Failure analysis on timber structures in Germany

A contribution to COST Action E55

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1 Introduction

At the beginning of 2006 many timber structures in Germany and in the adjoining foreign countries collapsed. Although in the most cases the failure occurred under weight of snow, one cannot conclude with certainty that snow weight out of the ordinary was the single reason. Many recent failures show that a combination of more than one reason has to be considered to explain failure.
At present there is no integral statistical and systematic reflection of failures concerning timber hall (or wooden roof) structures. Most cases discussed in the literature are single assessments of failures. Therefore it was the main objective of this investigation to create the basics for an integral reflection.
The first step was to build up a database which contains relevant data concerning failures of timber hall structures. In turn therewith an appropriate system was to be developed accessing, analysing and showing the data. In this way answers to different research questions can be given.
A comprehensive and detailed description of the investigation will be given by Blaß and Frese 2007.

2 Recording data of failed timber structures

As a rule timber structures are assembled of recurrent structural parts. These in turn are connected to each other by recurrent construction principles. Hence timber structures belonging to a particular group – in this case timber hall structures – are well comparable to each other. This simplifies data recording and the common contemplation of damage and failure, respectively.
Mainly data coming from reports was used to build up the database. A system was developed for a quick and reliable capture. Therefore an Excel sheet is the database. A problem-oriented statistical analysis system serves for evaluation and visually represents the relationship between data values. It is programmed in such a way that evaluation and representation both is easily possible even if the database grows in the future.
The data capture works with parameters which can only take on different keywords. The scheme is shown in Fig. 2. Therein the parameters and an easily understand-

able selection of the most important keywords are repeated. Keywords can be found at the end of the branchs in the treechart.
The data are divided into five groups: parameters concerning

- the building,
- the components,
- the material,
- the damage and failure
- and the cause of the fault.

The building parameters are to make possible the following answers: Where do data come from, in which regions of Germany were the buildings constructed, what was the year of construction and the predominant use? In contrast to this, parameters concerning components and material are directly connected with the damage and failure. They give information about the bearing system, damaged components and their material. Fig. 1 exemplifies some keywords for components. Damage parameters are to describe the damage and failure, respectively. Primary damage as cracks in grain direction, and failures in terms of shear or tensile strength are of great importance. They prove the reliability of strength values of wooden products under real conditions during life of construction. This is a perspective differing from laboratory methods, which are used to derivate those strength values. Hence strength and weakness of material can be demonstrated against the background of the load history. Many reports provide for stability assessments. These were recorded too.
12 causes of the fault were defined. Building physics and construction are repeated as an individual cause of the fault in spite of originating in planning. This improves the clarity and underlines the importance. For the same reasons material quality appears as an individual cause although being affected by quality of work during production.
Ideally planning, building physics and construction concern the planning of buildings and therefore the planners, carrying out and assembly affect the building contractor and material quality the manufacturer (nearly without exception) of glulam. In this respect it is possible to link causes of the fault with persons being involved in the building and having a different function.

