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SEISMIC MICROZONING AND RESONANT MAP FOR URBAN PLANNING

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Abstract

The today's cities are dealing with permanent demands to extend their residential and economical facilities. The existing urban zones are being revised with new regulating urban plans to increase their accommodation capacity by replacing, annexing or upgrading existing building structures. In other cases the urban zones are being expanded to neighboring areas, sometimes irrespective of vulnerable environment.

This study aims to identify the potential for resonance effect between soil sub-base and building stock in urban zones, being that existing settlement or new settlements foreseen in the stage of urban planning.

Prior to the development of the resonant map, several multidisciplinary site activities are necessary to be performed in order to have a working platform for decision making authorities. Procedure shall be initiated with seismic microzoning of the respective area, obtained with use of geotechnical examinations, geophysical investigations, and microtremor measurements. The obtained results shall then be used to develop the maps with predominant surface periods of vibrations, dynamic amplification factors and seismic zoning with design parameters. Following, predominant periods of vibrations for built structures are obtained with application of ambient vibration measurements (existing structures) or modal analysis (planned structures).

Seismic microzoning is the key to obtain the site specific data upon soil strata performance due to expected earthquake excitations. It gives information's upon the amplification/attenuation of seismic excitations from the bedrock to the ground surface. Modification of the seismic excitation is governed from the site specific ground conditions, presented on ground surface as mean values of the ratio of maximum accelerations at the surface versus acceleration of subsoil media – expressed through dynamic amplification factors (DAF). The excerpted values shall help to create initially the maps with isolines of DAF and then seismic microzoning map with expected maximum mean surface acceleration as a product of DAF with maximum accelerations at the respective bedrock.

Development of resonant map shall conglomerate the information's obtained from seismic microzoning in regard to expected predominant ground periods of seismic excitation and periods of vibrations of built/designed structures. Elastic dynamic properties of built structures can be obtained with application of ambient vibration measurements, with use of digital seismometers equipped by 3 orthogonal high resolution electrodynamics sensors (velocimeters) with frequency range 0.1 – 256 Hz.

All these information's can be concluded with draft of Resonant Map, which can be used as indispensible tool in early stages of urban planning to determine the most optimal zones for construction, structural systems and materials, range of buildings height, etc. Analysis could help to define the urban criteria's for zoning and construction, so the resonance of soil media with built structures is avoided.

Resonant Map can be used to identify the existing building stock with expected critical seismic response and also for assessment of seismic risk and vulnerability-damageability of existing urban environments.

Keywords: seismic microzoning, resonant map, urban planning.

1. Introduction

The study is based on a pilot project "Seismic microzonation of Ulpiana settlement – Pristina" developed from IZIIS (Institute of Earthquake Engineering and Engineering Seismology) under Ministry of Energy and Mines – Republic of Kosovo [1]. The project was developed in phases, producing three deliverables – reports:

Volume I: "Seismological Investigations, Regional Seismotectonic and Seismic Hazard Analysis" The document presents the results from the Seismological and Seismotectonic investigations related to the wider region of the location of interest. On this basis, the spatial distribution of seismic sources and their characteristics were defined and used for seismic hazard assessment of the Ulpiana settlement.

Volume II: "Geophysical Investigation"
The document presents the geological and geotechnical characteristics of the location defined through analysis of data available from previous reports, geological investigations as well as geo-mechanical investigations performed at the time of urbanization of the settlement and construction of the existing buildings.
Geophysical investigations were performed using seismic refraction, seismic reflection and microtremor measurements. The wave refraction was used to define the seismic V_P and V_S velocities in different layers along the geological strata that comprise the terrain down to the depths of 20 to 40 meters, while the wave reflection was used for determining the geological structure down to 200m, including the local tectonics features. The microtremor measurements were used to evaluate the predominant periods of vibration of the soil deposit on the location.

