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Original Research Article

NUMERICAL MODELING OF THE FATIGUE STRENGTH OF TIMBER JOINT CONNECTIONS WITH CONNECTOR PLATES

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A b s t r a c t

This study investigates the fatigue performance of timber joints with connector plates through experimental testing and numerical simulation. A displacement-controlled fatigue test was conducted on a timber connection composed of C24-grade wood elements and a T150 steel connector plate. Failure occurred due to progressive shearing of the plate teeth. Numerical analyses were performed using Abaqus (for static FEM simulation) and fe-safe (for fatigue prediction), applying two models: Morrow and Goodman. Simulations evaluated the effects of varying displacement amplitudes (0.5 mm, 2.5 mm, 5.0 mm), friction coefficients (0.1, 0.3, 0.5), and load frequencies (6 Hz, 10 Hz). Results show that increased displacement and friction lead to lower fatigue life due to localized stress concentrations. The predicted damage locations corresponded with experimentally observed failure zones. The applied Critical Plane methodology enabled reliable fatigue life estimation. The approach confirms the usefulness of FEM-based modeling in predicting fatigue failure in timber-steel joints and highlights key parameters affecting durability.

Keywords: fatigue strength, numerical analysis, wood, connector plates

1. INTRODUCTION

The design of modern timber structures requires consideration of fatigue phenomena, especially in elements exposed to long-term cyclic loads such as vibrations, wind, or service loads. Although wood has a different structure compared to steel or concrete, it also undergoes gradual degradation under repeated loading. Studies indicate that fatigue in wood can occur after a relatively lower number of deformation cycles than in steel structures, and wood shows particular sensitivity to stresses perpendicular to the grain (e.g., near connections) [1,2]. In real structures, cases of cracking and damage in timber joints have been observed, attributed specifically to the accumulation of fatigue damage [3-5]. Due to the stress and strain concentration in the joints of timber structures, fatigue analysis of connections becomes crucial for assessing the safety and durability of the entire system.

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The importance of fatigue analysis in the design of timber structures is growing with the increasing use of wood in applications subjected to dynamic loads (bridges, tall timber buildings, communication towers, etc.). Traditionally, design standards for timber structures have devoted limited attention to fatigue; however, work is currently underway to incorporate appropriate requirements into standards, such as the planned introduction of fatigue principles into Eurocode 5 [6]. The literature emphasizes that, unlike steel, for which fatigue criteria are mainly based on stress range, in the case of wood, the level of mean stress and environmental factors (e.g., humidity) also play a significant role [6]. The literature lacks a fully mature analytical model that enables accurate prediction of the fatigue life of timber elements. Therefore, knowledge in this field mainly comes from experimental studies based on determining the number of cycles to failure at given load levels (Wöhler curves) [6]. However, the results of these studies are still relatively limited. It is also noted that the available literature lacks comprehensive fatigue analyses of timber joints subjected to cyclic loading, which hinders precise determination of allowable loads and prediction of the fatigue life of such connections [7]. Therefore, further research in this area is necessary.

Against the background of the issues discussed above, connections using connector plates play a particularly important role—modern metal fasteners with stamped teeth that are pressed into the connected timber elements. The connector plate technology was introduced in the mid-1950s and revolutionized the timber construction industry. Thanks to these fasteners, it became possible to quickly prefabricate trusses and other frame structures without the need for traditional bolted or mortise-and-tenon joints. Connector plates are pressed into the wood, providing a large contact surface and efficient force transfer. Today, timber trusses joined with connector plates are the dominant type of truss in residential and industrial construction, valued for their ease of assembly, fast production, and high stiffness and load-bearing capacity of the joints. The use of these fasteners has also expanded to unconventional applications, such as lightweight timber bridges, where prefabricated girders with connector plates have proven competitive due to their low weight and simple installation [8]. Long-term operation of such connections requires assurance that variable loads will not lead to gradual loosening of the plates due to the teeth pulling out of the wood. It is emphasized that ensuring adequate fatigue resistance (preventing the so-called “pull-out” of the plates from joints) and corrosion protection is key to maintaining the durability of such connections. This challenge motivates ongoing research into the fatigue behavior of connector plate joints, both experimental and numerical.

The main objective of the presented numerical studies was to examine the concept of additional reinforcement of the connection against the loosening of connector plates, for example by bonding them to the timber elements using adhesive. It appears that this could significantly improve the fatigue durability of the joint. It can be assumed that the use of adhesive would limit relative displacements in the contact zone, reducing local stresses and lowering the risk of microcrack initiation and fatigue damage.

Numerical methods, in particular the finite element method (FEM), are playing an increasingly important role in the strength analysis of timber connections with connector plates. FEM models allow for the reproduction of complex phenomena occurring in the joint—from the deformation of the wood around the teeth, through contact and friction at the wood–steel interface, to local plasticization of the teeth or wood damage. Computer simulations provide insight into the stress distribution within the connection, identifying areas of stress concentration that may potentially initiate fatigue damage [9,10]. The literature describes a variety of FEM models for such joints: from simplified elastic models to advanced nonlinear models that account for contact and semi-rigid connection behavior [7]. For example, Ellegaard proposed a computational model of a timber truss with connector plate joints, in which special elements were used to simulate groups of teeth and the plate itself. This made it possible to reproduce the semi-rigid and nonlinear behavior of the joints and to account for friction between the wooden elements [11]. This model accurately predicted joint deflections and stiffness in the elastic range, although discrepancies were observed near ultimate loads due to crack development in the wood—a phenomenon difficult to capture in a simple elastic model. The development of simulation techniques now also enables modeling of stiffness degradation and damage accumulation under cyclic loading, making FEM a powerful tool for predicting the fatigue life of connector plate joints. The latest review studies indicate that combining experimental results with validated numerical models offers a promising path toward a fuller understanding of fatigue mechanisms in such timber joints [12]. Consequently, the application of FEM analyses in fatigue research allows not only for predicting the number of cycles to joint failure, but also for optimizing plate design (tooth arrangement and length) and assembly parameters to enhance the safety and durability of the designed structures.

