Uniform Concept for Structural Stability and Fire Protection

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Summary

The paper presents the development of a modern, risk-based safety concept for structural stability and fire protection. A risk analysis initiated by the increased numbers of collapses and fires in recent years revealed that it is imperative to adapt state measures for pre-emptive risk management more specifically than in the past to the safety risks arising during the planning, erection and use of a building. On the basis of parameters defining the level of risk, the intensity of state inspection and monitoring measures should in future be graduated in accordance with the consequences of failure as characterised by the Eurocode consequence classes CC1 to CC3 in EN 1990, as well as the probability of such an occurrence, i.e. according to the complexity of the supporting structures in case of structural stability or the evacuation conditions for fire protection. A concrete proposal for a risk-based safety concept is presented within the framework of the German regulations. The independent role and qualification of the check engineers is here of particular importance.

Keywords: risk-based safety concept, structural stability, fire protection, risk analysis, risk assessment, prevention of risk and hazard, 4-eyes principle, state monitoring, check engineers

1. Building safety

The increasing numbers of collapses, fires and other structural failures in recent years, including, among others,

- the collapse of an ice rink in Bad Reichenhall in Bavaria on 02.01.06, with 15 deaths and numerous persons injured,
- the collapse of a swimming baths in Chusovoy in the Ural region of Russia on 04.12.05, with 9 deaths and several persons injured,
- the partial collapse of a school building in Goldberg, near Parchim in North Germany, on 13.08.2004, with 5 deaths,
- the collapse of part of a terminal building at Paris Airport on 23.05.04, with 5 deaths and several persons injured,

- the collapse of the 5,000 m² roof of a modern swimming complex in Moscow on 14.02.04, with 28 deaths and 110 persons injured,
- the collapse of the roof of a swimming baths in Krefeld-Bockum, Northwest Germany, in August 2000, with 27 persons injured,
- the collapse on two separate occasions of a sports centre under construction in Halstenbeck near Hamburg in 1997 and 1998
- the collapse of the Roter Turm tower in Jena in Central Germany in August 1995, with 4 deaths,
- a fire in a discotheque in Buenos Aires on 21.12.2004, with 188 deaths and over 900 persons injured,
- a fire in an underground car park in Gretzenbach in Switzerland in November 2004, the reinforced concrete roof of which collapsed during fire-fighting, killing 7 firemen,
- a fire in the Anna Amalia Library in Weimar, Central Germany, on 02.09.04, which destroyed irreplaceable cultural treasures,
- a fire at Düsseldorf Airport on 11.04.96, with 16 deaths and over 60 persons injured,

demonstrate **that the risks for public safety emanating from buildings and other structures have not diminished, despite the enormous advances in computer technology and construction techniques; on the contrary, there has been a noticeable increase**. There are various aspects which contribute to this development, and these are to be investigated more closely in the following risk analysis.
Based on the results of the risk analysis, finally, conclusions are to be derived for improvements and a uniform system approach to pre-emptive risk management.

The aim of this system of consistent measures is to guarantee a sufficient level of building safety. Referring to DIN 1055-9, building safety is understood in its comprehensive sense of pre-emptive risk management according to the following definition:

> **“Building safety with regard to a particular risk is considered achieved where this risk, by way of suitable measures, has been limited to a socially accepted level.”**

This is generally specified in legislations, ordinances, guidelines and standards.

1.1 Historical development

Public demands placed on structural stability can be traced back to Ancient Babylon. In the famous code of laws drawn up by Hammurapi around 1700 BC, builders were threatened with draconian punishment should their inadequate work cause a house to collapse. During the Middle Ages, an era of devastating town fires due to the ever denser urban structures and the predominance of flammable building materials, the first fire protection regulations emerged. Many communities passed fire protection ordinances in the 16th century, demanding measures to prevent or at least contain fires and specifying rules for effective fire-fighting. These initial provisions on building safety have in the meantime developed into a scarcely surveyable flood of laws, ordinances, guidelines, technical building regulations, generally recognised engineering standards and lists of construction rules.

