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Propagation and Mitigation of Vibrational Effects in Structures

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Abstract

The paper addresses the problem of issues relevant to approaching and modelling propagation of dynamic vibrations, and handling and mitigating their effects on buildings and occupants, caused by different factors. Vibrations may derive from a number of different sources of natural and/or anthropic type, ranging from exceptional phenomena such as strong earthquakes, storms waves, explosions to swarms, machinery, menworks, railway or road traffic and so on. Besides safety issues more related to single strong intensity events, new themes should be complied with relevant to serviceability and human comfort during recursive or time-continuity low-intensity dynamic phenomena that during time may cause to structure and people inside damage, desease or discomfort. Attenuation objectives require as a premise new theoretical and operative models for properly representing their propagation mode and transmission from the source origin to the building/person receptor, and on this basis the development and setup of suitable approaches and devices to mitigation. In the paper some approaches to modeling and design are outlined whose effectiveness is proven by numerical results.

Keywords: viscoelastic energy, dissipation, protection systems, dynamic response control, supplemental damping, devices.

1 Introduction

Environmental or anthropic dynamic sources may cause damage and desease to buildings and people inside, also inducing a reduction in the well-being of the occupants and those who possibly carry out work near or inside the buildings themselves and in turn produce vibrations and noise with the use of equipment and tools. It should be noted that approaches to the problem of attenuating structural vibrations induced by exceptional dynamic events, for example seismic waves or wind storms in buildings allow the choice of different design alternatives, which are available in the literature and have been widely experimented, offering a variety of possible approaches to the problem.

The approaches include, among others, the development and implementation of dynamic control devices for the reduction of induced dynamic oscillations, and the development of structural reinforcement techniques, which may also involve the adoption of composite materials in order to produce an increase in the dynamic resistance of buildings to such events.

Actually a further problem is concerned with the need of guaranteeing the protection of buildings also against sources of vibrations of lower intensity, for which there is a notable variability in relation to the typology and the origin of the disturbances that can include either natural hazard events like seismic swarms or anthropic activities induced waves like in case of road or railway traffic or vibrations from machinery, manwork, etc.

The analysis of the sources of various types is necessarily accompanied by an analysis of the risk factors for structures and people, which represents a natural premise for the evaluation of the effects of the sources and, therefore, for the resolution regarding an adequate selection of strategies for the reduction and mitigation of such effects.

In this context, mitigation approaches are aimed at improving the reliability of the structure also in terms of increased usability by abating induced vibrations and managing a plurality of risks. This feature is of central importance in relation to the themes where environmental natural and anthropogenic sources may contribute to affect people comfort inside a building; in this case, the three risk classes related to safety risk, health risk, and transversal risks, with the relative description and for each of them a distinction based on the typology, should be referred to according to the national regulatory references, and the related in-depth analyses are aimed at highlighting what is expected in the case of risk assessments and what needs to be done to prevent, protect and reduce the damage caused in risk contexts.

2 Wave Propagation and Mitigation

2.1. Premise

Whilst dynamic exceptional phenomena, such as strong eartquakes' and storms' waves, are usually handled for safety reasons for protection of buildings, minor dynamic excitations that may be induced by other sources, like in case of traffic, are usually neglected for structural response attenuation purposes. In this case, focus should be addressed to the type of waves mainly transmitted to the final receptor-

building, which impact onto the most proper strategy to be adopted for response mitigation.
As concerns to traffic vibrations, railway vibration and noise come from forces at the contact point between train wheels and rails, which are characterized by quasi-static and dynamic parts. Quasi-static forces depend on the train's weight and not on the speed and mainly influence the track response within a quarter wavelength.
The deflection of a typical track under the train moving with constant velocity v_O and weight P, can be analytically evaluated by referring to the Euler's beam on an elastic foundation

$$u(x,t) = u(x - v_O, t) = \lfloor cos(\alpha|x - v_O t|) + sin(\alpha|x - v_O t|) \rfloor \frac{P + m_u g}{8 E_T I_T \alpha^3} e^{-\alpha|x - v_O t|} \quad (1)$$

with $u(x,t)$ the deflection at location x and instant t, and α depending on the Young's modulus E_T and inertia I_T of the beam, and on the stiffness k_F per unit length of the Winkler foundation

$$\alpha = \sqrt[4]{k_F / 4 E_T I_T} \quad (2)$$

Dynamic excitation depends on speed and results from factors like changes in stiffness, irregularities at the wheel/rail interface, and soil support conditions.
As regards to wave propagation which is a key issue, vibrations run from the wheel contact through the track as body or surface forces, with surface waves attenuated in the soil depth and body waves mainly moving in the soil volume under the surface, finally resulting in compressional P-waves in the longitudinal direction, shear S-waves in the transverse direction, and Rayleigh waves, where a kind of micro-seismic propagation is replicated with speed approximated by various formulas.

