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LONG SPAN PORTAL FRAME MADE FROM GLULAM AND CLT MOUNTED TOGETHER USING ONLY CARPENTRY JOINTS

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Abstract:

The paper presents the results of concept design for modelling, designing and producing long span portal frames and constructing buildings with them.

Ordinary portal frames of steel structure are not suitable in many cases for a variety of reasons. They are heavy and very fragile to transport, are not fire resistant, are present special difficulties in use because of possible corrosion and are always not satisfactory architecturally. Wood-steel assemblies such as flitch beams are also complicated because of possible condensed water on metal and fasteners.

Constructions using GLULAM and CLT (especially in the last decade) show rising trend. Timber has very many good properties as a building material if we know or remind ourselves of the skills how to handle it. The biggest enemy of wood and the reason for decay is moisture. All structures and finishing materials need very careful and qualified design to avoid collection of water on surfaces and consequent increasing moisture content.

This paper describes a method appropriate for the 21st century of how to design portal frames of GLULAM and CLT panels and construct of them without metallic fasteners.

Key words: *portal frame; hardwood pins; stiff eave node; carpentry joints.*

INTRODUCTION

Portal frames are commonly used for buildings that need long spans without any supporting system such as columns, load carrying walls or other systems similar to the column-truss system. Portal frames do not need any stiffening members perpendicularly such as diagonals or diaphragm walls that could spoil usage of the internal open area of the building. The perpendicular stiffness is assured with a structural scheme of only three hinge joints together with a stiff eaves joint. This enables them to be used in swimming pools, sport halls, riding grounds, buildings with inside active driving etc. The indoor climate must be controlled by heating and humidity control. Steel structures especially are vulnerable to condensation on metal parts that have the cold bridges through the insulated perimeter or in the zones above the dew point. It is preferable to use timber or timber-based structures in such types of buildings and even better without metallic plates and fasteners at the connection nodes. GLULAM and CLT technologies based on polyurethane glue do not have the decay problems in wood if other technical solutions support it.

Carpentry joints can succeed today with rapid development of modelling and designing software supported by CNC-technologies. A lot of old and known carpentry joints are used and the new ones come into being every day.

The present design gathers together different kinds of modelling and is based on several experiments on structural elements of wood and/or of timber-based materials in the Estonian University of Life Sciences who have given us additional knowledge and helped us to understand the already forgotten skills of carpenters from the past (Seliste and Teppand 2011).

OBJECTIVE

The main objective of the present concept design was to find out the technical solutions of how to use GLULAM and CLT in most optimised way to produce portal frame details with three hinged joints and to avoid using ordinary metallic fasteners as much as it is possible. All negative know-how was taken into consideration to avoid the problems they cause. All the positive know-how from the different tests and skills of old and present time was used in this concept design.

MATERIALS AND METHODS FOR PORTAL FRAMES

Comparison of materials

Steel portal frames are heavier than GLULAM and CLT. Because steel frames require transport and mounting (need bigger cranes), they cost more. Steel frames have less stability in exposure to fire. It is very difficult to avoid cold bridges if the structure must be continuous through the external insulated perimeter. Emission of CO_2 is one of the biggest among building materials. GLULAM is the most commonly used for beams or beams/rafters and it has often been used for portal frames too. Metal plates and lot of pins/bolts have been used in the eave node connection to make it stiff.

CLT-panels are currently used for walls.

Is it possible to use these technologies together to produce a new type of portal timber frames without metallic fasteners that are easy to mount at the building site?

Moisture in the wood

The problem of timber structures in the open environment is occurrence of condensation on metallic parts because of temperature drop on cold nights. This phenomenon wets the timber around the metallic fasteners. Slow decay can develop in the timber around the fasteners and therefore cause the joint to slacken after which the geometry of the whole structure can change and values of inside forces in it. Is it possible to avoid it at all or decrease the problem?

Fire protection

The other important difference is behaviour materials in fire. Steel does not burn but loses its stability at temperatures higher than 600°C when it becomes plastic and may collapse. Load carrying structures of steel as frames need to be protected against fire. Fire protecting coatings may only last 5 years and only some of them keep their fire resistance properties until 10 years. After that the old coating must be removed and needs to be changed. It is technically very complicated and expensive work. The quality at the building site is not the same as done in the factory.

There are very high requirements for the surface quality for undercoating before the fire protection coating is applied. Normally it needs to be shining metal but many surfaces of the steel profiles cannot cleaned of old coating because of too small gaps between the details. How to get the result following fire regulations and enough fire resistance time?

