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2-D analysis of circular tunnel against earthquake loading

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Abstract

The use of underground structures such as tunnel for subways, highways, material storage, and sewage and water transport is increasing in developed countries. The safety of these facilities during operation in areas with seismic activities such as in Japan, Taiwan and Turkey in recent earthquakes has been questioned. Dynamic effects on these structures are in the form of deformations that they experience during earthquakes. In this paper, first latest methods on the subject are reviewed and then the interaction between the ground and tunnel lining during earthquake excitation is investigated by a finite difference computer program (CA2). Analysis show that a good agreement between analytical closed form and numerical solutions exist. According to the results obtained in this study some practical suggestion for using closed form solution are also given.

Keywords: Earthquake; Flexibility; Lining; Seismic; Tunnel

1. Introduction

In recent years because of construction and increasing trend in using large tunnels and underground spaces, the safety of these structures during operation and their response against earthquake loading have been addressed by many researchers. For some times general belief has been that effect of earthquake on tunnels and underground spaces is not very important and have long been assumed to have the ability to sustain earthquakes with little damage. Nevertheless, some underground structures have experienced significant damage in recent earthquake including the 1995 Kobe, Japan earthquake, the 1999 Chi-Chi Taiwan earthquake and the 1999 Kocaeli Turkey earthquake (Hashash et al., 2001) and recently 2004 Baladeh Iran earthquake (principal author's personal experience regarding many rock falls in the vicinity of Kandouvan tunnel during the earthquake) proved otherwise. According to recent studies and observed failures of underground structures, researchers relate response of these structures during earthquake to various parameters. According to statistical studies following general conclusion in this regard are drawn (Dowding and Rozen, 1978; Owen and Scholl, 1981; Wang, 1993; Hashash et al., 2001):

1. The effect of earthquake on underground structures depend on factors such as; depth of tunnel below the ground surface, type of soil or rock surrounding tunnel, maximum ground acceleration, intensity of earthquake, distance to earthquake epicenter and type of tunnel lining.
2. Failures in rock tunnels are much less than those in earth tunnel.
3. Underground structures as compared to structures on the ground have more safety.
4. General failures occur when an active fault is crossed the axis of the tunnel.

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5. Failures of near surface tunnels such as a cut and cover tunnel is more than those of deep tunnels.
6. More damage occurs to portal structures than to the underground tunnel itself due to slope instability.
7. Lined and grouted tunnels are safer than unlined tunnel in rock, shaking damage can be reduced by stabilizing the ground around the tunnel and by improving the contact between the lining and the surrounding ground through grouting.
8. Tunnels are more stable under symmetric load, which improves ground–lining interaction. Improving tunnel lining by placing thicker and stiffer sections without stabilizing surrounding poor ground may result in excess seismic forces in the lining. Backfilling with non-cyclically mobile material and rock-stabilizing measure may improve the safety and stability of shallow tunnels.
9. Damage may be related to peak ground acceleration and velocity based on the magnitude and epicentral distance of the affected earthquake.
10. Duration of strong-motion shaking during earthquakes is utmost importance because it may cause fatigue failure and therefore, large deformation.
11. High frequency motions may explain the local spalling of rock or concrete along planes of weakness. These frequencies which rapidly attenuate with distance, may be expected mainly at small distances from the causative fault.
12. Ground motion may be amplified upon incidence with a tunnel if wavelength are between one and four times the tunnel diameter.

Because Iran is in an active seismic zone and because of increasing number of tunnels and underground construction in recent years in this country, the study of earthquake response of these underground structures needs special attention and treatment.

2. Effect of earthquake on tunnel

Earthquake effects on underground structures falls into two groups: (1) ground shaking; and (2) ground failures such as liquefaction, fault displacement, and slope instabilities (Hashash et al., 2001). In this paper item (1) will be considered. When an earthquake occurs various bodies and surface waves are produced. Effect of earthquake waves on an underground structure is related to three factors namely (i) source region, (ii) transmitting region and (iii) site region (Wang, 1993). After earthquake occurrence in source region, waves transmit the produced energy to the underground structure. Because of damping effects in the transmitting region,only fraction of total energy will reach the structure. Distance of the site from the source region and type of material affect final effect of earthquake on the structure.

The behavior of a tunnel is sometimes approximated to that of an elastic beam subject to deformations imposed by the surrounding ground. The response of tunnels to earthquake shaking appears in three forms of deformation (Owen and Scholl, 1981): axial compression and extension (Fig. 1(a),(b)), longitudinal bending (Fig. 1(c),(d)), and ovaling/racking (Fig. 1(e),(f)). Axial and curvature deformations in horizontal or near horizontal tunnel occur because of wave propagation parallel or at an angle to the axis of tunnel. Ovaling deformations on the other hand are due to wave propagating perpendicular or near perpendicular to the axis of tunnel.

According to Hashash et al. (2001) the assessment of underground structure seismic response consists of three major steps:

1. Definition of the seismic environment and development of the seismic parameters for analysis.
2. Evaluation of ground response to shaking, which includes ground failure and ground deformation.
3. Assessment of structure behavior due to seismic shaking including (a) development of seismic design loading criteria, (b) underground structure response to ground deformations and (c) special design issues in the following sections items (3a) and (3b) are discussed.

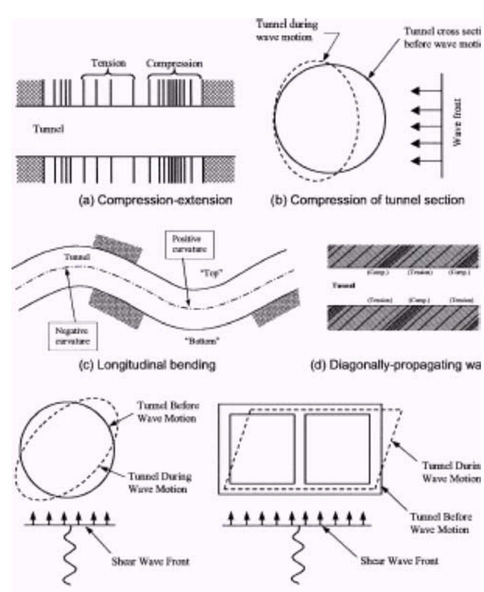

Fig. 1. Deformation modes of tunnels due to seismic waves (after Owen and Scholl, 1981).