Individual Training Course "Seismic Microzonation"

Report

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CONTENT

1. LOCAL SITE CONDITIONS MODELING ON SEISMIC MICROZONATION STAGE

1.1. Introduction

The basic task of modeling in our case is the reception of continuous 3D geophysical model of site conditions for territory Kishinev city. For this purpose it is necessary to know geometrical parameters of distribution of separate layers and their elastic properties, both on the area, and with depth. The modeling usually is the compelled measure, owing to our fragmentary knowledge of geological medium and is based therefore, as a rule, on averaging of geometrical and elastic parameters of layers. In other words, inevitable attributes of modeling are simplification of geological layers and averaging of elastic properties in them. It is natural, that the degree of a divergence of real seismic effects observable on a surface, from simulated entirely is explained by differences of local site conditions from averaged, used in model.

For last 50 years on Kishinev city sizeable volume of the geological, hydro-geological and geophysical data was assembled. It has allowed to create continuous simplified 3D-model of site conditions for territory of city. And then to use it as a basis for creation of a map of seismic microzonation. All cartographic drawing and calculations are executed with use of GIS technologies

The territory of city represents a valley with hilly slopes. The absolute heights from sea level change within the limits of 30-230 m (fig. 1.1). The area of city is equal 122,3 sq. km.

In fig. 1.2 points of seismic observation (21 - earthquakes, 45 - special explosions, 143 – microtremors) and 2673 boreholes (from which 1045 - geotechnic, 118 – seismic borehole logging) are shown.

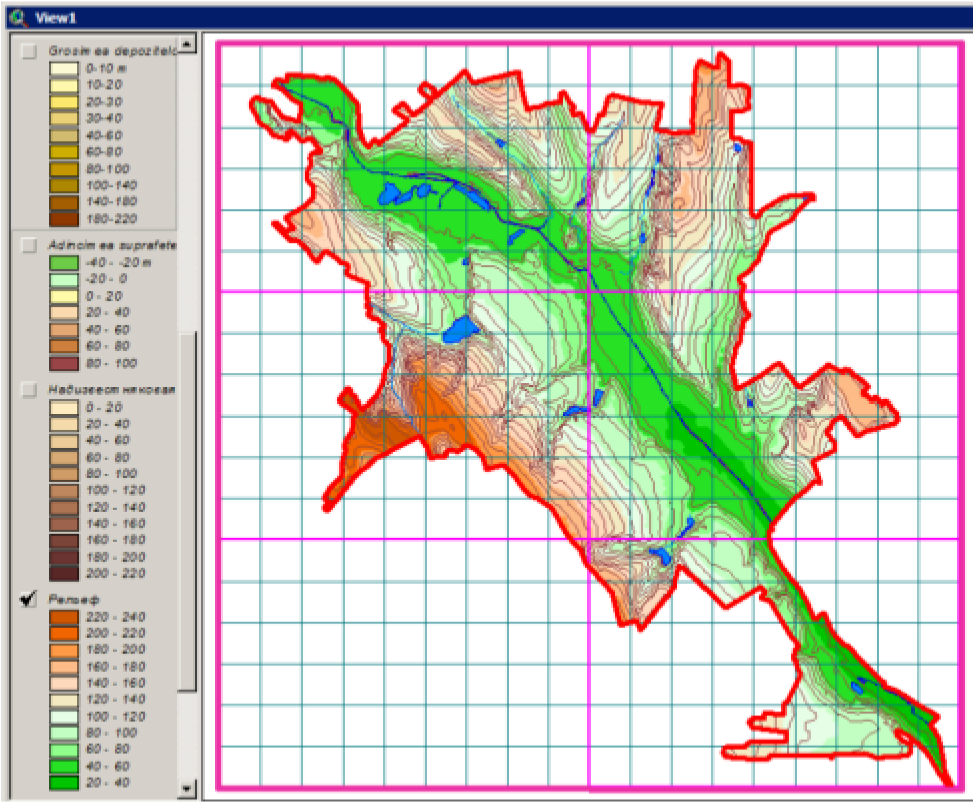

Fig. 1.1. Relief of Ground Surface

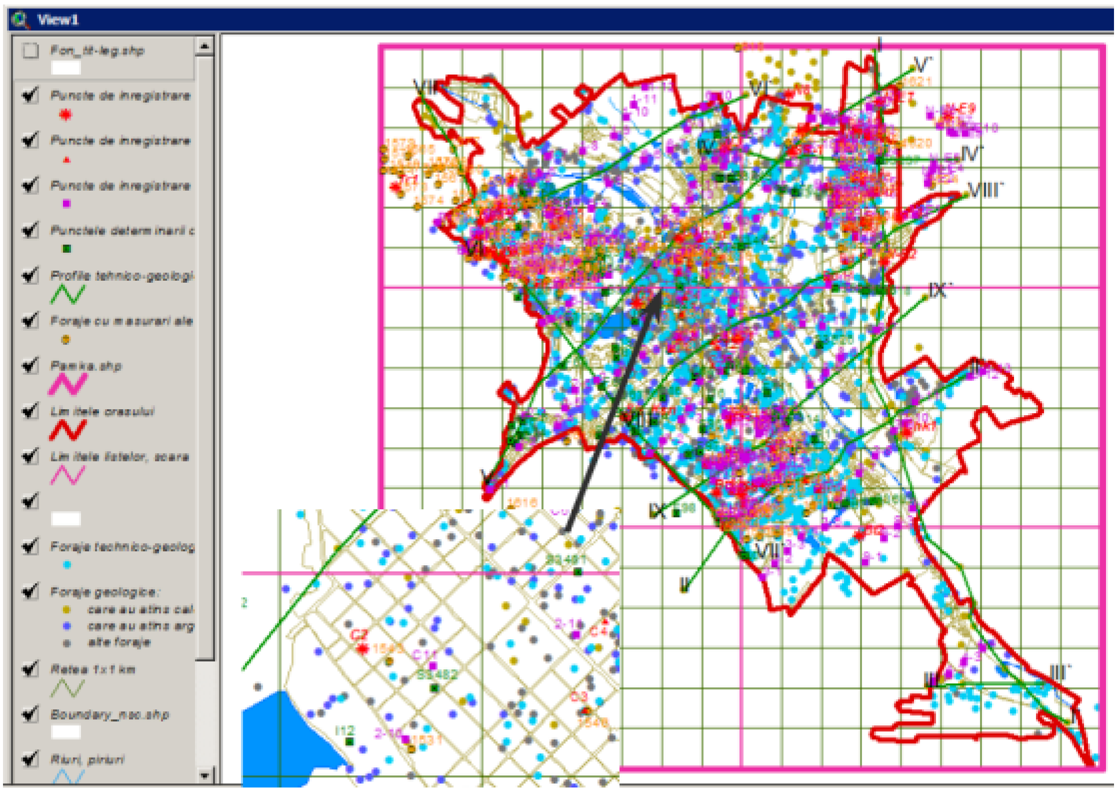

Fig. 1.2. Map of observation data

1.2. Geometrical parameters of model

The geometrical parameters of model were determined with the help of maps of various layers and geological cross-sections made on the data of drilling 2673 boreholes. In figures 1.3 and 1.4 the geological cross-sections on lines IV and XI are shown, giving representation about a geological structure of territory.

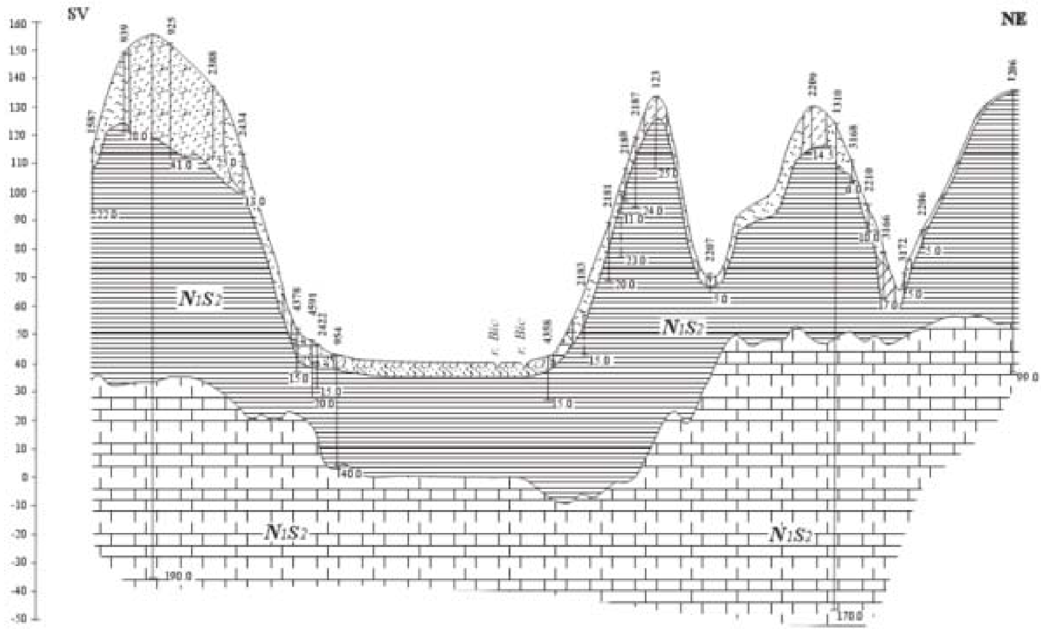

Fig. 1.3. Geological cross-section (line VI)

