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New method for timber-frame houses based on integrated stud-theory

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ABSTRACT

Load-bearing capacity of studs of timber-frame houses can be greatly improved if the contribution of wall-covering material and insulation is also taken into account (scheme C in figure 1). This principle is use to design a new construction principle for industrially produced dwellings [Moonen 1998]. In this paper the results are presented from experiments to prove the validity of this scheme. In total 16 wall elements with slimline studs and a very thin skin glued to the stud and insulation are tested under compression. The experiments are intended to investigate the minimum thickness of the skin to force the stud to buckle perpendicular to the wall plane. Therefore the slenderness of the studs and also the thickness of the skin is varied in the test specimen.

The composition of the tested wall elements is predetermined by commercial available elements (figure 2 and table 1) because the dimensions of these panels suited well in the scope of the research. And by using ready-made panels we were able to concentrate on the structural behavior of the panels instead of production issues of glued surfaces. These panels are in the Netherlands common used as roof boarding with integrated insulation.

The experiments confirmed the chosen scheme and indicated that a 3 mm ($^1/_8$ inch) skin is amply sufficient to support studs with a slenderness-ratio of 1:6 (width : height), forcing the stud to buckle across the strongest axis. The thin skin is also able to transfer 10 - 50% of the load to the adjacent stud. The test-results have good prospects to develop new elements for timber frame houses. The elements to be developed will lead up to a reduction of structural materials and an improvement of thermal insulation and are expressly tailored to industrial production with improved working conditions.

MATERIALS

The tested panels are manufactured in a standard production facility for roofing elements. Timber planks, European Spruce Strength class K17 according to NEN 6760, are joined lengthwise by means of finger joints to produce a continuous plank. The continuous plank is planed and cut off with a short extra length.

Table 1 Dimensions of test specimen, according to supplier specifications

Code:	number of specimen	core: insulation EPS15, thickness	studs: 2 longitudinal planks with cross-section: (European Spruce)	skin: chipboard at both sides with thickness	Lath	dimensions element (width * thickness * height)
S-PLS 97 8/8	4	97 mm $\approx 3\ ^7/_8$ "	22x97 mm^2 $\approx\ ^7/_8 * 3\ ^7/_8$ sq. inch	8 mm $^7/_8$ "	20x30 mm^2 $^6/_8 * 1\ ^1/_8$ sq. inch	1010*133x2850 mm^3 39 $^3/_4$*5 $^1/_4$ sq. inch x 9,4 ft
S-PLS 99 3/3	4	99 mm $\approx 3\ ^7/_8$ "	22x99 mm^2 $\approx\ ^7/_8 * 3\ ^7/_8$ sq. inch	3 mm $^1/_8$ "	20x30 mm^2 $^6/_8 * 1\ ^1/_8$ sq. inch	1010*125x2850 mm^3 39 $^3/_4$*5 sq. inch x 9,4 ft
S-PLS 120 8/8	4	120 mm $\approx 4\ ^3/_4$ "	22x120 mm^2 $\approx\ ^7/_8 * 4\ ^3/_4$ sq. inch	8 mm $^7/_8$ "	20x30 mm^2 $^6/_8 * 1\ ^1/_8$ sq. inch	1010*156x2850 mm^3 39 $^3/_4$*6 $^1/_8$ sq. inch x 9,4 ft
S-PLS 120 3/3	4	120 mm $\approx 4\ ^3/_4$ "	22x120 mm^2 $\approx\ ^7/_8 * 4\ ^3/_4$ sq. inch	3 mm $^1/_8$ "	20x30 mm^2 $^6/_8 * 1\ ^1/_8$ sq. inch	1010*146x2850 mm^3 39 $^3/_4$*5 $^3/_4$ sq. inch x 9,4 ft

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The EPS core (expanded polystyrene) is cut out from a block of 1250x1040x8080 mm^3 (4x3½x26½ ft^3 - w*t*l) without interior joints. Next in the production process two planks are placed at both sides of the EPS core. Two chipboard sheets, quality V-313 according to DIN 68783, are put in place after applying adhesive to the top and bottom of the EPS and planks. Several elements are piled up and pressure is applied. When the adhesive is hardened and the pressure is released, two laths are nailed to the planks. In the next production phase the exact width of the elements is sawn and the required profile for roofing elements at both longitudinal sides is cut.

