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Seismic Design Of Tunnels In Fault Zones

Ervin Paçi[1], Alma Afezolli[2] , Arben Dervishaj[3]

[1]Department of Civil Engineering, Polytechnic University of Tirana, Albania
[2]Department of Civil Engineering, Polytechnic University of Tirana, Albania
[3]Department of Civil Engineering, Polytechnic University of Tirana, Albania

ABSTRACT

The tunnels due to their restrictions as a infrastructure work often overpass very disturbed tectonic zones. In those zones due to overthrust geological processes the rock quality are extremely poor in one side, and changes abruptly on the other side. These changes impose differential deformation on soil and tunnel linings. Especially for near faults tunnels where the directivity pulse and fling step phenomena plays an important role in the characterization of the seismic motion. This article gives the theoretical explanation and design consideration concerning the above mention problems. A numerical simulation which is indented to study the behavior of the tunnel during this type of seismic events is presented. This example is taken from the design of a tunnel that shall be constructed in Albania.

INTRODUCTION

The Murriz tunnel whose entrance we have study is part of a new road from Tirana to Dibra in the center of Albania. The tunnel has two lanes with a cross section of 105m2. It has a closed shape in the flych zones with a 90cm thick inverter in the most difficult part. This article gives the main aspect of the tunnel seismic design. Historically, underground tunnels have experienced a lower rate of damage than aboveground structures; nevertheless, recently several large earthquakes resulted in heavy damage to underground structures in major urban centers and mountain territories. Earthquake effects on underground structures can be grouped into two categories [Hashash et al., 2001]:

1. Ground shaking, i.e. the deformation of the ground produced by seismic waves propagating through the earth's crust.

2. Ground failure such as uplift due to soil liquefaction, fault displacement, and slope instability.

A careful review of the seismic damages suffered by underground facilities shows that most tunnels were located in the vicinity of causative faults. The characteristics of ground motion in the vicinity of the source can be significantly different from that of the far-field. The ground motion close to an active fault may be characterized by strong, coherent (narrow band) long period pulses and is severely affected by the rupture mechanism, the direction of rupture propagation relative to the site, and possible permanent ground displacements resulting from fault slip. These latter two phenomena are usually referred to respectively as "rupture-directivity" and "fling step" effects.

Therefore, the seismic response of an underground structure is mainly controlled by the response of the surrounding ground and by the imposed ground deformation. The response of an underground structure to a seismic event is basically governed by the behaviour of the surrounding ground and not by the inertial characteristics of the structure itself, as the response to such an event is substantially dependent on the induced ground deformation.

SIMPLIFIED APPROACHES FOR SEISMIC ANALYSIS OF TUNNELS

The analyses are generally grouped into three categories:

- pseudo-static analysis
- simplified dynamic analysis
- detailed dynamic analysis.

For engineering purposes underground structures may be assumed to undergo three primary modes of deformation during seismic shaking (Owen & Scholl, 1981

- compression/extension
- longitudinal bending
- ovaling of the cross section

Only in a detailed dynamic analysis the coupling between the response in the longitudinal direction (i.e. along the tunnel axis) and along the cross-section (i.e. along the transversal direction) is considered.

