Stabilizing strategies for multi-story timber frame structures

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Summary

There is a strong tradition of constructing timber structures stabilized by sheets of wood or other material nailed to a timber frame. In many cases this is the best and most economical choice, but it can also place major restrictions on the design of the structure. This paper discusses alternative methods of stabilization. New methods of this sort can expand the possibilities for architecture, providing opportunities for expression not common if even possible in traditional approaches involving use of timber. Shear walls both with a nailed on sheeting and those consisting completely or in part consisting of solid elements composed of several layers of wood are discussed, along with stabilization by use of shafts and stairways.

1. Introduction

In many countries, use of a timber framework has long been the commonest choice in constructing one- and two-story buildings. In Sweden about 95% of all one- or two-story buildings designed for residential purposes are constructed with use of a timber framework. Since during the nineteenth century and earlier, however, several cities were devastated by fires, use of timber frameworks in Swedish buildings more than two stories in height was forbidden during most of the twentieth century.

Figure 1. Two tall timber-based buildings in southern Sweden: (a) one of the last multi-story buildings constructed 1902 around the time that the highly restrictive building laws were enacted and (b) Wälludden, the first modern multi-story wooden structure built in Sweden in 1995.
This only changed in about the middle of the 1990s, when performance-based building codes were created in which safety requirements were no longer tied in this way to the choice of material. Currently no restrictions are placed on the number of floors permitted in wooden buildings, as long as performance-based requirements are met.

Figure 1(a) shows one of the last multi-story buildings in Sweden constructed with a timber framework prior to introduction of the regulations forbidding this. It was built in Kisa in southern Sweden in 1902. Figure 1(b), in turn, shows the first five-story building, called Wälludden, constructed in accordance with the current performance-based code. It was built in 1995 and is situated in the southern Swedish city of Växjö. Since then, timber based structural systems in multi-story buildings have become increasingly popular.

Despite the obvious developments during the past century both in architecture itself and in the technical and economic prerequisites for it, there is a lack of knowledge and experience, and of major developments concerning the design of wooden frame systems and of methods of stabilizing multi-story wooden structures. There is a need of extensive research in this area. Questions of particular interest concern the development of more efficient production systems relating to this for use in factories and at building sites, and also methods and models for analysing the structural behaviour of such systems when subjected to loading. The task of constructing light weight structures based on wooden framework performing well when subjected to strong horizontal forces such as wind loads can create is particularly challenging.

Wind loads on multi-story buildings can be very heavy, with the large wind-catching area such building possess and in view of the wind speed also being greater high above the ground. In addition, the large sections of glass often used in modern architecture place high demands on the stabilizing system. Figure 2 shows a simplified section of a five-story building, indicating the horizontal force of the wind load acting on the floor at each level.

The present paper aims at providing a brief overview of some of the systems available for stabilizing tall wooden structures, and at discussing construction connected with this and the need of methods and models for analysing the structural behaviour that use of such systems involves.

![Figure 2. A simplified section of a five-story building showing the horizontal force of the wind load acting on the floor at each level.](image-url)
2. Stabilization by use of shear walls or shafts

Systems for stabilization purposes can be divided into those providing stabilization by use of shear walls and those providing it by means of shafts and stairways. Figure 3 shows a schematic drawing of the two principles, those of (a) shear walls and (b) shafts. The principle involved in use of shafts and stairways is relatively simple. Robust elements having continuity act as stiff columns, are firmly connected to the ground and are able to carry the horizontal loading transferred to them at each level by the floor. Stabilization through use of shear walls, on the other hand, is less straightforward, since the transmission of forces in the shear walls is complicated. The stiffness and strength of the connections between the different wall elements and between the walls and the floor elements, and the occurrence of openings for doors and windows, are of central importance here. The presentation that follows covers traditional shear walls consisting of sheeting nailed onto wooden frames, and solid timber elements made up of several crossed layers of wood glued together. Stabilization by use of shafts will be discussed briefly and exemplified. The stiffness of the different systems might vary considerably, Ellis et al. (2001).

![Figure 3. Principles of stabilization by use of (a) shear walls and (b) by shafts.](image)

2.1 Shear walls with nailed-on sheeting

Shear walls having sheeting that is nailed-on are commonly employed for stabilization purposes, especially in low buildings. Figure 4 shows a simple wall in which boards are nailed to a wooden frame. Since the board is very stiff in resisting in-plane deformations the wall's stiffness depends on the stiffness of the nails and the spacing between them.