The roofing elements used for testing are produce with a length of 6,0 meter (19,7 ft). Each element is sawn into two panels with a length of 2,85 meter (9,4 ft). In figure 5 eight of the tested panels are shown. This photo shows that the thickness of insulation, skin and height of the timber planks differs. But also the thickness of the timber planks varies although the supplier specification shows a uniform thickness. The minimum measured thickness is 15 mm, the maximum measured thickness is 26 mm where the specified thickness is 22 mm. The production process of the roofing elements causes this difference, as the elements are not properly centered when the profile in both longitudinal sides is cut. Due to this the cut off part of both planks is not the same. This inaccuracy does not affect the test results, because all data is worked out with the exact measured dimensions. The variation in thickness is in fact a plus for the research, since a wider range of slenderness of the studs gives more information about the required buckling support of the thin skin.
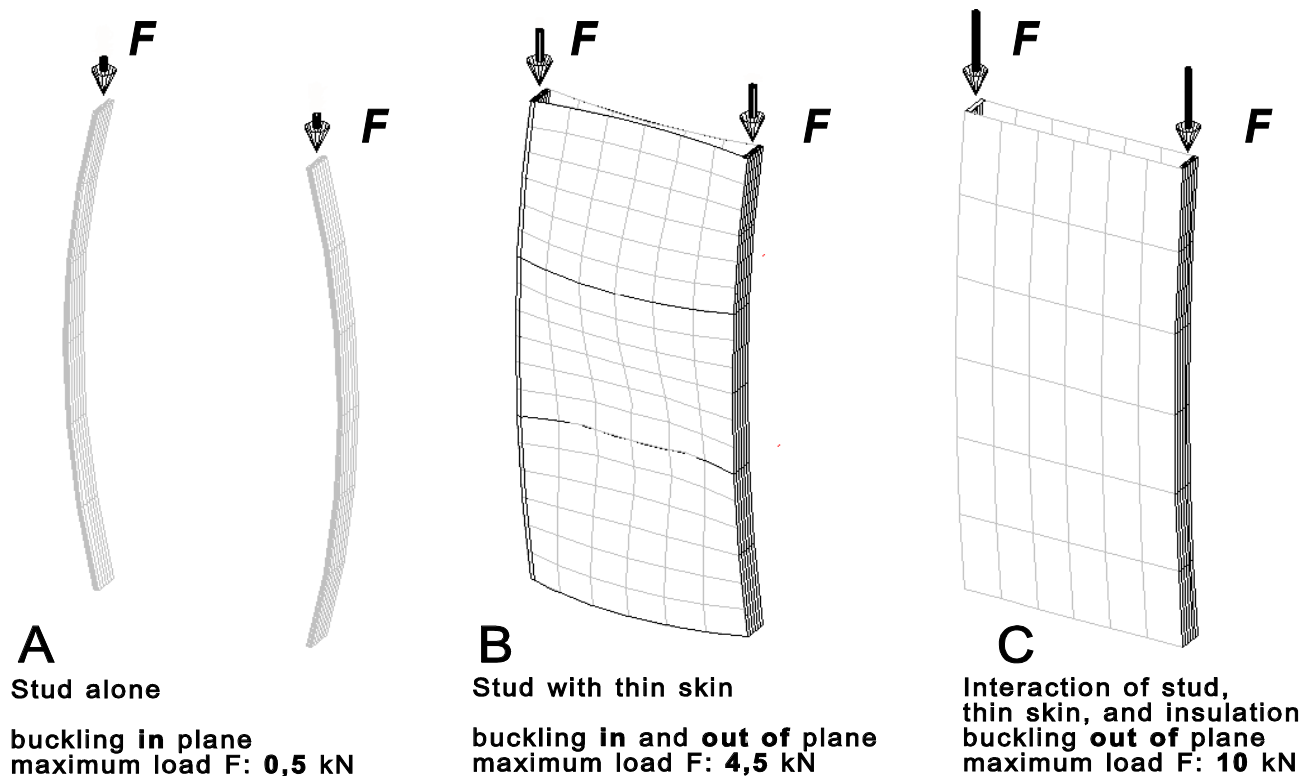
Structural schemes

A

Stud alone

buckling in plane
maximum load F: 0,5 kN

B

Stud with thin skin

buckling in and out of plane
maximum load F: 4,5 kN

C

Interaction of stud,
thin skin, and insulation
buckling out of plane
maximum load F: 10 kN

figure 1 Three different structural schemes for studs in timber frame houses:

In (**A**) the common used scheme for timber frame houses is given, in which the stud is considered a single structural member. Buckling is depending on the weakest axis of the stud. For a stud of 22x99 mm^2 [$^7/_8$ x 3 $^7/_8$ sq. inch], the maximum compression force is approximately 0,5 kN [120 lb.] per stud. But if sheet material -- in our case a very thin skin glued to the studs -- is taken into consideration (scheme **B**), the in plane buckling length is reduced, resulting in a maximum compression force of approximately 4,5 kN [1.030 lb.] on the same stud. In scheme **C** the insulation --a rigid plate of EPS glued to the thin sheet-- is also taken into account. Because of the rigid insulation, the thin skin can not deflect, forcing the stud to buckle across the strongest axis. The load bearing capacity is increased to approximately 10 kN [2.220 lb.] per stud, 20 times the load bearing capacity of a common used scheme, without adding extra material. (The calculation results are design values of the panels used in the experiments, according to the Eurocode EC5 with a buckling length of 2,85 m [9,4 ft]
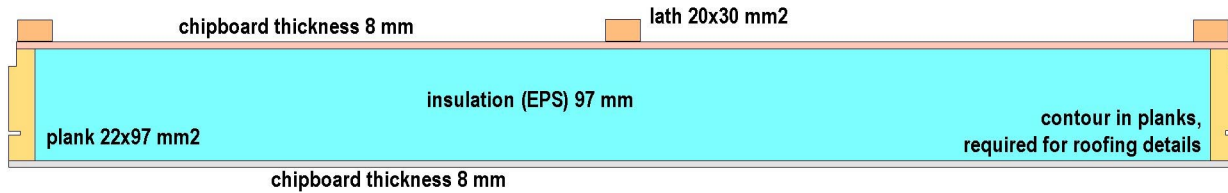
figure 2 Cross-section with nominal specifications of test specimen S-PLS 97 8/8. This element is normally used as a roofing element. In this research all roofing elements are loaded under compression parallel with the two planks