RESULTS AND DISCUSSION

Modelling, designing, structural analyses and fire-resistance

To design a portal frame the software Rhinoceros was used that has enough functionality and is even the best for modelling curved and/or two-curved surfaces. It is able to convert the modelling fail-format to the STEP-format using it with FEM-software (Finite Element Modelling) to make structural analysis. After finding the correct dimensions for cross-sections, a new type of carpentry joint at the eave node CNC machining format was generated for CNC-workstations.

During the designing process it is necessary to calculate the char speed of timber elements in the fire which in GLULAM and CLT is normally 0,65mm/per min. An increase in the size of cross-section of the elements of timber to get the needed fire-resistance time is allowed. This helps to avoid fire protection coatings that may not last the whole life-span of the building.

Construction materials and production method

The portal timber frame with a stiff eaves node has parts where it can use the best properties of both GLULAM and CLT.

The beam/rafter is made as GLULAM. The lower end of it at the eaves node has a routed dovetail male joint (Fig. 1). The upper end has a Knuckle Joint Hinge to connect the two different beams/rafters at the ridge node (Fig. 2).

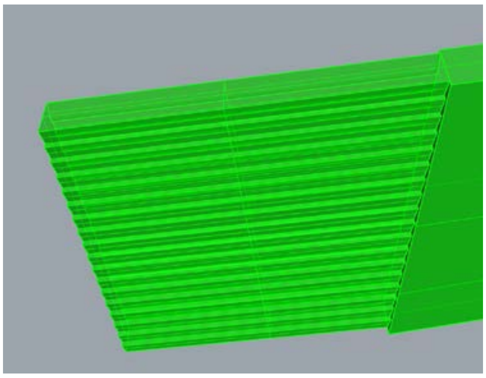

Fig. 1.
Dovetail male joint of the beam/rafter at eaves node.

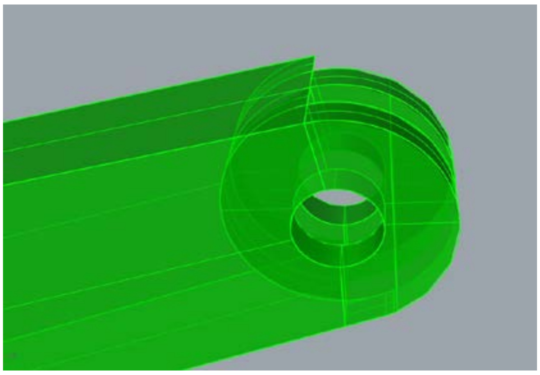

Fig. 2.
Knuckle Joint Hinge to connect two different beams/rafters at ridge node.

The post is made of two CLT-panels to get the horizontal stiffness and load carrying to a maximum value vertically at the same time. Two panels were used because of the need to rout dovetail female joints for the beam/rafter into the upper (Fig. 3) and mortise (Fig. 4) to the lower part of the post. Two parts of the post will be mounted together with beam/rafter between them at the building site.

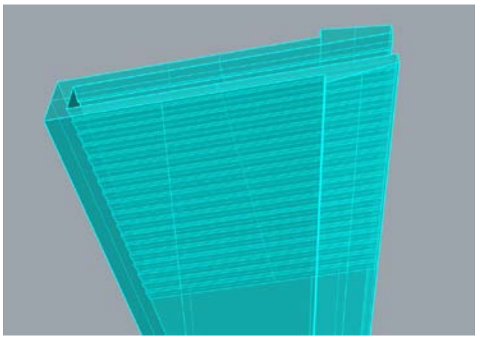

Fig. 3.
Dovetail female joint of the beam/rafter at eaves node.

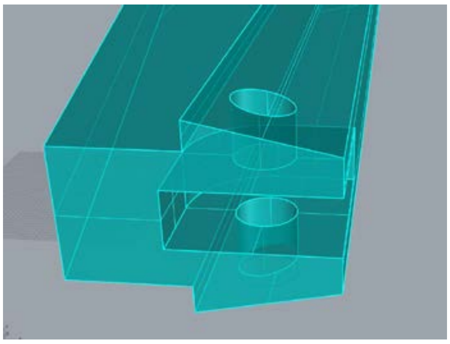

Fig. 4.
Mortise on the lower part of the post at base node.

