Outdoor tests of timber beams and columns

Anna POUSETTE
Researcher
SP Technical Research Institute of Sweden/ Wood Technology
Skellefteå, Sweden
anna.pousette@sp.se

Anna Pousette, M.Sc., Lic.Tech, has been working with timber bridges since 1993, with design and construction and also with inspections and inspection methods for timber bridges and other outdoor structures such as facades and decking.

Karin SANDBERG
Researcher
SP Technical Research Institute of Sweden/ Wood Technology
Skellefteå, Sweden
karin.sandberg@sp.se

Karin Sandberg, PhD, has been working with outdoor constructions such as windows, facades and decking, measurements of water absorption and desorption with CT scanning.

Summary

Durability is essential for outdoor structures to minimize life cycle costs. Timber beams and columns can get decay and cracks due to dimensional changes through shrinking and swelling by moisture changes during exposure. Cracks can lead water into wood and thereby increase the risk for decay and reduce strength and service life. This project deals with the assessment and prediction of development for timber structures with cracks. More than 100 test specimens are included in an outdoor test, glulam beams and columns made of Scots pine (*Pinus Silvestris*) or Norway spruce *(Picea abies)*. Most specimens are placed in the north of Sweden, but also some in the southwest of Sweden. The project started during 2007. The beams and columns are measured regularly concerning cracks and surface treatment, moisture content and modulus of elasticity on-site. Weather is measured. This paper describes tests and measurements and reports some initial results. The results so far show that cracks develop for every year. Some beams, preferable the oil treated ones, have already after three years lots of cracks while some of the painted are rather intact. The moisture content and modulus of elasticity is relatively unchanged. The research will continue.

Keywords: timber bridge, timber beam, glulam beam, checks, cracks, durability, moisture content, surface treatment, CT-scanning, outdoor test

1. Introduction

1.1 Service life of exterior wood

Service life assessments and life cycle costs are becoming gradually more and more important in the investment and planning of construction works. Durability is consequently essential for all outdoor structures where a long life is preferred to control costs. The ability of a construction to resist degradation depends on its materials and design, and also the maintenance and the surrounding environment. The durability of wood products depends on design, natural resistance of wood, moisture content, surface treatment, temperature, mechanical erosion and weathering. For wooden structures in outdoor environment, such as bridge beams and columns, it is important for safety reasons to be able to determine when they can no longer carry the intended load, and when actions are needed to repair various damages. Prolongation of the life of existing structures can be economic, but calculations should be done to demonstrate that a prolongation of life is more profitable than to demolish and build a new bridge.

Assessments of the most cost-effective measures are needed at any time during the design life and should be based on knowledge of decay rates. Timber bridges have lots of wood exposed to outdoor climate. Much research has been done on durability of exterior wood and also glulam [1] but it is not easy to determine the rate of degradation of various constructions and environments.

1.2 Inspections of timber bridges

In many countries several projects on the inspection of timber bridges have been completed and there are instructions for inspections and repairs, e.g. in the U.S. where open bridges are mainly protected by impregnation with creosote, [2]. Some general instructions for inspections and assessments of timber bridges have been developed for the conditions in Sweden by SP Trätek, [3], [4].

Inspections of timber bridges can detect cracks in timber parts. Some examples from inspections of bridges with cracked beams are shown in [4]. The Fällfors Bridge in Figure 1 is a pedestrian truss bridge of pressure treated pine that is surface treated with dark wood oil with a hint of pine tar. After two years there are cracks on the top and bottom chord. The Engarn Bridge in Figure 2 is a pedestrian beam bridge of pressure-treated pine painted with oil paint and façade paint, and after seven years has some minor cracks and delamination on the outer sides of the beams.


Figure 1. Fällfors Bridge


Figure 2. Engarn Bridge.

Moistening over time may affect the durability and strength as the moisture can cause rot if it is unable to dry out. Rot is caused by rot funguses that grow into the wood. The fungus uses some substances, such as cellulose, as nutrition for growth and thus breaks down the wood cells or the binding between the cells [5]. Decayed wood therefore gets a reduced strength when cells are damaged. A prerequisite for rot fungus growth is wet wood with moisture content of more than 20% and temperature between 0°C and 25°C. Surface treatments for wood have been studied in many projects based on wooden facades of houses, but not so much for their influence on moisture absorption and durability for outdoor structures with large dimensions. Surface treatment may contribute to reduced moisture exchange with the surroundings, but a risk is that moisture can lead to rot if it cannot dry out through the paint.

