IMPACT OF TBM TUNNELS ON BRICK SEWER DRAIN IN KANPUR METRO PROJECT, CONTRACT-KNPCC05

by

Swarup Maiti (Sr. Engineering Manager)

Gülermak Heavy Industry Construction and Contracting

smaiti@gulermak.com.tr

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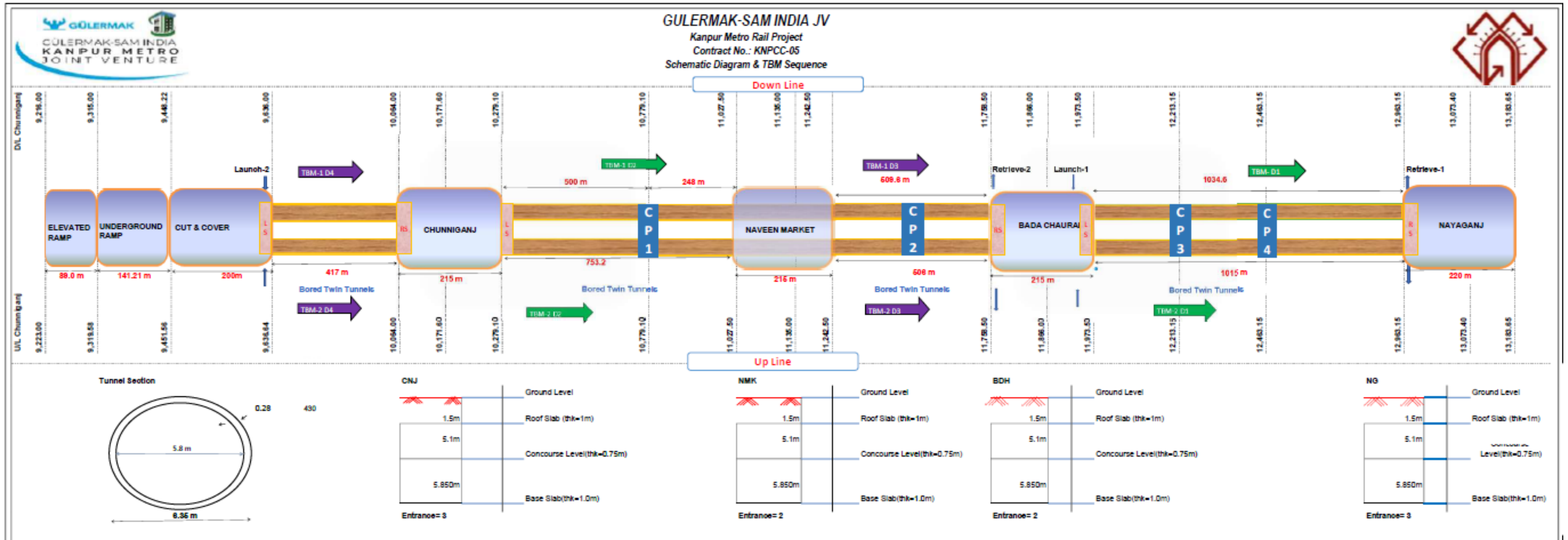


Summary	Average Length (m)		Rings @ 1400 mm	
Bored Tunnel	Upper line	Down line	Upper line	Down line
Section-01 (Bada Chauraha to Nayaganj)	1015.0	1034.6	724.0	738.0
Section-02 (Cut & Cover to Chunniganj)	417.2	415.8	298.0	297.0
Section-03 (Chunniganj to Naveen Market)	732.2	728.0	523.0	520.0
Section-04 (Naveen Market to Bada Chauraha)	506.8	509.6	362.0	364.0
Total for Bored Tunnel	**2671.2**	**2688.0**	**1907.0**	**1919.0**
Station	Upper line	Down line	3826.0	
Chunniganj station	215.0	215.0		
Naveen Market Station	215.0	215.0		
Bada Chauraha	215.0	215.0		
Nayaganj station	225.0	225.0		
Total for Stations	**870**	**870**		
C & C and Ramp	Upper line	Down line		
Elevated ramp	88.79	88.79		
Underground ramp	141.21	141.21		
C & C	200	200		
Total	**3971.20**	**4033.65**		

Bored Tunnel

Tunnel Outside Diameter (OD)	=	6.35	m
Tunnel Inside Diameter (ID)	=	5.8	m
Lining Thickness (t)	=	0.275	m
Segement Ring Width (L)	=	1.4	m
Number of segments (incl key)	=	6	Nos.
Total Length of Bored Tunnel	=	5336	m
Total Number of Rings @ 1.4 m	=	3886	Nos.
Total No. of Cross Passage	=	4	Nos.