TEST SETUP

16 wall panels are <u>horizontally</u> tested. Figure 3 shows the test setup, seen from above. Two 200 kN hydraulic jacks are used to apply the compression force. The two hydraulic jacks are linked together to ensure the same load. At each corner a 150 kN load cell is used (KMD0, KMD1, KMD2 and KMD3). The load is transferred via a steel girder HE150. Underneath the steel girder roller bearings are applied to minimize the friction with the underground.

In figure 3 and 4 the locations of the deflection measurements are given. For each plank the longitudinal deflection at the beginning (LVDT 6 or LVDT 4) and the end (SM 7 or SM 6), the deflection perpendicular to the wall plane at mid span (LVDT 7 or LVDT 5) and the deflection in the wall plane at three locations (SM 3 + SM 4 + SM 5 or SM 0 + SM 1 + SM 2) are measured. With these measurements the shortening can be calculated being the difference of SM 6 – LVDT 4 (plank on the right) or the difference of SM 7 – LVDT 6 (plank on the left). The other deflection measurements are used to decide whether buckling in the wall plane (measured with SM 0 up to SM 5) or perpendicular to the wall plane (measured with LVDT 5 or 7) is causing failure.
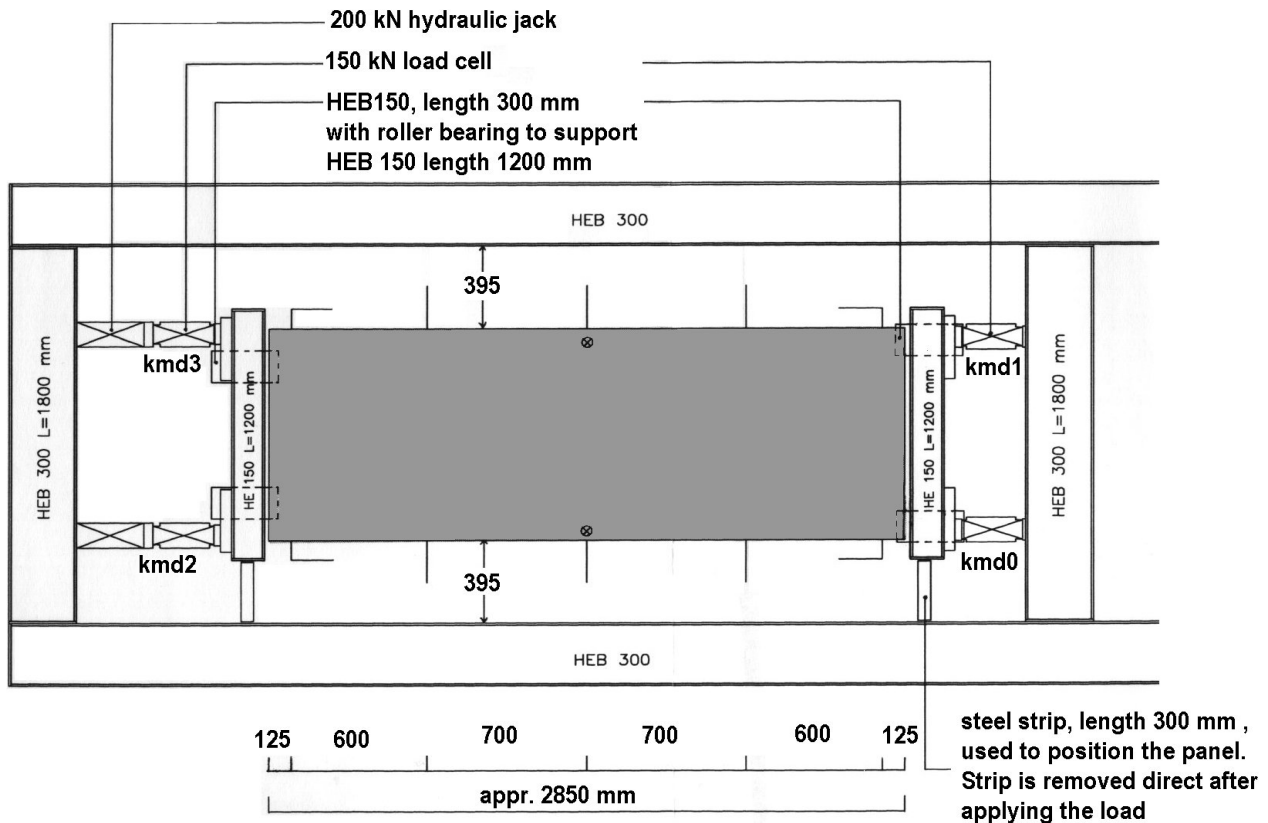