It was soon recognised that, in practice, the demands for preventive measures to avert risks, which frequently entail significant additional costs for the building owner, could only be enforced if the community or the state were to introduce effective monitoring and be able to impose sanctions. It was this realisation which led to the appointing of official building inspectors in the 19th century, as the precursors to the building inspectorates which developed during the 20th century and have since been active successfully at both local and national level. Building codes were drawn up as central rule books defining the public demands on buildings and similar structures, and placed a form of pre-emptive risk management at their focus. **The building code stipulation that all buildings and**

structures of relevance for public safety require a construction permit, and are thus subject to appropriate verification by the building authorities, finally asserted the concept of state control for Germany as a whole at the beginning of the 20th century.

For an example, it is possible to quote here a paragraph of the corresponding regulations drawn up by the responsible Prussian minister in 1904.
Article 1 states:

> "The erection of buildings or structures in ferroconcrete is to be preceded by a special evaluation by a building inspector. For this purpose, when seeking construction permission for a building or structure to be erected wholly or partially in ferroconcrete, the applicant is to enclose drawings, structural calculations and descriptions from which the overall arrangement and all important details can be seen."

As technical progress continued in construction engineering, the verification of the structural calculations and design drawings began to demand specialist knowledge extending beyond the traditional scope of duties for the building authorities. It was against this background, at the end of the 1920s, that the first independent verification engineers were appointed by the building authorities in Germany to perform official evaluations of the structural documentation for new buildings. Since the 1950s, independent engineers have been handling the verification of structural stability and monitoring of the construction phase on behalf of the state in all technical fields. To further relieve the building authorities, moreover, Saxony was in 1998 the first German state to delegate the evaluation of another safety-relevant sphere, that of preventive fire protection, to state-approved independent engineers. The success of their activities on behalf of the state, mirroring the benefits of the check engineers for structural stability, has led to independent engineers being employed increasingly throughout Germany, with the result that **check engineers are performing building inspection tasks in both areas of pre-emptive risk management – structural stability and fire protection.** To guarantee the independence of the building verification, it is imperative that the engineers be appointed by the building inspectorate.

1.2 System of pre-emptive risk management

As presented above, the current rules and regulations concerning pre-emptive risk management in construction have evolved empirically and portray differing levels of safety. The common basis in Germany is Article 3 of the Model Building Code (Musterbauordnung, MBO), which stipulates that building structures are to be planned, erected, modified and maintained in such a manner, that neither public safety and order nor the natural environment is endangered.

In the case of structural design planning, one of the tasks of which is to verify the structural stability of a building, the essential principles of the safety concept are contained in the Eurocodes EN 1990 [1] and EN 1991, and similarly in the German equivalent, DIN 1055-100 of March 2001 [2]. The requirement of dimensioning on the basis of boundary states and differentiated partial safety factors places high demands on the structural engineer, the building contractor and the user, but is able to guarantee the adequate reliability of the planned and erected structures if all detail specifications of the applicable standards are observed correctly. **The prerequisite, as expressly emphasised in DIN 1055-100, is that the structural design planning is verified by an independent office. Exceptions to this principle of independent verification are subject to a corresponding legal stipulation.** The grounds for this provision, which is decisive for the attainable level of safety, are supplied in Annex B to the aforementioned standard:

> "The actual frequency of failure is essentially correlated to the human error which is not taken into account when specifying the partial safety factors."

This statement is confirmed in all relevant studies. According to SCHNEIDER [3], around 75% of all cases of failure are attributable to human error. This includes, for example (cf. PROSKE [4])

- carelessness, negligence, disregard,
- forgetfulness, mistakes,
- insufficient knowledge,
- underestimating of decisive influences,
- lack of plausibility checks, blind faith in computer calculations,
- imperfect quality due to time and cost pressures,
- inappropriate reliance on others.

As the experience of both the building authorities and the verification engineers shows, the influence of human error can only be reduced significantly by way of independent evaluation on a four-eye principle. Applying aspects of probability theory, PROSKE reaches the conclusion that the probability of error can thus be lowered to around 10%.

In respect of fire protection, the second pillar of pre-emptive risk management, the situation is similar. Here, too, the experience of the building authorities, in particular, demonstrates that independent verification is indispensable to be able to guarantee the necessary degrees of safety. This applies also to the recurring inspection of existing buildings, which is defined more clearly with regard to fire protection than in conjunction with structural stability.

