# CHALLENGES OF GLOBAL EARTHQUAKE LOSS ESTIMATION IN EMERGENCY MODE

**Nina Frolova**

[1] *Seismological Center of IGE, Russian Academy of Sciences, Russian Federation*[1]

**Valery Larionov**

[2] *Extreme Situations Research Center, Russian Federation*[2]

**Jean Bonnin**

[3] *Institut de Physique du Globe, Strasbourg University, France*[3]

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## Abstract
This paper addresses the methodological and practical issues of near real-time loss assessment following strong earthquakes at global scale. The reliability of loss estimations is analyzed for three global system applications. The need for coordinated efforts and research at international level is stressed if one wants to increase the reliability of loss estimation in "emergency" mode.

## Introduction

Information on possible damage and expected number of casualties caused by strong earthquakes is very critical for taking the proper decisions about search and rescue operations, as well as rendering humanitarian assistance. The experience of earthquakes disasters in different earthquake-prone countries shows that the officials who are in charge of emergency response, at national and international levels, are often missing prompt and reliable information on the disaster scope.

At present, among the global systems that allow to provide earthquake loss estimation just after an event, three stand out. They are: the Russian "EXTREMUM" System which allows to simulate the distribution of seismic intensity, damage to buildings of different types, number of casualties in damaged and destroyed buildings and, optionally, identify effective response measures in case of emergency; the "Global Disaster Alert and Coordination System" (GDACS) developed jointly by the Joint Research Center (JRC) of the European Commission and the United Nations, which

[1] Seismological Center of IGE, Russian Academy of Sciences, Nikoloyamskaya str. 51, 109004 Moscow, Russian Federation
Email : frolova@comail.ru
[2] Extreme Situations Research Center, Yunykh Lenintsev str. 121/5-72, 109439 Moscow, Russian Federation
Email: lar@esrc.ru
[3] Institute of Physics of the Earth, Strasbourg University, 5 rue René Descartes, F - 67084 Strasbourg Cédex, France
Email: bonnin@selene.u-strasbg.fr

allows in near real-time to monitor the seismic situation and provide estimation of expected number of inhabitants in the affected area based on population density data; and the "Prompt Assessment of Global Earthquakes for Response" (PAGER) System of the US Geological Survey which allows to simulate expected shaking intensity and estimate expected number of inhabitants in zones of different intensities based on population density information.

The paper analyzes the methods and databases used in those three systems, as well as the reliability of loss estimation with different systems' applications. The need for coordinated efforts and research at international level is emphasized if one wants to increase the reliability of loss estimation in "emergency" mode.

## EXTREMUM System description

The "EXTREMUM" system has been designed for expected damage and loss assessment, as well as for identification of effective response measures to strong earthquakes. The system development started in 1990ies by joint efforts of Extreme Situations Research Center (ESRC) Ltd., Seismological Center, Institute of Environmental Geosciences, Russian Academy of Sciences, and Civil Defense and Disaster Management Research Institute, Emercom of Russia, within the framework of the Russian Federal Programs "Safety of Population, Buildings and Structures against Natural and Technological Hazards" and "Federal System of Seismological Observations and Earthquake Prediction". In 1999 – 2001, the system was further developed within the framework of EDRIM ("Electronic Discussions for Risk Managements") Program under the umbrella of the EUR-OPA Major Hazards Agreement ("Open Partial Agreement on the Prevention of, Protection Against and Organisation of Relief in Major Natural and Technological Disasters") of the Council of Europe.

