Chatuphat Savigamin

SEISMIC RESPONSE OF DEEP CIRCULAR TUNNELS SUBJECTED TO P- AND S-WAVES

Most of the attention to the seismic performance of tunnels has been devoted to shear waves propagating in a direction perpendicular to the tunnel axis, with motion perpendicular to the tunnel axis, causing the so-called “ovaling or racking response”. Body waves, however, can travel through the ground and intersect the tunnel at different angles, thus inducing a complex seismic response that requires a comprehensive understanding of all modes of deformation. This study provides analytical solutions to capture the behavior of the liner and the surrounding ground, for a deep circular tunnel subjected to body waves, for all five possible modes of deformation: (1) axial compression-extension; (2) transverse compression-extension; (3) ovaling; (4) axial shear; and (5) axial bending or snaking. The main assumptions used to derive the analytical solutions include: (1) the tunnel is deep and very long and has a circular cross section; (2) the ground and the support are homogeneous and isotropic, and their response remains elastic; (3) the interface between the ground and the liner is either no-slip or full-slip; (4) the pseudo-static approach, i.e. inertia forces can be neglected, is acceptable to estimate seismic deformations; (5) for the transverse compression-extension and ovaling deformation modes, plane strain conditions in the direction of the tunnel axis apply at any cross section; and (6) for the axial compression-extension and axial bending deformation modes, the wavelength of the seismic motions is much larger than the tunnel radius. Two and three-dimensional numerical simulations with the finite element codes ABAQUS, for static drained/undrained loading and dynamic drained loading conditions, and MIDAS GTS NX, for dynamic undrained loading conditions, are carried out to validate the analytical solutions and further investigate the seismic response of the tunnel. All the comparison results show good agreement between the analytical and numerical solutions. Dynamic amplification effects on the tunnel cross section are studied for the axial compression-extension, transverse compression-extension, and axial bending deformation modes, through a set of dynamic time-history models where the input frequency of the far-field seismic motion is changed. The results reveal the limits of the analytical solutions, in the form of minimum wavelength-to-tunnel diameter (λ/D) ratios within which the errors are less than 20%.

Keywords: Seismic response of tunnels, Axial compression-extension, Transverse compression-extension, Ovaling, Axial shear, Axial bending