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DYNAMIC TESTING BY FORCED AND AMBIENT VIBRATION METHODS OF DAMADGED AND REPAIRED BUILDINGS IN KOLUBARA COUNTY APPLYING TECHNOLOGY «SYSTEM DC 90»

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1. INTRODUCTION

The test results presented in this report represent first part of the global experimental program entitled " Experimental verification of DC 90 system under seismic conditions", which has been started in September 2003. The test activities consist of following phases:

1. In-situ testing of typical buildings by means of ambient and forced vibration methods before and after strengthening by DC 90 system.
2. Laboratory testing of DC 90 system: testing of damper efficiency for dissipation of seismic energy as well as testing of model of brick masonry building in scale 1:1 on seismic shaking table
3. Seismic monitoring of selected buildings strengthened by DC 90 system

Based on in-situ tests, the following parameters have been defined: dynamic stiffness in elastic range, natural frequencies, mode shapes and daming coefficients of the tested structures before and after strengthening. The forces distribution in strengthening system DC 90 as well as in infill walls has been defined under harmonic vibration at resonant stage produced by vibrators.

Based on laboratory tests, the force-deformation dynamic characteristics of the DC 90 damper in linear and non-linear range within frequency range of 1.0-15.0 Hz will be defined. Testing of 1:1 scale model of brick masonry building untill collabs will show the nonlinear behaviour of DC 90 system under extremly strong seismic condition (0.1-0.5 g).

Finally, the seismic monitoring of selected buildings by installation of strong motion accelerographs, LVDT's and strain gauges, will give information about structural behaviour under real earthquake conditions.

2. TESTING METHODOLOGY

For determination of dynamic behavior of selected buildings, i. e. definition of their dynamic characteristics: natural frequencies, mode shapes of vibration, damping coefficients and soil-structure interaction, two different experimental testing methods have been applied: ambient vibration and forced vibration testing methods.

2.1. Ambient vibration testing method

The ambient vibration testing method is based on recording and processing of structural response to wind and other ambient excitations. The advantages of this method are the light equipment easy for transportation and management and the fact that it doesn't affect normal functioning of the structure during testing and can be applied on structures in use. The experimental and theoretical procedure is based on the assumption that the exciting force is a stationary stochastic process with relatively flat amplitude spectrum.

The testing consists of real time recording of the vibrations and processing of the records by means of the Fast Fourier Transform i. e. obtaining of Fourier Amplitude Spectra.

The natural frequencies of the structure are defined by the peaks on the spectra, and the mode shapes are obtained by normalization of each recorded spectrum amplitude for different level, in respect to the amplitude of the reference point at corresponding frequency.

The damping ratio for each mode shape can be obtained directly from the amplitude spectrum applying the half power method which is based on the difference between the response magnitude at resonance and at particular frequencies near the resonant frequency.

The testing procedure is presented on figure below.

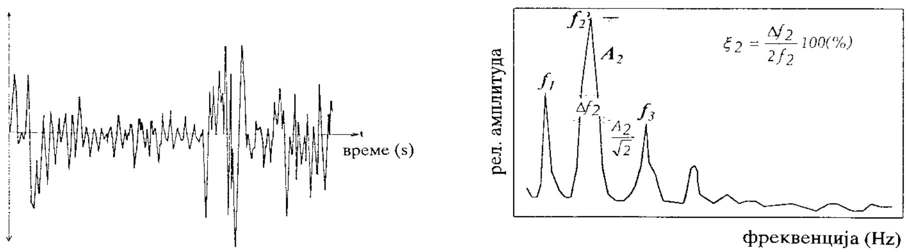


Figure 1. Ambient vibration testing procedure: real time record and Fourier amplitude spectrum

The signals x(t) recorded in real time can be transformed in frequency domain using the integral:

$$X(f) = \int_{-\infty}^{+\infty} x(t)e^{-i2\pi ft}dt$$

2.2. Forced vibration testing method

In case of dynamic testing by forced vibrations, harmonic sinusoidal force is generated by specially constructed vibrators. By gradually increasing of excitation frequency and measuring the amplitudes of the response of the structure in selected points, frequency response curves can be constructed from which resonant frequencies of the structure can be defined.

Mode shapes of vibration can be obtained by measuring the response amplitudes at resonance state in the selected points along the height of the structure and normalizing them to the amplitude of the reference level.

Damping ratio can be obtained by two methods: the half power method and the logarithmic decrement method. The second method is based on recording of the free damped vibration in which the structure enters after the steady state vibration in resonance, by sudden interruption of the applied force.

The forced vibration testing equipment is presented on figure below.

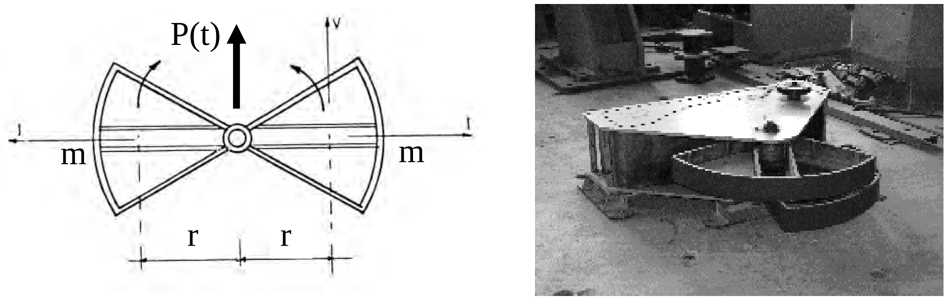


Figure 2. Equipment for generation of harmonic vibrations

Forces being produced by the shakers:

$$P(t) = P_0 \sin \omega t = Mr\omega^2 \sin \omega t,\ M = 2m$$

3. TEST RESULTS

3.1. Ambient vibration test results

Three selected two storey buildings have been tested by ambient vibration method. The building No. 1 was mixed masonry structure having first story stone masonry walls and second story brick masonry walls. The buildings No. 2 and No. 3 have almost the same structural system: brick masonry with RC light frames out of which No. 2 has not been strengthened while No. 3 has been strengthened by the system DC 90.

One week after testing, the building No. 2 was also strengthened and tested again by ambient and forced vibration test.

Figures 3, 5 and 7 show three selected buildings before and after strengthening while figures 4, 6 and 8 show the plan and cross section of the bildings.