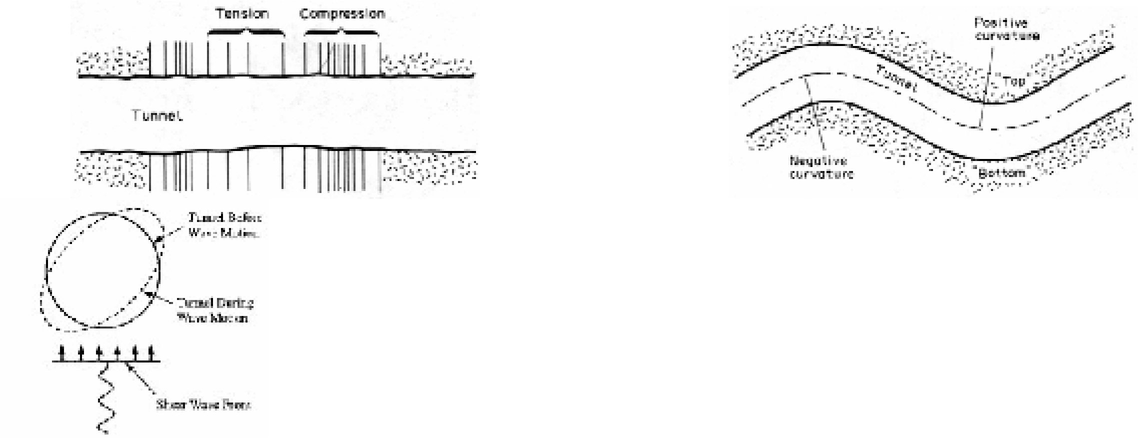

Figure 1. Modes of deformation of tunnels

Considering a free field St. John & Zahrah (1987) used Newmark's approach to develop an analytical procedure for estimating the free-field longitudinal, normal, shear strain and curvature, due to P, S, and Rayleigh waves. Solutions for all three wave types are shown in Table 1. Their procedure is used to determine the angle of incidence yielding the maximum deformations which are then used for design in view of the uncertainties involved in the problem.

According to the solution given Wang the most unfavorable angel φ is 45° towards tunnel axis as given in the figure below.

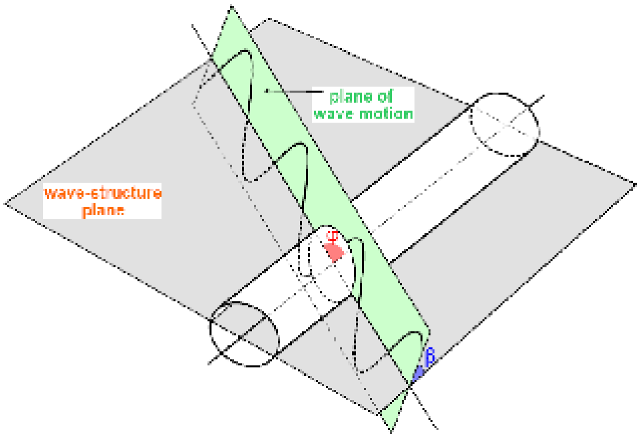

Figure 2. Angle of wave motion direction with tunnel axis

The results of these approaches gives:

Table 1. Maximum strains for different wave types

Wave type	Maximum longitudinal strain [-]	Maximum shear strain [-]	Maximum curvature $[m^{-1}]$
P-wave	$\varepsilon = \frac{PGV_P}{V_P}$ for $\phi = 0°$	$\gamma = \frac{PGV_P}{2V_P}$ for $\phi = 45°$	$\chi = 0.385 \frac{PGA_P}{V_P^2}$ for $\phi = 35°16'$
S-wave	$\varepsilon = \frac{PGV_S}{2V_S}$ for $\phi = 45°$	$\gamma = \frac{PGV_S}{V_S}$ for $\phi = 0°$	$\chi = \frac{PGA_S}{V_P^2}$ for $\phi = 0°$
R-wave (compressional component)	$\varepsilon = \frac{PGV_R}{V_R}$ for $\phi = 0°$	$\gamma = \frac{PGV_R}{2V_R}$ for $\phi = 45°$	$\chi = 0.385 \frac{PGA_R}{V_R^2}$ for $\phi = 35°16'$

SEISMIC INPUT FOR ANALYSIS OF TUNNELS

For many types of above-ground structures, the seismic action is often represented in the form of either acceleration or displacement response spectrum. On the contrary, underground structures are examples of problems in earthquake engineering that require the seismic input to be specified in terms of acceleration, velocity or displacement time histories. Different types of time histories can be used for the definition of the seismic input :

- artificial accelerograms generated through algorithms based on random vibration theory with the constraint to be spectrum compatible to a reference response spectrum (e.g. Gasparini & Vanmarcke 1976);

- artificial accelerograms generated through stochastic approaches but compatibles with some seismogenic constraints such as magnitude and epicentral distance (e.g. Sabetta & Pugliese, 1996; Boore, 2003; Halldorsson & Papageorgiou 2004);
- synthetic accelerograms generated through complex mathematical models of seismic source and propagation phenomena (Hisada & Bielak 2003). The generation of this kind of accelerograms requires a detailed knowledge of seismological and geophysical data. Furthermore, it is difficult to realistically simulate high frequency components of ground motion;

- real accelerogram selected from earthquake strong motion databases such as the European Strong Motion Database (ESD), the Pacific Earthquake Engineering Research Centre (PEER), and the Consortium of Organization for Strong Motion Observation Systems (COSMOS). These records are typically selected on the basis of proper geological and seismological constraints;

- artificial accelerograms generated through hybrid procedures which modify real accelerograms in the frequency or in the time domain in order to satisfy spectrum compatibility with a target spectrum, for instance a uniform hazard spectrum (Silva & Lee, 1987; Abrahamson, 1998).

