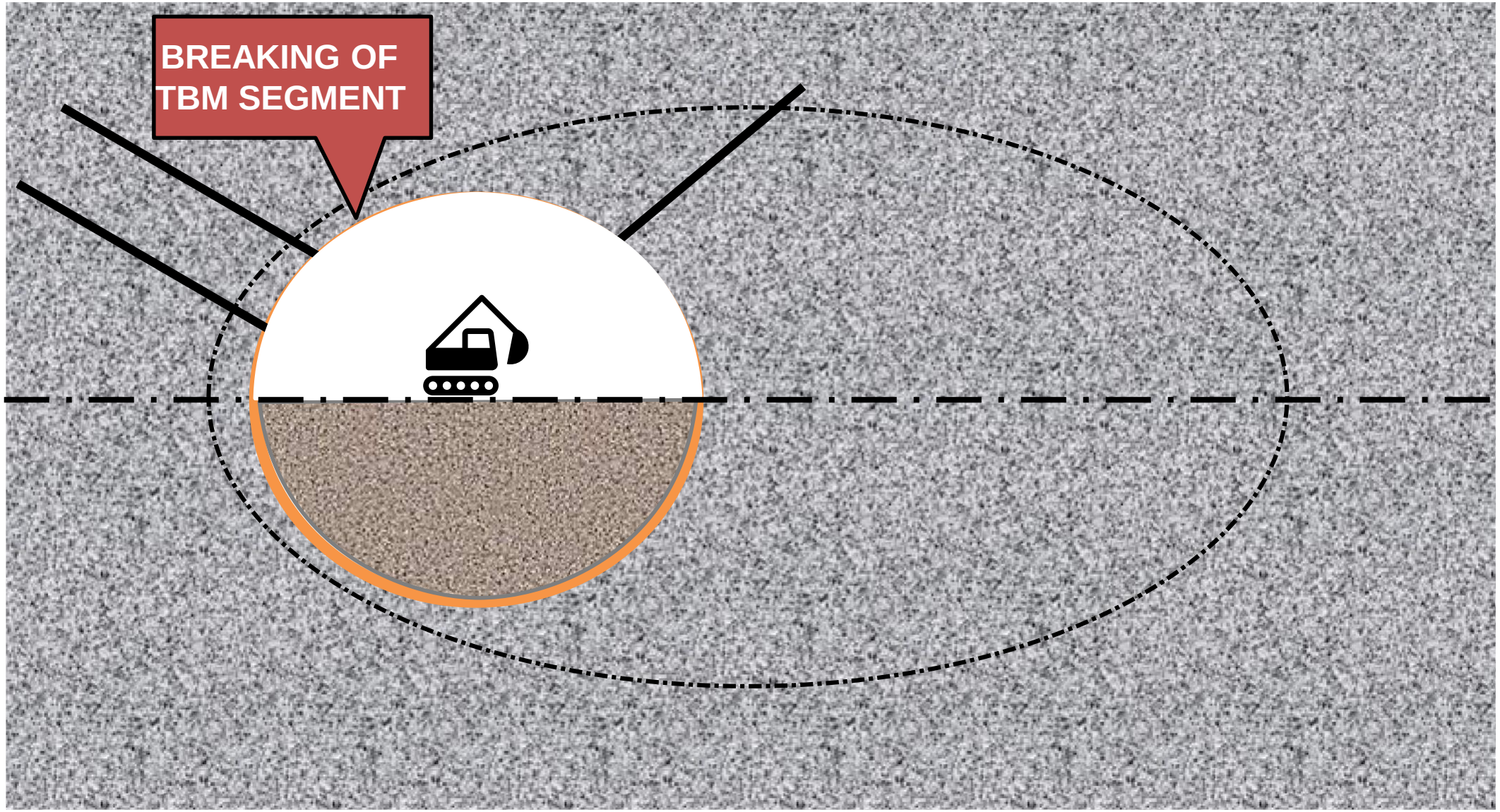

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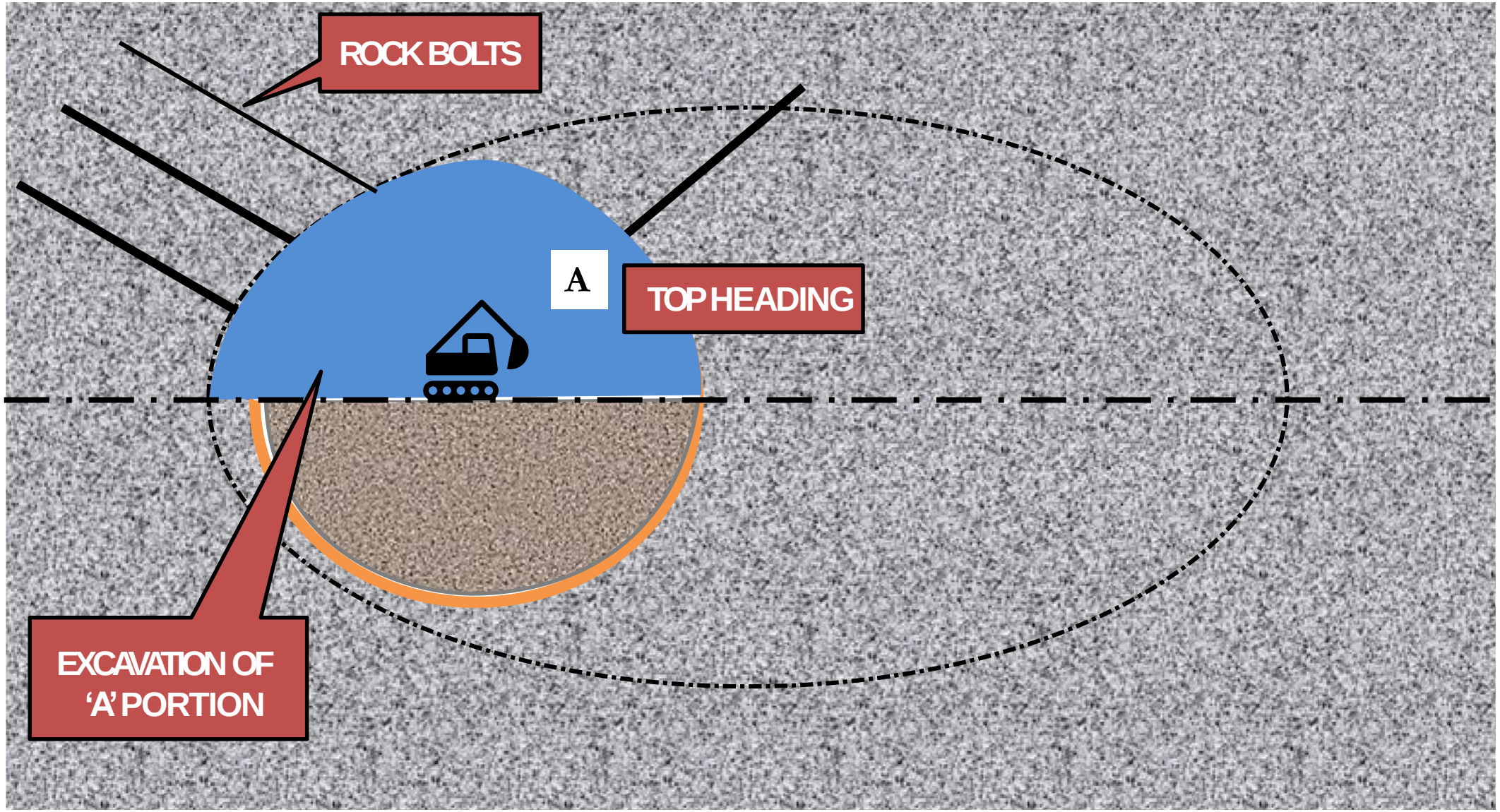

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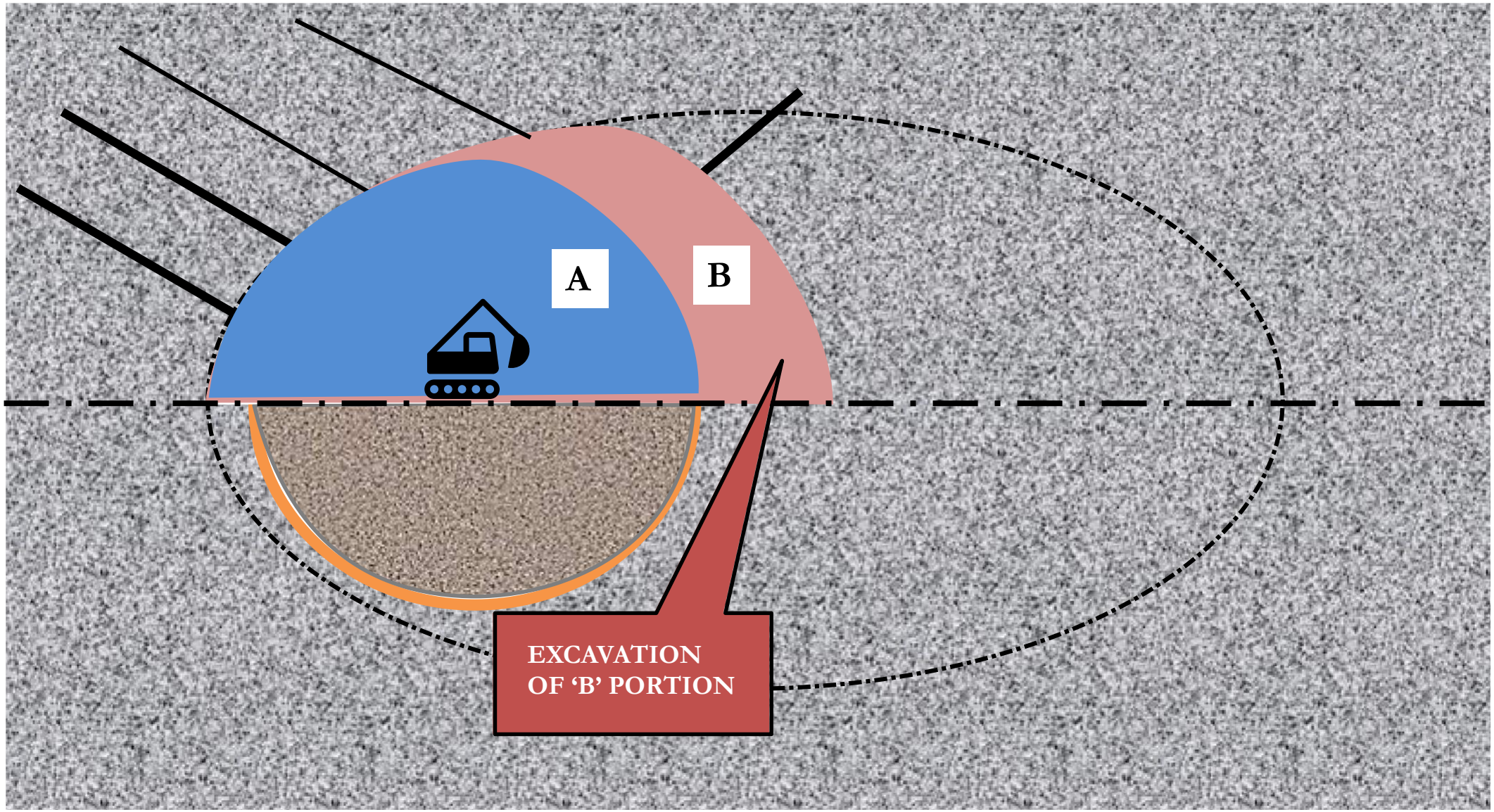

