SEISMIC ESTIMATION FOR SOFIA REGION WITH NEURAL MODELING

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ABSTRACT

A study of the site effects and the microzonation of Sofia region, based on the modeling of seismic ground motion along three cross sections were carried out. Realistic synthetic strong motion waveforms have been computed for an earthquake scenario applying a hybrid modeling method, based on the modal summation technique, finite differences scheme and neural modeling. Realistic synthetic seismic signals have been generated for all sites of interest. Two groups of experiments have been performed, where in first group the ground motion is modeled for one-dimensional layered anelastic media, applying an algorithm based on the modal summation method. In second group of experiments the ground motion is modeled for two-dimensional laterally heterogeneous media and with implementation of neural network, learned and trained with real earthquake seismic records.

The aim of suggested deterministic modeling is to provide site response estimates at Sofia due to the chosen earthquake scenarios and to show how to use the database of synthetic seismic signals, seismological and seismic engineering parameters. Modeling of site response for selected area on different distances from possible epicenter with synthetic time histories and neural networks will help to include developed models in structural control of important and high-risk structures.

KEY WORDS

earthquake engineering, stochastic modeling, seismic waves, neural networks.

INTRODUCTION

One of the very promising methods in earthquake engineering is application of structural control. One of the critical problems there is the problem of forecasting in general and in real-time of the behaviour of seismic waves for certain region. This forecast can be made on the bases of general, macro-seismic and site parameters for considered region and recorded

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strong motion records. The aim of this research is to develop a seismic estimation for Sofia region with neural modeling which will help to evaluate seismic risk for different part of the region. Sofia is a growing city with population around 1.22 million, which is exposed to a high seismic risk. Over the past centuries the macroseismic intensities have been larger than IX (MSK). There are a number of methods that have been used to estimate seismic risk (Botev et al. 1999, Field et al. 2000). The usual strategy to seismic risk assessment is to break the problem down into basic components that may be investigated individually (Matova, 2001, Paskaleva et al. 2002a). This multistage analysis requires critical investigation of: (a) sources of events, (b) intermediate transmission of energy from the sources, (c) the local site and (d) the particular facility of concern. The earthquakes may be thought of as originating at points, on lines or within zones (Paskaleva et al. 2002b, Solakov et al. 2001). They will have different sizes and occurrence times. The intermediate transmission of the seismic signal involves attenuation of energy with distance and depends on the media traversed (Frangov and Ivanov, 1999). Aspects of the local site include geology and ground type. In some studies the dynamic response and resistance of structures of interest are modeled and the fields of geology, geophysics, seismology and engineering are all involved. It needs to be mentioned that dynamic response and resistance of structures are beyond the scope of this work.

Geologists, seismologists, engineering seismologists, and geotechnical engineers have important roles in the analysis of strong ground motion records and in the construction ground shaking maps. This work briefly review existing materials on this matter (Frangov et al, 1998, Ilieva and Josiffov, 1998, Ivanov et al. 1998) and discuses some new scientific results for Sofia region.

The following parameters, which are related to the strength of ground shaking, have been mapped in the past for Sofia region, like Intensity (I); Peak ground acceleration (PGA), focusing mainly on the horizontal component; Peak ground velocity (PGV), focusing mainly on the horizontal component; Peak ground displacement (PGD), focusing mainly on the horizontal component; Spectral acceleration ordinates of the horizontal ground shaking at selected periods (SA) which are related, respectively, to the fundamental period of vibration of low- and high-rise buildings, or certain types of short-stiff or long-flexible infrastructure.

The first step in the construction of a ground shaking map is to choose the scale of the map and to prepare a grid of points for the calculations. A Geographic Information System (GIS) can be used to manage the multiple layers of information, which include such important parameters like geographic boundaries and all cultural features of the region at risk; the fault systems; the seismicity; the building stocks distribution etc.

