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

7-2

Analysis of Dynamic Parameters of Timber and Steel Observation Towers

Liga Gaile *(Riga Technical University)*

Keywords – **Damping, Frequency, Human-induced loads, Observation tower.**

I. INTRODUCTION

Observation towers located in the countryside are designed to allow viewers an unobstructed view of the landscape and their design is mostly driven by economic aspects. With generally flat terrain, Latvia has a numerous observation towers mostly located in Latgale and Kurzeme regions. The structural design of all of them is mostly based on the previous experience. It is because of lack of understanding how these structures dynamically perform under human induced loads [1].

II. METHODS AND MATERIALS

The purpose of this research is to identify the performance of most of the light weight observation towers open for public in Latvia. It analyzes their structure, condition, dynamic parameters (fundamental and natural frequencies, damping, frequency, which amplitude amplifies due to towers visitors' movement) as well it analyzes the loading scenarios to identify the critical ones based on the experimentally obtained data.

A. Experimental Program

During the experiment there have been measured and recorded the vibration accelerations of the observation towers. The accelerometers where located on the upper platform of the tower. The accelerations were measured under the following conditions: very mild wind and no visitors on the tower, two visitors moving upstairs and afterwards downstairs, two visitors moving along the upper platform in transverse direction and in circular direction. Additionally, there were measured the geometry of the structure and the weather conditions during the experiments.

B. Observation Tower Description

Locations of experimentally measured observation towers are presented in Fig. 1.

Fig. 1. Location of observation towers in Latvia.

The heights of the observation tower are in the range of 19m to 36m, a plan dimension of main lateral load resisting system varies from 1,5m to 9,5m. 70% of inspected towers are a traditional timber structure design towers with non-uniform cross section. Others are made of steel where in most cases the plan dimension over the height does not change. The slope of stairs is in the range of 30^0 to 70^0 but most of the observation towers' slop of stairs is around 45^0.

III. RESULTS

Although the most of observation towers are less than ten years old their technical condition widely varies. Only those timber towers that has less than five years are in good condition. Most of the damages are located in the main column areas (Fig.2), whereas the steel towers columns' splice seems to be affected by the tower's vibrations (Fig.3).

Fig. 2. Typical damage for timber structure

Fig. 3. Typical damage for steel structure

A. Dynamic Parameters and Dynamic Response

The critical range of the structure's frequencies *f* when it is prone to human-induced vibrations [3]:

$$0.666 \pm 0.147\,Hz \leq f \leq 3.300 \pm 0.147\,Hz \qquad (1).$$

All inspected observation towers in Latvia are in this critical range. The measured noticeable acceleration amplifications from human movement confirm that all lightweight observation towers should be designed considering human-induced dynamic loading. Timber observation towers' fundamental mode damping varies from 6% to 10% but steel towers' – 2,5% to 4,6%.

IV. CONCLUSIONS

Timber observation towers have very short service life but they perform better under human induced loads due to higher damping ratio than steel structure towers. Steel towers are very prone to human induced vibrations and there is a necessity to develop suitable damping devices. It has been observed that tower responded to human induced loads not necessarily with lowest frequency but with frequency that has lower damping ratio and still relatively close to the typical pacing frequency.

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".

VI. REFERENCES

[1] Gaile L., Radiņš I. Eccentric Lattice Tower Response to Human Induced Dynamic Loads, ICSV19: 19th International Congress on Sound and Vibration Proceedings of Recent Developments in Acoustics, Noise and Vibration, Lithuania, Vilnius, 8.-12. July, 2012. - pp 213-221.

[2] Gaile L., Radiņš I. Steel lattice sightseeing tower's horizontal vibrations induced by human movement, Proc.: ISMA2012/USD2012: 25th International Conference on Noise and Vibration Engineering, Belgium, Leuven, 17.-19. September, 2012. *(accepted for publication).*

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

Liga Gaile *(Riga Technical University)*, Ivars Radinsh *(Riga Technical University)*

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)

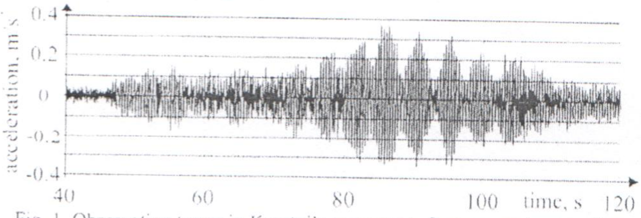

Fig. 1. Observation tower in Krustpils response to 2 person stair ascending

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

[1] L. Frank. *Synchronous Lateral Excitation of Footbridges.* Swiss Federal Institute of Technology. Swiss (2009).

[2] H. Bachman, W. Ammann. *Vibration in Structures Induced by Man and Machines.* Structural Engineering Document 3e. International Association for Bridge and Structural Engineering (IABSE), ch. 2: Man Induced Vibrations, Appendix A: Case Reports (1987).