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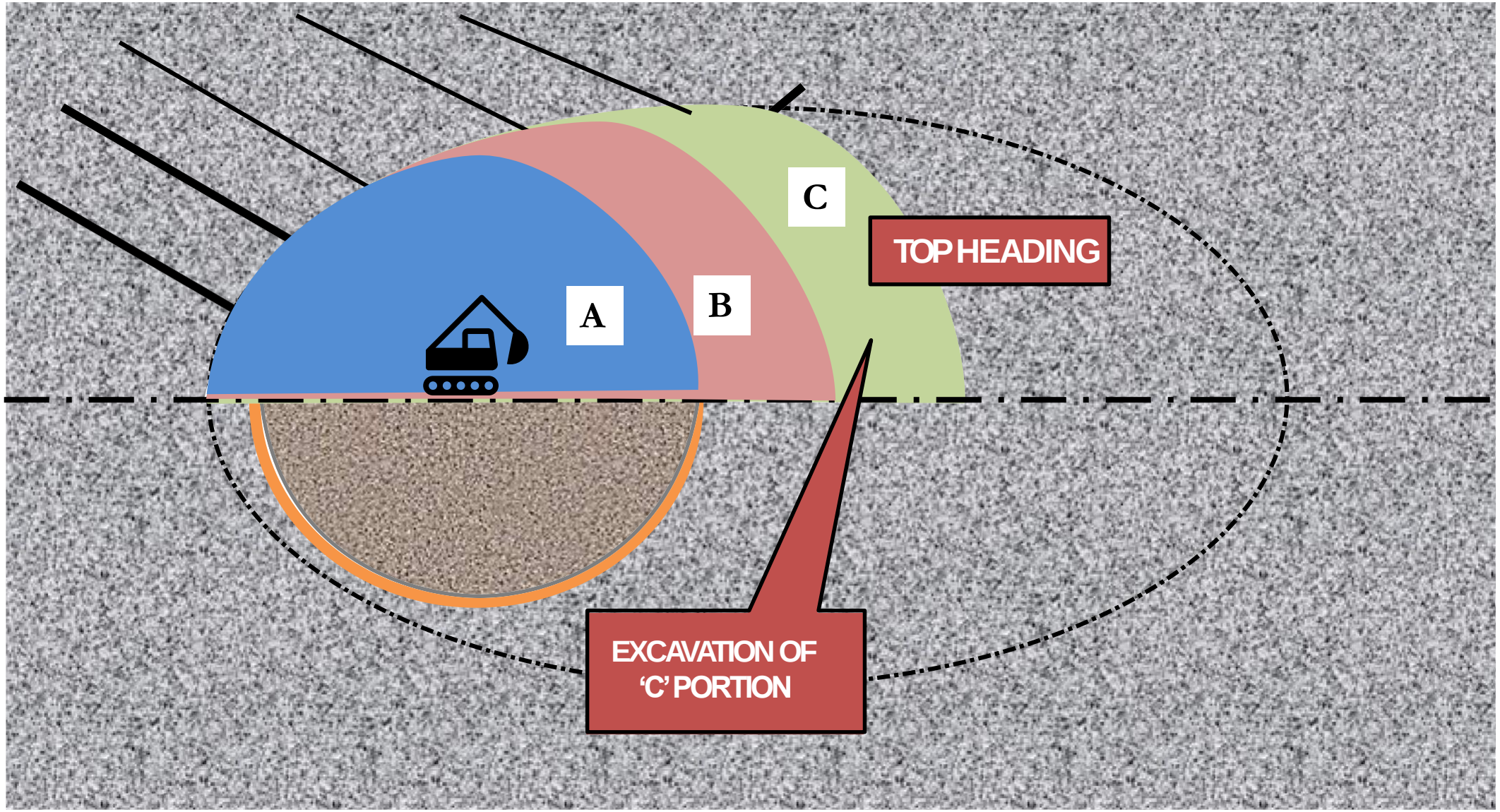

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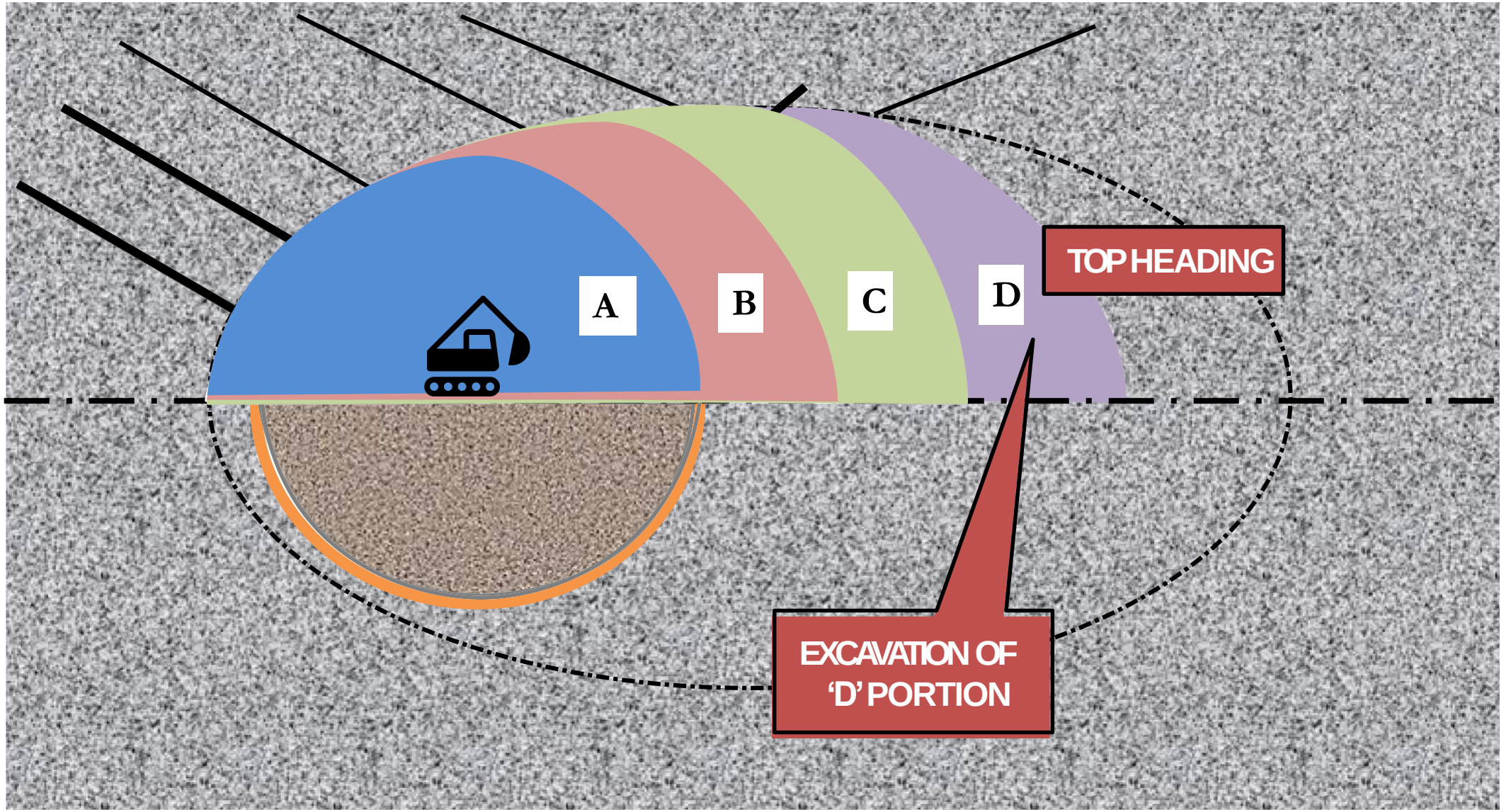

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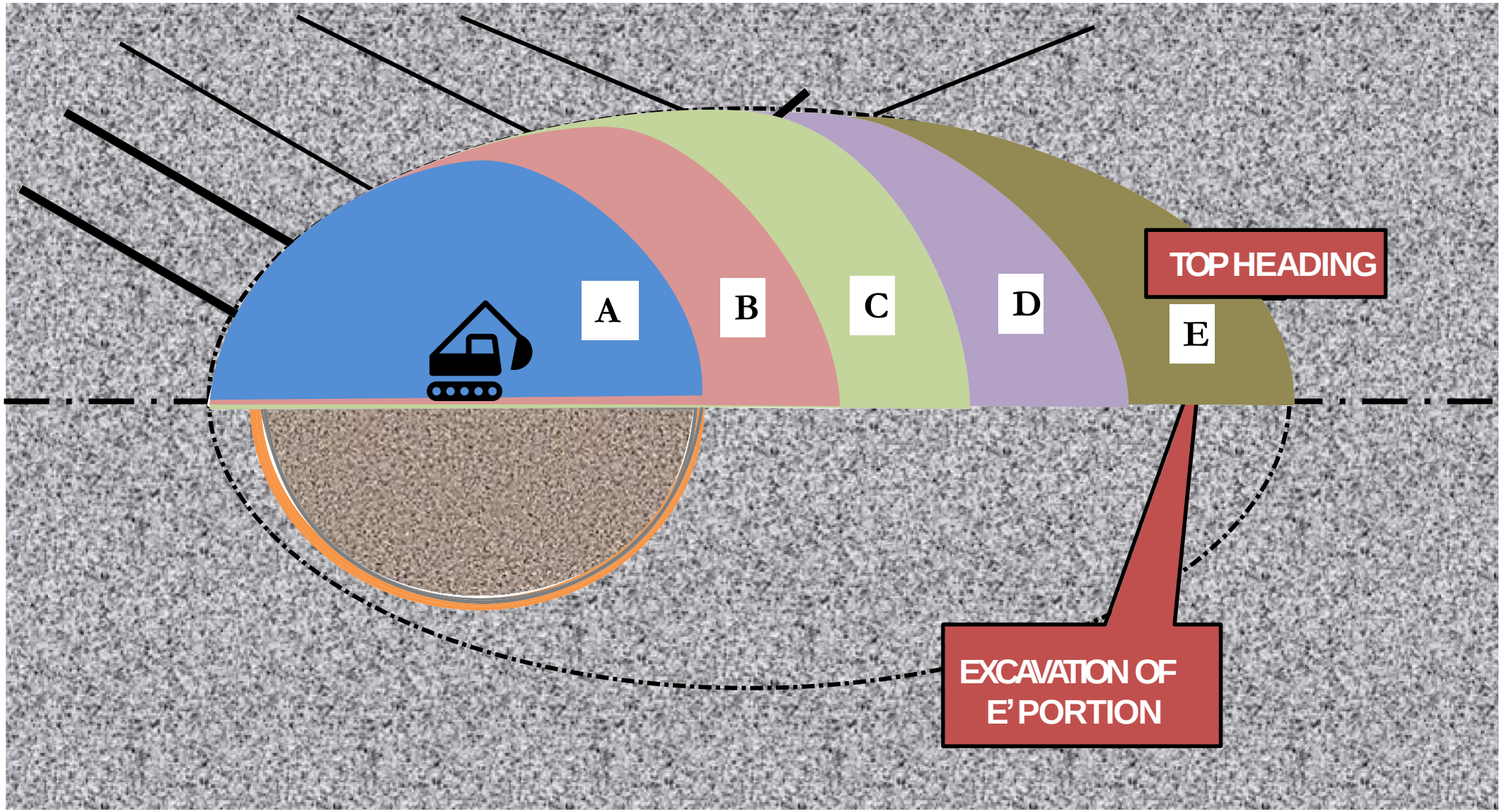

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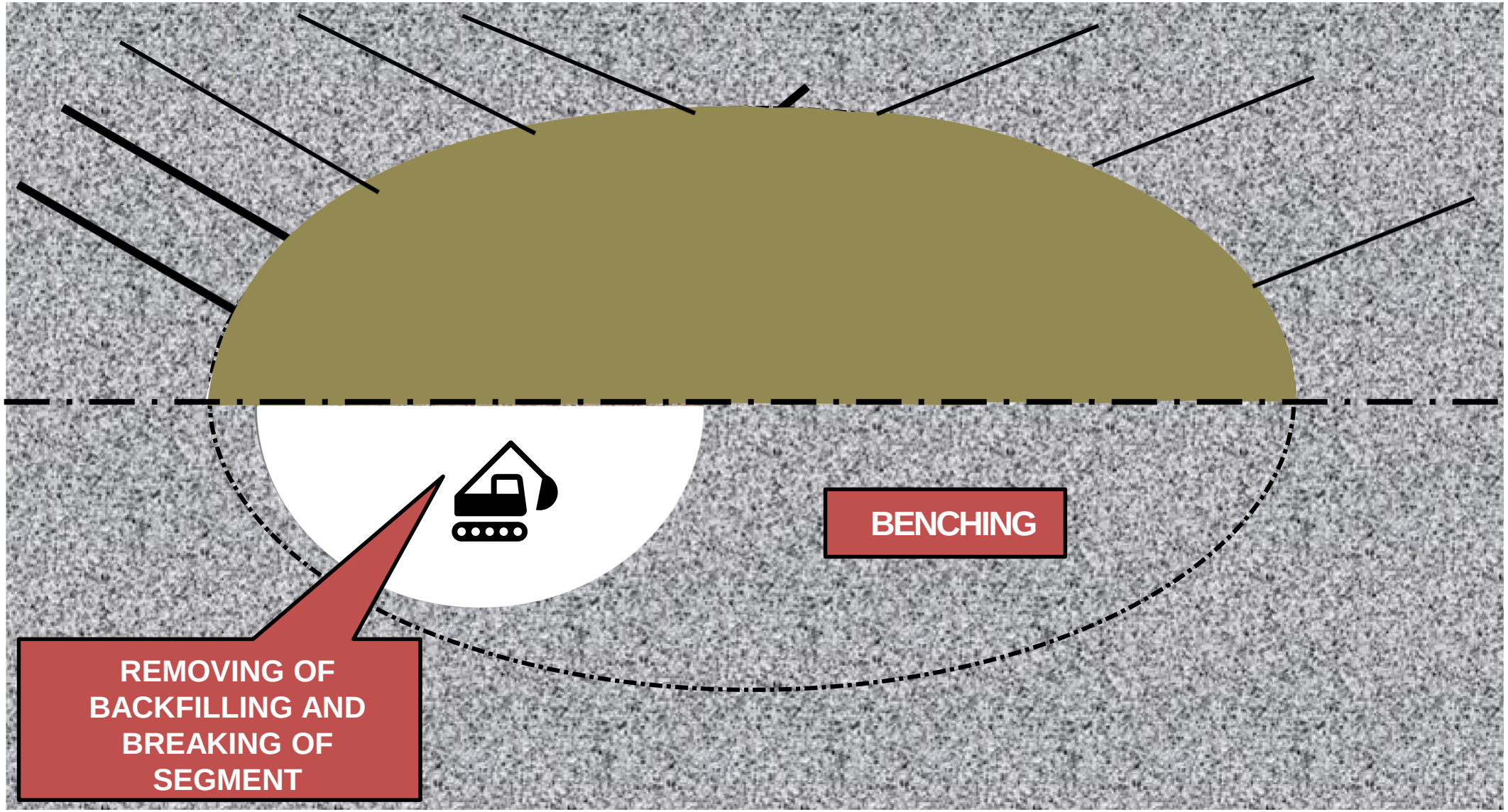