Figure 3. Building No. 1 under and after strengthening

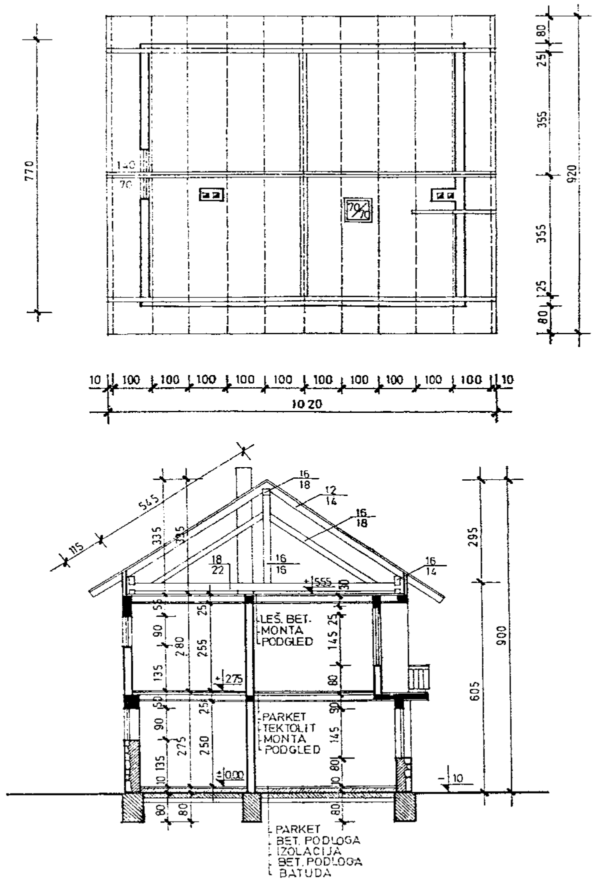


Figure 4. Roof plan and cross section of building No. 1

Figure 5. Building No. 2 before and after strengthening

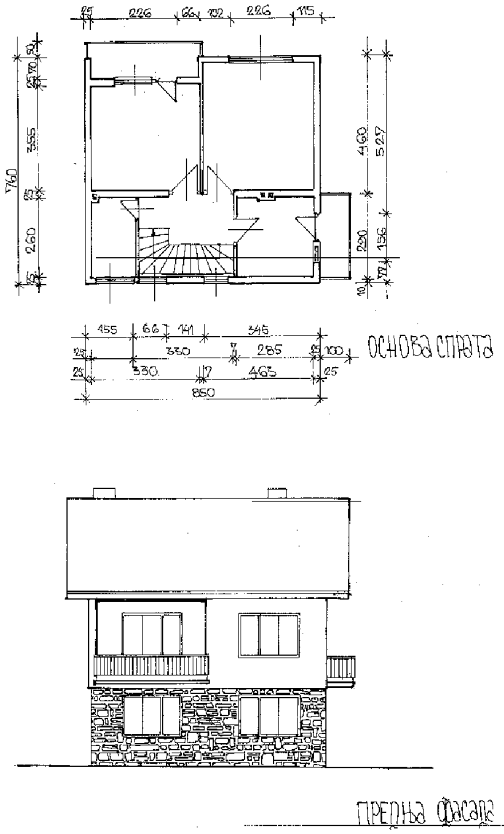


Figure 6. Floor plan and cross section of building No. 2

Figure 7. Building No. 3 during and after strengthening

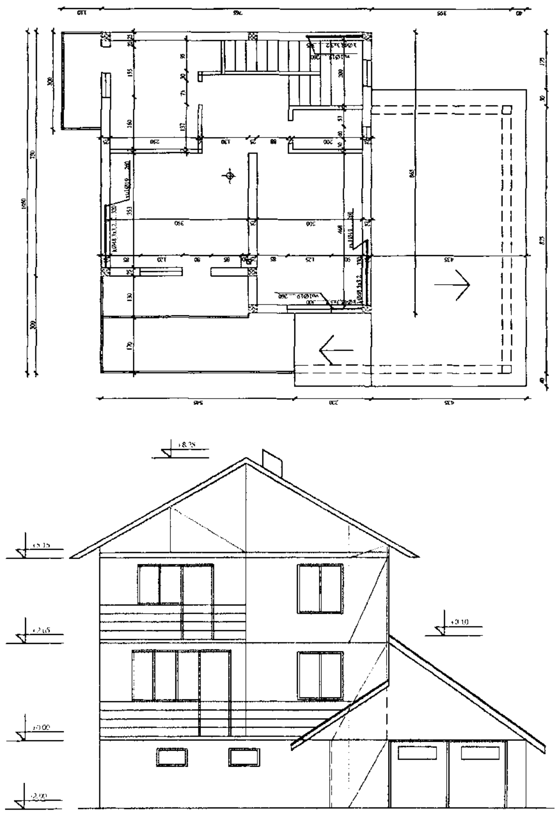


Figure 8. Floor plan and facade of building No. 3

Applying ambient vibration method on each of these buildings, the Fourier Amplitude Spectra have been defined in two orthogonal directions.

Figs. 9, 10 and 11 show the FAS for the buildings No. 1, 2 and 3 respectively.

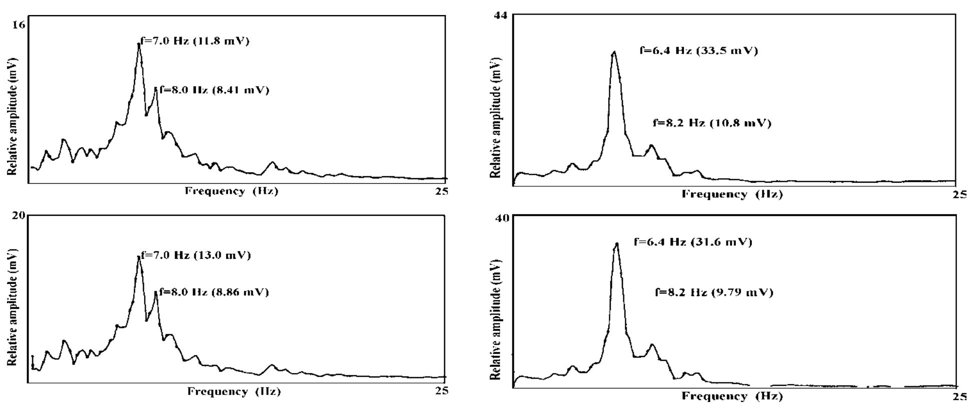


Figure 9. FAS for transversal and longitudinal direction for building No. 1 after strengthening

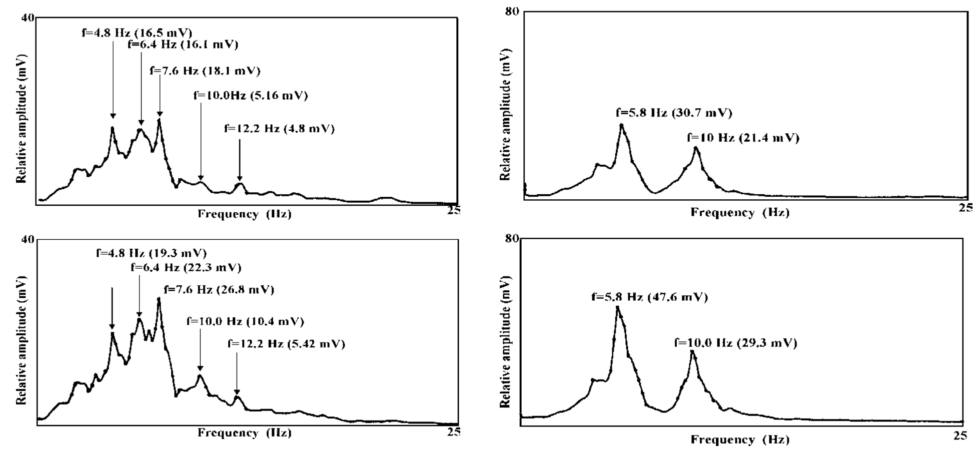


Figure 10.a FAS for transversal and longitudinal direction for building No. 2 before strengthening

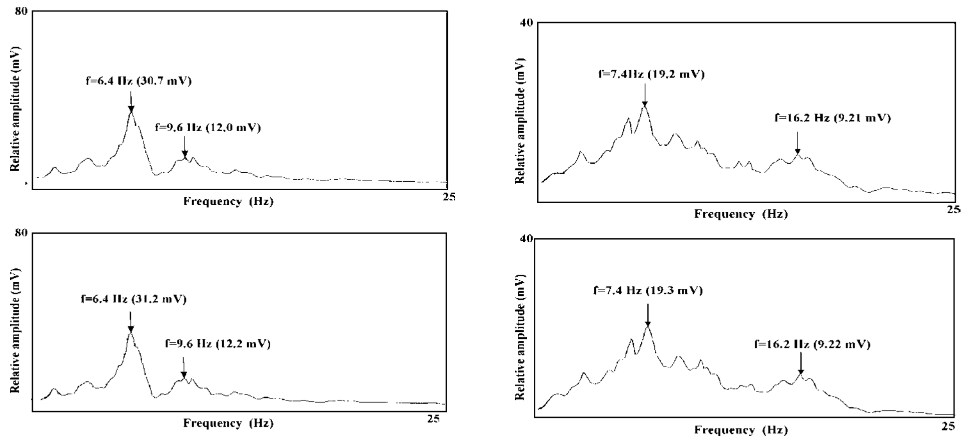


Figure 10.b FAS for transversal and longitudinal direction for building No. 2 after strengthening

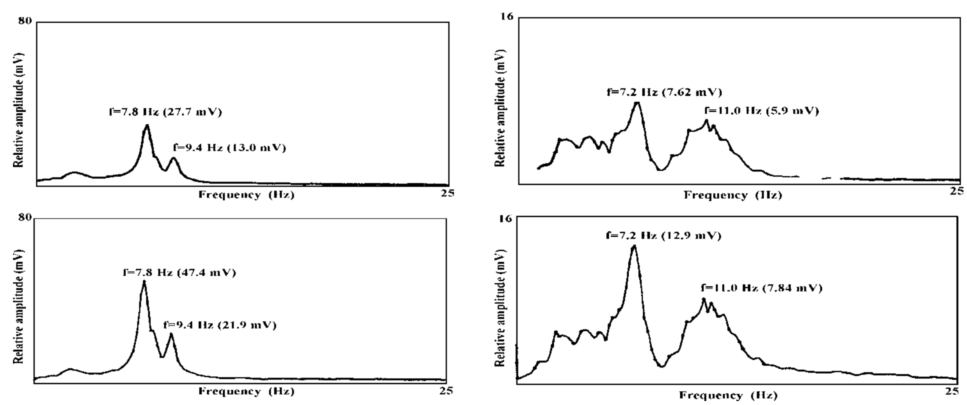


Figure 11. FAS for transversal and longitudinal direction for building No. 3 after strengthening

Table 1 shows the defined natural frequencies before and/ or after strengthening of structures in each orthogonal direction.

Building No.	Natural frequencies(Hz)			
	Before strengthening		After strengthening	
	Transversal direction	Longitudinal direction	Transversal direction	Longitudinal direction
1			7.0	6.4
2	6.4	5.8	7.4	6.4
3			7.8	7.2

Table 1. Natural frequencies of tested structures obtained by ambient vibration tests

It is visible that natural frequencies of the building range between 6-8 Hz. This shows that height of the structure is one of dominant factors influencing natural frequencies.

Concerning the influence of the strengthening system in changing the natural frequency, the test results from building No. 2 show that performed strengthening solution increased the natural frequencies about 15% in both directions, as a consequence of increased stiffness of about 35% comparing to the stiffness before strengthening.

3.2. Forced vibration test results

The building No 2 has been selected as a representative building for checking the dynamic behavior of the structure strengthened by DC 90 system (Fig 4).

As it was mentioned before, the building was tested by ambient vibration before strengthening by DC 90 system. After strengthening, the building was tested again by ambient and forced vibration methods in order to check if the natural frequencies are changed or not. Besides this, some special measurements have been performed in resonant conditions with acceleration response intensity of 2-3 % g in order to measure the stress distribution in the steel elements of DC 90 system as well as in the brick masonry walls, as well as the displacements and acceleration in characteristic points. The multy channel on-line data acquisition system specially designed for this test has been used for monitoring and recording the dynamic response of the structure as well as of the strengthening system.The continuous records of building vibration with variable frequency of 0.5-9.0 Hz. with duration of 10 min were obtained.