2. EXPERIMENTAL PROCEDURE

A real joint of two timber elements was subjected to a fatigue strength test to determine the failure mechanism. The test was carried out using an INSTRON 8804 testing machine, as shown in Figure 1.

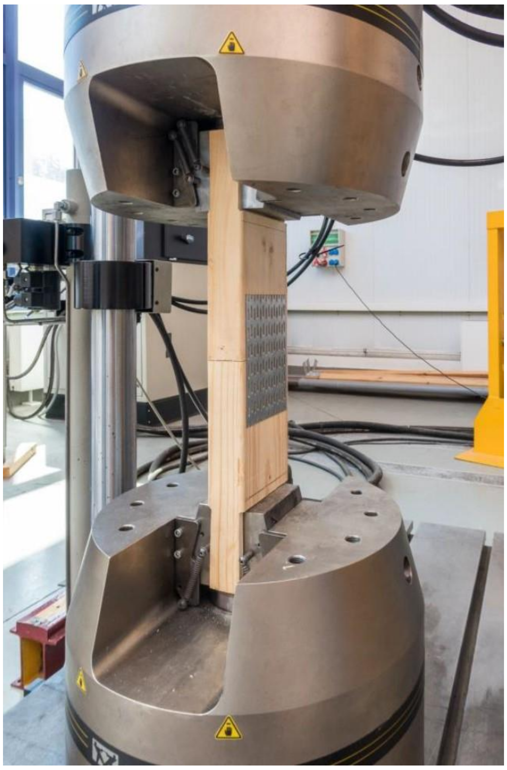

Fig. 1. The specimen on the test stand

The timber elements had dimensions of 116 mm x 42 mm x 250 mm and were made of C24-grade wood. The connector plate used was a T150 type with dimensions of 144 mm x 1.5 mm x 102 mm and a tooth height of 15 mm. The joint was subjected to cyclic loading by imposing a displacement with an amplitude of 0.5 mm at a frequency of 6 Hz. The test was performed in displacement-controlled mode and the applied force was not directly measured. The connection failed after approximately 9000 cycles. Figure 2 shows the characteristic features of the fatigue failure mechanism observed in the tested joint. Six samples were tested. All of them exhibited the same failure pattern and a similar number of cycles.

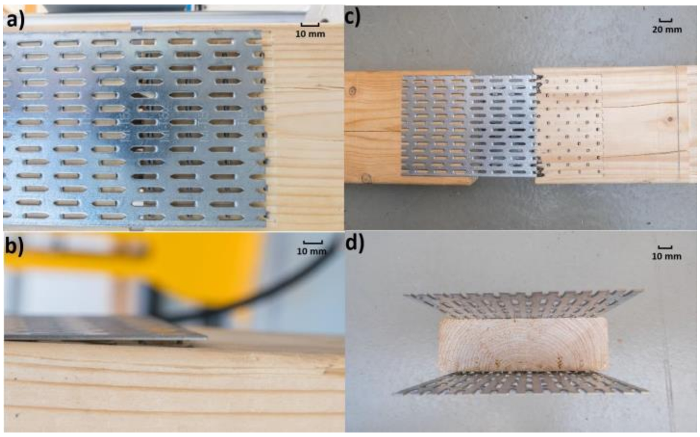

Fig. 2. Characteristic features of the failure mechanism

The entire fatigue failure process of such a joint can be divided into several stages. In the initial phase of failure, shearing of individual rows of teeth in the connector plate occurs (Figure 2a). The failure begins in the contact area between the teeth and the plate and is a consequence of the local exceeding of the material's yield strength. This process leads to the gradual degradation of successive rows of teeth.

The next observable stage is the gradual "detachment" of the steel connector plate from the surfaces of the timber elements (Figure 2b). This phenomenon results from plastic deformation of the plate in the area near its connection to the beams. Under cyclic loading, the plate begins to deform, which leads to the formation of a gap between the wood and the connector plate, particularly at the edges farthest from the center of the joint.

The final stage of the failure process is the complete rupture of the connection through the shearing of all rows of teeth (Figures 2c and 2d). This occurs after reaching a critical number of load cycles that results in the total loss of the joint's load-bearing capacity. At the moment of rupture, the connector plate teeth are completely separated from the metal plate, leading to sudden and total destruction of the tested structural element. This process illustrates the significant role of fatigue analysis, which enables the prediction of damage initiation and helps to prevent unexpected failures in engineering practice.

The fatigue test was interrupted upon a visible and complete loss of load-bearing capacity of the connection, defined by full shearing of all rows of the connector plate teeth, as observed during the experiment. This criterion corresponds to the mechanical failure of the joint and was selected to reflect the final stage of fatigue degradation.

