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Fault Networks in Earthquake Prediction

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RESPONSE TO BACKGROUND PREDICTION(ESTIMATION OF SEISMIC RISK): Insurance, legislation, safety regulations…

RESPONSE TO PREDICTIONS INDICATING TIME AND AREA COVERED BY THE ALARM

PUBLIC POLICY ISSUES

DECISION-MAKING PROBLEM:

- What preparedness measures to undertake in response to a prediction?

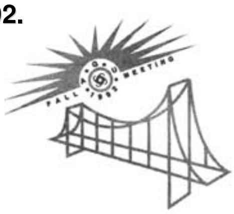
"*The nation's problems have become more numerous, more frequent, more severe, and in some cases more crisis related*" /F. Press/

"*Though this be madness, yet there is method in't*" /W. Shakespeare/

"*Of course, things are complicated…. But in the end every situation can be reduced a simple question: Do we act or not? If yes, in what way?*" /E. Burdick/

Example from the past: Northridge Earthquake, 1994.

American Geophysical Union 1992 Fall Meeting, published as supplement to *Eos*, October 27, 1992. Prediction made in 1992.



Application of Algorithm for Prediction of a Strong Repeated Earthquake to the Joshua Tree and the Landers Earthquakes' Aftershock Sequences

Tanya Levshina
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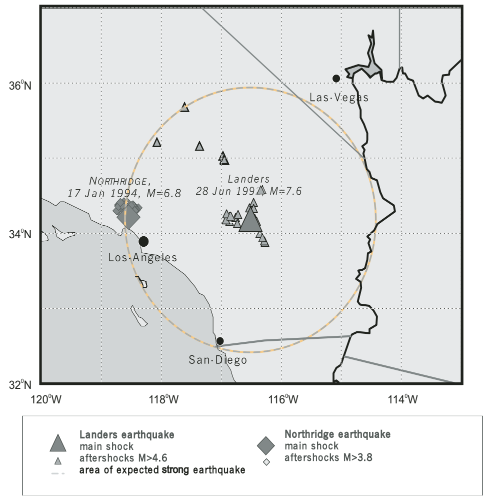
Inna Vorobieva
(International Institute of Theory of Earthquake Prediction, Moscow, Russia)

The analysis of the aftershock sequence of the Landers earthquake shows that the earthquake with magnitude M_a >= 6.5 may occur during the following 1.5 year within the radius R=169 km from the epicenter of the main shock.

Northridge Earthquake, 1994 – Outcome of prediction

Earthquake with M 6.8 occurred 20 days after termination of alarm.

Total damage was about $30bln. Several low-cost preparedness actions would prevent considerable part of that damage.



Above example illustrates
the problem confronting a disaster manager

- **A destructive earthquake is predicted** within certain *time interval, area*, and *magnitude range*.
- Prediction includes the *probability of false alarm* ***f*** **.**
- **Disaster manager has to decide *what, if any, temporary preparedness measures ("actions") to undertake*,** in addition to permanent ones, presumably undertaken already.
- **Decision depends on specific circumstances:**
  - *objects vulnerable to the predicted quake* (ripple effects included);
  - for each object – *possible actions*;
  - for each action – its *cost* and the *damage it prevents*.
- **Decision can't be postponed.**

See "An Example Scenario" below.

HOW TO USE PREDICTIONS WITH THEIR LIMITED ACCURACY FOR DAMAGE REDUCTION?

- ***BASIC PRINCIPLE:*** **escalate or de-escalate preparedness measures, according to what and were is predicted and what is the quality of prediction. Such is the standard practice in preparedness to all disasters, war included.**

- ***DIVERSITY OF DAMAGE:*** **failure of constructions; fires; release of dangerous materials; triggering of floods, avalanches, landslides, tsunami etc.**

Socio-economic impacts: disruption of vital services - supply, medical, financial, law enforcement etc.; epidemics; disruptive anxiety of population, profiteering and crime; drop of production and employment; destabilization of financial systems.