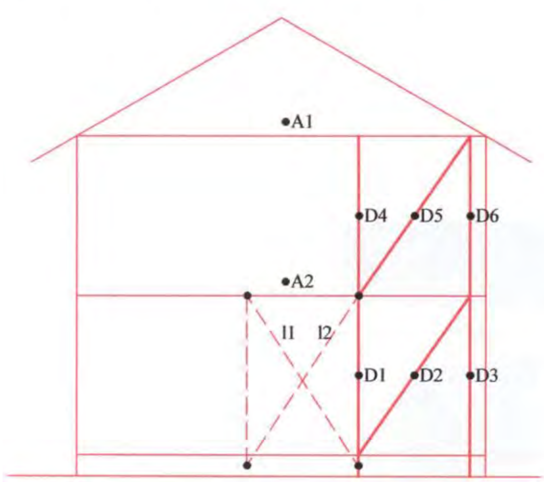
The testing was performed in transversal and longitudinal direction, by exciting the building at resonance. The acceleration at each story level, relative displacement in diagonals of the walls and stress in reinforcement bars of DC 90 system, have been measured at 20 measuring points. The numerical values and time history records of the response are given below at tables T1-T6 and Figs.12-16.

The test results show that tested building was excited in liner range of vibration even the level of vibration was so strong that excited the sorounding buildings too and provoked the psyhologycal reactions of the peuple. The acceleration on the roof of the building was beween 0.02-0.03g, the diagonal relative displacement of the walls was between 0.02-0.05 mm, while the strain in steel elements of DC90 system was: in vertical elements between 1.2-6.0 μstr, and diagonal elements:5.2- 10.4 μstr. It is obvious that the diagonal elements are more active than the vertical ones, keeping the integrity of the walls during vibration of the building.

The effectivness of the DC90 system under strong earhquake vibration (0.1-0.5g) could be checked by shaking table test on large scale of the model 1/1-1/3. The nonlinear behaviour of the structural system and damage mechanism should be investigated in order to optimise the DC90 strengthening system and incorporated damper mechanism. This will be next phase of the project investigation.

In the next pages the test results obtained by forced vibration test are presented. The sheme of the walls with disposition of measuring points, the tables with numerical values obtained in transversal and longitudinal direction, as well as the time history records of the respons parameters: acceleration, relative diagonal displacements and strain in steel elements of DC90 system are given for each of the performed tests. Each of the records are presented by different collor.

SCHEME OF THE WALL WITH MEASURING POINTS (CORNER)



DISPOSITION 1

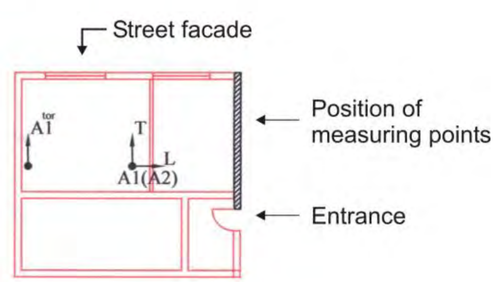
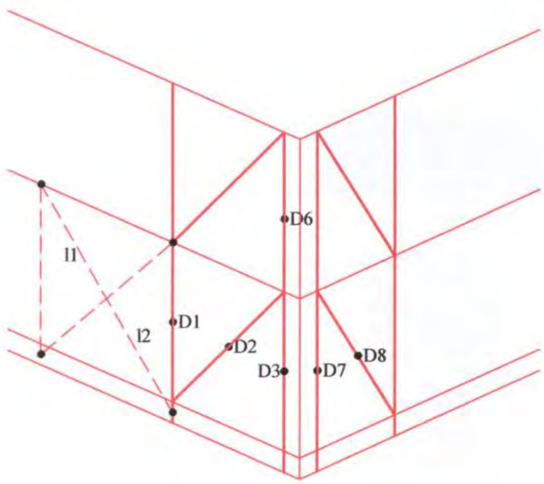


Table 1: Maximum values of acceleration, displacement and strain at characteristic points for excitation in transversal direction, disposition1

Test No	Direction	Frequen. of Excitat. (Hz)	Accel. Response (g)		Diagonal displacement (mm)				Strain in steel elements of DC 90 system (μ str)					
			A1	A2	L1	L2	L3	L4	D1	D2	D3	D4	D5	D6
1	Transv.	7.8	0.03	0.01	0.05	0.05	0.05	0.10	1.2	5.5	1.3	1.7	6.0	2.0

SCHEME OF THE WALL WITH MEASURING POINTS (CORNER)



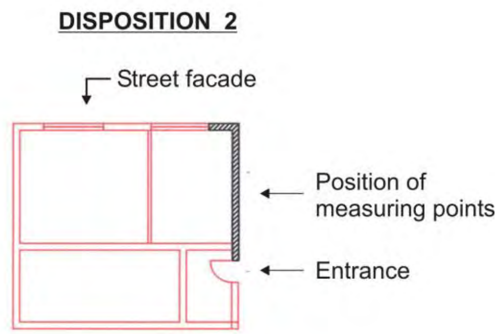
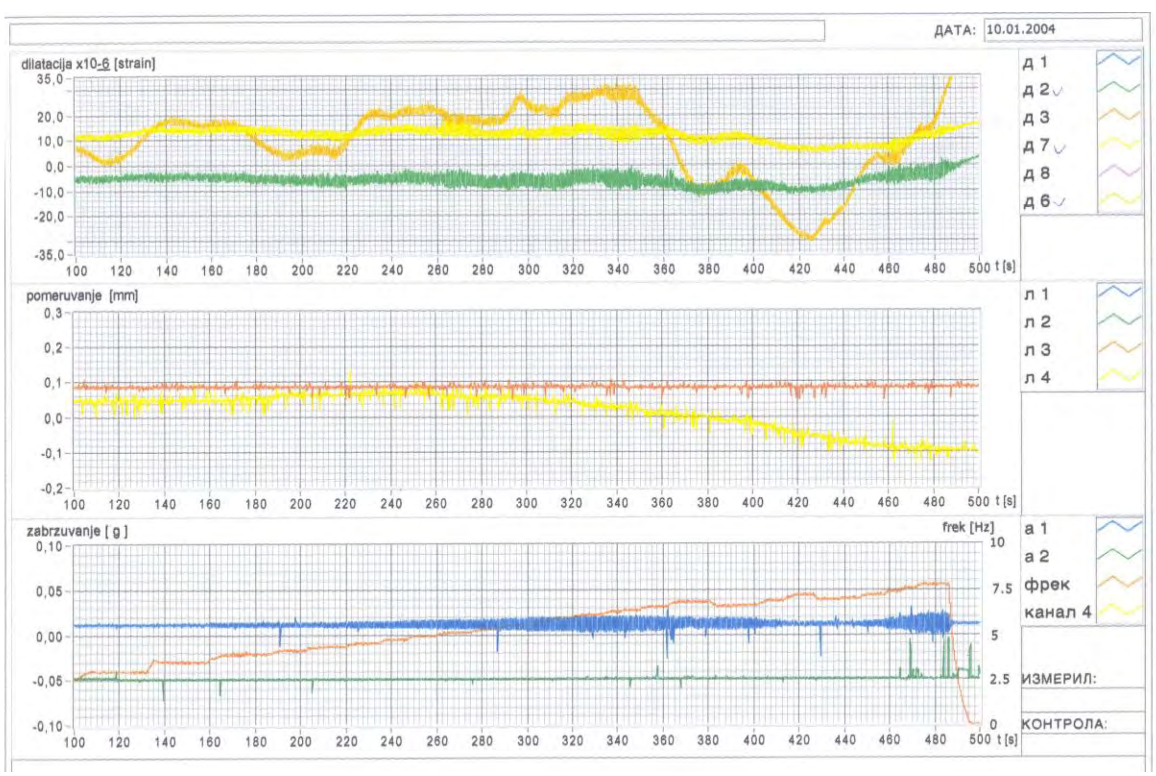


Table 2: Maximum values of acceleration, displacement and strain at characteristic points for excitation in transversal direction, disposition 2

Test No	Direction	Frequen. of Excitat. (Hz)	Accel. Response (g)		Diagonal displacement (mm)				Strain in steel elements of DC 90 system (μ str)					
			A1	A2	L1	L2	L3	L4	D1	D2	D3	D6	D7	D8
2	Transv.	7.8	0.03	0.01	0.02	0.02	0.02	0.03	5.6	2.2	5.7	5.2	6.0	10.4