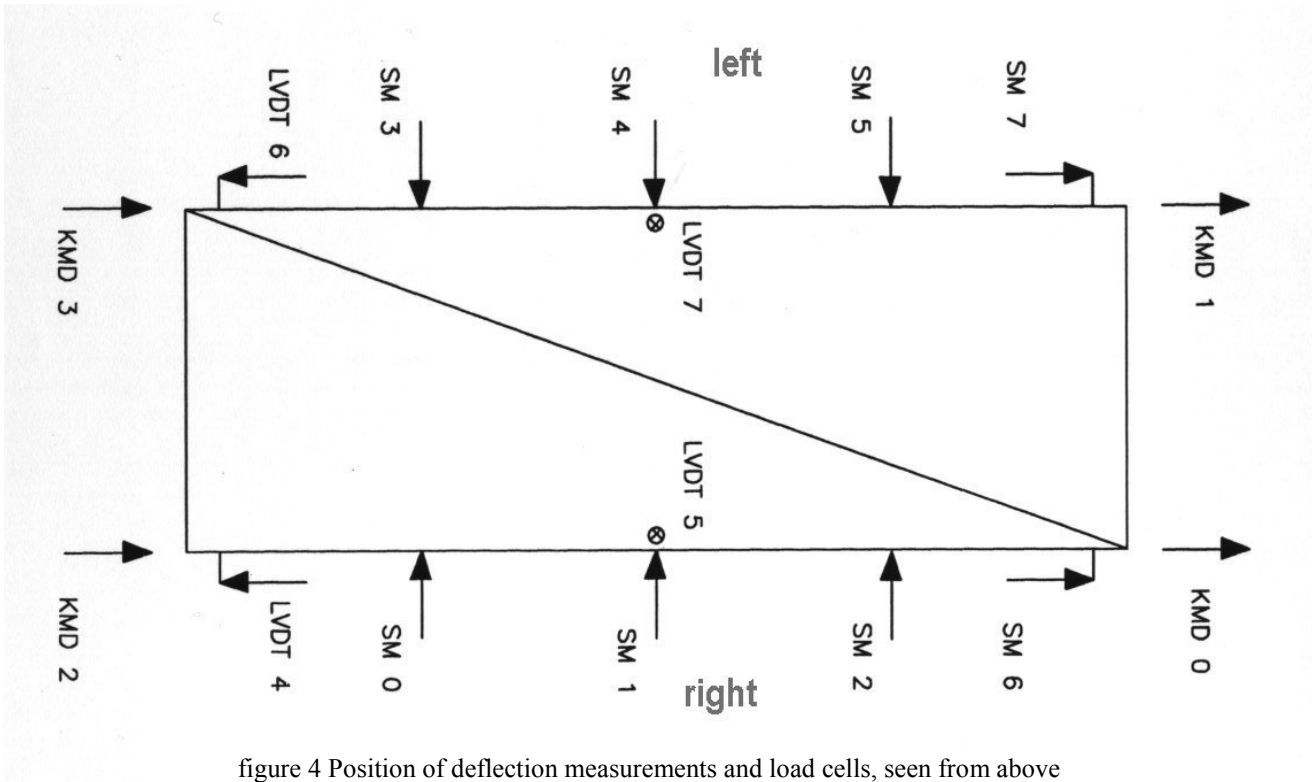figure 3 Test frame for wall element under compression, seen from above

figure 4 Position of deflection measurements and load cells, seen from above

TEST RESULTS

The characteristics of the four test-series with each four specimen is given in tabel 2 and figures 7 to 10. In these graphs the calculated buckling load is also reproduced. The calculated buckling load is based on the Euro-code EC-5. The ultimate compression strength in tabel 2 is calculated with a characteristic strength of 15,9 N/mm^2, a mean strength of 25,6 N/mm^2 and also with a 5% maximum strength of 36.7 N/mm^2[Linden M.L.R. v.d. 1992]. The buckling load calculated with the mean value is also represented in figures 7 to 10.

The maximum buckling load of both planks in the test specimen is derived from the deflection - load measurements. The plank is considered failed when there is a strong discontinuity in the ratio increase of axial load / increase of deflection perpendicular to the wall plane or when the 1/250 of the length of the panel. These buckl

The buckling load and maximum load of all surprising, since the load bearing capacity o section of the thin skin of chipboard increase

figure 5 8 test panels. The thickness of the core is 94 or 117 mm ($3^3/_4$ or $4^1/_2$ inch). The thickness of the skin is 3 or 8 mm ($^1/_8$ or $^7/_8$ inch). The mean thickness of the planks range from 21 to 27 mm (3/4 or $1^1/_8$ inch). Length of all panels is 2850 mm (9,4 ft), width is 1010 mm (39 ¾ inch).