These impacts may be inflicted also by undue release of predictions.

DIVERSITY OF PREPAREDNESS MEASURES

- ***A hierarchy of preparedness measures*** **is required by the diversity of damage from earthquakes.**
- ***Background measures*****: restriction of land use; building codes; insurance and bonds; preparedness of civil defense type; R&D.**
- ***Temporary measures*****, activated in response to a time prediction: enhancement of permanent measures - safety inspections, simulation alarms etc.; partial neutralization of high - risk objects; mobilization of post - disaster services; emergency legislation, up to martial law; evacuation of population etc.**
- **These measures are required in different forms on personal, local, provincial, national and international levels.**
- **Different measures require different lead time, from seconds to years, to be activated; having different cost they can be realistically maintained for different time - periods, from hours to decades; and they have to be spread over different territories - from selected points to large regions.**
- **No single measure is sufficient alone. On the other hand many important measures are inexpensive.**
- **As in national defence, a prediction is useful if its accuracy is *known*, but not necessarily high.**

RESPONSE TO ESTIMATION OF SEISMIC RISK

PROBABILISTIC ESTIMATION OF SEISMIC RISK

PLACES AFFECTED, DAMAGE INFLICTED,
STRONG MOTIONS REOCCURRENCE ...

EQUIVALENT OF THE FOLLOWING RANDOM SEQUENCE IS COMPUTED

(HYPOCENTER,TIME)$_i$ $\leftleftarrows$ M_i $\leftleftarrows$ STRONG MOTION (AREA) $\leftleftarrows$ GROUND CORRECTIONS $\leftleftarrows$ OBJECTS AFFECTED $\leftleftarrows$ DAMAGE INFLICTED

DISTRIBUTION FUNCTION OF THE FOLLOWING RANDOM VALUE IS ESTIMATED:

$$D = \sum_i d_i(hyp_i, M_i/t_i, sm_i) \qquad T_1 \le t_i \le T_2$$

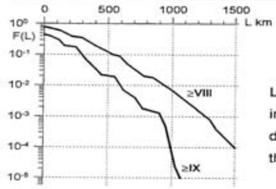
MEASURES OF D

DIRECT:	INDIRECT: **AFFECTED**
CASUALTIES ECONOMIC LOSSES	POPULATION, PROPERTY, SPECIAL OBJECTS **AREA**

Trans-Baikal railroad

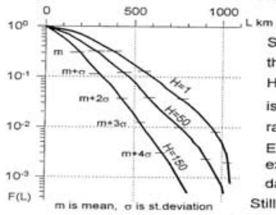
Only the damage to railroad track is analysed; bridges and other structures should be considered separately.

How to use available data which are imprecise and incomplete?
The answer: consider the lowest and the highest estimates.



Distribution functions
for strong motion of railroad track
(the highest estimate)

L is the total length of track, which may fall into the zone of intensity ≥VIII or ≥IX during 10 years. F(L) is the probability that this length will not exceed L.



m is mean, σ is st.deviation

Distribution functions for prevented damage
(the highest estimate)

Seismicity is overestimated by assuming that all shocks will occure not further than H km from the object; $M_{max} = 8$ and isosmals will be elongated along the railroad. Interest rate was assumed minimal. Efficiency of reinforcement of track was exaggerated too: complete prevention of damage.

Still, if the cost of reinforcement is above .6, then

there is only negligible probability that the cost of reinforcement of track will be returned in the form of prevented damage.

GJRAS (1971),**21**,323-335

Seismic risk for Caucasus
Rurlal dwellings in Georgia

Insurance premium for rural dwellings in Georgia

S=7908.6 mln. of roubles - Cost of all dwellings (1977)
λ =1.9 - average annual number of destructive earthquakes
β_o=1% - annual growth of the number of dwellings
β_1=8% - basic interest rate
U_T - insurance payment in T years

	Risk, $Pr\{X_T>U_T\}$	T=5 years	T=30 years	T=50 years
Total damage, X_T, % of S		.98± .89	2.91±1.24	3.32±1.25
Profit margin:		Rates:		
break even, $U_T=\lambda m$	> 50%	0.23%		
$U_T = m + 2\sigma$	6 %	0.65%	0.43%	0.41%
$U_T = m + 3\sigma$	2 %	0.86%	0.53%	0.50%

Note. m is average damage per event, σ is its st.deviation

The Geneva Papers on risk and Insurance, 1984, Etudes et Dossiers No.77. Natural Disasters and Insurance (IV).

