Overview of Nailed wood products to wood joints

Introduction

These publications are part of compilation of work of the author to a total theory according to the latest developments with possible goal of a thesis or a book. The appended articles are given in full as acknowledgment for the original journal publication. The developed exact theory is given in the appended 3 publications denoted by “F”, thus: vdPut **F(2008), F(2012a)**, and **F(2012b).** Other important derivations and applications are mentioned in these 3 publications. The theory in all appended publications was derived by T.A.C.M. van der Put.

F(2008): Explanation of the embedding strength of particle board

By applying the earlier derived exact theory of the tri-axial embedding strength, **D(2006b)** based on the exact method of limit analysis of plasticity, and by the derivation of the volume effect of the strength, it was possible to fully and precisely explain the empirical relations and test results of an extended investigation of the embedding strength of particle board, leading to a new insight for the right design rules, (which should be in Eurocode 5).

The basic theory of the embedding strength is given in: D(2008): “Derivation of the bearing strength perpendicular to the grain of locally loaded timber blocks"

The following is shown:

- The quasi linear dependence of the embedding strength on the density is explained. The 2 constants of the line have a constant ratio as explained by the theory.
- The high embedding strength is explained by confined dilatation due to the spreading effect as follows from the theory of plasticity.
- Splitting has no effect on spreading and therefore the embedding strength did not show an influence of the boundary conditions around the dowel (open or closed slit).
- Besides the plastic mechanism, a brittle splitting mechanism occurs at the dowel, explaining the volume effect for small dowels. Only due to this splitting, the succeeding embedment flow is possible.

The advantage of the power law approximation is that the powers of the spreading effect and of the volume effect can be summarized and the simple design equation is maintained.

- Based on the spreading and the volume effect, the empirical equations of the extended investigation of Budianto et al. (1977) can exactly be explained by the theoretical expressions. For instance, Eq. 18 explains as well the straight part as the curved part of the line of Fig. 4 and Eq. 26 explains the change of the slope of the lines of Fig. 5.
- The highest ultimate embedding strength is due to a local mechanism at the dowel as is verified in the TU-Delft investigation.
- The theory shows the embedding strength of Fig. 6 to be dependent on the *b/d* ratio and not on the *a/d* ratio of Fig. 3. This also follows from Dutch measurements at constant *a/d* with different *b/a* ratios. The verification of Eq. 9 or Eq. 27 follows from tests with one dowel diameter at different *b/d* ratios. These tests are lacking in Budianto et al. (1977) and it is necessary to adapt the Codes at these points for the right design.
- The theory and the TU-Delft investigation did show a very high embedding strength for nails with a limited working length due to 3-dimensional spreading.

F(2012) Nailed particle board to wood joints

This is published at the Toronto Conference and given by two articles in one file F(2012):

1. Explanation of the strength particle board-to-wood joints with nails and staples
2. Estimation of the Influence of Rows of Nails in Particle Board to Wood Joints

Sub 1:

By the earlier derived theory of the embedding strength, based on limit design, it is possible to explain the extremely high embedding strength of nailed particle board to wood joints leading to a new exact failure equation for the embedding strength as necessary correction for design and for the Codes.

The following is shown:

- The stress spreading theory explains the high embedding strength for nails with a limited working length due to 3-dimensional spreading. The test-results confirm this behavior.
- The nail head reaction is important for spreading in thickness direction of the nailed particle board to wood plate. Stress spreading in thickness direction of the particle board plate can not be accounted for head-less nails.
- To account for this very high embedding strength of nailed particle board to wood joints, an iterative adaption for the spreading strength is derived, verified by test data.
- Also the derivation for a direct analytical estimation method of this high embedding strength is given with the simplification of the formula and the very good fit to data is shown.
- Based on the local mechanism of fig. 4, the derivation is given of the highest possible ultimate embedding strength of particle board, which is verified by the discussed tests.

Sub 2:

The exact spreading theory, provides in article 1, the universal law of the embedding strength of nailed particle board to wood joints and even in the simplified power law form, this law is very precise. The consequence of the theory is that it also provides the right row factor for rows of nails, as is discussed in article 2, leading to a necessary application for design and for the Building Codes.

The following is shown:

- The stress spreading theory explains the high embedding strength for nails and the row factor for rows of nails. Test-results confirm this behavior.
- The test result of the designed critical specimen, which is critical for all different failure mechanisms (as combined bending–tension and shear failure of the plate with nail withdrawal) at the same time did indeed show the equal possibility of occurrence of all these mechanisms indicating the possibility of stress redistribution of the spreading stress and therefore no interaction of the failure mechanisms occurred (being all critical at about the same time).
- The derivation of the row factor is given, verified by data and a simplification for the Building Regulations is proposed.
- The necessary extension of the Johansen equation for nail head clamping and for stress spreading effect is given with the simplification of the formulas.

Correction factors of the strength for shorter nails are necessary.

All conclusions above also apply for nailed wood products to wood joints, when the wood products are quasi isotropic or are reinforced transverse to the nail loading direction (as e.g. wood, loaded perpendicular to grain or as plywood).