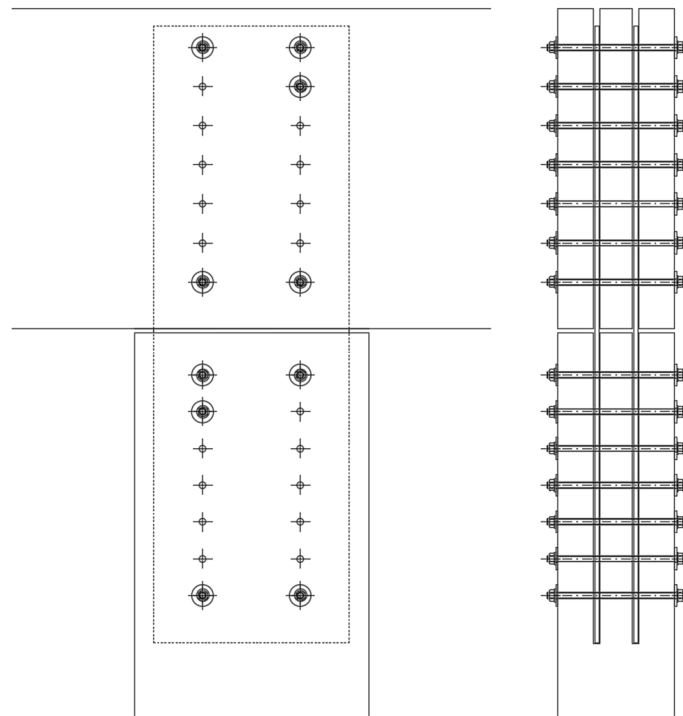


Moment-resisting timber connections with laterally loaded dowel-type fasteners

A critical look at the n_{ef} concept and the Porteous & Kermani method

1. Scope and problem statement

This article deals with moment-resisting timber connections with laterally loaded dowel-type fasteners: bolts, dowels, screws and nails. The scope covers both timber-to-steel connections, for example with a slotted-in steel plate, and timber-to-timber-to-timber connections with multiple shear planes. Connections with glued-in threaded rods, for example, fall outside the scope: their mechanical behaviour rests on a fundamentally different mechanism from that of dowel-type fasteners, and is not treated here.



As a concrete example, throughout this article we use a connection between a built-in timber column and a cantilevering timber beam, made with a centrally inserted steel plate and bolted connections. This example serves purely as an illustration: the principles and problem areas discussed apply in a comparable way to other types of dowel-type fasteners and to timber-to-timber-to-timber configurations.

Such a connection looks simple, but it is not. For comparable moment-resisting connections in steel or concrete structures, well-developed and unambiguous normative calculation methods generally exist; for timber connections of this type, no such framework exists.

This article sets out why that is so, and in doing so distinguishes between two things that are often conflated in practice: on the one hand, pure rigid-body theory, and on the other, the widely used method of Porteous & Kermani, which builds on that theory but does not coincide with it.

2. The normative framework of Eurocode 5

2.1. What the standard does regulate

Neither NBN EN 1995-1-1+A1:2015 nor the draft of the new standard FprEN 1995-1-1:2025 provides a calculation method for a moment-resisting connection with dowel-type fasteners. §8.1.1 states that a connection must be assessed taking into account the forces and moments acting on it. That provision, however, has only the character of a general verification principle and gives no guidance on the internal distribution of forces within such a connection.

§11.3.1(6) of FprEN 1995-1-1:2025 contains the instruction that, for a moment-resisting connection, the calculation must be carried out for all fasteners in order to identify the most heavily loaded fastener, without stating how the distribution of forces between the individual fasteners is to be determined. §11.4.3(2) and Table 11.21 do contain geometric detailing rules, but these are expressly limited to LVL/GLVL with fasteners in a circular pattern.

2.2. What the standard does not regulate: the role of testing

The Eurocodes do not rule out the use of connections that are not fully covered by the standards, but tie this to an established procedure. EN 1990, §7.3(1)-(2), permits physical testing to be used to determine design parameters or the behaviour of a structural element, precisely in situations where no suitable calculation model is available. §7.3(3)-(4) makes this conditional on the required level of reliability being ensured, taking into account both the statistical uncertainty of a limited number of tests and the uncertainty inherent in the calculation model used. Annex D of the standard elaborates this statistical framework further.

This route, however, is not without obligations. A design supported by testing requires a sufficient number of tests to demonstrate the required level of reliability statistically, which entails considerable cost and lead time. That makes testing feasible mainly when the same connection detail is applied repetitively, so that the cost of the test campaign can be spread over a large number of units. For a unique, non-repetitive connection, such substantiation by testing is often difficult to achieve in practice, precisely in the situation where no normative calculation method is available to fall back on.

