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INTEGRATED MODELLING AND PREDICTIVE ESTIMATION OF URBAN/RURAL SEISMIC LOSSES

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SUMMARY

An integrated, prediction model for large scale assessment of regional/urban seismic damage based upon seismological and instrumental data, regional and local studies, and damage records from past earthquakes is presented. Applicational margins are demonstrated by analyzing a general long-run aspect of an overall regional earthquake risk reduction program through studying two land-use scenarios in the same seismic environment, comprising the same regional, communal and zonal building gross area, but differing only in the adopted building typology.

INTRODUCTION

Experience has already demonstrated that natural disasters, and earthquakes in particular, have tended to become increasingly destructive since they ever affect a larger concentration of national property and population. Although significant efforts have been made for assessment of seismic hazard and mitigation of its possible consequences, the major earthquakes continued to cause enormous damage to the economy of the affected regions and the entire countries. For example, the direct economic losses caused by the Montenegro earthquake alone were estimated at about 10% of the gross national product (GNP) of Yugoslavia for 1979, which was four times the GNP of the Republic of Montenegro. A similar event, the 1963 Skopje earthquake cost the national economy about 15% of GNP for 1963. Taking into account other earthquakes that took place in Yugoslavia from 1963 up to now (Petrovac 1966, Debar 1967, Ulcinj 1968, Banjaluka 1969 and 1981, Kopaonik 1980, 1982, 1984 and 1985, Knin 1985), the penalty paid has been estimated at an average of more than 1.5% of GNP of Yugoslavia per annum.

In spite of that, specialized and comprehensive assessment of natural (and technological) hazards, including a rigorous scientific, technological and intellectual approach is required to solve this truly global problem of protecting the orderly industrial development and accompanied urbanization patterns such as investments in regional and local infrastructure, life-lines, housing, urban furniture and other public and social activities against losses at all stages of this development.

Recent research and field surveys have shed a new light on the effects of natural disasters that are pertinent to the technologically organized society,

indicating thus better approaches for providing more appropriate response of national and local policy planners and other authorities of concern.

OUTLINE OF THE MODEL, DEVELOPMENT AND OUTPUTS

An integrated large scale prediction model for estimation of regional/urban seismic damage (Refs. 2 and 7), Fig. 1, involve a series of complex procedures which require continuous and systematic approach for data collection, analysis and presentation. It incorporate four basic procedural steps that should consistently be carried out in the following sequence:

- Zoning of the region/urban area with identification, inventory and mapping of existing and planned elements at risk;
- Identification of the effects of local site-soil conditions in modifying the severity of the event at a given location with prediction of ground motion determinants in terms of average effective response spectra (\bar{S}_{eff}) - effective response spectra methodology, Fig. 2 (Refs 1, 2 and 7);
- Assessment of the vulnerability of identified elements at risk - loss prediction methodology, Fig. 3 (Refs. 2, 5 and 7); and,
- Seismic risk analysis and optimization of seismic losses (physical, functional and economic) for a current or improved land use scenarios.

The spatial interaction of these factors determine the regional/urban loss-producing potential to adopted seismic hazard scenario or single earthquake event providing urban planners, public and social policy makers, scientists, engineers and other authorities of concern with: 1) regional/urban specific loss maps for selected elements at risk; 2) regional/urban damage distribution maps for each element at risk and superimposed maps providing an information on cumulative damage distribution and spatial damage concentrations for all elements at risk; 3) cumulative figures on regional/urban losses pertinent to elements at risk adopted in urbanization policy; 4) estimates on total physical, functional and economic losses the region/urban area will suffer due to an earthquake event of predetermined magnitude or seismic hazard scenario justified by the level of economic development; 5) Information on convenience, applicability and needs for improvement of existing construction standards, regulations, codes, etc.

Only on this ground the layout and distribution of human activities, planing of development at the regional or local scale might be decided by accepting a compromise between exposure to seismic hazard and, economic and social necessities.

