LONG-TERM PERFORMANCE TEST OF ECCENTRICALLY LOADED SANDWICH WALL ELEMENTS WITH WOOD-BASED SKINS

EIN LANGZEITVERSUCH ZUR GEBRAUCHSTAUGLICHKEIT EXZENTRISCH BELASTETER SANDWICH-WANDELEMENTE MIT HOLZWERKSTOFFBEPLANKUNGEN

PERFORMANCE A LONG TERME SOUS CHARGE EXCENTREE D'ELEMENTS DE MUR SANDWICH AVEC PEAUX A BASE DE BOIS

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SUMMARY

The paper reports on background and realisation of a test set-up for a long-term full-scale test with wood-based sandwich wall elements. In detail, the investigation is intended to study the time dependant superimposed effects of highly eccentric axial loading and building practise relevant differential climate conditions at the inner and outer surface of exterior walls. The pronounced systematic eccentricity of the vertical load stems from the use of hangers for the fixation of floor beams.

For a realistic assessment of the mentioned issues a full-scale test cabin with adjustable interior climate and rather deliberate ratios of vertical load eccentricities was built-up in sheltered outdoor climate conditions. In future the test set-up will also serve for investigations on effects of different exterior wall claddings and related realistic damage scenarios.

ZUSAMMENFASSUNG

Der Aufsatz berichtet über Hintergründe und Realisierung eines Versuchsaufbaus für eine Langzeituntersuchung in Bauteilgröße an Sandwich-Wandelementen mit Holzwerkstoffbeplankungen. Im einzelnen sollen im Rahmen der Untersuchung die überlagerten, zeitabhängigen Einflüsse einer stark exzentrischen Axialbelastung und baupraktisch relevanter Differenzklimaeinwirkungen auf die innere und äußere Oberfläche von Außenwänden studiert werden. Die ausgeprägte Ausmittigkeit der Auflast resultiert aus der Verwendung von Balkenschuhen zum Anschluß von Deckenträgern.

Im Hinblick auf eine realistische Beurteilung der genannten Einflüsse wurde eine voll-maßstäbliche Testkabine mit einstellbarem Innenklima und weitgehend beliebiger Lastausmittigkeit erstellt. Zukünftig soll der Versuchsaufbau auch zur Beurteilung der Auswirkungen unterschiedlicher Außenwandverkleidungen und diesbezüglich realistischer Beschädigungsszenarios dienen.

RESUME

On décrit les principes et la réalisation d'un système d'essai de longue durée sur des éléments de mur sandwich à base de bois en vraie grandeur. L'objectif était d'étudier les effets associés de la durée du chargement et de l'excentricité de ce chargement correspondant à l'utilisation habituelle en construction de ces murs qui sont soumis à un environnement climatique différent sur les surfaces extérieures et intérieures. L'excentricité importante et systématique des charges verticales provient du système de fixation des poutres supportant le plancher.

Pour un contrôle réaliste des résultats mentionnés, on a construit une pièce en vraie grandeur dans laquelle on peut modifier le climat intérieur ainsi que les rapports d'excentricité des charges verticales. Cette pièce est construite à l'extérieur mais à l'abri. Plus tard, ce système d'essai servira aussi pour des investigations sur différents systèmes d'assemblage du mur extérieur et leur influence sur des scénarios d'endommagements.

KEYWORDS: sandwich wall panel, wood-based skins, vertical load eccentricity, beam-column, differential indoor-outdoor climate, creep, moisture deformations

1. INTRODUCTION

In German building construction the use of sandwich panels with skins made of wood-based materials such as plywood, particleboard or OSB started in the second half of the eighties. The first and until today sole German general building approval for an alike sandwich panel to be used for roofs and walls, Z-9.1-315, was issued in 1995. In the past years the constructions according to approval Z-9.1-315, about 200 houses, have forwarded a very satisfactory field experience.

The use of sandwich elements with wood-based skins as wall elements, especially for exterior walls however not directly exposed to weathering, necessitates awareness of the following potential areas of problems, being

- eccentricity of vertical load,
- compression and shear creep of skin resp. core materials,
- hygroscopicity of wood-based materials,
- damage susceptibility of wood-based skins in case of extensive direct liquid moisture contact.

Unavoidable eccentricities due to imperfections (initial curvature and building site irregularities) are of minor importance in general, nevertheless have to be considered in design. A considerably more serious issue evolves from large systematic eccentricities induced for instance by the use of hangers. In case the corresponding eccentricity moments are not counteracted by other constructive means, the wall is subject to long-term bending moments additional to long-term compression. This has to be seen in view of the pronounced creep behaviour of both, wood-based skin and solid foam core materials. The skin material reveals mechano-sorptive compression creep and the core material shows temperature dependant shear creep under the effect of the bending moment induced shear stresses (the effect of normal stresses in the core material can be assumed negligible).

