SEISMIC AND COMPLEX RISK ASSESSMENT AND MANAGEMENT FOR THE KAMCHATKA REGION

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SUMMARY

The Kamchatka area is one of the most seismically active regions of Russia and the world. It belongs to the Kuril-Kamckatka seismic zone, where earthquakes with magnitudes above 8 are possible. According to the intermediate forecast made by academician S.A.Fedotov strong earthquakes are possible in the Kamchatka area before 2005 with probability equal to 0.8. The area is exposed as well as to volcanic hazard, tsunami, flooding, hurricanes and storms, avalanches, forest fires. 35 explosion hazardous and 22 chemical hazadous facilities are in operation now in the area. The population of the area is equal to 478.7 thousands. 90% of the Kamchatka region population lives in three cities: Petropavlovsk-Kamchatsky, Elizovo and Ust-Kamchatsk.

To make the losses assessment more prescise the geographic information system (GIS) was developed for this area to estimate the possible losses from mentioned natural hazards and possible man made accidents. The GIS contains the initial data, which allows to determine the present level of different natural hazards, data about population, data on inventory of existing building stock and infrastructure, mathematical models and response block, which allows to estimate the possible number of military forces, equipments, food and so on for the case of emergency situation.

The computations were made of individual risks from separate natural hazards, as well as complex risk was estimated with taking into account all natural and technological hazards for the area.

The proposals were given for the preventive measures plan and for reducing the risks from separate hazards.The application of these results to disaster management practice may increase significantly the efficiency of measures aimed at seismic and complex risk reduction for population in this area.

INTRODUCTION

The Kamchatka area occupies the Kamchatka Peninsula with ajacent part of continent, as well as Karginsky, Verkhoturovka, Ptichij and Komandorskie Islands. The square of the area is 472.3 sq.km. More than 70% of the territory are characterized by high level of seismicity, the earthquakes with intensity from 8 to 10 according to MMSK-86 scale are possible here.

On the whole the seismic hazard level for the most cities and towns of the region varies from I=6 to I=9 according to the present standard map of seismic zonation and may reach the intensity 10 according to the draft of new map for this area.

Because of the intermediate forecast of strong earthquakes in the Kamchatka area before 2005 with high probability the investigations on seismic and complex risk assessment and management are especially vital for this area.

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Taking into account the fact that some part of existing building stocks in the Kamchatka cities and towns are constructed without earthquake resistant measures the consequences of the earthquake even with the intensity 6-7 may be catastrophic for this region. The experience of the 1995 Great Hanshin, 1995 Neftegorsk earthquakes and August 17, 1999 Izmit earthquake showed that unexpected events may cause significant losses even for the country, which is characterized by high level of earthquake resistant construction.

The investigations on vulnerability of existing building stock, estimations of expected number of different types buildings, which may suffer various damage states during possible earthquakes, the expected number of people killed and injured allow to develop the effective plans of preventive measures in order to reduce social and economic losses from future earthquakes in the region.

In present paper the results of vulnerability, complex and seismic risk computations with GIS application are given for the Kamchatka area.

SPECIAL GEOGRAPHICAL INFORMATION SYSTEM

The specisl GIS for vulnerability, seismic risk assessment as well as identification of effective response measures was developed. It is designed to store, analyze and use in the most effective way the considerable massif of spatially distributed information.

Within the GIS the information massifs (IM) are combined into four groups. The first IM group allows to describe in details the space under study. This group contains the digital topographic data. As the accuracy, completeness and reliability of this data is concerned, they correspond to the Russian standards for maps of scale M. 1 : 1 000 000; 1 : 100 000; 1 : 10 000. Small-scaled maps give the general information about the region topography. Large-scaled maps allow the structure of cities and towns to be described. The fault maps and maps of engineering geological conditions give the characteristics of geological medium. This information is added by detailed data about hydrography. The mentioned IM structure corresponds to the Russian standards for electronic maps. Taking into account the economical aspects the map of scale M. 1 : 1 000 000 is valid for the whole territory, and the maps of scale M. 1 : 100 000 and 1 : 10 000 are digitized only for the areas characterized by high density of population.

The second IM group is assigned for seismic hazard description. It contains the information from seismic zonation maps of different scale (review, detailed and microzonation). The review map of scale 1:1 000 000 and other maps of detailed seismic zonation (scale from 1: 500 000 up to 1: 200 000) and seismic microzonation (scale from 1:25 000 up to 10 000) for the Kamchatka territory are digitized and included in the input data block of special GIS. Figure 1 shows the standard map of seismic zonation of the Kamchatka territory, figure 2 - fragment of the map of seismic microzonation of the Petropavlovsk-Kamchatsky City. All the mentioned data forms the set of thematic maps, tables, networks and lists.

