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Soil-Tunnel Interaction under Medium Internal Blast Loading

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Abstract
A series of numerical simulations were carried out to study the interaction between subway tunnels and soils subjected to medium internal blast loading (< 200 kg of TNT equivalent). The excess pore-water pressure was studied with an existing soil model (FHWA) that can simulate pore-water pressure and effective soil pressure. A recently developed blast loading scheme that removes the necessity of modeling the explosive in the numerical models but still maintains the advantages of nonlinear fluid-structure interaction was used to study the process of blast wave propagation in the air domain inside the tunnel.

Keywords: soil-tunnel interaction, blast, underground structures, Finite Element method

1 Introduction

US transportation system has 337 highway tunnels and 211 transit tunnels in 2003 according to the Blue Ribbon Panel (BRP) on Bridge and Tunnel Security assigned by AASHTO [1]. These tunnels are facing threats of internal explosion which will cause large socioeconomic losses. However, mechanism of saturated ground-tunnel interaction under medium internal blast loading is still not well understood. There is no validated design guideline for tunnel linings in saturated soil due to medium blast loading.

Many transportation tunnels run through saturated soils [1]. Saturated soils subjected to blast loading generate drastic changes of compressive strain and excess pore pressure. Especially the residue of excess pore pressure will reduce effective stress and may result in soil liquefaction. The existing knowledge on explosion-induced compressive strain and pore pressure in saturated soil does

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not directly apply herein because explosion does not occur in soil and the tunnel modifies the characteristics of blast loading on soil [3].

Analyzing the effects of blast on tunnels and soils is a difficult task, as it involves highly nonlinear fluid dynamics, structural dynamics and fluid-structure interaction. At present, most blast resistant analyses make use of simplistic blast loading and structure models [2], but their accuracy cannot be guaranteed when complicated structure and loading scenarios are involved. The existing blast loading equations are focused on the free air blast, blast effect on plane rigid surface, or blast effect inside a rectangular structure [2]. The effects of confinement from tunnels on the blast loading are not studied or investigated thoroughly.

This research aims to study on the interaction between circular subway tunnels and saturated soils subjected to medium internal blast loading to improve the design and rehabilitation of transportation tunnels.

2 Literature Review

Responses of underground structures subjected to explosive loading have been extensively studied [e.g. 4-9] for its military importance. For explosions outside underground structures, most of the studies focused on cratering, earth pressure on underground structures, and corresponding structure damage.

Only few of these studies considered the coupling of pore fluid and soil particles [4], not to mention the change of effective stress and its effect on underground structures.

For explosions inside underground structures, air-blast, ground blast wave, blast pressure, collapse and debris of underground structures have been investigated. These studies are mostly related to large-scale explosions inside underground ammunition storages in rock mass, the findings of which cannot be directly applied to tunnels in saturated soils.

Few studies on the responses of underground structures subjected to internal blast loading [4] can be found. The subjects of Chille et al. [6] and Choi et al. [7] were both underground structures in rock masses. Preece et al. [9] investigated the response of a 13-ft-diameter aluminum tunnel in moist soil subjected to internal blast loading from 6600 pounds of TNT using centrifuge test, which is not realistic for the hazard facing general transportation tunnels. Port Authority of New York and New Jersey and several other transportation agencies investigated the blast vulnerability of specific tunnels after 9/11 but unfortunately their results are not released. Liu [4] found that under single blast loading, the tunnel vibrated drastically and applied multiple shocks to the ground media, which coincided with the finding of Feldgun et al. [8]

3 Finite Element Model

The blast loading was simulated with a new blast loading scheme (Load_Blast_Enhanced) available in LS-DYNA [10]. The air immediately around the tunnel lining is modeled by Eulerian air elements. A layer of special Eulerian elements works as the blast wave resource, which is herein referred to as the ambient layer. Time histories of incident blast pressure applied to the ambient layer are derived from embedded CONWEP in LSDYNA. The validity of this numerical approach was discussed by Han and Liu[11].

3.1 Base Model

As shown in the Figure 1, the Finite Element model consists of soil, soil-tunnel interface, tunnel lining, air and ambient layer. Due to symmetry, 1/4 model was simulated to save computer resources.