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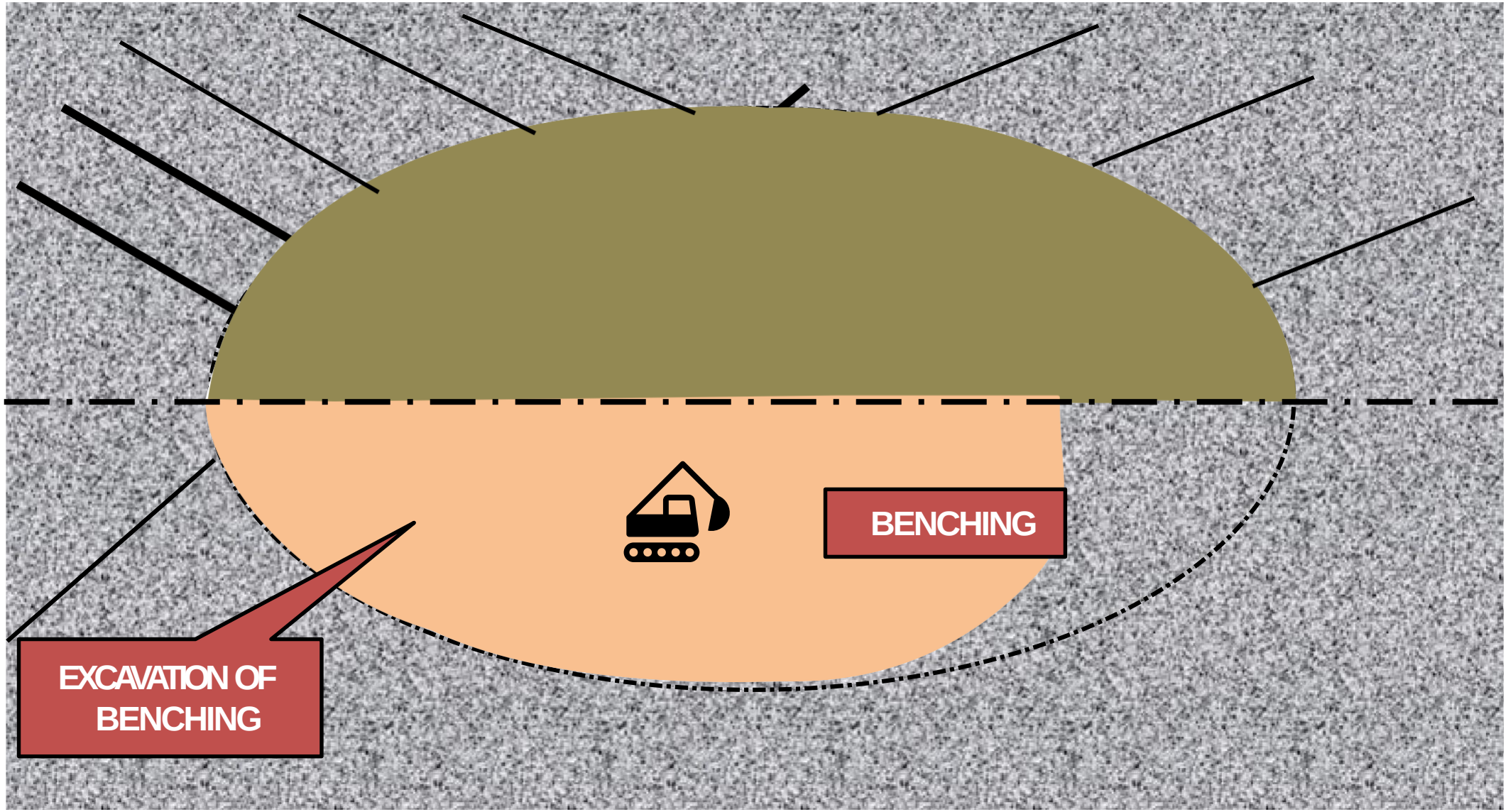

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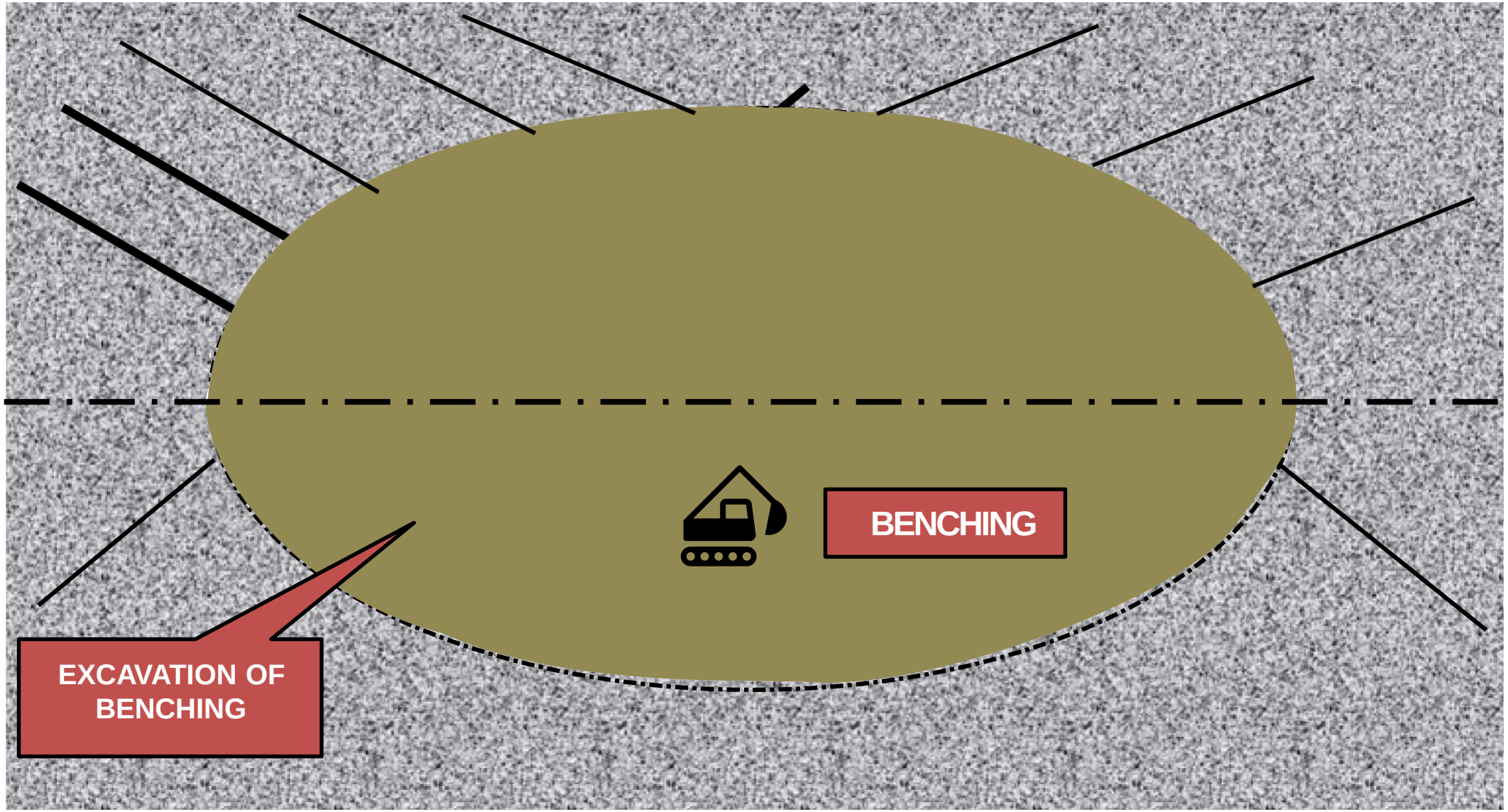
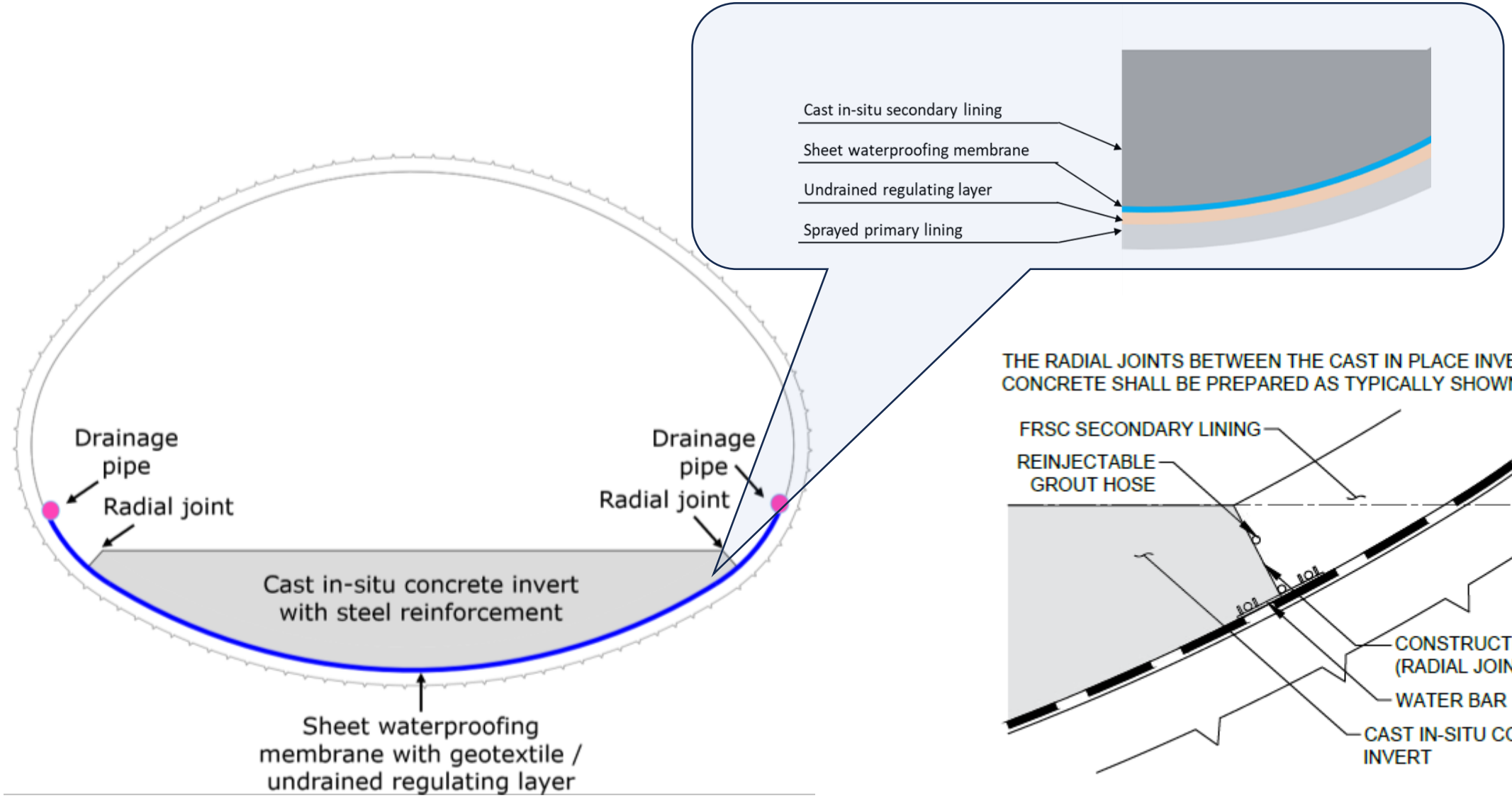