The third IM group provides the description of the different elements at risk. In the considered case there are population, buildings and structures, lifeline systems, hazardous facilities. The information about buildings may be detailed (type of structure, materials, date of construction, height and so on) as, for example, for the Petropavlovsk-Kamchatsky City and generalized, for instance, the distribution of buildings characterized by different earthquake resistance within the city districts. The information about the population distribution within the buildings and city districts for different time of day (Figure 3) is included in GIS.

The forth IM group combines the parameters of mathematical models for population distribution, buildings' damage distribution, that of people killed and injured, for rescue teams operations and so on.

All four groups of information massifs are interrelated by single coordinate space (coordinate system B, L, H) and by unified numeration system.

The GIS program tools provide the possibility of work in WINDOWS environment with PC usage. They make up the unified complex with commercial data bases (DBASE, ACCESS, ORACL, INFORMIX) management systems. The exchange of data with desk top GIS, ARCINFO, MAPINFO is provided.

The equipment, which is used for GIS realization, corresponds to the modern standard IBM PC for graphic stations.

The programs tools and equipment permit the input and manipulation of data, carrying out of computations according to different models, output in the form of maps and text files.

VULNERABILITY ASSESSMENT OF EXISTING BUILDING STOCK FOR THE KAMCHATKA CITIES AND TOWNS

The information on earthquake resistance of existing building stock is necessary for planning the preventive measures to protect the population against earthquakes and other natural and technological disasters, as well as for emergency response following these events.

The real earthquake resistance was estimated for almost all the cities, towns and settlements of the Kamchatka area (Petropavlovsk-Kamchatsky, Elizovo, Vilyuchinsk, Milkovo, Ust-Kamchatsk, Klyuchi, Ossora, Palana and others). The data about the buildings stock density in relative units, the buildings type according to MMSK-86 scale, the averaged height of buildings within the considered area, the type of occupancy or function of buildings were used for most cities and and towns. For Petropavlovsk-Kamchatsky City the information was collected for each building.

At the first stage the estimations made for typical buildings were applied to all buildings of the considered area and included into the GIS data base. At the next stage to verify the estimations of the real earthquake resistance of typical buildings the mobile diagnostic complex "Struna" was used.

Figure 4 shows the example of data base about the existing buildings' stock and population for each building in the Petropavlovsk-Kamchatsky City.

On the basis of statistical analysis of strong earthquakes engineering consequences the fragility laws were obtained for different types of buildings according to MMSK-86 scale. There are two types of laws: the probability $P_{\mathrm{Ai}}(I)$ of damage state not less than given value and probability $P_{\mathrm{Bi}}(I)$ of definite damage state. The normal law is used for construction the curve approximating the probability $P_{\mathrm{Ai}}(I)$. It is taken into account that buildings may suffer after earthquake any damage state (from d = 1 up to d =5), namely a building after earthquake may prove to be undamaged (event *B0*), to experience slight damage (event *B1*), moderate damage (event *B2*), heavy damage (event *B3*), to be partially destroyed (event *B4*), to be completely collapsed (*B5*).

The probability $P_{\mathrm{Bi}}(I)$ of definite damage state may be determined by the relationships providing the total group of events is considered:

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\begin{aligned}
P_{\mathrm{B5}}(I) &= P_{\mathrm{A5}}(I) \\
P_{\mathrm{B4}}(I) &= P_{\mathrm{A4}}(I) - P_{\mathrm{A5}}(I) \\
P_{\mathrm{B3}}(I) &= P_{\mathrm{A3}}(I) - P_{\mathrm{A4}}(I) \\
P_{\mathrm{B2}}(I) &= P_{\mathrm{A2}}(I) - P_{\mathrm{A3}}(I) \\
P_{\mathrm{B1}}(I) &= P_{\mathrm{A1}}(I) - P_{\mathrm{A2}}(I) \\
P_{\mathrm{B0}}(I) &= P_{\mathrm{A0}}(I) - P_{\mathrm{A1}}(I)
\end{aligned}
$$

where $P_{\mathrm{A1}}(I)$, $P_{\mathrm{A2}}(I)$, $P_{\mathrm{A3}}(I)$, $P_{\mathrm{A4}}(I)$, $P_{\mathrm{A5}}(I)$ = probabilities that buildings will suffer the damage state not less than 1, 2, 3, 4, 5; $P_{\mathrm{B1}}(I)$, $P_{\mathrm{B2}}(I)$, $P_{\mathrm{B3}}(I)$, $P_{\mathrm{B4}}(I)$, $P_{\mathrm{B5}}(I)$ = probabilities that buildings will suffer the damage state equal to 1, 2, 3, 4, 5.