Volume III: "Seismic Zoning"
The document presents the results from the performed investigations and the seismic microzoning of the Ulpiana urban area. Seismic microzoning was performed on the basis of the seismic parameters defined in the seismic hazard analysis and the investigations of local soil conditions influences. The seismic zonation was defined using maps of spatial distribution of maximum acceleration, predominant periods, response spectra and time histories of expected earthquakes as well as seismic parameters defined according to EC8.

With use of ambient vibration (AV) - microtremor measurements, 10 representative geotechnical models out of 20 in total were used to prescribe the elastic response of the soil deposit. A map with isolines of predominant periods of vibration of respective soil layers in elastic range is developed in DWG format. The measurements are performed with use of digital seismometers equipped by 3 orthogonal high resolution electrodynamic sensors (velocimeters) with frequency range 0.1 – 256 Hz.

In addition, AV measurements are realized on 13 typical buildings of the location. The measurements were performed on ground floor and roof level, and respective diagrams showing the maximal response in function of frequency (Hz) and horizontal to vertical spectral ratio are obtained. The predominant period of vibration for particular building is obtained from maximal response obtained with use of peak frequency conversion.

For comparative purpose, 9 mathematical models of model building types (MBT) are developed, based on original technical documentation from the time of construction. The MBT are selected such that quantitively and qualitatively represent the building stock of the urban area. To obtain the response of the respective structures, modal analysis is performed and the respective predominant periods of vibrations are obtained.

The results upon predominant periods of vibrations of the MBT are also compared with requirements from "*Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*"[2].

After analysis, synthesis, comparison and engineering judgment of all the data, the Resonant Map is developed in DWG format, showing the potentially hazardous buildings subjected to the resonance effect, respectively most unfavorable interaction effect between soil deposit and structure response.

2. Analysis and synthesis of available data

The settlement is developed from beginning of 1960's and continued intensively until late 1980's. Three different levels of Codes have been valid during the time of design and construction of building structures in the zone, classified as Pre-Code (<1965), Low Code (1965< <1981) and Moderate Code (>1981). Following the conflict of 1999 in Kosovo, many of the buildings have suffered changes to their destination and structure, with aim to convert their original residential destination to administrative and commercial purposes by weakening or removing structural elements from basement and ground floor levels, and on other cases to extend the accommodation capacity by annexing or upgrading the existing structures with overbuilds. A typical example to represent all the above degradation interferences is Ulpiana settlement.

Ulpiana is located in an inclined terrain configuration, with slope commencing from north-eastern part toward south west side, with maximal altitude of cca + 625 m. The terrain is characterized with small inclination of soil layers ($5\text{-}10^0$) with NNW azimuth (towards the central part of the depression).

The core of this study were the information's and the results gathered from Seismic Hazard Map for the territory of Kosova [3] and Seismic Microzoning of Ulpiana [1], an urban settlement in capital city of Kosovo, Pristina.

The Seismic Hazard Map of Kosovo is compiled using a new computation methodology for probabilistic seismic hazard assessment, based on the smoothed-gridded seismicity approach and on a logic tree, to fully characterize the seismic hazard and its associated uncertainties. The assessment has been carried out for rock conditions with average velocity of shear waves V_S=800 m/sec in the upper 30 meters of soil section, that corresponds to the Class A according to Eurocode 8 soil classification. The results are expressed in terms of peak horizontal acceleration (PGA), as well as spectral accelerations (SA) with 5%-damping, for 95, 475, 975, 2475, 5000 and 10000 years return periods, that correspond to probability of exceeding of 10% in 10 years, 10%, 5%, 2% and 1% in 50 years, and 1% in 100 years. The results are given for rock conditions, which means the effects of soil deposits shall be taken into consideration with utilization of seismic microzoning investigations and measurements.

Seismic Microzoning of Ulpiana is realized with use of available original technical documentation of existing structures, the geological and geotechnical investigation reports for individual buildings on the site, including all prior works related to tectonic, seismotectonic, geology, geomorphology of Kosovo and existing earthquake catalogues. In addition geophysical investigations and microtremor measurements on free field are performed along the site.