Description	Unit	Elevated Ramp	Underground Ramp	C & C	CNJ	NMK	BDH	NG	TBM	Total
Type of Construction	Type	Bottom-UP Construction		Bottom-UP Construction	Top-Down construction	Top-Down construction	Top-Down construction	Top-Down construction	Tunneling	
Length	Rm	88.79	141.21	200	215	215	215	225	2667.7	3967.7
Width	Rm	10		22.3	22.3	22.3	22.3	22.3	5.8	127.3
Depth	Rm	6		15.4	15.4	15.4	15.4	15.4		83.0
D-Wall	Nos				100	106	100	108		414
D-Wall	Rm				484.201	487.965	485.8	511		1969.0
Roof Slab	Sqm				4639	4639	4639	4744		18661
Concourse Slab	Sqm				4639	4639	4639	4744		18661
Base Slab	Sqm				4639	4639	4639	4744		18661
Platform Slab	Sqm				1650	1650	1650	1650		6600
Excavation	Cum				77305	77305	86629	78754		319993
Backfilling	Cum				7125	7125	7125	7125		28500
Concreting	Cum			8654	16673.34	16890.65	16506	17508		76232
R/F steel	Mt			1146.59	2356.04	2594.43	2499.27	2498.99		11095
UPE Walls	Rm									0
Water Proofing	Sqm				4639	4639	4639	4744		18661
Plunge column	Rm									
Tension pile	Sqm									

1. INTRODUCTION

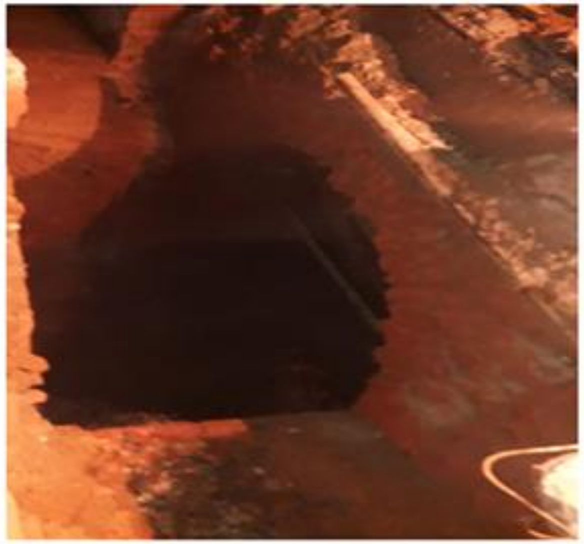
India has seen a huge development in the metro rail projects in the last 3 decades. Several Underground Metro projects have been constructed and many are in the under-construction and planning phase. Planning and design of the underground metro station is a challenging job. Most of the underground stations are planned in a densely populated area to gain more public ridership. Underground metro stations are usually planned under roads and empty ground. Planning of underground station under existing road has major issue i.e., protection of buildings and utilities adjacent to the metro station. In Kanpur Metro, Contract KNPCC05 all four underground stations are located under existing road and so many utilities (water line, storm water line, sewer line, electric cable, OFC duct etc.) are there. After station boundary, there is no space for traffic diversion, Roof slab of all four stations has constructed in stages along the alignment. **One old brick sewer drain is passing above the TBM Tunnel. Construction of TBM Tunnel below the old brick sewer drain was very challenges**.

2. SCOPE

- After awarded the contract, we have studied the existing utilities and Geological profile along the alignment. In the alignment there are so many utilities (water line, storm water line, sewer line, electric cable, OFC duct etc.) are there. **One old brick sewer drain is passing above Tunnel, the gap between TBM Tunnel and brick barrel is varying from 1.16m to 5m.** These sewer drains are critical public utility infrastructure for the city of Kanpur. Construction of TBM Tunnel below the old brick sewer drain was very challenges. This study is impact of TBM Tunnels on existing old brick sewer drain.