3. NUMERICAL PROCEDURE

For the numerical fatigue analysis of timber connections with connector plates, the integrated software SIMULIA Abaqus and fe-safe was used [13]. Abaqus, as an advanced FEM tool, enables detailed modeling of the joint geometry, definition of appropriate boundary conditions, loads, and material properties of wood and steel fasteners. The results of stress and strain distributions obtained from the static analysis in Abaqus served as input data for the fe-safe software, which allows for comprehensive fatigue life analysis. The use of fe-safe enables damage localization, determination of the number of cycles to failure, and assessment of the impact of varying loading conditions. The integration of both tools ensures accurate prediction of the fatigue life of connector plate joints, thus minimizing the need for costly experimental testing and allowing for optimization of the connection already at the numerical modeling stage.

In the conducted fatigue analysis of timber connections with connector plates, two classical computational models were applied: the Morrow model [14] and the Goodman model [15]. The Morrow model is based on strain amplitude and accounts for the influence of mean stress level in the load cycle, allowing for a more realistic representation of material behavior in low-cycle fatigue, where elastic-plastic deformations occur. In contrast, the Goodman model is based on stress amplitude and includes the effect of mean stress through a linear relationship, performing particularly well in the high-cycle fatigue range, where elastic stresses dominate.

The adoption of both models was justified by the nature of the analyzed timber–steel connection, in which the connector plates are subjected to cyclic loads that lead to damage accumulation both in the elastic zone and potentially in the plastic zone—especially in areas of stress concentration such as the tooth-to-plate interface. The use of both algorithms enabled a comparative analysis and assessment of the sensitivity of results to the chosen computational methodology.

As part of the numerical analysis, a simulation of the timber connection with connector plates was performed for different friction coefficient values (0.1; 0.3; 0.5) between the plate and the timber element. This approach was justified by the need to consider the variability of real contact conditions between the metal fasteners and wood. The friction coefficient is a significant parameter affecting the stress distribution and local deformations, which are critical for the initiation and propagation of fatigue damage. Investigating the influence of different friction coefficients made it possible to identify their impact on the joint's durability and to evaluate the concept of reinforcing such connections against the detrimental effects of cyclic loading through the application of adhesive. The idea was that a higher friction coefficient between the plate and timber element simulates a stronger bonded connection.

Thus, the analysis of the friction coefficient's influence became the basis for further considerations on connection optimization methods, including additional design and technological solutions to enhance its reliability and longevity under long-term cyclic operational loads.

The geometric model of the joint was developed using the Abaqus software environment (Figure 3). It consists of two timber bars ("Top" and "Bottom") connected by a steel connector plate ("T150").

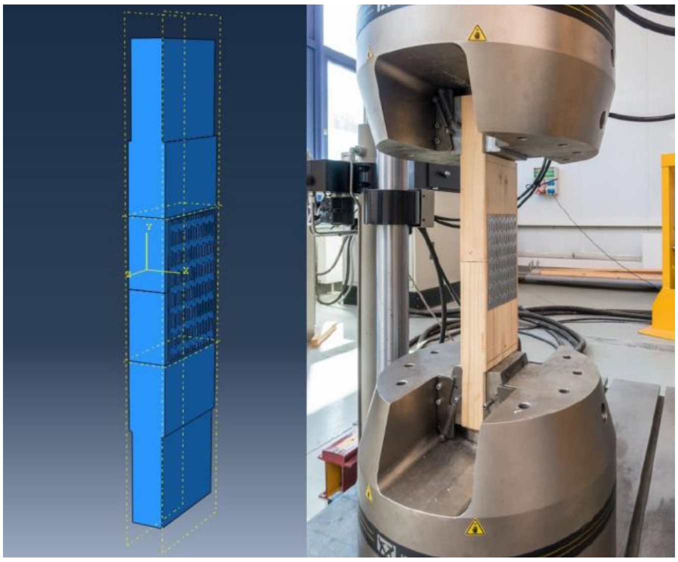

Fig. 3. Geometric model on the left and actual specimen on the test stand

The bars were modeled with holes that replicate the shape of the connector plate teeth. For computational efficiency and time savings, a symmetric approach was adopted, creating a model that represents a symmetrical half of the actual assembly (Figure 4).

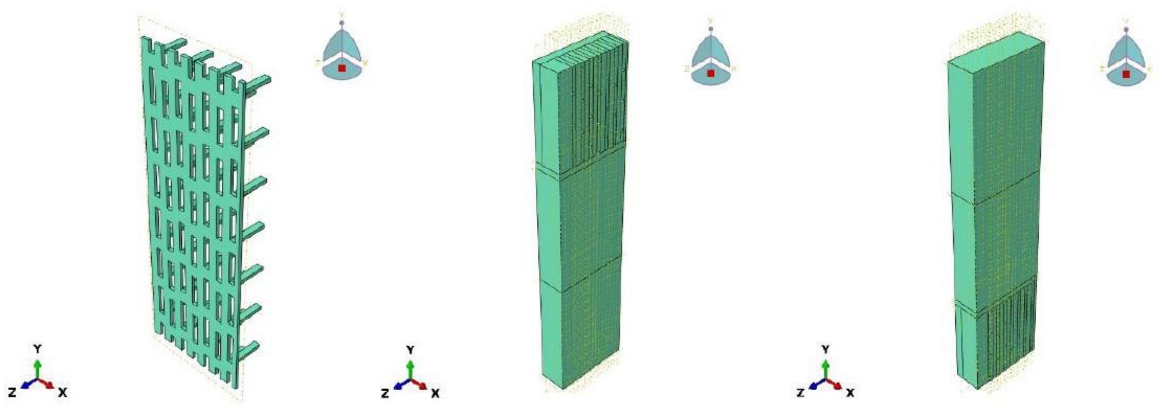

Fig. 4. Geometric model with symmetry considered, from left: connector plate, bottom timber element, and top timber element

The timber elements in the finite element model were defined as linear orthotropic elastic materials, reflecting the anisotropic nature of structural wood (C24 grade). The material properties were specified as follows: density 350 kg/m³, Young's moduli 11 GPa (longitudinal), 0.8 GPa (radial/tangential), Poisson's ratio 0.2. No plasticity or damage behavior was assigned to the timber.

