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A model study on the effects of input motion on the seismic behaviour of tunnels

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ABSTRACT

Tunnel behaviour under earthquake loading is affected by many factors such as shape, depth and stiffness of the tunnel lining and the nature of the input motion. However, current knowledge on the effects of these parameters on the seismic behaviour of tunnels is limited to lack of experimental or field data. Existing analytical methods are based on assumptions, the validity of which needs to be established using carefully conducted experimental studies and numerical analyses. This paper focuses on the effects of input motion characteristics on seismic behaviour of circular and square tunnels. Dynamic centrifuge tests were carried out on model tunnels using input motions of different amplitude and frequency. Accelerations and earth pressures around the tunnels were measured. Complementary Finite Element analyses were conducted with different types of input motions. Results show that magnitude of the maximum input acceleration plays a crucial role on the maximum and residual lining forces, which the tunnel experiences.

1. Introduction

Tunnels constitute a major part of civil infrastructure and serve as public transportation facilities, sanitation and irrigation utilities and storage places. In seismically active areas, these tunnels are under earthquake induced risks. Recent events such as Kobe Earthquake in Japan (1995), Duzce Earthquake in Turkey (1999), Chi-chi Earthquake in Taiwan (1999), Bam Earthquake in Iran (2003) and the Wenchuan Earthquake in China (2008) showed that tunnels are susceptible to receive irrecoverable damage due to seismic loading.

The few case studies that exist show that slope failure near the tunnel, shearing off the lining due to fault crossing the tunnel axis, liquefaction induced floatation or sinking or ovaling and racking of tunnel lining due to vertically propagating transverse shear waves are major causes of damage to the tunnels [1–3] Ovaling and racking of tunnel lining are reported to be the most critical sources of damage to the tunnel structure [4]. Damage is reported to be increasing as the duration of the earthquake increases, because repeated load cycles cause fatigue in the tunnel lining [1].

Current analytical design methods rely on elasticity solutions to calculate dynamic (incremental) lining forces a tunnel experiences during an earthquake event and generally ignore the inertial effects. Two main approaches exist: Free-field approach and Soil-Structure Interaction (SSI) approach. Free-field approach assumes that the tunnel linings conform to movements of the surrounding soil and uses free-field deformations to solve for the dynamic lining forces. Free-field deformations are calculated using either a simplified mode shape, a site response analysis or with more complex numerical methods [1].

This paper focuses on the effects of input motion characteristics such as frequency, amplitude and the duration on the dynamic behaviour of the circular and square tunnels under vertically propagating transverse shear waves. The aim is to present experimental data and numerical analyses regarding the effects of input motion amplitude, frequency and duration on the seismic behaviour of circular and square tunnels. Only cross sectional deformations in transverse direction were taken into consideration. Experimental data was obtained by conducting dynamic centrifuge tests on small scale model tunnels in dry, loose Fraction E silica sand. Complementary 2-D plane strain Finite Element (FE) simulations were also conducted for some of the tests.

2. Dynamic centrifuge tests

Geotechnical centrifuge testing is a commonly used technique in modelling of the geotechnical structures. The purpose of a centrifuge test is to model in-situ stress–strain behaviour in a small scale model through the application of high centrifugal accelerations. Scaling laws are needed to convert measured quantities from model scale to prototype scale and interpret the results. Common scaling laws [5] were derived by using dimensional analysis. Some of these are given in Table 1.

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