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Report IZIIS 2011-39

EXPERIMENTAL IN-SITU TESTING OF RESIDENTIAL BUILDING BUILT IN DC-90 SYSTEM, LOCATED IN BECICI, MONTENEGRO, BY AMBIENT AND FORCED VIBRATION METHODS

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1. INTRODUCTION

For the needs of SISTEM DC90 Co.ltd from Belgrade, Serbia, an experimental in-situ testing of the residential building in Becici, Montenegro, was performed by ambient and forced vibration testing method. The test was realized by the team consisting of researchers from three institutions:

1. Prof. Dr. Ljubomir Tashkov- IZIIS
2. Prof. Dr. Lidija Krstevska- IZIIS
3. Acad.Ing. Zoran Petrashkovic- Sistem DC-90
4. Ing. Tino Mihajlovic – DIGITEXX
5. Ing. Sasho Atanasovski-DIGITEXX

The testing program and measurements were realized in June 2011 under leadership of IZIIS professors mentioned above. DIGITEXX provided the equipment for data collection from both ambient and forced vibration tests. DC-90 provided vibrator-shaker for generating of forced vibrations.

2. OBJECTIVES OF THE TESTING

The objective of the testing was to investigate dynamic behaviour of the building based on which the dynamic properties - natural frequencies, mode shapes and damping coefficients could be defined. These parameters are important to be defined because they are strongly related to prediction of seismic behaviour of the structure under earthquake excitation as well as for calibration of the numerical model to be used for analysis.

3. DESCRIPTION OF THE STRUCTURE

The building is built of brick walls (Wienerberger blocks) strengthened by RC columns 25/25 cm, on distance 1.5-4.0 m. The gravity loads are carried by the brick walls and RC columns, while horizontal loads by vertical RC elements and diagonals with DC-90 dampers. The diagonals are made of steel profiles incorporated into the walls. The steel dampers are positioned in the bottom part of diagonals. The horizontal belts are with dimension 25/25 cm. The floor slabs are monolithic RC concrete plates with thickness of 12 cm. The building is incorporated in the complex of several building separated by construction joints but still interconnected each other by floors and infill material in the joints (Fig.1).

The building consists of 5 floor levels as shown on the figures bellow(Figs.2-9)

Figure 1: The residential building in Becici complex subject of the experimental testing

