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Our ref: 20248-Letter-210108
Date: 8 January 2021

Re. Greville Street Tunnel Assessment

Dear Sirs

In connection with the proposed development at Greville Street, we have carried out a greenfield ground movement assessment to advise on the predicted ground settlement, radius of curvature and distortion affecting the Crossrail tunnel underlying the site. The results have been updated as additional high quality information was received from nearby sites located at Farringdon Station and Newman Street. The new data included values of the coefficient of compressibility (m_v) from oedometer consolidation tests on London Clay samples. The principal update to the analysis was to replace the estimate of long term movements based on drained elastic stiffness to an approach based on m_v.

Using PDisp, we analysed a greenfield model of the piled option assuming 15m deep piles and used the unfactored loading provided by Atelier One. The model does not include loading from the existing buildings nor does it include the stiffness of the tunnel itself. We would expect that if we included additional structural elements to the model the predicted movements would all be significantly less. We found that the maximum predicted settlement affecting the crown of the tunnel is estimated as 4.1mm.

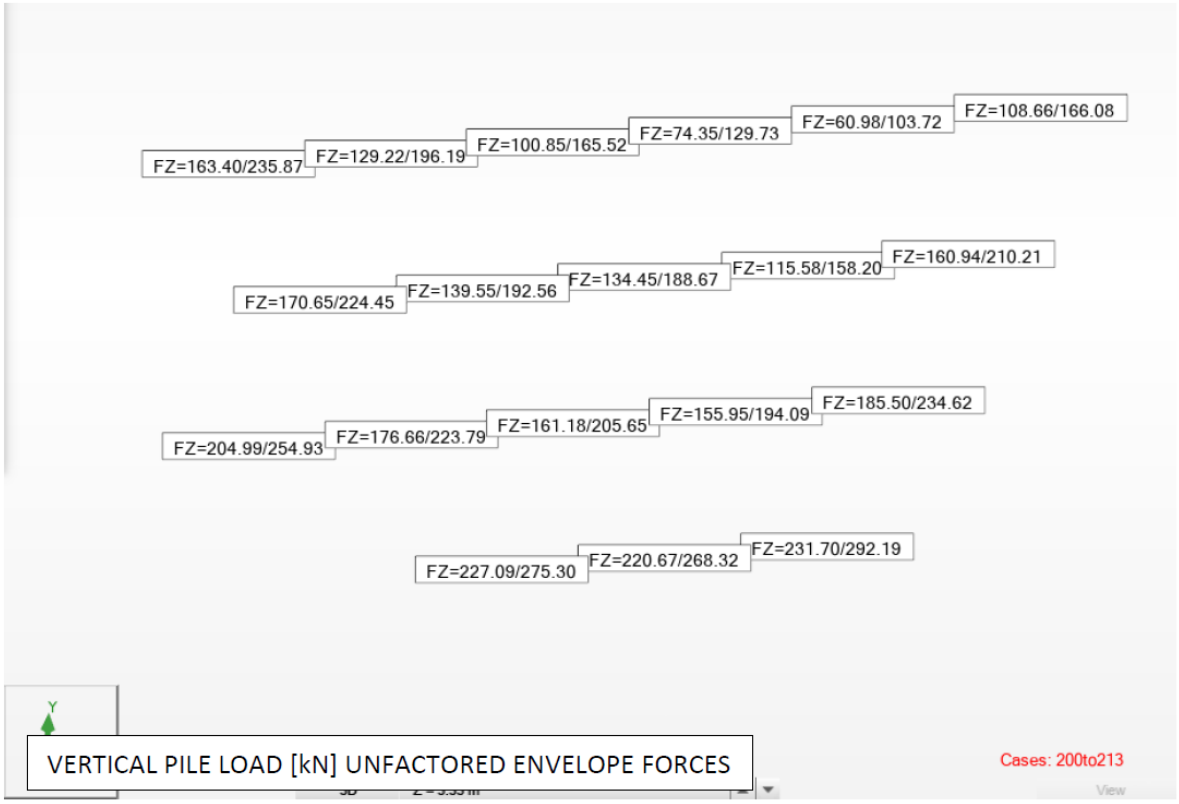
We calculated that the radius of curvature is greater than 10km and therefore it meets the Crossrail tunnel curvature criterion (Crossrail information for developers March 2019.pdf, Section 5.2.1).

