Glulam beams and columns after 5 years exposure to outdoor climate

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Summary

A field test started in 2007 to increase the knowledge about cracks and moisture in wooden structures in outdoor climate. The test included wooden beams and columns in two test fields in Sweden. Measurements and tests were made every summer in 2008-2012. In the current compilation of test results the main focus was to answer questions about the relationship between cracks and moisture contents and the influence of different surface treatments. The intention was to give directions for the assessment of the risk of cracks, rot or reduced bearing capacity. This paper includes parts of the collected data, and presents moisture contents and cracks in long beams and columns. The data give an overview of the development of cracks and moisture during 5 years. Surface treatment, wood material and impregnation give different amount of cracks. There are also significant differences between the north and south sides for some beam types.

Keywords: timber bridge, timber beam, glulam beam, checks, cracks, durability, moisture content, surface treatment, field test

1. Introduction

1.1 Service life of exterior wood

Long life and low life cycle costs are increasingly in demand in planning and construction. The ability of a structure to resist degradation by climate is therefore essential for any outdoor structures. It depends on the type of material and design but also on the maintenance. The durability of wooden structures depends on the wood material, impregnation, surface treatment, moisture content, temperature, and mechanical impact.

Extending the life of existing structures can be economical, but only if it is more profitable to repair and maintain than to demolish and rebuild. Much research has been done on sustainability of exterior wood and glue-laminated timber [1] but it is not easy to determine the rate of degradation and the remaining life for various structures and environments. Timber bridges can be constructed in many ways [2]. Structural parts can be provided with claddings to protect against the impact of the climate, but sometimes the designer wants to avoid claddings because of costs or aesthetics. The exposed wood can then be protected with impregnation and surface treatment. Cracks are often detected during inspections of these impregnated and painted beams and columns [3], [4].

1.2 Cracks in exterior wooden parts

Glulam beams often get cracks on the surface, and the cracks usually occur at or near the glue lines between the lamellas. Some small cracks in the wood can be considered a natural part of the wood, as wood is hygroscopic and has the ability to take in and give off moisture. Below the fibre saturation point, about 30% moisture content, wood shrinks when it is losing moisture and swells when moisture is gained. These moisture movements are different in different directions. For Swedish spruce and pine the movements are tangentially twice radially, which in turn is more than ten times greater than in the longitudinal direction.

Varying humidity due to annual fluctuations will affect outdoor wood. At low humidity the outside of the wood will dry out faster than the inside, and tensions will occur in the wood as shrinkage of the outer part is prevented by the moist interior. Consequently, cracks occur if these stresses exceed the strength of the wood. Surface cracks that are small can later be closed if the surface gets wet and they will be difficult to detect. But they still exist and can contribute to cracks in the paint.

Cracks in the laminations of glulam beams usually occur parallel to the fibers and along the fibers around knots or at growth disturbances [5]. Strength grading of structural timber limits the widths and lengths of cracks according to EN 14081 [6]. In the manufacture of glulam according to EN 386 [7] the gluing and delamination is controlled. Cracks from drying should not be mixed up with delamination.

Glulam industry in the U.S. has published guidelines for the evaluation of cracks in beams and columns [8], [9]. If beams have end-cracks that go through the beam but are short, they have little effect on the strength. Cracks on beam sides that are deep and long may affect the shear strength, and cracks parallel to the fibers should be observed [10]. The greatest risk of cracks is at the ends of beams where the shear stresses are greatest at the supports with a maximum value in the neutral layer. But the shear stresses are generally not often critical in beams. For columns, the cracks affect the compressive strength if they go through the wood and along the entire column.

1.3 Objectives

The aim of this project is to increase knowledge about cracks and degradation of wood for various factors, thereby providing a basis for lifetime assessments of timber structures in outdoor environment and recommendations for design and inspection of structures made of wood such as wooden bridges, wooden balconies, and wooden columns. This paper presents a compilation of some test results, with the main focus to answer questions about the development of cracks, relationship between cracks and moisture contents and the influence of different surface treatments.

2. Field test with glulam beams and columns

2.1 Beams and columns

This project included studies of beams and columns made of glulam and wood. They had different surface treatments, and factors like south or north side, height above ground and climate were considered. The field test and test objects were described in a Swedish report [11] and in [12].