Table II – Test results of 16 panels

Series:	Av. t plank [mm]	Test [kN] F buck, measured		F max, measured		F buck, calculated with average t [kN] Min. 5% (15,8 N/mm²)	Average (25,6 N/mm²)	Max 5% (36,7 N/mm²)
S-PLS 99 3/3	24	44,0		54,5		18,2	29,4	42,2
	24	82,0		87,0		18,2	29,4	42,2
	21	54,8		55,0		16,6	26,9	38,5
	22,5	63,3	Av: 58,6 s.d.: 13,6 (23%)	71,3	Av: 67,5 s.d.: 11,9 (18%)	17,4	28,2	40,4
	23,75	62,6		72,6		18,0	29,2	41,9
	23,5	59,6		67,2		17,9	29,0	41,6
	23,5	37,7		55,2		17,9	29,0	41,6
	23,5	64,5		77,4		17,9	29,0	41,6
S-PLS 97 8/8	22,5	56,9		56,9		18,6	30,1	43,2
	25,75	95,9		105,6		20,3	32,9	47,2
	23	89,3		90,1		18,9	30,6	43,8
	26	93,2	Av: 85,4 s.d.: 16,3 (19%)	93,2	Av: 90,8 s.d.: 14,8 (16%)	20,5	33,1	47,5
	23,75	96,0		96,1		19,3	31,2	44,8
	25,25	102,6		102,6		20,0	32,5	46,6
	23	64,1		91,1		18,9	30,6	43,8
	25	85,2		90,8		19,9	32,3	46,3
S-PLS 120 3/3	24,5	78,4		84,0		27,8	45,0	64,6
	21	92,0		92,0		24,8	40,2	57,7
	24	63,9		97,0		27,4	44,4	63,6
	24,5	97,3	Av: 66,2 s.d.: 23,3 (35%)	98,0	Av: 79,8 s.d.: 15,9 (20%)	27,8	45,0	64,6
	24	27,7		58,1		27,4	44,4	63,6
	21,4	51,8		67,4		25,2	40,8	58,4
	24	48,5		61,3		27,4	44,4	63,6
	24,5	69,9		80,2		27,8	45,0	64,6
S-PLS 120 8/8	22,75	74,2		99,4		27,5	44,6	63,9
	26	135,8		135,8		30,3	49,0	70,3
	24,5	132,5		132,5		29,0	47,0	67,4
	26	112,7	Av: 105,2 s.d.: 22,8 (22%)	113,7	Av: 108,4 s.d.: 19,5 (18%)	30,3	49,0	70,3
	21,75	98,9		98,9		26,6	43,1	61,9
	26,75	102,9		102,9		30,9	50,1	71,8
	25,25	75,3		75,3		29,6	48,0	68,8
	25,5	108,9		108,9		29,9	48,4	69,3

In all test specimens the deflections perpendicular to the wall plane (lvdt5 or lvdt7) was substantial. Also the typical failure showed that in all specimens buckling across the strongest axis caused initial failure. In figure 6, 15 and 16 the typical failure is shown. In figure 6 and 16 there is no doubt about the collapse mechanism. In figure 15 however the first impression is that failure across the weakest axis has occurred. But when the deflection perpendicular to the wall plane of this specimen is studied, we have concluded that buckling across the *strongest* axis indirectly causes this failure mechanism.
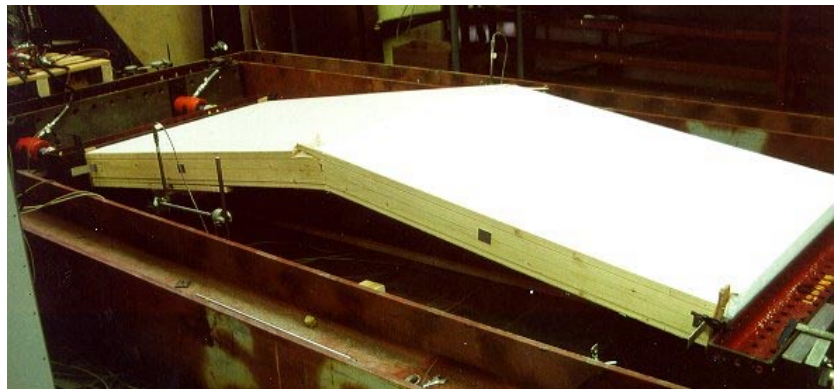

