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Intelligent damping layer under a plate subjected to a pair of masses moving in opposite directions

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ABSTRACT

Reducing displacements of a plate vibrating under a pair of masses traveling in opposite directions can be improved by adding a smart subsoil instead of a classical damping layer. We propose a material that acts according to the instantaneous state of the plate, i.e., its displacements and velocity. Such an intelligent damping layer reduces vertical displacements even by 40%–60%, depending on the type of load and the assumed objective function. Existing materials enable the application of the proposed layer in a semi-active mode. The passive mode can be applied with materials exhibiting direction-dependent viscosity.

1. Introduction

In this paper, we propose a concept of an intelligent damping material that allows reducing vibrations of structures significantly more than a classical damping material. We assume the unilateral behavior of the damping layer, which impedes the motion with a different force depending on the direction of the velocity. We incorporate such a material into a 2-dimensional plate in the form of an intelligent layer.

Plates and slabs subjected to loads moving in opposite directions are commonly employed in civil structures and transportation. Examples may include bridges, overpasses, pedestrian pathways and road surfaces. Nowadays, when the speed of vehicles has been increasing, the structures are loaded significantly more than ever before. The accompanying vibration may lead to critical states, causing serious structural damage. To face the undesired vibration levels, a number of control systems have been developed and tested in real engineering environments. Typical solutions in structural control are based on force actuators. They are characterized by high performance counterbalanced by significant energy consumption and with the risk of unstable states in the case of a failure of the control system. In [1], the authors suggested employing force actuators to suppress the vibration of bridges. A similar approach was proposed to control the shape of the railway tracks in [2].

Analyses regarding two or more masses moving in opposite directions are not numerous. Wu and Dai studied dynamics of a multi-span beam on which non-inertial loads were traveling with constant and varying speeds [3]. Zhu and Law investigated the effect of eccentricity of moving loads and found out that the multi-lane loading case was less critical than the single-lane one [4]. In [5] critical conditions related to speed and meeting point of vehicles moving in opposite

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directions were identified for the case of short- and medium-span bridges. The effect of variation of loads velocity, inertia and their spacing was analyzed in [6].

In the present paper, we focus attention on the so-called slab tracks, widely applied in railway transportation systems. Having put an elastic elastomeric layer between the track and the foundation, one can prevent transmitting the vibrations of the track to the soil and surrounding buildings or the supporting bridge structure. Compared to ballast tracks, floating slab tracks offer the possibility of adjusting the track to working conditions, such as soil parameters, or the mass and speed of the trains (see [7–9]).

An elastic dissipating layer that supports the main structure is always expected to be possibly the thinnest. In many cases, the simple use of elastic layers does not provide sufficient quality. We focus our attention on materials with direction-dependent velocity (see [10,11]) and propose a special intelligent material that is resistant to deflections and to the rate of deformation. The material exhibits properties defined by general parameters, which are going to be determined to obtain significantly higher damping performance than in the case of traditional bilateral damping materials. We are going to choose those parameters of the material that preserve possibly low stresses and displacements of the structure. Numerical simulations of the vibrations induced by a pair of moving masses prove that the damping dependent on the state of the structural displacement and the velocity of the displacements suppresses the vibrations considerably more effectively than a classical material having a similar viscosity.

Asymmetric damping is encountered in many engineering applications. Examples may include devices used in vehicle suspension systems, in which the dampers are able to yield asymmetric force-velocity characteristics in order to generate larger damping force in rebound than the one during compression [12]. A similar concept has been proposed in civil engineering to prevent buildings from seismic vibrations [13–15]. Designing of a thin, intelligent damping layer can be perceived as a challenge for modern material engineering. Lin and Trethewey presented a method to analyze elastic beams subjected to dynamic loads induced by moving mass [16]. Later, the first author pointed out some mistakes that can be made while analyzing dynamics of similar systems [17,18].

The idea used in the elaboration of the smart material is based on the principle of the lever (see Fig. 1). At the first stage, the plate under the load is supported rigidly, while the further part remains soft and tends to lift. Then, when the load arrives at the distant part, the soft layer becomes rigid and effectively supports the structure, while the previously subjected part of the layer becomes soft and can easily rise to the neutral position.

A series of publications has created a base for the present study. Early papers devoted to the semi-active control of vibrations (see [19,20]) demonstrated that a beam supported by a set of controlled dampers and subjected to a moving load is deflected less than an equivalent structure equipped with passive dampers. Experimental test were presented in [21]. Although the range of moving load velocity covered by the experiment was limited, the publication gave opportunities for further research and applications.

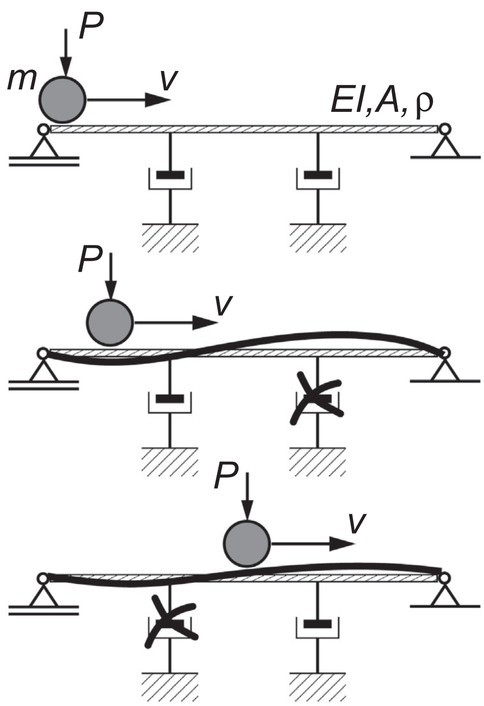

Fig. 1. The idea of the behavior of the smart foundation.