OPERATIONAL MODAL ANALYSIS OF SPORT ARENA STAND STRUCTURE

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ABSTRACT

This paper presents the results of theoretical and experimental investigations of reinforced ice arena stand structure by means of operational modal analysis. As a part of experimental study acceleration measurements of stand structure vibrations caused by natural oscillations were made. While measuring the reference point acceleration of the stand structure triaxial accelerometers were used. As a result of this study two first forms of acceleration with corresponding frequencies were identified by means of the program ARTeMIS Extractor. The natural frequencies identification of a stand section along one of the axis of the structure was made using SSI method.

Theoretical researches were carried out using finite elements method by means of ANSYS 11 program. In order to calculate dynamic properties of the stand the behavior of beams along with stand details was investigated.

When estimating the response behavior of the stand structure towards natural vibration it was found that the initial natural frequency of vertical oscillations is higher than 6 Hz, that does not restrict usage of the constructions mentioned for different purposes according to frequency response criterion.

Keywords: Operational, Modal, Analysis

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1. Construction design

Dimensions of ice arena construction in plan view are the following: 148,2x88,2m (Fig. 1 a,b). The top point of the roof is +19,35m. The building frame consists of reinforced concrete columns pin-supported by metal trusses with the width of span from 31 to 78 mm as well as reinforced concrete beams of the area underneath the grandstand, cast-in-place or precast floor slabs. Frame stiffness is provided by vertical bracing of columns, by stiffening diaphragms, by vertical and lateral bracing of roof truss and bracing beams.

(a)

(b)

Fig. 1. General view of the arena (a) and metal frame of the roof (b)

The grandstand of arena is made as a slab –frame structure, consisting of reinforced concrete columns, beams, grandstand parts and floor slabs. Spans between arena grandstand beams range from 5,5m to 12m, whereas spans between grandstand parts range from 1m to 12 m.

2. Methods

While conducting researches dynamic performance requirements for permanent grandstands subject to crowd action [1] were used. According to the requirements mentioned above high dynamic loads can occur in case of pop-concerts, when a crowd of people moves rhythmically (jumping, beating out) in time to music. Besides this, a crowd can move rhythmically while jumping, wagging in time to the music or applauding during different sport events. Such movements as sudden jumping up and sit down can cause dynamic loads. Thus while running invents crowd of people can impose vertical and lateral dynamic loads to the structure.

The grand stand of arena can be affected by vertical load induced by a crowd, causing dynamic loads within the following natural frequency range:

- 1,5-3,5 Hz for small crowd of people;
- 1,5-2,8 Hz for bigger crowd of people.

Horizontal loads induced by crowd range from 0,7 to 0,9 Hz.

According to requirements [1], a construction provides a safe and comfortable environment for visitors/spectators in such case, when the lowest vertical natural frequency is not less than 3,5 Hz for sport events and 6 Hz for all kind of invents. A minimum natural frequency for horizontal excitation is 3 Hz.

In order to compare the relevant natural frequencies of arena grandstand with rated values a natural frequency identification method were developed.

This method consists of 3 steps:

1. Initial analysis
2. Field work
3. Data processing.

This method includes the search of the most effective methods of dynamic properties identification namely identification of natural frequencies, mode shapes and damping ration.

In order to evaluate the acceleration of vibrations affecting the arena grandstand three-component accelerometers were mounted on the roof surface and were fixed by means of two-part adhesive “Cold Weld”. Monitoring of measurement points was carried out within 30 min for each measurement.

The areas with higher accelerations of natural frequencies were selected to conduct a study. The data selected were used for natural frequencies identification and for modal analysis by means of SSI method [3]. It is author’s belief that only one accelerometer mounted in the middle of load beam span can be used to identify natural frequencies of an arena construction element (reinforced concrete load beam).

For natural frequencies identification it is necessary to identify mode shapes, obtained by means of modal analysis. However modal analysis is a labor-intensive and time-consuming procedure because it needs to establish a network of sensors on the arena grandstand. In case the amount of sensors is less than the amount of network nodes, the modal analysis should be conducted by means of several measurement sessions for each structure. In this case some of reference sensors are staying fixed during all sessions, whereas other some have to be moved along the structure. This fact reduces the testing time for each particular structure. As far as the structure of arena grandstand consists of some reinforced assembled typical elements, it is reasonable to conduct modal analysis for few of the typical elements of arena grandstand, which should include reinforced beam and roof (Fig.2). Dynamical properties of typical elements will be very similar.