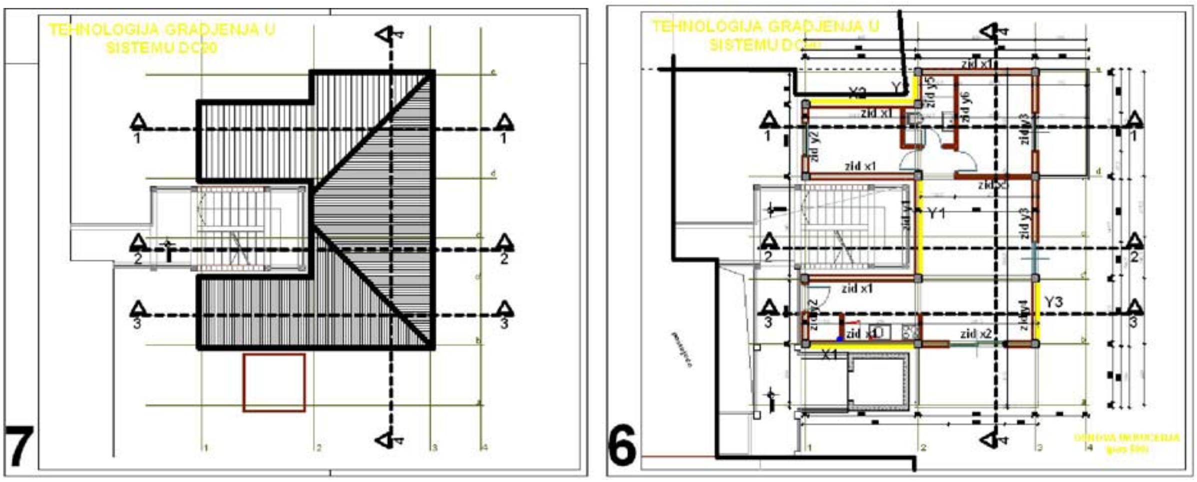


Figure 2: Plan view-Roof and Level 500

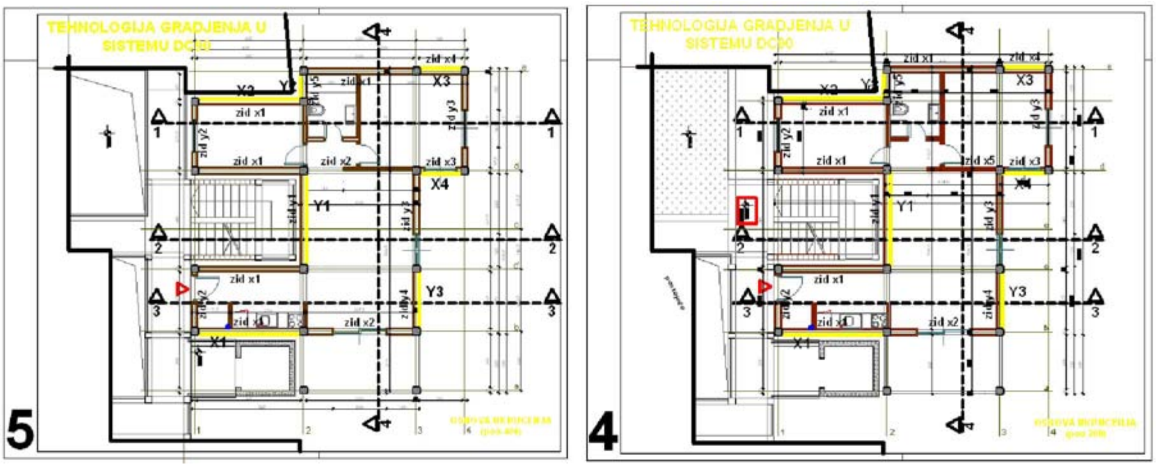


Figure 3: Plan view-Levels 400and 300

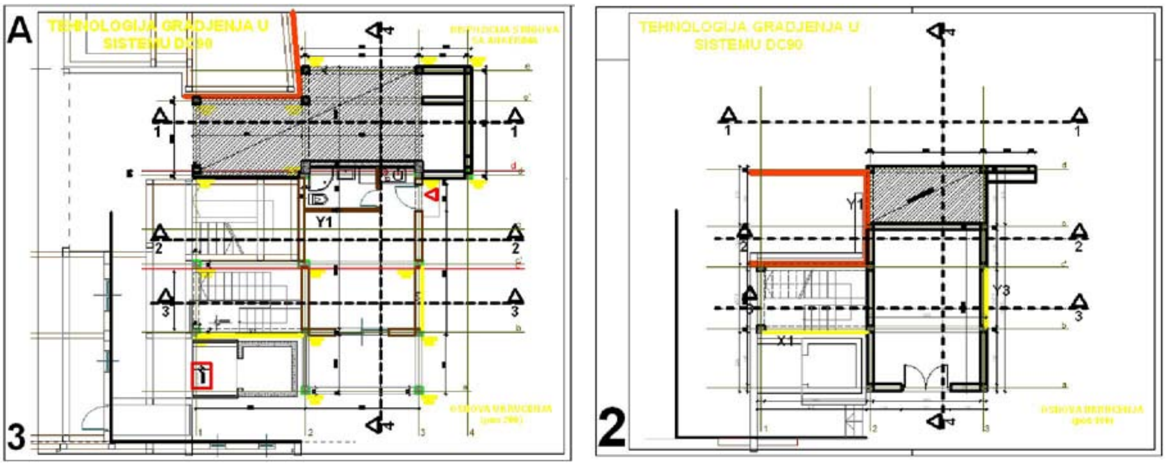


Figure 4. Plan view-Level 200 and 100

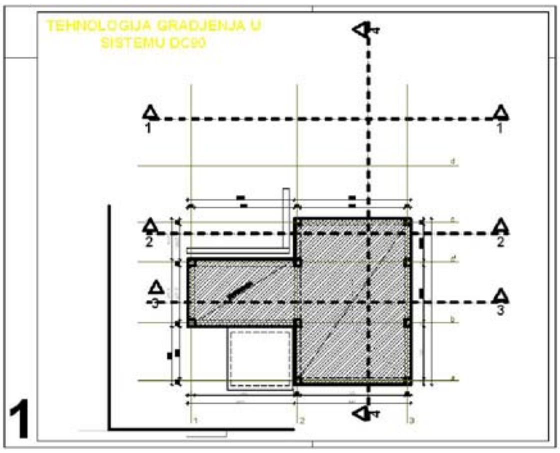


Figure 5. Plan view-Level 00

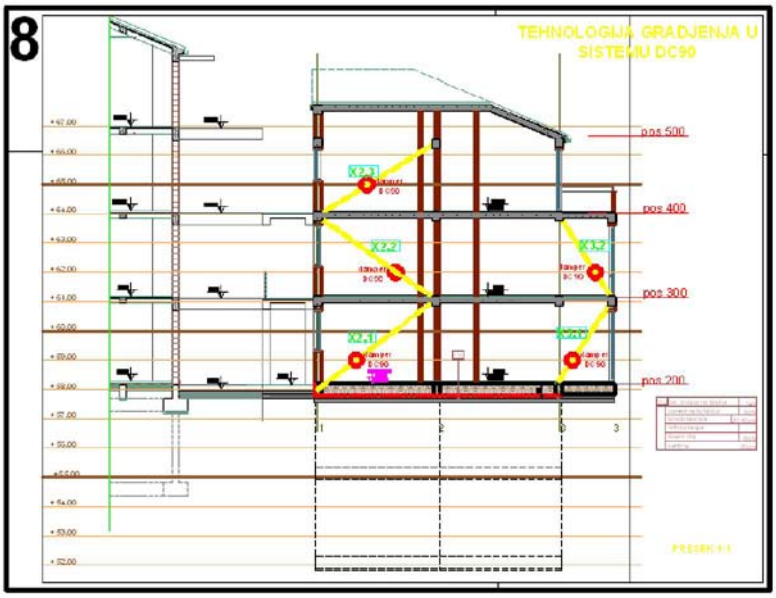


Figure 6. Cross section1-1

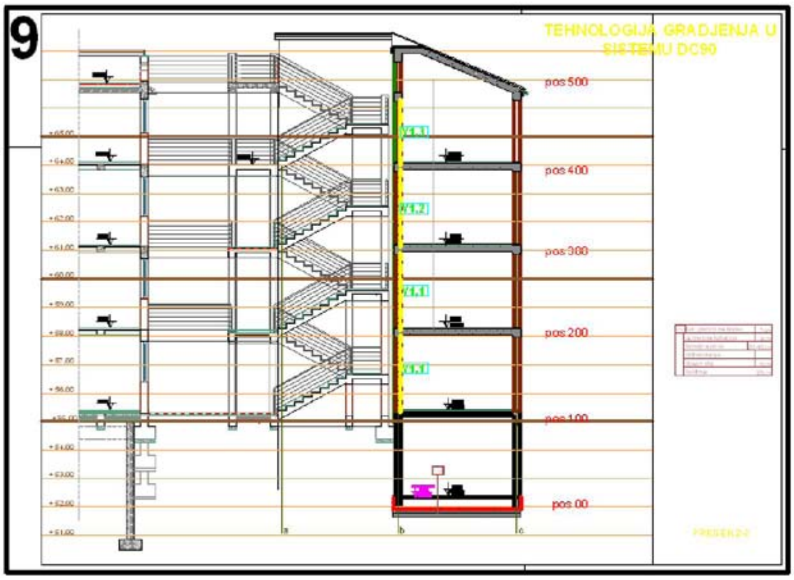


Figure 7. Cross section2-2

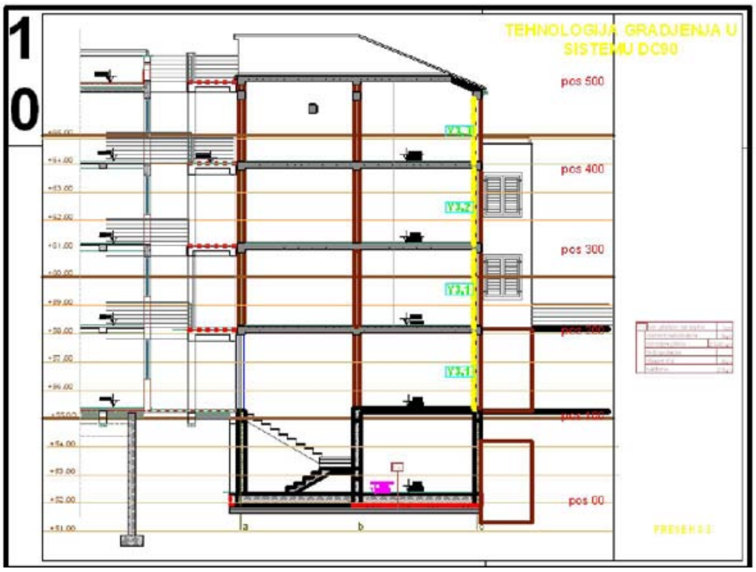


Figure 8. Cross section 3-3

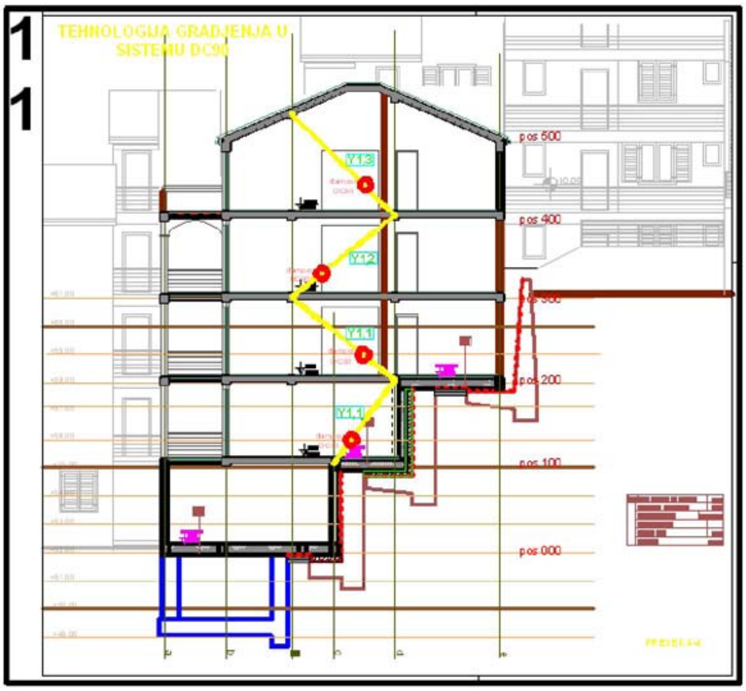


Figure 9. Cross section 4-4

4. AMBIENT VIBRATION EQUIPMENT AND TESTING PROCEDURE

For recording vibrations caused by ambient excitation, the DIGITEXX PDAQ 16 channels data acquisition system and 4 three-axial accelerometers type D110-T and 4 uni-axial accelerometers type D110-U were used (Fig.10).

Figure 10. DIGITEXX PDAQ 16 channels data acquisition system and accelerometers type D110-T and D110-U used for ambient vibration measurements

Dynamic characteristics of the building in Becici were obtained by ambient vibration testing method which is widely applied and popular full-scale testing method for experimental definition of structural dynamic characteristics. It is based on measuring the structural vibrations caused by the ambient, Fig.11. As ambient forces can be treated the wind, the traffic noise or some other micro-tremor and impulsive forces like wave loading or periodical rotational forces of some automatic machines. The method is very fast and the relatively simple procedure can be performed on a structure in use, without disturbing its normal functioning.

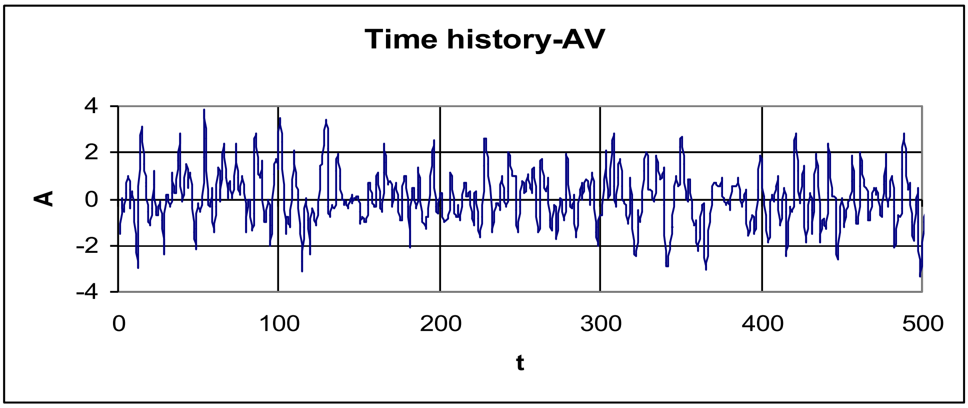


Figure 11. Time history of vibrations excited by the ambient

The basic assumption used in this method is that the excitation forces are a stationary random process, having an acceptably flat frequency spectrum. In such conditions, the structures will vibrate and their response will contain all their normal modes.

The ambient vibration testing procedure consists of real time recording of the vibrations and processing of the records. The initial test is the dynamic calibration test. During this test all sensors (accelerometers) are placed on the same position in the same direction (Fig.12) and the signals are recorded simultaneously and Fourier spectra obtained. Resonant frequencies of the structure can be preliminary defined using the dynamic calibration tests, but the final definition of the natural frequencies is possible after obtaining the mode shapes of vibration.

Figure 12. Dynamic calibration test of DIGITEXX accelerometers

After this calibration test, the accelerometers are placed at different levels and different points of the structure, measuring one, two or three directions simultaneously. This is necessary for obtaining the mode shapes of vibration. One point is chosen as a reference one, usually at the highest level of the structure. The duration of the recording should be long enough to eliminate the influence of possible non-stochastic excitations which may occur during the test. For post-processing and analysis of the recorded vibrations in all measuring points ARTeMIS software was used. This software is based on the Peak Picking technique and Frequency Domain decomposition and has possibilities for good graphical presentation of the obtained data and “avi” simulations of the mode shapes of vibration.

5. FORCED VIBRATION EQUIPMENT AND TESTING PROCEDURE

This method is based on the resonant theory. Harmonic force with max intensity of 10.000 KN produced by eccentric type vibrator DC-90 (Fig 13 and Fig.14) within the frequency range 1.0-10.0 Hz, is applied on the top of the structure by successive change of the exciting frequency by small steps (0.05 Hz). The force-frequency relation for the vibrator DC-90 is given on Fig. 15. The acceleration response at the measuring point versus forcing frequency gives the frequency response curve (Fig 16). The frequency corresponding to peak of the curve represents the resonant frequency of the structure. At that moment, the vibration intensity is much stronger than before or after, because of resonant state. Within the frequency range of 1.0-10.0 Hz, usually several resonant frequencies can be defined. The direction of excitation force can be changed by changing the position of the vibrator fixed to the floor slab.

