Timber frame houses - Serviceability

STEP lecture E11
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Objective

To describe the principles of design and detailing of timber frame houses with particular reference to serviceability requirements.

Summary

This lecture deals with the design and detailing of timber frame houses with particular reference to serviceability requirements. Important structural serviceability aspects which have to be considered in timber frame houses are vibrations in floors and load and moisture induced movements in timber and wood based materials. Non-structural aspects of design, such as sound and heat insulation, the provisions of installations and protection of timber against excessive moisture exposure during construction and use, are discussed. The necessity of an integrated approach in design, where structural and non-structural problems are considered simultaneously to achieve rational and economic solutions, is pointed out.

Introduction

Timber frame building systems consist basically of wall and floor units composed of timber studs or joists, covered with different types of sheathing materials and with insulation material in between. For floor units, light-weight elements may be used as an alternative to solid timber joists as shown in Figure 1. Such systems are rational since most necessary functions can be integrated in the same structural unit, such as:

- transfer of vertical loads
- stabilisation against horizontal loads
- physical separation
- heat insulation
- sound insulation
- fire separation

In contrast, a skeletal structural system is normally used in steel buildings. The only function of the structural skeleton is to carry the loads. All the other functions must be provided by other structural components such as infill walls.

The wall and floor units in timber frame building systems can be highly standardised, but still easy to modify if needed. The units can be assembled on site using simple equipment or they can be prefabricated either in a temporary shop at the building site or in a permanent factory. The technology is well known especially in Northern Europe, where a majority of single family houses are built with timber frame. In some parts of the world, timber frame building systems are widely used also in buildings up to four or five storeys. In North America, for instance, timber frame is the dominating system used in multi-residential construction.

In the design and construction of timber frame building systems, special care must be taken to ensure good serviceability taking into account the special properties of timber. Structural timber systems have very low weight compared to other types of building systems. This is advantageous with respect to ease of transport, erection and construction, requirements on the foundation and for earthquake resistance. However, light-weight structures are sensitive with respect to floor vibrations, deflections, sound transmission and fire resistance. Another special feature in timber construction is the fact that wood is a hygroscopic material which absorbs and desorbs moisture in response to climate changes in the environment. Changes in moisture content are associated with shrinkage or swelling, and the simultaneous influence of loading will enhance these movements. If wood is permanently exposed to high moisture levels, there is a considerable risk of growth of fungi and rot which may jeopardise the durability and serviceability of the building or its components. It is extremely important that such hazards are prevented by appropriate design of the building envelope and by using dry timber during construction. For the same reason the timber must be protected from extensive exposure to rain and snow during the construction period.

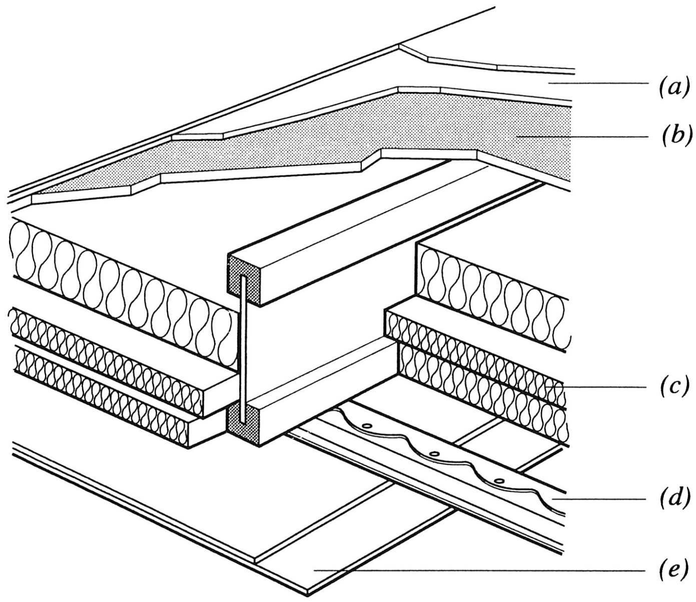

Figure 1 *Floor system with light-weight I-joists as primary load-bearing elements. (a) Gypsum plasterboard, (b) floor board, (c) light-weight I-joist, (d) insulation, (e) resilient channel.*

Many of the key issues in the design of timber frame building systems are related to serviceability, and floor systems especially are in many ways critical for the quality of the building.

