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# EXPERIMENTAL STUDY ON AN AEROELASTIC MODEL OF A TELEVISION TOWER IN THE BOUNDARY LAYER WIND TUNNEL

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***Abstract:*** *The aim of this paper is to present a detailed experimental procedure for investigating the dynamic behavior of an aeroelastic model of a television tower to the wind action in the boundary layer wind tunnel. The main objective of the procedure is to provide a framework for the calculation of the dynamic response based on the wind tunnel results. Wind tunnel tests were carried out on an already existing 1:500 scale aeroelastic model of the television tower, which is in the Aerodynamics and Wind Engineering Laboratory "Constantin Iamandi" from the Technical University of Civil Engineering of Bucharest. For this study were taken into account the specific characteristics of the Bucharest site. The investigation highlights the ability of the procedure to obtained an overview of the oscillating behavior of the television tower model to the turbulent wind action.*

***Key words:*** *aeroelastic model, television tower, boundary layer wind tunnel, vibration measurements, dynamic response*

## 1. Introduction

Special buildings, such as towers, chimneys, wind turbines, wind turbines masts etc., show some specific issues that affect their behavior to the wind action, so it is necessary to use a relatively different approach from ordinary buildings. According to the wind action codes, using the usual calculation methods for medium or low height structures might lead to irrational or unsatisfactory solutions in terms of structural performance for structures higher than 200 m [8-10]. As a result, for this kind of structures it were imposed studies on models placed in the experimental vein of a wind tunnel that simulates the atmospheric boundary layer, and can, thereby, precisely determine their behavior under wind action for both the model and the full-scale structure [4].

During the last decades, studies on the topic of wind effects on tall buildings have been made throughout the world and the main objective of this studies was to gain a deeper understanding of wind effects on tall buildings. The literature review reveals that the most important studies on this area include that of Isymov et al. (1984), Georgescu et al. (1996), Kareem et al. (1998), Irwin (2008), Fu et al. (2012), Tanaka et al. (2012), Bandi et al. (2013), Johann et al. (2015).

The study started from a 1:500 scale aeroelastic model, already existing in the

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Aerodynamics and Wind Engineering Laboratory “Constantin Iamandi” from the Technical University of Civil Engineering of Bucharest. The model reproduced the reinforced concrete structure of a television tower of about 425 m high and it was designed in the early 90s to be built in Bucharest for the television system of Romania. The model is constructed as an aeroelastic model, which reproduces the geometry of the full-scale structure, for both aerodynamic surfaces and details. The materials used for correct distribution of the model mass were an aluminium alloy ATS 12, characterized by the density $(\rho_s)_M = 2;68$ g/cm$^3$ and the modulus of elasticity $(E_s)_M = 0;69 \cdot 10^6$ daN/cm$^2$ and wood, characterized by the modulus of elasticity $(E_s)_M = 0;12 \cdot 10^6$ daN/cm$^2$ [3]. Thus, it were also complied the similitude conditions between the model and the prototype.

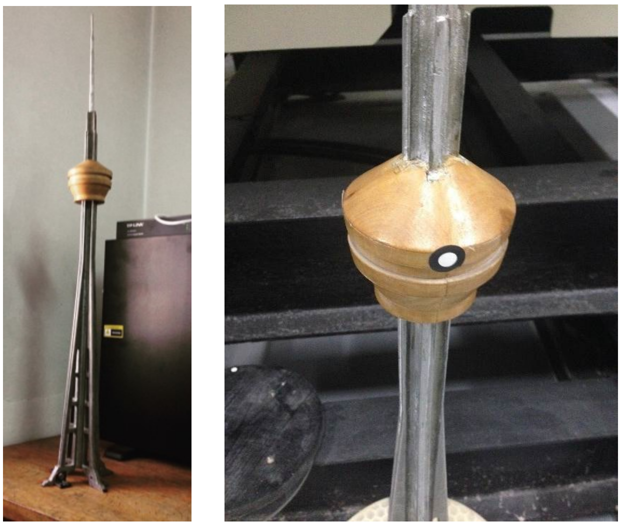

Fig. 1. *The 1:500 scale aeroelastic model of the television tower (left side) and the Gondola of the model (right side)* [1]

The experimental tests focused on the behavior under the turbulent wind action of the Gondola of the television tower model, because there were to be housed the technical emission-reception facilities, the water-tanks and a rotating restaurant. For this structure the Gondola was the most sensitive part of it and the study was also conducted to see if the human comfort conditions for this kind of structures are satisfied.

## 2. The Boundary Layer Wind Tunnel TASL1-M

Experimental tests were done in the boundary layer wind tunnel TASL1-M which is in the Aerodynamics and Wind Engineering Laboratory “Constantin Iamandi” from the Technical University of Civil Engineering of Bucharest. TASL1-M is an open-circuit wind tunnel, has a system of variable roughness and is characterized by a total length of 27;20 m and an experimental cross section of 1;75 m x 1;75 m [1].