Wood-based panels are highly hygroscopic. This results, especially in winter conditions with fairly high relative humidity of the air, in a moisture increase of the exterior skin. Contrary thereto, the moisture content of the interior skin, facing to the inside of the house, remains roughly constant or decreases according to specific heating and ventilation parameters. These differences in moisture evolutions and hereby induced strains result in a moisture driven bow of the wall element convexly to the outside which adds in some way to the bow from the load eccentricity.

Finally, sandwich elements employed for exterior, however systematically not directly weathered walls, sometimes provoke critical questions related to the problems assumed to occur in case of accidental direct liquid water contact of the skins. This scenario is bound to damaged facade systems enabling for instance water access in case of heavy rain/wind combinations.

The present version of the sandwich building approval Z-9.1-315 takes care of all above mentioned areas of potential problems by conservative prescriptions. In the frame of recently started investigations at FMPA – Otto-Graf-Institute – the basis of these prescriptions are studied in more detail as it is intended to use hangers for floor systems and a variety of facade systems. As the interacting effects of load eccentricity, climate deformations and occasional direct weathering were regarded too complex to be handled purely theoretically, it was decided that the theoretical considerations should be calibrated/verified by a full-scale experimental test set-up. This paper gives a description of the realised test cabin and relevant background informations.

2. DETAILS OF THE SANDWICH BUILT-UP

The regarded sandwich construction consists of panels with a 3layered symmetric cross-section (Fig. 1a). The interior core consists of expanded solid polyurethane foam and the two outer skins are made of particle board. The thicknesses of the core and of the skins c, t_D, are 110 and 16 mm, respectively. The glued connection between core and skins is achieved during the foam expansion process where the expanding self-adhering foam forms a rigid bond to the skins. The width of the elements is 1250 mm; the standard production length of the elements is between 6–9 m, whereof individual element lengths are cut.

