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ANALYTICAL DETERMINATION OF SEISMIC STABILITY OF PALASPORT-BOLOGNA

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ABSTRACT

The seismic stability of the Sport Hall (Palasport) in Bologna is investigated by analytical modeling based on experimental data. The mathematical model is considered as a 3D model with 203 nodes and 554 elements and concentrated masses at each node. SAP90 computer program has been used to perform the linear dynamic analysis. In the first part of the paper, some design aspects of the structural system are presented. In the second part, summary of the experimental results related to the dynamic properties of the is presented. Comparison between the experimental and analytical results related to the dynamic properties of the analytical model and actual structure has been performed. The prediction on the seismic behavior of the structure subjected to the considered ground motion are given at the end of the paper.

KEYWORDS

PlalaSport, full scale testing, mathematical modeling, seismic excitation, seismic stability

DESCRIPTION OF STRUCTURAL SYSTEM

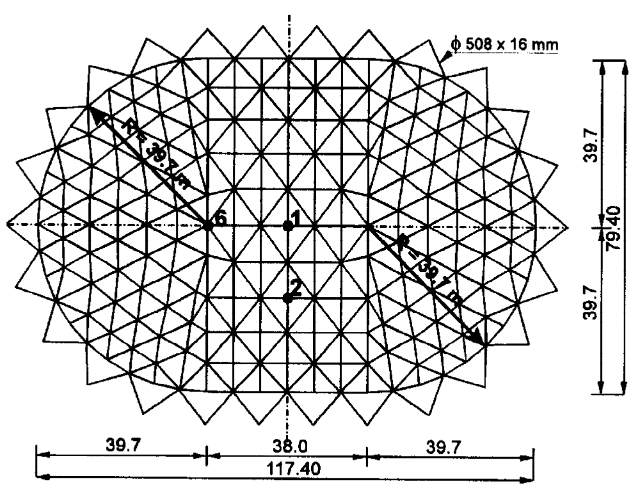

Fig. 1. Disposition of Palasport - Bologna

The Palasport in Bologna - Italy, is a special structure, almost elliptical in plan, with dimensions of the median axes of 80/120 m. The roof structure has been constructed of lamellar wooden beams linked by steel joints, forming one cylindrical and two half spherical parts. The lower part of this structure consists of 52 reinforced concrete columns, out of which 26 are supported by two steel braces from the external side of the structure. The connections between the wooden beams are made of steel rings (internal joints), while the external, joints between the columns and beams, of vertical steel plates and half rings. The plan of the Bologna Palasport is shown in Fig 1.

EXPERIMENTAL RESULTS

Experimental results from full scale testing

In order to define the dynamic properties of the structure, two different in situ testing methods have been applied: forced and ambient vibration methods.

The ambient vibration test was performed for preliminary checking of the resonant frequencies of the structural system in two orthogonal horizontal directions and vertical direction, respectively, within the frequency range of 0-30 Hz. The equipment consisted of two Ranger seismometers, model SS-1, Kinemetrics production , USA, Signal conditioner, type SC-1, Frequency analyzer, model 3582A, Hellwet Packard production - USA. The seismometers were placed on the top of the cover structure at points 1, 2 and 6, as shown in Fig. 1. The time history records have been transformed in frequency domain using a two-channel frequency analyzer for obtaining Fourier amplitude spectra. The peak values of the spectra correspond to the resonant frequencies of the tested structure.

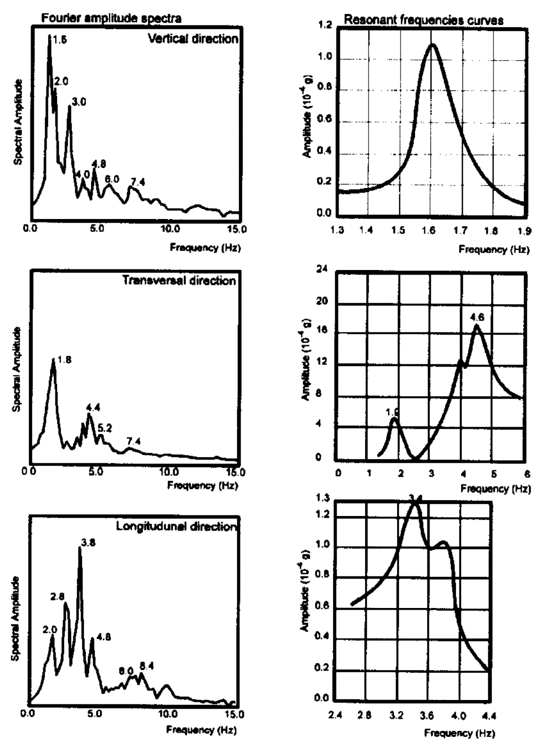

Fig. 2. Fourier Amplitude spectra and frequency response curves - full scale testing

