EXPERIMENTAL IN-SITU TESTING OF RECONSRUCTED OLD BRIDGE IN MOSTAR

L.S.Krstevska[1] , M. Kustura[2] and Lj.A.Tashkov[3]

[1] *Assoc. Professor, Dept. of Building Structures & Materials, Design, Analysis and Testing, Institute of Earthquake Engineering and Engineering Seismology - IZIIS, Skopje, Rep.of Macedonia*
Email: lidija@pluto.iziis.ukim.edu.mk

[2] *BSc, Graduated civil engineer, Civil Engineering Faculty, University of Mostar, Bosnia and Herzegovina*
Email: mladen.kustura@tel.net.ba

[3] *Professor, Dept. of Building Structures & Materials, Design, Analysis and Testing, Institute of Earthquake Engineering and Engineering Seismology - IZIIS, Skopje, Rep.of Macedonia*
Email: taskov@pluto.iziis.ukim.edu.mk

ABSTRACT :

Presented in the paper are the experimental results obtained by ambient vibration measurements of Old Bridge in Mostar, Bosnia and Herzegovina. The measurements and analysis are performed within the scientific cooperation between IZIIS, University St. "Cyril and Methodius", Skopje, Macedonia and the Civil Engineering Faculty, University of Mostar, Bosnia and Herzegovina. The stone-masonry Old Bridge in Mostar is a symbol of the town and it is well known in the world database of historical heritage. The original Old Bridge was built during 16th century. In 1993, during the war, the bridge was completely demolished by explosion and in 2003 completely reconstructed with the same appearance as the original one. The bridge is a stone-masonry arch structure 13.5m in height and 29m in length. For measuring the ambient vibrations three Ranger seismometers, Kinemetrics product, were used. Measurements were performed in transversal, longitudinal and vertical direction, in 22 points along the bridge with objective to obtain its dynamic characteristics. The measurements were conducted using a high speed data acquisition system. Modal analysis was performed with ARTeMIS software. The natural (resonant) frequencies of the bridge as well as the shapes of vibration were clearly expressed. The obtained experimental results are compared with analytically obtained values by SAP2000 as well as by TOWER5.0 computer software and they present a qualitative base for performing further non-linear analysis and evaluation of the seismic stability of this respective monument.

KEYWORDS: ambient vibrations, natural frequencies, mode shapes, damping, masonry

1. INTODUCTION

Many scientific and research activities within international projects worldwide recently are aimed to protection of historical heritage against earthquakes. Most of these historical monuments are constructed of brittle materials, with high rigidity which limits the possibilities for ductile behaviour. Therefore, for estimation of their seismic behaviour and response several important aspects should be considered. The estimation of earthquake ground motions based on amplitudes as well as on the frequency content of both local and distant seismic sources considering the modification by local soil conditions is one of these aspects. Other important factors that influence the determination of seismic response are the strength and deformability characteristics of the materials, as well as the interaction between the local soil and the structure. Further, the dynamic properties of the structure - the natural (resonant) frequencies, mode shapes, and damping capacity should be considered also as one of the main aspects. These means that definition of the actual state of a monument in respect to its dynamic characteristics should be performed by experimental in-situ testing, applying ambient or forced vibration testing method.

Presented experimental activity in this paper is related to dynamic in-situ testing of the Old Bridge in Mostar for definition of its dynamic characteristics. The measurements have been performed within the scientific cooperation between IZIIS, University St. "Cyril and Methodius", Skopje, Macedonia and the Civil Engineering Faculty, University of Mostar, Bosnia and Herzegovina for evaluation of seismic stability of this respective monument.

2. DESCRIPTION OF THE OLD BRIDGE AND EXPERIMENTAL SET-UP

The stone-masonry Old Bridge in Mostar is a symbol of the town and it is well known in the world database of historical heritage. The bridge is a simple arch structure 13.5m in height and 29m in length. The original Old Bridge was built during 16th century. In 1993, during the war, the bridge was completely demolished by explosion and in 2003 completely reconstructed with the same appearance as the original one, Fig. 1.

A special technique has been applied to connect the stones of the structure. It consisted of incorporating special iron clamps sealed with lead, as shown on details in Figure 2.

