Vibration control of buildings through Vibrating barriers

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Outline

- Introduction & Motivation
- Overview of the traditional and novel vibration control techniques
- Proposed approach
- Numerical and experimental results
- Concluding remarks
Introduction & Motivation

- Existing Buildings: Vibration Control devices rarely used in developing countries and for heritage buildings despite they are efficient. Why?

- Needing to find alternative approaches. What about protect a structure without altering it? What about try to protect more than one building with a single device?
Overview of the traditional vibration control techniques

Local/individual protection

- The use of vibration control devices is restricted to individual structures, and is therefore too localized to provide larger scale protection from seismic action, which remains an unsolved challenge, especially those in developing countries.

Devices such as isolators, dampers and tuned mass dampers are now widely used in the construction industry for earthquake engineering to reduce vibration in new and, in a few cases, existing buildings.
Non-local protection


Field Experiments on Wave Propagation and Vibration Isolation by Using Wave Barriers

Fig. 3. Trench barriers: a) Open trench, b) Water filled trench, c) Bentonite filled trench and d) Concrete filled trench.
Railways applications

Fig. 8. Vibration mitigation measures on the transmission path: (a) open trench, (b) soft or stiff wave barrier, (c) wave impeding block, and (d) heavy masses next to the track.
SCIENCE

SEISMIC INVISIBILITY CLOAK COULD HIDE BUILDINGS FROM EARTHQUAKES

ENGINEERING A PRECISE SERIES OF RING-SHAPED SHIELDS TO DEFLECT EARTHQUAKES AROUND A BUILDING

By Dan Smith   Posted June 26, 2009
**Experiments on Seismic Metamaterials: Folding Surface Waves**

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(Received 18 May 2013; published 31 March 2014)

**FIG. 1.** Schematics of (a) a seismic wave in an alluvium basin and (b) the seismic testing device cross section in the x-z plane (see Fig. 3 for a photograph of the experiment).
First Grant - Revised 2009

PROPOSAL

Organisation where the Grant would be held

<table>
<thead>
<tr>
<th>Organisation</th>
<th>University of Brighton</th>
<th>Research Organisation Reference:</th>
<th>ViBa</th>
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</thead>
<tbody>
<tr>
<td>Division or Department</td>
<td>Scho of Environment and Technology</td>
<td></td>
<td></td>
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Project Title [up to 150 chars]

Vibrating Barriers for the control of seismic waves (ViBa)

Start Date and Duration

a. Proposed start date 01 January 2013  
b. Duration of the grant 24 months

Applicants

<table>
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<tr>
<th>Role</th>
<th>Name</th>
<th>Organisation</th>
<th>Division or Department</th>
<th>How many hours a week will the investigator work on the project?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principal Investigator</td>
<td>Dr Pierfrancesco Cacciola</td>
<td>University of Brighton</td>
<td>Scho of Environment and Technology</td>
<td>7.5</td>
</tr>
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</table>
Proposed approach

Structure-soil-structure interaction

Design of the control system (ViBa)

Modelling of the seismic actions

Figure 1: Sketch of the proposed Vibrating Barrier
Modelling of the seismic action

- Selected recorded time histories
- Simulated artificial (response-spectrum-compatible time histories)
Proposed approach

Structure-soil-structure interaction

Design of the control system (ViBa)

Modelling of the seismic actions

Figure 1: Sketch of the proposed Vibrating Barrier
Structure-soil-structure interaction


Nupec experimental studies (2003)

Figure 4 Building Model Arrangement

Two Identical Building Model
(Reactors & Turbine Buildings)

Single Building Model
(Reactors Building)

Two Different Building Model
(Reactors & Turbine Buildings)

5

Two Identical Building Model

Figure 5 Building models in field Test

Figure 6 Vibration test using shaker
Proposed approach

Structure-soil-structure interaction

Design of the control system (ViBa)

Modelling of the seismic actions

Figure 1: Sketch of the proposed Vibrating Barrier
Figure 2 Discrete model for protection of two structures by the ViBa
Equations of motion: discrete model

\[
(\tilde{K} - \omega^2 M)U(\omega) = QU_g(\omega)
\]

- \(U(\omega)\) is the vector of absolute displacements

\[
U^T(\omega) = [U_i(\omega) \quad U_{f,i}(\omega) \quad \ldots \quad U_n(\omega) \quad U_{f,n}(\omega) \quad U_{Vi}]
\]

