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Some Remarks on Perceived Safety with Regards to the Optimal Safety of Structures

This paper gives a critical view about the development and application of optimisation procedures for the safety of structures. Optimisation techniques for the safety of structures have experienced major progress over the last decade based on, for example, the introduction of quality of life parameters in engineering. Nevertheless such models still incorporate many major assumptions about the behaviour of humans and societies. Some of these assumptions and limitations are mentioned briefly in this paper. These assumptions heavily influence the outcome of such optimisation investigations and can not be neglected in realistic scenarios. Therefore, the authors advise against the application of such optimisation techniques under real world conditions. An alternative for such optimisation procedures can be seen in the concept of integral risk management. Finally examples are given to illustrate effects of individual and social behaviour under stressed situations, which are not considered in the optimisation techniques mentioned. These effects are potentially considered within the concepts of integral risk management.

1 Problem

Over the last few years the question about the optimal safety of structures has been discussed intensively in the field of structural engineering. This question is of particular interest for the development of general safety requirements in codes of practices for structures. Within the last decades, the general safety concept has been updated from the global safety factor concept to the semi-probabilistic safety concept initiating debates regarding the optimal safety of structures.

The question of optimal safety has mainly been answered based on the idea of the optimal economical spending of resources. This includes the important and true consideration that resources for humans and societies are limited.

In structural engineering usually the sum of the production cost and the cost of failure are compared with the possible gains of creating such a structure. The combination of these two cost components mentioned gives an overall cost function with an minimum value according to some adaptable structural design parameters included, for example the chosen concrete strength (Fig. 1). This overall cost function is based on economic considerations. Sometimes additional measures such as those found within the quality of life parameters are incorporated. For example the Life Quality Index *LQI* by *Nathwani, Lind &*

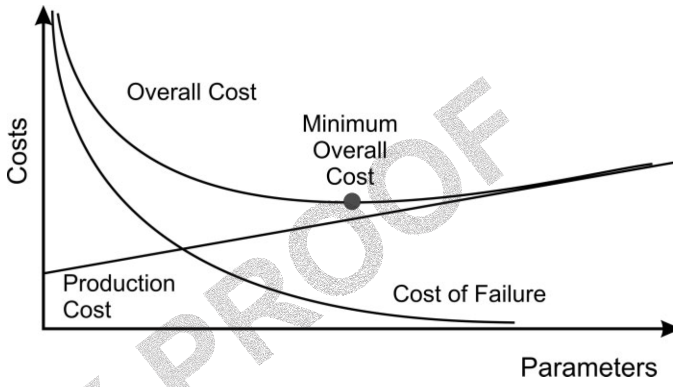

Fig. 1. Widely used function of overall structural cost depending on several parameters

Pandey [1] has become widely used in several engineering fields. The development of quality of life parameters can not only be seen in the field of structural engineering, but also in other fields like social sciences or medicine (*Proske* [2]).

2 Drawbacks of optimisation procedures for safety

2.1 Some limitations of LQI definitions

Although the search for performance measures as a basis of optimisation procedures has yielded in many fields to the application of quality of life parameters, it does not necessarily mean that this strategy has been successful. It shows only that entirely pecuniary based performance measures might be insufficient. If one considers for example the history of quality of life measures in medicine since 1948, now a huge variety of such parameters (more than 1000) has been developed for very special applications. Such a specialisation requires major assumptions inside the parameters. Considering for example the *LQI* it assumes a trade-off between working time and leisure time for individuals. Although this might be true for some people, most people enjoy working (*von Cube* [3]) if the working conditions and the working content is fitting to personal preferences. The choice of using the average lifetime as a major indicator for damage has also been criticized (*Proske* [4]). The question, whether a quality of life parameter can be constructed on only a very limited number of parameters remains. Fig 2. gives an impression about the dimensions of quality of life (*Küchler & Schreiber* [5]).