Seismic hazard analysis is performed in accordance with EC8 requirements, presented as:

- Cumulative distribution function of peak ground acceleration for different time periods;
- Peak ground acceleration for different time periods and different levels of probability that shall not be exceeded within the defined time period;
- Diagrams of return periods of peak ground acceleration.

The study derives bedrock horizontal ground motion estimates for 50%, 10% and 2% probability of exceeding in 50 years, that are equivalent to 95-year, 475-year and 2,475-year recurrence periods respectively. Finally the Acceleration Zone Graph (AZG) is obtained, defined as function of return period and the peak ground acceleration.

Geophysical investigations were performed using seismic refraction, seismic reflection and microtremor measurements. The refraction was used in defining the seismic V_P and V_S velocities in different layers along the geological strata that comprise the terrain down to the depths of 20-40 meters, while the reflection was used for determining the geological structure down to 200 m as well as the local tectonics. The microtremor measurements provided data for determining the predominant periods of vibration of the soil deposit on the location.

From the investigations it was defined that the terrain of the site is composed of Pliocene sediments consisting of sand, clay, gravel and sand, loosened upon the surface down to the depth of 20 m.

The values of the seismic V_P and V_S velocities were determined in loose Pliocene sediments in range of V_P = 270-2100 m/s and Vs = 110-800 m/s, whereas in the undisturbed Pliocene sediments, the values are V_P = 2200 – 2700 m/s and V_S = 850 – 1250 m/s.

The reflection investigations proved the existence of three geological media down to the depth of about 200 m, namely: loosened Pliocene sediments down to the depth of 20-30 m, undisturbed Pliocene sediments to the depth of 130-160 m and upper cretaceous flysch sediments situated below the Pliocene layers. Faults stretching along NW-SE and NE-SW directions have been defined also.

From microtremor investigations, the predominant periods of the terrain surface were defined. Their values are in function from the structure of Pliocene sediments, and amount to T = 0.50-0.52 s for the total vibration of the Pliocene layers and T=0.08-0.20 s for the vibration of the surface loosened Pliocene layers.

The analysis are synthesized based on 5 geotechnical models – extracted from original technical documentation and 20 Geodynamic models defined from geophysical investigation.

Seismic Zonation is realized considering the seismic effects of the local geotechnical medium, with utilization of analysis regarding elastic and geodynamic characteristics of the surface layers of the terrain and the amplitude frequency characteristics of the expected earthquakes that dominantly affect the amplification characteristics of the geotechnical medium. The analysis resulted in determination of:

- Dynamic amplification factors (DAF) for maximal ground acceleration (a_{max});
- Acceleration response spectra;
- Soil classification according to EC 8.

The DAF values have been defined by the ratio between the maximum accelerations at the surface (a_i) and the subsoil accelerations (a_o) of the geotechnical models (DAF =a_i/a_o), involving effects of amplification/attenuation of soil media in regard to seismic excitation from the bedrock to the ground surface. They are defined as mean values that refer to the foundation zone of the structures at depth of 2 m below the surface.

Finally, the ground is defined as type B according to EC 8, two seismic zones B1 and $B2^{II}$ the latter covering ~67 % of the area representing conditionally stable zone in depth from 2 to 7 meters. Representative DAF and predominant periods of maximal amplitude response of respective ground surface are defined to: DAF=1.4; T=0.10-0.20 s for B1 and DAF=1.6; T=0.20-0.35 s for $B2^{II}$.

Maximum surface accelerations a_{max}(g) at the reference foundation level -2 m are defined for RP95 and RP475 years as per EC 8 requirements, ranging from 0.12 to 0.20 g.

$$a_{max} = a_0 \cdot (DAF)_{rep} \tag{2.1}$$

The maximum values of surface accelerations at the reference foundation level are compared also with predictive relations for peak horizontal and vertical ground accelerations generated by earthquakes in the European area, Ambraseys, N. N. [4].

