DYNAMIC BEHAVIOR OF FIBER REINFORCED COMPOSITE SLAB INDUCED BY HUMAN WALKING

LEILA SOUFEIANI

Universiti Teknologi Malaysia

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To my beloved mother and father

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ABSTRACT

Composite floor systems are being increasingly used in building and footbridge constructions, as they are economical and easy to construct. These composite floor systems use high strength material to achieve longer spans and are thus slender. As a result, they are vulnerable to vibration induced under service loads. Resonance of such structure is one of the most critical problems which without considering dynamic aspects in design, may lead to unsafe and discomfort circumstances for the users. The purpose of this study is to provide an appropriate analysis methodology through finite element analysis to assess the dynamic responses of composite slab and corresponding human comfort problems. A linear elastic finite element analysis through consideration of walking load model (applied in mid-span) with respect to application of different percentages of ply orientation and stacking sequences of FRP laminate in slab is conducted. Variation in material properties for each case and damping ratio is established separately to capture the maximum responses in terms of deflection and accelerations. The dynamic responses of deflection and accelerations are compared with the serviceability deflection limits and human comfort levels (of acceleration) to assess these floor types.

ABSTRAK

Sistem lantai komposit semakin banyak digunakan di dalam pembinaan bangunan dan jambatan kerana ianya lebih berekonomi dan mudah dibina. Sistem lantai komposit ini menggunakan bahan berkuat tinggi untuk mencapai rentang yang lebih panjang dan langsing. Oleh sebab itu, ia terdedah kepada getaran di bawah beban khidmat. Resonansi di dalam struktur adalah salah satu masalah yang paling kritikal di mana jika aspek dinamik tidak diambil kira di dalam reka bentuk, ianya boleh membawa kepada keadaan yang tidak selamat dan tidak selesa kepada pengguna. Tujuan kajian ini adalah untuk menyediakan kaedah yang sesuai dalam menilai respon dinamik papak kompsit dan juga masalah keselesaan manusia melalui analisis unsur terhingga. Analisis unsur terhingga berciri linear elastik dijalankan melalui model beban berjalan (diletak di tengah rentang) dengan menggunakan peratusan orientasi lapis dan urutan susunan lamina FRP di dalam papak yang berbeza. Perubahan pada sifat-sifat bahan bagi setiap kes dan nisbah redaman dibuat secara berasingan bagi mendapat respon pesongan dan pecutan yang maksimum. Tindak balas dinamik tersebut dibandingkan dengan had pesongan kebolehkhidmatan dan juga tahap keselesaan manusia (pecutan) bagi menilai jenis-jenis lantai.

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LIST OF SYMBOLS

T	-	Period
f	-	Frequency
G	-	Static weight
T_p	-	Contact ratio
α_i	-	i^{th} harmonic forcing
r_n	-	Dynamic load factor
ϕ_n	-	Phase lag
DAF	-	Dynamic Amplification Factor
n	-	n^{th} harmonic of jumping load
u	-	Displacement
$\dot{u}$	-	Velocity
$\ddot{u}$	-	Acceleration
ω	-	Circular natural frequency
φ	-	Mode shape
ς	-	Damping ratio
E_c	-	Modulus of elasticity of concrete
E_s	-	Modulus of elasticity of steel
L	-	Length of floor
B	-	Width of floor

CHAPTER 1

INTRODUCTION

1.1. Background of the Study

Today's structures are built to cater to the expectations of the community aesthetically. They are pleasing and use high strength materials as well as new construction technology. These structures are thus slender which unfortunately exhibit vibration problems under various service loads, causing discomfort to the occupants and raising questions on their use for the intended propose. At times, these vibrations have also been the cause of structural failure. One such case of structural failure that caused many lives was the collapse of Hyatt Regency Hotel Walkway in Kansas City, US, which happened during a weekend "tea dance" in 1981 as shown in Figure 1-1 (McGrath And Foote,1981).

Figure 1.1 After Hyatt Regency Hotel walkway collapse in Kensas City in 1981 [1]

In the absence of appropriate theories and necessary information at that time, no one really understood the cause of this devastation. Some argued that the walkway buckled from the "harmonic" vibrations set up by people swaying or dancing, resulting in wavelike motion that caused it to collapse, while others argued that the walkways were overwhelmed by the weight of the large numbers of people unable to hold them (McGrath and Foote, 1981). Either way, the dynamic effect of crowd of people performing the dance-type activity, or exerting similar loads from other human activities has played a significant role to cause this devastation. Such dynamic events not only cause loads much greater that the static loads to which the structure could have been designed, but also excite modes of vibration due to higher harmonics of the forcing frequencies, ultimately forcing them to collapse.

