Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 158 (2016) 230 – 235

Procedia Engineering

www.elsevier.com/locate/procedia

VI ITALIAN CONFERENCE OF RESEARCHERS IN GEOTECHNICAL ENGINEERING – Geotechnical Engineering in Multidisciplinary Research: from Microscale to Regional Scale, CNRIG2016

Behaviour of a segmental tunnel lining under seismic actions

Stefania Fabozzi[a,*], Emilio Bilotta[a]

[a]*University of Napoli Federico II, DICEA, via Claudio 21, Napoli, 80128, Italy*

Abstract

Full dynamic analyses that follow a coupled approach for the soil-structure interaction, provides satisfactory interpretation of non-linear boundary problems during earthquakes. This paper illustrates the results of a numerical study aimed at modelling the performance of continuous and segmental linings of shallow tunnel under seismic loading. A set of 3D finite-element full dynamic analyses have been carried out, calibrated on the experimental results of a centrifuge test on a model tunnel in a dense dry sand layer subjected to transversal dynamic loading [1]. The numerical study was extended to model and compare the seismic demand of a continuous and a segmental reinforced concrete lining, including the effect of the excavation process on the pre-seismic conditions and the influence of different input signals. The results show that even in rather simple ground conditions, a suitable constitutive model for soil is needed to capture the effect of soil-lining interaction during and after the seismic event.

Peer-review under the responsibility of the organizing and scientific committees of CNRIG2016

Keywords: Circular tunnel; seismic actions; excavation process; segmental lining; three-dimensional FE analyses

1. Introduction

The complex interaction mechanism between the tunnel structure and the surrounding soil during dynamic shaking can be monitored during centrifuge tests on physical models at reduced scale. These tests allow the main mechanisms involved in the evolution of observed phenomena to be identified and provide an extensive base of experimental data to calibrate advanced numerical methods of analysis in ideal situations where soil properties, boundary conditions and dynamic loads are clearly defined.

* Corresponding author. Tel.:+39-081-7685915; fax: +39-081-7683456.
E-mail address: stefania.fabozzi@unina.it

Peer-review under the responsibility of the organizing and scientific committees of CNRIG2016
doi:10.1016/j.proeng.2016.08.434

The change of internal forces in a tunnel lining during earthquakes can be calculated following several approaches [2,3]. Existing guidelines suggest pseudo-static or uncoupled dynamic analyses; however, to take into account the influence of the existing stress state around the tunnel and of permanent ground deformation during shaking [4,5], full dynamic analysis must be performed. These achieve the most reliable seismic design of tunnels undergoing earthquakes, including soil-structure interaction and irreversible ground behaviour. In addition, finite element analyses should allow the complete three-dimensional structure of the tunnel to be taken into account, to model both the excavation process that affects the initial (static) conditions and the effect of seismic waves of any direction.

In this paper, three-dimensional finite element analyses were performed to simulate the behaviour of a circular tunnel lining during earthquake. The non-linear and irreversible soil behaviour was modelled through an elastic-plastic strain-hardening model with small strain overlay [6]. The effect of the static state of stress was explicitly taken into account by modelling the tunnel excavation process and validated against existing literature [7]. The effect of the segmental lining, that is important also in static conditions [8], has been considered by modelling the segmental layout of each ring of the lining, although with a few simplifying assumptions.

2. Numerical analysis

2.1. Experimental benchmark

The centrifuge test model T3, described in details by Lanzano et al. [1], is the experimental benchmark for the validation of the numerical model. It is the aluminium model of a tunnel (diameter D=75mm, thickness t=0.5mm, cover C=150mm) embedded in a layer of dry Leighton Buzzard sand (fraction E) at relative density of 75% (Fig.1a). At prototype scale (scaling factor N=80), the tunnel diameter is 6 m, the tunnel axis depth is 15 m and the lining thickness is comparable to that of a concrete lining about 0.06 m thick.

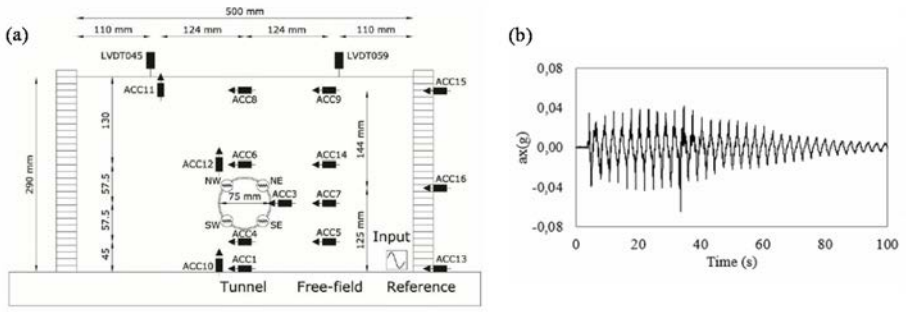

Fig. 1. (a) Layout of model T3 [1]; (b) Input motion EQ1 reference ACC13 (at prototype scale).

2.2. Numerical back-analysis

The numerical model has been implemented in the finite element (FE) code Plaxis 3D. Figure 2 shows the numerical mesh of model T3 at prototype scale: the vertical depth is 80 times the relevant small scale dimension (23.2 m), the width (200 m) has been established by a series of parametric analyses in order to reach a free-field condition and minimise the influence of boundaries. A longitudinal stretch of the model of 150 m has been considered to guarantee plane strain conditions in the central reference section, to be compared to the experimental results. The lateral boundary conditions consist on fixed displacements in the horizontal direction perpendicular to the vertical sides of the mesh in static condition; viscous dashpots are applied during dynamic stages of analysis [9]; the base of the model is fixed both in vertical and in horizontal directions, the nodes at the top surface instead are completely free. The minimum mesh size was set as a function of the maximum investigable frequency of the signal f_{max} = 0.375 Hz [9]. The pseudo-harmonic input signal, read by the reference accelerometer ACC13 and scaled up to prototype scale (Fig. 1b), was applied at the base of the numerical model. It was preliminary band-pass filtered in the interval of frequency 15–130 Hz in order to reduce the high-frequency content of the signal.