CONSTRUCTION METHODLOGY FOR SECONDARY LINING

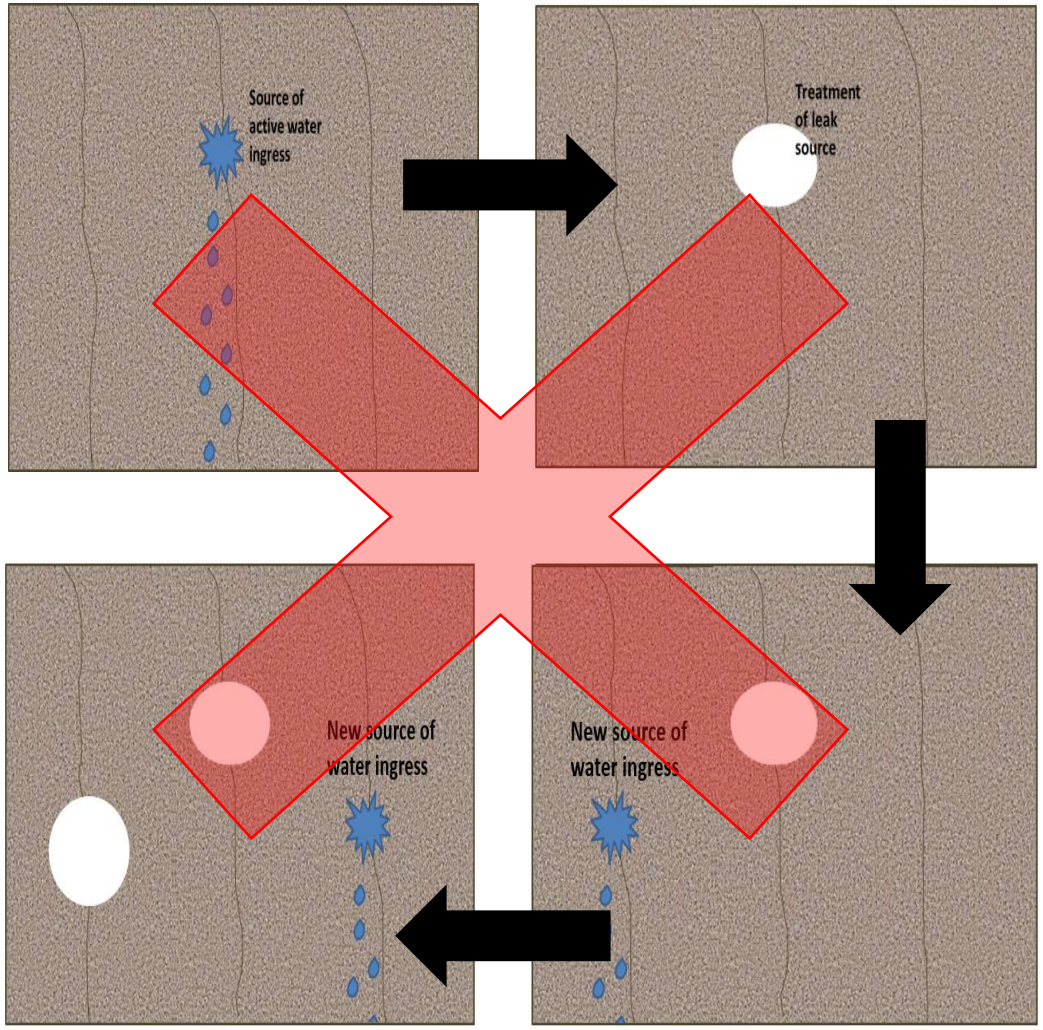
CONSTRUCTION METHODLOGY

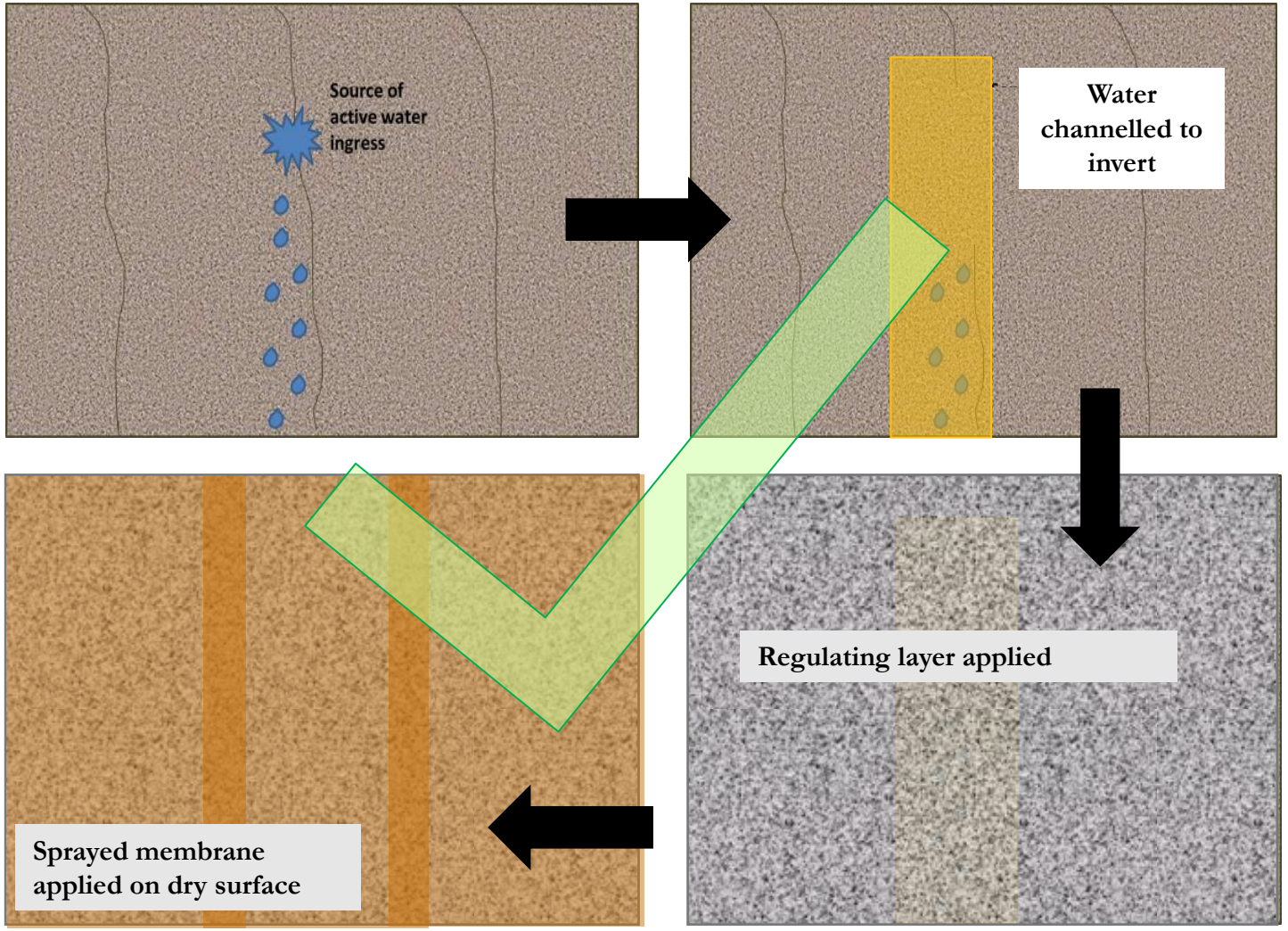
- Invert Construction
  - Drained tunnel, no water pressures acting on tunnel lining
  - PVC sheet membrane installed with drainage below to allow seepage to be channelled to temporary sumps.
  - CIP concrete invert placed and allowed to gain full design strength.

CONSTRUCTION METHODLOGY



SEEPAGE MANGEMENT CONCEPT





WATER PROOFING CONCEPT

- Sprayed membrane allows direct application of SCL (EVA polymer based membrane TAMSEAL 800)
- Sprayed waterproofing cannot be applied on active water ingress as it will not cure properly

Design solution - Engineered "Drained regulating layer"

Purpose – To channelise water ingress in to the invert sump temporarily

How? – PVC waterproofing at invert and sprayed waterproofing in arch

Why? – 1. Prevents building up of water pressure on the sprayed water proofing membrane and the secondary lining

2. Allows easy application of good quality sprayed membrane

3. Provide smoother surface for waterproofing application

CONSTRUCTION METHODLOGY

- Seepage Water Management (Drained System)

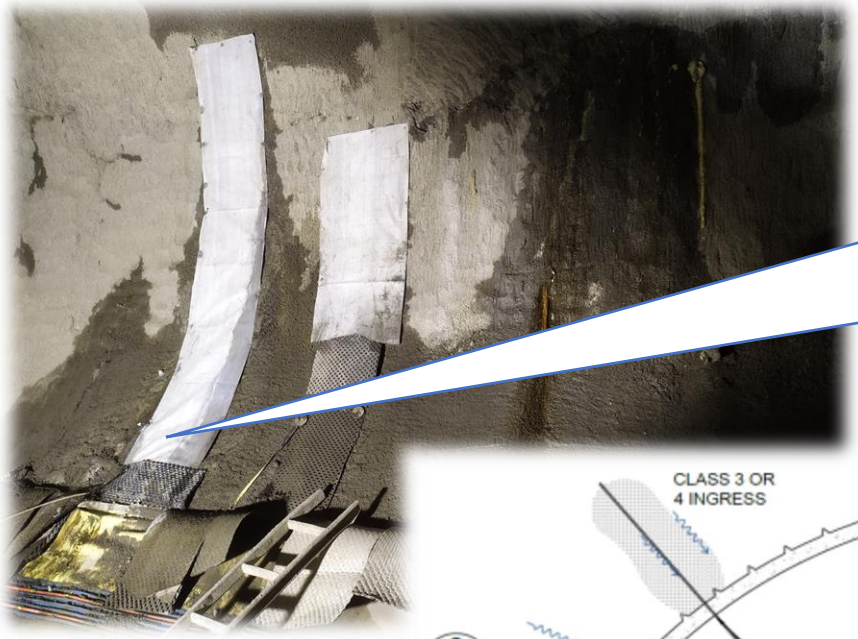
- To systematically manage groundwater ingress four no. water ingress classes were defined with a water management strategy to achieve a suitable substrate for application of the sprayed waterproofing membrane.

Water ingress class	Water Ingress Observed	Management Solution	Products to be used
Class 1	Damp patches (no running water observed)	No action required	None
Class 2	Trickling or seeping water through undefined localized imperfection of lining	Targeted chemical grout injection via systematic or local packer installation in sprayed concrete lining	Low viscosity (<20mPa.s) acrylic injection gel
Class 3	Steady stream of water ingress through visible cracks or construction joints	Systematic chemical injection through staggered injection packers into sprayed concrete lining	Flexible polyurethane grouts with reaction times to allow penetration into cracks and joints
Class 4	Localized significant water ingress through lining imperfections	Target deep drilled injection holes through lining into groundmass with chemical injection, or the use of water bleed pipes fed into back of invert PVC sheet membrane	Plastic bleeder pipes drilled and grouted into center of water ingress areas. Max dia. 20mm. Fixed to lining at 0.5m max centers Drainage mat/strips

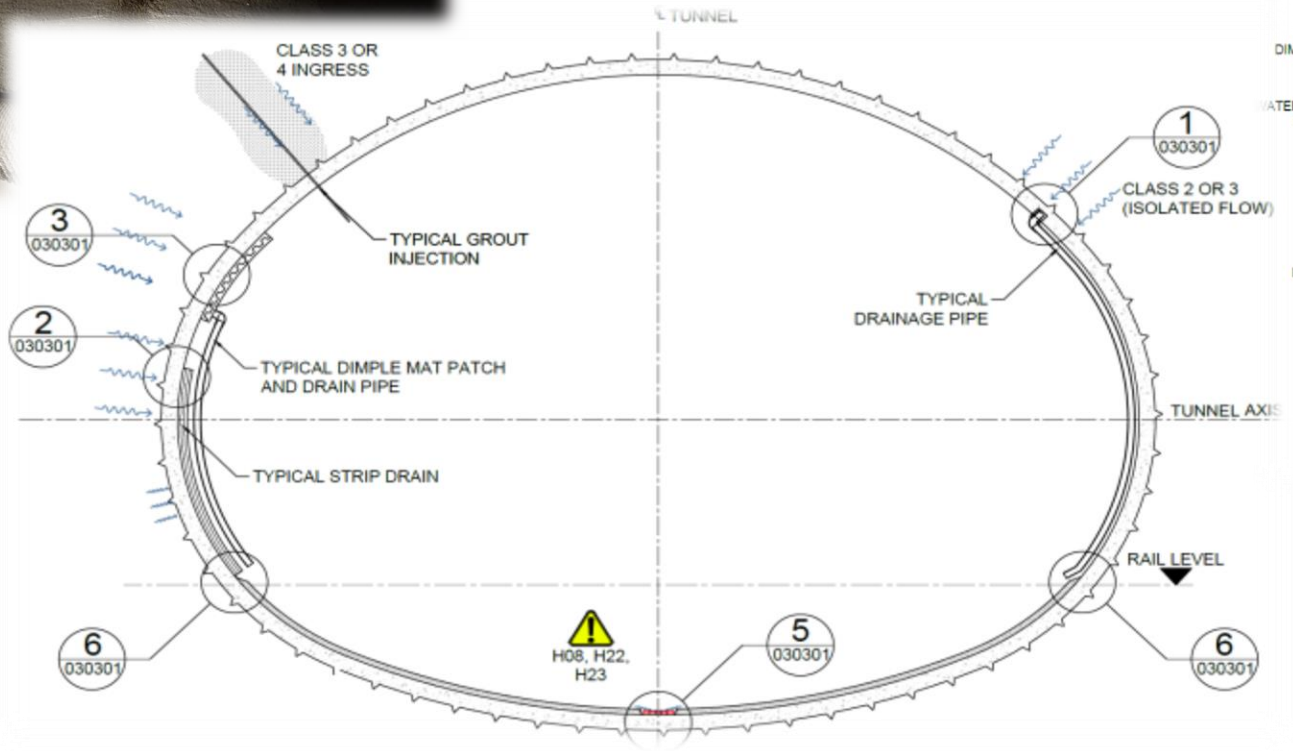
CONSTRUCTION METHODLOGY

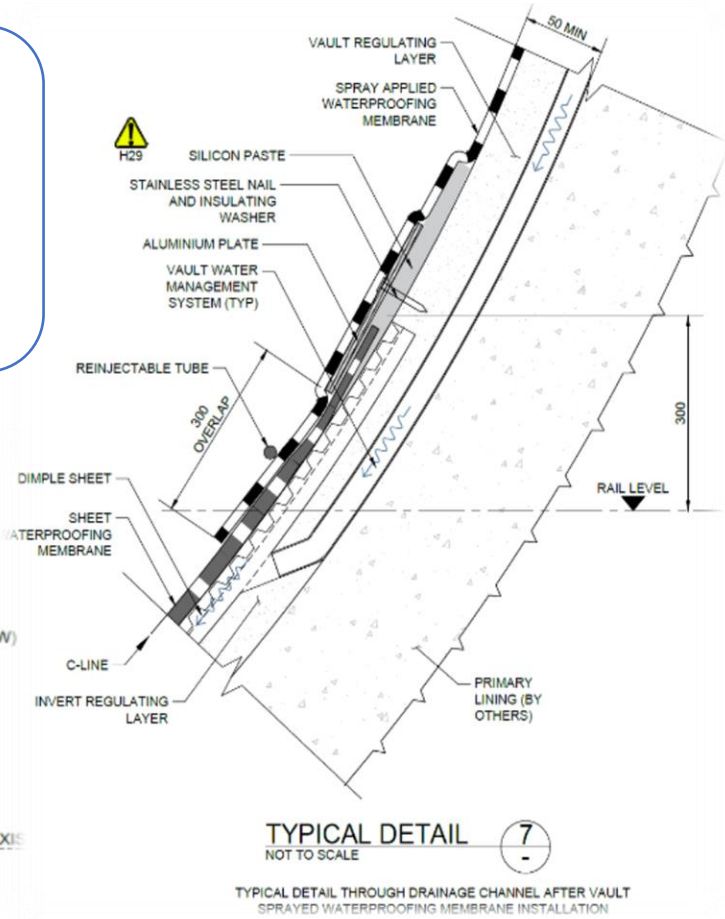
- Drained regulating layer was used to channelise water ingress in to the invert sump temporarily.
- It Prevents building up of water pressure on the sprayed water proofing membrane and the secondary lining. Allows easy application of good quality sprayed membrane
- The drained regulating layer consisted of drainage mats and strips, where required, directly installed onto the primary lining and covered with a layer of finer aggregate sprayed concrete.