3. Development of Resonant Map

3.1 Reproduction of Soil Predominant Periods Map

The map showing isolines of soil predominant periods of vibrations, developed under the previous project, has been reanalyzed with use of diagrams of normalized acceleration response spectra's for 10 out of 20 geodynamic models, as representatives of the site soil media.

Reproduction of the predominant periods were realized with use of normalized Spectral Acceleration for 5% damping with selection of SHAKE-Average Curve (an average curve of response spectra's for 5 representative selected earthquakes). Analysis of every single diagram lead to the identification of predominant periods for which the spectral acceleration amplitude reaches the peak response.

Predominant periods of ground vibration for the representative models were extrapolated in locations of neighboring building units of the site. Then under each building unit is defined the value of peak amplitude of spectral response for particular predominant period, global coordinates in Cartesian system. The respective numerical data were used to reproduce the map with isolines of predominant periods of vibrations, covering the entire considered site.

Table 3.1.Predominant ground periods of vibrations at foundation level from ambient induced microvibrations

PREDOMINANT SOIL PERIODS OF VIBRATIONS FROM AMBIENT INDUCED MICROVIBRATIONS								
Geotechnical Model	**DAF**	**Building**	**Model Building Type**	**Year Built**	**Design Code**	**Stories [no]**	**Height [m]**	**Surface Periods T (s)**
G01	1.8	Z	RC moment frames	1992	Moderate	B+GF+5	23.17	0.20 - 0.23
G01	1.6	A3	Composite slabs URM	1962	Pre-Code	B+GF+4	17	0.20 - 0.23
G03	1.8	C7	RC moment frames	1965	Low	B+GF+4	17.26	0.21 - 0.27
G03	1.8	S12	RC moment frames	1969	Low	B+GF+5(6)	22.1	0.21 - 0.27
G05	1.8	S6	RC shear walls	1965	Low	B+GF+4	15.2	0.20 - 0.24
G05	1.8	S7	RC shear walls	1965	Low	B+GF+4	16.6	0.20 - 0.24
G07	1.7	U1	RC shear walls	1975	Low	B+GF+5/6	20.23	0.32 - 0.38
G07	1.8	Y	RC shear walls	1978	Low	B+GF+5	22.94	0.32 - 0.38
G09	1.8	C2	Composite slabs URM	1963	Pre-Code	B+GF+4	16.55	0.20 - 0.22
G12	1.7	D9	RC moment frames	1970	Low	B+GF+4(5)	19.3	0.30 - 0.35
G13	1.7	E31	RC moment frames	1969	Low	B+GF+4	17.2	0.19 - 0.22
G14	1.8	C12	Confined masonry	1965	Low	B+GF+4	16.25	0.20 - 0.25
G20	1.5	D2	Confined masonry	1965	Low	B+GF+4	16.53	0.28 - 0.34
G20	1.4	U3	Confined masonry	1975	Low	B+GF+4(6)	19.5	0.28 - 0.34

Table 3.1 shows amplification of response for selected geotechnical models, e.g. DAF = 1.4-1.8 and ground predominant periods of vibrations at reference building foundation level, e.g. T = 0.19 to 0.38 s.

Below is presented the Figure 3.1, showing the isolines of predominant periods of ground vibrations.

Figure 3.1.Map of ground predominant periods of vibrations at building foundation level