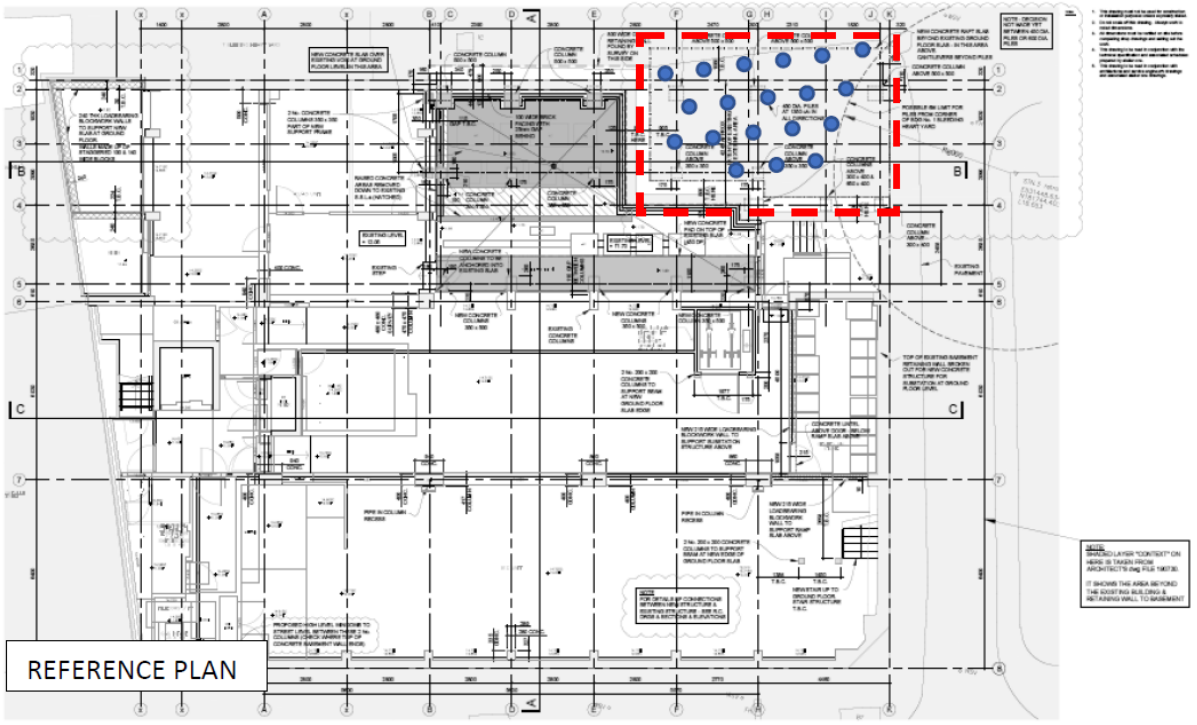
The vertical distortion was calculated based on the difference in movement between the top and the invert of the tunnel. The predicted movement at the crown of the tunnel is 2.1mm greater than the movement at the invert of the tunnel, creating a squatting distortion. The distortion of 2.1 mm is 0.03% of the tunnel's external diameter.

The analysis inputs and results are summarised below:

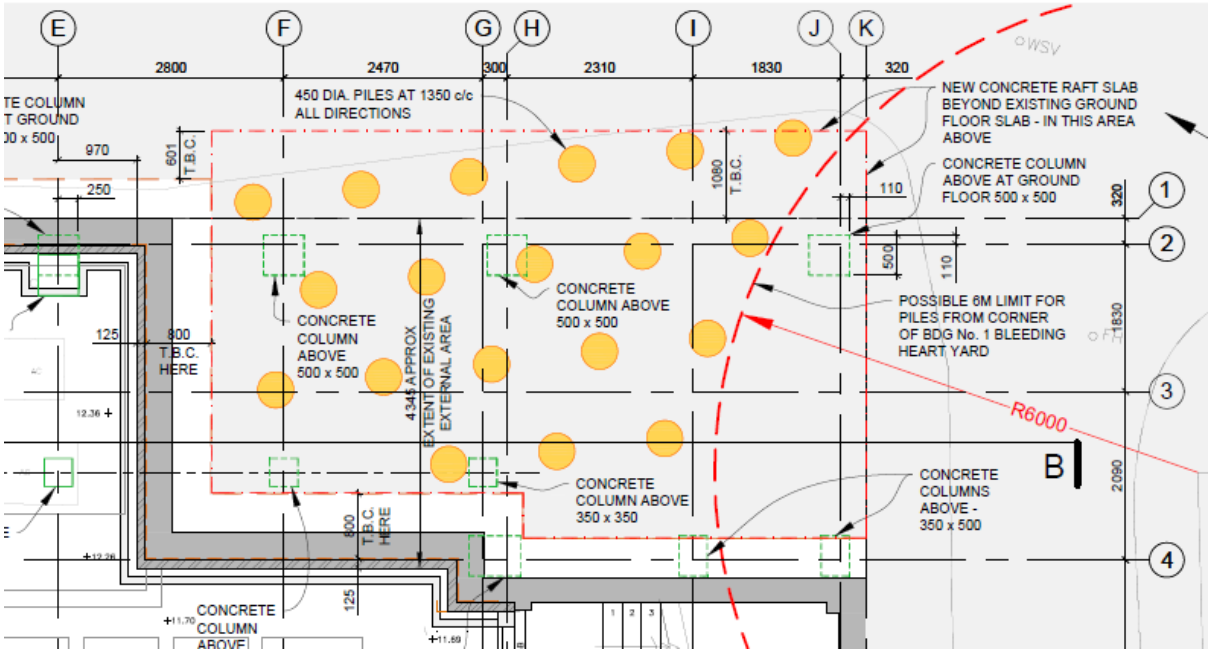
1. Pile loads

- Atelier One provided the following pile load layout. GDG have assumed the maximum loading in the PDisp calculation.





- The drawing provided by Atelier One shows that the foundation slab is approximately 8.1m by 4.5m.



- We applied the equivalent raft method to calculate the loading spread and depth to be used in the PDisp calculation. The load has been input into the model at 11.7m below existing ground level, over an area of 11m by 7.4m, with a load of 48kN/m^2. Note that the equivalent raft calculation did not account for contribution from the Made Ground layer.

