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ANALYSIS OF REAL TIME EARTHQUAKE INFORMATION APPLIED FOR POSSIBLE LOSS ASSESSMENT

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Keywords: earthquakes, near real time damage and loss assessment, geographical information system, discrepancies in event location, reliability of expected loss estimation

Abstract

The paper is analyzing the reliability of possible impact estimation due to strong earthquakes obtained in “emergency” mode with application of system “Extremum”. The influence of discrepancies in strong event location by Alert Seismological Surveys on expected damage and loss estimations is investigated. The special study was undertaken to reveal the priority of Surveys within the Flinn-Engdahl zones. As a result the right choice of earthquake parameters may be made in “emergency” mode with taking into account obtained weights for each Survey. The weight is understood as the value, which is inversely proportional to error in events’ parameters determination in “emergency” mode and verified parameters issued in several days and months after events.

Introduction

Near real time information about possible damage, expected number of casualties is very critical for taking the decision about search and rescue operations, as well as rendering humanitarian assistance in the case of strong earthquakes.

The experience of recent disasters in Turkey, Greece, India and other countries shows that the officials who are responsible for emergency response are lack of prompt and reliable information on the disaster scope.

The 1995 Kobe, Japan earthquake gave a great impact on development of near real time systems for possible damage and loss assessment. One of the first and most sophisticated systems of such type was READY-System (Real-time Assessment of earthquake Disaster in Yokohama). Using the ground motion data from the dense strong-motion monitoring system, the real time assessment system computes ground shaking hazard with taking into account potential of liquefaction and wooden-house damage within 20 minutes after the event. Since the Kobe events numerous agencies in Japan constructed similar systems for high-density monitoring of seismic motion and real-time damage estimation. Another example of such systems is SUPREME (Super High-density Real-time Disaster Mitigation System), which employs the New SI (spectrum intensity) sensor and a district regulator remote surveillance system installed at about 3,600 locations in Tokyo Gas Co. supply area. SUPREME allows to make the detailed, real-time detection of liquefaction, highly accurate estimates of damage and the rapid execution of emergency measures.

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In Taiwan the system for rapid response to large earthquakes is implemented by the Central Weather Bureau. Whenever certain trigger criterion is met, the digital waveforms are analyzed by two programs for automatic phase picking and earthquake location in order to avoid false alarms. The results from two programs must agree within certain limits and then an announcement is broadcasted using communication port to send the message via the Internet.

GIS based earthquake loss assessment and emergency response system operates in Daqing Oil Field, China. The system consists of an information system, which includes 68 layers, 28 analytical modules, decision-making subsystem and a user interface. The decision-making subsystem for seismic emergency response provides the whole system with functions of resources allocation and route search.

At present the near real time systems for loss assessment at regional and local levels due to strong earthquakes exist in Italy, Turkey and other countries. Similar systems exist in USA. CAT (Consequences Assessment Tool) and HAZUS are the most well know ones between the systems of this group.

Recently the attempts were made to develop global systems for assessment of real damage affecting a region after a disaster occurred in any place all over the world. One of such systems is based on the technique developed in Japan at the Disaster Prevention Research Institute of Kyoto University with American satellite NOAA images' application. Comparing the night lighting before and after the occurrence of a disaster yields a rough idea of the damage inflicted, as far as night lighting has been affected.

The real time systems, which use the data of dense monitoring networks, are rather expensive and it is hardly possible to develop such systems for all countries in nearest future. The system, which uses the high-resolution space images, gave their estimations with the delay more than 24 hours.

In Russia the attempt was made to develop not expensive and operative system. The system "Extremum" was developed at Extreme Situations Research Center Ltd., Seismological Center of IGE, Russia Academy of Sciences and VNII GOChS, Emercom of Russia in the middle of 1990-th. The system allows to compute expected damage, number of casualties at local, regional and global levels, as well as provides information about the effective response measures for strong earthquakes. The information on events parameters (magnitude, source depth and coordinates) determined by Alert Seismological Surveys is used as input data. Since August, 2000 the system is used in order to provide quick information on damage and casualties assessment of strong earthquakes all over the world within the framework of EUR-OPA Major Hazards Agreement Program EDRIM (Electronic Discussions in Risk Management).