- Influence vector

\[
Q^T = [0 \quad \tilde{k}_{f,i} \quad \ldots \quad 0 \quad \tilde{k}_{f,n} \quad 0 \quad \tilde{k}_{f,ViBa}]
\]
Mass matrix

- Lumped mass model

\[
M = \begin{bmatrix}
  M_1 & 0 & \cdots & 0 & 0 \\
  0 & M_i & \cdots & 0 & 0 \\
  \vdots & \ddots & \ddots & \vdots & \vdots \\
  0 & 0 & \cdots & M_n & 0 \\
  0 & 0 & \cdots & 0 & M_Y
\end{bmatrix}
\]

\[
M_i = \begin{bmatrix}
  m_i & 0 \\
  0 & m_{f,i}
\end{bmatrix}
\]

\[
M_V = \begin{bmatrix}
  m_{ViBa} & 0 \\
  0 & m_{f,ViBa}
\end{bmatrix}
\]
Complex Stiffness matrix

\[ \tilde{\mathbf{K}} = \begin{bmatrix}
\tilde{K}_1 & \tilde{K}_{1,i} & \cdots & \tilde{K}_{1,n} & \tilde{K}_{1,V} \\
\tilde{K}_{i,1} & \tilde{K}_i & \cdots & \tilde{K}_{i,n} & \tilde{K}_{i,V} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
\tilde{K}_{n,1} & \tilde{K}_{n,i} & \cdots & \tilde{K}_n & \tilde{K}_{n,V} \\
\tilde{K}_{i,1} & \tilde{K}_{i,i} & \cdots & \tilde{K}_{i,n} & \tilde{K}_V \\
\end{bmatrix} \]

- Hysteretic damping model

\[ \tilde{k} = k(1 + i\eta) \]

\[ \tilde{\mathbf{K}}_i = \begin{bmatrix}
\tilde{k}_i & -\tilde{k}_i \\
-\tilde{k}_i & \tilde{k}_i + \tilde{k}_{f,i} + \tilde{k}_{i,V} + \sum_{r=1 \neq i}^{n-1} \tilde{k}_{i,r} \\
\end{bmatrix} \]

\[ \tilde{\mathbf{K}}_V = \begin{bmatrix}
\tilde{k}_{ViBa} & -\tilde{k}_{ViBa} \\
-\tilde{k}_{ViBa} & \tilde{k}_{ViBa} + \tilde{k}_{f,ViBa} + \sum_{i=1}^{n-1} \tilde{k}_{i,V} \\
\end{bmatrix} \]

\[ \tilde{\mathbf{K}}_{i,j} = \begin{bmatrix} 0 & 0 \\
0 & -\tilde{k}_{i,j} \end{bmatrix} \]

\[ \tilde{\mathbf{K}}_{i,V} = \begin{bmatrix} 0 & 0 \\
0 & -\tilde{k}_{i,V} \end{bmatrix} \]

\[ \tilde{\mathbf{K}}_{V,i} = \begin{bmatrix} 0 & 0 \\
0 & -\tilde{k}_{V,i} \end{bmatrix} \]
Design of the ViBa

\[
\min\{U_i^{r,\text{max}}(\alpha)\} \quad i = 1, \ldots, n
\]
\[
\alpha = \{k_{\text{ViBa}}, m_{\text{ViBa}}, \eta_{\text{ViBa}}\} \in \mathbb{R}_0^+
\]
Vibration control of a single structure through the ViBa

