NAILS AND NAILPLATES AS SHEAR CONNECTORS FOR TIMBER-CONCRETE COMPOSITE CONSTRUCTIONS

NÄGEL UND NAGELPLATTEN ALS SCHUBVERBINDER FÜR HOLZ-BETON-VERBUNDKONSTRUKTIONEN

CLOUS ET CONNECTEURS COMME ASSEMBLAGES DE CISAILLEMENT POUR LES STRUCTURES COMPOSITES BOIS-BÉTON

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SUMMARY

In many European countries an increasing trend for use of timber-concrete composite constructions cannot be overseen. The range of applications comprises upgrading and post-strengthening of existing timber floors in residential / office buildings as well as newly errected constructions for buildings and bridges. Several Technical Approvals have been issued by German Institute for Building Technique (DIBt) for such constructions in recent years.

The composite action is highly dependant on the type of employed shear connectors which also determine considerably the economical aspects. A large variety of mechanical or glued connectors has been investigated and / or used, some of them being unmodified timber-timber connectors and others having been specially developed for timber-concrete compounds.

This paper reports on mechanical properties of nails and nailplates representing probably the most basic shear connectors for timber-concrete constructions. Both types of connectors are used in two timber-concrete systems covered by Technical Approvals issued with the involvement of Otto-Graf-Institute. In detail, medium-sized smooth nails and small threaded nails, and three nailplate types with different application methods are regarded. Besides the connectors some details of the relevant timber-concrete constructions are given. An emphasis is laid on the explanation of systematic differences of slip modulus and shear strength of the connectors when used either in timber-timber, timber-steel plate or in timber-concrete connections.

ZUSAMMENFASSUNG

In vielen europäischen Ländern ist ein zunehmende Tendenz bei der Verwendung von Holz-Beton-Verbundbauweisen nicht zu übersehen. Der Einsatzbereich dieser Bauweisen umfasst sowohl Ertüchtigung und nachträgliche Verstärkungen bestehender Holzdecken in Wohnhäusern und Geschäftsgebäuden als auch neu errichtete Konstruktionen bei Gebäuden und Brücken. In den letzten Jahren wurden seitens des Deutschen Instituts für Bautechnik (DIBt) in diesem Zusammenhang mehrere allgemeine bauaufsichtliche Zulassungen erteilt.

Das Verbundverhalten hängt hauptsächlich von der Art der Schubverbinder ab, die andererseits auch die ökonomische Rentabilität der Bauweise stark beeinflussen. Es wurde bereits eine größere Anzahl verschiedener nachgiebiger und geklebter Schubverbinder untersucht und / oder in der Baupraxis eingesetzt; einige von ihnen waren unverändert übernommene Holz-Holz Verbindungsmittel, andere wurden speziell für den Einsatz als Holz-Beton-Verbinder konzipiert.

Der vorliegende Aufsatz berichtet über die mechanischen Eigenschaften von Nägeln und Nagelplatten, die vielleicht die grundlegendsten Schubverbindungen für Holz-Beton-Verbundbauweisen darstellen. Beide Verbindertypen werden in zwei Holz-Betonverbundbauweisen eingesetzt, die durch entsprechende bauaufsichtliche Zulassungen, an denen das Otto-Graf-Institut maßgeblich beteiligt war, eingeführt sind. Im einzelnen werden glattschaftige Nägel mittlerer Größe, kleinere Rillennägel und drei Nagelplattentypen mit unterschiedlichen Befestigungsvarianten untersucht. Neben den Verbindungsmitteln werden auch die wichtigsten Details der entsprechenden Holz-Beton Verbundkonstruktionen erwähnt. Besonderes Augenmerk wurde auf die Erörterung der systematischen Unterschiede der Schubverbinder bezüglich Verschiebungsmodul und Schubtragfähigkeit bei Verwendung als Holz-Holz-bzw. Holz-Stahl-Verbinder einerseits und als Holz-Beton-Verbinder andererseits gelegt.

RESUME

Dans de nombreux pays européens, la tendance croissante à l'utilisation de structures composites bois-béton ne peut pas être overseen (ignorée ?). Les applications de telles structures se situent au niveau de l'amélioration et du renforcement de planchers bois dans des constructions résidentielles ou des bâtiments publics, comme dans la réalisation de constructions neuves, bâtiments ou ponts. Plusieurs avis techniques ont été délivrés par l'Institut Allemand des Techniques de Construction (DIBt) pour différentes constructions au cours des années récentes. L'action du composite dépend fortement du type de connecteur utilisé pour la reprise des contraintes de cisaillement, ce qui a par ailleurs un impact économique considérable. Une grande variété d'assemblages mécaniques ou collés a été étudiée et/ou utilisée, certains étant des assemblages de type bois-bois non modifiés, d'autres ayant été spécifiquement développés pour les composites bois-béton.

Cet article présente des résultats obtenus sur des assemblages cloués et par connecteurs métalliques, qui représentent probablement les assemblages de cisaillement les plus élémentaires pour les structures bois-béton. Les deux types d'assemblages sont utilisés dans deux systèmes bois-béton bénéficiant d'avis techniques impliquant l'Otto-Graf Institute. Plus précisément, nous avons étudié le comportement d'assemblages par clous, pointes torsadées, ainsi que trois types de connecteurs métalliques utilisant différentes méthodes de mise en oeuvre. Au-delà des assemblages eux-mêmes, des détails sur les structures bois-béton considérées ici sont donnés. On met l'accent sur l'explication des différences systématiques observées sur le module de glissement et la résistance au cisaillement des connecteurs, lorsqu'ils sont utilisés comme assemblages bois-bois, bois-plaques metalliques ou bois-béton.

KEYWORDS: timber-concrete composite constructions, shear connectors, smooth and threaded nails, nailplates, slip modulus, shear capacity, Technical Approval for timber-concrete constructions

1. INTRODUCTION

Timber-concrete constructions, although not that widely recognized, have a rather long tradition with prevailingly good experience especially for upgrading of (old) pure timber ceilings. Today, in Europe an increasing trend for use of this composite construction method for newly erected buildings can not be overseen, too. Perceivable and actually employed connectors comprise a wide variety of mechanical or glued connectors (Fig. 1). Some of them are unmodified pure timber-timber construction connectors and others have been specially adapted to or were developed for timber-concrete compounds.

In an attempt to categorize the different connectors quantitatively in terms of stiffness, strength and application features this paper, in a first step, reports on the probably most basic connectors, such as nails and nailplates, adopted (almost) unchanged from pure timber-timber applications. Altogether with the connectors some specifically related timber-concrete constructions, some of them recently approved by German Building authority (DIBt), are discussed.

