8th Workshop on Non-Linear Dynamics and Earthquake Prediction

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Fault Networks in Earthquake Prediction

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These are preliminary lecture notes, intended only for distribution to participants
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DECISION-MAKING PROBLEM: What preparedness measures to undertake in response to a prediction?

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/


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

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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 $M_a \geq 6.5$ 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

[Map showing earthquake locations and impact areas]

Earthquake with M 6.8 occurred 20 days after termination of alarm. Total damage was about $30bn. 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 where 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:
- EARTHQUAKE TIME
- EVENT LOCATION
- STRONG MOTION (AREA)
- GROUND CONNECTIONS
- OBJECTS AFFECTED
- DAMAGE INFlicted

DISTRIBUTION FUNCTION OF THE FOLLOWING RANDOM VALUE IS
ESTIMATED:

\[ D = \sum_{i} d \left( h_{i}, M_i, s_{i, m} \right) \]

DIRECT:

- CASH LOSSES
- ECONOMIC LOSSES

INDIRECT:

- POPULATION
- PROPERTY
- OBJECTS
- AREA
Trans-Baikal railroad

Only the damage to railroad track is analyzed; 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 fail into the zone of intensity of 8 or 9 during 10 years. P(L) is the probability that this length will not exceed L.

Distribution functions for prevented damage (the highest estimate)

Seismicity is overestimated by assuming that all shocks will occur not further than 15 km from the object. M_max = 8 and intensities will be elongated along the railroad. Interest rate was assumed maximal. Efficiency of reinforcement of track was exaggerated too: complete prevention of damage.

Still, if the cost of reinforcement is above 8, then there is only negligible probability that the cost of reinforcement of track will be returned in the form of prevented damage.

Seismic risk for Caucasus

Rural dwellings in Georgia

Insurance premium for rural dwellings in Georgia

S=7500-5 min, of earthq - Cost of all dwellings (1977)
λ = 1.9 - average annual number of destructive earthquakes
N=11% - annual growth of the number of dwellings
r=8% - basic interest rate
U - Insurance payment in T years

<table>
<thead>
<tr>
<th>Risk, Pr[X&lt;U]</th>
<th>T=5 years</th>
<th>T=30 years</th>
<th>T=60 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total damage, X, % of S</td>
<td>991.15</td>
<td>2.91 x 1.34</td>
<td>3.32 x 1.35</td>
</tr>
<tr>
<td>Profit margin: break even, U=Ul_min</td>
<td>&gt; 50%</td>
<td>0.23%</td>
<td></td>
</tr>
<tr>
<td>U1 = m + 2σ</td>
<td>6%</td>
<td>0.65%</td>
<td>0.43%</td>
</tr>
<tr>
<td>U2 = m + 3σ</td>
<td>2%</td>
<td>0.65%</td>
<td>0.53%</td>
</tr>
</tbody>
</table>

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

The Cameron papers on risk and insurance, 1984, Studies at Development No 77: Natural Dwellings and Insurance (IV).
Seismic risk for the largest cities of the world

**Number D of inhabitants**
affected by strong motion during 1971-2000
(residual N=69 MMR in the area > 100 km²)

<table>
<thead>
<tr>
<th>Category</th>
<th>n</th>
<th>Total exposure, min</th>
<th>m I</th>
<th>D, cases</th>
<th>a</th>
<th>Probability of death</th>
<th>A, 10000 cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exceptional risk</td>
<td>24</td>
<td>39,3 ± 15,5</td>
<td>48</td>
<td>65</td>
<td>6%</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>(Tokyo group, 1923)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very high risk</td>
<td>47</td>
<td>17 ± 16</td>
<td>46</td>
<td>65</td>
<td>6%</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>MRS 1575</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High risk (352)</td>
<td>176</td>
<td>2.9 ± 3.2</td>
<td>9</td>
<td>15</td>
<td>25%</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>All cities (76)</td>
<td>147</td>
<td>40.1 ± 21.6</td>
<td>79.8</td>
<td>131.7</td>
<td>0.2%</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

Note: n is number of cities; D is in years; m I is in magnitude; the value p will be exceeded with probability p; A is the mean number of the earthquakes, which generate with levels at least as one of the cities, when the area 100 km² interacted with > 100 km².

**Number N of cities**
affected by strong motion in 50 years
(residual N=69 MMR in the area > 100 km²)

<table>
<thead>
<tr>
<th>Category</th>
<th>n</th>
<th>s</th>
<th>Number of cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exceptional risk</td>
<td>7</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>(Tokyo group)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very high risk</td>
<td>17</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>MRS 1575</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High risk</td>
<td>352</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>All cities</td>
<td>76</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

Note: s is in mean; s is in standard; the value s(p) will be exceeded with probability p.

The Geneva papers on risk and insurance, x 9 (1984), N 32, 256-270.

Seismic risk in the largest cities of the world

Theoretical estimation and seismic history

- 52 cities in 1801-1980, 37-29
- 15 cities in 1701-1980, 37-40
- Tokyo in 1891-1970, 37-24

- Actual numbers in 37-year interval
- 100-year century
- 200 years
- Mean a deviation
- Actual
theoretical
- It is number of disasters in cities

The Geneva papers on risk and insurance (1984), v. 9, N 32, 256-270.
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

 Rome–Naples highway

 L or more km of the highway will be affected by strong
 motion with probability $F(x)$ 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 ≥III during 20 years

 Annot di Geofisica (1976), vol. XXVIII, n. 1-2, 343-365
RESPONSE TO PREDICTION INDICATING TIME AND AREA OF ALARM


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, $\tau$. 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.

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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 lieu of an adequate theory many such elements cannot be uniquely determined a priori. 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.

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**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 envelope.

*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:
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³International Institute of Earthquake Prediction Theory and Mathematical Geophysics (Moscow)
⁴Abdus Salam International Centre for Theoretical Physics (Trieste)
⁵Institut 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

<table>
<thead>
<tr>
<th>Action</th>
<th>DA  ($1,000)</th>
<th>DP  ($1,000)</th>
<th>Gain ($1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary: lasting for alarm period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Lower water level in Fragile Reservoir</td>
<td>2,000</td>
<td>7,500</td>
<td>4,750, 1,750, -125</td>
</tr>
<tr>
<td>3. Lower water level in Stout Reservoir</td>
<td>2,000</td>
<td>10</td>
<td>-1,991, -1,995, -1,998</td>
</tr>
<tr>
<td>4. Drain reservoirs</td>
<td>16,000</td>
<td>7,510</td>
<td>-9,240, -12,250, -14,120</td>
</tr>
</tbody>
</table>

\[
Gain = DP(1 - f) - DA
\]

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

T = Temporary: lasting for alarm period

About 20 actions were considered in similar way

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### 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.