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Long-term behavior of novel solid wood-concrete-composite floors with combined shear connectors

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ABSTRACT: The possible significance of natural and sustainable building materials and their application both in the existing and new building stock is the question of overriding importance in modern building trade. With a special focus on wood-based structural components, it can generally be explored on two levels: 1) Adaptation of existing wood structures in consideration of a sustainable design concept, 2) Development of new wood-based building components and optimization of its manufacturing processes. To combine these two approaches and with the objective to improve the structural performance of wood-based composite floor systems, a new combination of solid woods and reinforced concrete, inspired by the traditional "Dippelbaumdecke" (dowel beam floor), is developed and investigated by means of its load-bearing and deflection behavior. As the overall project-related research activities thereby generally cover a wide range of investigations, this paper primarily focusses only on the related long-term static load-bearing and deflection behavior of the assessed novel structural system. The presented publication withal aggregates the results of the related experimental and analytical long-term investigations and gives an insight into the consequential time-dependent load-bearing behavior of the examined structural system under short-term loads, as well as into the arisen deflection resp. displacement behavior of the structural component and its related creep mechanisms under permanent long-term loads.

KEYWORDS: timber, timber-concrete composite, connection, long-term behavior, load-bearing behavior

1 – INTRODUCTION

Especially in Europe and Austria, the traditional so called "Dippelbaumdecke" (dowel beam floor) was a common used floor structure in early days houses due to its high fire resistance and good soundproofing. From a structural view, halved and pre-cutted solid wood groundwork beams were laid side by side and coupled by wooden dowels to reach a shear connection between the single beams. Sand and rubble were poured on top to flatten the surface and a typical contemporary floor structure was additionally complemented. Due to the advent of reinforced concrete and brick structures, this traditional floor system disappeared because of a lack of structural and economic competitiveness.

To overcome these disadvantages and to enable a renaissance of this initial structural system, the Vollholz Hybriddecken Engelhart Ltd developed a patented novel multi-layered solid wood-concrete-composite floor system (cf. Figure 1) and studied it in cooperation with the Department of Structural Design and Timber Engineering (ITI) at the Vienna University of Technology (TU Wien) in order to determine the structural properties and the load-bearing behavior of the mentioned floor system as well as to develop calculation and sizing methods, therefore.

As seen in Figure 1, the introduced multi-layered solid wood-concrete-composite floor system is characterized by a combination of the given traditional approach and a furthermore novel formulation of structural design concepts based on specifically shaped solid wood groundwork beams and thereby applied shear connectors. In more detail, hexagonally formed, cutting optimized, solid wood groundwork beams with resulting interstitial v-shaped longitudinal joints are used within the novel structural system, whereby this given attribute thus leads to a unique base for the application of necessitative shear connectors, which more precisely is implemented in the form of a combined shear connector typology, consisting of longitudinal nailed puzzle strips (NPS) within the int-

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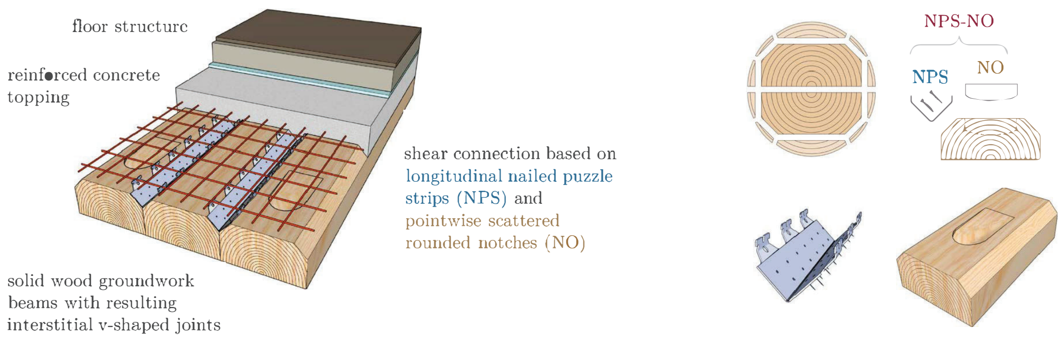

Figure 1. Novel multi-layered solid wood-concrete-composite floor system based on the traditional "Dippelbaumdecke" (dowel beam floor)