The forced vibration test was performed for more precise definition of the resonant frequencies (preliminary defined by ambient vibration method) as well as for definition of horizontal and vertical mode shapes. In this case, a small electrodynamic actuator, type 113 electro-seis shaker- USA, placed on the top of the structure, was used for the excitation of a harmonic force of 150 N within the frequency range of 0- 30 Hz. . After definition of the resonant frequencies, the mode shapes were defined by recording the response at several points along the longitudinal and transversal profiles, as shown in Fig. 1. The Fourier amplitude spectra obtained from the ambient vibration test as well as the resonant frequency curves obtained from the forced vibration test are presented in Fig. 2.

ANALYTICAL MODELING

The mathematical model is considered as a 3D model with 203 nodes and 554 elements- rectangular beams as shown in Fig. 3.

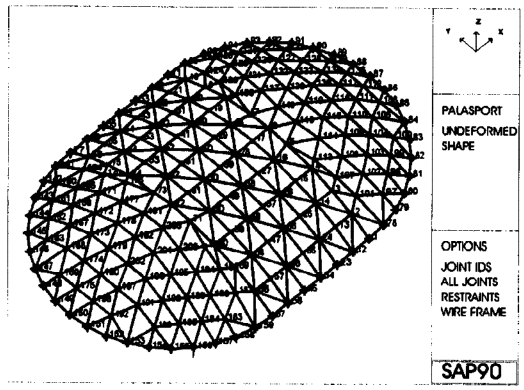

Fig. 3. Mathematical model of the structure

The model is simplified considering the following assumptions:

- Only the primary truss system is considered. The secondary and tertiary systems are neglected
- The lower part of the structure is not included in the model. It is assumed as ideally stiff, with fixed end boundary conditions
- Each node has six degree of freedom
- The masses are concentrated at the nodes

Analytical results

The mathematical model was estimated in respect to the available experimental data and verified using SAP90 computer program. Namely, the mathematical model related to the existing structure, was verified by comparison of the first two resonant frequencies and mode shapes (Table 2, Fig. 4). Spatial presentation of the characteristic mode shapes of the analytical model of the existing structure is given in Fig. 5.

Table 2 Fundamental frequencies of the structure - experimental and analytical

		Fundamental frequencies (Hz)	
		Asymmetrical mode	Symmetrical mode
Prototype	experimental	1.65	1.90
	analytical	1.75	1.94