Figure 4 Discrete model for single structure protected by the ViBa

\[
\begin{bmatrix}
\tilde{k} & -\tilde{k} & 0 & 0 & 0 \\
-\tilde{k} & \tilde{k} + \tilde{k}_f + \tilde{k}_{\text{SSI}} & 0 & 0 & 0 \\
0 & 0 & \tilde{k}_{\text{ViBa}} & -\tilde{k}_{\text{ViBa}} & 0 \\
0 & -\tilde{k}_{\text{SSI}} & -\tilde{k}_{\text{ViBa}} + \tilde{k}_{f,\text{ViBa}} + \tilde{k}_{\text{SSI}} & \tilde{k}_{\text{ViBa}} & 0 \\
0 & 0 & 0 & 0 & m_{f,\text{ViBa}}
\end{bmatrix}
- \omega^2
\begin{bmatrix}
m & 0 & 0 & 0 & 0 \\
0 & m_f & 0 & 0 & 0 \\
0 & 0 & m_{\text{ViBa}} & 0 & 0 \\
0 & 0 & 0 & m_{f,\text{ViBa}} & 0 \\
0 & 0 & 0 & 0 & m_{f,\text{ViBa}}
\end{bmatrix}
\begin{bmatrix}
U(\omega) \\
U_f(\omega) \\
U_{\text{ViBa}}(\omega) \\
U_{f,\text{ViBa}}(\omega) \\
U_{f,\text{ViBa}}(\omega)
\end{bmatrix}
= \begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
\tilde{k}_f
\end{bmatrix}
U_g(\omega)
\]
\[
H(\alpha, \omega) = \tilde{K}_{\text{dyn}}^{-1}(\alpha, \omega)Q = [H(\alpha, \omega) \quad H_f(\alpha, \omega) \quad H_{\text{ViBa}}(\alpha, \omega) \quad H_{f,\text{ViBa}}(\alpha, \omega)]^T
\]

\[
H(\alpha, \omega) = \frac{U(\omega)}{U_g(\omega)} = \frac{\tilde{k} \cdot \left[ (\tilde{k}_{\text{SSI}} \cdot \tilde{k}_{f,\text{ViBa}} + \tilde{b} \cdot \tilde{k}_f) (\tilde{k}_{\text{ViBa}} - \omega^2 m_{\text{ViBa}}) - \tilde{k}_{\text{ViBa}}^2 \cdot \tilde{k}_f \right]}{(\tilde{k} \cdot \tilde{k}_{\text{ViBa}})^2 - (\tilde{k}_{\text{ViBa}}^2 \cdot \tilde{a})(\tilde{k} - \omega^2 m) + \left[ (\tilde{a} \cdot \tilde{b} - \tilde{k}_{\text{SSI}}^2)(\tilde{k} - \omega^2 m) - (\tilde{k}^2 \cdot \tilde{b}) \right] \tilde{c}}
\]

where \( \tilde{\omega}^2 = \frac{\tilde{k}}{m} \) and \( \tilde{\omega}_{\text{ViBa}}^2 = \frac{\tilde{k}_{\text{ViBa}}}{m_{\text{ViBa}}} \); furthermore, the following positions have been made: \( \tilde{a} = \tilde{k} + \tilde{k}_f + \tilde{k}_{\text{SSI}} - \omega^2 m_f, \tilde{b} = \tilde{k}_{\text{ViBa}} + \tilde{k}_{f,\text{ViBa}} + \tilde{k}_{\text{SSI}} - \omega^2 m_{f,\text{ViBa}} \) and \( \tilde{c} = \tilde{k}_{\text{ViBa}} - \omega^2 m_{\text{ViBa}}. \)
Design for harmonic excitation

\[ \min \{ H(\alpha, \omega_0) \} \]
\[ \alpha = \{ k_{ViBa}, m_{ViBa}, \eta_{ViBa} \} \in \mathbb{R}_0^+ \]

- Closed form solution

\[ k_{optimal}^{ViBa}(\omega_0) = \frac{(\omega_0^2 m_{ViBa}) \left( \tilde{k}_{f,ViBa} + \tilde{k}_{SSI} \left( 1 + \frac{\tilde{k}_{f,ViBa}}{\tilde{k}_f} \right) - \omega_0^2 m_{f,ViBa} \right)}{\tilde{k}_{f,ViBa} + \tilde{k}_{SSI} \left( 1 + \frac{\tilde{k}_{f,ViBa}}{\tilde{k}_f} \right) - \omega_0^2 (m_{f,ViBa} + m_{ViBa})} \]

\[ k_{optimal}^{ViBa} = k_{ViBa}^{real}(\omega) \]
\[ \eta_{optimal}^{ViBa} = \frac{k_{ViBa}^{imag}(\omega)}{k_{ViBa}^{real}(\omega)} \]
Transfer functions of the undamped system for the a) structure and b) ViBa obtained for different mass ratio

![Graphs showing transfer functions](image-url)
Transfer functions of the undamped system for the a) structure and b) ViBa obtained for different coupling stiffness value.
Transfer functions of the a) structure and b) ViBa obtained for different mass ratio and null ViBa loss factor.
Figure 9 Transfer functions of the a) structure and b) ViBa obtained for different mass ratio and ViBa loss factor $\eta_{\text{ViBa}} = 0.18$. 
Reduction factor curves versus mass ratio for several ViBa loss factors.
Prototype structure protected by the ViBa.
Dynamics of Structures Lab
LMS/Siemens Acquisition system
Experimentally evaluated transfer functions of the structure for the uncoupled and coupled case and comparison with numerical results.
Experimental tests: single structure

