Development of wood-concrete composite floors

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Summary

The present paper describes research carried out to develop cost efficient floor solutions for wooden houses. Altogether five full size test floors were built and tested in laboratory conditions. Two basic wood-concrete composite floor types were designed: a floor for in situ casting and an element floor for prefabrication. The floors were tested for vibrations and deflections due to walking after which these where loaded to failure by standard procedures. Full size floors were also tested for acoustic insulation and for fire resistance. The test results demonstrate that these wood-concrete composite floors supported by nail-plate trusses are suitable and these fulfil all the requirements set for the floors of multi-storey houses.

Keywords: Wood-concrete composite, floor, timber structure, deflection, vibration, impact sound, fire, test

1. Introduction

Starting from 1997, a research project was carried out in VTT Building Technology to develop better performing floor structures for multi-storey timber houses. This project consisted on using nailplate trusses as the main load bearing structure of the floor. Some of the floors had a concrete top layer acting as a composite structure with the nailplate truss. The research was financed by Sepa Oy.

It was found that the floors with a concrete layer in composite action were performing much better than a bare wooden floor, mainly because of higher stiffness for deflections and vibrations. It was thus decided to develop two different nailplate truss concrete composite floors: a) in situ casted floor, where the concrete is casted on site and formwork is thus needed and b) element floor, where the concrete is casted in factory conditions upside-down without any formwork.

Both of the above floors were developed and tested to such a stage that these could be type-approved. The work started from calculations and sketches of possible structural alternatives on paper. Cost estimation of these new structures was carried out simultaneously. It was noted that the dimensioning of the floor is mostly effected by the vibration performance. In this case, the Canadian code vibration criteria were used (Onysko's point load criterion), which is tighter than the criterion given in Eurocode 5. The fundamental frequency should also be above 8 Hz as stated in most design codes. Properties as strength or stiffness for static deflections of live and dead loads are not critical.

The added structural parts achieve the acoustic and fire performance of a floor, which is required in a multi-storey house. These are : floating floor, thermal insulation, resilient channels of the ceiling underneath. The use of trusses in the central floor section gives also plenty of freedom for the installation layout. The theoretically modelled wooden truss-concrete floors were tested in laboratory conditions in VTT Building Technology by a rather extensive test programme as follows:

- The shear capacity of wood-concrete joints with nailplates
- Full size floor experiments loaded to failure
- Full size floor experiments for floor vibrations (dynamic loading of a test walker, vibration measurements, subjective scores, modal tests, point load deflection tests)
- Acoustic insulation tests (airborne and impact sound) of composite floors, with several kinds of floor toppings
- Fire test of full size composite floors for the fire endurance time of resistance, endurance and insulation.

In the following sections, the main results of the research will be given of the two floors, a) and b) described above. Detailed description of the test experiments or the test results is not possible to include here. These can be found from the literature references.

2. Floor Structures

2.1 In situ casted wood-concrete floor

The in situ casted wood-concrete composite floor is a structure, which is to be built on the building site. This is based on nailplate trusses, which support plywood sheets in-between. The concrete is casted on the plywood. Figure 1 shows a floor structure meant for multi-storey house use. For single or town houses, a simpler floor version may be used, due to less demanding fire and acoustic requirements.

The truss has a height of 290..340 mm and a width of 42 mm. Two trusses are nailed to each other in less than 640 mm spacing. Nailplates attached between the trusses form the connection between concrete and wood. The plywood is 12 mm thickness and made of at least 5 veneers (spruce), with the surface grain direction perpendicular to the trusses.