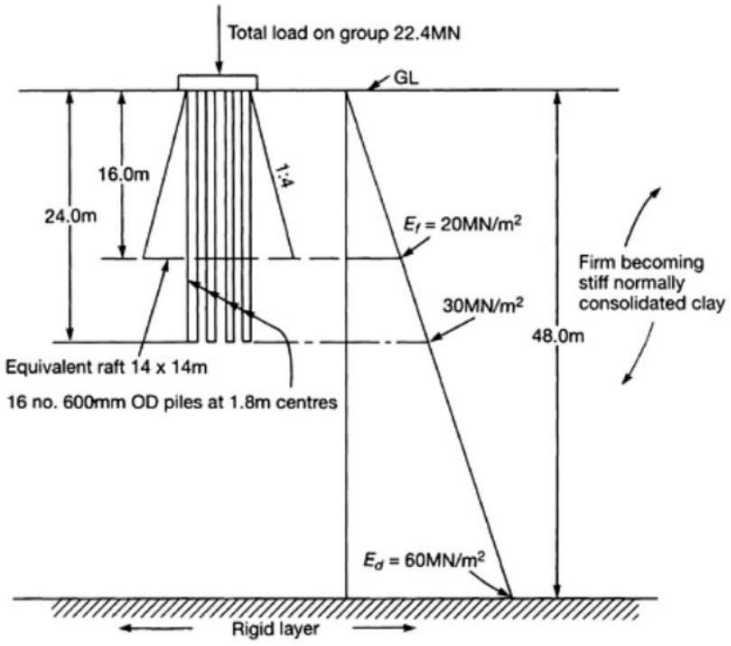
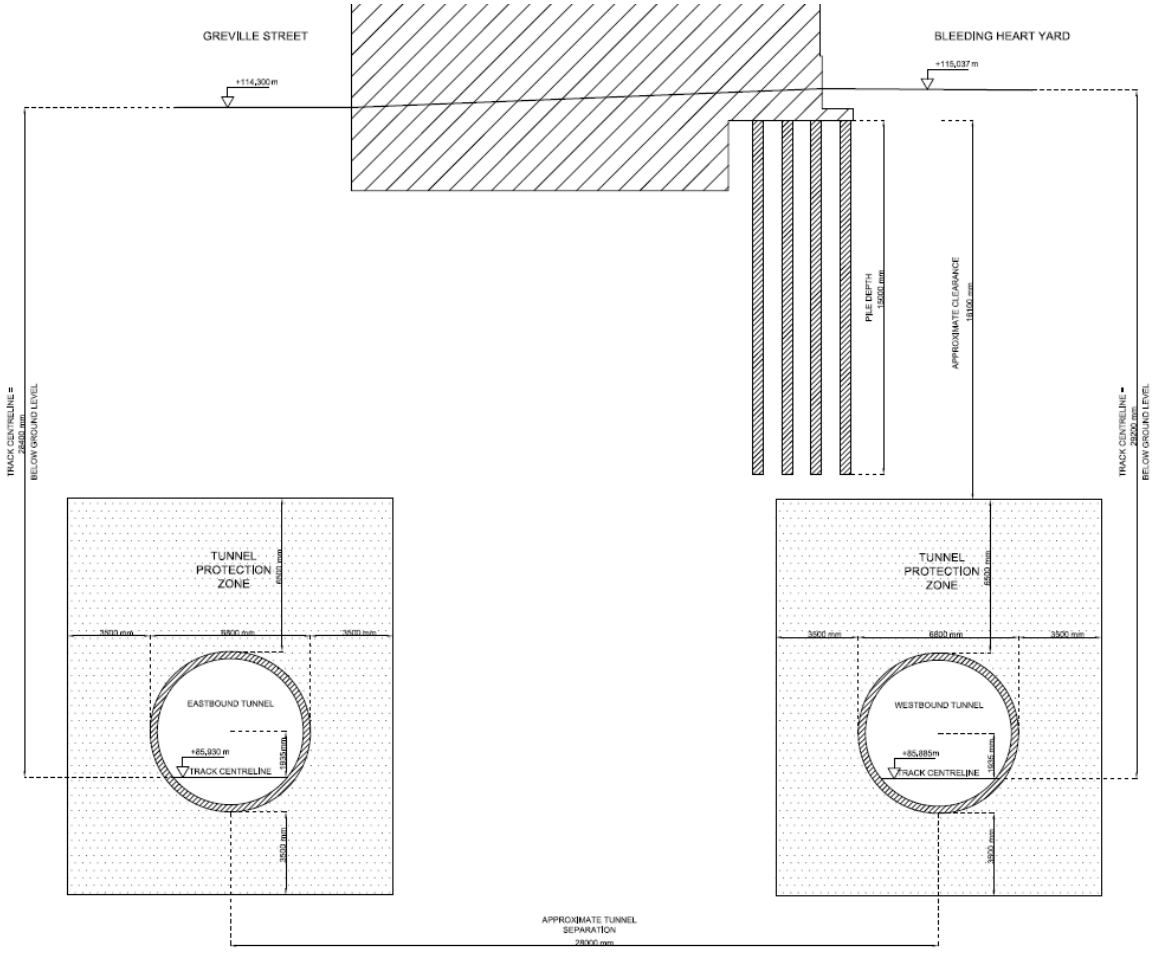


Fig. 5.26 Pile group settlement by equivalent raft method

From *Pile Design and Construction Practice, Fourth Edition, M.J.Tomlinson, 1994.*

2. Tunnel details

We allowed for the crown of the tunnel to be at 23.6m and the invert to be at 30.4m below the top of the existing ground level; hence the external diameter of the tunnel is 6.8m. We modelled the centre line of the tunnel offset by 5.8m from the centre of the pile loading. This based on the information in the drawing below and your advice that the top of the piles will be located at 1m below the existing ground level (see *Section 3. Ground Profile*).