Single Structure

Structure - ViBa

same harmonic signal!
Recorded acceleration of the structure subjected to harmonic base motion at the circular frequency $= 22.62 \text{ rad/s}$ in the case of single structure and structure coupled with ViBa.
VIBRATION CONTROL OF AN INDUSTRIAL BUILDING THROUGH THE VIBRATING BARRIER

Pierfrancesco CACCIOLA\textsuperscript{1}, Alessandro TOMBARI\textsuperscript{2} and Irmela ZENTNER\textsuperscript{3}

Figure 1 Subdomains of the considered global problem
Proposed approach

-Equation of motion

\[
[K_{\text{glob}}(\omega) - \omega^2 M_{\text{glob}} + i \omega C_{\text{glob}}] \mathbf{u}(\omega) = \mathbf{f}(\omega)
\]

-Craig-Bampton method

\[
\begin{bmatrix}
\mathbf{u}_{\text{ViBa}} \\
\mathbf{u}_{\text{str}} \\
\mathbf{u}_{\text{SF}}
\end{bmatrix}
= \mathbf{P}
\begin{bmatrix}
\mathbf{q}_{\text{ViBa}} \\
\mathbf{q}_{\text{str}} \\
\mathbf{q}_{\text{SF}}
\end{bmatrix}
\quad \mathbf{P}_{[n\times m]} =
\begin{bmatrix}
\mathbf{\psi}_{\text{ViBa}}^{\text{[pxl]}} & 0_{[pxl]} & \mathbf{\phi}_{\text{ViBa}}^{\text{[pxr]}} \\
0_{[qxi]} & \mathbf{\psi}_{\text{str}}^{\text{[qxl]}} & 0_{[qxr]} \\
0_{[rxl]} & \mathbf{\phi}_{\text{str}}^{\text{[qxr]}} & \mathbf{I}_{[rxr]}
\end{bmatrix}
\]

\[
[\mathbf{P}^T K_{\text{glob}}(\omega) \mathbf{P} - \omega^2 \mathbf{P}^T M_{\text{glob}} \mathbf{P} + i \omega \mathbf{P}^T C_{\text{glob}} \mathbf{P}] \mathbf{u}(\omega) = \mathbf{P}^T \mathbf{f}(\omega)
\]
Proposed approach

- Proof of concept – Design for harmonic excitation
- Simplified model

\[
\begin{bmatrix}
\ddot{\tilde{k}} & -\tilde{k} \\
-\tilde{k} & \ddot{\tilde{k}} + \tilde{k}_f + \tilde{k}_{SSI}
\end{bmatrix}
\begin{bmatrix}
\ddot{\tilde{k}}_VIBA & 0 \\
0 & \ddot{\tilde{k}}_VIBA + \tilde{k}_{VIBA} + \tilde{k}_{SSI}
\end{bmatrix}
\begin{bmatrix}
U_1(\omega) \\
U_2(\omega)
\end{bmatrix}
= \begin{bmatrix}
\ddot{u}_f \\
\ddot{u}_{VIBA}
\end{bmatrix}
\]

\[
\tilde{k}_{VIBA}^{optimal} = \frac{(\omega_0^2 m_{VIBA}) (\tilde{k}_f + \tilde{k}_{VIBA} + \tilde{k}_{SSI})}{\tilde{k}_f VIBA + \tilde{k}_{SSI} (1 + \frac{\tilde{k}_f VIBA}{\tilde{k}_f}) - \omega_0^2 m_{VIBA}}
\]

\[
\min\{H(\alpha, \omega)\}
\]

\[
\alpha = \{k_{VIBA}, m_{VIBA}, \eta_{VIBA}\} \in \mathbb{R}^n_0
\]

\[
H(\omega) = [K_{simp} - \omega^2 M_{simp}]^{-1} Q
\]