The first implementation of "EXTREMUM" system in the Russian Federation has been done in 1995 for damage and loss assessment after the Neftegorsk earthquake. The first implementation at the global level has been done following the recommendations of Moscow Seminar on the "Contribution to the Decision-Making Process in Seismic Risk Management: Models for Earthquake Damage Assessment", held on 29 June – 01 July, 2000, within the framework of the EUR-OPA Major Hazards Agreement. Starting on 01 August 2000, a version has been run on an operational basis. The system focused on earthquake prone areas all over the world with magnitude threshold from 5.5 and up for the European-Mediterranean region and 6.5 and up for the whole world. It has been used in order to provide operative information on expected damage and casualties after strong earthquakes: to the Euro-Mediterranean Centres of EUR-OPA Major Hazards Agreement, to specific national institutions appointed by national authorities, to the Executive Secretariat of the EUR-OPA Major Hazards Agreement.

At present, it exists at least 5-7 "Extremum" system versions with different names: LAT (Loss Assessment Tool), QUAKELOSS, WebLAT and others. Since October, 2002 the World Agency for Planetary Monitoring and Earthquake Risk Reduction (WAPMERR) uses another version; the Agency was provided with this version at its founding meeting in Geneva (Switzerland) in May 2000, as a contribution of the ESRC team to the WAPMERR membership. Nowadays, WAPMERR makes use of this version of the system and issues loss estimates, in collaboration with the Swiss Seismological Service, to the Swiss Corps for Humanitarian Help and OCHA (United Nations Office for the Coordination of Humanitarian Affairs), approximately 2 hrs. after an event occurs. Since May, 2004 the Geophysical Survey of RAS (GS RAS) uses another system version for estimation of intensity distribution.

The "EXTREMUM" System databases and mathematical models used for simulation of shaking intensity, damage to buildings and structures, number of fatalities and injuries, are regularly updated by Extreme Situations Research Center, Seismological Center of IGE, Russian Academy of Sciences. The detailed description of simulation models is given in the 6 volumes' monograph

"Natural Hazards in Russia", vol. 6 "Natural Risks Assessment and Management" (Larionov & Frolova, 2003a; Larionov *et al*. 2003b), in the Proceedings of SE-40EEE in Skopje-Ohrid, Macedonia in 2003 (Frolova *et al*., 2003b) and in the Proceedings of TIEMS Annual Conference in Trogir in 2007 (Frolova *et al*., 2007).

The sources of information about existing building stock are varied. For Russia, it is preferable to rely on data of inventories provided by the EMERCOM Regional Departments, or on that obtained through visual inspection by the ESRC team. For other countries, the main sources of information are publications in the proceedings of European and World Conferences on Earthquake Engineering, in journals, reports and other publications by UN Agencies, as well as the data collected from analysis of space images. For instance, distribution maps of rural and urban buildings types in Turkey published by O. Ergünay and P. Gülkan in the proceedings of the SEISMED Project Workshop II "Seismic Vulnerability and Risk Assessment" (Ergünay *et al*., 1990) allowed to construct 230 models of building stock distribution in the country. 156 models of different building types distribution for Greece are based on the data provided by M. Dandulaki from E.P.P.O. (E.P.P.O, 1998) and results of decoding the 2 m resolution space images of some Greek cities obtained by KVR-1000 installed on Russian satellite KOMETA (ESRC, 2000).

In the "Extremum" systems, information about event parameters is taken from alert seismological centers; at present, earthquake parameters are taken from Geophysical Survey of Russian Academy of Sciences (GS RAS), European Mediterranean Seismological Center (EMSC), National Earthquake Information Center (NEIC) of USGS, and occasionally national agencies: Kandilli Observatory and Earthquake Research Institute (KOERI), Japan Meteorological Agency (JMA), Japan Weather Association (JWA) and others. It is possible to read, with any pre-setting periodicity, the operative information about parameters of strong earthquakes (coordinates, origin time, magnitude, depth) from web-sites of the three principle agencies and/or to receive these data as *e*-mail messages.

After computations of expected damage extent, social and economic losses (and, eventually, identification of the effective response measures), expert review the results obtained, with the help of the impact knowledge-base about past events. Validated loss estimations are disseminated as *e*-mail messages.

