REPORT

From ambient vibration tests on Economic-Trade School Building in Pozarevac, Serbia

March, 2015

CONTENTS

1. SCOPE

The scope of this report is to analyse and identify the dynamic characteristics of the building of the Economic-Trade School in Pozarevac, Serbia from the performed ambient vibration tests. This report was initiated by the client System DC90 d.o.o. f rom Belgrade, Serbia after performed rehabilitation of the structural system of the building.

The building is located on 6 Jovan Sherbanovic st. (44°37'07.5"N 21°11'21.3"E) in the vicinity of the centre of the town. The geographical position is presented in Fig. 1-1.

Fig. 1-1. Location of the Economic-Trade School in Pozarevac, Serbia.

As reported in the technical documentation for static and dynamic analysis of the building, the building was constructed in 1904-1905 and changed its function several times during the years. Currently, the building is protected by law as cultural monument. Its overall dimensions are 35.22x24.68 m, it has complex structural shape in the layout (similar to letter E) and has basement, ground floor and one floor. The last reconstruction was performed in 1976.

The structural system of the building is composed from unreinforced masonry walls (URM) from solid clay bricks with dimensions 30x15x7 cm layout out in mortar with unspecified type and quality. The thickness of the basement floor walls is 83 cm and it further reduces to 66, 51 and 35 cm along the height of the building. The floor structure above the ground floor is constructed by timber beams, while in the hallways URM arches with height of 27 cm support the floors. The roof floor is timber with mud flings.

Figs. 1-2, 1-3, 1-4 and 1-5 present the views of the building, while Figs. 1-6 and 1-7 show the building layout and cross-sections.

Fig. 1-2. West façade of the building (main entrance).

Fig. 1-3. East façade of the building (backyard).

Fig. 1-4. North-East façade of the building.

Fig. 1-5. View of the hallway inside the building and view of the roof.

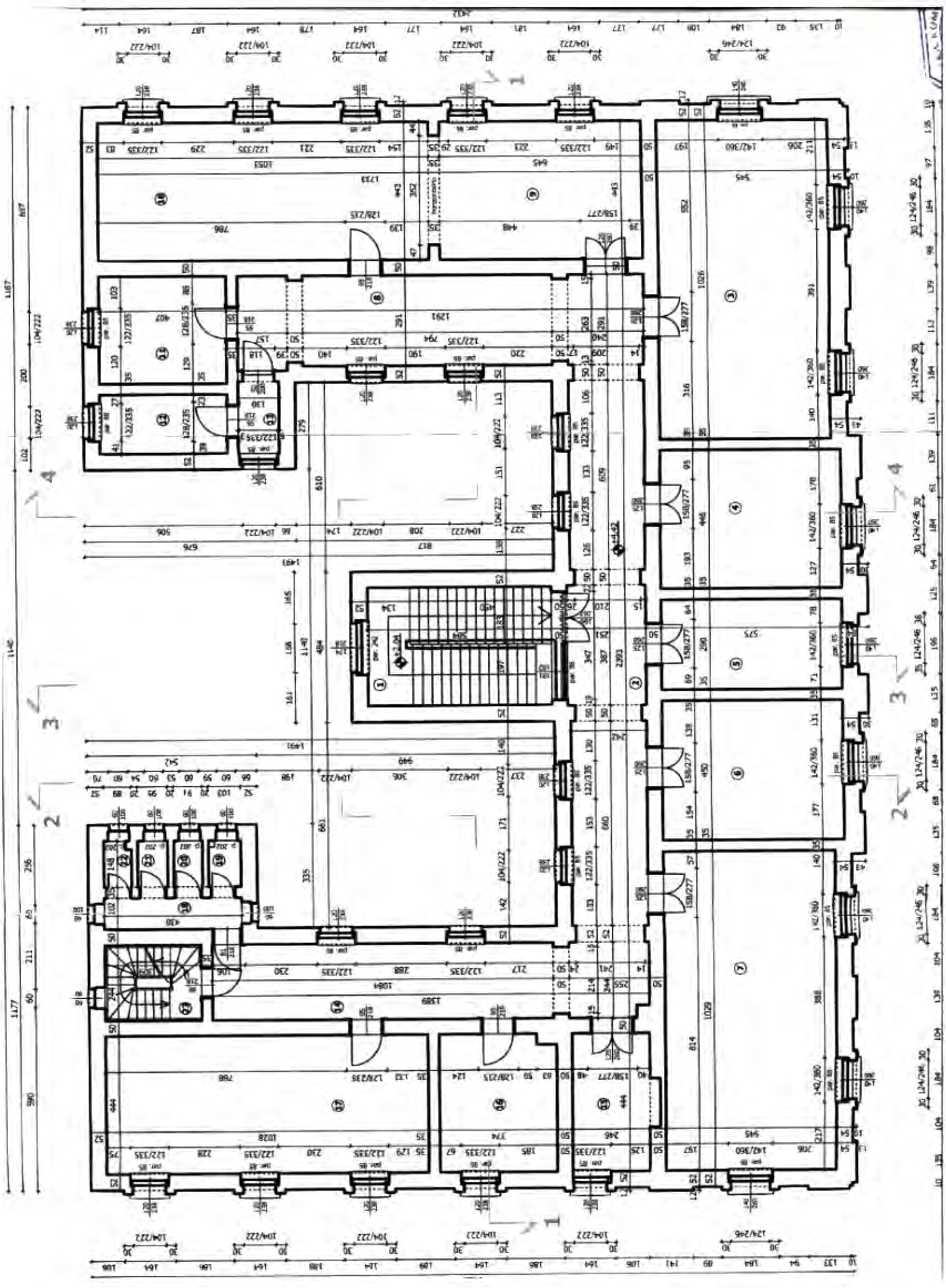

Fig. 1-5. Layout of the building.

