# Study on the Vibration Comfort of a Large-Span Composite Floor Gymnasium-Part II

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**Abstract.** In the context of a new elementary school under construction, an experimental study was conducted on the vibration comfort of a large-span steel-concrete composite floor gymnasium under various human-induced conditions. The entire gymnasium was modeled using finite element software, which simulated the acceleration time response and fundamental frequency under the same human-induced conditions. Additionally, the simulation examined the vibration response of the floor before and after the installation of Tuned Mass Dampers (TMD) based on existing but unimplemented vibration control designs for the sports hall. The results from the physical tests were compared with both theoretical calculations and finite element simulation outcomes against the standard limits. The findings indicated a good agreement between the test results, theoretical calculations, and finite element outcomes, suggesting the finite element analysis was accurate. Before the installation of TMDs, some measurement points did not meet the standard requirements; however, after installing TMDs, all measurement points complied with the standards. This highlights the effectiveness of TMDs in enhancing the vibration comfort by meeting necessary regulatory requirements.

**Keywords:** Steel-Concrete Composite Structure; Vibration Comfort; Peak Vibration Acceleration; Tuned Mass Damper (TMD).

## 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] conducted a study on the vibration comfort of multi-story sports and fitness venue floor systems. [2] researched large-span floors under rhythmic movements of crowds and proposed a random vibration model.


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Regarding the research on steel-concrete composite floor systems, [3] proposed a simple and effective method under walking actions. [4] conducted finite element simulations and verification. [5] carried out single footfall and walking tests on prefabricated concrete slabs.

Existing research often focuses on large-span floor slabs or composite floor slabs, which are more prone to issues with vibration comfort[6]. Therefore, this paper establishes a finite element model of a large-span steel-concrete composite floor slab in an under-construction elementary school[7].This approach addresses the unique challenges presented by the combination of large spans and composite materials in ensuring vibration comfort.

## 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.

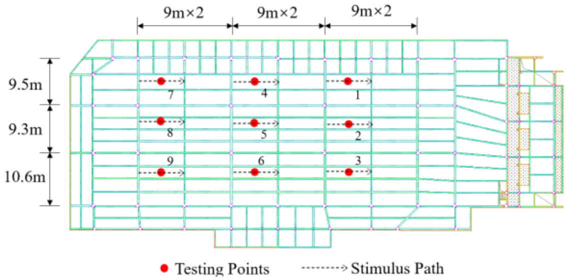


**Fig. 1.** Structural Plan of a Large-Span Gymnasium

**Table 1.** Beam Section Dimensions

| Part Number | $H\times B\times T_f\times T_w$ | Steel Designation |
|---|---|---|
| GKL1 | $H1100\times350\times20\times38$ | Q355B |
| GKL2 | $H1100\times450\times20\times38$ | Q355B |

## 3 Finite Element Simulation of the Sports Field Floor

A comprehensive finite element model of the sports field was developed using finite element software. The damping ratio was set based on the results discussed in "Study on the Vibration Comfort of a Large-span Composite Floor Gymnasium-Part I."

### 3.1 Vertical Natural Frequency Simulation

The modal data for the floor slab at test point 1 have been extracted and presented in Table 2. The modal analysis data for the floor slab at Test Point 1 revealed a vertical natural frequency of 5.02Hz, as detailed in Table 3.

A summary of the vertical natural frequencies for all test points is provided in Table 4.

