Conclusions from theoretical analysis, construction and behaviour of timber spatial structures

Straka, Bohumil

ABSTRACT

The paper summarises experience and conclusions from the author’s theoretical analysis, design and construction of selected types of spatial timber structures. The main focus is on the spatial structures with primary load-carrying system, which are complemented by secondary load-carrying members. The most significant item of analysis is the issue of spatial stability in the investigated types of timber structures. Due to the fact that their load-carrying capacity and deflections are considerably affected by the load-carrying capacity of the joints, it was desirable to verify the influence of structural design of fasteners and connectors on the overall behaviour of structural systems.

INTRODUCTION

Performance of timber spatial structures is greatly influenced by a number factors, among which the most relevant are the type of load-carrying system, support locations and support types, kind of materials used for load-carrying members, method of securing a structure against both local and global loss of stability, impact of joint slip, conditions of structure’s performance with respect to the combined effect of humidity and duration of loading or other factors. For the purpose of elaborating the paper, it was necessary to sum up the results for the timber spatial structures covering rectangular, irregular and circular ground plans. These structures are made from members with solid timber sections and glued laminated sections. Purpose of the analysis was to investigate the influence of mechanical joints made by using steel components on the load-carrying capacity and as well as deflections in spatial structures.

To a large degree, the load-carrying capacity and real behaviour are influenced by the type of joints used in timber structures and their ability to transfer loads. This well-known fact is even more emphasised in the case of spatial trusses, since these structures require a large number of connections and some members and hence their connectors transfer massive internal forces. A sufficient load-carrying capacity of joints is, however, only one of the tasks which must be solved when designing a structural system. No less serious problem is posed by the construction of details which should meet two criteria: to be relatively easy to produce and to correspond to computational assumptions.

The development of timber structural systems has always been linked with the development of new types of connectors. Traditional mechanical methods of connecting, in which timber members are interconnected directly, are not optimal for creating spatial systems. Load-carrying capacity of such connections is rather low in comparison with that of connected timber profiles. For that reason it is necessary to locate a large number of connectors in one joint. The analysis shows clearly that to the most advantageous types of connections belong those made by means of steel plates, or steel elements. Their major advantage lies in a significantly higher load-carrying capacity, the possibility of locating connectors in relatively small interfaces, the possibility of precise fabrication and simplicity of assembly.

The analysis of the load-carrying systems with connections based on steel plates was made at the Department of Metal and Timber Structures, Faculty of Civil Engineering, Technical University of Brno. It included especially the examination of structural spatial behaviour, solution of vital structural details, and it also considered effect of joint slip on the load-carrying capacity and the strain of structures. An impact of the interaction with the underlying structure was also covered.

1 Asst. Professor, Dept. of Metal and Timber Structures, Technical University of Brno, 95 Veveri St., Brno, 662 37, Czech Republic
Within the global analysis of spatial truss systems, the author explored the real behaviour of timber structures with connections made on the basis of steel plates slotted into timber profiles. Two types of connections have been considered, namely steel dowels with a diameter of 16 to 20 mm for steel plates 5 to 8 mm thick and nails with diameters 3,1 and 3,4 for thin steel plates 1,25 mm thick (system Greimbau).

The analysis aimed at theoretical problems involved in designing these structures and verifying their real behaviour in the process of their assembly and serviceability. The construction project of two structures described in this paper was worked out by MiTek Industries. In case of roofing a cylindrical shape with arched trusses, all load-carrying members were made from solid timber and in case of the structure with main trusses, the external members were made from glulam and other members from solid timber. Some experience with application of glulam elements connected by means of steel plates are adopted from abroad (Steck 1995), or the BSB system (Blumer and Jucker 1998). The structural systems shown here were used in the Czech Republic for the first time and that is why it was necessary to solve a number of conceptional and partial problems along with the issue of fabrication.

Fig. 1 Spatial truss system of sports hall
Spatial systems with arched or framed trusses
The major advantage of spatial trusses is the possibility of designing structures with large spans using common profiles with relatively short lengths. They also enable the combination of members from solid wood, glued laminated timber, or steel. These systems are suitable for creating complex geometrical shapes required in the architectural design.

Results of the structural analysis with nailed steel-to-timber joints were reflected in the system for roofing sports and multi-purpose halls. An example of this type was realised in the Czech Republic (Frydlant n. O.) in 1998 as the roof for sports halls with the ground plan dimensions of 40.5 x 60 m (Fig. 1). All members in the system are made of solid timber. Connections of member in the nodes are designed as four steel slotted plates 1.25 mm thick and nails with a diameter of 3.1 mm. The timber structure is supported on concrete frames by means of steel bars. For assembly and transportation reasons, the whole structure had to be divided into individual sections, which were later connected by steel plates 5 mm thick and by steel dowels 16 mm in diameter. Spatial behaviour of the structure results from the arrangement of its members which create a system of truss arches in the transverse direction and a system of framed trusses in the longitudinal direction. The whole system is complemented by bracings located at the level of the upper chords.

Fig. 2 Spatial truss system with concrete columns used for the tennis hall
The theoretical structural analysis was carried out on a spatial computational model, taking into consideration the slip which can occur in mechanically fastened joints, the influence of long-term loading, and the effect of assumed displacement and angular rotation of the support concrete frames. The Department of Metal and Timber Structures at the Technical University of Brno evaluated the results of the analysis of other structures made from both solid and glued laminated timber, which are useful even for their implementation in practice. Our experience from fabrication, assembly, erection and serviceability of the structure up to now have confirmed favourable features of these systems, especially their high spatial stiffness.