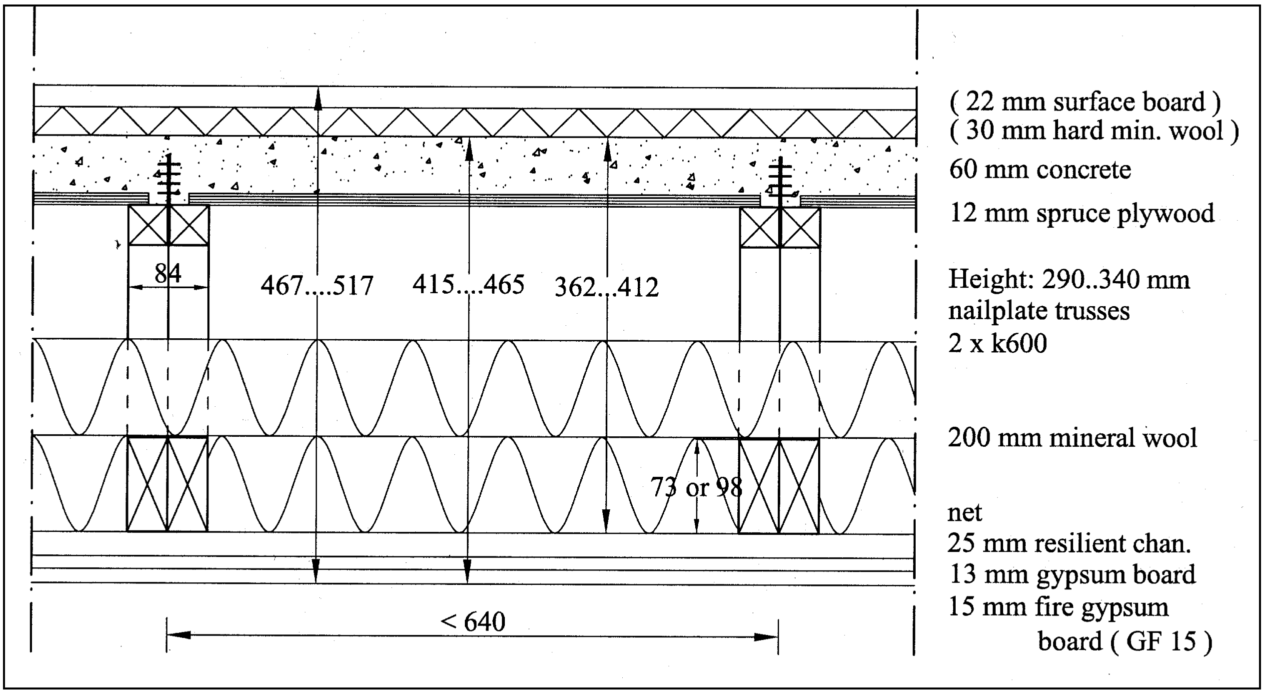

Fig. 1 Cross section of the in situ casted wood-concrete composite floor (multi-storey house case).

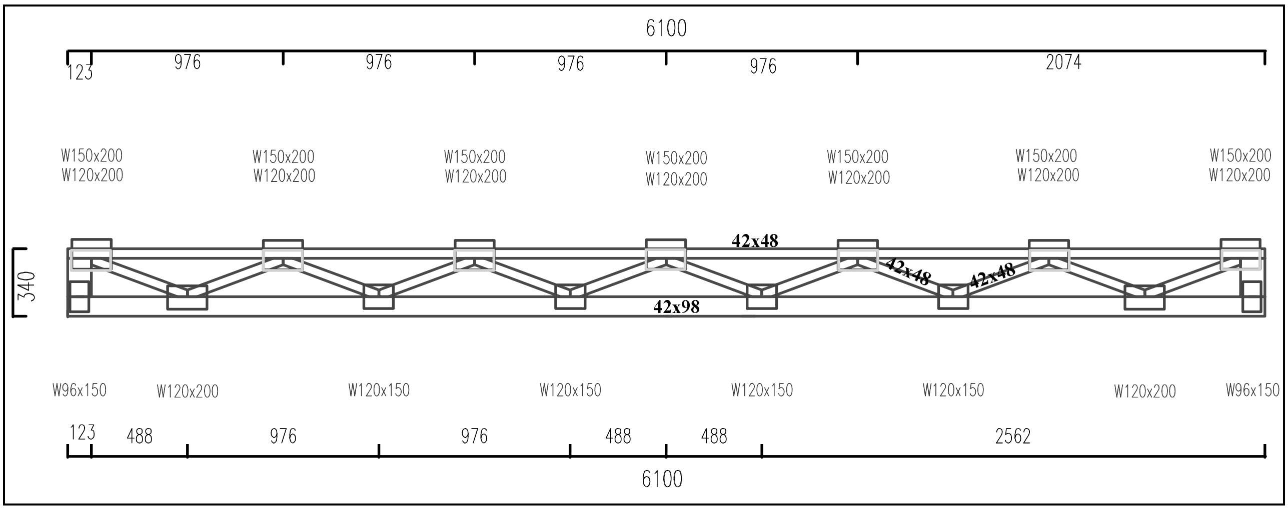

Fig. 2 Truss used in the floor of figure 1 -dimensions of the trusses used in the tests [1], [3] .

The concrete is reinforced with a ϕ6#150 steel net in the centre. The nailplates form a good and firm place of connection of the net. A more thorough description of the materials used can be found from the references.