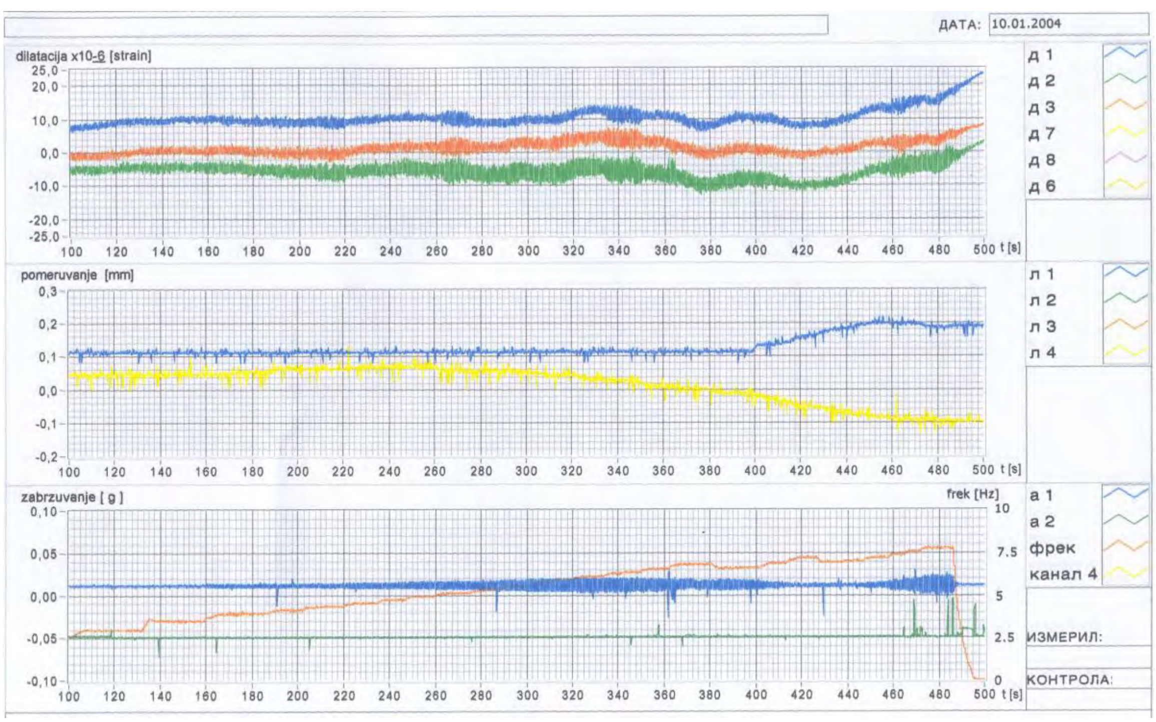


Fig.12. Time history records of strain, displacement and acceleration at characteristic points; Test 2, Disposition 2, Transversal direction

SCHEME OF THE WALL WITH MEASURING POINTS (CORNER)

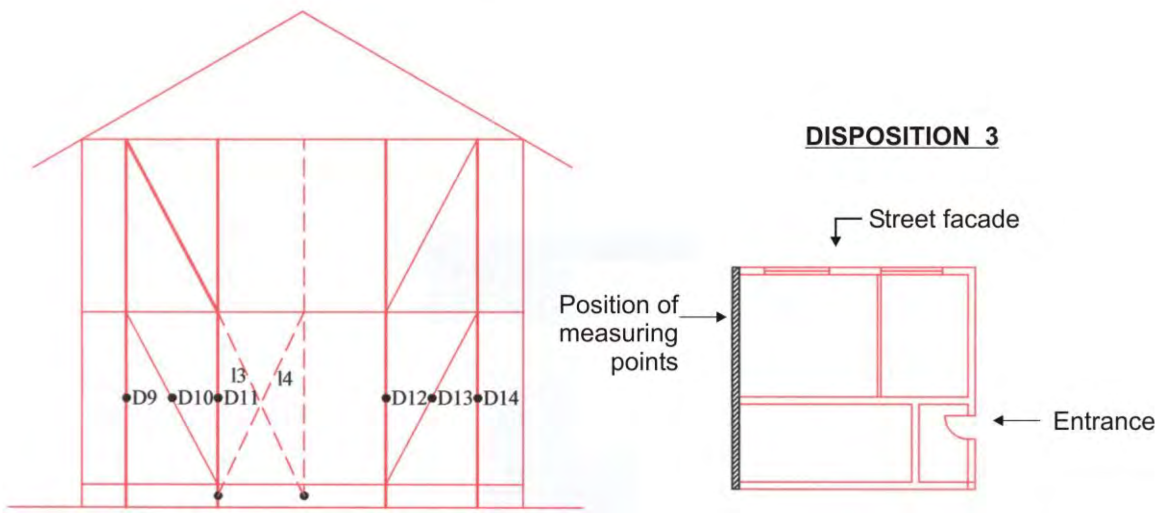


Table 3: Maximum values of acceleration, displacement and strain at characteristic points for excitation in transversal direction, disposition 3

Test No	Direction	Frequen. of Excitat. (Hz)	Accel. Response (g)		Diagonal displacement (mm)				Strain in steel elements of DC 90 system (μ str)					
			A1	A2	L1	L2	L3	L4	D9	D10	D11	D12	D13	D14
3	Transv.	7.8	0.03	0.01	0.02	0.02	0.02	0.03	6.0	5.2	4.3	5.8	5.2	1.66

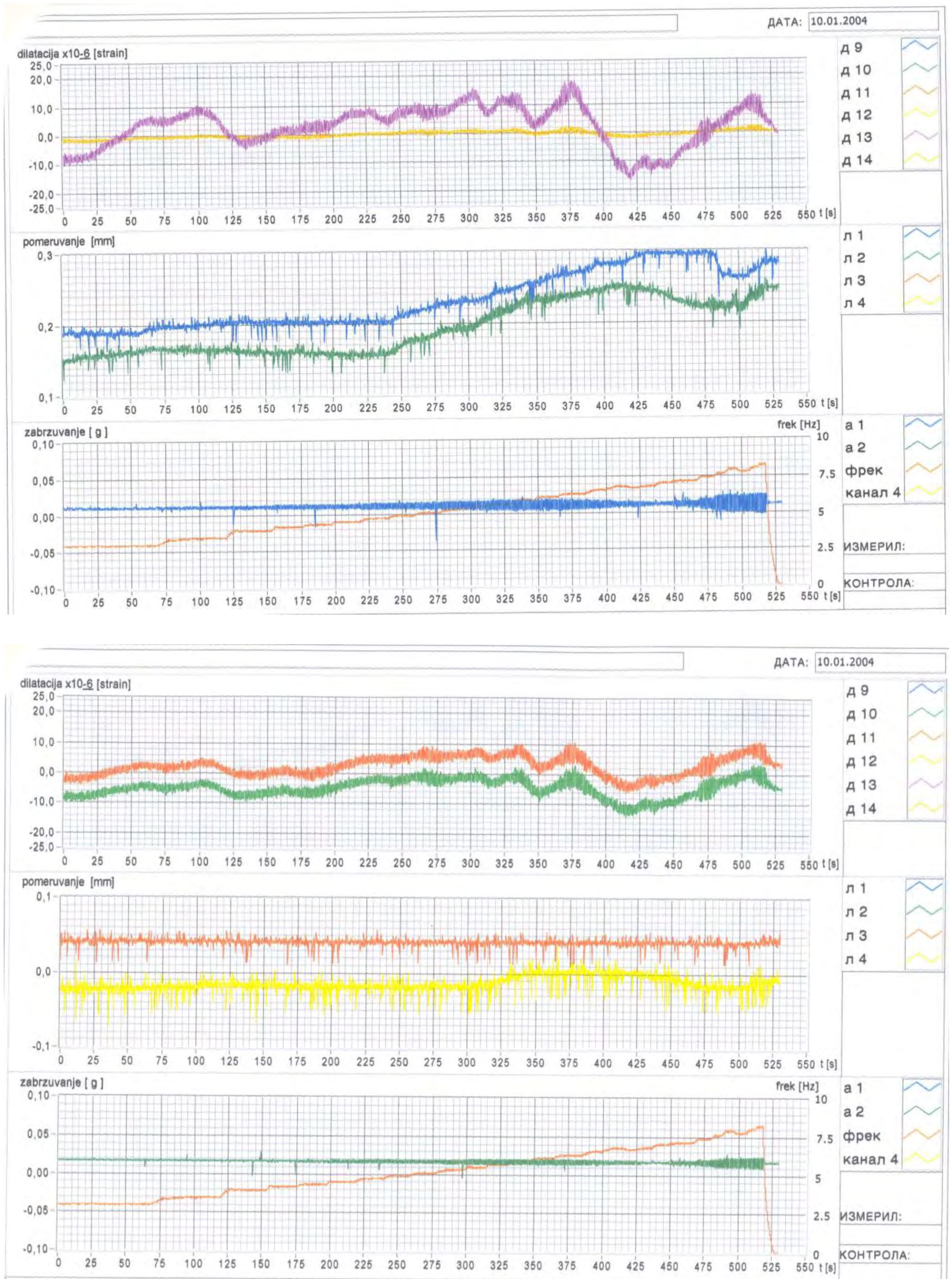


Fig.13.Time history records of strain, displacement and acceleration at characteristic points; Test 3, Disposition 3, Transversal direction

SCHEME OF THE WALL WITH MEASURING POINTS (CORNER)