For seismological and geotechnical applications real accelerograms are preferred because they are more realistic for frequency content, number of cycles, correct correlation between the vertical and horizontal components of ground motion and for the energy content in relation to the seismogenic parameters (EN 1998-1-5, 2004; Bommer & Acevedo, 2004). However, in order to use a real accelerogram in near-fault conditions it is required for the time histories to include directivity effects and fling step, in other words they should refer to real, near-field earthquakes.

In our approach we firstly has decided the seismic input data that are provided by a probabilistic seismic hazard calculation. From this analysis are taken the main parameters. Based on them is chosen a representative earthquake that gives the same indications towards the structures. Earthquake characteristics for amplitudes of acceleration, velocity, displacement, frequency content, etc. are taken considering also the near field ground motion influence. Some of the main parameters are given below.

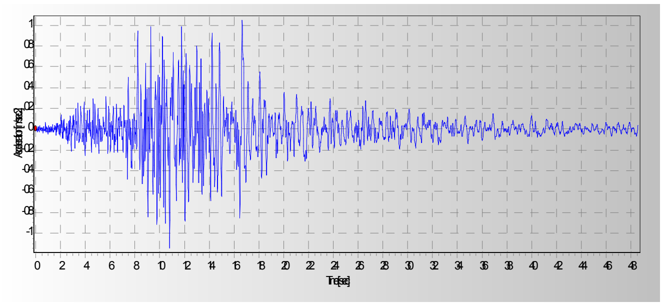

Figure 3 Time history of acceleration

Maximum Acceleration: 1.146m/sec2 at time t=10.790sec
Maximum Velocity: 0.082m/sec at time t=16.590sec
Maximum Displacement: 0.020m at time t=47.880sec

Vmax / Amax: 0.071sec. Predominant Period (Tp): 0.300sec

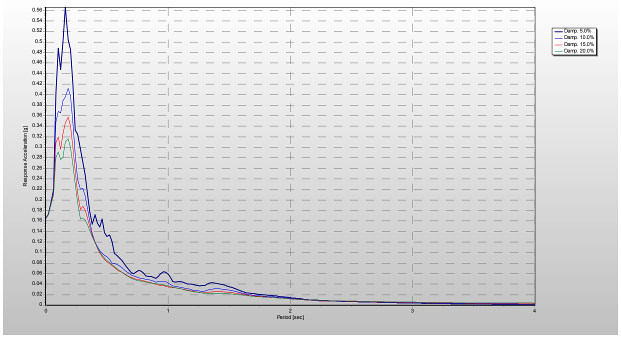

Figure 4. Accelerations response spectras

NUMERICAL SIMULATION OF MURRIZI TUNNEL

Due to the nature of the problem we have chosen different models for each step. At first we analyse a general model for all the massive. Although "over thrust fault" itself does not generate earthquakes it serves as a refracting plan and emphasize the basin effects. Based in convulsion methods is taken the motion in the bedrock. From this first model we have taken the time histories of acceleration in different points of the model and

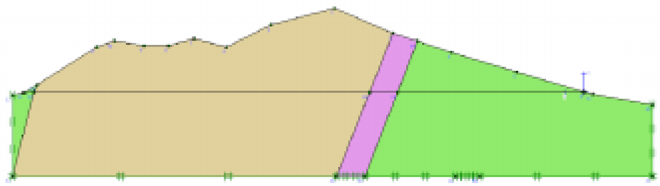

Figure 5. First model in longitudional direction

In the longitudional direction as in the first model we have performed another calculation considering the tunnel as a beam supported by springs every 50m with longitudional and lateral stiffness“$\mathbf{k_l}$” and “$\mathbf{k_t}$”. to the restraints are given displacement taken from free-field analysis (AFTES). This second model together with some results are given below.