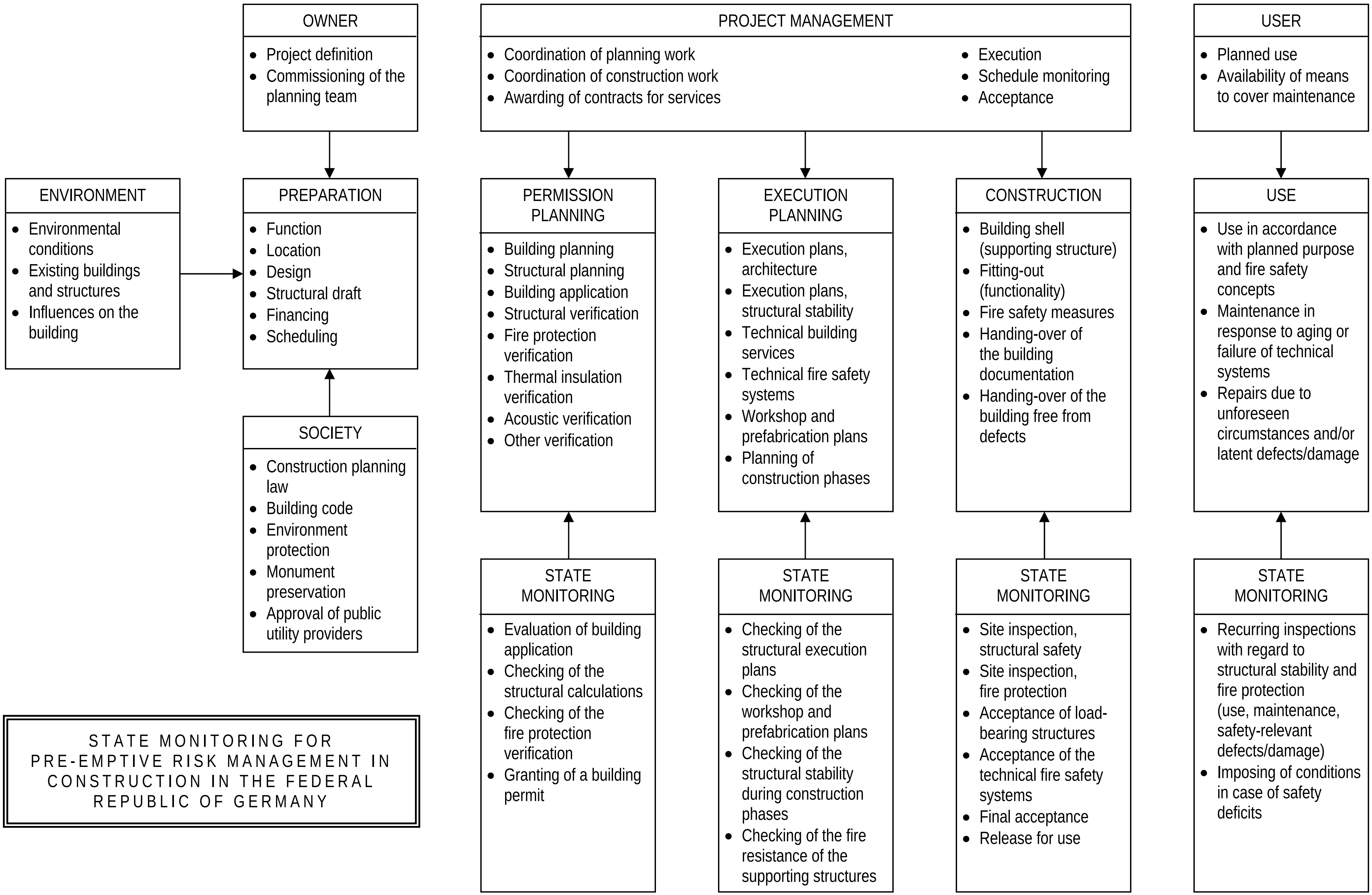
In the following block diagram, the state inspection and monitoring instruments which are currently binding in differentiated form in Germany are assigned to the key activities during the planning, execution and use of a building, illustrating the system of pre-emptive risk management in its full diversity.