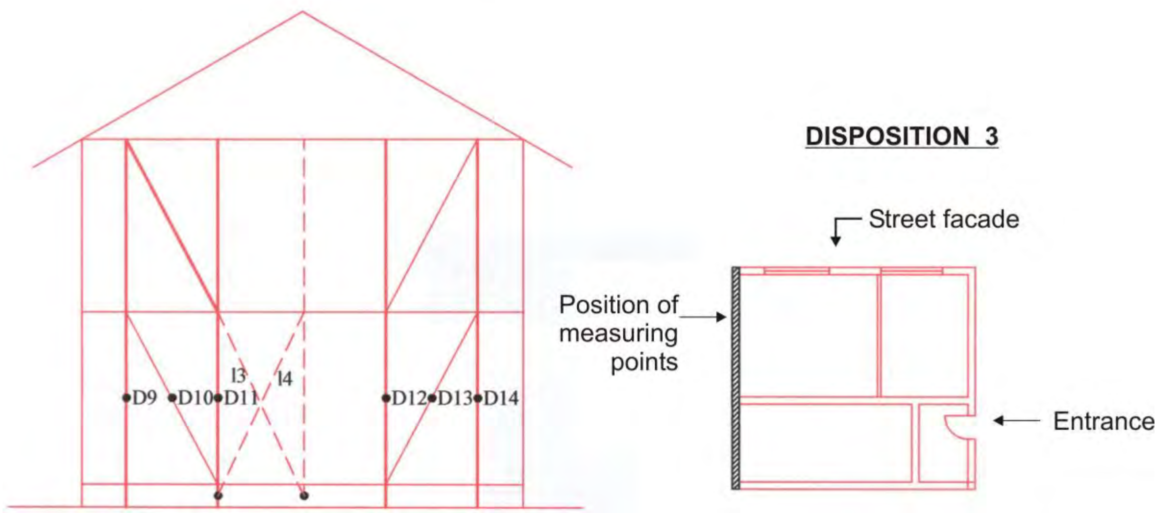
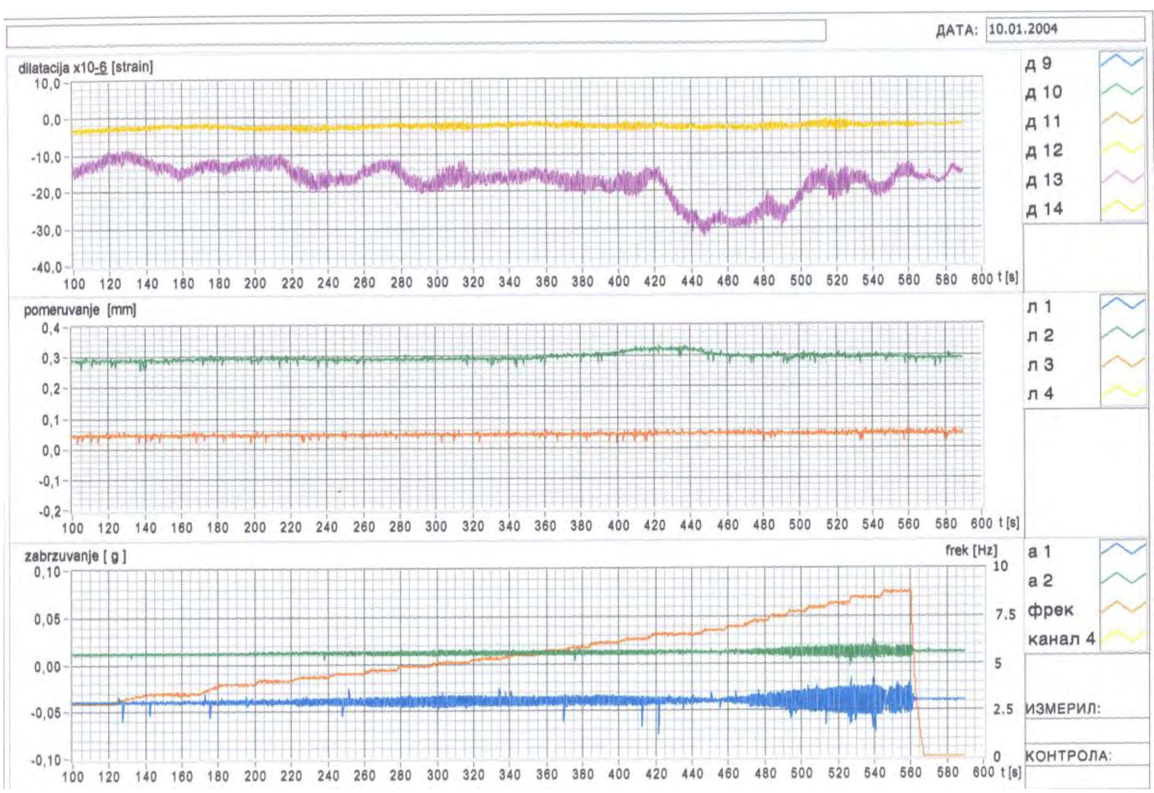


Table 4: Maximum values of acceleration, displacement and strain at characteristic points for excitation in longitudinal direction, disposition 3

Test No	Direct.	Frequen. of Excitat. (Hz)	Accel. Response (g)		Diagonal displacement (mm)				Strain in steel elements of DC 90 system (μ str)					
			A1	A2	L1	L2	L3	L4	D9	D10	D11	D12	D13	D14
4	Longit.	6.8	0.02	0.01	0.02	0.02	0.02	0.02	4.6	4.8	4.0	4.6	4.3	/



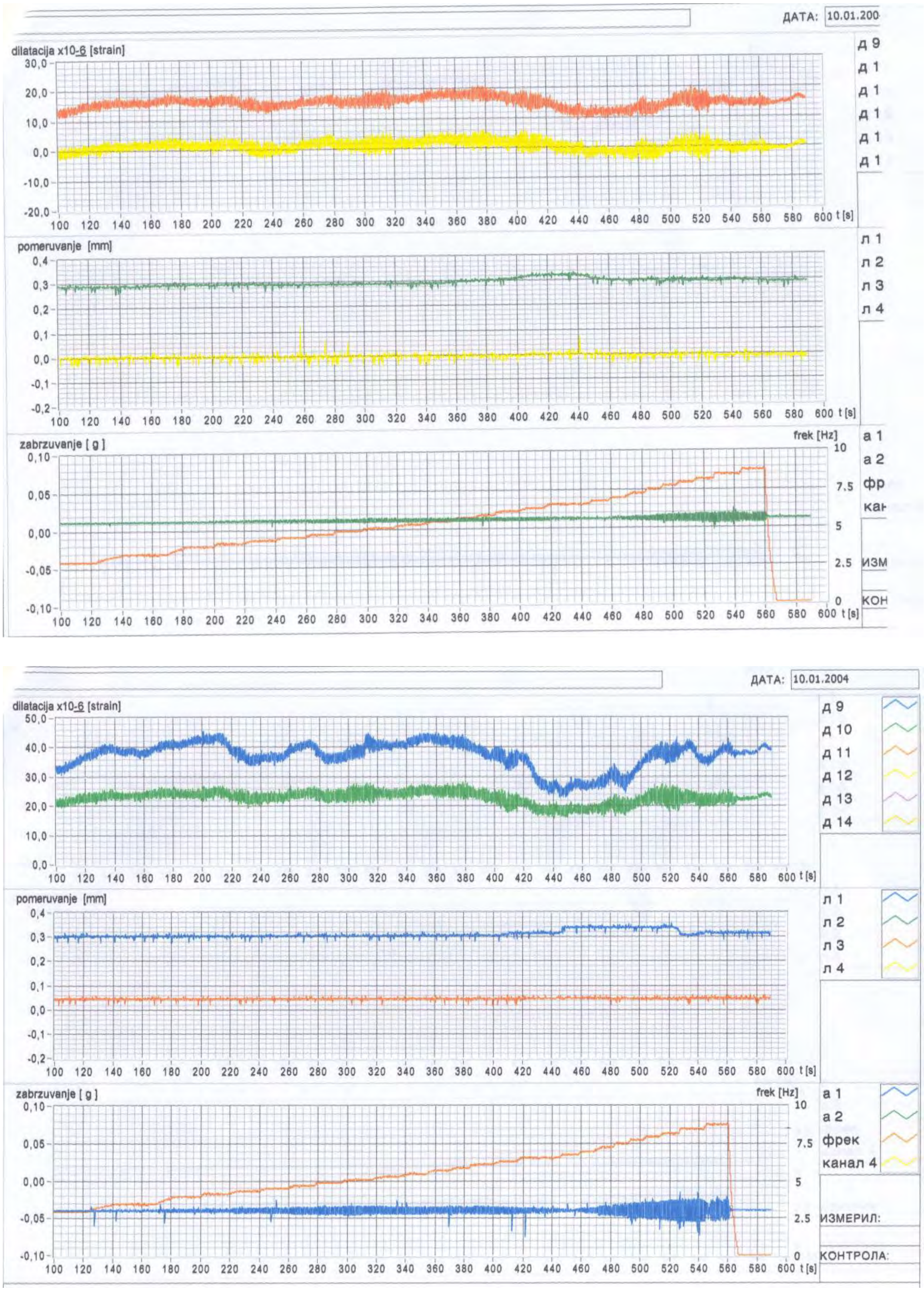
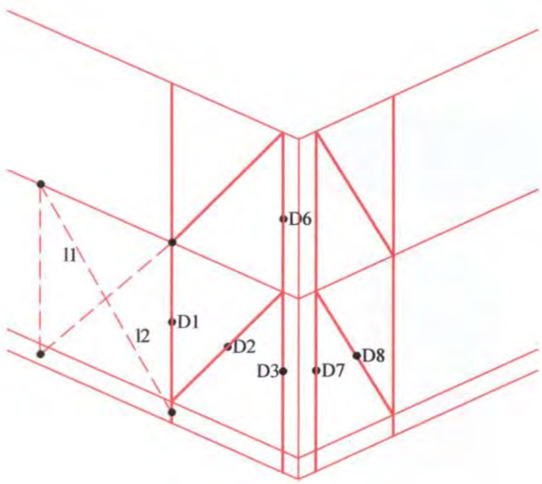