1.3 Cracks in timber parts

Glulam beams often get surface cracks, frequently in connection with the glue lines and the choice of surface treatment becomes important for these products. Covering of the beams can protect them and prolong the bearing resistance, but this costs extra and is not always desirable from an aesthetic point of view.

A certain amount of small cracks can be found naturally in wood and glued laminated wood. Cracks in wood can be formed during the growth of trees, the felling of trees, during sawing-drying process to planks and boards, during manufacture of wood products, such as poor gluing of glulam beams, during construction, such as screwing too close to the end, during the lifetime because of external moisture variations or fractures in wood fibers due to overload.

Wood is hygroscopic and naturally takes on and gives off moisture. Under the fiber saturation point, about 30% moisture content, wood shrinks when it loses moisture and swells when it gains moisture. These movements are proportional to the change in moisture. The magnitude of moisture movements is different in different directions, tangentially twice radially, which in turn is more than 10 times greater than in the longitudinal direction. Spruce and pine has approximately the same moisture movements. Cracking at the surface is a natural characteristic of wood when the surface is dried out too much compared to the wetter core. The outer fibers dry and shrink, while the inner fibers lose moisture at a slower rate. Quick drying increases this difference in moisture and thus the tendency of the wood to get surface cracks, end cracks or internal cracks. Surface cracks that are small can later on be closed and become difficult to detect, but they remain and can cause future problems as they can lead to cracking of a coating.

Cracks in laminations usually occur parallel to grain and at fibers around the knots [6]. Growth disturbances of various types can lead to tensions in fibers and cracks. Like knots, these are natural variations in wood. Strength grading of structural timber does not consider crack widths less than one millimeter in accordance with EN 518 [7]. For wider cracks the length is limited for different strength classes. In the manufacture of glulam according to EN 386 [8] delamination is checked, that is separation between the laminations at a glueline. Drying cracks should not be confused with delaminations [9]. Design values for glulam takes into account the beam size and "natural" cracks.

Weather changes will put considerable demands on surface treatment and wood. The sunlight can quickly give a surface a high temperature - dark surfaces can reach up to 70 degrees. This gives a rapid drying and movements in the surface with risk for wood and surface treatment to gradually crack. Larger cracks provide water to rapidly penetrate into the interior parts of timber members. The cracks are also pockets of moisture-holding debris and dirt that can accelerate attacks of mold or rot. Especially horizontal surfaces with large cracks are a high risk for decay.

The glulam industry in the U.S. has developed some guidelines for the evaluation of cracks in columns and beams [9], [10]. Glulam beams often have cracks at the end or on the sides or bottom of the lower lamella. Drying cracks are often close to the glue joint usually at the outer lamella which is the most exposed area and therefore maximum drying. End cracks that go through the beam but are short have little influence on the strength. Cracks on the beam sides that are deep and long may influence the strength. Cracks at the bottom which are parallel to the grain are usually not considered to be relevant for the strength, even if they go through the entire outer lamella.

Cracks parallel to the fibers should be recognized [11]. The tensile strength along grain is not affected by these cracks. The use of the timber member is significant for the effect of the cracks on the strength. For columns and posts the cracks are important for compressive forces if they are along the entire length and go through the wood member, cracks along a portion of the length are less severe. A column with long cracks can be considered as composed of several structural components, each with a lower slenderness than the full column and the bearing capacity will be significantly reduced. Cracks that coincide with the neutral layer of a beam will reduce the shear strength and moment of inertia. The greatest risk of drying cracks is at beam ends where shear stresses are greatest at the supports with maximum value in the neutral layer. For wooden beams however the shear stresses are generally low and therefore the cracks are usually not critical. It is concluded that the cracks effect the bearing capacity only in special cases, and only if they are relatively large and have a critical location.

1.4 Objectives

This paper describes tests with beams and columns that are measured regularly concerning cracks and surface treatment, moisture content and modulus of elasticity. The project started during 2007 and this paper reports some initial results.