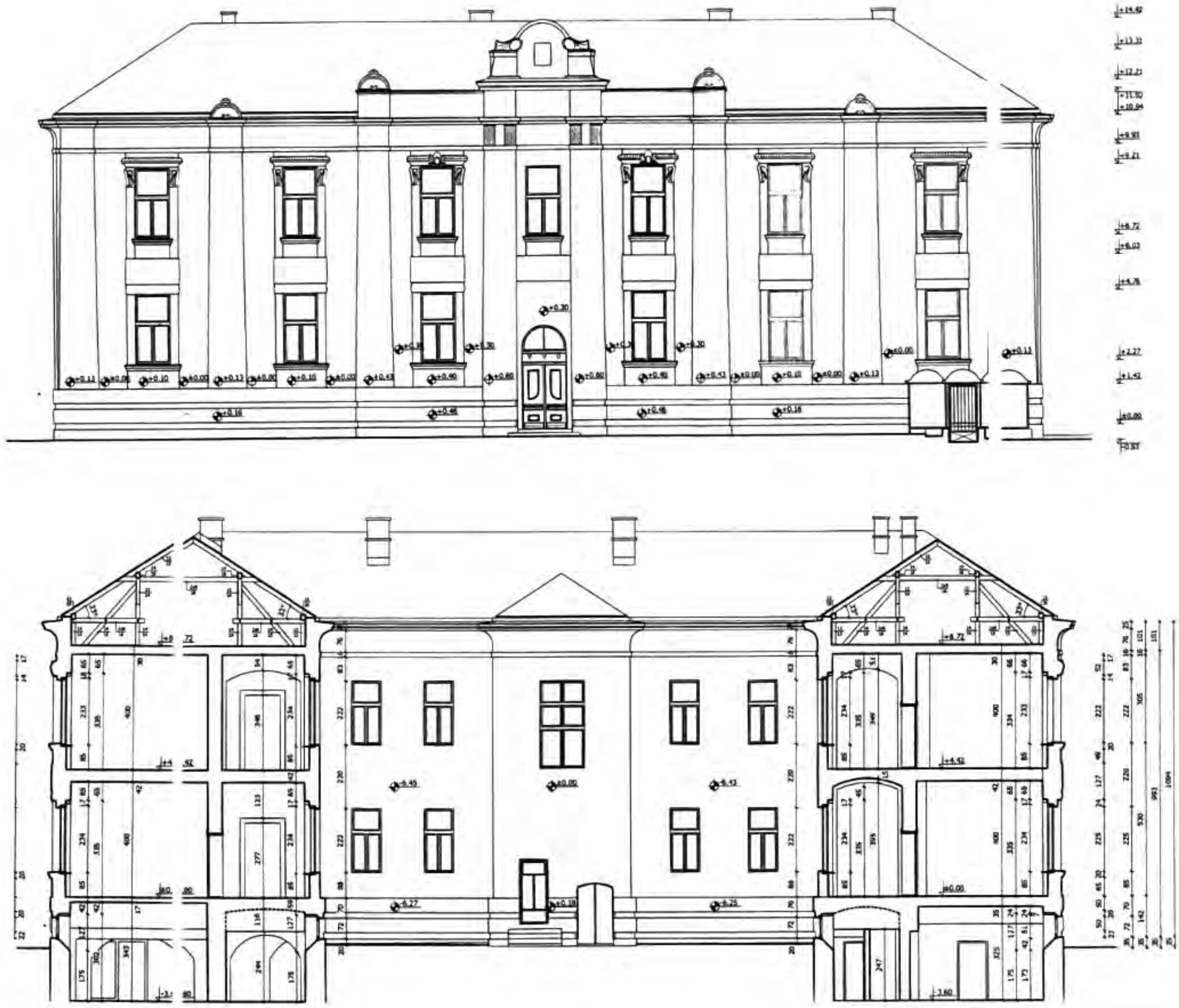

Fig. 1-6. Façade and cross-section of the building.

For the purpose of this report, the client delivered the available design documentation which was used during the preparation of this report. The following documents were used:

- Static and Dynamic Analysis of the rehabilitation of the structural system of the Economic-Trade School in Pozarevac, from the design engineer Zharko Petrashković, BSc.
  (original title: Статичка и динамичка анализа санације конструктивног склопа зграде Економско-Трговинске школе у Пожаревцу, Жарко Петрашковић, дипл.инг. грађ.)

- Design project for rehabilitation of the structural system of the Economic-Trade School in Pozarevac, from the design engineers, Zoran Petrashković, PhD and Zharko Petrashković, BSc.
  (original title: Израда пројекта санације конструктивног склопа зграде Економско-Трговинске школе у Пожаревцу, Др. Зоран Петрашковић и Жарко Петрашковић, дипл.инг. грађ.)

Also, this report uses the details from the ambient vibration tests performed in-situ that were arranged and composed in one document entitled:

- Ambient Vibration Measurement, School – Pozarevac, Serbia, 19 February 2015, prepared by Digitexx Data Systems, Inc.

For analyses of the measured ambient vibration signals and graphical presentation of the obtained results, the geometry of the buildings was taken from the available architectural plans, design drawings and the performed on-site measurements. Since the building was in operational function, very limited type of non-destructive structural investigations was possible. In-situ dynamic tests by recording the ambient vibration signals was performed on February 19, 2015.

To reveal the overall behaviour of the building and to identify the stiffness and dynamic properties of the structural system, two-stage analysis was performed:

- In-situ dynamic tests, by recording AV signals, and
- Operational Modal Analysis

With the information from the available design documentation, performed tests and analyses, basic conclusion with regards to the dynamic characteristics of the structural systems were made in this report.

2. OPERATIONAL MODAL ANALYSIS

2.1. Data acquisition

At the time of preparation of this report, the only possible reliable method to confirm the stiffness of the building was to conduct non-invasive, non-destructive tests by performing ambient vibration measurements. A series of ambient vibration measurements were carried out and these results were later used to identify the dynamic characteristics of the building.

The primary aim of the modal testing was to identify the lowest modes of vibration in both horizontal directions. For this purpose an ambient vibration survey was conducted by recording the ambient vibrations. Due to the importance of the test results, it is desirable to decrease the influence of other sources of vibration, such as operating A/C units, rotating machines, human interference with the equipment (sensors, cables) and etc.

Twenty one series of AV tests were conducted on the building with 3 fixed reference acceleration recording sensors and 2 roving sensors. Each series contains results from acceleration sensors for different sensor location in the building layout. Calibration of the sensors was applied prior the measurements. Total recording time was *300 sec*, the sampling frequency was fixed to *200 Hz* which gives about *60000* data points.

2.1.1. Test equipment

The ambient vibration measurements were performed with Digitexx PDAQ Premium portable system with physical dimensions *457 x 330 x 170 mm* as shown in Fig. 2-1. This system supports data acquisition and analysis from distance.

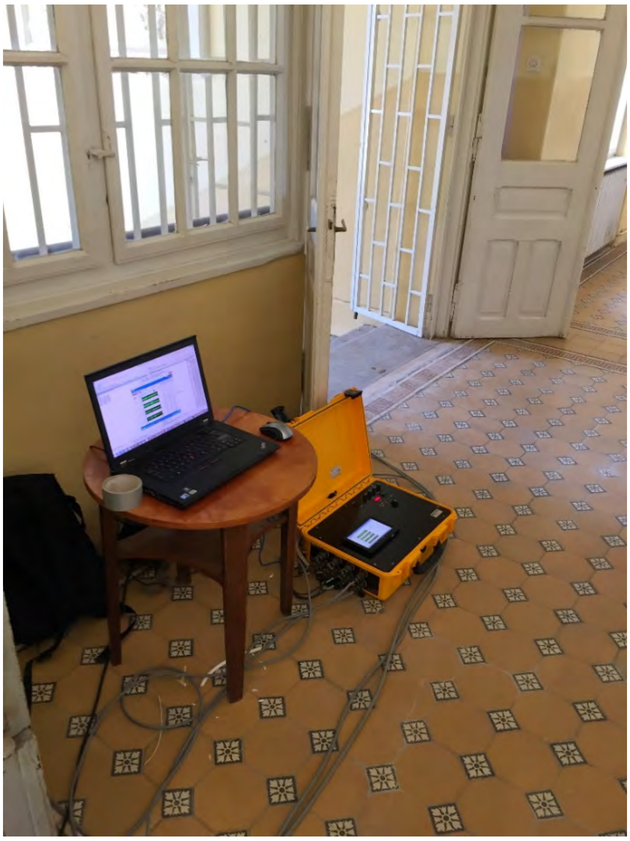

Fig. 2-1 Digitexx PDAQ Premium.

