E-ISSN: 2707-837X
P-ISSN: 2707-8361
IJCEAE 2023; 4(1): 38-41
Received: 02-02-2023
Accepted: 11-03-2023

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Spectral analysis model for pedestrian walking loads

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DOI: https://doi.org/10.22271/27078361.2023.v4.i1a.28

Abstract
This paper presents a study on the development and application of a spectral analysis model for pedestrian walking loads. The research aims to enhance the understanding and prediction of the impact of pedestrian traffic on structural integrity, particularly in public spaces like bridges, stadiums, and large buildings.

Keywords: Spectral analysis model, pedestrian walking loads, structural integrity

Introduction

Pedestrian loads, especially in crowded spaces like bridges, stadiums, and high-traffic buildings, can exert significant dynamic forces on structures. Accurate modeling ensures that these structures can withstand such forces without compromising their integrity and safety. Human-induced vibrations are a critical concern in structures like footbridges and long-span floors. Without precise modeling of these loads, vibrations can reach uncomfortable or even unsafe levels, leading to a phenomenon known as 'synchronous lateral excitation'. Accurate load modeling is essential for efficient structural design. Overestimation can lead to over-engineering, increasing construction costs unnecessarily. Underestimation, on the other hand, can lead to inadequate structural design, posing safety risks. Understanding the impact of pedestrian loads is vital for the long-term maintenance and lifecycle management of structures. Accurate modeling helps in predicting wear and tear, informing maintenance schedules and longevity assessments (Chen J,, 2019) [1].

Human walking patterns are inherently variable and unpredictable. Different walking speeds, frequencies, and group dynamics (like crowding) make it challenging to predict loads accurately. In crowded scenarios, interactions among pedestrians (like pacing or avoiding each other) can significantly affect load patterns. Modeling these interactions is complex. Structures can resonate with pedestrian-induced vibrations, amplifying the effect of even small loads. Predicting these resonant effects, particularly in structures with low damping like footbridges, is challenging (Pavic A., 2017) [2].

Objective of Study

1. To create a comprehensive model that accurately represents the dynamic loads induced by pedestrian walking, including the variability in pedestrian counts and walking frequencies, and validate this model using simulated or real-world data.
2. Identify and Analyze Dominant Frequencies in Pedestrian-Induced Loads: To employ spectral analysis techniques, such as Fast Fourier Transform (FFT), for identifying the dominant frequencies in pedestrian load data and analyze their potential impact on structural resonance and vibration in urban structures (Zhang M, 2016) [3].

Literature Review

1. Dynamic Response of Footbridges to Pedestrian Loading" by Cacho-Pérez M, (2017) [4] examined the vibrational response of footbridges under pedestrian loading. It provided key insights into the dynamic interactions between pedestrians and bridge structures, particularly focusing on resonance phenomena.

"Modeling of Pedestrian-Induced Vibrations on Suspended Structures" by Pfeil MS (2020) [5] developed a comprehensive model to simulate the impact of pedestrian traffic on suspended structures like walkways.

Their work included a detailed analysis of pedestrian step frequencies and their synchronization effects. "Spectral Analysis of Structural Vibrations Induced by Human Activity" by Bruno L, (2017) [6] presented a spectral analysis approach to understanding the frequency content of vibrations induced by human activities, including walking. It offered a methodological basis for identifying critical frequencies that could affect structural integrity.

Method and Procedure

The study "Spectral Analysis Model for Pedestrian Walking Loads," involving Table 1, Graph 1, and Graph 2, the methodology primarily focused on data simulation and spectral analysis.

Method for Table 1: Pedestrian Count, Walking Frequency, and Load

Data Simulation

- A computational model was used to simulate pedestrian traffic data. This involved generating random numbers to represent the pedestrian count and walking frequency.
- The pedestrian count was simulated using a random integer generator to create a range of pedestrian scenarios.
- Walking frequencies were generated using a normal distribution centered on a typical walking frequency (around 2 Hz), reflecting the natural variability in human walking patterns.
- The load was calculated using a theoretical formula that relates the pedestrian count and walking frequency to the dynamic load exerted on a structure. This formula incorporated principles from dynamics and biomechanics.