Fig.14.Time history records of strain, displacement and acceleration at characteristic points; Test 4, Disposition 3, Longitudinal direction

SCHEME OF THE WALL WITH MEASURING POINTS (CORNER)



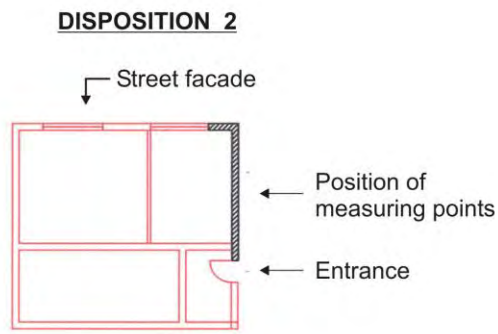
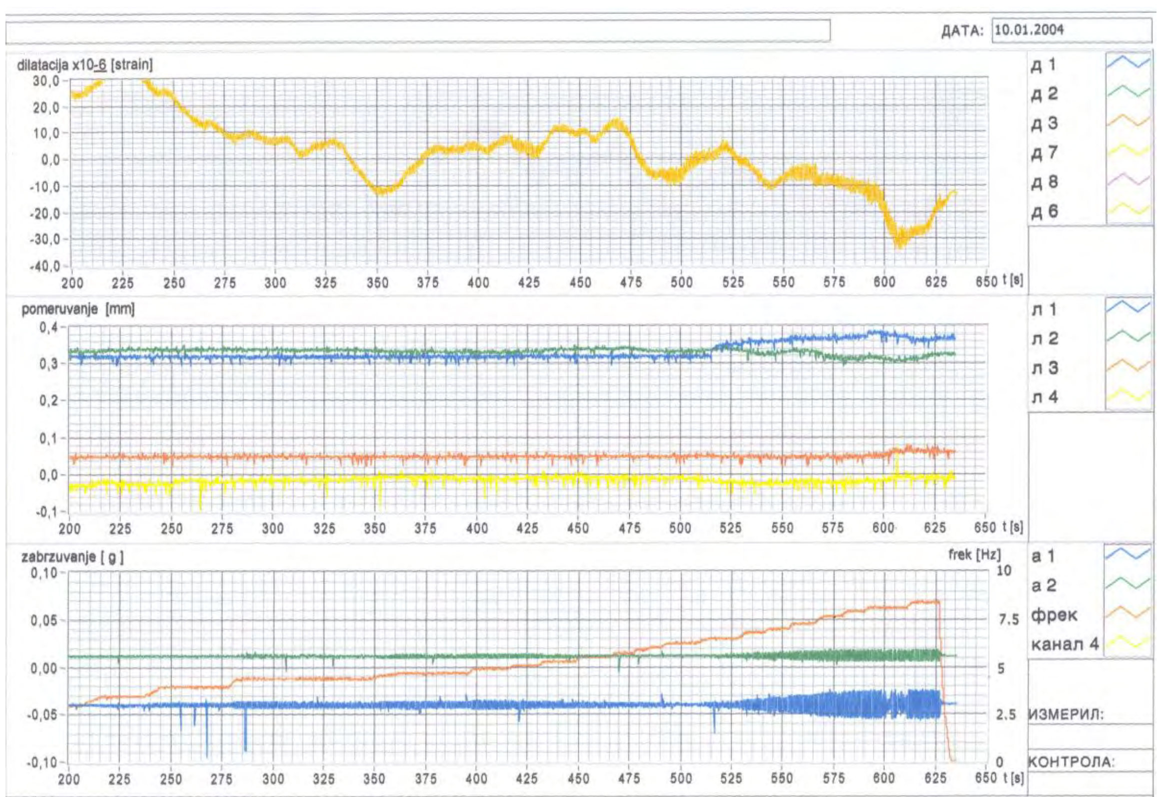
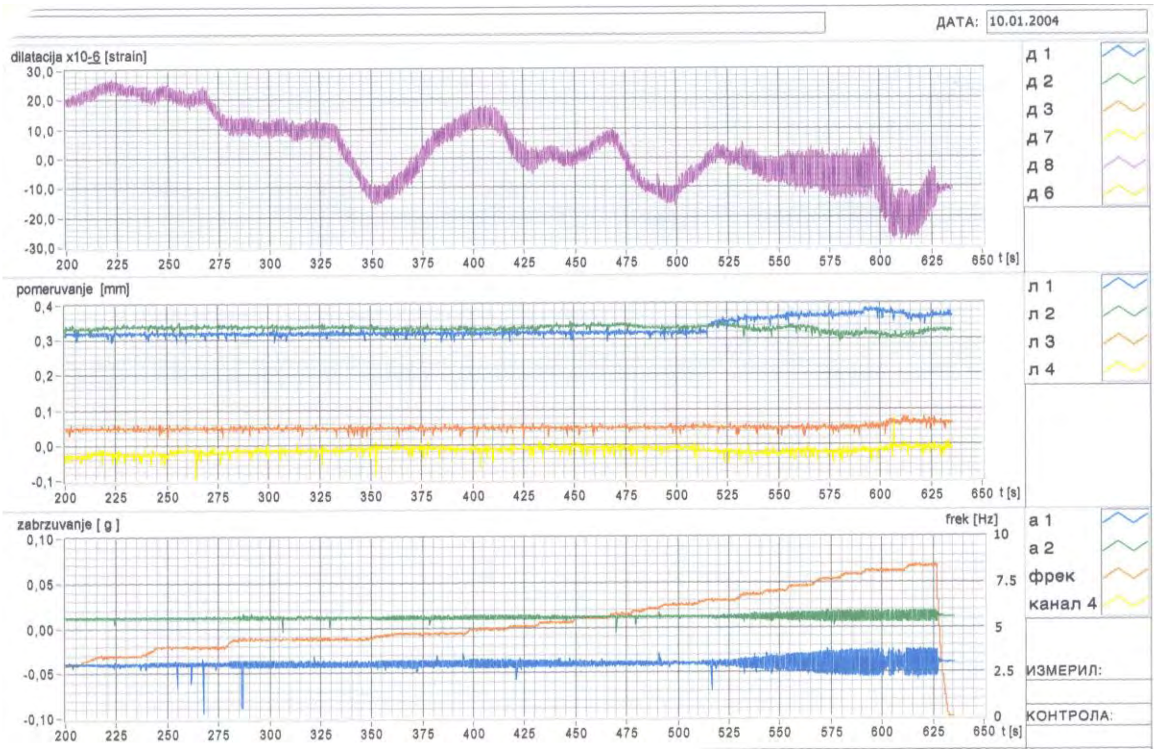


Table 5: Maximum values of acceleration, displacement and strain at characteristic points for excitation in longitudinal direction, disposition 2

Test No	Direction	Frequen. Excitat. (Hz)	Accel. Response (g)		Diagonal displacement (mm)				Strain in steel elements of DC 90 system (μ str)					
			A1	A2	L1	L2	L3	L4	D1	D2	D3	D6	D7	D8
5	Longit.	6.8	0.03	0.01	0.02	0.02	0.02	0.03	6.4	8.0	6.0	5.0	9.0	13.3

