Assessment and monitoring of the moisture content of timber bridges

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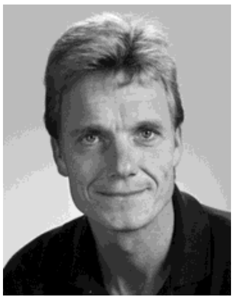

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Summary

Timber bridges are subjected to climate changes which result in the change of the moisture content of the wood and thus change of dimensions. But what happens with the wooden material due to the climate changes? Therefore four timber road bridges are long term monitored. In all cases, the moisture content in the wooden members was measured and analysed in relation to the prevalent climate. For the analyses of the distribution of the moisture content over the cross section or along the span, different sensors were positioned. The results confirm that the wood moisture content follows the climate changes. The reaction is delayed and with less variation compared to the calculated equilibrium moisture content. It was observed that the change of the moisture content differs over the cross section and along the span of the members.

Keywords: Timber Bridge, Monitoring, Moisture content.

1. Introduction

There are many historical timber bridge constructions around the world but also recently erected timber bridges in Europe and especially in Switzerland. Because of the hygroscopic material behaviour of wood, climate changes result in the change of the moisture content of the wood and thus change of dimensions as well (swelling and shrinking). For a reliable assessment, the material behaviour of wood due to the climate changes within a year or over the lifetime of the bridge has to be known. The changes of the moisture content have to be specified as well as the difference between the natural material axes or over the cross section of the structural members. The stress strain behaviour of wood under varying moisture content was mostly investigated in laboratory conditions, [1] - [4]. The investigations showed that there are differences in the moisture content over the cross section which leads to internal stress gradients. The research done by Häglund [5] - [8] showed that parallel to the absolute also the relative moisture changes and this influences the load capacity as well as the serviceability of timber structures. First investigations are also done for glulam and cross laminated timber, [9] - [15]. But the discussion for reliable approaches for the assessment or design is on-going and no recommendations have been published up to now.

Within a research project at the Bern University of Applied Sciences, four timber road bridges were long term monitored for two years and longer. The timber bridges are situated in different regions of Switzerland with various climate conditions. In all cases, the moisture content in the wooden member is measured in relation to the prevalent climate. The paper presents the measuring equipment used and the results of the moisture contents measured. For a comparison between the different measuring groups and positions, sensors were positioned close to the surface and further inside of the cross section. Furthermore sensor groups are located close to the end grain of the timber members as well as in a certain distance to the end grain or at the mid span in order to evaluate the distribution of the moisture content in parallel to grain direction.

2. Material and Method

2.1 Hygroscopic behaviour of the material

The hygroscopic behaviour of wood describes the adsorption and desorption of moisture to maintain equilibrium depending on the surrounding climate in particular relative humidity and temperature. The adsorption of moisture occurs in two steps in the range from 0 % to 30 % where the moisture is transferred into the cell walls of the wood. Above 30 % moisture content, the cell walls are completely saturated and the moisture is transferred into the cavities of the cells. The moisture content of 28 - 30 % is called fibre saturation point. The fibre saturation point varies depending on the wood species. Changes in the moisture content below the fibre saturation point affect the physical, mechanical and rheological properties of wood, like the shrinking and swelling, the strength values or the modulus of elasticity or rigidity, [16], [17]. The dimension changes are different in the three material axes (longitudinal, tangential or radial) as principle shown in Fig. 1.

