Managing the Risks from Natural Catastrophes: Are We Making Progress?

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Director, Cambridge Architectural Research Ltd
Outline

• Reducing catastrophic risks- what progress?
• The causes of catastrophes
• Risk modelling- earthquakes and volcanic eruptions
• Can we do better?
Numbers and costs of natural catastrophes – rising trend lines...

Numbers of catastrophic events have increased steadily since 1950s, with most of the growth in meteorological and hydrological events.

Overall and insured losses (at constant prices) have been rising exponentially, with a doubling time of about 2-3 decades.

Reasons are rising populations, concentration of values, and climate change.

*Data from Munich Re Publication*  
*Natural Catastrophes, 2008*
Annual death rates from earthquakes

The current decade has witnessed the highest annual death rate for the last 100 years.

Allowing for population growth, in the richer countries the death rate has been sharply reduced.

But in the poorer countries, there is no evidence of any sustained progress.
Earthquake deaths – worse to come?

Data on number of events globally causing a given number of fatalities over 5 centuries

Can be interpreted to suggest that with a global population of 10 billion we can expect a “one million fatality event“ once a century

Data from Iran show a similar trend

Cities most at risk include Tehran, Kathmandu, Lima, Xi’an

Source Roger Bilham, CIRES, University of Colorado
Risks from Volcanic Eruptions

- Financial losses from volcanic eruptions have been around $6 bn over the last 30 years, more than 50% from the 1980 Mt St Helens eruption.
- Deaths have been around 30,000 or 1000 per year.
- Human casualties have often been avoided by timely evacuation during a pre-eruption phase of unrest.
- There are many cities worldwide exposed to possible future eruptions, e.g. Quito, Naples.
- Except in Japan, Western USA and New Zealand little has been done to prepare populations for possible future eruptions.

<table>
<thead>
<tr>
<th>Year</th>
<th>Volcano</th>
<th>Country</th>
<th>Damage in US $ million (2007)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>Eldafjell</td>
<td>Iceland</td>
<td>93</td>
<td>EM-DAT</td>
</tr>
<tr>
<td>1980</td>
<td>Mount St. Helens</td>
<td>United States</td>
<td>3,327</td>
<td>EM-DAT</td>
</tr>
<tr>
<td>1982</td>
<td>Mount Galunggung</td>
<td>Indonesia</td>
<td>306</td>
<td>EM-DAT</td>
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<tr>
<td>1982</td>
<td>El Chichon</td>
<td>Mexico</td>
<td>224</td>
<td>EM-DAT</td>
</tr>
<tr>
<td>1983</td>
<td>Mount Gamalama</td>
<td>Indonesia</td>
<td>275</td>
<td>EM-DAT</td>
</tr>
<tr>
<td>1985</td>
<td>Nevado Del Ruz</td>
<td>Colombia</td>
<td>1,719</td>
<td>EM-DAT</td>
</tr>
<tr>
<td>1991</td>
<td>Mount Pinatubo</td>
<td>Philippines</td>
<td>300</td>
<td>EM-DAT</td>
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<tr>
<td>1994</td>
<td>Rabaul/Tavurvur</td>
<td>Papua New Guinea</td>
<td>531</td>
<td>EM-DAT</td>
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<tr>
<td>1996</td>
<td>Grímsvötn</td>
<td>Iceland</td>
<td>21</td>
<td>EM-DAT</td>
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<tr>
<td>1997</td>
<td>Soufriere</td>
<td>Montserrat (UK)</td>
<td>10</td>
<td>EM-DAT</td>
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<tr>
<td>2001</td>
<td>Etna</td>
<td>Italy</td>
<td>4</td>
<td>EM-DAT</td>
</tr>
<tr>
<td>2002</td>
<td>Stromboli</td>
<td>Italy</td>
<td>1</td>
<td>NOAA</td>
</tr>
<tr>
<td>2006</td>
<td>Tungurahua</td>
<td>Ecuador</td>
<td>154</td>
<td>EM-DAT</td>
</tr>
</tbody>
</table>
Annual death rates: natural catastrophes compared with other risks

