“CERTAINTY”, “SAFETY” AND “SECURITY” IN CIVIL ENGINEERING SCIENCE WITH RESPECT TO LCA

“CERTAINTY”, “SAFETY” UND “SECURITY” IM BAUINGENIEURWESEN IM HINBLICK AUF ÖKOBILANZIERUNG

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SUMMARY

In this paper, an attempt is made to work out fundamental differences with regard to the justification of trust in technical systems and to examine the relevance of these differences in particular in connection with environmental problems. It turns out that with regard to complex sustainability issues, substantially different forms of assessment are necessary than in the assessment of purely technical aspects. A procedure using interval arithmetic is proposed as a possible uniform approach to solving the difficulties described, especially in the field of life cycle assessment.

ZUSAMMENFASSUNG

In diesem Aufsatz wird der Versuch unternommen, grundsätzliche Unterschiede bzgl. der Begründung von Vertrauen gegenüber technischen Systeme herauszuarbeiten und die Relevanz dieser Unterschiede insbesondere im Zusammenhang mit Umweltproblemen zu untersuchen. Es zeigt sich, dass hierbei im Hinblick auf komplexe Nachhaltigkeitsfragen wesentlich andere Formen der Bewertung notwendig werden, als bei der Beurteilung rein technischer Aspekte. Als möglicher einheitlicher Lösungsansatz für die dargestellten Schwierigkeiten speziell im Bereich der Ökobilanz wird ein Verfahren, das sich der Intervallarithmetik bedient, vorgeschlagen.

KEYWORDS: Certainty, safety, security, reliability, LCA, sustainability, interval arithmetic, trust

1. INTRODUCTION

The fallibility of human beliefs, statements, decisions and actions is proverbial. The statement "To err is human" is accordingly assigned to various historical thinkers, including SENECA and CICERO. Human errors inevitably result in products of human activities being notoriously defective and the activities themselves are not free from unexpected and therefore undesirable side-effects. As a result, humanity necessarily experiences that problems or even catastrophes from which human beings suffer are caused by the actions of human beings themselves or that they are "anthropogenic", as it is called in modern parlance. On the other hand, the rational human being is capable and even ethically obliged to take precautions. At the same time, human beings also endeavour to assess the risks of his own fallibility and to limit them as far as possible. Within the framework of technical knowledge, this has been done systematically since the beginning of the era of mankind characterized by technology, with great and steadily increasing success. These successes have generally led to a certain degree of confidence in technical developments, which tragically in the end can even result in carelessness. More and more ambitious technical projects are tackled and regarded as "safe" in the sense that the existing risks are limited by scientific methods and thus ultimately remain tolerable for all concerned.

At the latest since the beginning of the discussions about observed irreversible anthropogenic damage to the world as a whole by human technology, this attitude to the risks and the associated scientific methods must be questioned in its entirety. In the course of these discussions, a global and holistic view of the problem situation is usually called for. Aspects of politics, economics, sociology, geology and numerous other scientific disciplines must also be included. An all too comprehensive multidisciplinarity, however, usually leads either to superficiality or to situations in which representatives of different disciplines and thus different points of view seek to mutually outdo each other. A typical example in this respect is the fact that environmentally friendly technical solutions are sometimes criticised as uneconomical and thus (allegedly) prove to be antisocial due to the phenomenon of job loss. More rewarding than such disputes and above all more scientific as a result seems to be the intensification and processing of the tasks at hand within each single discipline. In this sense, this essay is limited to topics from the field of civil engineering. First, some typical examples of how safety and security issues are dealt with in this field are presented. This amounts in each case to measures, by which project characteristics are changed in such a way that the result of the decisions lies finally "on the safe side", whereby this formulation is to be analysed first altogether regarding its sense content. The main part then shows that the procedure discussed above is not suitable for making those risks controllable which are related to the impairment of the environment. Finally, alternative concepts are proposed and discussed.

2. TRUST ON A STATISTICAL BASIS

What exactly is meant when we describe a conviction or a statement as "certain", a decision, an action or a technical object as "safe" or a situation as "secure"? How can the relevant circumstance be verified? How "certain" are statements about safety? It should be mentioned here, that the translation into german of “safe”, “secure” and “certain” is the same word in all cases: “sicher”.