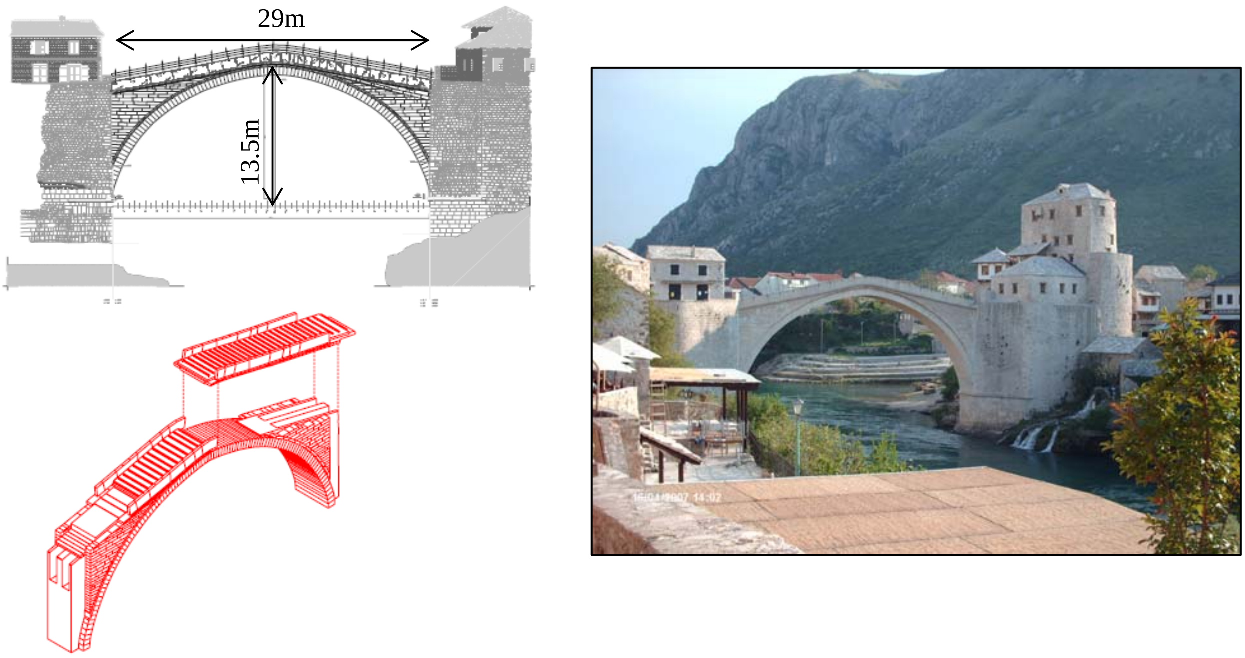

Figure 1 The reconstructed Old Bridge in Mostar

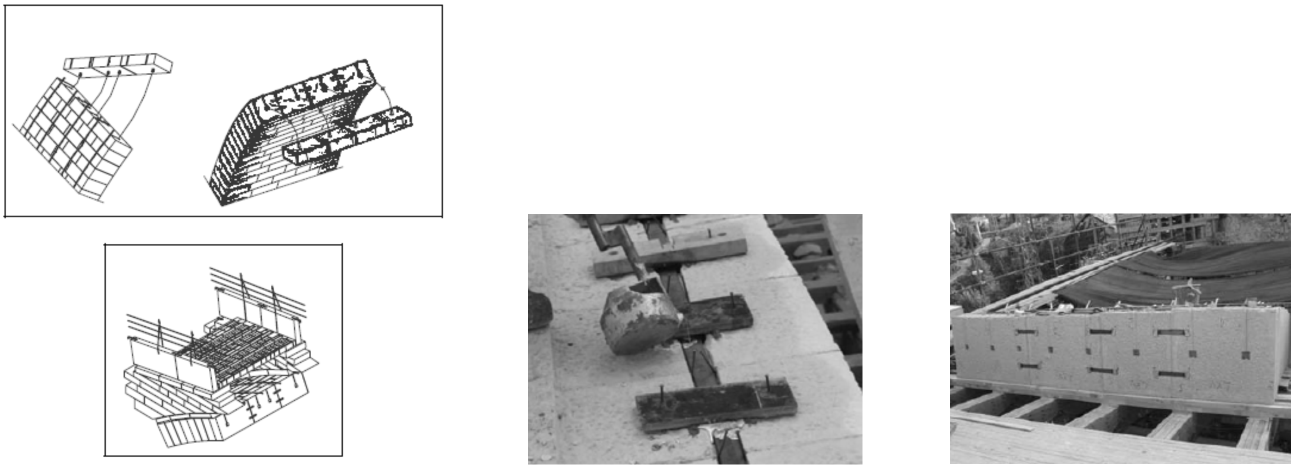

Figure 2 Details of stone connections

3. APPLIED EQUIPMENT AND EXPERIMENTAL SET-UP

The Old Bridge in Mostar has been tested by ambient vibration method, measuring the vibrations in selected points along the bridge and than processing the recorded signals to obtain the dynamic characteristics.

3.1. Equipment for ambient vibration measurements

During the ambient vibration measurements of the Old Bridge, three seismometers Ranger type, Figure 3-a, Kinematrics product, were used and the measured signals were amplified by four channel Signal Conditioner also Kinematrics product, 3-b. The amplified and filtered signals from the seismometers were than collected by high-speed data acquisition system, 3-c, which transforms the analogue signals to digital. Fourier analyzer (3-e) was also used for quick checking and analyzing of the signals in frequency domain and obtaining the Fourier amplitude spectra (FAS).

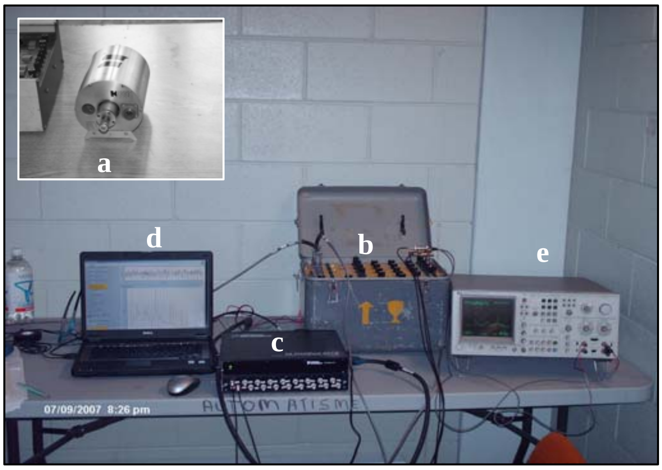

Figure 3 Applied equipment for ambient vibration measurements

3.2. Processing of data

Special software for on-line data processing has been used to plot the time histories of recorded velocities by the seismometers together with the Fourier amplitude spectra of the response at any recorded point.

For post-processing and analysis of the recorded vibrations in all measuring points ARTeMIS software was used. In this software the natural frequencies and the mode shapes of vibrations can be determined using the Peak Picking technique and the Frequency Domain decomposition (FDD) technique. This program has possibilities for very good graphical presentation of the obtained data.

3.3. Test set-up

Measurements of ambient vibration of the Old Bridge were performed in transversal, longitudinal and vertical direction in 22 points along the bridge, as presented in Fig. 4. 11 points were selected at the up-stream as well as at the down-stream side including the reference one and 88 tests were performed including the dynamic calibration tests. The data sets consisted on records of velocity signals with duration of 100 seconds and the sampling frequency was 200 samples/second. Some photos showing the position of the instruments are given in Fig. 5.