These ground shaking maps are being implemented to establish sitting and design criteria, disaster scenarios, as a policy tool in seismic zonation, loss estimates, and risk assessments (Yossifov and Paskaleva, 1999, Paskaleva 2002b). They are also an integral part of model building codes and provisions for seismic design.

Nowadays implementation of artificial intelligence methods for describing the behaviour of seismic waves is quite common. Most of them are based on neural networks, which are trained with real seismic records to return suitable artificial or earlier recorded seismic ground acceleration histories. In this paper is suggesting an approach for seismic estimation of possible earthquake excitation for Sofia region with implementation of classification methods and Kochonen neural modeling for microzonation of Sofia region.

GROUND SHAKING MAPS

Ground shaking maps are constructed as a triple integral for each point of interest calling for three different summations, which are solved numerically to calculate the values of ground motion parameters at each point on the grid. The result is a map depicting the spatial and temporal variations of the horizontal ground motion parameters. The following types of calculations are performed:

- The first summation captures contributions of all active faults, as constrained by the seismicity, in the region to the ground-shaking hazard at each point on the grid.
- The second summation, as constrained by the maximum magnitudes calculated for each fault, captures the contributions of each earthquake in the distribution.
- The third summation captures the distribution of ground motion values at each point on the grid by summing the contributions of seismic waves, which are attenuated by the earth as they propagate from each causative fault to each point on the grid. The constraints are the seismicity and the maximum magnitudes.

Ground shaking maps integrate many kinds of hazard information about the region and include:

- **Location of the active faults**. Earthquake sources (i.e., active faults) are identified and characterized on the basis of geologic, geophysical, and instrumental, historical, prehistorical data, and in recent year paleoseismicity data. Each active fault is classified in terms of its mode of rupture (e.g., strike-slip, normal, thrust, blind thrust, and subduction zone) and idealized as a point, line, planar, or volume source. Each type of fault contributes to the signature of the amplitude, frequency composition, and duration of ground shaking at a site. Magnitude is controlled by the length of the fault, its segmentation, the coupling of the individual fault segments, the dynamics of the fault rupture, and the physical dimensions of the fault rupture surface.
- **Geometry of the faults**. The mode of rupture of faulting (i.e., strike slip, reverse or thrust, and normal) and the fault geometry (i.e., the dip, depth, and source dimensions of the earthquake rupture plane) can affect both the amplitude and the geometric attenuation of earthquake ground motion. The style of faulting affects the radiation pattern of the seismic waves, and together with the geometry of the earthquake rupture plane, controls the rate of azimuthal decay of ground motion with distance from the fault plane.
- **Regional tectonic setting**. The active faults in the region of interest are classified and mapped in terms of their tectonic environment. The amplitude and geometric attenuation characteristics of strong ground motion vary considerably between earthquakes that occur in intraplate regions.

STRUCTURE OF THE PRENEOGENE BASEMENT IN SOFIA DEPRESSION

Sofia City is situated in the central southern part of the Sofia kettle. In a structural aspect the Sofia kettle represents a complex, asymmetric graben of block structure in the West

Srednogorie region. The active tectonic movements affected the basement of the kettle form its block structure (Ilieva and Josifov 1998). The most highly raised block is the one in the center of the capital, near the Sofia thermal spring, and the most deeply subsided block is in the region of the Elin Pelin town. The line of the greatest depression is in west-east direction and almost coincides with the contemporary riverbeds of the Blato and Lesnovska Rivers. The Preneogene basement structure of Sofia depression covers the space with a length about 60 km and width - 20 km. The morphological characteristics of the Preneogene basement are seen in the compiled structural map in a scale 1:25 000 shown on Figure 1.

