

RETROFITTING OF CRACKS IN CONNECTIONS WITH GLUED-IN RODS IN BEECH GLULAM

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ABSTRACT: Glued-in rods can provide efficient connections with a high loadbearing capacity and can be regarded as state of the art for softwood glulam. The use in combination with hardwood glulam is still quite seldom and further investigations are needed to get it accepted more widely. Several methods are known to avoid failure due to tension stress perpendicular to the grain during the service life of glued-in rod connections. Fully threaded screws are often used to reinforce or retrofit timber for tension perpendicular to the grain. Therefore, this method could present a convenient technique to retrofit cracks parallel to the rods in connections with glued-in rods. Tension tests using specimens with artificial cracks along the glued-in rods showed that the full loadbearing and yield capacity could be attained in case the cracks were retrofitted using fully threaded screws.

KEYWORDS: glued-in rods, retrofitting, beech glulam, fully threaded screws

1 – INTRODUCTION

Hardwood glulam enables higher load bearing capacities than softwood and extends the field for timber structures. Truss systems allow for an efficient use of the material and large spans and are therefore prone for structures built using beech glulam. Constraints due to transportation and production facilities often lead to the need of an assembly joint and therefore also at least one connection in the tension chord of a truss. Due to the high loadbearing capacity, the ductility and the high rigidity of glued-in rods (girods) they are prone for such connections and used often in combination with softwood. The structural application of girods in combination with hardwood glulam is not regulated in any European standard. However, in Switzerland a guideline how to design girods in hardwood glulam is already published [1]. As beech is more prone to shrinkage and swelling as other structural timber the risk that drying cracks occur during service life cannot always be denied. In case this happens in the regions where girods are installed a significant influence on the loadbearing behaviour is expected and some measures to retrofit such rare cases would increase the area of application for girods.

2 – BACKGROUND

The use of fully threaded screws to reinforce areas with tension perpendicular to the grain in timber structures is state of the art and included in design codes [2, 4]. Meyer investigated the application of the method to reinforce girods in beech LVL and could prove that fully threaded screws are a possible measure to avoid splitting due to tension perpendicular to the fibres [3]. This result and the availability of fully threaded screws with a thin diameter suitable for structural purposes in hardwood motivated the authors to investigate the possibility of retrofitting cracks along girods in beech glulam.

3 – MATERIAL AND METHODS

Beech glulam with a lamella thickness of 40 mm was used for the investigation. To simulate the cracks along the girods the bond lines between the lamellas were produced with defined voids. For the girods the GSA system with a rod diameter of 16 mm was selected as its performance in beech glulam is already known [1].

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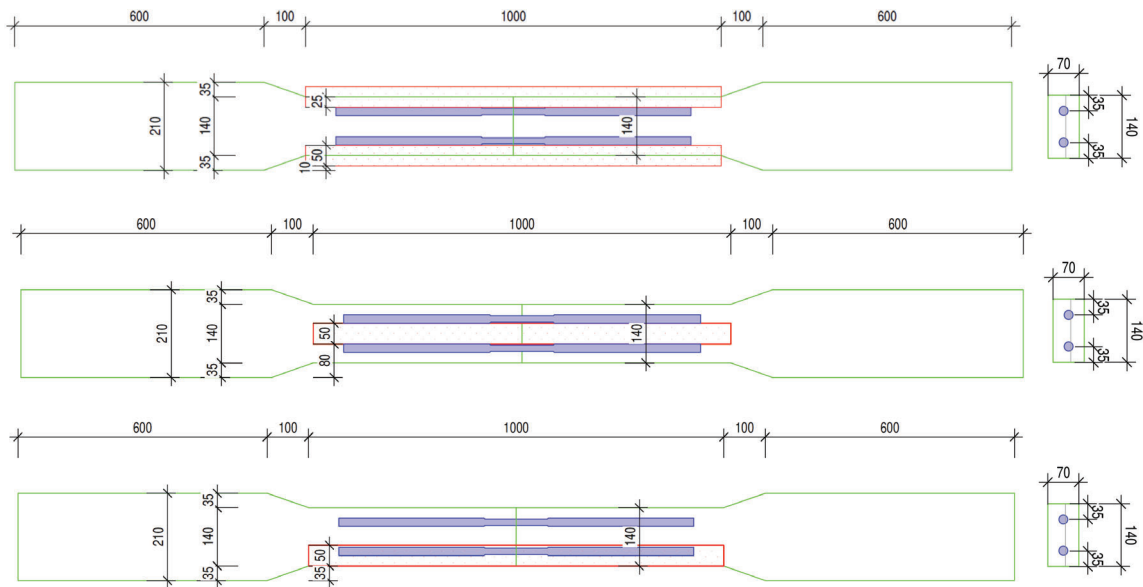