**Table 2.** Participation Mass of Mode Shape at Measurement Point 1 on the Floor Slab

| Mode number | Mode participation quality | | | | | |
|---|---|---|---|---|---|---|
| | TRAN-X | | TRAN-Y | | TRAN-Z | |
| | Mass (%) | Sum (%) | Mass (%) | Sum (%) | Mass /% | Sum (%) |
| 1 | 70.73 | 70.73 | 6.78 | 6.78 | 0.18 | 0.18 |
| 2 | 2.43 | 73.16 | 90.83 | 97.61 | 0.01 | 0.19 |
| 3 | 0.50 | 73.66 | 0.27 | 97.88 | 0.00 | 0.19 |
| 4 | 23.33 | 96.99 | 0.55 | 98.43 | 0.24 | 0.43 |
| 5 | 0.87 | 97.86 | 0.72 | 99.15 | 0.00 | 0.43 |
| **6** | 0.23 | 98.09 | 0.28 | 99.43 | **7.90** | 8.33 |
| 7 | 0.19 | 98.28 | 0.00 | 99.43 | 1.21 | 9.54 |
| 8 | 0.25 | 98.53 | 0.11 | 99.54 | 0.01 | 9.55 |
| 9 | 0.04 | 98.57 | 0.14 | 99.68 | 0.01 | 9.56 |
| 10 | 0.13 | 98.7 | 0.18 | 99.86 | 0.00 | 9.56 |

**Table 3.** Modal Analysis Data for Measurement Point 1 on the Floor Slab

| Mode number | Frequency (Hz) | |
|---|---|---|
| | (rad/sec) | (cycle/sec) |
| 1 | 27.08053 | 4.31 |
| 2 | 29.15398 | 4.64 |
| 3 | 29.53097 | 4.70 |
| 4 | 30.59911 | 4.87 |
| 5 | 31.10177 | 4.95 |
| 6 | 31.54159 | 5.02 |
| 7 | 32.23274 | 5.13 |
| 8 | 32.60973 | 5.19 |
| 9 | 33.04955 | 5.26 |
| 10 | 33.48938 | 5.33 |

**Table 4.** First Vertical Natural Frequency

| Test points | Frequency (Hz) | | Error(%) |
|---|---|---|---|
| | Test | Simulation | |
| 1 | 4.99 | 5.02 | 0.60 |
| 2 | 4.99 | 5.01 | 0.40 |
| 3 | 5.30 | 5.09 | 4.18 |
| 4 | 5.14 | 5.08 | 1.20 |
| 5 | 5.19 | 5.06 | 2.59 |
| 6 | 5.20 | 5.05 | 2.99 |
| 7 | 5.30 | 5.02 | 5.58 |
| 8 | 5.23 | 5.02 | 4.18 |
| 9 | 5.16 | 5.01 | 2.99 |

### 3.2 Vertical Peak Acceleration Simulation

As shown in Table 5, the results of the three scenarios are summarized as follows.

**Table 5.** Peak Vertical Vibration Acceleration

| Test points | Peak Acceleration ($m\cdot s^{-2}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Walk | | Error (%) | Run | | Error (%) | Aerobics | | Error (%) |
| | Test | Simu-lation | | Test | Simu-lation | | Test | Simu-lation | |
| Point 1 | 0.346 | 0.366 | 5.46 | 1.089 | 1.094 | 0.46 | 0.625 | 0.628 | 0.48 |
| Point 2 | 0.493 | 0.494 | 0.20 | 1.265 | 1.273 | 0.63 | 0.844 | 0.848 | 0.47 |
| Point 3 | 0.307 | 0.307 | 0 | 0.753 | 0.764 | 1.44 | 0.508 | 0.509 | 0.20 |
| Point 4 | 0.560 | 0.561 | 0.18 | 0.998 | 1.00 | 0.2 | 0.595 | 0.595 | 0 |
| Point 5 | 0.529 | 0.527 | 0.38 | 0.720 | 0.720 | 0 | 0.896 | 0.893 | 0.34 |
| Point 6 | 0.666 | 0.686 | 2.92 | 1.056 | 1.080 | 2.22 | 0.922 | 0.937 | 1.60 |
| Point 7 | 0.788 | 0.788 | 0 | 1.099 | 1.102 | 0.27 | 0.765 | 0.750 | 2 |
| Point 8 | 0.731 | 0.733 | 0.27 | 1.063 | 1.058 | 0.47 | 1.265 | 1.275 | 0.78 |
| Point 9 | 0.773 | 0.770 | 0.39 | 1.388 | 1.375 | 0.95 | 1.330 | 1.338 | 0.60 |
| Aver-age | 0.85 | | | | | | | | |