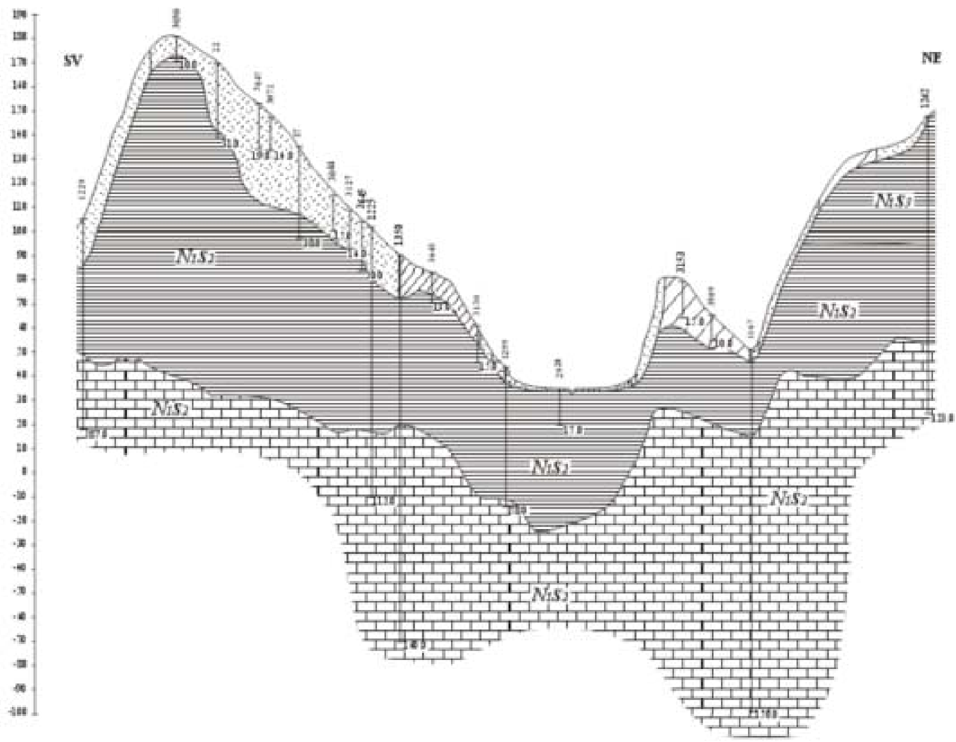

Fig. 1.4. Geological cross-section (line IX)

The bedrock of cross-sections is limestone of Neogene age, above lay hard clay of Neogene age, on them lay quaternary deposits consisting from loam, loamy sand, sand, clay and uppermost is the thin layer of soil. Quaternary deposits can be damped by ground water. Vertical scale in figures in 25 times stretches concerning horizontal scale.

We can know about behavior of layers within city's territory from map of top bedrock surface (fig. 1.5) and map of top hard clay surface (fig. 1.6).

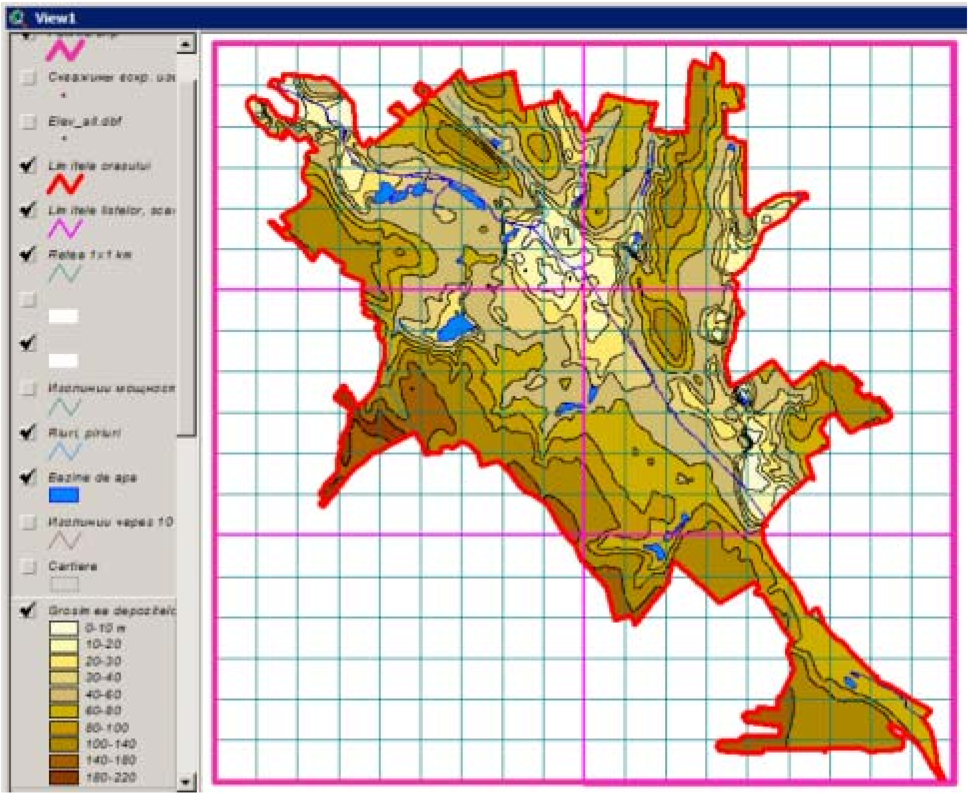

Fig. 1.5. Map of top bedrock surface (depth from ground surface)

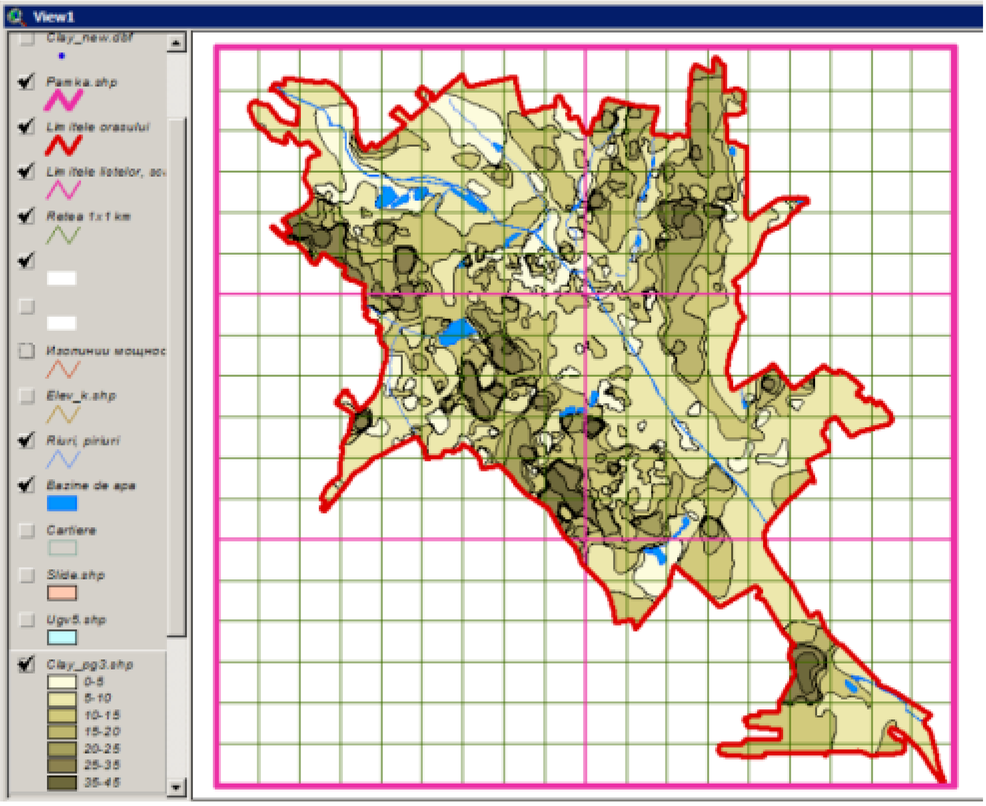

Fig. 1.6. Map of hard clay surface (thickness of quaternary deposits)

The map of water level (fig. 1.7) gives one more boundary of layers – between dry and damped quaternary deposits.

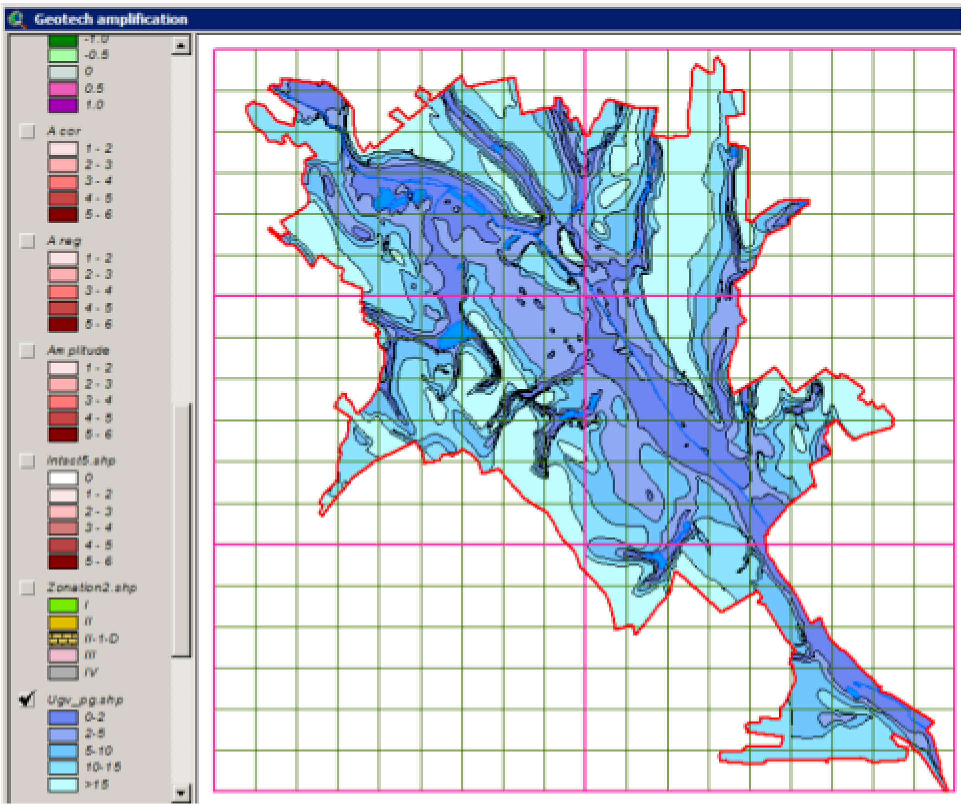

Fig. 1.7. Map of water level

The belonging to this or that geotechnical zone defines a degree of damping quaternary deposits. The map of geotechnic zonation is shown in fig. 1.8. We can specify three basic zones: I - low sites of river valleys, II - terraced and watershed sites, III - steep slopes and landslide sites.

