Analysis of NATM Tunnel Responses due to Earthquake Loading in Various Soils

Presented by
Zaneta G. Adme
*Florida State University*

Advisor
Makola M. Abdullah, Ph.D.
Outline

- Background
- Objective
- Methodology
- Results
- Conclusions
- Future Work
Reasons for Utilizing Tunnels

- Connect land masses
  - Channel Tunnel, English Channel

- Maintenance issues
  - Holland & Lincoln Tunnels, New York

- Bypass impeding geologic formations
  - Wolf Creek Pass, Colorado
Reasons for Utilizing Tunnels

- Stability issues
  - Devil’s Slide Tunnel, California

- Environmental concerns
  - Whittier Tunnel, Alaska

- Increase the flow of traffic
  - Central Artery, Boston, Massachusetts
Background

- 50% of the world’s population live in urban areas
  - 70% of that population live in earthquake prone areas
- Initially, tunnels were designed with no regard to seismic effects
- Recent enhanced awareness of seismic hazards for underground structures
Earthquake Effects on Tunnels

- **Ground Shaking**
  - Body Waves
  - Surface Waves

- **Ground Failure**
  - Liquefaction
  - Faulting
  - Tectonic Uplift & Subsidence
NATM

- New Australian Tunneling Method (NATM)
  - After tunneling, shotcrete is applied to surface
  - Surrounding rock or soil becomes integrated into the support structure
  - Adopted by many countries as primary method of tunnel construction
Objective

- To determine which soils types prevalent in different regions, when used in conjunction with a NATM tunnel, perform better when subjected to excitation caused by an earthquake.
Methodology

1. Identify the physical problem.
   - Describe physical structure.
   - Identify the source of dynamic excitation.
   - Determine expected outcomes.

2. Define the model
   - Define necessary inputs.
   - Find a model of the physical problem using inputs.

3. Find the solution of the numerical model.
   - Solve the problem to obtain response.
   - Review results.
Criteria for city selection

- Size
- Earthquake History
- Possibility of Tunnel Use
- Variation in Soil Types

San Francisco, California
Tokyo, Japan
Mexico City, Mexico
Avezzano, Italy
Tangshan, China
Chimbote, Peru
Agadir, Morocco

http://atlas.geo.cornell.edu/education
Global Soil Regions

[Map of global soil regions with color coding for different soil types.]

http://www.nrcs.usda.gov
<table>
<thead>
<tr>
<th>Location</th>
<th>Soil Order</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agadir, Morocco</td>
<td>Alfisols</td>
<td>Low Plasticity Clay</td>
</tr>
<tr>
<td>Avezzano, Italy</td>
<td>Ultisols</td>
<td>Low Plasticity Silt</td>
</tr>
<tr>
<td>Chimbote, Peru</td>
<td>Entisols</td>
<td>Gravel-Sand Mixture</td>
</tr>
<tr>
<td>Los Angeles, California</td>
<td>Mollisols</td>
<td>Organic</td>
</tr>
<tr>
<td>Mexico City, Mexico</td>
<td>Andisols</td>
<td>Medium Plasticity Silt</td>
</tr>
<tr>
<td>Tangshan, China</td>
<td>Inceptisols</td>
<td>Sandy Gravel</td>
</tr>
<tr>
<td>Tokyo, Japan</td>
<td>Oxisols</td>
<td>High Plasticity Clay</td>
</tr>
</tbody>
</table>
Physical Structure

Tunnel geometry—single circle, 22 m (diameter), buried 67m
Method of Analysis

- Finite Element Method
  - VisualFEA
  - Used to model and solve complex 2-D and 3-D engineering problems.
  - Converts data into a visual representation of output.
  - Can give data at specific points in the structure.
Finite Element Method

- Tunnel Parameters
  - 2-D plane strain model
  - Fixed vertical ends
  - Dynamic input placed at bottom boundary
  - Damper placed at bottom boundary
  - Rayleigh damping=0.05
  - Data taken from point between surfaces above tunnel
## Soil data

