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The evaluation of composite floor vibration frequencies

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Summary

Nowadays structural engineers are facing a significant challenge to develop lighter and economical composite steel-concrete floor systems. This trend increases the number of problems, some of which involve unwanted floor vibrations. This is a very frequent phenomenon encountered in a wide range of structures subjected to rhythmic or un-rhythmic dynamic actions. This article presents two composite flooring systems and an evaluation of their natural frequencies.

Keywords: composite slab; composite beam; Slimdek; ComFlor; frequency of vibration; dynamic behaviour.

1. INTRODUCTION

Composite slabs are made of steel decking and cast on site concrete. The steel decking has a double purpose: formwork and inferior reinforcement for the slab. After the concrete curing, the steel decking collaborates with the concrete creating a composite structure.

The floor beams are either hot rolled steel profiles or welded plate profiles. The composite behaviour of the beams is achieved by welding steel shear studs to the top flange of the beams. Usually, the studs are attached by welding to the beams through the steel decking. The shear studs provide a sufficient link between the concrete slab and the steel beams resulting in the composite behaviour.

Composite floors are frequently used in commercial, industrial and residential buildings due to the construction speed and structural economy [2]. Although these floors are used in steel frame structures, they can be also used in reinforced concrete or masonry structures.

One example of composite floor is presented in figure 1. The position of the beams is shown by the rows of steel studs.

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Figure 1. Typical example of a composite floor

The main benefits of this kind of flooring system are the following [1, 4]:

- high speed of construction,
- low weight,
- structural stability,
- reduced structure height,
- low transportation costs,
- durability,
- ease of buildings services integration.

Another composite floor system is „SlimFlor”. SlimFlor is a generic term used to describe a structural flooring system where the beams are encased in the slab thickness. This is achieved by resting the steel decking on the bottom flange of the beams. Although this concept isn’t a new one, it was improved in time. A very important improvement was made by the Corus Company from Great Britain (the former British Steel). The research results carried out by this company lead to the implementation of the Slimdek composite flooring system, consisting of steel beams and composite slabs made of steel decks and reinforced concrete [5].

The Slimdek composite flooring system allows for spans up to 9 m. Usually, the span values are between 5.5 m and 6.5 m, without the need of temporary propping. Another advantage is the lack of secondary beams.

An example of the Slimdek composite floor is depicted in figure 2.

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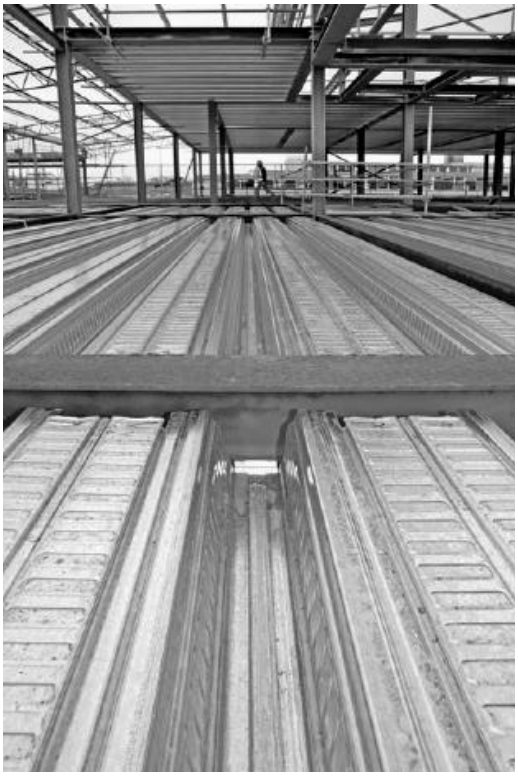

Figure2. The Slimdek composite flooring system.

Some examples of beams used for the Slimdek composite floor are depicted in figure 3. Some of these beams can be designed to collaborate with the concrete slab in order to eliminate the need of steel studs.

The advantages of this flooring system are similar to those presented for the classic composite flooring system. In addition, the Slimdek composite floor presents the following benefits:

- reduced depth of the system. This aids to the cost reduction for claddings,
- services can be integrated between the decking ribs passing through openings in the beams web,
- provides good fire resistance. This system provides 60 minutes inherent fire resistance.