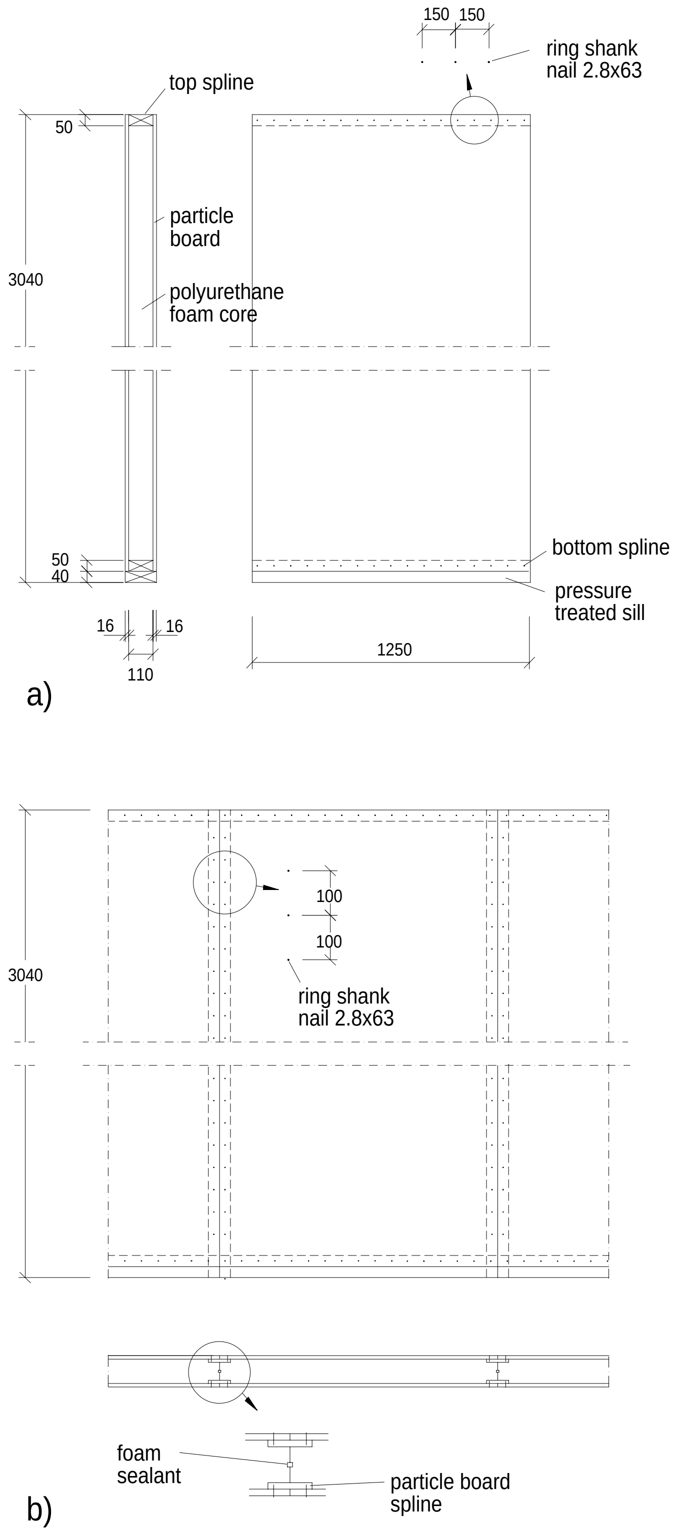

Fig. 1a, b. *Built-up and dimensions of sandwich wall element and respective connection of adjacent elements acc. to building approval Z-9.1-315 (presently panel height is restricted to 2,75 m)*

The length of a standard wall element is 2,5–3 m. The final wall element contains at the top and bottom edge lumber splines with cross-sections of 50 x 110 mm which are fitted into routed grooves and fixed to the skins by nailing at the building site.

At the building site the bottom beam is first bolted altogether with an underneath pressure treated sill to the foundation; a similar procedure exists for the wall attachments of the second floor. The lateral connection of adjacent standard wall elements is performed by means of continuous bottom and top splines; further, the vertical edges of adjacent elements are joined by means of a tongue and groove system as shown in Fig. 1b.

Amongst many specific items regulated in the approval two issues are important in conjunction with the presented project. First, the eccentricity e of the total vertical force is restricted to a rather small quantity of 1/6 of the panel thickness D what prohibits implicitly in most cases the use of hangers for attachment of floor beams. Second, exterior walls must be covered with a specially approved heat and moisture retention compound system which is primarily meant to prevent direct accidental water access to the exterior skin.

3. INVESTIGATED LOADING SITUATION

It was decided to study the effect of pronounced load eccentricity on the time and climate dependant long term performance of the discussed sandwich construction with a very unfavourable, however not unrealistic scenario with respect to magnitude of loads and eccentricity. The investigated loading situation is related somehow to a 1 ½ storey house with a rather small centric vertical load q_1 = 2,5 kN/m from the roof and a roughly 5times higher eccentric load q_2 = 12 kN/m with an eccentricity of (D/2) + e_2, see below, resulting from the floor fixation by hangers. The resultant eccentricity e of the vertical force q = 14,5 kN/m (see Figs. 2a, b)