The connector plate was modeled as an isotropic elastic–plastic material corresponding to SAE 950C steel, which has mechanical properties comparable to high-strength galvanized steels typically used in metal plate connectors. The following parameters were used: density 7800 kg/m³, Young's modulus 200 GPa, Poisson's ratio 0.3, and yield strength 400 MPa. Plasticity was introduced using an elastic–perfectly plastic model (idealized Von Mises yield criterion) without strain hardening.

This combination of material models allowed for a realistic reproduction of the local plasticization phenomena observed in the steel teeth of the connector plate, while preserving computational efficiency. The selection of the constitutive behavior was consistent with the assumptions adopted in the fatigue life prediction using fe-safe.

The numerical model included appropriate boundary conditions reflecting the real experimental setup of the tested joint (Figure 5). The bottom timber bar was fully fixed, with no possibility of translation or rotation, corresponding to the clamping in the testing machine during the actual experiment. The top timber bar was subjected to vertical displacement (along the Y-axis), simulating the cyclic action of the testing machine. This displacement was analyzed in three variants, corresponding to 10% (0.5 mm), 50% (2.5 mm), and 100% (5 mm) of the assumed maximum displacement. The model also incorporated symmetry conditions with respect to the X and Z axes, which allowed for a reduction in the number of finite elements and significantly improved computational efficiency.

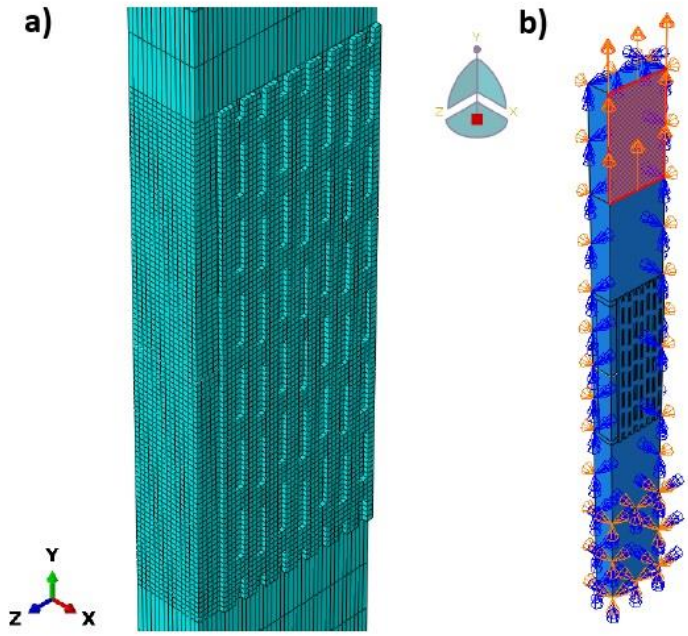

Fig. 5. Discretization (a) and boundary conditions (b)

An essential aspect of the simulation was the inclusion of contact interaction between the timber bars and the steel connector plate. Analyses were conducted for three different values of the friction coefficient: 0.1; 0.3, and 0.5. For each of these values, the distribution of von Mises equivalent stresses, displacements, and logarithmic strains was evaluated using the finite element method (FEM). A variable-density mesh was applied, with local refinement in areas expected to experience the highest stresses and strains, particularly in the region where the plate teeth connect with the wood.

The finite element model was constructed using 3D solid elements of type C3D8R (8-node linear brick elements with reduced integration and hourglass control), available in the Abaqus library. These elements provide a good balance between computational efficiency and accuracy for contact-dominated problems with moderate plasticity.

The connector plate and both timber elements were discretized using a structured mesh. To accurately capture the stress and strain gradients near the critical zones especially at the interface between the connector teeth and the timber local mesh refinement was applied. The characteristic element size in the refined contact region was set to 3 mm for the plate and wood, while coarser elements were used away from high-gradient zones.

A basic mesh sensitivity analysis was performed by comparing stress distributions and predicted damage locations using three different mesh densities. The selected mesh provided convergence in terms of peak von Mises stresses (within 5%) and location of critical fatigue zones. This mesh configuration ensured computational tractability and reliable resolution of critical damage regions under cyclic loading.

The next stage of the study involved performing a fatigue analysis in the fe-safe software. This analysis used the results obtained earlier from the FEM simulation conducted in Abaqus. The fatigue evaluation was carried out using two algorithms: Morrow and Goodman. The influence of cyclic loading at two frequencies (6 Hz and 10 Hz) was investigated, allowing for the determination of the number of cycles leading to damage initiation. This damage was defined as the moment when the first row of connector plate teeth shears off.

