Research on Vibration Comfort of High-Rise Buildings

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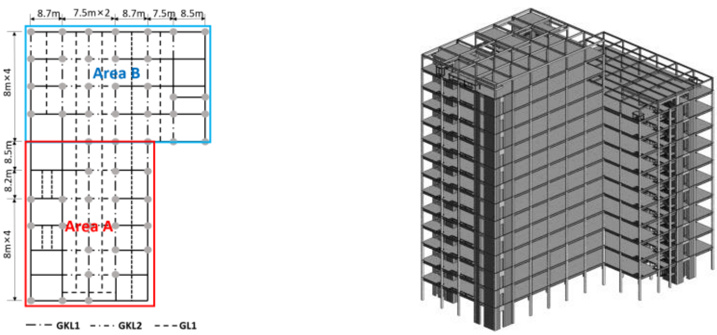
Abstract. In order to study the vibration comfort of high-rise industrial plants, this paper takes a high-rise industrial plant under construction as the background, uses the finite element software to establish the overall structure model of the plant, applies excitation to a certain floor, and extracts the vibration of the excitation floor Acceleration time-history curve to analyze the transmission of its vibration response; use the experimental test method to conduct field tests on the high-rise industrial plant project of the project, and use the excitation method to collect the vibration acceleration time-history data of the floor on a certain floor. Finally, according to the test data and finite element simulation results, and referring to the specification, it is concluded that the high-rise industrial plant meets the vibration comfort requirements; the vibration response of the floor can be transmitted on the same floor, which is the quantification of the subsequent transfer law and the high-rise industrial plant under different excitations. It provides a reference for the research on the law of vibration transmission in the medium.

Keywords: high-rise industrial plant; human induced vibration; vibration comfort; peak vibration acceleration; transmission law of vibration response.

1 Introduction



a) structural layout b) overall model diagram

Fig. 1. High-rise industrial factory layout and overall model schematic

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In the Guangdong-Hong Kong-Macao Greater Bay Area, an increasing number of high-rise industrial buildings are emerging. These structures often employ steel-concrete composite construction. Therefore, the study of vibration comfort for such high-rise industrial buildings is essential [1-2].

The structural layout and overall model are shown in Fig.1.

2 Comfort Evaluation Standards

This paper employs the dual-control standard of vertical vibration peak acceleration and the first vertical natural frequency from JGJT-441-2019 [3] to regulate vibration comfort. The vertical vibration peak acceleration should not exceed the limits specified in Table 1.

Table 1. Limit Values for Vertical Vibration Acceleration of Floor Structures

Floor Usage Category	Peak Acceleration Limit (m/s^2)
Workshop Office	0.20
Installation of Entertainment Vibration Equipment	0.35
Production Operation Area	0.40

Note: The cutoff frequency for this acceleration limit is 30Hz.

Hence, the vertical vibration peak acceleration limit for production operation areas is set at 0.4 m/s^2, while for workshop offices, it is 0.2 m/s^2.

3 Finite Element Simulation

3.1 Model Establishment

In the overall model, beams and columns are represented using line elements, while slabs and walls are modeled as shell elements[4]. The load model uses the classical and commonly employed Bachmann model [5].

The method of time-varying static load is used, where the static load is converted into a dynamic load equal to the static live load multiplied by the time-history load at the corresponding time point [6].

The application of the load should be arranged at points on the floor structure where larger deflections are likely to occur [7].

3.2 Finite Element Simulation Results

Floor Modal Analysis. Firstly, a modal analysis is conducted on the floor slabs. Due to the increased flexibility of high-rise industrial buildings with the addition of floors[8], the simulation focuses on floors 11 to 13.The modal analysis data extracted from the 13th floor reveals that its first vertical natural frequency is 16.98 Hz.

Using the same method, extract the mode shapes and first vertical natural frequencies for the 11th and 12th floor slabs. Compile the results into Table 2.

Table 2. First Vertical Natural Frequencies of Floor Slabs for Floors 11 to 13

floor	First Natural Frequency (Hz)
11th	17.96
12th	17.46
13th	16.98

Vertical Vibration Peak Acceleration Analysis. The vertical vibration peak accelerations of the floor slabs on floors 11 to 13 are summarized in Table 3.

Table 3. Peak Vertical Vibration Accelerations of Floor Slabs for Floors 11 to 13

Floor	Peak Vibration Acceleration (m/s2)
11th	0.154
12th	0.159
13th	0.175

3.3 Experimental Validation

Experimental Basic Information. Considering that the higher the floor, the greater its flexibility and the more significant its vibration response. Running excitation was applied to the floor slabs of the 12th and 13th floors to collect the vibration acceleration of the slabs.

Sensors should be placed at points where larger deflections are likely to occur under external excitation.

Floor Modal Analysis Results. The first vertical natural frequencies of the 12th and 13th floors are summarized in Table 4.