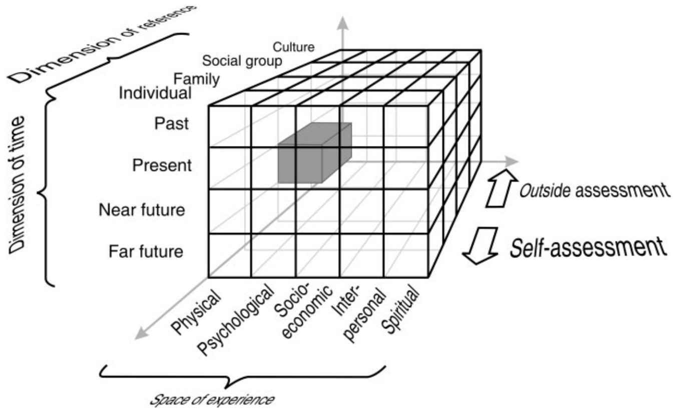

Fig. 2. Dimension of quality of life according to Küchler & Schreiber [5]

The comparison between the different dimensions and the simplified definition of the *LQI* makes limitations visible. For example, many psychological effects are not considered, which most of us can agree through personal experience will have an effect.

2.2 Some subjective judgement effects

Since people are so strongly affected by their personal experiences, this chapter discusses some issues of subjective and psychological judgement of safety which influences not only quality of life, but also the investigation of optimal safety. Many works have been done in the field of subjective risk judgement such as, *Fischhoff* et al. [6], *Slovic* [7], *Covello* [8], *Zwick & Renn* [9] or *Wiedemann*. For a general summary see *Proske* [10]. The authors here define "safety" as a feeling under which no further resources have to be spent to decrease a hazard or a danger (Fig. 3 bottom diagram – the change of slope in the function). By definition, this is a subjective evaluation of a situation and therefore the term "perceived safety" is actually a pleonasm. Often the term "subjective risk judgement" or "subjective safety assessment" are used as well. Nevertheless the term "perceived safety" has become very popular in scientific literature and shall be used here. Since the term safety considers subjective effects, the property of trust should be mentioned. *Covello* et al. [11] have stated that trust might shift the individual acceptable risk by a factor of 2000. That means, if one convinces people through dialogue that a house is safe, a much higher risk (no resources are spent) will be accepted, whereas with only a few negative words trust can be destroyed and further resources for protection are spent.

Incidentally the introduced definition of safety also gives the opportunity to define a relationship between the terms disaster, danger and safety and the freedom of resources (Fig. 3 bottom). The discussion on safety has already introduced danger as a situation, where the majority of resources are spent to re-establish the condition of safety, e.g. not spending resources. Under an extreme situation of danger, no freedom of resources exists anymore; since all resources are spent to re-establish safety. Actually the term disaster then describes a circumstance, where the resources are overloaded (negative). Here external resources are required to re-establish safety. This indeed fits

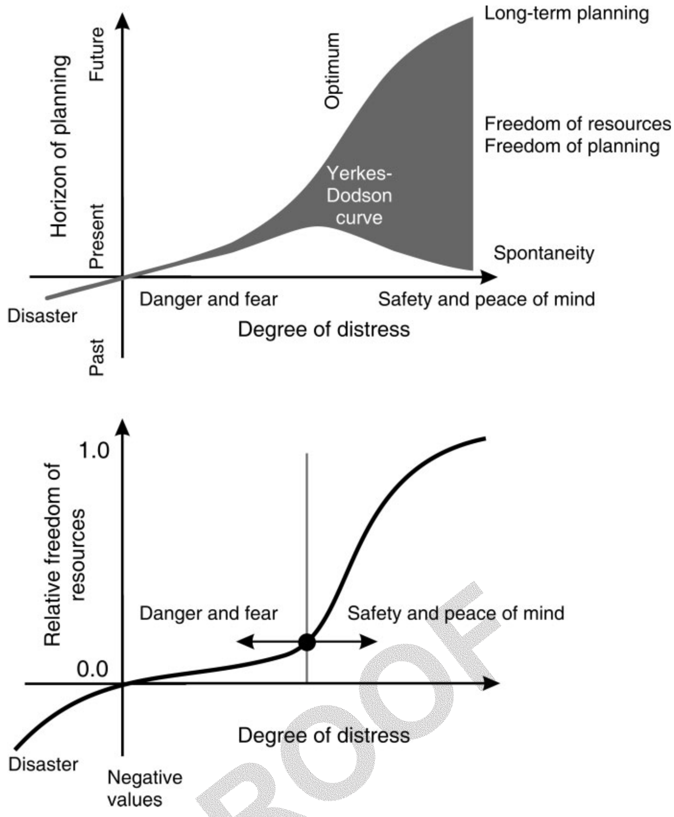

Fig. 3. Relationship between horizon of planning and degree of distress (top) and freedom of resources and degree of distress (bottom)

very well to common definitions of disaster stating, that external help is required. Additionally the introduced definitions can be transferred to the time scale of planning and spending resources, as shown in Fig. 3 top diagram.