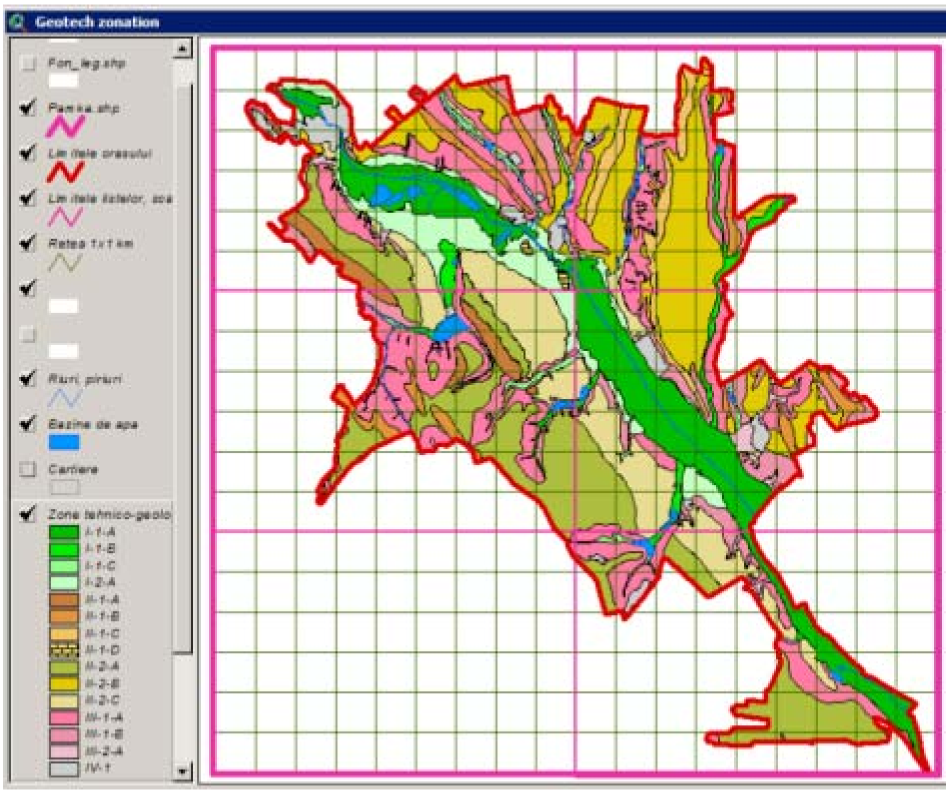

Fig. 1.8. Map of geotechnic zonation

The spatial crossings of each of four maps have allowed to receive contours model polygons with fixed geometrical and elastic parameters of site conditions. For example, polygon {geotechnical zone - II / water level = 10-15 m / top of clay = 25-30 m / top of limestone = 60-70 m} uniquely define depths of each of layers of a modeling site, and also their elastic properties. The procedure of allocation of model polygons was carried out with use GIS (fig.1.9). Total within the limits of city more 4300 polygons were allocated, that corresponds to 424 combinations of mapped parameters.

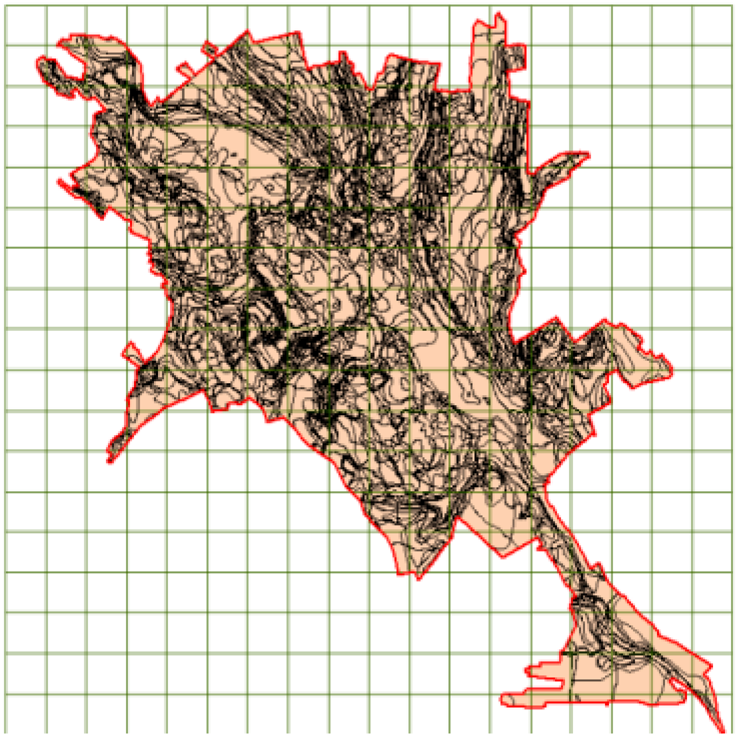

Fig. 1.9. Map of model polygons with fixed properties of site conditions

1.3. Elastic properties of model

The basic parameters determining elastic properties, are density and velocity of waves in layers. We have more than 1000 boreholes with measurements of density and 118 boreholes with measurements of velocity. It allows to define territorial and deep changes of the specified parameters for each layer of deposits.

After the analysis of distribution of density in layers it is possible to tell, most significant is the dependence of density with depth. On its background the territorial variations of density are insignificant. Distributions of density has large dispersion and low coefficient of correlation. The steady tendency of increase of density with humidifying quaternary deposits is observed.

As an example in a fig. 1.10 the correlations of density with depth and their approximation for various layers on the data seismic borehole logging is shown. Coefficient of correlation for various layers changes within the limits of 0,68 - 0,77. From figure it is visible, that quaternary deposits it is statistically difficult to separate by density. Quaternary and Neogene clay obviously differ by average meanings of density.

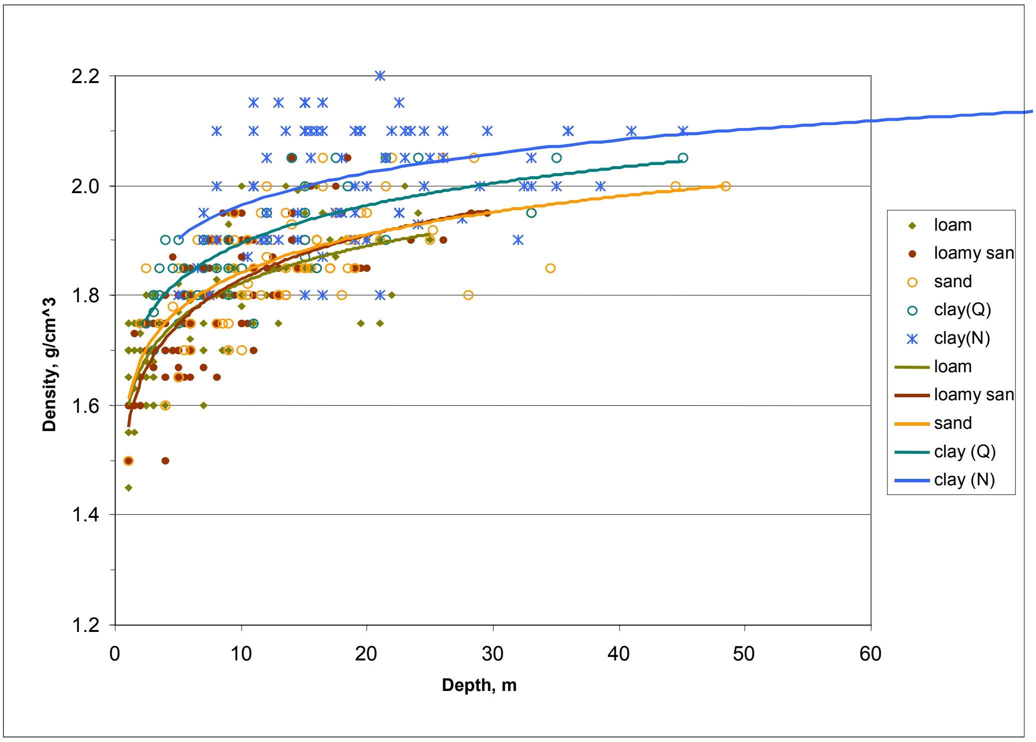

Fig. 1.10. Correlations of density with depth and their approximation for various layers

The analysis of wave velocities is best for considering depending from density of layers. In this case dependencies have more universal and stable character. They are less sensitive to a type of layers. The correlation of velocities of S-waves with density of deposits of various composition is represented in a fig. 1.11. Owing to large dispersion of the data, the coefficients of correlation are insignificant and make 0,5 - 0,65 for various layers. The tendency in distribution of the data however is clearly traced. The average meanings for various layers differ insignificantly, that specifies an opportunity of forecasting of average velocities of S-waves on the basis of the generalized dependence from density of various layers.

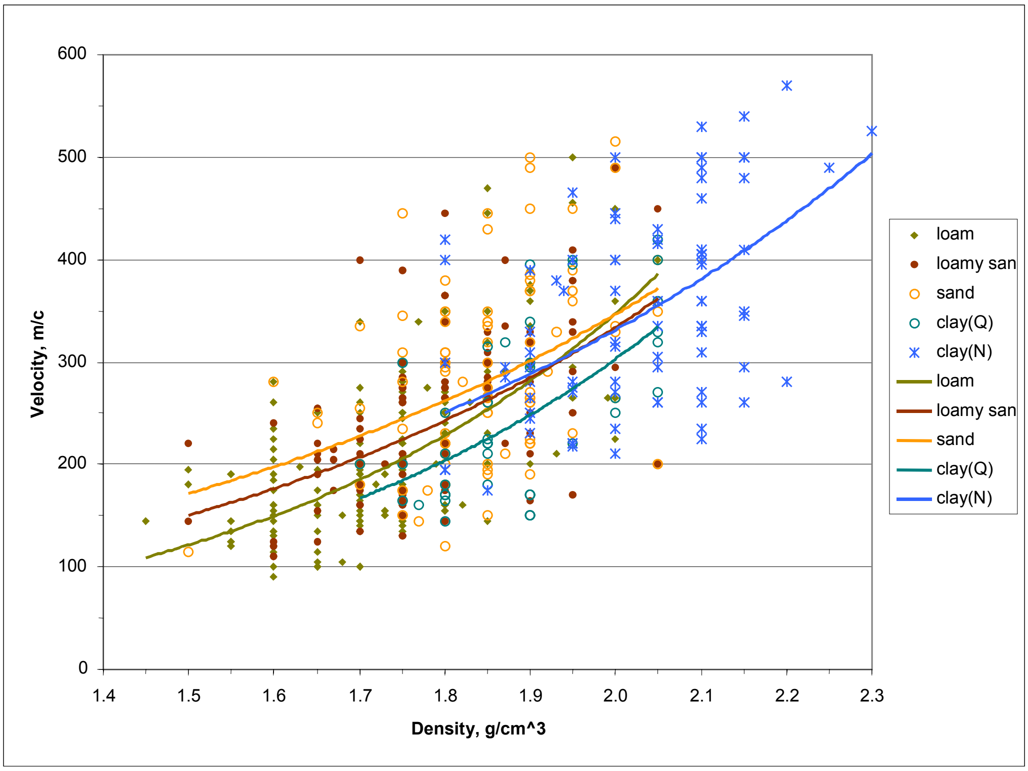

Fig. 1.11. Correlation's of velocity of S-waves with density and their approximation for various layers

Following the specified principles of modeling and knowledge of geometry and elastic properties of layers in territory of Kishinev, as geophysical model for cities we used a 5-layers medium. It is shown in the table 1 with the indication of range for properties in layers.