Hardwood pins were used to fix the different members together as in the past (Fig. 5). The pins do not carry over the loads. If the structure consists of softwood members (mostly of spruce) and pins of hardwood (mostly of oak) the speed of drying shrinkage and moistures expansion is different which keeps the connections tight.

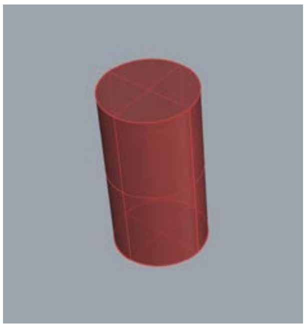

Fig. 5.
Pin of hardwood.

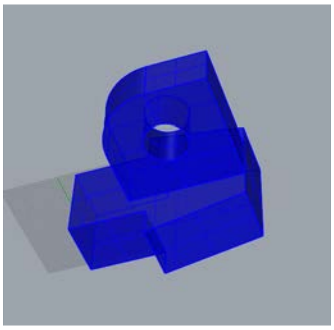

Fig. 6.
Support of hardwood.

Special supporting elements (Fig. 6) of hardwood (mostly of oak) are used under the posts to protect them. These elements are easily changeable if decay occurs and prevents moisture damage to the posts.

Mounting technology

The portal frame can be mounted on the building site with the help of two mobile cranes.

Firstly the posts will be mounted comprising two half pieces with beam/rafter together (Fig. 7). The barbed pins or pin-screws of hardwood are used to connect them. Both parts of the frame lay horizontally. The hardwood supports are fixed to the foundation after that. Then both sides of the portal frame can be lifted onto the supports. The connections are then fixed with hardwood pins. Last of all the ridge connection is fixed with a hardwood pin (Fig. 8).

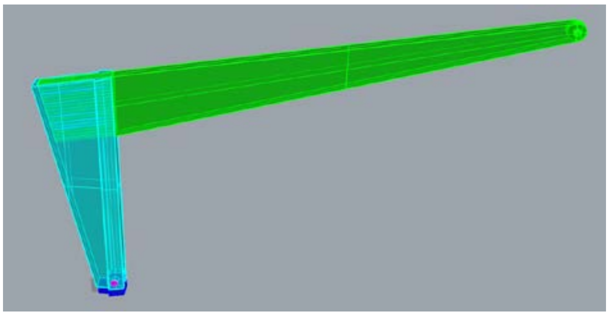

Fig. 7.
One half of the portal frame.

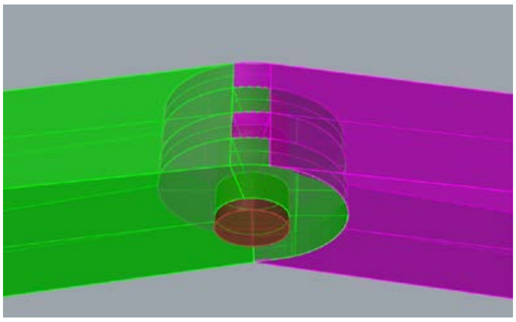

Fig. 8.
The ridge node fixed with a hardwood pin.

CONCLUSIONS

Using GLULAM and/or CLT in structures for portal frames needs careful handling because of different details needed to assemble them on the building site. It is most important to ensure the same moisture content in wood until all the details have been mounted in place so as to avoid damage and decay of timber elements because of moisture. Decay in timber can be minimised if the connections does not use metallic fasteners. The next important thing is geometry. The correct geometry of the whole structure from general to the smallest detail needs to be considered. Success with carpentry joints together with the development of CNC-workstation functionality permits the design and production of complicated joints even without gluing. The old skills with hardwood pins can be used to make corrosion and decay free connections between the members that need to act as hinge joints. Scheduled maintenance works are very important to get the desired lifespan of structures. They must be part of the project design developed by the architect and structural engineer. It is not possible and would be very expensive to predict every last detail for the total lifespan, thus designers have to predict/calculate the realistic lifespan of them. If some of the elements do not last until the end of total lifespan - such as supporting details under the posts - they have to design for easy (cheap) replacement technology.

ACKNOWLEDGEMENT

The patent application submitted for designing and producing technology of portal frames of GLULAM and CLT without metallic fasteners.

REFERENCES

Seliste V, Teppand T (2011) Testing and analysis of mortice and tenon wood joints for industrial timber wall constructions. Test Report. Estonian University of Life Sciences, Tartu, Estonia.