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д 1
д 2
д 3
д 7
д 8
д 6
pomeruvanje [mm]
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zabrzuvanje [g]
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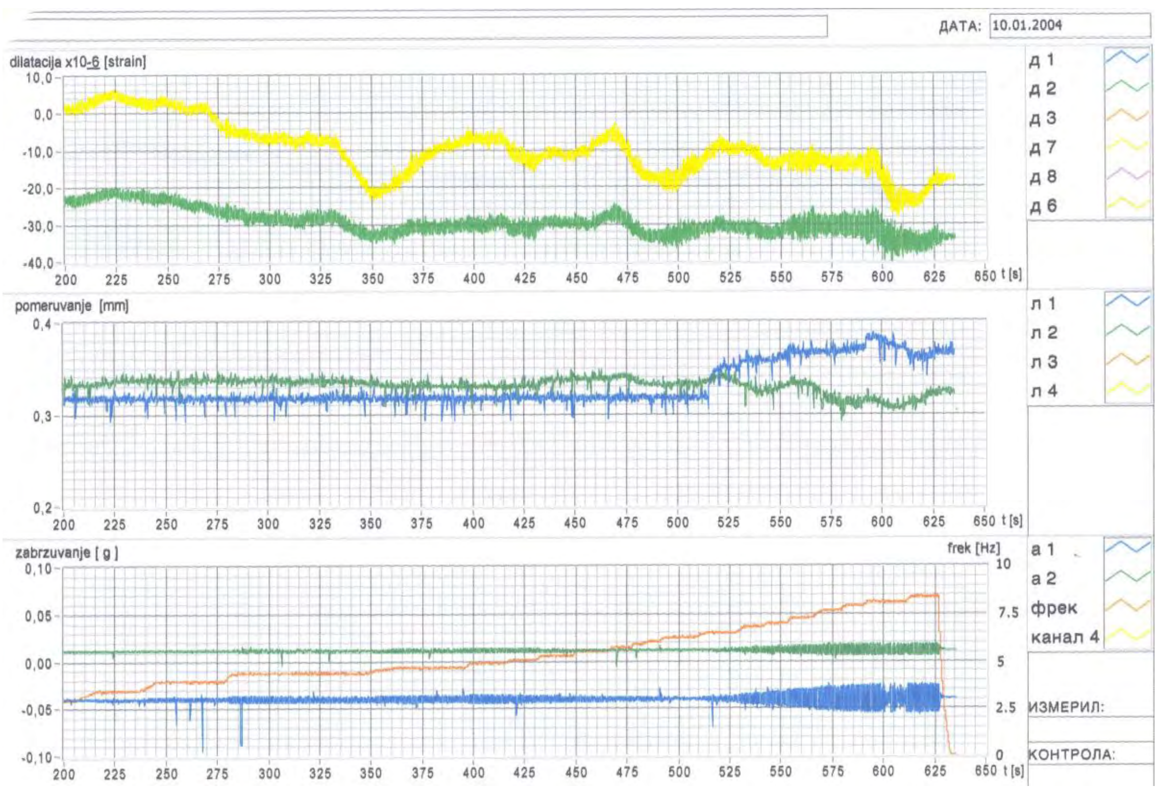
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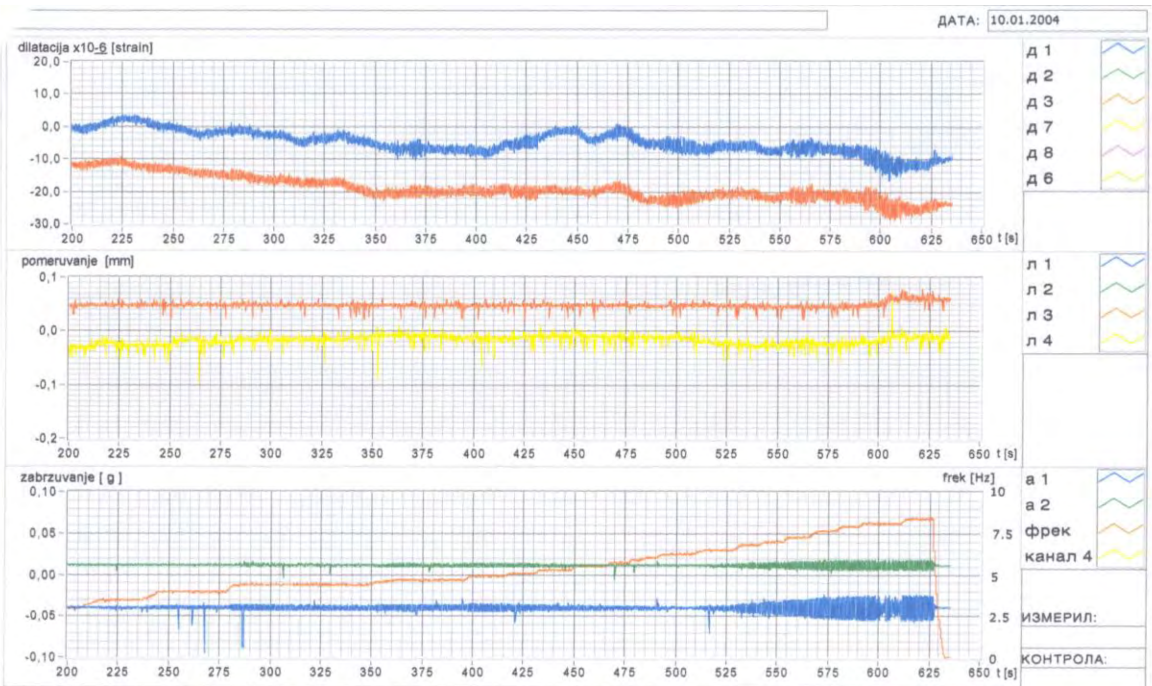
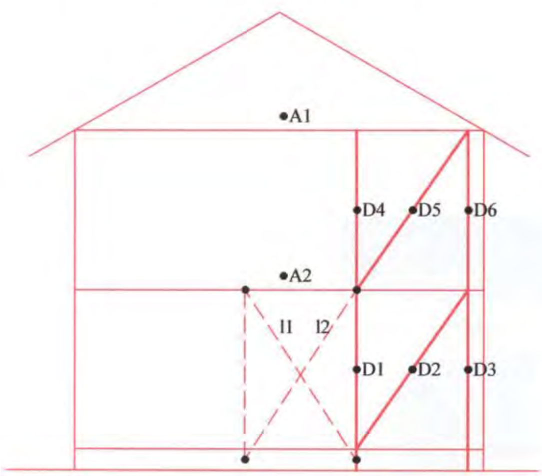


Fig.15.Time history records of strain, displacement and acceleration at characteristic points; Test 5, Disposition 2, Longitudinal direction

SCHEME OF THE WALL WITH MEASURING POINTS (CORNER)



DISPOSITION 1

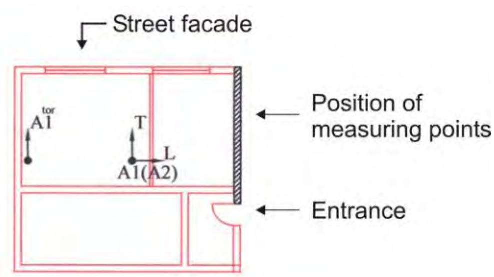
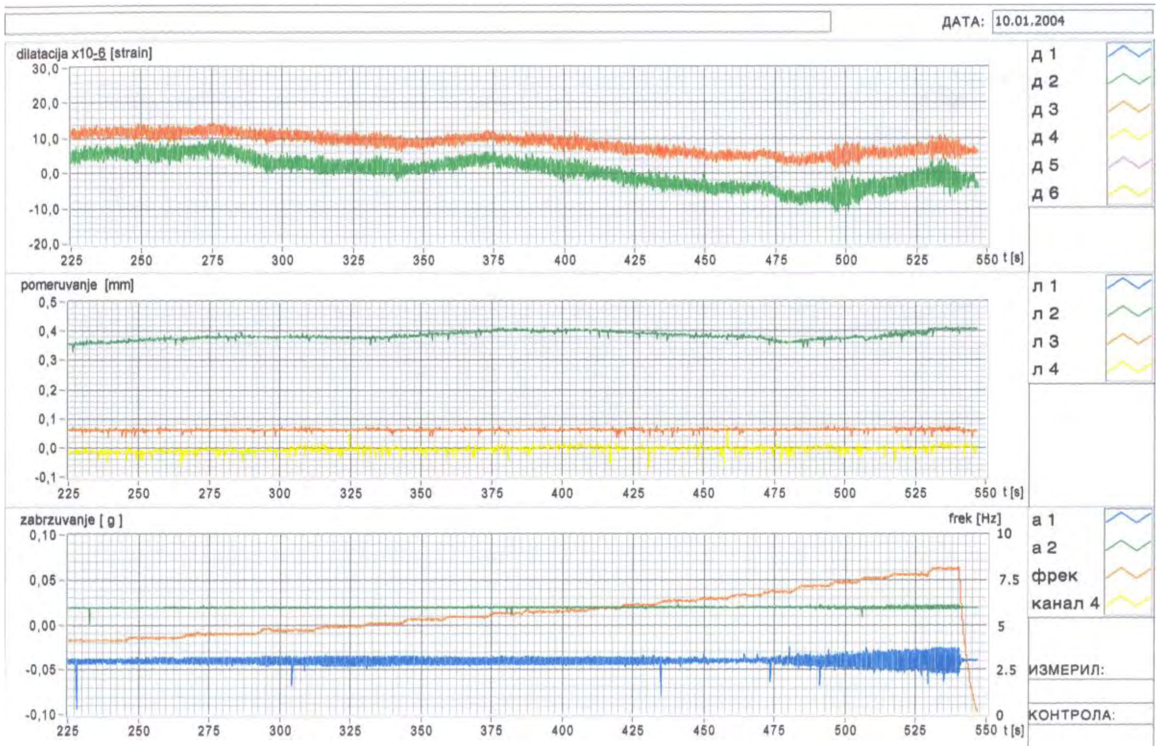


Table 6: Maximum values of acceleration, displacement and strain at characteristic points for excitation in longitudinal direction, disposition 1