The time horizon of planning alters dramatically in correlation with the states of danger and safety. Under the state of safety and peace of mind the time horizon shows a great diversity of planning times ranging from almost zero time to decades or even longer. In emergency states, the time horizon only considers very short time durations, such as seconds or minutes.

The choice of the time horizon is very important for optimizations: It determines the results. Short term optimization procedures are often criticized as yielding unethical results. If economic based optimizations are implemented with sufficiently long time horizons then more ethical solutions arise (*Münch* [12]). For example, *Imhof* [13] has chosen a time horizon of 50 years for the maintenance planning of Swiss railway bridges based on a cost-benefit-analysis optimization. In general such long time horizons are required not only for structures, but for many human activities (economical aid, school systems etc.). But using such long time horizons introduces major indeterminations through assumptions about the future behavior of the social system. An example of this is the uncertainty in predicting the traffic volumes in 50 years

But on which time horizon are usually decisions taken? Here the techniques of the human brain for identifying major hazards and therefore ruling resources should be of interest.

The awareness of danger depends very strongly on the presence of thoughts. But the presence of many different thoughts at the same time is limited. In general, the human short term memory can only consider up to ten items, but usually only three to seven items are used. This obviously limits the comparison of different risks and the consequent spending of resources to the most important ones. Secondly the repetition, for example in media, is important for human memory. Fig. 4 shows several thoughts about risk considering the intensity and *Ebbinghaus*'es memory curvature. It should be mentioned here, that after several years the amount of information about a certain event is less then $1/10^{12}$ of the original information. Therefore many scientists speak about the invention of reality. This is of utmost importance as it shows the high degree of individual risk judgement.

Fig. 4. fails to consider inconsistency of thoughts, which has been shown by many psychological investigations. Instead of a continuous flow of topics in thoughts, permanent interruptions of the topics can be experienced. Such intrusive thoughts might be considered as positive or negative depending on the situation. So far, there are no techniques for the evaluation of such switching of or missing thoughts in advance. But such intrusive thoughts can heavily influence the perceived safety (*Fehm* [14]).

