12th International Conference on Applications of Statistics and Probability in Civil Engineering, ICASP12
Vancouver, Canada, July 12-15, 2015

Risk Perception in Civil Engineering Application

Tatyana Micic
Dept. of Civil Engineering, City University London, United Kingdom

ABSTRACT: This paper uses both technical and intuitive risk formulations that are currently in use. Hybrid procedure for identification of risk perception for built infrastructure is used to establish format that can improve risk communication. In general for infrastructure the effect of uncertainty is defined through specific collapse models, physical variability, geometric variability, system behaviour, etc. Processing the outcomes of Portrait Value Questionnaires will provide the information about stakeholder values but also their perception of risk associated with the particular infrastructure. Therefore, there is an opportunity to complement the probabilistic analysis approach in civil engineering with distinct information about the perception of risk. For a sample structure and selected hazard differences in risk formulation are illustrated and options for risk communication highlighted. The cross-disciplinary approach offers a useful insight and could enhance options for risk communication.

1. INTRODUCTION

For built infrastructure such as bridges, roads and dams, risk quantification is increasingly in focus and new legislation such as the Flood and Water Management Act 2010 (FWMA 2010) is being developed to account for risks in a specific format. However, new requirements in respect to risk evaluation for built infrastructure can have high impact while being difficult to implement, as the statistical samples are site specific and very small. In general aspects of risk have emerged as a critical consideration in physical and biological sciences, but also for social scientists. Freudenburg (1988) challenged social scientists to engage with technical characteristics of risk and provide quantitative estimates in form of probabilities as well as insight into public perception. Slovic (1998) reflected on numerous parties involved with built infrastructure and consequently very large samples required to account, for their priorities and perceptions. Further critical issues emerge when adaptation to changing climate or sustainability and cost efficiencies are addressed. Without doubt, risk perceptions between diverse stakeholders will often reveal differences so developing sound methodologies that can address the communication of risk is attracting attention.

2. FORMULATION OF RISK

While intuitively, risk is assumed to be a measure of the individual's exposure to some danger. At the other end technical (engineering) approach to risk formulation is often explicit and a function of the likelihood of adverse event and its consequences. Aven and Renn (2009) identified two categories for as many as ten alternative definitions of risk that emerge in literature. Fully inclusive formulations of risk could be identified using following categories:

A. Risk expressed by means of probabilities
B. Risk expressed as a function of probabilities and consequences
C. Risk defined in terms of consequences only

Categories A and B imply quantitative information (probabilities) and therefore availability of data that is often missing. Pursuing a particular probability as representative of the engineering risk such as category A for built infrastructure could be a very expensive objective. The first two categories represent 'technical' risk and the final one implies that a known sequence of outcomes is in place. However, understanding all factors that contribute to consequences is a difficult task and unlikely to be complete.

Within these categories there are many alternative representations of risk however we are specifically concerned with the approach adopted in Flood and Water Management Act 2010 (FWMA 2010) that is effectively implementing formulation C.

If we consider a homogenous earth fill embankment dam it is often owned by landowners or leisure companies who have no expertise about technical matters but would have been responsible in cases where there is a breach or failure. Additional stakeholders are Panel engineers who are technical experts, local authorities but also often general public who use the dam (often unaware) for leisure. All of those involved would have considered risks associated with the dam. The engineer will use mathematical tools to quantify the risk in respect to certain limit states that the dam can reach and associated consequences. Here, however, the, implementation of the Act specifically identifies the risk as an explicit function of the number of fatalities in case of dam failure, irrespective of the likelihood of such event.

It is evident that the public and infrastructure owners can have diverse priorities (profit, speed of delivery, green agenda, etc.). Most of these stakeholders select to refer to risk without reference to legislation, (here is the challenge to reconcile their different treatment of risk). This is in line with Pidgeon (1998) who pointed to differences between 'public' and 'professionals' in respect to risk assessment criteria and lack of consistency in their approaches. Risk communication can play a major role in improving the status.