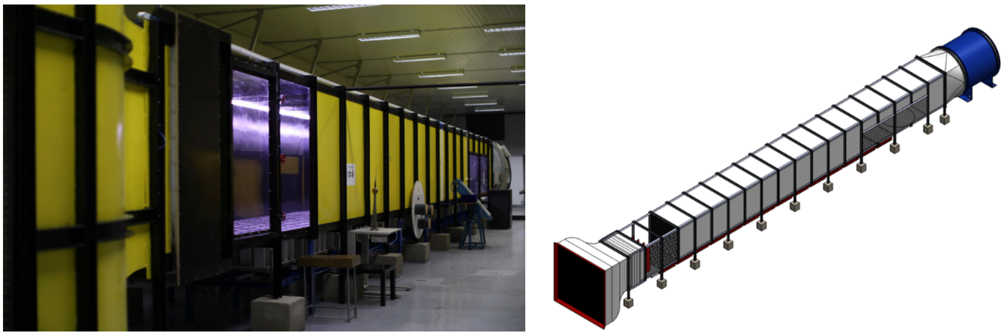

Fig. 2. *The boundary layer wind tunnel TASL1-M* [1]

By its characteristics, the wind tunnel assures the correct modelling of the atmospheric boundary layer, for both vertical velocity distribution and turbulent profile expected at the construction site using roughness elements [8-10].

In order to make a correlation between the mean wind speed profile and turbulent intensity profile for Bucharest site calculated according to CR 1-1-4/2012 and the mean wind speed profile and turbulent intensity profile resulted from the experimental investigations for the wind tunnel calibration, were taken into account the experimental results specific for a variable roughness of 0 cm, 5 cm and 10 cm and after that the results were compared with those achieved according to the code CR 1-1-4/2012 [1].

It was found that the best match between the mean wind speed profile and turbulent intensity profile calculated according to CR 1-1-4/2012 and the ones experimentally determined for the calibration of the wind tunnel are those specific for a variable roughness equal to 10 cm [1].

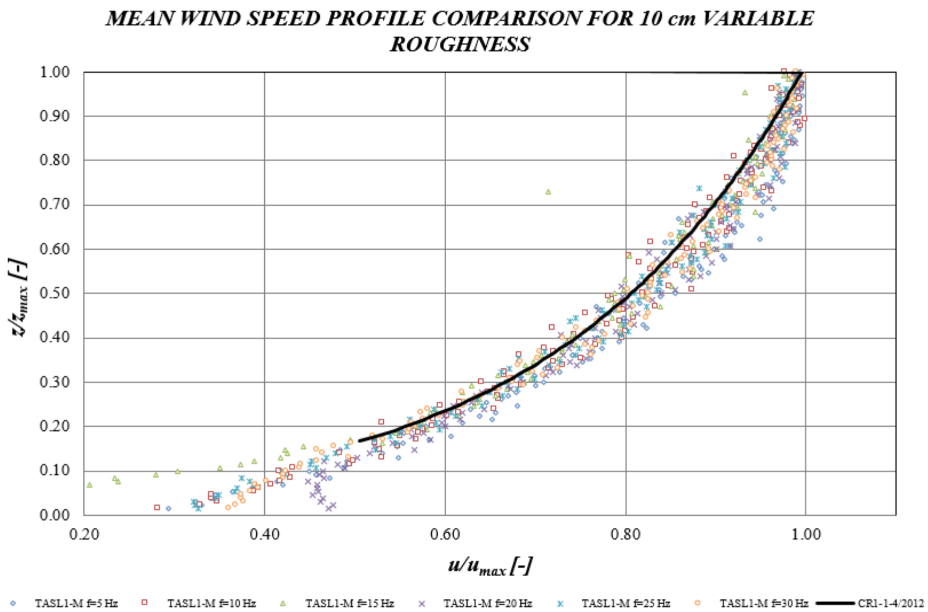


Fig. 3. *Mean wind speed profile characteristic for Bucharest site (according to CR 1-1-4/2012 and experimental tests)* [1]