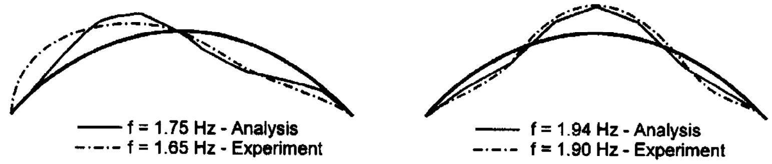

Fig 4. Mode shapes of the model determined analytically and experimentally

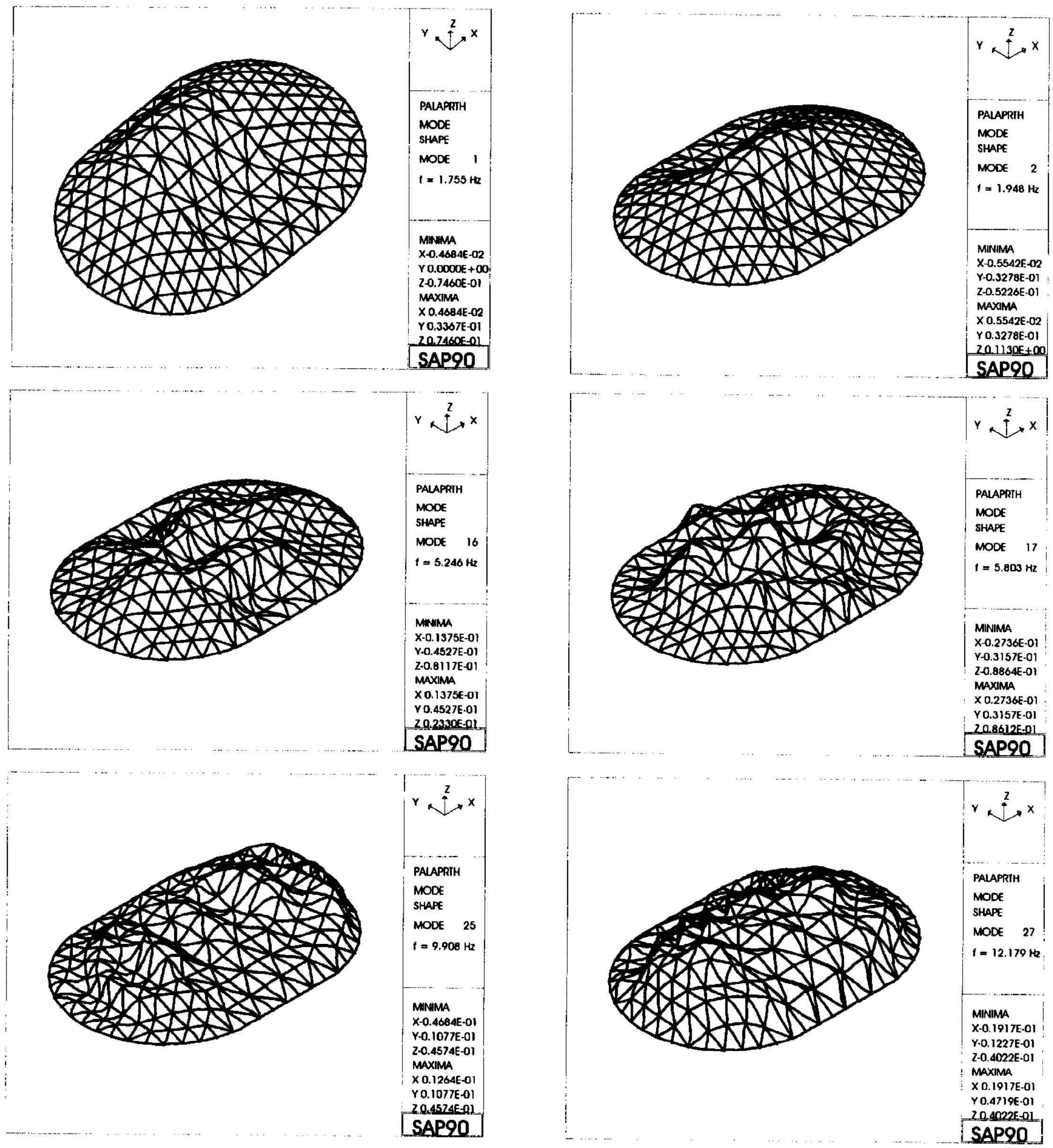

Fig. 5. Spatial presentation of characteristic mode shapes of the analytical model

PREDICTION OF THE SEISMIC RESPONSE

The verification of the reliability of the considered simple mathematical model has been discussed in the previous chapter. It was concluded that this model could satisfactorily represent the actual behavior of the existing structure.

Based on the previous experimental and analytical results, it was found out that the cylindrical part of the roof structure is more flexible than the spherical ones.. Consequently, considering the frequency content of the earthquakes as well as the resonant frequencies of the structure, it is expected that the structure will be excited in the first several modes, which correspond to the vibration modes of the cylinder.

The seismicity of the site, at which the existing structure is located, is not a subject of the investigation in this paper. As an example, it is considered that the expected peak ground acceleration is 0.15g. Considering the Ancona record as representative for the site (Fig. 6), the seismic response of the Sports Palace, in vertical direction, was predicted.. It was found out that the most intensive response is recorded at nodes 17,39,41 and 50, which are located on the cylindrical part of the roof (Fig. 3). The acceleration time history and the Response spectrum at node 39 are presented in Fig. 7. The amplification factors of the response, at the specified points ranges between 1 and 3.3 in respect to the peak ground motion. The tabular presentation of the points in which the acceleration response is most intensive, is given in Table 3.

