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ANALYSIS & DESIGN OF SECONDARY LINING OF A VENT SHAFT

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ABSTRACT:
This paper discusses the analysis and design of a Vent Shaft – Secondary Lining. The Vent Shaft is approximately 39m in depth. Top 10-m of shaft is composed of Precast segmental lining and RC secondary lining. The shaft below is composed of SCL primary lining and RC secondary lining. The general thickness of SFRC SCL primary lining is 450mm and thickness of secondary lining is varying from 400mm, 700mm, 1500mm. The thickness of the secondary lining is also increased to 4590 mm around the TBM opening locations (in form of reinforced concrete collar, RC collar). The openings in the shaft provide access to and from the tunnel and experience high stress concentrations, hence they require high stiffness in form of increased thickness. For independent design check, a 3D-FEM model is prepared on Autodesk Robot Structural Analysis (ARSA) software. All the loads applicable for the permanent stage and their combinations as per the Eurocode have been considered. Design check is done covering all the aspects such as minimum reinforcement, ULS & SLS. To start with Basic Reinforcement is adopted in the Horizontal (Hoop) and vertical direction in the shaft. Basic capacities are calculated based on the provided reinforcement and those are checked for the adequacy w.r.t M-N curve. Required reinforcement is calculated accordingly.

1. INTRODUCTION

1.1Description of structure

The secondary lining begins from an elevation of EL 36.20 mOD and continues upto an elevation of +2.920 mOD. The Shaft is approximately 34 m in depth. Top 10 m of shaft is composed of Precast segmental lining & RC Secondary Lining. The shaft below is composed of primary lining and RC secondary lining.

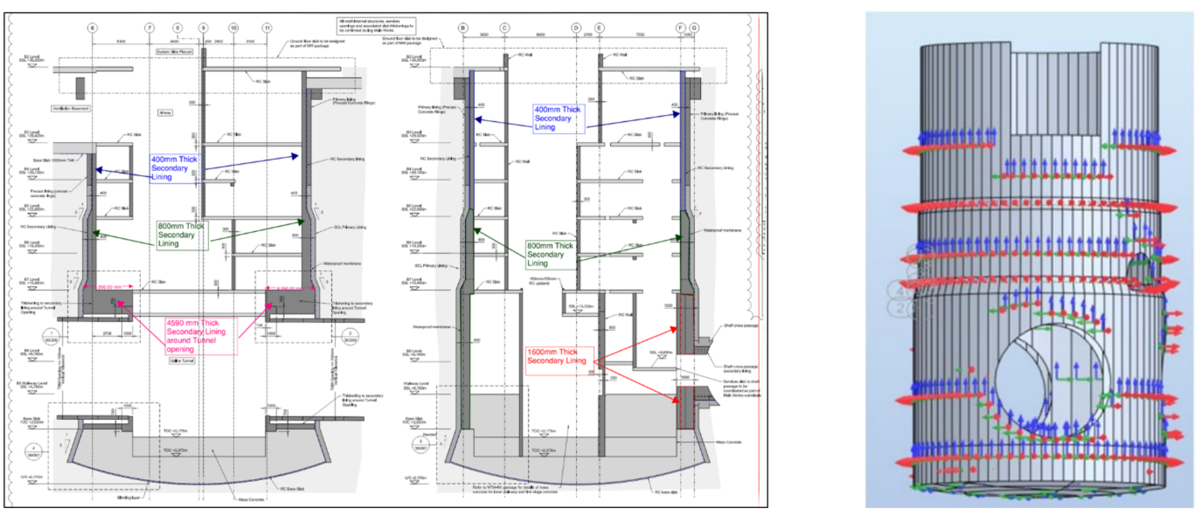

Fig. 1 – Geometry of Secondary Lining of Shaft

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The general thickness of primary lining is 450mm and thickness of secondary lining is varying from 400mm ,700mm, 1500mm and The thickness of 700 mm thick secondary lining has also been increased to 4590 mm around opening locations (in form of reinforced concrete collar, RC collar).

2. DESIGN APPROACH

The scope of the topic is to present the structural behaviour of the Secondary Lining of the Shaft, under a selected set of conditions. The following effects are analysed:

- Floatation Check
- Minimum reinforcement
- Crack development under service limit state
- Concrete stresses under service limit state
- Shear and flexural strength under Ultimate limit state

2.1 Modelling considerations

The Geo team will provide the soil loading and the soil stiffness to be applied to the model. Pressure on SL will be provided from PLAXIS 3D model. As the primary lining is the source of output for design check of the secondary lining the purpose of this approach is to Assess distribution of ground load onto secondary lining pro rata based on equivalent stiffness. The water pressure will be applied to Secondary Lining.