The simulated results about expected impact are usually checked later against field observations. The reason for that is first to ascertain the simulated damage for the event under consideration, and then to improve the whole "EXTREMUM" System by calibrating through records of reported damage and social loss kept in the "EXTREMUM" System impact knowledge-base (Bonnin *et al*., 2002; Frolova *et al*., 2003a; Bonnin & Frolova, 2004). The current impact knowledge-base about past events all over the world has been used to compute the simulation model parameters for earthquake prone areas of Russia and other countries all over the world, by minimizing the functional

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

where $W_i$ are weights assigned to events; $F_{ci}$ is the computed number of fatalities; $F_{ri}$ is the reported number of fatalities; $p_1, \ldots, p_n$ are the free model parameters used in the "EXTREMUM" System.

The results of computations are usually presented as maps and tables, where estimates of expected number of fatalities, injuries and homeless are given for the whole stricken area and for each settlement. Fig. 1 and 2 show maps with the results of expected damage and shaking intensity computations for the earthquakes occurred on 8 October 2005 in Pakistan and 26 May 2006 in Indonesia. Dots of different size and color show the settlements in the stricken area; the dot size depends on the number of inhabitants in the given settlement; the dot color tells the expected "averaged" damage state of the buildings.

***Fig. 1.*** Results of possible loss assessment caused by October 8, 2005 earthquake in Pakistan; dots are settlements in the stricken area; colour of dots shows the average damage state of building stock (black : total collapse, brown : partial collapse, red : heavy, yellow : moderate, green : slight damage, blue : no damage); figure on the right shows the values of expected shaking intensities.

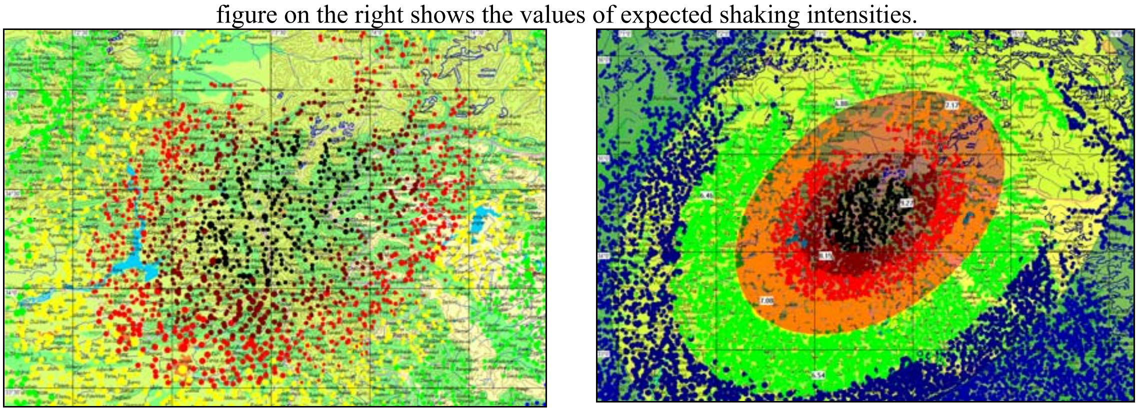
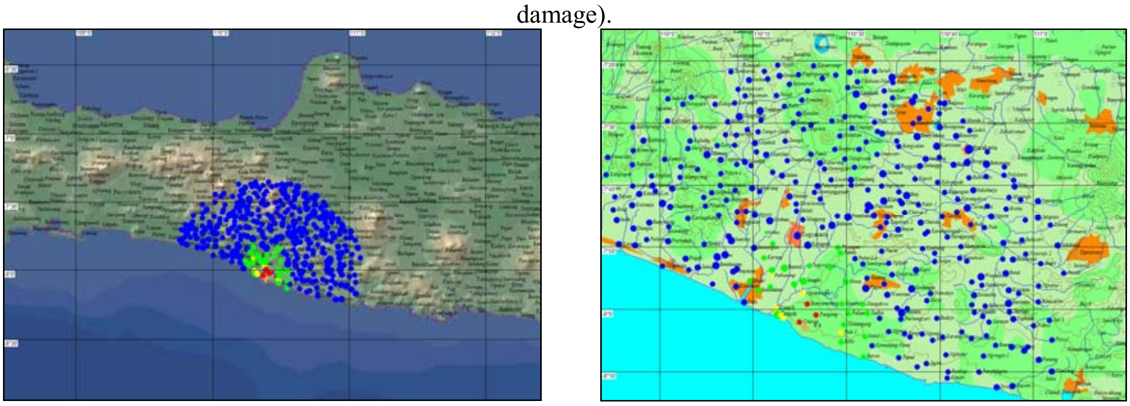