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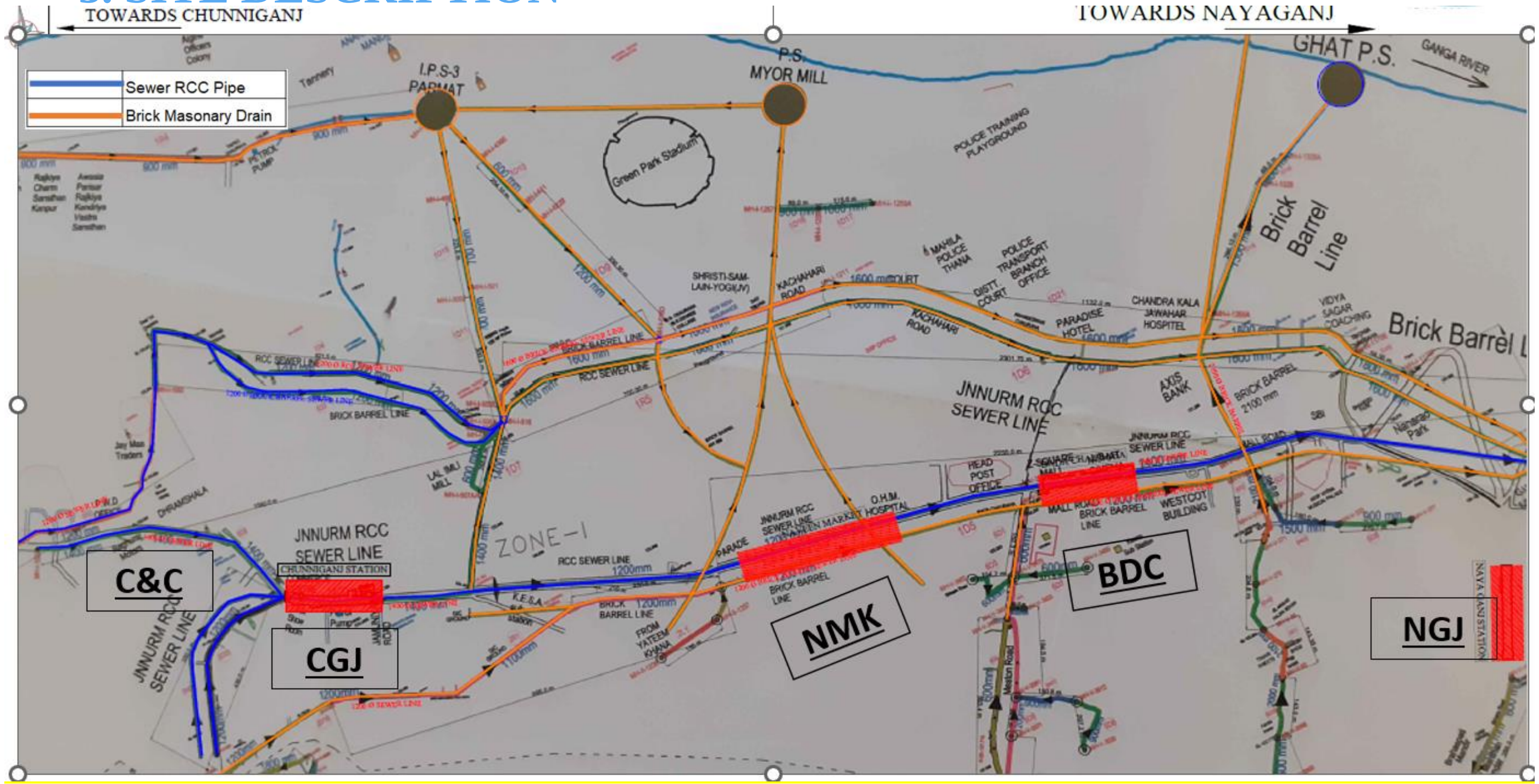
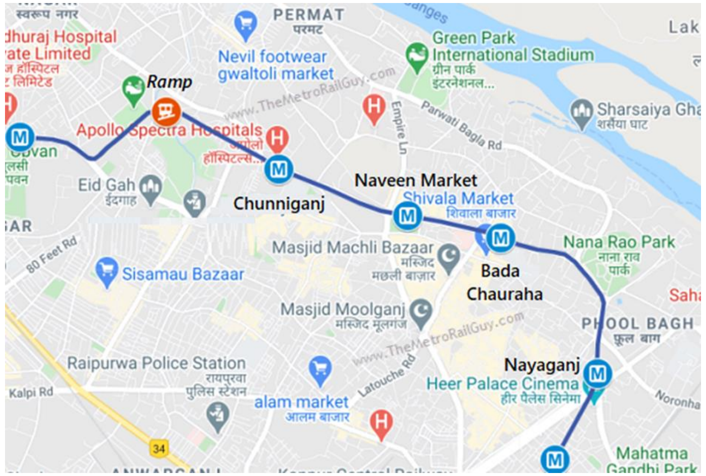
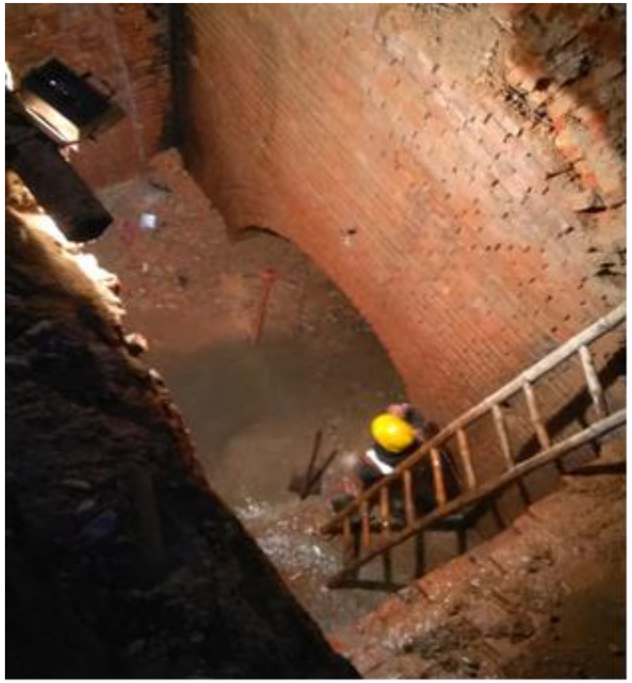
3. SITE DESCRIPTION