<table>
<thead>
<tr>
<th>Cause of death</th>
<th>Micromorts per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking 10 cigarettes a day</td>
<td>4000</td>
</tr>
<tr>
<td>All natural causes, aged 40, UK</td>
<td>1176</td>
</tr>
<tr>
<td>Accidental deaths, UK</td>
<td>350</td>
</tr>
<tr>
<td>Traffic accident, UK</td>
<td>125</td>
</tr>
<tr>
<td>Earthquake, in Iran</td>
<td>43</td>
</tr>
<tr>
<td>Accident at home</td>
<td>38</td>
</tr>
<tr>
<td>Accident at work</td>
<td>23</td>
</tr>
<tr>
<td>Floods, in Bangladesh</td>
<td>20</td>
</tr>
<tr>
<td>Volcanic eruption, Vesuvian popn</td>
<td>13</td>
</tr>
<tr>
<td>Homicide, living in Europe</td>
<td>10</td>
</tr>
<tr>
<td>Floods, Northern China</td>
<td>10</td>
</tr>
<tr>
<td>Earthquake in Turkey</td>
<td>9</td>
</tr>
<tr>
<td>All natural disasters, globally</td>
<td>7</td>
</tr>
<tr>
<td>Railway accident, Europe</td>
<td>2</td>
</tr>
<tr>
<td>Earthquake, Globally</td>
<td>2</td>
</tr>
<tr>
<td>Earthquake, Japan</td>
<td>1.1</td>
</tr>
<tr>
<td>Earthquake California</td>
<td>0.5</td>
</tr>
<tr>
<td>Volcanic eruption, Globally</td>
<td>0.5</td>
</tr>
<tr>
<td>Hit by lightening</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Note: 1 micromort = one in a million risk of death

Such comparisons are often used in policy-making

They are questionable as they mix voluntary and involuntary risks

For catastrophe risks the definition of the population exposed and the time period considered make an enormous difference
Earthquake risk reduction and public health campaigns – relative achievements

![Graph showing reduction in earthquake deaths, cholera deaths, infant mortality, and infectious diseases over time](image-url)
Causes of catastrophic events

- The location and magnitude of events
- The vulnerability of buildings, infrastructure and urban systems
- Human behaviour
Volcano losses depend on location, scale and type of eruption, and eruption frequency.

Locations of potentially hazardous volcanoes: Munich RE Globe of Natural Hazards
Earthquake losses depend on magnitude, location and frequency of large earthquakes.
Earthquakes losses also depend on location of settlements – attracted to fault zones

Thrust faulting leads to the creation of water storage in arid regions, and accounts for the development of human settlements directly alongside fault systems (eg Bam - shown, Tabas, Tehran in Iran).

Also along the mountain margins in India, China?
Earthquake losses depend on building vulnerability

traditional forms of construction often have extreme vulnerability to ground shaking

Bhuj, India, 2001: 14,000 deaths
rubble and adobe masonry

Bam, Iran, 2003: 32,000 deaths
adobe with vaulted roofs
Earthquake losses depend on building vulnerability

In modern forms of construction requirements for earthquake resistance are frequently ignored.
Building vulnerability can be reduced to a life-safe level by adopting modern codes

Western USA: earthquake-resistant buildings
Earthquake losses: secondary hazards

Landslides, tsunamis and fire following can be major sources of loss
Volcanic losses: building vulnerability

Tephra Fall: Mt Pinatubo, 1990

Pyroclastic density current: Montserrat, 1997
Casualties in earthquakes and volcanoes: the importance of human behaviour

- Pre-event preparatory behaviour
- Action during the earthquake
- Post-event rescue and subsequent treatment
Earthquake Risk Modelling: Typical Structure

Source Definition

Event Rates

Attenuation

Vulnerability

Event Loss Table

EP Curve

Source: Risk Management Solutions Inc.

Typical Structure

Event Loss Table

Event | Rate | Loss
--- | --- | ---
1 | .0001 | $
2 | .0002 | $
3 | .0001 | $

Exceedence Probability

Loss
Modelling earthquake risks for insurance

<table>
<thead>
<tr>
<th>Event ID</th>
<th>Annual rate</th>
<th>Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R1</td>
<td>L1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>N</td>
<td>Rn</td>
<td>Ln</td>
</tr>
</tbody>
</table>