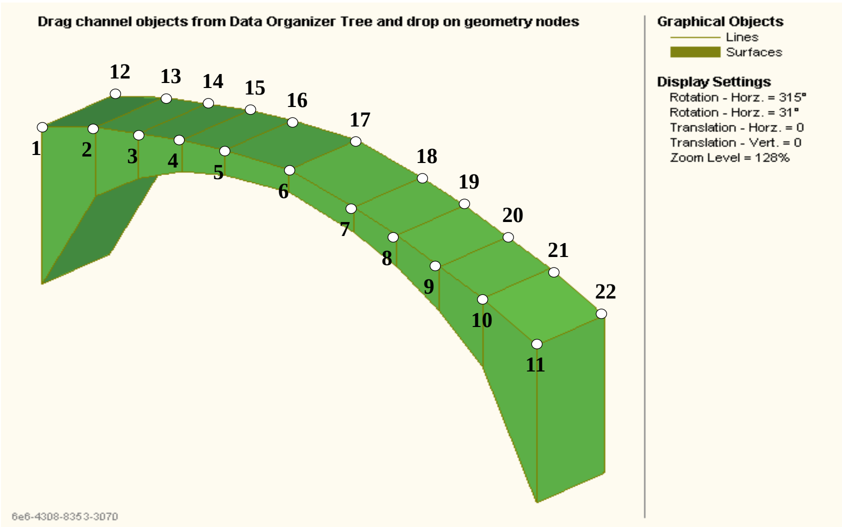

Figure 4 Measuring points along the bridge

Figure 5 Position of the instruments in some points

4. EXPERIMENTAL RESULTS

Presented in Figs. 6 and 7 is the peak-picking of the dominant frequencies for the Old Bridge in transversal, longitudinal and vertical direction, while in Table 1 presented are the values of these frequencies as well as the corresponding damping coefficients.

The frequency of 7.6Hz is the resonant frequency of translational-torsional vibration along longitudinal axis of the bridge; 11.43Hz is the resonant frequency of vertical antimetric (longitudinal) mode of vibration while

13.96Hz is the resonant frequency of vertical symmetric mode of vibration. Mode shapes of vibration at these resonant frequencies are presented in Figs. 8 and 9 for transversal and vertical direction and for longitudinal and vertical direction, respectively. The damping coefficients are in the range of 1.5 to 4.3%.

Table1. Dominant frequencies of Old Bridge in Mostar

Dominant frequency (Hz)	Damping coefficient (%)
7.2	2.3
7.6	1.5
11.43	2.6
13.1	3.1
13.6	2.8
13.96	2.4
14.6	4.3
23.7	3.4

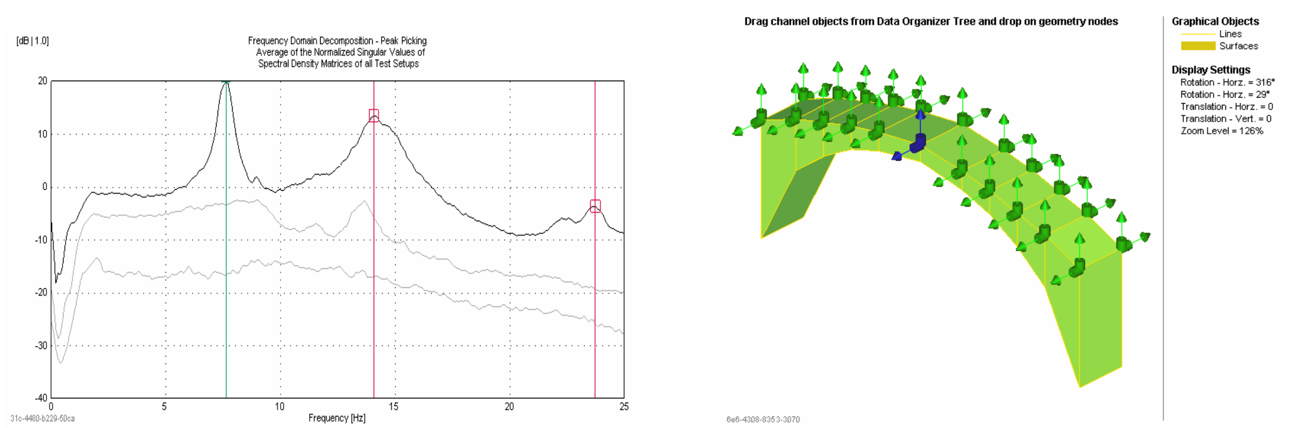

Figure 6 Peak-picking of the dominant frequencies in transversal and in vertical direction

