ISSN: 0976-3031

Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 9, Issue, 6(E), pp. 27499-27502, June, 2018

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

CONCRETE-STEEL COMPOSITE MUTLI-PANEL FLOOR STRUCTURE

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DOI: http://dx.doi.org/10.24327/ijrsr.2018.0906.2272

ARTICLE INFO

Article History:
Received 11th March, 2018
Received in revised form 6th April, 2018
Accepted 26th May, 2018
Published online 28th June, 2018

Key Words:

Concrete steel deck composite, multi model vibration, load intensity, Dynamic analysis and structural model.

ABSTRACT

Steel-deck composite floor systems are being increasingly used in high-rise building construction, especially in Australia, as they are economical and easy to construct. These composite floor systems use high strength materials to achieve longer spans and are thus slender. As a result, they are vulnerable to vibration induced under service loads. These composite floor structures are normally designed using static methods, which will not reveal the true behavior under human-induced loads. The one-way spanning behavior of composite floor structures makes them even more vulnerable to vibration problems in contrast to conventional two-way spanning reinforced concrete floor slabs. Reinforced concrete floors will be stiffer and less vulnerable to vibration caused by human-induced loads.

INTRODUCTION

In Australia, concrete-steel deck composite floors are used in office buildings, residential apartments, and shopping centers. These floor structures have experienced excessive vibration under human-induced loads and have caused some concerns. The main complaint was the annoying vibration, which was addressed by increasing the damping of the floor panel by using carpets and/or rubber mountings for the exciter. These could have been avoided if engineers had investigated the vibration characteristics of the floor at the design stage. In all of these cases, the floor structures seem to respond with the excitation of higher and multi-modal vibration, which occurred even when the load frequency was quite different to the fundamental natural frequency of the floor structure. This report discusses about the complex vibration of slender composite floor structures and the need to provide some design guidance for vibration mitigation. This paper will treat a particular type of concrete-steel deck composite floor structure that has a dovetail profiled steel deck (shown in Fig.1). Figure 1.2 shows a popular steel-deck composite floor system (dovetailed profile) used in Melbourne, Australia for a commercial and residential building.

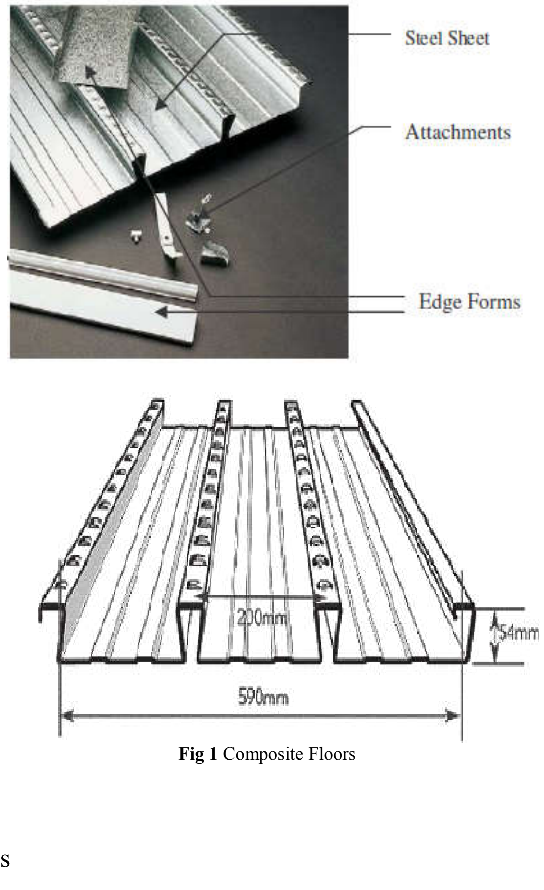

Fig 1 Composite Floors

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Fig 2 Composite floor. in construction for a high rise office and residential complex

Human-Induced Loads

Activities such as walking, running, jumping, and dancing induce vibrational forces on the floor panels. Among these, dance-type activities that are more energetic are more critical, as they usually generate higher dynamic forces; therefore, the vibration response of the composite floor panels under these types of loads is discussed. Four different dance-type loads defined by their foot contact ratios and at two different load densities are considered. These loads are applied to the FE models of the composite floor and analyzed to obtain the time histories of their acceleration (and displacement) responses. These responses are recorded against four levels of structural damping that can be present in typical floor systems.