1.3 Assignment of measures for pre-emptive risk management

As the measures for pre-emptive risk management involve a potentially considerable input of time and means on the parts of both the building owner and the building authorities, the individual safety specifications are reviewed at regular intervals to assess their continued necessity.

At the end of the 1990s, consequently, a number of German federal states decided to discontinue verification of the structural safety for low-height buildings and for residential buildings up to the so-called high-rise limit. As this definition disregarded completely the complexity of the load-bearing structure, there were massive protests from the check engineers, who saw a dramatic undermining of safety levels in such provisions. One result, for example, would have been that hall structures would no longer be subject to evaluation, irrespective of their form or the degree of complexity in their calculations. The Bad Reichenhall ice rink mentioned in the opening remarks would also not necessarily have been verified. With a catalogue of criteria taking into account the complexity of structural planning, finally, it was attempted to compensate the ensuing safety deficit.

If the threshold of socially accepted risk is exceeded, the consequence is generally the specification of safety-enhancing measures. Following the collapse of the ice rink in Bad Reichenhall, for example, the supreme building inspectorate in Germany published notes concerning the structural verification of existing buildings in cases of increased danger potential. The revised approach was based on a graduated inspection procedure. At the same time, exemplary reference was made to the stipulation of regular structural inspections for bridges in DIN 1076, which has been in force for several decades.


OWNER
Project definition
Commissioning of the planning team
PROJECT MANAGEMENT
Coordination of planning work
Coordination of construction work
Awarding of contracts for services
Execution
Schedule monitoring
Acceptance
USER
Planned use
Availability of means to cover maintenance
ENVIRONMENT
Environmental conditions
Existing buildings and structures
Influences on the building
PREPARATION
Function
Location
Design
Structural draft
Financing
Scheduling
PERMISSION PLANNING
Building planning
Structural planning
Building application
Structural verification
Fire protection verification
Thermal insulation verification
Acoustic verification
Other verification
EXECUTION PLANNING
Execution plans, architecture
Execution plans, structural stability
Technical building services
Technical fire safety systems
Workshop and prefabrication plans
Planning of construction phases
CONSTRUCTION
Building shell (supporting structure)
Fitting-out (functionality)
Fire safety measures
Handing-over of the building documentation
Handing-over of the building free from defects
USE
Use in accordance with planned purpose and fire safety concepts
Maintenance in response to aging or failure of technical systems
Repairs due to unforeseen circumstances and/or latent defects/damage
SOCIETY
Construction planning law
Building code
Environment protection
Monument preservation
Approval of public utility providers
STATE MONITORING
Evaluation of building application
Checking of the structural calculations
Checking of the fire protection verification
Granting of a building permit
STATE MONITORING
Checking of the structural execution plans
Checking of the workshop and prefabrication plans
Checking of the structural stability during construction phases
Checking of the fire resistance of the supporting structures
STATE MONITORING
Site inspection, structural safety
Site inspection, fire protection
Acceptance of load-bearing structures
Acceptance of the technical fire safety systems
Final acceptance
Release for use
STATE MONITORING
Recurring inspections with regard to structural stability and fire protection (use, maintenance, safety-relevant defects/damage)
Imposing of conditions in case of safety deficits
STATE MONITORING FOR PRE-EMPTIVE RISK MANAGEMENT IN CONSTRUCTION IN THE FEDERAL REPUBLIC OF GERMANY

With regard to fire protection, a similar requirement of recurring inspections for existing buildings exists in connection with special buildings characterised by high crowd densities. An administrative regulation pursuant to the Saxon Building Code dated 2005, for example, states:

> "Insofar as certain intervals for **verification by the building inspectorate** is not already to be derived from the regulations pertaining to special buildings, such verification inspections are to be performed at intervals of at most five years **in the case of special buildings with a typically high crowd density**. … … The building inspectorate is to keep a record book into which all results of inspections are to be entered."