Reliability of possible earthquake impact assessment with "Extremum" system application

The system "Extremum" consists of three main blocks: input data block, that of mathematical models, which allows to simulate distribution of earthquake intensities and peak ground accelerations, simulate the damage to buildings of different types and expected number of casualties, and block of optimal response measures. More than two years period of the system operation showed that on the whole the possible loss computations made with the "Extremum" simulation models application proved to be rather reliable and the system proved to be rather effective in spite on few unfortunate examples of possible loss forecast.

The reliability of loss assessment strongly depends on:

- completeness and reliability of databases on elements at risk (population and built environment) and hazard sources;
- reliability of vulnerability functions of elements at risk;

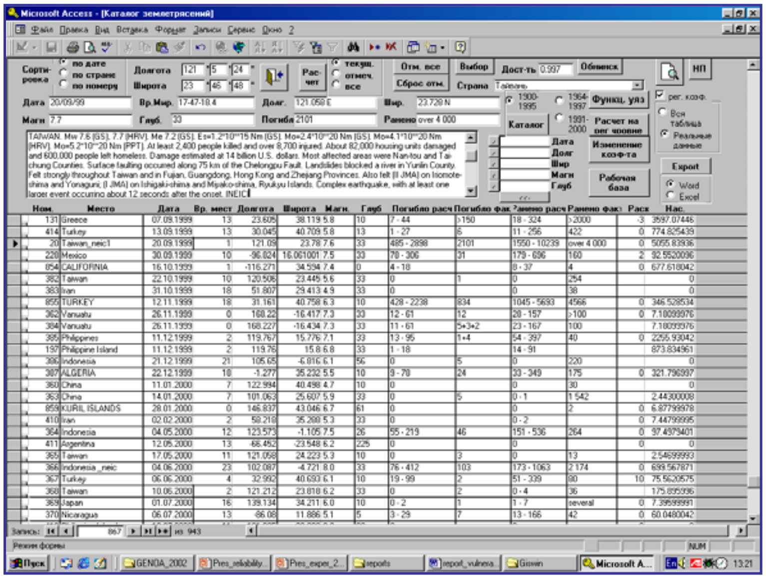
- errors in strong earthquakes' parameters determination by Alert Seismological Surveys.

Some of these factors may be taken into account at the expense of the system calibration with usage of well documented past strong earthquakes and high-resolution space images application in order to verify the data on buildings' inventory in earthquake prone areas.

The special software is created for earthquake impact data compilation, processing, analysis and storing. At present the knowledge base contains the description of more than 1000 events. The data are distributed almost homogeneously as the losses due to earthquakes, dates of events and their locations are concerned. The software allows to make computations of possible losses, to accumulate the results of computations in order to exclude the rough errors in the descriptions of events. It also allows to select events according to their date, earthquake prone areas and number of event in the base. Fig.1 shows the fragment of the knowledge base. The selection of events is done according to the date of events. The arrow shows the earthquake, which occurred in Taiwan on September 20, 1999.

The impact data base about strong events is compared with similar sets of data. Its comparison with the EM-DAT natural disaster standard data for 1976-2001, which contains 547 descriptions of earthquakes, allowed to update the information about some events. Unfortunately, EM-DAT has no information about the source depth, which is rather important for loss assessment.

<u>Fig. 1. Fragment of the knowledge base: the events are selected according to the dates of their occurrence</u>



Долгота 121 5 24
Широта 23 46 48
Дост-ть 0.997
Страна Тайвань
Дата 20/09/99
Вр.Мир. 17-47-18.4
Долг. 121.058 E
Шир. 23.728 N
Магн 7.7
Глуб. 33
Погибл 2101
Ранено over 4 000
● 1900-1995 ○ 1964-1997 ○ 1991-2000

TAIWAN. Mw 7.6 (GS), 7.7 (HRV). Me 7.2 (GS). Es=1.2*10**15 Nm (GS). Mo=2.4*10**20 Nm (GS). Mo=4.1*10**20 Nm (HRV). Mo=5.2*10**20 Nm (PPT). At least 2,400 people killed and over 8,700 injured. About 82,000 housing units damaged and 600,000 people left homeless. Damage estimated at 14 billion U.S. dollars. Most affected areas were Nan-tou and Tai-chung Counties. Surface faulting occurred along 75 km of the Chelongpu Fault. Landslides blocked a river in Yunlin County. Felt strongly throughout Taiwan and in Fujian, Guangdong, Hong Kong and Zhejiang Provinces. Also felt (II JMA) on Iriomote-shima and Yonaguni; (I JMA) on Ishigaki-shima and Miyako-shima, Ryukyu Islands. Complex earthquake, with at least one larger event occurring about 12 seconds after the onset. (NEIC)