These relationships are used for computations of damage extend and number of people killed and injured from possible earthquakes. Figure 5 shows the distribution of the damage rates due to the scenario earthquake (coordinates: $\varphi = 52^0\ 37'\ 58''$ N and $\lambda = 159^0\ 35'\ 53''$ E; M = 8; h = 20 km) for the Petropavlovsk-Kamchatsky City.

The mathematical expectation $M(N_d)$ of damaged buildings' number for the whole city:

$$M(N_d) = \int\int_{Sc}\int_{Imin}^{Imax} P_d(I)\, f(x, y, I)\, \varphi(x, y)\, \mathrm{d}I\, dx\, dy$$

where N_d = the number of buildings with damage state d within the unit area with coordinates x, y; $I_{\max}$ and $I_{\min}$ = the maximum and minimum possible earthquake intensity; $P_d(I)$ = the probability that buildings will suffer damage state d due to earthquake with intensity I (fragility law); $\varphi(x, y)$ = the buildings' density within the unit area with coordinates x, y; S_c = the city area.

The economic losses to the city buildings' stock is understood as the direct losses caused by damage and/or collapse of buildings during earthquakes in portions of initial cost of the building. The relative economic losses to the buildings stock within the unit area are determined as:

$$L(x, y) = \Sigma\; V_d\; P_d\,(x, y)$$

where P_d (x, y) = the probability that the buildings within the unit area will suffer the damage state d; V_d = losses resulted in buildings damage state d in the portions of initial cost of the building, namely vulnerability, which is taken to be equal to for various damage states:

$d = 1$ $V_1 = 0.03$;
$d = 2$ $V_2 = 0.15$;
$d = 3$ $V_2 = 0.50$;
$d = 4$ $V_2 = 0.90$;
$d = 5$ $V_2 = 1.00$.

The relative economic losses to the whole city buildings' stock are determined by:

$$L = \Sigma\; V_d\; P_d$$

where P_d = the probability that the buildings within the city will suffer the damage state d.

The damage states' distribution for some cities, towns and settlements of the Kamchatka and the values of economic losses resulted from damage and/or collapse of the buildings during earthquakes were computed.

SEISMIC RISK ASSESSMENT FOR THE KAMCHATKA CITIES, TOWNS AND SETTLEMENTS

The mathematical expectation of number of people killed and injured due to earthquakes and different rates of casualties with taking into account the population distribution in the affected area may be estimated as:

$$M(N) = \int\int_{Sc}\int_{0}^{24}\int_{Imin}^{Imax} P(I)\; f(x, y, I)\;\; \Phi(x, y)\;\; F(t)\; \mathrm{d}I\;\; dt\, dx\, dy$$

where S_c = the city area; I_{max} and I_{min} = the maximum and minimum possible earthquake intensity; Φ (x, y) = the population density within the unit area with coordinates x, y; $f(x, y, I)$ = the density function of earthquakes' intensity probabilities within the unit area with coordinates x , y; $F(t)$ = the function obtained on the basis of statistical analysis of data on population migration during the day time (Figure 3).

The total level of potential losses from future earthquakes for a given region, city or district is characterized by the individual seismic risk R_e - the probability of the inhabitant death in the given point due to earthquakes:

$$R_e = \frac{M_n(N)}{N_n\, n}\quad \text{, 1/year}$$

where n = the period of seismological observations; N = the number of inhabitants in the city; $M(N)$ = the mathematical expectation of the number of people killed.

Table 1 gives the results of individual seismic risk for some cities and towns of the Kamchatka region.

Analysis of the table 1 shows that the level of risk for all cities and towns exceeds the level of acceptable risk. It is observed the growth of the values of seismic risk by accumulating the data on seismic hazard. The estimations of risks made according to the standard map OSR78 and draft of new map of seismic zonation vary on average by factor 3 and in some cases the difference reaches 20 times (for instance, Bolsherechensk). Tor the cities and towns, which proved to be in zones of middle-term forecast, the values of risk increase and reach the values corresponding to the draft of new seismic zonation map. For the areas outside the possible source zones the level of risk is kept on the level corresponding to OSR78.

