Non-linear analysis of tunnel linings under longitudinal bending

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The Holland and PATH tunnels under the River Hudson have both settled much more than is usual for soft ground tunnels. The PATH tunnel 'A' emerges from hard rock into soft river deposits, with no special protective features to accommodate relative movement at the transition. Would not Dr Sucuoğlu then agree that, as apparently neither of these tunnels has suffered loss of serviceability from longitudinal bending during their long lives, the results confirm that it is unnecessary to consider longitudinal bending at the design stage except in very special circumstances?

50. In the past there has been a difference in practice between US and UK tunnellers: US engineers have tended towards high tensile bolts carefully tightened to considerable specified tension, whereas UK engineers have tended to regard circumferential bolts as a convenience for erecting the segments. One is tempted to suggest that all Dr Sucuoğlu's worries would disappear if all the circumferential bolts were removed or at least loosened, but not perhaps under the Hudson.

51. In my experience, even when building accurately-machined cast iron tunnel segments, it is impossible consistently to achieve a metal to metal bearing between rings. The tunnel needs 'packing on' to achieve desired line, level and shape, even if special taper rings are provided; and if dirt lodges between segments in the invert, what happens in the crown? It is normal to find a 'creep' of several metres in a kilometre of tunnel, and once the joints are hidden by caulking, who can say how well they have been formed? The Paper makes no mention of the grummets (or grommets) used to make the circumferential bolt holes watertight in these tunnels. I suggest that these factors may have a significant effect on the bolt stresses and flange distortions mooted in the Paper.

52. Has Dr Sucuoğlu investigated temperature effects? The PATH subway tunnels may have fairly constant temperatures, but presumably the Holland highway tunnels have a considerable seasonal temperature range.

Dr Sucuoğlu

The investigated tunnels did indeed have a serviceability problem although not displayed in a very significant form: this was the leaking of water through the deformed joints.

54. I agree that longitudinal bending does not deserve special attention in a routine design process; however, longitudinal bending behaviour is worth investigating in order to make the correct decision on whether it should be accounted for

DISCUSSION

or ignored in a special design case. In fact, engineering would not be an exciting profession if those special circumstances did not exist.

55. The conditions mentioned by Mr Bartlett, such as the effect of grommets on the circumferential bolt stresses, and the effect of temperature variation on the lining stresses, have not been investigated in the present study. In this sense, it has to be accepted that my study stresses the analytical model and that practical considerations in the field may often be different. Although the temperature-induced stresses may certainly be determined by the proposed method with slight modifications, analytical models devoted to calculating the overall response to a specific type of loading are usually not suitable for calculating the localized effects. A simple stress analysis approach, which focuses on a behaviour detail, is possibly more efficient than a general approach.