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AN APPROACH TO STRUCTURAL INTERGRITY OF BUILDINGS

METODA STABILNOŚCI KONSTRUKCJI DLA BUDYNKÓW

Streszczenie Na początku 2006 roku kilka budynków w centralnej i wschodniej Europie zawaliło się w wyniku dużego obciążenia śniegiem, pokazując poważne niedociągnięcia zarówno przy projektowaniu i budowie jak również w utrzymaniu i kontroli technicznej obiektów budowlanych. Mimo, że szczegółowe i kompletne normy budowlane (np. normy europejskie [1] [2] jak również normy krajowe [3] [4]) powinny zabezpieczać budynki przed zawaleniem, staje się oczywiste, że przestrzeganie norm jest konieczne, choć nie wystarczające aby zapewnić stabilność konstrukcji w całym okresie użytkowania. Odnosząc się do sytuacji w Niemczech, Normy dotyczące przeglądów technicznych istnieją tylko dla mostów, niektórych konstrukcji specjalnych [5] oraz ogólnie dla budynków należących do niemieckich kolei [6]. Reakcją rządu na zawalenie się zadaszenia lodowiska w Bad Reichenhall (Fot. nr 1) była decyzja o wydaniu rozporządzenia w sprawie generalnych przeglądów obiektów użyteczności publicznej [7]. We wrześniu 2006 roku na konferencji ministerstwa budownictwa opublikowano więcej ogólnych zaleceń, w tym zakresie [8]. Firmy TIS i LGA w 2006 roku, w oparciu o gruntowne przeglądy ponad 700 budynków pokazały, że stabilności konstrukcji budynków nie da się osiągnąć tylko poprzez przeglądy techniczne, lecz konieczne są również odpowiednie pomiary wykonywane zarówno w trakcie budowy jak i w czasie eksploatacji budynków.

Abstract In early 2006 several buildings in Central and Eastern Europe collapsed under heavy snow loads revealing severe shortcomings as well in planning, construction and erection as in maintenance and inspection. Although extensive and complete building codes (e.g. EUROCODE [1] [2], national standards [3] [4]) should prevent building structures from collapse it became obvious that observation of standards is necessary but not sufficient to assure life time integrity of structures. Referring to the situation in Germany codes for the inspection of structures existed only for bridges and some special constructions [5] and more general for civil structures belonging to the German Railways [6]. As a reaction of the collapse of an ice stadium in Bad Reichenhall (fig. 1) the federal government decided to issue a regulation for the inspection of all buildings under their possession [7]. In September 2006 a more general advice was published by the conference of the ministers of the ”Länder” responsible for civil engineering [8]. Based on inspections on more than 700 buildings done by TIS and LGA starting in 2006 this contribution will show that structural integrity of buildings cannot be achieved only by inspections but that adequate measures must be implemented in all phases of their life cycle.

1. Life Cycle Considerations

The life cycle of a structure is defined by the phases

- planning
- construction
- using period
- demolition

where the using period is normally the longest period, often attended by as well changes in use and structural characteristics as repair of structural components.

Structural changes and repair works are forming partial processes in the total life cycle as shown in fig. 2.

Fig. 1: Collapsed ice stadium (January 2006)