Design to control floor vibrations

The most common means to improve the vibrational performance of floor structures is to increase the stiffness in the principal load bearing direction. This can be done by increasing the joist dimension, and also by gluing the floor board to the joist, thereby providing a composite action between the joist and the floor board. The most efficient measure, however, is to increase the bending stiffness perpendicular to the principal bearing direction. This may be achieved by using a flooring material with higher stiffness or by strutting between the joists. Two commonly used methods of strutting are solid bridging and herringbone strutting as shown in Figure 2. The effectiveness of these strutting methods is limited, however, due to shrinkage and compression perpendicular to the grain in the joists. The best result is obtained with solid bridging, if the nogging pieces are glued to the board panels at the top and the bottom of the joists. In this way, the transversal load transfer capability is more or less independent of moisture movements in the wood.

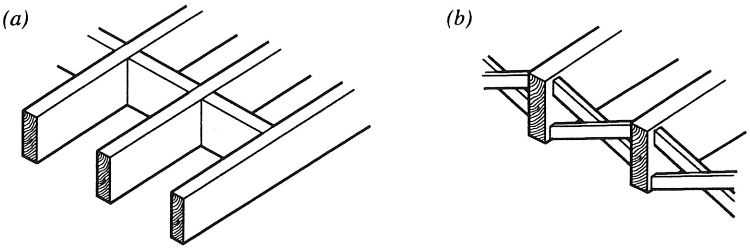

Figure 2 *Strutting between floor joists will increase the transverse stiffness of a floor. (a) Solid bridging, (b) herringbone strutting.*

To avoid disturbing vibrations between different rooms or flats, continuous beams should be avoided. It should be noted that, contrary to popular belief, reducing the joist spacing does not always improve the vibration performance.

Sound performance

One of the key issues in light weight timber frame design is acoustics. The concerns over acoustics fall into two categories:

- Airborne noise (e.g. stereo sounds, voices).
- Structure borne noise (e.g. footsteps, plumbing, elevators).

By careful design and construction the problem with air borne noise can generally be handled to achieve good sound ratings. As an example a wall separating two flats from each other is shown in Figure 3. This type of wall has a sound rating which is comparable with a 240 *mm* thick concrete wall. The performance may be further improved if the linings on one side of the wall are placed on resilient channels connected to the studs. It is important that the cavity between the two parts of the wall is not broken by structural connections. By similar measures, a good performance with regard to air borne noise in floor structures can be achieved.

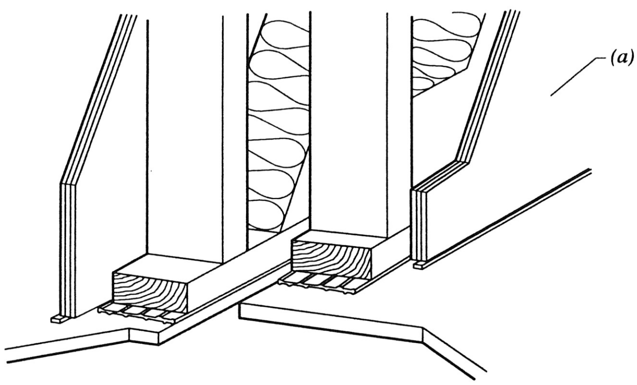

Figure 3 *Wall with high sound performance, designed as two individual wall units separated by a cavity. Each wall unit has plasterboard linings on its sides and is filled with insulation between the wall studs. (a) Gypsum plasterboard.*

The structure borne noises can be more difficult to address, especially in floor structures. To obtain good sound insulation in wooden floors, the top and the bottom part of the floor must be separated from the primary structure as much as possible. At the bottom, a very effective method is to place the ceiling structure on resilient acoustic channels, see Figure 1. The purpose of the resilient channel is to isolate the gypsum board from the supporting timber structure. Therefore, it is important to ensure that the screws which fasten the gypsum board to the resilient channels do not touch the timber floor joists.