Ном.	Место	Дата	Вр. мест	Долгота	Широта	Магн.	Глуб	Погибло расч	Погибло фак	анено расч	Ранено фак	Расх	Нас.
131	Greece	07.09.1999	13	23.605	38.119	5.8	10	7 - 44	>150	18 - 324	>2000	-3	3597.07446
414	Turkey	13.09.1999	13	30.045	40.709	5.8	13	1 - 27	6	11 - 256	422	0	774.825439
20	Taiwan_neic1	20.09.1999	1	121.09	23.78	7.6	33	485 - 2898	2101	1550 - 10239	over 4 000	0	5055.83936
220	Mexico	30.09.1999	10	-96.024	16.061001	7.5	33	70 - 306	31	179 - 696	160	2	92.5520096
854	CALIFORNIA	16.10.1999	1	-116.271	34.594	7.4	0	4 - 18		8 - 37	4	0	677.618042
382	Taiwan	22.10.1999	10	120.506	23.445	5.6	33	0	1	0	254		0
383	Iran	31.10.1999	18	51.807	29.413	4.9	33	0		0	38		0
855	TURKEY	12.11.1999	18	31.161	40.758	6.3	10	428 - 2238	834	1045 - 5693	4566	0	346.528534
362	Vanuatu	26.11.1999	0	168.22	-16.417	7.3	33	12 - 61	12	28 - 157	>100	0	7.10099976
384	Vanuatu	26.11.1999	0	168.227	-16.434	7.3	33	11 - 61	5+3+2	23 - 167	100		7.10099976
385	Philippines	11.12.1999	2	119.767	15.776	7.1	33	13 - 95	1+4	54 - 397	40	0	2255.93042
197	Philippine Island	11.12.1999	2	119.76	15.8	6.8	33	1 - 18		14 - 91			873.834961
386	Indonesia	21.12.1999	21	105.65	-6.816	6.1	56	0	5	0	220		0
387	ALGERIA	22.12.1999	18	-1.277	35.232	5.5	10	9 - 70	24	33 - 349	175	0	321.796997
360	China	11.01.2000	7	122.994	40.498	4.7	10	0		0	30		0
363	China	14.01.2000	7	101.063	25.607	5.9	33	0	5	0 - 1	1 542		2.44300008
859	KURIL ISLANDS	28.01.2000	0	146.837	43.046	6.7	61	0		0	2	0	6.87799978
410	Iran	02.02.2000	2	58.218	35.288	5.3	33	0		0 - 2		0	7.44799995
364	Indonesia	04.05.2000	12	123.573	-1.105	7.5	26	55 - 219	46	151 - 536	264	0	97.4973401
411	Argentina	12.05.2000	13	-66.452	-23.548	6.2	225	0		0		0	0
365	Taiwan	17.05.2000	11	121.058	24.223	5.3	10	0	3	0	13		2.54699993
366	Indonesia _neic	04.06.2000	23	102.087	-4.721	8.0	33	76 - 412	103	173 - 1063	2 174	0	699.567871
367	Turkey	06.06.2000	4	32.992	40.693	6.1	10	19 - 99	2	51 - 339	80	10	75.5620575
368	Taiwan	10.06.2000	2	121.212	23.818	6.2	33	0	2	0 - 4	36		175.895996
369	Japan	01.07.2000	16	139.134	34.211	6.0	10	0 - 2	1	1 - 7	several	0	7.39599991
370	Nicaragua	06.07.2000	13	-86.08	11.886	5.1	5	3 - 29	7	13 - 166	42	0	60.0480042

Запись: 867 из 943

The developed knowledge base is used for the System calibration in order to compensate the incompleteness of our knowledge about built environment, population distribution, regional vulnerability functions of elements at risk. The descriptions in the knowledge base are used as reference points. They allow the parameters of mathematical models to be determined by minimizing the functional

$$\Omega = \sum_{i=1\ldots n} W_i \left(F_{ci}\left(p_{1,}\ldots, p_n\right) - F_{ri} \right)^2 \Rightarrow \min\left(p_1,\ldots, p_n\right) \qquad (1)$$

where W_{i} – weights of events; F_{ci} – computed number of fatalities; F_{ri} – reported number of fatalities; $p_1,\ldots, p_{\mathrm{n}}$ - free models parameters, used in the System.