\textbf{Figure 2 Simplified model}
Figure 2 Approximate structural impedances of the LPM compared to those evaluated by BEM
Figure 3 Approximate ViBa impedances of the LPM compared to those evaluated by BEM
Figure 4 Approximate coupling impedances of the LPM (red curve) compared to those evaluated by BEM (black curve)
Figure 1 Comparison between two trajectories of the top of the structure obtained from the FEM and the LPM model.
Figure 1 Comparison between power spectral density functions obtained from FEM and LPM models.
The industrial building has been modelled according to the finite element approach by means of the Code_Aster open source FE-software whereas the BEM formulation has been used to model the soil by means of Miss3D.
Numerical results

Table 1 Significant dimensions of the Reactor Building

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
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<tbody>
<tr>
<td>Reactor Building shell radius</td>
<td>25.8 m</td>
</tr>
<tr>
<td>Basement shell radius</td>
<td>25.8 m</td>
</tr>
<tr>
<td>Height of springline above basemat</td>
<td>46.12 m</td>
</tr>
<tr>
<td>Embedded height</td>
<td>12.9 m</td>
</tr>
<tr>
<td>Wall thickness</td>
<td>1.07 m</td>
</tr>
<tr>
<td>Basemat thickness</td>
<td>3.05 m</td>
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</table>

Table 2 Dynamic properties of the soil deposits used in the work

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>$V_S$ [ms$^{-1}$]</th>
<th>$V_P$ [ms$^{-1}$]</th>
<th>$\rho$ [GPa]</th>
<th>$\mu$ [kg/m$^3$]</th>
<th>$\eta$</th>
<th>$\nu$</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>800</td>
<td>2653</td>
<td>3.9</td>
<td>2100</td>
<td>0.1</td>
<td>0.45</td>
</tr>
<tr>
<td>B</td>
<td>400</td>
<td>1327</td>
<td>0.97</td>
<td>2100</td>
<td>0.1</td>
<td>0.45</td>
</tr>
<tr>
<td>C</td>
<td>200</td>
<td>663</td>
<td>0.24</td>
<td>2100</td>
<td>0.1</td>
<td>0.45</td>
</tr>
<tr>
<td>BEDROCK</td>
<td>800</td>
<td>2653</td>
<td>0.06</td>
<td>2100</td>
<td>0.05</td>
<td>0.45</td>
</tr>
</tbody>
</table>
Numerical results

Figure 6 Amplification function of the node at the top of the dome for several mass ratio e ViBa damping set to 0 for case with the soil type B and ViBAD05
\[ RF = \frac{|U_{\text{coupled}}^{\text{str}}(\omega_0)|}{|U_{\text{uncoupled}}^{\text{str}}(\omega_0)|} \]

*Figure 7 RF curves obtained for case with the soil type B and ViBAD05*
Numerical results

Figure 7 Top Dome RFs curves for several damping and spacing for case a) ViBAD1 and b) ViBAD05
Time-history acceleration response of the node at the top of the dome in case of single structure and structure coupled with ViBa for the 1989 Loma Prieta earthquake event
Figure 1 Non-dimensional sensitivity of the second-order statistical moments of the nodal displacement of the structure with respect to the a) stiffness and the b) damping of the ViBa.
Vibration control of piled-structures through structure-soil-structure-interaction

Pierfrancesco Cacciola \textsuperscript{a,}\textsuperscript{*}, Maria Garcia Espinosa \textsuperscript{a,}\textsuperscript{b}, Alessandro Tomba\textsuperscript{a}

\textsuperscript{a} School of Environment and Technology, University of Brighton, Cockcroft Building, Lewes Road, BN2 4GJ Brighton, UK
\textsuperscript{b} Department of Engineering Science, University of Oxford, Parks Road, OX1 3PJ Oxford, UK
Discrete ViBa-soil-structure interaction model

\[(\tilde{\mathbf{K}}(\omega) - \omega^2 \mathbf{M}) \mathbf{U}(\omega) = \mathbf{F}(\omega)\]

\[
\begin{pmatrix}
\tilde{\mathbf{K}}_{SS,1} & \tilde{\mathbf{K}}_{SF,1} & 0 & 0 \\
\tilde{\mathbf{K}}_{FF,1}(\omega) & \tilde{\mathbf{K}}_{FF,c}(\omega) & 0 & 0 \\
0 & \tilde{\mathbf{K}}_{FF,c}(\omega) & \tilde{\mathbf{K}}_{FF,2}(\omega) & \tilde{\mathbf{K}}_{FS,2} \\
0 & 0 & \tilde{\mathbf{K}}_{FS,2} & \tilde{\mathbf{K}}_{SS,2}
\end{pmatrix}
\begin{pmatrix}
\mathbf{U}_{S,1}(\omega) \\
\mathbf{U}_{F,1}(\omega) \\
\mathbf{U}_{F,2}(\omega) \\
\mathbf{U}_{S,2}(\omega)
\end{pmatrix}