First, a distinction must be made between individual or "perceived" security and objective, statistically and scientifically based security. In many cases, relative security can be ensured through the use of statistical methods. The prerequisite for this is the existence of a large database. Ultimately, the security of a specific object or fact under consideration can be statistically justified if it is an individual case that falls into an already statistically evaluated totality. Statements about material properties that can be determined and verified in laboratory tests fall into this category, as the number of potentially available test results is practically unlimited. The situation is completely different for statements about the properties of components or entire structures. In some cases, a database may be available for standard components that makes statistical statements possible. In general, however, this is not the case and finally an assessment on a statistical basis is out of the question for large prototype-like structures. The practical justification, i.e. based on experiments and their statistical evaluation, of the assertion that such a structure will be able to withstand all requirements, is in principle impossible and must be replaced by a justification based on theories. New questions arise from this. To concretize and answer these is the essential object of scientific efforts in civil engineering.

3. THEORIES AND THEIR LIMITS OF VALIDITY; INTERACTION AND NONLINEARITY

If it is assumed that all relevant properties of all components of a system are known and statistically verified, statements can be made about the behaviour of the overall system. Such statements are necessarily based on theories that describe the interaction of the components with each other and their reaction to external influences. The decisive question now is whether the totality of the considered theories is capable of covering all conceivable influences and events and whether all theories are used appropriately, i.e. in particular without exceeding their respective validity limits. For engineering science in general, it can be stated that any theory is only valid in an approximate sense and that even this validity may only be assumed within certain parameter limits.

One of the most fundamental theories at all is the strength theory of uniaxially stressed bar-like components. In simple terms, this states that the load-bearing capacity of a bar-like component increases or decreases proportionally with increasing or decreasing cross-sectional area. This theory is intuitively correct but reaches its limits of validity in at least two cases:

1) In the case of slender components, the failure mode "buckling" limits the load capacity.
2) In the case of inhomogeneous components, i.e. in particular in the case of components whose homogeneity is disturbed by defects such as cracks, the loading capacity is limited by local phenomena ("crack growth").

Both problems can and must be dealt with in a way that further theories are taken into account. In the first case, for example, this is the theory of the EULER buckling bar and in the second case it is the linear elastic fracture mechanics (LEFM) that implies the size effect on the nominal strength of structures [1]. However, it is not always sufficient to apply the relevant theories individually to a given problem situation. It may happen that the load bearing capability of a component for certain parameter combinations is lower than all limit values that can be determined based on the individual relevant theories.

From this results the necessity to develop more comprehensive theories, which cover the possible realizations from the more elementary theories but by the coupling of these theories also permit statements about the behaviour in the range of critical parameter combinations. Often this is only possible by dropping the assumption of linearity, which is always assumed first in elementary theories, so that nonlinear coupled theories, whose proper interpretation is correspondingly more complicated, are created.

As an example, Fig. 1 (a) and (b) shows the related failure load for cracked beam-like components as a function of a size factor in a double logarithmic representation. The two straight lines correspond to the two elementary theories relevant here, i.e. strength theory and LEFM. The curve that nestles to these two straight lines represents the coupled nonlinear theory that is needed here in order not to make optimistic statements for components whose size factor roughly corresponds to the intersection of the boundary lines for the linear theories. Fig 1. (c) and (d) shows a similar situation for cracks of different length orthogonal to the boundary in a steel sheet under tensile load.