2.2 Long beams

A total of 60 beams were included in the test. Out of these beams were 20 long beams, and results for these are presented in this paper. There were five beams of each type, see Table 1. The beam size was 140 mm x 450 mm, and the beam length was 9 meters. The length in proportion to the height of the glulam beams was chosen according to EN 408 [13] for tests of modulus of elasticity. Most beams were made from pressure treated lamellas but also one beam type made of spruce was included. The top and end surfaces of the beams were covered with a sheet metal.

Surface treatments were chosen similar to what is used for many timber bridges in Sweden. The wood oil was solvent-based oil, based on a specially treated linseed oil. The paint system gave a thin film that showed the wood structure. It was an alkyd-based stain, fortified with linseed oil. The stain was waterborne and environmentally friendly. It gave coverage, but still showed the grain of the wood. The binder was water-soluble alkyd oil and the stain created a semi-glossy paint film. Pre-treatment was made with an impregnating oil primer used for exterior wood. It was waterborne and based on modified linseed oil.

Table 1. Beams 140 mm x 450 mm with length 9 meters, in test field Bygdsiljum

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

2.3 Columns

A total of 52 wooden columns were included in the test, solid wood, glulam, hollow glulam columns so called Comwood and Quattrolit. The 40 columns reported in this paper are described in Table 3. Five columns of each type were tested. All columns were covered with sheet metal or wood on top. Surface treatments were of same types as for the beams.

Table 3. Columns, length two 2 meter, in test field Bygdsiljum

Column type	**Support**	**Wood**	**Dimension (mm^2)**	**Surface treatment**	**Colour**
S1	Beam	Glulam, pine, pressure treated	90 x 135	Wood oil	-
S2	Beam	Glulam, spruce	90 x 135	Paint system	White
S3-1	Beam	Glulam, spruce	90 x 135	Paint system	Red
S4	Beam	Glulam, spruce (hollow)	90 x 135	Paint system	Red
S5	Foundation	Comwood, spruce	Diam. 400	Paint system	Red
S6	Foundation	Quattrolit, spruce	110 x 110	Paint system	Red
S7	Foundation	Solid wood, spruce	100 x 100	Paint system	Red
S3-2	Foundation	Glulam, spruce	90 x 135	Paint system	Red

2.4 Test fields

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). Some beams and columns were also placed in Borås (Lat 57°43′15″N, Long 12°56′24″E). The climate in Borås is warmer and wetter than in Bygdsiljum.

Beams were placed with one side to the sunny and warm south, and the other to the shaded and cooler north. The beams in Bygdsiljum were placed on supporting frames at different heights with the lowest beam approximately 1 m above the ground surface, see Fig. 1. All beams in Borås were placed 1 m above ground level, see Fig. 2. The columns were screwed to glulam beams that were 1 m above the ground, alternatively fastened to a concrete foundation, see Fig. 2.

Fig. 1 Beams, nine meters long, in Bygdsiljum

Fig. 2 Columns and short beams, in Borås

2.5 Measurements

Beams and columns were inspected and documented every summer during five years. The measurement methods were non-destructive. Visual inspections included cracks and other defects. Width, length and depth of the cracks were measured manually with a steel tape, ruler, precision feeler gauge and a crack depth gauge. Cracks with width at least 0.4 mm were measured, small cracks (0.2 to 0.4 mm) were only counted, and cracks less than 0.2 mm were not documented. Locations of the cracks were indicated by x and y coordinates of the starting point. The width was measured on the widest point of the crack. The length was measured as the straight distance between the start and end point of the crack, even if the crack could be slightly bent. This means that the length might be a bit underestimated but the width a bit overestimated. In this paper the amount of cracks is presented as crack area on the surface, i.e. length multiplied by width.

Measurements of moisture contents in long beams and columns were performed manually with fixed pins in the wood and a resistive moisture meter. The pins were placed in the middle of the beams on the south side at the bottom, centre and top, see Fig. 3. There were also pins at the bottom at one end of the beam on the south side and at the other end on the north side. Columns had pins at the bottom and the top on the south side, see Fig. 4.

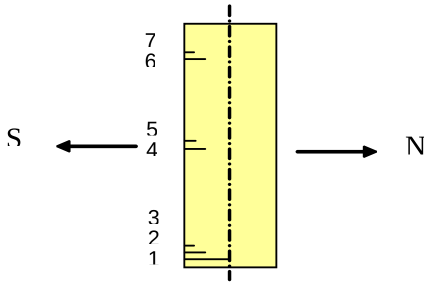

Fig. 3 Moisture contents in beams, pins at depths 10 mm, 35 mm and 70 mm

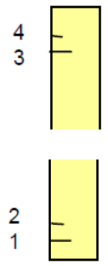

Fig. 4 Moisture contents in columns, pins at depths 10 mm and 45 mm.