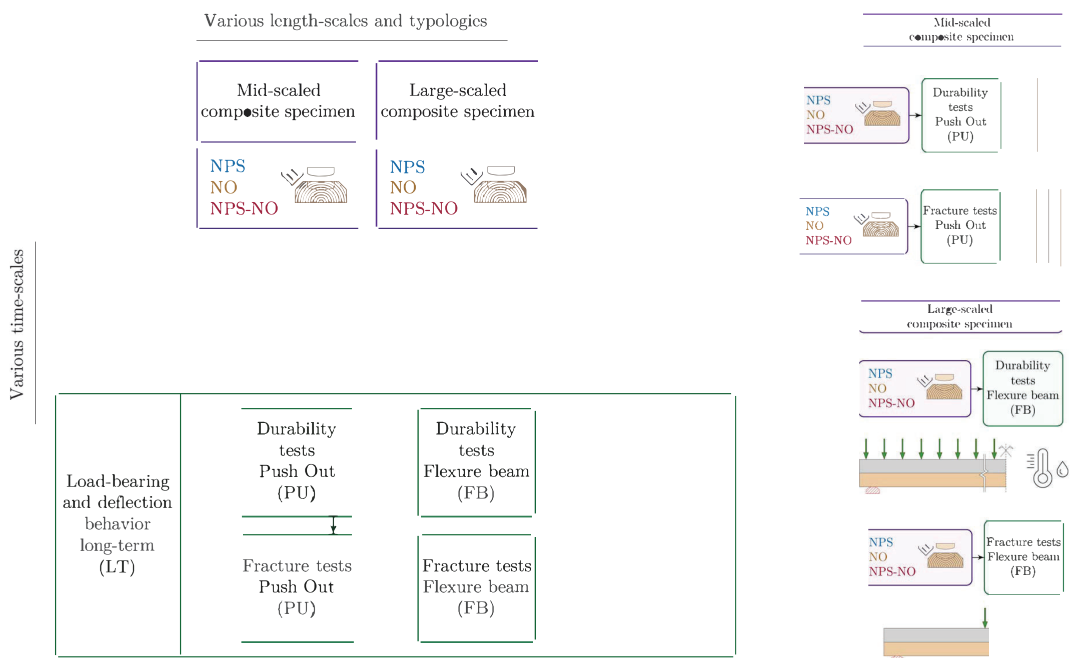

Figure 2. Presented scope of investigations of the novel multi-layered solid wood-concrete-composite floor system

ersticial joints as well as of additional pointwise scattered rounded notches (NO) on the top surface of the solid wood groundwork beams. Based on this given neoteric design concept a novel innovative structural floor system can be achieved, and shall furthermore be investigated based on its holistic requirements necessary for a practical application.

2 – SCOPE OF INVESTIGATIONS

As it can generally be concluded, the scope of investigations for the named practical application of the presented structural system is basically characterized by a wide range of examinations, reaching from perfunctorily early stage conceptual explorations to particularly detailed experimental and numerical investigations. Taking these circumstances into consideration, this paper, as a part of a broad series of project-related publications (e.g. [1, 2], resp. the first authors ongoing dissertation), shall primarily focus on the specific outcomes of the experimental and analytical long-term (LT) investigations, decisively describing the static load-bearing and deflection behavior of the assessed novel structural system (cf. Figure 2). In more detail and as seen in Figure 2, the research topic thereby fully contains experimental and analytical investigations concerning the arisen deflection and durability behavior of the structural component and its related creep mechanisms under permanent long-term loads (durability tests), as well as subsequently conducted explorations regarding the resulting time-dependent load-bearing and fracture behavior of the assessed structural system under short-term loads (fracture tests). Furthermore, the studies generally cover investigations on varying assessable scales, as the properties of the examined composite floor system can ideally be described based on a combination of mid-scale and large-scale level explorations (shear connector level resp. overall structural floor system level). The presented investigations thereby are executed in form of double symmetric push-out tests (PU) for the mid-scaled explorations as well as in form of four-point flexure beam tests (FB) for the large-scaled explorations. Furthermore, as the investigated structural system contains combined shear connectors in the form of longitudinal nailed puzzle strips (NPS) and additional pointwise scattered rounded notches (NO), all experimental and analytical investigations are conceptualized and conducted for each stand-alone typology as well as for the combined typology (NPS, NO and NPS-NO).

3 – TEST ACCOMPLISHMENTS AND RESULTS

As described in section 2, the presented scope of investigations of the novel structural system can be summarized by means of durability and fracture tests in each case conducted on a mid- as well as on a large-scaled level. With the aim of an ideally represented illustration of these investigations, the subsequent contents therefore are arranged based on the systemic and temporal experimental properties of the overall testing extent. In this context the mid-scaled double symmetric push-out tests (PU) shall be presented at first, as they contain the characteristic basic information about the explicit shear connection behavior, and are these pursued by the description of the large-scaled four-point flexure beam tests (FB), furthermore covering the contents with respect to the overall systemic behavior. In addition, the durability tests are generally described prior to the fracture tests, as, with respect to a temporal order, they also took place in the described chronology.