Fig. 2-2 Digitexx D110-T tri-axial sensor.

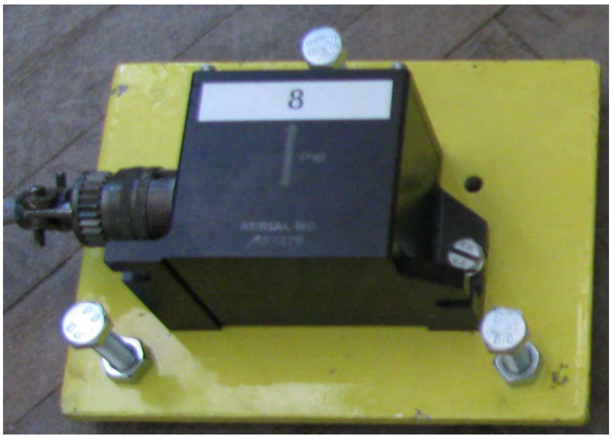

Fig. 2-3 Digitexx D110-U uni-axial sensor.

Main characteristics of the system are: 16 channels, 24 bits, local and remote real time data analysis, FFT, transfer functions, interstorey drift based on FEMA 351 and 274 seismic safety standards, hysteresis curve for the interstorey drift, computation of acceleration, velocity and displacement. This system is best option for permanent structural health monitoring for a period up to 6 months. The main characteristics of the acceleration sensors are: uni- and tri-axial micro electro-mechanical capacity sensors with wide dynamic range *+/- 3g*, perfect band and ultra low noise, which make them ideal for structural health monitoring, Fig. 2-2 and 2-3.

2.1.2. Full scale measurements

Ambient vibration tests were performed by using uni- and tri-axial acceleration sensors and measurements in 14 points per floor. All sensors were placed carefully and levelled on the floors. The sensors on the roof and some of the sensors in the classrooms were positioned on timber elements or hardwood floorings. The location of selected sensors are presented in Figs. 2-4 to 2-6. Figs. 2-7 schematically presents the layout and arrangement of the sensors in the building layout.

While the measurements were on their way, the movement and actions of the people present around the chimneys were restrained for the measuring interval. The outside temperature was in the range $0\text{-}6^0C$.

The recorded analog signals were digitized and saved in ASCII format on the hard disk of the computer used for data acquisition. The quality of the data was evaluated on site by visually inspecting the raw (untreated) time domain signals (acceleration versus time) for each channel. A preliminary Fast Fourier Transformation was also computed from the raw time domain signal from each output channel during this step. The time and frequency domain signals for each output sensor channel were examined to identify any noisy or malfunctioning sensors. The frequency domain signals were inspected to establish the frequency range that contained the majority of the significant responses.

Signals from measurement No. 21 had erroneous time-history for data point M and therefore this test set-up was ignored in the operational modal analysis.

Fig. 2-4 Location of the uni-axial reference sensors in point F on the 2nd floor.

Fig. 2-5 Location of a tri-axial sensor in office room.

Fig. 2-6 Location of a tri-axial sensor in the hallway of the building.

2.2. Sensor location

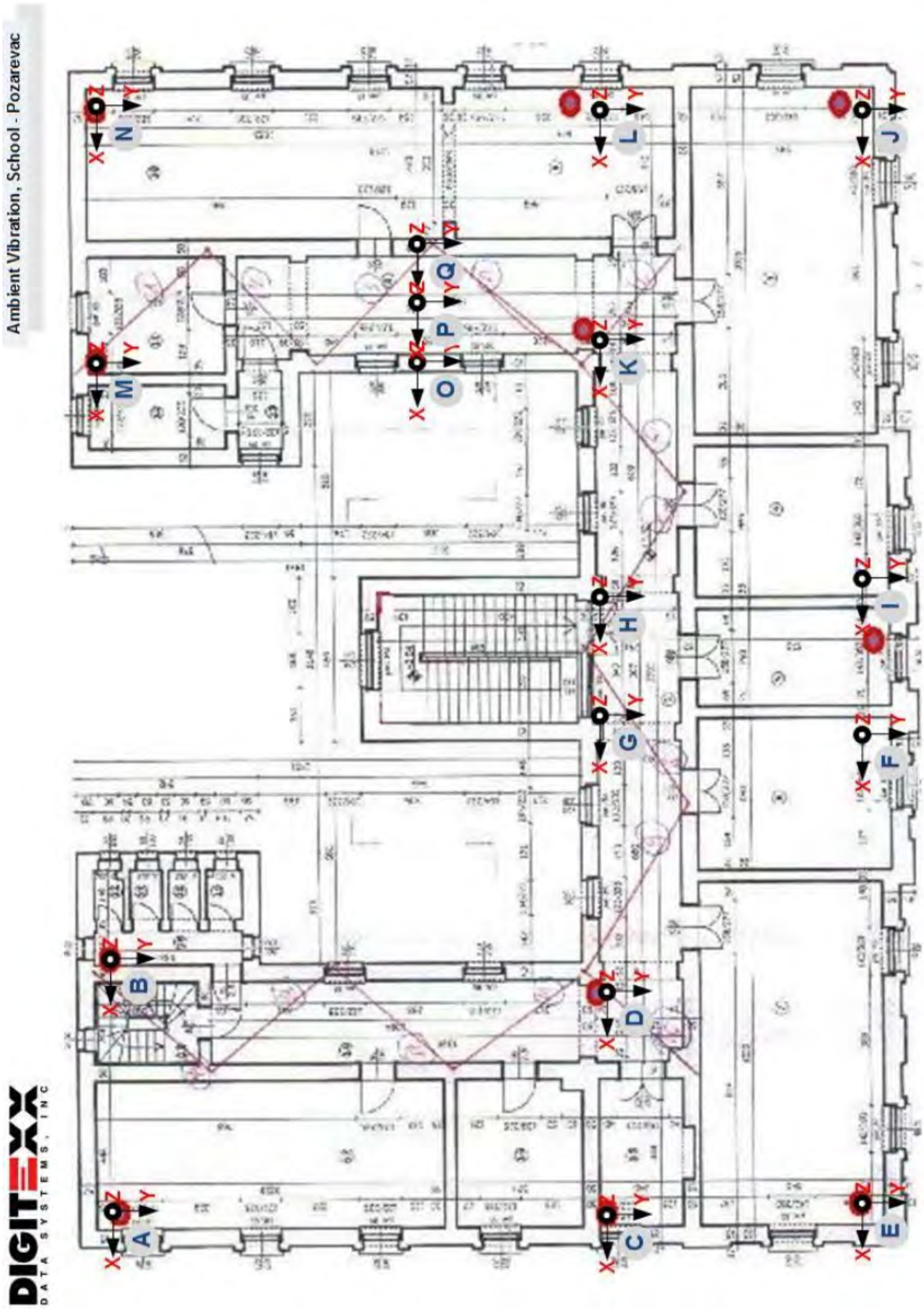

Fig. 2-7. Measuring points and axis orientation in the building layout.