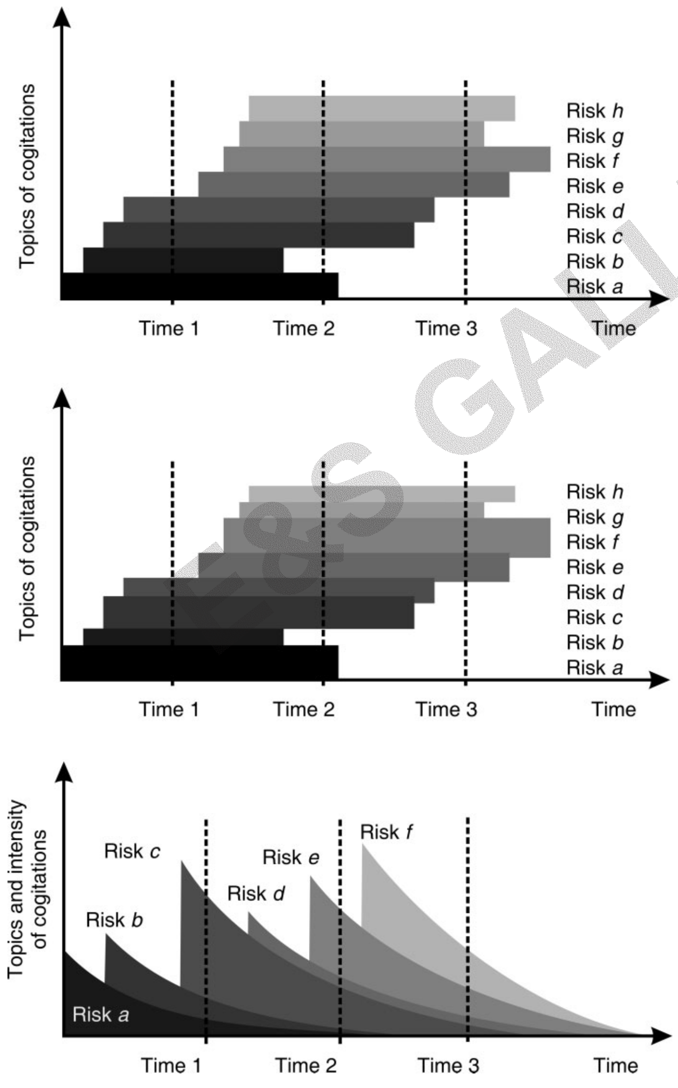

Fig. 4. Risks as topics of cogitations, first only considering the length of the thoughts (top), then considering the intensity (middle) and considering the memory function (bottom)

Even the intrusive thoughts might cause problems with safety assessments as it seems that they are rather important for humans. *Birkhoff* [15] has introduced a general numerical measure for the aesthetical assessment of objects based on a simple formula. Additionally many scientists have discussed the issue, whether high aesthetical evaluation is strongly correlated with high utility for humans. One additional issue of aesthetics is a positive disturbance of thoughts (*Piecha* [16], *Richter* [17]). Positive disturbing elements, such as a flower decoration on a table, might increase efficiency over the long term: a sparkling idea might be caused by the disturbance.

The briefly mentioned psychological effects are to the knowledge of the authors not included in the optimisation techniques for the safety of structures; however, these effects influence heavily the way in which decisions under real world conditions are made.

2.3 Limitations of the economic models used

Most quality of life parameters consider the economy as a system, which functions under all circumstances. For example, assuming a major disaster killing one billion people, the *LQI* assumes that the economy still functions as before. Such assumptions only become visible under extreme situations, such as some of the major economical crises which have occurred in the last century or the current decline of states such as Zimbabwe or Iraq. Changes in economical behaviour under such conditions can occur and will be shown in one example.

Many people live in countries where the social conditions motivate people to produce further wealth. This seems to be valid for all developed countries in the world, especially for countries, where scientists investigate the optimal safety of structures. This is not, however, a concrete behaviour of humans, since one can also detect countries where the social conditions motivate people to take wealth from other people instead producing the wealth (*Knack & Zack* [18], *Knack & Keefer* [19], *Welter* [20]). Those countries can be easily described as having a lack of trust in the social system. After major disasters in developed countries such behaviour can also be observed. Here people have the impression that the state as a representative of the society is unable to fulfil the duty of safety, the major task of states (*Huber* [21]). As already mentioned, people lose trust in the functioning of the social system. But how is the property of trust influenced by the actions of a state and can this trust be destroyed? To answer this question a short look into the properties of trust is worthwhile.

Trust is a main indicator of social capital and the basis for developing cooperation with other humans and/or organisations. Since the success of the economy is mainly based on specialization, which requires cooperation then the success of the economy in terms of developing wealth is connected to trust. It is not the main goal of this paper to define trust, just one adapted definition should be mentioned (*Conchie & Donald* [22]):

"*Interpersonal trust is a psychological state that involves the reliance on other people in* certain *situations based upon a positive expectation of their intentions or behaviour*."

Beton- und Stahlbetonbau 2008:
Sonderheft engl. Nr. 10110

Coming back to the simple example mentioned above, where potential economic actors cannot trust each other, the private returns of predation increase while the returns of production decrease. Unfortunately over the long term, this strategy yields to the complete failure of the society and the individuals. So if actions destroy trust, they also destroy the social system including the economy.

As an example the information inserts in pharmaceutical products are mentioned. These inserts are not only considered as information material, but also as a protection measure because they inform about the risks. Recent investigations, however, have shown that the inserts actually increase risk, since people in real need of the medication refuse to accept it due to the fear caused by the inserts. They simply do not trust the medicaments.

In contrast the safety regulations in air planes, such as lifejackets on board, increase the trust and the perceived safety of the passengers. In reality, however, the number of people actually saved by the lifejacket is negligible. Therefore this equipment could be saved and the resources spent on other activities based on optimisation investigations. Nevertheless not only the authorities, but also the airlines themselves refuse to implement this, since the major goal of the lifejacket is to create an atmosphere of carrying and trust, not to function under real life conditions. Only if such subjective effects are considered during the optimisation procedure can realistic results be yielded.