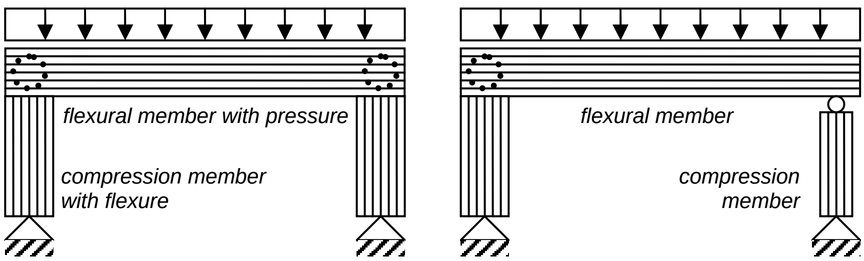

Fig. 1 Exemplifying keywords for components

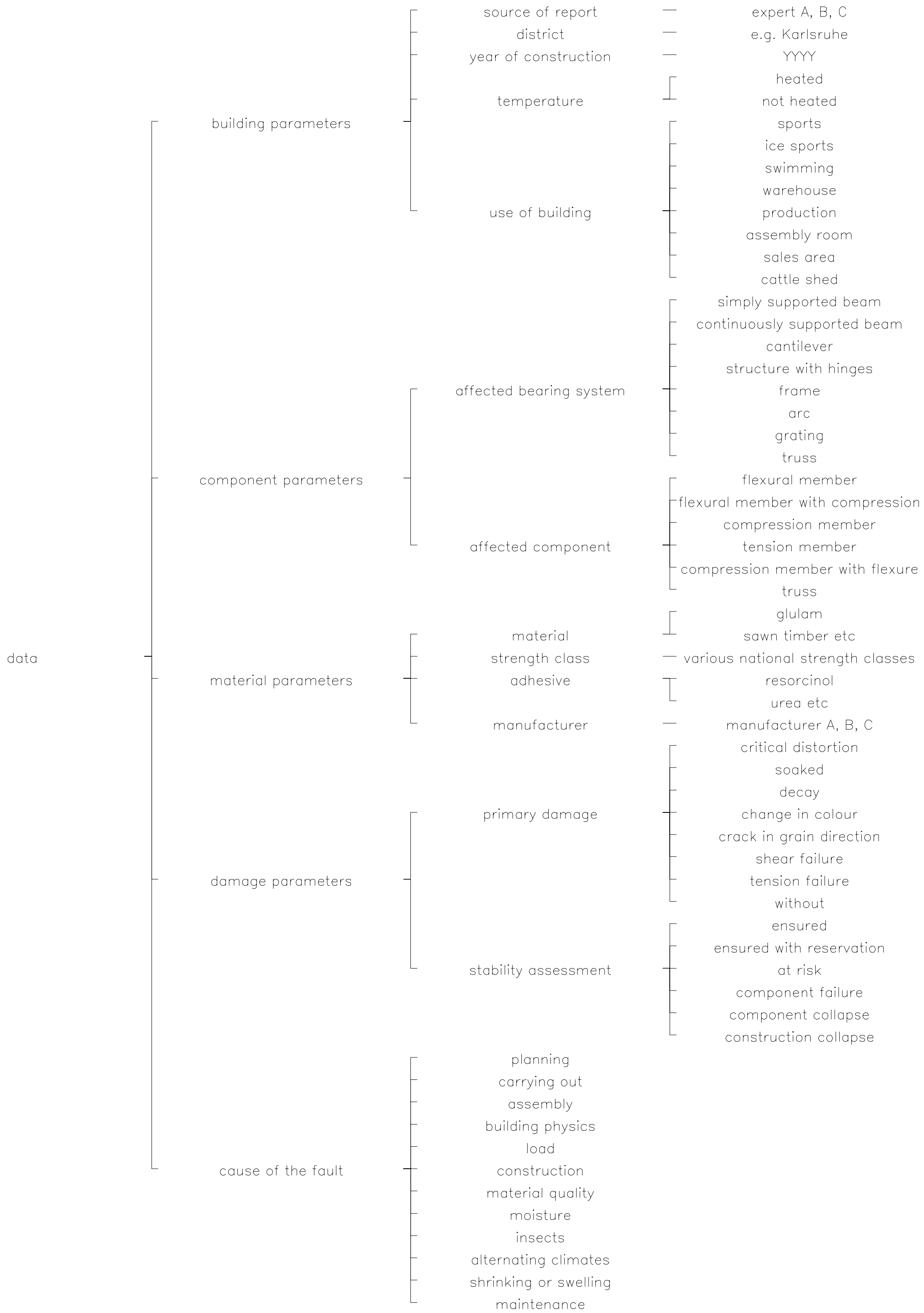

Fig. 2 Data structuring and small selection of keywords repeated at the end of the branchs at a time

Moisture, insects and alternating climates are wood specific critical influences. Shrinking or swelling is a physical law and occurs only in combination with e.g. the cause construction.