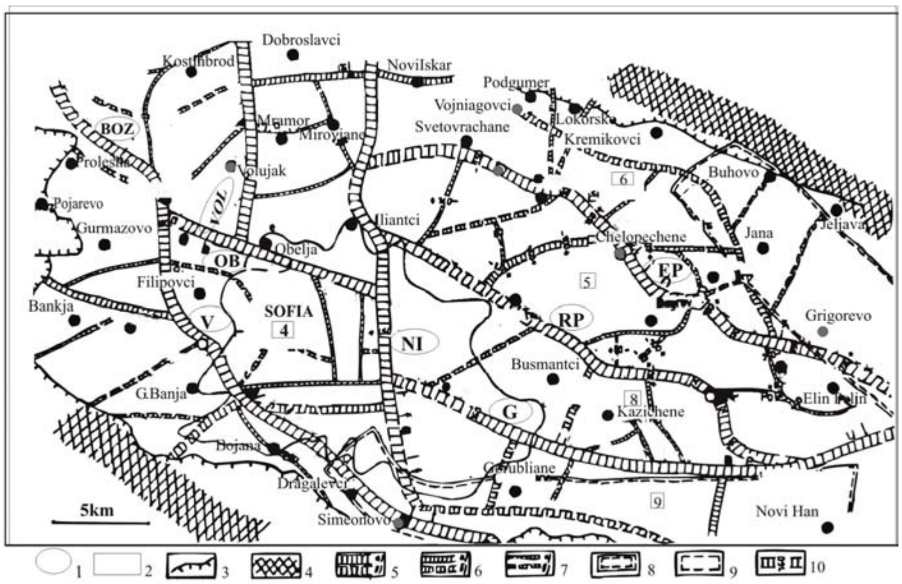

Figure 1: Scheme of the fault and block structures of the Preneogene basement in the Sofia Depression: 1.naming the block structures of 1st rank; (V-Vitosha North fault, NI- Novi Iskar fault, G-Gorubljane fault, RP-Ravno Pole fault, VOL-Volujak fault, Boz-Bojhurishte fault; 3. boundary of the basement outcrop; 4 - deep fault 5, 6, 7 - faults of the basement of first, second and third rank; 8 - zones of possible listric faulting; 9 - naming the block structures of 1st rank; 10 - vertical amplitude of the fault.

The analysis of the basement structural map shows that the interface has strongly changeable hypsometry - from the positive above 600 m values with respect to the sea level to the negative ones under -700 m depth (over 1250 m from the surface). In fact the basement relief consists of elevated and depressed sectors of various sizes. The boundaries between these sectors arc most frequently faults. Depending on the depth at which the Preneogene basement surface is situated the Sofia depression can be divided into two parts - a western uplifted one and an eastern subsided one. In the western part the absolute depths of the basement are everywhere above sea level, the highest ones being above 600 m. In the eastern part, excluding the boundary sectors, the absolute depths are negative. On Figure 2 are presented contour lines on the basement surface of the Preneogene basement in Sofia depression, in plane view and on Figure 3 is presented the three-dimensional view of the Preneogene basement in Sofia depression, called further Sofia region.