Table 4. First Vertical Natural Frequencies

floor	Frequency (Hz)
12th	16.82
13th	16.14

Floor Vibration Acceleration Test Results. The peak vertical vibration accelerations of the 12th and 13th floor slabs are summarized in Table 5.

Table 5. Peak Vertical Vibration Accelerations

floor	Peak Acceleration (m/s2)
12th	0.091
13th	0.095

Note: Since the tests were conducted during quiet periods without construction activities, external environmental excitation signals had minimal interference, and thus the test data were not filtered.

Comparison and Analysis of Test Results and Finite Element Simulation Results. The first vertical natural frequencies obtained from the tests were compared with those obtained from the finite element simulations, as shown in Table 6.

Table 6. Comparison of First Vertical Natural Frequencies between Test Results and Finite Element Simulation Results

floor	First Vertical Natural Frequencies (Hz)		error
	Test	FES	
12th	16.82	17.46	3.80%
13th	16.14	16.98	5.20%
	average error		4.5%

The test peak vibration accelerations were compared with the reduced peak vibration accelerations from the finite element simulations, as shown in Table 7.

Table 7. Comparison of Peak Vibration Accelerations between Test Results and Reduced Finite Element Simulation Results

floor	Peak Acceleration (m/s2)		Error
	Test	FES	
12th	0.091	0.08	12.09%
13th	0.095	0.088	7.37%
	Average Error		9.73%

From Table 6 and Table 7, it can be seen that both the simulated and tested first natural frequencies are greater than 3 Hz, with an average error of 4.5%.

4 Study on the Impact of Vibration Transmission Laws on Comfort

The peak vertical vibration accelerations of the floor slabs on floors 11 to 13 are summarized in Table 8.

Table 8. Peak Vertical Vibration Accelerations for Floors 11 to 13

Floor	Near Excitation Site (m/s2)	Far Excitation Site (m/s2)	Transmission Ratio
11th	0.154	0.046	29.87%
12th	0.159	0.047	29.56%
13th	0.175	0.053	30.29%
	Average Transmission Ratio		29.91%

According to Table 8, the vibration response attenuates as it transfers from the floor slab near the excitation site to the one far from it during running excitation.

5 Conclusion

This paper utilized finite element numerical simulation software to model a high-rise industrial factory building and conducted field tests to verify the accuracy and reliability of the finite element model. The following conclusions were drawn:

1. Under running load excitation, the high-rise industrial factory building does not resonate, and the vibration comfort meets national standards.
2. The higher the floor in a high-rise industrial building, the greater its flexibility and the higher the vibration acceleration.
3. Within the floor structure, there is a discernible pattern in the transmission of vibration responses between slabs on the same floor. When the excitation transfer distance is 16.45m, the vibration response decreases to about 30% of its original level.

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References

1. He, Y.; Zhang, Y.; Yao, Y.; He, Y.; Sheng, X.(2023) Review on the prediction and control of structural vibration and noise in buildings caused by rail transit. Buildings, 13, 2310:1-23. https://doi.org/10.3390/buildings13092310.
2. Li, X.; Chen, Y.; Zou, C.; Wu, J.; Shen, Z.; Chen, Y. (2023) Building coupling loss measurement and prediction due to train-induced vertical vibrations. Soil Dyn. Earthq. Eng, 164: 10-44. https://doi.org/10.1016/j.soildyn.2022.107644.
3. Ministry of Housing and Urban-Rural Development of the People's Republic of China. Technical standard for vibration comfort of building floor structures: JGJ/T 441-2019[S]. Beijing: China Architecture & Building Press, 2019.
4. HUANG S. Study on the Vibration Response of Large-span Steel-concrete Composite Beam with Precast Hollow Core Slabs Due to Human induced Excitation [D]. Chongqing: Chongqing University, 2019: 41-41.
5. DAVIS, B., LIU, D., MURRAY T M. (2014) Simplified experimental evaluation of floors subject to walking-induced vibration. Journal of Performance of Constructed Facilities, ASCE., 28(5): 1-8. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000471.
6. GUO Lei, WANG Hao, WANG Menghong. Vertical vibration comfort analysis on large-span steel-concrete composite floor system [J]. Building Structure, 2019, 49(2): 649-652. 10.19701/j.jzjg.2019.S2.121.
7. Xu, W.; Li, R.; Qiu, J.; Li, Q.; Yu, Z.(2023) Study on wind-induced human comfort of the SEG plaza under local excitation based on wind tunnel test. Sustainability, 15, 3067: 1-17. https://doi.org/10.3390/su15043067.
8. Gaur, H; Khidhir, B; Manchiryal, R.K(2022). Solution of structural mechanic's problems by machine learning. International Journal of Hydromechatronics, 5, 22-43. https://doi.org/10.1504/IJHM.2022.122459.