VULNERABILITY ASSESSMENT

In order to forecast damages that are expected to occur during future earthquakes, it is necessary to know how various types of structures (elements at risk) have behaved when exposed to ground shaking of different intensities, i.e., to develop vulnerability functions (VF's) for various elements at risk and to incorporate them in loss prediction methodology of Fig. 3. This study uses vulnerability functions derived purely on empirical basis. However, the model presented, (Figs 1, 2 and 3) may efficiently incorporate any set of consistently developed VF's (theoretical, empirical or experimental).

Three basic steps were employed in derivation of VF's, i.e.: 1) examination of losses experienced due to Montenegro earthquake with statistical processing of damage data by prevailing structural classes, site-soil conditions and observed damage degree; 2) determination of site-dependent \bar{S}_{eff} for each settlement for which the damage data have been compiled; and, 3) synthesis of 1) and 2) into empirical vulnerability functions through correlating observed losses with obtained \bar{S}_{eff} 's.

The damage data sample used is obtained by post-earthquake inventory as well as damage, usability and serviceability classification performed on building stock exposed to April 15, 1979 Montenegro earthquake. The uniform methodology and procedure for earthquake damage assessment (Refs. 4, 5 and 7) has been carried out on more than 60,000 buildings within the seven Montenegrin communes (334 settlements in total). Originally applied five damage rating and three usability level classification scheme was later confined and inter-related as follows: 1) None (no damage - usable /D&U-C-I/); 2) Moderate-to-severe (considerable structural and extensive non-structural damage - temporarily unusable /D&U-C-II/); and 3) Total (partially or totally destroyed or collapsed structural system - permanently unusable, to be demolished /D&U-C-III/).

The vulnerability model, proposed by IZIIS - Skopje (Refs. 2, 4, 5, 6 and 7) is presented in Fig. 4. The curves denoted by I, II and III refer to vulnerability functions defined through corresponding damage ratios.

$$DR_i(\%) = 100 \cdot NBD_i / NB \quad (\text{for } i = I, II \text{ and } III) \quad (1)$$

where NBD_I = Number of buildings where only slight nonstructural but negligible structural damage has been observed, NBD_{II} = Number of buildings with reported intensive nonstructural and moderate structural damages; NBD_{III} = Number of destroyed buildings where "destroyed" means collapse during, or immediately after the April 15, 1979 earthquake, or buildings damaged to the extent that neither economic nor technical justification is found for their repair and strengthening; and NB = total number of buildings at the same level of seismic hazard determinant \bar{S}_{eff} , defined (Refs. 2 and 7) as:

$$\bar{S}_{eff} = \int_{0.1}^{0.4} S_{eff}(M, \Delta, s, Td, \mu, h, T_o, sc) dT_o \quad (2)$$

where (M) = earthquake magnitude, (Δ) = source-to-site distance, (s) = local site-soil conditions, (Td) = duration of predominant package of ground motion, (μ) = ductility, (h) = structural damping, (T_o) = first mode period of the structure and (sc) = group of parameters related to structural capacity.

For the considered elements at risk (stone /SM/, brick /BM/ and strengthened /STM/ masonry and R.C. frame /RCFS/ buildings) vulnerability models are derived (Fig. 5), based upon $DR_i(\%) - \bar{S}_{eff}$ data scattergrams and histograms, (Refs. 2 to 7). Semi-log regressions of the form

$$VF_i = DR_i(\%) = a_{1,i} \exp(a_{2,i} \bar{S}_{eff}) \quad (\text{for } i = II \text{ and } III) \quad (3)$$

were found to give the best fit to the observed data. Typical vulnerability models, based on damage data on 21,873 buildings are presented in Fig. 5 for SM building class. Similar models, based upon damage data on 1,594, 13,727 and 1,418 damaged buildings are respectively derived for BM, STM and RCFS building classes. However, it should be noted that more specific VF's are incorporated in the large scale model for predictive estimation of regional/urban seismic losses that, besides the listed parameters consider the variations in number of stories and local site-soil conditions.