- **Aim is to produce a Loss Exceedence Probability (EP) Curve for the client’s portfolio, which can be used to determine pricing and reinsurance needs**
- This is derived from an event-loss table which gives expected losses from a large number of simulated events, each assigned an annual probability.
- In the last decade, commercial modelling companies (e.g., RMS) have developed country earthquake risk models for most countries.
- There are also flood and hurricane risk models, but no volcano risk models yet.
- These models are of great importance in insurance, and are now part of the regulation of insurance companies.
- Methods and outputs are confidential to clients, so methods of treating uncertainty are unknown.
Modelling earthquake risk for urban mitigation

Aims: provide quantified statements about the benefits of possible mitigation actions, to support decision-making by urban authorities

- Scenarios and site effects:
  - Inventory data
  - Building vulnerability data, empirical, calculated

- Casualty estimation
  - Scenarios and site effects:
  - Loss estimation software: building damage, casualties, homeless, financial losses

- Uncertainties

- Effects of mitigation actions

- Quantified mitigation actions
Vulnerability estimation: observed vulnerability

Limitations of observed vulnerability:

- Can’t use for (eg) newer buildings for which no damage data exists
- Single parameter of ground motion cannot capture relationship between ground motion, subsoil and structural behaviour
- Assessment of earthquake ground shaking depends of building damage

After Coburn and Spence, 1993
Vulnerability estimation: calculated vulnerability

Limitations of calculated vulnerability:
• Models of building assumed do not adequately represent real structural form
• Models of structural behaviour assumed unlike real behaviour of the worst buildings
• Extension of single building model to large populations of buildings
Understanding uncertainties in loss modelling: the logic-tree approach

- Mean Damage Ratio to a given set of buildings (portfolio) estimated for a given earthquake.
- Typically values with 10% exceedence probability were between 4 and 6 times 50% exceedence values.
- Most of this MDR uncertainty results from the ground motion uncertainty.

Where () is the assigned probability and \( \beta \) = standard deviation on ln (PGV).
Comparison of alternative earthquake loss models: LessLoss

- Three leading academic European loss models were applied to a common data set:
  - Predefined earthquake ground motion time-histories (2) and soil profiles (3)
  - Predefined number and distribution of building classes and occupants

- Models computed:
  - Surface ground motions
  - Proportions of buildings damaged and collapsed
  - Numbers of casualties

- Variations in computed results for each separate ground motion were:
  - Surface ground motion estimate by a factor of 5
  - Proportion of collapsed buildings by a factor of 30
  - Proportion of occupants killed by a factor of 60

![Surface PGA distribution](image1)

![Death rate distribution](image2)
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Proportion of uncertainty in casualty estimate attributable to different elements of the model:
- Ground motion estimate, 13%
- Proportion of collapsed buildings, 24%
- Proportion of occupants killed, 63%
Earthquakes: modelling human casualties
Post event rapid impact assessment: the USGS PAGER system

- Alerts to emergency response and aid agencies within 30 minutes of earthquake occurrence
- Currently gives estimates of population affected at different levels of ground shaking

Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. A magnitude 5.8 earthquake 396 km West of this one struck Indonesia on September 26, 1997 (UTC), with estimated population exposures of 137,000 at intensity VIII and 196,000 at intensity VII, resulting in an estimated 17 fatalities. On November 29, 1998 (UTC), a magnitude 7.7 earthquake 258 km Northeast of this one struck Indonesia, with estimated population exposures of 5,000 at intensity VIII and 6,000 at intensity VII, resulting in an estimated 41 fatalities.
The Cambridge Bet...

WAPMERR claims to be able to estimate casualties within 1 hour within a factor of 2.

At the Second Workshop on Casualties in Disasters in June, Andrew Coburn challenged WAPMERR to substantiate this claim, with a bet of $1000.
The outcome

The first major test was the W Sumatra earthquake of 30.9.09
WAPMERR Initial Estimates of Fatalities at T+1 hr 36mins: 0-200 dead
Actual Fatalities: at least 1,115 so far recorded
Volcano risk modelling:
probabilistic event-tree for alternative scenarios at Vesuvius

Aimed at providing an assessment of possible different categories of eruption and the probability that the next eruption will be of each type.

Probabilities estimated by a formal elicitation process among professional volcanologists, and presented as ranges 5%, 50%, 95%.

Each eruption category is associated with probable consequent hazards.

Wide range of expert opinion a problem for Civil Protection.
Modelling impacts of volcanic scenarios

The Sub Plinian I
Time History chosen

Input from hazard
Credible Intervals

Phase I
Duration: EQs (15 days)

Duration & No. 6 damaging EQ events of intensity in
the range [V–VII].