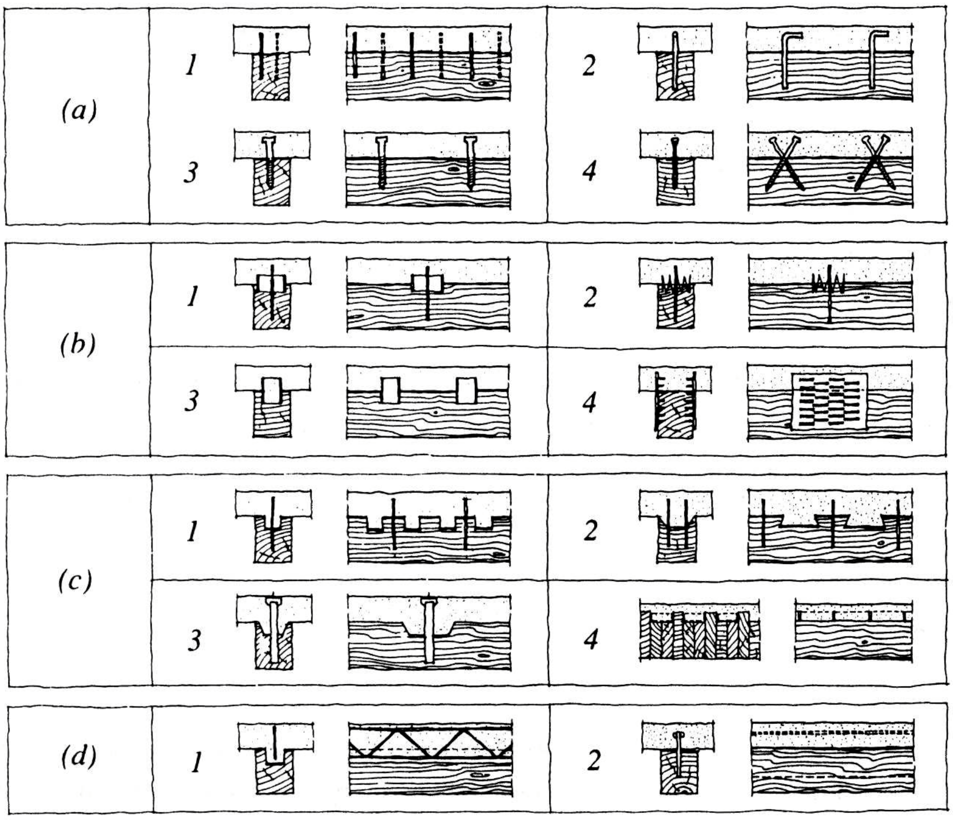


Fig. 1: Examples of timber-concrete connection systems from [1]

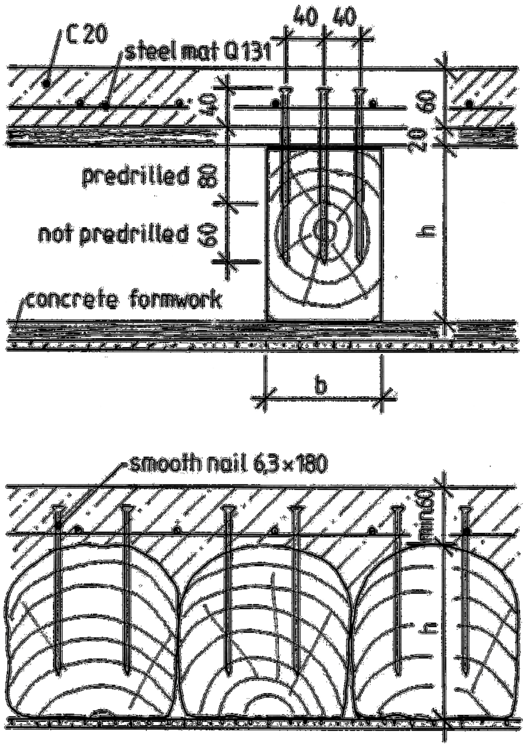
2. NAILS AS TIMBER CONNECTORS

2.1 Medium-sized smooth nails

2.1.1 Timber-concrete joint

Smooth steel nails represent certainly the most basic and most extensively employed shear connector alternative for timber-concrete composites. Especially in former Czechoslovakia several 10 000 m^2 of originally pure solid timber beam ceilings have been post-strengthened with an additional concrete slab via smooth steel nails in the last four decades since its first reported application in 1960 [2, 3].

In the upgrading procedure of timber beam ceilings (Fig. 2a, b), followed up in Czechoslovakia, almost throughout smooth nails with dimensions of 6,3 × 180 mm were / are used. Depending on the type of construction, either with or without lost sheeting, the anchorage length of the nails in the timber varies between 120 to 140 mm and is about 40 mm in the concrete (C20) which is reinforced with one steel mat (Q 131). The nails are driven into partly (about 50% of anchorage length) predrilled holes.



a)

Fig. 2a, b: Timber-concrete connection with medium sized smooth nails after [3]

Some results of the mechanical behavior of the specific timber-concrete connector test configuration, shown in Fig. 3, are reported by [3]. The compression shear tests gave, per nail, a mean shear load capacity and an initial slip modulus of

$R_{mean} = 4.5$ kN and $K_{ser} = 30$ kN/cm.

As no coefficient of variation of the test results is specified, a C.O.V. of about 10 - 15 % for ultimate load is assumed, resulting in a characteristic (5percentile) load capacity estimate in the range of $R_k = 3.4 - 3.8$ kN. The strongly non-linear range of the connection starts at about 1/3 of ultimate load capacity.