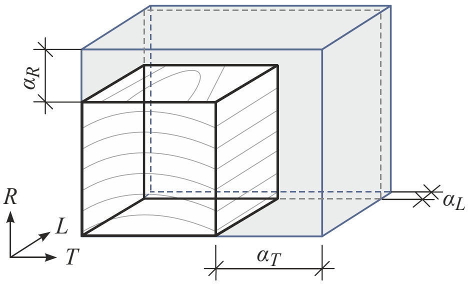

Fig. 1 Differential shrinking or swelling depending on the material direction

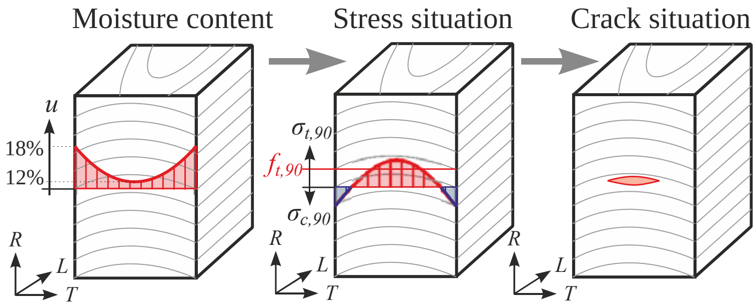

Fig. 2 Gradual increase of the moisture content and the stress reaction respectively crack growth

To reduce the initial change of moisture content in wooden members, they should be conditioned in such way that they meet the average moisture content which is expected in service. However, glulam and also block-glued glulam is been produced with a moisture content of 8 % to 15 % according to EN 386:2001 and will then mostly be installed with this moisture content, but the moisture content in service can be much higher depending on the application. Members in bridges in normal European climate conditions are expected to have a moisture content of around 15 % to 20 %, [18]. The moisture content within service class 2, for example, is allowed to vary of 8 % according to EN 1995-1-1:2004. It has to be noticed that a gradual increase of the moisture content of less than 1 % moisture content can theoretically already lead to excess of the material strength perpendicular to the grain (applying the characteristic properties for GL 24h). A gradual increase or decrease of the moisture content happens easily within the constructions and results in dimensional changes of the cross section and also in internal stresses, as shown in Fig. 2.

2.2 Bridges

The Bern University of Applied Sciences, the department of Architecture, Wood and Civil Engineering has been long term monitored four timber road bridges in Switzerland. The timber bridges are situated in different local regions with various climate conditions. The bridge “Horen” was erected in June 2008 and spans in total over 31 meters. The structural system consists of two main members of block-glued glulam four times supported and with secondary members spanning across for the deck construction, as shown in Fig. 3. The second bridge “Muotathal” is an arch bridge of glulam spanning a length of 32 meters, as shown in Fig. 4. The beam bridge “Obermatt” spans also over 32 meters. It is built with two main members with crossing secondary members, as shown in Fig. 5. The fourth bridge “Schachenhaus” is a timber concrete composite bridge, as shown in Fig. 6, which spans over 20.4 meters. The characteristic and details of the measuring equipment for each road bridge are summarized in Table 1.

2.3 Measuring the moisture content

The measuring of the moisture content can be done directly by the oven drying process in the laboratory of wood samples taken from the structure (destructive), or indirectly using moisture meters (non-destructive). Moisture meters work with the relation of the moisture content to certain physical properties like e.g. the electrical resistance, capacity or microwaves. Moisture meters are commonly used in praxis and also for long term measuring. For the investigation of the bridges, the

Fig. 3 Bridge Horen

Fig. 4 Arch bridge Muotathal

Fig. 5 Bridge Obermatt

Fig. 6 Bridge Schachenhaus

Table 1: Monitoring details of the timber road bridges

Bridge	Erection	Characteristics	Measuring period/ Measuring rate/ Measuring system	Measuring data, system
Horen	2008	Beam bridge Spruce Glulam Block glued	since Oct 2009 every 6 hours local system Mulitsensor + Materialfox	20 moisture content sensors 1 air temperature sensor 1 relative air humidity sensor
Muotathal	2009	Arch bridge Spruce Glulam Block glued	Oct 2009 - Dec 2011 every 6 hours local system Mulitsensor + Materialfox	16 moisture content sensors 4 wood temperature sensors 2 air temperature sensors 2 relative air humidity sensors
Obermatt	2007/2008	Beam bridge Spruce Glulam	since Dec 2010 every 6 hours remote system Gigamodul + Thermofox	16 moisture content sensors 4 wood temperature sensors 2 air temperature sensors 2 relative air humidity sensors
Schachenhaus	2000	Timber-concrete composite bridge	since Mar 2011 every 6 hours local system Gigamodul + Thermofox	8 moisture content sensors 2 wood temperature sensors 1 air temperature sensor 1 relative air humidity sensor

electrical resistance measurement method is used in combination with local data loggers or remote systems. Chrome steel screws with insulated shanks are used as electrodes, as shown in Fig. 7. Screws with certain lengths are applied in predrilled holes to measure the moisture content in different member depths. One measuring position for the electrical resistance always consists of one pair of screws with a distance of 32 mm between them. The orientation of the screws per pair is perpendicular to grain as known for the use of common moisture meters. The measuring result, the electrical resistance, is logged by commercial data loggers Gigamodul or Multisensor from Scanntronik Mugrauer GmbH Germany. After collecting the data, the moisture content is then calculated by the relation to the electrical resistance and corrected depending on the temperature.

