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Flooring-systems and their interaction with furniture and humans

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Abstract

Flooring-system designs may be sensitive in terms of their vibrational performance due the risk that serviceability-limit-state problems may be encountered. For evaluating the vibrational performance of a flooring system at the design stage, decisions must be made by the engineer in charge of computations. Passive humans and/or furniture are often present on a floor. Typically, these masses and their way of interacting with the floor mass are ignored in predictions of vibrational behaviour of the flooring system. Utilizing a shell finite-element model, the paper explores and quantifies how non-structural mass can influence central parameters describing the dynamic behaviour of the flooring system with focus on elevated non-structural mass.

Keywords: Modal properties of floors; floor dynamics; numerical prediction; serviceability-limit-state; estimation accuracy.

1. Introduction

A simple assumption for a vibration serviceability check of a floor design would be to assume that the floor is not carrying any non-structural members and masses. However, this is seldom a correct assumption as many floors are equipped with furniture or equipment of some sort. Also the floor might be occupied by humans and it is established that these and simple masses (such as furniture) added to the floor will influence floor dynamic characteristics [1–3] and thus the basis for the vibration serviceability check. Ultimately there is the risk that the engineer in charge of the vibration serviceability check overlooks or does not account for important influences that in-service usage of the floor area might have on floor dynamic characteristics, and eventually the outcome of the serviceability-limit-state evaluation performed for the floor might not be representative for the actual in-service conditions.

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The paper has focus on the potential interaction between elevated non-structural masses attached to a floor and the natural frequencies of the floor computed on the basis of the assumed elevation of these masses above the floor. Simple added non-structural mass on a floor is most frequently considered as a mass that does not contribute with stiffness but with additional mass moving in the vertical direction together with the floor mass. Assuming this type of behaviour, a simple equation would predict decreases in floor frequencies resulting from the presence of the added mass. However, the centre of gravity of items on the floor such as bookshelves or desks would be elevated above the floor plane and the bending of the floor experienced during floor vibrations would (in some scenarios and for some modes) cause the centres of gravity of such items to move horizontally, hereby adding rotational inertia and consequently modal mass to the floor.

Hence, it is chosen to study how a set of elevated non-structural masses attached to the floor can influence floor natural frequencies. Different elevation heights of the set of non-structural masses and different sizes of the set of non-structural masses will be considered, in order to draw a picture of the basic mechanisms.

For a floor there would be a number of different types of excitations that could be problematic and could cause excessive floor vibrations disturbing human occupants on the floor or causing problems for sensitive equipment placed on the floor area. Internal action resulting from humans in motion on the floor might be the source of vibration [4], or problematic floor vibrations or noise might be due to nearby road or rail traffic, above or below ground level [5–7], nearby construction works or similar. The list of possible vibration sources could continue, but bottom line is that a quite wide range of excitation frequencies can cause unwanted vibrations of floors. Hence, it is chosen to monitor floor natural frequencies and how these change due the presence of elevated non-structural masses in a frequency range covering frequencies up to 250 Hz. Doing so ensures capturing the frequency behaviour of the floor resulting from interaction with the elevated masses for many possible types of excitation that may cause annoyance, for example, in the form of whole-body vibration or re-radiated noise.

The floor subject to investigation is described in Section 2 which also describes the finite-element (FE) model constructed for the floor and the scenarios assumed for usage of the floor. Section 3 presents and discusses the results. Finally, Section 4 gives the conclusions of the study.

2. Methodology

2.1. Computational model of the floor

For the studies of this paper, a reinforced concrete floor was assumed. The floor was assumed to be rectangular and pinned along all four sides. Side lengths of 8 m and 9 m, respectively, were assumed and the thickness of the floor was assumed to be 180 mm and the mass density was assumed at 2400 kg/m^3. Due to the dynamic behaviour of reinforced concrete concerning the prerequisites of the problem at hand, the composite material was modelled as being homogeneous, isotropic and linear elastic. For calculations, Young's modulus (E) was assumed to be 30 GPa and Poisson's ratio (ν) at 0.15. These values are fairly realistic for a reinforced concrete floor.

The next step was to create an FE model of the floor. Since inertial energy of elevated non-structural masses was to be accounted for, it was chosen to employ an FE model using shell elements [8]. Each element had nine nodes and considered five degrees of freedom per node, involving three translational displacements and two rotations associated with bending. The drilling degree of freedom was controlled by adding a small artificial stiffness. A second-order Lagrange interpolation approach was used for computing displacements and rotations, and selective integration of the stresses was employed to avoid shear locking.

Natural frequencies $f_{(k)}$ (for mode number k) were extracted from the FE model by solving the undamped eigenvalue problem. A 12-by-12-element grid for the entire floor proved sufficient in terms of providing converged estimates of frequencies of the empty floor for modes up to 250 Hz. A plate model of the floor was also tested and it gave, as expected, minor differences in floor frequencies compared to those extracted using the shell model. The code employed for computations reported in this paper was verified by comparison with an FE model created in ABAQUS [9] using Mindlin-Reissner shell elements with eight nodes and reduced integration. For scenarios in which non-structural mass was assumed to be placed on the floor, the eigenvalue problem was solved taking offset in the stiffness matrix, $\mathbf{K}$, and the mass matrix, $\mathbf{M}$, of the combined system that includes the non-structural masses attached to the floor. The first mode of the empty floor was found to have a frequency just over 8 Hz.