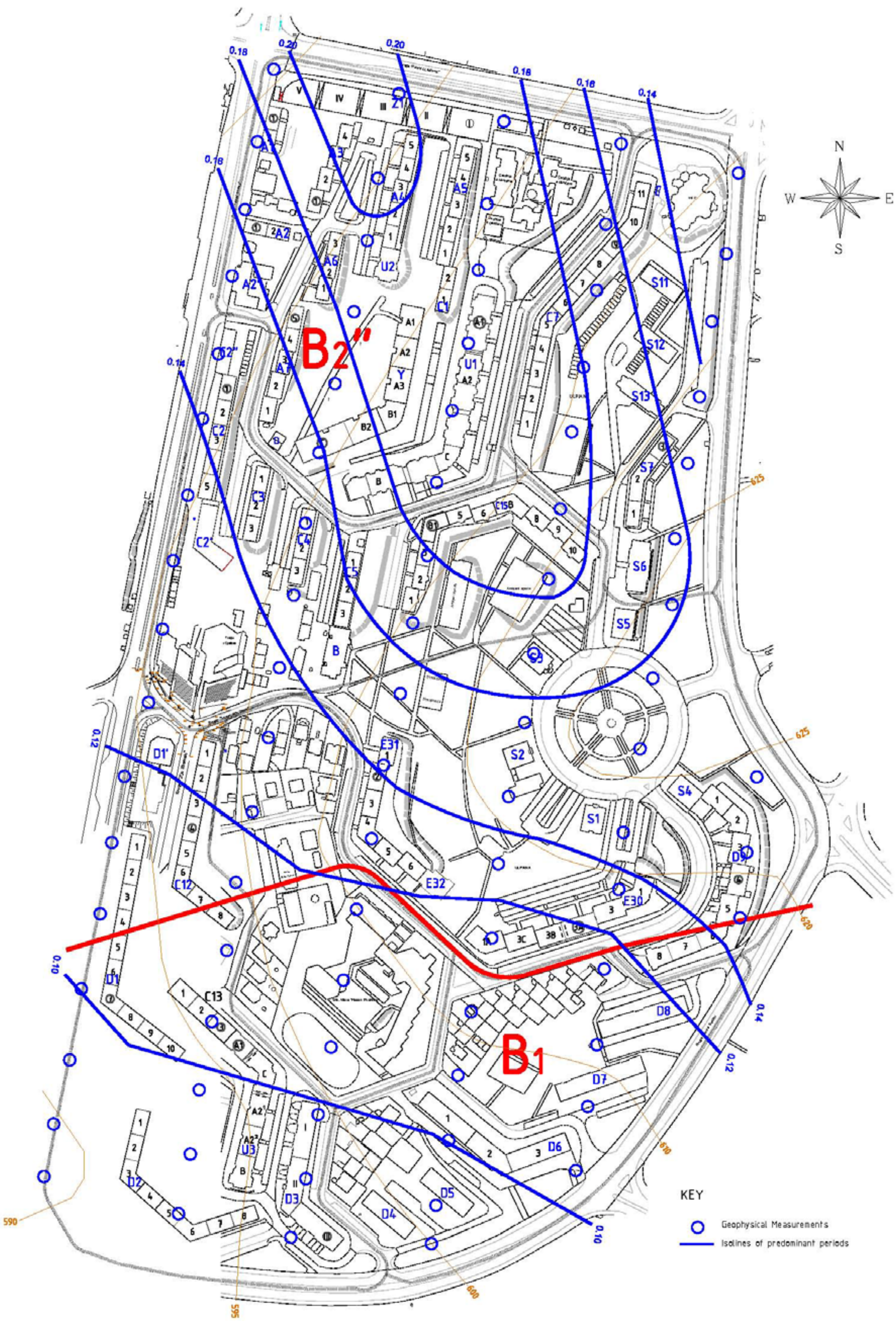

Figure 3.2.Map of ground predominant periods of vibrations from geophysical investigations

3.2 Determination of building elastic dynamic characteristics

In total 26 typical buildings were subjected to ambient vibration measurements by use of digital seismometers equipped by 3 orthogonal high resolution electrodynamic sensors (velocimeters) with frequency range 0.1 – 256 Hz. For this study, 13 of these measurements were used to obtain the general perception of model building type's response. The equipment was located simultaneously on ground and top floor of the respective buildings, synchronized in the same direction, measuring the frequency and amplitudes of microvibrations induced from the ambient. The typical values of respective buildings maximal amplitude response are presented on Table 3.2.

