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Methods for risk analysis in disaster reduction

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risk analysis, disaster reduction, natural hazards

Abstract

This paper discusses a proposal for a risk management tool for applications to risk reduction of natural hazards.

1. Natural Hazards

It is always a difficult dilemma with research projects on natural hazards if it should focus on certain aspects of the hazard (its probability of occurrence, its damage potential, the effectiveness of mitigation measures and building codes, its human behaviour and injury causation during the catastrophe, etc), or if the project should be addressed as a complete entity which involves physical, technological, economic and social realities. In this paper the first option is chosen, although now and then parts of the second option are presented.

Many books on natural hazards too often fall to an anecdotal level of 'horror stories' lacking a serious academic treatment of the subject. This is in contrast with one of the first complete treatises on natural hazards by White et al. [16]. Since the book is over 30 years old, many of the issues in this book are outdated unfortunately. It describes the status of natural hazards research in the USA in the 70s, and it gives recommendation for future research. The main message in their book is that research in the 1970s concentrated largely on technologically oriented solutions to problems of natural hazards, instead of focusing equally on the social, economic and political factors which lead to non adoption of technological findings, or which indicate that proposed technological steps would not work or only tend to perpetuate the problem (according to the authors). For floods the authors propose five major lines of new research: Improving control and prediction, Warnings and flood proofing, Land Management, Insurance, relief and rehabilitation, basic data and methods. For other natural hazards, 15 in total, similar lines are outlined. Interesting is that the authors already present methods of estimating research results within an evaluation framework, including economic efficiency, trade-offs and values.

Natural hazards considered under climate change have been studied by McGuire et al [12] and is heavily based on the results of the 3rd assessment report of 2001 by the IPCC (Intergovernmental Panel on Climate Change), who upgraded their temperature rise forecasts to 8 degrees Celsius by the end of the century. The natural hazards in McGuire [12] are described in the light of IPCC's forecasts. Windstorms are described to anthropogenic climate change and are shown to have the potential for large changes for relatively small changes in the general climate. Its natural patterns of climate variability are discussed by McGuire, amongst which ENSO, NAO, and PNA (Pacific North American tele-connection). Studies are presented which try to observe and predict the frequency and severity of extreme windstorms on a spatial and temporal scale. Also river and coastal floods under global warming are examined. Most research on river floods has concentrated on changes in observed precipitation and prediction methods, but the authors also present non-climatic factors involving human influences on the river basin. Coastal flooding from tropical and extra tropical storms under sea level change is investigated, as well as sea temperature changes (heat - and cold waves). The 1999 Venezuela landslides, causing 50 000 fatalities, have put this undervalued natural hazard on the agenda again. The authors concentrate on the water accumulation below the surface of unstable slopes. The landslide's theological properties (which resist the movement) are studied under environmental change.

Sea level change is discussed under the uncertainties of response to warming of the Greenland and Antarctic ice sheets and the effect of CO_2 gas mitigation in the coming decades. The effect of sea level rise on submarine landslides and as a consequence ocean-wide tsunami is analysed. Coastal erosion and other geomorphologic effects of sea level rise are left out here.

Also asteroid and comet impacts as initiators of environmental change are included in McGuire [12]. Time domain simulations of a 20km/s impact in a 4 km deep ocean are presented.

McGuire [12] ends with some results from a recent paper in Science (v 289, p 2068-74, DR Easter ling et al) on different forecasts of climate extremes. The authors plead for political will from industrialized countries such as USA, Japan and Australia to invert their increase in gas emissions before the hazardous aspects of climatic shift make themselves felt.

Bryant [5] gives a complete overview on natural hazards, as well as its social impacts. Apart from how natural hazards occur, the author also presents (controversial) methods how to predict hazards from occurring again (on short and long term). The author claims that there is sound scientific evidence that cosmic / planetary links exist with the occurrence of earthquakes and floods. The 11-year sunspot cycle and the 18.6-year lunar cycle (caused by the moon's orbit fluctuation) are used to show a correlation with the ENSO index, occurrences of floods and droughts in North America, Northern China, Australia, Patagonia, amongst others. Very surprising Bryant [5] shows that in some parts of the world (such as the Mediterranean) the sunspot frequency and the seismic activity are correlated, via fluctuations in the Earth's rotation (in the order of milliseconds). However, if earthquake occurrence is dominated by some force external to the Earth (as mentioned by the author), then one would expect clustering to be taking place at the same time worldwide, which is not supported by the data.

Cannon et al [7] claim that natural disasters are not only caused by the natural environment, but also (or maybe even more) by the social, political and economic environment. This is shown throughout their work when they concentrate on the various hazard types: floods, coastal storms, earthquakes, landslides, volcanoes, biological hazards and famine. The authors consistently use a flow diagram describing the framework of the root causes, dynamic pressures, unsafe conditions (on the one side), the hazard (on the other side), and the disaster (in the middle).