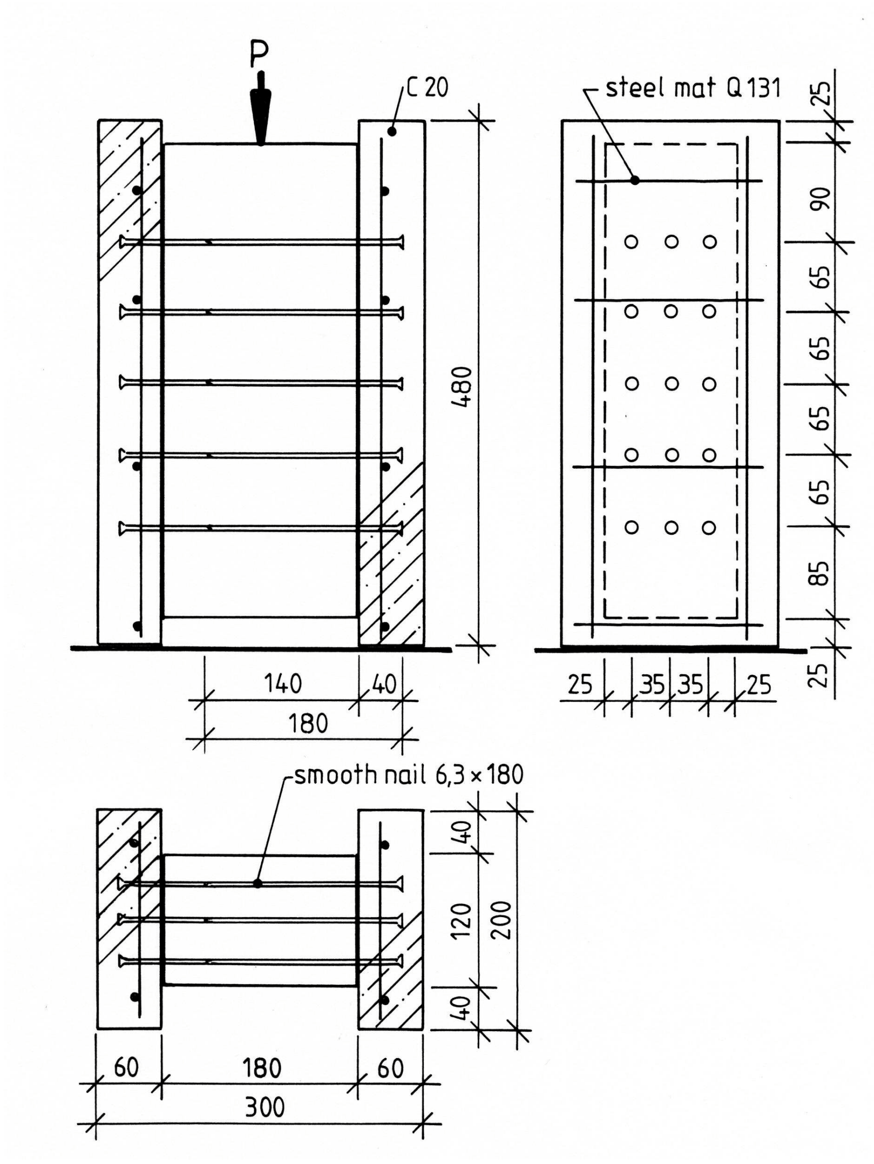


Fig. 3: Timber-concrete composite compression shear test specimen used for smooth nail connections [3]

2.1.2 Comparison with analogous timber-steel plate connection

It is of interest how the stiffness and strength values obtained for the timber-concrete connection are related to (mean) slip modulus and characteristic load capacity of a nailed timber-steel plate connection (thick steel plate) in single shear. Obviously, the latter material / geometry configuration should forward a similar load capacity as the failure mechanisms resemble each other closely. In both cases the steel nail shows a plastic hinge at the interface of timber to steel or concrete and a second one inside the timber (Fig. 4a). According to German draft timber design code E DIN 1052:2000 [4] the characteristic shear load capacity of a nailed timber-thick steel plate connection is (d = nail diameter)

$$R_k = R_{k,\text{smooth\_nail}} = 2\sqrt{M_{y,k} \cdot f_{h,k} \cdot d} \tag{1}$$

where the characteristic values of the nail yield moment $M_{y,k}$ (steel tensile strength ≥ 600 N/mm^2) and of the embedment strength, $f_{h,k}$, are

$$M_{y,k} = 180 \cdot d^{2.6} \qquad \text{(d in mm)} \tag{2}$$

$$f_{h,k} = 0{,}082 \cdot \rho_k \cdot d^{-0{,}3} \qquad \text{(hole not predrilled)} \tag{3a}$$

$$f_{h,k} = 0{,}082 \cdot \rho_k \cdot (1 - 0{,}01\ d) \qquad \text{(hole predrilled)} \tag{3b}$$

and ρ_k is the characteristic density of the timber in kg/m^3.

In the given case for comparison with above stated test results, where $d = 6.3$ mm and $\rho_k \leq 350\ \text{kg/m}^3$ (i. e. timber strength class roughly C 24) one obtains with $f_{h,k}$ = 21.7 N/mm^2 (average between predrilled and not predrilled hole) and $M_{y,k}$ = 21.56 x 10^3 Nmm a characteristic shear resistance of R_k = 3.4 kN. This value corresponds very well with the above specified range of the characteristic load capacities of 3.4 – 3.8 kN for the timber-concrete connection.

Regarding slip modulus, E DIN 1052:2000 specifies for nails in predrilled and not predrilled holes, respectively, for timber-timber as well as for timber-steel connections at single shear condition

$$K_{ser} = \rho_k^{1.5} \cdot d / 20 \qquad \text{and} \qquad K_{ser} = \rho_k^{1.5} \cdot d^{0.8} / 25 \tag{4 a, b}$$

The average slip modulus for predrilled and not predrilled holes ($d = 6.3$ mm, ρ_k = 350 kg/m^3) then follows as K_{ser} = (20.6 + 11.4) / 2 = 16 kN/cm. When comparing this value to the above given experimental timber-concrete connection result of 30 kN/cm it has to be stated that the K_{ser} design value for the analogous timber-steel connection (here: timber-timber) is only about one half. The reason for this is, that the K_{ser} design equation for a timber-steel connection, i.a. due to the generally oversized (1 mm) hole in the steel plate, does not consider any stiffness increase vs. pure timber-timber connections.

Comparing the deformation shapes of the nail in the timber-concrete and the timber-timber connection situation (with sufficiently thick members), see Figs. 4a, b, however, it is obvious that K_{ser} in the timber-concrete application should be very roughly 2times higher. This actually is fully supported by the above specified K_{ser} values.