In this paper the modal analysis is carried out for only one element of the grandstand, which has the widest beam and roof spans. For all other similar elements of the grandstand the natural frequencies were identified. The natural frequencies obtained were compared to allowable value.

Below is given an example of usage of this method for one of typical elements.

3. Modal analysis of an arena grandstand element

Modal analysis for an arena grandstand element, shown on the Fig 2 with extra bold pick line, was conducted by means of finite element analysis. This element is characterized by widest span between grandstand elements.

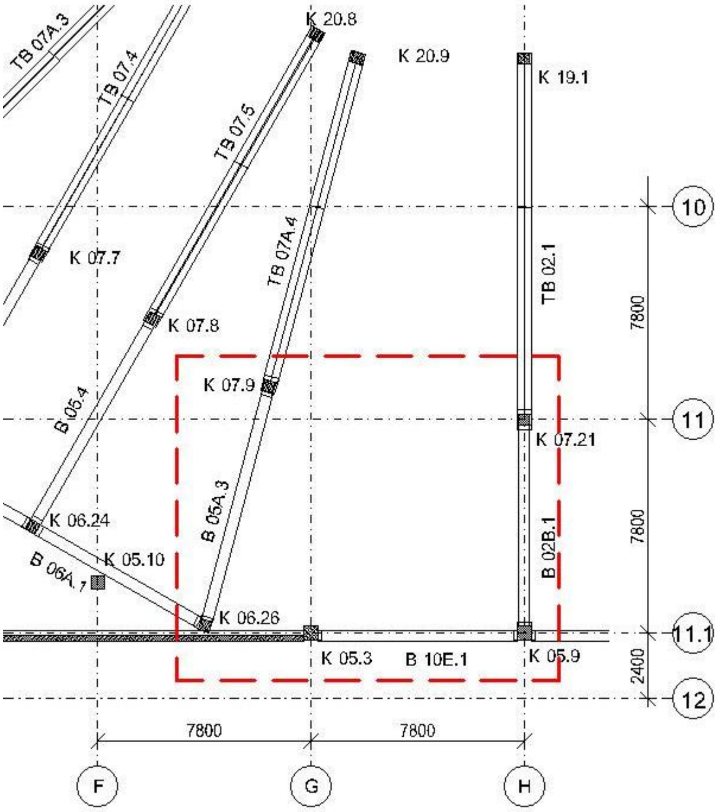

Fig. 2. Grandstand elements in axis 11-11.1_G-H

Calculation was carried out by means of ANSYS 11.0 Workbrench [2].In order to calculate dynamical properties of arena grandstand the behavior of beams along with roof elements were studied. Columns and floor slabs were not taken into consideration.

According to engineering specification the following materials for beams and grandstand elements were used (specification for reinforcement is not given here, because reinforcement was not estimated in this model as a separate structural element):

- Concrete type B30 for grandstand beams and elements: initial elasticity modulus $E_b = 32{,}5$ GPa, Poisson ratio 0,18, specific gravity 7850 кг/м^3.
- Steel for reinforcement and for embedded parts with an elasticity modulus $E_b = 206$ GPa, Poisson ratio 0,3, specific gravity 2500 kg/m3.

The model created by means of ANSYS contains the following types of finite elements: SOLID186, CONTA174, TARGE170. To model grandstand elements, beams and embedded parts a finite element named SOLID186 was used. CONTA174 and TARGE170 were applied to model contacts between structural elements.

As a result the two natural frequencies of 9,3 Hz and 16,2 Hz were obtained. Mode shapes obtained from experiments are shown on the Fig. 3, 4.

4. Experimental modal analysis of arena grandstand element

The arena grandstand element (Fig. 2) was investigated by means of modal analysis through FDD and SSI methods using ARTeMIS Extractor [3].

4 accelerometers (one accelerometer used was a three-component accelerometer and three of them were single-component accelerometers) were applied in this experiment. During the experiment the three-component accelerometer was used as a main one and was not moved to other measuring points. Single-component accelerometers were moved to different measuring points. Four sessions of measurements for grandstand element were carried out in total. To merge data of different measurement sessions the procedure given in paper [4] was used.