A relatively recent but very significant change is that, for existing infrastructure that has been in use for some time there are increasing sources of new information through monitoring, use of sensors, etc. that lend themselves to quantitative analysis. Equally, the availability of ever more sophisticated analytical tools, enables engineers to generate constantly increasing quantitative information. It is difficult to identify if the 'public' is accepting this quantitative information. Kaspersson et al. (1988) have already identified that there is a distinct lack of integration between what some consider 'technical analysis of risk and the cultural, social and individual response structures that shape public experience of risk'. They also established that it would be helpful to develop understanding how interaction between different 'forms' of understanding of risk leads to its social amplification with often negative impacts. Even Kaspersson et al. (1988) confirmed that large flux of information, through news and personal information channels, is an amplifier of risk. It is very easy to identify that since the late 80s the potential for social amplification of risk has greatly increased as at present the number of information channels is formidably greater and it will be increasing in the future. In addition, the need for rapid response through modern communication channels raises sometimes technical risk assessments as priority over social ones and therefore the need for effective risk communication is increasing.

3. BUILT INFRASTRUCTURE RISK

Built infrastructure components, bridges, dams, etc. (systems in themselves) are often taken for granted by the wider public. It is only when faced with consequences of major disruption caused by rare events such as earthquake, or in UK, sudden flooding that questions arise how are risks associated with built infrastructure evaluated and what are acceptable levels of risk for the public. While rare events attract attention of the public establishing acceptable risk levels in respect to normal operation is not talked about too much but is possibly more critical and has greater impact on day-to-day management of infrastructure. In some cases cost optimization could have effect on risk that public might become exposed to from the built infrastructure. Looking ahead if there is a need to consider the effect of future climate scenarios on risks associated with infrastructure there is a very strong case to establish a consistent risk formulation and communication.

3.1 Uncertainties associated with existing infrastructure

Many issues that have been identified above are implying uncertainty and it is evident that risk formulation and communication have to reconcile uncertainty, perceptions, physical models, data availability and technology. Rule based expert systems are limited in terms of quantification when new evidence is introduced or when assessment of existing structures is considered. Neural networks, have been seen in recent past as a useful tool for decision making however they have significant disadvantage when site specific information needs to be considered and rules updated.

For many old structures data available about the design is often very limited. In UK for example, there are many earthfill embankment dams and there is almost no available design data but only records from inspections that have taken place, mostly in recent times. While for larger dams regular inspections are compulsory, for smaller structures this is unlikely to be a case so even recent records would not be available. Sometimes, even for newly constructed infrastructure uncertainty in available design stage information, is limited and likely to remain so as the current requirements are only for late revision drawings to be submitted to authorities. Records of construction issues, various inspections, abnormal load, etc. will often be limited. Variability in the quality of data for say meteorological data such as precipitation records and physical deterioration such as, in case of dams, settlement, piping, etc. is high. An established practice in design and assessment to some extent has been to account for uncertainty using FOSM and take advantage of the notional probabilities of events as comparative measures for decisions. Considering the scale of above uncertainties, they need to be taken into account for risk quantification and communication and formulation C would certainly not be sufficient.

3.2 Engineering risk formulation

Technically, in line with regulatory framework, the performance of infrastructure is defined in terms of ultimate and serviceability limit states. However, considering the risks associated with specific limit states is difficult as associated consequences are distinctly different between various limit states. While the ultimate limit state has low probability of occurrence it is often more likely to be associated with fatality. At the same time the serviceability limit states might sometimes have even higher probability of occurrence then ultimate ones but irrespective of being less critical in terms of fatality they are more visible due to associated discomfort.

Technical risk formulation (B) requires consideration of consequences and it is often expressed as:

$$Risk = P_f\, C \qquad \text{Eq (1)}$$

where P_f is the probability of event and C represents the consequences. For engineers ‘technical’ part of the above equation, namely probability of the limit state occurring is decipherable, however, the complex nature of consequences is more difficult to quantify consistently. It is also possible that identification of consequences would be influenced, in an explicit way, by the risk perception of non-professionals. The term consequences could represent the loss of life but also some critical performance states, such as breach of serviceability, maintenance and repair requirements, loss of amenity, etc. For stakeholders the risk perception is intuitively linked to identification of consequences while, apart from engineers (technical experts in general) probability of events will be less in focus.