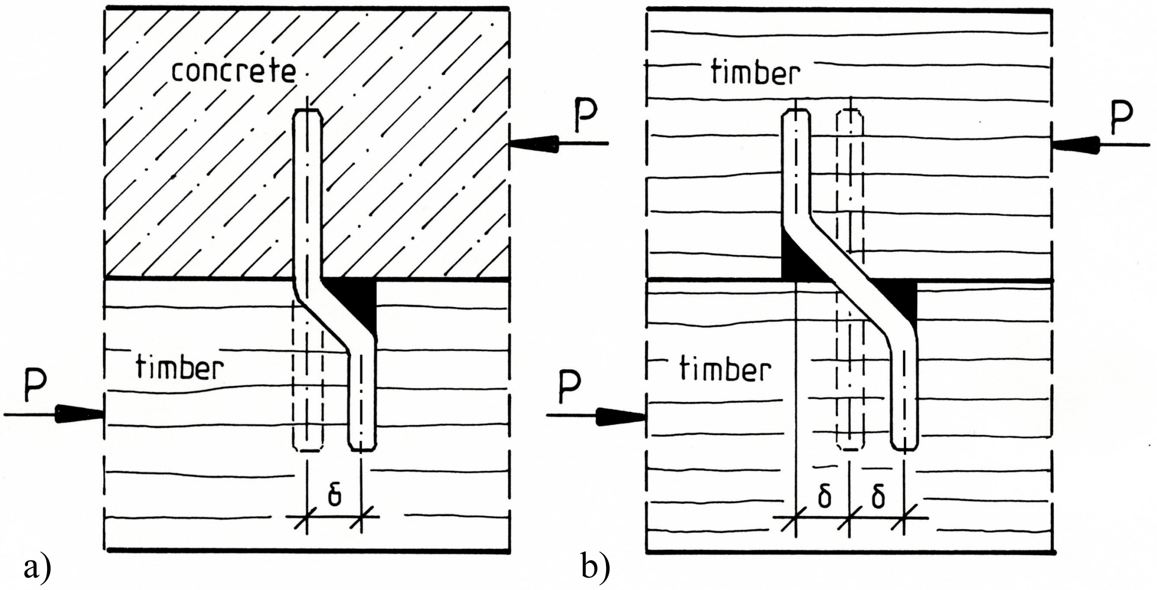


Fig. 4a, b: Shape of deformed dowel type fasteners in a concrete-timber (a) and a pure timber-timber joint (b)

2.2 Small-sized threaded nails

2.2.1 Timber-concrete joint

In 1998 the first two German Technical Approvals for timber-concrete constructions and their respective connectors were issued by German Institute for Building Technique (DIBt). One of them, not regarded in this context, deals with special screws (Z-9.1-342 [5]) and the other (Z-9.1-331 [6]), considered here, is based on the application of usual small-sized threaded (ring shank) nails with dimensions 3.4×60 mm (Fig. 5a). The electro-galvanically corrosion protected nail (company Paslode) must conform, proven by certificate KA 028 [7], to load bearing (axial withdrawl) class III.

The nail is employed in a prefabricated timber beam-concrete slab construction as shown in Fig. 5b. The gun-shot nails must be arranged in two rows along the small edge of the solid wood beams (minimally conforming to strength class C24) with cross-sectional dimensions (width×depth) of 45-72 mm × 170-250 mm. The thickness of the concrete slab (C35) can vary from 50-85 mm. The anchorage length of the nail in the concrete must be 20-25 mm and correspondingly 35-40 mm in the timber. Prefabricated elements of the described type with maximum dimensions of 3 × 7 m were / are successfully employed in buildings in Sweden and Germany.

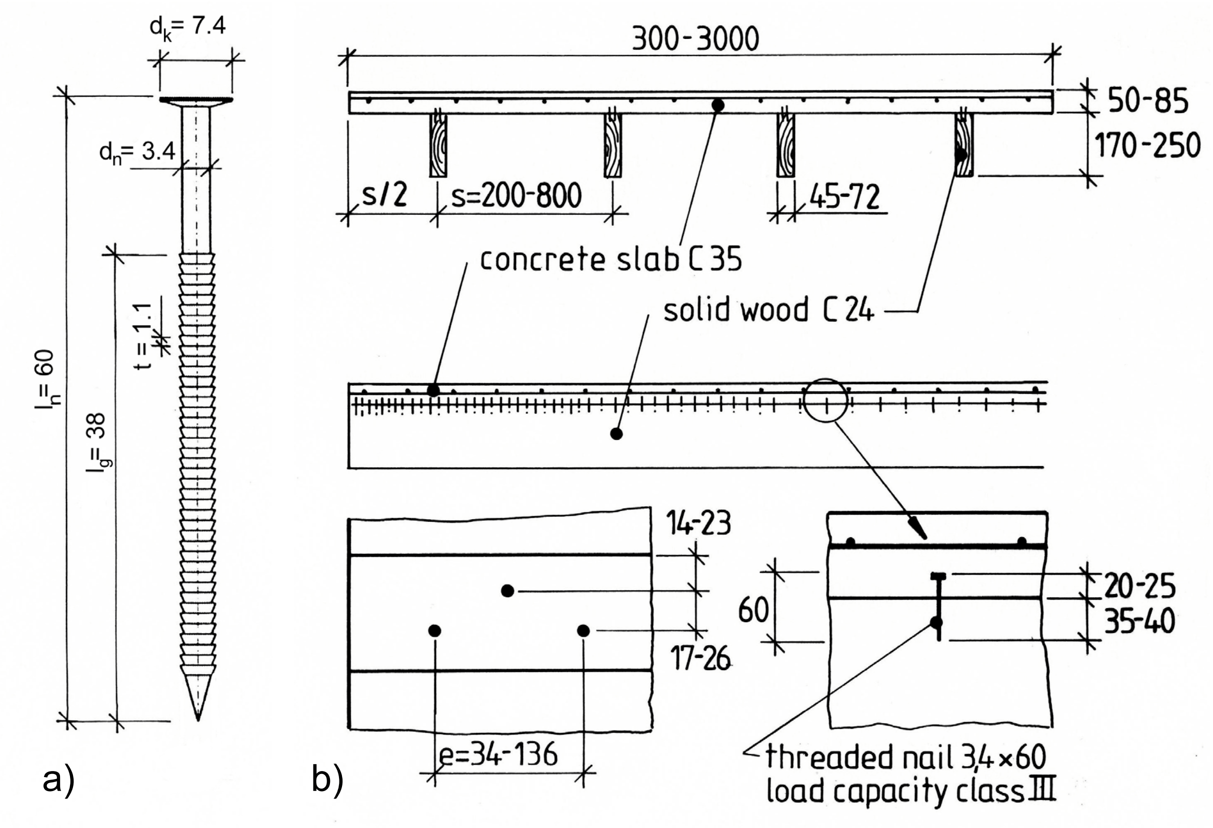


Fig. 5a, b: Timber-concrete connection system with small sized threaded nails for the EW element acc. to Z-9.1-331 [6]

a) fastener b) lay-up and dimensions of the timber concrete construction

According to the Technical Approval [6], which is based on extensive tests at Swedish National Testing and Research Institute and test evaluations / expertise at Otto-Graf-Institute, the characteristic and allowable shear capacity and the slip modulus shall be assumed, per nail, as

$R_k = 1.2$ kN, $R_{allow.} = 0.5$ kN and $K_{ser} = 12$ kN/cm.