Cannon et al [7] describe 12 principles towards a safer environment. It cannot be made by technical measures alone. It should address the root causes by challenging any ideology, political or economic system that causes or increases vulnerability. It should reduce pressures by developing by macro forces such as urbanization, re-forestation, a.o. It should achieve safe conditions by protected environment, resilient local economy and public actions, such as disaster preparedness. Together with technical measures to reduce certain hazards (such as flood defences, shelter breaks, etc), it should all lead to a substantial reduction in disaster risk.

The authors illustrate natural hazards from a social studies point of view, with striking observations, such as the bureaucratic blindness and biased relief assistance in South Carolina following hurricane Hugo in 1989 to the needs of many African Americans who lacked insurance and other support systems. The huge North Vietnam floods in 1971 only resulted in a few hundred deaths, largely because of a highly efficient wartime village-level organization that allowed rapid evacuation and provision of first aid, whereas the similar 1970 Bangladesh floods killed a record 300,000 people.

2. Ten steps for a structured approach of risk analysis and risk reduction of natural hazards

In recent years probabilistic and statistical approaches and procedures are finding wider and wider applications in all fields of engineering science, starting from nuclear power aeronautic applications down to structural mechanics and engineering, offshore and coastal engineering, and in more or less sophisticated forms are the base of many of the most recent versions of Structural Codes of Practice throughout the world. Detailed commentaries of these codes have been written as CIRIA (1977) or ISO (1973) reports. Applications to civil engineering are described by the comprehensive text of Benjamin & Cornell [3]. More recent similar comprehensive texts are Augusti & al. [1] and Thoft-Christensen & Baker [15]. A general application to structures in a coastal environment is provided by Burcharth [6].

Risk analysis is usually structured in:

1. analysis of hazard (risk source, natural processes causing damages),
2. analysis of failure (risk pathway, mechanisms through which hazard causes damages).
3. analysis of vulnerability (behaviour of the risk receptors).

For the first analysis, extreme events and joint probabilities of natural processes making up the hazards should be statistically described. In the second analysis, components of the defence systems should be identified, characterized and processes leading to failure are deterministically described. In the third analysis, understanding and assessment of direct and indirect damages and intangible losses including risk perception and acceptance from population, social and ecological reaction (resilience). The second step is process specific and will be described below, separately for each considered hazard. This step structured however in identification and prediction of failure modes, reliability analysis of defence structure or systems (combination of hazard statistics and structure behaviour) and modelling of post failure scenarios aiming to identify damages.

Damages caused by natural disasters can be distinguished as economical and non-economical, depending on whether or not a monetary value can be assigned to a specific damage. In addition, these damages are distinguished as direct and indirect, depending on whether the damage is the results of direct contact with the natural hazard or whether it results from disruption of economic activity consequent upon the hazard [13]. The economic approaches on the valuation of disaster generally pursue an objective of public policy: Given a set of courses of action to take to alleviate damages from hazardous events, what is the one with highest economic value? To answer that question, the literature has followed two approaches.

The first approach is that in which the value of a given public policy comes from the avoided damage. There is a series of damages associated with hazardous events, some of those that come to mind are loss of property, injury and loss of human life, or natural habitat disruption. Farber [9] and Yohe et al. [17] illustrate complex cases of valuation of property loss and disruption of economic activity caused by potential storm and flooding events. A qualitative list of potential losses can be found in Penning-Rowsell and Fordham [14]. A benefit transfer exercise consists in a statistical estimation of a function based on existing evidence in order to transfer value (“benefit”) from the various study sites to the policy site, see Brouwer [4] and Bateman et al. [2]. On the basis of the evidence gathered to estimate the transfer function, it is possible to assess the risk of error in transferring values. End-users may then decide what risk they are willing to run for a particular application. The trade-off is between administering an expensive valuation survey (with low risk of error) and an inexpensive transfer of values with a potentially high risk of error depending on the particular site analysed.

The second approach is more direct in the sense that the researcher directly asks the relevant public to value the public policy itself, including its effects on flooding risk and potential physical damage. This approach has been illustrated in Penning-Rowsell and Fordham [14] and relies on “stated preferences” methods such as the contingent valuation or choice experiments; see Carson [8] and Haab and McConnell [10] for recent reviews on the former and Louviere et al. [11] on the latter. Contingent Valuation surveys consisted of the following steps: survey design, whose aim is to draw up a questionnaire suitable for the specific situation considered; sample design, to provide guidelines to obtain a random sample; pre-test of 30/50 interviews to check the wording of the questionnaire; main survey on the field of at least 600 interviews. As regards sites under risk of flooding, in general it is possible to carry out: site specific surveys to obtain data about property damages and to estimate damages from flooding, and post-flood household surveys to identify the immediate needs of the flood victims and to assess the intangible or non-economical flood effects [13].

Historically human civilizations have striven to protect themselves against natural and man-made hazards. The degree of protection is a matter of political choice. Today this choice should be expressed in terms of risk and acceptable probability of failure to form the basis of the probabilistic design of the protection. It is additionally argued that the choice for a certain technology and the connected risk is made in a cost-benefit framework. The benefits and the costs including risk are weighed in the decision process. Engineering is a multi-disciplinary subject, which also involves interaction with many stakeholders (individuals or organizations who have an interest in a project). This paper addresses the specific issue of how numerical occurrence probability levels of natural hazards are both formulated and achieved within the context of engineering design and how these relate to risk consequence.

