LOAD CARRYING CAPACITY OF LARGE MORTISE AND TENON JOINTS IN WOODEN MITRE GATES

Jan-Willem van de Kuilen¹,², Geert Ravenshorst¹, Peter de Vries¹, Jorick van Otterloo¹

ABSTRACT: Wooden mitre gates are used for centuries in waterways and canals. For newbuilt as well as the renewal of such gates, a number of wood species is used, ranging from oak to dense tropical hardwoods. As mitre gates have high loads to withstand, their strength verification has become more and more important. As strength verification rules for the complex mortise and tenon joints are lacking in most design codes, a research project has been performed to understand better the stress flow in these connections. A literature survey, an analytical analysis and a FEM analysis have been performed within this research project. The results allow for a much better understanding of the stress flow and of the resistance of these joint types.

KEYWORDS: mortise and tenon joints, mitre gates, FEM Modelling, Notches, Eurocode 5.

1 INTRODUCTION

Lock gates are an essential part in many waterways in Europe and North-America. Originally the mitre gates were made of wood species like oak or elm, treated for durability with tar. During the last century such doors have been increasingly made from Azobé (Lophira alata), a heavy tropical hardwood. These gates are still built with real craftsmanship and according to traditional designs that have been perfected during hundreds of years.

A picture of a mitre gate in a dry lock is shown in figure 1. In this case, wood species azobe (Lophira alata) has been used. Timber sizes in such an application are around 350 x 350 mm. Construction companies are recently obliged by building authorities to prove the structure satisfies safety standards on e.g. strength more extensive than formerly. However, construction companies are not able to prove whether the mortise and tenon joint between the crossbeams and posts in such a wooden mitre gate satisfies strength requirements [1],[2]. Experience from practice show however damage in relation with these connections. The main goal of this research is to obtain a valid and sensible method for the strength analysis and verification of the mortise and tenon joint in a mitre gate made of hardwood. Therefor it is important to figure out how the internal forces and stresses are distributed and how this connection can satisfy the requirements from standards and codes. In addition, the question is raised whether any modifications to design rules are necessary when hardwoods are used in these kind of notched connections.

2 STRUCTURAL ANALYSIS

2.1 MITRE GATES

A mitre gate has main beams with tenons on both sides. These are fixed in the mortise using wooden dowels, often made of wood species demerara greenheart. The principle of the connection is shown in Figure 2. Calculations common in practice assume a simple force distribution. However, the specific geometry of the joint including the specific supports and the combined loading in compression
parallel, compression perpendicular, shear force and bending makes the joint a very complex detail. A literature survey has been performed for the analysis of the tenon, as here typical tensile stresses perpendicular to the grain are expected when the beam is loaded in bending. A fracture energy approach has been used by [3][4],[5].

![3D exploded view of a mortise and tenon joint](image1)

**Figure 2: 3D exploded view of a mortise and tenon joint**

2.2 EXPERIMENTAL RESEARCH

As current design equations in Eurocode 5 for notched beams are based on tests of spruce, they should not be applied on similar notches made with other wood species. Therefore, an experimental program was setup, in order to obtain more information on the fracture energy for hardwoods. A number of beams were tested as shown in Figure 3. The results of these test show that modifications are necessary and possible, in order to use an EC5 approach.

![Test on a tenon](image2)

**Figure 3: Test on a tenon**

2.3 FEM MODEL

Using finite element modelling the force distribution is researched in detail using a 2D FE-model. The 3D effect is taken into account by adding an elastic support to the lower part of the post. The model is used to determine the force flow and the stresses near the supports. The analysis shows that tension stresses perpendicular to the grain reach a maximum value of around 1.5 N/mm², which does not pose a serious problem for heavy hardwoods. At the same time, the FEM model shows that the traditional approach of a notched beam as presented in Eurocode 5 needs modifications in order to be applicable to mortise and tenon joints such as discussed here.

3 CONCLUSIONS

For a wooden mitre gate manufactured according to traditional design the most important conclusions read:

- The shear force from the crossbeam is transferred to the rear post for the largest part through the tenon. A 3D effect is present in the joint whereby the shear force from the tenon is transferred to the sides of the mortise and is then transferred to the seal strip via the full section of the rear post.
- Due to the 3D effect the line of action of the reaction force on the tenon lies closer to the pit of the tenon than the line of action of the reaction force at the seal strip support does. Therefore a negative moment is present in the rear post which is counteracted by a frictional force at the back of the rear post.
- Appearing stresses throughout the joint satisfy design strength values.

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REFERENCES