Table 1

Type	Age	Thickness	Density	Velocity
Soil	Q_4	0.5	1.5	120
Dry deposits	Q_{1-4}	0-20	1.52-1.78	140-230
Humid deposits	Q_{1-4}	0-22	1.71-2.03	200-350
Clay	N_1	0-200	1.86-2.17	260-450
Limestone	N_1		2.45	1300

Layers 2 - 4 have not only variable thickness, but also variable elastic properties dependent from depth. Depending from local conditions any of these layers can be absent in some sites.

Thus, it is possible to consider creation of model completed. It has the fixed geometrical parameters (fig. 1.9) and certain elastic properties for various layers.

1.4. Comparison of amplitude-frequency characteristics of modeling and real sites

For definition of similarity degree of amplitude-frequency characteristics of modeling and real sites we shall consider some examples. In a fig. 1.12-1.15 are given pair characteristics of four real sites and appropriate by them modeling. The depths of real bedrock are equal accordingly 19, 40, 55 and 111 meters.

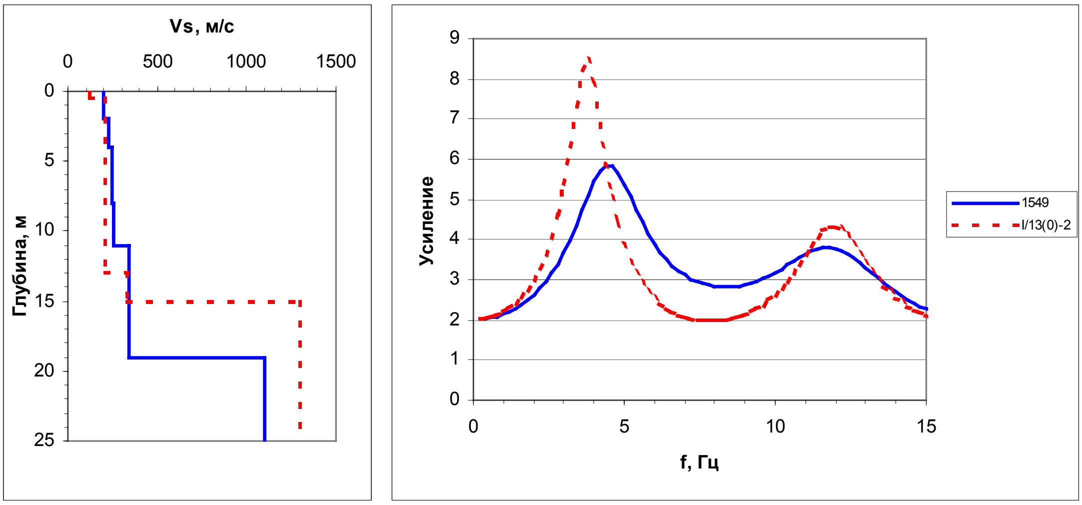

Fig. 1.12. Comparison of the characteristics of sites: real borehole 1549 and modeling for this area I/13 (0) -2.

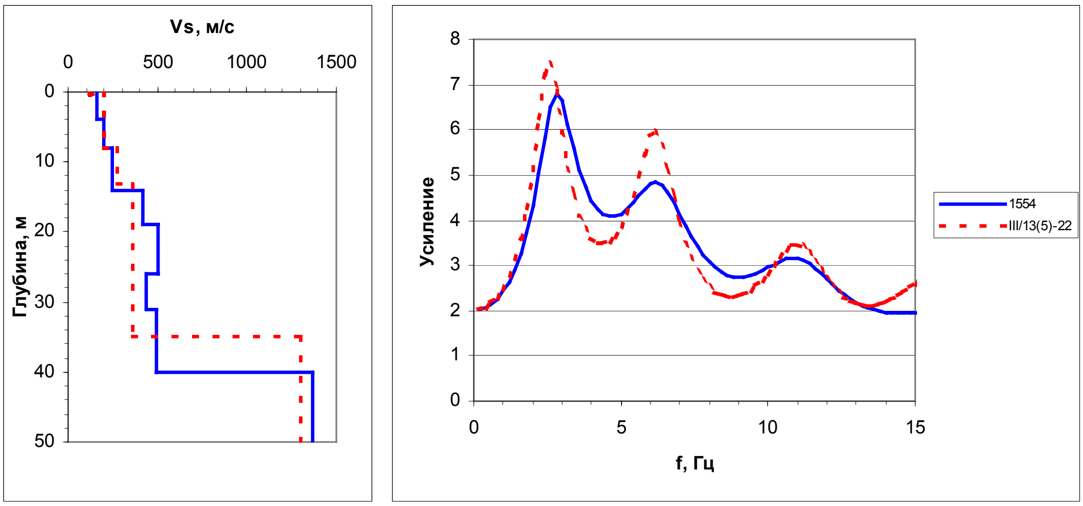

Fig. 1.13. Comparison of the characteristics of sites: real borehole 1554 and modeling for this area III/13(5)-22.

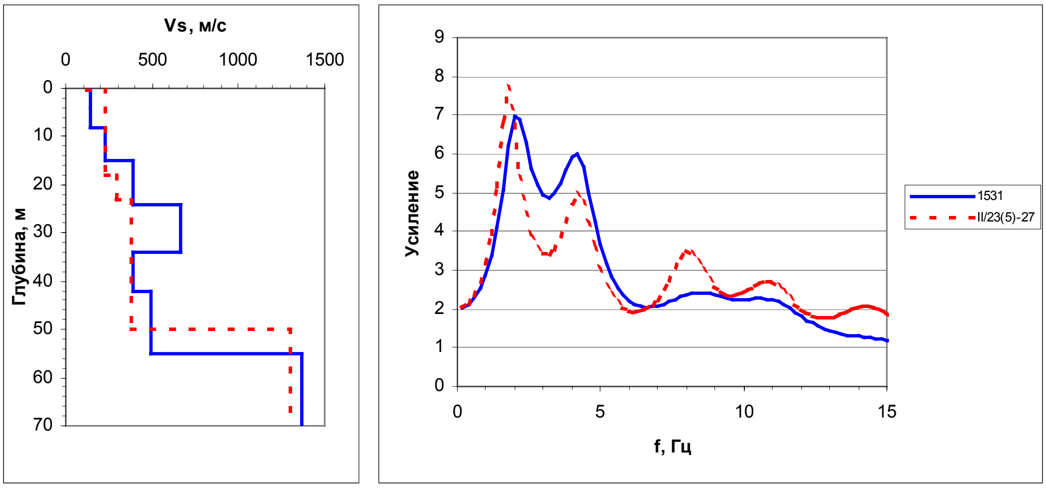

Fig. 1.14. Comparison of the characteristics of sites: real borehole 1531 and modeling for this area II/23(5)-27.

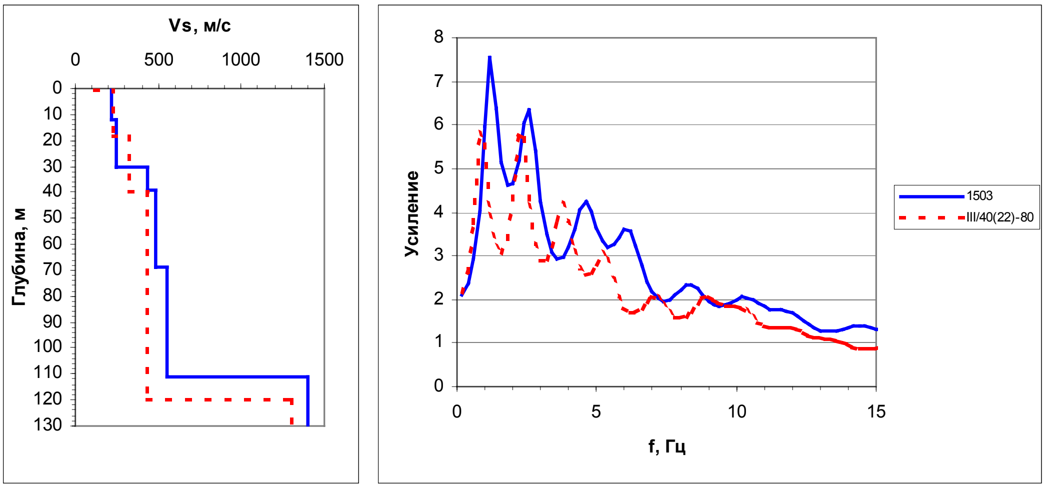

Fig. 1.15. Comparison of the characteristics of sites: real borehole 1503 and modeling for this area III/40(22)-80.

The observable divergences entirely are connected to difference in geometrical and elastic properties of model and real site. The model operates with average geometrical and elastic properties, real site – local properties.

The comparison of the characteristics of real and modeling sites shows their close enough similarity and allows to use such modeling for the further analysis.

1.5. Comparison of modeling characteristics and H/V ratio of microtremors spectra

As a result of the spectral analysis of records of microtremors in different areas of city the spectra of horizontal and vertical oscillations were received. In themselves spectra of microtremors already allow to define the predominant periods of sites oscillations. From the theory of a method also it is known, that the ratio of spectra H/V with realization of some conditions can express amplitude-frequency characteristic of a site.

In a fig. 1.16-1.19 the examples not bad similarity modeling characteristics and H/V of spectra are shown.