The human activity described by dance-type loads produces discontinuous load-time functions. The load-time history of these types of loads can be modeled as a function with two parts: 1) a force function to capture the load applied when the feet are in contact with the structure for a time phase, which is called contact duration; followed by 2) a zero force when the feet are off the floor. The first phase can be described by a half-sinusoidal curve. To represent an entire event of dance type load activity, a sequence of these half-sinusoidal pluses can be used. Equation (1) presents the mathematical model for this dance-type activity.

$$F(t) = \left(\frac{\pi Q}{2\alpha}\right) sin\left(\frac{\pi t}{t_p}\right) \qquad 0 \leq t \leq t_p \qquad \text{Eqn (1)}$$

$$F(t) = 0 \qquad t_p \leq 1 \leq T_P$$

where Q is the human load density (weight per unit area); tp is the contact duration; Tp is the period of the cyclic loading; and $\alpha = t_p/T_p$ is the foot contact ratio

Structural Model and Finite Element Model

The major objective of this study is to evaluate the dynamic response of multiple panel floor systems under pattern loads. Thus full-scale FE models of multiple panel floors comprising of different number of panels were developed. These models then used for computer simulations of varied human induced loadings under different pattern loads.

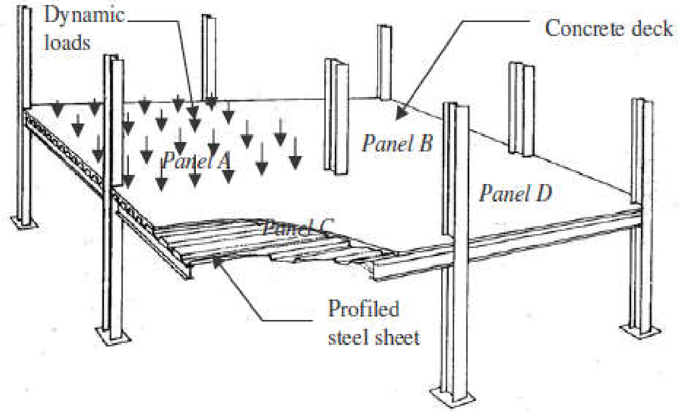


Fig 1 Typical pattern loading case on multiple panel floor system

Figure 1. shows a four panel floor system. Herein, pattern loading occurs when different panels are subjected to different loads. When pane A is subjected to human induced dynamic loads, the adjacent panels Panel B, Panel C and Panel D will be subjected to loads other than human-induced dynamic loads.

Damping

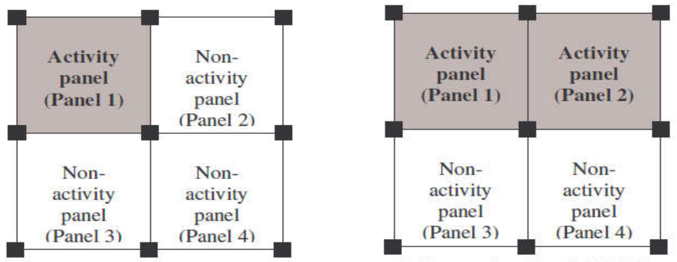
Damping is an important parameter in mitigating excessive vibration in floor structures. A precise value for the damping for a concrete-steel deck composite floor system is, however, mostly unknown. There are a number of damping levels reported. In general, damping for bare composite floors is reported to be between 1.5 and 1.8%, whereas Wyatt used a damping of 1.5% for a composite steel deck floor. Furthermore, heel-impact tests performed on the tested floor panels revealed damping levels of 1.75 to 2.0% for the bare floor. It should be noted, however, that these damping levels would be rare, as the objects that cause external forces and other standing objects will provide additional damping that would not have been included in this value. For example, the use of partitions on the finished floor system could yield higher damping. Hewitt and Murray used damping of 3% for an office without permanent partitions and damping of 2 to 2.5% for electronic or paperless offices. Even higher damping could also arise in a floor with permanent, drywall partitions-it could be as much as 5 to 6%.Sachse proved that the presence of stationary humans could increase the damping of the structure up to 12%. Thus, to observe the responses of the two floor models across a range of credible values of structural damping, this study used four damping levels of 1.6, 3, 6, and 12%.