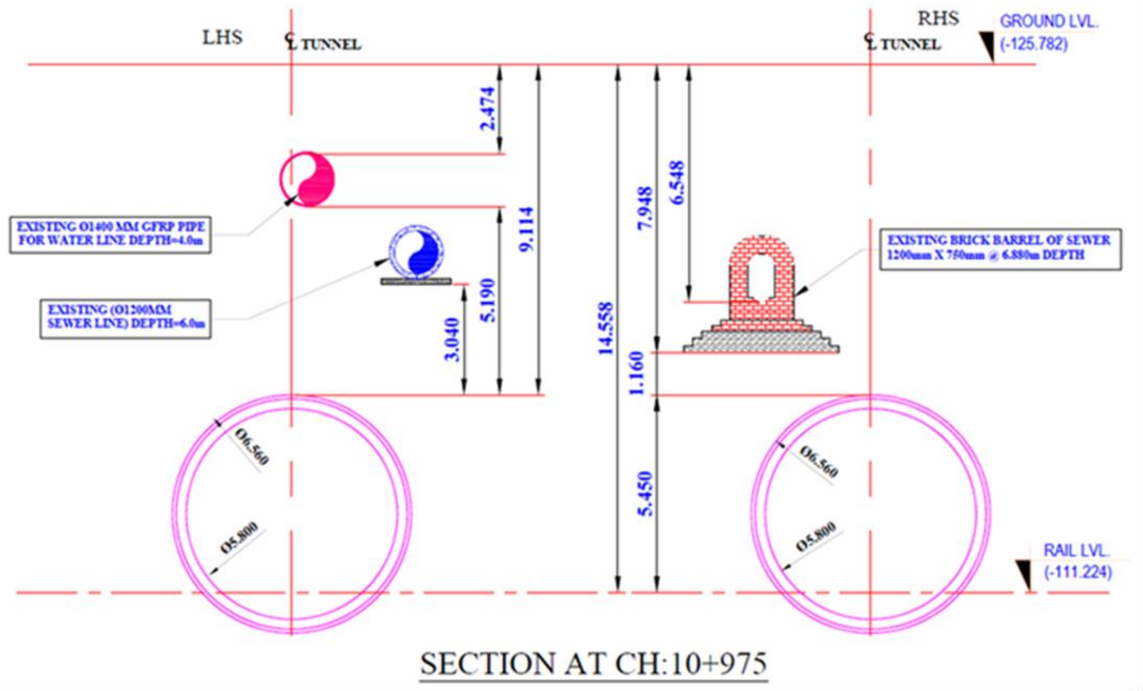




Sewer Network in influence zone of **KNPCC05**



Photographs of existing brick sewer drains



Proposed TBM tunnels and Brick Sewer Drain – Critical Section CH 10+975 (Near Naveen Market Station)

4. PROJECT GEOLOGY

- Kanpur is situated on the banks of river Ganga.
- The Kanpur Nagar district is part of Indo Gangetic Plain. The alluvial soils comprising clay, silt, gravel, and sands of different grades are main sedimentary constituents of project geology.
- The groundwater table was observed at depths deeper than 23m below ground at some locations and was not encountered under most of the alignment.
- The construction of TBM tunnels is likely to be in dry / unsaturated alluvial soils.

5. ASSESSMENT OF TBM TUNNELLING ON EXISTING SEWER

- Finite element analysis is carried out using the software program PLAXIS to study the potential impact of the proposed TBM tunnel construction on existing brick sewer drain.

- The borehole ABH-13 is closest to the critical section and is considered in this study. The geological profile and parameters are shown in table.

Soil Unit	Depth (m below ground)		SPT ‘N60’	Bulk Unit Weight	Drainage Conditions	c’	Φ’	E50 = Eoed	Eur	K0	μ’
	From	To		kN/m³		kPa		MPa	MPa		
Made Ground	0	2	9	17	Drained	1	27	9	27	0.54	0.3
Silty Clay (Medium Plastic)	2	5	9	17	Drained	1	27	9	27	0.54	0.3
Sandy Silt	5	12	19	18	Drained	2	28	19	57	0.53	0.3
Silty Clay (Low Plastic)	12	14	27	19	Drained	3	30	27	81	0.50	0.3
Sandy Silt	14	26	50	19	Drained	5	32	50	150	0.47	0.3
Silty Sand	> 26		55	20	Drained	5	33	55	165	0.45	0.3

- TBM tunnel is to be constructed using 275mm thick (M 50 grade) precast concrete segmental lining. TBM tunnel lining is modelled as plate element in finite element analysis. The properties of plate element are described in Table.

