Experimental and FE updating techniques for the unseating vulnerability assessment of a footbridge structure

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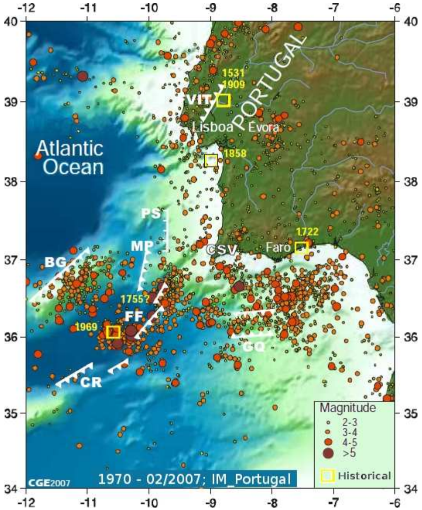
Lifelines interruption due to natural hazards

Can have major economic and social impacts, leading to much higher losses than the value of the damaged infrastructures.

Although footbridges are not usually considered as critical lifeline structures, their collapse during a natural hazard such an earthquaque can be critical, as it might cause severe lifelines interruption.



Project PTDC/ECM/117618/2010

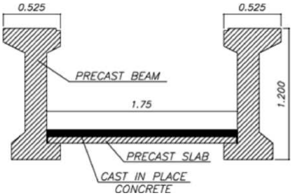
Launched to asses the unseating vulnerability of several footbridges in this region.

PP3141 footbridge on EN 125-10 Portuguese motorway

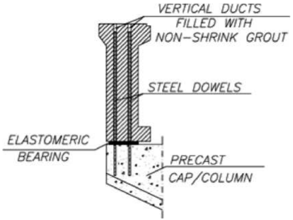
Typical pedestrian crossing, located in a particularly sensitive area on a motorway with intense traffic (Faro airport and railways station, 3 hospitals, 2 fire departments, large shopping center, a large university and several schools).

The structure is a simply supported reinforced concrete footbridge, having a span of 29m and a vertical clearance of 5.4m.

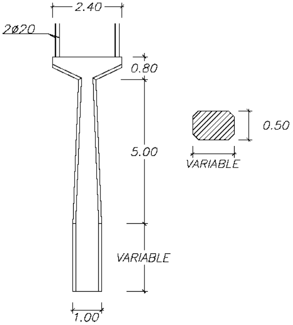
PP3141 footbridge - design details



Deck cross section



Deck/pile connection

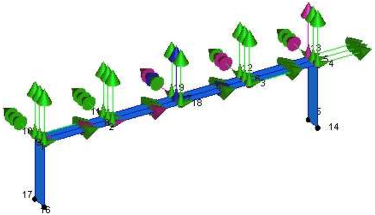


Main pile

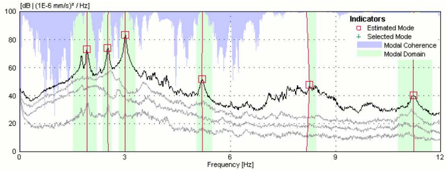
- Deck: two 1.2m height I-shaped prestress girders, connected by a 0.12m thick deck slab;
- Connection main girders and piles: two Φ20mm steel dowels and a neoprene bearing pad;
- Main piles: precast reinforced concrete elements with variable cross section ($0.6 \times 0.5\text{m}^2$ to $1.0 \times 0.5\text{m}^2$) and superficial precast foundations;
- Access ramps/stairs: precast reinforced concrete ribbed slabs.

Ambient vibration tests

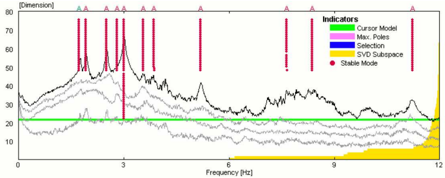
- Three MR2002-CE vibration monitoring systems equipped with MS2003+ triaxial velocity sensors;
- Three reference channels at mid-span of the footbrige;
- The remaining roving sensors were used in seven setups to cover all 15 grid points;
- Data acquisition sampling-rate of 100Hz for 15 minutes.