3. Results beams

3.1 Cracks in long beams

Total crack areas during 2007-2012 for each beam type are presented in fig. 5-8, for south and north side. The figures show the average of measured cracks on the five beams of each type. But some beams were not measured every year so the average is sometimes from fewer beams. Beam types B1 and B4 had most cracks and maximum amount on the south side especially beam type B4. Also the other red painted beam type, B3, had many cracks on the south side, but fewer on the north side. The white painted beam type, B2, had little crack area both on the south and north side.

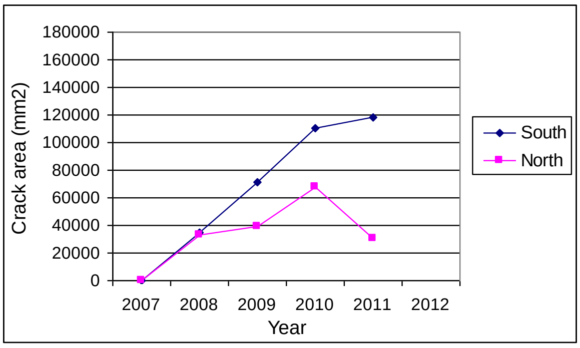

Fig. 5 Crack area (mm^2) in beam type B1, on south and north side, average of five beams (year 2011 only one beam measured)

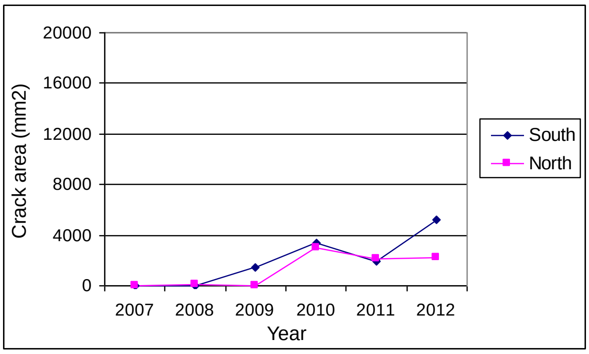

Fig. 6 Crack area (mm^2) in beam type B2, on south and north side, average of five beams

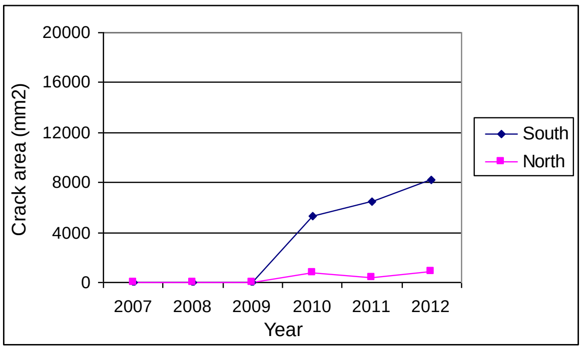

Fig. 7 Crack area (mm^2) in beam type B3, on south and north side, average of five beams

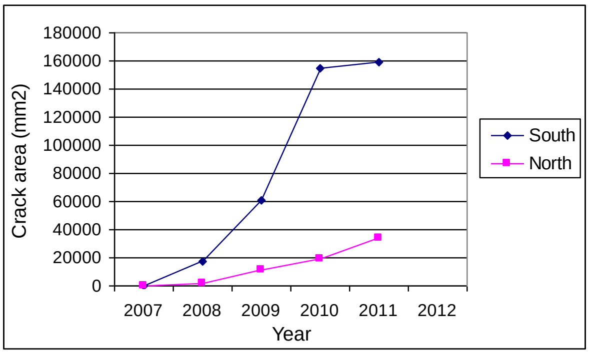

Fig. 8 Crack area (mm^2) in beam type B4, on south and north side, average of five beams

3.2 Moisture contents in long beams

Fig. 9 shows the average moisture contents in beam types B1-B4 during 2007-2012. The values for 2011 are sometimes from fewer beams because several beams had no measurements for 2011. The average values were calculated from the values of all pins 1-7 in the middle of the beams. At the start in 2007 there were some high moisture contents at some pins and variations in moisture were large in all beams. The summers in 2010 and 2011 were dry, but the summer in 2012 was rainier. The beam type B3 (red spruce) had the lowest moisture contents all years.