Within the cities, towns and settlements the risk is distributed heterogeneously as well. It depends on ground conditions and prevailing type of existing building stock. The example of seismic hazard and risk assessment on local level is given with taking into account secondary engineering geological processes (landslides and liquefaction).

Table 1. Individual seismic risk distribution for the Kamchatka region due to different scenario earthquakes (draft of new map of seismic zonation, middle-term forecast of earthquakes, OSR78)

City/Town/ Settlement	Population, thous.people	Individal Seismic Risk, 10^{-5}		
		OSR97A	Middle-term forecast	OSR78
Petropavlovsk-Kamchatsky	207.800	428.92	359.91	155.16
Elizovo	40.900	408.31	408.31	51.24
Klyuchi	10.700	190.19	-	19.90
Ust-Kamchatsk	9.700	543.30	137.11	340.52
Bol'sherestk	7.384	71.64	4.06	3.38
Sosnovka	1300	290.77	279.92	38.46
Termalnyj	1800	274.44	255.56	36.11
Razdolnyj	2.700	274.44	250.51	35.92
Lesnoj	1500	175.33	20.00	18.00
Ozernovskyj	3.200	175.31	34.38	18.43
Mokhovaya	11.300	495.84	1033.63	273.89
Zhupanovo	1.477	461.75	-	175.36
Paratunka	2.193	477.88	241.68	208.39
Pionerskyj	3.000	510.67	490.00	274.33
Svetlyj	0.810	523.46	691.36	267.90

The computations of co-seismic and post-seismic displacements of slopes were carried out according to the Ambraseys's method (Ambraseys & Srbulov 1995). The results of losses computation for the hospital site in the Petropavlovsk-Kamchatsky City (Figure 6) due to scenario earthquake with taking into account unfavourable ground conditions give an evidence that induced hazards contribute considerably to expected social and economic losses. The values of risk may reach $4\,600 \bullet 10^{-5}$ in the zones of possible liquefaction. As Figure 6 shows the values of risk for strengthened hospital buildings are close to acceptable level ($1 \bullet 10^{-5}$) outside such zones.

The analysis of risk values on regional and local levels with taking into account secondary factors shows the necessity of preventive measures aimed at building strengthening for the most cities, towns and settlements of the Kamchatka area. Within the zones characterized by unfavourable ground conditions it is effective to change the functional purpose of buildings and structures.

COMPLEX INDIVIDUAL RISK ASSESSMENT FOR THE KAMCHATKA CITIES, TOWNS AND SETTLEMNTS

As the Kamchatka area is exposed not only to earthquakes, but to volcanic hazard, tsunami, flooding, hurricanes and storms, avalanches, forest fires as well. Risk of technological emergency also exists because 35 explosion hazardous and 22 chemical hazadous facilities are now in operation in the area. In order to plan preventive measures against these hazards and their negative consequences the complex risk was estimated with taking into account all natural and technological hazards for the area.

The individual complex risk is the probability of the inhabitant death in the given point due to natural or technological hazards. If different natural and techological hazardous events may occur in the considered area, the complex individual risk R may be computed under the condition that all events are statistically independent.

$$R= \{ 1 - (1 - R_1) (1 - R_2) \ \dots (1 - R_n)\},$$

where R - complex individual risk; R_1 , R_2 ,… R_n -individual risks due to definite natural and technological hazards.

In the considered case earthquakes, volcanic hazard, tsunami, flooding, hurricanes and storms, avalanches, forest fires, as well as technological hazards (fires, explosions, chemical pollutions) were taken into account. The maps of complex individual risk for the Kamchatka region was compiled (fig. 7). The table 2 shows the results of complex risk computations for some cities and towns of the area and contribution of separate hazards to risk value.

Table 2. Individual complex risk for the Kamchatka region

City/Town/ Settlement	Individual complex risk, 10^{-5}	Contribution of different individual risks to complex one in %							
		Earth-quakes	Volca-noes	Tsuna-mi	Flood-ing	Hurri-cance	Avalan-ches	Fire hazardous facili-ties	Che-mical hazardous facili-ties
Petropavlovsk-Kamchatsky	370.89	97.04	-	-	-	0.38	0.75	0.005	1.83
Elizovo	415.61	98.20	-	-	0.1	0.4	-	-	1.30
Klyuchi	101.95	19.52	78.46	-	0.05	0.28	1.25	0.43	-
Ust-Kamchatsk	187.45	73.14	-	26.67	-	0.03	-	0.14	0.04
Bol'sherestk	5.42	100.00	-	-	-	-	-	-	-
Sosnovka	278.32	99.50	-	-	-	0.5	-	-	-
Termalnyj	256.96	99.46	-	-	-	0.54	-	-	-
Razdolnyj	101.40	98.62	-	-	-	1.38	-	-	-
Lesnoj	21.40	93.46	-	-	-	6.34	-	-	-
Ozernovskyj	34.73	99.00	-	-	-	-	-	-	1.00
Mokhovaya	401.39	99.75	-	-	-	0.25	-	-	-
Zhupanovo	185.34	94.60	-	5.4	-	-	-	-	-
Paratunka	243.08	94.42	-	-	-	5.58	-	-	-
Pionerskyj	491.39	99.72	-	-	-	0.28	-	-	-
Svetlyj	692.75	99.80	-	-	-	0.20	-	-	-