In addition to the measuring of the moisture content the theoretical equilibrium moisture content of the wood is calculated based on the isotherms of sorption for spruce, the Keylwerth-Diagram [19].

As an example, the measuring plan for the Obermatt bridge is shown in Fig. 8. The measuring points are positioned at both ends symmetrically to the span of the bridge. They are grouped to measure the air temperature (LT_S) and relative air humidity (LF_S) as well as the moisture content at the surface (HF_S_OF) or inside the structure with a depth of 200 mm (HF_S_T). Furthermore two temperature sensors (HF_S_T) for the temperature correction are installed next to the moisture sensor groups. For long term monitoring, a remote data transmission system was installed in cooperation with the company mageba SA, [18], [20]. The data is collected every 6 hours and remotely transmitted every week. This provides a sufficient period to react when extensive changes in the moisture contents happen, e.g. because of any damages or defects in the construction.

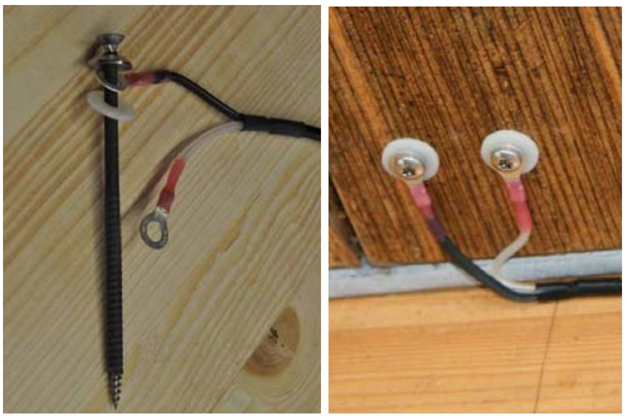

Fig. 7 Electrodes used with moister meter, uninstalled (left), and installed (right)

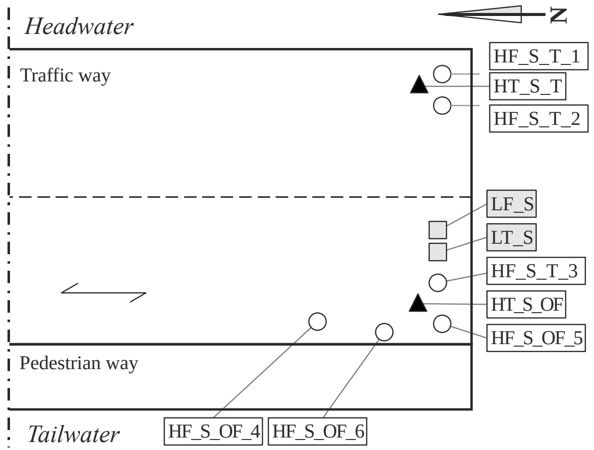

Fig. 8 Layout of measuring points including sensor names, south side of the Obermatt bridge

3. Results and Discussion

3.1 Climate data and moisture content

For the Obermatt bridge, the measuring results of the climate and moisture contents are shown in Fig. 9 to Fig. 11 for a period of 25 months. The climate data observed includes temperature and relative humidity of the air. The seasons of the year can be clearly distinguished, for the winter with low temperatures from -5 to 5 °C and high relative humidity, for the summer with temperatures of 15 to 20 °C and the two transition seasons spring and fall with the increase respectively decrease of the temperature and the relative humidity reversely. The equilibrium moisture content calculated is added in Fig. 9. The moisture content results theoretically between 10 % in summer and 32 % in winter.

