Assessment Of The Structural Safety And The Dynamic Behavior Of The “Monument And Mausoleum To The Paulista Soldier Of 1932”-Obelisk

Marco Antônio Juliani, Liana Becocci
Ieme Brasil Consulting Engineering, São Paulo, Brasil

ABSTRACT: The “Monument and Mausoleum to the Paulista Soldier of 1932” was built in the 1950s to pay tribute to the paulista soldiers’ dead during the Constitutional Revolution of 1932. In this Monument the Obelisk is emphasized because it is the part above the soil, formed by a tower with 72 meters height and a 13 meters square base foundation, totally built in reinforced concrete. Recently, during a monument’s restoration, several doubts about the structural safety of the Obelisk appeared, originated from the settlements resulting from the Ayrton Senna tunnel construction and the vibration due to wind and traffic road in the streets near the Monument. To assess the actual structural safety of the Obelisk, the following theoretical and experimental activities were done: development of a three-dimensional dynamic mathematical model by the Finite Element Method, calibrated from the experimental results, vibration measurements and modal analysis to determine the mechanical dynamic properties of the Obelisk, extraction and rupture of concrete samples, settlements instrumentation measurements during the Ayrton Senna tunnel construction analysis, and checking of the concrete structural sections. These activities allowed the assessment of the structural safety of the Obelisk.

1 INTRODUCTION

After the 1932 Constitutional Revolution, there was an interest in glorifying paulista soldiers killed during the conflict that set a mark in the history of São Paulo, and then a special commission was formed to study what should be done.

Mario Pucci engineer at São Paulo City Hall, along with sculptor Galileo Emendabili were responsible for the monument that today can be appreciated: the Obelisk and the Ibirapuera Crypt, Fig. 1.

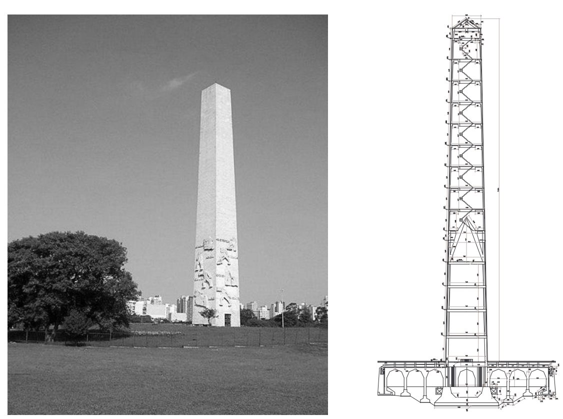


Figure 1: Obelisk

The Obelisk is formed by a tower with 72 meters height and a 13 meters square base foundation, totally built in reinforced concrete.

Although it is a traditional way as the ancient Egypt or the modern Washington, the authors introduced on the side of the building elements in high relief capable of identifying the monument for the purpose of highlighting the constitutional revolution.

2 DYNAMIC TESTS ON STRUCTURES

Structure excitation was achieved by the wind and the traffic in the streets near the Monument.

The accelerometers used for measurement were of the piezoresistive type, whose features are presented on Table 1:.

Table 1: Monitoring accelerometers features

Manufacturer:	ENDEVCO
Accelerometer model:	2262-25
Natural Frequency:	2500 Hz
Frequency field:	0-650 Hz
Sensitiveness:	20 mV/g
Static acceleration limit:	250 g
Sinusoidal acceleration limit:	250 g
Weight:	2,4 N

For data acquisition, Iotech amplifiers and filters, model DBK43A, Daq Board 2000 schedule and Daq View 7.9.3 software were used. Data analysis was done by using Math Soft Mathcad 8 Professional Software calculation routines.

Nine tests of 10 minutes were performed, some of them with replicates. Excitation and accelerometers locations are shown in Fig. 2.

The summary of the tests characteristics is shown on Table 2 and the highest accelerations and velocities are presented on Table 3.

