Physical and Numerical Modelling of Tunnel Intersections Under Impact and Blast Loads

ABSTRACT

A rapidly growing human population entails infrastructure development particularly to cater the transportation facilities. Owing to the space shortage for expansion of facilities on the ground, underground space is being increasingly and excessively utilized not only limited to transportation but for material storage and conveyance as well as shelters and dwellings. Optimisation of underground space usage is equally important and hence, tunnel networks with interconnected tunnels are being constructed making tunnel intersections inevitable in the system. Given the global geopolitical scenario, countries have resorted to military attacks involving the use of missiles and blast weapons. Instances of terror attacks also keep on capturing the headlines with history of major attacks on subway networks. The omnipresence of tunnels which are expensive and important civil engineering structures makes these prime targets of possible attacks involving projectiles and blasts. Once the tunnel is subjected to hazardous load, its structural performance takes a major and sharp dip significantly affecting the serviceability.

The present thesis aims to understand the deformational and damage response of tunnel intersections when subjected to impact and blast loads. This has been carried out through detailed physical model tests and numerical analyses of unlined and lined tunnels. Shallow tunnel surrounded by weak and weathered rockmass has been scaled down to laboratory scale. The representative rock is synthetically prepared in laboratory by combining Plaster of Paris, Badarpur sand and kaolinite clay. A novel methodology has been outlined for casting tunnel models with tunnel intersections for different intersecting angles (30°, 60°, 90°) and cover depth to diameter ratio (C/D) (0.5, 0.7, 1.0) representing the tunnel placement at shallow

depths. A drop hammer type impact loading setup, Impact Testing Facility (ITF) has been utilised for studying the deformation and damage of tunnel models by subjecting the tunnel models to surface impact. The results obtained from physical model tests are used for verifying and validating the results from numerical modelling. The numerical modelling is performed using finite element-based package, Abaqus/Explicit.

The behaviour of unlined tunnel intersections as a response to surface blasts has been studied numerically using Abaqus/Explicit. The blast load is generated by assigning John-Wilkins-Lee (JWL) equation of state to Trinitrotoluene (TNT).

The major findings of the thesis comprise (1) Determination of the most susceptible tunnel intersection angle (60°) to deformation and collapse for surface impact load above the junction; (2) Representation and quantification of distinct localized damage zone and patterns that develop at junction on crown for different intersection angles; (3) A predictive equation for obtaining peak crown deformation at junction for surface impact and blast loads; (4) A predictive equation for obtaining longitudinal displacement profile of main tunnel following surface impact; (5) A five class damage classification system based on critical strain method; (6) Relative suitability and behaviour of two different linings in control the deformation and altering the failure mode in the surrounding rock.

The findings and recommendations of the thesis are insightful for understanding the tunnel intersections aiming at development of safe and resilient tunnel networks with optimum utilisation of underground space.