In general, the moisture content measured in the timber follows the seasonal effective climate changes. The response is delayed and with lower variations for both sensor locations at the surfaces and inside. The variation of the moisture content at the surface between the summer and winter period is practically of about 5.5 % where theoretically the calculated equilibrium changes of 22 %, as shown in Fig. 10. The moisture content varies between about 14 and 20 %. The phase shift between the theoretical calculated equilibrium and measured moisture content is about 2 to 3 months depending on the gradient of climate change and the phase of adsorption or desorption.

The moisture sensor results measured in a depth of 200 mm show a smaller seasonal variation than the results of the surface sensors, Fig. 10 and Fig. 11. The curves of the moisture content at the inner structure are more evenly distributed and compact to each other, with a range of the variations of 2.5 %. The difference between the sensors at the surface and inside is around 3 % of moisture content in average independent of the season. The difference between the inner and outer moisture content of 3 % results in internal moisture induced stresses.

In general the measured moisture content did not exceed 20 %. The behaviour determined and shown for the bridge Obermatt could, in a similar range, also be observed for the other three bridges, [20].

3.2 Moisture transfer/distribution in the different material directions

With the measuring set up at the bridge Horen, the moisture transfer over the depth (in radial direction) and width (in tangential direction) was also observed. Fig. 12 shows the cross section of one block-glued glulam member with the positions of the sensors grouped in two measuring lines 755 and 1475 mm from the outside and 400 mm from the end grain. Each measuring group includes 5 sensors for the moisture content distributed over the beams depth. The distance between each