Normal Stiffness (EA) (kN/m)	9.72 x 106
Flexural Rigidity (EI) (kN m2 / m)	61.27 X 103
Thickness (d) (m)	0.275
Unit Weight (w) (kN/m/m)	6.875
Poisson’s Ratio	0.15

- ❖ Volume loss of 0.8% as per technical paper of DMRC.
- ❖ The material properties of the existing brick sewer drain are not known. The brick sewer drain geometry is simplified in two-dimensional form and modelled as to have linear elastic properties. In the absence site specific test data, the following properties are considered to be reasonable for purpose of this analysis.

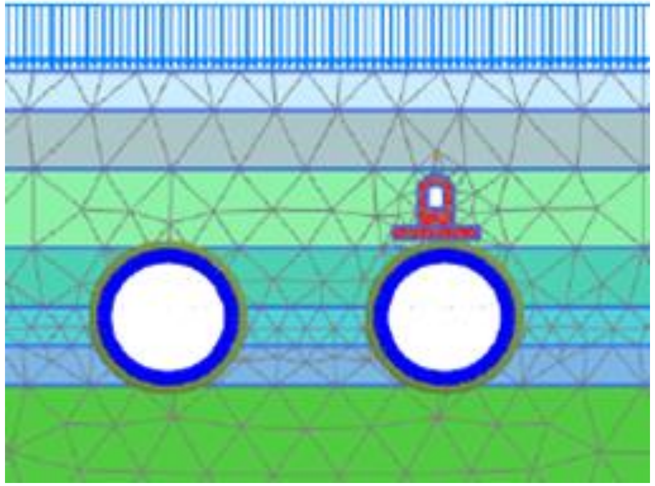
Unit Weight (kN/m3)	18
Young's Modulus (kN/m2)	2.4 X 106
Poisson's Ratio	0.25

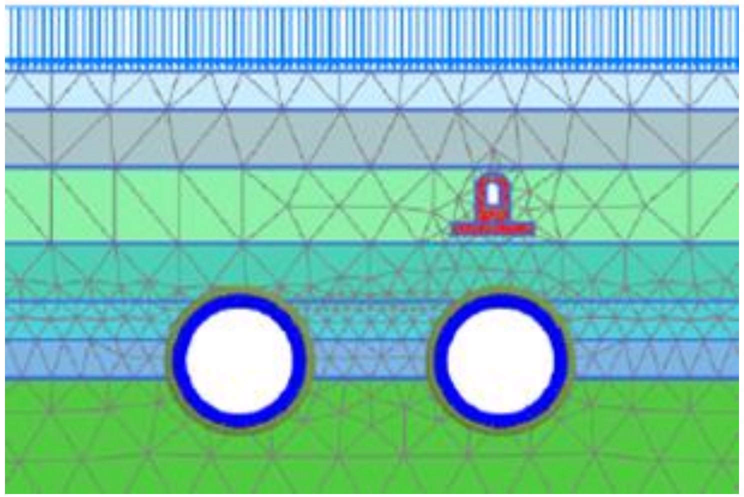
❖Construction Sequence Modelled in FEA

The following two cases with specific objectives are modelled in PLAXIS.

a) **Base Case**: Critical section with minimum vertical clearance of 1.16m between base of drain and tunnel crown

b) **0.5 D Vertical Clearance**: Vertical clearance of 3.28m between base of drain and tunnel crown to analyse effects of lowering of tunnels on settlements at the base of drain





- Construction sequence is modelled in PLAXIS:

i. Initial phase to generate in-situ stresses in ground

ii. Activation of Sewer Drain

iii. Application of ground surcharge of 20 kPa to simulate the traffic loading

iv. Left tunnel excavation and activation of lining

v. Application volume loss of 0.8 % to left tunnel

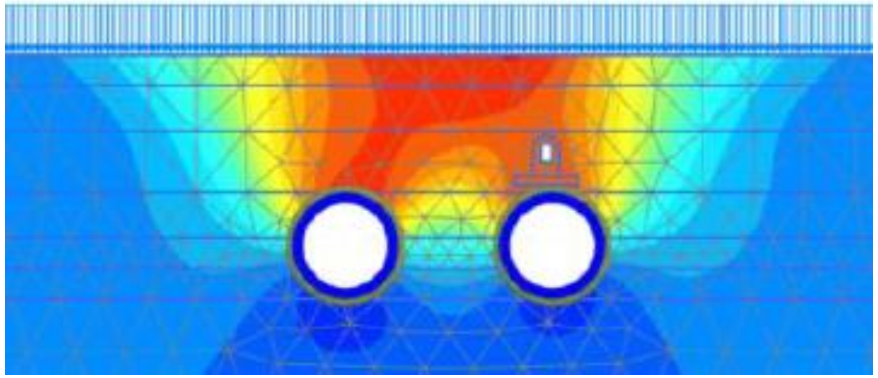
vi. Right tunnel excavation and activation of lining