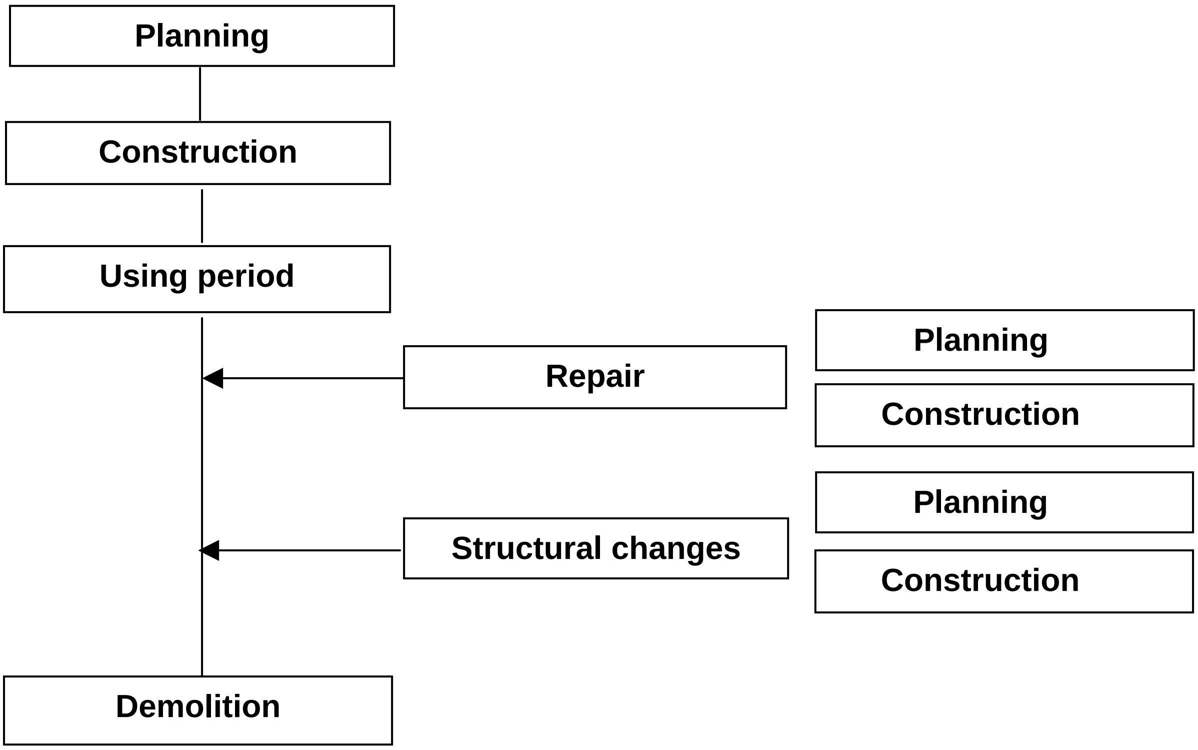

Fig. 2: Life cycle of building structures

From the very beginning until the end of the life cycle the structure will be affected by negative influences from nature or man made (fig. 3) which will be shown later on some examples we found during our inspections.

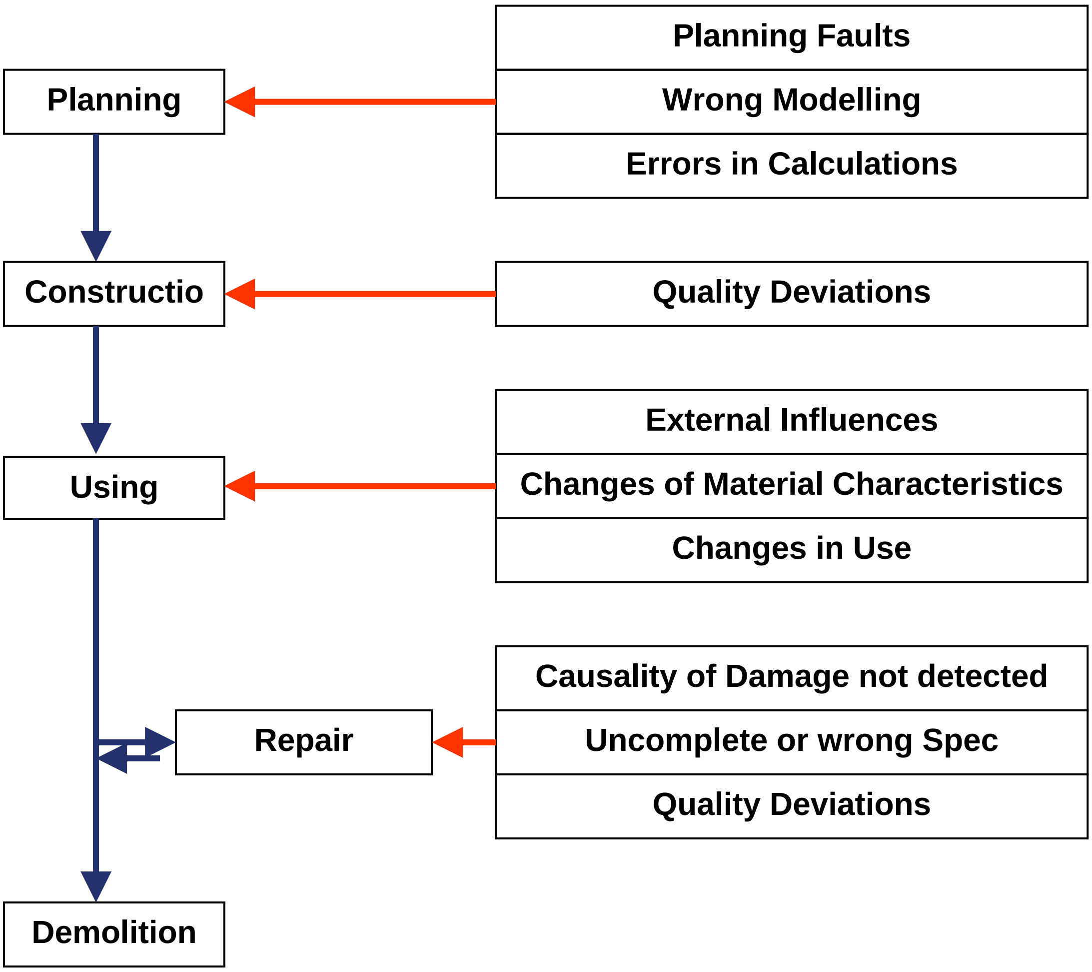

Fig. 3: Affections of structural integrity during life cycle

2. Some Examples

Faulty Planning

The example in fig. 4 and 5 shows a connection of the ceiling structure to an under dimensioned wooden window construction resulting in 250 % exceeding of allowable stress.