It is also advantageous to place insulation material between the beams. From an acoustic point of view, there is no significant difference between solid timber beams and light-weight composite beams, as those shown in Figure 1. At the top the floor sheathing may be placed on a thin insulation underlay (floating floor) as shown in Figure 4. To improve the footstep sound performance it is advantageous to increase the mass of the flooring. This can be accomplished by placing gypsum plasterboard on top of the structural floor sheathing and using double plasterboard sheathings in the ceiling underneath the floor. An alternative is to apply a thin (30 - 40 *mm*) concrete or plaster layer on top of the floor boarding instead of gypsum boards.

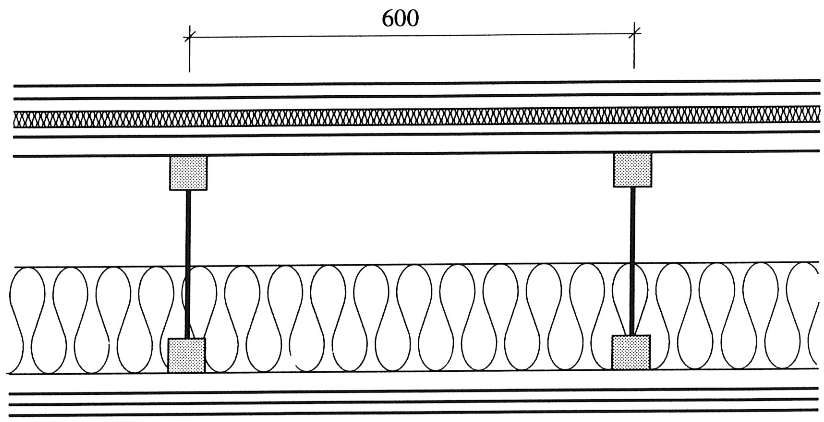

Figure 4 *Floor system with very high impact sound rating.*
From top: *2x13 mm gypsum board,*
20 mm mineral wool,
13 mm gypsum board,
22 mm chip board,
300 mm light weight I-joists,
145 mm mineral wool,
25 mm resilient acoustic channel,
2x13 mm gypsum board.

The choice of floor covering is one important factor which influences the impact sound level. A thick carpet is more advantageous than a hard floor covering such as wooden parquet or PVC carpets. Many structure borne noise problems can be avoided through careful suite layouts. In multi-residential buildings it is best to line up bathrooms and kitchens from storey to storey. A bathroom or a kitchen should not be placed above a bedroom in the apartment below. Finally, it is extremely critical for a good sound performance to ensure that no plumbing pipes are touching the gypsum board ceiling or the wall linings.

It can be concluded, however, that very good sound performance can be achieved with light-weight timber construction. The floor design shown in Figure 4 has been shown to have an impact sound rating comparable to a 290 *mm* thick concrete floor.

Moisture movements in structural timber systems.

Moisture induced deformations in timber framed systems are inevitable due to environmental changes in temperature and relative humidity. The largest deformations occur perpendicular to the grain, i.e. in the transverse directions of timber members. The difference between the highest and lowest values in moisture content is 2-4 percentage units in indoor climate and 8-10 percentage units in outdoor climate. The most serious situation occurs when the timber is wet during construction. The subsequent drying will then lead to significant shrinkage. If the timber is installed in green condition, it may shrink 3-4% in the transversal direction, when exposed to indoor climate. This shrinkage corresponds to a dimensional change of 6-8 *mm* over the depth of a normal floor joist. It is therefore very important to use dry timber in construction, especially for multi-storey buildings.