Analysis of Table 2 shows that for the majority of the cities and towns the main contribution to complex individual risk is made by seismic risk (the exception is Klyuchi City). The contribution of all other risks varies from 0.03 to 26.67 %.

CONCLUSIONS

In the present study the special geographic information system was developed in order to estimate the possible economic and social losses from future earthquakes and other natural and technological hazards for the Kamchatka region. The digital input data base characterizing the seismic hazard level of the region with taking into account secondary natural and man-made processes, population distribution, existing building stock, infrastructure and critical facilities of the region was created.

When creating the GIS structure it was managed to minimize the volume of cartographic and thematic data. This fact allowed to provide the real price of the project and real time for the project implementation, as well as to obtaine the reliable results based on application of statistical methods of modelling.

The parameters of the fragility laws for typical buildings of the region were computed. The real earthquake resistance of typical buildings of the region was estimated.

The level of seismic risk for all cities and towns of the Kamchatka area exceeds the level of acceptable risk. The estimations of risks made according to the standard map OSR78 and draft of new map of seismic zonation vary on average by factor 3 and in some cases the difference reaches 20 times (for instance, Bolsherechensk). The values of seismic risk with taking into account unfavourable ground conditions of the site may reach $4\,600 \bullet 10^{-5}$.

The complex individual risk with taking into account different natural and technological hazards was determined for the Kamchatka region. For the majority of the cities and towns the main contribution to complex individual risk is made by seismic risk. The contribution of all other risks varies from 0.03 to 26.67 %.

Zonation of the Kamchatka area territory according to the level of individual seismic and individual complex risks allowed to plan the measures aimed at strengthening of existing building stock in order to withstand expected seismic loads and change the functional purpose of buildings in the zones characterized by unfavourable ground conditions.

On the basis of obtained estimations about possible economic and social losses the preventive measures plans were refined and more effective strategy of immediate response was developed.

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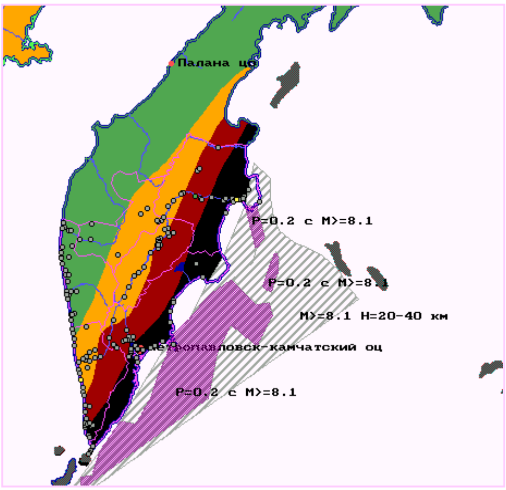

Fig. 1. The map of seismic zonation for the Kamchatka region territory

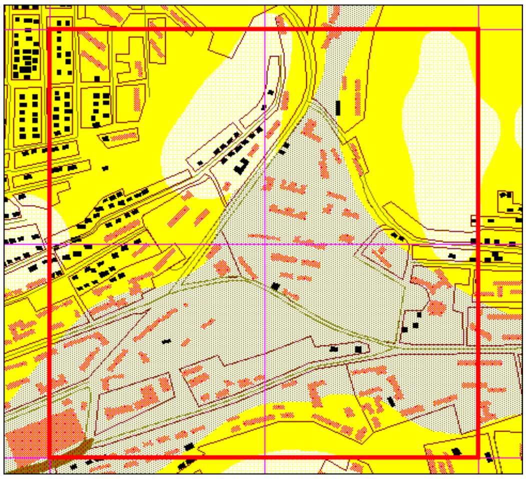

Fig. 2. The map of seismic microzonation for the Petropavlovsk-Kamchatsky city territory (fragment)