Table 2: Tests and accelerometers locations

Configuration	Tests	Accelerometers locations							
1	1-1	A1X	A1Y	B1X	B1Y	B2Y	B3X	C1X	C1Y
2	2-1 2-2	A1X	A1Y	D1X	D1Y	D2Y	D3X	C2Y	C3X
3	3-1 3-2	A1X	A1Y	E1X	E1Y	E2Y	D3X	—	—
4	4-1 4-2	A1X	A1Y	F1Y	F1Z	F2Z	F3Z	—	—
5	5-1 5-2	A1X	A1Y	B3X	C1X	C2Y	F4Y	—	—
6	6-1 6-2	A1X	A1Y	D3X	E3X	F1X	F4Z	—	—

Table 3: Maximum accelerations obtained

Accelerometers positions	Acceleration (mm/s^2)	Velocities (mm/s)
A1Y	14	1,78
A1X	15	1,91
F1Y	7	0,89
F3Z	9	1,15

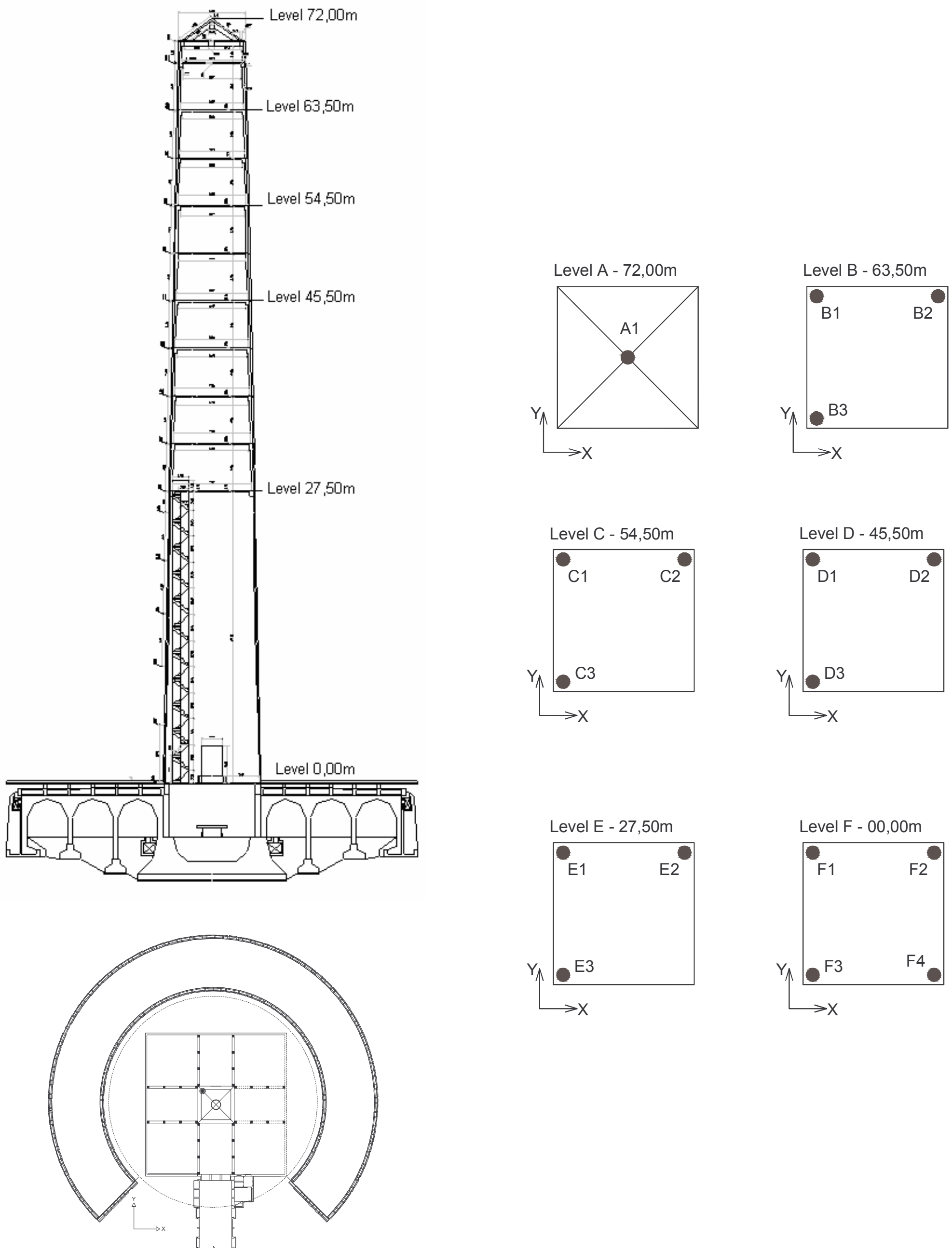


Figure 2: Accelerometers

Maximum velocities were 1,91mm/s. Such values are below the limit of 40 mm/s, recommended for structural safety, according to DIN 4150 (1986).

A modal analysis was carried out based on data in the frequency domain generated from acceleration and Fourier transform results.

The presence of peaks in graphs such as the shown in Fig. 3 corresponds to amplifications of excitation spectrum or natural frequencies.

Obtained natural frequencies are presented in Table 4.

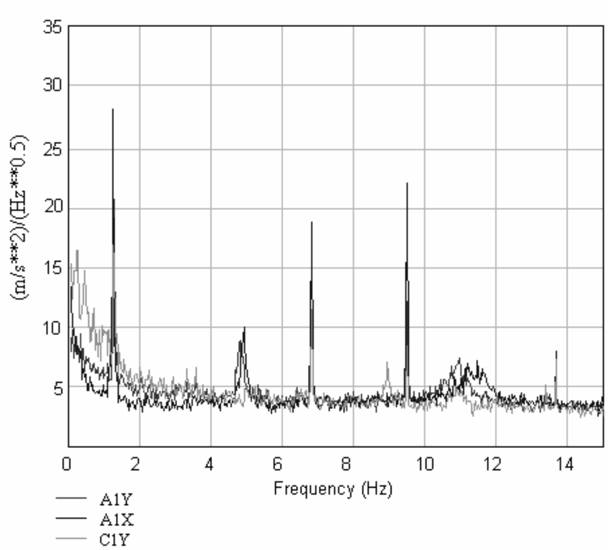


Figure 3: Obtained spectrum

Table 4: Summary of natural frequencies

Mode	Natural frequency (Hz)
Mode1	1,25
Mode2	4,8
Mode3	6,8
Mode 4	9,5
Mode 5	11,0
Mode 6	13,7

3 MATHEMATICAL MODELS

Two mathematical models were done. The first one was a plane model to evaluate the influence of the construction of Ayrton Senna tunnel in the Obelisk structure (Fig. 4) and the second was a tridimensional model, formed by frame and shell elements, to evaluate the dynamic behaviour and the structural safety of Obelisk (Fig. 5).

The plane model was done in ANSYS and the tridimensional model was done in SAP 2000.

Table 5 presents the adopted physical and mechanical properties for the models. The concrete properties were found by extraction and rupture of concrete samples. In tridimensional model the foundation was simulated by vertical springs with stiffness coefficient: $k_v = 5 \times 10^7$ N/m^3.

Table 5: Concrete and soil physical and mechanical properties adopted for model calibration

	E (MPa)	ν	ρ (kg/m3)
Soil (plane model)	100	0,20	2000
Concrete (plane and tridimensional)	31300	0,20	2400