$$e = \frac{q_2(D/2 + e_2)}{q_1 + q_2} = \frac{M_e}{q} \tag{1}$$

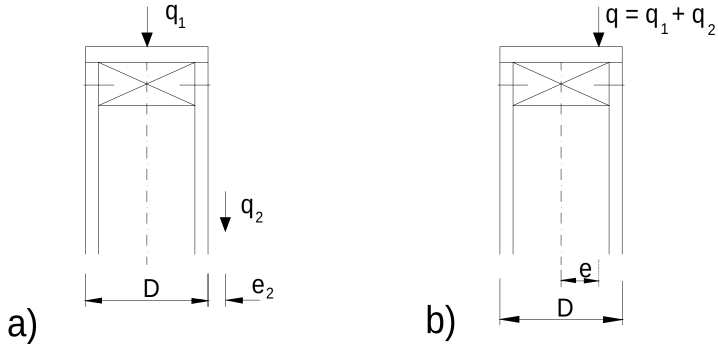

Fig. 2a, b. *Eccentricity definitions of partial and total vertical loads*

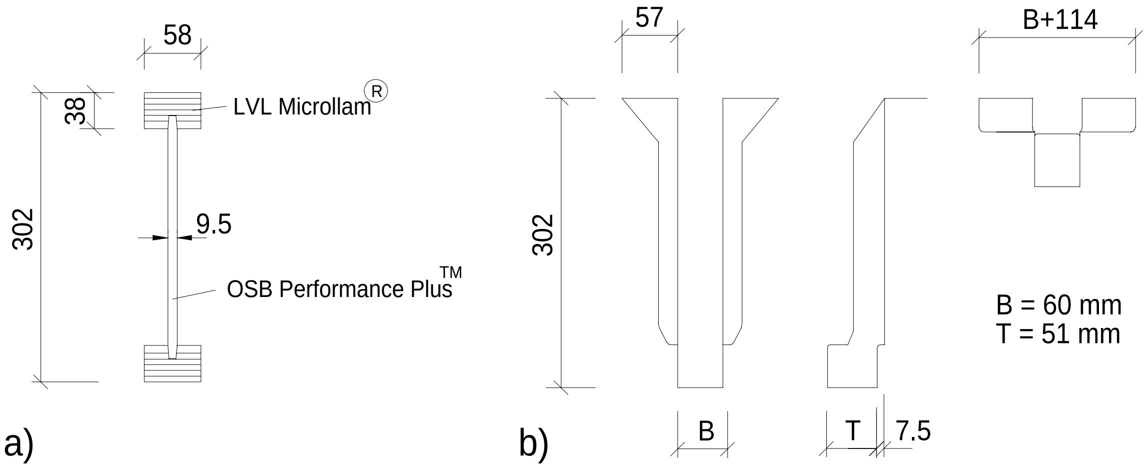

Fig. 3a, b. *Employed I-beams and hangers*

a) I-beam TJI®/PRO™350, approval Z-9.1-277

b) hanger ITT3511.88, approval Z-9.1-302

depends to some extent on the specifically chosen hanger type, defining eccentricity dimension e_2. Of course, hanger type and size depend on the employed I-beam. For the specific load configuration a TJI® floor I-beam of type TJI®/PRO™350, conforming to general building approval Z-9.1-277, company Trus Joist MacMillan, Boise, USA, was used (Fig. 3a). As suitable hanger for the given beam-load-configuration the hanger type ITT 3511.88 according to general building approval Z-9.1-302, company BULLDOG-SIMPSON, Syke, was chosen (Fig. 3b). The permissible vertical load of the hanger is 5,4 kN (I-beam without reinforced web: V = 6,08 kN). Assuming the bearing resultant of the I-beam roughly at the center of the hanger shoe we obtain eccentricity e_2 =T/2+7,5 mm = 33 mm and hence e = D/1,65 = 86 mm acc. to eq. (1). The stated eccentricity is about 3,6times higher than the presently approved value. The eccentricity ratio, usually considered in beam column analysis, is extreme. Employing as core radius s according to sandwich membrane theory s = Z/A = d/2 = 63 mm (where Z and A are section modulus and area of the skins, d = D - t_s: distance of skin centroids, t_s = skin thickness) we obtain for the eccentricity ratio ε = e/s = 1,37! The induced eccentricity moment M_e = 1,247 kNm/m represents 62% of the permissible moment. The centroid stress of the bending compression skin is

$$\sigma_{S,C} = \frac{q}{2t_s} + \frac{M_e}{t_s} = 0{,}45 + 0{,}62 = 1{,}07 \ \text{MN/m}^2$$

whereas permissible short term skin compression stress is 2,75 MN/m^2.

The short term deflection of the posed beam-column situation can be evaluated from solutions given in [Aicher, 1989]. The bow due to uneven cross-sectional moisture distribution is given in [Aicher, 1987]. So, employing creep limit values for the skin MOE and core shear modulus, and setting plausible moisture contents of the skins [Drewes, 1985], the range of the limit deformations can be assessed. This and a transient analysis of the problem is revealed in a seperate paper.

4. TEST SET-UP

4.1 Test cabin

The test cabin was built-up in a four-sided widely open test hall of Timber Division at FMPA – Otto-Graf-Institute –, providing sheltered (no rain access) outdoor climate conditions, which in terms of Eurocode 5: Design of timber structures, are referred to as service class 2 conditions. Side and top views of the test cabin are shown in Figs. 4 and 5.

The actual test walls 1 and 2, each consisting of two standard panels of 1,25 m width and 3 m height are loaded via six equally spaced (a = 0,42 m) single span (ℓ = 2,5 m) I-beams fixed to the test walls by hangers. The side walls 3 and 4 (No 3 containing a door) are mounted completely detached from the load bearing walls 1 and 2. The roof element serving for climate relevant closure of the cabin as well as for the transfer of the centrical vertical loads is supported exclusively by the walls 1 and 2.

All spaces between the load bearing and the not loaded walls and those between walls and roof element are completely filled with in-situ foamed polyurethane. Further all spaces are covered from the outside by a diffusion tight sealing tape consisting of an interior self-adhering bituminous layer and an aluminium foil on the outside. In order to reduce heat losses and possible condensation, the cabin was provided with a 70 mm thick floor layer made of LVL where again all spaces at the periphery were completely filled by in-situ applied foam.

The I-beams and hence the hangers were loaded by four dead load assemblies delivering 14,5 kN each, in such a way that the force of one dead weight assembly was equally distributed on the top chords of 3 I-beams via six points (see Fig.5). Figure 6 shows the one-sided open test cabin after load application to the I-beams; Fig. 7 shows a top view – before installment of the roof element – and features the load distribution to the top chords of the I-beams. The roof element was placed via intermediate teflon sheets on a LVL distance beam necessary to bridge the height of the dead weight fixation (see Figs. 4 and 7). After the complete insulation work was done, the centrical vertical load, necessary additional to the weight of the roof element, was placed via steel plates at the edges of the roof element at mid-thickness of the wall elements.

Figure 8 shows the completely loaded test cabin revealing the moisture diffusion sealing tapes and the load plates on the upper side of the roof element.