2. Outdoor tests of timber beams and columns

2.1 Objectives of outdoor tests

This project includes studies of how outdoor wooden structures develop and how cracking affects the moisture penetration and rot growth that may affect the future strength. A practical test for the investigation of change of decay in structural elements, as a function of moisture, temperature, time, cracks, colour, etc. is used. The aim is to clarify for users and industry what can be expected from outdoor products of wood and how the development of decay and the lifespan can be assessed.

The long-term goal is an instruction for inspections of wooden outdoor structures. The test objects consist of glulam beams with different materials and surface treatments, and columns with different materials of wood, glulam and glued columns. The results are expected to be a support for inspectors to examine and assess timber bridges. This can provide better and more effective inspections of timber bridges, and a better basis for future actions which will secure the sustainability of the bridges.

2.2 Beams and columns

The test objects consist of glulam beams made of different materials and surface treatments, and columns made of glulam and glued columns. They were chosen for the study of cracks and moisture content at various conditions, such as south or north side, and different paints. The trail is fully described in a Swedish report [12].

The length in proportion to the height of the glulam beams was chosen and tested according to EN 408 for determining the modulus of elasticity. The beam size was 140 mm x 450 mm, and the beam length was 9 meters. The beams were made from pressure treated lamellas that have been kilned dried before painting. Also beams made of spruce were included. Surface treatments were chosen similar to what is used today for many timber bridges in Sweden. Beams (B) of each type of material and surface treatment involves a total of 20 beams, see Table 1.

Table 1. Beams (B) 140 mm x 450 mm and length 9 meters.

Beam type	Number	Wood	Surface treatment	Colour
B1	5	Glulam, pine, pressure treated	Wood oil	-
B2	5	Glulam, pine, pressure treated	Paint system	White
B3	5	Glulam, pine, pressure treated	Paint system	Red
B4	5	Glulam, spruce	Paint system	Red

Several shorter beams were studied concerning crack development, moisture content and root development using a tomograph (CT scanner using X-rays). The dimensions, 140 mm x 315 mm and length 2 m of the short beams were adapted to the tomograph and so that they could easily be lifted and transported. The beam width may be relevant to cracking and moisture content and therefore also widths 90 mm and 215 mm were included. The four side surfaces were scanned and the paint thickness and colour were measured before the short beams were placed on the test site. Five pieces of each type of material and surface treatment were used. The surface treatment had the same paint system as the long beams but also red oil paint was included, see Table 2.

Table 2. Short beams (MB) 140 mm x 315 mm and length 2 meters.

Beam type	Number	Wood	Surface treatment	Colour
MB1	5	Glulam, pine, pressure treated	Wood oil	-
MB2	5	Glulam, pine, pressure treated	Paint system	White
MB3	5	Glulam, pine, pressure treated	Paint system	Red
MB4	5	Glulam, spruce	Paint system	Red
MB4-Borås	5	Glulam, spruce	Paint system	Red
MB5	5	Glulam, spruce	Paint system, alt.	Red
MB6	5	Glulam, spruce (width 90 mm)	Paint system	Red
MB7	5	Glulam, spruce (width 215 mm)	Paint system	Red

Some different types of columns and posts were included in the test, solid wood, glulam, hollow glulam columns so called Comwood and Quattrolit. Cracking and moisture content were studied for these objects. The columns were documented with tomograph through the cross section and scanning of the side surfaces before they were placed on the test site. All columns were covered with sheet metal or wood on top. Surface treatment was performed with the same paint system that was used for the beams. Five columns of seven different types of materials were used, see Table 3.

Table 3. Columns (S), length two 2 meter.

Column type	Number	Wood	Dimension	Surface treatment	Colour
S1	5	Glulam, pine, pressure treated	90 mm x 135 mm	Wood oil	-
S2	5	Glulam, spruce	90 mm x 135 mm	Paint system	White
S3-1	5	Glulam, spruce	90 mm x 135 mm	Paint system	Red
S3-2	5	Glulam, spruce	90 mm x 135 mm	Paint system	Red
S4	5	Glulam, spruce (hollow)	90 mm x 135 mm	Paint system	Red
S5	5	Comwood, spruce	diameter 400 mm	Paint system	Red
S6	5	Quattrolit, spruce	110 mm x 110 mm	Paint system	Red
S7	5	Solid wood, spruce	100 mm x 100 mm	Paint system	Red
S7-1 Borås	5	Solid wood, spruce	100 mm x 100 mm	Paint system	Red
S7-2 Borås	5	Solid wood, spruce	100 mm x 100 mm	Paint system	White
S8-1	1	Quattrolit, heat treated	110 mm x 110 mm	Wood oil	-
S8-2	1	Quattrolit, heat treated	110 mm x 110 mm	Paint system	Red