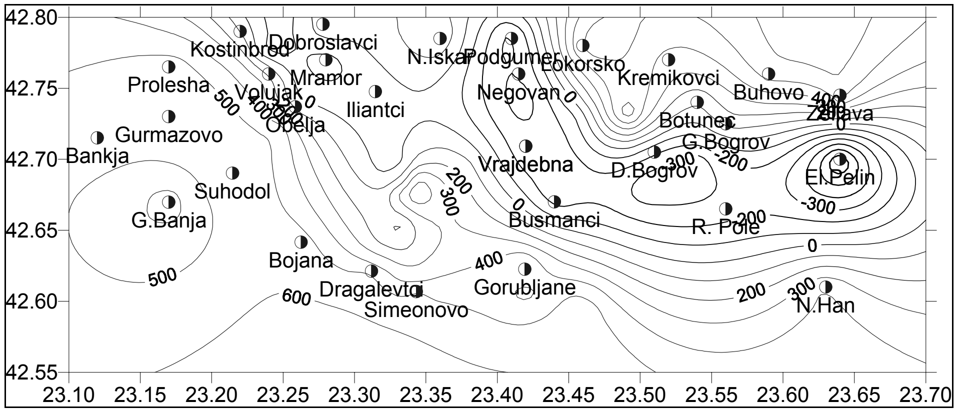

Figure 2: Contour lines on the Preneogene basement surface in Sofia depression

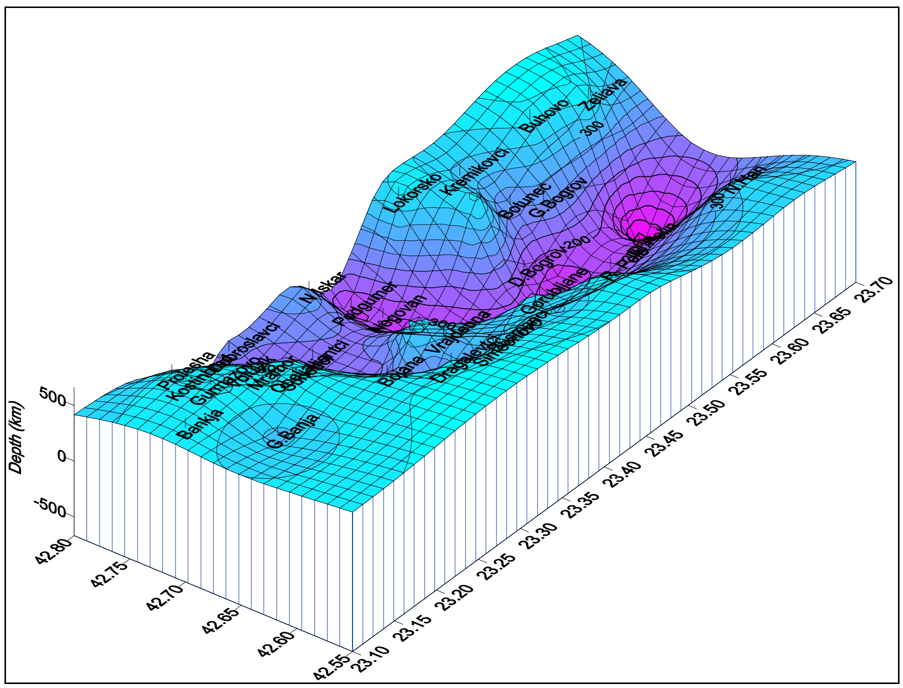

Figure 3: Three-dimensional view of the Preneogene basement in Sofia depression

The spatial distribution of the epicenters of strong and moderate earthquakes shows some regularities (Matova, 2001). The seismic activity is related mainly to the following faults and fault zones: a) longitudinal faults (the *Bozhurishte* fault, the *Vitosha* fault zone) of the middle and southern parts of the Sofia graben, also the *Sub-Vitosha* fault zone of the southern part of the *Vitosha* blocks-horsts; b) transversal faults (the *Bankya*, the *Chepintsi*, the *Vladaya*, the *Ravno Pole* faults) of the middle and the eastern parts of the Sofia graben and the adjacent areas, c) oblique faults of two general directions: submeridional one (the *Gnilyane*, the *Busmantsi*, the *El. Pelin*, the *Draganovo* faults) of the central and the eastern parts of the graben; subequatorial direction (the *Gorublyane* fault zone) in the eastern part of the graben. The epicenters of numerous weak earthquakes (M<3.5) are localized mainly along the

Negushevo and the *Vitosha* fault zones of the northern and the southern boundaries of the Sofia graben. Some epicenters are along the Bozhurishte, the *Bankya*, the *Gnilyane*, the *Ravno Pole*, the *El. Pelin* faults and the *Sub-Vitosha* fault zone. The field study of the seismic active faults is a very difficult task, as the investigated territory is covered by numerous large settlements, as well as by some long-term cultivated terrains. The surface traces of the fault with seismic origin are established along the *Vitosha* fault zone. There is a mobile sector of the *Vitosha* faults in the vicinity of the *Boyana* quarter of the Sofia City, whose occurrence is related to the 1858 Sofia earthquake (M = 6.5 - 7.0) (Solakov et al., 2001). That same earthquake caused the activation of old landslides and rockfalls, also the appearance of new ones along the *Vitosha* fault zone between the *Boyana* and *Dragalevtsi* quarters of the city. On Figure 4 are depicted zones of seismic events with magnitude M = 4.00-7.00.

