Numerical Analysis of Interaction Between Twin Tunnels and Tunnel-Foundation Systems under Static and Seismic Conditions

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Due to the increased transportation demands and less utilizable space on the ground, metro transportation by underground means has become the preferred alternative in many developing economies. The capital city of India, New Delhi is no exception. But in congested cities like New Delhi, it becomes important to quantify the construction stage interactions between infrastructure facilities and metros. Another issue at hand is the high seismicity of New Delhi. Thus it becomes imperative that seismic interactions also need to be incorporated. Finally as an engineer, it also becomes important to ensure the safety of tunnel liner against static and seismic loads irrespective of ground conditions (liquefiable or non- liquefiable).

In this study, an attempt was made to capture the aforementioned interactions for the geotechnical/site specific seismic conditions in New Delhi. Hence studies were subdivided in to twin-tunnel interactions, tunnel-shallow-foundation interactions, tunnel-pile-foundation interactions and behaviour of tunnels in liquefiable soils. After extensive numerical studies performed for geotechnical conditions in New Delhi, a pillar width of '*2D*' between twin tunnels was deemed safe against static and seismic interactions (Here '*D*' represents tunnel diameter). However, it was clear that cumulative strains induced on the tunnel liner during seismic activity caused serviceability issues. A critical observation during the course of this study was the manifestation of earthquake energy as amplified spectral responses around the pillar, especially for shallow tunnels (Cover depth < *2D*). Thus it could be safely concluded that, any ground response analysis should include the presence of underground cavities (if present) for a realistic surface response. After performing tunnel foundation interaction studies, it was clear that, tunnel liners should be designed for additional safety factors, by incorporating the presence of foundations, if foundations were allowed to undergo maximum permissible settlements. The trend of safety factors with cover depth revealed an evident decrease of the same, as improvement of soil modulus happens with depth, especially for Gibson soil profiles. Load displacement curves of the footing under varying construction sequence of the tunnel were observed and trends were understood. Volume loss phenomenon during the course of tunnel construction evidently resulted in the bearing capacity loss, when the effects of tunnel construction on existing foundations were considered. The reverse problem revealed the stiffening of soil deposits due to un-load reload phenomena, that occurs during tunnel construction. It was observed that, foundations constructed around the pillar of the tunnel were subjected to amplified spectral responses, resulting in high zonal factors. Tunnel- pile-foundation interaction studies revealed an evident "zone of large pile displacements" where tunnels were constructed near pile foundations. These zones were observed at 45° with respect to the tunnel springing line. Any pile constructed at an offset ratio of less than 1.0 was subjected to high pile displacements, where ground improvement was unavoidable. On the similar lines a safe offset ratio (where only 20% of pile load reduction) of 2.5 have been identified. For any pile constructed at a safe clearance (i.e. pile tip to tunnel crown distance) of more than 0.5*D*, tunnel liner was found to be safe against safety and serviceability issues. Like it was observed for shallow foundations, piles constructed around the pillar were found to be subjected to amplified seismic responses. For tunnels constructed in liquefiable soils, especially at shallow cover depths, thrust increments on the tunnel should be given importance in design. Uplift was also observed as a serious problem in these cases for tunnels. The thrust increments on tunnels in liquefiable soils were identified due to the load-transfer phenomena between liquefied soil pockets and tunnel liner. While increasing the tunnel cover depth was suggested to be an option, considering practicality, ground improvement by grouting was suggested as a method to encounter these problems. All the mentioned studies regarding interactions and the behaviour of tunnels in liquefiable soils finally resulted in simplified design suggestions which could be easily incorporated to the design of underground structures, especially in New Delhi (or in similar geotechnical profiles).