The maximum allowable span of the floor is determined by the vibration properties. Table 1 summarises the maximum spans based on the calculations and experiments carried out [1]. Using these spans the composite floor structure performs satisfactorily for strength, stiffness, vibrations and point loads. The floor may also be a continuous structure (3 or more supports), in which case the span signifies the largest single span of the floor. Over 12 m length floors should be however avoided due to problems in handling.

Table 1 Maximum allowable span of the in situ casted wood-concrete floor. Truss spacing is k 600 mm. Deformation of floating floors is not considered here.

Height of truss (mm)	Height of composite floor (mm)	Full floor height (mm)	Max span (mm)
290	362	415	5730
300	372	425	5880
310	382	435	6030
320	392	445	6180
330	402	455	6330
340	412	465	6480

2.2 Element wood-concrete floor

In this case, the floor is built in an element factory and thus no formwork is necessary to be applied on the floor. The nailplate truss used here lack the top chord, since the concrete layer in itself forms the compression member and no support during casting is necessary. The element is pre-casted in an upside down position. The truss height may be between 235..335 mm and the member width is 72 mm. The height of the concrete layer is 80 mm. The trusses are spaced at max. 600 mm . The width of the element is 2400 mm. the concrete layer is reinforced with a net ϕ8#200 in both the top and bottom sides. Additional reinforcement may be installed if required.

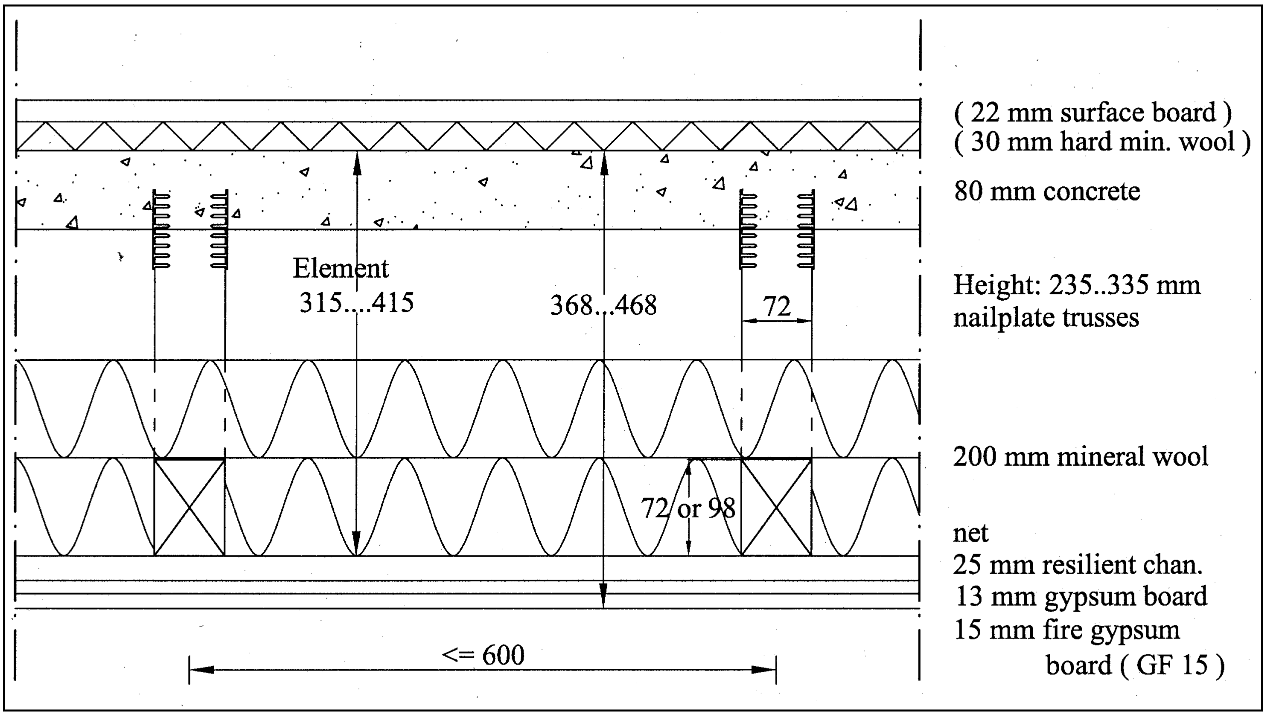

Fig 3. Cross section of the element wood-concrete composite floor (multi-storey house case).