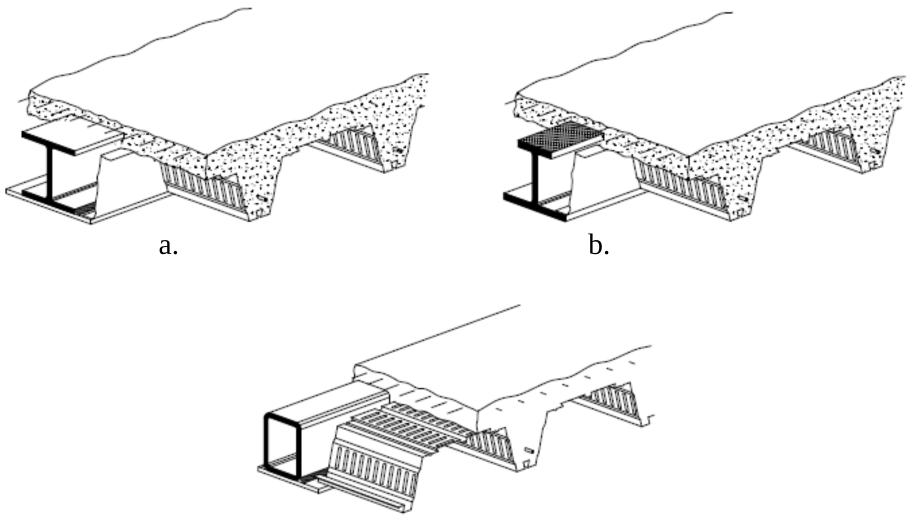

Figure 3. .Beam types: a – non-composite compound beam; b – asymmetrical composite beam; c – rectangular cross-section non-composite beam [5].

2. DESIGN REQUIREMENTS FOR VIBRATIONS DUE TO HUMAN ACTIVITY

2.1. Human induced vibrations

Most of the vibrations which occur within a floor are due to the dynamic actions created by equipment and human activity, such as: walking, dancing, running or aerobics. The problem associated to the dynamic response determination of floors under dynamic actions induced by human activity is complex due to the difficult modelling process of this kind of actions.

Reducing the effects of human activities can be achieved in many ways: by using dampers, by increasing the structural stiffness, by varying the mass of the slab etc.

Generally, the design requirements for floors under human walking induced vibrations are based on the following principles. In the case when the sinusoidal forces are small, such as those created by people walking, it is more efficient to limit the maximum acceleration of the structural system with an additional resonance condition. This control of the acceleration value can be done by increasing the damping or the mass of the system. Also, the system's natural frequency of vibration is important because by increasing this value a decrease in the force/dynamic effect intensity is achieved.

In the case of rhythmic activities (dancing, aerobics) the control can be done by increasing the value of the natural frequency of vibration above the value of the system applied action frequency. Thus, the system resonance is avoided. The minimum accepted values are 9 Hz – 10 Hz.

2.2. The evaluation of actions induced by human walking

One method for computing the dynamic response is proposed in the „Floor Vibrations Due to Human Activity" by Murray et al. [6] design guide. The criteria presented in this guide may be applied at structural systems for office buildings, shopping malls, footbridges and residential buildings. The following hypotheses are considered:

- the limitation of acceleration values according to ISO 2631-2 specifications, figure 4,
- modelling the action induced by people walking is made for the „i" harmonic according to relationship (1):

$$F_i(t) = P\alpha_i \cos(2\pi i f_s t) \tag{1}$$

Where:

P is the weight of one human – it is considered to be equal to 700 N – 800 N,
α_i – the dynamic coefficient for the „i" component of the harmonic force,
f_s – the frequency due to human walking,
t – the time expressed in seconds.

The values for the frequencies and dynamic coefficients are presented in table 1.