In search for forms of quantification for risk perception Micic (2013) has addressed a group of specialists (engineering biased) to find out what is their perception of risk associated with some common concerns. In contrast, Freudenburg

(1988) tried to establish how social scientists understand the probabilistic nature of risk. Freudenburg (1988) implied that social scientists should provide quantitative estimates of the probabilities however, it is a major challenge to achieve such quantitative estimates due to diverse (often conservative) risk perceptions even from technical professionals. It is no help that gathering data from a broad sample of interested parties in a systematic manner is a challenging task as Fischhoff et al. (1993) have identified for health risks. Traditional form of gathering information such as interviewing can be of limited reach and could introduce bias towards risk perception.

Regulatory documents such as codes of practice like BS5400 were calibrated so that for particular structural material (steel structures for BS 5400) the acceptable performance is in line with that delivered by the predecessor code. Similar approach would have been followed when UK's Health and Safety Executive introduced the ALARP principles across industries. Difficulty with wide scale applications of this nature is that availability of data, say between manufacturing and construction is very different. Furthermore, between industries term 'low' probability will reflect different values but also 'high' consequence will not be unique measure. Even if fatalities are unlikely to occur significant costs can arise for the public due to facility loss, delays, disruption, etc.

Micic (2013) has identified that it is difficult to find evidence that acceptable/target engineering risk levels have been established between professionals say bridge engineers and offshore engineers. There certainly isn't consistent evidence that engineering risk has been related to risk perception or communicated in a consistent manner. However, due to advancing technology and ever increasing information streams future decision making will require demonstration that uncertainty, physical models, data availability and expected target performance have been considered comprehensively when risks are quantified. As stakeholders are often diverse groups technical arguments that engineers follow have often been communicated to a limited extent, mostly indirectly through compliance with regulatory principles.

4 RISK PERCEPTION

Term risk perception is used here to identify individual's beliefs, attitudes, judgments and feelings in respect to risk. This is a complex phenomena and different techniques have been established to identify main drivers when risk perception is concerned. It has been demonstrated in the past that demographic variables (gender, age, etc.) as well as educational background determine to some extent the motivational values, Koivula & Verkasalo (2006). Here, it is further accepted that motivational values, influence individual's perception of risk. We explore an opportunity that such link could provide a sound base for effective risk communication.

Micic (2013) has established a sample and evaluated the motivational values using 40 Question Schwartz Portrait Value Questionnaire (PVQ). From alternative formulations for motivational values Micic (2013) followed the classification of motivational values with 4 higher order value types.

- Self Transcendence
- Conservation
- Self Enhancement
- Openness to change

Nordenstedt & Ivanisevic, (2010) have identified that motivational values (benevolence, universalism, self-direction, stimulation, hedonism, achievement, power, security, conformity and tradition) are useful for estimates of risk perception as they transcend demographic boundaries It is of help that from a comparative study by Koivula & Verkasalo (2006) we can observe that differences in motivational values between individuals of the same demographics but different educational level and employment associations can be identified using the 40 Question PVQ. Both Koivula and Verkasalo (2001) and Nordenstedt and Ivanisevic (2010) identify that Schwartz Portrait Value

Questionnaires can be implemented successfully to ascertain motivational values for particular relatively small stakeholder groups. It is therefore viable to consider how can these findings be used in construction industry procurement for quantification and communication of risk for relatively small stakeholder groups.

To establish risk perceptions Nordenstedt and Ivanisevic (2010) applied the 20 questions format, for 10 common hazards and asked the participants to rate dimensions of 'dread' and 'unknown' as most significant for the perception of risk. They have considered samples in different countries and found that the link between motivational values and risk perceptions is in evidence and Micic (2013) identified that this approach can lend itself to provide for improvement in understanding risk perceptions between diverse stakeholders as is the case within construction industry. This is of special importance if effects of future climate change need to be evaluated, quantified and communicated.

5 SAMPLE STAKEHOLDER GROUP RISK PERCEPTION

Micic (2013) has considered a small sample group that represents stakeholders in the civil engineering procurement, graduate civil engineers. From the outcomes of the 40 questions Schwartz Portrait Value Questionnaire the profile in terms of motivational values was found to be close to the outcomes for students in study carried out by Koivoula & Verkasalo (2006).