CONSTRUCTION METHODLOGY



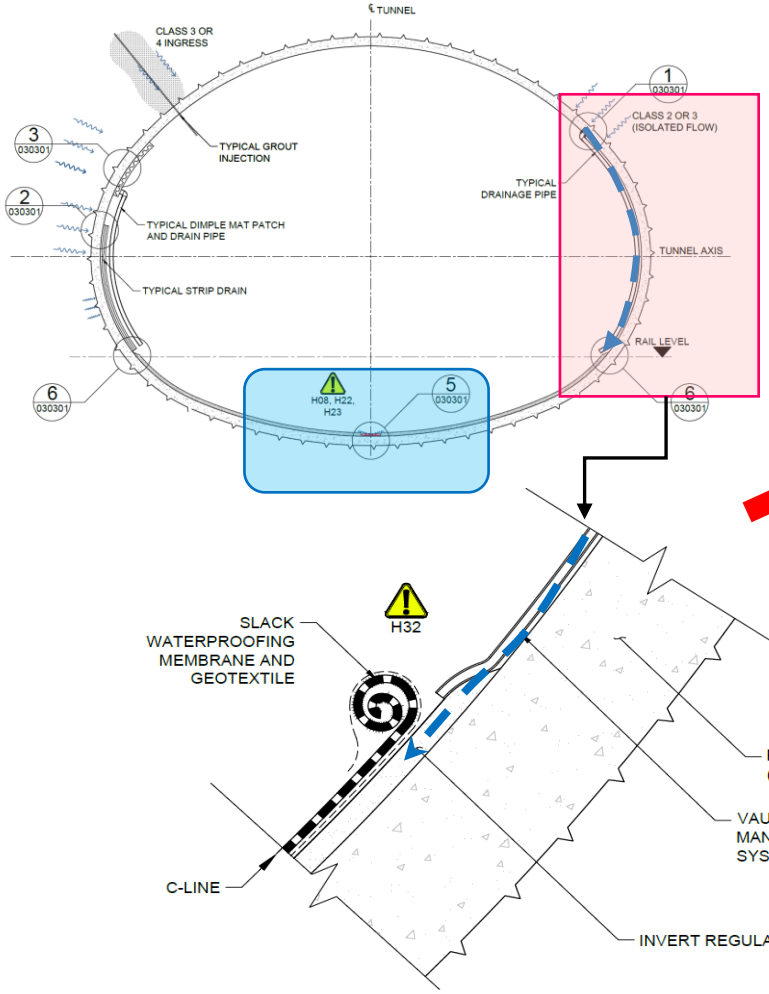
DRAINAGE MAT AND STRIPS DRAINS WATER FROM OVERT AND CHANNEL WATER INTO THE INVERT DRAINAGE AND PROVIDE A DRY SUBSTRATE



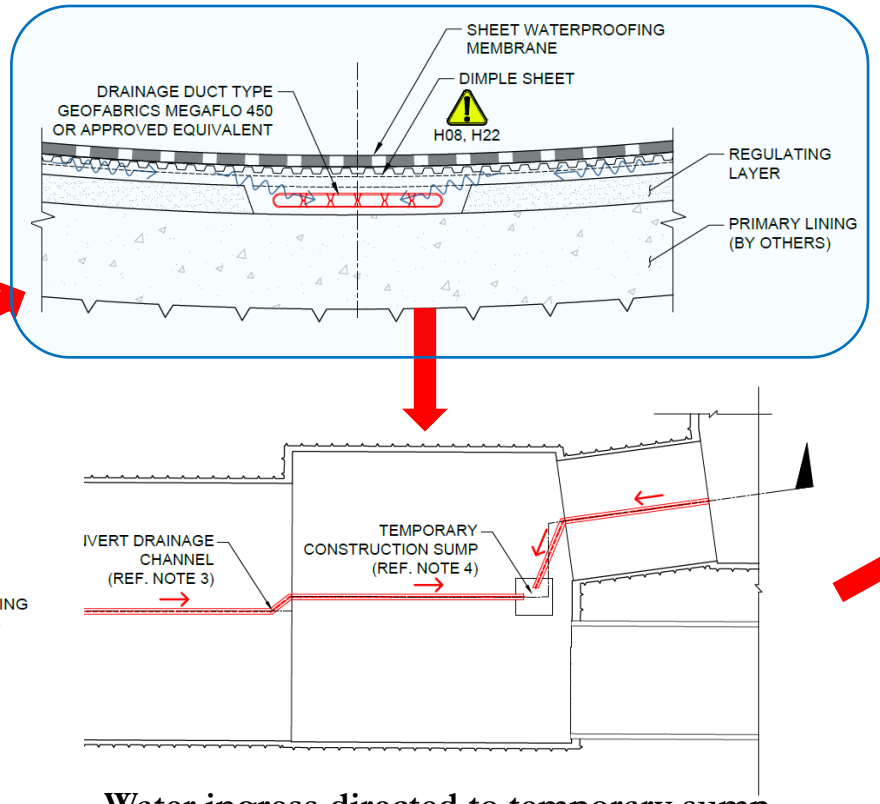


CONSTRUCTION METHODLOGY

- **Channelise water ingress from the arch into invert drain**

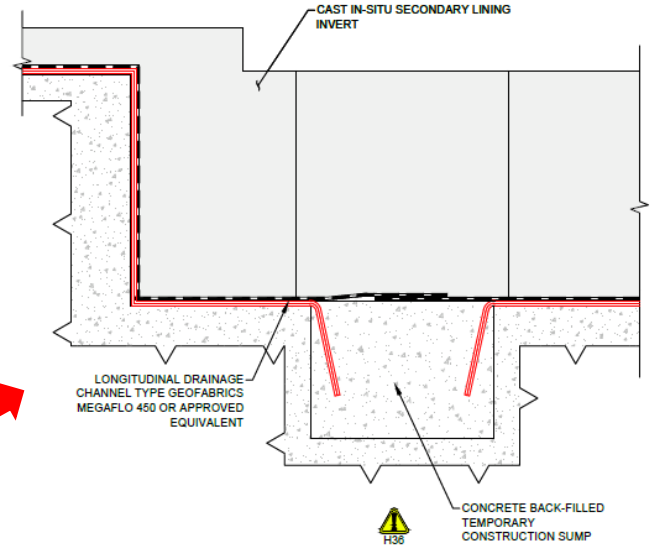


- **Invert waterproofing includes:**
  - **Drainage channel (Mega flow)**
  - **Dimple sheet**
  - **PVC membrane**
  - **Protection layer**



Water ingress directed to temporary sump

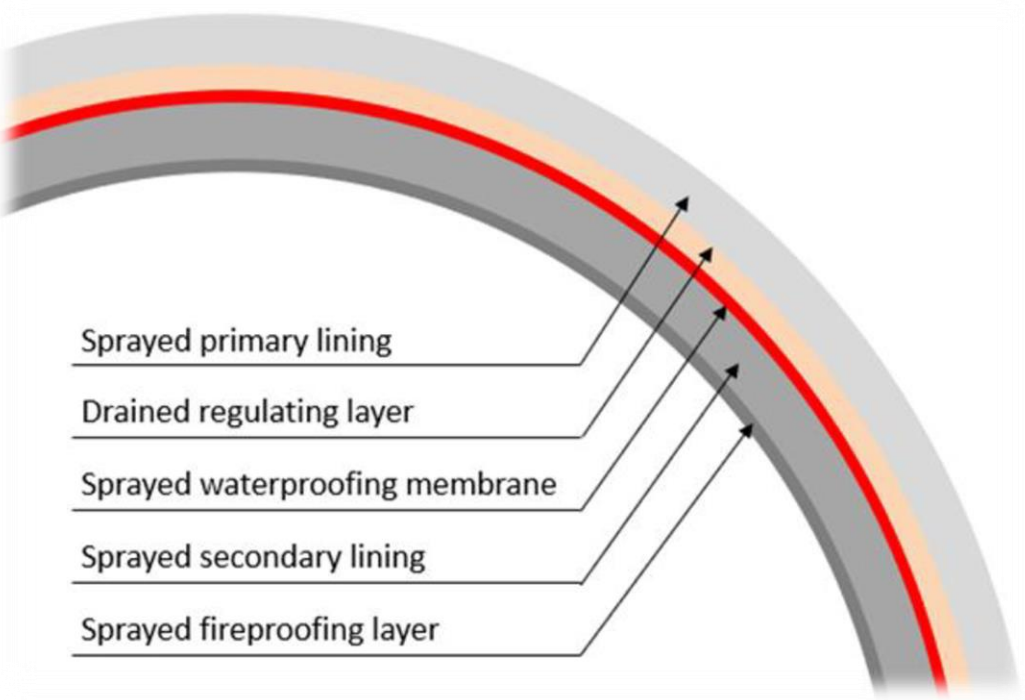
- **Back grouting**
- The temporary drainage back grouted after the secondary lining has attained 28-day strength
- The sump will be back-filled and sealed leading to a fully-tanked waterproofing system



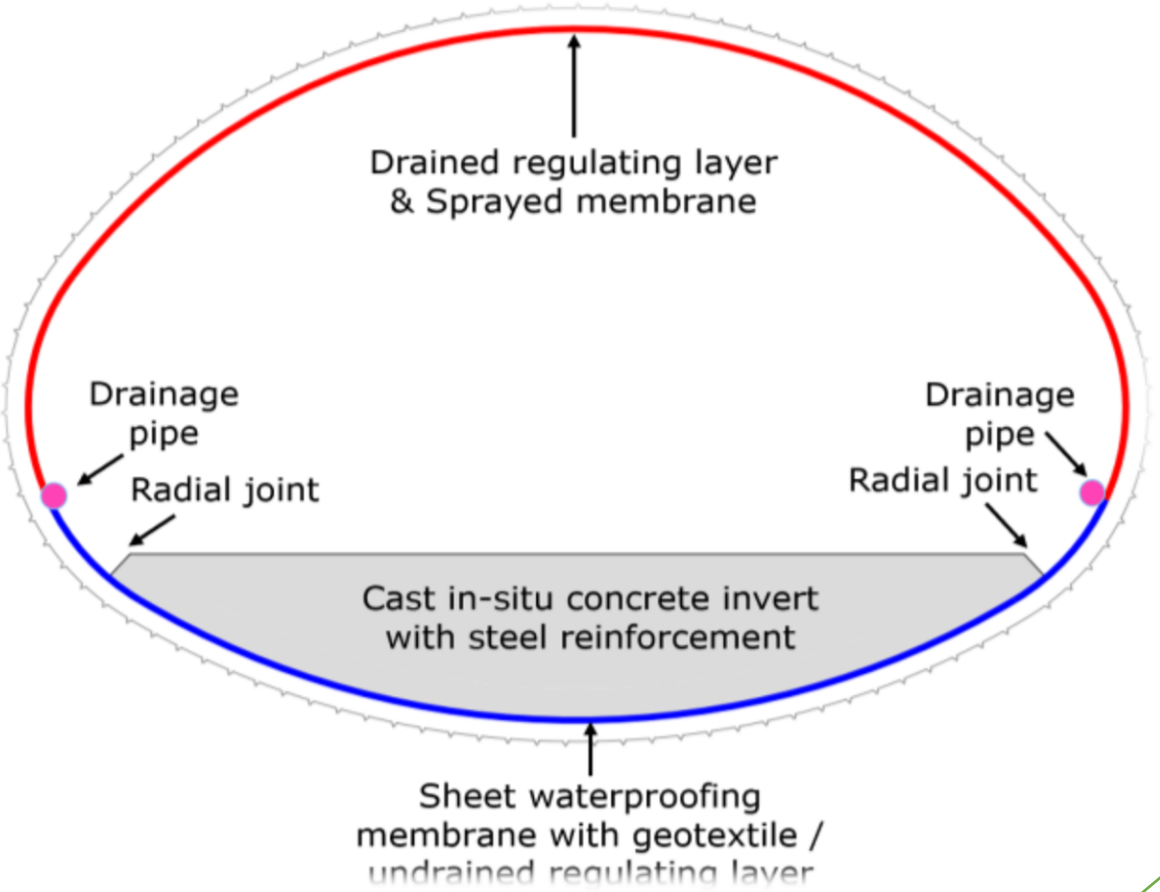
CONSTRUCTION METHODLOGY

- **Overt Waterproofing**

  Once dry regulating layer is done then the EVA material as waterproofing membrane is applied in arch portions in 2 layers of different colour. The sprayed waterproofing membrane adopted for the SRCC was the TamSeal 800 Ethylene-Vinyl-Acetate (EVA),