In Fig. 10 the moisture contents are shown for each pin 1-7 in the middle of beams. These are average values for all years. The pins 3, 5, and 7 had in general the lowest moisture contents, which means the surface was dryer than the inner of the beams. There was little difference between the moisture contents at pins 1 and 2, which means the moisture contents at 35 mm depth and at 70 mm depth were almost the same. The moisture contents were quite similar at top and bottom of the beams.

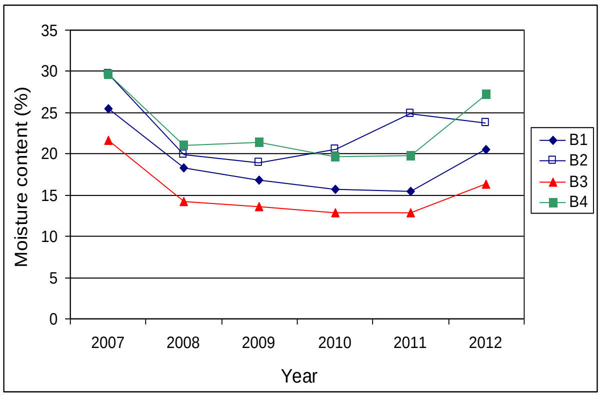

Fig. 9 Moisture contents in beam types B1-B4, average of all pins 1-7 in middle of beam.

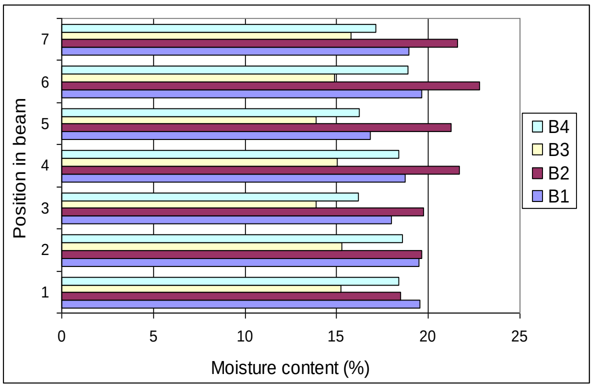

Fig. 10 Average moisture contents at pins 1-7 in middle of beams, in beam types B1-B4.

4. Results columns

4.1 Cracks in columns

Fig. 11 displays the average amount of crack area for the different sides of the columns. The crack area was calculated in the same way as for the beams. Cracks in columns were not measured every year. Fig. 11 shows the maximum measured crack area for each column type, which can be for different years 2009, 2010 or 2012 (no measurements in 2011). The oiled glulam columns had most cracks, except on the north side. Also the Comwood columns had quite a lot of cracks. All the other columns had very little cracks.

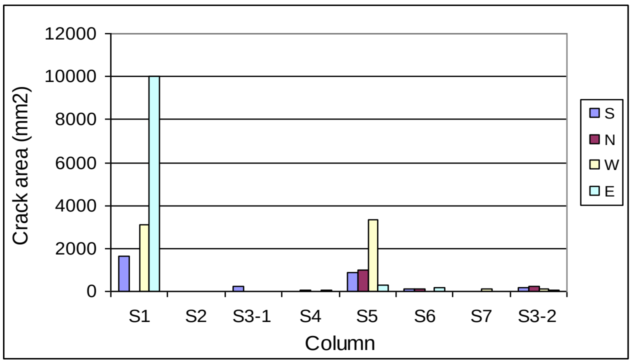

Fig. 11 Crack area (mm^2) for the different sides south (S), north (N), west (W) and East (E)

4.2 Moisture contents in columns

The columns were quite dry when they were placed in the test field, about 12-15 %, see Fig. 12. The moisture contents of the Comwood columns (S5) were not measured. No measurements were made during 2011 and 2012, and until 2010 the moisture contents had not changed very much.

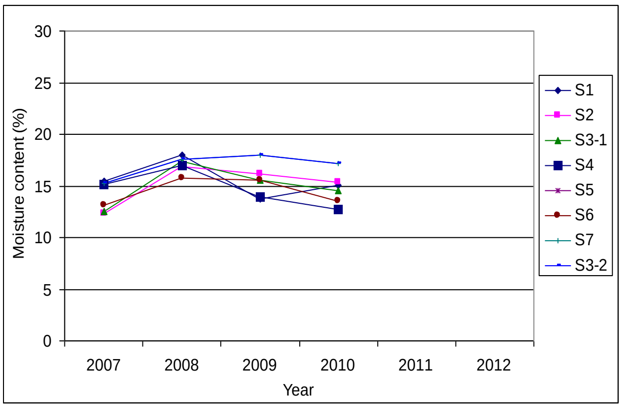

Fig. 12 Moisture contents in the different types of columns

5. Discussion and conclusions

Data presented in this paper give an overview of the development of cracks and moisture contents in glulam beams and columns. There are a lot of collected data, and this paper presents only some of the results from the field test. Test results can be further studied concerning details, such as in which areas the beams mostly crack and the influence of different factors.