Similar concerns in vibration hazards have been also reported in human assembly structures such as stadiums, grandstands and auditoriums [2, 3]. Some examples are the Cardiff Millennium Stadium [4], Liverpool’s Anfield Stadium and Old Trafford Stadium [5]. The structures mentioned above are all slender with natural frequencies that fall within the frequency of the human-induced loads, which consequently produced vibrations. As a result, they caused human discomfort, crowd panic or in the extreme case, the collapse of the structures [6].

Steel-deck composite floor structures are another example of slender structures used in multi-story buildings and have been known to experience vibration problems under human activity. There are a number of different configurations of these floor slabs, but they are all slender as they use high strength materials to achieve longer spans and hence reduce sections. They are being used in high-rise buildings especially in Australia, as they are economical and easy to construct. These composite floor slabs are normally designed using static methods which will not reveal the true behavior under human-induced dynamic loads, resulting in the vibration problems.

The vibration problem in different types of composite floor system has been first identified by Chien and Richie [7]. This later resulted in other researchers to investigate the behavior under dynamic loads on floors. Bachmann et al. [8], Allen and Murray [9], Williams and Waldron [10] presented experimental investigations and da Silva et al. [11], Hicks [12] and Ebrahimpour et al. [13] used finite element method of analysis to contribute research information under various human-induced loads on composite floor systems. The current methods of designing composite floors against vibration are based on this information and are found in the Steel Design Guide series11 [14] and design guides on the vibration of floors [15].

During the last decades, the new promising material has slowly entered the civil engineering market. In this case, arguably the most advances popular material which will be considered in this study, refers to a matrix which is reinforced with fibers, Fiber Reinforced Polymer (FRP).

Due to the high strength to low weight ratio, resistance in fatigue and low damping factor, composite materials have a wide range of applications in car, aerospace and aviation industry, where it has been in use for many years. In composites, the fiber reinforcement carry load in pre-designed directions and the polymer matrix acts as a medium to transfer stresses between adjoining fibers through adhesion and also provides protection for the material. However, the lack of design codes and guidelines for FRP bridge decks is the reason that FRP decks have not been applied widely.

By considering all, a proper evaluation of the floor based on its dynamic response is needed. With this in mind, a comprehensive research project was undertaken to study the different lay-up and orientations of laminate (FRP) composite floor using dynamic computer modeling. This research information is used to evaluate the response of composite floor under walking load and to assess human comfort and hence the suitability of the FRP floors.

1.2.Statement of Problem

Modern construction techniques make use of lightweight, high-strength materials to create flexible, long-span floors. These floors sometimes result in annoying levels of vibration under ordinary loading situations. Due to these types of loading the structure may not experience the ultimate loading but causes discomfort for occupants, particularly whom are in non-vibrated adjacent panels. On the other hand, in the design procedure, almost all engineers ignore these criteria and they just check serviceability for deflection of the floor and it can give rise to discomfort feeling for occupants resulting in complains. So far, many studies have been done about the long span floor susceptibility against vibration due to human induced load. But we still observe the lack of information about the effectiveness criteria of material and type of loading and location of impact loading and properties of composite material in the structure.

In the case of composite floors, the most controversial problem seems to be the dynamic response of the structure against loading, which is induced by human motion. Vibration caused by dynamic loading leads to different responses in terms of dynamic amplification factor (DAF), acceleration and displacement, depending on the stiffness and mass matrices of the material. In the design of the structure of the floor, the dynamic effect of loading has been considered as a coefficient of static loads, the problems of excessive acceleration and displacement are common, which lead to discomfort and unsafe conditions for the people walking on it. As an engineer, we must be aware of possible problems and find the proper method to overcome these drawbacks. Thus far, the effects of contact ratio, period of loading, human body, and damping ratio have been provided. In some details such as the effect of stacking sequence of laminate in response of the structure, we can observe the lack of information.