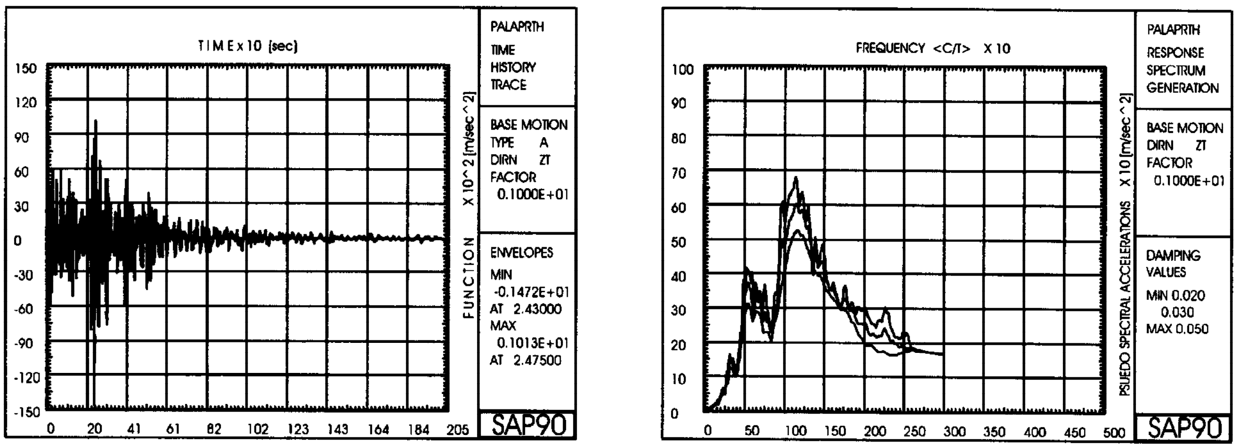

Fig. 6. Acceleration time history and response spectrum of Ancona earthquake - vertical direction

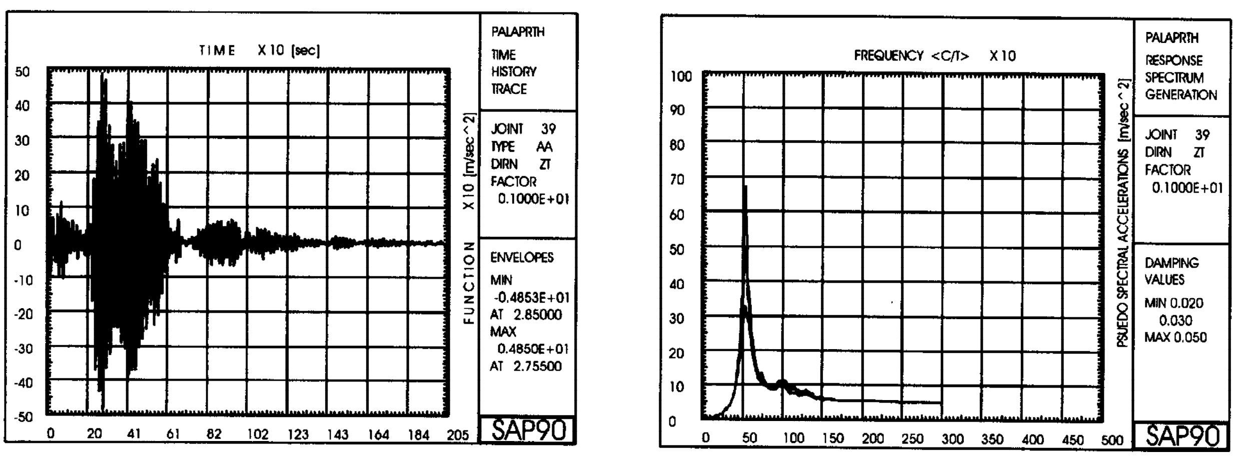

Fig. 7. Earthquake response in vertical direction - Acc. time history and response spectrum at node 39

In order to investigate the distribution of the vertical displacements, produced by the expected earthquake, the displacement time histories have been analyzed at different nodes of the cylinder and the spherical parts. The dynamic displacement time history at node 39 is presented in Fig. 8. The peak values have been compared with the static displacements (Table 4). It was found out that the cylindrical part is deflecting more than the spherical parts (both in static and dynamic case). The maximum displacement is obtained in the central part of the cylinder (node 39). The ratio between the dynamic and the static displacement ranges between 7 and 78 %.