ARTeMIS
(operational modal analysis software)



EFDD: singular values of the spectral density matrices



SSI-UPC: stabilization diagram

Finite element updating

- Define the finite element model as a function of several parameters associated to a certain degree of uncertainty (geometric and material constants, boundary conditions, inter-element connections).
- Compare the numerical with the experimental natural frequencies and mode shapes. When significant discrepancies are found, one seeks to correct inaccurate parameters, $\boldsymbol{\theta}$, in the finite element model, in order to improve the agreement between the numerical estimates and the experimental results.
- From a practical point of view, one has to solve an optimization problem, in which the optimal values of the parameters are obtained by minimizing an objective function, $J(\boldsymbol{\theta})$, defined in the present work as:

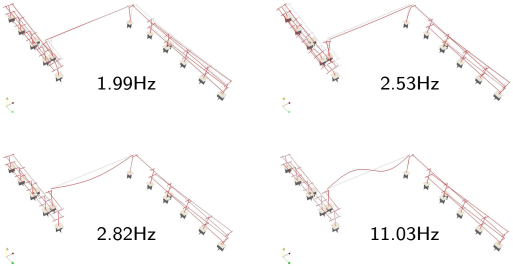
$$J(\boldsymbol{\theta}) = \sum_{i=1}^{N} \left\{ \left(\frac{\omega_i - \bar{\omega}_i}{\omega_i} \right)^2 - \log \left[\frac{(\boldsymbol{\Phi}_i^T \bar{\boldsymbol{\Phi}}_i)^2}{(\boldsymbol{\Phi}_i^T \boldsymbol{\Phi}_i)(\bar{\boldsymbol{\Phi}}_i^T \bar{\boldsymbol{\Phi}}_i)} \right] \right\}$$

$(\omega_i, \boldsymbol{\Phi}_i)$ and $(\bar{\omega}_i, \bar{\boldsymbol{\Phi}}_i)$ are the identified and simulated modal parameters of the N observed modes.

Updated finite element model (OpenSees)

Optimization parameters:

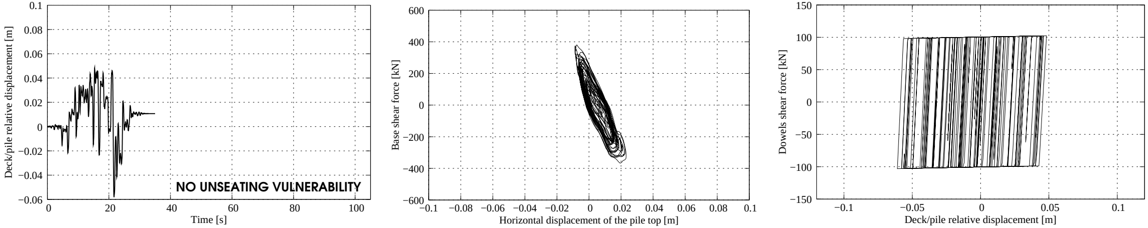
- the bending stiffness of the main girder;
- the stiffness of the connections between the piles and the rigid foundations;
- the stiffness of the neoprene elastomeric laminated bearings (including the steel dowel connectors) between the main girders and the piles.



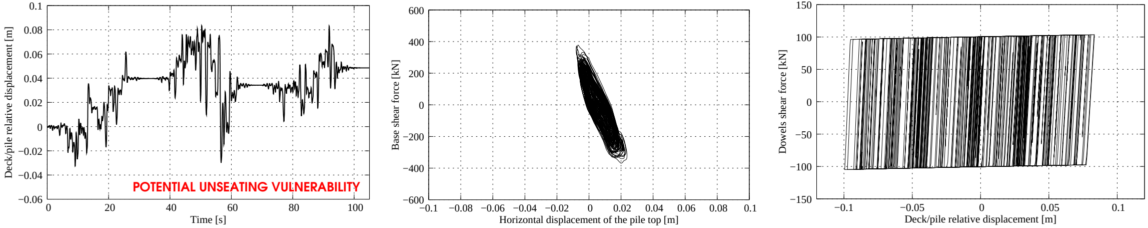
MAC		Numerical Freq. [Hz]			
		1.99	2.53	2.82	11.03
Exp. Freq. [Hz]	1.90	0.96	0.03	0.00	0.00
	2.52	0.04	0.82	0.00	0.00
	3.02	0.00	0.00	0.99	0.00
	11.22	0.00	0.00	0.00	0.94

Modal Assurance Criterion matrix

Design earthquake (PGA 0.3g)

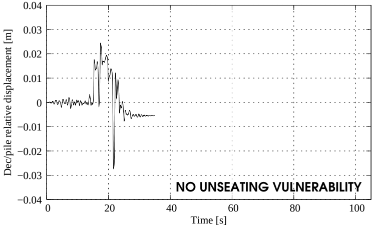


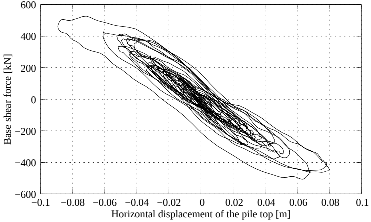
Cascading aftershocks (PGA 0.3g main shock, 0.2g foreshock and aftershock)