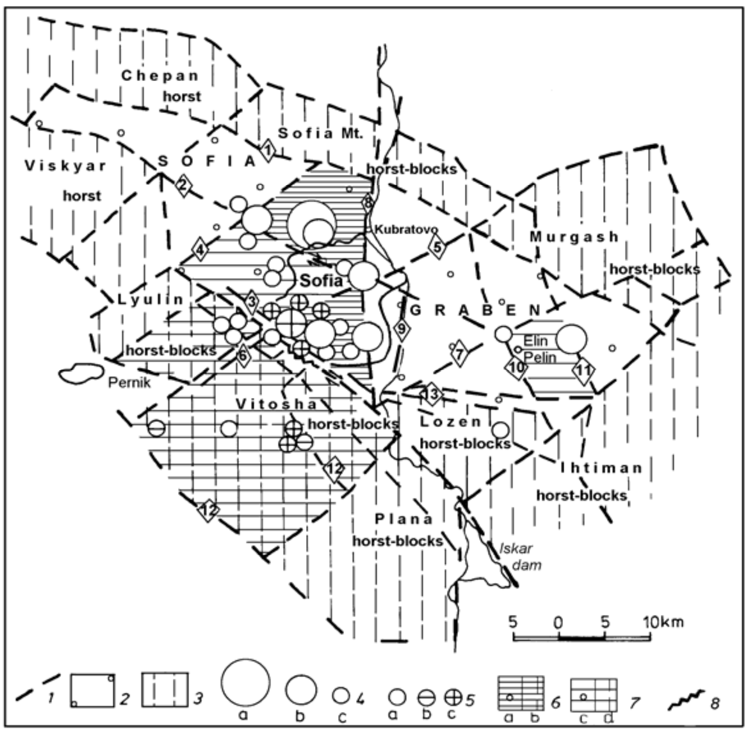

Figure 4: Seismic events with magnitude M=4.00-7.00 in the blocks of the Sofia graben and the adjacent horsts. 1 – faults of the block boundary; 2 – block of the Sofia graben, 3 – block of the adjacent horsts, 4 – epicenters of earthquakes with magnitude: a – M=6.0-7.0; b – M=5.0-5.9, c - M=4.0-4.9; 5 – depths of earthquake hypocenters: a – up to 10 km, b – 11-20 km, c – 21-30 km; 6 – blocks of considerable seismic mobility: a – of the graben, b – of the horsts; 7 -– blocks of moderate seismic mobility: a – of the graben, b – of the horsts; 8 – seismic active sector of Vitosha fault during 1858 Sofia earthquake.

The weak earthquakes are localized in different blocks during the 1966-1976, 1976-1979 and 1996-1999 periods. The number of low seismic activity manifestations is the highest in the *Plana* Mountain horst block during the 1966-1976 periods. The same quantity is the most significant in western *Lyulin* Mountain where horst blocks are relatively most active during the 1996 - 1999 periods. The seismotectonic study shows that the blocks of the Sofia graben are involved in more frequent and intense strong and moderate seismic movements than the blocks of the adjacent horsts. It is the opposite in the instances of low seismicity, when the adjacent horst blocks are more mobile than the Sofia graben blocks.