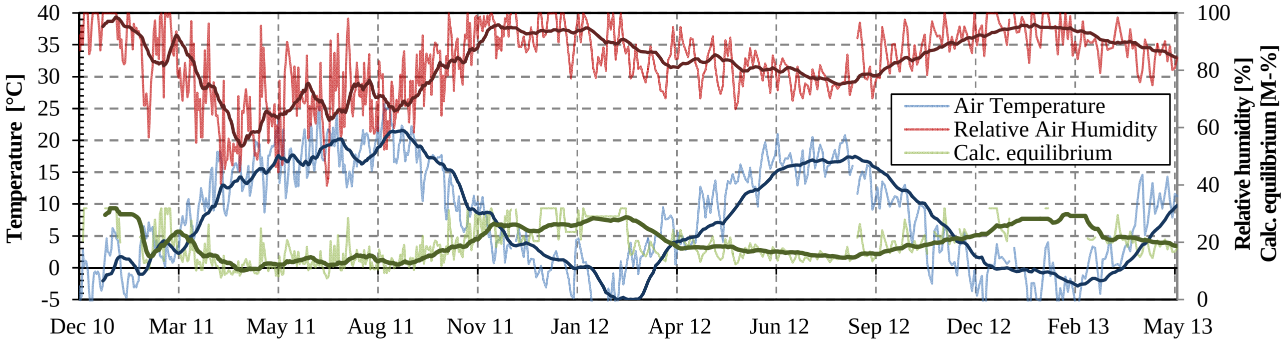

Fig. 9 Climate results and calculated equilibrium for the bridge Obermatt

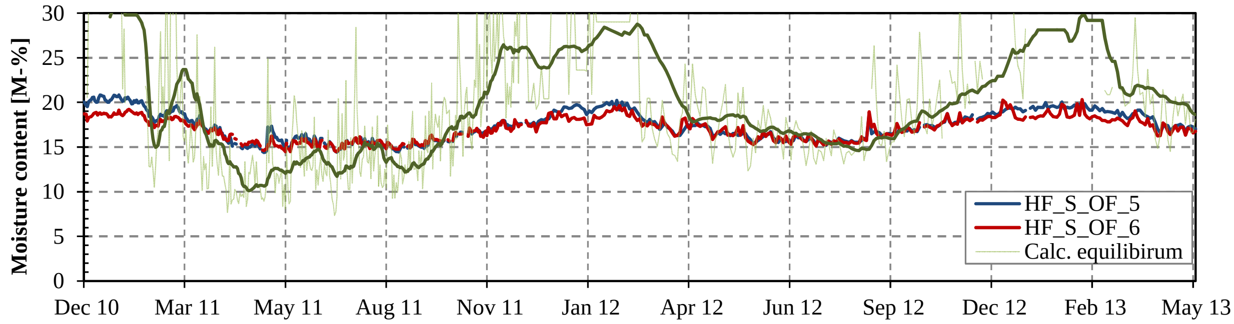

Fig. 10 Moisture content of the sensors at the surface

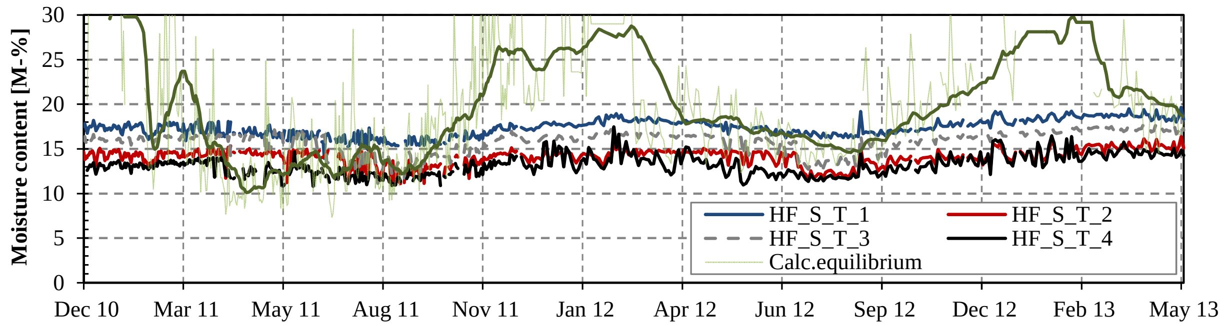

Fig. 11 Moisture content of the sensors in the inner structure, with a depth of 200 mm

other is around 100 mm. The moisture content in the wood was analysed for a period of 5 months beginning in May 2011. Within this period the increase of the mean relative humidity represents a theoretical increase of the moisture content from 12 to 27 %, as shown in Fig. 13.

However, the moisture content within both measuring groups, outside and inside, shows almost no differences in the variation due to the change of the outer climate, as shown in Fig. 14 and Fig. 15. The small changes are within the range of the measuring accuracy of around 1.5 %, [15]. Also, the construction at the positions of these sensors seems to be well protected against rain or other wet situations. Even wet conditions due to rain do not influence the moisture content for these measuring positions. Therefore the hazard of decay is minimized or can even be excluded.

For the investigation of the moisture transfer in longitudinal direction, the measuring results observed at the bridge Muotathal are used. The measuring setup is shown in Fig. 16, where the first measuring line is installed in longitudinal distance of 800 mm from the end grain and the second line with a distance of 2000 mm. The cross section is width x depth =1000 mm x 800 mm and the sensor groups were installed in a depth of 200 mm (tangential direction). Each measuring group includes 5 sensors for the moisture content. The vertical distance between each sensor is around 175 mm. The moisture content was analysed for a desorption period of almost 5 months beginning in December 2010. Within this period the decrease of the mean relative humidity represents a theoretically decrease of the moisture content from 25 % to 9 %, as shown in Fig. 17.

The results show at both positions a decrease of the moisture content in the wood of about 2 %, as shown in Fig. 18 and Fig. 19. No major differences in longitudinal direction could be observed. The measuring position of the first group shows already a large distance from the end grain in order to