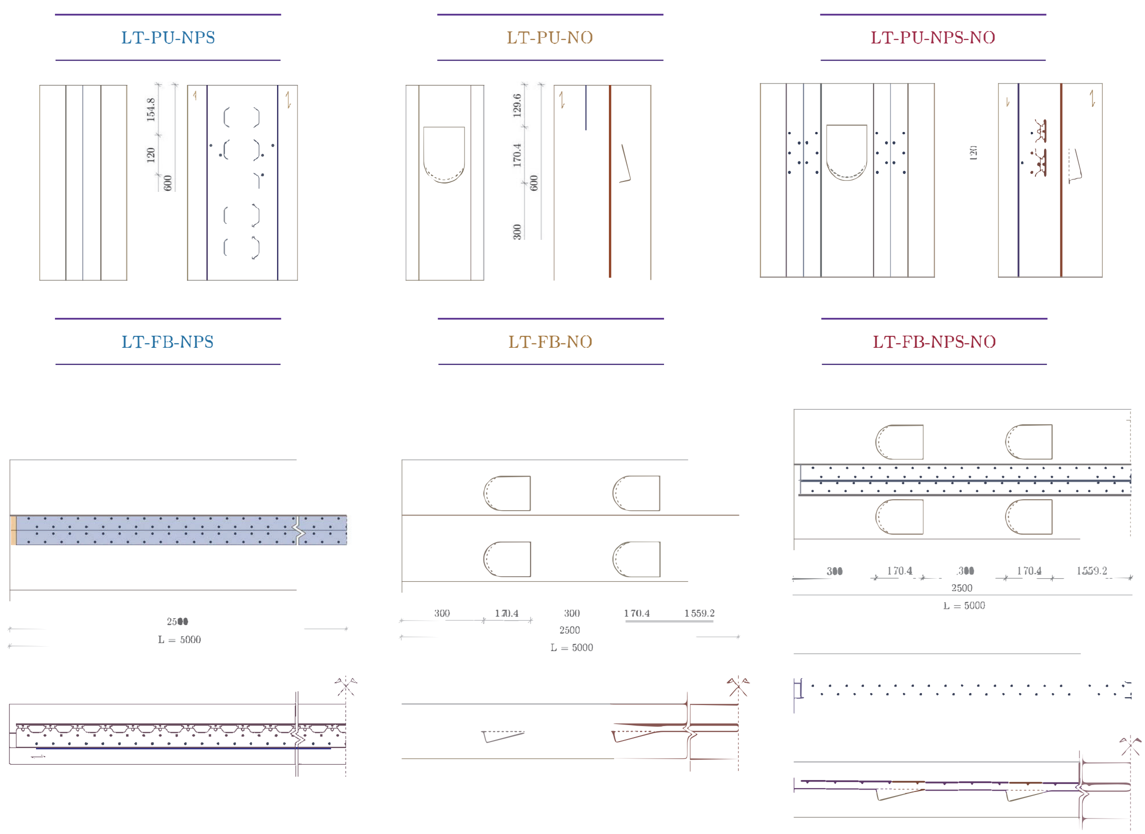

Figure 3. Typological configurations of the mid-scaled and large-scaled test specimen | Double symmetric push-out tests (PU, top), Four-point flexure beam tests (FB, bottom)

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With a moreover contextual respect to the present typological test specimen configurations within these named investigations, and as already described in section 2, the overall test accomplishments for the mid- and large-scaled explorations are thereby generally conducted for the stand-alone typologies (NPS resp. NO) as well as for the combined typology (NPS-NO). Summarized as a whole, the scope of presented investigations consequently covers collectively six typologically varying types of test specimen, whereby three can be assigned to the mid-scaled double symmetric push-out tests (LT-PU-NPS, LT-PU-NO and LT-PU-NPS-NO) and three can be allocated to the large-scaled four-point flexure beam tests (LT-FB-NPS, LT-FB-NO and LT-FB-NPS-NO).

Under an accordingly more detailed consideration of the mid-scaled double symmetric push-out test specimen (cf. Figure 3 top), the thereby realized arrangements of shear connectors can generally be described based on double-sided implementations, ether consisting of partially nailed puzzle strips (LT-PU-NPS), notches (LT-PU-NO) or a corresponding combination these two (LT-PU-NPS-NO). With a furthermore present respect to the embodiments of the large-scaled four-point flexure beam test specimen (cf. Figure 3 bottom), the thereby realized arrangements of shear connectors moreover are defined based on the respective typological properties of the individual structural systems. Considering these properties, the realized arrangements can therefore be described as composite systems with ether a continuously nailed puzzle strip (LT-FB-NPS), ordered pairs of notches (LT-FB-NO) or again a corresponding combination of these two (LT-FB-NPS-NO).

Based on these declarations, an exhaustive description of the six decisive test specimen configurations can be concluded leading to the detailed individual test accomplishments as well as the thereof gained general test results within the following subsections.

3.1 MID-SCALED DURABILITY TESTS

The given durability tests based on the mid-scaled double symmetric push-out test specimen generally aim to describe the arisen displacement behavior as well as the thereto related creep coefficients of the investigated shear connector typologies (NPS, NO and NPS-NO) under permanent long-term loads (load duration 365d) and thereby particularly defined climate conditions.

With respect to the named particularly defined climate conditions, these boundary conditions can generally be described based on a constant temperature T (23°C) and a furthermore cyclic varying relative humidity RH (between 40 and 80%), whereby the individual phase durations of the varying relative humidity RH lie between 29 d and 123 d (constant phase of 40% RH at the beginning for 123 d followed by varying phases between 40 and 80% RH for 242 d, cf. Figure 4). Based on these defined boundary conditions it shall become possible to derive resulting displacements u_v and thereto related creep coefficients φ for on the one hand constant conditions (0-123 d) as also for varying conditions (123-365 d) on the other hand as well, the influences of varying conditions compaired to a constant one as well as the relations between them deductively aim to be the focus of these explorations. With a furthermore respect to the applied permanent long-term load level within the investigations, this entity can generally be described as individual for each test typology, in each case basically depending on the respective connection shear strength F_{vR} gained from the short-term investigations, whereby in more detail the resulting load levels are defined as 30% of the particular variant-specific connection shear strength F_{vR} leading to load levels of 13, 62 and 80 kN for the three test typologies LT-PU-NPS, LT-PU-NO and LT-PU-NPS-NO. The experimental realization of the related load application can moreover conclusively be described by means of specifically developed load application devices based on lever arm constructions with additionally given tensioning fixtures.