GENERATION OF SYNTHETIC SEISMIC SIGNALS

Complete synthetic seismic signals have been generated for all sites of interest along the investigated profiles, depicted on Figure 4 following the earthquake scenarios M = 7, depth 10 km, distance 10 km. Two groups of experiments have been performed: (A) ground motion one dimensional modeling, applying an algorithm based on the modal summation method and (B) two-dimensional modeling with hybrid technique (Fäh et al., 1994) and Neural network. The chosen frequency interval (up to 5 Hz) covers practically the whole range of elements of the built environment present at Sofia. Seismic waves along the investigated profiles are computed and acceleration, velocity and displacement time histories are obtained for all ground motion components, transverse (TRA), radial (RAD) and vertical (VER). Different quantities of earthquake engineering interest, like peak ground accelerations (PGA), peak ground velocities (PGV), peak ground displacements (PGD), response spectra amplitudes (SA) and PGA/PGV ratios, are derived from the computed seismic signals. On Figure 5 – left is shown map of mean PGA distribution on the area and on Figure 5 – rights is shown map of PGV distribution on the area, where with solid line V_{max}=20cm/s limits the area where major degree of damages have to be expected for old residential buildings.

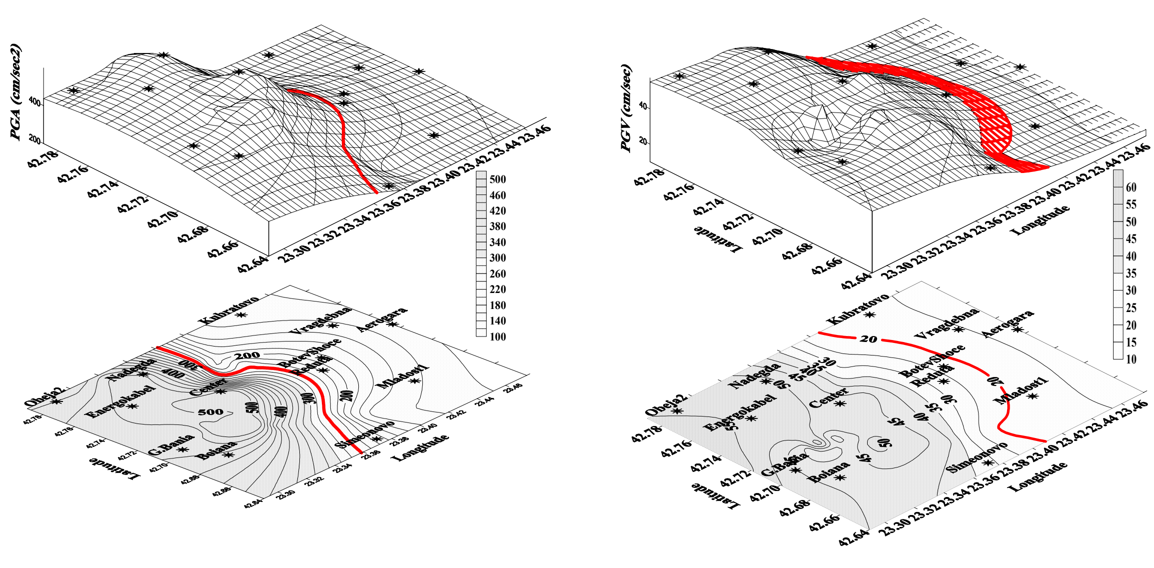

Figure 5: Map of mean PGA and PGV distributions on the area along the profiles

It is clear that most of the City in epicentral distances higher than 17 km will expire the PGA amplitudes 2-3 times bigger that those prescribed by Bulgarian seismic code. The maximum of the predominant period in the response spectrum for the horizontal components using program WAVES is T= 0.42-0.95 s and mean T = 0.2 –0.47 s, as is shown on Figure 6.

