An Unravelling of the Effect of Partially Embedded Punched Metal Plate Fastener on the Lateral Anchorage Strenght

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Aalborg **UNIVERSITY**

An Unrav

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Jacob Nielsen

Paper No 3
Structural Design

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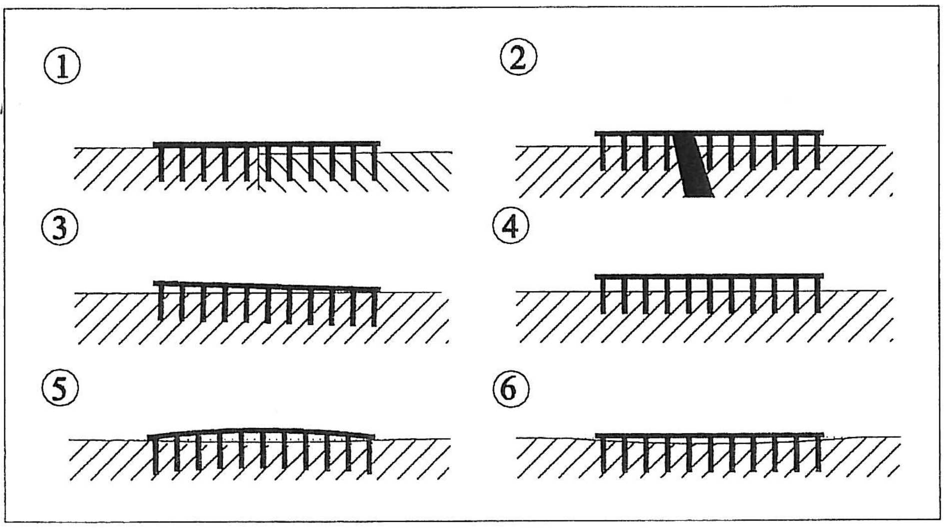
Jacob Nielsen, February, 1999



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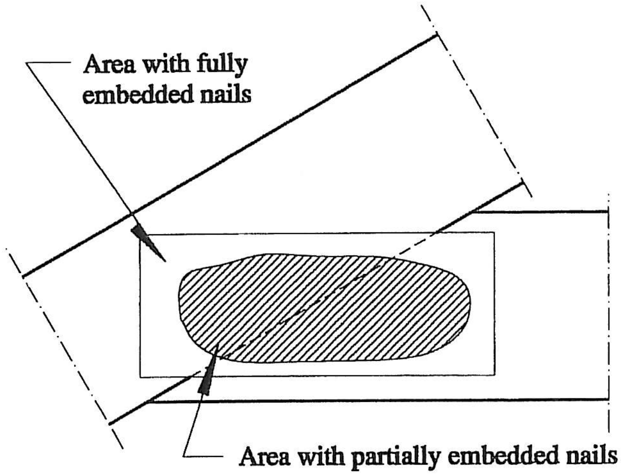
1 Introduction

In recent years a punched metal plate fastener with short nails (< 10mm) has been used in truss production. The embedding of the plate must fulfil the existing rules in accordance with prEN 1059:1997, item 6.2.4, Fastener installation:

Any gap between the timber surface and the underside of a punched metal plate fastener shall not exceed 1 mm and shall not occur over more than 25% of the anchorage area in any member.

However, the controlling authority of truss manufacture in Denmark, The Truss Control (TRÆSPÆRKONTROLLEN), and the truss manufacturers have observed a problem: even if the plate edges are observed as fully embedded, a gap can occur between the plate and the wood at the centre of the plate area, see the example in figure 1.



Figur 1: Area with partial embedment of the plate.