2.2.2 Comparison with analogous timber-steel plate connection

For assessment of the specified load capacities and slip property an analogous timber-steel plate connection (thick steel plate, single shear) is regarded. The characteristic shear capacity of a threaded nail (load capacity class III acc. to E DIN 1052:2000 [5]) is

$$R_k = R_{k,smooth\_nail} + \Delta R_k \tag{5}$$

$$\Delta R_k = \min\left(0.5 \cdot R_{k,smooth\_nail}; 0.25 \cdot R_{ax,k}\right) \tag{6}$$

with $R_{k,\, smooth\_nail}$ acc. to Eq. (1) and

$$R_{ax,k} = f_{1,k} \cdot d \cdot l_{ef} \quad \text{with} \quad f_{1,k} = 50 \cdot 10^{-6} \rho_k^2 \qquad (7), (8)$$

The additional load capacity term ΔR_k, as compared to smooth nails, accounts for the tension force activation in the bent nail resulting from the grip / friction of the profiled nail surface in the timber. Evaluating the shear capacity with $d = 3.4$ mm, $\rho_k = 350$ kg/m^3 and $l_{ef} = 35$ mm (embedment length of the nail in the timber), which results in $f_{1,\,k} = 6.1$ N/mm^2, we obtain

$R_{k,\, smooth\_nail} = 1.08$ kN, $R_{ax,\, k} = 0.73$ kN

and then $R_k = 1.08$kN + 0.18kN = 1.26 kN.

As anticipated, the calculated timber-steel plate shear capacity is very close to the experimentally based value specified above for the timber-concrete connection (difference = 6%).

Regarding the slip modulus of a threaded nail in a timber-steel plate connection the same equation (4b) as for smooth nails in not predrilled nail holes applies, giving $K_{ser} = 7$ kN/cm. So, very similar to the situation with the medium-sized smooth nail, the calculated slip modulus for the timber-steel plate connection is only about 60% of the stiffness of timber-concrete connection.

3. NAILPLATES

3.1 Timber-concrete joints

The first thorough investigations on the use of punched metal plate fasteners (short: nailplates) as timber-concrete connectors in timber-concrete composites used for walls and floors were reported by Girhammar [8, 9].

A later extensive research work on nailplates as timber-concrete connectors was performed at University of Karlsruhe [10, 11, 12]. In the year 2003 the first German Technical Approval for a timber-concrete construction based on nailplates was issued (Z-9.1-474 [13]); the respective tests and expertises were done at Otto-Graf-Institute. In the following it is focussed on the nailplate constructions investigated in Karlsruhe and in Stuttgart. Figures 6 and 7 show the specific connector applications used.

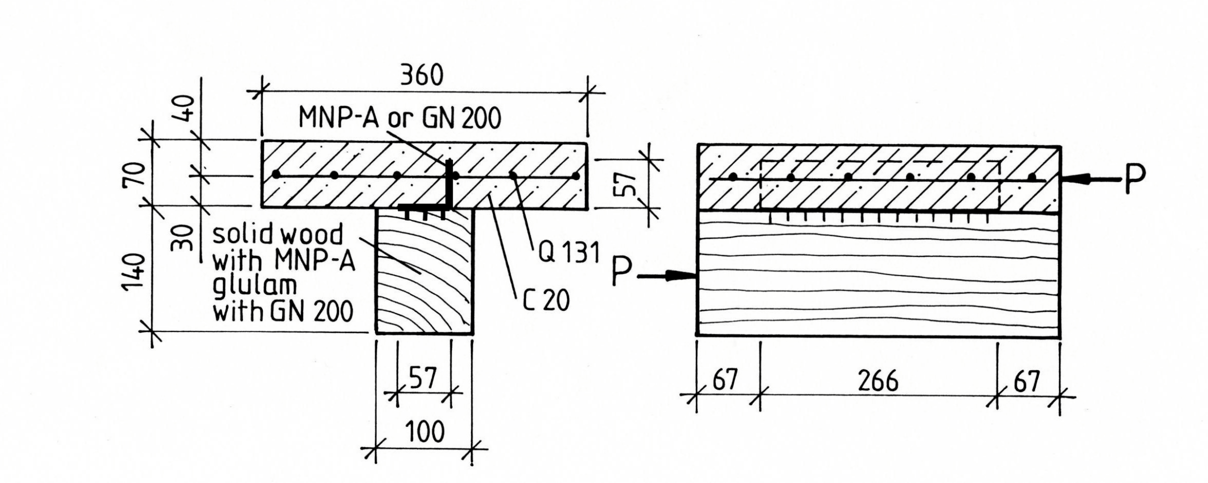


Fig. 6: Nailplate connection investigated in [10]. The figure shows the shape / dimensions of the investigated compression shear specimens

The connectors investigated in Karlsruhe were nailplates bent at mid-width, as shown in Fig. 6. One half of the plate with not removed nails is pressed into the narrow timber beam face, whereas the other half with removed nails is embedded in the concrete.

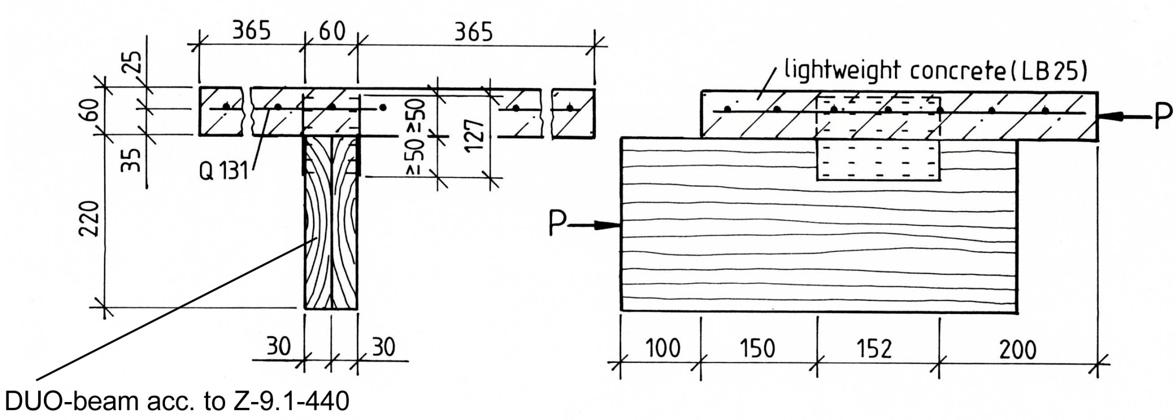


Fig. 7: Nailplate connection system and compresion shear specimens investigated for Z-9.1-474 [13]

Two test series (A-NAG and B-NAG) with two different nailplates of equal width and length dimensions of 114×266 mm were performed. In the first test series, A-NAG, with 5 specimens, the nailplate type "Gang Nail GN 200" acc. to Z-9.1-230: 1966 [14] was used. In the second test series, B-NAG, with a considerably higher specimen number of 46, nailplate type "Merk nailplate MNP-A" acc. to Z-9.1-273 [15] was employed. Figure 8 shows a view of the latter nailplate type MNP-A with nail length, width and thickness of 20 mm, 3.2 mm and 2 mm, respectively.