Test No	Direction	Frequen. of Excitat. (Hz)	Accel. Response (g)		Diagonal displacement (mm)				Strain in steel elements of DC 90 system (μ str)					
			A1	A2	L1	L2	L3	L4	D1	D2	D3	D4	D5	D6
6	Longitud	6.8	0.03	0.01	0.02	0.02	0.02	0.02	4.2	5.5	3.2	3.2	3.3	3.5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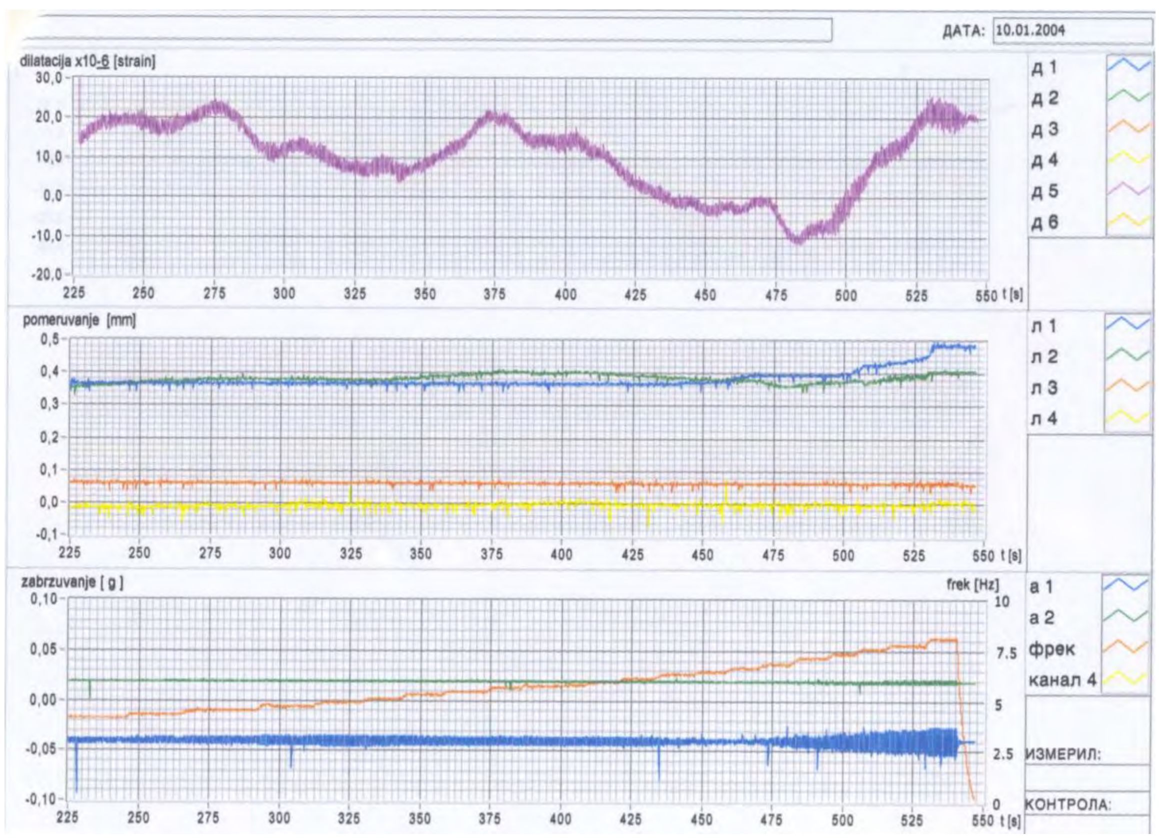
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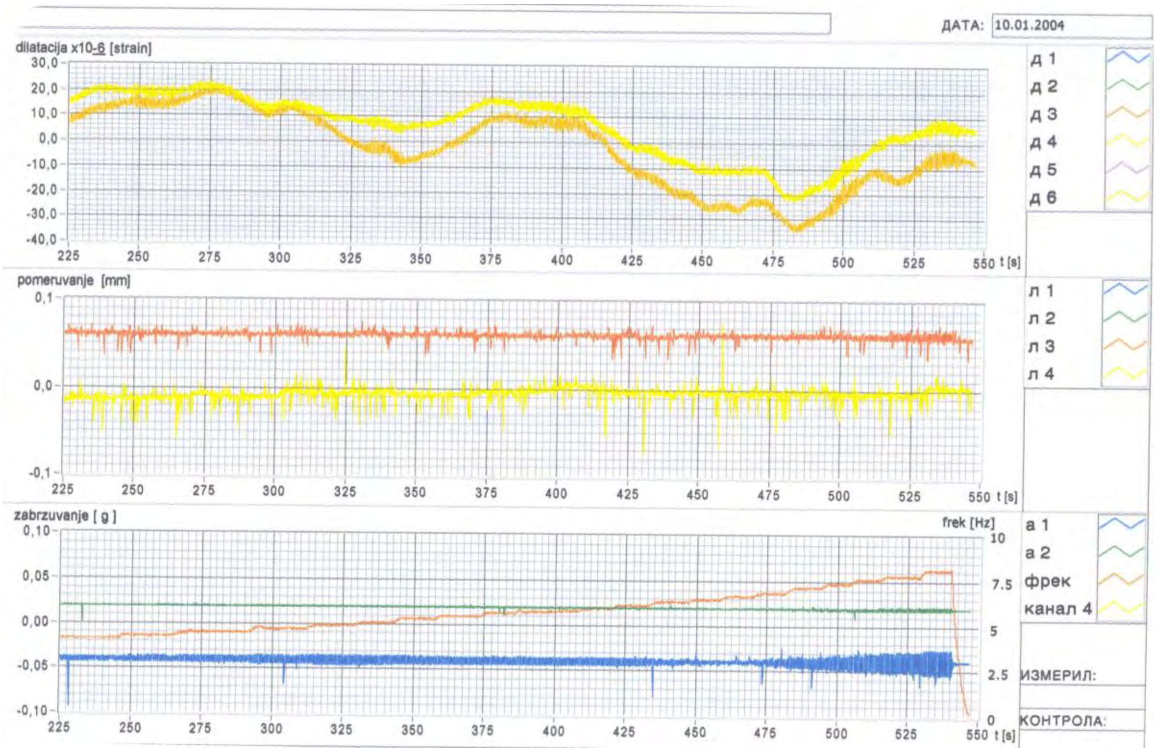

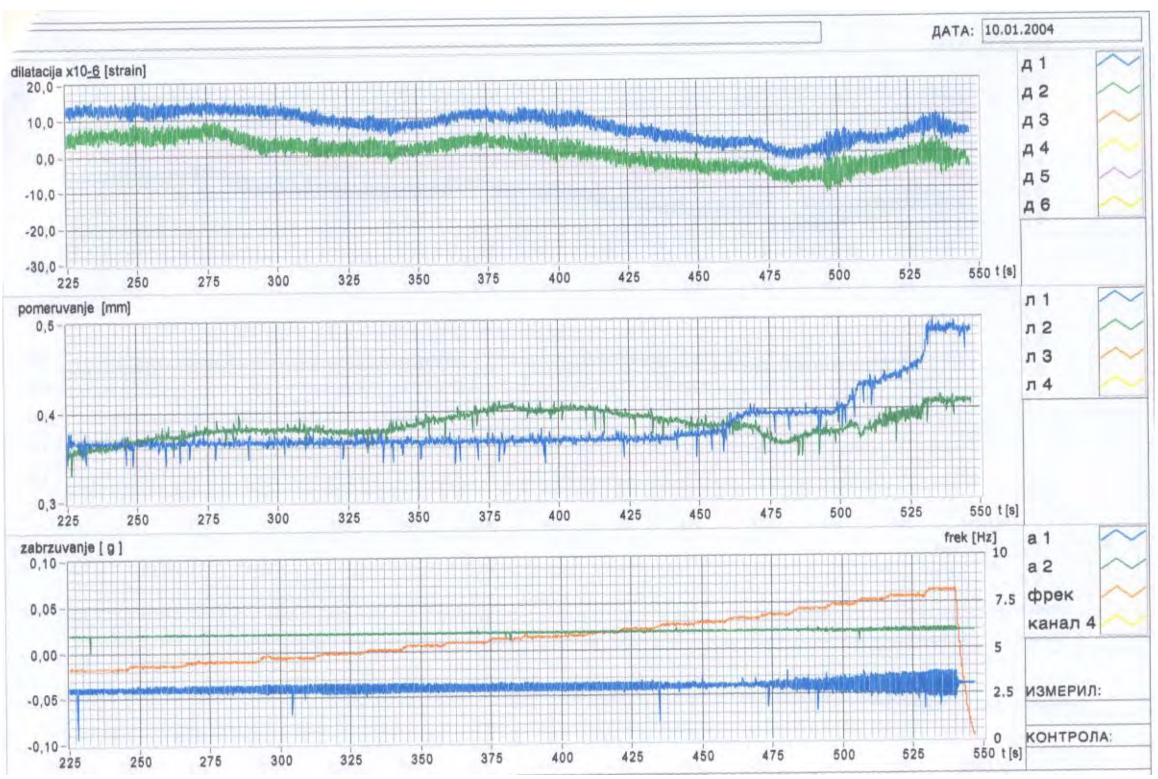

Fig.16.Time history records of strain, displacement and acceleration at characteristic points; Test 6, Disposition 1, Longitudinal direction

4. CONCLUSIONS AND RECOMMENDATIONS

The experimental verification of dynamic behavior of a system DC 90 under seismic condition is very important task as a base for further improvement and application of the system in practice. The experimental results obtained from in situ measurements by ambient and forced vibration methods represent very accurate base for verification of analytical design procedure.The following conclusions could be drawn:

- Defined natural frequencies clearly show that the damaged buildings have the natural frequencies 6-8 Hz, which are very close to predominant frequencies of the happened earthquake in the year 1998. It is an indicator that the the houses in this region are very vulnarable and should be subjected to strengthening.
- By strengthening of the buildings applying DC 90 system the elastic stiffness increase about 35% in both orthogonal directions, increasing the natural frequencies about 15%. This strengthening is good prevention against new expected earthquakes.
- The forced vibration tests performed on one strengthened buiding show that the ground base is very soft and transmit the vibrations on large distance from the source. A special measures for strengthening of the foundation of the buildings should be undertaken.
- The mesured values: acceleration on floor levels, diagonal displacements of the walls and strain in steel elements of DC-90 system, show that the building vibrated in linear range under excited vibration of 0.03g. For higer excitation in real earhquake conditions (0.10-0.50g), shaking table test of a model in scale 1/1-1/3 should be performed.
- The shaking table test of large scale model until nonlinear stage, will give the answer of the question whether the existing system is adequately dimensioned for expected earthquakes or should be improved.