1.3.Objectives of the study

The specific objectives of this study are as follows:

1.3.1. To provide finite element methodology for modeling the dynamic responses of laminated composite floor with loads induced by human walking

1.3.2. Comprehensive study on the effect of percentage of ply orientation and stacking sequence on the structural dynamic behaviors.

1.4. Scope of the Study

The aim of this project is to generate the fundamental research knowledge on the vibration characteristics of stacking sequence of laminate composite floor structures subjected to human-induced loads in order to evaluate their compliance against the serviceability and comfort requirements in the current design standards. In this study, a simply supported deck system (7x9m) is considered and the steady-state dynamical response analysis is performed. Individual human weight is to be considered 700 N and the damping ratio of the structure is considered 3% for concrete-steel deck and varies between 0.166 - 2.2% for different lay-ups of fibers in

FRP laminate. In addition, beams are considered as 3 dimensional, in which the flexural and torsion effects are considered. Also, full interaction between steel and concrete slab is assumed for the composite system. Linear analysis in elastic region will be performed and AISC Design Guide 11 is the basic code to be used which specifies the limits for floor vibration due to human activities. The finite element software SAP2000 will be used as the tool to perform all numerical evaluations. The model provides the natural frequency of the floor as well as the dynamic response of the floor to a given load. Data from these models are compared to current design standards recommended by the American Institute of Steel Construction Design Guide 11 *Floor Vibrations Due to Human Activity*. All procedure of analysis is performed under linear elasticity region.

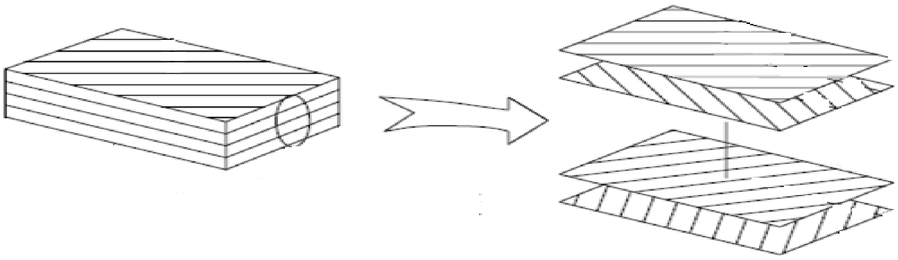
In case of FRP components, the following assumptions are considered:

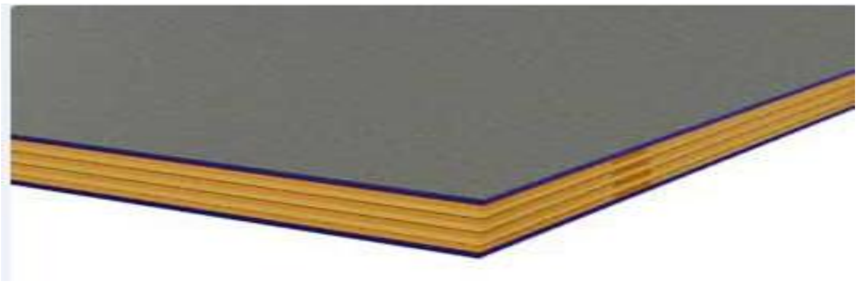
a) All components are completely bonded together;
b) Each deck component has orthotropic material properties that will be modeled as flaw-free and uniform orthotropic continuum.
c) The behavior of deck component as well as the deck system is linear elastic, no creep and no time-dependent evaluation will be modeled;
d) The material is carbon fiber/ epoxy with 0.63 fiber volume fraction.

Material properties:

Steel: 300 MPa yield stress, E=2.05x10^5 MPa
Concrete: 25 MPa compression strength, E=2.4x10^4 MPa

Laminate is made up four lamina or ply stacked together at various orientations, in wiling 0; ±45; and 90.





This study investigates one panel as a sample by altering the material properties and damping ratio from concrete-steel deck to FRP laminate and considers only as walking human induced loading. The load parameters will be frequency and location of the activity.

1.5.Significant of study

Human-induced dynamic loads originate from various human actions. A number of serviceability problems were reported due to properties of today's structures, which have longer spans, are lighter and have a reduced damping. Bridge type structures are the most vulnerable to human induced-dynamic loads, which caused them to vibrate. The vibrations were reported after construction, while servicing. To avoid such problems, it is desirable that a proper understanding of this behavior is considered in the design.

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