Seismic risk for the largest cities of the world

Number D of inhabitants

affected by strong motion during 1971-2000

(intensity ≥ VIII MMS in the area ≥ 100 km^2)

Category, n[1]	Total population, mln.	D, mlns			Probability of no events	A per 100 years[3]
		$m\pm\sigma$ [2]	x(p)			
			p=5%	p=1%		
Exceptional risk (Tokyo group, 7 cities)	24	20 ± 15.5	48	65	8 %	8
Very high risk (17)	47	17 ± 15	46	65	8 %	8.6
High risk (52)	76	2.9 ± 3.3	9	15	28 %	4.3
All cities (76)	147	40.1 ± 21.6	79.8	101.7	0.2 %	21

Note. 1) n is number of cities. 2) m is mean; σ is st.deviation; the value x(p) will be exceeded with probability p. 3) A is the mean number of the earthquakes, which geherate I≥VIII MMS at least in one of the cities, while the area of VIII MMS isoseismal is ≥ 100 km^2.

Number N of cities

affected by strong motion in 30 years

(intensity ≥ VIII MMS in the area ≥ 100 km^2)

Category	Number of cities	N		
		$m\pm\sigma$ *)	$x_N(p)$	
			p=5%	p=1%
Exceptional risk (Tokyo group)	7	4.1 ± 2.8	10	13
Very high risk	17	2.6 ± 1.7	6	8
High risk	52	1.3 ± 1.2	4	6
All cities	76	8.0 ± 3.5	15	18

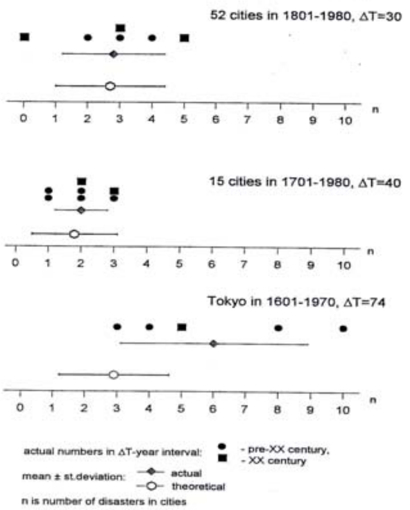
Note.*) m is mean; σ is st.deviation; the value x(p) will be exceeded with probability p.

The Geneva papers on risk and Insurance, v. 9 (1984), N 32, 255-270.

Seismic risk, 16

Seismic risk in the largest cities of the world

Theoretical estimation and seismic history



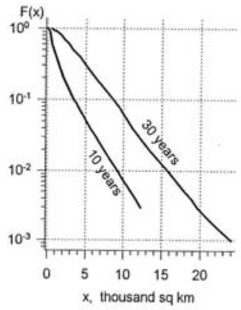
The Geneva papers on risk and Insurance (1984), v. 9, N 32, 255-270.

Seismic risk for eight provinces of Central Italy

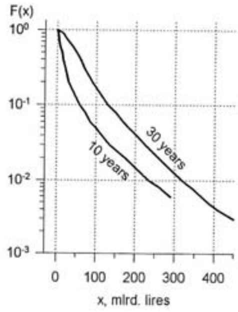
Territory, population and industrial facilities
affected by strong motion of intensity ≥VIII MMS