3 Description of the buildings and their failures

At present the database contains 140 records of explainable damage or failures. This number is suitable to show several typical mutual relations between parameters. It is therefore possible to give pointing the way statements to damage and failures of timber hall structures. This also presents the performance of the system to capture and to represent data. Significant statistics will only be possible until further cases of damage are recorded.
In the rule it is the owner’s care of construction stability, of stability in value and of absolute use which triggers an expert report. Against this background the following data is to be seen. They do not reflect a representative picture of all timber hall structures.
Exemplary constructions with regard to planning, erection and proper use do not cause care. Hence data of those constructions nearly do not appear in the database. This should lead to the consideration why e.g. certain use, bearing systems and components are rarely or not mentioned in the statistics. And this necessitates a careful interpretation of the statistics, because no comparable data is given in the following charts.
Fig. 3 shows both the number of buildings about which expert advice was given and the number of detected primary damage. Hence 144 (140 explainable) cases of primary damage are apportioned to 92 buildings. The year of construction ranges from 1965 to 2006. The locations are scattered all over the former West German states (Fig. 5). An important statement is that data concerning failures in the former East German states was almost not available. Hence it can not be concluded that timber hall structures in the former East German states are free from failure. It is Sports or ice sports halls being frequently affected by damage (Fig. 4). Damage was mainly observed in simple or continuously supported beams (Fig. 6). This pie chart also shows clearly the frequency of the structural components referring to the different bearing systems. In most cases damaged components consist of glulam belonging to the national strength classes Güteklasse II and I (comparable with GL24 and GL28). Many different glulam manufacturers produced the material. Accumulations concerning particular manufacturers therefore can be excluded with certainty. The span of the bearing systems ranges from 6 m to 48 m. A histogram is given in Fig. 7 showing that large span is rare.
70% of the damage is allotted to cracks in grain direction. 6% each belong to shear failure, decay and tension failure (Fig. 8). The rest of 12% concerns serviceability and appearance of the components, which does therefore not affect the stability. The distribution of failure time indicates an accumulation in the months January to March.

According to the expert's assessments of stability one third of the constructions or components are at risk. Just under one third collapsed or failed. One quarter had an ensured stability. About the rest no statements were available (Fig. 9). This pie chart has a close connection to way of looking at life of construction. The great portion of constructions having stability at risk is striking (yellow slice). It is obviously possible to detect signs for stability at risk when a construction is inspected. Through it, it is timely possible to take steps to ensure stability and prolong construction life. A pie chart without the yellow slice would be a serious problem: That means constructions will loose their stability without any announcement. Hence the preventive maintenance (inspection and restoration) is very important.
Fig. 10 shows that individual constructions (hindrance of shrinking, curved beams or connections of cross girders) are the main cause of the fault. In addition alternating climates are of importance for cracks in grain direction. The influence of shrinking or swelling and causes of the fault concerning planning, building physics, load, carrying out and material quality is moderate. Undesirable consequences in terms of poor maintenance and assembly as well as moisture are rare.

4 Further research and outlook

The overall aim and exercise of future research is an analysis on some hundreds of failures of timber hall structures. Because of that it is planned to extend the database. At present 300 more cases of damage are available. An evaluation plus these cases enables a subtly differentiated analysis on damage and failures. This serves a deeper understanding of damaged timber hall structures, malfunctions and their systematology. The practical benefits may be:

- knowing about typical structural defects
- timely recognizing of beginning failures during inspections
- avoiding collapses
- extending the life of timber structures
- making use of the gained experiences in new timber structures

This will strengthen the position of timber buildings concerning safety and sustainability. Apart from this the knowledge can be used to develop a kind of manual for monitoring of existing timber structures and for critical constructions as well as their rules. This improves the safe handling of timber structures not only in case of damage.

5 References

Blaß HJ, Frese M (2007). Analysis on damage, cause of the fault and stability assessment of existing timber structures (only available in German language: Schadensanalyse, Schadensursachen und Bewertung der Standsicherheit bestehender Holzkonstruktionen). The report will be published by Universitätsverlag Karlsruhe, Karlsruhe.