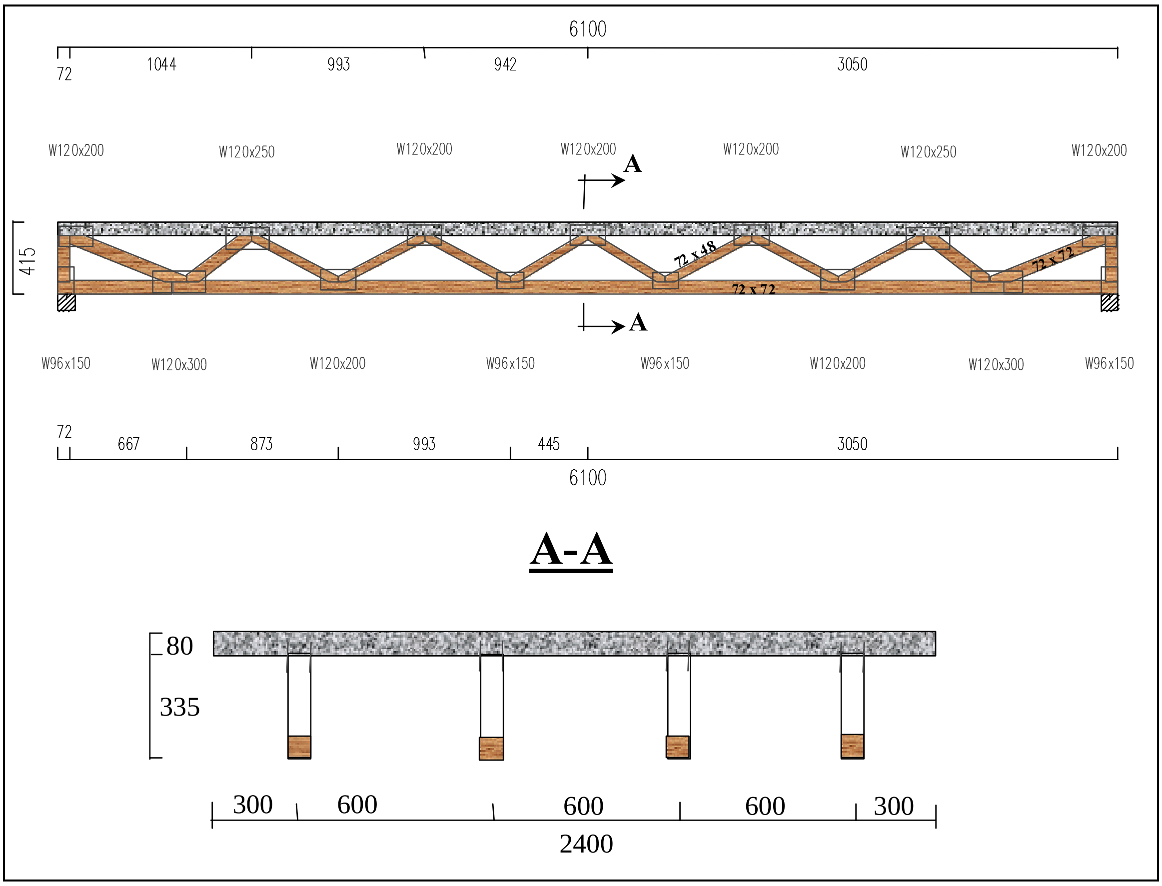

Fig 4. Basic structure of the element wood-concrete composite floor - This floor was tested in [1], [3].

Similarly to the in situ casted floor, the maximum allowable span of the floor is determined by the vibration properties. Table 2 summarises the maximum spans based on the calculations and experiments carried out [1] for the element floor case. Using these spans the composite floor structure performs satisfactorily for strength, stiffness, vibrations and point loads. The floor may also be a continuous structure (3 or more supports), in which case the span signifies the largest single span of the floor. Over 12 m length floors should be however avoided due to problems in handling.

Table 2 Maximum allowable span of the element wood-concrete floor. Truss spacing is k 600 mm. Deformation of floating floors is not considered here.

Height of truss (mm)	Height of composite floor (mm)	Full floor height (mm)	Max span (mm)
235	315	368	5320
250	330	383	5510
265	345	398	5710
280	360	413	5900
295	375	428	6090
310	390	443	6280
320	400	453	6410

335	415	468	6600

2.3 Basic floor properties of the floors

Self-weight: The weight of the in situ casted floor is around 200 kg/m^2, and of the element floor is 240 kg/m^2.