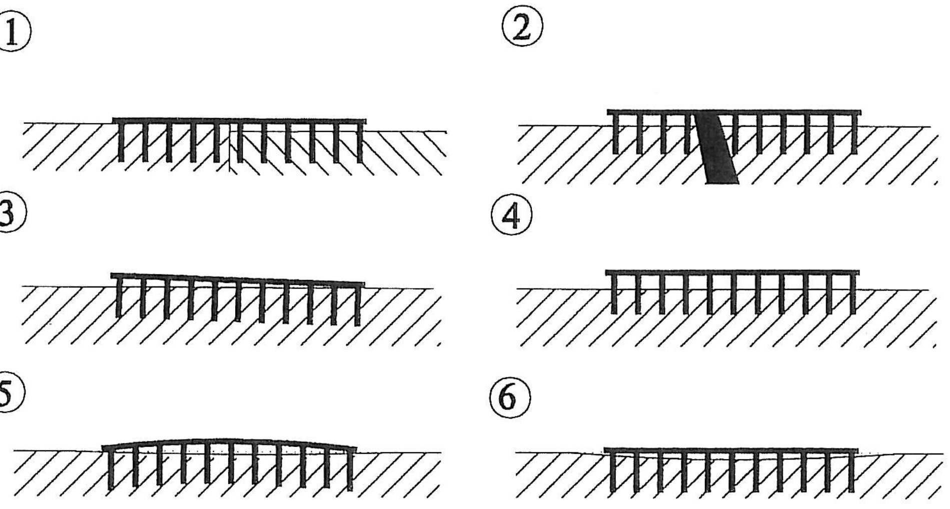
In the spring of 1997 the Truss Control made a special registration of max. gap measurements in 661 different joints with different types of short nailed punched metal plate fasteners used on 5 different truss plants. The results are shown in the table 1 below:

	Fulfils prEN 1059						Total
Gap [mm]	0,0-0,5	0,6-1,0	1,1-1,5	1,6-2,0	2,1-2,5	2,6-3,0	
No. of joints	49%	26%	13%	7%	3%	2%	100%

Tabel 1: Max. gap on 661 different joints.

A gap $\leq$ 1mm has been measured at the edge at all joints, i.e. apparently prEN1059 is fulfilled. However, in 25% of the joints a gap > 1 mm was found in some area of the plate. Reembedment of the plate does not decrease the gap size due to the fact that the plate edges are already in contact with the timber. This effect is observed for many different plate types.

There are different reasons for the partial embedment of nail plates. In figure 2 some of the reasons are given.



Figur 2: Six different reasons for partially embedded plates.

The reasons shown are:

1. different timber thickness,
2. unevenness at the timber surface (a knot),
3. unequal embedding pressure, tilted pressing plane, or tilted plane for the timber,
4. too low embedding pressure,
5. a phenomenon called "*spring back*",
6. crushing of the timber (*cushioning*).

Items 1 to 4 can be avoided by ensuring a quality timber planing and careful maintenance, and adjustments of the pressing tool. However, *spring back* and *cushioning* are controlled by the properties of plate and timber and maybe also the embedding velocity.

1.1 Scope

The main object of this paper is to analyse the effect of spring back or cushioning on the lateral strength - i.e. a plate with the following conditions: (see also 5 or 6 in figure 2.

- gap at plate edges ≤1mm
- gap at the centre of the plate area >1mm

The analysis will be based on:

- literature on this subject.
- contact persons who may know something about the subject:
  - researchers in this area
  - plate manufacturers

A summary of each reference is given in the appendix. All authors refferred to will receive a copy of the paper. The analysis will not be based on any experimental tests.
If possible the analysis will end with a recommendation showing how to come closer to a solution of this problem. I hope this paper may start a discussion of a solution/analysis of the problem.

Any comments on this paper are very welcome and can be mailed to the address:

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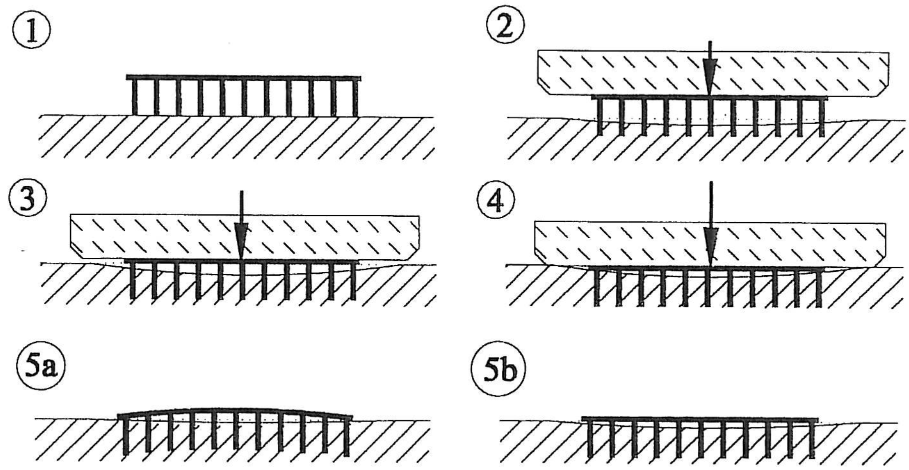
2 Reason for Spring Back and Cushioning

In figure 3 the deformations of nail-plate and timber during the pressing process are shown. The force is shown by an arrow. In practice the force will be applied by a pressing plane which ensures a plane plate during the pressing process. The length of the arrow denotes the size of the force applied to the pressing plane. The deformations of timber and plate are scaled.



Figur 3: The deformation of nail-plate and timber during the pressing process.

Comments on the above figures:

1. The plate is located on the timber surface before any load is applied.
2. The hydraulic pressing tool is activated and the pressing plane is applied to the plate. It is assumed that the pressing plane and the plate are plane during pressing. The nails start to penetrate the wood and the force added perpendicular to the grain will deform the timber surface. The deformation will be elastic.
3. During pressing the load increases to embed the plate further. The embedding resistance from the nails is increased caused by the resistance from the point of the nails (constant) and the resistance from the surface friction (increasing). The surface of the timber will deform further and the underside of the plate is now in the same plane as the initial plane of the timber. Some of the deformation in the timber may now be plastic.
4. The pressing plane is now touching the surrounding timber surface and the pressing resistance is increasing rapidly. At the edges of the plate there is contact between plate and timber. The timber has deformed further.

5. The pressing process has ended and the pressing plane is removed. Caused by unloading and elastic deformations the timber has expanded. As the elastic deformation has a maximum at the centre of the plate area the elastic expansion of the timber can deform the plate as shown in 5a. This phenomenon is called *spring back*. The plastic deformations of the timber will cause a permanent deformation of the timber surface as shown in 5b. This phenomenon is called *cushioning*. In both 5a and 5b a gap will exist below the plate. The gap will be maximum at the centre of the plate. In reality the gap will be caused by a combination of spring back and cushioning.

The deformation of the wood during the pressing process is dependent on:

- the embedding resistance, which is affected by: nail pattern, nail design, plate area, strength and friction properties of the wood, angle between plate and grain, angle between the annual ring and the nails,
- the stiffness properties of the wood itself.

The properties of the wood are represented in both items. Spring back and cushioning are therefore highly affected by the moisture content and the density of the wood, see section A.3 on page 13.