GOFFIN, a key representative of the supreme building inspectorate, had already in 1996 formulated demands in his fundamental appraisal of pre-emptive risk management and an analysis of the Düsseldorf Airport fire [5]:

> "… The danger potential arising from subjectively unrecognised hazards, from inappropriate or improperly realised building measures, from consciously or unconsciously neglected hazards and from misjudged risks also shows clearly that **verification on the 'four-eye principle' is an essential element of any safety system**.
>
> **Logically autonomous monitoring systems adapted to the individual risk** should thus – with the graduated levels of monitoring: full, statistically reliable, random checks – incorporate in particular all phases of construction and the duration of use of special buildings (thus, for example, also in the case of airports)."

2. Risk analysis

As buildings are usually unique structures, which are not only planned, erected and used individually, but also exposed to the most varied influences, construction is a field in which the risks with regard to life, health and the natural environment are higher than in other branches of industry. This fact has already been taken into account for many years, as pointed out above, in the form of building code requirements. Furthermore, more recent standards pertaining to structural planning also deal explicitly with this topic. Both DIN EN 1990 and DIN 1055-9 describe measures to preclude failure states and to reduce the risks arising from exceptional influences.
On the basis of more recent literature, e.g. BERGMEISTER, CURBACH et al. [6], risk can be defined as a **function of the probability and the consequences of a failure**. It can be derived from this, that the risk analysis serving as a basis for a uniform concept structural stability and fire protection must address both aspects.

2.1 Current trends in construction

Referring to the subprocesses of preparation, planning, erection and use of a building, as summarised in the preceding block diagram, the following current trends can be identified:

- Constantly increasing numbers of persons congregated in any particular building and the increasing sizes of the buildings themselves; examples here are high-rise residential buildings, meeting venues and retail centres with high crowd densities, and industrial facilities.
- The full exploitation of design possibilities and the use of new building materials are leading to ever leaner, bolder and more demanding supporting structures.
- As construction engineering continues to advance, building processes are becoming increasingly complicated and complex.
- The targeted minimisation of construction costs often causes building materials to be pushed to the extremes of their capabilities, accompanied by a safety-relevant reduction of the planning and erection work actually done.

- The frequently demanded short construction periods generate extraordinary time pressures, impairing the reliability of the planning and erection work.
- The widespread use of computers in the calculation and designing of buildings is highly sensitive to errors should no plausibility checks be performed (blind faith).
- The demands placed on planners and building contractors in terms of quality and experience are often disregarded.
- The independent verification of structural stability and fire protection, including the associated construction monitoring, has been systematically reduced over the past years as a consequence of the increasing cost pressures faced by public authorities.
- The independent inspections which remain necessary during use in case of buildings with a high danger potential are frequently not performed, or else are performed inadequately.

Further detailed specifications, in particular concerning risks in the spheres society and politics, project ownership, project management, planning, construction process and use, are contained in the conference contribution presented by ANDRÄ to the Deutsche Bautechnik-Tag 2007 [7] and reaffirm the necessity of state monitoring.

2.2 Analysis of the causes of failure

From an analysis of the failures attributable to human error, which account for three-quarters of the total, it can be derived after SCHNEIDER [3] that planning errors dominate with approx. 40%, following by construction errors with 30% and materials at around 15%. The remaining sources of error (technology application and other errors) each lie below 10%. Referred to the various significant elements of the construction process, the situation is as follows: The overwhelming majority of the damage is manifested in the load-bearing structure, namely 72% according to [3]. A further 11% can be assigned to auxiliary structures and staging, and 8% to the fitting-out and miscellaneous services; 6% of the damage concerns technical systems, and 3% the excavation work.

The principal causes of failure indicated by these statistics coincide well with the experience of the check engineers and building authorities, and are in line, furthermore, with the key focus of state measures for pre-emptive risk management with regard to structural stability:

- Verification of the structural design planning
- Monitoring of the actual construction
- Inspection of the certificates of applicability for the relevant building products.

To prevent damage to auxiliary structures and staging, the structural inspection also considers the applicable documentation for all necessary phases of the construction. The same applies to damage surrounding excavation work: Inspection of the excavation lining is similarly an integral part of any appraisal of structural stability.