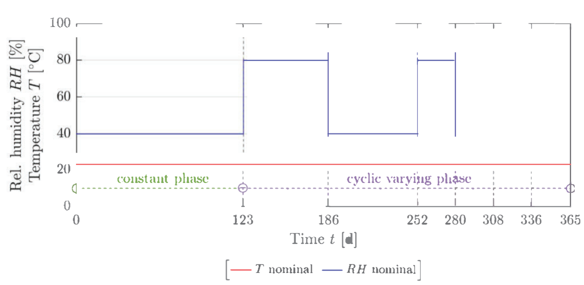

Figure 4. Defined climate conditions within the mid- and large-scaled durability tests

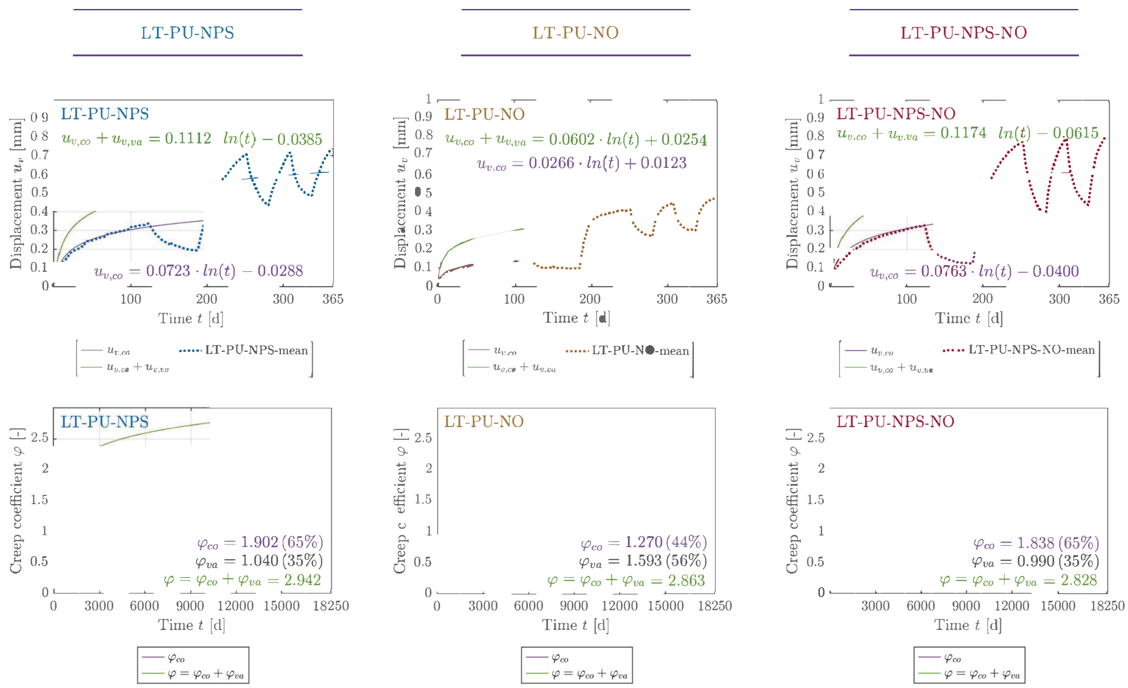

Figure 5. Resulting displacements u_v (top) and creep coefficients φ (bottom) within the mid-scaled durability tests

Based on the described boundary conditions, the related results concerning the occurring displacements u_v as well as the thereof analytically derived creep coefficients φ can be delineated as presented in Figure 5. As seen from this representation, all three main test typologies in general show a for the climatic conditions characteristical displacement behavior based on displacement increases in the dry phases (RH = 40%) and displacement decreases in the humid phases (RH = 80%), whereby a specific markedness furthermore can thereby generally be observed starting with the first dry phase of the cyclic varying phases (cf. Figure 5 top).

A strong impact of the given humidity shifts on the resulting displacement behavior as well as on the thereof derived creep coefficients can basically be concluded. As seen from Figure 5 bottom, this mechanism thus leads to resulting overall creep coefficients φ between 2.828 (LT-PU-NPS-NO) and 2.942 (LT-PU-NPS), whereby the varying ratios of the creep coefficients φ_{va} thereby constitute up to 56% (LT-PU-NO) of the overall creep coefficients φ and consequently up to more than the half of these entities. A significant influence of the occurring climate conditions on the consequential test results can accordingly be once more stated, a consideration of these effects within a related design process moreover conclusively seems to be especially essential.

3.2 MID-SCALED FRACTURE TESTS

The given fracture tests based on the mid-scaled double symmetric push-out test specimen generally aim to describe the consequential time-dependent load-bearing behavior of the investigated shear connector typologies (NPS, NO and NPS-NO) under short-term loads.

In more detail, and as already described inductorily, the named fracture tests thereby are basically conducted after the application of the for the durability tests necessary permanent long-term loads and therefore also after a defined period of time. As within the overall research project mid-scaled fracture tests based on a short-term test setting are equally conducted, the resulting temporal development of certain substancial test related entities thus shall take center stage within the present investigations. Under a more detailed consideration of these entities, they can thereby generally be described as related mechanical properties based on associated load-displacement curves such as the mean slip modulus $K_{ser,mean}$ and the mean connection shear strength $F_{vR,mean}$ on the one hand, as at the same time also occurring damage and failure mechanisms on the other hand as well. With a furthermore present respect to the experimental realization of the given mid-scaled fracture tests, the thereby applied load application process can generally be described based on a contextual procedure according to EN 26891 [3].