3 Gap observation

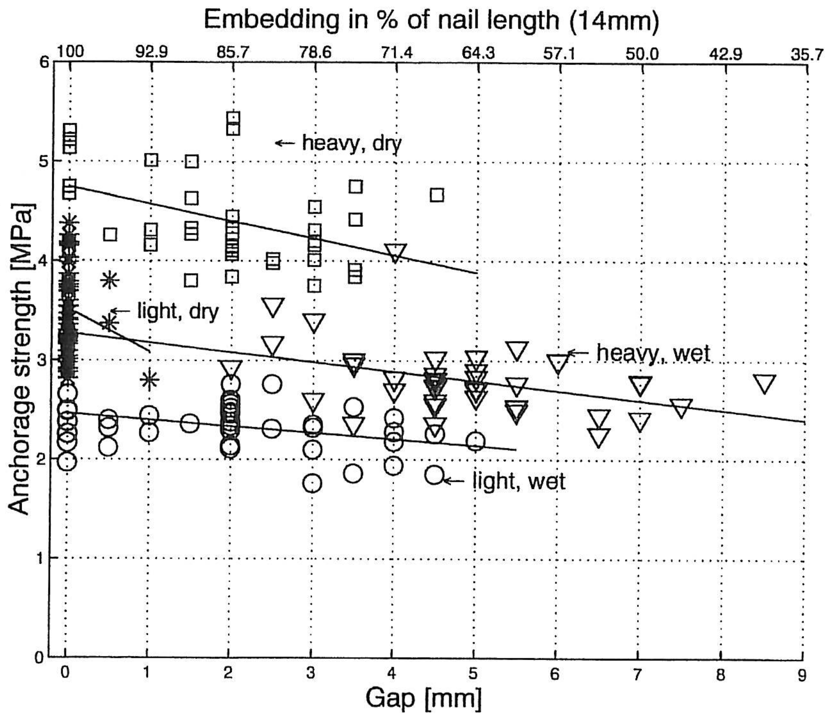
If the gaps below the plate are examined very closely no connection will be "fully embedded" into the timber. There will always be a small gap below some area of the plate - also in the tests made according to prEN 1075 (test to determine the characteristic anchorage values for the plate). *Triche(1995)* made specimens intended to have fully embedded plates, see section A.1. The plate connections have passed a visual inspection, but an exact measuring gave an average gap size of 0.5 mm. As shown in figure 5 on page 12, not only the plate deformation can affect the gap measuring. If the gap is measured too closely to the nails a larger gap caused by the deformation of the wood at the nail will be registered.

A gap size of 0.5 mm can easily be seen by a human eye. However, when the gap is located below a plate the eye and the light must be in an exact position to register the gap. The shadow caused by a gap can be difficult to see, because it can easily be taken as the plate edge by mistake.

4 Strength reduction

If there is a gap between the underside of the plate and the timber the anchorage strength will be reduced compared to a fully embedded plate. If the gap size is constant and equal to 1 mm below the whole plate the anchorage strength will be reduced by 18-40%, see *Ljørring(1989)*, *CSIR* and *Tadich*. The 40% value is found for a short tooth plate embedded in timber used in Denmark.

Tests made to determine the strength reduction at plates with gaps located at the centre of the plate only have been made by *Ringstad(1979)*. It was not intended to have a fixed gap below the whole plate. The gap size has maximum at the centre of the plate and therefore the effect of spring back and cushioning is found in these tests. In figure 4 the results are given.



Figur 4: Anchorage strength dependent on gap size. Data are taken from test on nail-plates with 14 mm nails, *Ringstad(1979)*.

In figure 4 it is seen that the gap size reduces the anchorage strength, but the reduction is rather small $\sim$ 5-7% at 2 mm gap (86% embedment of 14 mm nail), which is smaller than the reduction estimated by *Ljørring(1989)* (10%). Due to very few tests with a gap in series with light and dry timber the best fit line is very steep.

Partially embedded plates are often observed at plates in timber with high density, see *Ljørring (1989)* and *Ringstad(1979)*. However, it is also known that the anchorage strength is increased with increasing density of the timber. The overall effect of a partially embedded plate in timber with high density may give a plate connector with "average" anchorage strength. In *Ringstad(1979)* it is found that connections with ∼2 mm gap in timber with a density between 450-500 kg/m^3 have 26% higher anchorage strength than connections with ∼0 mm gap in timber with a density between 300-350kg/m^3, see table 3 on page 14 and figure 4. Is can then be stated that "only" connections with a plate embedded in timber with high moisture content might be "on the unsafe side".

Triche(1995) recommends a reduction factor of 0.84 on all plates with gap sizes below 0.8 mm. The following is taken from Commentary & Appendices to ANSI-/TPI 1-1995 pages 2 and 3 (the America National Standard) :

$$V_{LR} = \frac{T_{LR}(1 - 1.645 \cdot COV)0.84}{DOL \cdot SF} \quad (1)$$

$$= \frac{T_{LR}(1 - 1.645 \cdot 0.14)0.84}{1.6 \cdot 1.3} = \frac{T_{LR}}{3.2} \quad (2)$$

where

V_{LR}: is the design anchorage strength (MPa).