4. RESULTS AND DISCUSSION

In the conducted numerical analysis of the timber joint with connector plates, results were obtained from both the static and fatigue simulations.

The static simulation, carried out in Abaqus, enabled the determination of stress distribution, displacements, and logarithmic strains within the components of the timber joint. The analysis was conducted for three different values of the friction coefficient (0.1, 0.3, 0.5) to investigate its potential influence on the static response.

The results, presented in Figures 6–8, show that the variation in the friction coefficient had no significant effect on the global behavior of the connection under static loading. The von Mises stress distributions (Figure 6) remained practically unchanged, with the highest stress concentrations consistently observed at the base of the connector teeth near their interface with the steel plate. The maximum stress value across all cases reached approximately 400 MPa.

Similarly, vertical displacements of the upper timber element (Figure 7) and the distribution of logarithmic strains (Figure 8) exhibited only marginal differences among the tested friction values. The deformation pattern remained consistent, with localized strain intensification in the first row of connector teeth, which aligns with the experimentally observed damage zone.

These findings suggest that under monotonic (static) loading, the effect of contact friction is negligible in the global structural response. This justifies the focus on frictional effects primarily in the fatigue analysis phase, where cumulative damage and local interface behavior become more critical.

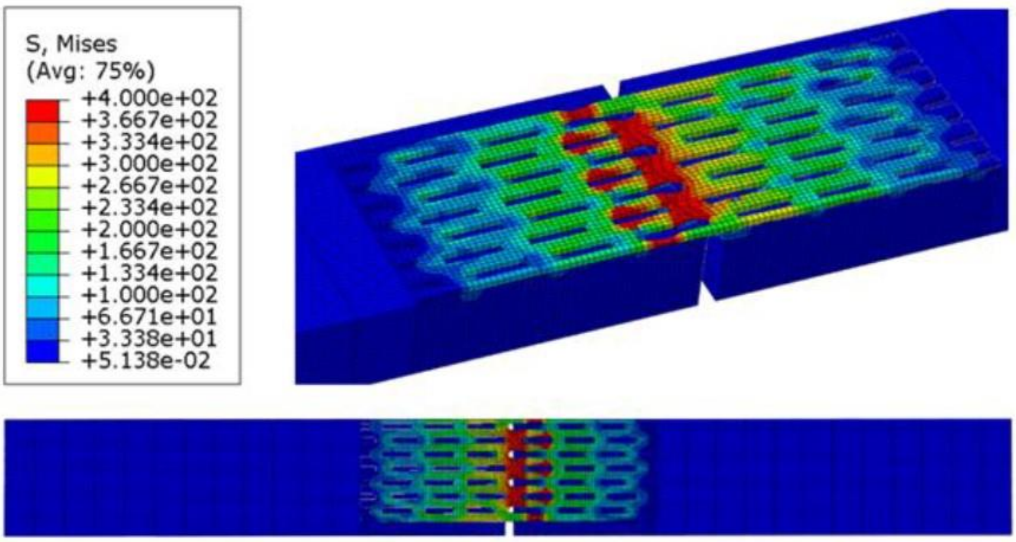

Fig. 6. Von Mises stresses for friction coefficient values of 0,1; 0,3; and 0,5

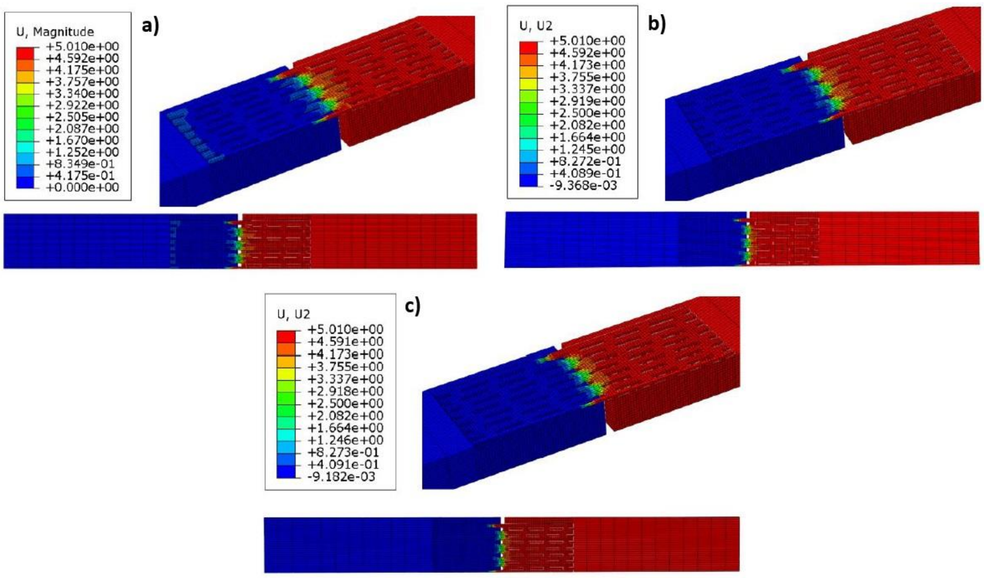

Fig. 7. Vertical displacements U2 for friction coefficient values: a) 0.1; b) 0.3; c) 0.5