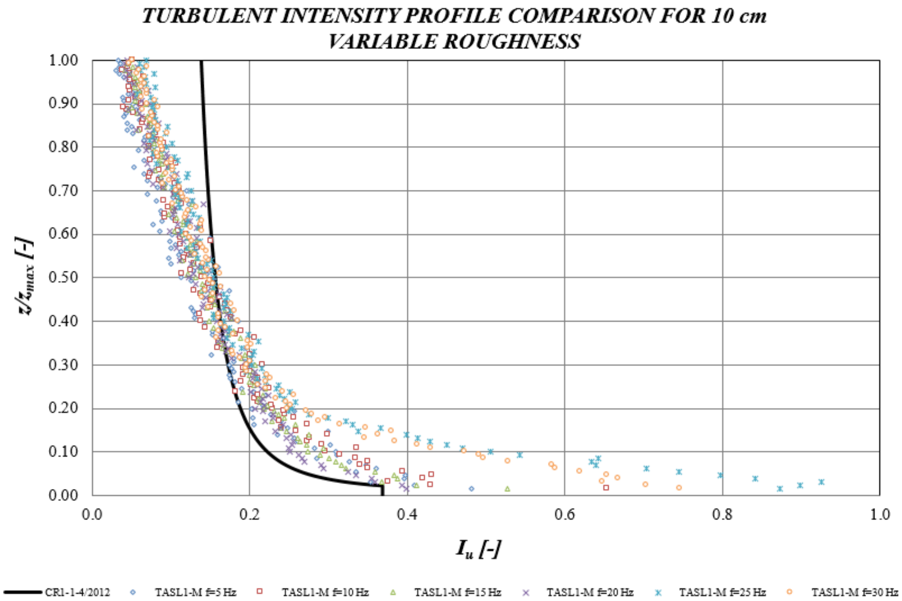


Fig. 4. *Turbulent intensity profile characteristic for Bucharest site (according to CR 1-1-4/2012 and experimental tests)* [1]

## 3. Measurement Equipment and Data Acquisition

The experimental tests were performed by measuring the vibrations of the aeroelastic model under the turbulent wind action in the boundary layer wind tunnel TASL1-M. It was not necessary to make measurements for velocity and turbulent fluctuation because the data already existed from the calibration of the wind tunnel TASL-1M [1].

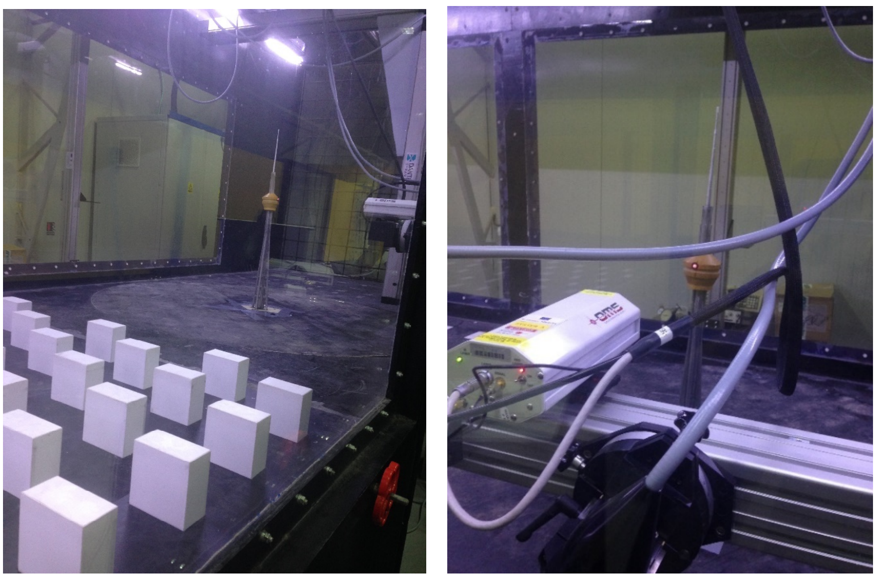

Fig. 5. *Data acquisition during the vibration measurements* [1]

For vibration measurements it was used the laser Doppler vibrometer OMS LaserPoint LP01, which is in the Aerodynamics and Wind Engineering Laboratory "Constantin Iamandi" from the Technical University of Civil Engineering of Bucharest. One of the two laser heads of the OMS LaserPoint LP01 was fixed on the girder system which is in the experimental vein of the wind tunnel and after that, it was positioned on the Gondola surface in order to make measurements on two horizontal directions, by turn. It were also applied markers to the Gondola in order to get a stronger signal for data acquisition. Also, it was raised up the system of variable roughness in order to respect the mean wind speed profile and the turbulent intensity profile previously set.

Measurements were made in two directions, for various frequencies of the axial fan of the wind tunnel. The first direction was the direction of the air flow and the second one was perpendicular to the air flow direction. Finally, 12 sets of vibration measurements were achieved, 6 measurements for each considered direction.

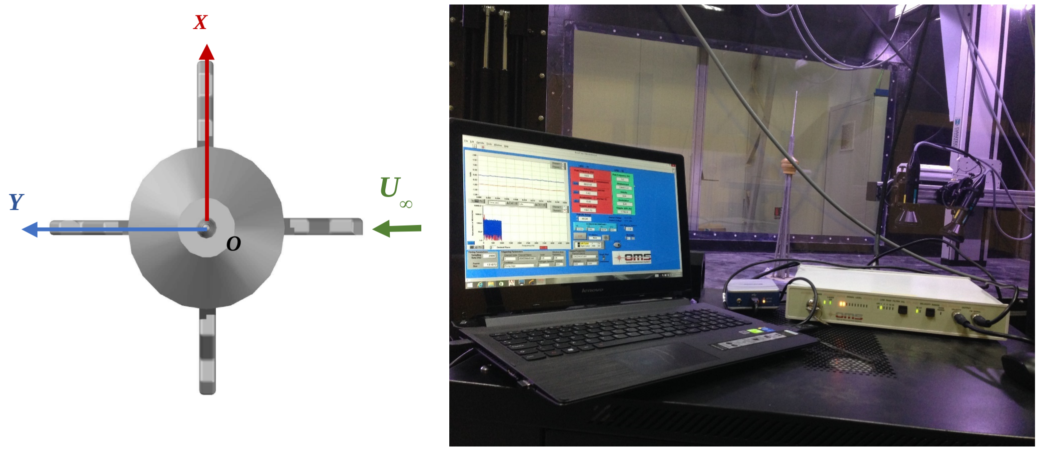


Fig. 6. *The two horizontal directions (X,Y) in which the vibration measurement were carried out and the air flow direction ($U_\infty$)* [1]