= \begin{pmatrix}
0 \\
\mathbf{F}_{F,1}(\omega) \\
\mathbf{F}_{F,2}(\omega) \\
0
\end{pmatrix}

\[\tilde{\mathbf{K}}_{rs,i} = \mathbf{K}_{rs,i}(1 + j \eta_{rs,i}) \quad (i=1,2; \ r=F,S; s=F,S)\]
Input PSD function defined at bedrock

\[ \beta = \begin{bmatrix} M_{SS,1}; K_{SS,1}; \eta_{SS,1} \end{bmatrix} \]

\[ G_{UU}(\omega, \beta) = H_{glob}(\omega, \beta) H_{glob}^*(\omega, \beta) G_{UgUg}(\omega) \]

\[ H_{glob}(\omega) = \tilde{\mathbf{K}}_{\text{dyn}}^{-1}(\omega, \beta) \mathbf{Q}(\omega) \mathbf{H}_{\text{soil}}(\omega) \]

\[ \min \{ X_{Ur}(Ts, p, \beta) = \eta_{Ur}(Ts, p, \beta) \sqrt{\lambda_{0,Ur}(\beta)} \}, \quad \beta_{\text{min}} < \beta < \beta_{\text{max}} \]

\[ \eta_{Ur}(Ts, p) = \sqrt{2 \ln \left\{ 2N_{Ur} \left[ 1 - \exp \left[ -\delta_{Ur}^{1.2} \sqrt{\pi \ln(2N_{Ur})} \right] \right] \right\}} \]

\[ G_{0_s0_s}(\omega_i) = \frac{4\zeta_0}{\omega_i \pi - 4\zeta_0 \omega_{i-1}} \left( \frac{R_{\text{SA}}(\omega_i, \zeta_0)^2}{\eta_{\text{ur}}^2(\omega_i, \zeta_0)} - \Delta\omega \sum_{k=1}^{i-1} G_{0_s0_s}(\omega_k) \right) \]

\[ \lambda_{i,Ur} = \int_0^{+\infty} \omega^i G_{UUrU}(\omega) d\omega \]
Reduction factor curves for soil type a) A, b) B, c) C, and d) D

\[ RF = \frac{X_{U_{U,U_{r}}}^{coupled}}{X_{U_{U,U_{r}}}^{uncoupled}} \]
RF curves obtained for several soil types after tuning the ViBa for spacing = 1 m
Acceleration PSD functions for soil type a) A, b) B, c) C, and d) D obtained for mass ratio = 0.75 and spacing = 1m
Acceleration PSD functions of the ViBa for soil type a) A, b) B, c) C, and d) D obtained for mass ratio $= 0.75$ and spacing $= 1$ m.
Figure 1 Set up of the experiment for shaking table (case with structure protected by ViBa device)
Figure 1 Reproduction of the experimental test by SAP2000 for both cases: a) without and b) with the protection by ViBa
Figure 1 Test models realized in the laboratory and placed over a shaking table for a) single structure and b) structure coupled with ViBa.
Figure 1 Comparison between desired and measured Power Spectral Density curves at the shake table platform

Figure 1 Cumulative average of the recorded maximum accelerations of the structure for single structure and structure coupled by ViBa
Figure 1 Numerical and experimental averaged power spectral density functions of the recorded accelerograms of the structure without and with the coupling of the ViBa.
Single structure

ViBa not well designed

ViBa well designed
Remarks
1) The direction of the seismic wave is irrelevant
2) Out of plane protection
3) All of them benefit from the presence of the ViBa
PROTEZIONE

«Una scatola nelle case per assorbire l’energia dei terremoti»

Il brevetto di un ricercatore italiano in Inghilterra: «VI Ba attutisce dal 40 all’80 per cento di una scossa e può essere inserita in edifici esistenti senza alterarli»

di ANDREA INDIANO
Motion for a European Parliament resolution on the importance of the building sector in relation to seismic activity