2.3. Data analysis

The data acquisition parameters adopted in the tests are given in Table 2-1, while the measured (raw) time histories for selected measurement points are shown from Fig. 2-8 to 2-10.

Table 2-1. Data acquisition parameters used for ambient vibration tests.

Parameter	Value
Acquisition time (s)	300
Time step (s)	0.005
Sampling frequency (Hz)	200

The analysis of the recorded acceleration time-histories was performed using the Artemis Modal 3.6.0.9 software.

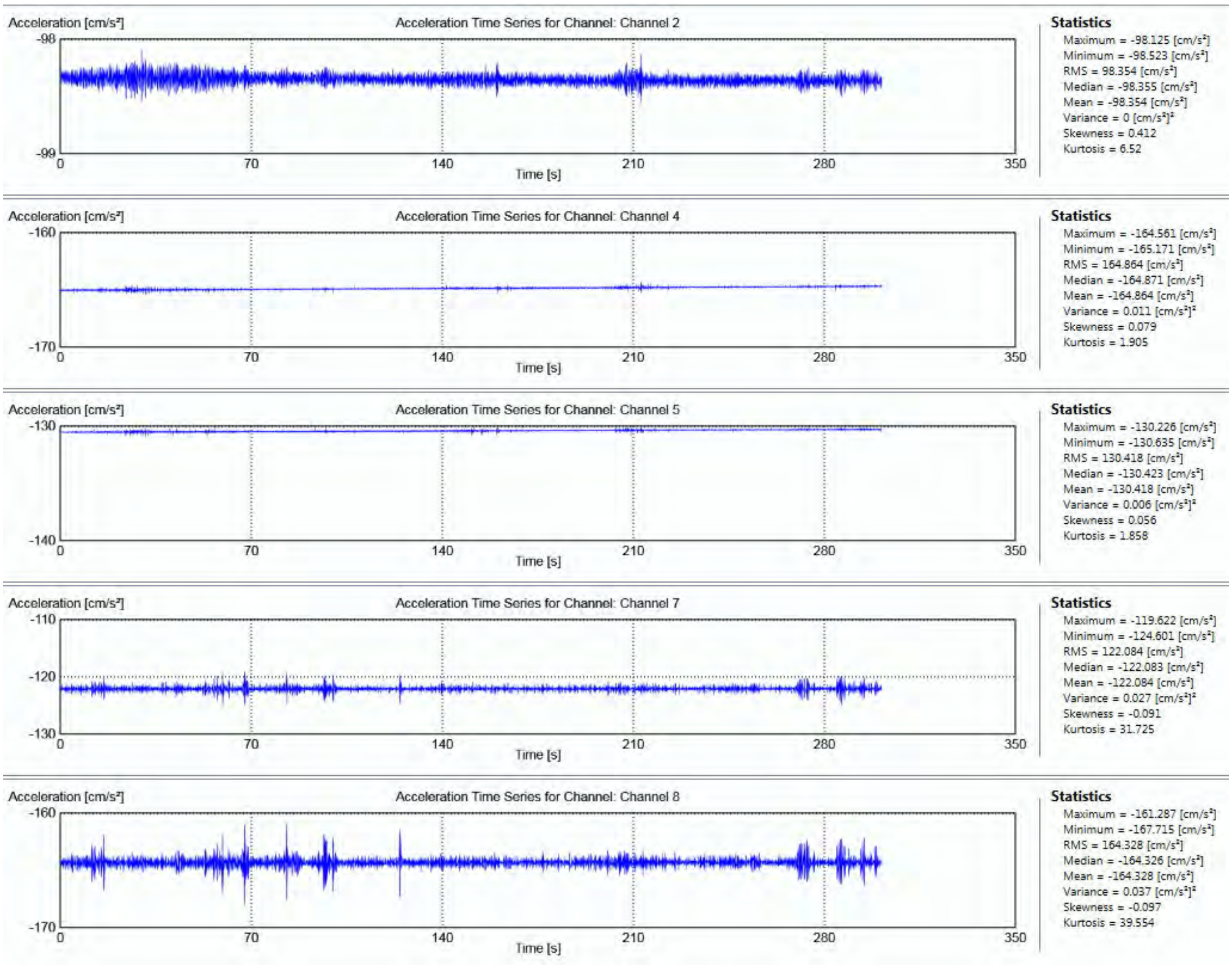

Fig. 2-8 Measurement 1, points A, B and F (reference), ground floor.

