Study on the Vibration Comfort of a Large-span Composite Floor Gymnasium-Part I

Xinxin Zhang[1,a], Ruoyang Zhou[2,b], Xiaoxiong Zha[2,c*]

[1]China Construction Science and Industry Corporation LTD, Shenzhen, 518054, China
[2]School of Civil and Environmental Engineering, Harbin Institute of Technology (Shenzhen), Shenzhen, 518055, China
[a]149361958@qq.com, [b]ruoyangchou@163.com
[c*]Correspondence: zhahero@126.com

Abstract. This study assesses the vibration comfort of a large-span steel-concrete composite gymnasium floor system in an under-construction primary school. The analysis considers human-induced vibration conditions before and after soil coverage and grass planting. Acceleration time histories were recorded, and spectral analysis identified fundamental frequencies and damping ratios. Additionally, vibration response calculations were performed according to standard methodologies. The theoretical calculation methods provided in the standards were used to compute the vibration responses under various human-induced conditions. The results from the tests were compared with the theoretical calculations and finite element simulation results against the standard limits. The findings indicate that the test results and theoretical calculations are closely aligned, suggesting that the test results are reasonably accurate.

Keywords: Steel-Concrete Composite Structure; Vibration Comfort; Peak Vibration Acceleration; Large-span structure.

1 Introduction

In recent years, an increasing number of sports venues have adopted large-span floor systems, which effectively meet the functional requirements of such facilities. For structures that fail to meet comfort requirements, vibration control measures must be implemented.

For the study of vibration in large-span floor systems, [1] introduced the moving load method based on human-induced load models. [2] used a damping human body model to calculate the vibration response. [3] conducted finite element simulations on large-span floors crowds. [4] and [5] calculated the acceleration response of large-span pedestrian bridges. [6] performed calculations on the vibration response.

Therefore, this paper conducts multi-condition vibration tests under human-induced loads on the large-span steel-concrete composite floor of a specific under-construction primary school. Compare the test results with the theoretical calculations to verify the accuracy of the test outcomes.

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2 Project Overview

The area of the large span is indicated within the framed region in Fig.1 The beam material is Q355B steel, with specific section dimensions provided in Table 1.

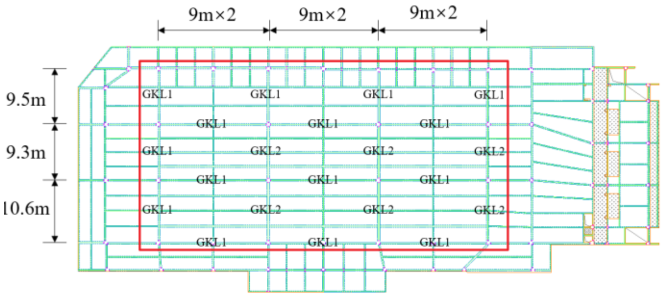

Fig. 1. Structural Plan of a Large-Span Gymnasium

Table 1. Beam Section Dimensions

Part Number	$H \times B \times T_f \times T_w$	Steel Designation
GKL1	$H1100 \times 350 \times 20 \times 38$	Q355B
GKL2	$H1100 \times 450 \times 20 \times 38$	Q355B

3 Vibration Testing of the Sports Field Floor

3.1 Testing Background

Real-life images of the large-span sports field at the primary school, both before and after soil covering and grass planting, are shown in Fig.2.

a) before covering the sports field with soil and grass

b) after covering the sports field with soil and grass

Fig. 2. Real-Life Image of a Large-Span Sports Field

3.2 Test Plan

The testing points before the soil and grass covering were set at the mid-span of the floor slab, with a total of 9 testing points. The stimuli were applied in the direction of the longer span at the mid-span of the floor slab. The locations of the testing points and the stimulus path are shown in Fig. 3.

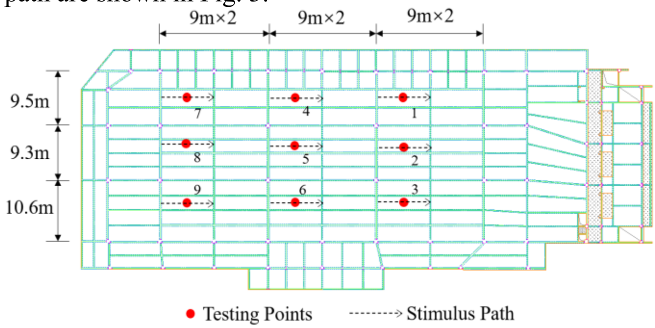

Fig. 3. Schematic Diagram of Test Points and Excitation Path

The stimuli were applied in the direction of the longer span at the mid-span of the floor slab. The locations of the testing points and the stimulus path are shown in Fig. 4.