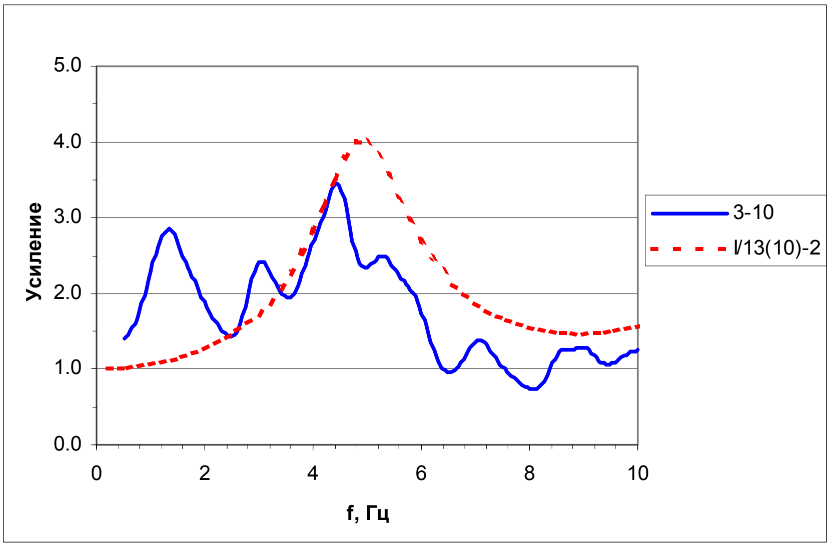

Fig. 1.16. H/V ratio p.3-10 and modeling characteristic I/13(10)-2.

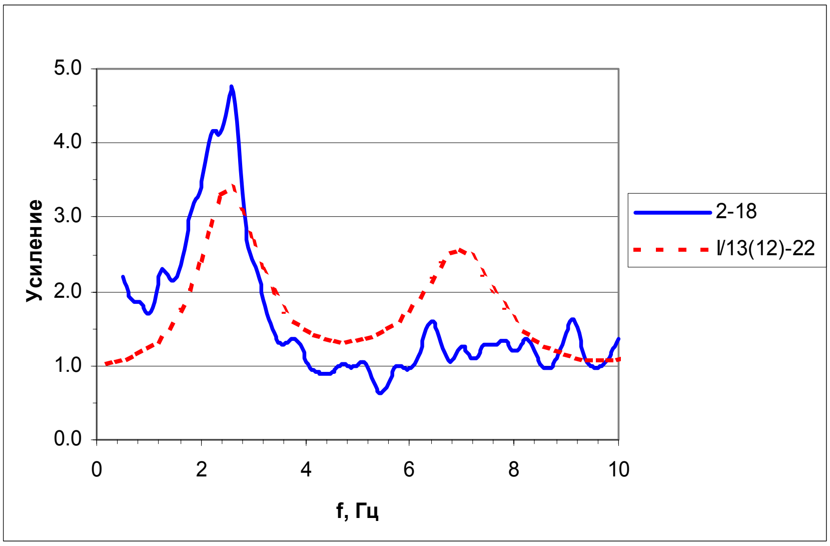

Fig. 1.17. H/V ratio p. 2-18 and modeling characteristic I/13(12)-22.

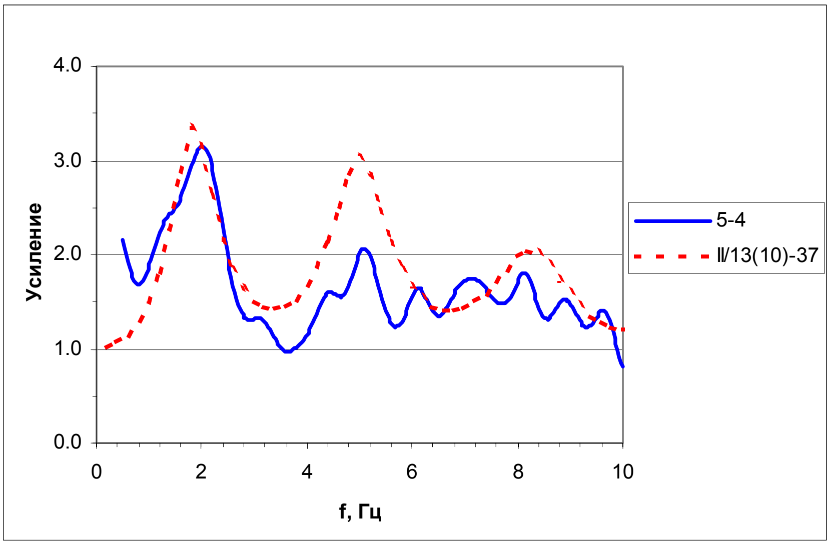

Fig. 1.18. H/V ratio p. 5-4 and modeling characteristic II/13(10)-37.

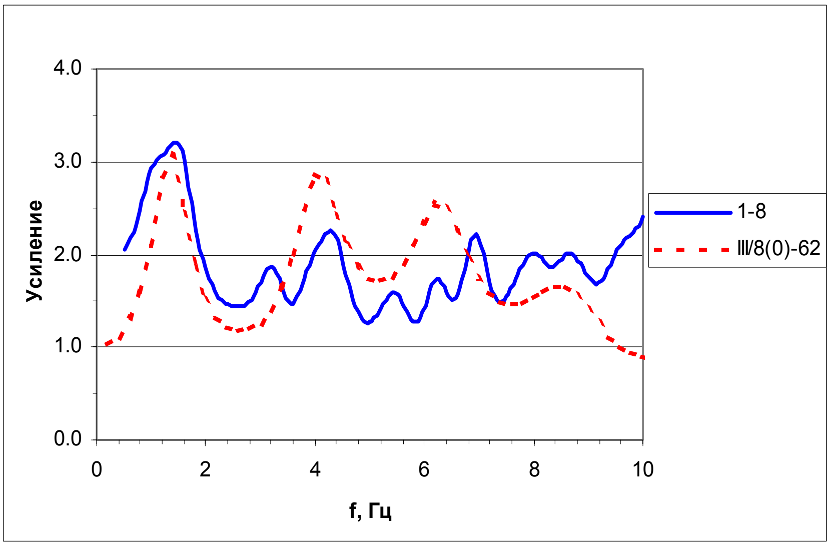

Fig. 1.19. H/V ratio p. 1-8 and modeling characteristic III/8(0)-62.

1.6. Amplification properties of sites

After modeling local sites the amplitude-frequency characteristics were calculated. On the basis of the characteristics the average amplifications of sites were determined. In other words, for all city territory the map of average amplification was received. The fragment of this map for the central part of city is given in a fig. 1.20. In limits of city the peak amplification has range 1.6-4.7, on the shown fragment of a map – from 2.0 to 4.7.

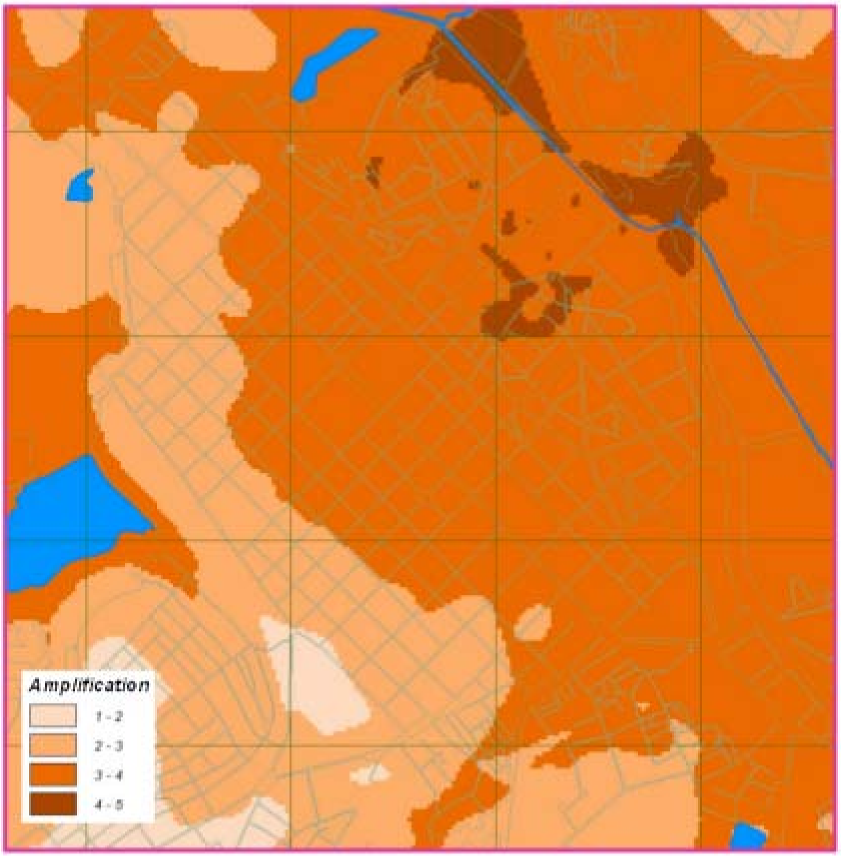

Fig. 1.20. Modeling amplification (Kishinev, Center)

For check of correctness of modeling of amplifications we compare a map of modeling amplification with a map of damage buildings in central part of the city at earthquake 30.08.86 (fig. 1.21). The given comparison is shown in a fig. 1.22 as a field of correlation of a damage degree and modeling amplification of sites.