3. Ground Profile

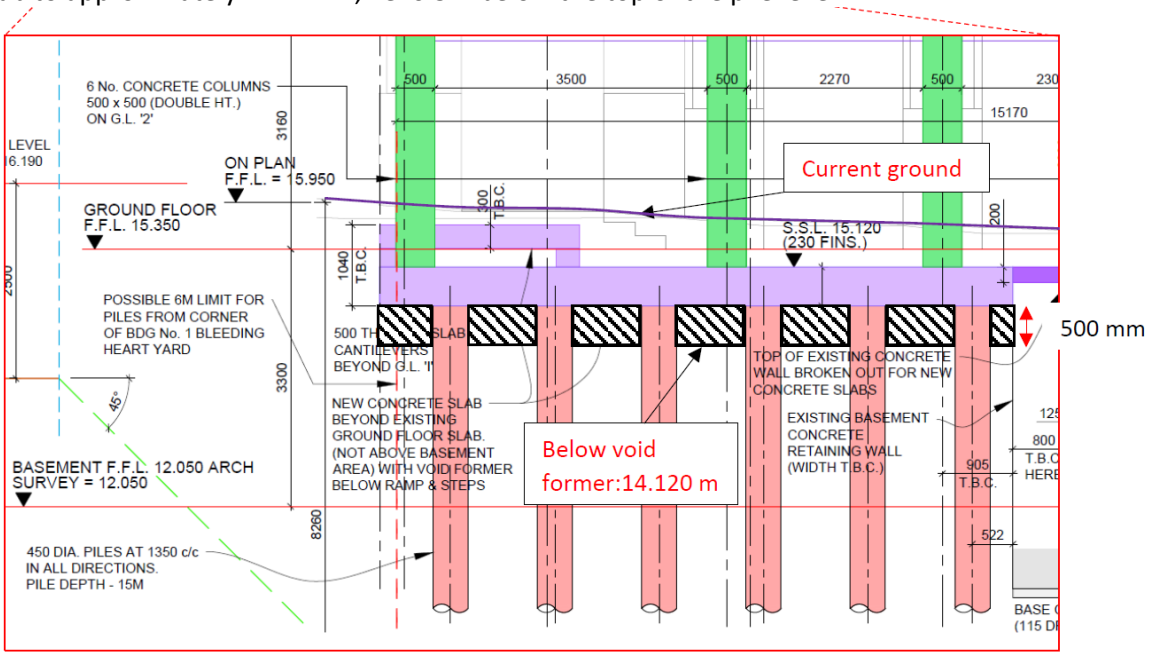
The soil profile and geotechnical parameters were based on information provided in GDG Technical Note 20051-TN-000-01 *Greville Street TN* and information received for sites located nearby at Farringdon Station and Newman Street.

The ground level varies across the site. In the model, the ground level was assumed to be at RL 15.6m as you advised. You also advised GDG that the existing ground level will be lowered to approximately RL 14.1m; i.e. 0.5m below the top of the pile. Therefore the top of the piles will be located at 1m below the existing ground level.

- Ground profile provided in GDG Technical Note 20051-TN-000-01, assumed to start at RL 15.6m based on information from Atelier One

Stratum	Depth to top of stratum (mbgl)
Made Ground (Clayey Sandy GRAVEL)	0
River Terrace Deposits (Gravelly SAND)	3.1
Reworked London Clay (Sandy Gravelly CLAY)	3.4
London Clay (Weathered – Silty CLAY - CLAY)	4
London Clay (Silty CLAY - CLAY)	8
Stiff London Clay (Silty CLAY - CLAY)	12

- Excerpt from Atelier One drawing showing that soil will be excavated below the foundation slab to approximately RL 14.1m; i.e. 0.5m below the top of the pile level



SOUTH ELEVATION

- An uplift load of 24kN/m^2 was included in the PDisp model at 1.5m below the existing ground level over the area of the slab (assumed 8.1m by 4.5m) to account for the excavation to approximately RL 14.1m in the area of the slab/piles.

4. Ground conditions

Groundwater was observed at 3mbgl during stage 2 of the investigation, settling at 2.3mbgl after 20 minutes. This has been inferred to represent possible perched water within the Made Ground or

River Terrace deposits. Groundwater has been conservatively assumed to be at existing ground level in the PDisp model.