### 3.3 Floor Vibration Control Simulation

Given that the sports field floor slab exhibited vibration comfort levels below the required standards in multiple test areas, a simulation was conducted to evaluate the vibration comfort improvement after the installation of Tuned Mass Dampers (TMDs).

### 3.3.1 TMD Plan Layout and Parameters.

The plan layout for the Tuned Mass Dampers (TMDs) is shown in Fig.2, while the specific parameters for the TMDs are detailed in Table 6.

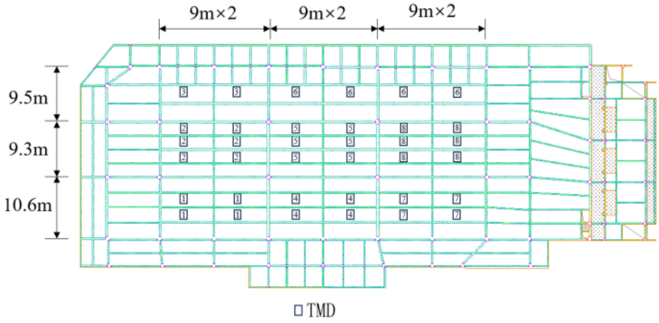


**Fig. 2.** TMD Plan Layout Diagram

**Table 6.** TMD Parameter Table

| Number | $m$ (kg) | $f$ (Hz) | $\xi$ | Maximum stroke (mm) |
|---|---|---|---|---|
| TMD1 | 500 | 3.11 | 0.08 | ±30 |
| TMD2 | 500 | 3.39 | 0.08 | ±30 |
| TMD3 | 500 | 3.84 | 0.08 | ±30 |
| TMD4 | 500 | 3.26 | 0.08 | ±30 |
| TMD5 | 500 | 3.46 | 0.08 | ±30 |
| TMD6 | 500 | 3.77 | 0.08 | ±30 |
| TMD7 | 500 | 3.15 | 0.08 | ±30 |
| TMD8 | 500 | 3.40 | 0.08 | ±30 |

### 3.3.2 Comparison of Vertical Peak Acceleration Before and After TMD Installation.

This comparison is illustrated in Table 7.

**Table 7.** Peak Vertical Vibration Acceleration

| Test points | Peak Acceleration (m/s$^{-2}$) | | Vibration damping effect (%) |
|---|---|---|---|
| | Before TMD installation | After TMD installation | |
| 1 | 1.089 | 0.371 | 65.93 |
| 2 | 1.265 | 0.392 | 69.01 |
| 3 | 0.753 | 0.261 | 65.34 |
| 4 | 0.998 | 0.354 | 64.53 |
| 5 | 0.720 | 0.246 | 65.83 |
| 6 | 1.056 | 0.371 | 64.87 |
| 7 | 1.099 | 0.369 | 66.42 |
| 8 | 1.063 | 0.384 | 63.88 |
| 9 | 1.388 | 0.442 | 68.16 |
| Average value | | | 66.00 |

Based on Table 7, it's observed that after the installation of Tuned Mass Dampers (TMDs), there is a significant reduction in the vertical peak acceleration at all test points, with an average decrease of 66%. Moreover, all test points now comply with the specified limit of 0.5 $m/s^2$ as per the standard requirements.

## 4 Conclusion

Effectiveness of TMD Installation: Installing specifically designed Tuned Mass Dampers (TMDs) in vibration-sensitive areas significantly reduces the vibrational response, allowing the large-span steel-concrete composite floor of the sports field to meet vibration comfort requirements under human-induced load conditions.

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