3.3 Determination of fundamental period of vibration according to EC 8

For comparison and validation purposes of building predominant periods of vibrations, obtained with AV measurements, determination of the fundamental period of vibration for buildings with heights up to 40 m, is obtained with formulas according to EC 8, "Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings" [2]:

$$T_1 = C_t \cdot H^{3/4} \tag{3.1}$$

where:

C_t - 0.075 for moment resistant space concrete frames and for eccentrically braced steel frames and
- 0.050 for all other structures;

H - height of the building, in m, from the foundation or from the top of a rigid basement.

The typical values of respective buildings maximal amplitude response are presented on Table 3.2.

3.4 Determination of fundamental period of vibration from modal analysis

For verification of the results upon predominant periods of vibrations, obtained through AV measurements and EC 8, several mathematical models of selected model building types were developed, the technical data extracted from original technical documentation of the original buildings.

Since the actual version of SAP 2000 cannot model directly the stiffness of masonry infill walls, their effect is introduced with use of equivalent strut tie members attached to the structure on boundary conditions with elastic hinges. The struts have only compressive strength properties with mechanical characteristics of base material.

The mechanical characteristics of the infill masonry walls are acquired based on standard masonry mechanical characteristics and as such can slightly deviate from actual capacity of infill walls in situ, respectively the response of the whole structure may differ especially on elastic range.

The work done from first coauthor of this study Milutinovic, Z. and Trendafiloski, G., within a RISK-UE project - An advanced approach to earthquake risk scenarios, with applications to different European towns, specifically part WP4: Vulnerability of current buildings [5], with emphasis on LM2 Method. The concept and the results obtained from the author with use of LM2 Method is used to understand the overall behavior of the considered model building types. Development of capacity curves and their intersection with appropriately damped demand spectra are used to identify the extent and the pattern of expected damage.

The results from the study made by coauthor of this study F.G. Grajçevci, *Seismic behavior and vulnerability of existing buildings in Prishtina – Kosova* [6] are also taken for consulting and refining the mechanical and physical characteristics of the typical materials used from similar buildings in the considered location. Strength and deformation characteristics are considered in synthesis and analysis process.

The typical values of respective buildings maximal amplitude response are presented on Table 3.2.

Table 3.2. Predominant ground and building periods of vibrations (Ambient Vibrations, EuroCode 8 and Mathematical Models)

PREDOMINANT SOIL PERIODS OF VIBRATIONS FROM AMBIENT INDUCED MICROVIBRATIONS										
Building Name	Unit Number	DAF	Model Building Type	Year Built	Design Code	Height [m]	Ground T (s) <AV>	Building T (s) <AV>	Building T (s) <EC 8>	Building T (s) <Model>
S6	1	1.8	RC ShW	1965	Low	15.2	0.20 - 0.24		0.38	0.36
U1	A1	1.7	RC ShW	1975	Low	20.23	0.32 - 0.38	0.29	0.48	0.33
Y	B2	1.8	RC ShW	1978	Low	22.94	0.32 - 0.38	0.32	0.52	
S5	1	1.8	RC shear walls	1965	Low	30.03	0.20 - 0.24		0.64	
S7	3	1.8	RC ShW	1965	Low	16.6	0.20 - 0.24	0.29	0.41	
S13	1	1.8	RC ShW	1975	Low	22.2	0.21 - 0.27	0.33	0.51	
C7	5	1.8	RC MRF	1965	Low	17.26	0.21 - 0.27	0.3	0.64	0.51
S12	1	1.8	RC MRF	1969	Low	22.1	0.21 - 0.27	0.3	0.76	0.68
Z	I	1.8	RC MRF	1992	Moderate	23.17	0.20 - 0.23	0.27	0.79	
D9	4	1.7	RC MRF	1970	Low	19.3	0.30 - 0.35		0.69	0.62
E31	2	1.7	RC MRF	1969	Low	17.2	0.19 - 0.22		0.63	
C15	B1	1.6	RC MRF	1970	Low	17.87	0.32 - 0.38	0.27	0.65	
D3	III	1.5	RC MRF	1966	Low	16.47	0.28 - 0.34		0.61	
C12	4	1.8	Confined masonry	1965	Low	16.25	0.20 - 0.25		0.61	0.55
D2	6	1.5	Confined masonry	1965	Low	16.53	0.28 - 0.34		0.61	0.55
U3	A1	1.4	Confined masonry	1975	Low	19.5	0.28 - 0.34		0.70	
A1	1	1.6	URM	1962	Pre-Code	16.55	0.20 - 0.23	0.42	0.41	0.42
C2	1	1.8	URM	1963	Pre-Code	16.55	0.20 - 0.22	0.27	0.41	0.42
A7	5	1.7	URM	1963	Pre-Code	16.22	0.20 - 0.23	0.25	0.40	
A3	1	1.6	URM	1962	Pre-Code	17	0.20 - 0.23	0.28	0.42	
A2	1	1.8	URM	1962	Pre-Code	17	0.20 - 0.23	0.27	0.42	
AV tests	Models									