Damping level used for the single-panel behavior

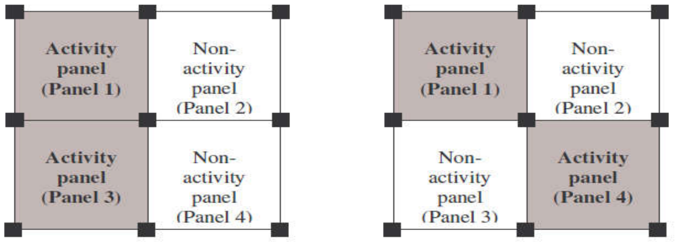
Damping level	Damping ratio(%)
Low damping	1.6
Mild damping	3.0
Medium damping	6.0
High damping	12

Analysis under Pattern Loads

The response of the four- and nine-panel steel deck composite floors is obtained under different pattern loading cases. The pattern loads used in this report cover a range of possible loading combinations on single and double panels for the four-panel floor structure and three panels for the nine-panel floor structure. They could excite the fundamental and higher modes of vibration of the floor structures.



(a) Pattern loading 1 (PL1-1)   (c) Pattern loading 3 (PL3-1)



(b) Pattern loading 2 (PL2-1)   (d) Pattern loading 4 (PL4-1)

Acceleration Responses

Acceleration response of the floor structure provides the means for assessing human perceptibility to vibration to ensure comfort and avoid annoyance. This assessment is used in establishing the possible occupancies of the floor panels under the different operating conditions.. PL1 under normal jumping activity described by contact ratio of 0.33 for a human density of 0.2 kPa gave the acceleration responses. According to this activity panels can be operated at 3.0% or higher damping and non-activity panels can be used for occupancy 2 with 6.0% or higher damping. When the high impact jumping event described by contact ratio of 0.25 was simulated under PL1, the perceptibility indicated that a damping level of 6% or more is required in order to comply with the acceleration limits of both the activity panel and the non-activity panels. The acceleration responses under the other two events described by contact ratios of 0.50 and 0.67, pertaining to high impact aerobics and low impact aerobics respectively, were within the limits in the activity panel for all the damping levels. The response of the structural floor system in terms of DAFs in deflections and accelerations depended on the pattern loading case and operating conditions such as damping, load density, contact ratio and the panel of interest.

Four-Panel Floor Structure

Depending on the pattern loading, the deflection responses at different contact ratios and damping levels gave maximum responses at activity frequencies of 2.0, 2.7, and 2.9 Hz. This information was used to investigate the excitation of higher and multi-modal vibration in the floor structures through Fourier amplitude spectra for the acceleration response. The Fourier amplitude response spectrum for the acceleration of the structural system under Pattern Loading PL1-1 at an activity frequency of 2 Hz, a damping level of 1.6%, and a contact ratio $\alpha = 0.25$. It can be seen that there are two distinct peaks at frequencies of 4.0 and 6.0 Hz depicts a similar spectrum of the acceleration at an activity frequency of 2.95 Hz, in which a single peak can be found near 5.9 Hz. These peaks in the Fourier amplitude spectra are due to the excitation of different modes by the harmonics of the particular human-induced pattern loading. In this particular case, Pattern Loading PL1-1 at an activity frequency of 2 Hz causes the floor system to vibrate at the first mode of 4 Hz and the third mode of 6 Hz by the second and third harmonics, respectively, of the load frequency. Thus, the two peaks in correspond to the excitation of the first and third modes of the floor system by the second and third harmonics of the forcing frequency of 2 Hz. The single peak in corresponds to the excitation of the third mode by the second harmonic of the forcing frequency of 2.95 Hz. Analogous results were obtained for Pattern Loading PL2-1 at the activity frequencies of 2 and 2.95 Hz, and the corresponding Fourier spectra are similar Fourier amplitude spectra for the accelerations under Pattern Loadings PL3-1 and PL4-1 had only a single dominant peak for each activity frequency. Under Pattern Loading PL3-1, these dominant peaks were at or near 6 Hz caused by the activity frequencies of 2 and 2.95 Hz. The third mode near 6 Hz was excited by both the third harmonic of the activity frequency of 2Hz and also by the second harmonic of the activity frequency of 2.95 Hz. Under Pattern Loading PL4-1, the dominant peaks occurred at frequencies of 5.4 Hz and 5.9 Hz caused by the activity frequencies of 2.7 Hz and 2.95 Hz