F(x) is the probability that the measure of seismic risk will be x or more

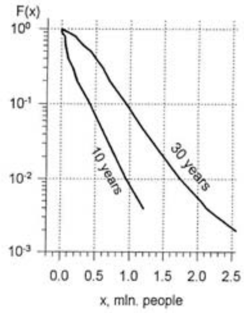
Territory



Yearly industrial output



Population outside the capitals

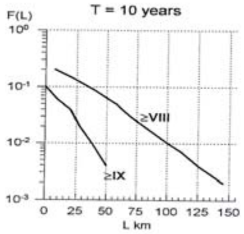


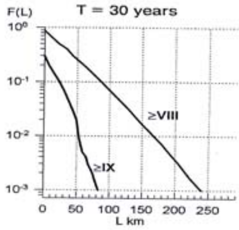
Annali di Geofisica (1974), vol.XXVII, N 1-2, 349-365

Seismic risk for Italy

Rome-Naples highway

L or more km of the highway will be affected by strong motion with probability F(L) during T years





Northern shore of Sicily

L or more km of the northern shore of Sicily will be affected by tsunami waves of intensity ≥1 during 30 years

L km	1	25	30	35	36	70
F(L)%	9.79	9.72	9.22	8.23	.5	.36

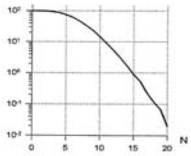
Intensity 1 is the amplitude of the tsunami wave for M=8 and epicentral distance Δ=800 km

Annali di Geofisica (1974), vol.XXVII, N 1-2, 349-365

Seismic risk for Argentina

Capitals of 17 provinces

Cities in dizaster zones



N or more cities will be affected by strong motion with probability F(N) during 30 years.
m is mean, σ is st.deviation

Intensity ≥ VII (left panel)
$m \pm \sigma = 6.1 \pm 2.8$

Intensity ≥ VIII (table)
$m \pm \sigma = .52 \pm .75$

N	1	2	3	4	5
F(N)%	67.9	22.7	4.8	.4	.1

Population of capitals in dizaster zones

16 capitals (Cordoba excluded)

x or more people will be affected by strong motion with probability F(x) during 30 years.

	x, thousand people			Probability
	mean	st.deviation	95% quantile	of x=0
VII	793	441	1600	.26%
VIII	69	122	230	49.9%

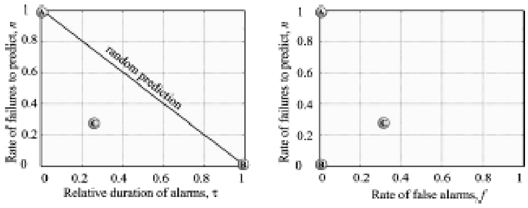
VII curso international sobre microzonification y su aplicacion al planneeamiento urbano para la mitigation de desasters; Oct. 16-Nov.10 de1995; Lima, Peru, 12 pp.

RESPONSE TO PREDICTION INDICATING TIME AND AREA OF ALARM

Molchan G.M., 1990. Strategy of earthquake prediction. Physics of the Earth and Planetary Interiors, 61, pp.1-7. Elsevier Science Publishers B.V., Amsterdam.

Molchan G.M., 2002. Strategy of Earthquake Prediction. In Keilis-Borok, V.I., and Soloviev, A.A.(eds.), 2003. Nonliner dynamics of the Lithosphere and Earthquake Prediction, Springer-Verlag, Heidelberg, 337p.

Error diagram - definition



A prediction algorithm is applied to a certain territory during the time period *T*. A certain number of alarms is declared, and A_f of them happened to be false. *N* strong earthquakes did occur and N_f of them have been missed by alarms. The alarms cover altogether the time *D*.

Scheme of the error diagram (ED). Points *A*, *B* and *C* show performance of a prediction method: the trade-off between the rate of false alarms, *f*; the rate of failures-to-predict, *n*; and the relative time-space occupied by alarms, τ. Points on the diagonal on the left plot correspond to a random guess. Point *A* corresponds to the trivial "optimistic" strategy, when an alarm never declared; point *B* to the trivial "pessimistic" strategy, when an alarm takes place all the time; point *C* to a realistic prediction.