The problem with shrinkage is accentuated when a timber member is loaded in compression perpendicular to the grain, e.g. in a wall-floor connection as shown in Figure 5. The transverse compression in the horizontal members cannot lead to failure in the usual sense, but it will lead to large deformations especially when it is combined with shrinkage in the member. The deformations at each floor level can be of the order 5-10 *mm*. For single family houses up to two storeys the consequences of these movements are less serious, since the load levels are normally lower and the additive effects are limited. For timber buildings with several storeys, however, the loads are higher and the deformations from a number of connections may add up to very large deformation in the upper part of the building. Also for buildings with large horizontal dimensions, moisture movements over long lengths may give rise to large displacements in critical points of the structural system.

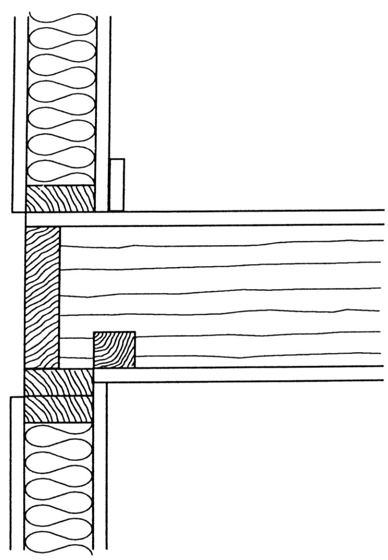

Figure 5 Wall-floor joint in typical platform frame construction, Sunley et al (1985).

The moisture and load induced displacements in the structural system may affect the serviceability of the building in various ways. Large movements may cause damage to plumbing, electrical and mechanical systems and differential movements between exterior brick veneer and the structure may lead to cracking. Similar problems may arise for other types of exterior cladding with limited deformability. Normally the major part of the deformations develop during the construction period, but those parts of the movements which occur after the building is finished, may cause damage to linings, paint and wallpaper. In particular, differential settlements of the supports leads to slopes and level differences on floors. For instance if a floor is supported on a concrete or a brick wall on one side and on a timber frame wall on the other side significant slopes can be created. For buildings with several storeys a special "shrinkage analysis" of the structural system should be made to avoid such detrimental effects.

The settlements in floor-wall connections are most significant in platform framing type systems as shown in Figure 6a. In this case the wall units are constructed in storey heights and the intermediate floor is placed on top of these panels to form a platform and a stabilisation for erection of subsequent wall panels. A way to limit the settlements is to use so called balloon framing, i.e. using wall units two storeys in height with the intermediate floor suspended between the walls, see Figure 6b. In this case the vertical load is transferred through the connection via stresses parallel to the grain, and the settlement due to shrinkage is also minimised in this type of connection. In spite of its disadvantages with regard to settlements, the platform framing technique is almost always used in practice. The reason is that this method is considered to be far more rational and efficient in the construction process.

Another way to reduce settlements in timber frame systems is to block the vertical movements in the floor-wall connections by using short vertical pieces of timber which can transfer the vertical loads by stresses parallel to the grain. The disadvantage with this solution is that it is time consuming and it can also be difficult to combine with good solutions to obtain efficient heat insulation in wall-floor connections at the exterior walls.