vii. Application volume loss of 0.8 % to right tunnel

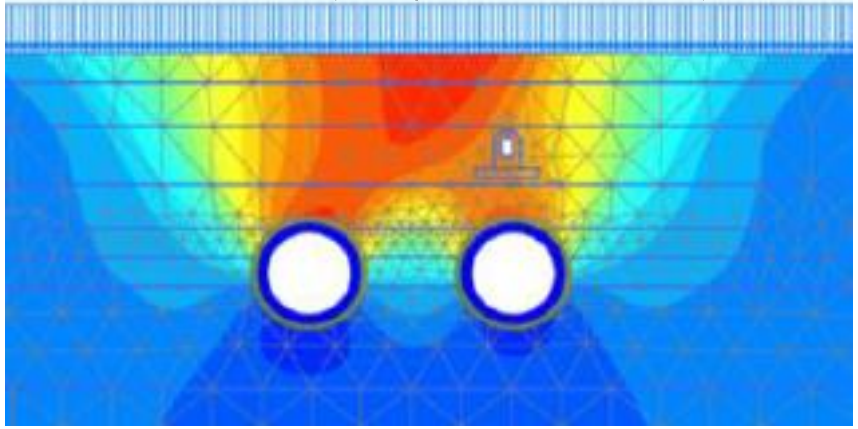
6. Result and Discussion

- The major concern is the ground settlements around the brick sewer drain and its potential impact on sewer drain.
- The FEA outputs of vertical deformations of ground (settlements) are shown in figure.
- It is observed the settlement pattern resembles a shape of chimney (i.e. settlements reaching the ground surface). There is potential of chimney to extend up to the surface.
- This could impact the sewer and propagate the settlements to the surface.

Base Case:



0.5 D Vertical Clearance:



- The magnitude of settlements is limited to about 25mm. The maximum and differential settlements for each analysed case are summarised in Table.

Case Analysed	Total Maximum Settlement (mm)	Differential Settlement (mm)	Slope of Settlement below base of sewer drain
Base Case (Existing Condition)	24.8	5	1 / 850
0.5 D Vertical Clearance	23.3	1.5	1 / 2800

- Potential risk of settlements is extending up to the ground surface, however the magnitude of settlement is limited to about 25mm and differential settlements at the base of sewer drain is about 5mm (which is less than 1 in 800). The expected category of damage is likely to be "Slight" i.e. Category 2. Therefore, the sewer is not likely to have sudden instability / serviceability issues. Any potential damage should be repairable.

Risk Category	Maximum slope of the building	Maximum settlement of the building (mm)	Description of Risk
1	<1/500	<10	**Negligible**: superficial damage unlikely
2	1/500 to 1/200	10 to 50	**Slight**: possible superficial damage which is unlikely to have structural significance
3	1/200 to 1/50	50 to 75	**Moderate**: expected superficial damage and possible structural damage to building, possible damage to relatively rigid pipelines
4	>1/50	>75	**High**: expected structural damage to buildings and rigid pipelines or possible damage to other pipelines

Rankin's Typical Values for Maximum Building Slope and Settlement for Damage Risk Assessment

- Risks factor for the above impact assessment:

- Existing condition of sewer drain including cracks, reduction in strength of bricks/mortar, and damage cannot be quantified. If the existing condition is poor, then any additional settlement would cause higher degree of damage i.e. Moderate to High (instead of 'slight').
- The current assessment only takes into account transverse (i.e. orthogonal to alignment) settlement trough. However, the additional tensile strains are likely to be developed due to settlement trough extending in the longitudinal direction (i.e. parallel to alignment). This could cause higher degree of damage i.e. Moderate to High.
- The brick sewer is running parallel to the upline tunnels. In the event of tunnel intervention / stoppage there is risk of loss of face pressure and higher than estimated ground loss (of 0.8 %). Higher ground loss would result in higher risk of damage to the sewer drain.
- At the locations of cross-passages a higher volume loss is expected due to the NATM excavations.
- The settlement analysis presented in this report should be reviewed and revised based on the instrumentation and monitoring data from initial tunnel drives. The site-specific settlement data shall be analysed to update the risks and potential impact assessment of sewer drains presented in this report.

7. MITIGATION MEASURES

The risk factors as explained above could lead to more than "Slight" damage of brick sewer drain. Therefore, following mitigation measures are suggested for consideration.