6 Appendix

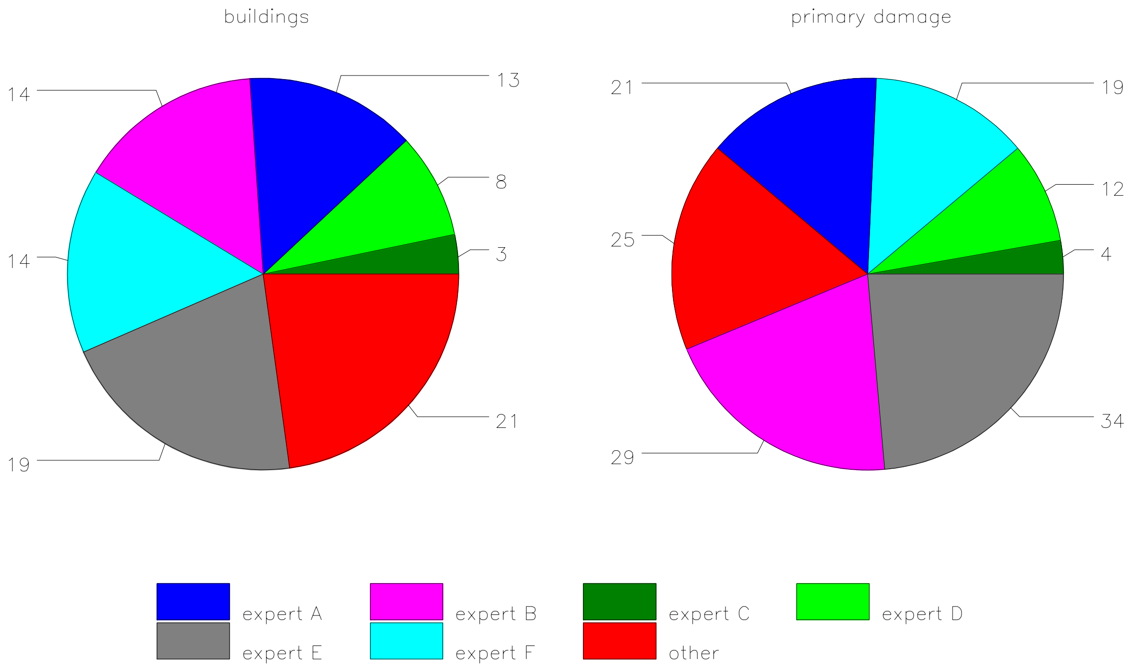

Fig. 3 Distribution of expert's reports and examined buildings, respectively (left) and detected primary damage (right)