***Fig. 2.*** Results of possible loss assessment caused by May 26, 2006 earthquake at Indonesia in different scales; dots are settlements in the stricken area; colour of dots shows the average damage state of building stock (black: total collapse, brown : partial collapse, red : heavy, yellow : moderate, green : slight damage, blue : no damage).

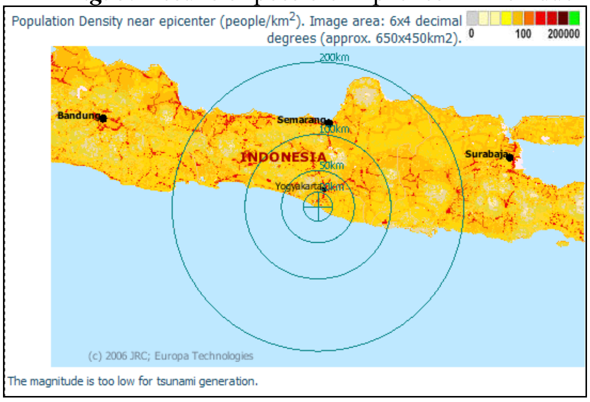


## GDACS description

GDACS is jointly developed by the European Commission's Joint Research Centre and the United Nations Office for Coordination of Humanitarian Affairs (OCHA) since 2005. The main aims of the system are to alert the international community in case of major sudden-onset disasters and to facilitate the coordination of international response during the relief phase of the disaster (de Groeve, 2006; de Groeve et al., 2008). The disaster alerts are based on automatic hazard information retrieval and real-time GIS-based consequence analysis. The GDACS earthquake impact model is built on the existing seismological infrastructure. Every 5 minutes, GDACS collects information on rapid estimations of earthquake location, magnitude and depth of source from different agencies, like NEIC, EMSC, GEOFON, JMA and others. By reporting the epicenter on the map of population density, GDACS estimates the total population in the affected area within the radii of different sizes. Then, it estimates the likelihood need for international humanitarian intervention.

Fig. 3 shows a fragment of the alert event report for the earthquake in Indonesia on May 26, 2006 from the web site of the system (http://www.gdacs.org).