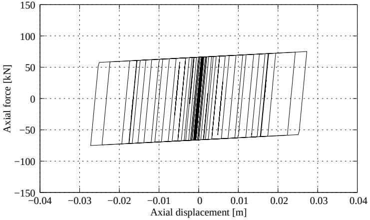


Seismic response of the retrofitted structure - 4 STEEL rods (0.4m, Φ10mm)

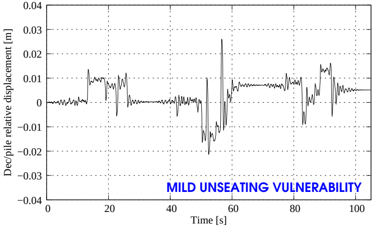
Design earthquake (PGA 0.3g)

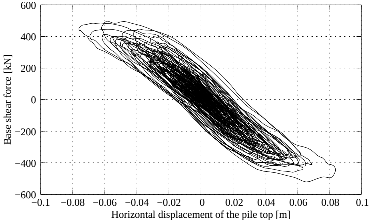


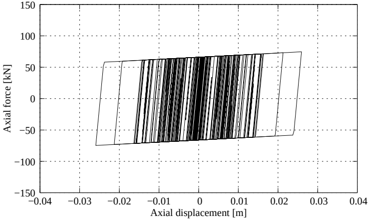




Cascading aftershocks (PGA 0.3g main shock, 0.2g foreshock and aftershock)

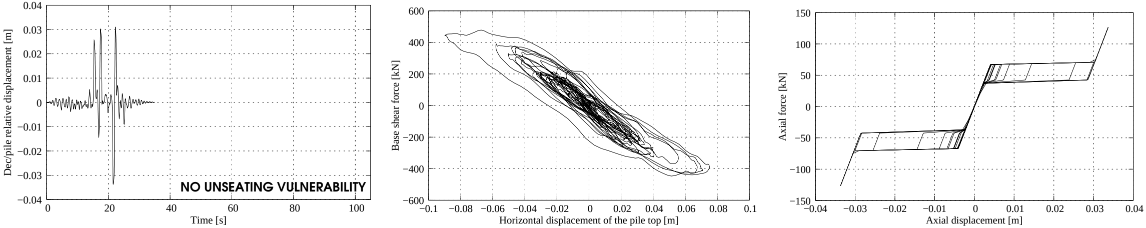




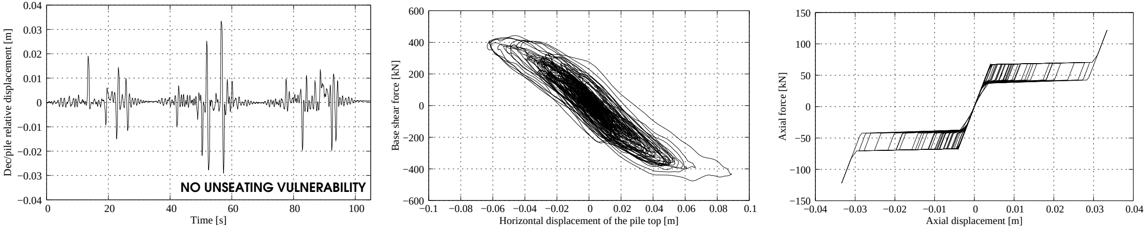


Seismic response of the retrofitted structure - 4 SMA rods (0.4m, Φ11mm)

Design earthquake (PGA 0.3g)



Cascading aftershocks (PGA 0.3g main shock, 0.2g foreshock and aftershock)



Conclusions

- Original footbridge structure
  - No unseating vulnerability for the design earthquake;
  - Plastic deformation concentrated at the dowels connection; No recentring capabilities;
  - High unseating vulnerability in case of cascading aftershocks.
- Retrofitted structure with steel rods
  - Small part of the plastic deformation is distributed to the piles;
  - Large energy dissipation in the seismic links; No recentring capabilities;
  - Moderate unseating vulnerability in case of cascading aftershocks.
- Retrofitted structure with SMA rods
  - Small part of the plastic deformation is distributed to the piles;
  - Moderate energy dissipation in the seismic links; **Recentring capabilities**;
  - **Safe in a scenario of cascading aftershocks**.

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