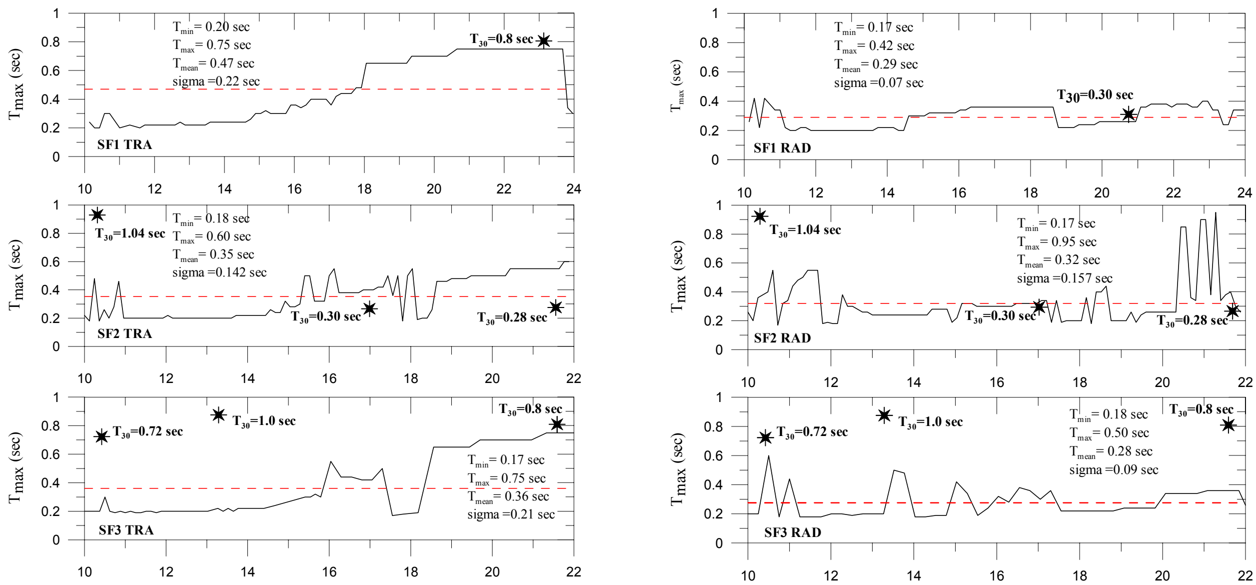

Figure 6: The maximum of the predominant period in response spectrum for the horizontal component with star shaped -predominant first period for depth 30 m from the surface

PRINCIPLE AXIS TRANSFORMATION AND VECTOR CLUSTERING

The principle axes transformation is based on the composition of the components corresponding to the maximum, medium and minimum eigenvalue of registrated in three direction accelerogram from all time windows (Radeva et al., 2004). This transformation will result in accelerogram time histories that are ordered by seismic energy for each chosen time interval. These transformed components are called the stochastic principal axis transformed accelerogram T1, T2 and T3. This process of time-series transformation gives possibility to use for empirical hazard analyses T1 and T2 as most significant (Radeva et al., 2005b). For probability density estimation of selected zones in this research is suggesting a modification of two-dimensional vector quantization (VQ), where on axes are absolute values of T1 and T2. Afterward with one layered neural network and self-organizing map, according to approach, suggested at Radeva and Radev (2005a) is determined the function of density distribution with amplitudes, received from transformed accelerograms. The self-organizing map has one-layered neural competitive structure, which can learn to detect regularities and correlations in the input patterns. The neural maps learn both, the distribution and topology of the input vectors, to recognize neighboring clusters of the attribute space. Kohonen's network algorithm provides a tessellation of the input space into patches with corresponding code vectors. It has an additional feature that the centers are arranged in a low dimensional structure (usually a string, or a square grid), such that nearby points in the topological structure (the string or grid) map to nearby points in the attribute space. The Kohonen learning rule is used when the winning node represents the same class as a new training pattern, while a difference in classes between the winning node and a training pattern causes the node to move away from training pattern by the same distance. In training, the winning node of the network, this is nearest node in the input space to a given training pattern, moves towards that training pattern. It drags with its neighboring nodes in the network topology. This leads to a smooth distribution of the network topology in a non-linear subspace of the training data. As a result of vector clustering for each of selected areas are identified five cluster classes, which centers are depicted with black dots, shown on Figure 7 for absolute values of T1 and T2, where: Cluster 1 shows a low level of destructive damages, Clusters 2 and 3 – middle level and Clusters 4 and 5 – high level of destructive damages.