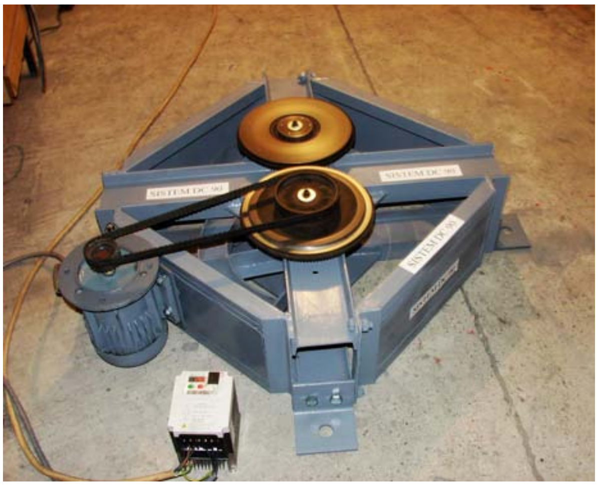


Figure 13. DC-90 shaker

Figure 14. DC-90 equipment- test set-up

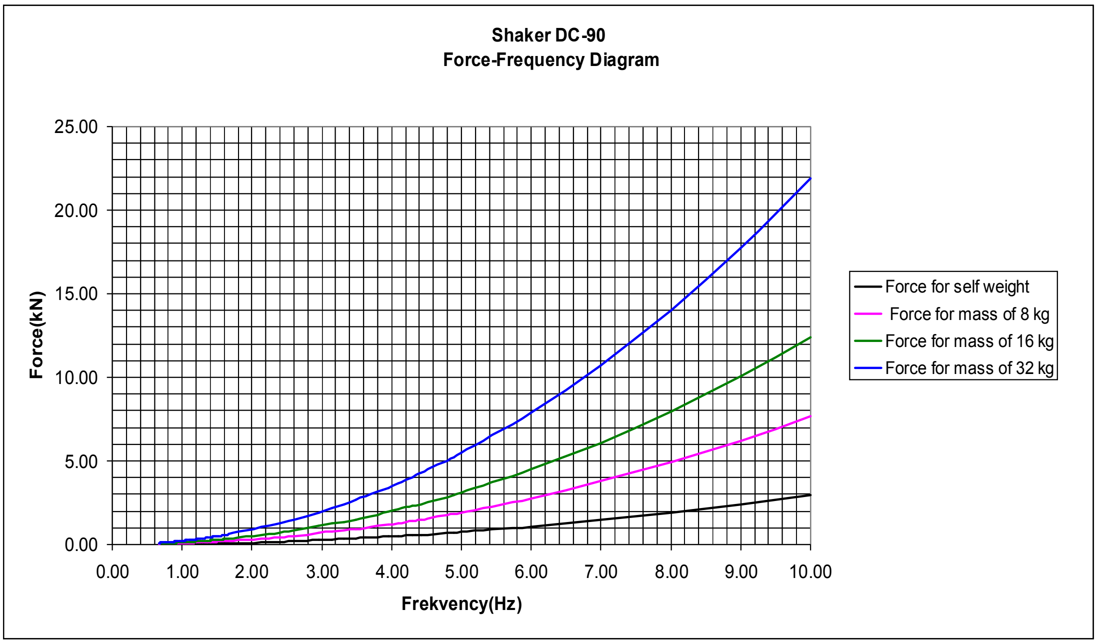


Figure 15. Force-frequency diagram of DC-90 shaker

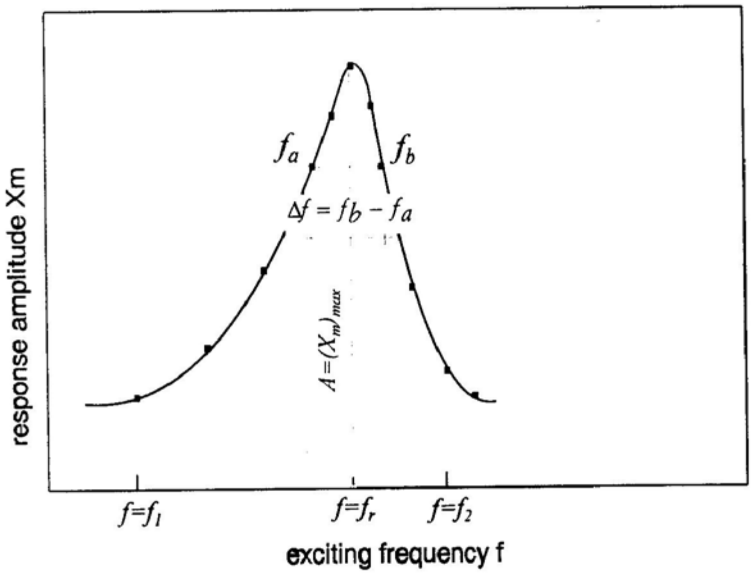


Figure 16. Frequency response curve

6. TEST SET-UP

The measurements were performed in 21 points in two orthogonal directions – transversal and longitudinal(X and Y). The reference accelerometers were placed at level 400. The position of the points was the same for ambient and forced vibration test. The data sets consisted on records of acceleration signals with duration of 100 seconds and the sampling frequency was 200 s/sec. In the first phase, ambient vibration test was performed, then forced vibration in x and y direction respectively. Based on these measurements, the dynamic characteristics: resonant frequencies, mode shapes and damping coefficients were defined. The data processing was performed by ARTeMIS software.

7. EXPERIMENTAL RESULTS

7.1. AMBIENT VIBRATION TEST RESULTS

The disposition of the measuring points is shown on Fig.17

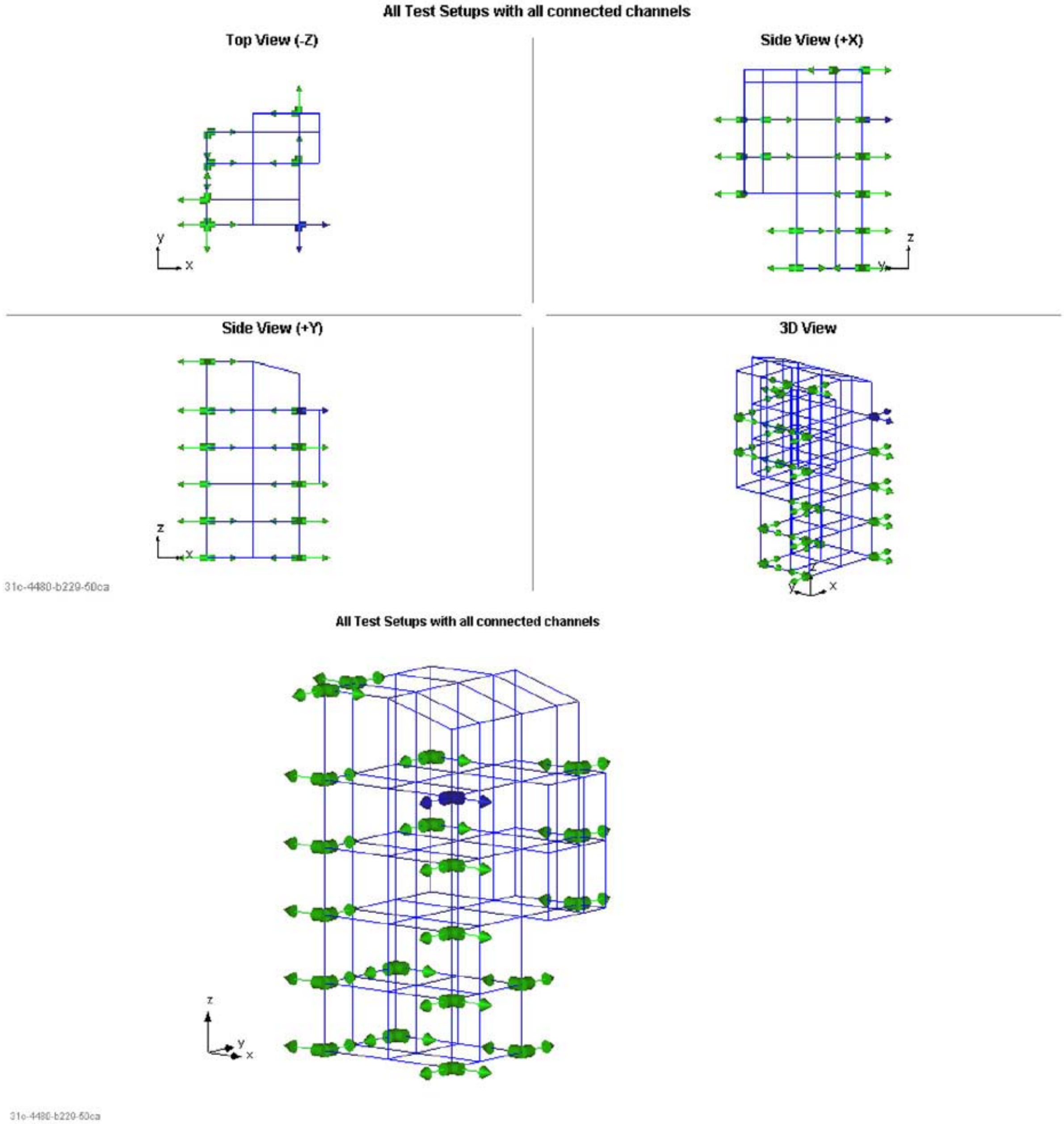


Figure 17. Disposition of the measuring points

The Spectral density curves are presented on Fig.18 showing the peaks representing the dominant frequencies. Tabular presentation of the defined modes is given in Table.1