The question then arises, whether optimisation procedures can increase or decrease trust. This has not yet been proven, but simple considerations show, that trust is decreased by optimisation procedures in safety. See also the examples at the end.

2.4 System Requirements

Whereas the one chapter discussed mainly some effects of individual information processing, this chapter focuses more on the behavior of social systems and system theory. The membership of elements, such as humans, belonging to a system might influence required safety levels. First of all, the objectivity of risk assessment depends very strongly on the distance of the endangered elements to the damaged system. A scientist usually works in safe environment thinking about the optimization of the safety of structures. What would happen, however, if the concrete slab inside the office crunches and shows cracks? Would the scientist continue to work or would he spend resources checking the safety of the office? Here system theory might help: If elements of a system are endangered, the system will spend resources in a short term non-optimal way, just defending the integrity of the system. Only if the system exceeds a certain degree of seriousness, then the behavior of the system might shift back to taking economical considerations into account. This has been heavily investigated by looking at parent animals protecting their children. Under normal conditions the parents attack even stronger animals therefore endangering their own life; however, under extreme situations (hunger or drought) they leave their children without care. Also rules for military rescue actions quite often endanger more people to rescue a small number of military staff. Based on a theoretical optimisation analysis these actions should never be carried out, but

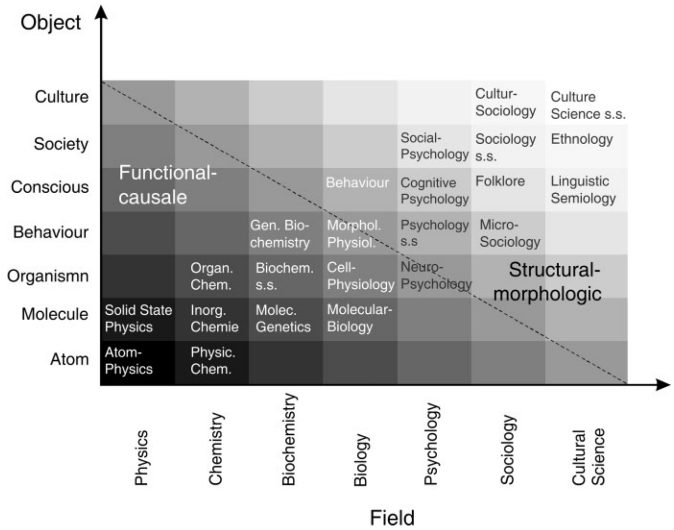

Fig. 5. Causality and field of science: High causality exists at the bottom left (in many cases), whereas low causality exists in the top right area (Riedl [25])

under real world conditions it is of overwhelming importance that the people keep their trust in the system.

This behaviour can also be seen in constitutions: Here governments promise some properties without any considerations of limited resources. Such statements might be complete nonsense but their goal is to give the elements of the system the impression and the trust, that the system itself will do everything required to save the element.

In general, treating elements of a system with a short term optimal solution can yield to long term failure of the system, since the elements will not function anymore. The problem of long term efficiency, however, can not yet be solved, since that would require the prediction of the behaviour of humans and social systems. Further research especially in the social systems field needs to be carried out. Where we have *Newton*'s law in physics, we do not yet have something comparable for societies and predictions are difficult (Fig. 5). In other terms, the behaviour of humans and social systems is highly indeterminate (*Proske* [23]).

This yields to another problem in the field of optimal safety of structures. It is known, that most structural failures are caused by human failure (*Matoussek & Schneider* [24]). But the overwhelming number of probabilistic calculations used as input data for optimisation procedures does not consider human failure (avoiding the prediction of human and social behaviour). Therefore the optimisation procedures are only partly connected to realistic problems.

3 Examples

The following few examples should illustrate the considerations.

① The famous Fort Pinto Case (Fig. 6) in the US in the 70s is the first example. Here the company Ford made an optimisation analysis about whether to make changes in the construction of the car concerning safety against fire and explosion. The analysis recommended no

Fig. 6. Ford Pinto Case in the US

Fig. 7. Collapsed sport hall in Bad Reichenhall, Germany

changes but financial compensation should be provided. During the court case (Ford vs. Romeo Weinberger) the analysis become public and Ford was heavily punished in terms of compensation (128 Million US $). During the public discussion the question whether the number of fatalities exceeded a permitted level was not so much of concern, but the idea, that any fatalities were accepted was the major critic. General Motor also used such a procedure and experienced the same effects in public in the 90s [26]. In both cases the loss of trust and other individual and social effects of the optimisation strategy were not considered, but heavily affected the outcome. The actual optimisation procedure did more harm than good.