Figure 1: Specimen containing a general joint with two girods and an artificial crack marked in red colour (dimensions in mm); top: series A; middle: series B; bottom: series C; left: cross section of the general joint.

Two different configurations were tested in tension. In the first step specimens containing a general joint in the middle with two girods and different location of the artificial cracks were tested to investigate the influence of the artificial cracks on the loadbearing behaviour. Three different crack locations were simulated: Series A had one crack on each side penetrating to the steel rod, series B had a covered crack between the two girods and series C had on one side a crack penetrating 7 mm past the rod

(Figure 1). In a second step series D with retrofitted specimen containing a general joint with four girods and artificial cracks on one side penetrating 7 mm past the rods were tested (Figure 2). The retrofitting was installed after the specimen was loaded to the expected service load (Figure 4). For the retrofitting two fully threaded screws with a diameter of 5.6 mm and a length of 160 mm were used (Figure 3).

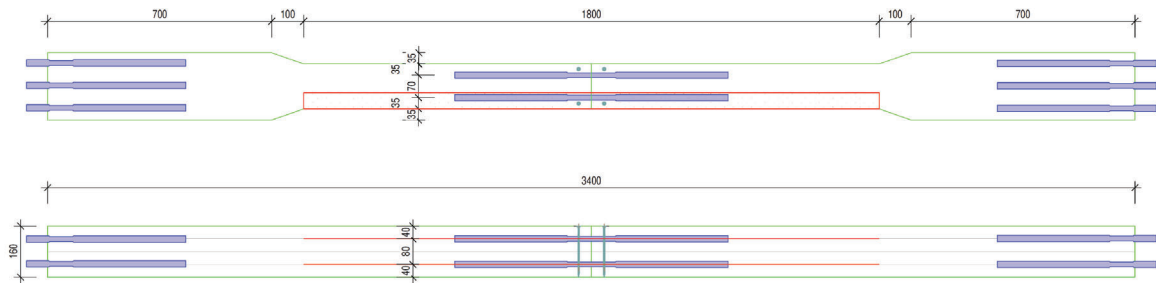


Figure 2: Specimen containing a general joint with four girods and two artificial cracks marked in red colour (dimensions in mm)

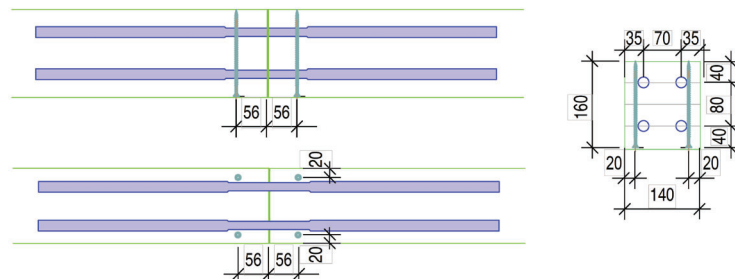


Figure 3: Detail of the reinforcement used to repair the connection with the artificial crack

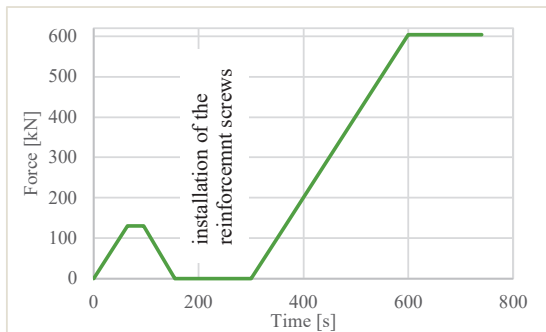


Figure 4: Systematic description of the loading routine used for test specimens with four girds.