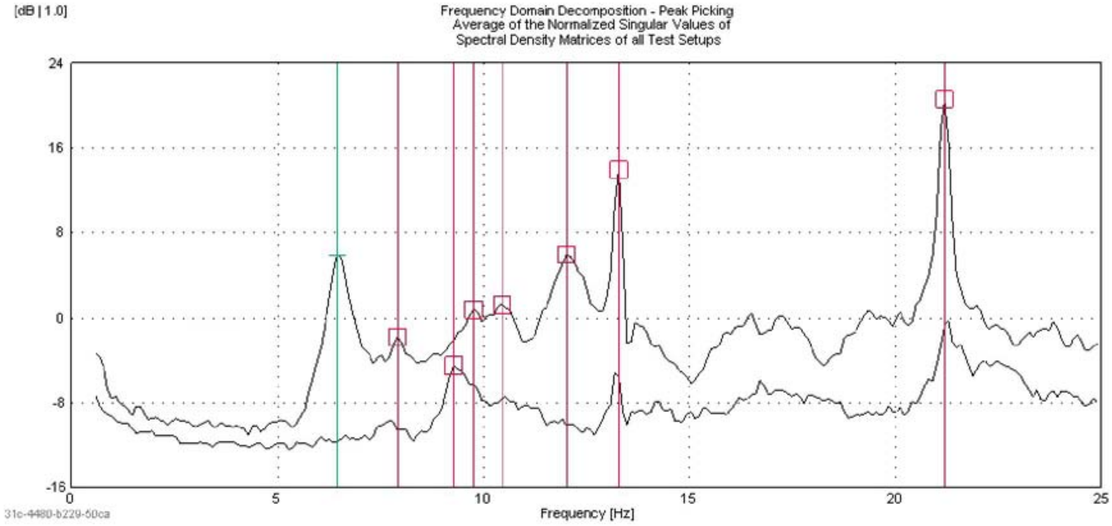
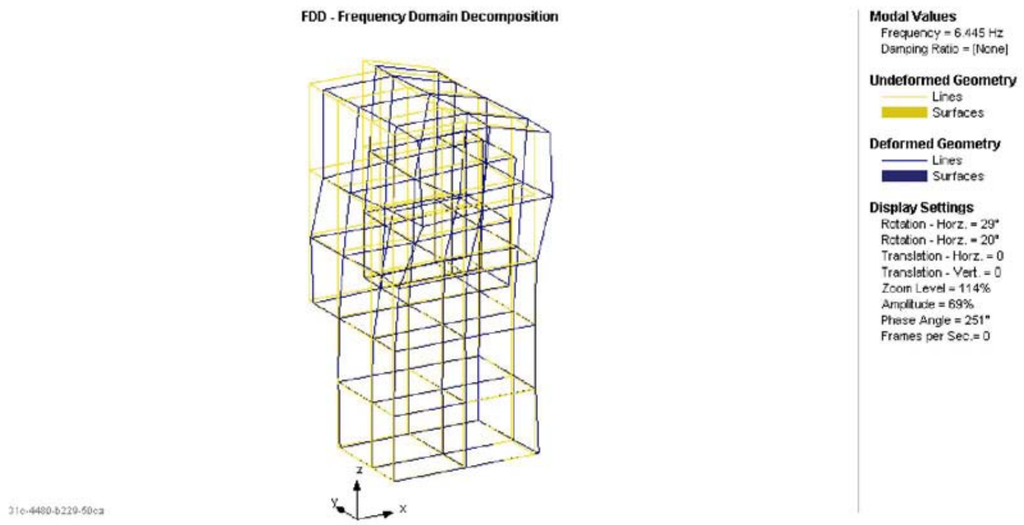


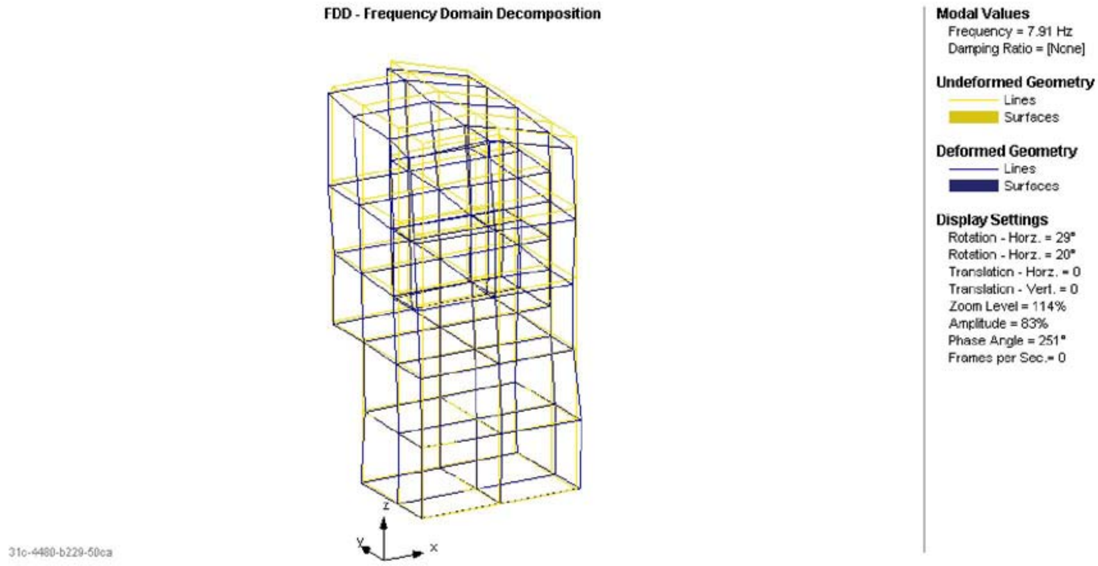
Figure 18 Peak-picking –spectral density curves

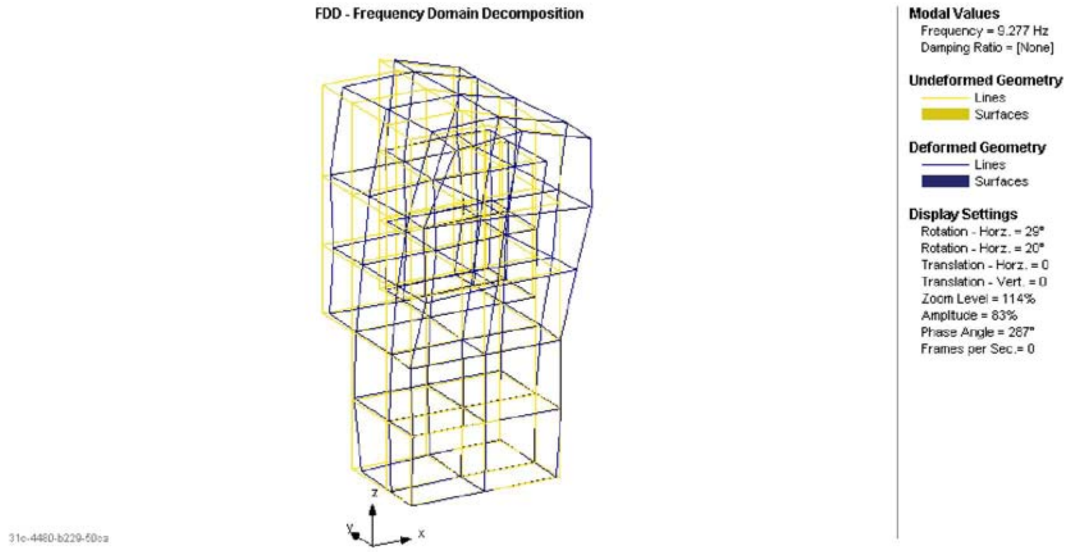
Table.1 Tabular presentation of modes and damping coefficients

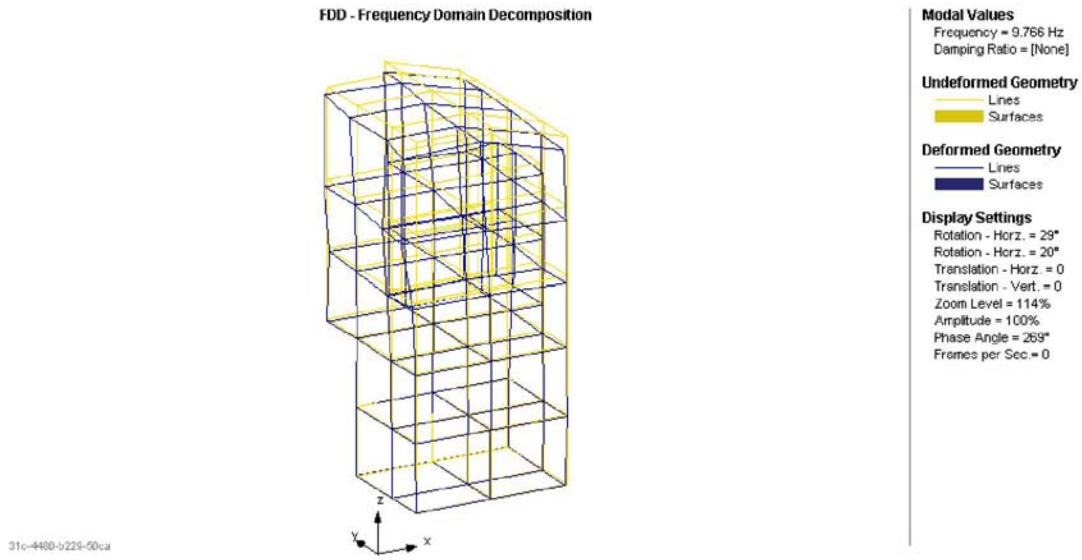
Mode	Frequency [Hz]	Damping [%]
FDD Mode 1	6.45	3.1
FDD Mode 2	7.91	2.4
FDD Mode 3	9.28	1.4
FDD Mode 4	9.77	2.5
FDD Mode 5	10.45	2.9
FDD Mode 6	12.01	3.1
FDD Mode 7	13.28	2.1
FDD Mode 8	21.19	-

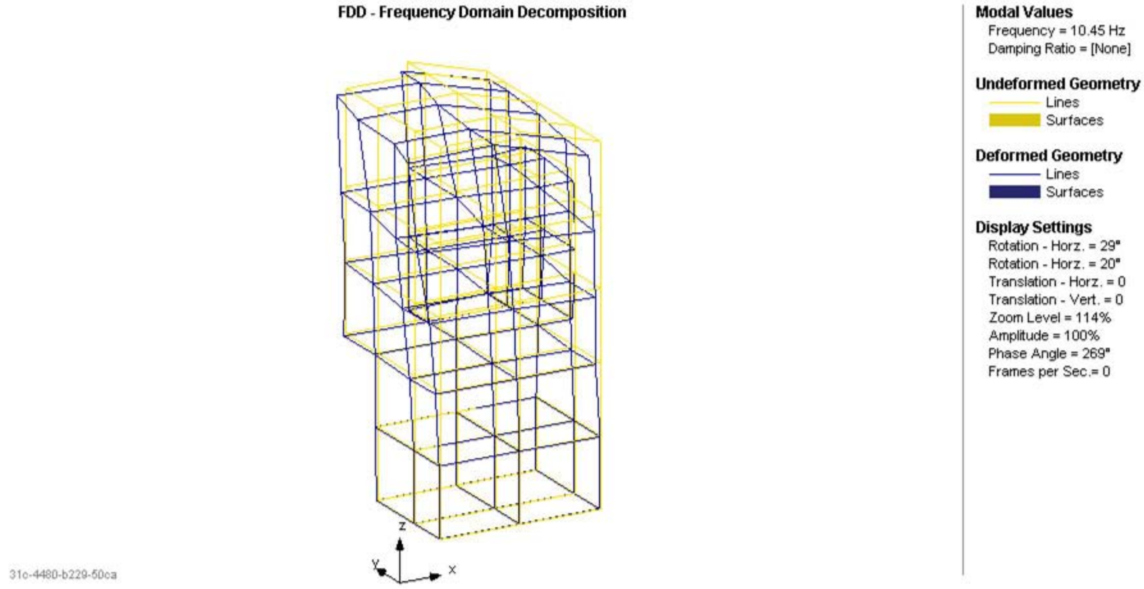
The spatial presentation of the modes corresponding to dominant frequencies is given on Fig. 19 below.