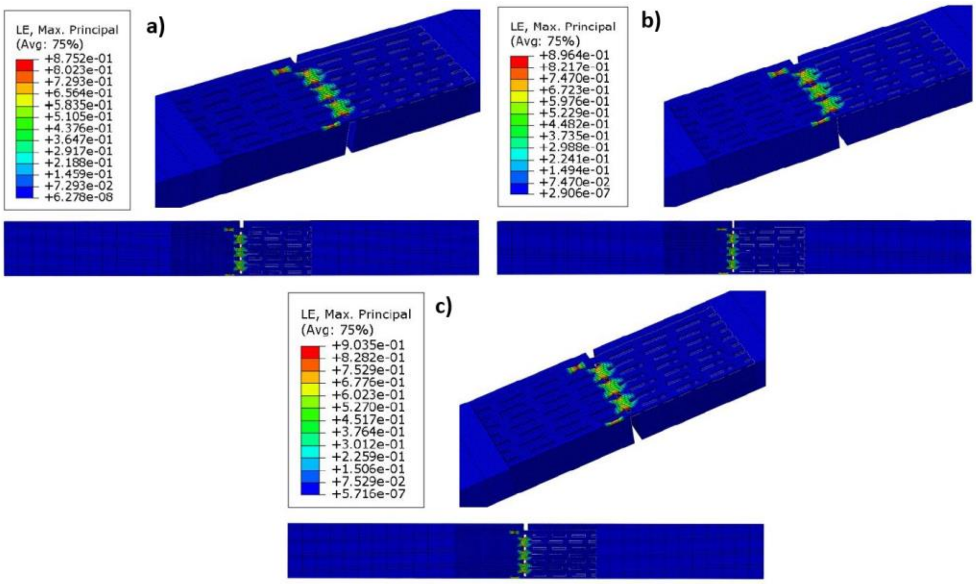

Fig. 8. Logarithmic strains for friction coefficient values: a) 0.1; b) 0.3; c) 0.5

As part of the fatigue simulation performed using the fe-safe software, the influence of cyclic loads at two frequencies—6 Hz and 10 Hz—was analyzed. The loads were applied at three different displacement amplitudes of the upper bar: 0.5 mm (10%), 2.5 mm (50%), and 5 mm (100%). The results clearly indicate that the number of cycles leading to the initiation of joint failure, defined as the shearing of the first row of connector plate teeth, significantly depends on both the displacement amplitude and the friction coefficient. For smaller displacement amplitudes (e.g., 0.5 mm), the joint was able to withstand a substantial number of cycles (on the order of several thousand), whereas at higher displacements (5 mm), this number dropped sharply, reaching values from a few to several dozen cycles. The results of the fatigue analysis are presented in Tables 1–3.

Table 1. Fatigue analysis results for a friction coefficient of 0.1

	6 Hz			10 Hz		
	0.5 mm	2.5 mm	5 mm	0.5 mm	2.5 mm	5 mm
Morrow	8584.115	44.119	9.047	8100.565	41.653	8.543
Goodman	8403.693	42.587	8.681	8100.565	41.653	8.543

Table 2. Fatigue analysis results for a friction coefficient of 0.3

	6 Hz			10 Hz		
	0.5 mm	2.5 mm	5 mm	0.5 mm	2.5 mm	5 mm
Morrow	5714.818	46.220	8.314	5393.019	43.637	7.851
Goodman	5589.961	44.622	7.975	5393.019	43.637	7.851

Table 3. Fatigue analysis results for a friction coefficient of 0.5

	6 Hz			10 Hz		
	0.5 mm	2.5 mm	5 mm	0.5 mm	2.5 mm	5 mm
Morrow	4439.107	46.519	7.855	4189.206	43.919	7.418
Goodman	4339.762	44.912	7.534	4189.206	43.919	7.418

The fe-safe software offers various fatigue analysis modes. In this study, the Critical Plane method was used, specifically the Critical Plane Morrow and Critical Plane Goodman approaches, which differ in how they account for the effect of mean stress on the material’s fatigue life.

Critical Plane Morrow [16] is a strain-based fatigue method, particularly useful for low-cycle fatigue (LCF), where the material undergoes significant plastic deformations over a relatively low number of cycles. This method involves analyzing multiple planes within the material and identifying the one where fatigue strains are most critical. The influence of mean stress is included through the nonlinear Morrow correction, which allows for a more accurate representation of material behavior under load. Application of this method requires material data in the form of ε-N (strain-life) curves, which relate strain to the number of cycles to failure.

Critical Plane Goodman [16], on the other hand, is based on stress analysis and is especially suitable for high-cycle fatigue (HCF), where the material operates within the elastic range and the loads are repeated over a very large number of cycles. This variant also analyzes different planes in the material, but mean stress is accounted for using a linear Goodman correction. To apply this method, classical S-N (stress-life) curves are required, which relate stress amplitude to the number of cycles to failure.

Both methods allow for precise fatigue analysis under complex stress states and are significantly more advanced than traditional approaches that do not consider the crack plane orientation.

The fatigue parameters used in the Morrow and Goodman models were sourced from the fe-safe material database for SAE 950C steel. For the strain-based Morrow model, the material constants were: fatigue strength coefficient 1100 MPa, fatigue strength exponent −0.12, fatigue ductility coefficient 0.5, fatigue ductility exponent −0.6, and Young’s modulus E = 200 GPa. For the Goodman model, an endurance limit of 450 MPa and ultimate tensile strength of 950 MPa were assumed. These values are representative of the material properties implemented in the fatigue analysis. The connector plate was modeled using material properties representative of SAE 950C steel. Although actual connector plates are typically manufactured from galvanized cold-formed steel such as S350GD according to EN 10346 or EN 14545, the selected material provides a conservative basis for assessing fatigue performance and locating critical failure zones.