EQ intensity sequence from 1631 Chronicles Guidoboni,
note

AF intensity distribution from HazMap Model (Macdonald
Costa)

Phase II
AF (1 day)
line movement up to the Max. vertical load on the

Phase III
PF (3 hours)
3 impulsive events per cell

EQ intensity sequence from 1631 Chronicles Guidoboni,
note

AF intensity distribution from HazMap Model (Macdonald
Costa)

PF intensity distribution from 3D Model Neri,
UnicaMeto

Source

Probability of death vs external temp flux
External temperature flux = peak temp - 175 (duration, min)

1.000

0.800

0.600

0.400

0.200

0.000

0

500

1000

1500

2000

Ext temp flux

Probability of death

10 ac/h

4 ac/h

2 ac/h

BUILDINGS LOST
N. per cell

1

2 - 3

4 - 9

10 - 20

20 - 50

50 - 100

100 - 200

200 - 250

IMPACT SCENARIO
- E.Q. sequence
- A.F. 100%
- P.F.
How can we do better?

- Improve understanding of active faults and global seismicity
- Collect and organise impact data post event
- Improve understanding of “at risk” buildings and infrastructure
- Improve global collaboration
- Improve understanding of uncertainty
- Connect with business processes
Mapping active faults

Many large and growing cities lie close to active faults which have been affected by destructive earthquakes in the past. In many cases the responsible fault is not known.

New forensic techniques developed at the Bullard Lab will enable the recently active faults to be identified.

This knowledge could have a profound effect on urban development over the next 20 years.

The Cambridge China project joins the Depts of Earth Sciences and Architecture at Cambridge with Chinese Partner institutions to develop this potential.
Improving post-earthquake reconnaissance methods, using remote sensing

- EEFIT has been active in data collection since 1982 with increasing sophistication
- Damage Case-Study: YingXiu Township, Wenchuan earthquake
Archiving earthquake consequence data

FREE web-accessible source of building typology/damage data on >1m buildings from 32 earthquakes since the 1960s. Plus casualty data
Use to create vulnerability curves

www.arct.cam.ac.uk/eq
Understanding global exposures: application of remote sensing and “mass observation”

Unsupervised segmentation using Gabor filters and Self Organising Maps (SOM) to segment image (urban area) into clusters where building type distribution is similar. Selection of sampling area

A: Google Street View

B: “Mass observation” (example from NASA’s moon crater mapping project)
Collaboration: The Global Earthquake Model (GEM) Project

GEM integrates developments at the forefront of seismological and engineering knowledge in three interconnected modules:

**HAZARD**
- Probability of earthquake occurrence
- Probability of ground motion

**RISK**
- Building inventories
- Vulnerabilities
- Probability of damage
- Probability of loss of lives

**SOCIO-ECONOMIC IMPACT €**
- Probability of direct financial loss
- Probability of indirect financial loss

Earthquake probabilities
Building Code input

Earthquake impact
User awareness of risk

Financial tools
Cost-Benefit Analysis
Engaging with uncertainty

Uncertainty needs to be acknowledged in:

- Specific future events
- Quantities/parameters in a model
- Assumptions underlying the ‘best’ model (both internal and external)
- Inadequacies of our ‘best’ model

*David Spiegelhalter, Risk Centre Talk, Oct 22 2009*
Connecting with business processes

Risk modelling can:

- Help owners of global building estates identify and modify or avoid high-risk premises
- Help the insurance industry model its likely losses and avoid insolvency
- Help improve codes of practice for new buildings
- Help urban authorities identify zones for future expansion

Study for British Council by CAR Ltd

Tehran to be replaced as Iranian capital amid quake fears
The Guardian, 2.11.2009
Conclusions

- Losses from natural hazards including earthquakes and volcanic eruptions have been increasing as human populations and their activities and investments grow into hazardous areas.
- We have a very incomplete knowledge of the hazards and the vulnerability of people and buildings to them.
- Risk modelling has and can have important contributions to improving decision-making for government, businesses, and individuals.
- Risk modelling for earthquakes and volcanic eruptions is still in its infancy, and uncertainties in estimates are very large.
- There is much that research can contribute to make it a more effective tool, but large uncertainties will remain.
- Research is also needed on how best to communicate those uncertainties to decision-makers.