The same group was asked to rate hazards to identify the risk perception. In line with Nordenstedt and Ivanisevic (2010) two dimensions were considered, dread and unknown and same 10 hazards identified. The respondents were asked to rate their fear (dread) within 7-point scale from 'no fear' to 'very great fear' (fear is sometimes considered as more acceptable form of words). Sample outcomes of that survey can be found in Micic (2013).

Specifically it was also possible to identify that climate change is associated with significantly less 'dread' then from nuclear power plants despite 'comparable' 'knowledge' of the respondents about both hazards. Technically, there should have been limited confidence about climate change as all models are only predictions and uncertainty content is very high while nuclear power plants failure is a very rare but catastrophic event with the unfortunate knowledge about consequences that is extensive and specific. In comparison, results for a more diverse population samples, Nordenstedt and Ivanisevic, (2010), have shown differentials between the two hazards perceptions as being more pronounced. Thus, the stakeholder group perception of risk should be addressed when risk is communicated. Increasingly decisions are needed in respect to the effects of future climate scenarios and knowledge of perceived risks would be very beneficial for risk communication. However on the basis of the surveys the technical stakeholders might be overly confident about the effect of the climate scenario risks and therefore underestimate them.

Micic (2013) points that these contradictions are a signal that systematic approach to, ultimately quantification of risk perceptions for distinct stakeholder groups would be valuable. Importantly the perception of risk did not appear to reflect person's knowledge about the hazard. Similarly, Fischhoff et al. (1993) have identified difficulties of intuitive approaches to risk communication that are significant in many industries.

Considering the Eq (1) it is evident that both probability of certain limit states and consequences are structure and site specific. However, in order to ensure safety and regulate provision of built infrastructure but also communicate risks to all stakeholders quantification of risk has to be more comprehensive then currently and certainly benchmarked. We propose here that risk mapping would be helpful. Namely the expression of quantitative measures of risk (A and B formulations) have to be mapped to alternative parameters.

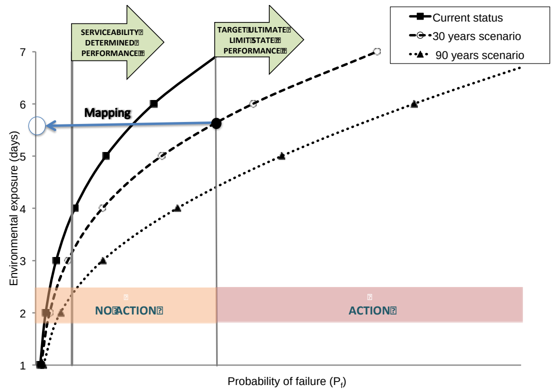

Figure 1 Illustration of alternative future scenarios for infrastructure risk

An illustrative mapping is shown in Figure 1. It is assumed that a sample infrastructure component is considered and its performance analysed for three alternative future scenarios for a sample environmental variable. If risk formulation C is accepted the risk for all scenarios for this structure is constant and dependent on agreed consequence criteria. If formulation A is implemented for an ultimate limit state, serviceability criterion would be long breached and the time of action is strictly defined. Communication of this information would include acceptance of significant serviceability encroachment The Figure 1 reveals alternative formulations of risk and identifies options for communication of risk. It can be observed from the figure that probabilities associated with the ultimate limit state and probability that ultimate limit state is reached at the time of serviceability breach are quite different. However these probabilities are for infrastructure rather small say 10^{-3} and 10^{-4} and for many stakeholders the difference between them is difficult to appreciate. It is necessary to carry out mapping of risk from non-dimensional form to one that is easier to understand. In Figure 1 it is identified that constant probability is associated with different duration in days of exposure to environmental variable. Such tangible measure improves understanding of risk and facilitates easier communication. Alternatives for mapping are numerous but understanding motivational values and consequently risk perceptions can facilitate the selection between them and certainly improvement in risk communication.