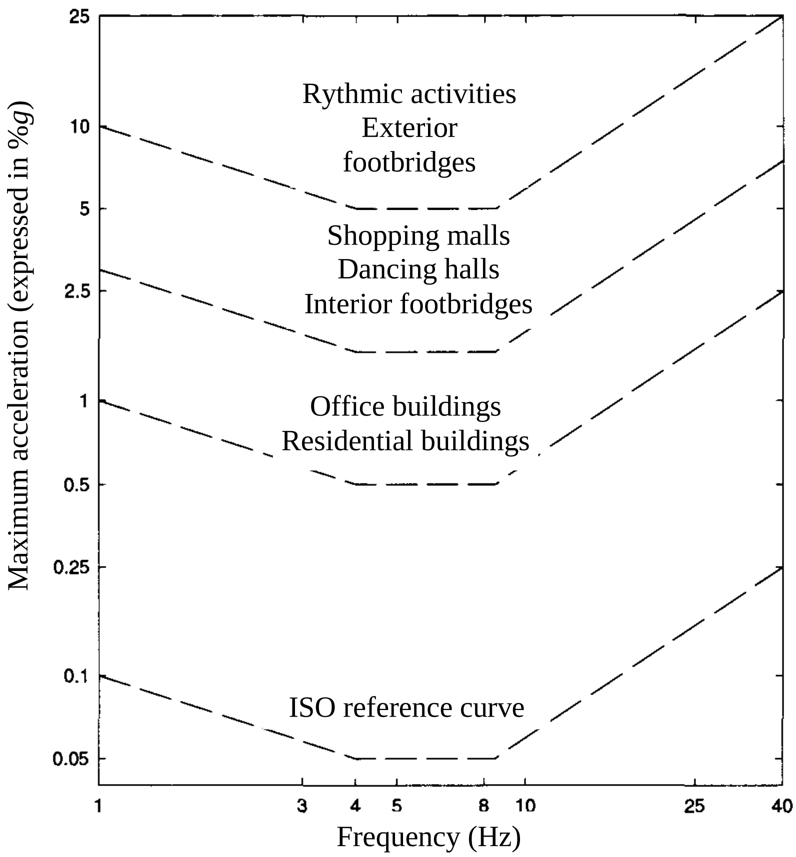

Figure 4. Comfort recommended maximum accelerations caused by human activities (Allen and Murray, 1993; ISO 2631-2: 1989) [6]

Table 1. Frequency values (f_s) and dynamic coefficients (α_i) [6]

Harmonic (i)	Walking		Aerobics hall		Dancing hall	
	f_s (Hz)	α_i	f_s (Hz)	α_i	f_s (Hz)	α_i
1	1,6 - 2,2	0,5	2,2 - 2,8	1,5	1,8 - 2,8	0,5
2	3,2 - 4,4	0,2	4,4 - 5,6	0,6	3,6 - 5,6	0,1
3	4,8 - 6,6	0,1	6,6 - 8,4	0,1	-	-
4	6,4 - 8,8	0,05	-	-	-	-
α_i = maximum sinusoidal force/human weight						

Considering the previous hypotheses, the resonance response function with respect to the maximum acceleration can be expressed as follows:

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$$\frac{a}{g} = \frac{R\alpha_i P}{\beta W}\cos(2\pi i f_s t) \tag{2}$$

Where:

a/g is the ratio between the floor acceleration and the gravitational acceleration,
g – the gravitational acceleration (g = 9.81 m/s^2),
R – the reduction factor,
β – the dynamic amplification factor,
W – the total weight of the floor.

The reduction factor, R, has a value of 0.7 for footbridges and 0.5 for floors. This factor takes into consideration that the action applied on the floor is not in the same place as the human factor which perceives the vibrations.

The dynamic coefficient, α_i, can be expressed with the relationship:

$$\alpha_i = 0{,}83 e^{-0{,}35 f_n} \tag{3}$$

Equation (2) can be written as follows:

$$a_p = \frac{P_0 e^{-0{,}35 f_n}}{\beta W} g \le a_0 \tag{4}$$

Where:

a_p is the maximum estimated acceleration for the floor (expressed as a percentage of g),
a_0 – the limit acceleration recommended by ISO 2631-2 (expressed as a percentage of g),
f_n – the floor's fundamental frequency of vibration,
P_0 – a constant force (P_0=0.29 kN for floors and P_0=0.41 kN for footbridges).

The product $P_0 e^{-0{,}35 f_n}$ represents the harmonic force due to people walking.

The floor's natural frequency of vibration can be evaluated by using relationship (5).

$$f_n = 0{,}18\sqrt{\frac{g}{\Delta}} \tag{5}$$

Where:

Δ is the maximum deflection in the mid span due to the own weight of the floor.