- In the absence of precise utility surveys, the risk of sewer foundations obstructing the TBM tunnels cannot be ruled out. This could cause damage to the cutterhead and potentially stop the tunnel drive. Any stoppage of tunnel drive would lead to the loss of face pressure and sudden instability of tunnel face. This could result in ground and sewer subsidence without any warning. **Therefore, a clearance of minimum 0.5 times tunnel diameter i.e. 3.28m should be maintained at all locations**. Either lowering of the tunnel alignment to increase the clearance between the base of sewer drain and tunnel crown or diversion of brick sewer drain would greatly mitigate the risk of sudden collapse.
- The existing ground properties has no cohesion and low frictional strength. The increase in strength and stiffness of ground below and around the sewer drain would help to reduce the ground loss and settlements. Appropriate grouting techniques should be adopted considering the ground characteristics prior to tunnel excavation.
- TBMs can be designed and equipped with a supplemental ground stabilisation system. This system can be comprised of regularly spaced grout ports built into the shield for drilling into and grouting the ground ahead of the tunnel face. The location and number of ports should be adequate for implementation of face stabilisation measures in all types of expected ground conditions. The number of ports and its location shall be decided in consultations with TBM manufacturer. Such grouting treatments executed from the surface may be preferable to those from inside the tunnel, in case of low cover, to avoid interfering with the production cycle. But the surface treatments have the drawback of creating inconvenience to the citizens.

- Tube and Manchette (TAM) grouting technique could be considered for effective treatment in the case of grouting from surface / sewer drains. It is important to organize an efficient system for monitoring grout injection operations during and after treatment. During treatment, this involves continuous monitoring and recording of operational parameters such as water/cement/chemical ratio, injection pressure and total volume injected. Grouting trials can be performed for different ground granulometry to validate the theoretical assumptions, confirming the overall quality of the grouted material.

- As a suggestion, grouting trials may be performed at the stations / launching shaft locations where columns will be exposed after excavation, allowing a careful check of the quality of grouted material. Suitability of various grouting materials (such as cementitious, chemical) for effective treatment can be studied during such trials.

- Launching of downline TBMs to precede the upline would help to understand the ground response through instrumentation and monitoring data. The settlement data collected from first tunnel drive would help to calibrate the magnitude of expected ground loss. The protective measures for sewer drain could then be suitably modified based on field instrumentation data collected from the first tunnel drive.

- Tunnelling beneath sewer drain will require tight control of the TBM tunnelling operation to ensure that settlements are minimized. A 'feedback loop' should be established between:

  i. surface monitoring, and

  ii. TBM operations

  This should be used to both validate the pre-construction estimates of settlement and potential damage prior to entering the zone potentially at risk and determine the optimum driving set-up to control ground movements.

  If the results of this exercise indicate that an unacceptable level of settlement/damage would result from continuing the TBM drives, then options for protection of affected structures must be considered.

8. CONCLUSIONS

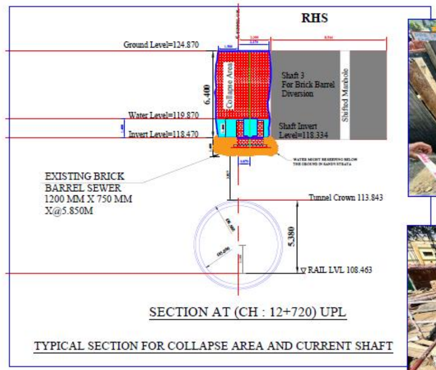
- The impact of TBM tunnelling on existing brick sewer drain using finite element analysis has been presented.
- The full extent of the potential impact cannot be estimated in advance owing uncertainties in the available information. Therefore, a risk-based approach is necessary to mitigate any potential impact and ensure safety during TBM tunnelling as well as cross-passage constructions.
- **A shift in vertical alignment or diversion of brick sewer drain has shown to be effective in reducing settlements and should be considered to minimize potential risk to the sewer drains.**
- Ground improvement using grouting techniques would result in minimizing the ground loss and settlements.
- A 'feedback loop' to calibrate the TBM tunnelling operating parameters based on monitoring of ground movements would be a useful tool for the risk-based construction approach to ensure safe tunnelling under sewer drains.