figure 6 failure of test panel caused by buckling perpendicular to the wall plane (across the strongest axis of the plank
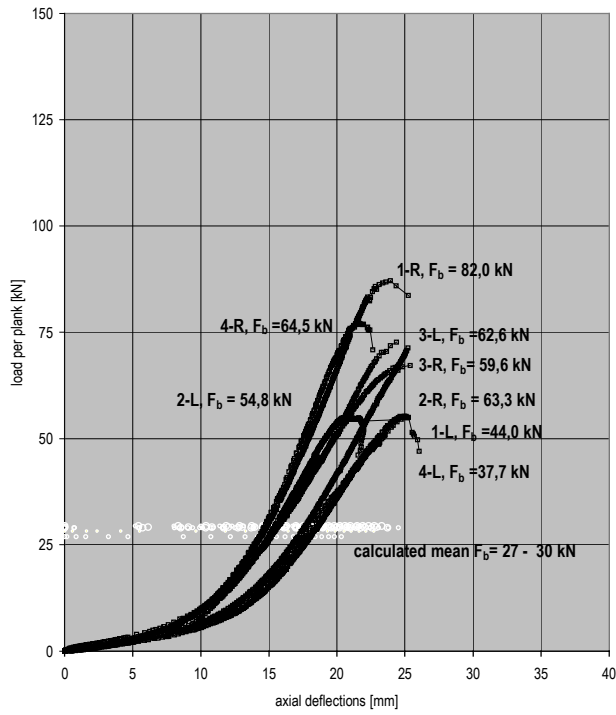
Figure 7 - Load-deflection graph per plank of panels with a 94 mm core and a 3 mm skin at both sides (mean values: F_{buck}= 58,6 kN; F_{max}= 67,5 kN)
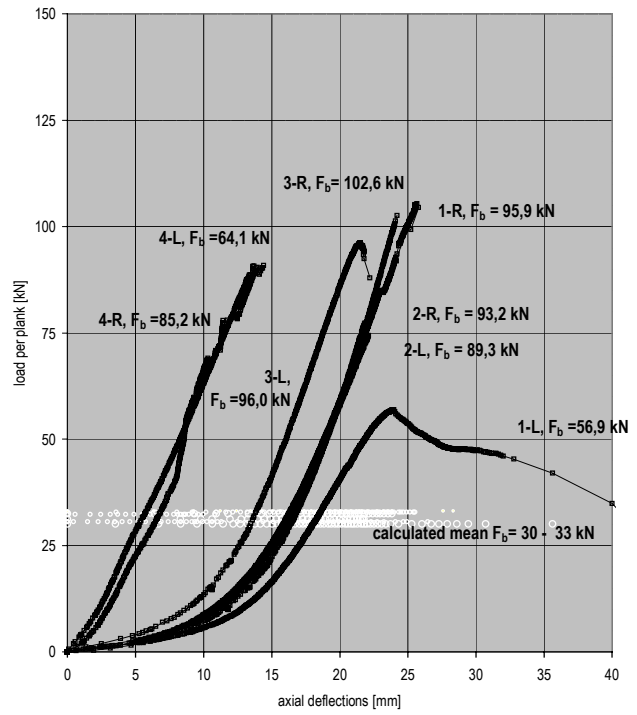

Figure 8 – Load-deflection graph per plank of panels with a 94 mm core and a 8 mm skin at both sides (mean values: F_{buck}= 85,4 kN; F_{max}= 90,8 kN)
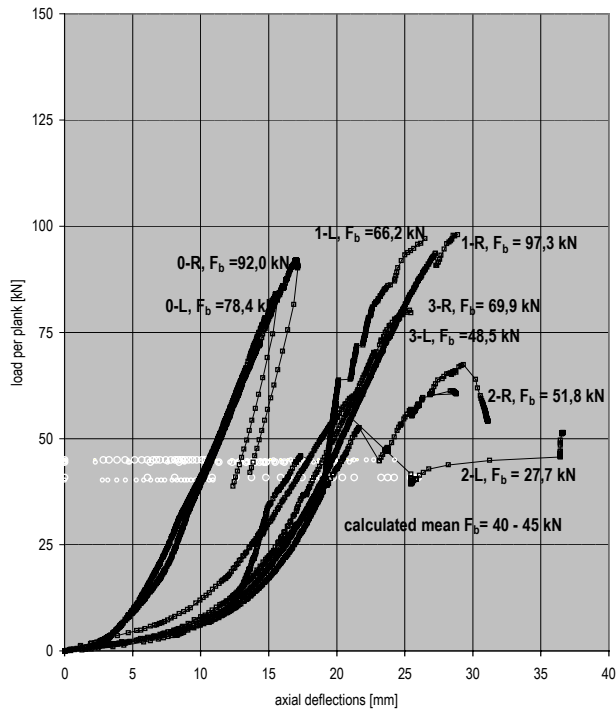
Figure 9 - Load-deflection graph per plank of panels with a 117 mm core and a 3 mm skin at both sides (mean values: F_{buck}= 70,3 kN; F_{max}= 79,8 kN)
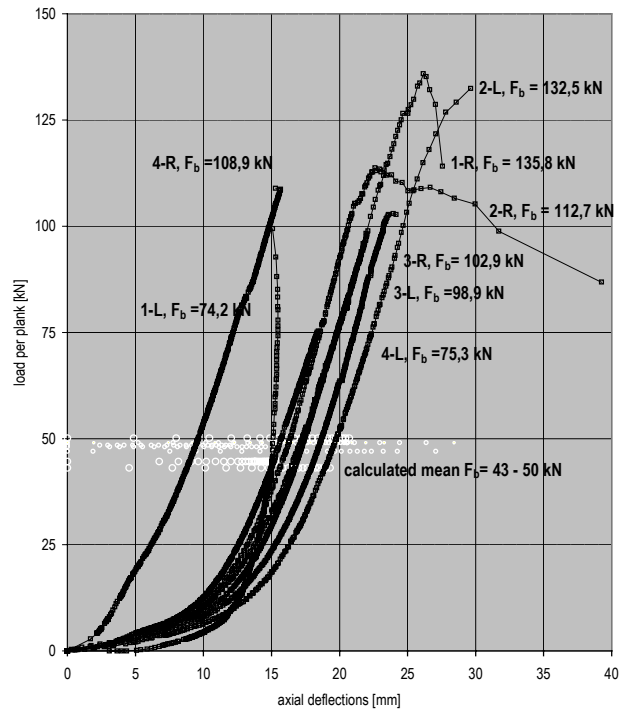