Table 1: Assumed properties of materials.

Stratum	Unit weight, γ (kN/m^3)	Undrained stiffness, E_u (MPa)	Poisson's ratio, ν (-)	Coefficient of compressibility, m_v (m^2/kN)**	Permeability, k (m/year)**	Secondary consolidation, $C_{\alpha e}$ **
Made Ground	16	-	0.3	-	-	-
River Terrace Deposits	16	-	0.3	-	-	-
London Clay (Weathered)	19	24	0.5	$6x10^{-5}$	0.315	0
London Clay (Weathered)	20	35	0.5	$6x10^{-5}$	0.315	0
London Clay	20	35+1.75z*	0.5	$6x10^{-5}$	0.315	0
Stiff London Clay	20	42+1.75z*	0.5	$5x10^{-5}$	0.315	0

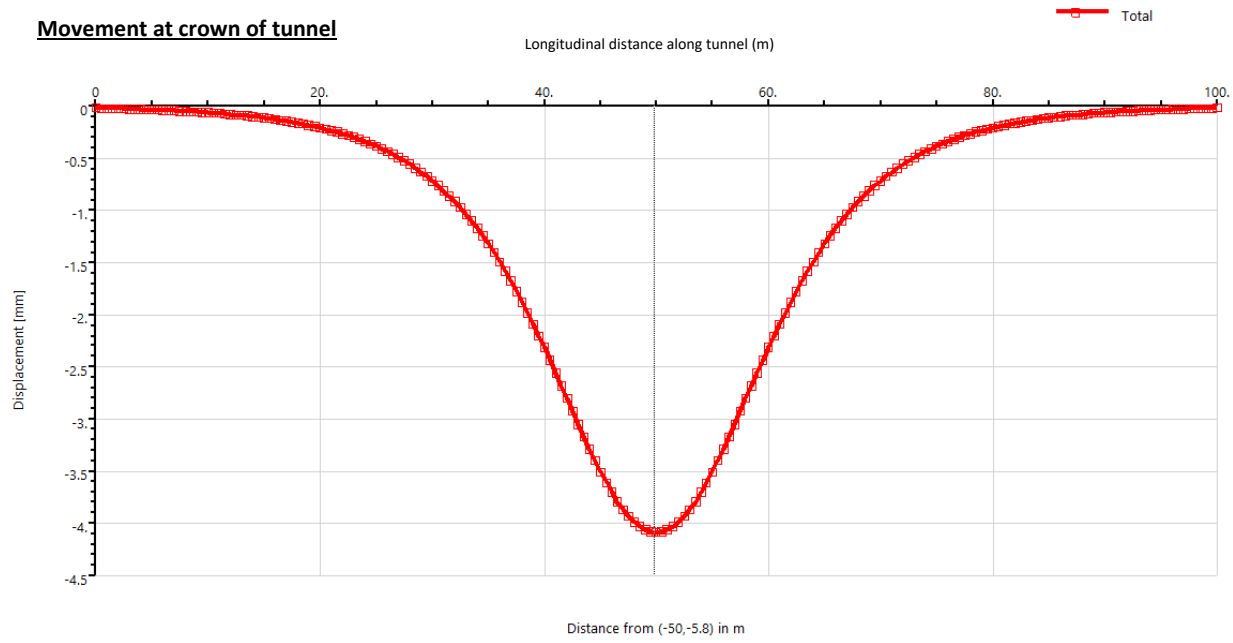
* z is depth below the top of stratum level.

** consolidation and permeability parameters are assumed values based on our experience with London Clay and tests results from a nearby sites located at Farringdon Station and Newman Street, as there were no site specific tests carried out.