T_{LR}: is the average ultimate anchorage strength (MPa).

$(1 - 1.645 \cdot COV)$: is the adjustment of normal mean to 5% fraction. COV is the coeffecient of variation for ultimate load.

0.84: a strength ratio to adjust for 1/32" tooth embedment gap, see table 2 on page 13.

DOL: is the "duration of load factor" that adjusts a 10 minute test to a standard 10 year load duration ($DOL = 1.6$).

SF: is the safety factor for unknowns such as overloading conditions, stress reversals, environmental effects, handling, ect. ($SF = 1.3$).

A gap of 1/32" or less is assumed, which is a selection based on extensive in plant observations in USA. A third party Quality Check agency inspects the truss plants every 3 months to ensure that they are meeting the gap requirements.
If the agency finds a plate connection which does not fulfil the requirements (ex. 1/32" $<$ gap $<$ 1/16" for 20% of the anchorage area) then the truss designer may perform a recalculation of the joint using another reduction factor ($0.84 \cdot 0.6 = 0.50$) for the selected area to ensure that the joint has the necessary strength resistance. The factor is taken from table 2 on page 13.

According to the rules from South Africa, "only" one plate in the truss is partially embedded, see section C.1. It rises the question: If there is a partially embedded plate at one side of a connection, will there also be a partially embedded plate at the other side of the connection? It seems to be the case, because the moisture content and the density of the wood are unchanged, but *Ljørring(1989)* and the

SP Report 1996:15 have stated that partial embedment is most common on the sap-side of the wood. This leads to the knowledge that the stiffness and strength properties (spring back effect) are also affected by the direction of the growth rings in the wood. If "only" one plate in a connection is partially embedded it will be too conservative to reduce the anchorage strength for both plates.

5 Conclusion

In the following some proposals for the solution are given. The order of the proposals is *not* a priority order.

1. When determining the characteristic anchorage strength, individual tests can be made to determine the effect of spring back and cushioning in dependence of density, moisture content and annual ring orientation in the timber. The test method is to be developed.
2. Add a reduction factor to the anchorage strength, as in the America National Standard, ANSI/TPI 1995, see page 7.
3. Optimize the nail design and nail pattern. Today there are no rules for the sharpness of nails.
4. Relax item 6.2.4 in prEN 1059:1997 to affect the gaps at edges of the nail-plates only.

In order to get more knowledge of the problem with partially embedded plates some proposals to further investigation are given:

- Analyse the reduction in anchorage strength of partially embedded plates with short nails and with a 1-3 mm gap in the middle of the plate and (almost) no gap at the edge - as *Ringstad(1979)* but with tests on short nailed plates.
- Develop test method and demands for embedment of punched metal plate fasteners.

Acknowledgments
This work is funded by TRÆSPÆRKONTROLLEN, (The Truss Control), Dansk Teknologisk Institut, Postboks 141, DK-2530 Taastrup
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6 Resumé på dansk

I foreliggende udredning behandles problemet omkring delvis indtrykkede tandplader. Kravene i de gældende danske standarder om tandplade ipresning kan i mange tilfælde ikke opfyldes af spærfabrikkerne. Formålet med denne udredning er at få indsigt i, hvilke parametre der har indflydelse og hvor stor styrkereduktionen er.

Mange forskellige personer over hele verden er blevet kontaktet ligesom flere artikler om emnet er blevet studeret. Et kort resumé af artikler og svar er vedlagt. På baggrund af den indsamlede information er problemet beskrivet og udredningen afsluttes med en konklusion. I konklusionen er givet følgende løsninger til problemet:

1. Ved bestemmelse af karakteristiske forankringsstyrker kan separate forsøg udføres til undersøgelse af effekten af "spring back" og "pudevirkningen" af træet under pladen i afhængighed af densiteten, fugtindhold og åreringenes forløbet i træet. En forsøgsmetoden hertil skal udvikles.
2. Multiplicere en reduktionsfaktor til forankringsstyrken, som angivet i America National Standard, ANSI/TPI 1995, se side 7.
3. Optimere designet af en tand og mønstret af tænderne. I dag findes ingen regler om skarpheden af tænderne.
4. Nedsætte kravet i punkt 6.2.4 i prEN 1059:1997 til kun at gælde for luft under pladekanterne.

