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INSPECTION AND MAINTENANCE OF STRUCTURES OF LARGE FAILURE CONSEQUENCE CLASS - EXAMPLE TROPICAL ISLAND

All sustainable structural maintenance and therefrom excepted Life Cycle Performance has to be based on reasonable data management, done by the owner or the user. Knowing this, a few decades ago (in 1998) the German Federal Highway Research Institute led the development of a computer based building data management system for bridges. By limiting project on the bridges, which are up to 99% public property, the demands of the such system were reduced to reasonable size. At the time, the approach would not have been suit-able for other civil engineering structures for the reasons as: high variability of structural concepts, large amount of different structural components, concepts even within one single structure, multiple contractors at one building, high owner change rate, bad database, and so on. The structural failures during the winter 2005/06 demonstrated the urgent need for clear concept of Data Management and Controlled Structural Maintenance for other civil engineering structures, besides bridges, once again. Responsible owners recognise that and react accordingly, with the fundamental demand of controlled maintenance for structures. It can be facilitated with appropriate model similar as for the bridges. As example, a-step-towards-a solution is presented on the Tropical Islands Dome south-east of Berlin, the largest free span Dome in Europe. Basic considerations herein are: practical use for the owner from today onwards, easy updating, long durability, low permanent costs, and some others. This can be done following High-Brain/Low-Tech concept knowing that such basic electronic formats are often used to deal with a very complex structures. The expected result is an easy-to-use database for the structure and controlled maintenance of structures over their service time in next decades. It is an example for treating the problem with the aim of keeping maintenance costs predictable and aims to fulfil the precondition of every structural design code in order to keep the calculated safety level – *adequate maintenance over the structure service time*.

Keywords: structures, inspection, data management, assessment, maintenance

1. INTRODUCTION

1.1 PROBLEM

The collapse of a couple of wide-span structures during the last decades and the accumulated failures during the winter 2006 (after the structural collapse of a glulam roof of an ice hall in Bad Reichenhall in Germany, a steel roof of single-story exhibition in Katowice in Poland and a reinforced concrete roof of a supermarket in Moscow in Russia with a death toll of 120 persons) forced officials to focus on the problem of scheduled and controlled maintenance on high rise structures.

Basis of all proposals is the existing system for assessing and maintaining bridges. Here, a staged schedule in intensity is given (DIN 1072). The system and according software for structural maintenance and documentation were developed by the German Federal Highway Research Institute and prescribed (BMV, 1998).

As reaction on these accumulated failures of the fundamentally well-designed structures, the new system was established, with intention to be used later for building constructions within large failure consequence classes (ARGEBAU, 2006). The task is not easy as it may seem.

1.2 REGULATION BY LAW

The owner of a structure is responsible by the law for obtaining sufficient safety, §3 MBO (ARGEBAU, 2002). This is also the fundamental demand of Eurocode 1 (EN 1990-1). Despite a couple of regulation on fire safety and the safety of other technical components (fume outlets, elevators etc., summarized list in (AIG, 2006)).

Until now in Germany there was nearly nothing that introduced such structural demands to the owners. An exception are some hints in (DIN 32736). Also, regarding Swiss concept of a safety and utilization plan, less or nothing is known by engineers in practice (Schneider, 1994). The demand of a sufficient structural documentation is neglected both by the owners and the officials at the moment. Anyone can prove this by simply visiting any public archive.

1.3 APPLICABILITY TO BUILDING CONSTRUCTIONS

It is not possible to apply unmodified the system for bridges (BMV, 1998) to building constructions, opposite to what the guideline by the ARGEBAU (ARGEBAU, 2006) suggests. There are two main reason. These are the higher diversification both in the ownership and in the structural details. Both is linked to significant higher reconstruction rates. These are some reasons which prevent the development of a special software. At the moment, the question arises if the simple sufficient inspection system can be reached easier and with less technological effort. This shall lead to a higher acceptance by the owners than a statement “it is prescribed by law” does.

2. SOLUTION APPROACH

2.1 PREPARATION OF A BUILDING DOCUMENTATION

Usually every structural work is completed with an “As Build” documentation. For building constructions this must be done by architects and engineers in the “Service Rendering Phase 9” (HOAI 2002).

In times of budget control this position is sometimes not included in the according contracts. Even if this Service Rendering Phase is done during erection of the building, documents were very seldom carried forward. So, the first step is the preparation of a building documentation. Of course, this documentation can be made in a scientific database as e. g. the one used by the Gemeinsamer Ausschuss Elektronik im Bauwesen (GAEB, 2007). But until now, these approaches are still under development and the main demands: sustainability and accessibility of the data are not fulfilled. So, the best practice approach is, in the opinion of the authors, a simple text document, accompanied by drawings in a *.pdf; *.dxf and *.dwg format. These documents shall contain all necessary information about the structural details according to (DIN 1072). Especially important are overviews As-Built drawings in an appropriate scale. From a practical point of view these blueprints shall not exceed the size DIN A1. These drawings are needed to document all future inspection results.

