DYNAMIC ANALYSES OF COMPOSITE FOOTBRIDGES EXCITED BY PEDESTRIAN INDUCED LOADS

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"To my beloved mother and father, for their endless support and care, and my beloved brother for his encouragement"

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ABSTRACT

In this study, various types of human running dynamic loads are numerically studied and compared to assess serviceability characteristics of light and slender composite footbridges, with and without the implementation of Textile Reinforcement Concrete (TRC) as compliment composite material. Running, which is a common human activity, has been categorized with respect to its intensity as jogging, normal running, and sprinting. In the model verification, the acquired first natural frequency of structure has shown good agreement with the value reported in the literature. The structural performance of the slender composite footbridge is then evaluated in regard to the serviceability requirement given by the current design standards. It is generally found that the maximum acceleration of the composite footbridge due to the excitation of one person running varies under different running types because of diversities in the velocity and the step frequency. Furthermore, it is shown that the investigated structure provides sufficient human comfort against vibration for all examined types of running loads. In the present study, the use of numerous layers of the TRC demonstrates that the serviceability properties are improved by enhancing the layers numbers. Besides, the TRC employing the high strength carbon as fabric is more effective than AR-glass on the improvement of serviceability properties.

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ABSTRAK

Dalam kajian ini, pelbagai jenis beban manusia larian dinamik. Dikaji dan dibandingkan secara berangka untuk menilai ciri-ciri kebolehkhidmatan jambatankak komposit dan ringan langsing, dengan dan tanpa implementasi konkrit (TRC) sebagai bahan gantian komposit. Larian, yang merupakan aktiviti biasa manusia, telah dikategorikan melalui intensiti sebagai berjoging, berjalan biasa, dan berpecut. Dalam pengesahan model, frekuensi asli pertama struktur yang diperolehi telah menunjukkan persetujuan yang baik dengan nilai yang dilaporkan dalam literatur. Prestasi struktur jambatan komposit langsing kemudian dinilai berdasarkan keperluan kebolehkhidmatan yang diberikan oleh piawaian reka bentuk semasa. Secara umumnya, kajian mendapati bahawa pecutan maksimum jambatan komposit disefalkan pengujaan oleh larian individy berubah mengikut kepelbagaian halaju dan frekuensi langkah. Kajian juga menunjukkan bahawa struktur yang disiasat memberikan keselesaan manusia yang mencukupi terhadap getaran untuk semua jenis bedan larian diperiksa. Dalam kajian ini, penggunaan pelbagai lapisan TRC telah menunjukkan bahawa sifat-sifat kebolehkhidmatan adalah lebih baik dengan meningkatkan bilangan lapisan. Selain itu, TRC menggunakan karbon kekuatan tinggi sebagai kain adalah lebih berkesan daripada AR-kaca dalam penambahbaikan sifat kebolehkhidmatan.

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LIST OF SYMBOLS

A_0	-	Initial amplitude of the heel impact
A_n	-	Acceleration amplitude
$a(t)$	-	Displacement vector
$\mathring{a}(t)$	-	Velocity vector
$\ddot{a}(t)$	-	Acceleration vector
b_e	-	Beam spacing
C_f	-	Fourier component factor
$[C]$	-	Structural damping matrix
D	-	Percentage of damping
E	-	Modulus of elasticity
F_p	-	Dynamic load
$F_{p.max}$	-	Peak dynamic load
f_1	-	First natural frequency
f_c	-	Component frequency
f_n	-	Fundamental natural frequency
f_s	-	Step frequency
g	-	Acceleration of gravity
ΔG	-	Harmonic of the load component
I	-	Second moment of area
$[K]$	-	Stiffness matrix
k	-	Stiffness
k_p	-	Dynamic impact factor
L	-	Beam span

L_{eff}	-	Floor beam effective span
l_s	-	Stride length
$[M]$	-	Mass matrix
m	-	Mass
n	-	Cycle
P	-	Person weight
R	-	Response factor
S	-	Floor effective width
T_p	-	Step period
t_p	-	Contact duration
v_s	-	Speed or pedestrian propagation
W	-	Effective weight of the floor
y_c	-	The static deflections under weight, due to axial strain for column
y_g	-	The static deflections under weight, due to bending and shear for girder
y_i	-	The static deflections under weight, due to bending and shear for the beam or joist
α_i		The dynamic coefficient of the harmonic force
β	-	Modal damping ratio
Δ	-	Mid-span deflection
φ	-	Phase angle
w	-	Uniformly distributed load per unit length

CHAPTER 1

INTRODUCTION

1.1 Introduction

Lightweight and slender footbridges as modern structures attract considerable attention in recent years. Although from the structural point of view, the prevalent design and construction proficiencies are truly established for footbridges, in the recent years more accurate analyses are required for some sophisticated structures [1]. The vast majority of the studies indicated that in slender and light structures, the footbridges natural frequencies domain frequently coincide with frequencies of dynamic load like human walking, running, dancing and jumping [2-3]. The footbridge vibration response is considered through an analysis in terms of natural frequency, acceleration, displacement and velocity. The debatable subject in procedure of footbridges analysis is the modeling of the human induced loads like people running which is limited in experimental evidence [1]. Therefore, in this study we are aiming to generate fundamental research knowledge on the vibration characteristics of slender footbridge composite structures induced by human running in order to evaluate serviceability requirement of these structures against the current design standards.