The characteristics parameters of each measurement were time, voltage, frequency and Fast Fourier Transform. Using the formulas below, it were determined the amplitudes, displacements, velocities and dynamic accelerations for the model of the television tower:

$$v\ [\text{mm/s}] = \text{Voltage} \cdot 5;093, \tag{1}$$

$$d\ [\text{mm}] = (v_1 - v_0) \cdot (t_1 - t_0) + d_0, \tag{2}$$

$$a\ [\text{mm/s}^2] = \frac{\Delta v}{\Delta t} = \frac{v_1 - v_0}{t_1 - t_0}, \tag{3}$$

$$A\ [\text{mm}] = \frac{v}{2\pi \cdot f}, \tag{4}$$

where: $v$ - the velocity; $d$ - the displacement; $a$ - the dynamic acceleration; $A$ - the amplitude; 5;093 - a calibration constant of the laser according to the speed domain chosen for each measurement.

For the 12 vibration measurements were achieved signals similar to those in Figure 6, Figure 7 and Figure 8 for displacements, velocities and accelerations and it could be process the data acquired from measurements to establish the oscillating behavior of the television tower model under the turbulent wind action.

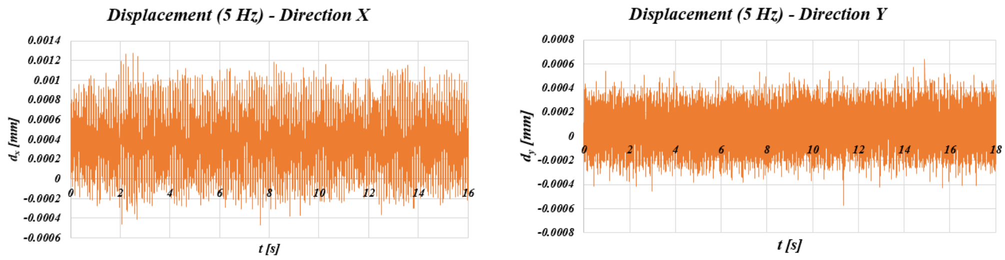


Fig. 7. *Signals obtained for displacement for the two horizontal directions*

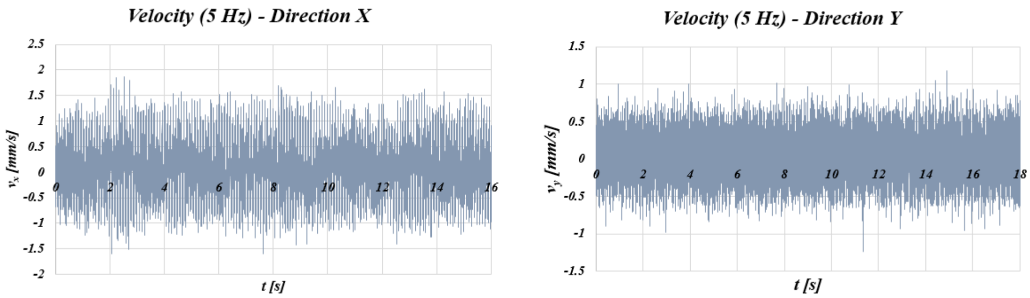


Fig. 8. *Signals obtained for velocity for the two horizontal directions*

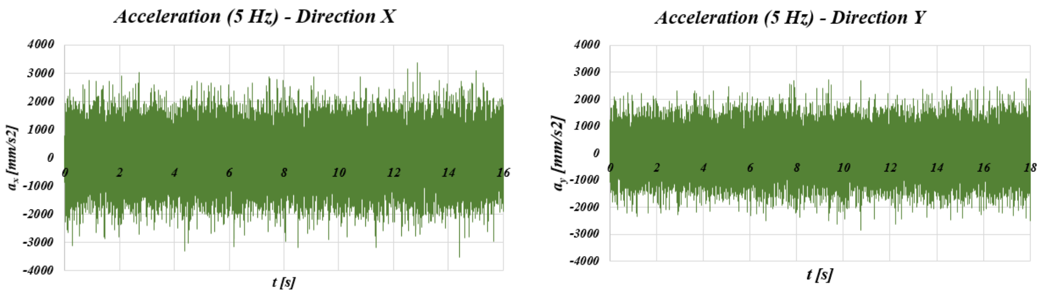


Fig. 9. *Signals obtained for acceleration for the two horizontal directions*

For an overview of the behavior of the model to the wind action, for each signal it were determined the maximum values, the minimum values, the average values, the root mean square (R.M.S.) values, the positive mean values, the negative mean values for displacements, velocities and accelerations. The results will be discussed in the next section.