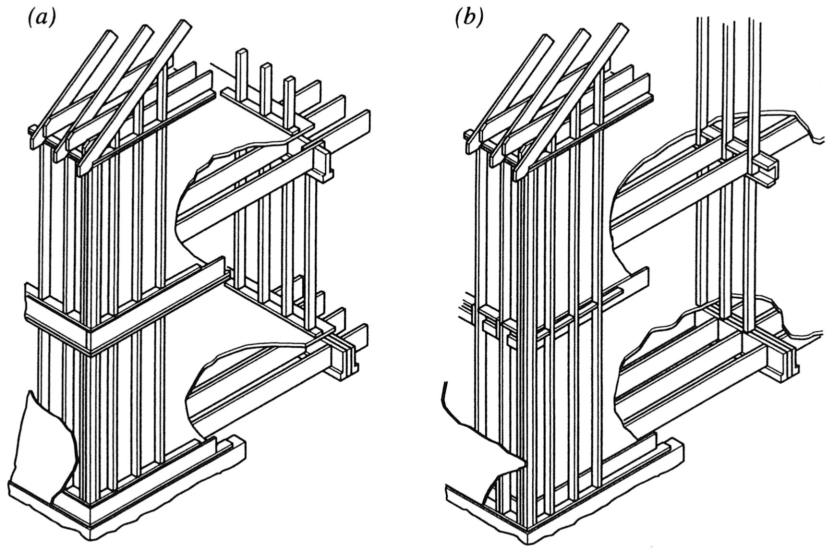

Figure 6 (a) Platform frame construction. (b) Balloon frame construction.

The building envelope

The exterior wall plays a vital part in creating the desired indoor climate in the building. The exterior wall should therefore:

- provide thermal insulation,
- prevent air leakage,
- prevent damage from internal and external moisture exposure.

Thermal insulation in a timber framed wall is easily provided by fixing insulation material between the studs, see Figure 5. If high insulation capacity is required an extra insulation layer may be placed outside the timber frame as shown in Figure 7. In the latter case a special design of the wall-floor connections has to be made to minimise the effect of thermal bridging. To prevent air leakage and to protect the wall from moisture diffusion from the inside, a vapour barrier is normally provided on the inside face of the studs, i.e. on the "warm" face of the insulation. Behind the exterior cladding a breather membrane is provided, which protects the wall against wind and prevents air circulation which can impair the thermal insulation performance of the wall. The exterior surface of the breather membrane should be water repellent to prevent water from penetrating the exterior cladding, which could damage the membrane, the heat insulation or the timber frame. It is important, however, that the breather membrane is permeable enough to allow moisture to ventilate out from the wall construction. To ensure ventilation of moisture behind the exterior cladding, an air cavity should be provided as shown in Figure 7.

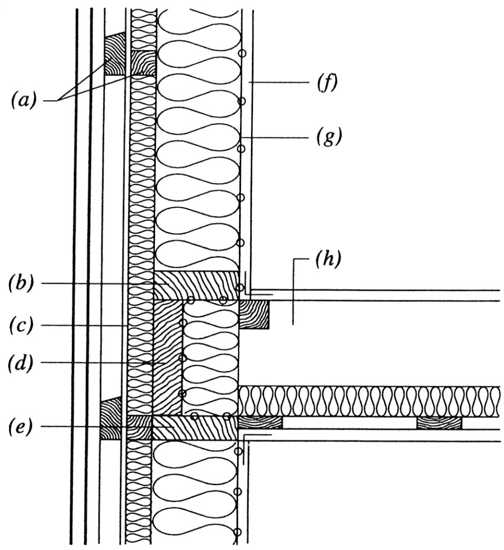

Figure 7 *Exterior wall and wall-floor connection with high thermal insulation performance, Träinformation (1992). (a) Horizontal batten, (b) bottom plate, (c) breather membrane, (d) rim joist, (e) top plate, (f) internal sheathing, (g) vapour barrier, (h) floor joist.*

Figure 7 shows an exterior wall with a wall-floor connection designed to fulfil high requirements for thermal insulation, which may be relevant in colder climates. In timber framed building systems the exterior walls are normally also load bearing. It is quite evident that an optimal design of such a wall and its detailing is obtained only if all relevant requirements are taken into account simultaneously. Optimising the design from the structural point of view only, would lead to a design which would be inappropriate in view of other functions, such as thermal insulation and moisture protection.

Concluding remarks

Special care must be taken in design and construction to ensure good serviceability in timber frame systems. The most important aspects are performance with regard to acoustics, vibration and springiness, and avoidance of adverse effects of moisture during construction and use. Most of these problems can be solved in a satisfactory way with proper design and workmanship.

References

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