Table 1. Service Rendering Phase 9

standard activity	special activity:
- Inspection for warranty covered defects - Inspection of rehabilitation of warranty covered defects	- As build drawings - Inspections - Inspection and maintenance plans - Generation of an object documentation - …

2.2 INSPECTION SCHEDULE

The inspection schedule is proposed in the guideline by the ARGEBAU (ARGEBAU, 2006). This guideline rules the minimum qualification of the personal and the minimum inspection amount. If this guideline is sufficient, and if it is applicable to a structure with a large consequence class in practice will be presented at an example in the succeeding chapter.

2.3 INSPECTION AND MAINTENANCE DOCUMENTATION

It is not described how the results have to be documented and how an assessment of the condition of the structural components has to be done. The existing grading system for bridges may be a solution. There, grades were assigned for the load carrying capacity, the usability and the durability of components or the building. This assignment is done according to the influence of a damage. These grades provide a decision support to schedule maintenance and other actions.

Table 2. Inspection Schedule

category	type of building	inspection	detailed inspection	extensive inspection
		every N years		
I	Buildings with more than 5000 users	1-2	2-3	6-9
II	Structures with more than 60m height; 12m span; 6m cantilever beams and all other structures with high damage potential	2-3	4-5	12-15

Table 3. Inspection Guideline

performed	inspection	detailed inspection	extensive assessment
by whom	owner	e.g. structural engineer	e.g. check engineer
how	without tools	without tools	with tools, handclose
	checking structural elements for: cracks, excessive deflection, corrosion,… Check for decay promoting conditions: like leakage	As before and e.g. additional check by structures: Concrete: carbonization / chlorides / concrete cover corrosion / … Steel: loose screws / cracks in welds / corrosion / coating thickness / … Timber: splits / decay / moisture contend / … to be continued…	

3. EXAMPLE OF THE DOME OF TROPICAL ISLANDS

3.1 INTRODUCTION OF THE BUILDING NAMED TROPICAL ISLANDS

At the end of the 20th century a new generation of airships has been developed by the CargoLifter AG. Therefore, a new hangar for two airships has been built. With a span of 210 m, a height of 107 m and a length of 363 m it has been the largest single-story building in the world. The central part of the hangar is of a half-cylindrical shape consisting of five steel arches covered with a textile membrane. At both ends of the building are the doors which consist of two fixed and six moving elements. They form a semicircle in plan and a quarter-segment of a circle in elevation.

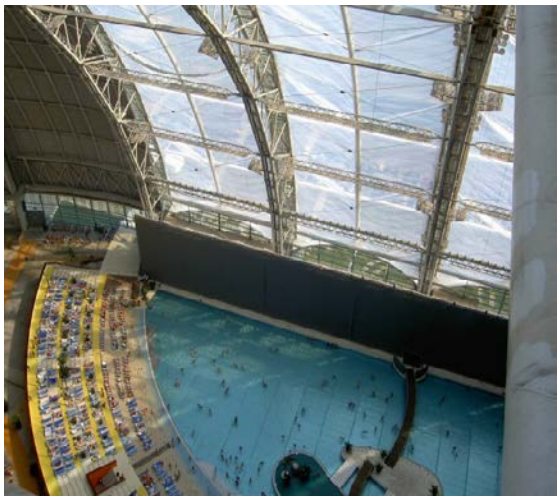

Figure 1. Tropical Islands Dome

After the breakdown of the Cargo-Lifter AG the real estate was bought by Tropical Island, and converted to a leisure facility. Within the former hangar houses in native tropical style (Fig. 1), a lagoon, a sauna and many other facilities were built-in. To generate tropical climate, raise a rain forest and gain additional sunlight it was necessary to dismantle the membrane from the southern side. Transparent ETFE cushions, supported by a cable net, were installed. The capacity is 8000 visitors, so the building belongs to the category I (Tab. 2).

3.2 BUILDING DOCUMENTATION / AS BUILD OVERVIEW DRAWINGS

Not only the first owner, Cargo-Lifter AG, but also some contractors went bankrupt during the last decade over this structure, so the owners changed several times. Also, the design-responsible officers were changed. This caused a significant loss of information about structural details. So, the first step was to write a summarizing building documentation As-Built overview drawings, including some standard details too (Fig.2).

3.3 INSPECTION SCHEDULE

The inspection guideline (Tab. 3) had to be extended and changed in detail. A couple of reasons therefore can be named. Structural parts have a different potential of structural failure. So, it will make sense to inspect the main arches more often or more in detail, than the infill of the gates. Also, it makes sense to check innovative and new structures, as the cushions, more often to detect early failure. At least, some inspection is already covered by inspection contracts like fume outlets, cushion and membrane structures, or need more often inspection like guard rails. A part of the inspection plan, here for the cushions, including technical components, is given in the Table 4.