For at få yderligere indsigt i problemet med delvis indtrykkede plader kan forslås følgende undersøgelser:

- Analyse af styrkereduktionen af delvis indtrykkede plader med korte tænder og 1-3 mm luft under midten af pladen og (næsten) ingen luft ved pladekanterne. Ligesom forsøgene udført af *Ringstad(1979)*, men nu med korttandede plader.
- Udvikle testmetoder og krav til ipresning af tandplader.

7 References

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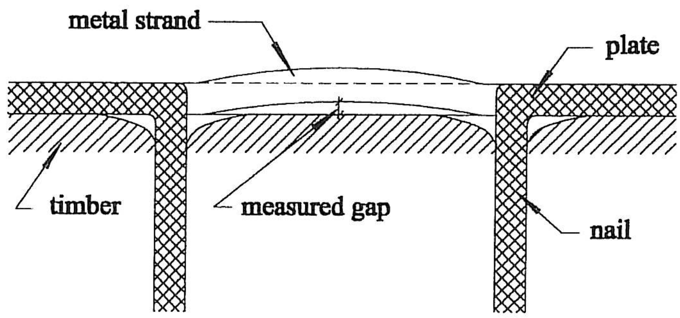
A Review of the literature

A.1 Effect of Partially Embedded Metal Connector Plates on Joint Strength. Michael H. Triche, Ph.D., Wood Design Focus, Winter 1995, USA.

Triche has tested 17 different plate types embedded in two different lumber types: southern yellow pine (SYP) and spruce-pine-fir (SPF). The tooth length on the tested plates was <9 mm and 10 mm. It was planned to make specimens with a 1/32-inch gap (0.8 mm) and compare the strength with the strength of specimens with fully embedded plates. However, the specimens intended to have 0.8 mm gap actually had a larger gap (1.1 mm on average) and the specimens intended to have a fully embedded plate also have small gaps (0.5 mm on average). Close examination of several plates revealed that the strands of metal between the teeth were arched upwards, as shown in figure 5.



Figur 5: Metal strand between the nails bend upwards which increases the gap measurements.

Cushioning (see the phenomenon in figure 2 (6) on page 2) occurred in ~10% of the SYP specimens and in none of the SPF specimens.
By a visual examination it was concluded that in the majority of cases there was firm contact between the plate and the wood.

The work ends up with an recommendation: The anchorage strength must generally be reduced with 16%. This reduction is used for embedment gap below 1/32-inch (0.8 mm). If the gap exceeds 0.8 mm the reduction factor in table 2 should be used.

Embedment gap, g		Strength ratio
inch	mm	-
g ≤ 1/32	g ≤ 0.8	1.0
1/32 < g ≤ 1/16	0.8< g ≤ 1.6	0.6
1/16 < g ≤ 3/32	1.6< g ≤ 2.5	0.4
3/32 < g	2.5< g	0.0

Tabel 2: ANSI-TPI 1-1995 embedment gap strength ratios.

This recommendation is adopted in ANSI/TPI 1-1995.

A.2 Fastening of Punched Metal Fasteners. Jens Ljørring, Technological Institute, 1989, Taastrup, Denmark

This section is a summary of the report given above and a summary of a discussion with Jens Ljørring.
When determining strength values the plates are normally fully embedded plate (visually inspected). The tested plates are 76x113 mm (small).
It is difficult to reproduce the "springback" effect.
Ljørring recommends a reduction of the anchorage strength based on "simple calculations". A plate with short nails and an embedding which just fulfils the requirement in prEN 1059 has 10% strength reduction. A plate with long nails and an embedding which just fulfils the Danish rules (a max gap of 2 mm) has a 9% strength reduction.
Problems with plate embedding occur in timber with high densities or in sap-side of the timber. (The fact that the anchorage strength is dependent on sap-side/heart-wood is also confirmed in the report "Factors Affecting the Anchorage Capacity of Nail Plates in Nordic Spruce" Henning Duwe, SP, Swedish National Testing and Research Institute, Building Technology, SP Report 1996:15).