Error diagrams in prediction problems

A ***cloud of points*** is usually given on an ED. This is necessary for the following goals:

***Stability tests*.**

--Prediction algorithms inevitably include adjustable elements(e.g. the values of numerical parameters; the observations used; definition of precursors; selection of magnitude scale, etc).

--In liue of an adequate theory many such elementscannot be uniquely determined a priory. They have to be chosen retrospectively: we design the algorithm which performs well in the past.

--That creates a danger of self-deception: "With four exponents I can fit the elephant"- E.Fermi /J.von Neumann/.

To reduce this danger we put on ED the points corresponding to different combinations of adjustable elements. This test takes a lion share of the work.

-- A prediction algorithm makes sense only if its performance is

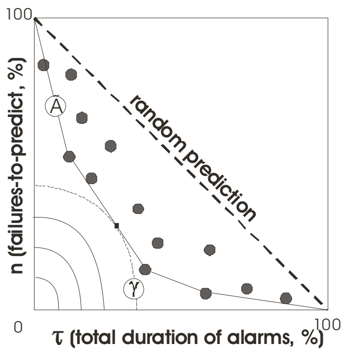
(i) Sufficiently better than random one, and

(ii) Not too sensitive to variation of adjustable elements.

Comparison of different algorithms

Communication of predictions: using in parallel several versions of prediction algorithm. Then prediction is presented by an ED, indicating the points giving an alarm. This fits the interests of an end user much better that a single "best" prediction.

Strategy of response to prediction



- **Optimal strategy of preparedness**

(optimal control theory approach)

After G.M.Molchan

Dots **show points on error diagram defined on the left. A is their evnelope.**

Thin contours **show "loss curves"with constant value of a prevented "loss".**

Optimal strategy **is the tangent point on contour.**

Response to a single alarm:

An Example Scenario:

Escalation of preparedness for water supply system located in rural territory and delivering water to metropolitan territory.

From:
C. Davis[1], V. Keilis-Borok[2,3],
G. Molchan[3,4], P. Shebalin[3,5], P. Lahr[1],
and C. Plumb[1]

[1]Los Angeles Department of Water & Power

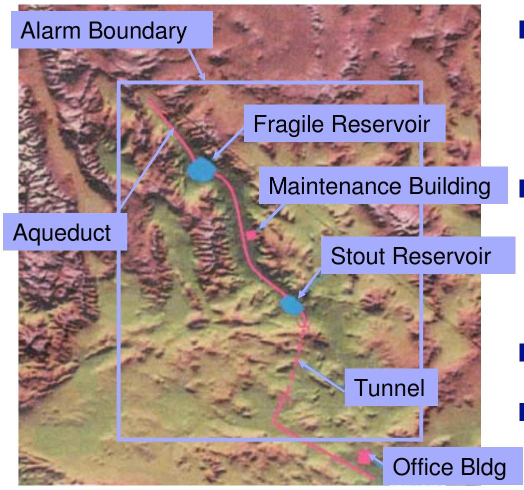
[2]University of California, Los Angeles

[3]International Institute of Earthquake Prediction Theory and Mathematical Geophysics (Moscow)

[4]Abdus Salam International Centre for Theoretical Physics (Trieste)

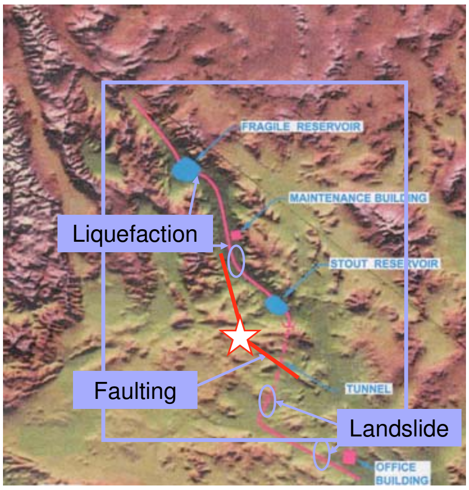
[5]Institut de Physique du Globe de Paris