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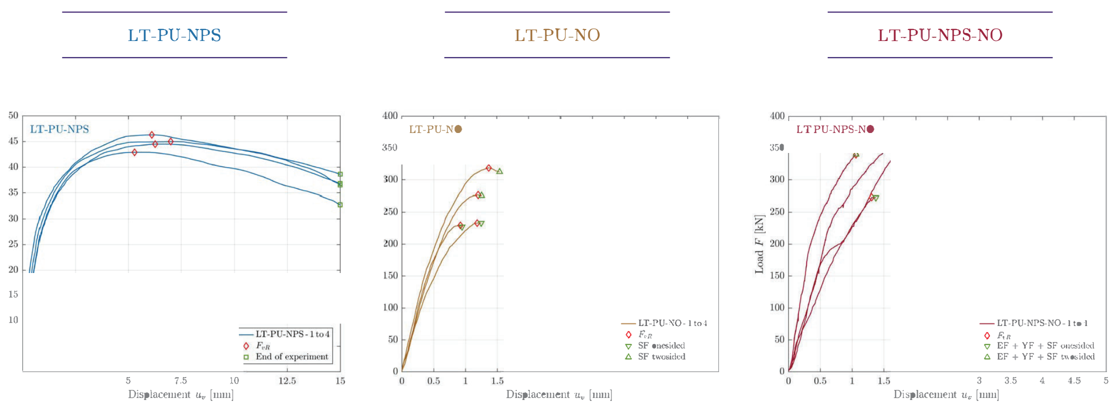

Figure 6. Resulting load-displacement curves with associated damage and failure mechanisms within the mid-scaled fracture tests

Based on these described boundary conditions, the related results of the present investigations can be delineated as presented in Figure 6, as well as can furthermore be derived thereof. As seen from this representation, the three main test typologies thereby generally show a typology-dependent characteristical load-bearing behavior, which moreover can be summarized based on a high ductility and a low load-bearing capacity for the sole nail-based typology (LT-PU-NPS, occurring damage mechanisms embedment failure EF of the wood and yield failure YF of the nails during the test procedure, no direct failure mechanisms) on the one hand, and a low ductility and a high load-bearing capacity for the notch-based typologies (LT-PU-NO and LT-PU-NPS-NO, occurring failure mechanism and additional damage mechanisms shear failure SF of the notches resp. additional embedment failure EF of the wood and yield failure YF of the nails during the test procedure) on the other hand. Under the named detailed consideration of the temporal development of these qualitative entities, they can generally be described as concluding time-independent properties, as the test results based on the short-term test setting basically show equivalent characteristics.

Contrastingly, the furthermore related quantitative test entities (related mechanical properties) show significant time-dependent properties, which moreover can be stated in an partially noticeable increased manner, whereby especially the partial test results of the notch-based typologies (LT-PU-NO and LT-PU-NPS-NO) shall be emphasized in this context. While the sole nail-based typology (LT-PU-NPS) shows rather minor time-dependent changes ($K_{ser,mean}$ -11%, $F_{vR,mean}$ +3%), the notch-based typologies (LT-PU-NO and LT-PU-NPS-NO) show significant time-dependent increases ($K_{ser,mean}$ +11% resp. +18%, $F_{vR,mean}$ +27% resp. +25%), and furthermore a clear influence of the concrete curing within the concrete-based shear connector notch.

3.3 LARGE-SCALED DURABILITY TESTS

Similar to the already described durability tests based on mid-scaled specimen, the according large-scaled equivalent based on four-point flexure beam test specimen generally aims to describe the arisen displacement behavior as well as the thereto related creep coefficients of the investigated shear connector typologies (NPS, NO and NPS-NO) under permanent long-term loads (load duration 365d) and thereby particularly defined climate conditions.

With respect to the named particularly defined climate conditions, these boundary conditions can generally be described as equivalent to the conditions within the mid-scaled explorations, related details thus can basically be taken from section 3.1. Nevertheless, the conceptually resulting aims of the investigations also remain the same, as again occurring displacements u_v and thereto related creep coefficients φ for constant and varying conditions (0-123 d resp. 123-365 d), as well as the detection of the influences of varying conditions compaired to a constant one and the relations between them deductively aim to be the consistent focus of these explorations. With a furthermore respect to the applied permanent long-term load level within the investigations, this entity can generally be described as consistent, whereby in more detail the resulting load level is based on a combination of the deadload and a contextual payload under a quasi-permanent load combination, leading to an overall load q of 3.24 kN/m for the three main test typologies LT-FB-NPS, LT-FB-NO and LT-FB-NPS-NO. The experimental realization of the related load application can thereby moreover conclusively be described by means of specifically manufactored individual weight bodies made out of concrete structures.

