Seminar: Vibrations and Structure-Borne Sound in Civil Engineering – Theory and Applications

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Low -frequency vibrations in constructions.

(Floating floors.)

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Saint-Petersburg

2006

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Preface.

The sounds transmitted by floors are either air-borne sounds, such as those of speaking, or sounds having their origin in some physical impact such as walking or the moving of furniture. Air-borne sounds seldom pass through floors to such an extent as to be of annoyance to the occupants of the room below or above the floor, owing to the fact that the floors are usually heavier, for structural reasons, than walls.

Part 1. **Sound-Insulated Masonry Floors.**

Sounds due to physical impact are usually the most serious floor problem. When a person walks upon a bare concrete floor, or a hard object strikes the floor, the sound may be transmitted with considerable facility. On the other hand, when a sharp object strikes a padded floor the impact is largely absorbed and much less sound is generated than when the object strikes the solid concrete.

The simplest method of insulating masonry floors against impact sounds is to deaden the sound at the source.

There are various adaptations and modifications of the methods of sound-insulating construction floors and ceilings. These constructions can involve the use of certain special accessories including deadening felt and metal strips. The sound-insulating efficiency of this construction may be increased by using the suspending ceilings.

These patented systems generally involve special types of construction including combinations of sound-insulating materials and patented springs, clips or others devices for isolating machinery noise and vibration, and for reducing sound transmission.

Part 2. Index of the level of impact sounds.

In Russia for determining the soundproofness of the floor it would be necessary to obtain the index of the level of impact sounds under the floor.

In this part this calculation of the soundproofness are presented, using the real structure of the floor and necessary tables and equations from the reference books.

We can obtain the index of the level of impact sounds under the floor, using the equation of the vibration frequency of the floor.

The vibration frequency of the floor depends on:

1) the dynamic module of elasticity of the sound-insulating material,
2) the thickness of this layer in the state of compression,
3) the relative compression of the material,
4) the surface density of the material.

Part 3. Laboratory experiments.

Unfortunately, the theoretical functions got with the help of calculations can't always reflect the properties of the construction in project.

For this purposes special investigations should be held.

In this part the results of some laboratory measurements are presented.

Dynamic forces caused by humans.

1. Footfall forces

Forces from footsteps and jumping have been studied for various reasons ranging from ergonomic considerations to the detection of intruders as well as to prediction of floor and footbridge vibrations (for example Galbraith & Barton 1970, Matsumoto et al. 1978, Ohlsson 1982, Wheeler 1982, Rainer & Pernica 1986, Baumann & Bachmann 1988 and Ebrahimpour & Sack 1989).

One phenomenon that might affect the shape of the vertical force pulse is the interaction between the floor and the human body. The presence of a floor resonance will cause the force to drop at the resonance frequency. However, for low-frequency floors, which are of main interest here, this effect can probably be ignored as the weight of the floor system is large compared to the weight of the walkers.

The continuous load from a single person walking, running, jumping or performing other rhythmic activities could be described as a series of footfall force pulses.

For low-frequency floors where the response is dominated by resonances below 8 Hz, the steady-state forces caused by successive footsteps are most important. If the person walks (or runs or jumps) at a constant step frequency and with a constant stride (walking and running), the continuous force is dominated strongly by distinct harmonic force components. In practice there are few cases where pedestrian motion is well coordinated. Especially where the force arises from the activity of more than one person, it is more appropriate to treat it as a random process.

The computational model is sensitive to the overlap chosen between the individual steps, especially in the lower frequency range.

It is preferable to represent the forces as a spectrum or function in the frequency domain. This is due to the fact that the simplest way of describing the dynamic behaviour of a complex, but linear, structure is in terms of its modal properties (eigenfrequencies, mode shapes, modal masses and modal damping). If these properties are known, a transfer function between force and response can be established and, given the force spectrum, the steady state response of the floor structure can be easily calculated. A time domain representation of the forces will be computationally much less efficient for response calculations and is also significantly more difficult to describe for information transfer purposes.