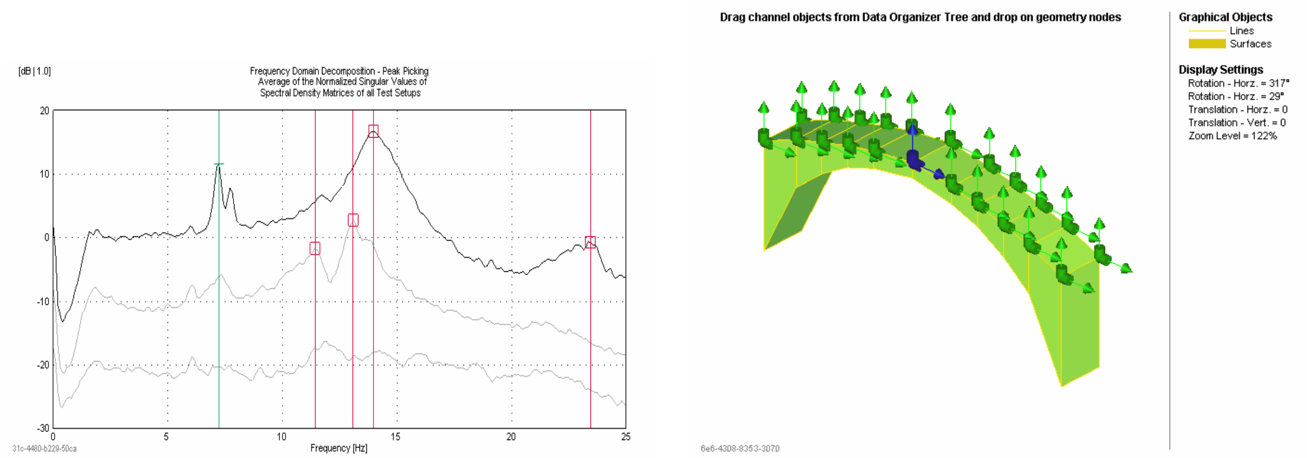

Figure 7 Peak-picking of the dominant frequencies in longitudinal and in vertical direction

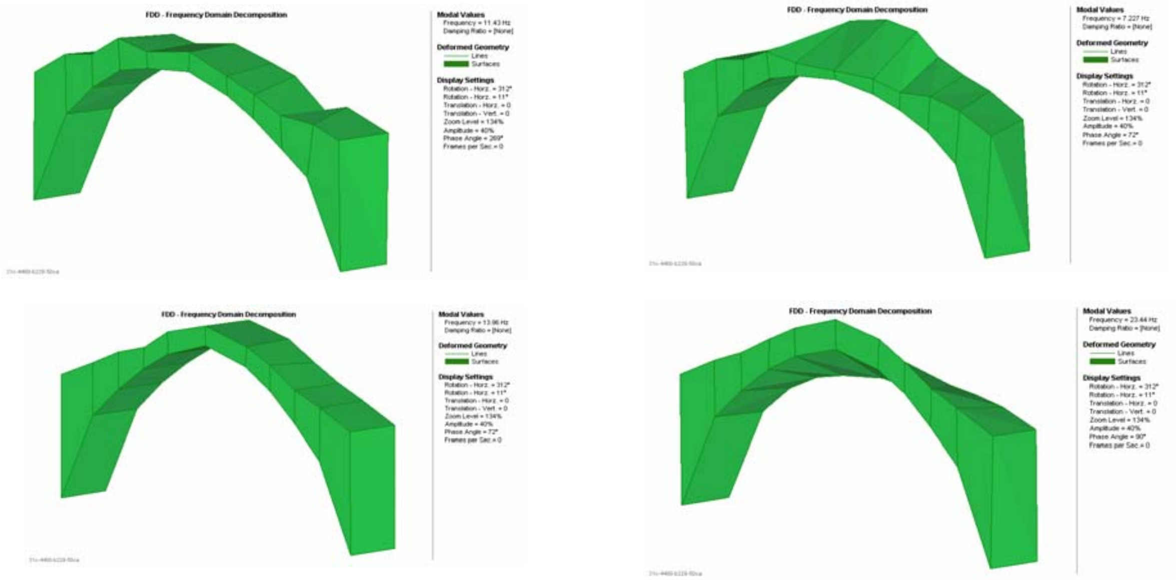

Figure 8 Shapes of vibration at dominant frequencies, longitudinal & vertical direction