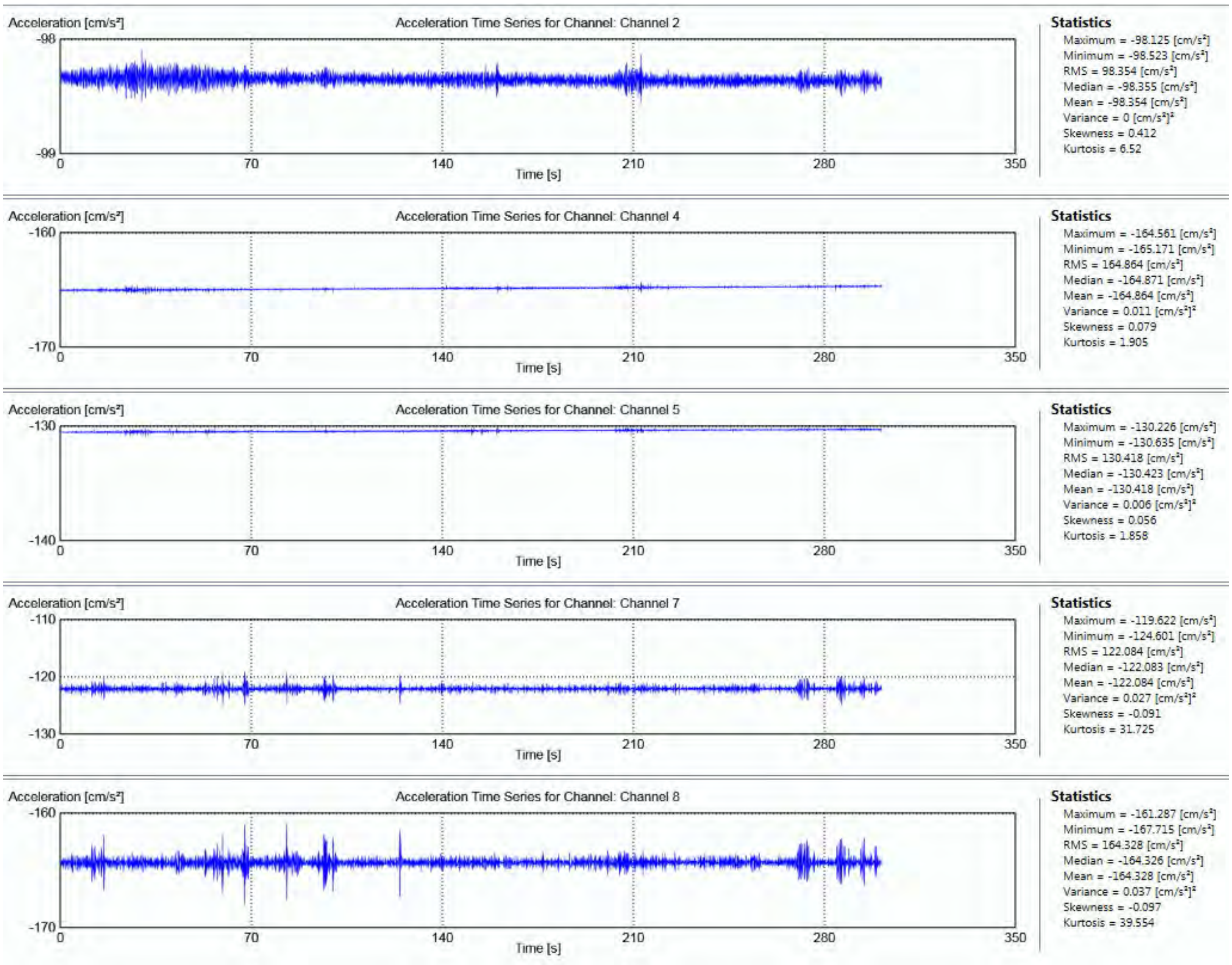

Fig. 2-9 Measurement 10, points E and F (reference), first floor.

Digital filtering

Having in mind the structural system and structural material used in this building as well as from obtained AV test results for similar structures, it was indicated that the frequency response spectrum of the building shall be located in the frequency band between 1 - 15 Hz. Therefore, the cut-off frequencies selected for digital filtering are 0.5 Hz at the low end and 20 Hz at the upper end of the spectrum. It was expected that these cut-off frequencies would retain the majority of the vibration responses for the building. The digital filter used in this step was a 7th order Low-pass filter.

A view of the graphical presentation of the measurement points of the building with sensor direction is shown in Figs. 2-10 and 2-11.

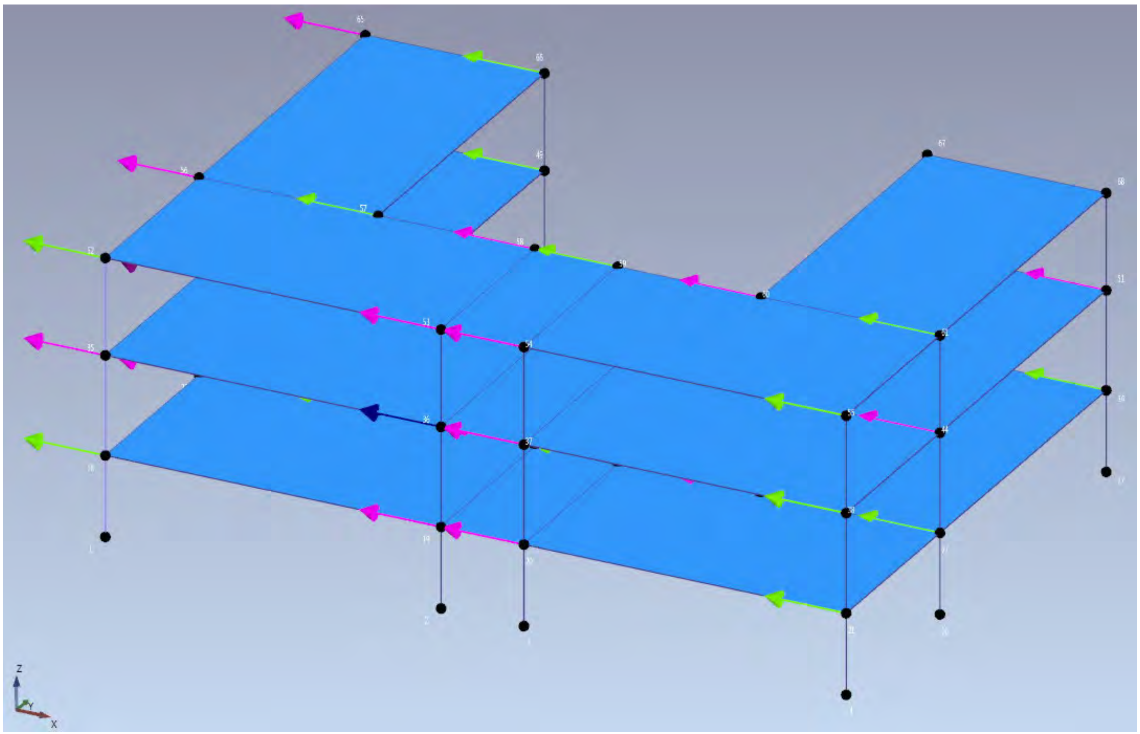

Fig. 2-10. Sensor location for direction X.