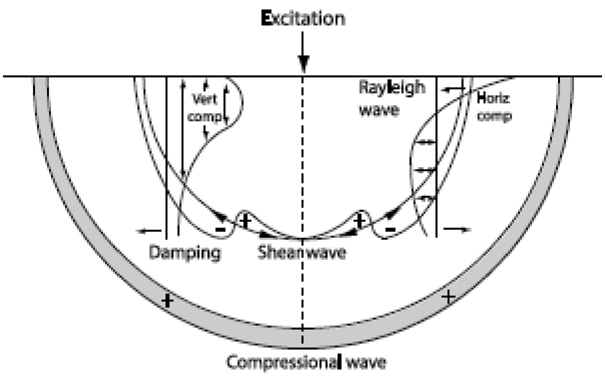

Figure 1: Soil waves' propagation scheme under vertical moving load.

Other types of waves, such as Lamb waves in layers and Stoneley waves at interfaces may theoretically occur but are less common, while major emphasis is usually concerned with the propagation of Rayleigh waves since about two thirds of the total excitation energy is transmitted through them. Finally more complete analytical modelling about traffic waves transmission, both from road and railway traffic, from the source up to the receptor-building should be required for including all steps in one single tool that can be usefully referred to also for correctly driving the process of correct selection of mitigation interventions.

2.2. Mitigation Approach

In the following one refers to a control approach to mitigation of structural vibrations in buildings, which is modified in order to take into account at the same time both seismic waves possibly induced by earthquakes and micro-waves caused by moving vehicles. A viscous elastic damper (VED) control system is referred to consisting of separate components able to account for higher or lower intensity dynamic solicitations possibly caused by the various sources with different frequency contents, and made of combinations of fluid viscous dampers (FVDs) and linear units (LUs). The components may activate or not according to the type of incoming dynamic excitation, allowing high flexibility in the active configuration which is changed depending on the current need, on one side improving the system restoring capability when the response keeps in the elastic range and, on the other side triggering high energy dissipation under higher intensity vibrations and possibly preventing the inelastic phase entries or allowing a partial restoring of residual deformations.
The selection of the optimal parameters is set on the basis of a design approach leading to identifying the control algorithms, generally, as aimed at the maximization of the response attenuation under the minimum control cost.
All quantities and involved functionals are expressed in energetic terms according to the following setup for a sdof system

$$Search\begin{cases} \left\| \Re_e\left(\mu_m, \xi_m \left\| f \right\|\right) \right\| = min \\ \left\| G_e\left(\mu_m, \xi_m \left\| f \right\|\right) \le \gamma \left\| S_e\left(0,0 \left\| f \right\|\right) \right\| \right\| \end{cases} \tag{3}$$

where $||R_e(\cdot)||$, $||G_e(\cdot)||$, $||S_e(\cdot)||$, denote the energy functionals of the monitored controlled response variables, shear and control force as a given percentage γ of the uncontrolled shear, under active microwave vibrations, and μ_m, ξ_m the VED coefficients' selection.
By looking at the inversion of the energetic operators of response variables in Figures 1 and 2 that drive towards one single solution, the VE selection may be finally set up as follows

$$Search\begin{cases} \left\| \Re\left(\psi_w \left\| f \right\|\right) \right\| = min \\ \left\| G\left(\psi_w \left\| f \right\|\right) \le \gamma \left\| S\left(0,0 \left\| f \right\|\right) \right\| \right\| \end{cases} \tag{4}$$

allowing to identify the coefficient ψ_w..

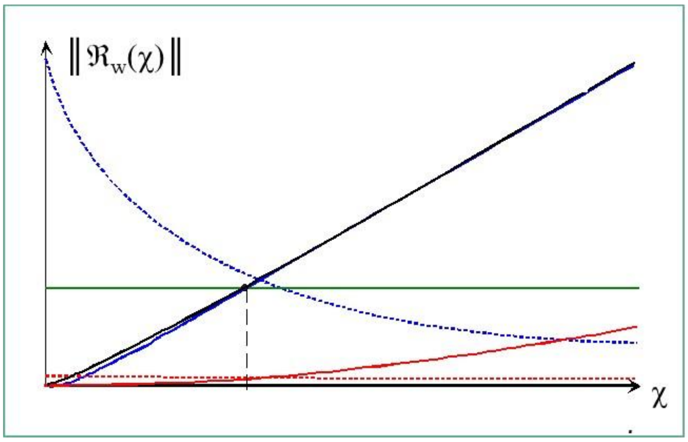

Figure 1: Energetic measures of structural response indexes under prevalent linear/nonlinear ratio contribution.