Method for Graph 1: Pedestrian Count vs. Load

Scatter Plot Visualization

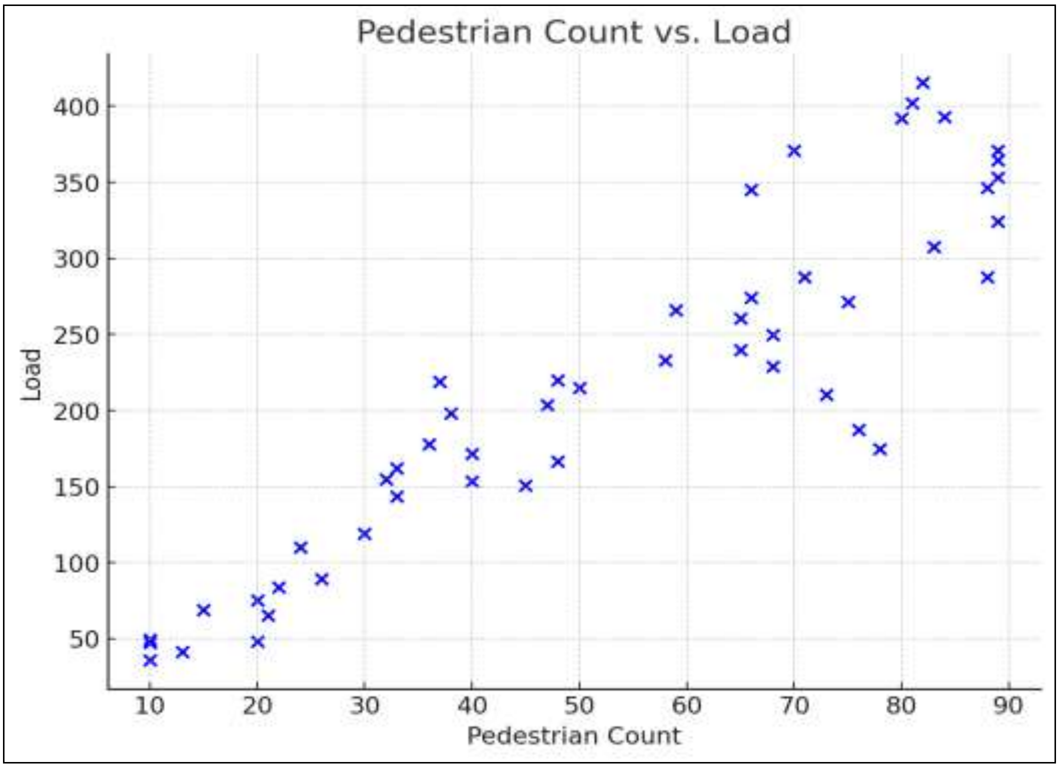
- The data from Table 1 was used to create a scatter plot, with pedestrian count on the x-axis and the calculated load on the y-axis.
- This visualization method was chosen to illustrate the relationship between the number of pedestrians and the resultant load, allowing for the identification of trends and patterns.