The cast in situ secondary lining will be modelled using 3D shell model ROBOT. The secondary lining will be restrained at the top with compression only spring with high stiffness. Spring stiffness is calculated using Terzaghi approach (Ciria Report 103 Cl 4.2.1). For tangential spring stiffness it will be used the 20% of the radial.

The loading to be applied to the model are based on the plaxis analysis for the primary lining. The loading that will be used are based on the pressure profile at the long term. In order to consider the presence of the primary lining with the relative load sharing and the ground relaxation it is chosen to consider the 30% of the effective soil pressure and the 100% of the water pressure to be applied to the secondary lining model. The water pressure is considered 100% because at the long term we assume the primary lining can crack and the water can filter and acts on secondary lining

The following loads are considered in the 3D model.

- **Self-Weight**:- Self-weight of the structure is directly considered in the FE-model. Weight due to the fill of the PCC on base slab is applied on FE-model.
- **Effective Earth pressure:-** Effective lateral & uplift earth pressure loads from Plaxis analysis are considered as inputs. Due to presence of other structures (Satellite shaft, TBM tunnels & ADITs) in influence region, earth pressure is varying around the shaft.
- **Lateral Water Pressure**:- Water pressure on secondary lining & uplift on base slab calculated from hydrostatic method. As per GIR parameter, the ground water level is considered at Ground level.
- **Heave Vertical Loads**
- **Water Pressure below Base slab**
- **TBM Loads-1**:- Grouting Loads
- **TBM Loads -2**:- Loads due to steel can around opening

Following types of load combinations are used in the analysis of the structure.

1. SLS Characteristic
2. SLS Quasi-permanent
3. ULS cases

The design of the elements are carried out based on the criteria mentioned above.

2.2 Codes and Standards

1. EN-1992-1-1 “Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings”
2. EN-1992-1-1 “Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design”
3. Eurocode 0 : Basis of structural design
4. Eurocode 1 : Actions on structures

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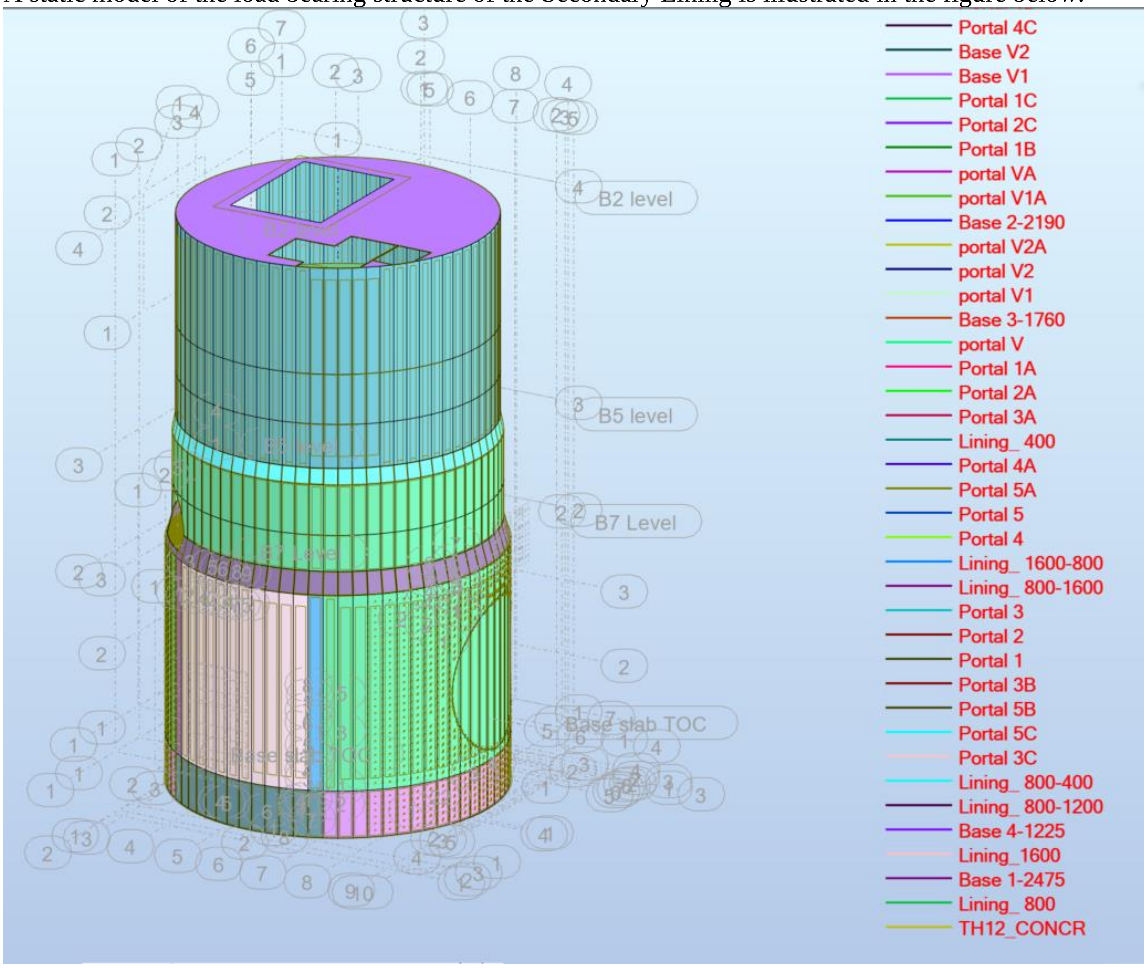
5. CIRIA C76 : Control of cracking caused by restrained
6.