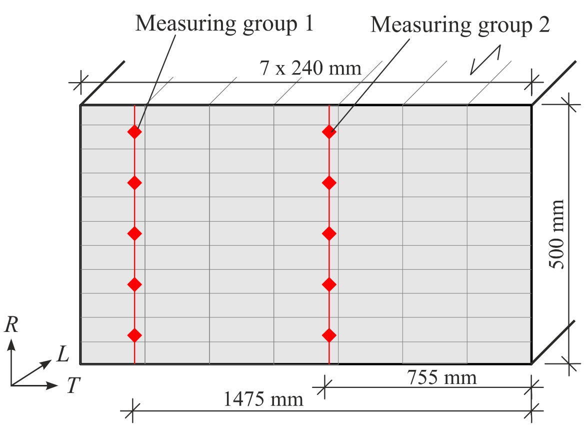

Fig. 12 Measuring plan of bridge Horen, cross section at the support

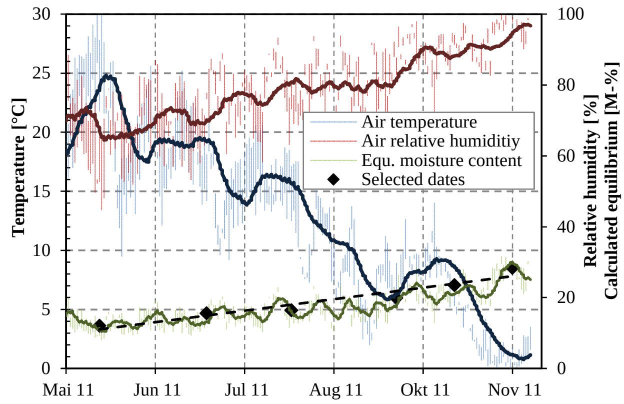

Fig. 13 Climate data and equilibrium moisture content of bridge Horen for a adsorption period

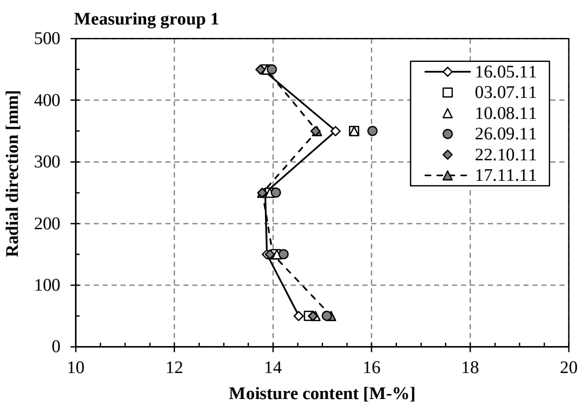

Fig. 14 Distribution of measured moisture content over the beams depth at 1475 mm from the beams side

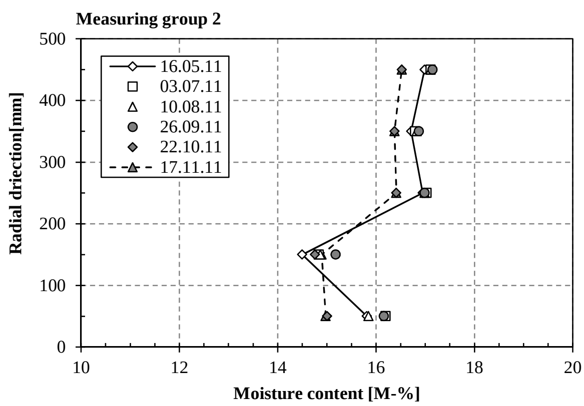

Fig. 15 Distribution of measured moisture content over the beams depth at 755 mm from the beams side

detect a dependency of the moisture content variations in longitudinal direction. The less influence of moisture adsorption/desorption from the end grain is in this case also reduced due to the steel plate as a part of the connection covering the end grain area and thus to a certain extent acting like a seal.

4. Conclusions and view

The electrical resistance measurement method used in the case studies is capable to determine the moisture content in the context of long term monitoring of timber structures. In case of construction deficiencies or later damages, the long term monitoring gives the possibility to observe extensive and unusual moisture accumulations at an early stage to avoid decay/fungal development. However, the monitoring can realistically not be done at every position of the construction, but could be done at important locations.

The monitoring of four timber road bridges and the analyses of their moisture contents confirm generally that the wood moisture contents follow the climate changes. The reaction against the calculated equilibrium moisture content due to the climate changes is delayed and with less variation depending on the distance to the surface. It could be shown that the moisture content in timber members subjected to the shown outdoor climate conditions varies between about 12 % and 22 %, which is below the critical moisture content of about 25 % for decay hazards. But a well-planned and applied structural protection of the wood against rain or snow is required, so that a general penetration of moisture into the timber members/construction is prevented.

