

Abstract

Segmental cast iron tunnel linings are ubiquitous in London and throughout the world. It is known that the material properties are quite variable and that fundamentally, the material is brittle and weak in tension. Many of these tunnel linings have been in-situ for over 100 years and when the status quo is broken by the construction of new sub-surface works nearby, the tunnel linings inevitably displace and distort. Designers make the assumption that the tunnel lining effectively behaves as a beam within the ground (i.e. it is continuous); designers derive the radius of curvature from ground movement predictions (often based on empirical approaches) and use beam-theory (Euler-Bernoulli) to derive the strain and stresses within the tunnel lining; by using this approach, it is often the case, that the material limits are breached and measures must be mobilised to mitigate damage to the structure.

In practice, tunnel linings are observed to undergo seemingly tight radii of curvature without evidence of damage or failure. This, allied to research that has modelled the interaction of the tunnel linings in numerical simulation, has indicated that the behaviour is complex and not necessarily akin to a beam; hence, this research looks to more closely assess the mechanisms by which the existing segmental tunnel linings accommodate ground movement, and in doing so, to establish if the current methods of setting damage criterion and assessment, need to be updated.

To this end, instrumentation was installed within a cast iron tunnel lining that underwent displacement as a result of nearby tunnelling. To observe the localised movements that occur at the tunnel joints, strain gauge instrumented tunnel bolts, displacement transducers, crack meters were installed and distributed fibre optic strain sensing was conducted. To observe the global displacements, an automatic total station system was used.

The observed data indicate that the tunnel rings compress together at the circumferential joints, suggesting that gaps between the segmental rings are present from installation. Also, the rings are seen to differentially shear. The act of shearing reduces the longitudinal strain within the tunnel lining as some of the vertical displacement is accommodated as the rings slip in this shearing mode.

In addition, a numerical simulation was performed to better understand these localised observations in a global context. It is found that there is a disparity in the soil movements

in the longitudinal direction, between prediction and observation (when the prediction assumed constant volumetric straining conditions). The horizontal component of displacement required interrogation of the soil / structure boundary; this was performed as a parametric study. In evaluating this boundary, it is found that the compressive stiffness of the tunnel lining must be reduced in order to re-produce the compressive behaviour observed by the monitoring instruments. Thus confirming that gaps are likely to pre-exist between the segmental tunnel rings.

The tunnel lining is seen to have a displacement mechanism dominated by the soil movement, with the flexural stiffness of the tunnel lining effectively negligible in determining the structure response. It is seen that as the tunnel lining is stretched by the soil movements, the circumferential flanges distort and pivot around the circumferential bolts. Where the circumferential flanges are restrained by the radial joints, much more strain (and load) is transferred into the circumferential bolts (i.e. those circumferential bolts adjacent to the segment radial joints).

Furthermore, as shearing is seen as a significant component to the tunnel lining displacement, an alternative beam-theory by Timoshenko is used to assess the tunnel lining in light of the observation data. The model considers shear stiffness of the beam and shear displacement can be isolated along the beam (tunnel). In performing this analysis, it is found that the model has the potential to generate strains at the beam fibre akin to the observation, and in doing so, provides designers with an updated tool to perform assessment of segmental tunnel linings under the existing analytical framework.

Further observations are required to give more validation to the findings here, but nonetheless, the alternative assessment methodology could give improved assessment results for similar scenarios, giving stakeholders more confidence that the structures are safeguarded, whilst also giving scope to relax damage mitigation measures.