In the case of major construction projects, where numerous structural planning engineers are involved in preparing the structural calculations at the permission and execution planning stages, and later the execution drawings, including the necessary prefabrication and workshop plans, the verification engineer is often the only person to see the whole structural documentation, and is thus the last instance able to compensate the frequently lacking coordination of the planning documents by imposing additional conditions.

SCHEER reaches similar conclusions in his comprehensive and detailed investigations of structure failures [8], here incorporating also many international reports. In the section “Learning for practice”, following a summary of the causes contributing to 318 analysed cases of failure, he emphasises the special role played by the structural verification engineers in Germany, whose influence has averted considerable damage and numerous potential collapses.

The same applies with regard to fire protection. Here, too, the official evaluation of the building application documents, together with random site monitoring by the building authorities and check engineers for fire protection verification, has prevented many fires, or at least reduced their dramatic consequences. Despite all the measures geared to preventing fires, however, it can never be excluded that a fire will break out nevertheless. The causes range from criminal arson to the negligent handling of open flames, from defective electrical installations to the improper operation of electrical equipment. A remarkable court judgement in this context (OVG Münster, 1987) points out:

> "It is inherent to our life experience, that we must reckon with an outbreak of fire at practically any time. The fact that, in many buildings, no fire has broken out over a period of even decades, is still not proof that no risk exists; it is for the party involved merely a fortunate circumstance, an end to which must be expected at any time."

It is decisive, therefore, that fire protection planning and project execution employ suitable measures to limit the consequences of a fire to the extent that "life, health and the natural environment" are no longer endangered.

2.3 Risk assessment in building codes

The focus for risk assessment in building codes is the potential endangering of public safety by buildings and similar structures. The conditions imposed on the basis of such risk assessment, if properly observed, are able to guarantee an acceptable safety level. This empirically evolved safety level represents a social consensus balancing the preventive measures it is reasonable to demand against an accepted residual hazard.

Since the mid-1990s, there have been renewed heated discussions of the fundamental measures contained in building codes, championing catchwords such as liberalisation, deregulation and privatisation, but without adequate studies of the effects for the attainable safety level. It is generally only after disastrous cases of failure, such as the Düsseldorf Airport fire in 1996 or the Bad Reichenhall ice rink collapse in 2006, that more appropriate approaches are taken.

The discontinuation of official acoustic and thermal insulation verification at the end of the 1990s resulted in a distinct loss of quality, but was not decisive for public safety. On the other hand, the planned exemption from structural inspection for special buildings and the private commissioning of check engineers, which have already been implemented in some German states, constitute serious impairments of the safety level.

The fact that changes in building designs, e.g. extremely lightweight roof constructions, may also result in safety deficits, was made visible by the numerous collapses of lightweight hall roofs under exceptional snow loads during the winter of 2005/06. Increasing of the standard snow loads with introduction of the new DIN 1055-4, in mountain areas up to 150% in some cases, has now taken this into account.

Another example for the consequences of a controversial softening-up of building code requirements is presented in an essay in the German fire services journal [9]. Whereas the roof constructions of areas and rooms for public use were still required to display a fire resistance of 30 minutes into the 1990s, this provision is no longer to be found in the new model building code. Consequently, more and more nail-plated timber trusses are encountered, with the risk of almost immediate collapse in case of fire. The afore-mentioned journal contribution lists 15 supermarkets in Germany where an outbreak of fire led to a total collapse within only a few minutes, fortunately without fatal consequences. In the USA, however, fire-fighters have been killed in similar cases.

3. Risk-based safety concept for pre-emptive risk management

To improve the efficiency and transparency of the system for pre-emptive risk management, it is necessary for the safety concept underlying this system to be adapted more specifically than in the past to the results of risk analysis. Applying the previously mentioned definition of risk, this demand, which GOFFIN already raised in similar form in 1996 in his fundamental assessment of building safety [5], means that both the consequences of failure and the probability of occurrence must be investigated more precisely to assess the safety concept.

3.1 Classification of the consequences of failure

When the fundamentals of structural design planning were established finally for the whole of the EU with the publishing of the European standard EN 1990, which as DIN EN 1990 also acquired the status of a German standard in 2002, definitions became available for the now generally binding classification of the consequences of failure. Although the standard refers primarily to structural stability, the general formulations of failure consequences in the resultant table enable the same classification to be applied equally to the risks in case of fire.