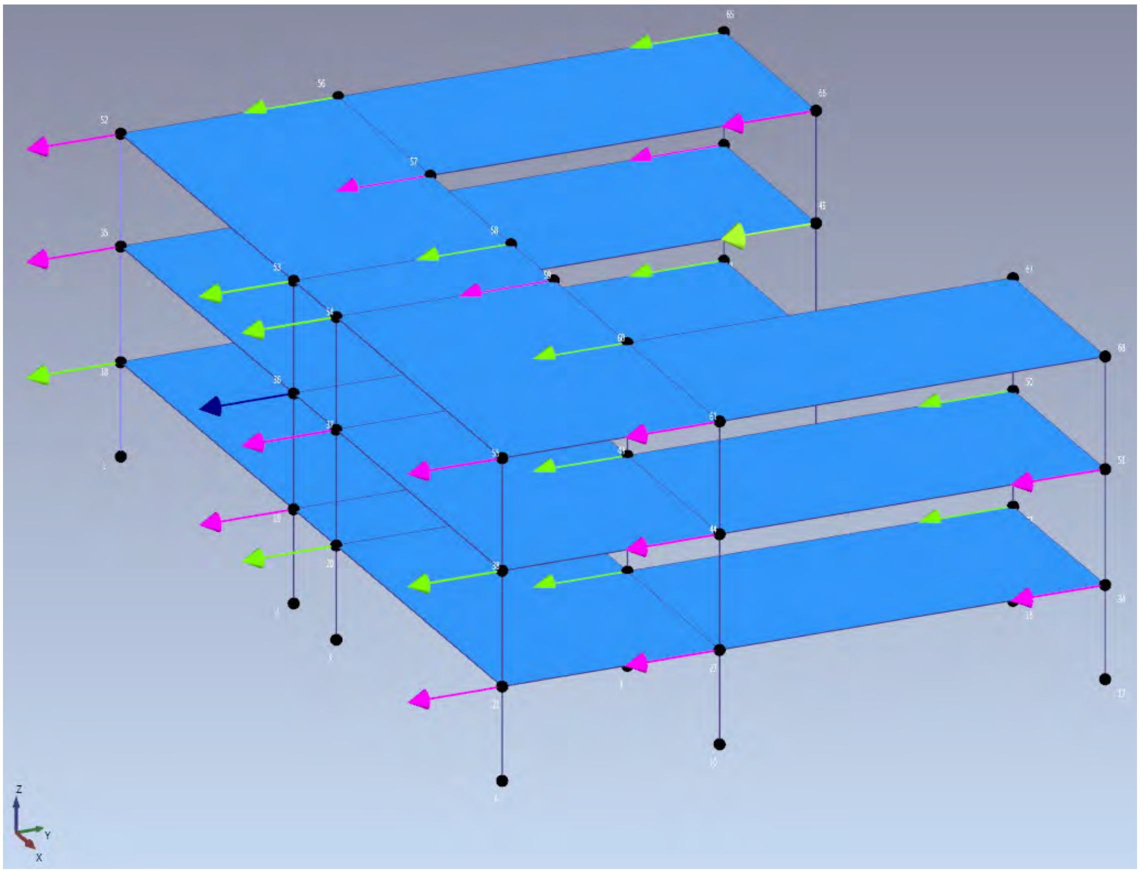

Fig. 2-11. Sensor location for direction Y.

2.4. Modal Analysis

The natural frequencies of the structure were identified from the measured responses using the common Frequency Domain Decomposition-Peak Picking (FDD) method. Artemis Modal 3.6.0.9 software was used to identify the dominant frequencies and mode shapes. The frequencies corresponding to the locations of spectral peaks in the ANPSD functions should theoretically correspond to the natural frequencies of the building.

In order to simulate the operational behaviour of the structure, the responses for different directions (X and Y) of the building were combined using the Average Normalized Power Spectral Density (ANPSD) function. Direction Z was inspected and since it was not dominant direction it was not considered in further modal identification. The plots of ANPSD functions for the building are shown in Figs. 2-12 and 2-13.

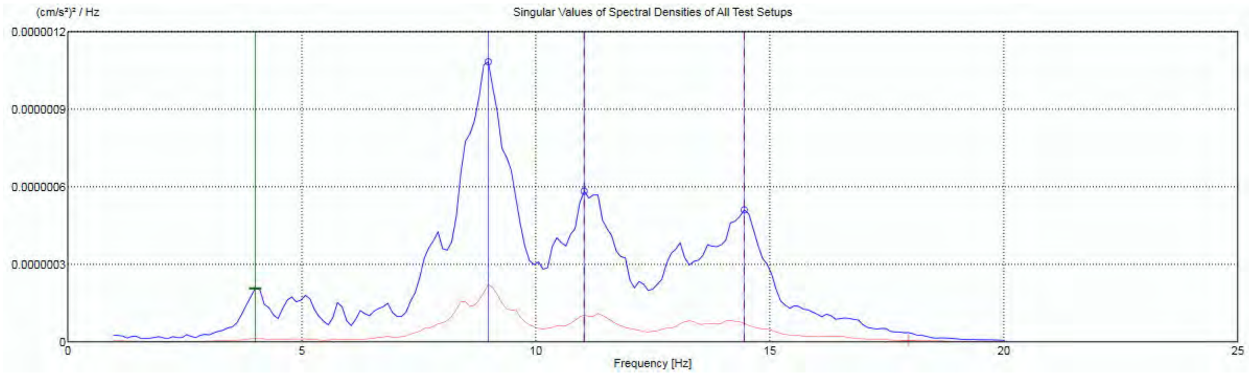

Fig. 2-12. ANPSD functions for direction X.

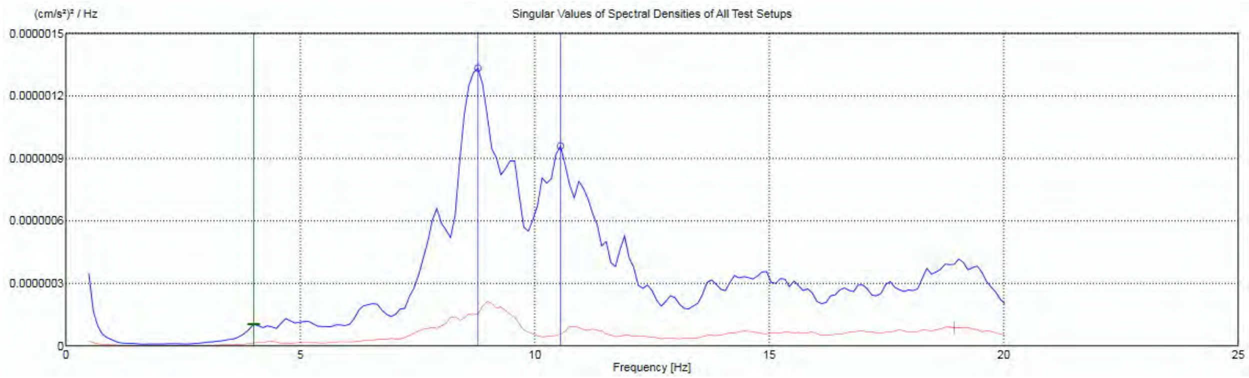

Fig. 2-13. ANPSD functions for direction Y.

Dominant frequencies

The dominant peaks for both directions of the building identified from the modal analysis are presented in Tables 2-2 and 2-3. The first modes for both directions were estimated and correspond to a mode with a natural frequency in the range of *4.0 - 8.9 Hz*. The next peaks were identified in the frequency range of *10.5 - 11 Hz.*

The first peaks in both directions that could be identified as frequencies for global vibration of the building correspond to a frequency of *4.0 Hz*, but the amplitude in the spectrum density plots are very low in comparison to the peaks at frequency of app. *9.0 Hz*.

Table 2-2. Estimated values for natural frequencies in direction X.

Estimation	Freq. (Hz)	Period (sec)
1	4.004	0.250
2	8.984	0.111
3	11.035	0.091
4	14.453	0.069

Table 2-3. Estimated values for natural frequencies in direction Y.

Estimation	Freq. (Hz)	Period (sec)
1	4.004	0.250
2	8.789	0.114
3	10.547	0.095

Mode shapes

The first frequency that could be identified as global mode shape correspond to frequency of *4.004 Hz* in both directions, but its magnitude is very small. On the other hand, the dominant frequencies, that have greater magnitudes, correspond to a local mode shapes. The identified mode shapes are shown in Figs. 2-14 to 2-19.