2.3 Testing ground

The project started during 2007, and is planned to continue during at least five years. The beams and columns were placed on the test field in Bygdsiljum in Skellefteå in northern Sweden (Lat 64°20′57″N, Long 20°30′14″E). Climate, temperature and humidity at the test site was measured with a weather station at the test field. Some extra beams and columns were also placed in Borås (Lat 57°43′15″N, Long 12°56′24″E). They will enable comparisons between different places with different climates. Borås has a milder climate with more rain than Bygdsiljum.

The beams were placed on supporting frames at different heights with the lowest beam approximately 1 m above the ground surface, see Figure 3. Five beams were placed on each frame. Beams were placed with one side to the sunny and warm south, and the other to the shaded and cooler north. The top surface was covered with a sheet metal that was mounted in a way that no water can penetrate into the beam from above. Beam faces should be exposed to rainfall, sunlight and the surrounding environment. The frames were placed so that they do not shade each other. The beams were distributed between the four frames so that at least one beam of every type was placed on each frame and at each height. The short beams were placed in a similar way with five beams above each other on supporting frames, see Figure 4.

Figure 3. Beams, nine meters long

Figure 4. Beams, two meters long

The columns were screwed to glulam beams that were 1 m above the ground, alternatively fastened to a concrete foundation, see Figure 5. The columns should be fully exposed to rainfall, sunlight and the surrounding environment. The top surface was covered with a sheet metal or wood.

Figure 5. Columns with top surface covered with a sheet metal.

2.4 Measurements

Documentation at the start included dimensions of beams and columns, visual inspection, measuring of moisture contents, measuring of thickness of surface treatment, measuring of modulus of elasticity, tomography through the cross section and photography of the surfaces.

Beams and columns will be inspected and documented during at least five years. The chosen methods are non-destructive. Visual inspection includes cracks, biological attacks and other visible defects. Width, length and depth of cracks were measured manually with a steel tape, ruler, precision feeler gauge and a crack depth gauge. Cracks with width less than 0.2 mm were not counted. Small cracks (0.2 to 0.4 mm in width) were only counted, not measured. Location of the cracks was indicated by x and y coordinates of the starting point. The crack direction was indicated by the angle to the x-axis.

Photos of the beams were taken with a camera with lightning on a rig mounted on the beam, to get images from the same distance and with the same light so that they can be combined and used for image processing.

Colour is measured with a Minolta Chroma Meter CR-310 to quantitatively describe colour, by measuring the reflected colour of the surfaces. The Chroma Meter illuminates the surface and measures the colour of an area of diameter 50 mm. The chosen colour coordinates were expressed in the L * C * h colour space, where L is lightness from 0 (black) to 100 (white), C is the chroma from 0 (grey) to more saturated colour the higher value, and h is the hue angle where 0º is red, 90 º is yellow, 180 º is green and 270 º is blue.

Paint thickness was measured using a paint thickness gauge, DeFelsko Model 200, that measures with high frequency ultrasound to reflect from surfaces with different densities, in this case the layer between paint and wood. Measurements were made on short beams and colums once a year.

Moisture contents were measured in specified positions at the surface and a bit into the wood to get a moisture gradient. Moisture content was measured with a resistive moisture meter, Delmhorst RDM-2S, and fixed pins in the beams at different levels and depths, see Figure 6. The pins were placed in a box that was screwed onto the beams and columns.

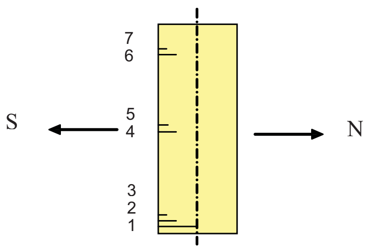

Figure 6. Moisture content measurement

Modulus of elasticity was tested for beams with loads and a test rig on the test site. The deflection was measured at the beam centre, according to EN 408. The supports consisted of jacks that were let down for the loading and then lifted up into position for readings of the deflection, see figure 7. Masses of 200 kg and 500 kg were used, and each point was loaded with a maximum of 1400 kg.