## 4. Results

As it was previously specified, the most relevant results for the XOY system considered for the model of the television tower are presented in the tables below.

For graphical representation of the results mentioned above, it was considered that the X axis of each graphic is represented by the speeds mode output characteristic for TASL1-M, which was determined from experimental tests and the Y axis is represented by the specific value of displacement, velocity or acceleration.

*Maximum and minimum values for X direction* Table 1

| Fan frequency [Hz] | Wind speed in the tunnel [m/s] | MAXIMUM VALUES | | | MINIMUM VALUES | | |
|---|---|---|---|---|---|---|---|
| | | Displacement [m] | Velocity [m/s] | Acceleration [m/s²] | Displacement [m] | Velocity [m/s] | Acceleration [m/s²] |
| **5 Hz** | **2;85** | 0;0000013 | 0;0018770 | 3;3710461 | -0;0000005 | -0;0016060 | -3;5285735 |
| **10 Hz** | **5;70** | 0;0000009 | 0;0034019 | 3;1193234 | -0;0000022 | -0;0027670 | -3;2591543 |
| **15 Hz** | **8;55** | 0;0000019 | 0;0090281 | 3;1528767 | -0;0000066 | -0;0078377 | -3;0807936 |
| **20 Hz** | **11;40** | 0;0000110 | 0;0218329 | 36;5753062 | -0;0000062 | -0;0126443 | -46;9131336 |
| **25 Hz** | **14;25** | 0;0000122 | 0;0234254 | 19;8207372 | -0;0000105 | -0;0219403 | -24;1860112 |
| **30 Hz** | **16;98** | 0;0000163 | 0;0444892 | 57;8073703 | -0;0000316 | -0;0511664 | -68;8415727 |

*Maximum and minimum values for Y direction* Table 2

| Fan frequency [Hz] | Wind speed in the tunnel [m/s] | MAXIMUM VALUES | | | MINIMUM VALUES | | |
|---|---|---|---|---|---|---|---|
| | | Displacement [m] | Velocity [m/s] | Acceleration [m/s²] | Displacement [m] | Velocity [m/s] | Acceleration [m/s²] |
| **5 Hz** | **2;85** | 0;0000006 | 0;0011846 | 2;7390749 | -0;0000006 | - 0;0012453 | -2;8583053 |
| **10 Hz** | **5;70** | 0;0000007 | 0;0018657 | 2;5070586 | -0;0000011 | - 0;0017187 | -2;3008231 |
| **15 Hz** | **8;55** | 0;0000068 | 0;0137494 | 20;6171785 | -0;0000026 | - 0;0050310 | -17;9800939 |
| **20 Hz** | **11;40** | 0;0000046 | 0;0069300 | 4;4759714 | -0;0000022 | - 0;0067749 | -3;7276185 |
| **25 Hz** | **14;25** | 0;0000111 | 0;0197927 | 25;7672818 | -0;0000040 | - 0;0102224 | -38;7491483 |
| **30 Hz** | **16;98** | 0;0000135 | 0;0226928 | 32;8785673 | -0;0000048 | - 0;0140194 | -36;7454966 |

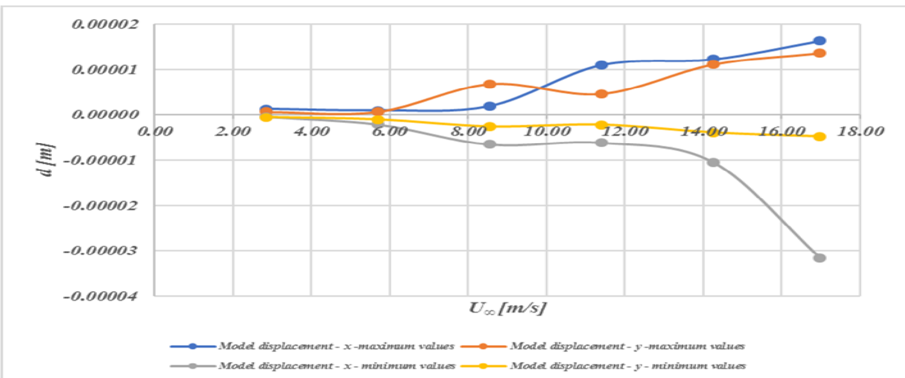


Fig. 10. *Comparison between maximum and minimum values of the model displacements*