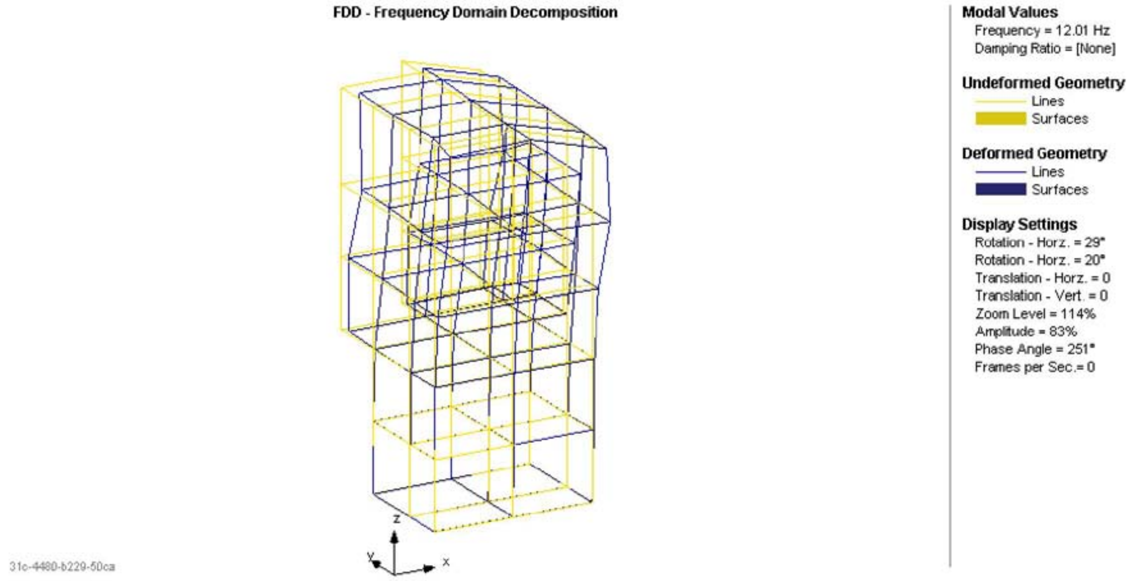


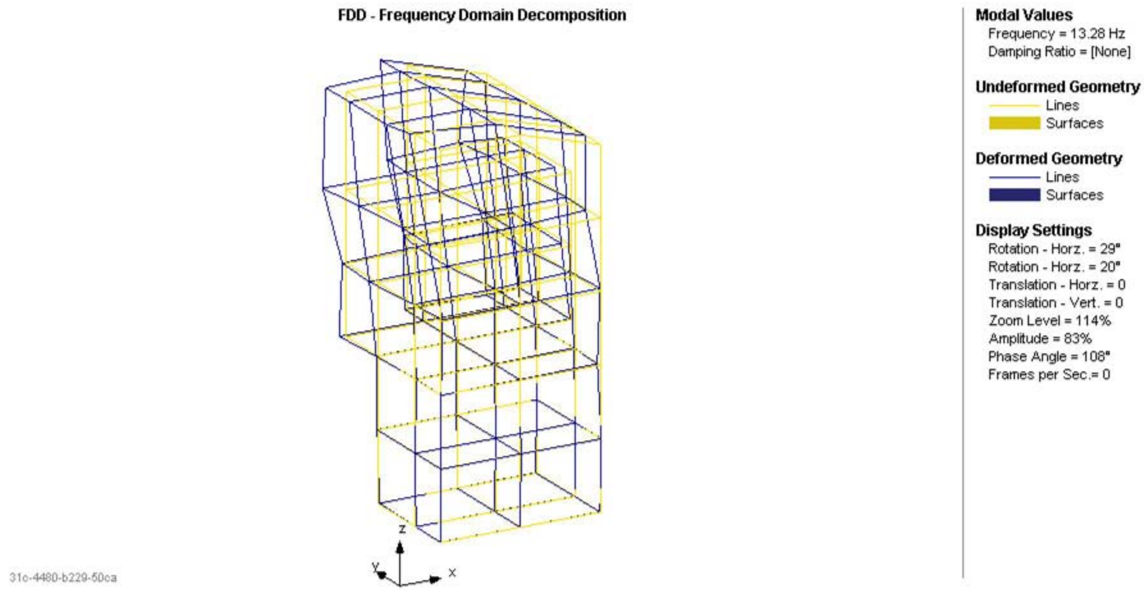

FDD - Frequency Domain Decomposition
Modal Values
Frequency = 7.91 Hz
Damping Ratio = [None]
Undeformed Geometry
Lines
Surfaces
Deformed Geometry
Lines
Surfaces
Display Settings
Rotation - Horz. = 29°
Rotation - Horz. = 20°
Translation - Horz. = 0
Translation - Vert. = 0
Zoom Level = 114%
Amplitude = 83%
Phase Angle = 251°
Frames per Sec.= 0
z
y
x
31c-4480-b229-50ca


FDD - Frequency Domain Decomposition
Modal Values
Frequency = 9.277 Hz
Damping Ratio = [None]
Undeformed Geometry
Lines
Surfaces
Deformed Geometry
Lines
Surfaces
Display Settings
Rotation - Horz. = 29°
Rotation - Horz. = 20°
Translation - Horz. = 0
Translation - Vert. = 0
Zoom Level = 114%
Amplitude = 83%
Phase Angle = 287°
Frames per Sec.= 0
z
y
x
31c-4480-b229-50ca


FDD - Frequency Domain Decomposition
Modal Values
Frequency = 9.766 Hz
Damping Ratio = [None]
Undeformed Geometry
Lines
Surfaces
Deformed Geometry
Lines
Surfaces
Display Settings
Rotation - Horz. = 29°
Rotation - Horz. = 20°
Translation - Horz. = 0
Translation - Vert. = 0
Zoom Level = 114%
Amplitude = 100%
Phase Angle = 269°
Frames per Sec.= 0
z
y
x
31c-4480-b229-50ca


FDD - Frequency Domain Decomposition
Modal Values
Frequency = 10.45 Hz
Damping Ratio = [None]
Undeformed Geometry
Lines
Surfaces
Deformed Geometry
Lines
Surfaces
Display Settings
Rotation - Horz. = 29°
Rotation - Horz. = 20°
Translation - Horz. = 0
Translation - Vert. = 0
Zoom Level = 114%
Amplitude = 100%
Phase Angle = 269°
Frames per Sec.= 0
z
y
x
31c-4480-b229-50ca


FDD - Frequency Domain Decomposition
Modal Values
Frequency = 12.01 Hz
Damping Ratio = [None]
Undeformed Geometry
Lines
Surfaces
Deformed Geometry
Lines
Surfaces
Display Settings
Rotation - Horz. = 29°
Rotation - Horz. = 20°
Translation - Horz. = 0
Translation - Vert. = 0
Zoom Level = 114%
Amplitude = 83%
Phase Angle = 251°
Frames per Sec.= 0
z
y
x
31c-4480-b229-50ca


FDD - Frequency Domain Decomposition
Modal Values
Frequency = 13.28 Hz
Damping Ratio = [None]
Undeformed Geometry
Lines
Surfaces
Deformed Geometry
Lines
Surfaces
Display Settings
Rotation - Horz. = 29°
Rotation - Horz. = 20°
Translation - Horz. = 0
Translation - Vert. = 0
Zoom Level = 114%
Amplitude = 83%
Phase Angle = 108°
Frames per Sec.= 0
z
y
x
31c-4480-b229-50ca