A.3 Embedding of Punched Metal Fasteners - the Influence of the Timber. (Innpressing av spikerplater - trevirkets innflytelse av.) Haldor Ringstad, Norsk Treteknisk Institutt 1979, Oslo, Norway

Reports from the controlling authority of truss manufacturing in Norway show that there are problems with embedding of the plates. Several factors may affect the embedding effectiveness and in the report only the influence of the moisture content and the density of the timber is taken into consideration. Tests on splices with Gang-Nail 18 plates have been made (nail length 14 mm). A summary of the results is given in table 3.

Density	kg/m^3	300-350		450-500	
Moisture content	%	12-15	20-23	12-15	20-23
Anchorage strength	MPa	3.49	2.33	4.40	2.81
Gap	mm	0.0	2.0	2.0	4.9

Tabel 3: Average anchorage strength and average embedment gap of 4 series each with 40 duplicates.

The maximum gap is normally located at the centre of the plates. The plates were embedded until contact with the timber. The specimens were made in a test machine where also the embedding force as a function of the movement of the compression head was measured (not produced at a truss plant). The tests show that a high moisture content or a high density of the timber may lead to partially embedded punched metal fasteners. However, plates embedded in timber with a high density have an increased anchorage strength and for this reason timber with high density should not be avoided. To solve the embedding problems the pressing equipment and the design of the plates should be taken into consideration.

A.4 Dynamic Embedment of Metal Plate Connections, Nagele T. C. et al. Forest Products Journal Vol. 48 No. 2, February 1998, USA

It is assumed that improper embedment is generally manifested in either the compression strength of the wood being exceeded, or in plate rejection, where the plate springs partially back from the wood after pressing. A technique was investigated in which the plates were pressed into the timber under vibrating load at frequencies of 30, 50 and 70 Hz. Comparisons were then made to similar "static" splices fabricated in traditional pressing technique.

The static pressing of the plates was performed by a constant rate of loading that required 25 and 30 seconds to reach full plate embedment. (This is very slow compared to traditional manner.)

A better degree of embedment was obtained at 50Hz, but the result was not significant. In total no distinguishable changes in the tensile properties were observed.

B Response from researchers

B.1 Michael H. Triche, Associate Professor, University of Alabama, USA

No further response than the paper given in section A.1.

B.2 Jens Ljørring, Technological Institute, Taastrup, Denmark

See section A.2.

B.3 Ari Kevarinmäki, Lic.Tech. Senior Research Scientist, Timber Structures, VTT Building Technology, Finland

He has investigated this problem theoretically: the calculation model is based on the behaviour of individual nail plate teeth and it has been published as report number 20 of Helsinki University of Technology - Laboratory of Structural Engineering and Building Physics (1991, in Finnish). It is included in his Ph.D.-thesis and the translation of this particular section should be completed by the end of this year.

The effect (reduction to anchorage strength) of already 1 mm gap is significant and it depends greatly on the nail plate type and on the loading direction of plate (α). With thinner nail plates and shorter teeth the reduction is higher. The effect is most significant in the main direction ($\alpha = 0$). For example plate thickness 1,3 mm, tooth length 13 mm, gap 2 mm => reduction = 35% in main direction and 25 % when the load is perpendicular to the grain ($\alpha = 90$). Much higher reductions will occur to the anchorage stiffness.

B.4 Odd Ellingsryd, NTI, Norway

He knows the problem as "spring back". There are many factors causing the problem:

- the number of nails (quantity of steel)
- the points of the nails,
- design of the plate (large plate areas are unfavourable),
- pressing tools (roll or hydraulic press),
- loading rate,
- the density and moisture content of the timber.

Gaps occur both for plates with short and long nails. NTI has made an internal report (1979) to analyse the influence of the timber, see section A.3.