The current knowledge base was used to compute the models parameters for earthquake prone areas of Russia and other countries all over the world.

The only factor, which can't be compensated by the system calibration, is the influence of the discrepancies of events location by different Alert Seismological Surveys.

Experience of the system operation showed that in practice one of the Surveys provides the input data, which allows to estimate expected damage and casualties with the error, which does not exceed 60% (table 1).

Table 1

Events	**Survey**	**Number of fatalities**		**Error**
		Computed	**Reported**	$\mathbf{\Delta L/L \bullet 100}$
Greece, September 7, 1999	NEIC	30	>150	80
	Greece Survey	1070	>150	613
	EMSC	29	>150	80
	GS RAS	132	>150	12
Taiwan, September 20, 1999	EMSC	92	2101	96
	GS RAS	4786	2101	128
	NEIC	2730	2101	30
Turkey, August 17, 1999	EMSC	9025	17127	47
	GS RAS	628	17127	96
	NEIC	14001	17127	18

Discrepancies in earthquake locations by different Seismological Surveys are dealt with number of stations, their distribution in earthquake prone areas and procedure of data processing in alert mode. Therefore, it is important to estimate in advance the rating (weight) of each Survey in order to make the right choice of earthquake parameters just after the event with taking into account obtained weights for each Survey. The weight is understood as the value, which is inversely proportional to errors in parameters determination in "emergency" mode and verified parameters of events issued in several months after events.

Procedure of rating estimation for Alert Seismological Surveys

Estimation of discrepancies in event locations by different Alert Seismological Surveys: Geophysical Survey of Russian Academy of Sciences (RGS), European Mediterranean Seismological Center, National Earthquake Information Center of USGS, was carried out for 50 seismic regions (fig.2) proposed by Flinn & Engdahl in 1965 (Flinn & Engdahl, 1965) and widely used now in seismological practice.

Two catalogs of GS RAS, which contains information about strong earthquake parameters, issued 1-2 hours after events in "emergency" mode and revised one issued 2-3 months after events occurred in 1990 – 2002 were analyzed. The distribution of events according to Flinn & Engdahl zones is shown in Fig.3.

To estimate the errors in earthquake parameters determination the following procedure was used:

1. All events were distributed between the 50 seismic regions of Flinn & Engdahl and the groups of events were made.
2. For each group and each event the difference between corresponding values of earthquake parameters (coordinates, depth, magnitude) determined in "emergency mode" and verified parameters issued in several days after events were computed. These differences were considered as errors in parameters determination.
3. Probability distribution of parameters' errors was constructed. The hypothesis of normal distribution was verified. The mathematical expectation of corresponding parameters' errors and deviations were estimated.

4.Obtained estimations were used for zoning of the world territory according to mean square deviations of distance from epicenter to any point σ_D.

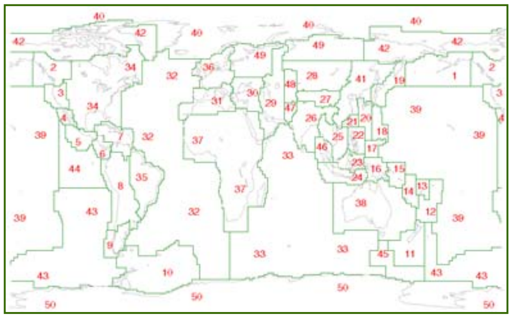


Fig. 2. Seismic zones according to (Flinn & Engdahl, 1965)