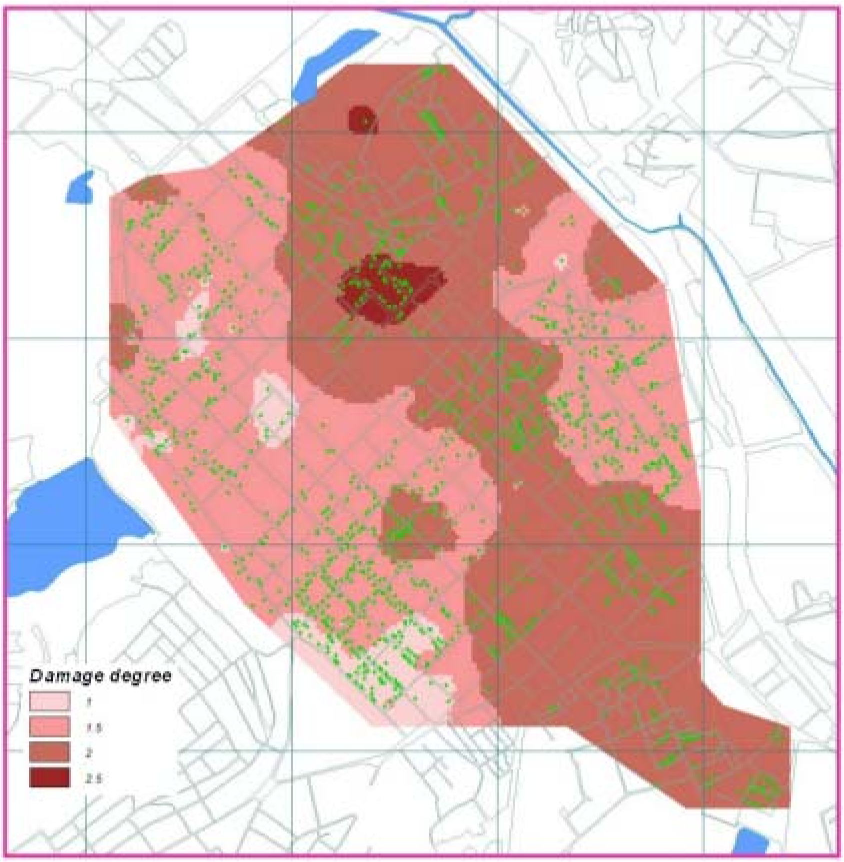

Fig. 1.21. Map of damages (Kishinev, Center, 30/08/86)

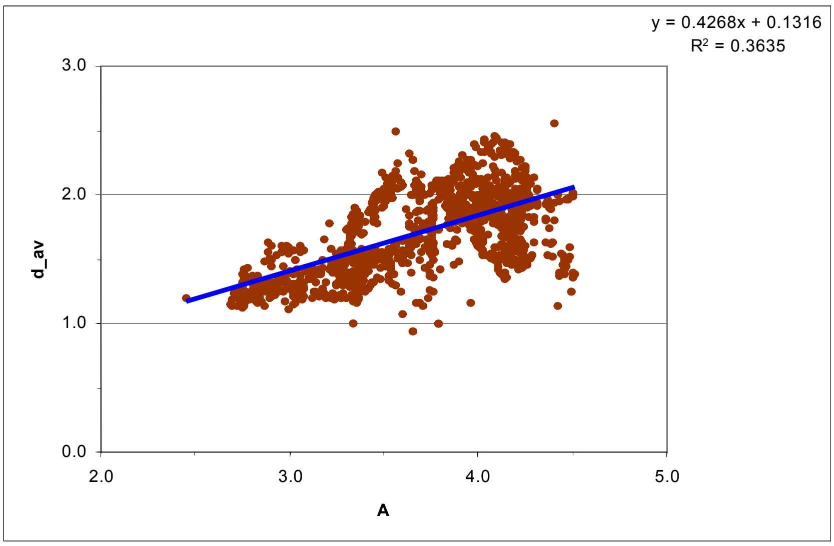

Fig. 1.22. Correlation of a damage degree and modeling amplification

It is necessary to note that the data of damages differ very large dispersion. Owing to what the correlation them with any other parameters, as a rule, is low. In our case at small coefficient of correlation (r=0.6), the linear tendency of increase of damage degrees with amplification factor of sites is traced.

Having transformed amplification in increment of intensity concerning the chosen reference site, we shall receive usual correlation of intensity and damage degree (fig. 1.23). The specified transformation is carried out with the formula: $\Delta I = 3.3 \lg (A_i / A_o)$, where A_o - amplification on a reference site.

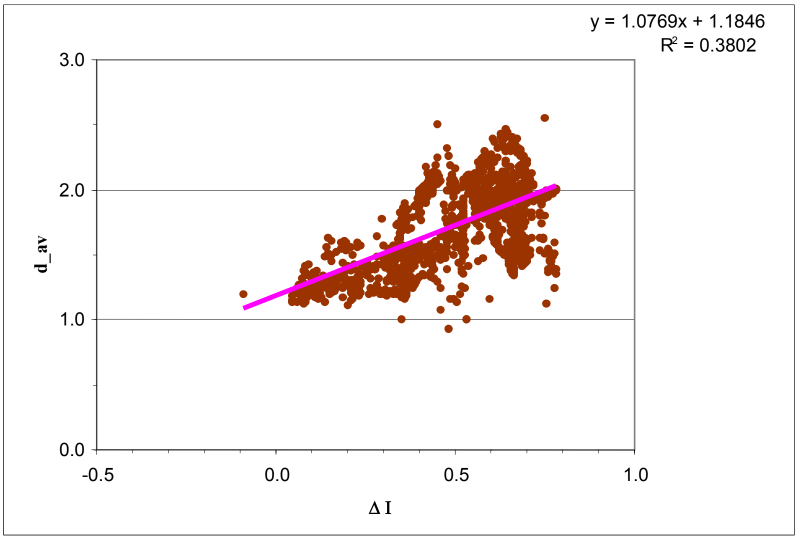

Fig. 1.23. Correlation of a damage degree and modeling increment of intensity

Main in this diagram, that a ratio $\Delta d / \Delta I \approx 1$. Such ratio value connects a degree of damage with intensity in our region. It speaks about a correctness of the created model of sites, its ability through amplification correctly to predict possible damages of buildings.

1.7. Resonance properties of sites

The resonance phenomena are inherent for high buildings at closeness of the own periods of a site and building. In practice resonant effects are expressed as additional forces and damages received by buildings. In conditions of Kishinev the main border of layers capable to create strong enough resonant effects is the top of limestone. In amplitude-frequency characteristics the resonant period from this border occurs by the first low-frequency maximum.

In a fig. 1.24 the correlation of the site periods with depth of bedrock is shown. The periods of sites were calculated with the formula $T_s = 4H / V_s$. In correlation the data all 118 seismic borehole logging are used. The received high degree of correlation allows with high accuracy to use this dependence for definition of the resonant periods of sites.

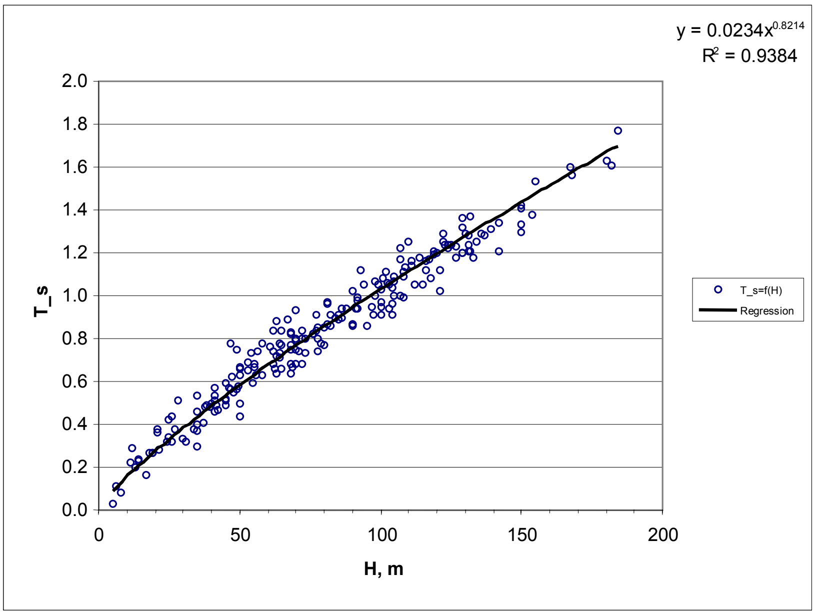

Fig. 1.24. Correlation of the sites periods with depth of bedrock

The analysis of resonance effects can be carried out in territory with regularity built up by high buildings (for example, Botanica area). For this purpose it is necessary to compare damages of high buildings with ratio of the periods of buildings and sites. 164 buildings of height 8 and more floors participated in calculations. The analysis has shown, that search of theoretical curve, approximating experimental data optimum to do as polynomial n-power from $|\ln (T_b / T_s)|$:

$$d_R = P \{|ln(T_b / T_s)|\}$$

The initial data of damage degrees were grouped depending value $|\ln (T_b / T_s)|$ with an interval of averaging 0,2. Thus in each interval of grouping got from 15 up to 39 buildings. The simple and reliable result (r=0.99) can be received from the fourth polynomial power. The equation looks like:

$$d = -2.0123x^4 + 6.0164x^3 - 4.5847x^2 - 0.7644x + 2.2085 \ ,$$

where x = |ln (T_b / T_s) |. The specified dependence of damages from ratio building and site periods is shown in a fig. 1.25.

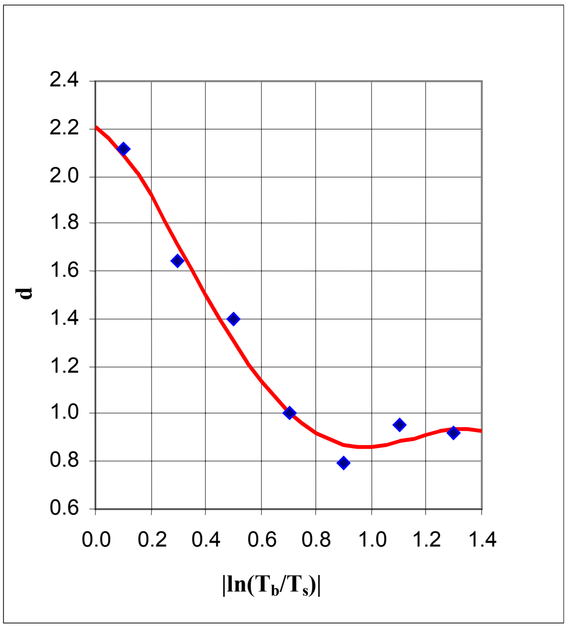

Fig. 1.25. Dependence of resonant damages from ratio of the building and site periods

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If on x-axis to not use absolute value, the general view of a resonant curve of damage amplification can be received. It is presented in a fig. 1.26 and has typical bell-shape.