Vulnerable Objects in the Area of Alarm



- 150 miles of aqueduct pipes and tunnels
- Two reservoirs
  - “Fragile” (old dam)
  - “Stout” (new dam)
- Office Building
- Maintenance Building

Hazards



- Fault movement damaging tunnel
- Strong ground motion
- Landslide damaging aqueduct along slopes
- Liquefaction damaging pipeline and/or “fragile” dam

Possible Actions (A Sample)
Lowering Reservoir Water Level

	Action	DA ($1,000)	DP ($1,000)	Gain ($1,000)		
				f = 10%	f = 50%	f = 75%
T	Lower water level in Fragile Reservoir	2,000	7,500	**4,750**	**1,750**	**-125**
T	Lower water level in Stout Reservoir	2,000	10	**-1,991**	**-1,995**	**-1,998**
T	Drain reservoirs	16,000	7,510	**-9,240**	**-12,250**	**-14,120**

$$Gain = DP(1-f) - DA$$

DP = Damage Prevented
DA = Cost of Action
f = Probability of false alarm

T = Temporary: lasting for alarm period

About 20 actions were considered in similar way

PUBLIC POLICY ISSUES

PREPAREDNESS AND PREDICTION

- THE PROFESSIONS OF EMERGENCY MANAGEMENT AND DISASTERS PREDICTION ARE INTERTWINED
- PREDICTIONS POINT TO THE URGENCY OF THE EMERGENCY MANAGER'S WORK
- PREDICTIONS ALSO HELP FOCUS THE PREPAREDNESS EFFORTS
- DISASTER PREPAREDNESS PROVIDES UNDERSTANDING – WHAT PREDICTIONS ARE USEFUL

PREPAREDNESS IS THE FOUNDATION OF

- EMERGENCY MANAGEMENT IS BUILT ON PREPAREDNESS
- PLANNING
- TRAINING
- EXERCISES (STAFF and POPULATION)
- PARTNERSHIP BUILDING
- STANDARDS
- EMERGING TECHNOLOGIES
- DENIAL IS THE LARGEST OBSTACLE

STANDARDS

- LAWS AND AUTHORITIES
- PROGRAM ADMINISTRATION
- HAZARD IDENTIFICATION AND RISK ASSESSMENT
- EMERGENCY PLANNING
- HAZARD MITIGATION
- RESOURCE MANAGEMENT
- COMMAND AND CONTROL

STANDARDS CONTINUED

- MUTUAL AID
- FINANCE AND ADMINISTRATION
- CRISIS COMMUNICATION
- WARNINGS AND NOTIFICATION
- TRAINING
- EXERCISES AND EVALUATION
- LOGISTICS AND FACILITIES

PERSONAL PREPAREDNESS

requires simulation alarms and education

- Develop a plan of action
- Agree with friends and family on a contact point that is outside of the quake zone to avoid tying up phone lines
- Locate the safe and the dangerous spots around your home and office so that you can act quickly
- Check buildings and houses to make sure up to earthquake codes

Seismic vulnerability of humankind is rapidly growing.

- **Earthquakes joined the ranks of the disasters that are "a threat to civilization survival, as great as was ever posed by Hitler, Stalin or the atom bomb /J. Wisner/“. Few examples:**
- **Hundreds of thousands of lives were taken by a single earthquake in China (1976), and near Sumatra (2005).**
- **Reoccurrence of the 1923 Tokyo earthquake will cause today a global economic depression.**
- **A single earthquake might simultaneously affect 20 nuclear power plants (e.g. in Eastern Europe); destabilize military balance in a region (e.g. Middle East).**

- Highly vulnerable became many low seismicity regions, e.g. Central and Eastern US.

- In North America the great earthquakes of 1811-1812 occurred near New Madrid, Missouri about 8 on the Richter scale.

  The quake was so wide-spread it was felt as far away as Boston. Mississippi River ran backwards for three days.