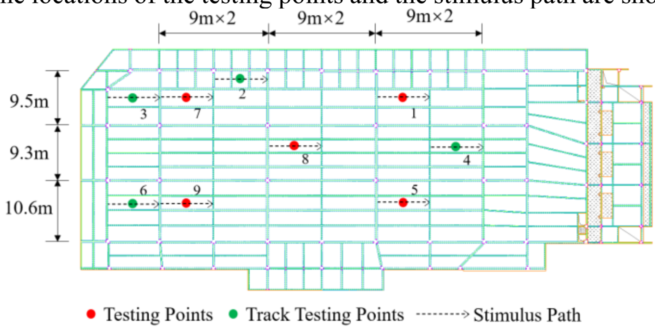

Fig. 4. Schematic Diagram of Test Points and Excitation Path

3.3 Test Condition

(1) Jumping Condition: Utilized a tester weighing 80kg. Before the test began, the tester remained stationary at the test point with knees bent at a 90-degree angle. Upon starting, the tester jumped up and then naturally fell back down, maintaining body stability. Data collection ceased once the test data returned to a stable state.

(2) Aerobics Condition: Involved three testers weighing 80kg, 70kg, and 65kg, respectively. They performed jumping jacks in unison at a frequency of 1Hz.

(3) Walking Stimulus Condition: Utilized a tester weighing 80kg, who walked at a steady pace of 1m/s and a step frequency of 2Hz along the stimulus path.

(4) Running Stimulus Condition: Employed a tester weighing 80kg, who ran at a steady pace of 2m/s and a step frequency of 2Hz along the stimulus path.

The control of movement frequency for the above conditions was achieved through the use of a metronome app downloaded on a smartphone. The app was set to the desired beat interval for the test conditions, such as striking a beat once per second, allowing testers to jump, walk, or run to the beat, thereby achieving a movement frequency of 1Hz.

For controlling the pace of walking and running:

During the walking test, control points were set at intervals of 0.5m along the stimulus path. The metronome was set to beat twice per second, and testers moved to the next control point at each beat, thereby maintaining a step frequency of 2Hz and a pace of 1m/s.

During the running test, control points were placed at 1m intervals along the stimulus path. With the metronome also set to beat twice per second, testers ran to the next control point at each beat, achieving a step frequency of 2Hz and a pace of 2m/s.

3.4 Testing Result

3.4.1 Limitation Value.

The limitations are based on the "Technical Standards for Vibration Comfort of Building Floors JGJT-441-2019"[7] in Table 2.

Table 2. Limit Value for Peak Vertical Vibration Acceleration

Floor usage category	Peak acceleration (m/s-2)
Sports venues, dance halls, performance stages, aerobics-only gyms	0.50
A gym that offers both aerobics and equipment fitness	0.20

3.4.2 Vertical Natural Frequency Test.

The first-order natural frequencies are summarized in Table 3.

Table 3. First-Order Vertical Natural Frequency

Test points	Frequency (Hz)	
	Before covering with soil and grass	After covering with soil and grass
Point 1	4.99	7.11
Point 2	4.99	
Point 3	5.30	
Point 4	5.14	
Point 5	5.19	6.89
Point 6	5.20	
Point 7	5.30	7.12
Point 8	5.23	7.18
Point 9	5.16	7.56
Track 2		5.66
Track 3		4.93
Track 4		4.75
Track 6		5.64

3.4.3 Damping Ratio.

The results of these calculations are presented in Table 4.

Table 4. Calculated Damping Ratio of the Floor Slab

Test points	f_2	f_1	f_0	ξ
Point 1	5.51	4.68	4.99	0.083
Point 2	5.49	4.69	4.99	0.080
Point 3	5.55	4.68	5.30	0.082
Point 4	5.47	4.66	5.14	0.079
Point 5	5.59	4.7	5.19	0.086
Point 6	5.60	4.75	5.20	0.082
Point 7	5.44	4.62	5.30	0.077
Point 8	5.64	4.78	5.23	0.082
Point 9	5.45	4.62	5.16	0.080
Track 2	5.80	4.92	5.66	0.078
Track 3	5.32	4.52	4.93	0.081
Track 4	5.43	4.65	4.75	0.082
Track 6	5.82	4.89	5.64	0.082

3.4.4 Vertical Peak Acceleration Test.

The vertical peak accelerations derived from these tests are summarized in Table 5.

Table 5. Peak Vertical Vibration Acceleration

Test points	Peak Acceleration / (m/s^{-2})					
	Walk		Run		Aerobics	
	Before covered	After covered	Before covered	After covered	Before covered	After covered
Point 1	0.346	0.084	1.089	0.177	0.625	0.186
Point 2	0.493	/	1.265	/	0.844	/
Point 3	0.307	/	0.753	/	0.508	/
Point 4	0.560	/	0.998	/	0.595	/
Point 5	0.529	0.163	0.720	/	0.896	/
Point 6	0.666	/	1.056	/	0.922	/
Point 7	0.788	0.181	1.099	0.946	0.765	0.386
Point 8	0.731	0.210	1.063	0.594	1.265	0.464
Point 9	0.773	0.166	1.388	0.201	1.330	0.098
Track 2	/	0.128	/	0.107	/	0.197
Track 3	/	0.211	/	0.594	/	0.612
Track 4	/	0.230	/	0.565	/	0.345
Track6	/	0.164	/	0.438	/	1.195

4 Conclusion

Vibration Comfort Compliance: The large-span steel-concrete composite floor of the sports field does not meet vibration comfort requirements under human-induced load conditions.

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