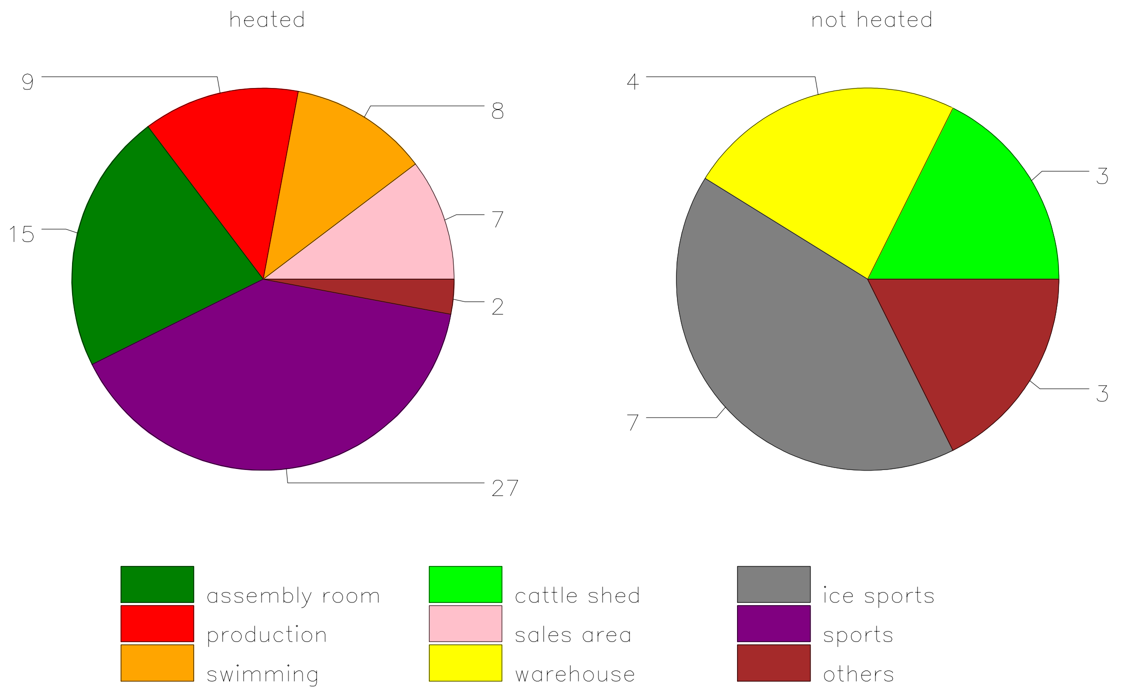

Fig. 4 Distribution of building use grouped according to heated and not heated constructions