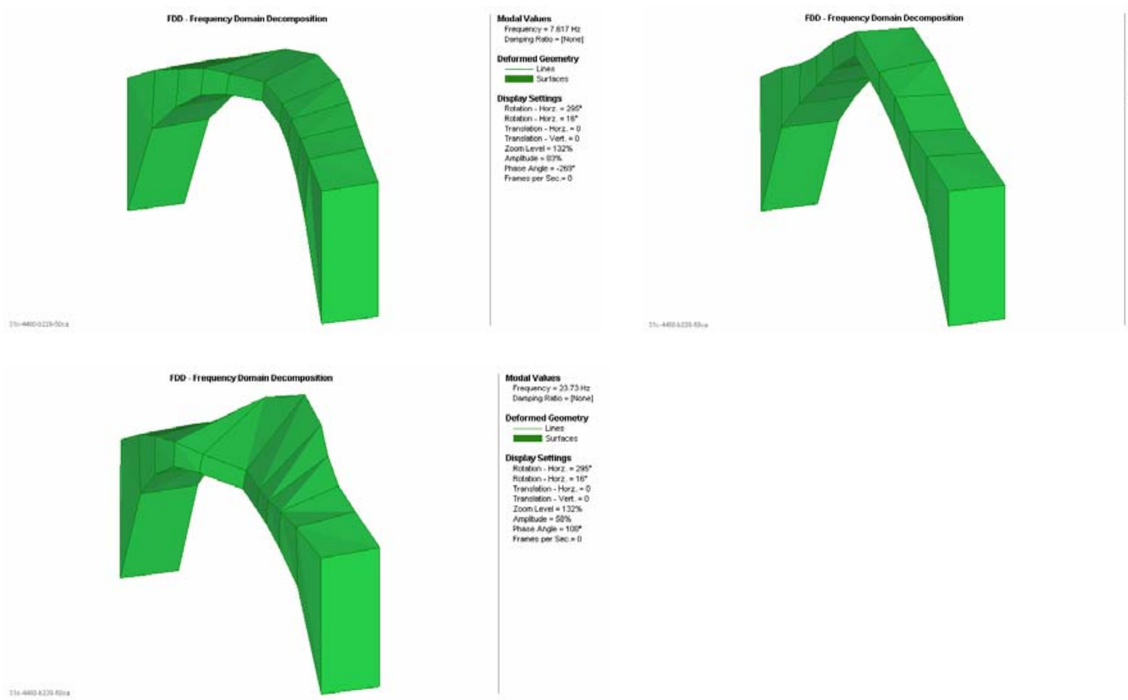

Figure 9 Shapes of vibration at dominant frequencies, transversal & vertical direction

5. COMPARISON BETWEEN EXPERIMENTAL AND NUMERICAL RESULTS

The structural analysis of the Old Bridge was carried out by SAP2000 as well as by TOWER5.0 computer programs, both based on FEM, using the mechanical properties for the structural materials obtained by testing of representative samples. Presented in Table 2 are the values of the natural frequencies obtained numerically comparatively to the experimental ones, while in Figs. 10 and 11 shown are the mode shapes of vibration obtained by SAP200 and by TOWE5.0, respectively. It can be seen that there is a satisfactory agreement between the vibration modes as well as the respective values of the natural frequencies obtained for the Old Bridge by different ways - experimentally and numerically.

Table 2. Comparative presentation of the natural frequencies

Mode	Natural frequency (Hz)			Mode description
	experiment	TOWER5.0	SAP2000	
1	7.6	7.86	6.88	Transversal
2	11.4	11.04	10.48	Vertical antimetric - longitudinal
3	13.96	13.93	14.68	Vertical symmetrical