CONSTRUCTION METHODLOGY



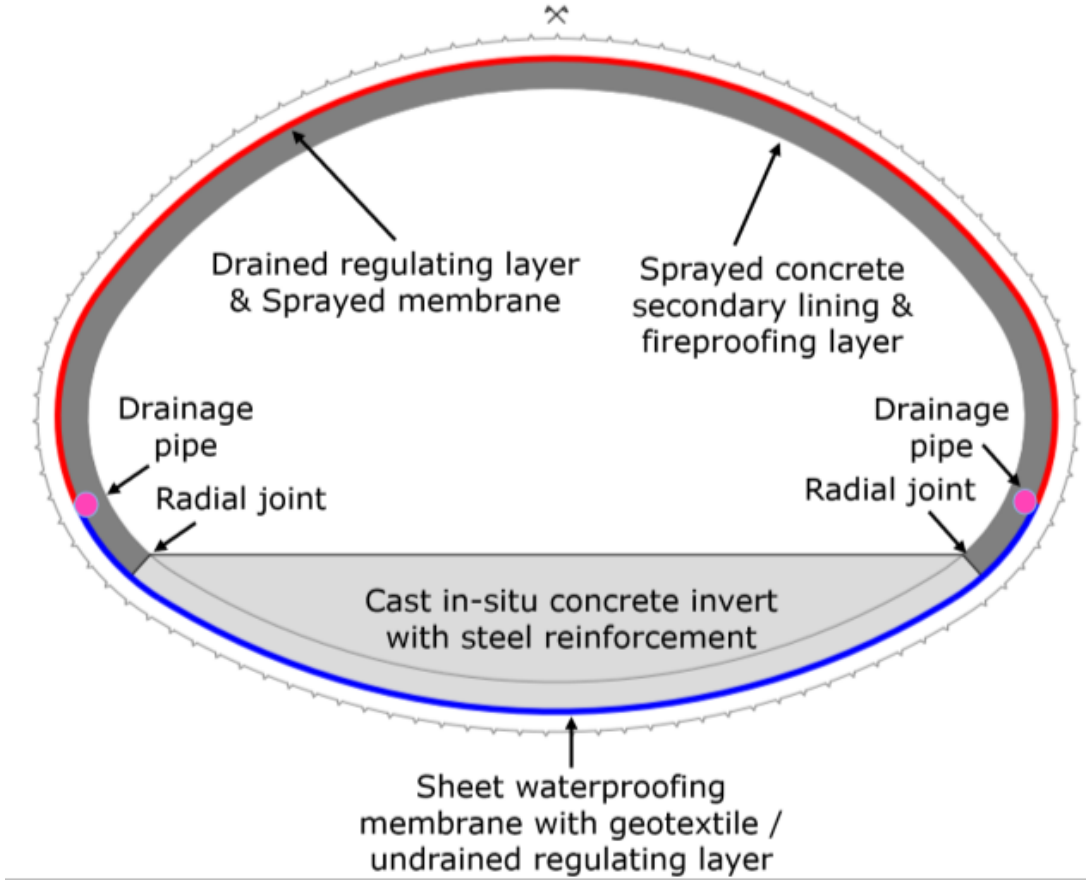
SPRAYED WATER PRROFING MEMBERANE

DRAINED REGULATING LAYER

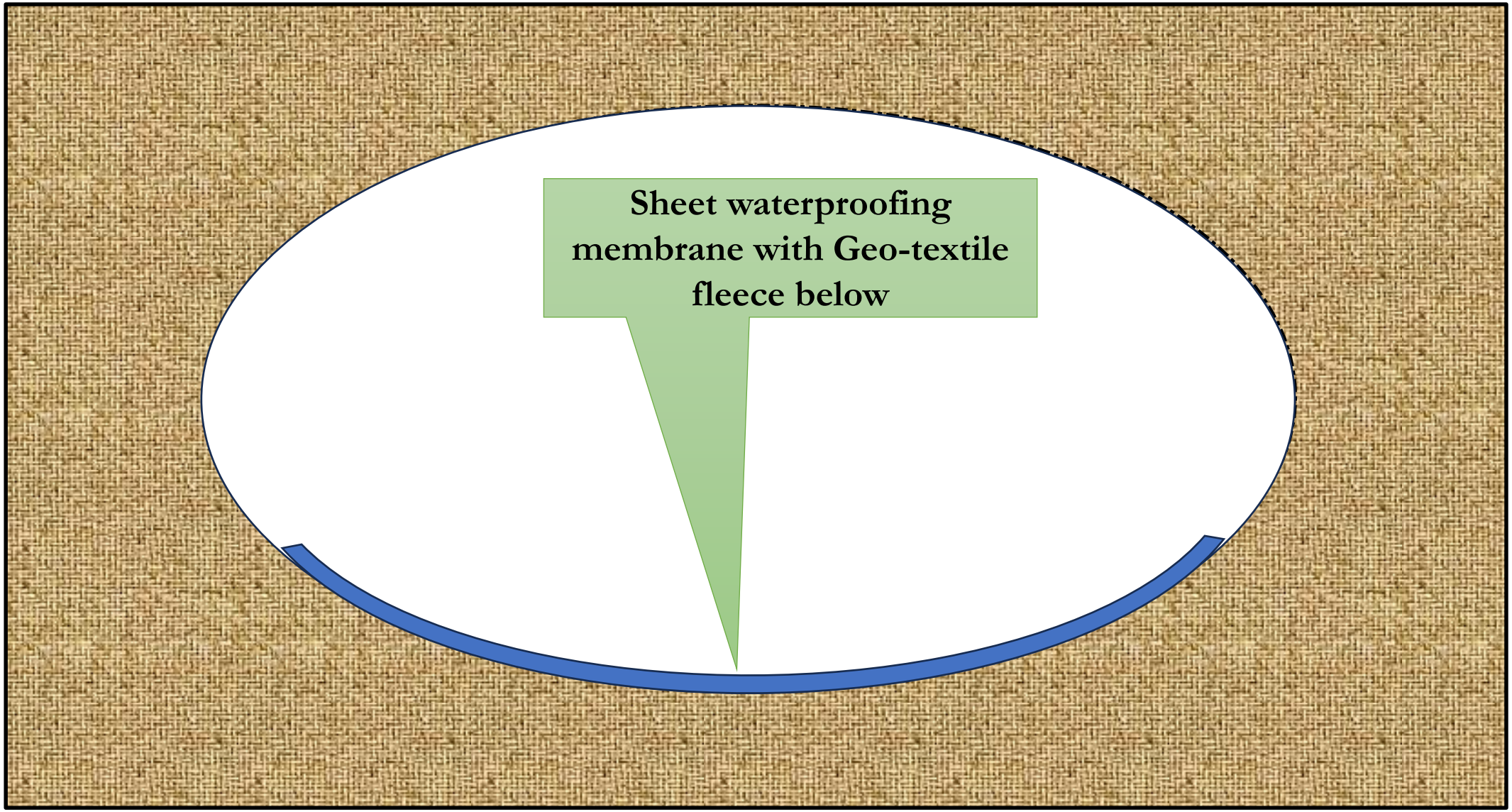
CONSTRUCTION METHODLOGY

- Spray steel fibre reinforced secondary lining shotcrete (ranging from 300 mm to 450mm) & fireproofing layer
- All water-management remains active and no water pressures allowed on secondary lining
- Wet mix process was used for shotcrete.
- The SFRSC was checked through ongoing production trials for consistency, strength, density, residual flexural strength and water permeability during construction
- Sprayed fire proofing lining was applied on final lining by adding microfilament polypropylene fibres in mix same as regulating layer to release create channel for water vapours to release and preventing or limiting explosive spalling of concrete.

CONSTRUCTION METHODLOGY



CONSTRUCTION METHODLOGY



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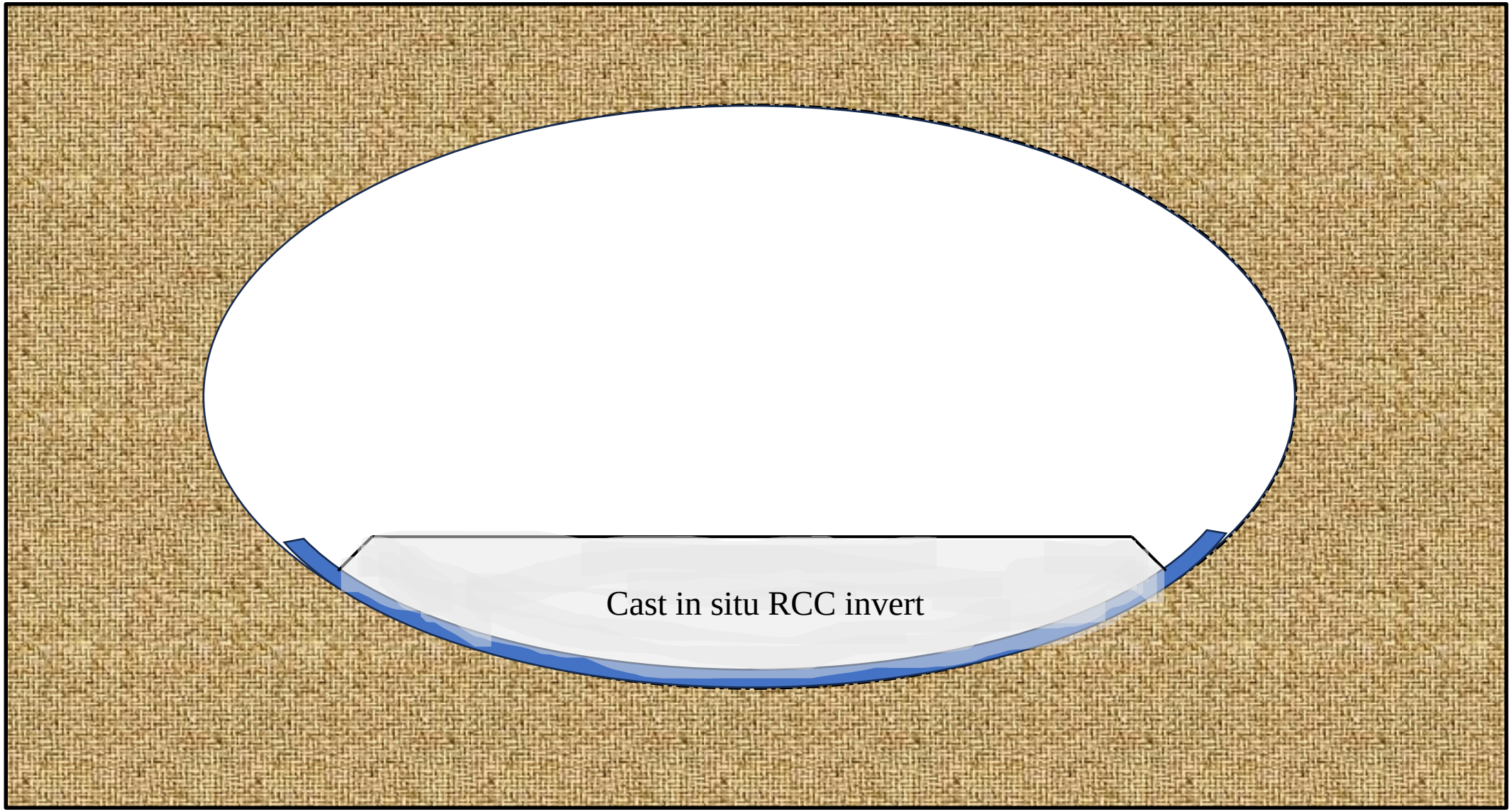