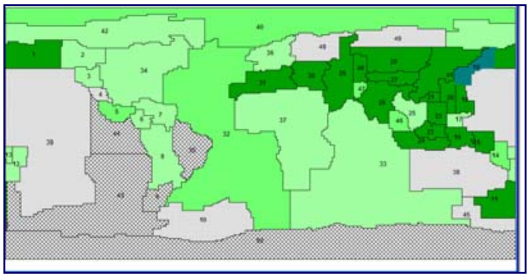


Fig. 3. Number of events in Flinn & Engdahl zones

The computations were made for Flinn & Engdahl zones and the dependences of error distribution for latitude, longitude, magnitude and source depth were constructed for each zone. The errors' probability distributions were approximated by different laws. The wide variety of approximating functions should be noted. Rather complex approximation functions with great number of parameters were met. The analysis showed that complex distributions are usually met in the cases when the initial data may be referred to rough errors. If we manage to exclude these rough errors when processing statistics data, then it is possible to approximate the sets of data for each zone by normal law. For instance, the results of computations showed that error distribution for latitude determination in the seismic region no. 19, which includes Kamchatka and Kuril Islands, follow the normal law (M=0 and σ=0.15). The hypothesis about the normal law was checked with application of χ^2 criterion. It was established that the hypothesis may be adopted with probability equal to 0.8. The mathematical expectation and mean square deviations of magnitude were computed (M=0 and σ=0.15). The probability for adopting the hypothesis about normal law for error distribution in magnitude determination in this region is also equal to 0.8 according to χ^2 criterion.

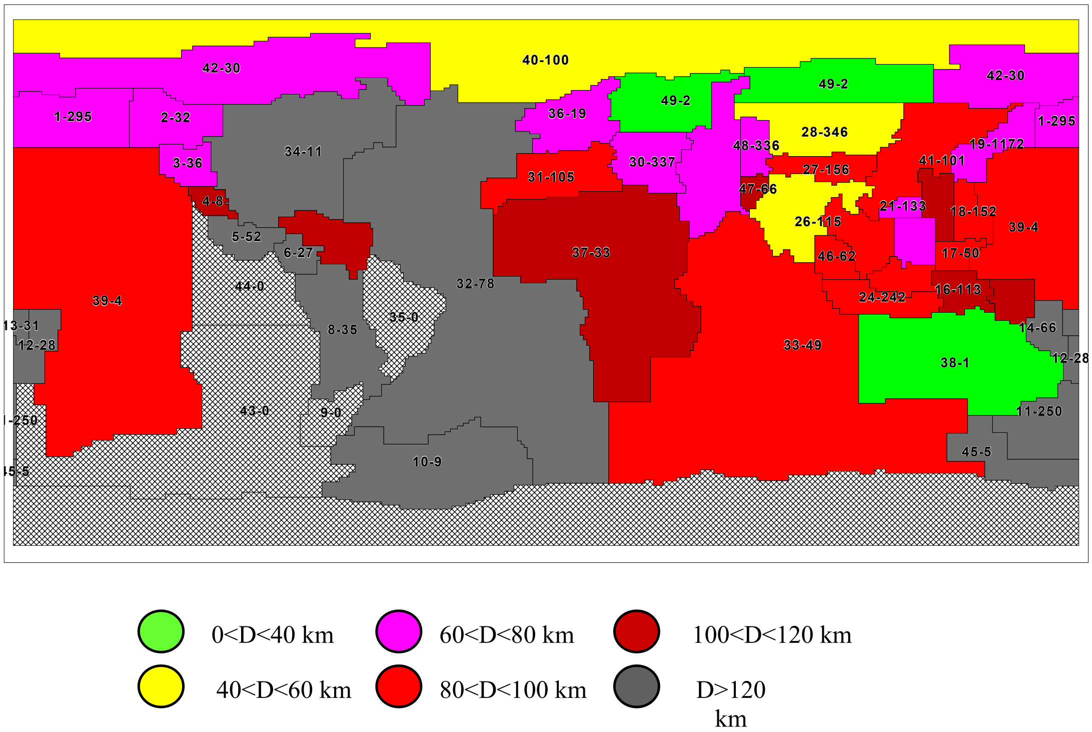
The great number of parameters of complex distributions made it rather difficult to distinguish zones according to one synthetic criterion, which characterizes the quality of epicenter location by GS RAS in alert mode. It resulted in necessity to approximate all distribution by normal law.

The obtained estimations of errors in coordinates, source depth and earthquake magnitude determination for 50 zones of Flinn & Engdahl were used to identify the boundaries of territories, which are characterized by different level of reliability for strong earthquake parameters determination by GS RAS.