3. MODELLING PHILOSOPHY

A static model of the load bearing structure of the Secondary Lining is illustrated in the figure below.



3D FEM model, Secondary Lining of Shaft

The cast in situ secondary lining will be modelled using 3D shell model ROBOT. The secondary lining will be restrained at the top with compression only spring with high stiffness. The bottom nodes of the model will be restrained using full fixity (Ux,Uy,Uz,Rx,Ry,Rz) whilst the top representing the connection with the segmental lining will be pinned on the vertical axis.

In the 3D FEM model, the nodes of the shell elements are supported by ground springs (in radial & tangential direction). The stiffness of the tangential springs is considered as 20% of radial spring (as per Dixon (1971)- Soft ground). To calculate the ground spring stiffness, the Terzaghi approach for calculating ground springs for laterally loaded piles has been adopted for all soil stratums except Seaford Chalk (Ref. CIRIA Report 103, Cl. 4.2). Seaford chalk is considered a soft rock which is not appropriate for the Terzaghi approach which calculates the spring stiffness using the undrained shear strength. Muir-Wood's approach (The circular tunnel in elastic ground – Muir Wood 1975) considers the Young's modulus of the ground and has therefore been adopted for radial and tangential spring calculation for Seaford Chalk formation.

Base slab lies in Lower Mottled Clay, the vertical spring stiffness for base slab is calculated from Vesic (1961) equation (refer equation 9.6 of Bowles, E. (1997) Foundation analysis and Design).

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The Portal & Openings in Secondary Lining are also modelled.

3.1. Material Properties

The material The material properties considered in FEM model & design check are listed below: - .

Element	Concrete Grade (Mpa)	Nominal Cover (mm)
Shaft Secondary Lining	C40/50	50
Shaft Base Slab	C32/40	40 – External 60 - Internal

Partial factor of concrete	γ_c	1.50	
Concrete coefficient for compression (to consider long term effect)	α_{cc}	0.85	
REINFORCEMENT BAR PROPERTIES			
Grade of steel		B500B	
Characteristic yield strength of steel	f_{yk}	500	MPa
Modulus of elasticity of steel	E_s	200	GPa
Partial factor of steel	γ_s	1.15	
Other Material Properties			
Water Density		10.00	kN/m^3
Plain concrete density		24.00	kN/m^3
Reinforced concrete density		25.00	kN/m^3

As per the exposure class, allowable crack width considered is 0.3mm (Table 7.1N, BS EN 1992-1-1).

3.2. Analysis & Design – Step by step method

The design and analysis were done according to the following steps.
STEP 1: The uplift check is performed 1st to see whether the geometry of secondary lining is adequate to resist the very high uplift force.
STEP 2: As mentioned in the above sections the geometry of robot model is prepared as per the clients requirement.
STEP 3: All the load cases as mentioned above are applied in the model. The support conditions with adjoining structure aa well as soil spring stiffnesses were applied in the model.
STEP 4: Load combinations are applied in the models considering the factor from EN-1992-1-1 to get the worst possible result.
STEP 5: Basic Reinforcement is adopted in the Horizontal (Hoop) and vertical direction in the shaft. Basic capacities are calculated based on the provided reinforcement and those are checked for the adequacy w.r.t M-N curve. Required reinforcement is calculated accordingly.