Figure 7. Modulus of elasticity.

Computer tomography (CT) scanning was performed with a Siemens SOMATOM AR.T at Luleå University of Technology in Skellefteå. The principle for CT scanning involves an X-ray tube and detector array that rotate around the test object being examined. The transmitted X rays are attenuated in the object and detected by the array and direction opposite the source. When the X-ray tube and detector array have rotated around the object, a large number of measurments of the X ray´s absorption are acquired. These values are then used to construct an image of the object using mathematical algorithms. This image describes the density variation in the cross-section. CT scanning was carried out every 10 mm along the beam with a scan width of 5 mm. Figure 8 shows a CT image of a beam.

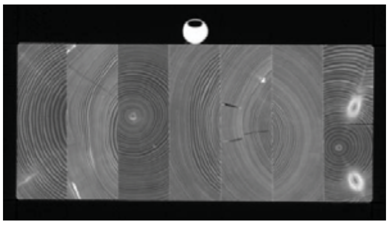

Figure 8. CT image of a cross-section of a beam. On top of the beam is a jar containing water as a density reference.

The short beams and the columns were surface scanned in a laboratory with a camera equipped with a sensor line for the best colour reproduction. A LED ramp was used to minimize the need to calibrate for uneven illumination. A calibration of white balance was made against a gray card. Scanning was made at project start, and is planned to be carried out at some point during the project and at project end.

Temperature, relative humidity (RH), wind, precipitation and solar radiation were measured at the test field.

3. Results and discussion

3.1 Cracks and surface treatment

Some discoloration from tape or staples existed on the test objects from start. Besides some beams had holes/wane at lamella edges or thin cracks in the paint or some mechanical damage on the surface coat from transport. Those damages were not repaired since we found it interesting to follow these injuries during the test.

Inspections after three years showed that
- the pressure treated beams treated with wood oil has significant cracking on both southern and northern side, see figure 9,
- there are some significant cracks in the painted beams, especially on the south side of the red spruce beams, see figure 10,
- there are some beams with few cracks, especially red and white pressure treated beams,
- the red colour had faded somewhat.

Sizes and positions of cracks were measured. Sometimes it is difficult to measure the true depth of the crack as it is not completely straight but can bend up or down inside the beam. Measurements have been carried out manually by different people, and it is possible that experience and accuracy can affect the outcome. Different weather conditions at the inspections can cause more or less open cracks depending on how dry the wood is at the surface. Many cracks are small and short, but with many small cracks close to each other they will possibly in the future grow into one long crack. Assessment of whether to count the cracks as one or more cracks can sometimes be difficult. The measurements of the cracks will be analyzed in the autumn of 2010 to study in more detail what factors that mainly influence the development of the beams.

Figure 9. Inspection 2010 of beams treated with wood oil

Figure 10. Inspection 2010 of painted beams.

The measurements of cracks have proved to be complex and difficult to document for some beams. This experience from the test may provide a basis for guidelines for bridge inspections, which should have definitions on how cracks should be measured, what instruments and data points are appropriate, and definition of crack size for documentation and periodic follow-ups. The construction works should also include checks of moisture content on the main points for having as a reference for future follow-ups of cracks.

3.2 Moisture contents

Generally the beams (B) had quite high moisture contents (mean 25.8%) at start of the test period and after three years exposure they had dried (mean 18.9%). Figures 11 and 12 show the moisture content (MC) in one beam during three years.

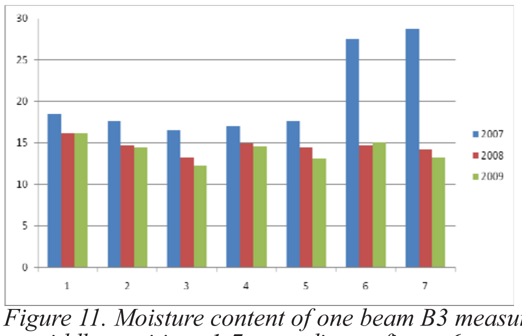

Figure 11. Moisture content of one beam B3 measured at middle, positions 1-7 according to figure 6.