B.5 Bo Källsner, Trätek, Sweden

Trätek has not made any investigations concerning partially embedded metal plate fasteners. Bo has often heard about the problem from the industry. He was told by the industry that it sometimes happened for low-density timber and when the punching tools were worn. He was also told that the problem mainly came up for plates with a high number of teeth per unit area.

B.6 Hans Blass, Karlsruhe University, Germany

They are doing some experimental investigation on this subject at the moment. A report with the results is expected to be finished at the beginning of 1999.

B.7 Carl Johan Johansson, SP Swedish National, Testing and Research Institute, Sweden

No further response than the report given in section A.2.

C Response from Plate Manufacturers

C.1 Lew Wasserstein, Technical Director-Europe, Mitek Inc., Birmingham, U.K.

Lew has asked for information within the Mitek organization. Here is a summary.

CSIR in Pretoria, South Africa.
Tests have been made at CSIR, Pretoria, South Africa. The results are given in table 4. There is no information on tooth length or plate type.

Embedment gap	Strength ratio
mm	-
0	1.0
1	0.82
2	0.56
3	0.30
4	0.06

Tabel 4: Embedment gap strength ratios.

A gap of 1 mm could be allowed in exceptional circumstances:

- The plate with the gap is the only plate on the truss which is not pressed in completely.
- No two adjacent trusses may have a plate on them which is not pressed in completely.
- The maximum gap on the plate is 1 mm.

John Tadich, Technical Director, Gang-Nail Australia Ltd.
Some tests on an Australian GN20 plate have been made. The results are given in table 5.

Embedment gap (both sides)	Strength ratio
mm	-
0	1.0
1	0.7
2	0.52

Tabel 5: Embedment gap strength ratios.

They have also tested a GNQ plate in Slash Pine. The results are given in table 6.

Load Applied N/tooth	No gap	One side 1 mm gap	One side 2 mm gap	Both sides 1 mm gap	Both sides 2 mm gap
Parallel to grain	114	61	34	44	44 (?)
Reduction factor	1.0	0.54	0.30	0.39	0.39
Perpendicular to grain	99	67	49	30	20
Reduction factor	1.0	0.68	0.49	0.30	0.20

Tabel 6: Basic Lateral Working Loads.

There is no information on tooth length. The significant reduction on tooth shear values in this plate is due to crushing of the timber below the plates.

C.2 Juha Elomaa, Design Manager Mitek Inc., Riihimaki, Finland

In general Juha refers to Ari Kevarinmäki. He has discussed this problem with the quality controlling authorities, because they feel that this is very dangerous phenomenon and even worse if nails are short.
Juha thinks that the potential gap in joints with thin plates is more often caused by different wood thickness than a pressing problem. With a roll press system the problem should not appear at all.

C.3 Per Kärlberg, Area Director, Gang-Nail Systems AB, Mitek Inc., Tranås, Sweden

Refer to the report from Jens Ljørring Technological Institute, Denmark.

C.4 Steve Cabler, Vice President of Engineering, Mitek Inc., St. Louis, USA

Mr. Cabler has provided Triche with some data on partial plate embedment developed for Mitek plates. Cabler says:
"Partial plate embedment research, to my knowledge, has generally involved investigation of controlled gaps involving the entire plate area. In reality it is more as you described where the edges are fully embedded and the center is not. This condition may be difficult to create in the laboratory because it is often unpredictable. This condition may potentially cause an increase in lateral resistance if the allowable capacities are based on average specific gravity and the condition exists predominantly for higher SG (stress grade) material. There may also be increased densification in the area of partial embedment.
I agree that once this occurs there is nothing that can be done. Further pressing does

not help. I have seen the lumber crush before the plate is embedded any deeper.
This is a good research project because it addresses a real problem. Moisture content, species, grain orientation and density all influence this phenomenon".

C.5 Håvard Thorsrud, Design Manager, Nordisk Kartro, Olso, Norway

They have solved the problem by making the end of the nails sharper. This seems to solve the problem for plates with both long and short nails.

STRUCTURAL DESIGN PAPERS

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