***Fig. 3.*** Results of possible impact estimation due to May 26, 2006 earthquake in Indonesia.

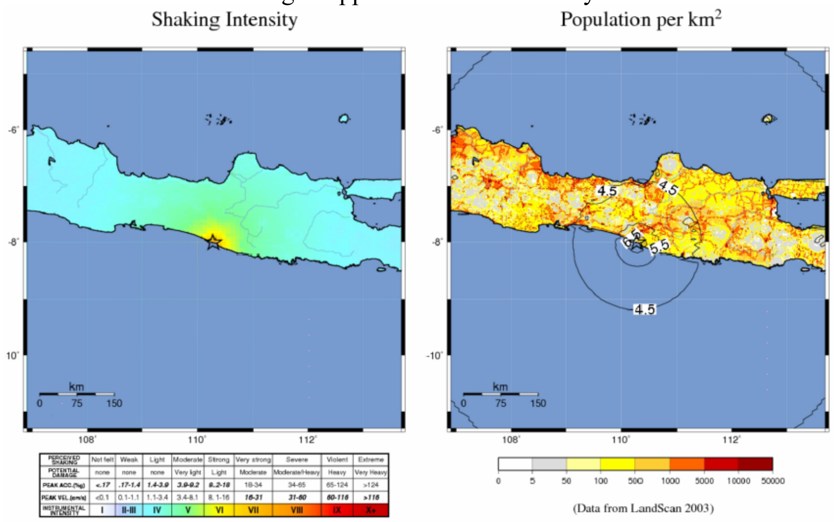



| Radius (km) | Population | Density (people/kmI) |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 4699 | 373 |
| 5 | 80357 | 1023 |
| 10 | 234254 | 745 |
| 20 | 730872 | 581 |
| 50 | 4906096 | 624 |
| 100 | 16924410 | 538 |
| 200 | 50065860 | 398 |

## PAGER description

PAGER System of US Geological Survey allows to simulate expected shaking intensity by using the methodology and software developed for ShakeMap (http://earthquake.usgs.gov/shakemap). Then, the expected number of inhabitants within the zones of different level of shaking intensity *I* is estimated by using the information on population density from Oak-Ridge National Laboratory's Landscan population database. PAGER is an automated system; it monitors the NEIC near real-time detections of domestic and global earthquakes and issues alarm to emergency agencies and other end-users at national and international levels. Its estimations of exposed population could be revised in case subsequent information about event parameters becomes available and a replacement alarm is issued. Fig. 4 shows an example of possible consequences estimation following the 26 May 2006 earthquake in Indonesia. The population exposed to shaking was estimated as the following: for *I* = VIII : 8,000; for *I*=VII : 558,000 and for *I*=VI : 2,780,000.

***Fig. 4.*** Results of possible consequences estimation following the May 26, 2006 earthquake in Indonesia according to application of PAGER System



At present, the PAGER team is developing and testing a more comprehensive version of the system which will include simulation models for casualty assessment (Wald *et al*., 2008). It is planned that different models from fully empirical to largely analytical approaches will be used for simulation of casualties.

## Reliability analysis of expected loss estimations applying the three global systems

Reliability of near real-time expected loss estimations with simulation application is influenced by many factors such as lack of reliable data on elements at risk (population and built environment) and hazard sources; lack of reliable regional vulnerability functions for different elements at risk caused by earthquakes and secondary hazards; discrepancies in strong earthquakes' parameters determination by different alert surveys and lack of access to confidential sources of information. At present, much efforts are under way in order to update the information about existing building stock with global coverage within the "EXTREMUM" System and collect information about building distribution, collapse and fatality rate within the PAGER project by collaborative efforts with Earthquake Engineering Research Institute (EERI)'s World Housing Encyclopedia (WHE, http://www.world-housing.net).

Comparison of expected population exposed to two strong events, obtained by different systems' applications in "emergency" mode (Tabl. 1) gives a certain "*bonus*" to the "EXTREMUM" System which uses simulation models at all steps of earthquakes consequences estimation, from modeling of shaking intensity distribution to different types of building behavior during shaking of different intensities, to estimation of number of fatalities and injuries in collapsed and damaged buildings.

***Table 1***. Estimations of social loss caused by strong earthquakes in 2006, through application of the three global systems.

