ABSTRACT

Sandoval V., Eimar A. Ph.D., Purdue University, May 2019. Undrained Seismic Response of Underground Structures . Major Professor: Antonio Bobet.

Underground structures must be able to support static overburden loads, as well as to accommodate additional deformations imposed by seismic motions. Progress has been made in the last few years in understanding the soil-structure interaction mechanisms and the stress and displacement transfer from the ground to the structure during a seismic event. It seems well established that, for most tunnels, the most critical demand to the structure is caused by shear waves traveling perpendicular to the tunnel axis. Those waves cause distortions of the cross section (ovaling for a circular tunnel, and racking for a rectangular tunnel) that result in axial forces (thrusts) and bending moments. While all this has been well-studied for structures placed in linear-elastic ground, there is little information regarding the behavior of buried structures placed in nonlinear ground, especially under undrained conditions, i.e., when excess pore pressures generate and accumulate during the earthquake.

Two-dimensional dynamic numerical analyses are conducted to assess the seismic response of deep circular tunnels located far from the seismic source, under drained or undrained loading conditions. It is assumed that the liner remains elastic and that plane strain conditions apply. A new cyclic nonlinear elastoplastic constitutive model is developed and verified, to simulate the nonlinear behavior and excess pore pressures accumulation with cycles of loading in the ground, The results of the numerical analyses show negligible effect of input frequencies on the normalized distortions of a tunnel for input frequencies smaller than 5 Hz (the distortions of the tunnel are normalized with respect to those of the free field); that is, for ratios between the wavelength of the seismic input and the tunnel opening larger than about eight to

ten. The results also show that undrained conditions, compared with drained conditions, tend to reduce deformations for flexible liners and increase them for stiffer tunnels, when no accumulation of pore pressures with cycles of loading is assumed. However, when pore pressures increase with the number of cycles, the differences in distortions between drained and undrained loading are reduced, i.e., the normalized distortions increase for flexible and decrease for stiff tunnels, compared to those with drained conditions.

Undrained loading produces larger thrust in the liner than drained loading for stiff tunnels with flexibility ratio $F \leq 2.0$. For more flexible tunnels with $F > 2.0$, the behavior is the opposite, i.e., smaller axial forces are obtained for undrained loading than for drained loading. Including excess pore pressure accumulation does not introduce significant changes in the axial forces of the liner, irrespective of the flexibility of the tunnel, compared to those obtained from undrained loading without pore pressure accumulation. The drainage loading condition (drained or undrained) or the magnitude of the free-field excess pore pressures during undrained loading do not affect the normalized bending moments for flexible tunnels, with $F \geq 2$. For stiffer tunnels, with $F < 2$, the normalized distortions increase from drained to undrained loading, and with the free field excess pore pressures.