Spatial trusses with columns
Spatial truss systems can be successfully applied to roof surfaces with curved or polygonal shapes, if they are supported on peripheral columns with variable heights. Their main asset is a simple structure which is reflected in its economical production and fast assembly. Basic roof parts are designed in the form of trusses, whose geometrical shape meets the requirements of both architects and users. The columns can be made of steel, concrete, or glued laminated timber. The systems are suitable for sports and multi-purpose halls, shopping centres, or for other applications.

The results of the theoretical analysis were used again in 1998 in the design a of a roof structure (Frydlant n. O., Czech Republic) for a tennis hall (Fig. 2). The required cylindrical shape of the roof was created by supporting the structure on concrete columns with variable heights. Its external chords are manufactured from glued laminated timber with a profile of 180 x 300 mm, other members are from solid timber. The connections of members in the nodes and the assembly connections were carried out by means of four to six steel-to-timber joints 1.25 mm thick and nails of 3.1 and 3.4 mm diameter. The principal structural detail to be solved was the connection of the lower chord (Fig. 2). It was necessary to place a relatively high number of nails in the area of the connection and to find a technological method of preventing the glued layers from delamination and from crack formation in the region of faces of the connected profiles. A critical issue to be solved from the point of view of designing and fabrication was the shape and magnitude of camber. The resulting parabolic camber of an amplitude of 40 mm was calculated considering joint slip, combined impact of humidity, and duration of loading. The intermediate trusses, which transfer load actions from the roof coat onto the primary trusses are connected by means of bolted joints to the vertical members. Spatial stability of the structure is secured by diagonal bracing trusses in the end roof bays.

SELECTED SPATIAL SYSTEMS FOR TIMBER ROOF STRUCTURES

The major advantage of spatial systems is the possibility of optimal use of material while respecting user’s and architect’s requirements (Natterer, 1998). The latest overview of types of structures built in Europe which shows their basic characteristics is found in (Nevado 1999). The remaining part of this paper is devoted to two types of spatial structures, namely a pyramid-shaped structure spanning over a chapel and a roof structure formed by curved ribs, which was used over a school building. Vital structural details found in both types could be solved by means of steel connectors.

Pyramid-shaped roof structure
A spatial load-carrying system from glue laminated timber, solid timber and steel members (Fig.3) was designed for a chapel with a star-shaped ground plan (Chudcice u Brna, Czech Republic, 1994). The main corner purlins are from glue laminated timber, other load-bearing members from solid timber and frames over the entrance from steel. The upper part of the structure houses the ceiling of a campanile which also serves for stiffening the structure. The computations were made both according to a simplified model of the basic load-bearing system and according to a more accurate model, which included secondary load-bearing elements as well, whose effect on the favourable serviceability of the system is significant. Basic structural details of spatial trusses is represented by the nodes, in which more members converging at different angles must be connected. Member connections were carried out with the help of steel elements and bolted joints enabling the transfer of compression and tensile forces.

Roof structures made from curved ribs
Systems made from curved or framed ribs are used for roof structures over circular, rectangular and irregular ground plans (Straka 1991). Curved ribs can be manufactured in two ways. Either as arched ribs of glue laminated cross section or as members composed of lamellas connected by mechanical connectors (on the de L Orme principle). The spatial systems formed by mechanically connected arch ribs might be, under certain conditions, suitable for structures with smaller spans. The ribs can be manufactured even in firms equipped with usual machinery.
Spatial trusses consisting of curved lamellar ribs have been theoretically analysed. The analysis took into account various types of connectors such as different variants of joint bolts, dowels, nails, toothed plate connectors, connections using steel plates or punched metal plate fasteners.

After evaluating more options, a spatial system from arched ribs was developed (Fig. 4). It was fabricated and assembled for a school building (Brno, Czech Republic, 1995). Timber ribs are hinge-supported on a steel wall beam. Theoretical span of the structure is 14.5 m. Basic load-bearing elements are arched ribs designed as two lamellas with cross sections 50 x 200 mm, corner ribs are formed by three lamellas with identical cross sections. The lamellas were interconnected by bolted joints 16 mm in diameter. In the regions with maximum bending moments, the connections are solved as steel plates. The load-bearing layer of the roof coat is formed by boarding, the ceiling by gypsum fibreboards. Deformations of individual ribs were tested on selected segments, overall deformations of the structure were evaluated during the assembly and in different periods of time during the serviceability of the structure. Thus, the assumption of sufficient structural rigidity was confirmed. Maximum theoretical value of deflection (48.3 mm), corresponding to 1/300 of the span, proved to be satisfactory. In comparison with other types of structures, it displayed favourable economic factors, simplicity of fabrication and speed of assembly. These structures can find application for roofs of houses if a more complex geometrical roof shape is required.
CONCLUSION

The main objective of this paper is to present the results of theoretical analysis and implementation of several types of timber load-bearing systems. Attention is focused on spatial truss systems with connectors based on steel node elements. Spatial truss systems with mechanical joints can be more advantageous than the systems with massive glued laminated frames or arches. One of the positive features is an easy location of technological equipment in the space between the chords. Objective evaluation of real behaviour of load-bearing elements and connectors can be best acquired by analysing behaviour of complete structural systems in the process of assembly and both short-term and long-term serviceability of the structures. Results and guidelines derived from the analysis will be used in designing similar load-carrying systems. This paper was elaborated as a partial task within the framework of the research task reg. no. CEZ: J22/98:261100007.

REFERENCES