Consequence class	Characteristics	Examples of buildings or other civil engineering works
CC3	Severe consequences regarding loss of human life, and very serious economic, social or environmental consequences	Grandstands, public buildings where the consequences of failure are high (e.g. concert hall)
CC2	Medium consequences regarding loss of human life, and considerable economic, social or environmental consequences	Residential and office buildings, public buildings where the consequences of failure are medium (e.g. office building)
CC1	Minor consequences regarding loss of human life, and minor or negligible economic, social or environmental consequences	Agricultural buildings without regular public access (e.g. barns, greenhouses)

3.2 Classification according to the probability of failure

Risk assessment must be based not only on the consequences of a failure, but also on the probability of its occurrence. This aspect plays a role above all in the evaluation of safety deficits in the field of structural stability. The decisive factor contributing to the probability of failure due to human error is indisputably the complexity of the load-bearing structure of a building. In both the scale of fees for architects and engineers [10] and in practically identical wording in the model ordinance pertaining to check engineers and verification experts, load-bearing structures are divided into five zones or classes in accordance with their degree of complexity:

- load-bearing structures with a very low degree of complexity
- load-bearing structures with a low degree of complexity
- load-bearing structures with an average degree of complexity
- load-bearing structures with an above-average degree of complexity
- load-bearing structures with a very high degree of complexity

Whereas, as experience shows, the frequency of errors in connection with sload-bearing structures with a low or very low degree of complexity is still quite limited, a significantly greater number of errors can be expected in case of average or higher degrees of complexity, and such errors are at the same time more serious.

3.3 Differentiation in the state inspection and monitoring of buildings

Based on the results of the risk analysis, backed up by many years of experience, the German Association of Check Engineers (BVPI) proposes a uniform concept for structural stability and fire protection. On the basis of this risk-related safety concept, the state inspection measures could be organised more efficiently and with differentiation.

In accordance with the individual phases of planning, execution and building use (cf. block diagram), the following state inspection and monitoring measures are necessary:

1. **Buildings and structures with high danger potential or high safety risk (CC3)**
   This category includes, in the sense of the model building code, all special buildings and all buildings or installations whose supporting structure displays a high or very high degree of complexity (fee zones IV and V of HOAI). In the classification defined by EN 1990, this building category corresponds to consequence class CC3.
   - In the case of new projects, the processing of the building application must include evaluation of the structural stability and fire protection verification, as well as corresponding monitoring during construction.
   - In the case of existing buildings and structures, a recurring inspection of the structural stability and fire protection should be performed at least every five years.

2. **Buildings and structures with medium danger potential or medium safety risk (CC2)**
   This category includes, in the sense of the model building code, all buildings of building classes 4 and 5, as well as all buildings or installations whose load-bearing structure displays an average degree of complexity (fee zone III of HOAI). In the classification defined by EN 1990, this building category corresponds to consequence class CC2.
   - In the case of new projects, the processing of the building application must include evaluation of the structural stability and fire protection verification, as well as corresponding monitoring during construction.
   - In the case of existing buildings and structures, a recurring inspection of the structural stability and fire protection could be necessary in case of safety-relevant damage or defects.

3. **Buildings and structures with low danger potential or low safety risk (CC1)**
   This category includes, in the sense of the model building code, all buildings of building classes 1 to 3, insofar as their supporting structure displays only a low or very low degree of complexity (fee zones I and II of HOAI). In the classification defined by EN 1990, this building category corresponds to consequence class CC1.
   - In the case of new projects, the inspection could be limited to a simplified evaluation of the building application, insofar as no serious defects or errors are revealed.
   - In the case of existing buildings and structures, a recurring inspection is only necessary in case of safety-relevant damage or defects.

To relieve the building authorities, the evaluation of structural stability and fire protection verification, together with the corresponding construction monitoring, should be handled as far as possible by state-approved check engineers. The renewed inspections of existing buildings should in general also be entrusted to check engineers. To ensure their necessary independence, it is important that the check engineers be appointed by the building authorities.

To guarantee proper functioning of the system of state inspection and monitoring, it is indispensable to maintain the technical responsibility of the building authorities.

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