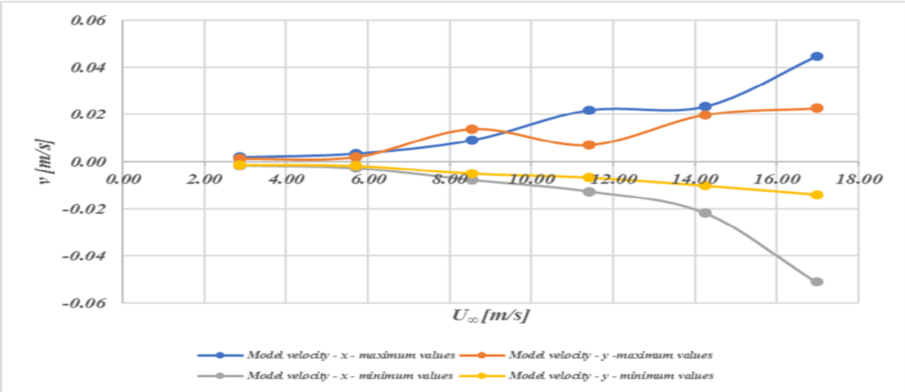


Fig. 11. *Comparison between maximum and minimum values of the model velocities*

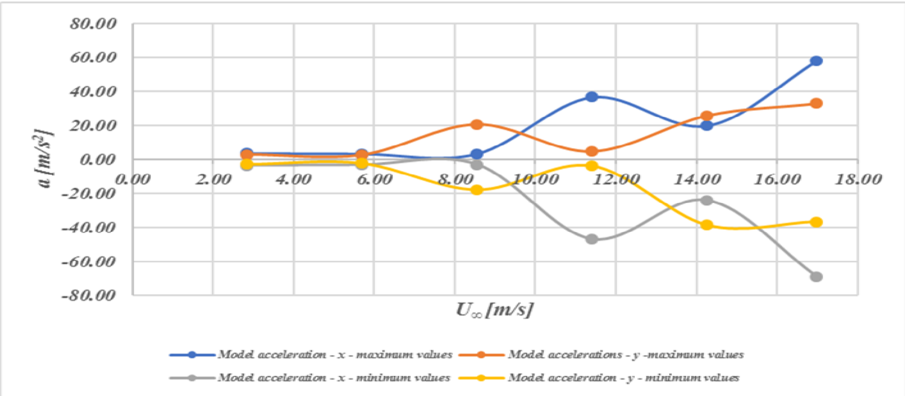


Fig. 12. *Comparison between maximum and minimum values of the model accelerations*

*R.M.S. values for X direction* Table 3

| Fan frequency [Hz] | Wind speed in the tunnel [m/s] | R.M.S. VALUES | | |
|---|---|---|---|---|
| | | Displacement [m] | Velocity [m/s] | Acceleration [m/s$^2$] |
| **5 Hz** | **2;85** | 0;0000005 | 0;0002662 | 0;8291093 |
| **10 Hz** | **5;70** | 0;0000008 | 0;0007217 | 0;7762952 |
| **15 Hz** | **8;55** | 0;0000028 | 0;0023018 | 0;5833708 |
| **20 Hz** | **11;40** | 0;0000019 | 0;0038169 | 3;3302903 |
| **25 Hz** | **14;25** | 0;0000029 | 0;0057584 | 1;3557263 |
| **30 Hz** | **16;98** | 0;0000100 | 0;0160069 | 2;9963380 |

*R.M.S. values for Y direction* Table 4

| Fan frequency [Hz] | Wind speed in the tunnel [m/s] | R.M.S. VALUES | | |
|---|---|---|---|---|
| | | Displacement [m] | Velocity [m/s] | Acceleration [m/s$^2$] |
| **5 Hz** | **2;85** | 0;0000001 | 0;0002626 | 0;6987700 |
| **10 Hz** | **5;70** | 0;0000003 | 0;0004607 | 0;5604440 |
| **15 Hz** | **8;55** | 0;0000007 | 0;0013089 | 1;9514594 |
| **20 Hz** | **11;40** | 0;0000016 | 0;0021393 | 0;7218419 |
| **25 Hz** | **14;25** | 0;0000020 | 0;0031864 | 1;1847920 |
| **30 Hz** | **16;98** | 0;0000032 | 0;0046927 | 1;6720088 |