There are many old structures with mostly sparse records about their condition, maintenance etc. and quantification of risk and communication of findings are a challenge. By implementing any of the 3 alternative formulations of risk mentioned earlier communication remains difficult but with mapping to familiar parameters taking account of risk perceptions communication could become easier.

In recent public debate about strengthening of a system of small earthfill dams in an affluent London neighborhood a participant was disheartened with "….advice of unelected unaccountable engineers". This was a reaction to expert's submissions about different risk estimates in respect to the structures condition. While quantitative measures that engineers use are essential there is a scope for improvement of risk communication. It would have been beneficial if the risk is, in addition to the explicit formulation in Eq (1), considered as a comparative measure where the driver for comparison is risk perception of particular stakeholders.

In the past, such consideration in engineering practice would be impossible as data availability was poor and communication techniques limited however at present, increasingly, data is available and communication options are expanding. The communication can be improved through further development of cross-discipline approach and bring significant benefits. The hybrid methodology, Schwartz Portrait Value Questionnaire and psychometric experiment should be routinely applied to establish motivational values and perceptions of risk for stakeholder groups. Further research is needed to establish the explicit link between perceived risk and acceptability of risk. Exploring inclusion of risk perception and engineering risk in regulatory documentation remains a challenge.

The main issue remains to find appropriate forms of mapping between quantitative and descriptive outcomes. While for small-scale problems with limited number of critical limit states this is feasible, for diverse systems much work remains. As a further consequence improvement in risk quantification and communication could lead to more efficient sequencing of inspection, maintenance and repair activities.

6 CONCLUSIONS

Novel for engineering practice, and alternative to traditional methods, hybrid methodology that integrates psychology and engineering analysis is considered. This methodology includes identification of motivational values for a sample group and their risk perceptions. Previous studies have identified that:

- It is possible to risk perceptions for diverse hazards as a function of motivational values.
- Risk perceptions are distinct for specific stakeholder groups.
- Even for low probability events such as failure of nuclear power plant it is possible to identify the scale of risk perception of the specific stakeholder group.
- When stakeholder group's risk perception is identified most effective risk communication can be pursued through mapping of risk analysis to carefully selected formats.
- Ideally, an explicit and site specific risk communication that reflects the understanding of stakeholders might be feasible.

7. REFERENCES:

Aven, T and O. Renn, 2009, On risk defined as an event where the outcome is uncertain, Journal of Risk Research, Vol. 12, No 1, pp. 1-11.

Fischhoff, B., A. Bostrom and M.J. Quadrel; 1993, Risk perception and communication; Annu. Rev. Publ. Health; 14:183-203

Freudenburg, W.R. 1988, Perceived risk, real risk: social science and the art of probabilistic risk assessment, Science, Vol 242, pp-44-49.

Kasperson, R.E., O.Renn, P. Slovic, H.S. Brown, J. Emel, R. Goble, J.X. Kasperson and S. Ratick; 1988; The social amplification of risk: a conceptual framework; Risk Analysis, Vol. 2, No. 2, pp. 177-187.

Koivula, N & M. Verkasalo; 2006; Value structure among students and steelworkers; Journal of applied Social Psychology, Vol 36, 5, pp. 1263-1273.

Micic, T. 2013. Risk perception vs. risk reality; in Proc Safety, Reliability, Risk and Life-Cycle Performance of Structures & Infrastructures – Deodatis, Ellingwood & Frangopol (Eds), pp. 97-102

Nordenstedt, H. and J. Ivanisevic; 2010, Values in risk perception-Studying relationship between values and risk perception in three countries; J. of Disaster Risk Studies, Vol. 3, No.1.; pp. 335-345.

Pidgeon, N.; 1998, Risk assessment, risk values and the social science programme: why do we need risk perception research; Reliability Engineering. and System Safety; Vol. 59, pp. 5-15.

Schwartz, S.H; Universals in the Content and structure of Values: Theoretical Advances and Empirical Tests in 20 Countries; Advances in Experimental Social Psychology, Vol.25; pp. 1-6.

Slovic, P.; 1998, The risk game; Reliability Engineering and System Safety; Vol. 59, pp. 73-77.

The UK Statute Law Database. 2010, Flood and Water Management Act 2010 (c.29).