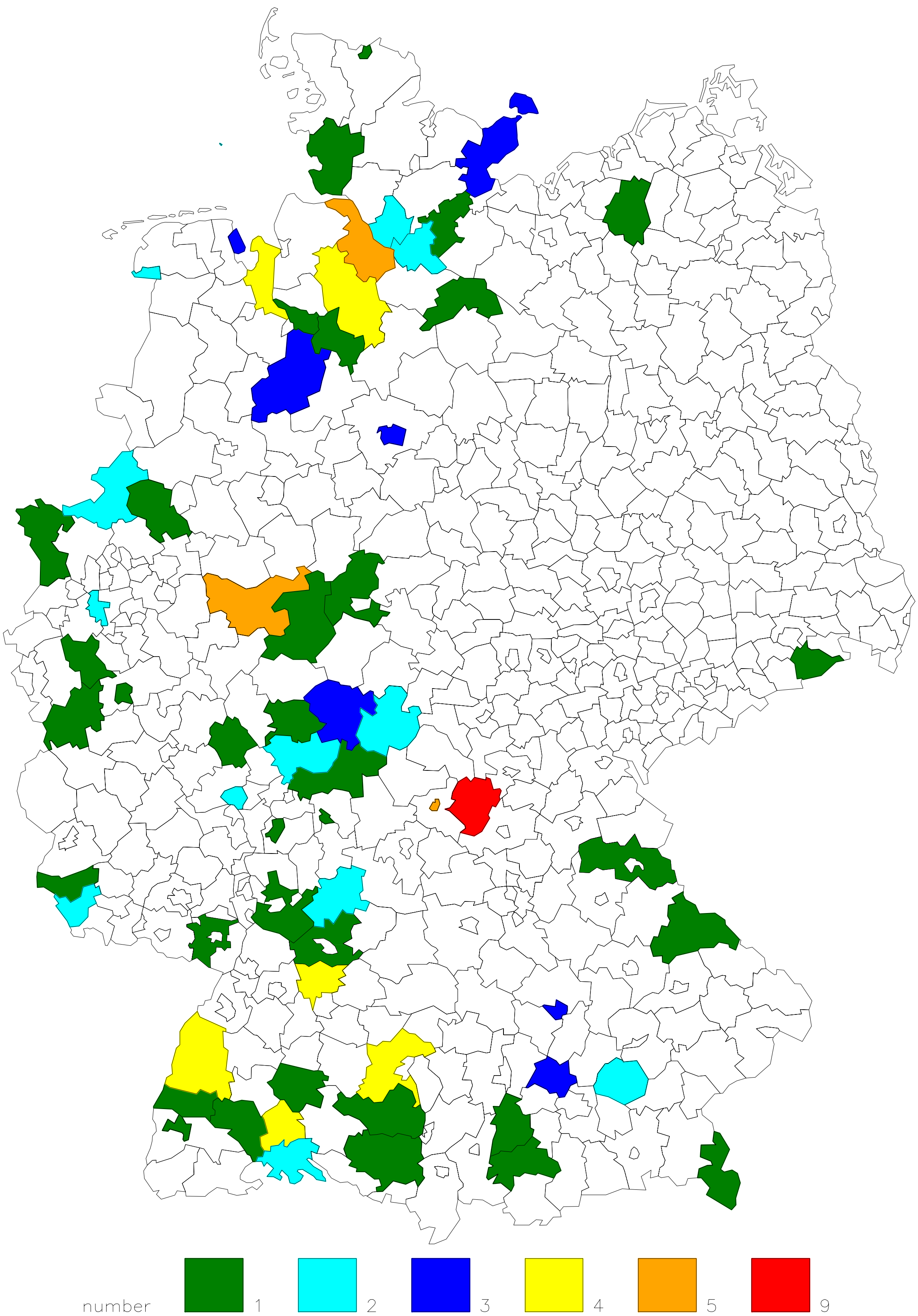

Fig. 5 Number of primary damage related to districts

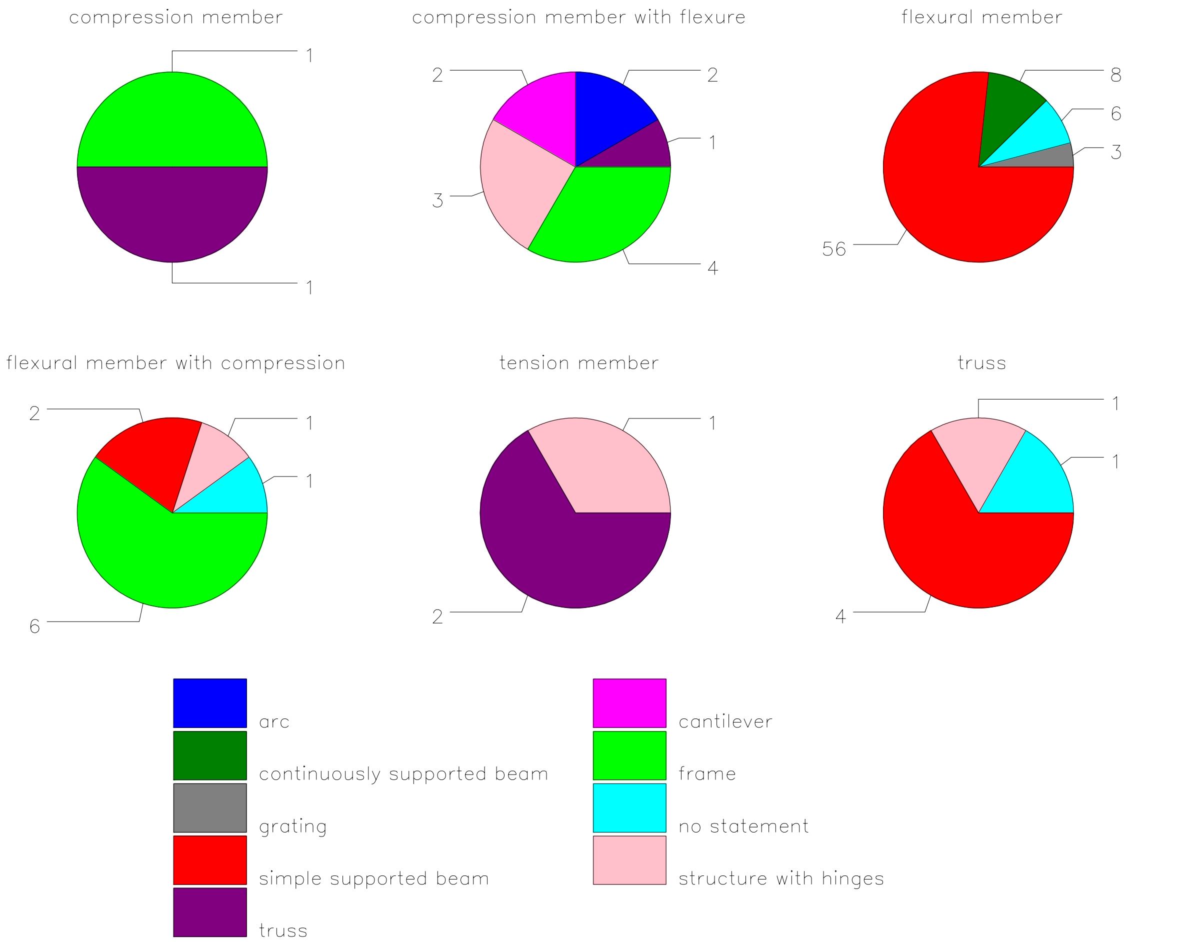

Fig. 6 Distribution of bearing systems grouped according to affected components; components with more than one case of damage are repeated once