ESTIMATION AND MAPPING OF REGIONAL LOSSES

Two urban forms comprising the same regional, communal and zonal building gross areas, Table 1, but differing in the prevailing building typology only, are studied for seismic hazard levels corresponding to 50 and 200 years return period. In total, 4,164,150 sq.m. gross building area have been considered for land-use scenarios A and B; out of which 1,890,900 sq.m. allocated to SM building class (LU-S-A) are relocated to BM (30%) and STM (70%) building classes (LU-S-B). Results, in terms of 200 years return period percent loss maps superimposed for SM, BM, STM and RCFS building classes are presented in Figs 6 and 7 for LU-S-A and LU-S-B, respectively. Cumulative figures on total loss estimates are estimated in Table 2 for seismic hazard levels corresponding to return periods of 50 and 200 years.

CONCLUSIONS

Specific contribution of the model to the land-use planning in seismic-prone regions is an integral consideration and evaluation of seismic hazard, vulnerability and seismic risk expressed in terms of cumulative physical and functional loss figures (Table 2) or mapped as partial or cumulative seismic losses for different elements at risk and land-use scenarios (Figs 6 and 7). Applicational margins of the model presented are demonstrated by analyzing a general long-run aspect of an overall regional earthquake risk reduction program. It was shown that altering and replacing the gross area of highly vulnerable stone masonry building class by brick (30%) and strengthened (70%) masonry classes (LU-S-B, Table 2) decrease the total physical losses from 1,408,205 sq.m. to 518,145 sq.m. (or for 63,2%) and from 1,590,857 sq.m. to 700,885 sq.m. (or for 55,9%) for seismic hazard levels related to specific return periods of 50 and 200 years, respectively. The methodology and results presented are providing rational approach for creating an urbanization policy at a minimum cost for an acceptable level of seismic risk. The presented model and technique have been already implemented in the physical and urban planning process in Montenegro and other regions in Yugoslavia.

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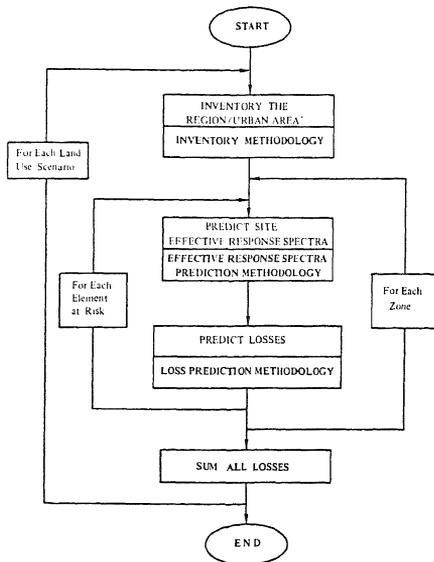