Since in low buildings the stabilizing capacity of such a system is very high relative to the horizontal loading which is present, a moderate number of nails is normally sufficient. Relatively simple hand calculations, carried out to be on the safe side, cf. Källsner et al. (1995), can be used for analyzing the system. Figure 5 shows the design approach employed. Only the shear stiffness of the continuous vertical strips that are marked in grey in the Figure 5 is accounted for in the analysis. For taller buildings it is much more difficult to obtain sufficient stabilizing capacity, and the design approach of utilizing only continuous vertical strips of shear walls for stabilization purposes is both inconvenient and uneconomical. As calculations indicate, such an approach can lead to unacceptable deformations occurring and to very strong and concentrated uplift forces relative to the ground and to the floors on the lower levels developing.
In reality, elements other than continuous vertical strips in the stabilizing walls can contribute to the overall stiffness of the walls. The possibilities for utilizing this are particularly important in tall buildings. In order to analyze adequately the effects involved, elaborate models making use of the finite element method need to be employed. The development of such models, along with the development of strong components for stiff force distribution at critical positions, i.e. close to openings for doors and windows, are of importance and are in need of further investigation.
2.2 Solid timber elements in shear walls

An alternative to use of shear walls with nailed on sheeting is the use of solid wooden elements consisting of several layers of wood successively glued together perpendicular to each other. Figure 6 shows a drawing of such an element. Such elements are manufactured in dimensions and thicknesses that differ, depending on the purposes to which they are to be put. Further details regarding their technical properties are given by Blass (2004) and by Dujic (2004).

Shear walls of solid elements are much stiffer, of course, than traditional shear walls with nailed-on sheeting are and have the capacity as well of distributing forces around openings for doors and windows. Since some half of the layers of the elements involved are oriented vertically the capacity for vertical loading is also good and very tall buildings and to create challenging architecture, it may be possible in constructing with use of solid wooden elements. Figure 7 shows a four-story building under construction that has solid wooden walls. The construction is built in Trondheim, Norway.

Figure 6. Wooden elements consisting of several layers of wood glued together successively perpendicular to each other.

Figure 7. A four-story building under construction that has walls of solid timber elements.
Figure 8. Stiff in-plane connections can be obtained by use of hard board, both screwed and glued to adjacent elements so as to join them.

When solid timber elements are used for stabilization purposes, the connections between these elements, and between these and the surrounding horizontal parts of the system, are key factors in the structural performance of the system and the demands regarding stiffness and strength that are to be met. If these connections are not adequate, the qualities of the solid elements cannot be fully utilized. At least in the case of in-plane connections between elements, very stiff joints can be obtained by use of hard board screwed and glued to the adjacent elements so as to join them, Vessby (2004). Figure 8 shows such a connection.

2.3 Combinations of traditional and solid walls

The quite different shear walls described above, those with nailed-on sheets and solid walls, respectively, can be combined in different ways aimed at finding economically competitive solutions of architectural interest. Figure 9 illustrates (a) a wall stabilized by nail sheathing (b) a solid timber wall and (c) a wall combining solid elements and nailed-on sheathing. Having already discussed the first two alternatives, alternative (c) will now be considered. This sort of wall can be analysed in a manner similar to what was described above for low buildings with walls involving nailed-on sheets and that only utilize vertical continuous strips for stabilization. It may be reasonable in such a
case to consider the entire strip of solid material (the dark strip in Figure 9(c)) to provide stabilization to resist horizontal loading, despite it containing openings for windows. This strip is stiffer and broader, than continuous vertical strips of nailed-on sheets are, but for tall buildings the uplifting forces in the lower parts on the one side of the solid elements will still be very strong. The contribution to the overall stabilization provided by the parts of the wall on which there are nailed-on sheets may also of course be considerable, but elaborate models as well as knowledge regarding the stiffness, strength and deformation capacity of various details of the wall, are required to analyze it properly.

2.4 Stabilization by shafts and stairways

A method for stabilizing tall timber structures alternative to that of using shear walls is to employ an elevator shaft or a stairway for this purpose. These parts of the structure can be constructed of concrete, steel or timber and represent the main stabilizing system. The system of joists in the system serves as a stiff diaphragm and distributes the forces from the walls to the shaft. The connection between the diaphragm and the shaft is clearly of considerable importance for the functioning of the system. An example in which a concrete elevator shaft is used for stabilization of a timber structures is the building Uppfinnaren in Växjö, shown in Figure 10.

![Figure 10. Example of a timber structure stabilized by elevator shafts.](image)

3. Conclusions

Because of the long tradition in Sweden and many other European countries of only building timber structures up to two stories in height, the stabilization of multi-story timber structures has mainly followed the same principles as in the construction of low houses buildings of this sort. Use of nailed-on sheets to stabilize walls is often an appropriate choice for taller buildings as well, although advanced models for analyzing the structural behavior of such buildings are needed in order to take adequate account of the stabilization that the walls provide.

Other types of shear walls can be constructed of solid elements consisting of several layers of wood glued successively at 90-degree angles to each other. This makes the elements very stiff and improves the possibilities of finding modern architectural solutions that are very challenging in character. Such elements can be used in the structure as a whole or as stabilizing elements in parts of the shear walls.

Since the ability of methods and models employed to adequately analyze the structural behavior of the stabilizing systems is very important, in order to enable the
potential qualities of the systems created to be fully utilized. Further research concerned with the appropriate modeling of stabilizing systems is needed. Research on the modeling of still taller wooden buildings than those considered heretofore may also be needed as new structural components suitable for handling force distributions of many different types in interfaces between a variety of further elements are developed.

4. References