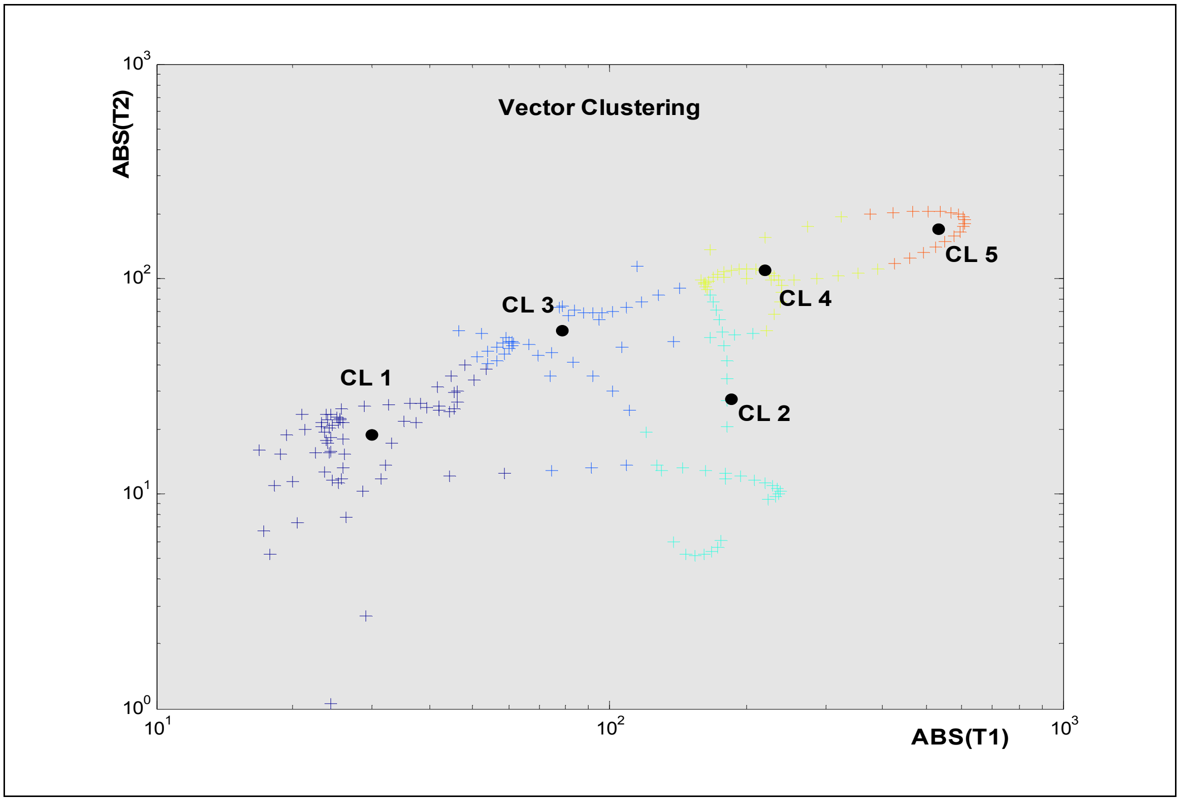

Figure 7: Vector clustering for absolute values of T1 and T2

This approach gives possibility to evaluate the level of damages for selected area. For example, for experimental input accelerograms shown above (center of Sofia city - station on 17 km from possible epicenter), is expected high level of damages in clusters 4 and 5 for area with thick red line on Figure 5, where the level of damages is calculated equal to 29.06%.

CONCLUSIONS

An approach for seismic estimation of possible earthquake excitation for Sofia region with implementation of classification methods and Kochonen neural modeling is suggested. Realistic synthetic strong motion waveforms have been computed for an earthquake scenario applying a hybrid modeling method, based on the modal summation technique, finite differences scheme and neural modeling. With self-organizing map are determined weight centers of selected classes and for each cluster is determined probability density function. Suggested model is useful for seismic activity analyses of Sofia region and structural control.

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