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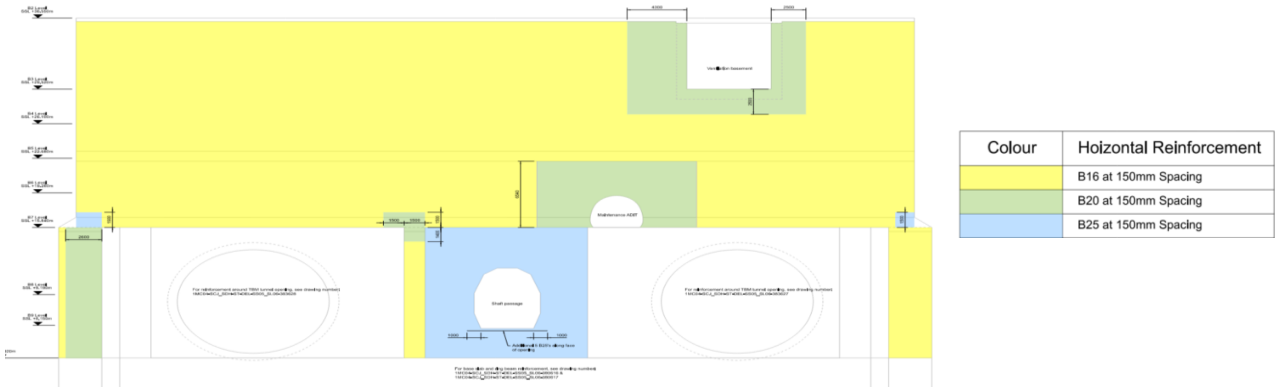
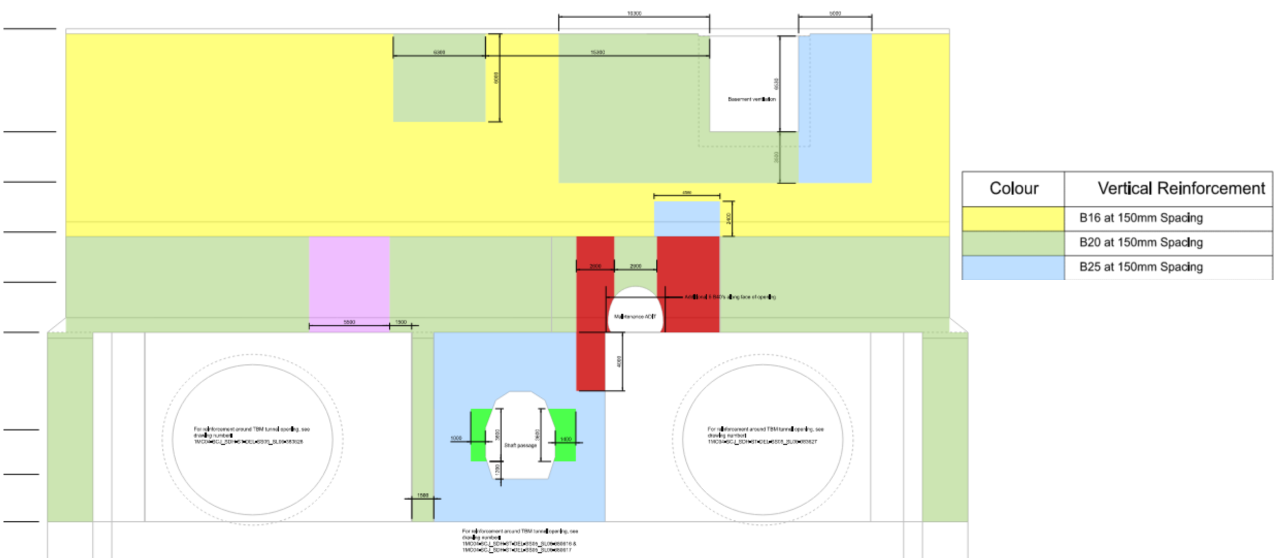


Shaft Secondary Lining _ Section reinforcement adopted for Horizontal Direction



Shaft Secondary Lining _ Section reinforcement adopted for Vertical Direction

STEP 6: For the envelope of all these load combinations the design of structure is performed by an automated excel sheet for both service cases & strength & accidental cases. The crack width has been checked for frequent load combinations. The deflection of the structure is checked for the quasi-permanent combinations & the stress in concrete & steel is verified for the characteristic combinations. For the reinforcement of all the elements the most governing case is the crack width check. All the elements are checked in ULS. Shear check of all elements are done with the ULS load combinations.

STEP 7: Fire and Fatigue checks were also carried out for structural elements in direct contact with movement of train/

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4. CONCLUSION

The objective of the study mentioned above is to have a robust design of the Secondary Lining of the Shaft with all checks required to make it serviceable for its life period. A detailed analysis as mentioned above is required for any structure to work efficiently throughout its life period.

Based on the steps as mentioned above, the required reinforcement is calculated for fulfilling the following outcomes

- Verification of the structure for Uplift
- Analyzing & designing SL of shaft for 120 years' service period
- Analyzing & designing the structure for different service cases which can occur in its life period
- Checking the structure for stress in concrete & steel
- Checking the structure for fire
- Checking the structure for fatigue due to cyclic loading

5. ACKNOWLEDGEMENTS

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6. REFERENCES

EN-1992-1-1 "Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings“
EN-1992-1-1 "Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design“
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