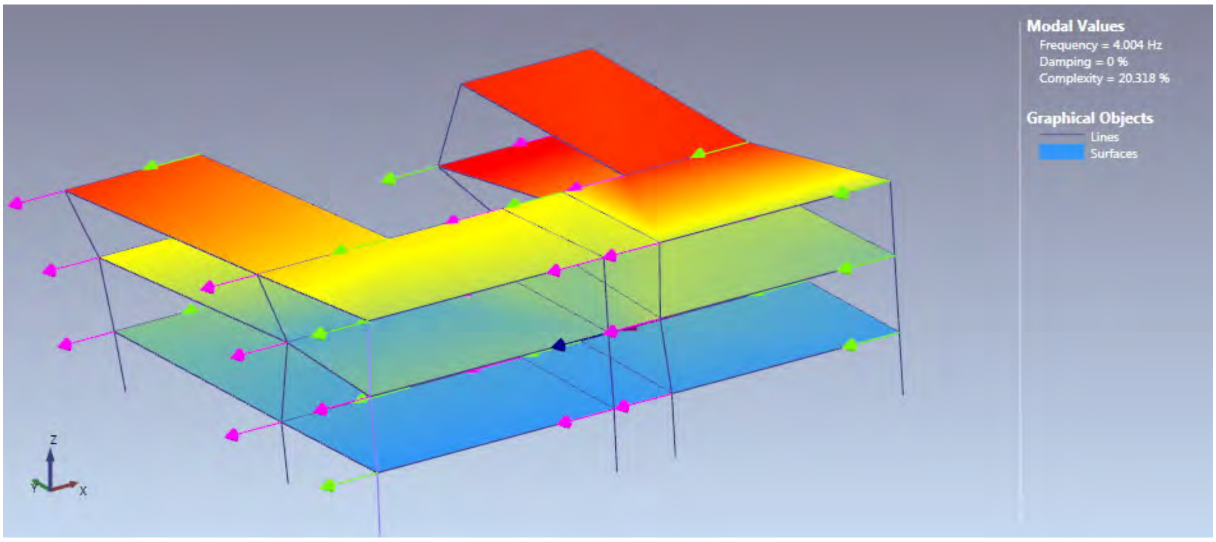

Fig. 2-14 Mode shape for f_1=4.004 Hz in direction X

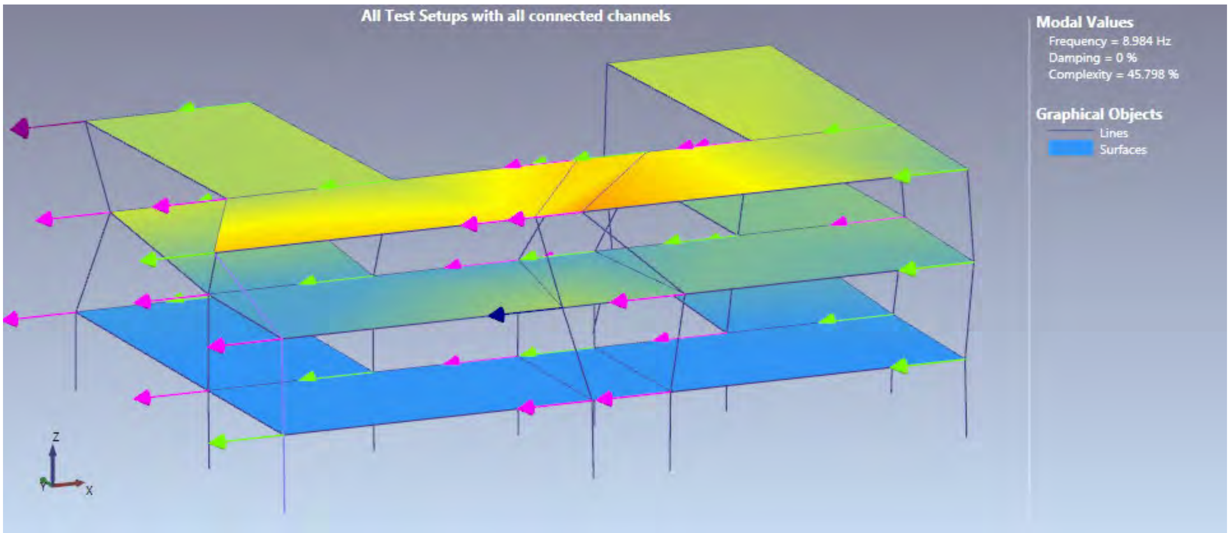

Fig. 2-15 Mode shape for f_2=8.984 Hz in direction X

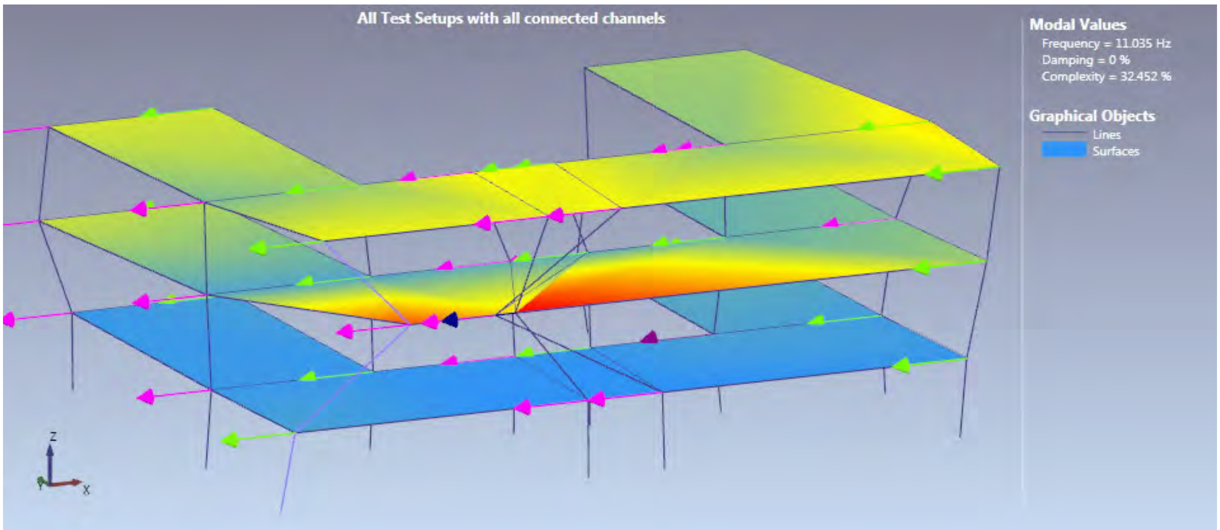

Fig. 2-16 Mode shape for f_3=11.035 Hz in direction X

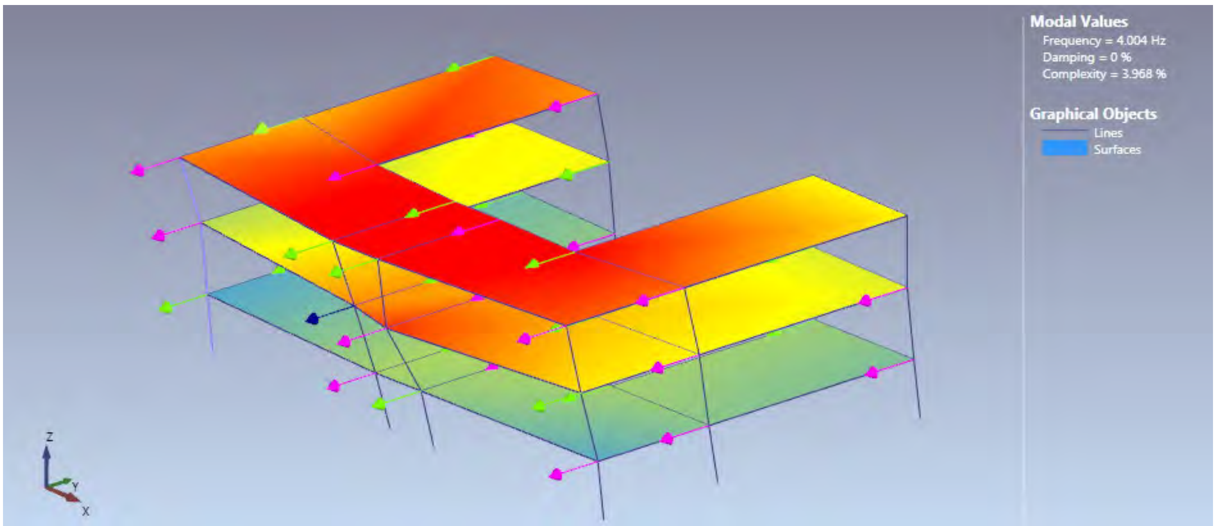

Fig. 2-17 Mode shape for f_1=4.004 Hz in direction Y

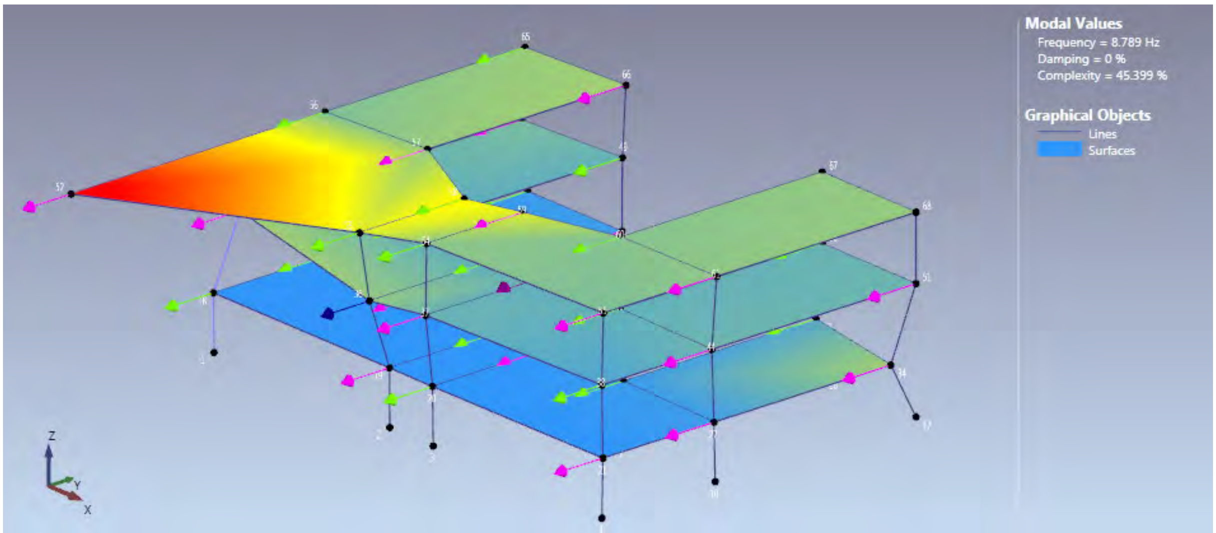

Fig. 2-18 Mode shape for f_2=8.789 Hz in direction Y

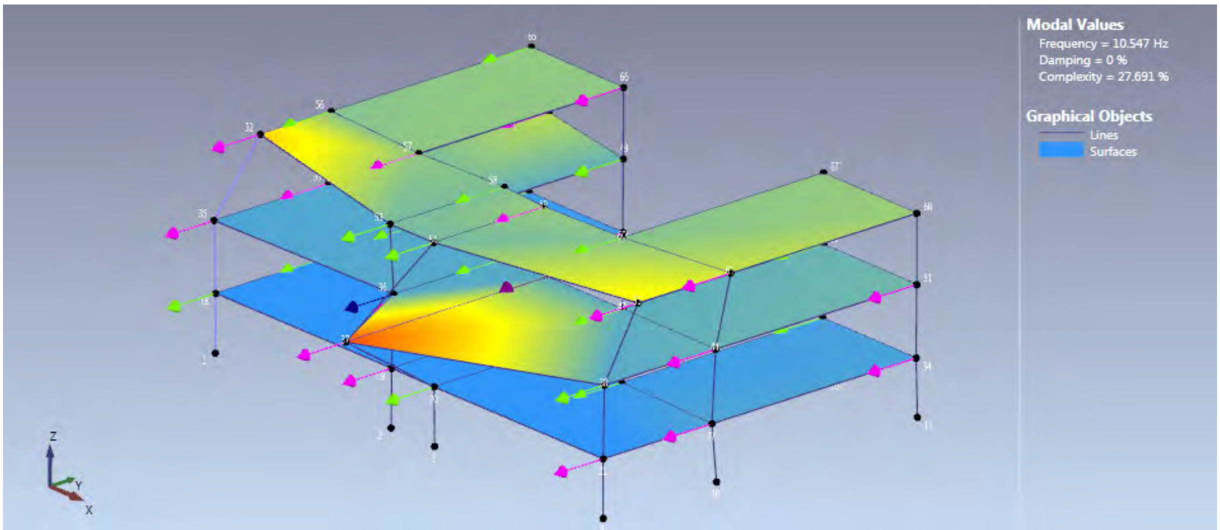

Fig. 2-19 Mode shape for f_3=10.547 Hz in direction Y

Damping

With respect to the client request to determine the damping ratios of the individual modes of vibration, the Enhanced Frequency Domain Decomposition-Peak Picking method was used. The obtained values for damping are presented in Table 2-4.

Table 2-4. Estimated damping values for both directions in %.

Estimation	Direction X	Direction Y
1	5.5	2.4
2	4.2	1.9
3	3.4	2.3

3. COMMENTS

Upon the results of performed in-situ dynamic tests of the Economic-Trade School building in Pozarevac, several comments can be made.

- The dynamic characteristics of the building were estimated by in-situ dynamic tests by means of measuring accelerations in three directions originating from ambient sources.
- Operational modal analysis was performed with the software Artemis Modal 3.6.0.9 and natural frequencies and mode shapes were identified using the FDD method.
- The first peaks at *4.00 Hz* which have very small magnitudes in comparison to the dominant peaks could be identified as global mode shape. However the building would dominantly vibrate with higher frequency or frequency app. *9.00 Hz* in both directions.
- The identified dominant frequencies (app. *9.00 Hz*) in both directions of the building were not found to correspond to a global mode shape of the building. This conclusion was derived from the fact that no consistent modes of vibration were found for the measured points that match the theoretical definition of the mode shapes.
- The fact that no mode shape could be identified can be supported by the fact that the structural system of the floors is flexible in its plane and does not have the capacity to provide robust and integral oscillation of the building. Instead, most of the individual walls of the buildings oscillate by their own without connection to the rest of the walls.

Prepared by:

Prof. Elena Dumova-Jovanoska,PhD

Asist. prof. Sergey Churilov, PhD