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3. COMPUTATIONAL MODELS

3.1. Computational models presentation

Two models were considered in order to evaluate the frequencies of vibrations. The first model is a composite floor with the classic format and the second having the Slimdek system. The slab thickness is 37.5 cm including the depth of the deck ribs. The ratios of the slab is 1:1 (6x6 m), the concrete grade is C25/30 and the steel grade is S275. The beam cross-section is presented in figure 5, and the decking is ComFlor 210 available at Corus. This decking is depicted in figure 6.

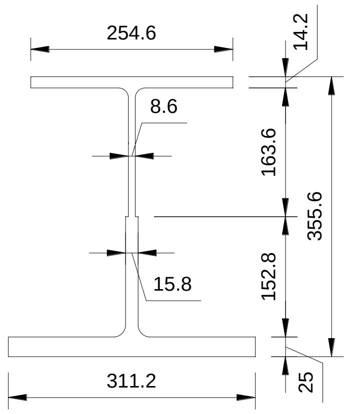
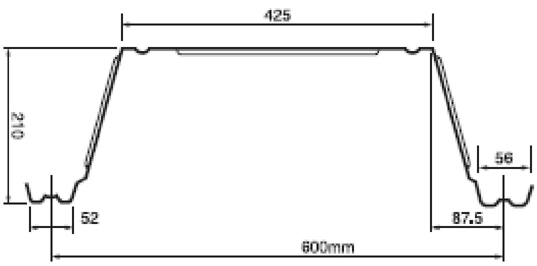


Figure 5. Beams cross-section



- thickness: 1.22 mm
- unit weight: 0.16 kN/m
- cross-sectional area: 2009 mm^2/m
- moment of inertia: 816 cm^4/m

Figure 6. ComFlor 210 steel decking [5]

3.2. Results

The considered loads are the structure own weight and the live load equal to 400 daN/m^2. The vibration frequencies computation was based on Eurocode 4 and on the „Floor Vibrations Due to Human Activity" design guide [6]. There are a few differences between these two codes, but the most important is the effective width of the slab denoted as b_{eff}.

According to Eurocode 4, b_{eff} is evaluated by using relationship (6):

$$b_{eff} = b_{e1} + b_{e2} \tag{6}$$

Where:

b_{eff} is the effective width of the slab.

On each side of the beam condition (7) is considered:

$$b_{ei} = \min(\frac{L_0}{8}; \frac{b_i}{2}) \tag{7}$$

Where:

L_0 is the approximate distance between successive null moment sections,
b_i – the distance between two beams [3].

According to the „Floor Vibrations Due to Human Activity" design guide b_{eff} is evaluated by using relationship (8):

$$b_{eff} = 0,4L \tag{8}$$

Where:

L is the beam length.

Although there is a big difference between the two design codes regarding the effective width of the slab evaluation, the results are similar and the differences are negligible. In the case of the classic composite floor, the floor natural frequency of vibration is equal to 13.83 Hz according to the design guide and 14.96 Hz according to Eurocode 4. The results for the second model are 5.96 Hz according to the design guide and 6.71 Hz according to Eurocode 4.

The values of the maximum accelerations for the first model are 0.102 %g according to the design guide and 0.069 %g according to Eurocode 4, the values for the second model are 1.227 %g and 1.595 %g, respectively.

The classic composite flooring system can be used for all building types specified in ISO 2631-2, while the Slimdek somposite floor presents unacceptable maximum acceleration values for buildings with office and residential destinations. In order to use the Slimdek composite flooring system in these cases, the slabs can be provided with damping layers either under the bottom flange of the beam or on the top surface of the floor.

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4. CONCLUSIONS

This paper highlights the importance of correctly choosing the structural type of the composite flooring system. The two proposed flooring systems are widely used in Great Britain, each providing a high number of advantages. The classic composite flooring system provides a high stiffness, but also presents a number of disadvantages which refer to the increase of material consumption, the increase of the total height of the structure, the need of shear studs and an increase of the construction time. The main advantage is the possibility of using this composite floor in most types of buildings.

On the other hand, the behaviour of the second composite floor under dynamic actions is poorer but acceptable, complying with specifications in design norms. This system also provides several advantages such as lowering the total height of structure, ease of services integration within the depth of the slab and there is no need for shear studs wich leads to a high speed of construction. The composite beam effect is achieved by using castellated beams and by machining the top flange in order to obtain collaboration with the concrete slab.

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