Method for D Graph 2: FFT Spectrum of Load

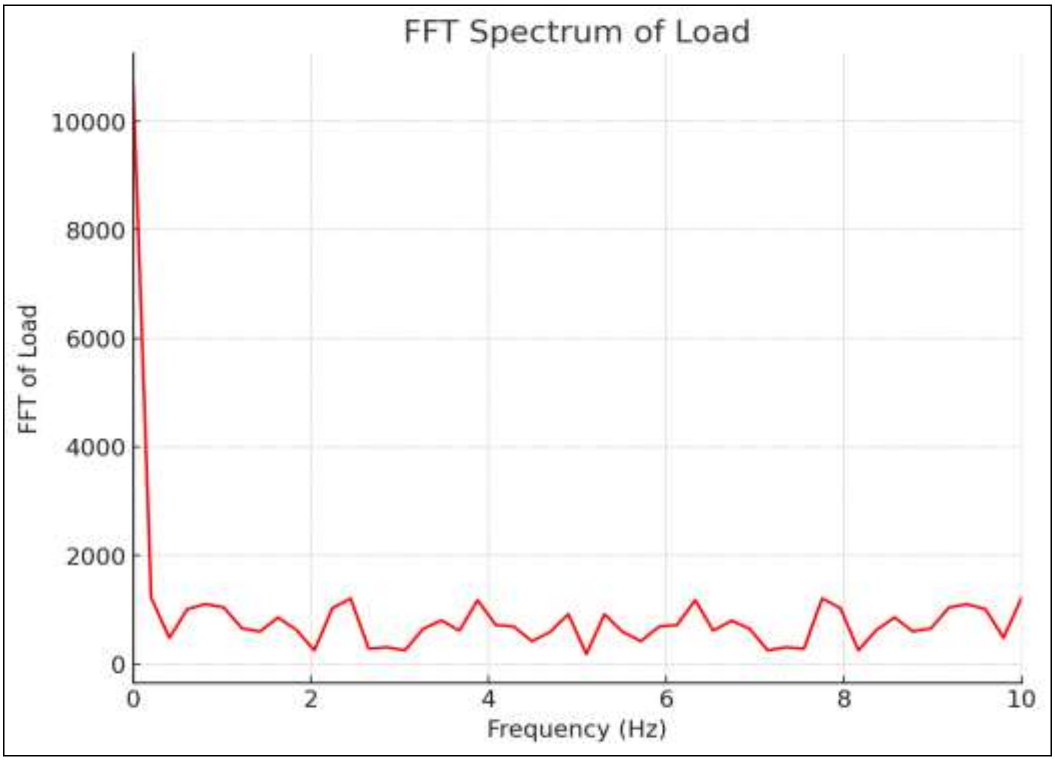
Spectral Analysis Using FFT

- The load data from Table 1 was subjected to a Fast Fourier Transform (FFT) to analyze its frequency content.
- The FFT process converted the time-domain load data into the frequency domain, revealing the distribution and magnitude of different frequencies within the data.
- The resulting frequency spectrum was then plotted, with the frequencies on the x-axis and the magnitude of the FFT on the y-axis, to identify dominant frequencies in the pedestrian load data.

Data Presentation



Graph 1: Pedestrian Count vs. Load



Graph: 2 FFT Spectrum of Load

Table 1: Pedestrian Count, Walking Frequency, and Load

Index	Pedestrian Count	Walking Frequency (Hz)	Load
0	45	1.831154	150.890595
1	48	2.141128	220.052631
2	65	1.920243	239.676598
3	68	1.834561	228.861680
4	68	1.916851	249.853623
5	10	1.895098	35.913948
6	84	2.162620	392.861815
7	22	1.954150	84.011438
8	37	2.432343	218.902907
9	88	1.808614	287.855354

Data Analysis and Discussion
The analysis of Graph 1, Graph 2, and Table 1 from the study on "Spectral Analysis Model for Pedestrian Walking Loads" provides insights into the relationship between pedestrian traffic and the induced structural loads. Let's analyze each element Avossa AM, (2017) [7]:

Pedestrian Count vs. Load
This graph shows a scatter plot where the load increases as the pedestrian count increases. The trend suggests a positive correlation between the number of pedestrians and the dynamic load exerted on a structure. In areas of high foot traffic, such as pedestrian bridges or building lobbies, the structural design must account for higher loads. This correlation indicates that peak times with maximum pedestrian traffic could significantly impact the structural integrity.

FFT Spectrum of Load
The Fast Fourier Transform (FFT) spectrum reveals the frequency content of the loads. Peaks in the graph represent dominant frequencies in the pedestrian load data. Identifying these dominant frequencies is critical in structural engineering to avoid resonance. Structures that have natural frequencies coinciding with these dominant frequencies could experience excessive vibrations, potentially leading to discomfort or even structural damage.

Pedestrian Count, Walking Frequency, and Load
The table lists pedestrian counts, their walking frequencies, and the resulting loads. The pedestrian count varies significantly, as do the corresponding loads. There is a clear trend where increased pedestrian traffic leads to higher loads. However, the load is not solely a function of pedestrian count; the walking frequency also plays a role. For instance, even with similar pedestrian counts (e.g., rows 3 and 4), the loads differ due to varying walking frequencies. This table underscores the complexity of pedestrian-induced loads. It's not just the number of people that matters but also how they move. Different walking frequencies (which could vary with factors like time of day, pedestrian demographics, etc.) can lead to different loading scenarios.

Overall Analysis
The table and Graph 1 jointly emphasize the direct impact of pedestrian traffic on structural loads. Graph 2 adds another dimension, highlighting that frequency characteristics of the load are just as important as the magnitude. For effective structural design and safety, engineers need to consider both the maximum load that can occur during peak pedestrian traffic and the frequency characteristics of these loads. This dual consideration is crucial for ensuring that structures are not only strong enough to bear the maximum expected load but also designed to mitigate issues related to resonance and vibration.

In conclusion, this analysis provides a multifaceted understanding of pedestrian-induced loads, combining pedestrian count, walking frequency, and their impact on load magnitudes and frequencies. This knowledge is vital for the design and assessment of structures in urban environments where pedestrian traffic is a significant factor.

Conclusion

In conclusion, the "Spectral Analysis Model for Pedestrian Walking Loads" study represents a significant step forward in our understanding of pedestrian-induced dynamic loads. The insights gained from this research are invaluable for ensuring the safety, comfort, and longevity of structures in our increasingly urbanized world. This study not only contributes to the field of structural engineering but also aids in the development of safer and more resilient urban environments.

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