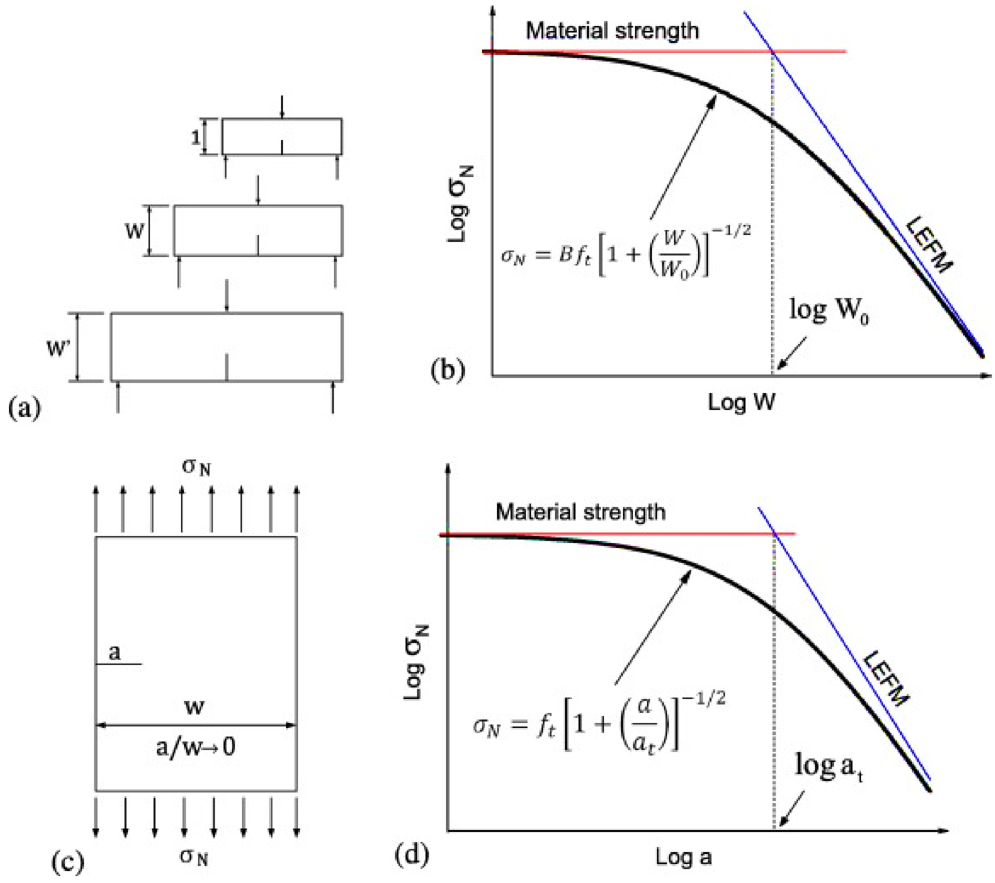


Fig. 1: Size effect in fracture mechanics [2]

It is important to recognise that the need to add necessary elements to the canon of required theories cannot be quantified statistically. As soon as there are doubts about the completeness of a theory canon, all statements that are nevertheless made are to be classified as scientifically uncertain.

4. THE FATE OF THE MORANDI BRIDGES

The more complicated the systems are whose load-bearing capacity is to be assessed and the more varied the stresses are under which a system under consideration is placed, the more difficult it is to ensure that all the theories relevant for the assessment, including all validity limits, are actually observed. Since buildings are operated over very long periods of time, further theoretical concepts become relevant in the course of forecasting operational safety. The fact, that in large projects a large number of people are responsible for the final assessment, and that different people may have different priorities, also causes problems.

Two bridges designed in a very similar way by the Italian engineer R. MORANDI, both victims of unforeseen failures, should be considered as examples. In the aftermath of such catastrophes, the fundamental question of cause must be clarified, so that ultimately further theoretical basis for assessment can be provided for other structures.

The “General En Jefe Raphael Urdaneta Bridge” over Lake Maracaibo in Venezuela collapsed after an oil tanker, which is typical for the bridged waterway, collided with a bridge pier as a result of an accident.

Fig. 2: General En Jefe Raphael Urdaneta Bridge [3]

The Polcevera viaduct in Genoa failed due to corrosion of the prestressed reinforcement. It is noteworthy that the critical evolution of the condition of the bridge was known for years. A tie belt on another section of the bridge, which was not involved in the structural failure, had been refurbished a few years earlier by external additional elements, i.e. by enlarging the cross-section.

Fig. 3: Polcevera viaduct in Genoa [4]

Both events, the unforeseen accident and the failure due to unobserved or incorrectly assessed ageing, are not properly addressed by the concepts discussed above. Ensuring the operational safety of the structure and the security of its users requires further consideration. These are resulting in the necessity of pessimistic assumptions ("heuristics of fear" see H. Jonas [5]).

The following statement can be made for the bridge in Genoa: A premature demolition of the structure would have been scientifically justified; operation until the catastrophe was not. The assumptions that justified this continued operation were too optimistic and were not based on sound scientific theory.