| ***Event*** | ***Estimation of expected social loss by different systems*** | | | ***Reported loss*** |
|---|---|---|---|---|
| | ***EXTREMUM*** | ***GDACS*** | ***PAGER*** | |
| 22 February, 2006,<br>M = 7.5, Mozambique | expected number of fatalities : 7 – 40, injuries 20 – 240 | estimated population in zones:<br>*R* = 10 km : 1,870<br>*R* = 20 km : 7, 340<br>*R*= 50 km : 36, 370<br>*R* = 100 km : 221,308 | estimated population in zones:<br>*I* = X : 1, 000<br>*I* = IX : 8, 000<br>*I* = VIII : 32, 000 | Reported number of fatalities : 17 persons |
| 26 May, 2006, M = 6.2, Indonesia | expected number of fatalities : 950 – 6,100, Injuries : 2,500 – 20,000 | estimated population in zones:<br>*R* = 10 km : 234,254<br>*R* = 20 km : 730,872<br>*R*= 50 km : 4,906,096<br>*R* = 100 km : 16,924,410 | estimated population in zones:<br>*I* = VIII : 8, 000<br>*I* = VII :558, 000<br>*I* = VI : 2,780, 000 | Reported number of fatalities : 5,778 persons |

It should be mentioned that errors in event parameter determinations by different Seismological Surveys contributes significantly to degrading the reliability of expected loss estimations. In order to estimate the influence of this factor, a special study has been carried out (Frolova *et al*., 2003a). The study has shown that surveys could be ranked according to achieved accuracy within the different Flinn-Engdahl zones. As an outcome, the "right choice" of earthquake parameters may be made in "emergency" mode, taking into account weights assigned to each survey in the relevant Flinn-Engdahl zone. The weight is understood as the value inversely proportional to error in events' parameter determinations in "emergency" mode as compared to parameters issued several days and months after events.

In addition to errors in event parameter determinations by different seismological surveys, some factors which influence reliability of expected damage and loss assessment in "emergency" mode with near real-time systems application may be compensated, to a certain extent, thanks to system calibration using knowledge-base about well-documented past strong earthquakes.

## Conclusions

The present paper gives a brief description of three global systems used for loss assessment following strong earthquakes, in "emergency" mode. The analysis of results from near real-time loss estimations allows to draw the conclusion that priority should be given to simulation models for consequences estimation at all steps in order to increase the reliability of the results.

On the whole, analysis of three global systems for expected loss assessment in "emergency" mode showed good and less good things for many reasons. In future many refinements should be introduced in order to avoid existing limitations in simulation models and databases on population and built environment distribution. The work is huge and coordinated efforts and research at international level is badly needed if one wants to increase the reliability of loss estimation in "emergency" mode at global level.

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## Author Biographies:

Dr. Nina Frolova is a senior scientific researcher with Seismological Center of IGE, Russian Academy of Sciences. She has contributed to studies on earthquake hazards and risk reduction and activities of UNDRO, UNESCO, IDNDR on earthquake preparedness since 1985. The Soviet of Ministries awarded Dr. Nina Frolova, along with others, the USSR prize in 1984 for her work on the seismic load assessment and earthquake resistance of high dams. In 2005 she was awarded by UNESCO, the GARD Medal for distinguished professional leadership and personal commitment to ongoing programs on disaster reduction. Dr. Nina Frolova is a responsible scientist for the ESC WG "Earthquake Preparedness and Civil Defence". She is a TIEMS Directors' Board Member and GARD Vice-President for the Asian Region.

Dr. Valeri Larionov is Vice General Director of Extreme Situations Research Center. He has contributed to research on emergency response since 1972. He is an expert in assessment and management of natural and technological risk; organization of management and response to emergency situations; industrial safety, assessment and management of seismic risk. At present he has conducted researches on expected losses assessment due to natural and technological hazards and emergency management with GIS technology application. The Russian Federation government awarded Dr. Valeri Larionov, along with others, the prizes in 1999 and 2001 for the work on development of the Russian Federal system for monitoring and forecast of emergency situations.

Dr. Jean Bonnin is (honorary) full professor with the Institute of Physics of the Earth, Strasbourg University, France. He has devoted a large part of his activity to the problems posed by usage of data in solid Earth geophysics. He has been awarded in 2004 CODATA International Prize for his contributions in the field. Since a few years he has contributed to topics related to risk management by trying to improve the dialogue between scientists/engineers and decision makers.