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ISBN 978-9934-10-360-5

RIGA TECHNICAL UNIVERSITY
53rd INTERNATIONAL SCIENTIFIC CONFERENCE

DEDICATED TO THE 150th ANNIVERSARY AND

THE 1st CONGRESS OF WORLD ENGINEERS AND RIGA POLYTECHNICAL INSTITUTE / RTU ALUMNI

11-12 October 2012
Rīga, Latvija

Rīga-2012

Riga Technical University 53rd International Scientific Conference dedicated to the 150th anniversary and
The 1st Congress of World Engineers and Riga Polytechnical Institute / RTU Alumni

Dynamic Loading and Response of Observation Towers

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Keywords – **Dynamic response, observation tower, walking induced loads.**

I. Introduction

The excessive vibrations of some observation towers in Latvia highlights the lack of the understanding and inadequate design information of the building codes, regarding the slender tower dynamic response to human induced loads. Research demonstrates that in areas with a low seismicity and relatively low wind loads the human induced dynamic loads are determinative to a slender and light-weight observation tower design and mostly due to checking the serviceability criteria.

II. Theoretical and Experimental Background

A. Loading from Human Movement on Stairs

Human walking induces dynamic and time varying forces. These forces have components of vertical, lateral and longitudinal directions. The lateral forces are the consequence of the sideway oscillation of the gravity centre of human body while stepping alternatively with the right and left foot forwards [1]. The lateral force walking frequency is found to be a half of the vertical and longitudinal one [2].

The acceleration of the person's center of gravity (COG) in vertical, lateral and longitudinal directions during stair ascent and descent were measured to obtain individual continuous walking force time histories. Based on these histories there was established the mean one and further analytically approximated.

B. Calculations and Measurements of the Tower Vibration

Slender sightseeing towers are line-like structures. The response of the system with viscous damping to induced harmonic excitation can be written in the form of well-known linear non-homogenous differential equation:

$$M\ddot{x} + C\dot{x} + Kx = F_{max}\sin(pt + \delta), \qquad (1)$$

where M, C and K are mass, damping and stiffness of the system correspondingly, but $F_{max}\sin(pt+\delta)$ is harmonic excitation. To take into account human movement initiated excitation, the lateral and longitudinal human walking force in the time domain is represented as a sum of Fourier harmonic components and equation (1) updated with human induced lateral or longitudinal walking forces are:

$$M\ddot{x} + C\dot{x} + Kx = \sum_{i=1}^{m} G\alpha^{i}\sin(p_i t + \delta^{i}), \qquad (2)$$

where G is a static weight of the subject's bodies (N), i – order number of the walking harmonic, m – the total number of contributing harmonics, α^i – the Fourier coefficient of the i^{th} harmonic often referred as dynamic loading factor (DLF), p_i – i^{th} harmonic angular frequency (rad/s), δ^i – the phase shift of the i^{th} harmonics.

Research analyses experimentally measured response of the tower's structure to the excitation caused by human movement upstairs and downstairs. During the experiment there have been measured and recorded the vibration accelerations of the top platform of several observation towers.

III. Results

Dynamic loading factors and corresponding phase shifts for the first five harmonics of continuous walking force history in case of the stair ascend and descend are presented. The imperfectness of individual footfall forcing functions and differences between continuous walking force histories among individuals were taken into account. During the stair ascend at 2Hz the averaged vertical reaction force peak amplitude is 1.6 times of body weight, during descent - 1.8 times of body weight. During ascent the longitudinal reaction force peak amplitude was 0.28 times of body weight and during descent 0.23 times of body weight. During ascent the lateral reaction force peak amplitude was 0.28 times of body weight and during descent 0.24 times of body weight.

It was experimentally identified that human movement up and down the stair significantly amplifies the observation tower's vibrations (Fig. 1)

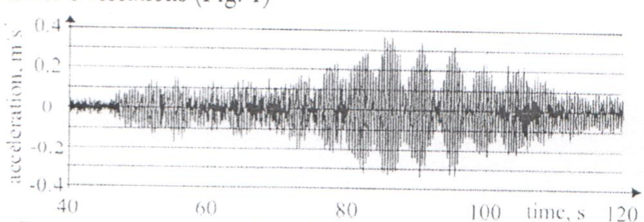

Fig. 1. Observation tower in Krustpils response to 2 person stair ascending

IV. Conclusions

The obtained analytical mean functions of human walking force histories during the stair ascent and descend may be used in numerical and analytical assessments of structure's dynamic response. The obtained parameters of the vertical force are within agreement of other researchers' work.

It was experimentally established that typical observation towers are susceptible to remarkable human induced vibrations.

V. Acknowledgements

This work has been supported by the European Social Fund within the project "Support for the implementation of doctoral studies at Riga Technical University".

V. References

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