Figure 10 - Load-deflection graph per plank of panels with a 117 mm core and a 8 mm skin at both sides (mean values: F_{buck} 105,2 kN; F_{max}= 108,4 kN)

Because when the panel is substantially curved, the glued connection of thin skin and plank is likely to collapse. But when the thin skin is disconnected over a short length, the plank will buckle across the weakest axis, because the planks are very slender.

In figure 11 to 14 the difference of axial load per plank is represented. For each panel there is one curve for the difference of axial load of the plank on the left (kmd3 – kmd1) and for the plank on the right (kmd2 - kmd0). Since the hydraulic jacks are linked together, the introduction of the axial load (measured with kmd3 and kmd2) is equal. However the supporting loads (measured with kmd1 and kmd0) are far from equal. This is only explicable by a certain load distribution by the thin skin. The load distribution by a 3 mm thin skin (shown in figure 11 and 13) is maximum 10 – 20%. The load distribution of the 8 mm skin is 30 –50% of the axial load (figure 12 and 14).

CONCLUSIONS

The scope of this research is to determine whether a thin skin can force the stud to buckle perpendicular to the wall plane. The test results on axial compression of 16 commercial available roofing elements showed that a thin skin of 3 mm [$^1/_8$ inch] glued to a rigid core forces a stud of approximately 20 x 120 mm^2 [$^6/_8$ by 4 ¾] to buckle across the strongest axis.

With this knowledge a new wall element for timber frame housing will be developed with a considerable reduction of material required for the load bearing capacity. This reduction of structural material will decrease costs and slightly increase the insulation of the wall elements.
The cross-section of the wall to be developed will be quit different from the shown test specimens, since there are additional materials required to substantially improve the fire resistance and to improve the sound insulation
The wall elements will be specially designed for industrial production and timesaving execution. The dimensions of the stud will be determined by insulation requirements (minimum thickness 120 – 200 mm [5 – 8 inch]) and practical requirements (minimum width of the stud is 12 - 15 mm [$^1/_2$ – $^5/_8$ inch]).
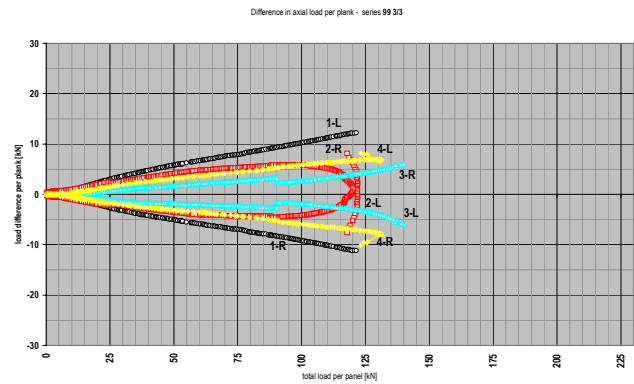

figure 11 Graph showing the difference of axial load at the introduction [kmd2 or kmd3] and support [kmd0 or kmd1] of a plank (series 99 3/3)
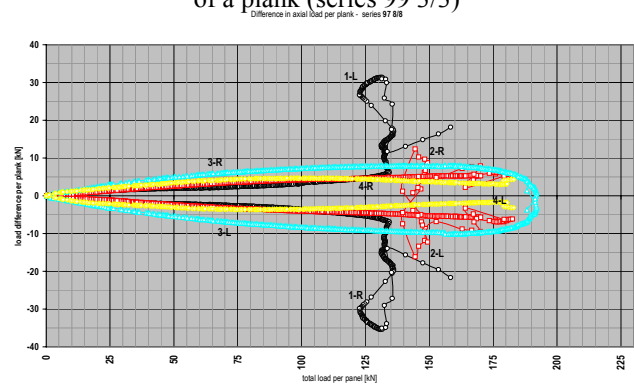