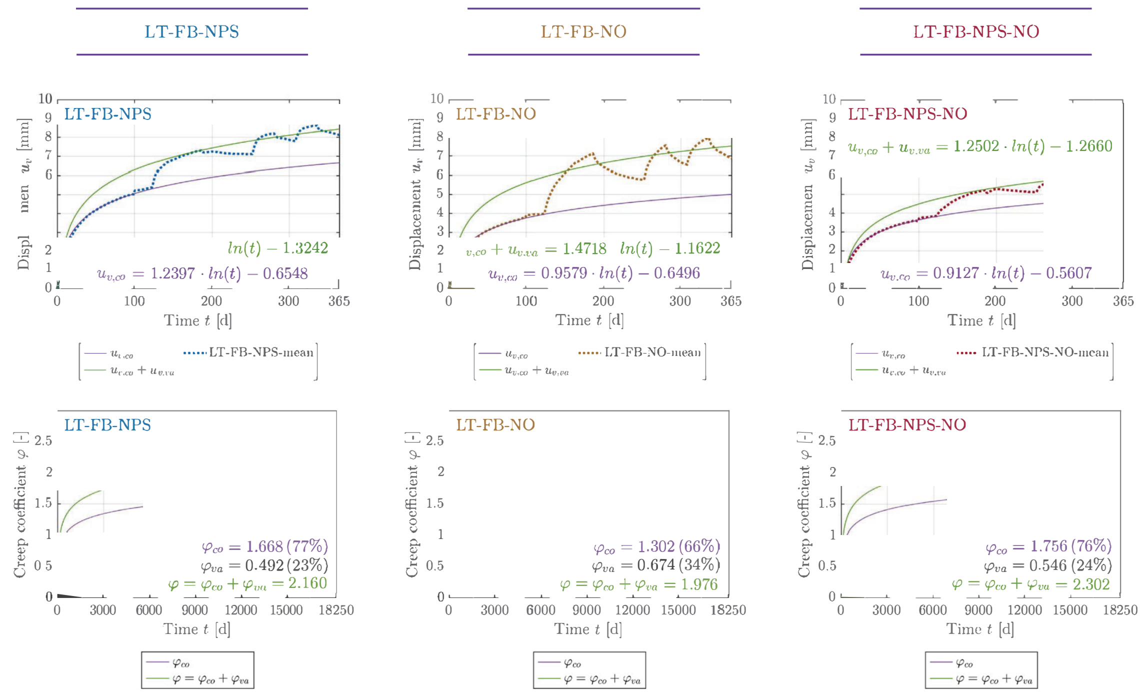

Figure 7. Resulting displacements u_v (top) and creep coefficients φ (bottom) within the large-scaled durability tests

Based on the described boundary conditions, the related results concerning the occurring displacements u_v as well as the thereof analytically derived creep coefficients φ can be delineated as presented in Figure 7. As seen from this representation, all three main test typologies in general show a for the climatic conditions characteristical displacement behavior, contrary to the mid-scaled durability tests the resulting behavior though differs. In this context all typologies show displacement increases not only in the beginning constant dry phase (RH = 40%) but also in the following first humid phase (RH = 80%), a strong impact of the given humidity shifts within this test setting can deductively already be obtained starting with a beginning increase of the relative humidity RH. With a continous focus on the moreover following cyclic varying phases similar influences can generally be observed as the humidity shifts again lead to varying de- and increases (cf. Figure 7 top).

Summarized as a whole, a determined impact of the given humidity shifts on the resulting displacement behavior as well as on the thereof derived creep coefficients can basically be concluded. As seen from Figure 7 bottom, this mechanism thus leads to resulting overall creep coefficients φ between 1.976 (LT-FB-NO) and 2.302 (LT-FB-NPS-NO), whereby the varying ratios of the creep coefficients φ_{va} thereby constitute up to 34% (LT-FB-NO) of the overall creep coefficients φ and consequently up to a third of these entities. A given influence of the occurring climate conditions on the consequential test results can accordingly be once more stated, a consideration of these effects within a related design process moreover conclusively seems to be especially essential again.

3.4 LARGE-SCALED FRACTURE TESTS

Similar to the already described fracture tests based on mid-scaled specimen, the according large-scaled equivalent based on four-point flexure beam test specimen generally aims to describe the consequential time-dependent load-bearing behavior of the investigated shear connector typologies (NPS, NO and NPS-NO) under short-term loads.

In more detail, and as already described for the mid-scaled test setting, the named fracture tests thereby are basically conducted after the application of the for the durability tests necessary permanent long-term loads and therefore also after a defined period of time. As within the overall research project large-scaled fracture tests based on a short-term test setting are equally conducted, the resulting temporal development of certain substancial test related entities thus shall take center stage within the present investigations. Under a more detailed consideration of these entities, they can thereby generally

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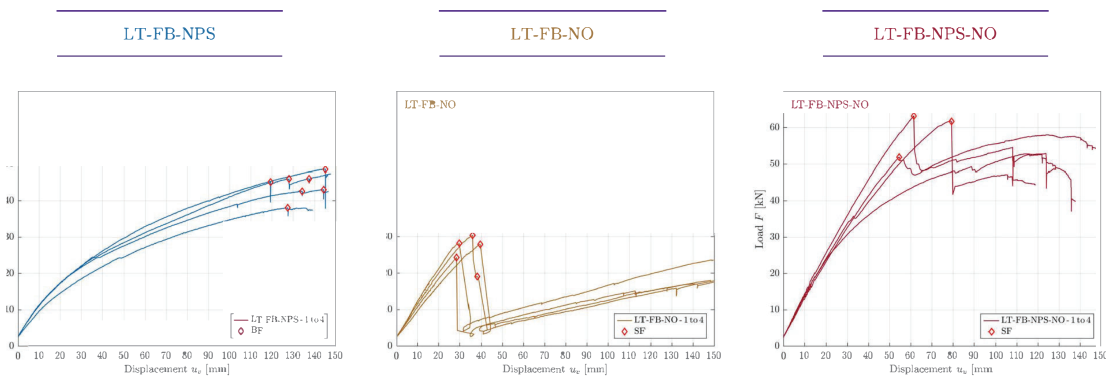

Figure 8. Resulting load-displacement curves with associated damage and failure mechanisms within the large-scaled fracture tests

be described as related mechanical properties based on associated load-displacement curves such as the mean maximum load $F_{max,mean}$ and the mean slope k_{mean} (starting slope in a load-range between 10 and 20 kN) on the one hand, as at the same time also occurring damage and failure mechanisms on the other hand as well. With a furthermore present respect to the experimental realization of the given large-scaled fracture tests, the thereby applied load application process can generally be described based on a contextual procedure according to EN 26891 [3].