A proper inspection plan contains also information about work preparation, inspection facilities.

3.4 INSPECTION RESULTS AND DOCUMENTATION

In Figure 3 two usual maintenance problems are shown. In the left picture of figure 3 the effect of the leakage in the facade is shown. Here it is linked to a basin-like structural detail. The water was already removed by vacuum cleaner. The solution is fixing of the leakage. On the right picture beginning of corrosion on the bracings is shown. It may be that the bracings have the thinnest paint cover. Here a new paint job is advisable during the next years.

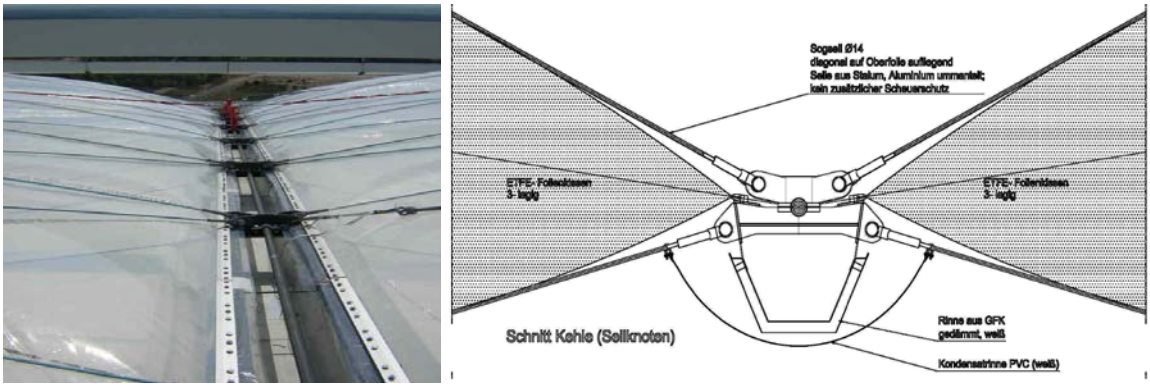

Figure 2. As-Built overview drawing: Detail of cushion

Table 4. Part of the inspection plan

every .... year				
0.25	1	3	6	
				Check Service Contract (DIN EN 13269)
				Check of emergency kit
				simple visual inspection on water penetration / damages
				Technical Components
				Check trouble indicator, document errors
				Check suction hole
				Open and close hatches
				Check sensors (Pressure / Temperature)
				Check sensor (Snow)
				Check sensor (Wind)
				Service Compressor VDI 3801
				Service Dehumidifier VDI 3801
				...

Figure 3. Some inspection results

Table 5. Documentation and assessment of inspection results

Date	Component	Subcomponent	Position	Who	Action	Result	Safety	Durability	Usability
???	Crane Runway	Crane Runway		Check Eng. Prof. Pasternak	Check Eng. Report	Acc. To report, not finished, no loads allowed	0	0	4
???	Fixed Gate	Weather Strip	D / 7-4	Trop.-Islands	Visual Inspection	Weather strip, heavy leackage, water at framework knots	0	2	1
???	Bracings		G-H / 4-7	Ceno-Tec	Check Pretension	Pretension to small	3	0	3
???	Main Arches	Windows	All Arches		Check	Cracks at the covering bead	1	1	1
???	Pillows	Inside Membran		Ceno-Tec	Check	Cracks, where the ropes separate	2	1	2
???	Gate 2	Gate Rails	B-C 6-7	????	Check	Drainage defect, 10cm water	0	2	1

It may be advantageous to document this inspection results (and the according maintenance) in a sufficient form. Here the grading system from the bridges may be adopted.

The three categories may be adopted: for safety, durability and usability. A grade of 0 means, similar to bridges, no effect. With a grade of 4 the component is not safe, durable and usable. An easy example for this case is the crane runway. It was not completed after the break down of CargoLifter AG. So, the cranes were not approved, but only the static load-carrying system by the check-engineer. So, it has no effect for safety, because using it is prohibited.

3. SUMMARY

It was possible to show, that even simple tools and limited efforts, can lead to a sufficient management of inspections and maintenance. So, the public demand on safety is accomplished. From point of view of owners, immediate advantages are arising: structural maintenance can be scheduled more efficiently, early failures are found during warranty. This win-win situation shall be communicated more aggressively to gain additional acceptance for the common aim: sustained and well maintained structures.

The retention requirements have been transferred to the owners in the newer building regulations, see e.g. §16 of the Brandenburg Building Regulation (BbgBauVorlV) of 2016. At the same time, the archiving requirements for the building authorities were reduced. Whether this increases the quality and availability of the inventory files is to be proved yet. It remains to be seen how the more recent efforts for introducing digital approval procedures (see final DBGV NRW from 2019) will ensure the long-term availability of the construction files. Together with the transfer of the retention obligation to the owners, permanent availability in this digital form is very questionable.

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