To assess the validity of the numerical model, a direct comparison was made between the simulation results and the experimental fatigue life. In the laboratory test, the joint failed after approximately 9000 cycles under displacement-controlled loading with an amplitude of 0.5 mm and a frequency of 6 Hz.

The corresponding numerical predictions using the Morrow and Goodman models (for friction coefficient 0.1) yielded 8584 cycles and 8403 cycles, respectively. This shows a deviation of less than 7% from the experimental result, indicating very good agreement between the simulated and observed fatigue behavior. Such consistency validates the modeling assumptions, including the choice of material parameters, boundary conditions, and the adopted fatigue algorithms. It also confirms that the finite element–based approach can reliably predict the onset of fatigue failure in timber connections with connector plates under cyclic loading.

The result of the fatigue analysis in fe-safe can be presented as a damage map, shown in Figure 9. The presented legend of the fatigue damage map illustrates the distribution of damage in the material on a scale from 0 to 1. The red color corresponds to no damage, i.e., full material durability, while the blue color indicates complete fatigue failure. As seen in Figure 9, the fatigue failure process of the joint begins with the first row of teeth. A similar failure pattern was observed in the laboratory tests.

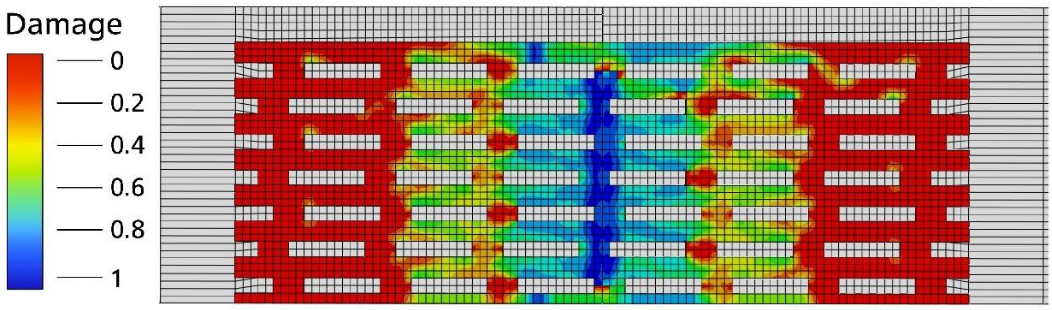

Fig. 9. Fatigue damage map of the connector plate

Figures 10–12 present a graphical comparison of the predicted number of cycles to failure at a loading frequency of 6 Hz, based on two fatigue life prediction models: Goodman and Morrow. The figures correspond to different displacement amplitudes applied to the timber joint: 0.5 mm (Figure 10), 2.5 mm (Figure 11), and 5.0 mm (Figure 12). For each case, the results are shown for three values of the friction coefficient (0.1, 0.3, 0.5), allowing for the evaluation of combined effects of displacement amplitude and interface conditions on fatigue performance.

In all cases, the Goodman model predicts a lower fatigue life compared to the Morrow model. This trend is consistent across all friction values and displacement amplitudes, and results from the linear nature of the Goodman approach, which tends to overestimate the detrimental effect of mean stress, especially in low-cycle fatigue regimes.

The largest differences between the two models occur at the intermediate displacement amplitude of 2.5 mm (Figure 11). In this range, the stress and strain conditions induce partial plastic deformation, and the Morrow model, which accounts for strain-based fatigue mechanisms, predicts a noticeably longer fatigue life. The divergence between models is particularly visible for higher friction coefficients, where stress concentrations are more pronounced.

At the lowest displacement (0.5 mm), the predictions are closer, although the Morrow model still yields slightly higher fatigue lives. At the highest displacement (5.0 mm), both models predict significant fatigue degradation and reduced durability, but the difference between them narrows again, as the fatigue life drops to a similar low level.

These results emphasize that, even under constant loading frequency, the choice of fatigue model has a notable impact on life prediction. The Goodman model may provide a more conservative estimate, whereas the Morrow model offers better representation of strain-driven fatigue behavior, particularly at moderate load amplitudes and in partially plastic regimes.