Based on these described boundary conditions, the related results of the present investigations can be delineated as presented in Figure 8, as well as can furthermore be derived thereof. As seen from this representation, the three main test typologies thereby generally show, equivalent to the mid-scaled investigations, a typology-dependent characteristical load-bearing behavior, which moreover can be summarized based on a high ductility and a low load-bearing capacity for the sole nail-based typology (LT-FB-NPS, occurring failure mechanism and additional damage mechanisms bending failure BF of the timber beams resp. embedment failure EF of the wood and yield failure YF of the nails and the puzzle strip during the test procedure), a low ductility and also a low load-bearing capacity for the sole notch-based typology (LT-FB-NO, occurring failure mechanism shear failure SF of the notches) and furthermore a high ductility and also a high load-bearing capacity for the nail- and notch-based typology (LT-FB-NPS-NO, occurring failure mechanism and additional damage mechanisms shear failure SF of the notches resp. embedment failure EF of the wood and yield failure YF of the nails and the puzzle strip during the test procedure). Under the named detailed consideration of the temporal development of these qualitative entities, they can generally be described as concluding time-independent properties, as the test results based on the short-term test setting basically show equivalent characteristics.

Contrastingly, and as already seen from the mid-scaled explorations, the furthermore related quantitative test entities (related mechanical properties) show significant time-dependent properties, which moreover can be stated in an partially noticeable increased manner, whereby especially the partial test results of the notch-based typologies (LT-FB-NO and LT-FB-NPS-NO) shall be emphasized in this context. While the sole nail-based typology (LT-FB-NPS) shows rather minor time-dependent changes ($F_{max,mean}$ +4%, k_{mean} +8%), the notch-based typologies (LT-FB-NO and LT-FB-NPS-NO) show significant time-dependent increases ($F_{max,mean}$ +27% resp. +29%, k_{mean} +27% resp. +15%), and furthermore again a clear influence of the concrete curing within the concrete-based shear connector notch as well as the general concrete-based composite layer.

4 – TEST RESULTS IN A LITERARY AND NORMATIVE CONTEXT

Considering the presented contents according to section 3 in a more general manner, a comparative contemplation of those seems reasonable for a further classification. For this reason, the given test results shall be regarded in the context of literary and normative sources, as summarized can be taken from the subsequent Figure 9. Under a specific detailed consideration of this given illustration, it can thereby furthermore be noted, that the named figure moreover contains the resulting comparative contemplations of all conducted investigations according to section 3 and therefore aims to be an initial summary of the successive written subsections.

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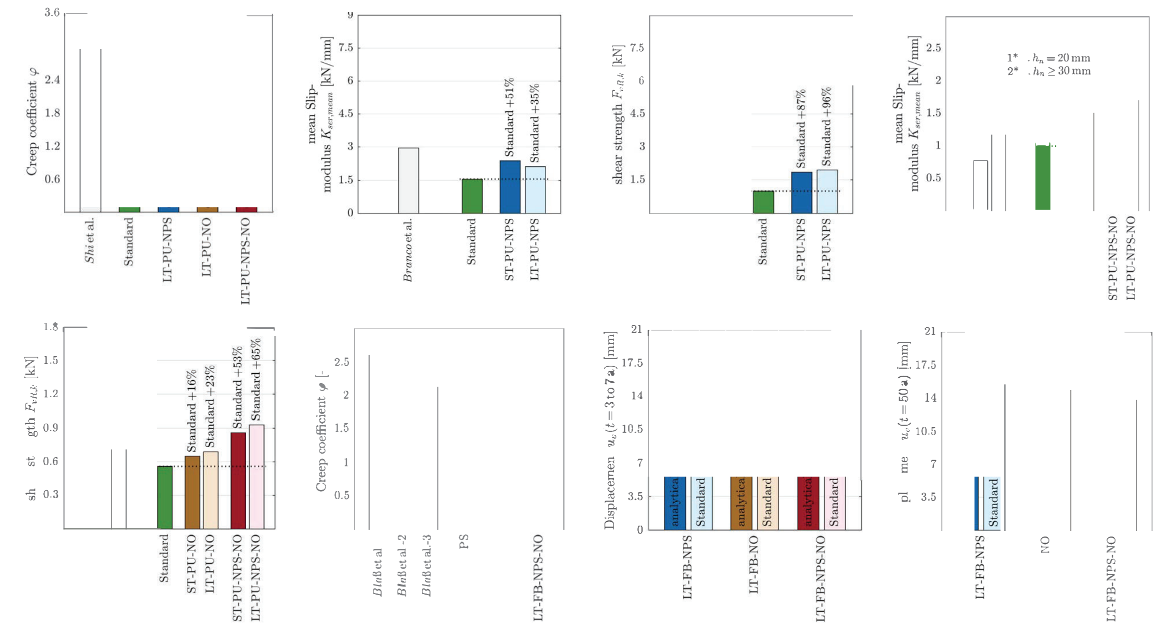

