VIBRATIONAL TESTS OF HOODOOS NEAR LOS ALAMOS, NM

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What are Hoodoos?
(uncertain or balancing rocks)
Why did we shake hoodoos?

What level of ground motion will topple the cap Rock?

How old is the hoodoo?

= Maximum probable ground motion during the life time of the hoodoo.
What level of ground motion will topple the cap Rock?

It depends on:

• Ground acceleration,
• Amplification of ground motions through the pedestal, and
• Bonding strength and geometry of material between the cap rock and the pedestal.

The main focus of this study was to determine the amplification due to the pedestal by evaluating the resonant frequencies and damping ratios of hoodoo structures.

Experimental study
Tested Four Hoodoos of Different Materials

Hoodoo #1 - Cemented gravelly soil
Hoodoo #2 - Rock
Hoodoo #3 - Rock
Hoodoo #4 - Hybrid
Sensors
3D MEMS Accelerometer (2V/g)
Five 3D MEMS Accelerometers at Different Heights

Acc. #1
Acc. #2
Acc. #3
Acc. #4
Acc. #5

T-Rex inline direction (SL)
Across slope (strike direction)

T-Rex transverse direction (ST)
Downslope (dip direction)
Vibrational Sources
Evaluation using three different sources of seismic energy

(1) Ambient vibrations
   - not enough energy for MEMS accelerometers

(2) Impacts with an instrumented hammer
   - small amplitude

(3) T-Rex, a large, mobile, hydraulic tri-axial shaker
   - medium to large amplitudes
   - Controlled force amplitude
T-Rex

- Tri-axial shaker
- Push-button transformation of shaking orientation
- 32 ft long, 8 ft wide, Wt. = 64,000 lbs
- Only operating tri-axial vibroseis we are aware of in the world
Example Results from Hoodoo #3
Modal resonances of Hoodoo #3 measured with Acc. #1 located on the top cap.
Transfer functions from shaking with T-Rex between accelerometers in the **strike** direction.

- Acc. #1
- Acc. #2
- Acc. #5

**Strike direction**
Probable resonant motion of Hoodoo #3 tested with T-Rex

<table>
<thead>
<tr>
<th>Resonant frequency, Hz</th>
<th>Direction of motion</th>
<th>Probable motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>Dip</td>
<td>Cap rock motion in the dip direction independent from the pedestal</td>
</tr>
<tr>
<td>9.3</td>
<td>Strike</td>
<td>Rotation against the front tip of the pedestal base in the strike direction</td>
</tr>
<tr>
<td>11.2</td>
<td>Strike</td>
<td>Cap rock motion in the strike direction independent from the pedestal</td>
</tr>
<tr>
<td>18.0</td>
<td>Dip</td>
<td>Rock against the base of the pedestal in the dip direction</td>
</tr>
<tr>
<td>24.9</td>
<td>Strike</td>
<td>Bending or rocking motion of the hoodoo in the strike direction</td>
</tr>
</tbody>
</table>
**Fundamental (lowest) resonant frequencies of each of the four hoodoos excited using an instrumented hammer**

<table>
<thead>
<tr>
<th>Hoodoo</th>
<th>Height, ft (m)</th>
<th>Material Type of the Pedestal</th>
<th>Resonant Frequency, Hz</th>
<th>Damping Ratios, %</th>
<th>Direction of Vibrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>30 (9.1)</td>
<td>Gravel mixed with Soil</td>
<td>3.75</td>
<td>1.8</td>
<td>Strike</td>
</tr>
<tr>
<td>#2</td>
<td>25 (7.6)</td>
<td>Rock</td>
<td>5.9</td>
<td>1.4</td>
<td>Strike</td>
</tr>
<tr>
<td>#3</td>
<td>20 (6.1)</td>
<td>Rocklike</td>
<td>9.75</td>
<td>1.3</td>
<td>Strike</td>
</tr>
<tr>
<td>#4</td>
<td>22 (6.7)</td>
<td>Upper: Gravel mixed with Soil Lower: Rock</td>
<td>4.1</td>
<td>2.2</td>
<td>Between strike and dip</td>
</tr>
</tbody>
</table>

Accelerometer measurements located at the top of each pedestal
Conclusions

• Vibrations generated by T-Rex are about 100 times higher than those from an instrument hammer and can provide clear spectral phase plots between sensors which are instrumental in determining probable resonant modes.

• The lowest recognizable resonant frequencies from all four hoodoos ranged from 3.75 Hz at Hoodoo #1 to 9.75 Hz at Hoodoo #3. A shorter and stiffer hoodoo is expected to have a higher resonant frequency (i.e. Hoodoo #3).

• Because of the geometry of their bases, resonant frequencies are lower in the strike direction than in the dip direction.
Thank you!

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Questions?