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Mass Density (kg/ m^3)</th>
<th>Elastic Modulus (Pa)</th>
<th>Poisson's Ratio</th>
<th>Internal Friction Angle (deg.)</th>
<th>Cohesion (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uniform</td>
<td>1600</td>
<td>4.00E+07</td>
<td>0.25</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Sandy w/ few fines</td>
<td>2100</td>
<td>4.00E+07</td>
<td>0.25</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>Sandy w/ silt or clay</td>
<td>2100</td>
<td>4.00E+07</td>
<td>0.25</td>
<td>35</td>
<td>1000</td>
</tr>
<tr>
<td>Mixture of gravel and sand</td>
<td>2000</td>
<td>1.50E+07</td>
<td>0.25</td>
<td>38</td>
<td>3000</td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uniform, fine</td>
<td>1600</td>
<td>1.50E+07</td>
<td>0.25</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>Uniform, coarse</td>
<td>1600</td>
<td>2.50E+07</td>
<td>0.25</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Uniform, well-graded</td>
<td>1800</td>
<td>2.00E+07</td>
<td>0.25</td>
<td>33</td>
<td>0</td>
</tr>
<tr>
<td>Silt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low plasticity</td>
<td>1750</td>
<td>4.00E+06</td>
<td>0.25</td>
<td>28</td>
<td>2000</td>
</tr>
<tr>
<td>Medium to high plasticity</td>
<td>1700</td>
<td>3.00E+06</td>
<td>0.25</td>
<td>25</td>
<td>3000</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low plasticity</td>
<td>1900</td>
<td>2.00E+06</td>
<td>0.28</td>
<td>24</td>
<td>6000</td>
</tr>
<tr>
<td>Medium plasticity</td>
<td>1800</td>
<td>1.00E+06</td>
<td>0.25</td>
<td>20</td>
<td>8000</td>
</tr>
<tr>
<td>High plasticity</td>
<td>1650</td>
<td>6.00E+05</td>
<td>0.25</td>
<td>17</td>
<td>10000</td>
</tr>
<tr>
<td>Organic</td>
<td>1550</td>
<td>5.00E+05</td>
<td>0.25</td>
<td>20</td>
<td>7000</td>
</tr>
<tr>
<td>Rock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granite</td>
<td>2700</td>
<td>7.40E+10</td>
<td>0.25</td>
<td>51</td>
<td>5.51E+07</td>
</tr>
</tbody>
</table>
Source of dynamic excitation

- Acceleration record
  - 1995 Kobe, Japan

- Acceleration input applied to a flexible base.
Results: Comparison

Uniform Gravel
Disp. = 0.5753 cm

Medium to High Plasticity Silt
Disp. = 0.2838 cm
# Results

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil Type</th>
<th>Maximum Displacement (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agadir, Morocco</td>
<td>Low Plasticity Clay</td>
<td>0.4304</td>
</tr>
<tr>
<td>Avezzano, Italy</td>
<td>Low Plasticity Silt</td>
<td>0.2129</td>
</tr>
<tr>
<td>Chimbote, Peru</td>
<td>Gravel-Sand Mixture</td>
<td>0.05604</td>
</tr>
<tr>
<td>Los Angeles, California</td>
<td>Organic</td>
<td>0.1704</td>
</tr>
<tr>
<td>Mexico City, Mexico</td>
<td>Medium Plasticity Silt</td>
<td>0.2839</td>
</tr>
<tr>
<td>Tangshan, China</td>
<td>Sandy Gravel w/ Silt</td>
<td>0.02057</td>
</tr>
<tr>
<td>Tokyo, Japan</td>
<td>High Plasticity Clay</td>
<td>1.419</td>
</tr>
</tbody>
</table>
Conclusions

- The soils that contain between ten and fifty percent fine particles performed better under excitation than the soils with smaller amounts (<10%) of fine particles.

- Soils with the greatest amounts of fines (>50%) performed unfavorably as compared to the other soils.

- Finite element programs possess great tools for the exploration of complex problems and are, also, fine educational tools.
Possible Future Work

- 3-D analysis.
- Incorporation of other rock types and water table.
- Increase in layers to better represent ground layers.
References

- www.dot.state.co.us/WolfCreekPass/index.cfm
- www.eurotunnel.com/ukcMain/ukcCompany/ukcAboutUs/ukpAboutUsHistory
- www.ctrl.co.uk
- www.panynj.gov/tbt/Itframe.HTM
- www.gel.civil.nagasaki-u.ac.jp/text/example/ex27/kan2.html
- www.who.int/archives/inf-pr-1997/en/pr97-08.html
- www.geolsoc.org.uk/pdfs/earthquakes.pdf
- www.fao.org/ag/agl/agll/wrb/mapindex.stm
- atlas.geo.cornell.edu/education
- www.pbs.org/wgbh/buildingbig/tunnel/basics.html
- pghbridges.com/termsTun.htm
- www.mrtunnel.com/frame2.htm
- www.dot.state.ak.us/creg/whittiertunnel/virtualdrive.htm
Acknowledgements

- FAMU Undergraduate Program
- National Science Foundation
- REUJAT Program
- University of Tokyo
- Makola M. Abdullah, Ph. D.
- Terri R. Norton, M.S.C.E.
Thousands occur every year but are not sensed by humans. The strong motion earthquakes are of more interest to engineers.

Thank You!