Load bearing: A live load of 2 kN/m^2 may be applied on the floor. The strength and stiffness properties are not critical (these do not effect the max span values given).

Stabilisation: The floor performs as a horizontal diaphragm, which should be designed on case by case.

Fire endurance:The floor satisfies a 60 minute resistance, REI60 [4].
Impact and airborne sound insulation [5]: The measured airborne sound insulation was R_w = 64 dB, same value with or without a floating floor. The impact sound was $L_{n,w}$ = 51 dB with the floating floor, but with no floor surface material and $L_{n,w}$ = 52, 53 dB without the floating floor with wooden parquet and carpet surface respectively.

3. Summary of test results

The floors were tested in laboratory conditions once these were first drafted on paper. Testing different methods joining concrete and wood started the experiments. It was found that nailplate is a very effective and stiff connection between these materials and a rather small anchorage of 23 mm into the concrete is needed in practical cases to avoid anchorage failures. Full size floor tests were carried out in a second stage to verify the floor stiffness and failure loads as well as the vibrations due to walking persons. These tests were done with floors of size 2.4 x 6.0 m. The load was applied as four point bending by standard procedures. The failure load was on minimum 4.2 times the design load (when using the design load values of 1,5 x 2 kN/m^2). The failure mode is tension failure of the bottom chord. The deflection of the floor at service design load was 5.1 mm. The natural frequency of the floor was 9.7 Hz and the 1 kN point load deflection was 0.33 mm (without floor toping). Eurocode 5 allows deflection values up to 1.5 mm. Also fire and acoustic experiments were carried out with full size floor elements in laboratory conditions [4], [5]. The fire tests was stopped at 62 minutes and the acoustic results are as shown in the previous section. These values satisfy the requirements set for the floors of multi-storey houses in Finland.

4. Conclusions

The wood-concrete floor is a medium weight floor, which is heavier than a bare wooden floor but lighter than a full concrete floor. The floor is however stiff and light enough to be a high frequency floor (f_0 > 8 Hz). The floor would probably be unsatisfactory if the natural frequency was lower. This has been the span limiting property of the floor. Being a high frequency floor, it performs much better against vibrations and deflections than a standard wooden floor. The floor is about three times stiffer than a similar height floor without the concrete layer. This was clearly noted also in the subjective tests, when rating the floor vibrations due to a walking person.

Although the floor may be used in any frame structure, it is presently meant to be used in timber frame houses and more particularly in a platform frame house. The floor is light enough to be supported by a timber frame. Currently technical details and floor jointing techniques are looked at so that the wood-concrete element could be incorporated in a platform frame system. As an example of a floor supporting wall connection, see fig. 5. The floor has not yet been used in practice, however there is a plan to have a first pilot building built where these wood-concrete floors are to be applied. Once such are built, on site experiments of acoustic insulation and vibration will be carried out again.

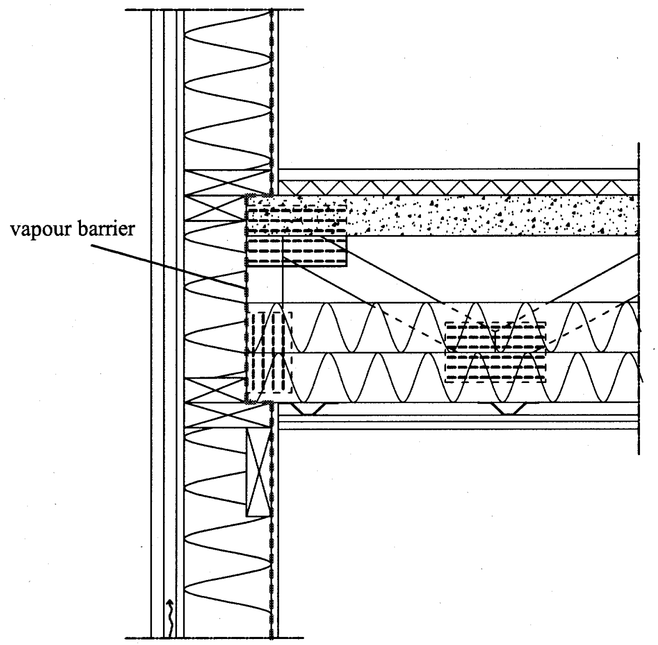

Fig 5. An example of a floor - supporting wall connection showing the vapour barrier position

This research and development work was initiated and funded by Sepa Oy, who is also the producer of these floors. The funding and development co-operation is gratefully acknowledged.

4. References

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