Fig. 1. General Earthquake Loss Prediction and Risk Optimization Methodology

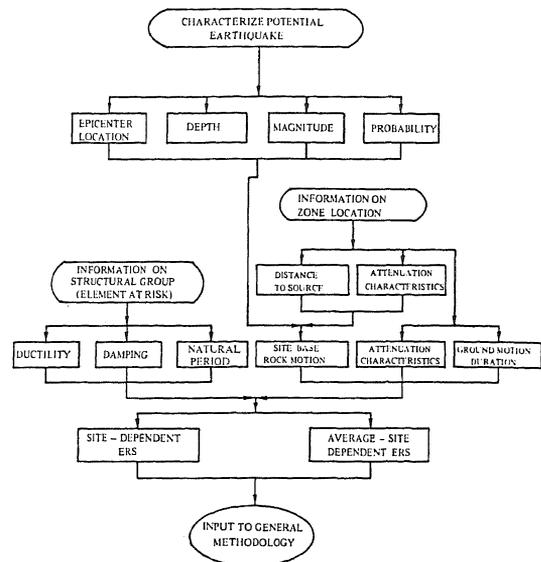


Fig. 2. Site Dependent Effective Response Spectra Prediction Methodology

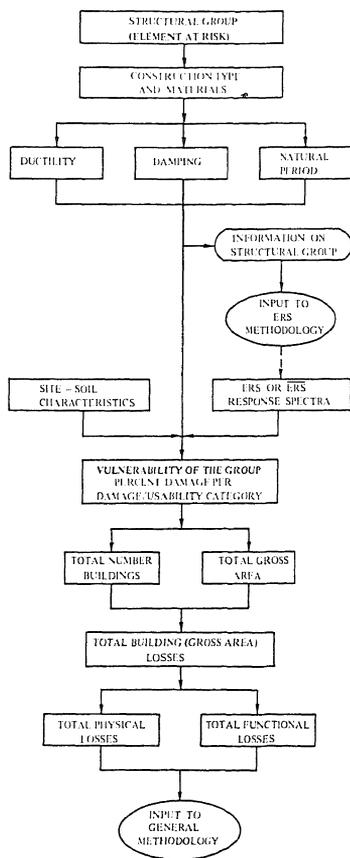


Fig. 3. Loss Prediction Methodology for Group of Structures (Element at Risk)

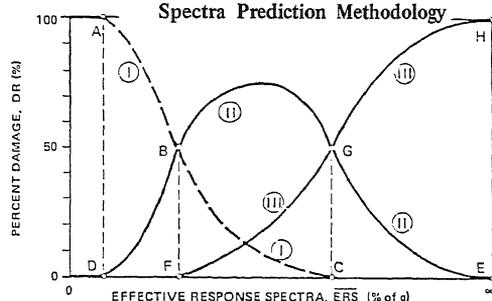


Fig. 4. Physical/Functional Vulnerability Functions for Adopted Damage/Usability Categories

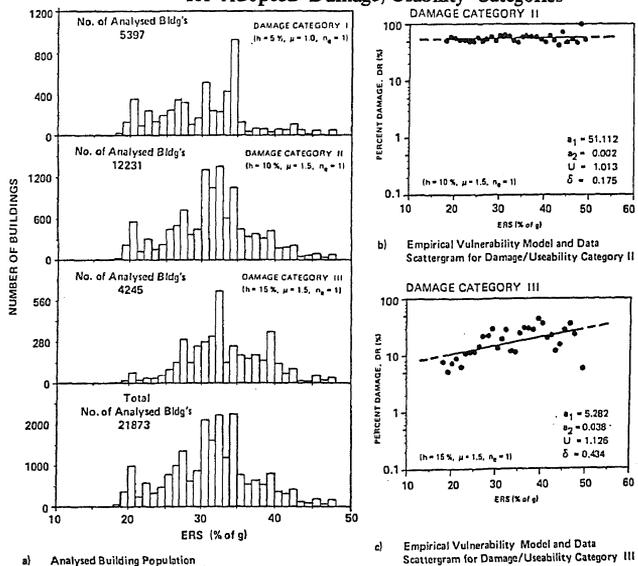


Fig. 5. Generalized Empirical Vulnerability Models and Data Scattergrams for Stone Masonry Building Class

Table 1. LU-S-A and LU-S-B Communal/Regional Distribution of Considered Element at Risk

Commune	Elements at Risk (Building Classes)												Total Gross Area	
	Stone Masonry SM		Brick Masonry BM		Strengthened Masonry STM		RC Frame Buildings RCFS		Strengthened Masonry STM		RC Frame Buildings RCFS		Total Gross Area (sq. m)	Total Gross Area (sq. m)
	Gross Area (sq. m)	%	Gross Area (sq. m)	%	Gross Area (sq. m)	%	Gross Area (sq. m)	%	Gross Area (sq. m)	%	Gross Area (sq. m)	%		
A	268050	42	58850	12	122550	24	108300	22	498750	22	498750	22	498750	
B	41850	52	10550	13	20350	25	4700	5	47100	5	47100	5	47100	
C	214500	56	65500	17	145500	38	54500	14	54500	14	54500	14	54500	
D	315000	38	78500	10	151200	18	286500	34	286500	34	286500	34	286500	
E	268000	46	81000	13	180500	31	62100	10	62100	10	62100	10	62100	
F	390000	39	101250	10	210000	21	303750	30	303750	30	303750	30	303750	
Total for the Region	1890900	45	470250	11	947250	23	855750	21	4164150	21	4164150	21	4164150	
A	-	-	172765	25	268185	54	108300	21	498750	21	498750	21	498750	
B	-	-	145295	20	536130	55	536130	15	47100	15	47100	15	47100	
C	-	-	132220	26	236130	52	536130	24	54500	24	54500	24	54500	
D	-	-	172250	21	371700	45	286500	34	286500	34	286500	34	286500	
E	-	-	165240	27	2717400	65	62100	11	62100	11	62100	11	62100	
F	-	-	218250	22	483000	48	303750	30	303750	30	303750	30	303750	
Total for the Region	-	-	1097520	25	2270880	55	855750	20	4164150	20	4164150	20	4164150	