3.5. Synthesis of specific building results and extrapolation for development of Resonant Map

All the information's upon maximal response for predominant periods obtained from above procedures are used to validate and determine the reliable representative values of predominant ground and building responses. Extrapolation of the values on other buildings is realized by considering similitude characteristics in respect to geodynamic models, isolines of predominant periods, DAF, structural systems, design code, building heights, including seismic zone defined from microzoning study.

Finally, a map combining the results obtained for ground predominant periods of vibrations versus the period characteristics of the existing Ulpiana building stock is developed.

The map highlights the potential for resonance conditions between ground and building interaction. The Resonant Map can be viewed as an indicator on the sites for potential resonance effect where an increased damage and loss, relative to other sites, shall be expected in the case of maximal expected earthquake action.

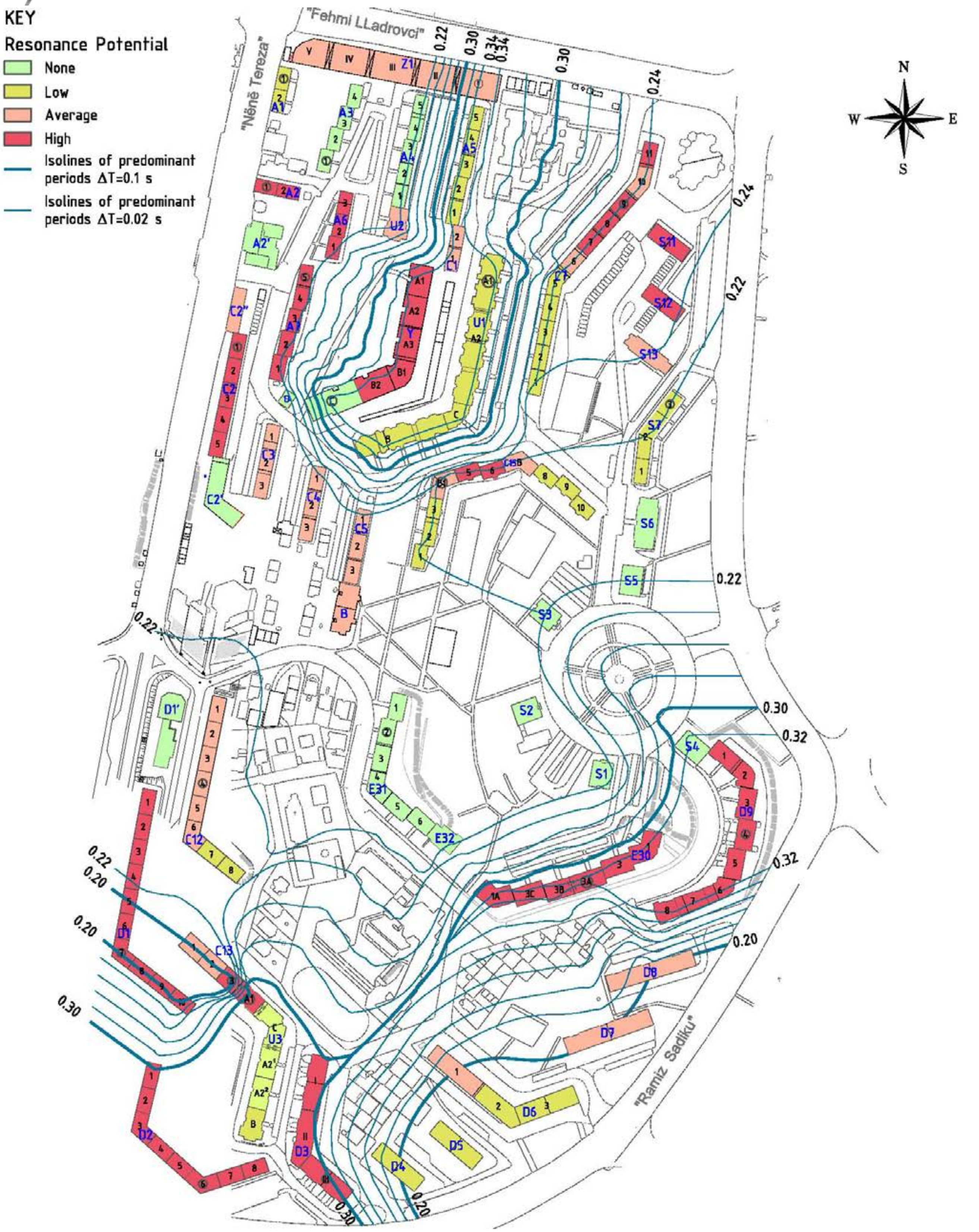

Figure 3.2. Resonance Map – Interaction between predominant periods of vibration – Ground vs. Buildings

4. Conclusions

For this study are taken into consideration large amounts of previous investigations and measurements, including technical documentation of the original building stock.

The Resonant Map, Figure 3.2, of the considered urban zone, shows that there is relatively large number of buildings with high potential for realization resonance phenomena. Counting, from 162 building units, there are 66 units with high, 47 units with average, and 32 units with low potential to develop the resonance effect, resulting in anticipated large damage and disruption of physical content and socio-economical welfare.

However, the values of the ground predominant periods of vibrations mapped throughout the considered zone are valid only for elastic behavior of soil layers, while should a strong earthquake motion occur, their values will scatter and will depend on the severity and frequency of ground acceleration.