Figure 9. Test results in a literary and normative context | creep coefficients φ of the mid-scaled durability tests (top left), mean slip-moduli $K_{ser,mean}$ of the mid-scaled fracture tests (top center left and top right), characteristic connection shear strengths $F_{vR,k}$ of the mid-scaled fracture tests (top center right and bottom left), creep coefficients φ of the large-scaled durability tests (bottom center left), time-dependent displacements u_v of the large-scaled durability tests (bottom center right and bottom right)

4.1 MID-SCALED DURABILITY TESTS

The comparative contemplations of the mid-scaled durability tests (cf. Figure 9 top left) basically aim to assess the resulting (analytically derived) creep coefficients φ for the life cycle (t = 50 a) of the three main test typologies LT-PU-NPS, LT-PU-NO and LT-PU-NPS-NO in comparison to literary (Shi et al. [4], notch with joint based shear connection) and normative (ONR CEN/TS 19103 [5]) sources. As seen from the associated illustration, the conducted investigations and the literary source thereby generally show similar results, but also exceed the defined standard property simultaneously. Concludingly, the generated test results can generally be classified with respect to the literary source on the one hand, but a recommendation for a modification of the contextual normative content shall furthermore be given on the other hand as well. As seen from (1), the normative determination of the creep coefficient φ for the life cycle (t = 50 a) is formed by a product of a coefficient for the effect of composite action Ψ_{conn} (t = 50 a) and twice the deformation factor k_{def}, whereby Ψ_{conn} (t = 50 a) is by default set to 1.0.

$$\varphi = \Psi_{conn}\,(t = 50\text{ a}) \cdot 2 \cdot k_{def} \qquad (1)$$

This definition however underestimates the experimentally gained creep coefficients φ for the life cycle (t = 50 a), wherefore a modification of this entity to 1.9 is recommended by the authors to meet not only the experimentally gained values but also the literary one.

4.2 MID-SCALED FRACTURE TESTS

The comparative contemplations of the mid-scaled fracture tests (cf. Figure 9 top center left to top right and bottom left) basically aim to assess the resulting time-dependent mechanical properties (mean slip-modulus $K_{ser,mean}$ and characteristic connection shear strength $F_{vR,k}$) of the three main test typologies LT-PU-NPS, LT-PU-NO and LT-PU-NPS-NO in comparison to various literary and normative (ONR CEN/TS 19103 [5] and EN 1995-1-1 [6]) sources. With a given more detailed respect to the named literary sources, it can thereby moreover be differentiated between nail- and notch-based literature, whereby the nail-based content comprises the work of Branco et al. [7] (nail based shear connection) and the notch-based equivalent covers the works of Jiang et al. [8] and Zhang et al. [9] (notch without joint based shear connections). As seen from the associated illustrations, the conducted investigations thereby generally show comparatively reasonable characteristics, not only accompanying the related literary results but also covering the normative requirements (with partially significant safety reserves). Concludingly, the generated test results can generally again be classified with respect to the literary sources on

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the one hand, and can furthermore also be considered as safety related in a normative standardization context on the other hand as well.

4.3 LARGE-SCALED DURABILITY TESTS

The comparative contemplations of the large-scaled durability tests (cf. Figure 9 bottom center left to bottom right) basically aim to assess the resulting (analytically derived) creep coefficients φ for the life cycle (t = 50 a) of the three main test typologies LT-FB-NPS, LT-FB-NO and LT-FB-NPS-NO in comparison to a literary source (Blaß et al. [10], timber-concrete-composite structures with shear connections based on nailplates – Blaß et al.-1, notches with joints – Blaß et al.-2 and notches without joints – Blaß et al.-3) as well as try to evaluate the related standard based calculation procedure for the determination of long-term deflections according to ONR CEN/TS 19103 [5] (decisive points of time t = 3 to 7 a and t = 50 a). As seen from the for the creep coefficients φ associated illustration (cf. Figure 9 bottom center left), the conducted investigations and the literary source thereby generally show similar results, a corresponding classification of the given findings becomes once more possible. Furthermore, this positive assessment, not only comprises the contemplations in a literary context, but also embrace the findings with respect to the normative calculation procedure. As seen from Figure 9 bottom center right to bottom right, the analytically derived displacements u_v for the normatively decisive points of time t = 3 to 7 a and t = 50 a mostly fall below the related calculation based displacements u_v (safety reserves up to 25%) and therefore generally certify the standard based calculation procedure. However, it should moreover also be noted that the calculation based displacements u_v thereby are premised on the test related, modified coefficient for the effect of composite action Ψ_{conn} (t = 50 a) = 1.9 and therefore an contextually increased entity. Concludingly, a given consideration of this relation in the normative calculation procedure is again recommended by the authors, as a non-consideration may lead to underestimated time-dependent displacements u_v.

5 – CONCLUSIONS

Summarized as a whole, the results of experimental and analytical investigations regarding the long-term load-bearing and deflection behavior of an introduced novel solid wood-concrete-composite floor system with combined shear connectors are presented within this paper. For an ideally holistic contemplation, the conducted explorations hence generally comprise mid- and large-scaled investigations, in each case incorporating various nail- and notch-based specimen typologies. Superordinate aim of the given research activities thereby is not only to describe the resulting typology-dependent individual properties of the given specimen configurations, but furthermore also to contextualize these entities based on literary and normative sources. With this in mind, multiple decisive mechanical parameters can be derived and moreover be contrasted in a literary and normative context, leading to a classification of the existing test results as well as to an assessment of the present standard based calculation procedure.

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