On the other hand, in present design, usage of high quality materials and knowledge about their properties to achieve more slender structures have been widely attended. Applying substitute and supplementary high performance fiber materials with the aim of repairing or strengthening on the surface of concrete is effective in durability of the lightweight and slender structures. One of these customary composite materials is fiber reinforcement concrete (FRC). Fiber reinforced concrete (FRC) is widely spread in area of construction materials due to its mechanical productivity and eligible execution. The FRC is a blend of disorganized chopped fibers which have incomplete distributions through cross section (Figure 1.1).

To eliminate this problem, Textile Reinforcement Concrete (TRC) with advantages of FRC and steel reinforcement concrete is utilized. TRC is consisting of continuous rovings in two directions and three directions as reinforcements that lead to an increase in load bearing capacity. Each rovings are consisting of over hundreds filaments. For sufficient bond between the fibers and matrix, fibers are embedded in fine grained concrete. Furthermore, due to corrosion resistance of non-metallic (fibers) materials, concrete cover is not imperatively required in TRC as in contrast to steel reinforcement concrete. Generally, the serviceability properties of reinforced concrete structures are appraised in terms of load bearing capacity subjected to tension and compression through a short term loading. Experimental evidences point that using layers of textile reinforcement concrete for strengthening of reinforced concrete slabs are effective in serviceability [4].

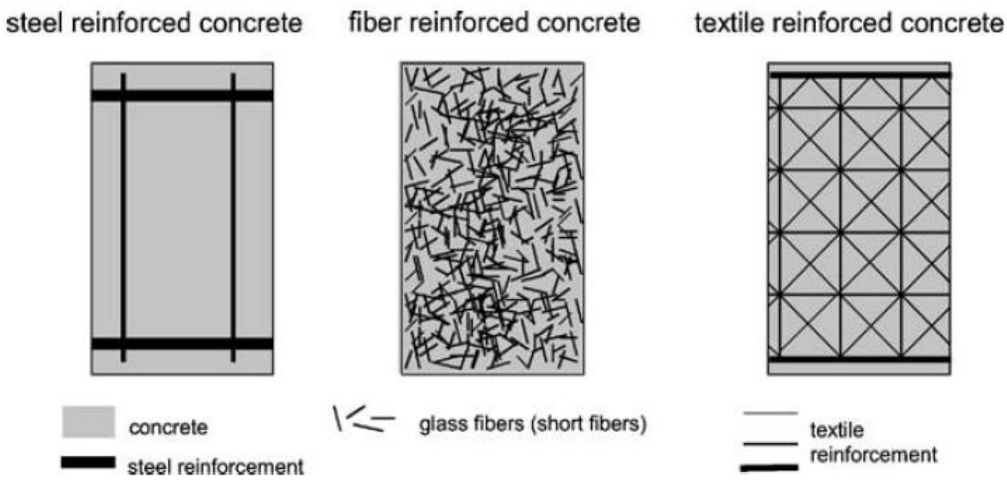

Figure 1.1: Reinforcing systems of concrete

1.2 Problem Statement

The main problem of this project is to generate fundamental research knowledge on the vibration characteristics of slender footbridge composite structures subjected to different types of loading, which are induced by human activities, in order to evaluate their compliance against the serviceability and comfort requirement in the current design standards. Excessive acceleration and displacement due to dynamic loads are major problems in footbridges. To eliminate these problems, the footbridge dynamic response is determined through an analysis in terms of frequency, acceleration and displacement. On the other hand, the key issue of dynamic analyses is the availability of reliable models for the structure and for loads, and in particular case, the effect of applying TRC as compliment composite material on the serviceability properties is still limited. This issue therefore provides motivation for the current study.

1.3 Objectives of Study

The main objectives of this project are:

- To develop comprehensive finite element models to carry out dynamic computer simulations for composite footbridges due to human activities.
- To study and compare various types of human running dynamic loads such as jogging, normal running and sprinting to assess vibration characteristics of the light and slender composite footbridges.
- To investigate the effect of the textile reinforcement concrete (TRC) as substitute or supplementary material in dynamic response of composite footbridges in terms of different application of layers numbers.

1.4 Scope of Study

This investigation involves a footbridge composite system subjected to different human running induced loadings. The primary scope of this project is to present linear elastic analyses as basic principles of design criteria to evaluate vibration serviceability of composite footbridges under various human running induced loads. In the present research, the structural system includes a reinforced concrete slab and three dimensional steel beams. The Textile Reinforced Concrete (TRC) as supplementary composite material to improve serviceability requirement was utilized on the surface of reinforced concrete slab. The outputs were in terms of critical accelerations and displacements. In the case of textile composite, two types of bi-dimensional orthotropic fabrics were employed as reinforcements. The fabrics were alkali resistance glass and high strength carbon which were used in different textile composites to compare their effect in serviceability properties. These fibers are bundled in rovings which consist up to several thousand single filaments embedded in the fine grained concrete.

1.5 Significance of Study

This study provides a basic numerical methodology regarding human running induced load on lean structures. In addition, the lack of knowledge and hence the research gap of the effect of TRC on serviceability features are to be practically addressed.

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