The connection configuration tested in Stuttgart [13], resembles closely the nailplate joints used by Girhammar [8, 9]. In both cases, different from the Karlsruhe approach, unmodified nailplates (not bent, no removed nails) are used. In detail, the timber-concrete joint is based on the "Wolf nailplate, type 15N" acc. to Technical Approval Z-9.1-210 [16], shown in Fig. 9.

Length and thickness of the nail (15.5 and 1.5 mm) now are considerably smaller as compared to afore mentioned nailplate type MNP-A. No difference exists with respect to width of the nails, being b = 3.2 mm. Although not of primary importance for the slip and shear load capacity of the nail plate joint of Technical Approval Z-9.2-474 [13] it should be mentioned that the regarded joint is employed in a quite unusual timber concrete construction where the timber beams are used in compression and the steel bar reinforced concrete is loaded in tension. The reason for this at first view rather awkward use stems from the specific application of the prefabricated element in a specific prefabricated house construction. There the concrete slab provides an immediate usable wall and ceiling surface.

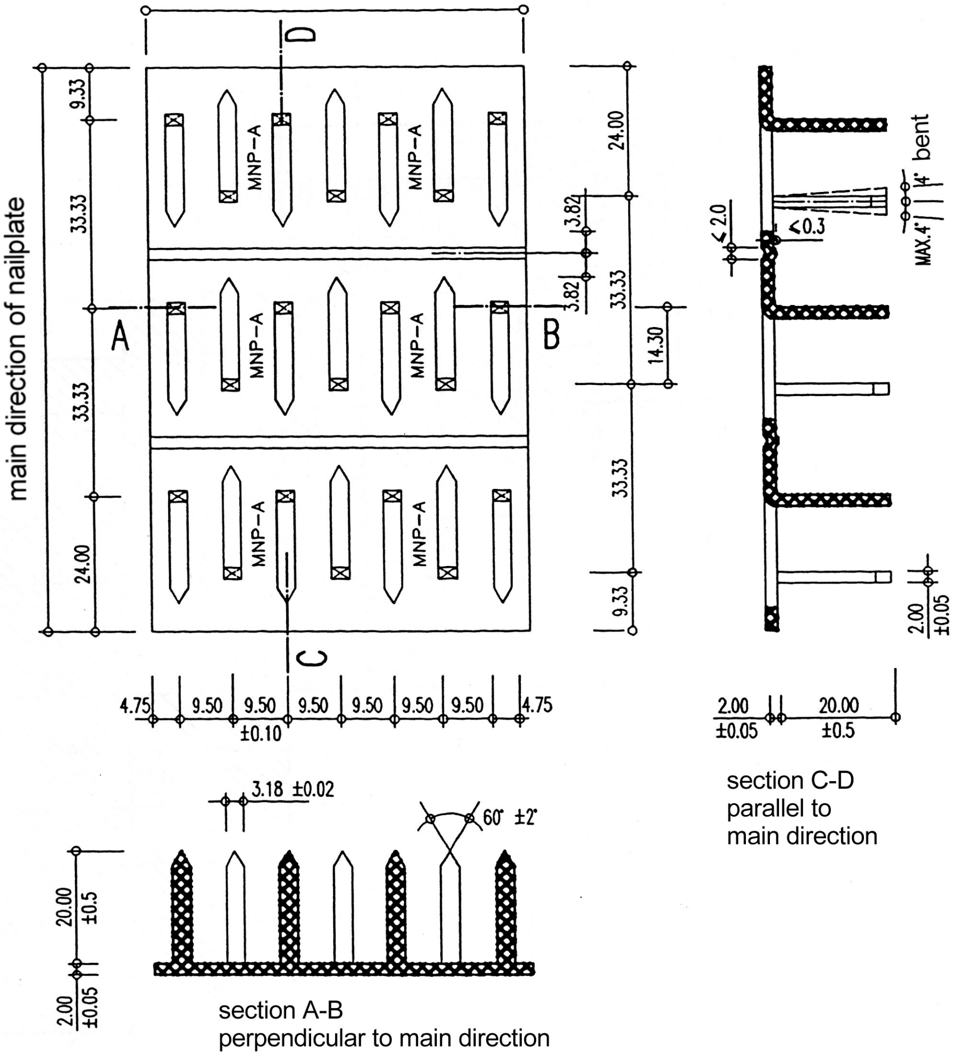


Fig. 8: View of "Merk nailplate, type MNP-A" acc. to Z-9.1-273 [15]

Table 1 contains a compilation of the test results concerning slip modulus and shear load capacity of the timber-concrete nailplate joints with "GN 200" and "MNP-A", given in [10], and the results obtained in Stuttgart for "Wolf 15N".

The table specifies the results for the total plate and for better comparison, also per centimeter of plate main direction being parallel to the timber-concrete interface. It can be seen that the slip moduli obtained for the three different nailplate types, however with similar anchorage depth in the timber, are very closely together, i. e.

$$\overline{K_{ser}} = 18.7;\quad 18.4;\quad 18.4\ \frac{\text{kN}}{\text{cm}}\left(\frac{1}{\text{cm}}\right)\ \text{for GN 200; MNP} - \text{A; Wolf 15N}$$

Second, also the mean load capacities differ very little:

$$f_{v,\,0,\,\mathrm{mean}} = 2.0; \quad 1.8; \quad 2.1 \quad \mathrm{kN}\left(\frac{1}{\mathrm{cm}}\right) \quad \text{for GN 200; MNP – A; Wolf 15N}$$

The specified scatters (C.O.V.s) of the load capacities have to be seen in view of the different specimen numbers tested, being higher for "MNP-A" with n = 46 and considerably lower for "GN 200" and "Wolf 15N" with 5 and 14 tested joints, respectively. So, following, for a rough calculation of a 5% fractile an equal C.O.V. of 14% (= that of "MNP-A") was assumed for all three configurations.

Reference	**nailplate type**	**slip modulus**		**shear load capacity**				
	in timber-concrete connection	per nailplate K_{ser}	per cm of nailplate length $\overline{K_{ser}}$	per nailplate $R_{V,0}$			per cm of nailplate length $f_{V,0}$	
				x	C.O.V.	x_{05} [1)]	x	x_{05} [1)]
--	--	kN/cm	(kN/cm) (1/cm)	kN	%	kN	kN/cm	kN/cm
Karlsruhe tests [10; 11]	GN 200 [Z-9.1-230]	**500**	**18.7**	**53.5**	**9.2**	**41.2**	**2.0**	**1.5**
	MNP-A [Z-9.1-273]	**490**	**18.4**	**47.9**	**14.0**	**36.9**	**1.8**	**1.4**
Stuttgart tests [Z-9.1-474]	Wolf 15N [Z-9.1-210]	**280**	**18.4**	**31.5**	**12.1**	**24.3**	**2.1**	**1.6**

1) all x_{05} values based on C.O.V. = 14%, see text

Table 1 Results of compression shear tests on timber-concrete connections with different types and application modes of nailplates

The obtained estimates for the characteristic values range from $f_{v,0,k} = 1.4 \text{ to } 1.6 \text{ kN}\left(\frac{1}{\text{cm}}\right)$.