Table 3 Acceleration response of the structure in vertical direction - Ancona earthquake

Node	Acceleration (m/sec^2)		Amplification factor
	Input	Response	
17	1.5	4.76	3.24
39	1.5	4.58	3.30
40	1.5	1.22	0.83
41	1.5	1.57	1.07
42	1.5	3.19	2.17
43	1.5	4.02	2.73
50	1.5	4.49	3.05
61	1.5	4.76	3.24
72	1.5	3.62	2.46
182	1.5	3.53	2.40

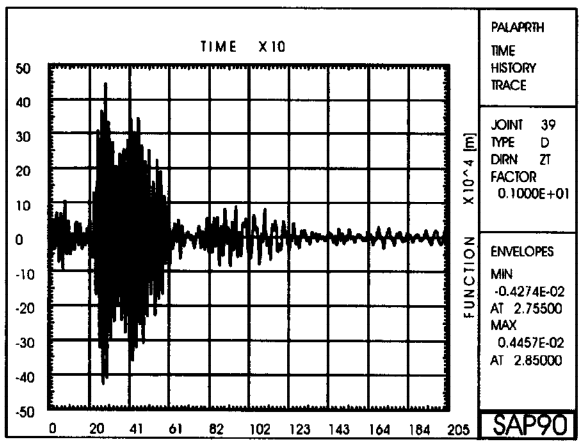

Fig. 8. Dynamic response of the structure - Displacement time history node 39 in vertical direction

Table 4 Comparison between static and dynamic displacement of the structure

Node	Vertical displacement (mm)		Dyn/ Stat (%)
	Static self weight	Dynamic Ancona - 0.15g	
29	21.2	1.50	7.1
39	25.2	4.50	17.9
40	21.1	1.30	16.2
41	13.5	1.90	14.1
42	3.6	2.80	77.8
43	0.01	3.60	/
50	23.2	4.10	17.7
61	21.0	4.40	21.0
72	15.3	3.30	21.6
182	10.4	3.10	29.8

Finally, the force distribution has been investigated in the similar manner. It was found out that larger forces are distributed to the cylinder (Fig. 9) The comparison between the static and the dynamic forces in the most loaded elements is given on Table 5. The highest forces are produced at the contact between the cylinder and the spherical parts (elements 65,66 and 101,102) and at the central arch of the cylinder (elements 38,39). The dynamic/static force ratios ranges between 17 and 37 %.

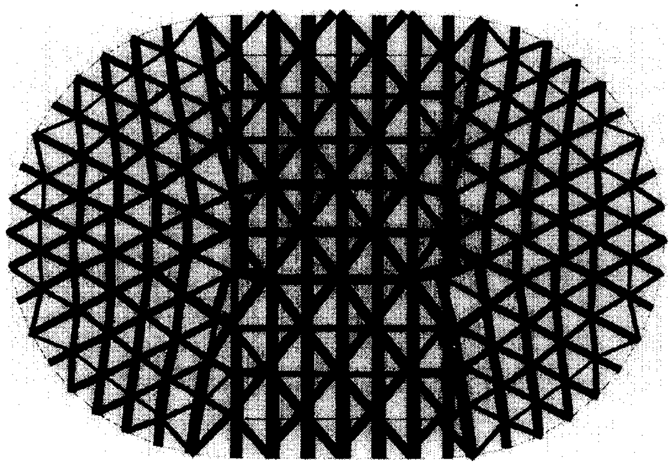

Fig. 9. Static force distribution

Table 5 Comparison between static and dynamic forces of the structure

Node	Axial force (kN) Static self weight	Axial force (kN) Dynamic Ancona - 0.15g	Dyn/ Stat (%)
31	329.3	65.0	19.7
32	304.7	65.8	22.4
33	268.5	48.6	18.1
34	256.1	48.5	18.9
35	250.4	43.8	17.4
65	376.5	86.0	22.8
101	194.6	69.9	35.9
102	194.6	71.9	37.0
103	223.6	70.5	31.5
107	256.0	78.3	30.6
108	222.2	65.2	29.3
109	222.2	66.1	29.9

CONCLUSIONS

The analytical modeling of the structural systems is very important and useful approach for the investigation of the structural behavior under static and dynamic conditions. SAP90 computer programme offers a variety of possibilities for 3D linear analysis, considering different loading and boundary conditions. The graphic options make the analysis very illustrative and easy understandable. However, the lack of experimental data makes the physical interpretation of the analysis difficult, especially in case when some input data errors have been introduced. The correlation between the analytical model and existing structure shows that prediction of the earthquake response of the structure can be considered as realistical one.

The above mentioned facts give the opportunity to predict the seismic behaviour of PalaSport in Bologna summarized as follow:

- Considering the expected earthquakes, the roof structure will vibrate most intensively in vertical and lateral direction mainly in fundamental symmetric and anti - symmetric mode.

- Cylindrical part of the roof will be more excited than the spherical one.

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