For all series the opening of the joint was measured during the tension test. In series A, B and C the force was introduced using the clamps of the tension tester (Figure 5).

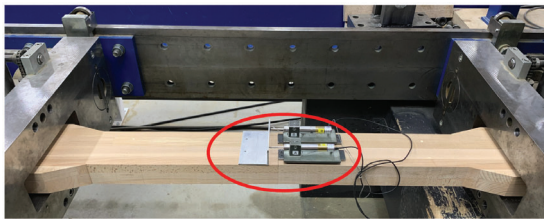


Figure 5: A specimen of series B during the tension test, the red circle highlights the general joint with the installed equipment for the deformation measurement.

Due to the dimension of the specimens of series D, they could not be inserted in the clamps, therefore on each end of the specimen 6 girds were placed and then connected to the travers of the tension tester (Figure 2 and Figure 6).

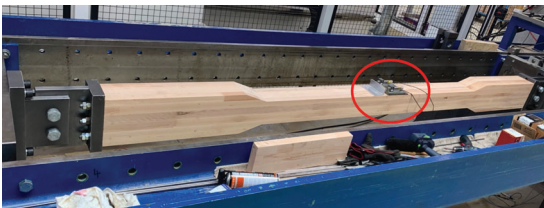


Figure 6: A specimen of series D during the tension test, the red circle highlights the general joint with the installed equipment for the deformation measurement.

4 – RESULTS

The results of the specimens without retrofitting showed in series A and C a clear influence on the load bearing behaviour but not for the series B with covered crack between the two girds, where yield in both steel rods was

reached and the connection did perform as it is desired for structural design (Figure 7, Figure 8 and Figure 9).

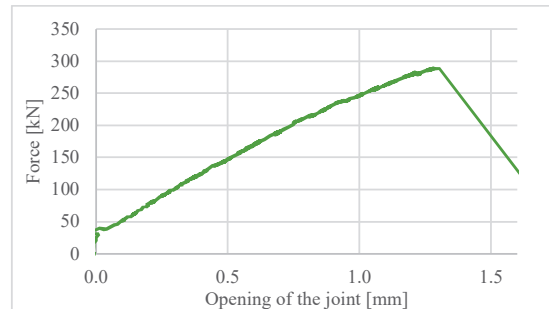


Figure 7: Typical load - joint opening diagram of series A with a brittle failure at the maximum load.

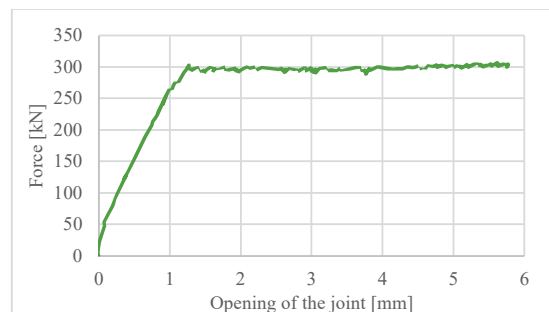


Figure 8: Typical load - joint opening diagram of series B where no failure occurred, and the test was stopped after 5 mm deformation at the joint was reached.

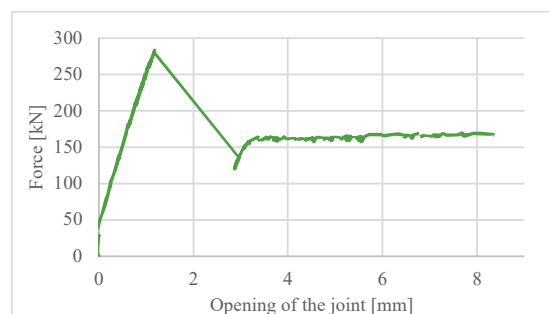


Figure 9: Typical load - joint opening diagram of series C with a brittle failure of the girrod with the artificial crack and then a plateau where the second girrod (without artificial damage) yielded the test was stooped 5 mm deformation after the part failure.

Series B also showed the highest load bearing capacity combined with a very low scattering of the results (Figure 10). The low variation can be explained as the girds yielded and therefore the steel strength was governing the failure. The specimens of series A and C showed lower strength and a quite high scattering as one could expected because tension perpendicular to the fibres led to splitting of the timber which was governing the failure.