The slip modulus $\overline{K_{ser}} = 15.1 \frac{\text{kN}}{\text{cm}}\left(\frac{1}{\text{cm}}\right)$ specified in the Technical Approval Z-9.1-474 [13] for the timber-concrete application of the "Wolf 15N" nailplate, see Table 2, is somewhat reduced (about 20%) as compared to the test results (see Table 1) but quantitatively correct. The allowable shear force per centimeter plate length parallel to plate length ($\alpha = 0°$) is specified in [13], obviously highly conservative, as $f_{v,0,allow} = 0.4$ kN/cm; further, no characteristic design values are given.

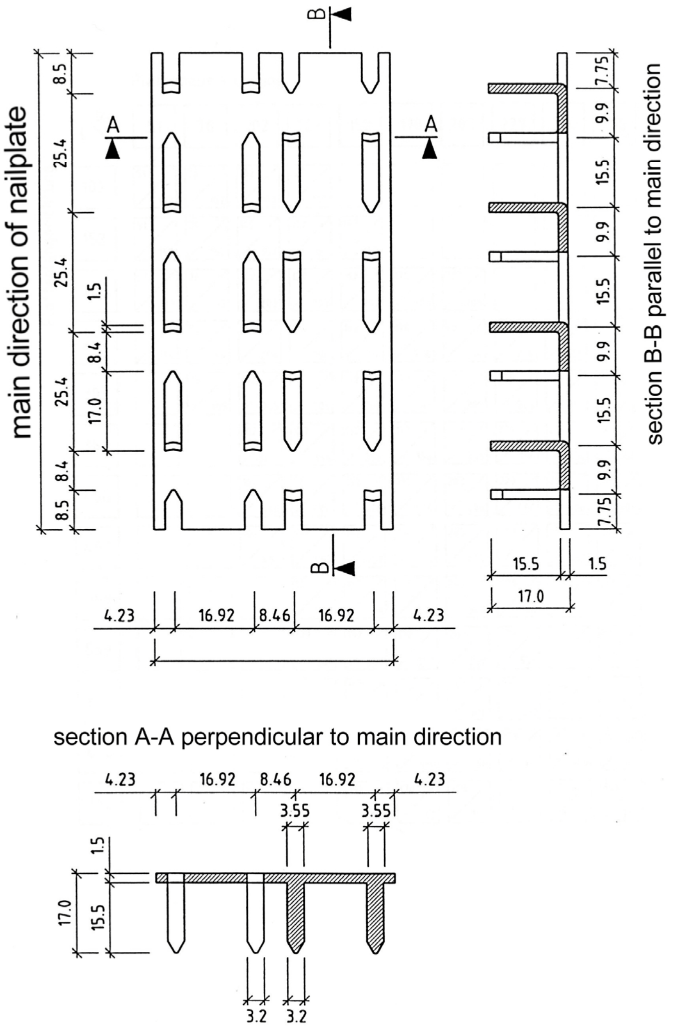


Fig. 9: View of "Wolf 15 N" nailplate acc. to Z-9.1-210 [16]

3.2 Comparison with timber-timber connections

As in case of the pure nail connections discussed in chapter 2, it is of interest, how the quantity of the slip modulus of the "Wolf 15N" timber-concrete nailplate is related to pure timber-timber joints with this nailplate type.

According to Technical Approval Z-9.1-210 [16] , the slip modulus for pure semi-rigid timber-timber composite action (see Fig. 10) for a couple of nailplates is

$$K_{ser} = K^{o}_{ser} \cdot 0{,}25 \cdot \text{ef}\,A\, \frac{1}{(1 + \kappa_c)} \tag{9 a}$$

where $K^{o}_{ser} = 3.75\,\text{kN}/\text{cm}, \quad \text{ef}\,A = 2\,(b - 2c) \cdot \ell$ (9 b, c)

and ℓ, b = length and width of nail-plate, c = marginal plate strip (c = 10 mm) and

$$\kappa_c = \frac{3 \cdot (b + 2c)^2}{(b - 2c)^2 + 4\,\ell^2} \tag{9 d}$$

So, in case of the regarded nailplate dimensions of "Wolf 15N" with $\ell = 152$ mm and b = 127 mm, slip modulus per nailplate, K_{ser}, and for a single nailplate length, $\overline{K_{ser}}$, evolve as

$$K_{ser} = 94\,\frac{\text{kN}}{\text{cm}} \qquad \text{and} \qquad \overline{K_{ser}} = 6.2\,\frac{\text{kN}}{\text{cm}}\left(\frac{1}{\text{cm}}\right).$$

The slip modulus for ultimate limit state is defined in [16], as usual, by $K_u = 2/3\,K_{ser}$.

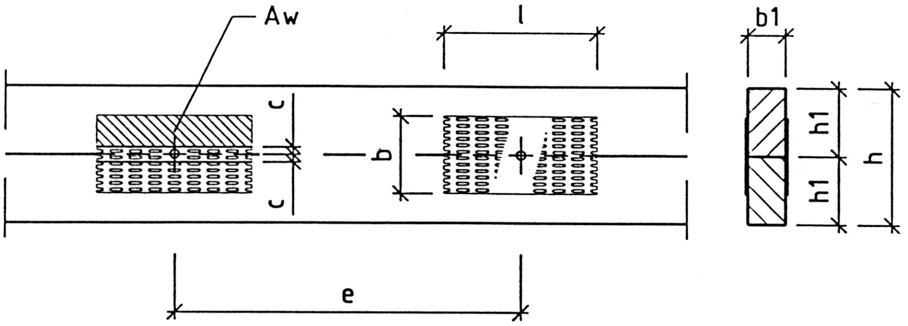


Fig. 10: Semi-rigid connection of timber-timber compounds with "Wolf" nailplate acc. to Z-9.1-210 [16]

Assuming, that the obtained slip modulus for the timber-timber connection can be taken as a realistic estimate of an experimental mean value underlaying the Technical Approval, an even more marked difference between the timber-timber and the timber-concrete joint as in case of the afore regarded nailed connections is obvious. Now, in case of the nailplate (specifically "Wolf 15N") the slip modulus of the timber-concrete application is 3times higher as compared to the timber-timber joint. (Note: in case of the nails, the increase was by a factor of 2.) It is presumed that the restriction of any rotation of the nailplate as a total contributes to the extra stiffness increase. A thorough explanation for this will be forwarded separately.