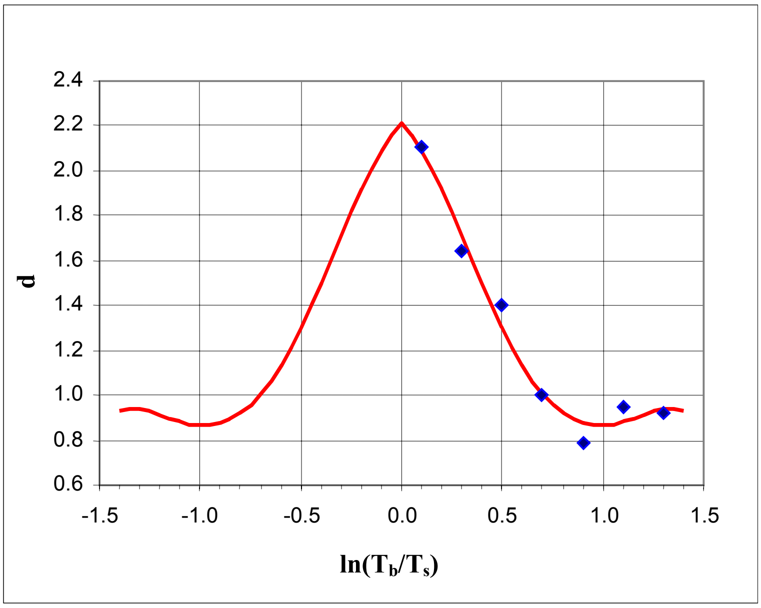


Fig.1.26. General view of a resonant curve of amplification of damages.

Now it is interesting to look, what becomes with an initial field of damages in Botanica area, if from him to subtract resonant effects at high buildings? Or, in other words, what could be a map of damages with absence of additional forces connected to a resonance? The answer to this question can be received from comparison of a fig. 1.27 and 1.28.

Fig.1.27. Map of buildings damages (Kishinev, Botanica, 30.08.86).

Fig.1.28. Map of buildings damages with the removed resonance effect (Kishinev, Botanica, 30.08.86).

Conclusion

In conclusion it is possible to tell, that all results of modeling were used for creation of a final map of seismic microzonation. The amplification of sites has given a basis for allocation of zones of various intensity, and the analysis of resonant properties of sites has allowed to add on a map of microzonation isoline of the resonant periods. The map of seismic microzonation is shown in a fig. 1.29.

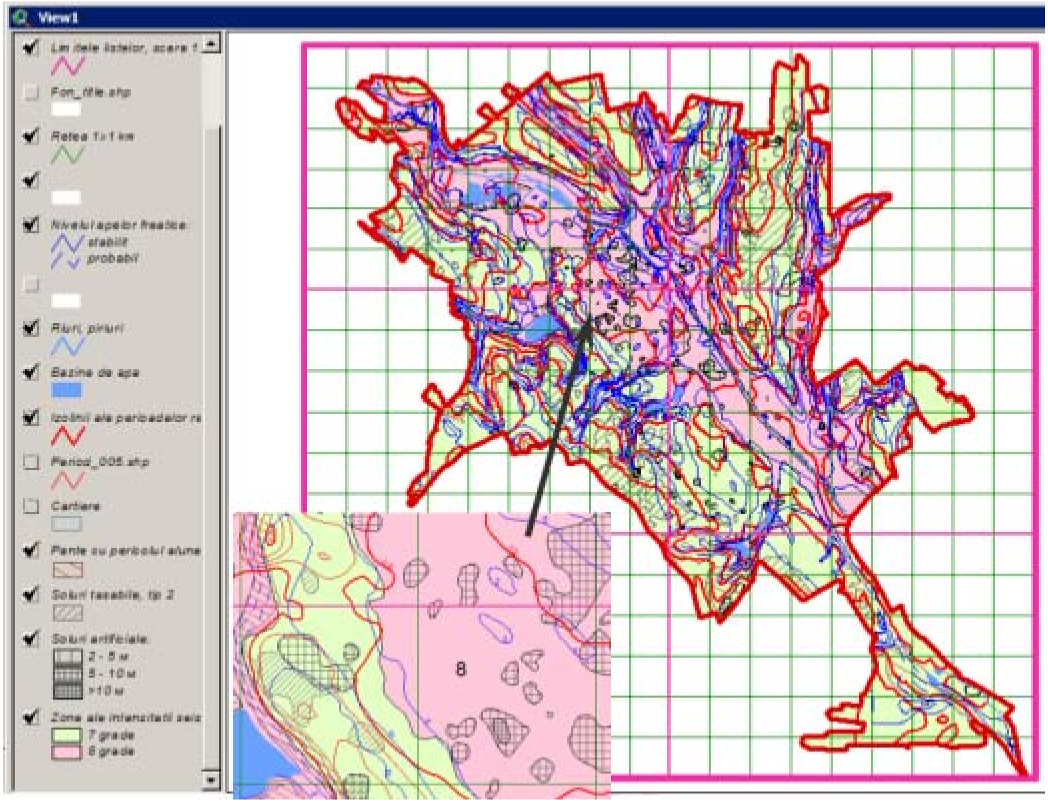


Fig. 1.29. Map of seismic microzonation

Literature

1. Ratnikova L. Methods of calculation of seismic waves in thin-layer medium. M., Science, 1973, 124 p.
2. Y. Nakamura. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. QR of RTRI, vol. 30, No 1, pp.25-33.
3. Shebalin N. Distribution of damage degrees of buildings and use it for an estimation intensity. In book: A seismic scale and methods of measurement of seismic intensity. M., Science, 1975, p. 253-266.

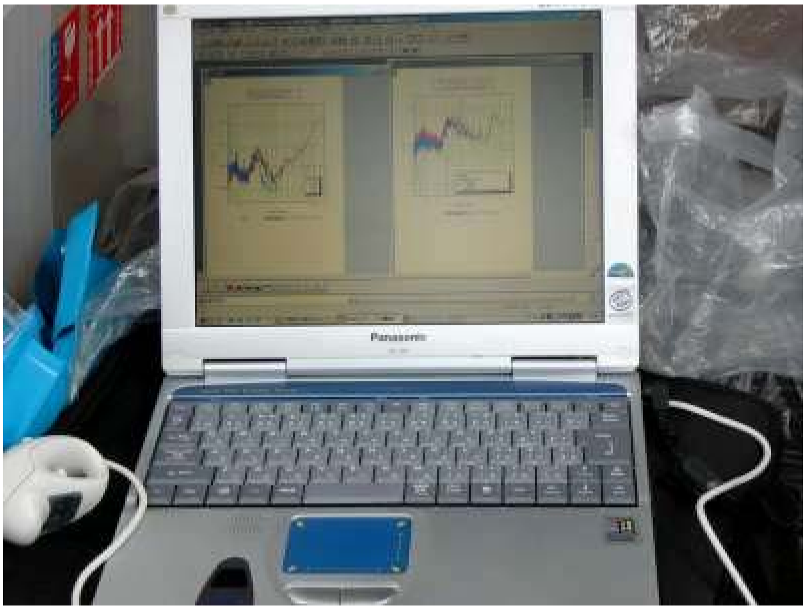
2. STUDY TRIPS

2.1. Study trip to Kochi

The trip to Kochi (13-14/09/2004) was undertaken with the purpose to see real microtremors measurements, both single point, and array. The microtremors measurements were carried out by a team from Tokyo Soil Research Co. under the direction of the Dr. Fukumoto. We observed huddle test and measurements of small array microtremors.

Huddle test.

Microtremors measurement.



Processing of measurements.

Unfortunately weather conditions have prevented (was a strong typhoon) to execute for us the planned program fully.

2.2. Study trip to Fukuoka, Kyushu University

The travel in Kyushu University (4-8/10/2004) was undertaken specially for meeting with Prof. Kawase. During four days we had with him intensive conversations about seismological problems interesting for us.

In the beginning Prof. Kawase has told about his the interests in seismology. These interests are extraordinary wide: from earthquake source mechanism up to local site conditions. Later he has presented some of recent works concerning an estimation strong ground motion by modeling scenario of earthquakes in Kyushu area, site effects on strong ground motion and others.

Then I have presented my work about modeling local site conditions for the purposes of seismic microzonation. The discussion was long and useful. Prof. Kawase was interested in fine details. On behalf of the Prof. Kawase I have found the attentive and interested interlocutor. Great thanks to him therefor.

2.3. Study trip to Hokkaido

During travel to Hokkaido (25-29/10/2004) we had an opportunity to visit some scientific centers and unique objects representing interest from the point of view of seismology and earthquake-resistant design.

Usu Volcano Observatory. Have heard the information about work of station for monitoring of Usu volcano activity. We also had an opportunity to observe a new crater of Usu volcano and damaged area by eruption in 1977.

Volcano Observatory.

Rupture zone.

New crater of Usu volcano.

<u>Hokkaido Northern Regional Building Research Institute</u>. The general information about activity of Institute was heard. We also were acquainted with the equipment and work of some laboratories of Institute, such as: Building Materials, Structural Testing, Seismic Resistance, Fire Testing, Sound Insulation Testing, Durability Testing, Cement and Aggregate Testing, Outdoor Environment Simulator, Wind and Snow Environment Simulator.

Building Research Institute.

Air and Water Tightness Testing Equipment.

3D Vibrating platform.

<u>Hokkaido University. Institute of Seismology & Volcanology</u>. We were acquainted with work of laboratory of seismology. Have heard some lectures of Institute collaborators connected with problems of allocation of signals in seismology and system of observation and the warning of a tsunami.

In laboratory of seismology.

Lecture about a tsunami.

<u>Headquarter of Nozai Kogyo Co.,Ltd.</u> We have learned about activity of the company on manufacture of ceramic products for the purposes of construction, have looked samples of production. After we have visited Nopporo Ceramic Factory, where directly have seen process of manufacture of ceramic products from clay.

Story about activity of the Company.

Samples of production of the Company.

Ceramic factory, production lines.

Chitose Shimin Hospital. The authors of the project acquainted us with a design of this unusual building. The building stands on special LRB (Lead Rubber Bearing) and RB (Rubber Bearing) amortization bearings. In result it is completely unreceptive to external influences. During earthquakes the building goes under its laws.

Rubber Bearing.

Rubber bearing.

Kushiro Government Building. Have got acquainted with a design of this building standing on three kinds of shock-absorbers: rubber bearing, lead damper, steel damper. In a building the equipment of strong motion is established. As has shown Tokachi earthquake, is achieved reduction acceleration in some times, and high frequencies cut off absolutely. Later have looked the equipment Meteorological Observatory and work of the center of processing meteorological data, which are taking place in the same building.