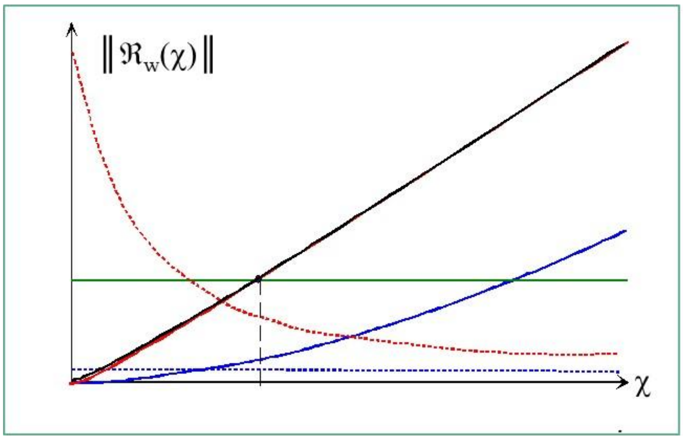

Figure 2: Energetic measures of structural response indexes under prevalent nonlinear/linear ratio contribution.

3 Results

The implementation stage in calculus codes shows effective results under the approach outlined in Sect. 2 and indicated as A in Figures 4 and 5, where numerical data are reported referred to a sdof shear frame subject to randomly generated shot noises.
Also from numerical investigation, one may assess that different approaches to the problem where similar optimization setup is adopted still lead to identify limitations on the involved response variables and active forces operators that keep valid and reliable for effectively mitigating structural effects (B), as clearly shown by

comparison of numerical results in Figures 4 and 5 where the varied objectives and constraints result in different but still significant response attenuations.

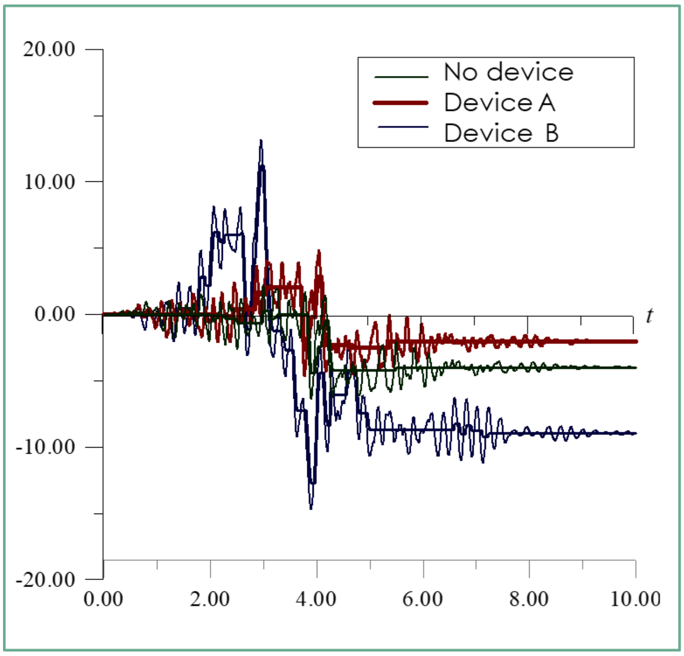

Figure 3: Comparison of devices' performance under changes in the objective functional setup.

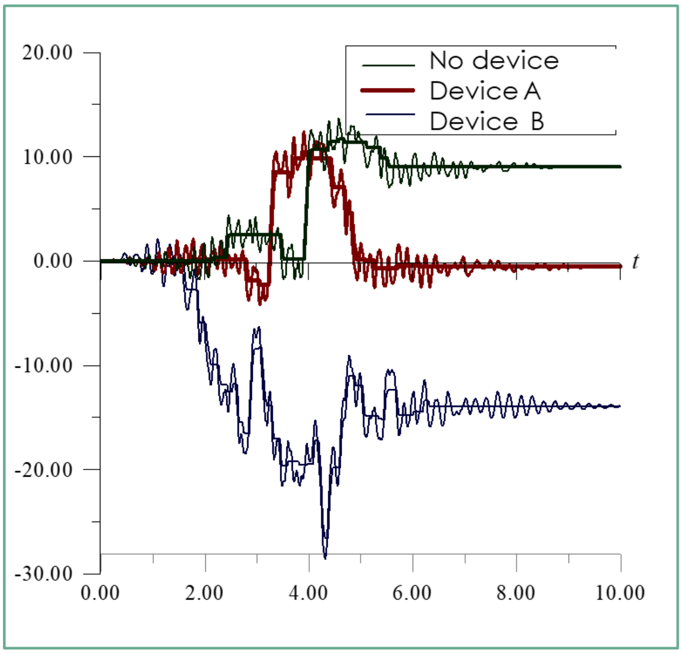

Figure 4: Comparison of devices' performance under changes in the objective functional setup.

4 Conclusions

The paper addresses the problem of propagation, containment and mitigation of structural effects induced by wave transmission through the soil induced by multi-varied dynamic sources, which may affect the serviceability besides the safety of the building and its occupants. Mitigation tools for attenuating different types, intensities and frequency contents of vibrations, should involve de-coupling of devices that nevertheless should be able to be somehow coupled in synergic terms for contributing to afford and successfully handle different needs. This final objective may be accomplished within more complex systems compounded by a series of devices somehow designed according to a main common strategy but obeying different objectives and structures in the design setup, finally able to effectively comply with active dynamic solicitations.

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