E: Elasticity Modulus
ν: Poisson's ratio
ρ: specific mass

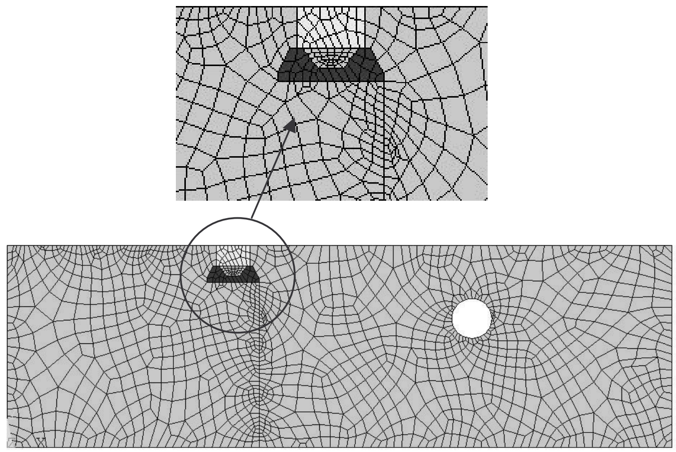


Figure 4: Plane mathematical model

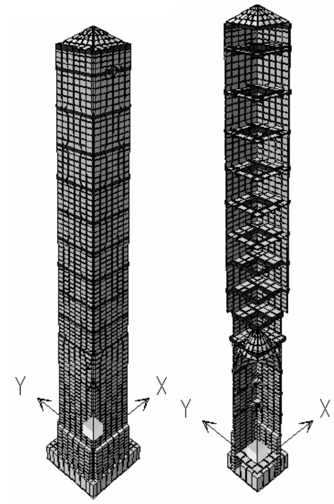


Figure 5: Tridimensional mathematical model

4 THEORETICAL ANALYSIS

4.1 Plane Model

For the plane model two cases were made.

The first processing determined the reaction in the mass of soil, on the charge of Obelisk. This processing defines the relief stress to be applied in the section of the tunnel, to simulate the excavation.

In the second processing the relief stresses were applied with the excavated section of the tunnel. The relief stresses were obtained using elements nodes “coupling”.

The loads considered were: the weight of soil and loads in the foundation of the monument.

In the base foundation, the differential settlement observed after the excavation of the tunnel (variation of displacement) was equal to 0,2mm. These deformations are not sufficient to cause any damage to either structure.

On the surface above the tunnel, there was a settlement compatible with the values obtained by the instrumentation during the construction, proving the reality of the model, Table 6.

Table 6: Experimental e theoretical settlements

Instruments	Exper. settlements (mm)	Plane model settlements (mm)
M1012-C	11,0	9,8
M1012-D	11,8	11,4
M1012-E	11,3	9,8

4.2 Tridimensional Model

A comparison between the natural frequencies obtained with mathematical models and with experimental analysis results is shown in Table 7. The vibration modes are shown in Fig. 6.

From the calibrated model the loads were applied and the stresses were determined in the structure of Obelisk.

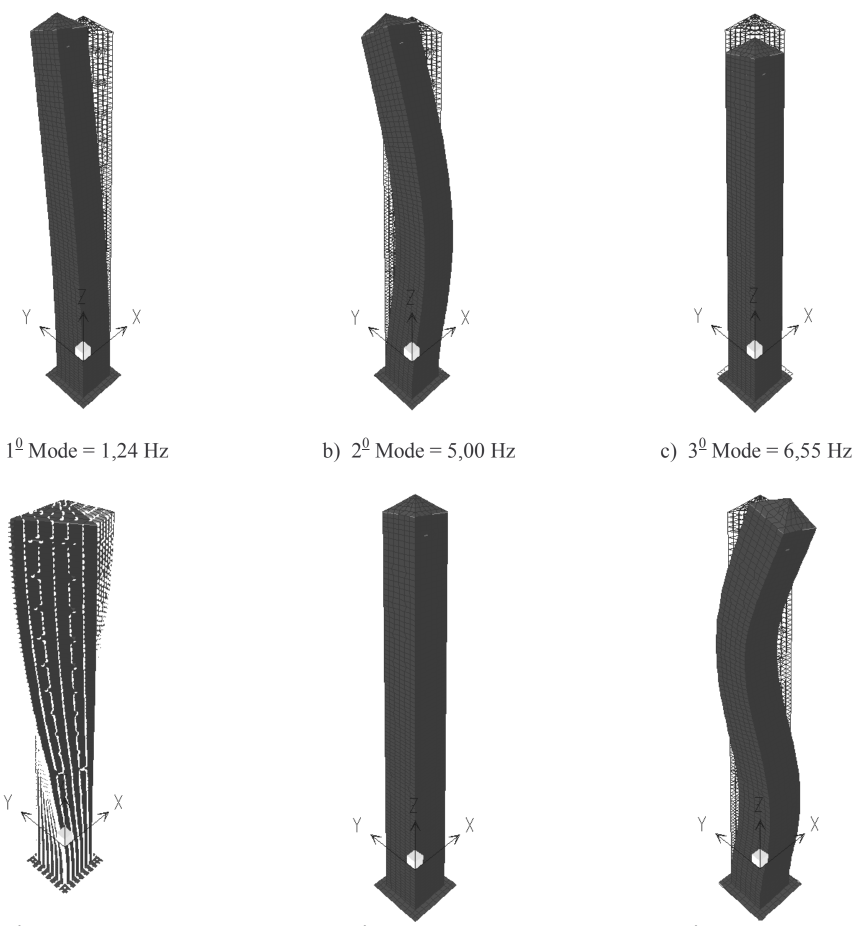
The loads were considered as follows: the actual weight of the structure, wall coatings and the wind pressure.