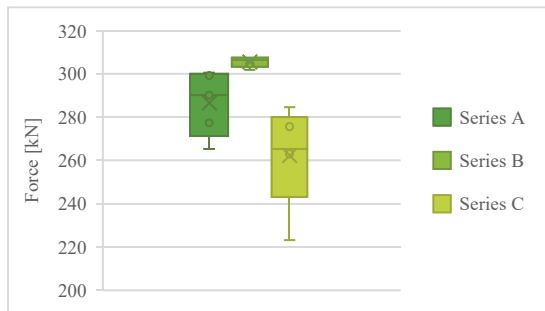


Figure 10: Results for the specimens containing two girods and no retrofitting.

In the series A and C with an artificial crack at the surface the opening of the crack during the loading was clearly visible before the ultimate load was reached (Figure 11).

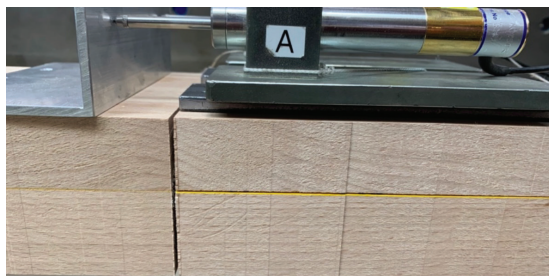


Figure 11: Opening the artificial crack under load. Before loading, the yellow adhesive tape used to simulate the crack was not visible.

All specimen containing four girods and fully threaded screws as a retrofitting (see Figure 3) reached the expected yield force and the desired yield deformation of 5 mm. The full loadbearing capacity could even be reached when the specimens containing the artificial cracks were loaded to the expected service load prior to installation of the retrofitting.

All test specimens in the series D could be loaded to the specified preload of 130 kN without any problems in their unreinforced state. When tested after reinforcement, none of the test specimens failed and the tests were stopped after a joint opening of at least 6 mm (Table 1 and Figure 12).

Table 1: Results of the tension tests on the retrofitted specimens.

Sample	$F_{\max}$ [kN]	Joint opening [mm]	F_{end} [kN]
D-1	613	6	594
D-2	604	7.3	570
D-3	606	7.1	582
D-4	607	7.9	547
D-5	604	6.8	541

The tests showed that the fully threaded screws prevent the crack from opening even under maximum load and that the test specimens achieved the expected load-bearing capacity and ductility of a connection without damage.

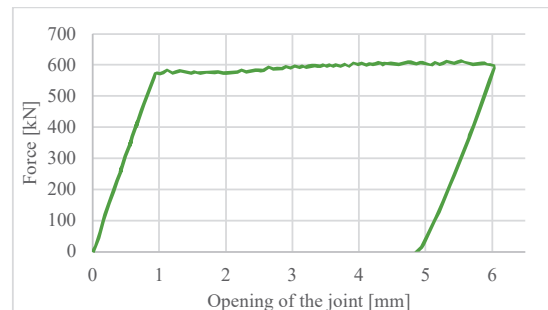


Figure 12: Typical load - joint opening diagram of series D where no failure occurred, and the test was stopped after 5 mm deformation at the joint was reached.

5 – CONCLUSIONS

The investigation clearly shows that cracks along girods can lead to a lower ductility and loadbearing capacity. However, the tested method to retrofit such cracks proved that the full loadbearing capacity and behaviour can be reached again by applying a few fully threaded screws in the region of the cracks.

6 - ACKNOWLEDGEMENTS

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6 – REFERENCES

- [1] Bernasconi A., Ehrhart T., Eschmann M., et al. 2021: *Verklebte Laubholzprodukte für den statischen Einsatz*, Lignatec, Vol. 33, Lignum, Holzwirtschaft Schweiz, Zürich
- [2] Blass H.J. und Sandhaas C. 2017: *Timber Engineering - Principles for Design*, KIT Scientific Publishing, Karlsruhe
- [3] Meyer N. 2020: *Tragfähigkeit mechanischer und geklebter Verbindungsmittel in Buchenurnierschichtholz*; Dissertation, Karlsruher Instituts für Technologie, Karlsruhe
- [4] SIA 265:2021 Holzbau; SIA Schweizerischer Ingenieur- und Architektenverein, Zürich, 2021