Table 2. LU-S-A and LU-S-B Cumulative Total Losses (in %) Related to Seff Hazard Levels of 50 and 200 Years Return Period

Building Class	Total Gross Area (sq. m)	Total Losses (in %)					
		DU-C-II		DU-C-III		DU-C-(II+III)	
		50 Years	200 Years	50 Years	200 Years	50 Years	200 Years
Stone Masonry SM	1,890,900	52.3	53.2	8.2	12.0	60.5	65.3
Brick Masonry BM	470,250	23.0	29.5	4.7	6.2	27.7	35.8
Strengthened Masonry STM	947,250	6.4	10.1	1.2	1.3	7.6	11.4
Reinforced Concrete Frame Buildings RCFS	855,750	7.3	9.4	-	-	7.3	9.4
Brick Masonry BM	1,037,520	22.9	29.2	4.6	6.2	27.5	35.4
Strengthened Masonry STM	2,270,880	6.3	9.8	1.2	1.3	7.5	11.1
Reinforced Concrete Frame Buildings RCFS	855,750	7.3	9.4	-	-	7.3	9.4
Total for the Region	4,164,150	29.3	31.7	4.5	6.5	33.8	38.2
Land - Use Scenario A		10.6	14.6	1.8	2.3	12.4	16.8
Total for the Region							
Land - Use Scenario B							

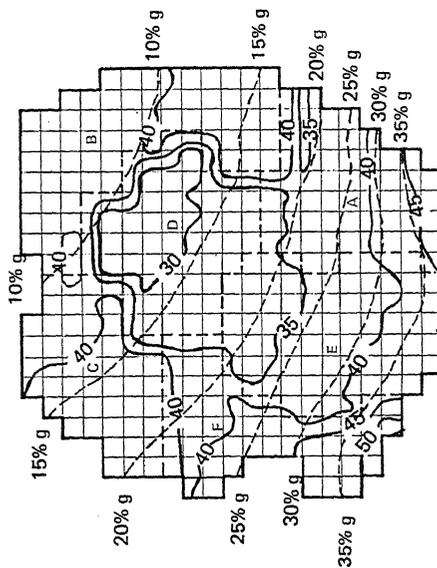


Fig. 6. 200 Years Return Period Seff Hazard Map and Corresponding Isoblasts (in %) for LU-S-A

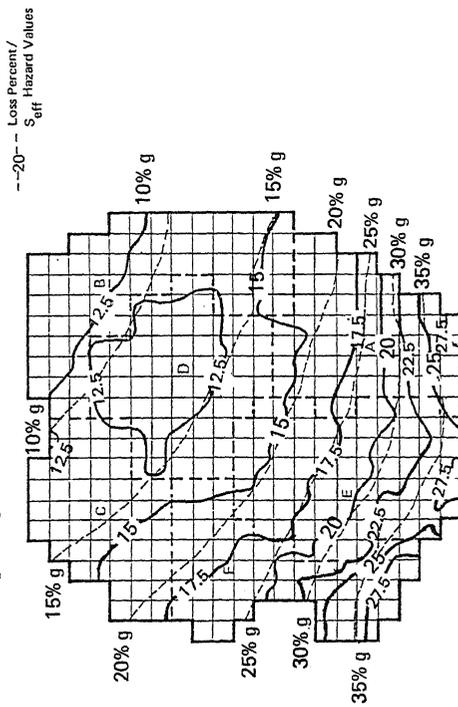


Fig. 7. 200 Years Return Period Seff Hazard Map and Corresponding Isoblasts (in %) for LU-S-B

LEGEND:

- Seff Hazard
- Isoblasts
- 20--- Seff Hazard Values
- Loss Percent/Seff Hazard Values