DISCUSSION

Two multiple panel floor models, one with four panels and the other with nine panel, constituted the investigation of multiple panel vibrations. These two models were subjected to various pattern loading cases, which caused multi-modal vibration. Thus the floor vibrated not only in its fundamental mode of vibration, but also in higher modes of vibration depending upon the location of the human activity summaries the pattern loading cases and the excited mode shapes and natural frequencies.

Pattern loading cases, excited modes and frequencies

Excitation mode	Pattern loading case	Frequency
First	PL1-1	4.0 Hz
	PL2-1	4.0 Hz
Second	PL2-2	4.3 Hz
	PL4-1	5.4 Hz
Third	PL2-2	4.8 Hz
	PL3-1	5.9 Hz

These modes were excited by either second or third harmonic of human activity frequency, demonstrating the importance of obtaining not only the fundamental natural frequencies, but also the higher natural frequencies along with their respective mode shapes. These mode shapes provide clue to determining the areas where the dance-type loads should or should not be permitted. Preferably, it’s advisable to fit-out occupancies to avoid excitation of such mode shapes. The research considered different operating conditions, such as damping levels, type of activity, activity frequency and occupant densities and their responses were obtained. These responses were compared with serviceability state limits of deflection for structural control and acceleration limits, for human conformability. The results revealed mixed operating conditions in “activity panels” and “non-activity panels” for different modes of vibration.

CONCLUSION

Concrete-steel composite multi-panel floor structures often exhibit higher and multi-modal vibration under pattern loads and, hence, the simplified guidance for vibration mitigation in the present codes or best-practice guides, which consider only the fundamental mode, will be inadequate. Under pattern loading, the second and third modes of the floor structure can be excited by the higher harmonics of the activity frequency. There is potential for an adverse dynamic response of these types of floor structures due to the excitation of the higher- and multi-modal vibration unless appropriate provisions are made for them. It is important to consider the entire floor and its occupancy fit-out instead of a single-floor panel, as the vibration problem in any panel may not be due to the activity in that floor panel but, rather, due to activity in a different floor panel in the same floor. At low levels of damping up to 6%, there is a greater possibility of the excitation of higher modes of vibration of the floor structure. The role of damping-usually higher than 6%-in suppressing some of the higher and multi-modal vibration in these types of structures is thus evident.

- It is important to consider the higher modes of vibration of steel-deck composite floors, in addition to the fundamental mode, as they could all be excited by the higher harmonics of the forcing dynamic activity resulting in multi modal and possibly coupled vibration. Current simplified methods of assessing floor vibration are primarily based on the fundamental natural frequency and may not be adequate under all operating conditions.
- Load frequency alone does not cause vibration problems. Higher (2nd and 3rd) harmonics of the load frequency can excite the higher modes of vibration of the floor.
- Effects of pattern loading needs to be considered as they can be realistic and will account for a comprehensive vibration evaluation.
- Vibration assessment in terms of deflections and accelerations need to be considered together.
- The dynamic amplification in deflection and the acceleration response of the floors are significantly influenced by the type of activity or foot contact ratio, with lower contact ratios giving higher responses.

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How to cite this article:

Sabari Sri.G.2018, Concrete-Steel Composite Mutli-Panel Floor Structure. *Int J Recent Sci Res.* 9(6), pp. 27499-27502.
DOI: http://dx.doi.org/10.24327/ijrsr.2018.0906.2272

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