Moisture content readings at the start showed some high moisture contents, over 20% and up to 60%, suggesting that water got into the beams at the pins probably because some boxes were not directly sealed. Some of these have dried out after the first year, but some are still wet after some years.

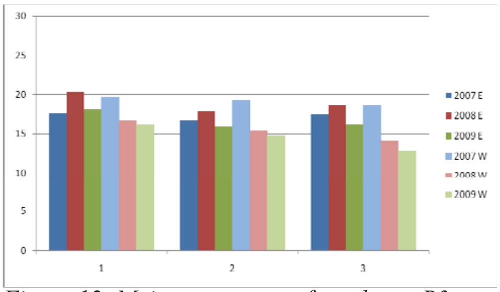

Figure 12. Moisture content of one beam B3 measured at end positions (east and west), positions1-3 according to figure 6.

3.3 Modulus of elasticity

Modulus of elasticity of the 20 long beams has been measured twice, at project start in November 2007 and in June 2010. The result from 2007 was a mean modulus of elasticity 11 480 MPa and from 2010 a preliminary result is 11 210 MPa, i.e. an average decrease of 2%.

Difference in temperature and humidity must be considered. In November the temperature was between -3 ºC and 7 ºC, and air humidity about 80 %. In June the temperature was 11-16 ºC, and the air humidity about 55%. Different types of beams should also be analysed separately.

Most likely the modulus of elasticity will not change very much during the first five years of this project.

The method of measuring the modulus of elasticity with loading the beams on site is time consuming. Other methods e.g. dynamic measurement will probably be used in future monitoring.

4. Future work

Continued evaluation of measurement data will be made during the project. Hopefully, the research continue and will be followed up further after the first five years of exposure.

Work within the nearest future:

- study of methods to evaluate the photos with image processing will be in progress.
- use of CT scanning to investigate how cracks and damages on surface affect the inside of the beam.
- comparison of modulus of elasticity on-site with dynamic methods
- evaluation of crack measurements

Future work is development of simulation models. Tests results can be used to validate models of beams with cracks. The models will then be used to simulate the development for various conditions.

In the future, larger cracks can be used to study repair measures, different methods to fill the cracks with suitable material to prevent further cracking.

Improved inspection instructions based on test results will be put together to support bridge inspectors in the assessment of timber bridges.

5. Acknowledgements

The authors would like to express their thanks to EU Structural Funds together with TräCentrum Norr, Luleå University of Technology and SP Technical Research Institute of Sweden for providing funding for this project.

6. References

[1] Pitzner B., Rambøl A., Lind P., Evaluation of glulam beams after 6 years exposure to outdoor climate. B, Treteknisk, Report 57, Oslo, September 2004, ISSN 0333-2020

[2] Ritter M.A., 1990, Timber Bridges – Design, Construction, Inspection and Maintenance, Washington DC

[3] Pousette A ., Jacobsson P., Gustafsson M., Fjellström P.-A., 2002, Inspektion av träbroar, Trätek Rapport P 0211039

[4] Pousette A., Fjellström P.-A., 2004, Broinspektion – Träbroar, SP Rapport 2004:41

[5] Zabel R.A., Morrell, J.J. , 1992, Wood microbiology decay and its prevention, San Diego, Academic Press

[6] APA, 2001, Checking in glued laminated timber, APA Technical Note EWS R465E, November 2001

[7] SS-EN 518, Träkonstruktioner – konstruktionsvirke – Utformning av standarder för visuell hållfasthetssortering, 1995

[8] SS-EN 386, Träkonstruktioner – Limträ – Funktions- och produktionskrav, 2003

[9] APA, 1999, Evaluation of check size in glued laminated timber beams, APA Technical, Note EWS R475C, June 1999

[10] AITC, 2004, (American Institute of Timber Construction) Technical Note 18, Evaluation of checking in glued laminated timbers, March 2004

[11] APA, 2006, Understanding Checking in Glulam, www.apawood.org, 2006-06-28

[12] Pousette A., Sandberg K., 2007, Träbalkar och trästolpar i utomhusförsök – planering och utplacering, SP Rapport 2007:35