9. LIMITATIONS OF ANALYSIS

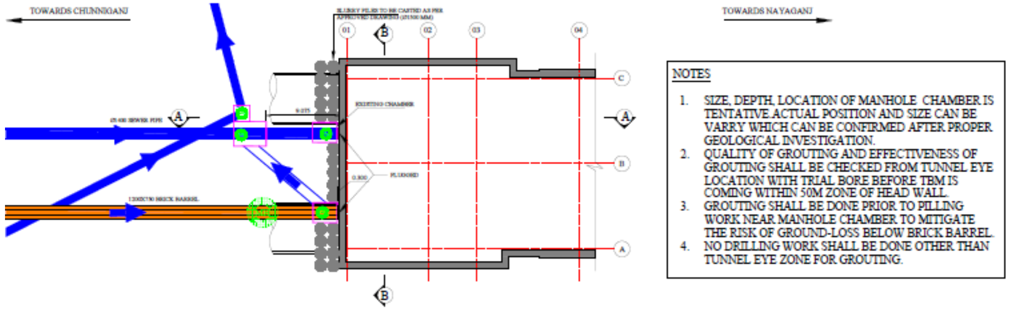
- The analysis and suggestions provided are based on the results of soil investigations carried out by third party agency.
- Using generally accepted engineering methods and practices, this report has made every reasonable effort to analyse potential impact of TBM tunnelling on sewer drain.
- However, the likelihood that conditions may vary from any specific location tested is still possible, and careful assessment of ground conditions should be undertaken during the time of construction by qualified personnel.
- The analysis and suggestions provided in this report shall be reviewed and revised based on instrumentation and monitoring data and ground response observed during initial tunnel drives.

10. REFERENCES

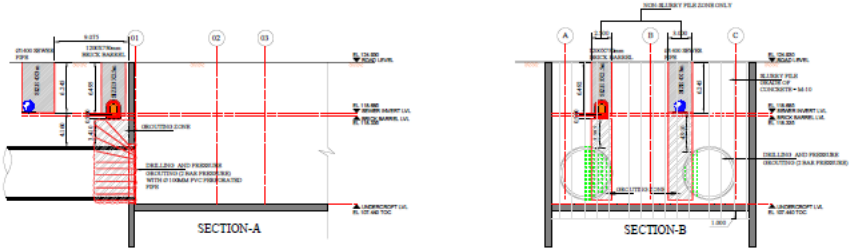
- Geotechnical Interpretative report
- Rankin, W.J.: Ground Movements Resulting from Urban Tunnelling: Predictions and Effects. Eng. Geol. of Underground Movements (1988), pp.79–92.
- Schanz, T., Vermeer, P. A. & Bonnier, P. G. (1999). The hardening soil model: formulation and verification. Conf. Beyond 2000 in Computational Geotechnics, 1–16.



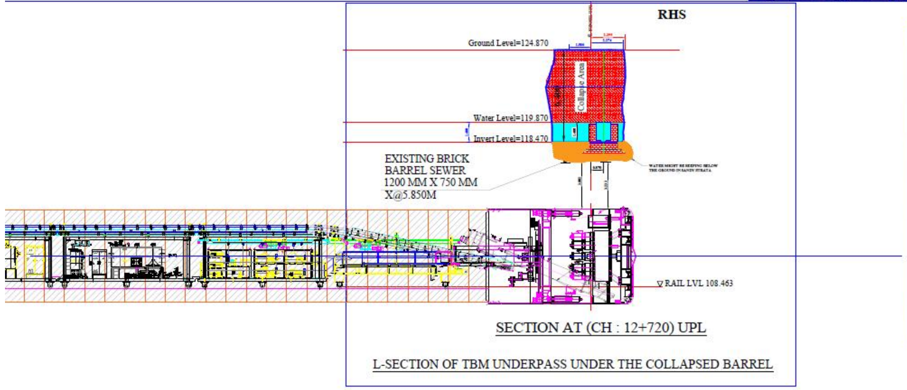
RHS
Ground Level=124.870
Water Level=119.870
Invert Level=118.470
Collapse Area
Shaft 3 For Brick Barrel Diversion
Shaft Invert Level=118.334
Shifted Manhole
EXISTING BRICK BARREL SEWER 1200 MM X 750 MM X@5.850M
Tunnel Crown 113.843
RAIL LVL 108.463
SECTION AT (CH : 12+720) UPL
TYPICAL SECTION FOR COLLAPSE AREA AND CURRENT SHAFT



TOWARDS CHUNNIGANJ
TOWARDS NAYAGANJ
NOTES
1. SIZE, DEPTH, LOCATION OF MANHOLE CHAMBER IS TENTATIVE ACTUAL POSITION AND SIZE CAN BE VARRY WHICH CAN BE CONFIRMED AFTER PROPER GEOLOGICAL INVESTIGATION.
2. QUALITY OF GROUTING AND EFFECTIVENESS OF GROUTING SHALL BE CHECKED FROM TUNNEL EYE LOCATION WITH TRIAL BORE BEFORE TBM IS COMING WITHIN 50M ZONE OF HEAD WALL.
3. GROUTING SHALL BE DONE PRIOR TO PILLING WORK NEAR MANHOLE CHAMBER TO MITIGATE THE RISK OF GROUND-LOSS BELOW BRICK BARREL.
4. NO DRILLING WORK SHALL BE DONE OTHER THAN TUNNEL EYE ZONE FOR GROUTING.



SECTION-A
SECTION-B



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SECTION AT (CH : 12+720) UPL
L-SECTION OF TBM UNDERPASS UNDER THE COLLAPSED BARREL

Thank You