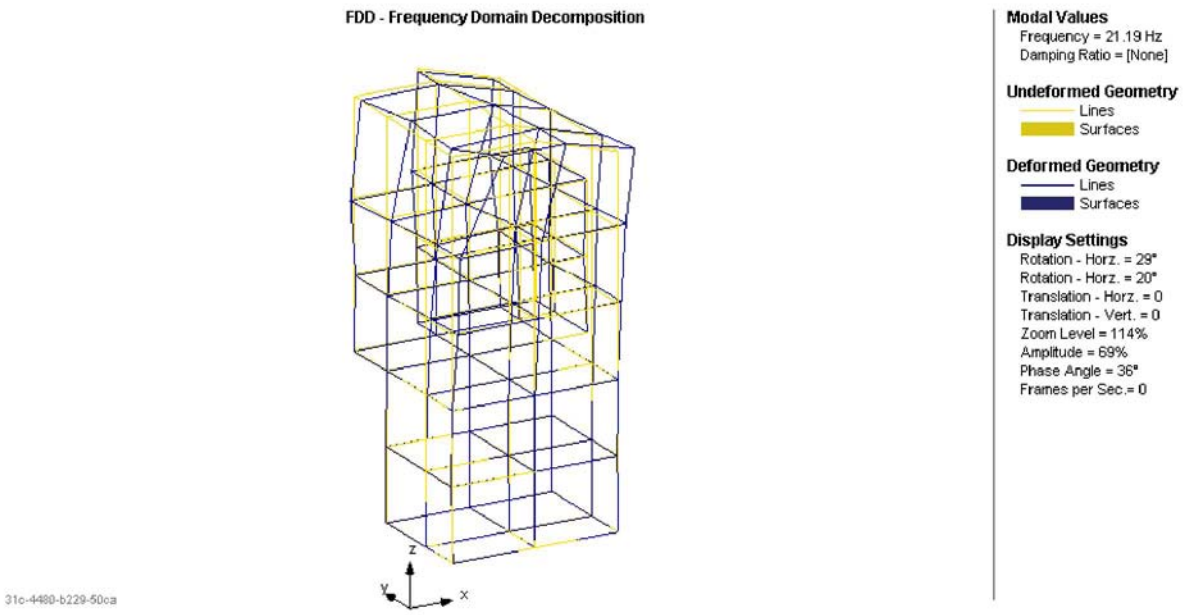
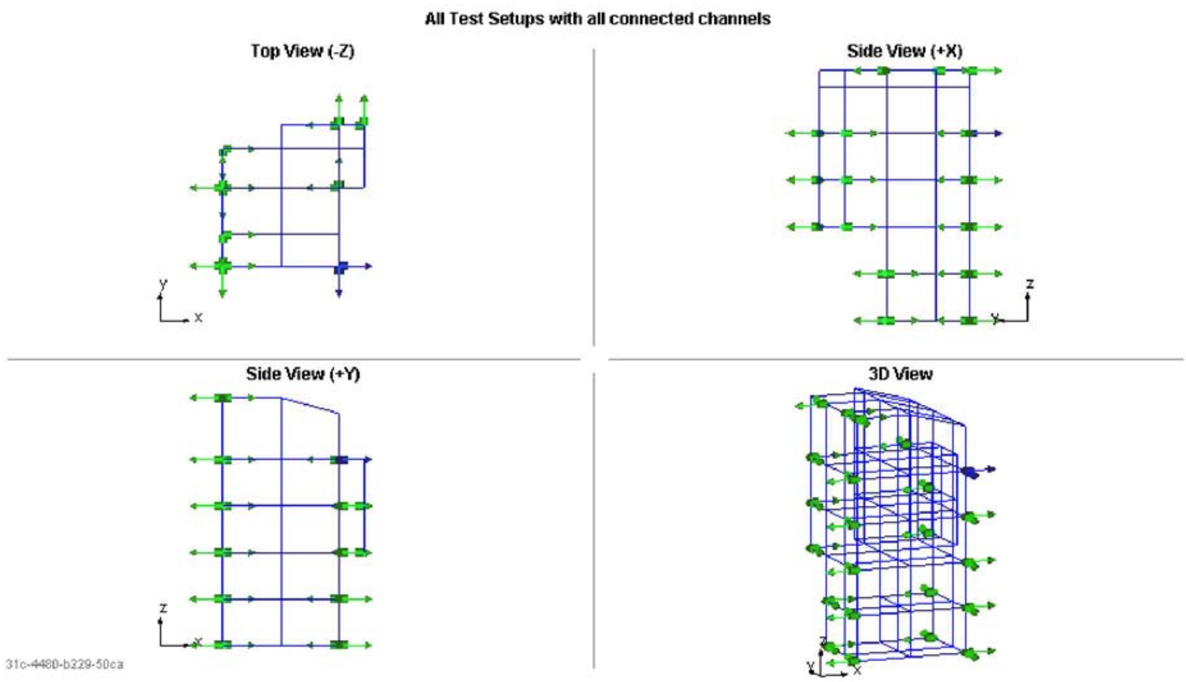


Figure19. Mode shapes- spatial presentation

As can be seen from the mode shapes as well as from the "avi" video clips (which are integral parts of this report) the torzional modes are prevailing.

7.2. FORCED VIBRATION TEST RESULTS

The generated force was in the frequency range of 4.0-10.0 Hz . The frequency step was 0.5 Hz. The shaker was fixed on the floor slab by 4 bolts at level 400. The direction of excitation was first "X"(according to generated geometry) i.e. direction "Y"(according the position of the accelerometers). Measurements were performed at the same points as for ambient vibration in two orthogonal directions as shown on Fig.20 below:



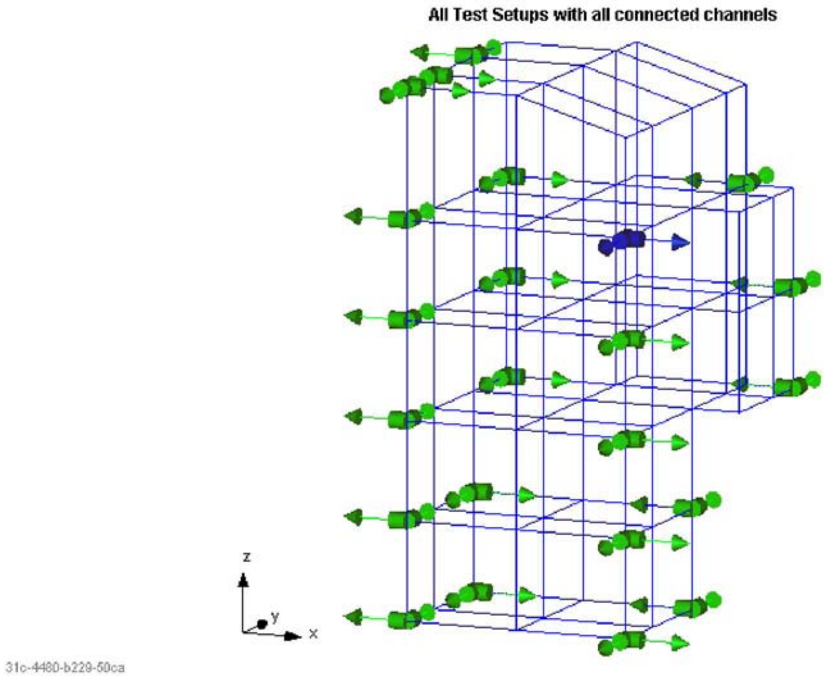


Figure 20. Forced vibration- measuring points

7.2.1. Forced vibration with excitation in Y direction (DIGITEXX sign)

The frequency response curve for Y direction is presented on Fig.21 given bellow.

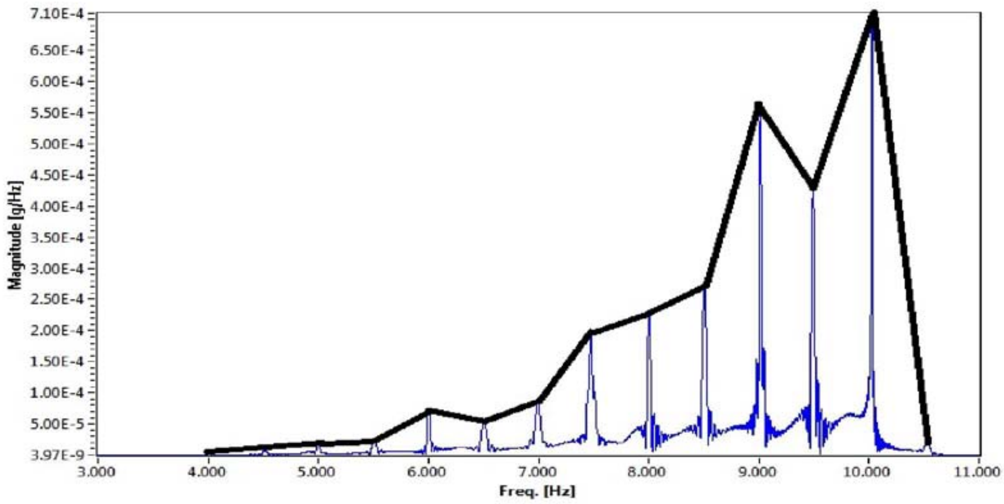


Figure 21 Frequency response curve in Y direction obtained from forced vibration test

The spectral density curves obtained by ARTeMIS are presented in Fig 22. It is obvious that the peaks of both curves are compatible.

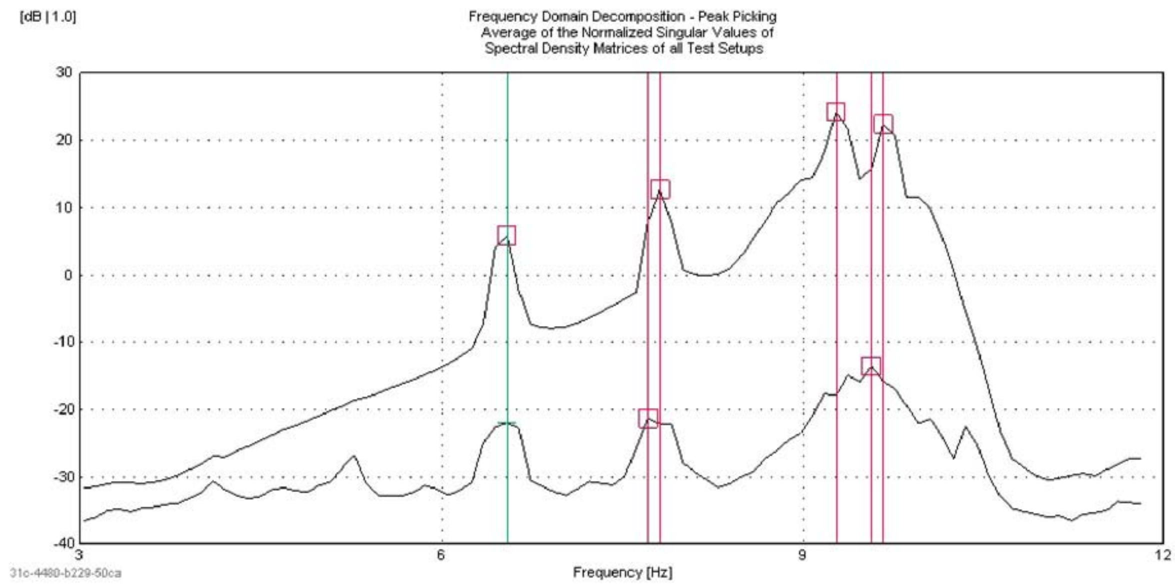
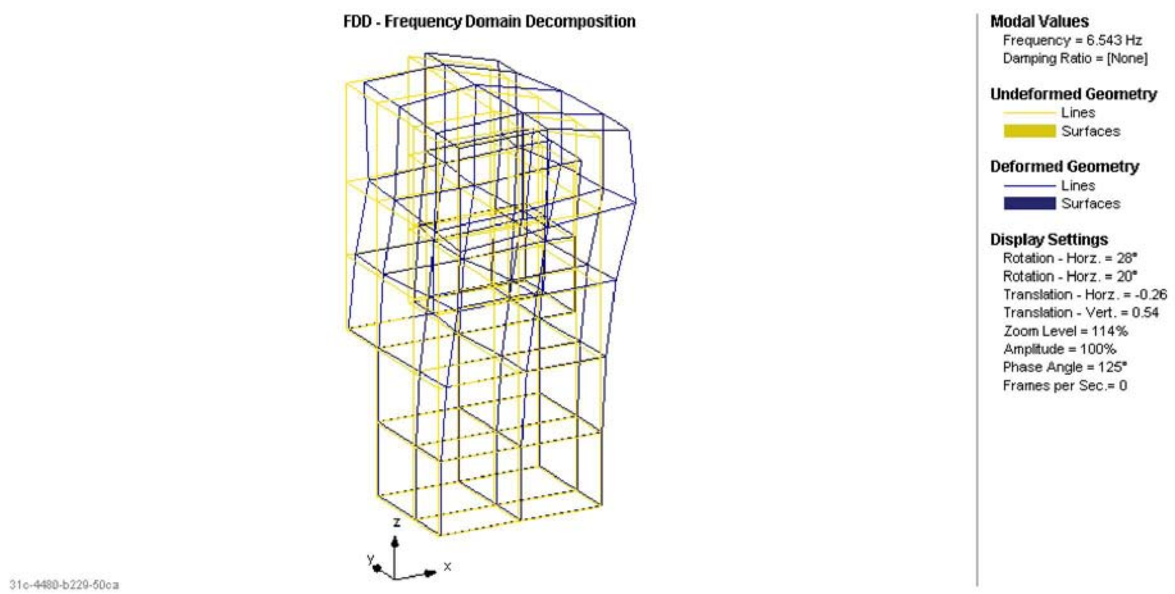