Technical Approval	**type of joint**	**type of connector**	**slip modulus**		**shear capacity $f_{V,0}$ per cm of nailplate length**		
			per nailplate	per cm of nailplate	allowable	mean	characteristic
--	--	--	K_{ser} kN/cm	$\overline{K_{ser}}$ (kN/cm)(1/cm)	$f_{V,0,allow}$ kN/cm	$f_{V,0,mean}$ 1) kN/cm	$f_{V,0,k}$ 2) kN/cm
Dennert timber-concrete composite [Z-9.1-474]	timber-concrete	Wolf 15N [Z-9.1-210]	**230**	**15.1**	**0.4**	**1.2**	**1.0**
Wolf nailplates as timber connectors [Z-9.1-210]	timber-timber		**94**	**6.2**	**0.4**	**1.2**	**1.0**
Merk nailplates MNP-A as timber connectors	timber-timber	MNP-A [Z-9.1-273]	--	--	**0.48**	**1.4**	**1.2**

1) not specified in Technical Approval; here assumed: $f_{V,0,mean} = 3\ f_{V,0,allow}$

2) not specified in Technical Approval; here assumed normal distribution, C.O.V. = 15%

Table 2 Compilation of slip moduli and allowable shear capacities of regarded nailplates specified in Technical Approvals for timber-concrete and timber-timber joints

Comparing the shear capacities of the nailplates in timber-concrete connections vs. timber-timber joints no published characteristic or mean shear load capacities are known to the authors for the regarded timber-timber nailplate joints. According to the current approach for derivation of allowable stresses / capacities a global safety factor of 3 is applied to the mean value. This procedure delivers the mean load capacity value estimations in Tab. 2; the characteristic values (5%-fractiles) are estimated by assumption of a C.O.V. of about 15%. Not focussing on the absolute numbers of the estimated mean / characteristic shear capacities of the MNP-A and Wolf 15N nailplates, when applied in a timber-timber joint, the comparison with the related timber-concrete joints clearly indicates a significant, very roughly 1.5 times increase of the load capacity in case of the timber-concrete joint. This statement does not include a minor, here unknown correction factor for a deviating yield strength of the nailplates in the timber-concrete joints as compared to the nominal requirements.

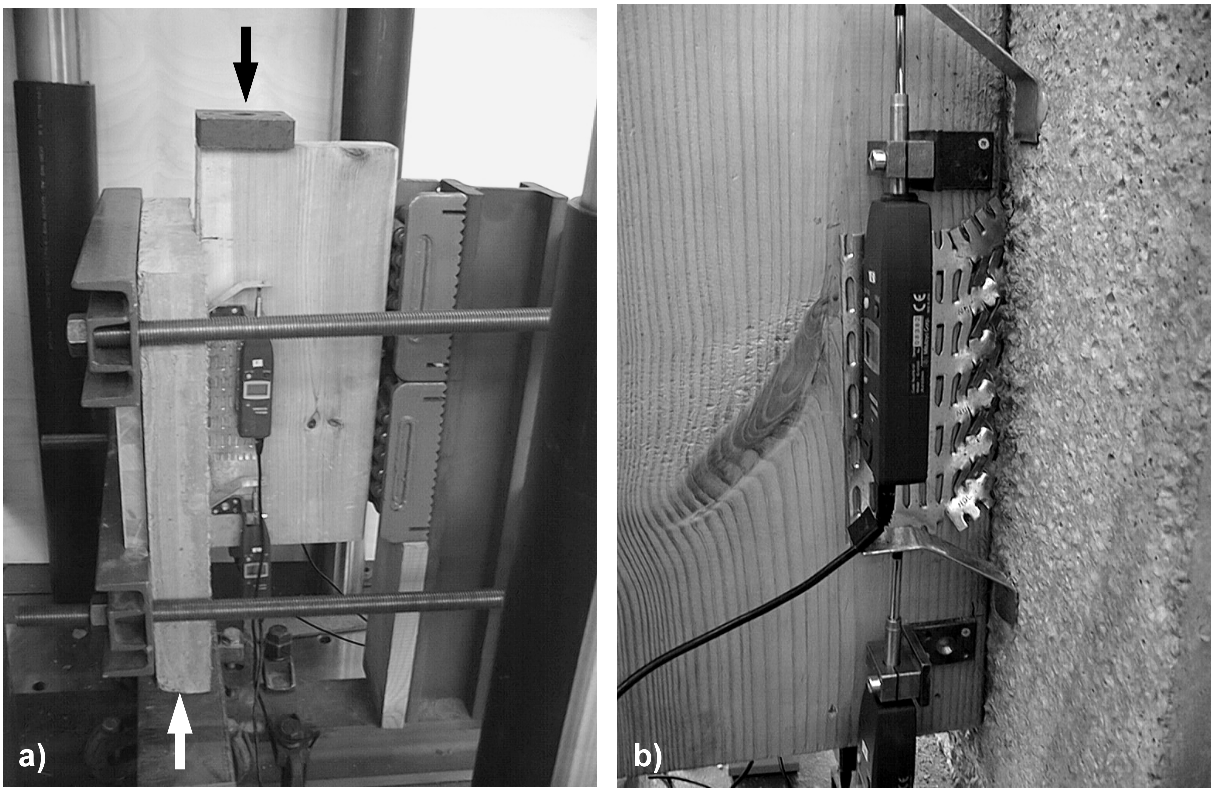


Fig. 11: View of timber-concrete nailplate connection acc. to [13] in a compressive shear test
a) test set-up b) failure state of the nailplate

One of the reasons for the load capacity increase could be, that the failure of the nailplate in the timber-concrete joint is fully determined by yielding and destruction of the nailplates in the concrete-timber interface, as shown in Fig. 11, which in that expressed manner does not occur in pure timber-timber connections. Here, clearly further research is needed.

4. CONCLUSIONS

Recapitulatory, it can be stated that conventional smooth and threaded nails of medium and small sizes, when used for timber-concrete connections, should show very roughly

- the same (characteristic) shear capacity and
- a 2 times higher slip modulus

as obtained / calculated for a timber-(thick) steel plate connection subjected to single shear. Both findings are qualitatively sensible.

Nailplates subjected to shear loading and embedded roughly equally in timber and concrete show considerably increased stiffness and strength values as compared to an analogous timber-timber joint. In a very rough approximation, valid for the discussed dimensional range of regarded nailplates, it can be well assumed, that, compared to timber-timber joints

- mean / characteristic shear capacity increases by a factor of about 1.5
- slip modulus increases by a factor of about 2.5 – 3.

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