3. The n_{ef} concept: two mechanisms in one empirical formula

3.1. The rigid-body theory of Lantos

§8.1.1(4) of NBN EN 1995-1-1:2015 prescribes that the effective characteristic strength of fasteners placed in one row parallel to the grain is determined by means of an effective number of fasteners, n_{ef} . The basis of this concept is the research of Lantos (1969). Lantos does not start from rigid-body theory in its purest form, in which the elements to be connected are assumed to be non-deformable, but takes into account that both the timber members and the fasteners behave elastically. This leads to the finding that the outermost fasteners in a row transfer more load than the more central ones, depending on the stiffness of the members, the stiffness of the fasteners, their mutual spacing and their number. This results in an equivalent number of fasteners, n_{ef} .

This expression, however, does not apply without further ado when the central element is considerably stiffer than the surrounding timber, as with a slotted-in steel plate. In that case the ratio between the stiffnesses of the intermediate elements changes substantially, so that the deviation of the forces occurring in the fasteners from pure rigid-body theory differs from timber-to-timber connections.

3.2. Brittle failure due to tensile stress perpendicular to the grain

Around a fastener, not only embedment stresses occur, but also tensile and shear stresses, both parallel to the direction of force action and perpendicular to it. Jorissen (1998) already demonstrated this in his doctoral thesis on timber connections with dowel-type fasteners: for fasteners arranged in a line, the tensile stress increases through accumulation, whereas that effect diminishes as the spacing between the fasteners becomes larger. The stress effect and the geometric effect, the unequal force distribution arising from rigid-body considerations, thus act in opposite directions.

Jorissen summarised the results of 950 tests on timber-to-timber connections in an empirical regression model, in which the influence of the spacing between the fasteners is explicitly incorporated. That regression shows that, for the connection type investigated, the resistance increases as the fasteners are placed further apart: the stress effect therefore dominates the geometric effect. The model does not, however, distinguish between the two underlying causes of strength reduction, the non-uniform force distribution on the one hand and brittle splitting on the other. A further simplification of that model is applied in the current approach to n_{ef} in Eurocode 5.

3.3. Why the distinction matters

Yurrita & Cabrero (2021) point out that the current approach in Eurocode 5, in which n_{ef} is used as a single global reduction parameter, combines different failure mechanisms and does not sufficiently distinguish between ductile and brittle failure modes. That distinction is precisely what is needed to assess the actual behaviour of dowelled connections correctly. Aquino et al. (2026) confirm this from a numerical approach: the current n_{ef} formula covers two separate physical effects, the non-uniform load distribution resulting from elastic deformation and the build-up of tensile stresses perpendicular to the grain between successive fasteners, without

modelling them separately. The scope of such empirical formulae must therefore, as these authors emphasise, be restricted to clearly defined limits; extrapolating them, for example to steel-to-timber connections, can lead to systematic and non-conservative deviations.

4. From axially loaded rows to moment-resisting connections

The experimental basis of Jorissen, like the earlier analysis of Lantos, concerns linear rows of fasteners that are loaded in the same axial direction, with fasteners of equal stiffness. In a moment-resisting connection this is fundamentally different: the force vector per fastener differs in both magnitude and direction, and the stiffness of a fastener is a function of the angle between that force vector and the grain direction, an angle that differs for each fastener within the same connection.

The determination of the splitting capacity perpendicular to the grain, Expression (8.4) of NBN EN 1995-1-1:2015 and further elaborated in §11.6 of FprEN 1995-1-1:2025, is likewise derived for a configuration in which the force component perpendicular to the grain is equally directed and evenly distributed for all fasteners, so that the tensile force in the main member is greatest at the fastener furthest from the loaded edge. That assumption is not satisfied in a moment-resisting connection: the force vectors differ in magnitude and direction per fastener, so that the total tensile load at each fastener must be checked individually. Applying the empirically determined n_{ef} reduction factor, and the standard formula for splitting capacity, to a moment-resisting connection therefore always presupposes an extrapolation to a fundamentally different loading configuration from the one for which both were developed and validated.

5. The Porteous & Kermani method

5.1. Starting points: rigid-body theory with corrections

The method of Porteous & Kermani (Structural Timber Design to Eurocode 5, Chapter 12), widely used in engineering practice, is an attempt to apply the existing provisions of EN 1995-1-1 to moment-resisting timber connections with dowel-type fasteners, for which the standard itself provides no specific calculation methodology. The method is built around rigid-body theory: the forces in the fasteners are in essence calculated as if the connection behaved as a rigid body, supplemented with corrections that build on the principles for dowelled connections contained in Eurocode 5.