Rubber bearing and lead damper.

Steel damper.

Center of processing meteorological data.

2.4. Study trip to Kobe

Task of this travel (15-16/11/2004) was visiting Nojima Fault Preservation, the Great Hanshin-Awaji Earthquake Museum and EDM (Earthquake Disaster Mitigation Research Center).

Nojima Fault Preservation.

The Great Hanshin-Awaji Earthquake Museum.

In EDM we had meeting with Dr. Nelson Pulido. During which he has told about the works on estimation strong ground motion based on source modeling. During lecture Dr. Pulido told also two concrete works about estimation of strong motion: "Near-fault strong motion complexity of the Tottori earthquake (Japan) from a broadband source asperity model" and "Strong ground motion estimation in the Sea of Marmara region (Turkey) based on scenario earthquake".

Meeting with Dr. Pulido.

2.5. Study trip to Yokohama, Kanagawa University

The purpose of trip (22/11-3/12/2004) - study of a seismic microzonation method in Kanagawa University. From the Japanese part the curator of our activity at Kanagawa University was the Prof. Enomoto. He has acquainted us with the approaches used by him during seismic microzonation of Caracas city (Venezuela), about application of microtremors measurements to risk assessment for buildings in Caracas, about the experience of work on microzonation of Granada (Spain).

During 25-27/11 we had trip together with the Prof. Enomoto in epicentral zone recent strong Niigata earthquakes. The purpose of trip was the microtremors measurement in three towns, injured of earthquakes: Nagaoka, Ojiya, and Kawaguchi. In passing we had an opportunity to look consequences of earthquakes.

Kanagawa University.

Nagaoka, microtremors measurement.

Ojiya, microtremors measurement.

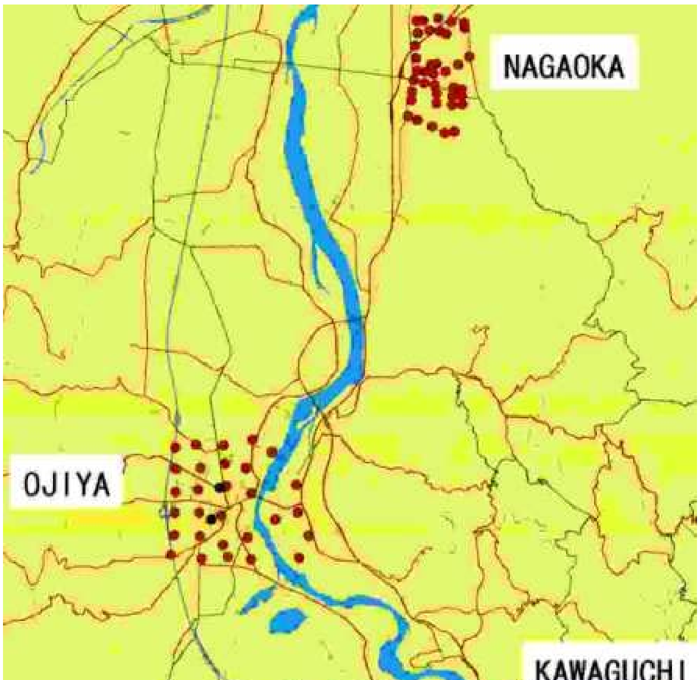
Nagaoka, destructions at school.

Nagaoka, landslide.

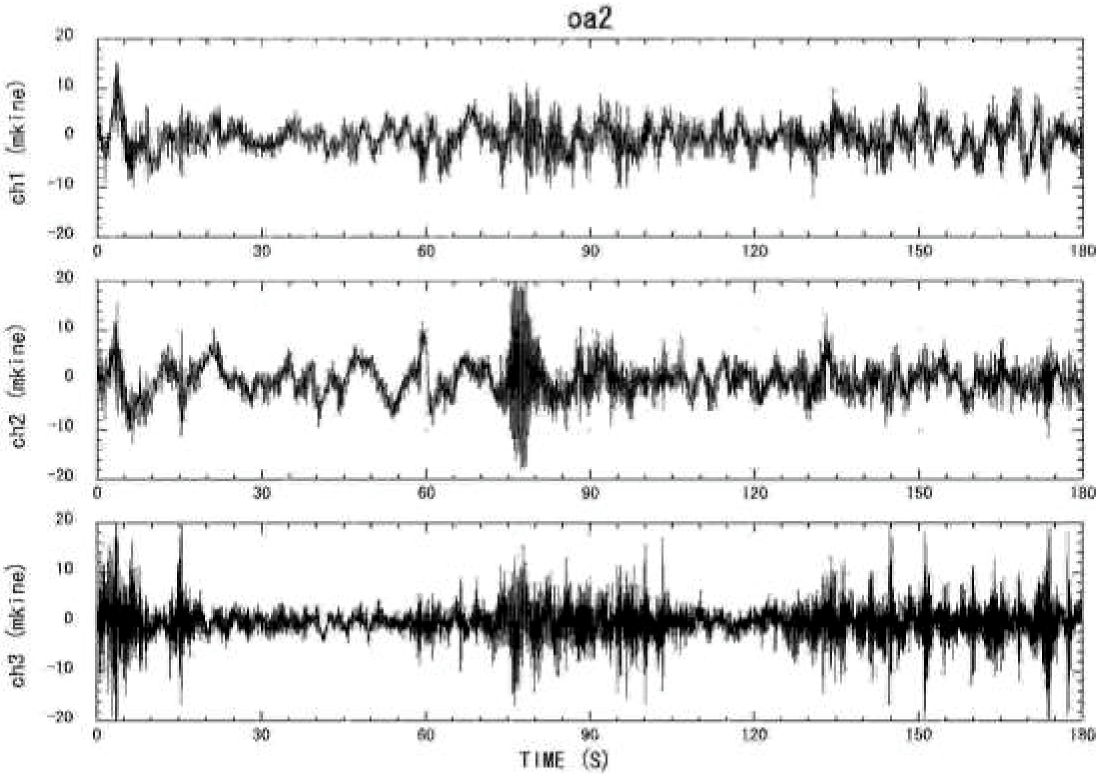
Ojiya, liquefaction of soils.

Kawaguchi, destruction zone.

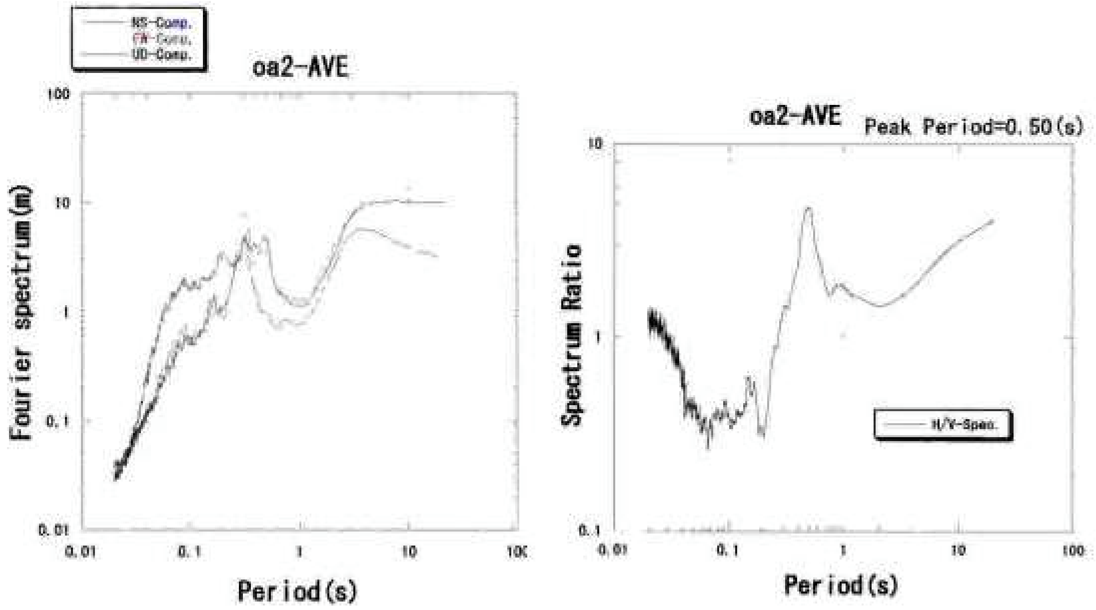
On returning in Yokohama the processing of records was made, the Fourier spectra and H/V ratio are calculated. At the request of the Prof. Enomoto the presentation of my work on seismic microzonation of Kishinev city before the personnel of laboratory and students of the Prof. Enomoto was made.



Points of microtremors measurements.



Example of records microtremors in a point “a2” (Ojiya).



Fourier spectra and H/V ratio for point “a2” (Ojiya).

3. LECTURE COURSE IN BRI, IISEE AND OTHER ACTIVITY IN TSUKUBA

During stay in Tsukuba we heard some lectures from the staff of BRI, IISEE Institutes Dr. Kayama and Senior Eng. Kashima. In them such questions as were mentioned:

- theoretical bases of application of a microtremors method for study of local sites and buildings,
- classification and characteristics microtremors,
- the equipment for measurement of microtremors,
- features of Fourier transformations of a long time series, smoothing of spectra,
- site conditions near BRI Institute,
- strong earthquake motion observation in Japan, strong motion observation of BRI,
- dynamic behavior of 9-story base-isolated building (Kushiro Government Building) during the 2003 Tokachi earthquake, and others.

Besides we operatively and regularly received from them the seismological information, interesting for us, on the earthquakes, which have occurred during our visit, which was much.

Also were in Tsukuba, we had an opportunity to make excursion visit in National Research Institute for Earth Science and Disaster Prevention and to take part in a symposium "The 50th Anniversary of Strong-Motion Earthquake Observation in Japan".

GRATITUDE

Let to express heartfelt gratitude to Management and staff BRI, IISEE, hospitably accepting us during long time, and in particular Kayama-san and Kashima-san, with who direct we had deal each day. They helped us to decide any arising scientific questions.

I want to express gratitude to Professors Kawase and Enamoto hospitably accepting me in the laboratories and generous shared by their knowledges and experiences.

Let to express thanks to all personnel TBIC, for hospitality and kindliness, and especially Sakamoto-san, Hagiwara-san, Kubota-san and Iizuka-san, who helped us to overcome living, transport and other problems.