After 5 years the crack area in beam type B1 (impregnated, oiled) was about 25 times larger than in B2 (impregnated, white painted) on the south side and about 15 times larger on the north side. Beam type 4 (impregnated, red painted) had crack area in the same order as in type B1. This indicates that the surface treatment made a difference, especially the colour. In the sunshine a light colour will not get as hot as a darker colour, and thus for the white beams the difference in the moisture contents between the surface and the inner of the beams is little.

Beam type B4 (impregnated, red painted) had about 20 times more cracks on the surface than beam type B3 (spruce, painted red) after 5 years. This shows that the wood material is also important and not just the colour. It is the sapwood in pine that is impregnated. Impregnated pine wood that cracked very much probably had more sapwood than spruce. The amount of sapwood and heartwood depends on how the laminations are sawn from the log. This will also influence the annual ring orientation in the laminations and the beam surface, which could affect the amount of cracks.

The amount of manually measured cracks reported in this paper are presented as crack area. This could also be used if photography and image processing is used as a method to determine the crack amount on the beam surface. For example the oiled beams had after some years very many cracks which was not practical to measure manually and therefore other more effective methods were also investigated, but they are not presented in this paper.

Beams with most cracks had a crack area of about 3-4 % of the total area of the beam surface. After 5 years these relatively small cracks should not significantly reduce the strength of the beams. The maximum measured crack depth was 85 mm in one beam B3, but most cracks of all beams were not deeper than 50 mm, see Fig. 13. The average depths were about 8-12 mm, see Fig. 13. The maximum measured width was 12 mm, but most cracks in all beams were not wider than 2 mm. It should also be taken into account that the depths and widths were only documented with the maximum values, which means all crack areas were overestimated.

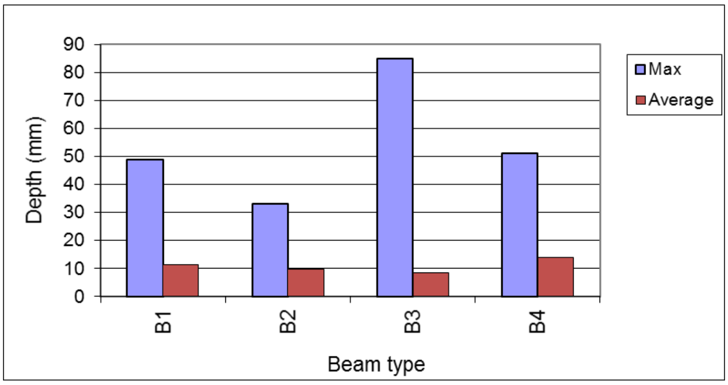

Fig. 13 Maximum and average crack depths (mm) for beam types.

It is difficult to answer the question if cracks give higher moisture contents in the wood. Measured moisture contents were measured in fixed points, which were not always where the cracks occurred. The measured moisture contents therefore mostly gave a general representation of the moisture conditions in the different beams and columns. After 5 years, moisture contents had not increased compared with the first year. During the first year the beams were dried out, as they were quite wet from lying outside in the rain before installation on the test field. The pins were placed in boxes for protection. Some cover boxes were not tight and water penetrated into the wood at the pins. This gave high moisture contents which were not dried out for some beams. After the first year the moisture contents decreased further. During the summer of 2012 the moisture contents were slightly higher again. Probably this was because of the rainy weather.

One side of an oiled beam B1 was filmed during a few days, and when it rained the wood swelled quite quickly and the cracks were closed. This means that not much rain water could enter the beam. When the rain stopped the cracks opened up again and any moisture could dry out. A painted beam has a protective film against the rain and the wood can not react and swell as quickly as an oiled beam. Further studies are needed on this.

For the columns, the moisture contents had not varied much during 5 years and there were few cracks. Probably one reason compared with the beams was the smaller cross sections. The stresses from moisture differences were thus smaller. The oiled columns had more cracks than the other beam types and this indicates that the surface treatment with white or red paint protected against the climate. It would also be interesting to study beams and columns with larger dimensions to see how much the crack development depends on size.

6. Acknowledgements

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