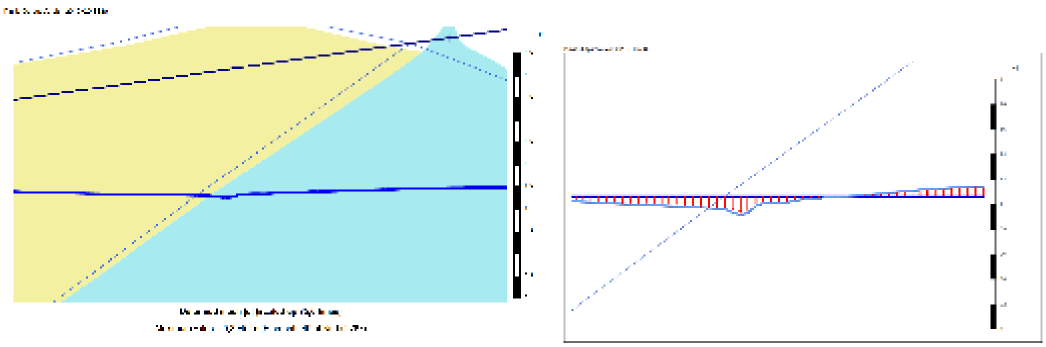

Figure 6. Deformation of tunnel

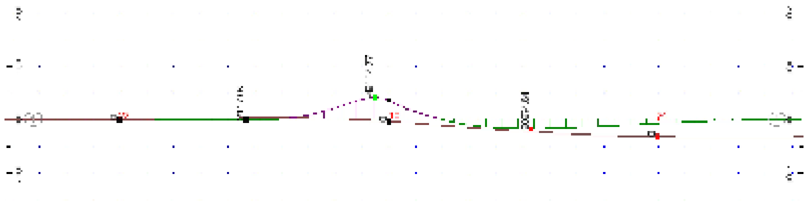

Figure 7. Deformation and internal moments for the model beam supported by springs

In the trasversal direction we have to take into consideration the ovaling effect of induced strains from earthquake wave propagation. As mentioning above we have made analitical calculation with two methods. Free- field deformation method based on closed form elastic solution and dynamic soil-structure interaction analysis. Then we have performed a numerical calculation taking as seismic input the time history of acceleration taken from first model. These models together with some results are given below.

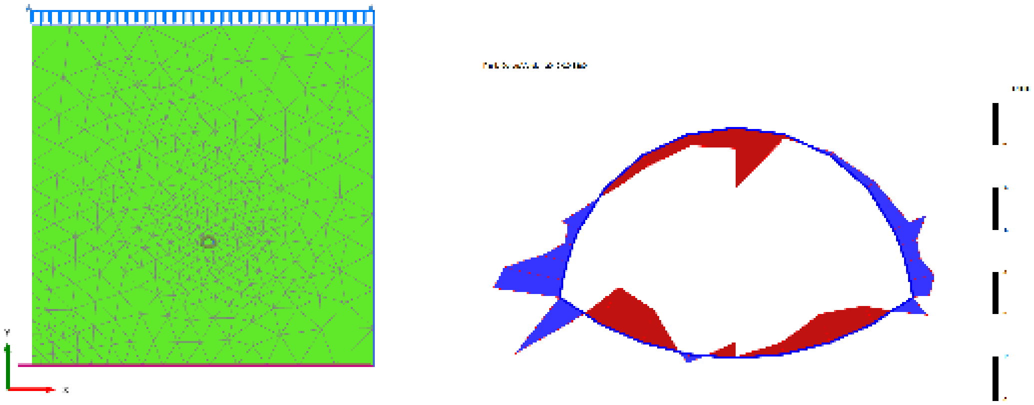

Figure 8. Model and moments in the lining

CONCLUSIONS

We have given in this article a general view of the problems and design approches for the seismic calculation of tunnels.

Numerical simulation has many uncertainces due to the lack of data for seismic input parameters in near field conditions and dynamic properties of the surrounding soil. However numerical simulation if we consider the sesmic input reliable gives realistic values for the strains in soil and internal forces in the tunnel linings.

ACKNOWLEDGMENTS

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