The maps of the world territory zoning according to error distribution in depth, coordinates, magnitude determination by GS RAS were compiled. Fig. 4 shows the map of the world territory zoning according to the mean square deviations of distance from epicenter to any point σ_D, which was compiled with taking into account the errors in source depth and event coordinates determination. According to the obtained results the error in source depth determination may reach 70 km for unfavourable zones. The error in coordinate estimations for unfavourable zones may reach 120 km. The errors in estimation of the distance from epicenter to any point with taking into account the errors in coordinates and depth determination may vary from values close to zero up to values exceeding 100 km. The errors are mainly in the ranges of 1-25 km and 25-50 km. The highest values of errors are obtained for the following seismic regions: no. 5- Mexico Guatemala, no. 6 - Central America, no. 8 - Andean South America, no. 32 – Atlantic Ocean, no. 34 – Eastern North America.

The analysis of the zones' distribution with different level of discrepancies allows to make a conclusion that earthquake location determination made by GS RAS in "emergency" mode are rather reliable for the events occurred in south and north of the line connecting western and eastern boundaries of Russia. The worst estimations are obtained for the events occurred along this line. It may be explained by topology of GS RAS network, which basis is oriented mainly from west to east.

Fig. 4. Distribution of location discrepancies between GS RAS in emergency mode and the same Survey issued in 2-3 months



The main idea of the present investigation to reveal the influence of discrepancies in strong earthquake location on the accuracy (reliability) of expected impact computations with application of simulation models in "emergency" mode.

Estimation of influence of event location errors on reliability of loss estimations with "Extremum" system application

Analytical complex used for possible damage and losses estimation due to strong earthquakes includes 4 groups of models:

First group – seismic hazards models, which allows to estimate the intensity distribution for any point providing the definite epicenter.

Second group – models, which allows to estimate the buildings' behavior during strong events and identify the probability that buildings of definite types will survive the definite damage state.

Third group – models for estimation of possible earthquake impact on population providing the building of different types will survive definite damage states.

Forth group – models for taking into account people behavior during different time of day and night, and different seasons.

This complex was used for computations of expected losses due to test events. The test earthquakes were chosen in order to meet the following requirements:

- the events should be distributed homogeneously in time;
- the events should be distributed homogeneously in territory of earthquake prone areas of the world in accordance with Flinn & Engdahl classification;
- the events should be thoroughly studied and well documented; reliable information about events parameters are necessary, as well as about extend of damage and social losses.

Table 2 shows the list of test events, which includes 41 earthquakes.