That makes the method something different from the pure rigid-body calculation: whereas the latter takes no account of any strength reduction, the Porteous & Kermani method attempts to build in a correction via the existing EC5 provisions. As far as can be ascertained, however, this specific application is not supported by results of its own finite-element simulations or experimental tests on moment-resisting connections. The method is presented as a theoretical

derivation from existing code principles, not as a design method supported by tests or numerical validation.

5.2. What the method does not check

In the strength verification of the connected members, the method assumes that the splitting formula of Eurocode 5, Expression (8.4), is not directly applicable to this loading configuration. That is also correct, as explained above, given the deviating configuration. On that basis, however, the check in the method is limited to a verification of the shear strength of the elements concerned, without an adapted check of the tensile stress perpendicular to the grain.

That is problematic, because EN 1995-1-1 contains in §8.1.4(1)P a mandatory principle, with an analogous provision in §11.6 of FprEN 1995-1-1:2025, which prescribes that, whenever a force acts at an angle to the grain direction, the possibility of splitting caused by the tension component perpendicular to the grain must be taken into account. This verification is therefore not optional. In other words, the fact that the standard formula is not straightforwardly applicable to this configuration does not release the designer from the obligation to carry out the splitting check nonetheless, by means of an adapted assessment.

5.3. Place within the design process

None of this means that the Porteous & Kermani method is useless, quite the contrary. Despite the limitations outlined above, it remains one of the most accessible and most widely used methods in engineering practice for sizing moment-resisting timber connections with dowel-type fasteners. It is, however, not recommended or declared applicable in any standard, neither in NBN EN 1995-1-1:2015 nor in FprEN 1995-1-1:2025, and therefore does not release the designer from the obligation to critically assess its underlying assumptions and scope.

The method should therefore be regarded as a first step within a broader design process, useful as an analytical starting point but not as a stand-alone, adequately validated sizing method. Additional verification is always advisable. For a unique application, this verification by testing is often difficult to achieve, which calls for an all the more critical look at the assumptions used.

6. Scientific state of the art

The mechanism of brittle failure through cracking parallel to the grain direction has meanwhile been documented by a series of independent publications, also specifically for moment-resisting connections with a slotted-in steel plate. Yurrita, Cabrero & Quenneville (2019) investigated precisely that connection type and found that its capacity may be governed by brittle failure rather than by a ductile failure mechanism. Rebouças, Mehdipour, Branco & Lourenço (2022) describe a laboratory test on a moment-resisting connection with glued laminated timber, steel bolts and a

slotted-in steel plate, in which the test was terminated because of cracking attributed to high tensile stress perpendicular to the grain. The same publication also establishes that the fixed centre of rotation assumed by the rigid-body approach does not hold up experimentally: the centre of rotation of the connection was found to shift during loading.

Non-linear finite-element simulations of this connection type also generally show that the tensile stresses perpendicular to the grain around the most heavily loaded fasteners can exceed the acceptable limit value by a considerable margin, a finding consistent with the experimental literature above. A recent follow-up study by Aquino et al. (2025) generalises, for the first time, the numerical model of this research group to situations with combined forces and bending moment, and finds that normal force and bending moment interact in distinct ways in the failure of the connection. That such a fundamental generalisation was only published recently confirms that a reliable mechanical description of moment-loaded dowelled connections is not yet fully available: this remains an active research area, in which experimental validation still plays a central role.

7. Conclusion

The foregoing leads to a number of conclusions relevant to any designer dealing with this connection type:

- No version of the applicable Eurocode standard, current or draft, contains a calculation method for a moment-resisting timber connection with dowel-type fasteners.
- Rigid-body theory is the theoretical starting point for this type of connection, but is not sufficient on its own: it takes account neither of the non-uniform stiffness distribution nor of brittle failure mechanisms.
- The Porteous & Kermani method builds on that rigid-body theory with corrections derived from Eurocode 5, but in doing so extrapolates an empirical reduction factor beyond its validated scope and fails to systematically carry out a mandatory code check of the tensile stress perpendicular to the grain.
- The mechanism of brittle failure due to tensile stress perpendicular to the grain has been experimentally documented for this connection type.
- In accordance with the principle of EN 1990, §7.3, applying a non-standardised calculation method requires substantiation by testing, taking into account both the statistical uncertainty and the model uncertainty.
- That substantiation by testing is not optional and requires a sufficient number of tests; it is therefore feasible mainly for repetitive application of the same connection detail. For a unique, non-repetitive connection, such substantiation is often difficult to achieve in practice, precisely in the situation where no normative calculation method is available to fall back on.

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