As a result two initial oscillation forms with corresponding frequencies were identified by means of ARTeMIS Extractor.

It is common practice to state the level of similarity of two mode shapes by means of modal assurance criterion [5], which is calculated by formula:

$$MAC = \frac{\left|\{\varphi_A\}^T\{\varphi_B\}\right|^2}{(\{\varphi_A\}^T\{\varphi_A\})(\{\varphi_B\}^T\{\varphi_B\})},$$

where $\{\varphi_A\}$ and $\{\varphi_B\}$ -natural mode vector.

Table 1 presents MAC criteria matrix, obtained through comparing of natural modes identified by means of FDD and SSI methods. Frequencies are presented in accordance with the applied method and modes; at the intersection of columns und rows the rate of MAC criterion is given.

Table 1 MAC criteria matrix

	SSI 10,04 Hz	SSI 15,51 Hz
FDD 9,766 Hz	0,9862	0,03099
FDD 15,38 Hz	0,04245	0,8209

As it is seen from the table 1 the mode shapes obtained by means of different methods are very similar. In Fig.3, 4 are shown first and second mode shapes, obtained in the experiment and by means of finite element model.

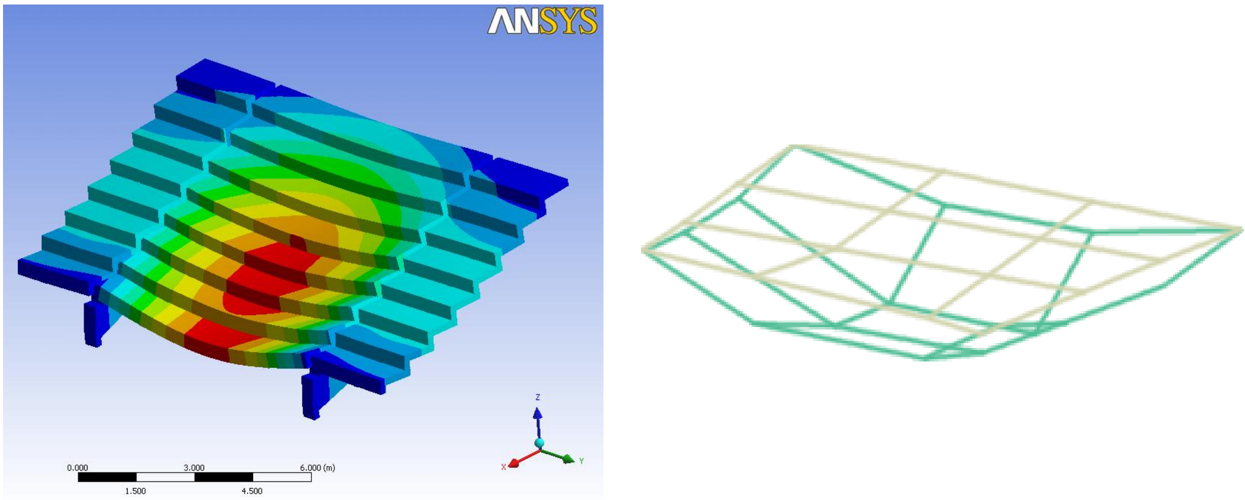

Fig. 3. First mode shape at the frequency of 10,04 Hz

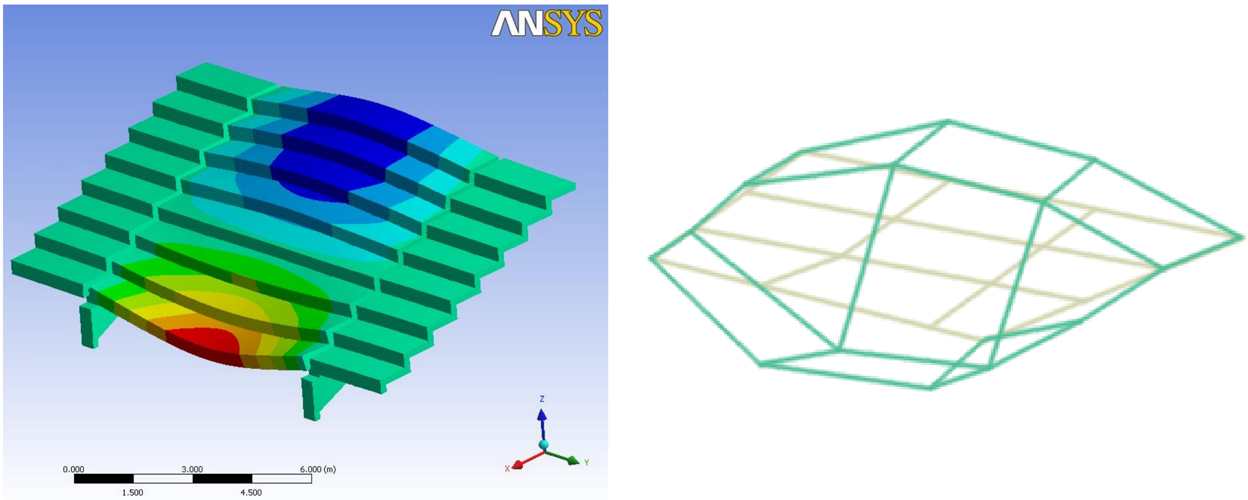