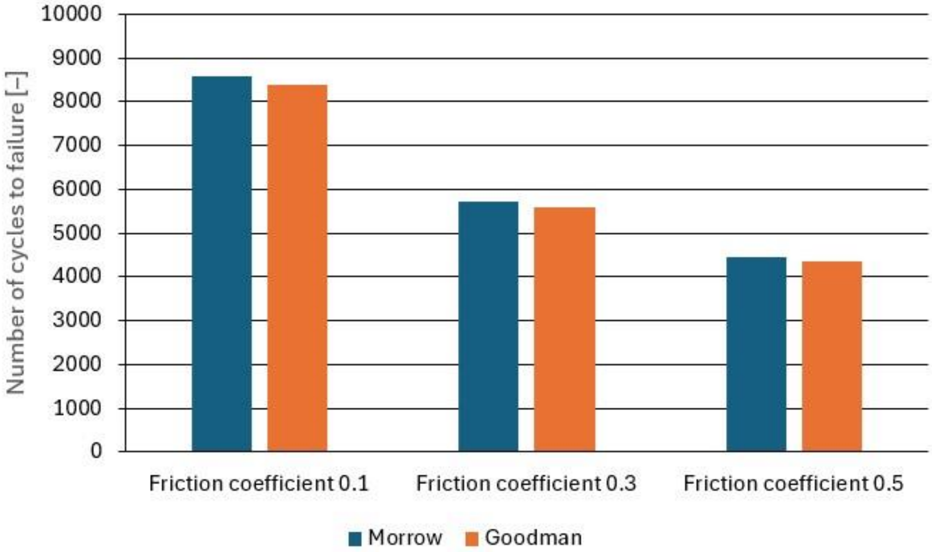

Fig. 10. Number of cycles to joint failure at a displacement amplitude of 0.5 mm

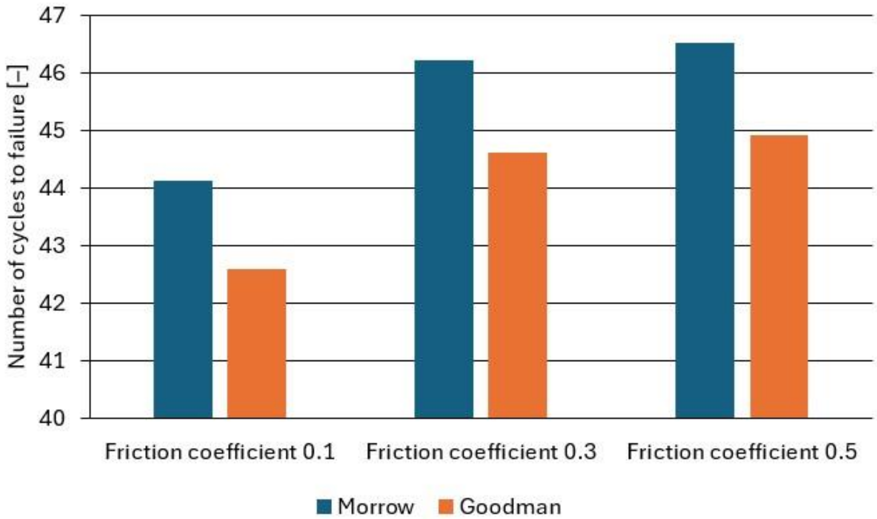

Fig. 11. Number of cycles to joint failure at a displacement amplitude of 2.5 mm

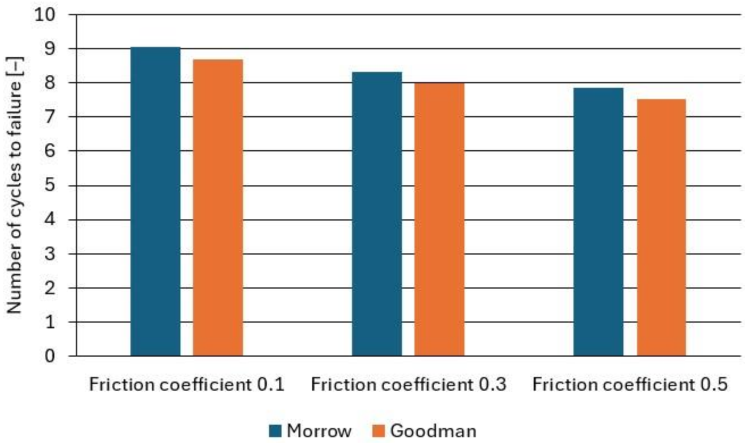

Fig. 12. Number of cycles to joint failure at a displacement amplitude of 5.0 mm

5. CONCLUSIONS

The conducted study demonstrated that the fatigue durability of timber connections using connector plates is significantly influenced by parameters such as the friction coefficient in the contact zone, displacement amplitude, and the fatigue analysis algorithm used. The results confirmed that larger displacement amplitudes lead to a significant reduction in the number of cycles to failure and, consequently, to faster joint degradation. Moreover, an increase in the friction coefficient—simulating strengthened bonding through adhesive application—also resulted in reduced joint durability, suggesting that an overly rigid connection may cause local stress concentrations and accelerate damage.

Two well-established fatigue models were used in the analysis—Morrow and Goodman—representing strain-based (for low-cycle fatigue) and stress-based (for high-cycle fatigue) approaches, respectively. A comparison of the results obtained from these models showed that, at a lower frequency of 6 Hz, the choice of algorithm affected the predicted fatigue life, whereas at 10 Hz, these differences became marginal. This variation highlights the importance of carefully selecting the analytical model depending on the nature and scope of the cyclic loading.

The application of the finite element method (FEM), combined with fatigue analysis in the fe-safe environment, proved to be an effective tool for identifying critical areas within the joint where damage initiation is likely to occur. The numerical model made it possible to reproduce local phenomena such as material plasticization in the plate or localized deformation of the wood in the contact area with the teeth, and to track the development of fatigue damage.

The numerical simulation results were consistent with the laboratory test outcomes, confirming the validity of the adopted modeling methodology and justifying the use of FEM as a tool for designing and assessing the safety and durability of such connections in timber structures. At the same time, the need for further experimental work was emphasized, aimed at validating the numerical models across a broader range of loading parameters and service conditions.

In summary, the conducted research, in the authors' opinion, provides valuable insights into the fatigue failure mechanisms of timber joints with connector plates and points to directions for further numerical and technological analyses aimed at optimizing these connections. The proposed modeling approach can be effectively applied both at the design stage of new structures and for assessing the durability of existing load-bearing systems, particularly in the context of the future inclusion of fatigue in timber design standards.

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