② On January 2nd 2006 at 3:54 pm the sport hall in Bad Reichenhall (Fig. 7) collapsed. 15 people, many of them children, died in the collapse and 30 people were hurt. The failure of the structure led to an intensive debate about the safety of public buildings in Germany. First, it was assumed that snow overload caused the failure, since during the same winter a hall collapsed in Poland for this reason. This discussion reminds one very much of a discussion in the beginning of the seventies, when many light weight constructions in East and West Germany failed under the snow load. Here first sabotage was assumed to be the cause of failure in East Germany. Later, however, very optimistic assumptions about snow load and a change of construction material from wood to steel were identified as the causes. The discussion about the cause of failure in Bad Reichenhall turned more into a discussion on maintenance and the required level of safety over time.

"*The question of safety is now answered by business people and legalese, not by engineers.*" said the president of the German Association of inspection engineers on German television (ZDF) in 2006. He actually complains about an inherently economic based optimisation procedure. Independent from such optimisation considerations the ministers for building structures decided in December 2006 to change the law considering the safety requirements of public buildings in terms of additional inspections based only on the singular event in January 2006. This is very common in politics. Still, even with that event, structures in Germany remain an extremely safe technical product (17293678 residential buildings in Germany 2004, 5247000 non-residential buildings in Germany, 120000 bridges in Germany [27], [28], [29], 20 hours exposed per day, less then 10 fatalities per year on average) either in terms of mortality, fatal accident rates, *F-N*-Diagrams or optimisation procedures using quality of life parameters. As clearly seen from the words by the president of the Germany Association of inspection engineers, the optimisation procedures (using risk parameters) are criticised and not helpful in the case of a collapse. One can not simply state after a disaster, that the disaster was an acceptable one and business as usually should continue. For an example the goal of predictions is referred to (*Torgerson* [30]).

Here trust in the safety of buildings can be identified as a major requirement which has to be included in optimisation investigations. It should be mentioned, that the efficiency of trust destroying actions is three times higher than trust building. If optimisation procedures for safety are really considered as trust decreasing actions, the procedure itself has to be balanced by much higher investigations.

③ The Saxon Newspaper (Sächsische Zeitung) from November 8th 2003 reported that the permission to work as a physician has been withdrawn for a doctor due to the uneconomic treatment of patients (Fig. 8). Currently in Germany physicians have a budget which they can spend to treat people. If the budget is completely spent, either the doctor works for free or they may receive a penalty if they stop working. Nevertheless it is prohibited to inform patients about the current status of the budget or give any information about the budget to the patients in the waiting room. Most patients are not aware about such budgets and officials and politicians blame doctors if they refuse to treat people due to an exhausted budget. Here an optimisation procedure is carried out but is kept confidential. Obviously there must be a reason to keep it confidential, and the reason might be feared loss of trust.

So if people are aware of optimisation procedures for safety, they feel a strong damage of trust and develop social prevention actions, which yield to political decisions in terms of laws. If one assumes, that the definition for safety given in this paper is valid, then it can be proved, that optimisation procedures for safety are actually decreasing safety. Consider the definition of safety as the freedom of resources which have not to be spent immedi-

Beton- und Stahlbetonbau 2008:
Sonderheft engl. Nr. 10110

Hausarzt

Zu viel verordnet – Zulassung weg

Görlitz. Zum zweiten Mal ist in Sachsen jetzt einem Arzt wegen „unwirtschaftlicher Verordnungsweise" die Zulassung entzogen worden. Dies ist auf Antrag aller Krankenkassen in Sachsen geschehen, bestätigte am Freitag Ulrich Bergk vom Ersatzkassenverband einen Bericht der „Ärzte-Zeitung". Der Görlitzer Hausarzt habe jahrelang die für Arzneimittel-Verordnungen vorgegebenen Richtgrößen um bis zu 300, 400 Prozent überschritten.