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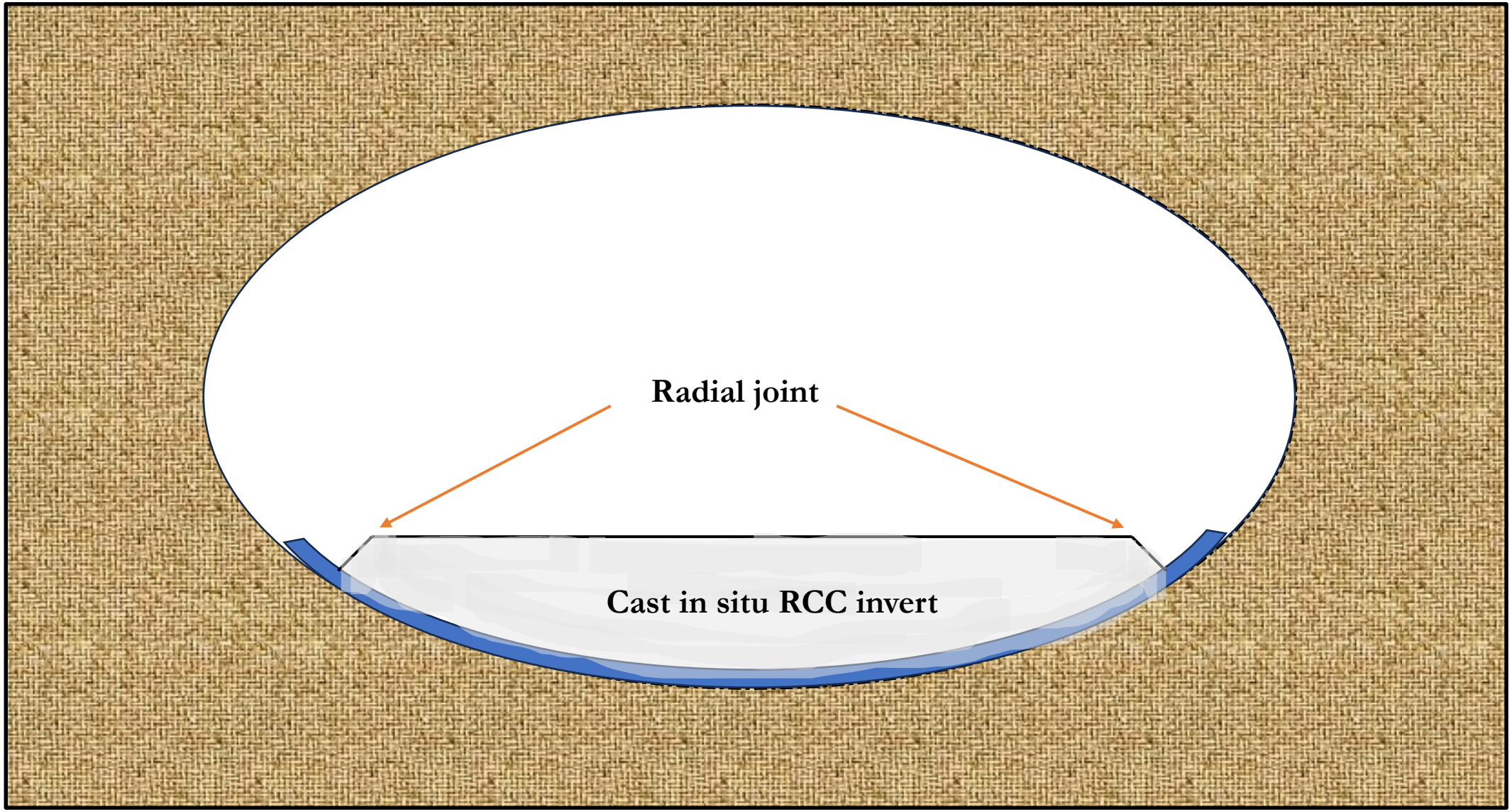

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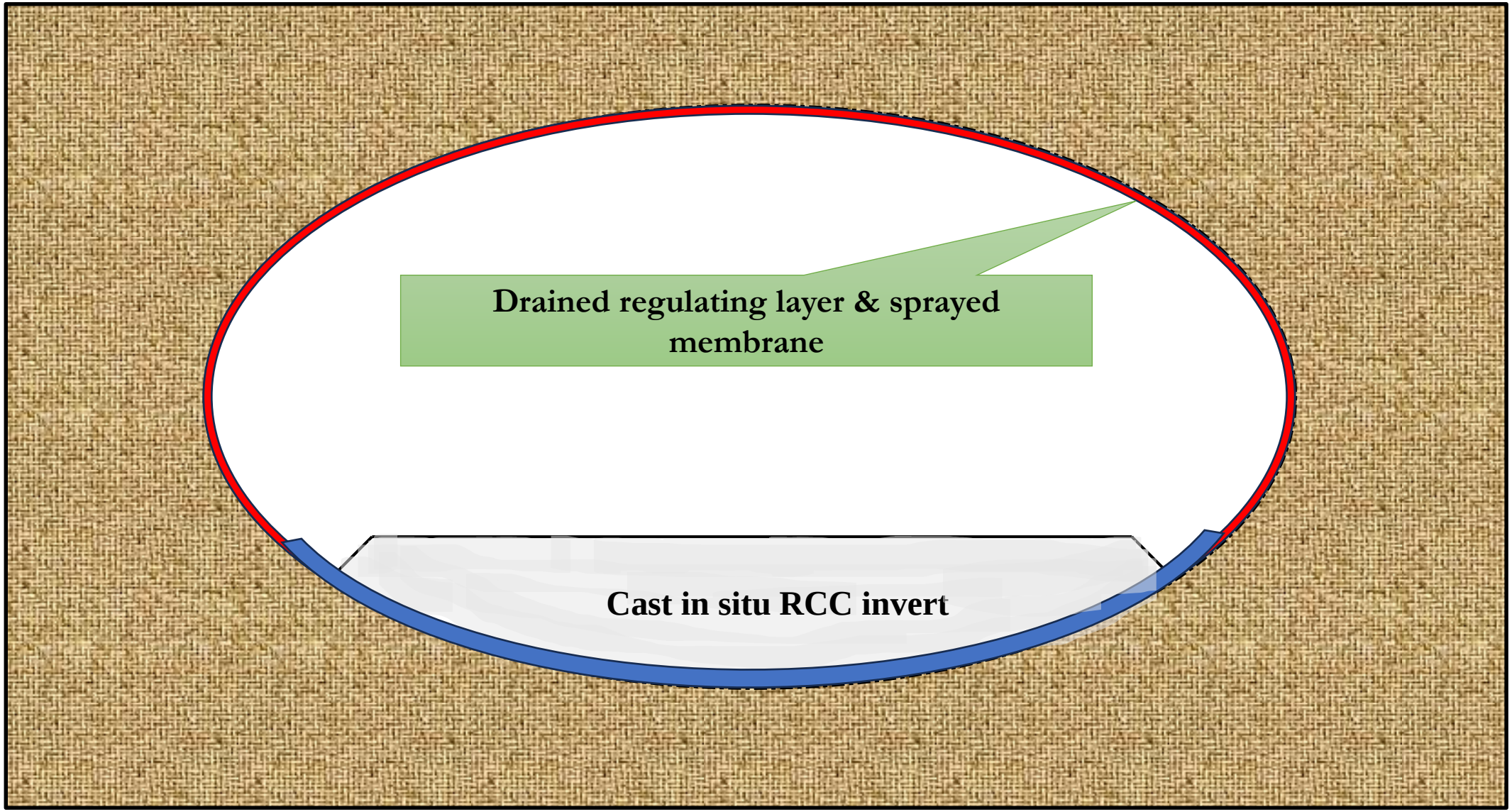
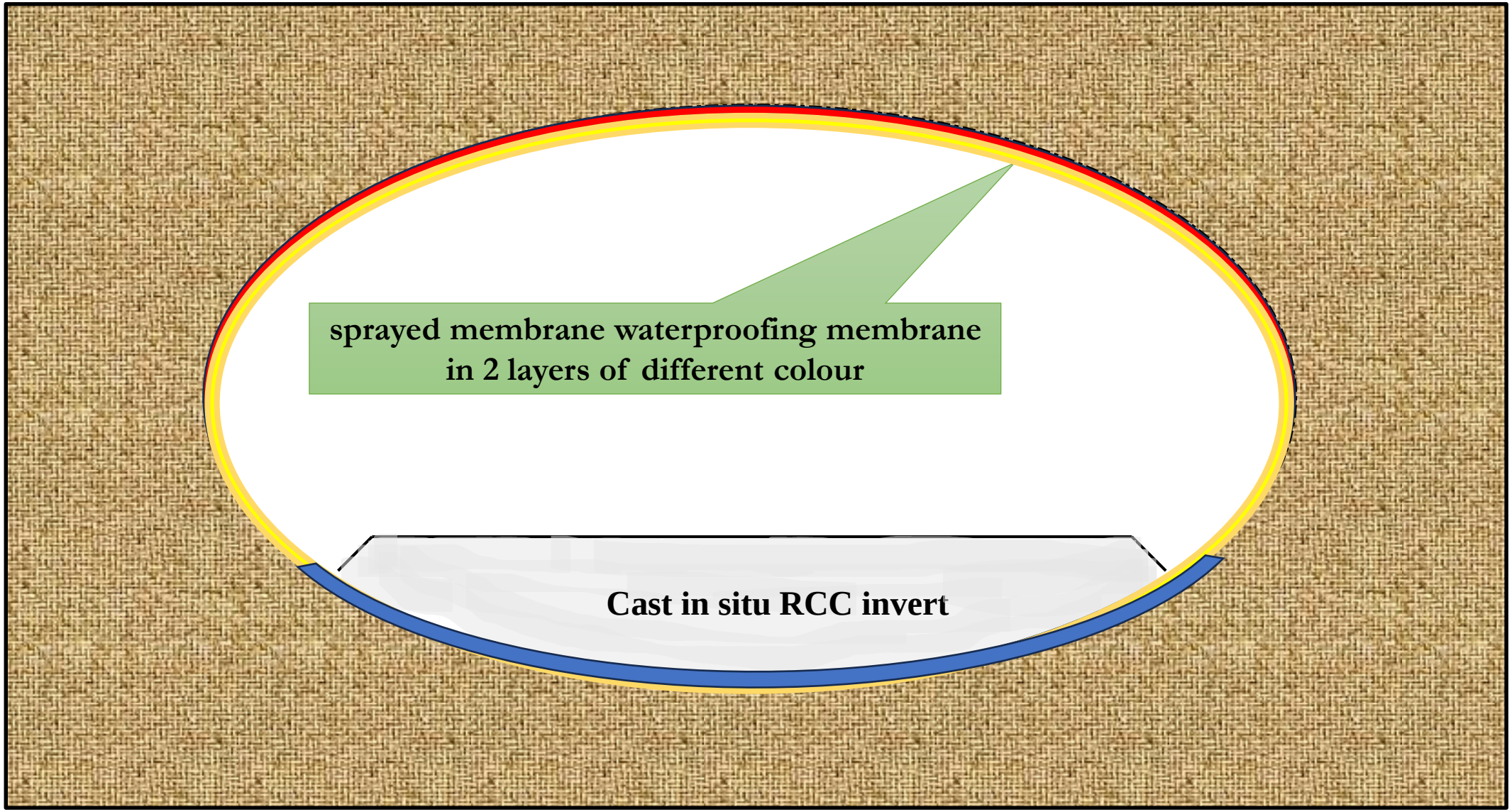
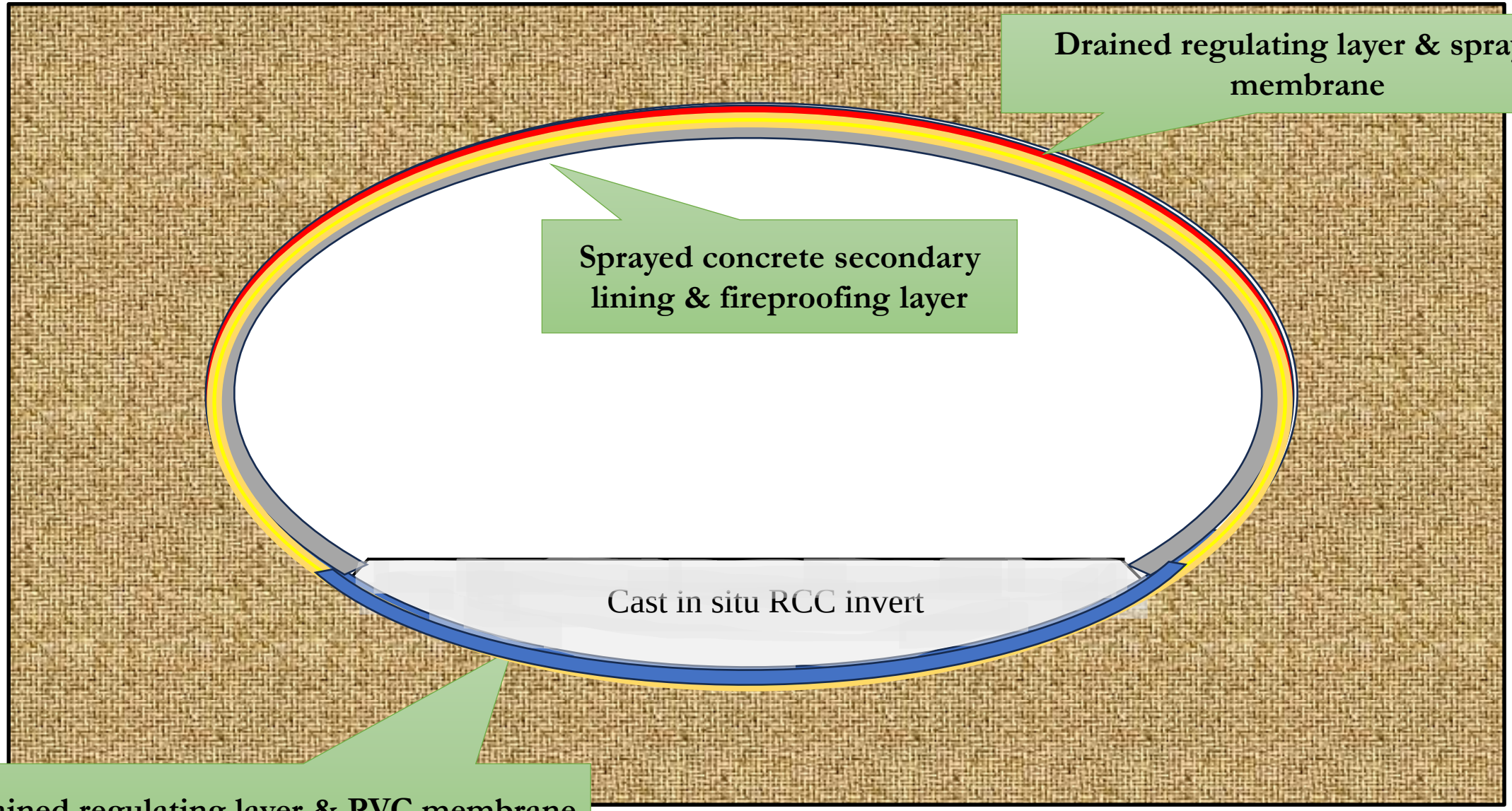