Fig. 6 shows damages of a concrete structure resulting from shear forces acting in the beam – column connection.

Fig. 4: Ceiling on wooden window frames

Fig. 5: Detail of connection ceiling to window frame

Fig. 6: Concrete structure with insufficient shear resistance

Faulty Construction

The construction in fig. 7 shows a connection of trusses with insufficient distances of bore holes to the end of the inner beam.

Fig. 7: Insufficient distance of bore holes

A very common fault are sinks on flat roofs not situated at lower points resulting in an additional load from the weight of water (fig. 8). Especially when frozen this weight together with snow loads can exceed design loads. The same effect – even worse -results from tamped sinks which is a problem of a lack of maintenance.

Fig. 8: Wrong position of a sink on a flat roof

An even worse situation is shown in fig. 9. Here an extremely bad repair of the roof coating led to a penetration of water to the bearings of the wooden trusses. The concrete structure of the bearings are heavily affected by corrosion (fig. 10)

Fig. 9: Bad repair of roof coating

Fig. 10: … resulting in corrosion of the bearing

Changes of Material Characteristics

Especially wooden constructions tend to form fissures in longitudinal direction of the fibres resulting from the drying process of the material. Although fissures with a depth not exceeding 60% (bending) resp. 46 % (shear) of the beam width should not affect the bearing capacity of the structure [9] a total separation of beam parts will heavily decrease the load resistance of the structure (fig. 11).

Fig. 11: Wooden truss divided by a penetrating fissure

Many problems in wooden structures arise from humidity causing growth of mould fungus and subsequently drastic changes in material strength (Fig. 12).

Fig. 12: Wooden truss affected by humidity

In steel and concrete structures changes of material properties are widely caused by corrosion (fig. 13 and 14).
Moreover the characteristics of structures can be altered by mechanical damages (fig. 15).

Fig. 13: Corrosion of ferro-concrete due to insufficient covering

Fig. 14: Corrosion of a steel column due to leaks in water draining

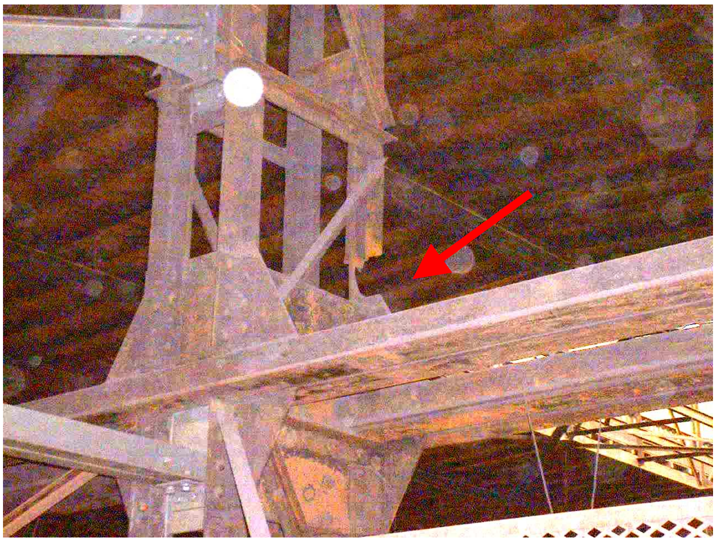

Fig. 15: Destruction of a steel structure by shell fire

Uncalculated Loads

Beside unexpected natural phenomena like very heavy storms, ice and snow heavily exceeding the load assumptions of the standards which are extremely singular changes resulting in increased loads not assumed in the static calculations will form a significant risk for the structure.

Additional Water load on flat roofs was mentioned above already. One more hidden effect of rain on not tight roofs or condensate is the penetration of isolating material in the roof construction by water. In some cases up to 600 l per square meter of water were found resulting in a load increase of 6 kN/m² (fig. 16).

Fig. 16: Water penetration into isolating material

Fig. 17: Additional roof loads

More obvious is the increase of loads by additional equipment on the roof without any static proof. An illustrative example is shown in fig. 17 where water filled pipes were laid on the roof.

3. Measures to Minimize Risks for Structural Integrity

From the examples shown above it is evident that a broad variety of risks affects the structural integrity of structures.
A strategy with the aim to minimize these risks must implement

- prevention
- detection

Prevention asks for a quality control process – preferably by an independent third party surveyor – of all partial processes during planning and construction of the structure including a final delivery inspection to guarantee that the necessary characteristics are realized. This survey procedure has to be adapted also to later changes and repair works.