A proposal for a common framework for risk assessment of any type of natural hazard is given by adapting the general theoretical approaches to the specific aspects of natural hazards, such as mass movements, and extreme waves. The specific features of each case will be presented in this paper and it will be shown that the common procedure proposed is able to deal appropriately with the specifics of each of the natural hazards considered.

Statistical methods are abundantly available to quantify the probability distributions of the occurrences of different hazards with special topics such as treating very seldom events, dealing with spatial and temporal variability of data, as well as with joint occurrences of different types of data. The two cases will demonstrate the applicability of the general methods to the specific aspects of the data from mass movements, and extreme waves. The 1st step in a structured risk analysis of natural hazards is:

Step 1. Statistical analysis of observations

Data is collected from mass movements, flooding, extreme waves and earthquakes and analysed with statistical methods. Proper tools are used in order to harmonies data, which comes from different sources (for instance instrumental or historical observations of natural hazards).

Step 2. Integration of mathematical-physical models in probabilistic models

The possible progress of a natural hazard from phase I to phase I+1 is described with transition probabilities in Markov models. Mathematical-physical models are used to generate data to be combined with observations and measurements for statistical analysis.

Step 3. Estimation of dependencies between natural hazards

Collected data from mass movements, flooding, extreme waves and earthquakes in some instances are analysed with respect to linear correlations and non-linear dependencies. Mathematical-physical-based reasons can be investigated to explain the existence of correlations and dependencies between the occurrences of hazards at the same time.

Step 4. Use of multivariate statistical models

Joint probability distribution functions (JPDFs) describe the probability that a number of extreme events happen simultaneously. Dependencies between events cause difficulties in deriving these JPDFs.

Elements characterizing the degree of the past and future hazards can be combined with indicators for the vulnerability of the inhabited areas or of infrastructure installations. In databases, the damage is expressed in terms of fatalities and damage costs for private buildings, infrastructure installations and agricultural land. In the next steps it is necessary to relate the expected physical damage to the expected economic losses and expected losses of life.

Step 5. Economic models to derive (in)direct consequences of hazards: FD-curves

Risk is considered as the product of probability and consequences. All natural hazards are analysed with respect to their economic impacts on society. This leads to so-called FD-curves (the cumulative distribution function of the amount of damage D). Economic expertise is an important part in this step.

Step 6. Models to estimate loss of human lives: FN curves.

Apart from economic damage, natural hazards can also lead to human casualties. Estimates are derived and covariates are found of the possible number of casualties caused by natural hazards.

Step 7. Cost-Benefit transfer

The aim of step 7 is to examine whether or not it possible to transfer values from natural disasters mitigation, and in case it is, to extract a transfer function. First the different methodologies used to value hazardous events are compared and whether and how they can be aggregated. Then, the construction of the actual value database can be carried out. Finally, if sufficient data quality criteria are met, a statistical analysis is performed in order to extract a benefit transfer function for one or several categories of values of hazardous events.

The methods presently accepted to set the acceptable risk levels related to industrial risks can be considered and their applicability to set acceptable risk levels of natural hazards can be studied. An approach is proposed to determine risk acceptance levels for different types of natural hazards, discussing in particular the specific aspects of mass movements, flooding, extreme waves and earthquakes.

Step 8. Acceptable risk framework development

Decisions to provide protection against natural hazards are the outcome of risk analyses and probabilistic computations as an objective basis. Development of concepts and methods to achieve this are available from literature. It covers both multi-attribute design and setting of acceptable risk levels. The research reinforces the concept that efficient design not only requires good technical analysis, but also needs to consider the social aspects of design as well and incorporate the concerns and aspirations of stakeholders. Each stakeholder has a different perspective on the objectives of a particular project and it is the designer's challenge to manage these multiple concerns and aspirations efficiently. If the efficiency of decision-making can be improved then it is quite possible that a 5% saving or larger can be achieved.

The main approaches to assess costs and benefits of different risk reduction measures can be analysed dealing in particular with the approaches to deal with multiple risk and to take in consideration their interaction. An approach is proposed to determine actions leading to as low as reasonably possible (ALARP) levels of risk for different types of natural hazards, discussing in particular the specific aspects of mass movements, flooding, extreme waves and earthquakes. For cost benefit analysis it is necessary to have models of the costs and of the benefits. Rough estimates on these numbers for the two cases will be shown in Sec. 3 and 4.

Step 9. Cost analysis of mitigation measures

In order to reduce the risks of natural hazards, mitigation strategies are applied. To answer the question if more mitigation is necessary (or in general the question "how safe is safe enough"), insight is developed in the costs of mitigation measures of natural hazards.

Step 10. Effectively analysis of mitigation measures

Apart from insight in the costs of mitigation measures, it is also necessary to quantify the effectively of these measures, in other words, how much can they reduce the consequences of natural hazards or reduce the probability of occurrence of these negative impacts.

3. Conclusion

The above 10 steps are proposed as an overall integrated and structured way to analyse risks from natural hazards and are identified as 'best practice'.

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