CONSTRUCTION METHODLOGY



CONSTRUCTION METHODLOGY



MIX DESIGN OF SFRSC

M40 - NATM Scissor Crossover Shotcrete . Final Lining						
	Shotcrete Mix Design		**M40**	**NATM Sahar Scissor Crossover works-Permanent**		
	Water- Cementitious Ratio		**0.36**	Supplied from UGC 06 . Location Batching Plant, Mahulgaon		
	Constituent Materials A	**Sp. Gravity**	**SSD Condition Kg /m3**	**Vendor**	**Source**	**Note:**
1	**Cement OPC 53**	3.14	498	ACC	Gujrat	Contractor shall be notifying the Engineer for change in the materials source and mix proportions for the Engineer approval. Mix design does not relieve contractor from the responsibility to requirements of the contract
2	**Micro Silica**	2.19	44	Normet	.	
3	**Steel Fibre 4D**	.	36	Bekaerat	Belgium	
4	**Manufactured Crushed Sand (Air washed ONLY)**	2.72	1324	WaterFront	Khundevahal	
5	**Coarse Aggregate 10 mm**	2.77	380	Kumar	Ulwe	
6	**Water**	1	197	MCGM	MCGM	
7	**Admixture WRA Tamcem 60mm**	1.12	7.05	Normet	Jaipur	
8	**8 Admixture HCA Tamcem**	1.09	5.42	Normet	Jaipur	
9	**Optimum Doze . Accelerator Tamshot 90AF**	1.44	6.00%	Normet	Jaipur	Accelerator doze should be controlled for given direction unless agreed with Engineer
	Constituent Materials B		**Dosage Rate**	**Vendor**	**Source**	**Note:**
1	**Admix Accelerator (Tamshot 90F)**		Dosage were tried at 6% and 7%	Normet	Jaipur	Contractor shall not increase dosage without engineer's approval

WHY SFRSC AS FINAL LINING

CONEVNTIONAL CAST IN-SITU LINING	SFRSC LINING	
Complexity in staging works	No staging works	Adopted for first time in India based on various advantages it offers and established credentials in London TfL Underground metro. Our team personally visited London to see results before adoption of this option.
Procurement of varying size shutters	Same spray robot for primary and secondary lining	
Time and cost intensive	Reduced cost and construction programme	
Sheet waterproofing membrane -> work at height	Improve H&S with sprayed waterproofing solutions	

CODES/STANDARDS FOR SFRSCL

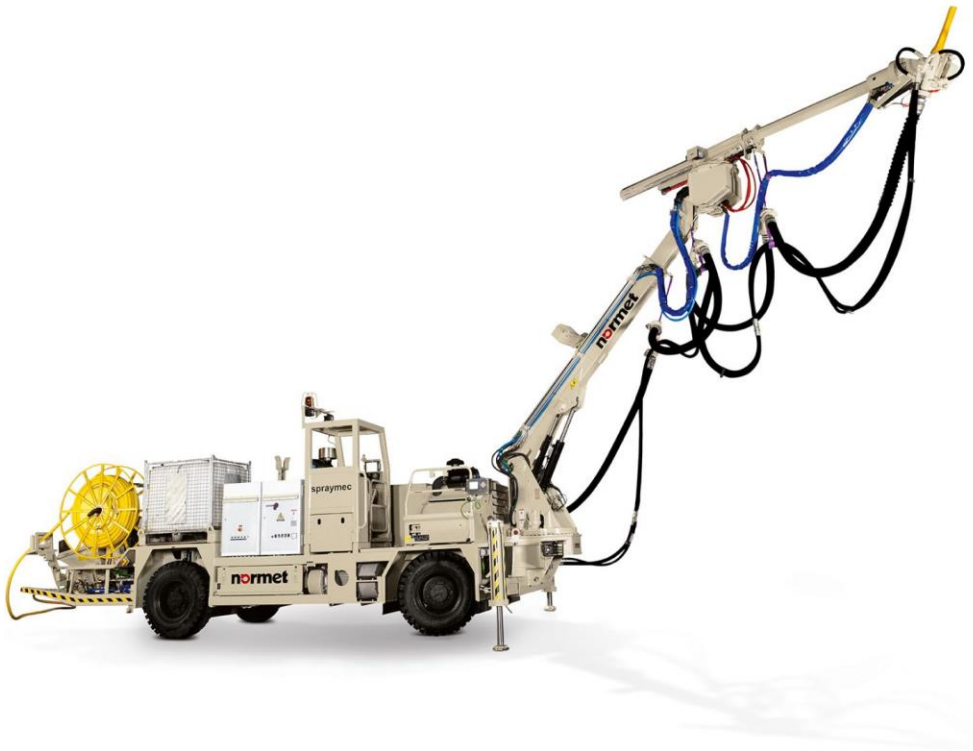
Sr. no.	Design parameters (for Soil-Structure interaction)	Governing code/standard
1	Ground parameters	GIR and GFR
2	Concrete parameters	Eurocode 2 (BS EN 1992-1-1)
3	Analysis and design	Eurocode 7 (BS EN 1997-1:1)

Sr. no.	Design parameters (for structural design)	Governing code/standard
1	Sprayed concrete specification	BS EN 14487:1 – Definition, Specification, and Conformity
2	Sprayed concrete compressive strength	BS EN 14487:1 Clause 4.3 & 4.4 & BS EN 206-1
3	Sprayed concrete tensile strength	BS EN 14487:1 Clause 4.5.2 & Table 2

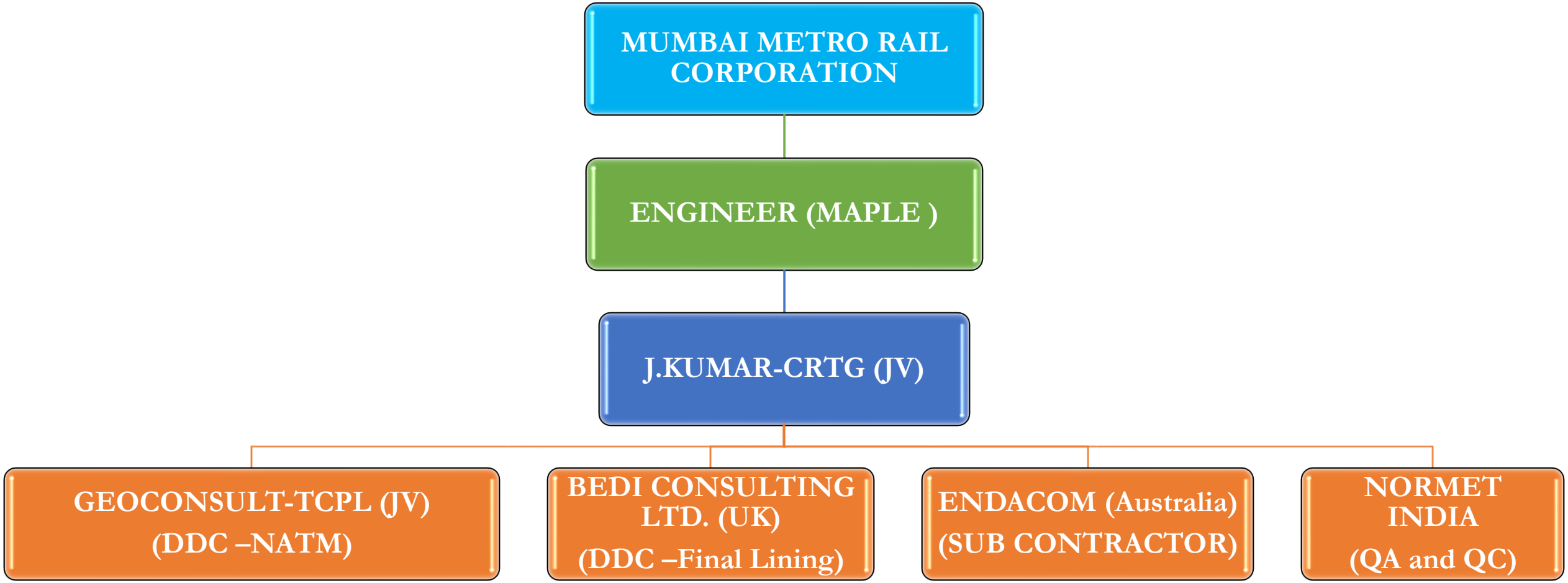
TESTING

Performance requirement	Test method	Rate of sampling	Times of testing
Early age compressive strength	BS EN 14488-2	1 set every third advance	1hr, 3hr, 6hr, 12hr
Compressive strength-cores	AS 1012.14	1 set per 50m3	1day (every 20m3), 28days, 90 days
Density	BS EN 12390-7	As per cores	As per cores
Workability	BS EN 12350-2	Every batch	After batching and prior to spraying
Estimated fibre and aggregate rebound	Site weighing	1 test every 2 months	During spraying
Water permeability	BS EN 12390-8	1 set per month	28 days
Flexural strength	BS EN 14488-3	1 set per month	28 and 90 days
Concrete drying shrinkage	ASTM C157	1 set per month	28 and 90 days
Modulus of elasticity	BS EN 12505-1	1 set of 3 Cores for each age	1st 50m of tunnel 1 day
Adhesion- - Bond test	BS EN 1542 or EFNARC 1996	1 set for every 1250m3	28 days
Adhesion-Hammer - test	NCA 1993	Periphery of tunnel crown every 5m of tunnel advance	28 days
Encapsulation	Inspection of cut test panel	1 set per month	N/A
Excavation profile	Contractor defined	1 set	Each advance
SCL thickness	Contractor defined	1 set	Each advance
Finished profile	Contractor defined	1 set	Each advance

MACHINERIES USED



ASSOCIATE PARTNERS



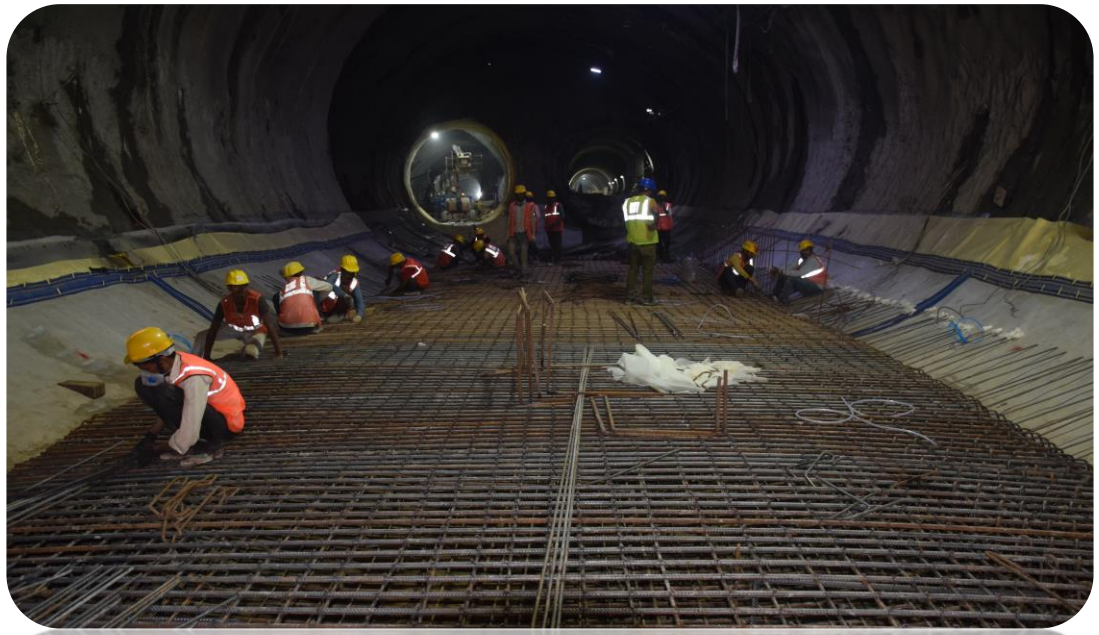
PHOTOS


SANY


BOOMER


SANY


4017




LIFT


GROVE
AB MANLIFTER
JLG
LIFT
VISITOR
03.11.2021 15

THANK YOU
FOR
YOUR ATTENTION

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