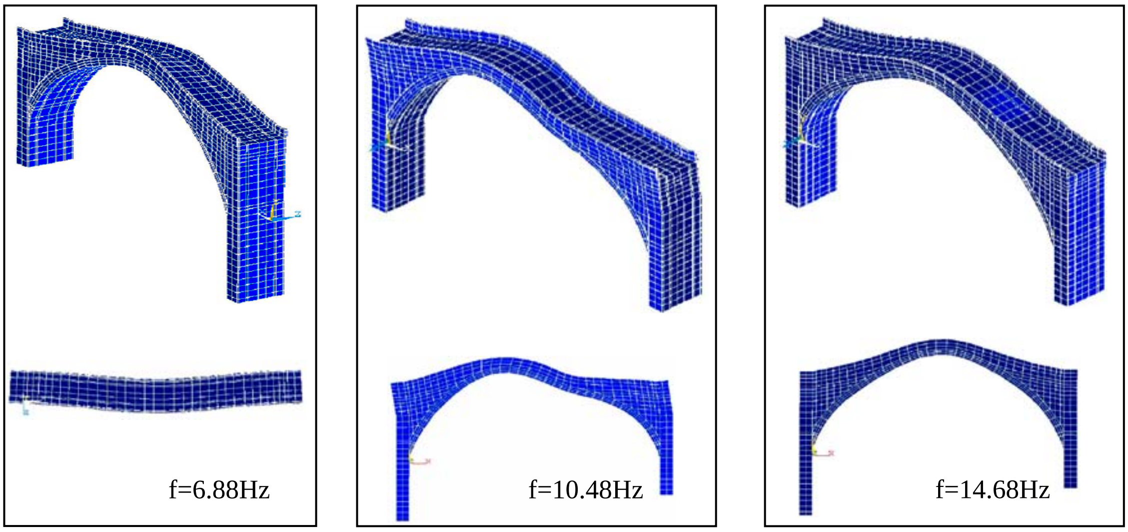

Figure 10 Mode shapes obtained by SAP2000

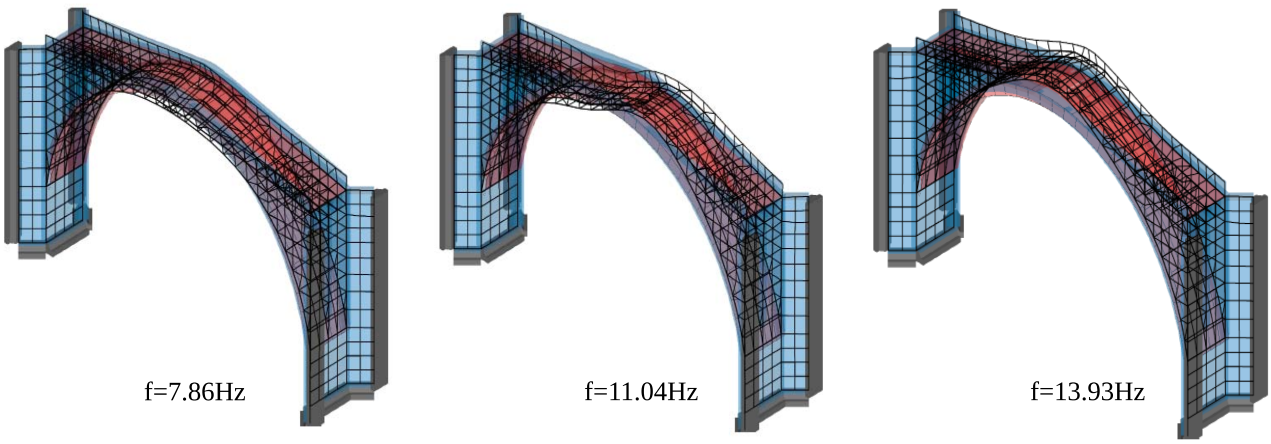

Figure 11 Mode shapes obtained by TOWER5.0

6. CONCLUSIONS

- Dynamic characteristics of the Old Bridge in Mostar are obtained by ambient vibration testing method in frequency range up to 30 Hz in three directions: transversal, longitudinal and vertical direction;
- The natural frequencies of the bridge as well as the shapes of vibration are clearly expressed;

- Comparison between the natural frequency values and the mode shapes of vibration to the ones obtained by numerical analysis by SAP2000 and TOWER5.0 FEM software showed very good agreement;
- The obtained dynamic characteristics by the experimental testing can be further used for calibration and improving of the mathematical model to be used for analytical investigation of the seismic stability of this respective monument.

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