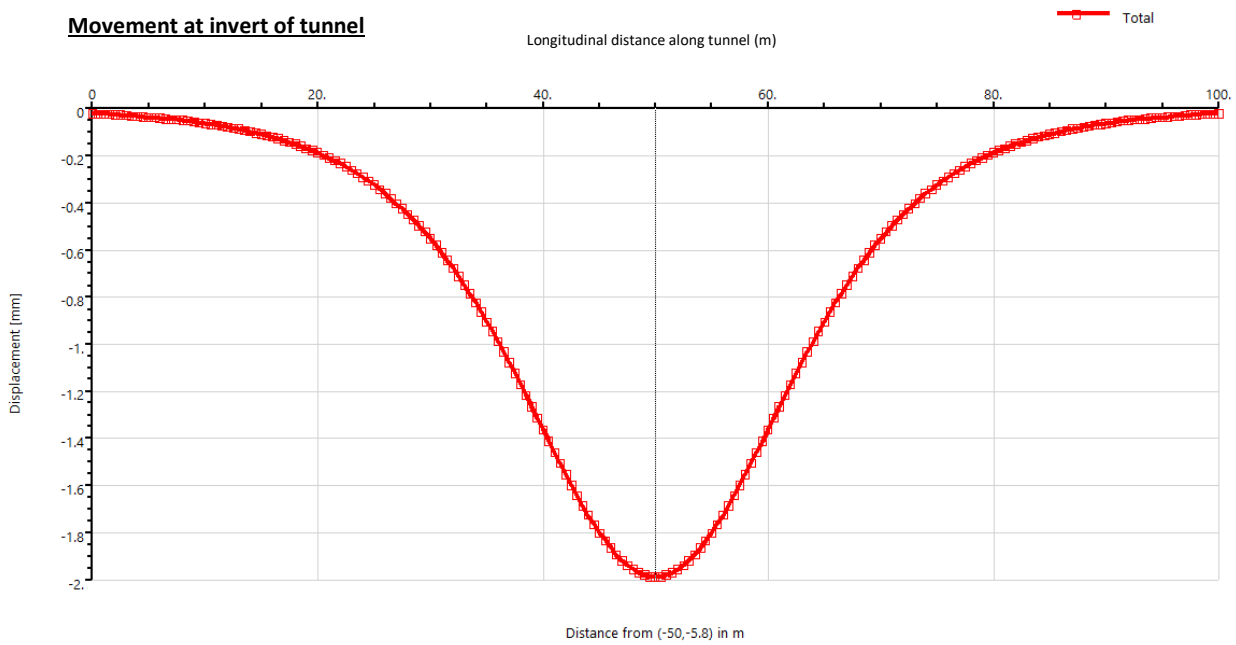
5. Displacement results

The displacement results account for the estimated total settlement; i.e. the immediate settlement plus long term consolidation.

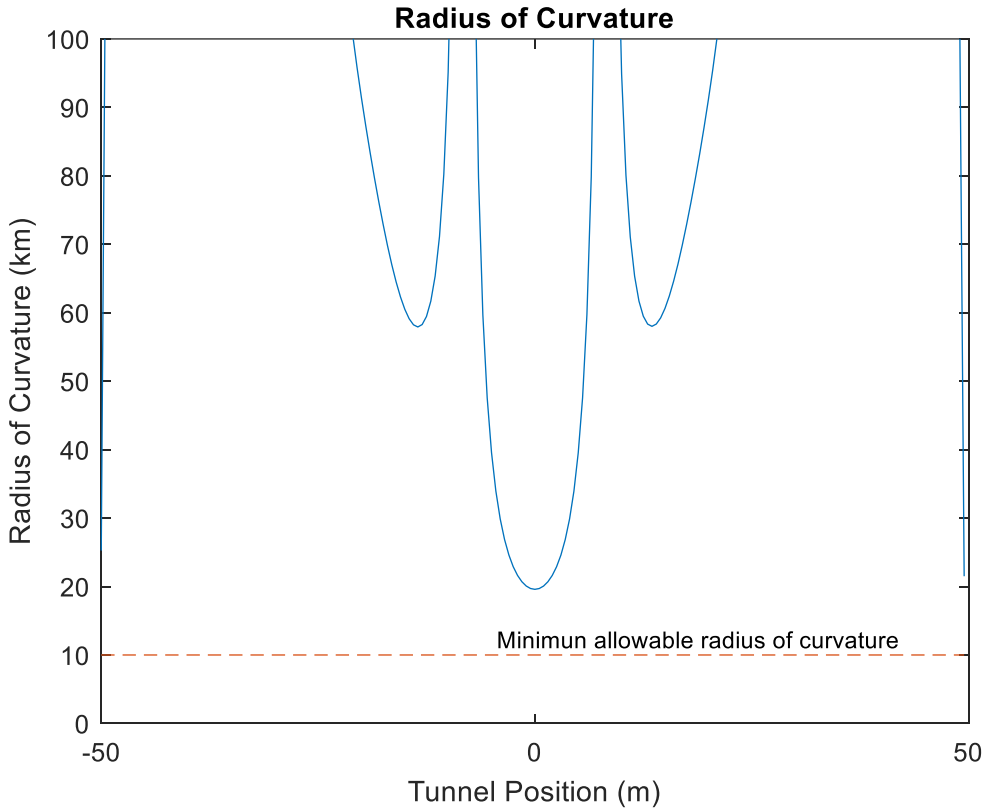
The crown of tunnel is assumed at 23.6m below existing ground level (RL -8m). The maximum total settlement at the crown of the tunnel is predicted to be 4.1mm. The diagrams below show the predicted settlements along the tunnel crown and invert.