Mathematical modeling of building types under category of “Confined Masonry”, “Composite slabs with Unreinforced Masonry”, and "RC Slender Moment Resisting Frames with infill walls", is realized using “Equivalent Strut Tie System”, that are valid only for response of buildings in elastic range, respectively only for seismic excitations with 2% probability of exceeding in 50 years (RP 95) - low intensity earthquakes. In case of moderate and high earthquake excitations the infill masonry walls are expected to fail in initial phase of response, causing also collateral damages to the main resisting structure.

Actual vulnerability of the building stock is expected to be higher than anticipated from general analysis, due to the fact that most of the buildings, especially along the main roads, have experienced destructive interventions in the structures and adaptations on destinations, including weakening of bottom stories structure, overbuilding and various annexing.

Resonant Map maps wide range of parameters and as such highlights the areas with higher potential risk for increased damage and loss in the zone.

As can be observed from the Resonant Map of this case study, the results can be viewed in discrete manner, giving the decision making authorities an useful tool to access and consider with high priority the buildings with high resonance potential. The map can be used also for revision of urban planning and seismic rehabilitation programs toward mitigation of critical facilities.

In case of developing new settlements, RM could be used as indispensible tool in early stages of urban planning to determine the most optimal zones for construction, structural systems and materials, range of buildings height, etc. It could help to define the urban criteria’s for zoning and construction, so the resonance potential of soil media with built structures is avoided.

5. Acknowledgements

Base core of this study is the previous work from IZIIS "Seismic Microzoning of Ulpiana Urban Zone". The guide and support from co-authors enabled in-depth and multidisciplinary treatment of the collected material for the study, their respective synthesis and analysis, and withdraw the conclusions.

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