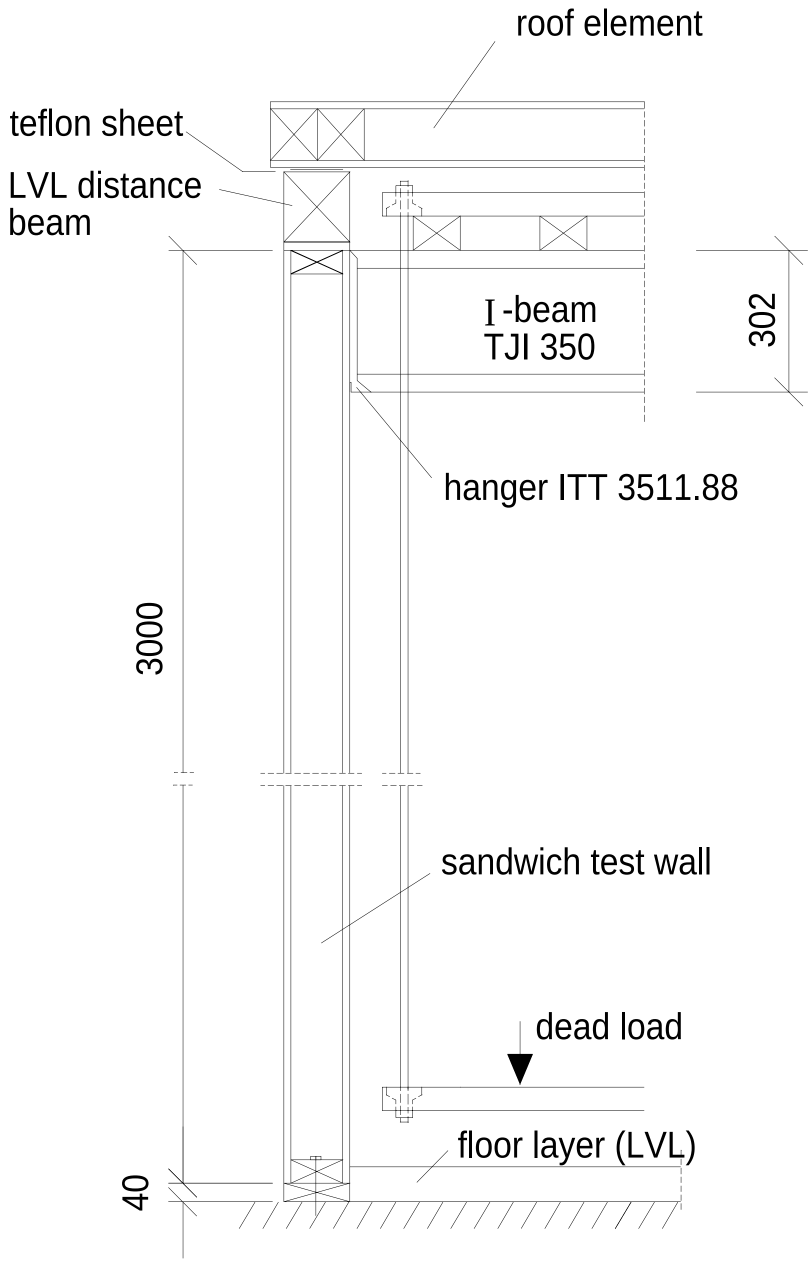

Fig. 4. *Side view of the test cabin*

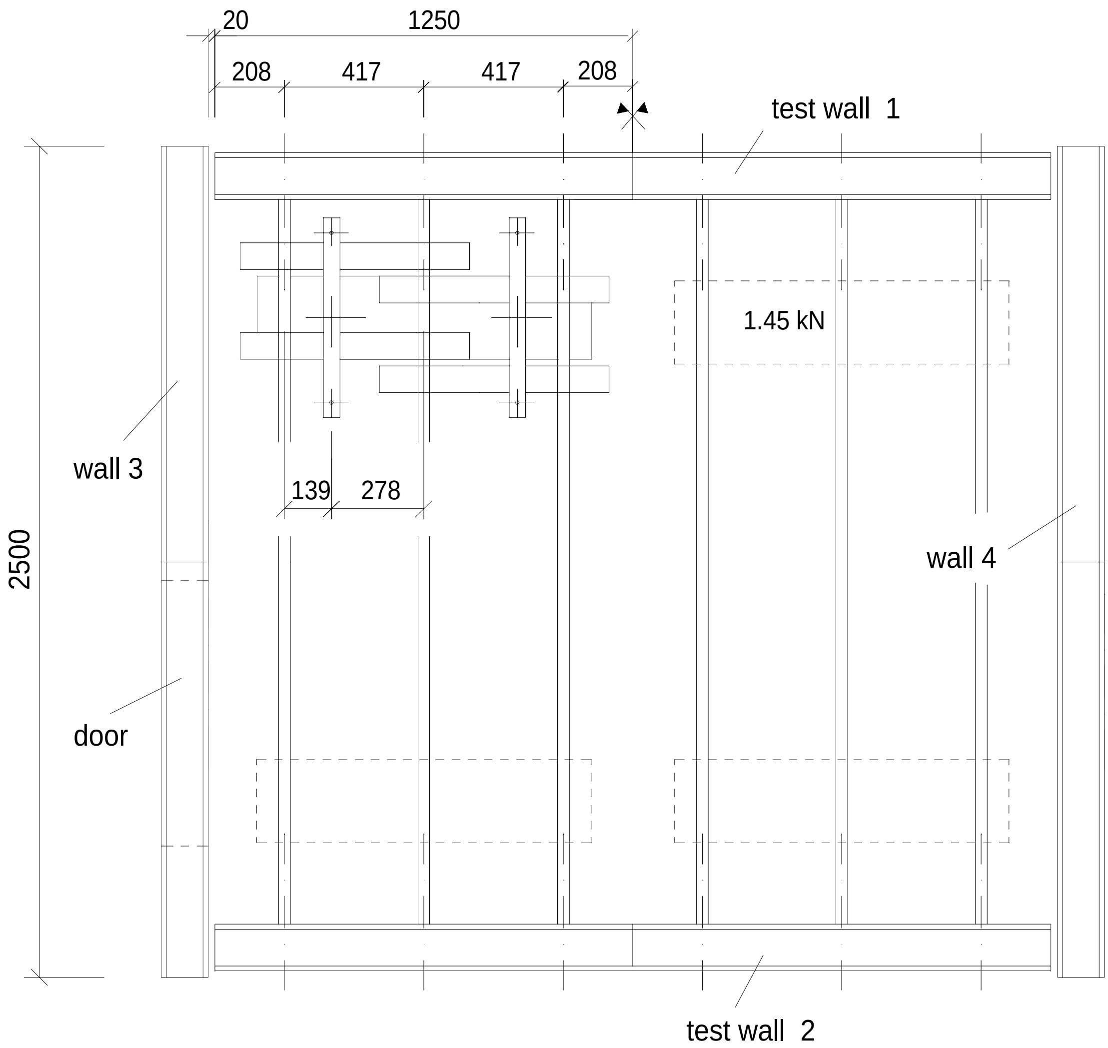

Fig. 5. *Top view of the test cabin without roof element including load application at the top chords of the I-beams; the roof element is not indicated*

4.2 Indoor climate control

The indoor climate target values, equal for winter and summer period were chosen according to the building physics design values in DIN 4108 as 20 °C and 50 % relative humidity (RH). The constant temperature in autumn, winter and spring time is realised with an electric oven controlled by a temperature sensor. The chosen system provides a constant temperature of 20 ± 0,3 °C. Before summer season a cooling device will be employed, too. The relative humidity is controlled by means of satured salt solutions. At the time Natriumdichromat $Na_2Cr_2O_7$ is used, delivering a rather constant value of 55–57 % RH. By employment of an additional solution of Kaliumcarbonat K_2CO_3, delivering solely 47 % RH, the target value of 50 % RH should be closely matched.

