Experimental investigation of damping for stone masonry

-Hari Parajuli, Ph. D. Student, Kyoto University
-Junji Kiyono, Associate Professor, Kyoto University
-Yusuke Ono, Assistant Professor, Kyoto University
Overview of dry stone masonry houses

Typical stone houses in Nepal

Wall cross section
Overview of dry stone masonry houses

Traditional mud mortar stone masonry, Uttaranchal, India

Contemporary Bhatar construction, Tarand-NWFP-Pakistan
General characteristics of stone houses

• Nos. of storey: 1-2
• Storey height: 2m (approximately)
• Nos. rooms: 1-2
• Room size: 3-4m
• Roofing materials: Dry grass, slate, corrugated galvanized iron sheets
• Wall: 45cm width with double wythe
• Binding: earth (mud or clay) mortar
• Openings: small doors and windows and almost dark in day time also.
Formulation of FEM Model
Formulation of FEM Model

Equation of motion

\[
\begin{bmatrix}
M
\end{bmatrix}\{\ddot{u}\} + \begin{bmatrix}
C
\end{bmatrix}\{\dot{u}\} + \begin{bmatrix}
K\end{bmatrix}\{u\} = -\begin{bmatrix}
M\end{bmatrix}\{\ddot{u}_g\}
\]

\begin{align*}
[M] & \text{– Mass matrix} \\
[K] & \text{– Stiffness matrix} \\
[C] & \text{– Damping matrix} \\
\{u\} & \text{– Displacement response} \\
\{\dot{u}\} & \text{– Velocity response} \\
\{\ddot{u}\} & \text{– Acceleration response} \\
\{\ddot{u}_g\} & \text{– Ground displacement}
\end{align*}

\[
[C] = \alpha[M] + \beta[K]
\]

\(\alpha\) and \(\beta\) Raleigh constant for taking consideration of highest and lowest mode of vibration
Experiment set up

Kyoto University-Katsura- Uniaxial shaking table
Plateform :1.5mx1.5m
Frequency range: 0.5Hz-30Hz
Maximum acceleration : 2g
Maximum displacement: 10 cm
Models for Experiments

Model 1
Dry joint stones laid one over other
Element size : 0.30mx0.30mx0.065m

Model 2
Mud (clay) joint stones laid one over other
Element size : 0.30mx0.30mx0.065m
Input motion design

\[ u(t) = u_0 \sin(2\pi ft) \]

\[ \ddot{u}(t) = -(2\pi f)^2 u_0 \sin(2\pi ft) \]

\[ u_0 = \frac{\ddot{u}_{\text{max}}}{(2\pi f)^2} \]
# Model houses

Frequency is given by

\[ f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]

<table>
<thead>
<tr>
<th>S.N</th>
<th>Input Frequency (Hz)</th>
<th>Stiffness (KN/m)*100</th>
<th>Calculated Frequency (Hz)*10</th>
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<tbody>
<tr>
<td>1</td>
<td>5.0</td>
<td>11.62</td>
<td>4.23</td>
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<td>5.0</td>
<td>15.90</td>
<td>4.90</td>
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<td>4.12</td>
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<td>6</td>
<td>4.5</td>
<td>11.32</td>
<td>4.10</td>
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<td>7</td>
<td>4.5</td>
<td>12.68</td>
<td>4.40</td>
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<td>8</td>
<td>4.5</td>
<td>14.33</td>
<td>4.60</td>
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<tr>
<td>9</td>
<td>4.5</td>
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<td>4.10</td>
</tr>
<tr>
<td>10</td>
<td>4.5</td>
<td>13.22</td>
<td>4.50</td>
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</table>
Force displacement curve for dry joint stones
Force displacement curve for mud joint stones

Experiment
Estimate 1
Estimate 2
Equivalent viscous damping is given by

$$\xi_{eq} = \frac{1}{4\pi} \frac{E_D}{E_S}$$

- $E_D$ = Area under hysteresis loop
- $E_S$ = Energy stored in the system
# Damping Estimate

## Damping estimate for dry joint stones

<table>
<thead>
<tr>
<th>Estimate</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Avg.</th>
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</thead>
<tbody>
<tr>
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<td>52.16</td>
<td>56.23</td>
<td>56.29</td>
<td>54.75</td>
<td>54.3</td>
<td>54.5</td>
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<tr>
<td>2</td>
<td>46.12</td>
<td>46.06</td>
<td>48.29</td>
<td>46.23</td>
<td>46.63</td>
<td>46.8</td>
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</table>

Average equivalent viscous damping (%) 51.0

## Damping estimate for mud joint stones

<table>
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<tr>
<th>Estimate</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>27.39</td>
<td>29.29</td>
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<tr>
<td>2</td>
<td>34.20</td>
<td>40.27</td>
<td>40.27</td>
<td>40.87</td>
<td>35.03</td>
<td>38.1</td>
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</table>

Average equivalent viscous damping (%) 34.0
Conclusion

1. Damping is higher in discontinuous systems such as dry joint walls than in low quality material such as mud bonded walls.

2. High portion of energy is damped out due friction between the elements.

3. Bigger portion of energy damping out might be the one of the reasons of surviving historical stone masonry during earthquakes
Thank you