Fig. 4.Second node shape at the frequency of 15,51 Hz

5. Identification of natural frequency

Natural frequency identification of grandstand element was made by means of SSI method [3]. The frequency spectrum obtained is shown in the Fig.5.

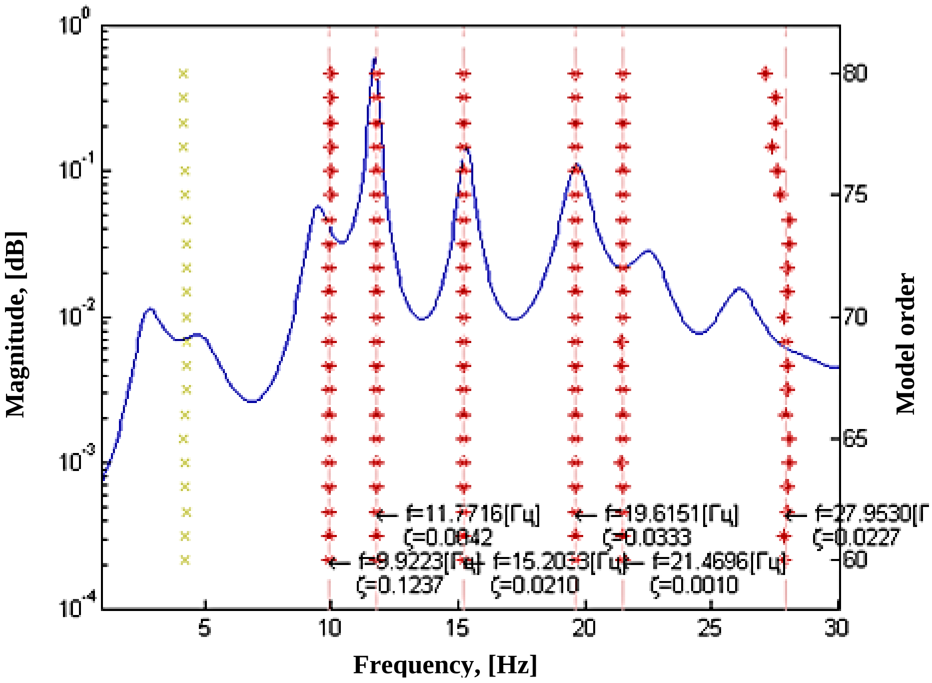

Fig. 5. Grandstand element response

The first natural frequency is 9,92 Hz, damping ratio is 0,124. A harmonic oscillation at the frequency of 11,77 Hz was identified.

Conclusion

The measurement of grandstand structure response due to natural frequencies has shown that, the first natural frequency of vertical oscillation of the studied structure is higher than 6 Hz, this does not restrict the usage of this structure for different events including different sport events and concerts as to the frequency criterion [1]. Nevertheless, it should be mentioned that the method used in this paper ensures safe usage of the studied structures only while standard loads impacted by crowd of people (viewers) and provides no safety when differential settlement of column foundation occurs or while overloading of grandstand structure due to excessive loads and other factors.

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