The European Parliament,

– having regard to the objectives of the European Institute of Innovation and Technology,
– having regard to paragraphs 17 and 19 of Decision No 1386/2013/EU,
– having regard to paragraph 10 of Decision No 553/2014/EU,
– having regard to Rule 133 of its Rules of Procedure,

A. whereas at the Built Environment and Civil Engineering Department of the University of Brighton, the ViBa vibrating barrier has been invented, an instrument which absorbs the impact of an earthquake by 40-80% and can be inserted into existing buildings without modifying them;

B. whereas, in recent years, several earthquake disasters have caused millions of casualties all over the world, including the earthquake in L’Aquila, Italy, in 2009;

C. whereas investing in housing which includes innovative instruments to combat seismic activity also contributes to the economic development of the building sector;

1. Calls on the Commission to establish a fund to finance building companies which intend to invest in innovation with a view to tackling seismic activity.
Future and ongoing developments
ViBa (series and parallel)
Future developments A-ViBa

Figure 2 Simplified model

Adjust stiffness in real time

Measure FFT input
Future developments L-ViBa
Future developments

- Numerical and experimental model of the ViBa in urban environment
- Technological development with industrial support
Vibrating barrier: a novel device for the passive control of structures under ground motion

P. Cacciola and A. Tombari

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A novel device, called vibrating barrier (ViBa), that aims to reduce the vibrations of adjacent structures subjected to ground motion waves is proposed. The ViBa is a structure buried in the soil and detached from surrounding buildings that is able to absorb a significant portion of the dynamic energy arising from the ground motion. The working principle exploits the dynamic interaction among vibrating structures due to the propagation of waves through the soil, namely the structure–soil–structure interaction. The underlying theoretical aspects of the novel control strategy are scrutinized along with its numerical modelling. Closed-form solutions are also derived to design the ViBa in the case of harmonic excitation. Numerical and experimental analyses are performed in order to investigate the efficiency of the device in mitigating the effects of ground motion waves on the structural response. A significant reduction in the maximum structural acceleration of 87% has been achieved experimentally.
Vibration control of piled-structures through structure-soil-structure-interaction

Pierfrancesco Cacciola\textsuperscript{a,*}, Maria Garcia Espinosa\textsuperscript{a,b}, Alessandro Tombri\textsuperscript{a}

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Ground motion excitation
Vibrating barrier
Piled-structures

\textbf{A B S T R A C T}

This paper deals with the vibration control of existing structures forced by earthquake induced ground motion. To this aim it is proposed for the first time to exploit the structure–soil–structure mechanism to develop a device, hosted in the soil but detached from the structure, able to absorb part of the seismic energy so as to reduce the vibration of neighbourhood structures. The design of the device is herein addressed to protect monopile structures from earthquake induced ground motion. By modelling the ground motion as zero-mean quasi-stationary response-spectrum-compatible Gaussian stochastic process, the soil as visco-elastic medium and the target monopile-structure as a linear behaving structure the device, herein called Vibriating Barrier (ViBa), has been designed through an optimization procedure. Various numerical and experimental results are produced to show the effectiveness of the ViBa. Remarkably, a significant reduction of the structural response up to 44\% has been achieved.
Sensitivity of the stochastic response of structures coupled with vibrating barriers

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ABSTRACT

The sensitivity of the stochastic response of linear behaving structures controlled by the novel Vibrating Barrier (ViBa) device is scrutinized. The Vibrating Barrier (ViBa) is a massive structure, hosted in the soil, calibrated for protecting structures by exploiting the structure–soil–structure interaction effect. Therefore the paper addresses the study of the sensitivity of soil–structure coupled systems in which the soil is modelled as a linear elastic medium with hysteretic damping. In order to accomplish efficient sensitivity analyses, a reduced model is determined by means of the Craig–Bampton procedure. Moreover, a lumped parameter model is used for converting the hysteretic damping soil model rigorously valid in the frequency domain to the approximately equivalent viscous damping model in order to perform conventional time-history analysis. The sensitivity is evaluated by determining a semi-analytical method based on the dynamic modification approach for the case of multi-variate stochastic input process. The ground motion is modelled as non-stationary zero-mean Gaussian random process defined by a given evolutionary Power Spectral Density function. The paper presents the sensitivity of the response statistics of a model of an industrial building, passively controlled by the ViBa, to relevant design parameters. Comparisons with pertinent Monte Carlo Simulation will show the effectiveness of the proposed approach.

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Concluding remarks

It is worth investigating!!

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