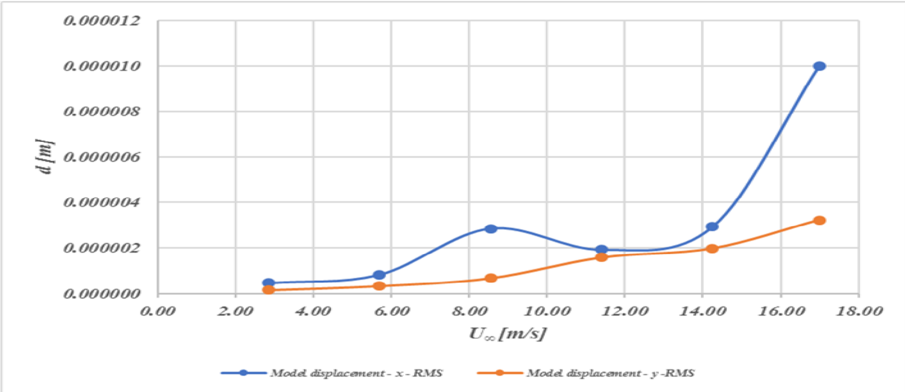


Fig. 13. *Comparison between R.M.S. values of the model displacements*

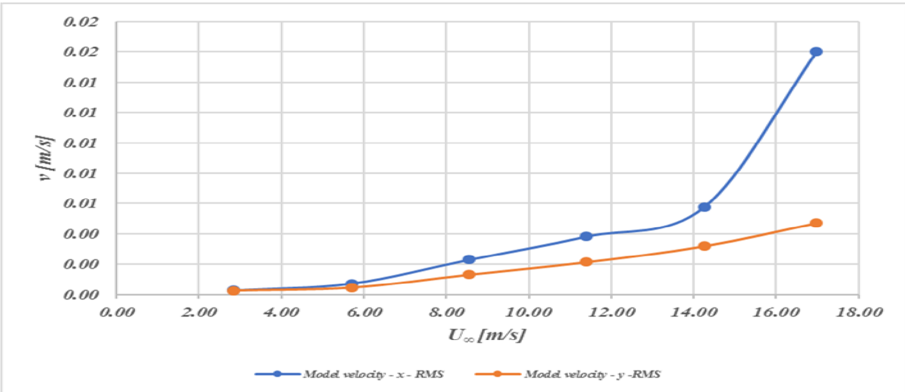


Fig. 14. *Comparison between R.M.S. values of the model velocities*

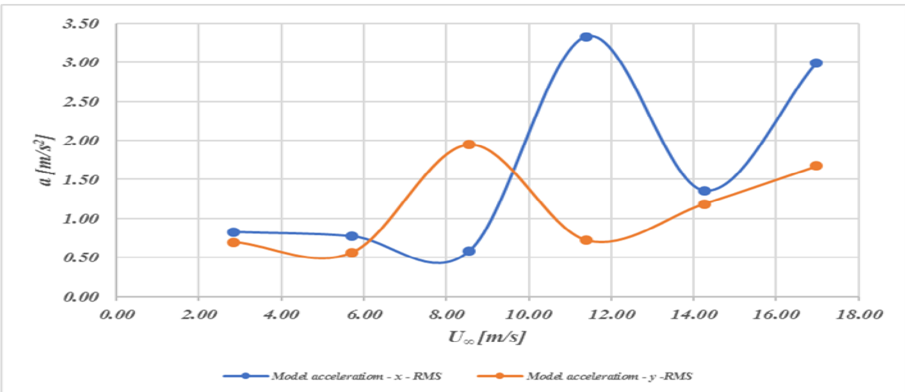


Fig. 15. *Comparison between R.M.S. values of the model accelerations*

*Average values for X direction* Table 5

| Fan frequency [Hz] | Wind speed in the tunnel [m/s] | AVERAGE VALUES | | |
|---|---|---|---|---|
| | | Displacement [m] | Velocity [m/s] | Acceleration [m/s$^2$] |
| **5 Hz** | **2;85** | 0;0000004 | 0;0000832 | 0;0000156 |
| **10 Hz** | **5;70** | -0;0000007 | 0;0000716 | -0;0000873 |
| **15 Hz** | **8;55** | -0;0000026 | 0;0000433 | -0;0003650 |
| **20 Hz** | **11;40** | 0;0000002 | 0;0000007 | 0;0001375 |
| **25 Hz** | **14;25** | 0;0000005 | -0;0000039 | 0;0004564 |
| **30 Hz** | **16;98** | -0;0000060 | 0;0000127 | -0;0003442 |

*Average values for Y direction* Table 6

| Fan frequency [Hz] | Wind speed in the tunnel [m/s] | AVERAGE VALUES | | |
|---|---|---|---|---|
| | | Displacement [m] | Velocity [m/s] | Acceleration [m/s$^2$] |
| **5 Hz** | **2;85** | 0;0000001 | 0;0000396 | 0;0000064 |
| **10 Hz** | **5;70** | -0;0000002 | 0;0000175 | -0;0000229 |
| **15 Hz** | **8;55** | -0;0000001 | -0;0000076 | -0;0000954 |
| **20 Hz** | **11;40** | 0;0000011 | -0;0000145 | 0;0002139 |
| **25 Hz** | **14;25** | 0;0000012 | 0;0000087 | 0;0003620 |
| **30 Hz** | **16;98** | 0;000022 | 0;0000191 | 0;0002299 |