Figure 22 Peak-picking – spectral density function for excitation force in Y direction

Mode	**Frequency [Hz]**
FDD Mode 1	6.543
FDD Mode 2	7.813
FDD Mode 3	9.277
FDD Mode 4	9.668

The mode shapes obtained for excitation in Y direction are given on Fig 23. It is obvious that the frequencies and mode shapes are compatible with those obtained by ambient vibration test.



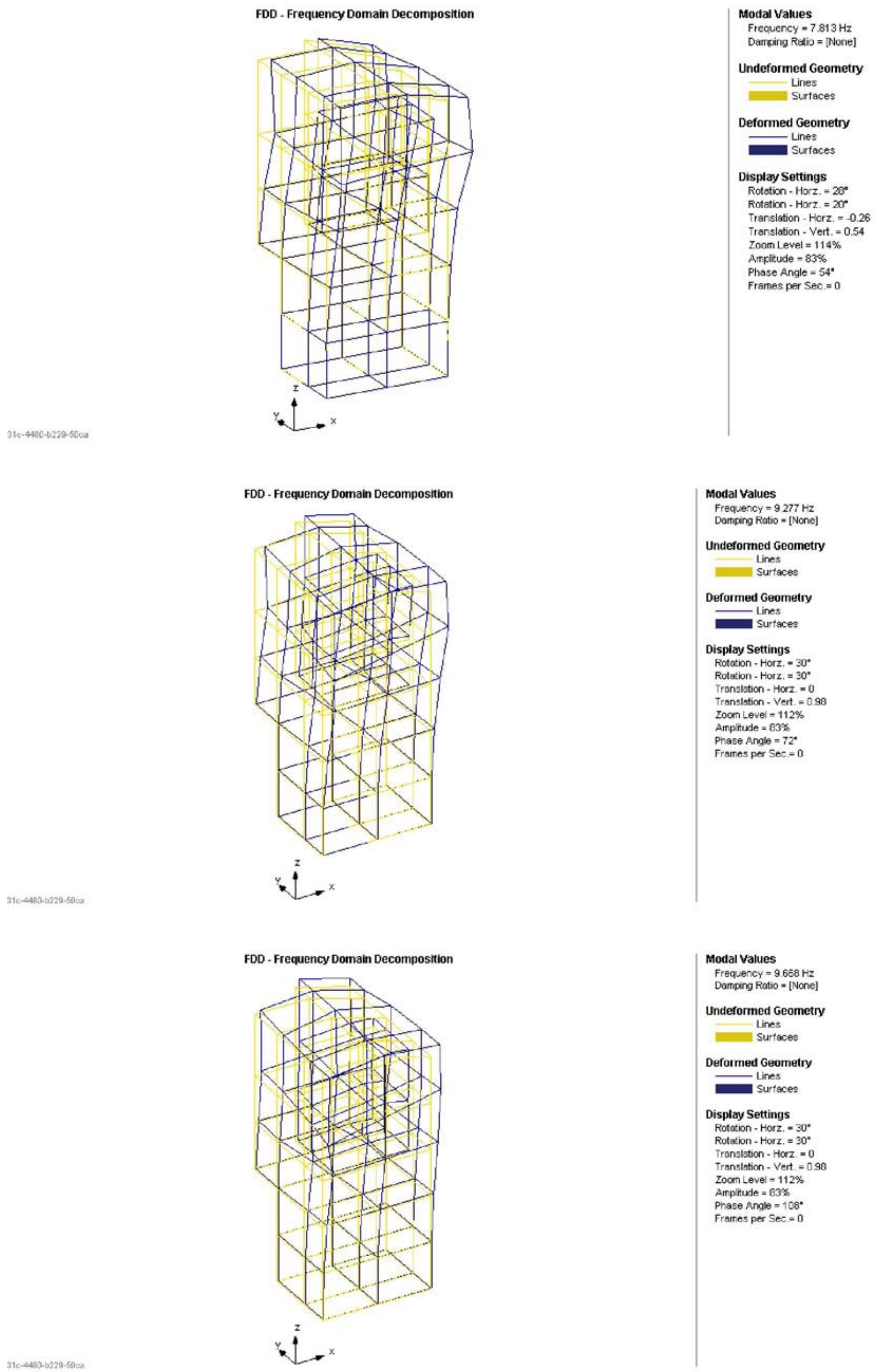


Figure 23. Mode shapes of the building obtained from forced vibration test in Y (DIGITEXX)

7.2.1. Forced vibration with excitation in X direction (DIGITEXX sign)

The test in X direction was performed on the same way as for Y direction. The frequency response curve as well as the Spectral density curve is shown on Figs. 24 and 25 respectively.

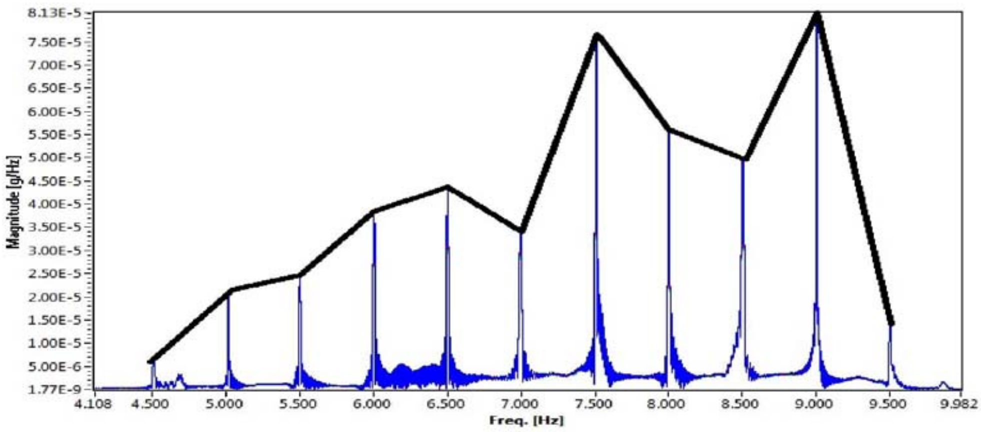


Figure 24. Frequency response curve obtained from forced vibration with excitation in X direction (DIGITEXX sign)