The invert of the tunnel is assumed at 30.4m below existing ground level (RL -14.8m). The maximum total settlement at the invert of the tunnel is predicted to be 2.0mm.

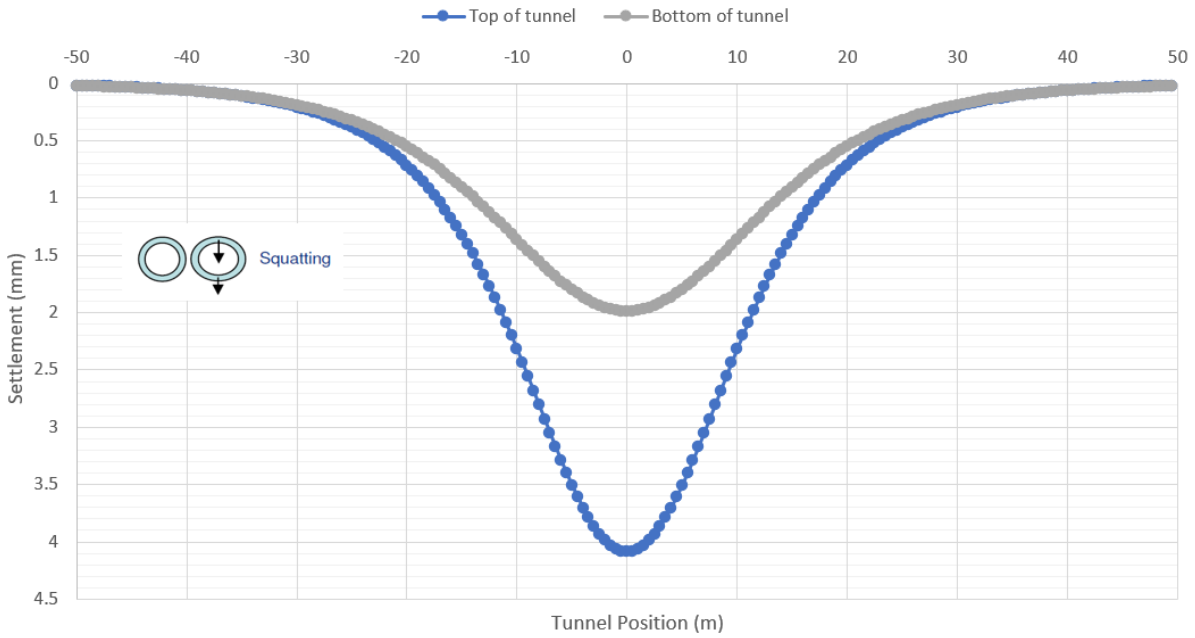


6. Radius of curvature (always greater than 10km)



7. Distortion (maximum distortion is 0.03% of the tunnel's external diameter)

The predicted distortion is 2.1mm, less than 3mm and therefore within Crossrail criteria.



Yours faithfully
For and on behalf of
Gavin and Doherty Geosolutions

Clare Brennan

Senior Engineer

cc Neil Smith