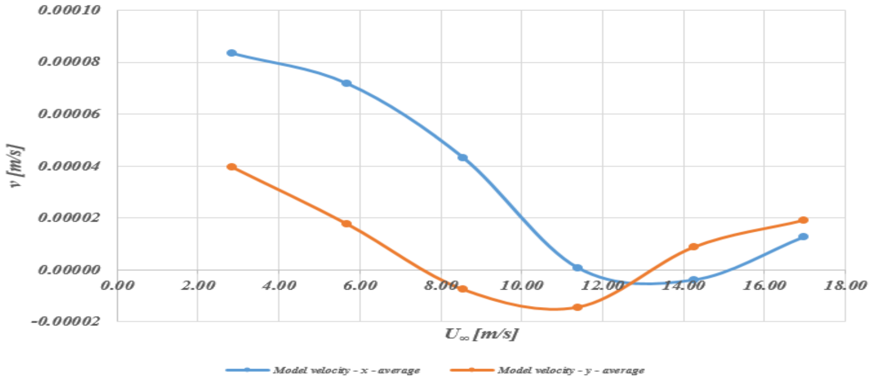


Fig. 16. *Comparison between average values of the model displacements*

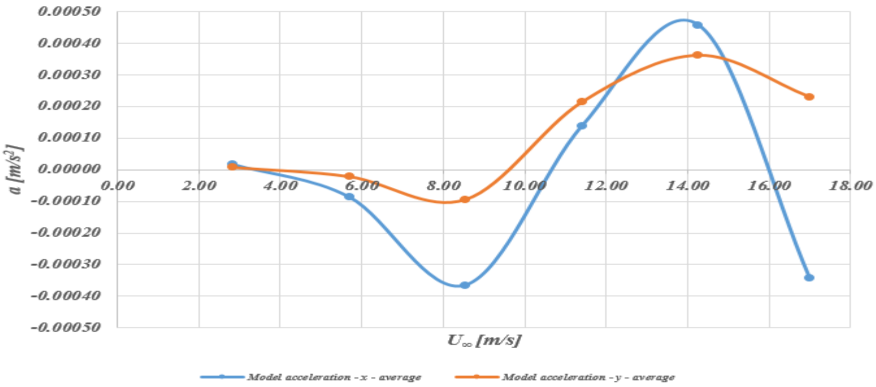


Fig. 17. *Comparison between average values of the model velocities*

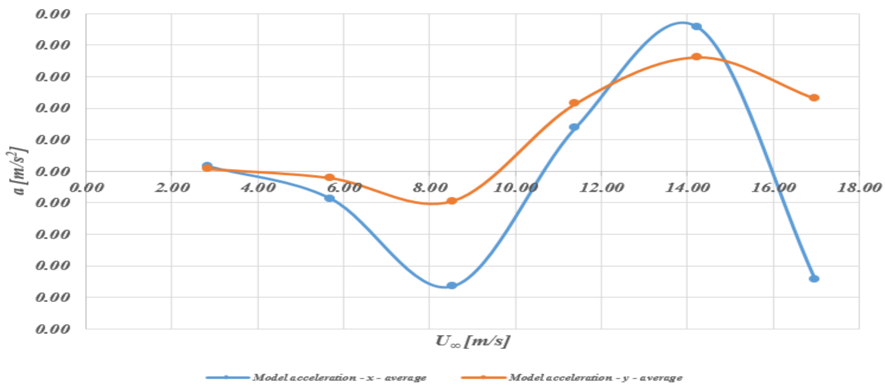


Fig. 18. *Comparison between average values of the model accelerations*

Analysing the presented results it could be emphasize that from all the characteristics of the oscillatory response of the structure of special interest for this study were the dynamic accelerations and displacement, the latter compared to the static displacement corresponding to the same speed of the undisturbed current upstream of the structure.

From the analysis of the graphics, it could be noted that the accelerations increase as the wind speed increases, reaching for a speed of air flow of 16;98 m/s a value of 57;80 m/s for the X direction and 36;75 m/s for the Y direction on the model.

The values of the dynamic displacements compared to the repose position of the tower, are also higher with the increase of the wind speed, reaching at a speed of the wind of 16;98 m/s values equal to 0;016 mm for the X direction and 0;012 mm for Y direction on the model of the television.

As regards the dynamic displacement in relation to the static displacement of the tower, which also increase with in increase of the wind and are reaching values of 0;012 mm on the X direction and 0;011 mm on the Y direction on the model.

The study also revealed low values of the static and dynamic displacement and low values of the accelerations which were experimentally determined for the model. These low values of displacements and accelerations are due to the fact that experimental tests have been carried out in an experimental vein, without turbulence generators, characterized by a low level of turbulence.

Under these conditions, it was not permitted to reach the inertial subdomain, which is characterized by high values of Reynolds number, which would lead to higher results than those experimentally determined.

In addition, the investigations were not conducted at Reynolds numbers corresponding to the separation of alternating vortices with separation frequency equal to the natural frequency of the aeroelastic model, which would lead to important oscillations of the television tower model.

Moreover, given the results previously obtained, it can be said that the conditions of human comfort are satisfied for the maximum wind speed of 16;98 m/s considered in the investigation.

## 5. Conclusions

The main purpose of the paper is to present a framework for the dynamic response prediction of the television tower model under the turbulent wind action simulated in the boundary layer wind tunnel TASL1- M, which is in the Aerodynamics and Wind Engineering Laboratory "Constantin Iamandi" from the Technical University of Civil Engineering of Bucharest.

One of the most important conclusion of the investigation is that for a maximum wind speed of 16;98 m/s the aeroelastic model of the television tower behaves well at the turbulent wind action.

Given the fact that the results achieved from the experiments could not offer so much information as we expected, our future research will focus on achieving better results regarding to the oscillatory behavior of the television tower under the turbulent wind action and we will also have a complete picture of the phenomenon and useful data for the specific design activity.


## Acknowledgements

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