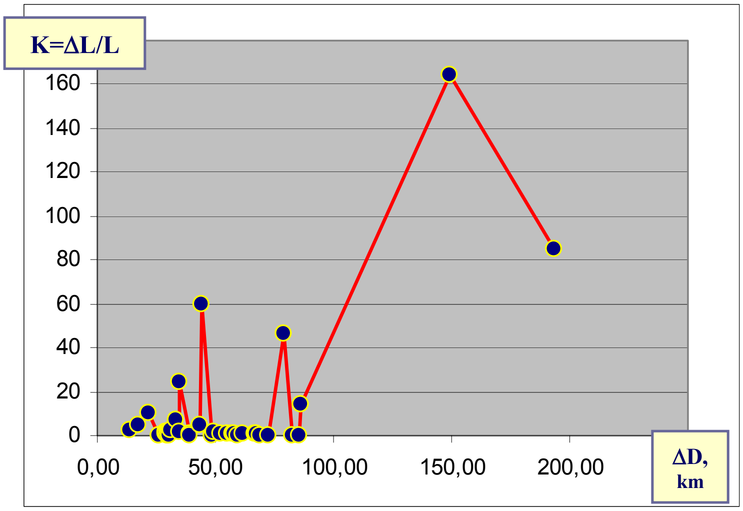
Table 2. List of test events

Number of event in GS RAS catalog	Date	Country/ region	Magnitude	Source depth	Flinn & Engdahl zone
910003	05.01.1991	Burma	7.2	33	25
910058	08.03.1991	Russia	7.2	33	42
910077	05.04.1991	Peru	7.1	33	8
910100	29.04.1991	Northern Caucasus	7.1	33	30
910173	15.06.1991	Northern Caucasus	6.4	33	30
910182	20.06.1991	Sulawesi	7.5	33	23
910202	13.07.1991	California	6.8	33	3
910258	18.09.1991	Guatemala	6.1	33	5
910285	19.10.1991	India	7.0	33	26
910316	19.11.1991	Panama	7.3	33	6
920109	25.04.1992	USA	7.1	33	3
920126	15.05.1992	Uzbekistan - Kirgizia	6.2	33	48
920131	20.05.1992	Pakistan	6.4	33	47
920139	25.05.1992	Cuba	7.2	33	7
920166	28.06.1992	USA	6.9	33	3
920211	19.08.1992	Kirgizia	7.3	20	28
960001	01.01.1996	Indonesia	7.4	33	23
960029	03.02.1996	China	6.7	33	26
960040	17.02.1996	Indonesia	7.9	33	16
960064	19.03.1996	China	6.4	33	27
960085	03.05.1996	China	6.2	33	27
960200	09.10.1996	Cyprus	6.6	33	30
970016	21.01.1997	China	5.9	33	27
970029	04.02.1997	Iran	6.6	33	29
970049	27.02.1997	Pakistan	7.1	33	47
970053	28.02.1997	Iran	6.0	33	29
970147	10.05.1997	Iran	7.1	33	29
970161	21.05.1997	India	5.8	33	26
970267	26.09.1997	Italy	6.0	33	31
970355	21.11.1997	India	5.7	60	26
990892	17.081999	Turkey	7.5	33	30
990974	07.09.1999	Greece	5.9	33	30
991024	20.09.1999	Taiwan	7.8	33	21
991072	30.09.1999	Mexico	7.4	33	5
991115	16.10.1999	California	7.3	33	3
991200	12.11.1999	Turkey	7.2	20	30
991309	11.12.1999	Luzon	6.9	33	22
200077	28.01.2000	Kuril Is.	7.1	33	19
200488	04.05.2000	Sulawesi	7.2	33	23
200622	04.06.2000	Sumatra	7.7	33	24
201023	04.08.2000	Sakhalin	7.1	33	41

The computations of possible losses were made with “Extremum” system application for two variants of source depth: taken from GS RAS catalog in “emergency” mode and averages one, which were determined by instrumental catalog for the period 1900 – 2002.

The obtained results of influence of errors in events location on expected loss estimations are shown in fig.5. Along axis x the errors in determination of distance from epicenter to any point ΔD are plotted, along axis y – values of errors in loss determination K= ΔL/L are plotted, where ΔL - difference between computed and reported number of fatalities; L – reported number of fatalities.

Fig.5. Influence of source location errors on consequences estimation



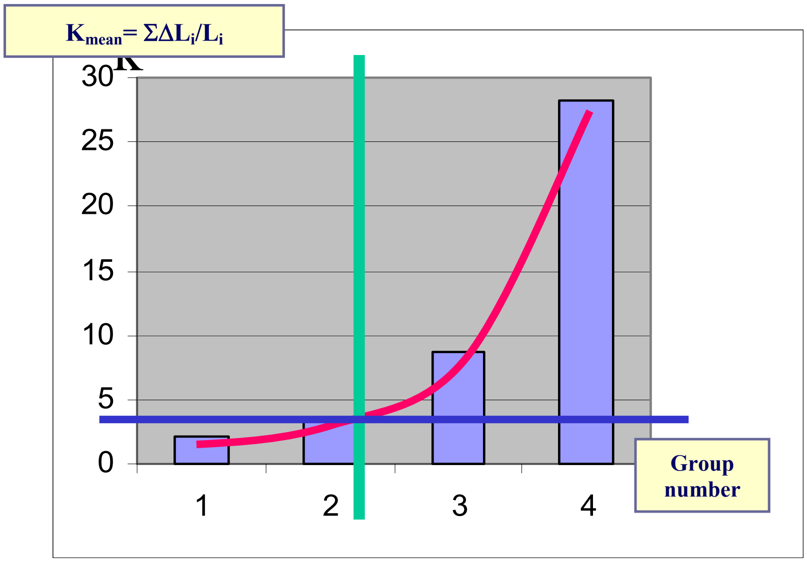
The analysis of fig.5 shows that in the case when the error in distance determination exceeds 100 km, the error in possible loss estimation may reach 100 times. The growth of error in possible loss assessment with the growth of error in distance determination is observed. Four groups of errors in distance determination were identified to reveal the main tendency (red line in fig.6) more definitely. These groups are the following: the first one – $0<\Delta D\leq 20$ km; the second one – 20 km $<\Delta D\leq 40$ km; the third one – 40 km $<\Delta D\leq 60$ km; the forth one -$\Delta D>60$ km. Within each group errors in losses $K_{mean}= \Sigma \Delta L_i/L_i$ were averaged, they are shown in fig.9.