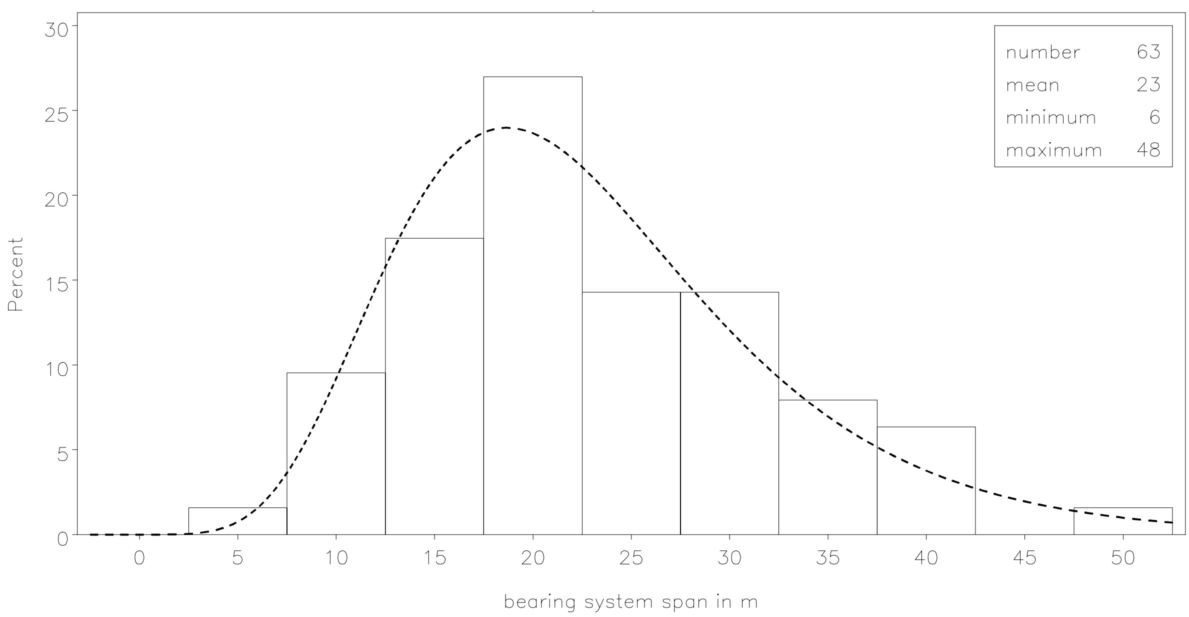

Fig. 7 Histogram and fitted lognormal density of the bearing system span

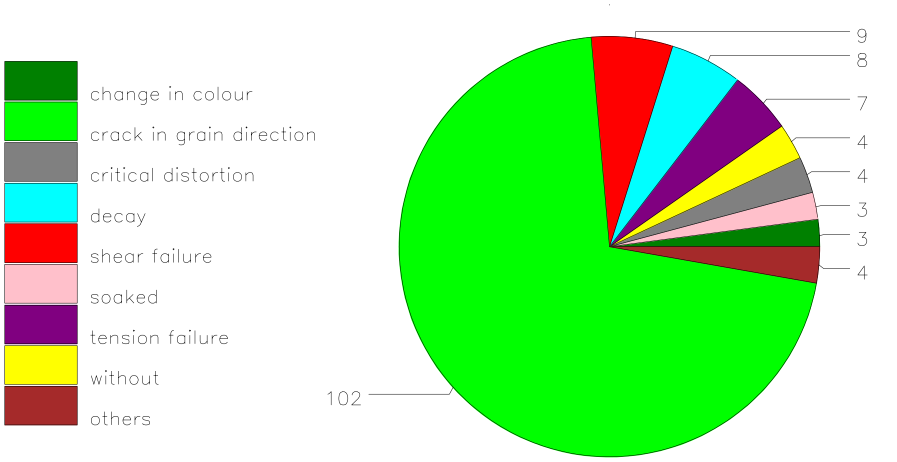

Fig. 8 Primary damage distribution

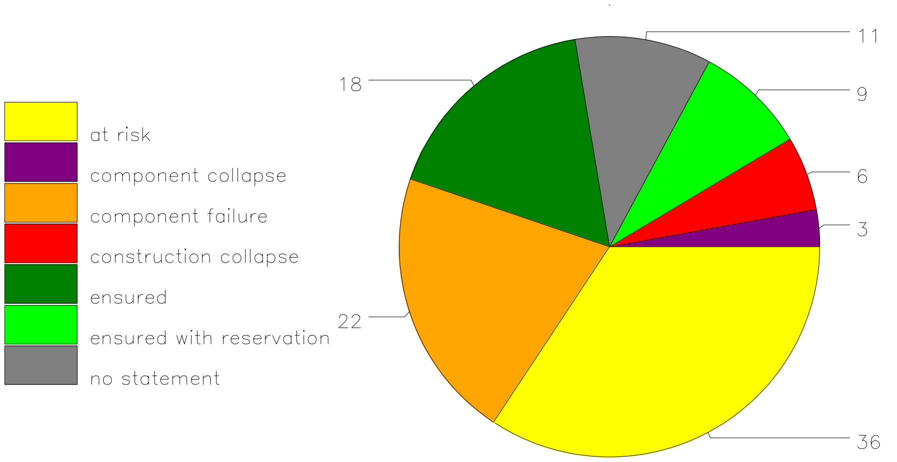

Fig. 9 Distribution of stability assessments; not only related to whole constructions but also to single components within a construction

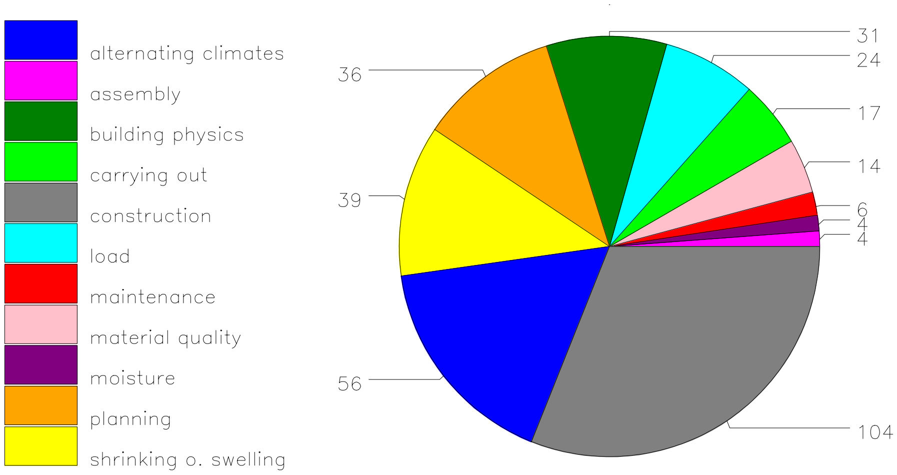

Fig. 10 Cause of the fault distribution; The total amounts to 335 due to multiple naming of cause of the fault with regard to a single damage.