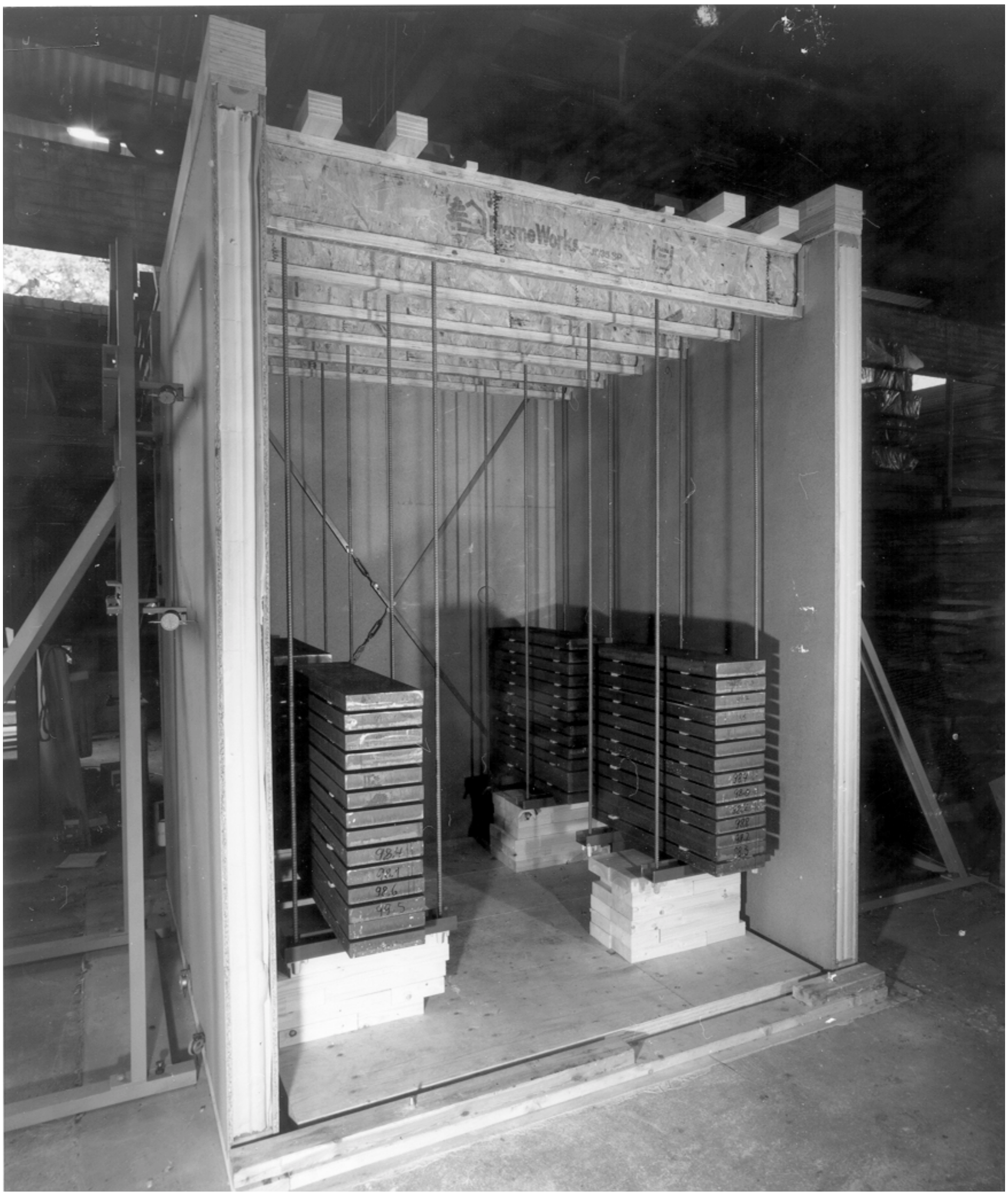

Fig. 6. *Photograph of the one-sided open test cabin after load application to the I-beams*