The value of averaged error K_{mean} gives the difference between computed and reported number of fatalities for each zone. The assumption was made that the error in loss estimation, which does not exceed the reported one in 2-3 times ($K_{mean}\leq 2,\ldots 3$), is acceptable for taking the decision about emergency response. This assumption allowed to make the conclusion that the reliable estimation of possible impact in “emergency mode” may be obtained if the error of earthquake location ΔD does not exceed 40 km. In the case ΔD > 40 km the System “Extremum” does not allow to reach acceptable level of loss estimations due to strong earthquake.

With taking the proposed criterion into account the zoning of the world territory was undertaken (fig. 10). In fig. 10 the zones where is possible to obtain the reliable estimations of expected number of fatalities in ‘emergency’ mode with “Extremum” system application are shown by green color. The system can not give reliable estimations of possible losses with the use of GS RAS data for zones shown by red color.

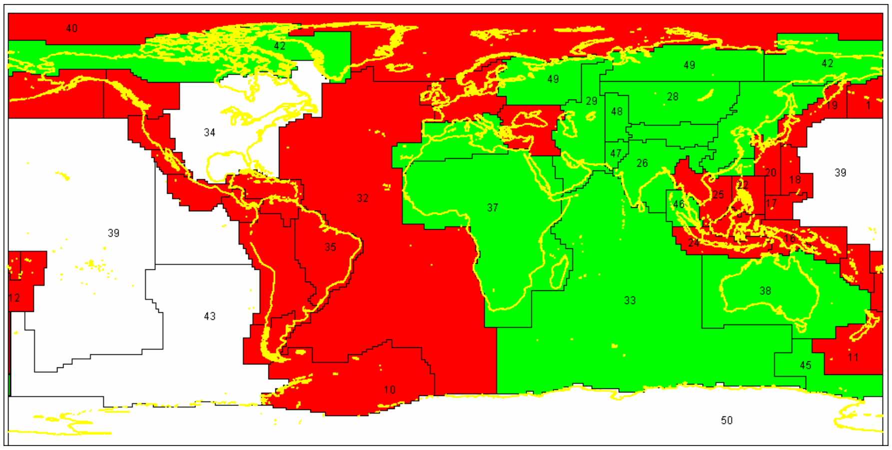
In green zones the expected number of fatalities obtained with “Extremum” system application and reported ones are not differ more than in 2-3 times. In red zones the errors in social losses computations may reach 1-2 orders (may differ in 10-100 times).

Fig.9. Influence of accuracy of event location determination on the reliability of expected loss estimation (blue line - acceptable level of error in possible fatalities estimation; green one - unacceptable level of error in possible fatalities estimation)



The analysis of the map (fig.9) shows that for the countries adjacent to Russian Federation: China, India, Pakistan, Iran, Afghanistan, GS RAS data allows to obtain the most reliable estimation of expected damage and losses due to strong earthquakes in "emergency" mode. The green zone in the fig.9 corresponds to the areas, where the priority is given to GS RAS when you choose the parameters of the strong event in near real time provided by different Alert Seismological Surveys.

Fig.10. Boundaries of zones of world territory according to the rate of error in possible fatalities estimations with GS RAS data application are determined



🟩 Acceptable level of error in possible fatalities estimation
🟧 Unacceptable level of error in possible fatalities estimation

Conclusions

The number of stations in the networks of different Seismological Surveys, the distributions of these stations along earthquake prone areas, as well as the procedures used by these Surveys for strong events parameters (coordinates, source depth, magnitude) determination in “emergency” mode strongly affect on expected loss estimations in near real time.

In order to increase the efficiency of near real time systems for damage and loss assessment due to strong earthquakes the additional study should be carried out to reveal the priority of other Seismological Surveys, which provide information about strong event parameters in “emergency” mode.

Biographies

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