5. THE GLOBAL ECOSYSTEM AS AN OBJECT OF ENGINEERING SCIENCE

Probably the most complex system that can be investigated with the means of engineering science with regard to its operational safety is the worldwide ecosystem. Ensuring this operational safety is understood as a political task and this task in turn is delegated to science and engineering. It is known that the global ecosystem is a system in which countless non-linear individual processes are coupled in a highly complex manner, and that an actual prediction of the fate of the world is therefore not possible in principle. However, this cannot serve as a justification for abstinence from action. It is the ethical duty of those people and groups who are able to stop or at least slow down fatal developments to do so.

However, it is also reasonable to avoid unjustified actions, i.e. actions that are based on assertions that do not correspond to a demanded level of certainty.

6. INTERVAL ARITHMETIC

By consistently considering upper and lower limit values in all calculation steps and statements, the difficulties mentioned in the previous chapters can be avoided in a uniform manner.

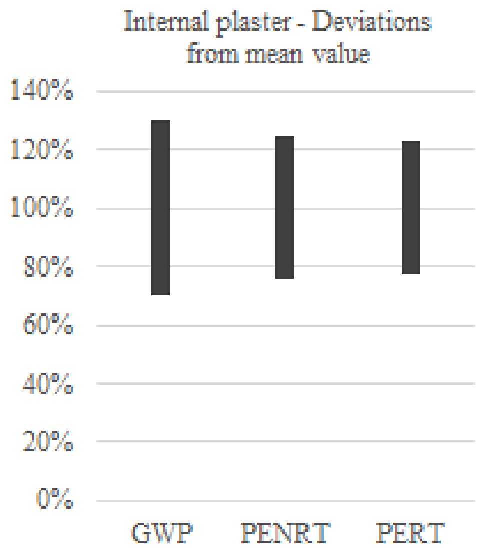
By linking interval-based statements, new, more specific statements are generated whose parameter intervals, however, are generally wider than those of the initial statements. This can result in the final statements of a corresponding study not appearing to say anything at all, since the validity limits are so broad that the necessity given by the corresponding interval degenerates into banality, as in the sentence: "The expected service life of a prestressed concrete bridge is between zero and one hundred and fifty years". The appearance of such senseless observations, however, is not a shortcoming of the method proposed here. Rather, such findings make it clear that in the chain of argumentation leading to such a result there is too much inaccuracy and unclear assumptions with regard to existing circumstances and decisions. Thus, the task arises from this to concretize the statements that make up the course of argumentation.

In the field of life cycle assessment [6], the benefits of an interval-based approach were demonstrated using the example of an innovative, aerogel-based plaster that is still under development. The primary objective of the development was to achieve the highest possible thermal insulation performance in addition to the required strength. In the course of the development of the plaster, its composition and the amount of raw materials used changed, which in turn affected the results of the life cycle assessment.

If the results obtained at an early stage of development are to provide valid information on the possible environmental impact of the future product, the validity limits must be extended accordingly. The example concerned the type and quantity of raw materials used, for which intermediate values were defined, the limit values of which represented the minimum possible or maximum possible quantities.

By applying the interval-based approach, result intervals were defined within the LCA, on the basis of which statements can be made about the environmental impacts of the global warming potential (GWP), the non-renewable primary energy demand (PENRT) and the renewable primary energy demand (PERT). Fig. 4

shows the result intervals for a 50 mm thick plaster and an area of one square metre in tabular form (right) as well as the deviations of the results from the mean value in percent (left).



	Result interval	**Unit**
GWP	[38.1, 70.3]	kg CO_2 eq.
PENRT	[734.2, 1214.6]	MJ
PERT	[564.7, 892.0]	MJ

Fig. 4: Result intervals of a 50 mm thick plaster per m² (right) and percentage deviation from mean value (Left) [6]

Obviously, possible statements that can be read from this figure are still quite vague. As long as such vagueness exists, the most pessimistic statement is to be used in further investigations in the sense of H. Jonas.

7. OUTLOOK

Every technical product that is produced and used by mankind represents a burden on the environment and a risk for users and other groups of people through its mere existence. It is an ethical duty to minimise this risk and engineering has a key role to play in fulfilling this duty.

The consistent application of the interval arithmetic method proposed here can support the process of identifying worthwhile individual activities. The focus here is less on improving specific values than on reducing the uncertainty when using such values.

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