Since every structure is exposed to an aging process maintenance is an unaffordable effort to secure the value and integrity of buildings. In this context detection of changes in structural properties needs regular inspections of the structure as well by the owner or his delegate as by experts.

The elements for the prevention and detection of structural risks are shown in fig. 18.
From this four crucial demands can be derived:

Demand I: **Planning must include the requirements of maintenance and inspection**

Demand II: **Quality procedures must be integrated in all planning and construction phases to secure the observance of standards and specifications. This includes also a final delivery inspection.**

Demand III: **Maintenance and inspection plans must be specified, realized and adjusted if necessary.**

Demand IV: **Planning, construction, inspection results, maintenance activities and changes of the structure must be documented.**

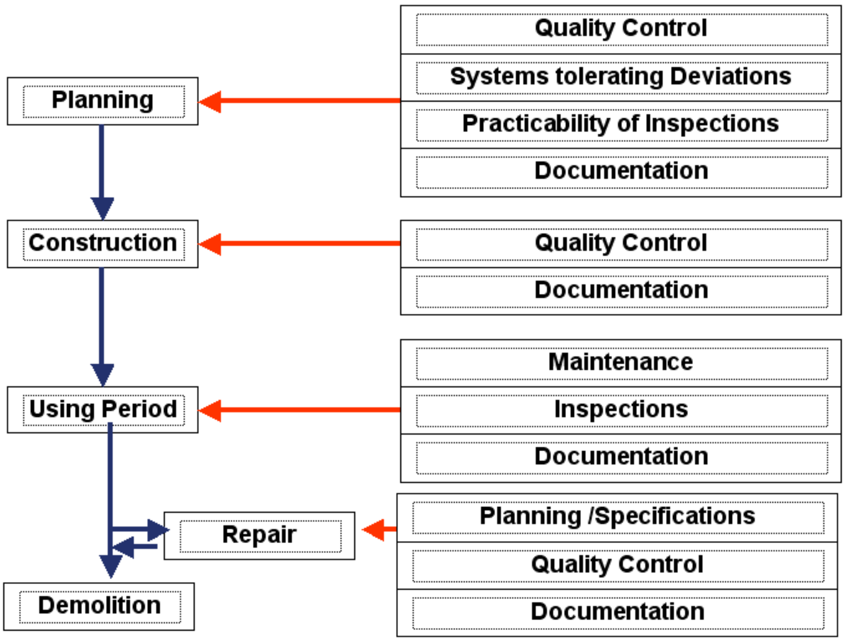

Fig. 18: Elements for the prevention and detection of structural risks

4. Inspection Plan

From long time experience with inspection of bridges an other civil structures a hierarchy of inspection intensity is preferable:

- Continuous observation of the structure by skilled persons (owner)
- Inspection by inspectors specialized on integrity of structures
- Inspection by experts for the integrity of structures
- Special inspection when singular incidents have acted on the structure

The inspection density should depend on the characteristics of the structure defined by:

- Vulnerability
- Loads (intensity and density)
- Risk of injuries and damages

From this ArgeBau in Germany came to the inspection schedule presented in fig. 19.

1	2	3	4	5
Category	Type of Structure and Exposed Parts	Observation after … years	Inspection after … years	Intense Inspection after … years
1	Assembly halls for more than 5000 people	1 – 2	2 – 3	6 - 9
2	Building structures more than 60 m high Buildings and parts of buildings with spans > 12 m and/or cantilevers > 6 m and large roof constructions Exposed parts of buildings with special risk potential	2 - 3	4 - 5	12 - 15

Fig. 19: Inspection intensity after Argebau [8]

Further the regulations of ArgeBau demand for a building documentation including all relevant plans, specifications, static calculations and inspection reports.

Significantly shorter inspection periods are given in DIN 1076 (referring on bridges) RiL 804 of the German Railways (Fig. 20):

	DIN 1076	RiL 804
Observation	Continuous/ 1/2 year	½ year
Survey	1 year	---------------
Inspection	3 years	3 (6) years
Intense Inspection	6 years	6 (-) years

Fig. 20: Inspection intensity after DIN 1076 and RiL 804

RiL 804 defines two categories of structures to which buildings are related according a numeric valuation scheme. This procedure was recently extended by the author [10].

Future experience must show whether the extended inspection intervals of ArgeBau will be sufficient. Especially the observation periods should be reduced to ½ year since skilled persons should report changes in the behaviour of the building structure as continuous as possible to induce necessary measures in the scope of a preventive maintenance strategy which is the most economic variant to minimize financial and safety risks.

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