figure 12 Graph showing the difference of axial load at the introduction [kmd2 or kmd3] and support [kmd0 or kmd1] of a plank (series 97 8/8)
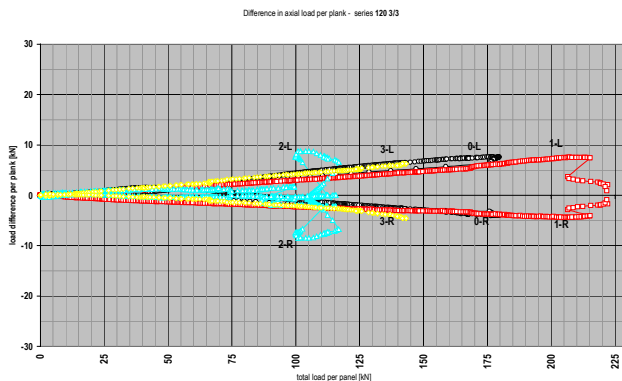

figure 13 Graph showing the difference of axial load at the introduction [kmd2 or kmd3] and support [kmd0 or kmd1] of a plank (series 120 3/3)
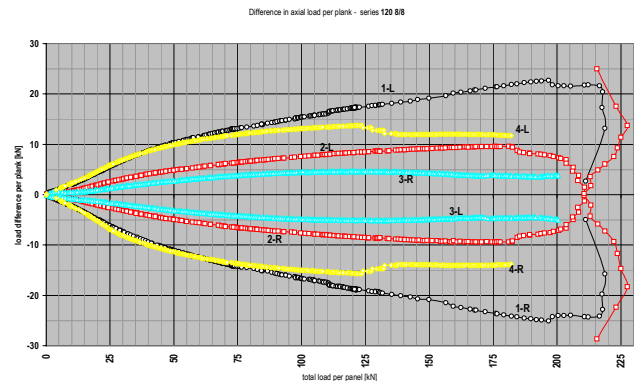

figure 14 Graph showing the difference of axial load at the introduction [kmd2 or kmd3] and support [kmd0 or kmd1] of a plank (series 120 8/8)

The load bearing capacity of the studs in the new wall elements can be simply calculated if the load bearing capacity of the skin is neglected. When the scheme in figure 1 is used the load bearing capacity of a 12x98 mm^2 [$^1/_2$ by 4] stud is comparable with a stud of 48x98 mm^2 [2 by 4] (table 3).

Since the 3 mm skin can distribute the load to adjacent studs, the mean calculation strength is likely to improve.

These improvements have good prospects to develop a new method for timber frame housing. But because the newly developed wall elements will have different materials, sizes and production methods, supplementary test are still essential. Also thermal experiments, acoustical experiments and experiments to determine the fire-resistance have to be carried out.

Table 3 Theoretical load improvement or material reduction for standard studs (buckling length 2.5 meter [8,2 ft], based on the EuroCode EC5).

	48 x 98 mm^2 [2 by 4]	36 x 148 mm^2 [1½ by 6]
standard size for frame-timber housing	48 x 98 mm^2 [2 by 4]	36 x 148 mm^2 [1½ by 6]
ultimate load per stud (single column, studs alone, scheme A in figure 1)	6.9 kN [1.550 Lb]	4.5 kN [1.000 Lb]
ultimate load per stud (interaction of studs, skin and insulation, scheme C in figure 1)	26.6 kN [6.000 Lb]	57 kN [12.825 Lb]
factor of load improvement	**3.85**	**12.65**
required size (equal ultimate load with scheme of interaction of studs, skin and insulation)	12 x 98 mm^2 [$^1/_2$ by 4]	3 x 138 mm^2 [$^1/_8$ by 6]
theoretical material reduction	**75%**	**90%**

Some of these experiments are already prepared, more experiments are planned.

Since the width of the structural elements in the new wall elements will be very small (12 – 20 mm [$^1/_2$ – ¾ inch]) standard connecting methods of other components (such as windows, doors et cetera) are of no use. These aspects of the new method for timber frame housing are already solved in broad outlines. These new details are tested in two experimental houses (Moonen – 1998).

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Figure 16 typical failure caused by buckling perpendicular to the plane of the panel
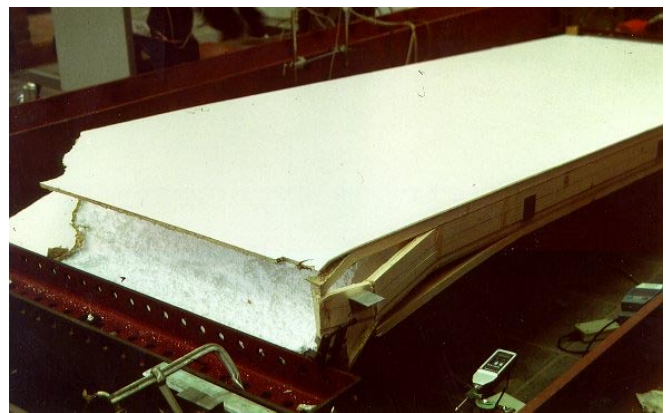

Figure 15 Local failure of panel. Buckling perpendicular to the wall panel indirectly causes this failure. Because when the panel is substantially curved, the glued connection of thin skin and plank collapses. And when the thin skin is disconnected over a short length, the plank will local buckle across the weakest axis.