Der Görlitzer Arzt hat gegen die Entscheidung des Zulassungsaus-

Fig. 8. Newspaper report in Germany, 2003

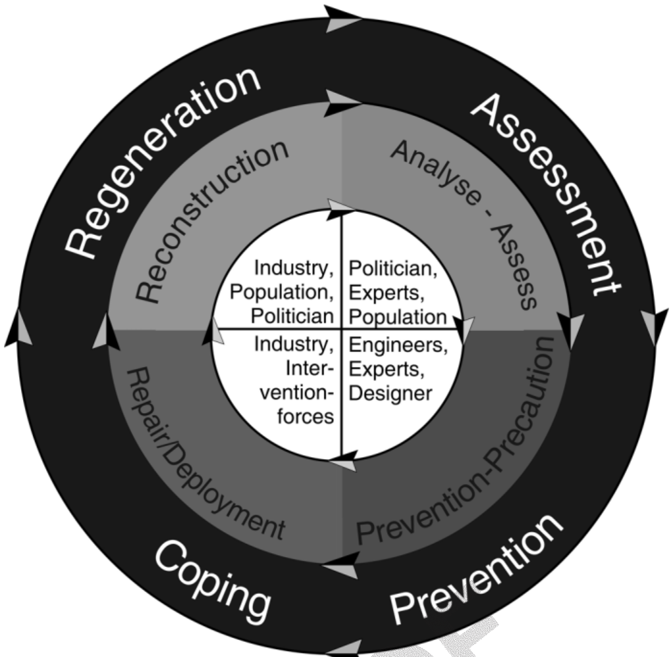

Fig. 9. Integral Risk Management Concept

ately for safety measures against a danger. If optimisation procedures, however, imply that resources should be spent in one way or another, people lose the freedom of resources. Actually the goal of optimisation procedures to improve safety, fails since the definition of safety is not fulfilled, e.g. freedom of resources. One could argue that optimisation procedures extend the life time of a person but this does not necessarily mean freedom of resources.

4 Possible solution and conclusion

In the last few years the topic of the optimisation of the safety of structures has been of major importance in engineering, especially since the wide spread application of quality of life parameters. Nevertheless in medicine the application of quality of life parameters has been discussed for over 50 years now. As shown in this paper, social, psychological and other effects have to be considered in the optimisations of safety. Additionally here *Arrows* [31] the impossibility theorem should only be mentioned to give an impression about the magnitude of problems.

Nevertheless somehow some decisions have to be made. The only ones able to carry out decisions are empirics. They never declare their solutions as optimal, are aware of the limitations of their models and check carefully the validity. Consider for example the idea of integral risk management, which follows the concept of empirics not assuming an optimal solution, but inherently including an indefinite improvement. From the authors' point of view this seems to be the most promising way. It responds better to social and psychological needs, such as disaster management and increased resources in disaster situations independent of some synthetic optimisation criteria. Therefore integral risk management builds, as just mentioned, a never-ending circle (Fig. 9). Sometimes also the term risk informed decision making is used and helpful (*Arrow* et al. [32]).

Considering the mentioned drawbacks for optimisation, it is not surprising, that in different fields of science, many authors actually have turned away from optimisation, looking for substitution parameters, such as robustness (*Harte* et al. [33], *Bucher* [34], *Marczyk* [35]). Without going into detail, one of the definitions of robustness of structures consists of satisfying behaviour under non-considered conditions. Again here by definition the limitation of the current knowledge is accepted.

This critique about the possible application of optimisation procedures for the safety of structures will be finished by some remarks taken from a mathematical research project called "Robust mathematical modelling" [36].

1. There is no such thing, in real life, as a precise problem. As we already saw, the objectives are usually uncertain, the laws are vague and data is missing. If you take a general problem and make it precise, you always make it precise in the wrong way. Or, if your description is correct now, it will not be tomorrow, because some things will have changed.

2. If you bring a precise answer, it seems to indicate that the problem was exactly this one, which is not the case. The precision of the answer is a wrong indication of the precision of the question. There is now a dishonest dissimulation of the true nature of the problem.

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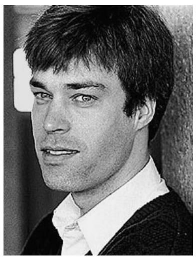

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