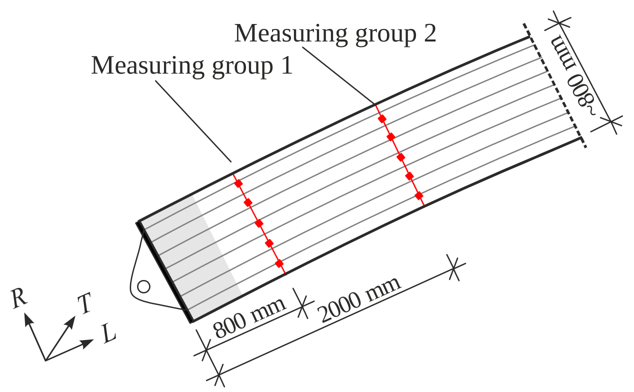

Fig. 16 Measuring plan of arch bridge Muotathal

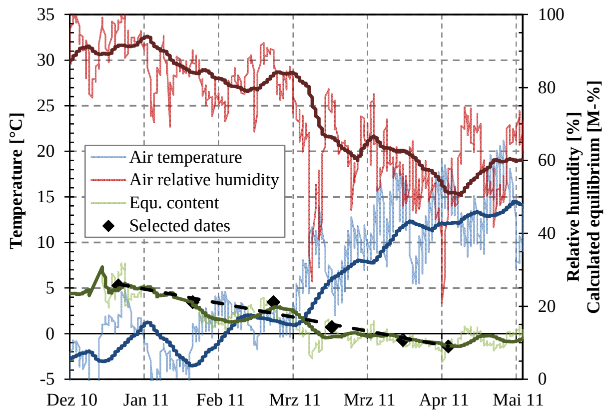

Fig. 17 Climate data and equilibrium moistore content of bridge Muotathal for a desorption period

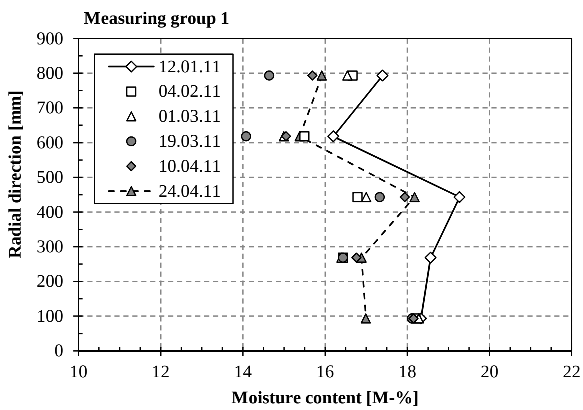

Fig. 18 Distribution of moisture content over the beams depth in a distance of 800 mm from the beams end

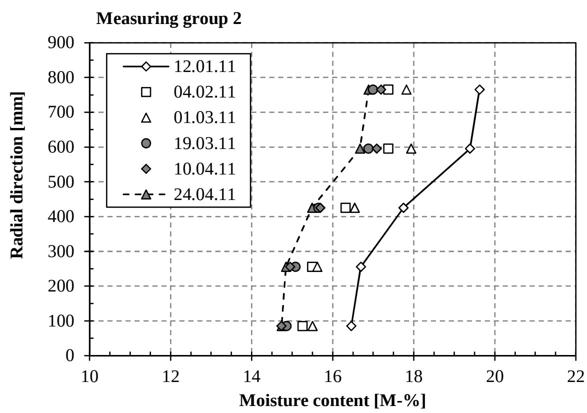

Fig. 19 Distribution of moisture content over the beams depth in a distance of 2000 mm from the beams end

In first steps, the behaviour of the moisture content could be determined over the cross section of block glued glulam members in radial and tangential direction and along the span of the member in longitudinal direction. In the cases observed, no major differences could be detected between the positions measuring sensors because of too large distances from the surface or the end grain. For a prediction model, the sensors should be positioned in a closer range for specification of differences in material axes and also investigated in specified and controlled climate changes.

The measuring results observed show that it is important to respect the moisture of the wood according to the climate change. Especially close to the end grain, cross section and in the outer glulam members of block-glued members the moisture gradients observed can lead to moisture induced stresses and furthermore to internal and/or external cracks.

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