Step frequencies for walking are generally in the range 1.5 to 2.4 steps per second, or Hz.

The treatment of forces from walking and running is further complicated by the fact that the force is not stationary in space. The movement of the load source can be modelled in the time domain by varying the location of the force as well as the force magnitude with time. Such models are however computationally inefficient.

2. Laboratory measurements

2.1 Measurement setup and programme

In order to mesure the dynamic load from groups of people walking or running in an ordinary manner it is necessary to use a large test floor. The method chosen for this study was to determine the vertical dynamic force indirectly from measurements of the response of a floor structure with well-known dynamic properties to excitation from walking, running and jumping. The measured quantity was the vertical acceleration at midspan.

Experiments were carried out with different activity frequencies and with a varying number of participants. For the experiments with one subject, the main objective was to study the effect of various footstep frequencies f_s. The frequency was kept constant by means of a metronome. For walking, f_s was varied from 1.3 to 2.5 Hz in increments of 0.1 Hz, for running from 2.0 to 3.0 Hz and for jumping from 1.8 to 3.2 Hz, the latter two in increments of 0.2 Hz. For tests with several walking subjects the response was measured when walking in step (1.7 or 2.0 Hz) as well as for irregular step frequencies, that is each subject used his/her own rate although all moved with the same speed. The largest group size studied was 11 people.

2.2 Test floor properties

The test floor was a precast concrete element. It was 2.4 m wide and 0.4 m deep. It was 10 m long and simply supported at both ends. The weight of the element was 6500 kg.

2.3 Force estimation and generalizations

The estimated forces are thus described in terms of force spectral densities.

The calculations typical force spectral density for a group of walking people of involves a division by the squared magnitude of the point accelerance for point no. 17.

The local minimum of the force spectral density at the first natural frequency is worth commenting upon. This is partly explained by the higher flexibility of the floor element at that frequency, which may cause the force to drop.

3. Experimental results.

3.1 Walking, one person.

The footstep frequency was varied from 1.3 up to 2.5 Hz. The results discussed in this section refer to a male person with a mass of 75 kg. The spectral densities of the force caused by the person walking at four different step frequencies are given.

The peaks at each "harmonic" have a certain width. This means that the deterministic description of the force (as a sum of harmonic forces at the harmonics of the step frequency) is not exactly true. Therefore, the force power $\overline{F}^2$, or the mean square force, determined within various bandwidths Δf around the peak, was studied. $\overline{F}^2$ at each harmonic is calculated from the measured force spectral densities.

3.2 Walking, groups

The groups consisted of 7 and 11 people respectively and the mean weight of the subjects was 800 and 745 N respectively. Coordinated walking at the step frequencies 1.7 and 2.0 Hz and uncoordinated walking at a leisurely stride as well as at a fast stride was performed. The leisurely stride seems to have corresponded to a mean step frequency of about 1.65 Hz.

The resulting force spectral densities for all different footstep frequencies are presented.

3.3 Running

The footstep frequency was varied from 2.0 up to 3.0 Hz in increments of 0.2 Hz. The shapes of the spectral density functions are very similar to those obtained for walking, but their magnitudes are higher.

The spread of force power around each harmonic is nearly identical to that for walking (one subject).

3.4 Jumping

The jumping frequency was varied from 1.8 up to 3.2 Hz in increments of 0.2 Hz. The resulting force spectral densities for three different jumping frequencies are presented. These are somewhat different in shape as compared to those for walking and running. Compared to the magnitudes of the peaks for running the magnitudes of the spectral density functions for jumping are higher.

Conclusion:

Sounds due to physical impact are usually the most serious problem for occupants. Unfortunately, the solid concrete floor slab can’t provide the necessary soundproofness.

There are many methods of the sound protection. There are many sound-insulating constructions of the floor. There are many sound-insulating materials. But we can’t describe the response of the real construction to the force power, using theoretical functions.

Therefore it is necessary to carry out different laboratory experiments and experiments in natural conditions for understanding the behaviour of the real construction in the future.

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