An equally distributed surcharge of 1200N/m^2 was applied on the surface of the walls in vertical direction, as seen in the original project. The effect of the coating plates was simulated by putting up the equivalent nodal masses along the walls of the structure.

Table 8 shows the values of the masses for the different levels together with the wind pressure.

Table 7: Natural frequencies obtained from both modal theoretical and experimental analyses

Mode	Experimental Frequency (Hz)	Theoretical Frequency (Hz)
Mode1	1,25	1,24
Mode2	4,8	5,00
Mode3	6,8	6,55
Mode 4	-	7,78
Mode 5	9,5	8,95
Mode 6	11,0	11,33



a) 1º Mode = 1,24 Hz b) 2º Mode = 5,00 Hz c) 3º Mode = 6,55 Hz

d) 4º Mode = 7,78 Hz e) 4º Mode = 8,95 Hz f) 4º Mode = 11,33 Hz

Figure 6: Vibration modes

Table 8: Masses (Kg) and wind pressure

Level	Masses (Kg)	Wind pressure (N/m^2)
70,00	3005,75	506,35
67,75	1440,00	630,69
63,25	3337,25	724,38
58,75	3445,25	799,74
54,25	3465,00	863,80
49,75	3572,50	886,55
45,25	3682,75	935,26
40,75	3790,75	979,67
36,25	3898,75	1020,63
31,75	4039,25	1058,74
27,25	4114,75	1094,46
25,3	4244,50	1128,14
20,3	4740,00	1160,05
15,3	4860,00	1190,40
10,3	5040,00	1219,39
5,5	5160,00	1233,41
0	5220,00	1245,63

The following combinations of loading were examined:
- Combination 1: structure weight + coating;
- Combination 2: structure weight + coating + wind (global directional –X).

The maximum stresses specified in Table 9 were obtained while analyzing the stresses in the structure.

The compressive stresses are smaller than the maximum allowable concrete strength (f_{ck} = 24 MPa).

The tension stresses obtained are also low and they are absorbed by the existing reinforcement, although the concrete itself resists to the tension stresses of such intensity.

Table 9: Maximum stresses (N/m2)

Structure	Maximum compression stress (N/m^2)	Maximum tension stress (N/m^2)
Walls	2,28 x 10^6	1,14 x 10^6
Slabs	1,00 x 10^6	2,00 x 10^6
Foundation slabs	0,15 x 10^6	0,14 x 10^6

5 CONCLUSIONS

Based on the results obtained we may conclude that the structure of Obelisk presents appropriate behaviour regarding structural safety, the current strength of the concrete being compatible with the stresses and the safety coefficients of the technical Brazilian standard, ABNT.

Maximum velocity values were bellow 40 mm/s, which is recommended by DIN 4150 (1986) for structural safety.

Regarding the Ayrton Senna tunnel, we found that its influence on the differential settlements of the foundation of the structure is considered negligible.

REFERENCES

Bachmann, H. et al. 1995. *Vibration problems in structures:* Practical guidelines. Birckhäuser. Berlin.
COMITÉ EURO-INTERNATIONAL DU BÉTON. 1991. Bulletin d' Information no. 209: Vibration problems in structures: Practical guidelines.
DIN 4150 1986. part 3. Structural Vibration in Buildings - Effects on structures.