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Failure modes and reinforcement techniques for timber beams – State of the art

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HIGHLIGHTS

- Review of typical materials, cross sections and forms of timber beams.
- Description of general failure modes and their possible causes.
- State of the art of established retrofitting and reinforcement techniques.
- Discussion of case studies for reinforcement techniques.

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ABSTRACT

Highly loaded and large span timber beams are often used for halls, public buildings or bridges. Reinforcement of beams may be required to extend the life of the structure, due to deterioration or damage to the material/product or change of use. The paper summarises methods to repair or enhance the structural performance of timber beams. The main materials/products cross sections and geometries used for timber beam are presented. Furthermore, their general failure modes are described and typical retrofitting and reinforcement techniques are given. The techniques include wood to wood replacements, use of mechanical fasteners and additional strengthening materials/products.

1. Typology of timber beams

Timber beams can mainly be classified according to the span, the geometry and the material/product used, as summarized in Table 1. The focus within this article is on high-performance, long-span structures. Table 2 gives an overview of typical timber beams in relation to the sizes of the cross section and the span ratio. In Europe, glulam members or block glued glulam members are the main construction elements used for large open span spaces, stadium roofs or bridges in which the primary structure is timber. The typical layered cross section of glulam reaches from 100 to 250 mm in width and up to 2500 mm in depth but also in larger dimensions as block glued glulam. Box or composite beams are alternatives providing a lower self-weight.

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2. Failure modes

2.1. General

Structures have to adopt, and transfer external loads to the ground and also to deal with the corresponding internal loads (normal force, shear force and moment). This leads to stresses and deformations in the structure which must not exceed design strength and deformation limits. In designing new structures, a full cross section with minor damage and correct material grades are assumed. However, in existing timber structures the cross section and/or the properties of the material/product of the members can be reduced due to mechanical and biological damage. Both types of damage influence the load carrying capacity and serviceability of single members or the complete construction. Within the assessment of timber structures, damage or failure has to be detected and assessed for the resistance and serviceability of the timber structure. The net cross sections observed at failures or damages must be compared to the designed cross sections.

Table 1
Classification of timber beams.

Category	Representatives, options
Material/product	Solid wood; glulam, block glued glulam; laminated veneer lumber; plywood; (OSB, LSL); cross laminated timber
Cross section	Solid cross section; box-beam; I-beam; T-beam; C-beam
Geometry	Straight beam; curved beam; tapered beam; truss

The failure analysis on timber structures in Germany carried out by Blass & Frese [1,2] gives a good overview of the distribution of main types of failure classified according to the construction, use and region. Most assessment reports state that the timber structures have been built using glulam beams of quality GL28h (see Table 3). Their shape, however, is more varied with the most common being, by order: straight (154/426), tapered straight (124/426), pitched cambered (90/426) and curved (47/426). 80% of the failure cases could be detected in bending members, followed by 8% in compression members. Furthermore in 75% of the failure cases cracks could be detected. Typical reasons and types of failure are summarized in Figs. 1 and 2. For high performing and long span timber members the typical failure modes are described in detail in the following sections.

2.2. Cracks

The most common type of failure, Fig. 2, was observed as the appearance of cracks in grain direction. The variation of the surrounding climate at a timber beam changes the moisture content and lead to shrinkage or swelling of the cross section. Non uniform distributions of the moisture content over the cross section and/or restraint deformations lead to internal stresses and, if the material strength is exceeded, to cracks in the cross section which can significantly reduce the capacity, Figs. 3 and 4. For the determination of the influence of cracks in timber beams on the residual load carrying capacity or stiffness no comprehensive methods are known. Methods and guidelines for this evaluation are currently under development at the Bern University of Applied Sciences.

The amount and distribution of cracks depends on several factors, such as timber, defects, loading situation, beam shape and the glueline quality for glued members. Regarding the distribution of cracks in the timber beams, a summary of their characteristics can be found in Table 4.

Table 3
Most frequent characteristics of the timber structures assessed, from [1,2].

Characteristic	Main result	Corresponding no. of assessments	
Material/Product	Glulam	594	80%
Quality (or equivalent)	GL28h	68	72%
Load type	Bending	470	80%

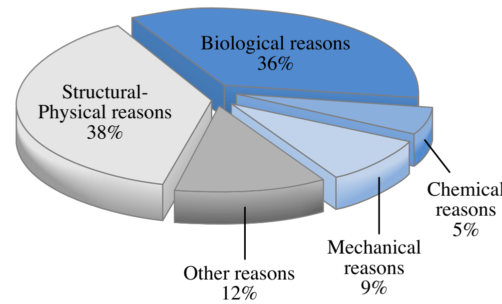


Fig. 1. Reasons for damages, [1,2].

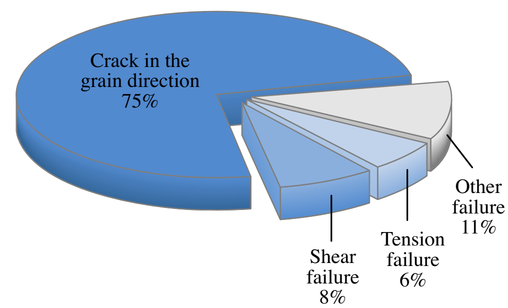
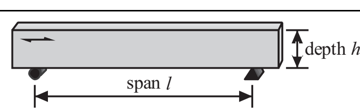
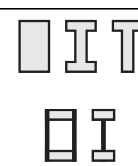
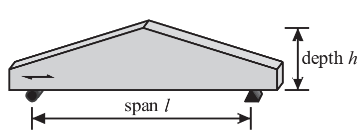
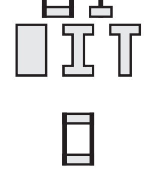
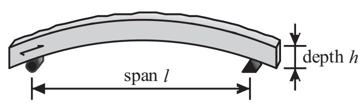
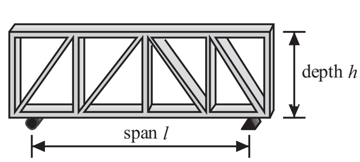
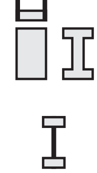


Fig. 2. Types of failure, [1,2].

Table 2
Overview of timber beam forms.

Timber beam form		Cross section	Span, depth ratio
Straight beams			10 m ⩽ l ⩽ 40 m $h \approx l/17$
Tapered beams			12 m ⩽ l ⩽ 25 m $h \approx l/15$
Curved beams			15 m ⩽ l ⩽ 35 m $h \approx l/17$
Trusses			20 m ⩽ l ⩽ 85 m $h \approx l/10$