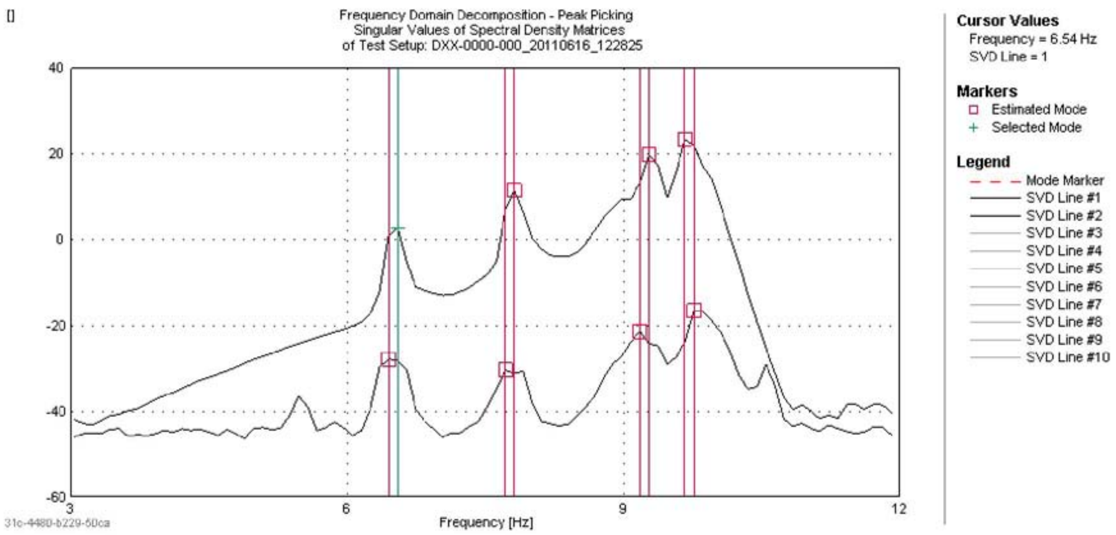
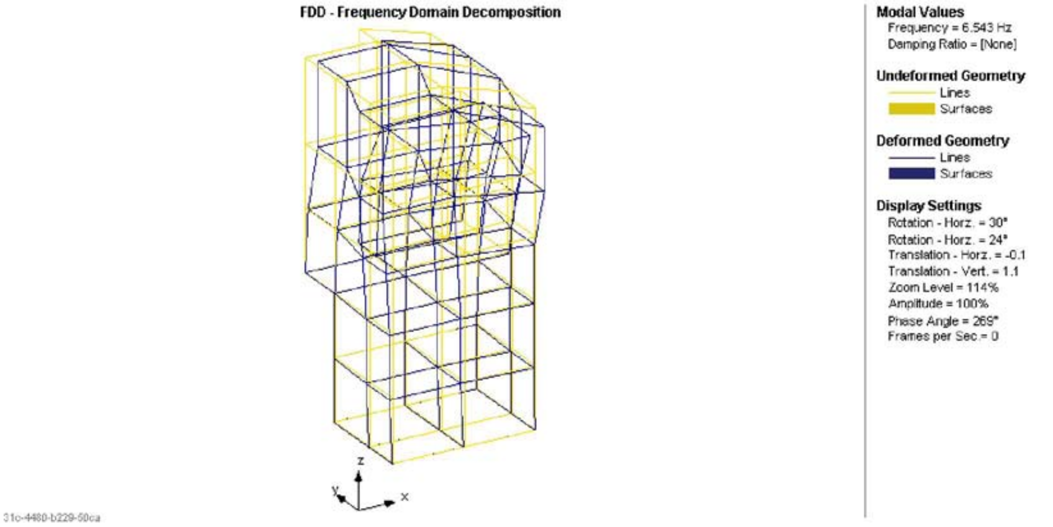
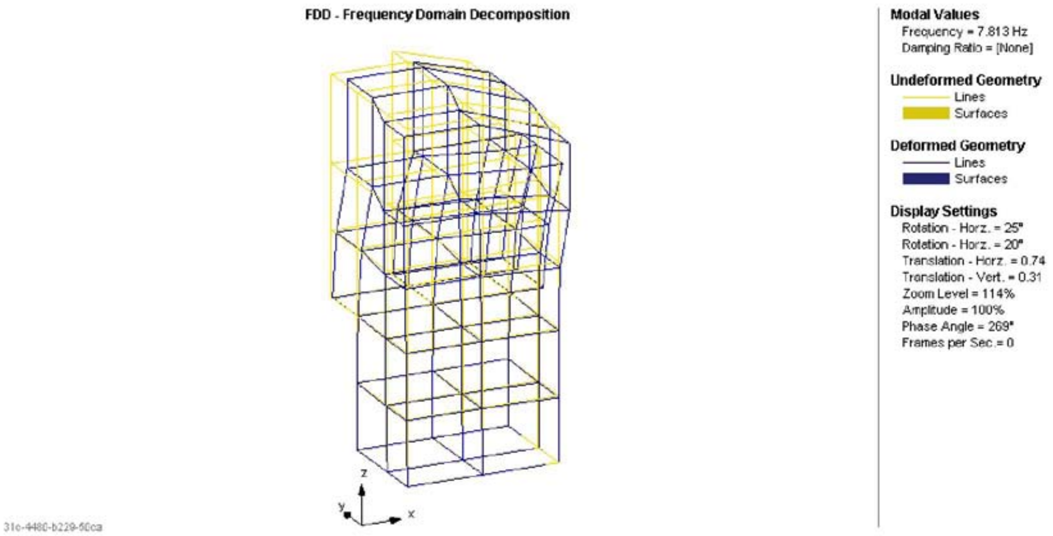


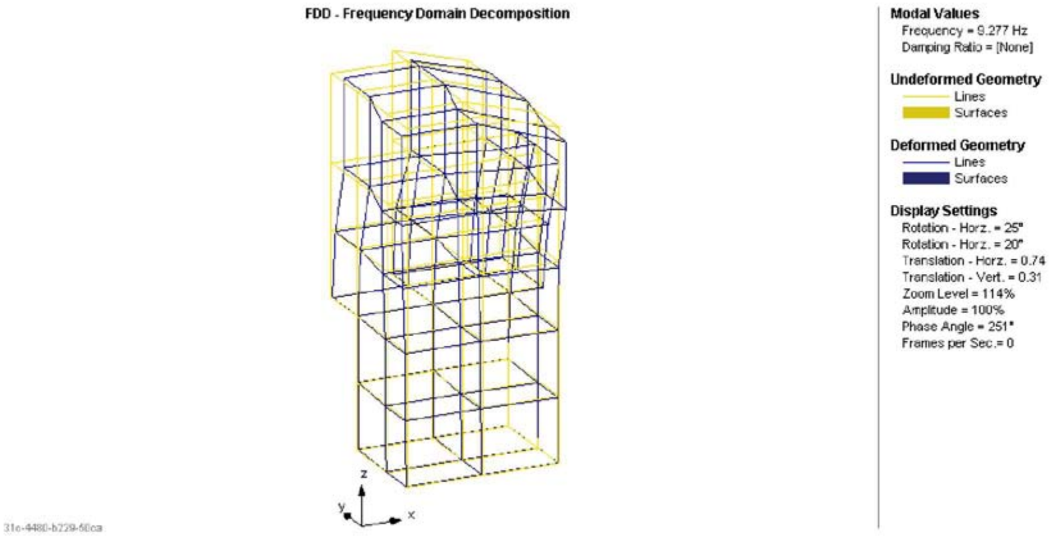
Figure 25. Peak-picking - spectral density function for excitation force in X direction (Digitexx)

Mode	**Frequency [Hz]**
FDD Mode 1	6.543
FDD Mode 2	7.813
FDD Mode 3	9.277
FDD Mode 4	9.668

The curves are very similar each other for both directions. Actually, because of "coupling" of the modes, the resonant frequencies of both directions are always present in the response curves, independently of the direction of force excitation. The mode shapes of the building for excitation in X direction are shown on the Fig. 26.







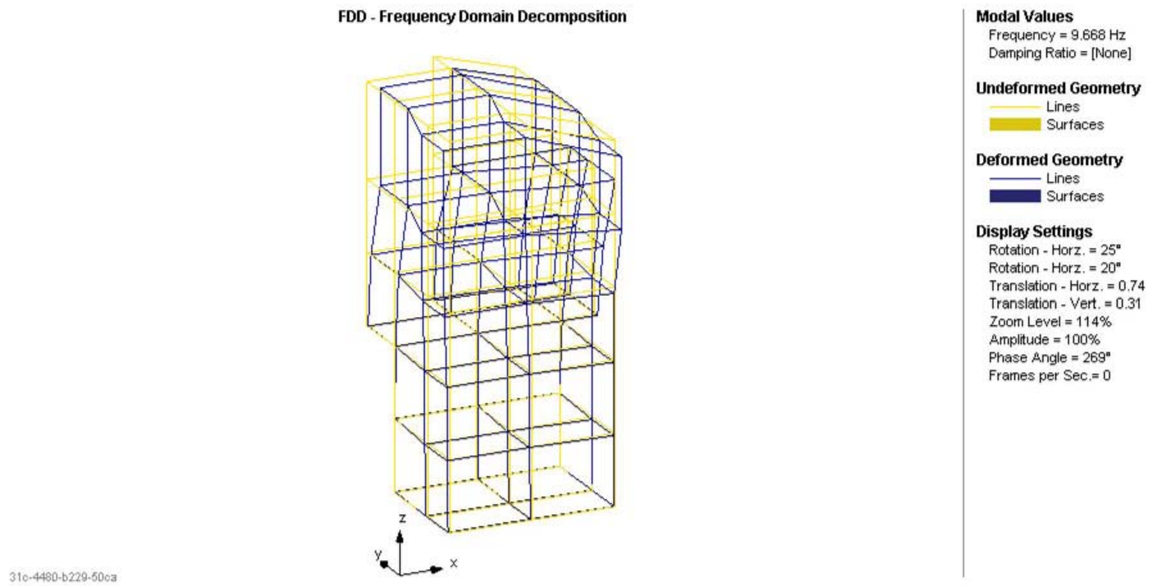


Figure 26. The mode shapes of the building for excitation in X direction

In order to check the separation joint effectiveness, two positions of accelerometers have been selected during the forced vibration test (in both directions) as shown on Fig. 27. The results show that the joint doesn't functioning properly, because of infilling the join with mother and covered by floor plates.

Figure 27 Separation joint- forced vibration test

8. COMPARISON BETWEEN EXPERIMENTAL AND ANALITICAL RESULTS

The analytical and experimental resonant frequencies and mode shapes have been compared. Table2 shows the resonant frequencies obtained analytically and experimentally. For the estimated modulus G=1.500.000 kN/m2 the analytical resonant frequencies as well as the vibration modes correspond very good with experimental ones. The analytical and experimental "avi" clips show that very clear, which confirm the proper mathematical modeling of analytical model. To fit the frequencies, some modification of the supporting conditions can be made.

Table-2 Comparative presentation of analytical and experimental resonant frequencies

Resonant frequency		
(Hz)	Analytical	Experimental
y-direction	5,20	6.50
x-direction	7,07	7.50
torsion	10,18	10.00

9. CONCLUSIONS

The dynamic in-situ testing of the residential building in Becici, Montenegro was performed with objective to obtain the dynamic characteristics of the new constructed building by DC-90 system applying the ambient and forced vibration testing methods. The measurements have been performed in two orthogonal directions. In frequency domain of 0 to 25 Hz the dominating frequencies are: 6.50 Hz, 7.50Hz, and 10.0 Hz. for direction y, x and torsion respectively. For all frequency, the torzional vibration was dominating in the mode shapes, which is visible from “avi” records. This is because of irregular geometry of the building. The obtained dynamic characteristics by this experimental testing of the building were compared by numerical model developed after the test. The shear modulus was varied from 250.000-1.500.000 kN/m2. The best fitting was obtained for the value of 1.500.000 kN/m2.

The general conclusion is that considering the number of stories and resonant frequencies the tested building is rigid one, but it vibrates torsionaly because of large eccentricity of the mass and stiffness. The torsional effect should be accepted by diagonals and dampers incorporated into the structural walls. Having in mind the frequency content of the response spectrum of Montenegro Earthquake, the building will not be excited in resonance conditions, which is on the side of safety.