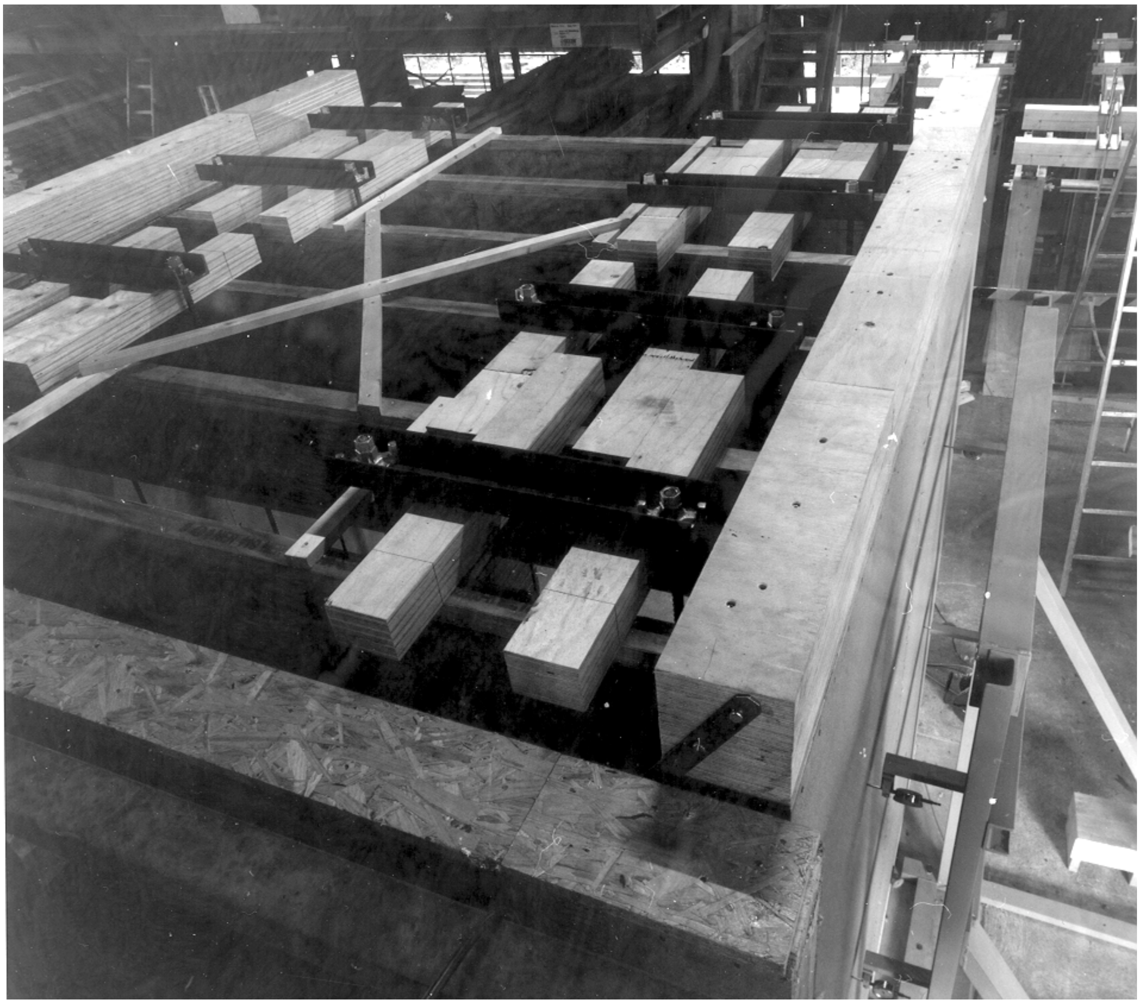

Fig. 7. *Top view of the test cabin before installment of the roof element*

4.3 Deformation, climate and moisture recording

The bending deformation of both test walls, each consisting of two panels, are measured at all 4 panels of walls 1 and 2 at two points along mid-width, one at mid-length and one at quarter length distance from the top end. It was decided to rely on mechanical dial gauges with visual reading as the tests shall last for some years throughout possibly very unfavourable climate conditions in winter. The dial gauges are mounted on very stiff frames. Additionally the vertical compression deformation of the bottom sill is measured. Figure 8 reveals for wall No 1 the deformation recording set-up.

Temperature and relative humidity of indoor and outdoor climate are registered continuously by capacitive humidity sensors and electrical resistance temperature sensors with data storage on a PC. Mechanically driven thermographs are installed additionally.

The moisture evolutions of the skin and core materials are monitored in two ways. In order to obtain the average moisture content of the materials small plates of particle board resp. cubes of solid foam are stored outside and inside of the cabin and weighed at regular intervals. In order to obtain insight into the actual moisture content of the wall cross-section subject to a heat and diffusion gradient, two cylindrical bore hole specimens (∅ 100 mm) were drilled out of the unloaded wall No 4. The bore hole specimens are carefully cut, along the glued interfaces, into the two skins and the core material; reassembled but no glued and diffusion tight sealed at the cylinder surface, the assembly fits tight into the original hole; the cleavages at the skin

5. CONCLUDING REMARKS

The first measurment data of deformations at all four loaded elements reveal that the realised built-up and loading of the test cabin is very symmetric. The initial deflections of the elements conform to expected values. The effect of creep and moisture of the recently started tests is qualitatively as anticipated.

Quantitative test and simulation results will be reported in future.

It should be stated that all non-standardised components of the test cabin, i.e. the I-beams, the hangers and the sandwich panels received their respective general building approval, issued by Deutsches Institut für Bautechnik, Berlin, on the basis of tests and expertises by Timber Division of Otto-Graf-Institute.

Fig. 8. *Photograph of the completely closed test cabin with diffusion tight sealing tapes along the edges*

REFERENCES

AICHER, S.: *Zum Einfluß des Randabschlusses bei Sandwichelementen unter Feuchtigkeits- und Temperaturbeanspruchung.* Bauingenieur 62, pp. 263-272, (1987)

AICHER, S.: *Berechnung und Bemessung axial gedrückter Sandwich-Wandscheiben mit Holzwerkstoffbeplankungen.* Bautechnik 66, pp. 159–168, (1989)

Z-9.1-315: *Allgemeine bauaufsichtliche Zulassung "Sandwichelemente mit Beplankungen aus Flachpreßplatten und einem Polyurethan-Hartschaumkern als Wand- und Dachbauteile".* Antragsteller: TEK Dach und Wand Bauelemente GmbH, Klosterfelde

DREWES, H.: *Ausgleichsfeuchten von Holzwerkstoffen für das Bauwesen.* Holz Roh-Werkstoff 43, pp. 97–163, (1985)

Z-9.1-302: *Allgemeine bauaufsichtliche Zulassung "Simpson-HWS-Formteile als Holzverbindungsmittel".* Antragsteller: BULLDOG-SIMPSON GMBH, SYKE

Z-9.1-277: *TJI-Balken und -Stiele mit Doppel-T-Profil mit Gurten aus Microllam® LVL und eingeleimtem Steg aus OSB-Flachpreßplatten.* Antragsteller: Trus Joist MacMillan, Boise, Idaho, USA