Developments in the design and construction of wood structures

Seminar X

Developments in the Design and Construction of Wood Structures

Développements dans la construction en bois: projet, calcul et exécution

Fortschritte im Ingenieurholzbau

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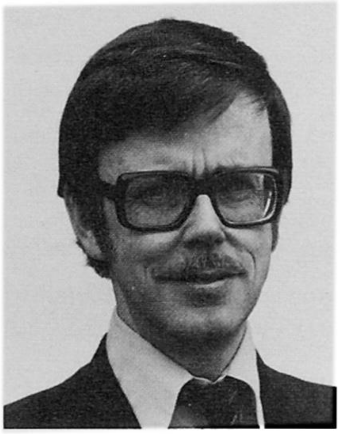

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SUMMARY
The field of timber structures comprises questions concerning material properties, fasteners and connections, structural components, structural interaction between components in buildings and bridges, transportation and erection, protection and maintenance. This report focuses the attention on some specific problems which deserve special attention by structural engineers and researchers.

RESUME
Dans le domaine des constructions en bois, il y a des questions concernant les propriétés des matériaux, les liaisons, les éléments structuraux, l'interaction entre différents éléments dans les bâtiments et les ponts, le transport et le montage, la protection des structures et l'entretien. Cet article attire l'attention sur quelques problèmes particuliers méritant l'attention des ingénieurs et des chercheurs.

ZUSAMMENFASSUNG
Im Ingenieurholzbau stellen sich Fragen im Bezug auf Baustoffeigenschaften, Befestigungsmittel und Verbindungen, Bauteile und ihr Zusammenwirken im Hoch- und Brückenbau sowie Probleme aus den Bereichen Transport und Montage, Holzschutz und Unterhalt. Dieser Einführungsbericht macht sowohl den praktisch tätigen Ingenieur als auch den Forscher auf einige Probleme aufmerksam, die spezielle Aufmerksamkeit verdienen.

1. INTRODUCTION

There is a clear trend of increasing the effort to use timber resources more efficiently. This will among others mean a change in methods and material selection with the changing raw material supply. This also forms a background for the need for the development of new or improved methods for the design and construction of wood structures. Since wood species and other conditions are different all over the world the solution might come out differently in various countries.

Developments are expected to take place within the following main areas :

- New or improved knowledge of existing wood materials. Development of new types of wood based materials.
- Better knowledge of the behaviour of fasteners and connections. Development of new types of fasteners and connections.
- Better knowledge of the behaviour of different types of structural elements and structures. Development of new types of structural components and structural systems.
- Progress in standardization of wood structures, design and construction.
- Improved methods for the analysis of timber structures. Increased use of computer aided design (CAD). Improved application of reliability based design.
- Improved methods for wood construction.

At the 11th Congress in Vienna |2| the majority of the contributions to the theme on Timber Structures treated glued laminated timber elements or structures made of such elements. Only one paper in the Final Report concerns fasteners and connections. Therefore, papers on basic problems of timber strength and stiffness related to structures - such as duration of load, moisture effects and fracture mechanics applications - as well as papers on joints and fasteners and on structural components are especially welcome for the coming 12th Congress.

2. MATERIALS

The designer must have basic knowledge of the peculiarities of the natural material wood. Such knowledge is of utmost importance for the understanding of the behaviour of various timber connections and structural components.

2.1 Timber

Better knowledge is still needed of timber as a material both on a microscopic and on a macroscopic scale. Some subjects within this field will, however, fall outside the theme of this paper.
The properties of structural lumber are related to the stress grade obtained by visual or machine stress grading. By in-grade testing the properties of each grade of a certain species are determined for a large number of specimens selected at random.

In many European countries except the United Kingdom hardwood has barely been used for structural purposes. In Germany for example tropical hardwood such as Bongossi has been used for footbridges etc. This material has high strength, but is rather heavy. Some hardwoods have a natural preservation against fungi attack etc.

In some countries experiments with different modifications of wood have been carried out. Some of these modifications aim at structural purposes.

2.2 Wood based materials

There are a few developments concerning the use of new wood based materials, which may serve structural purposes. Typical such products are sheets (plates) of chipboard and flakeboard, fibreboard and plywood.

The use of plywood for structural elements is widespread and well-known. Fibreboard, mainly hardboard, has been increasingly used for many structural applications. Special care is required with respect to moisture influence and creep. Therefore, hardboard-webbed beams are used for rather small structures.

Some interesting possibilities are offered by new types of chipboard and flakeboard, which may be designed with oriented chips, with chips of different sizes and types and layered with respect to strength requirements. The low tensile strength perpendicular to the board plane creates a problem. Long-term behaviour and durability are questions that need further study before such boards can be used with full confidence.

In recent years there has been an increased use of veneer laminates, which are made from veneers of usually 3 to 12 mm thickness glued together with parallel fibre orientation. Although a number of research papers (mainly from the USA) exist on this type of wood-based material more research is needed to determine different properties especially when other species are used.

2.3 Material properties

2.3.1 Stiffness properties

Some effort has been made to establish theoretical models for the determination of the modulus of elasticity from basic material data for a wood-based material such as chipboard. Such models may then be used to simulate the change in stiffness due to changes in different basic parameters.

2.3.2 Theories for wood strength

It has been a tendency in recent years to turn to the questions of basic behaviour of wood at cracking and up to final failure. Some failure stress formulas, which have been popular during a few decades, such as the Norris formula, have been questioned repeatedly. It is therefore important to determine the limitations of such theories and to try to find new ways of describing and predicting timber failure. It has been shown, see e.g. |6| , that the simple empirical formula by Hankinson for typical situations in a highly anisotropic material like wood gives a very good approximation to the actual failure stress.
In 1978 the First International Conference on Wood Fracture was arranged at Banff, Canada |3|. Many of the contributions treat problems concerning wood as an anisotropic, brittle material. It is shown how Fracture Mechanics can be applied to determine wood fracture in different situations. After that Conference further research within this field has been carried out and some of the results ought to be brought forward as contributions to the IABSE Congress, when it now will be held in Vancouver, Canada.

Some paper on analytical studies aiming at either biaxial or even triaxial failure criteria for anisotropic materials is certainly also welcome. Such criteria are often formulated as interaction type formulas including biaxial (or triaxial) stresses or strains and other parameters of importance. They are therefore well suited as a basis for design criteria.

2.4 Load effects

Wood is a viscoelastic material and the long term behaviour is of great importance for the proper design of wood structures. The effects due to duration of load are

of two kinds :
(1) Deflection increase (creep),
(2) Strength reduction.

There have recently been different proposals of viscoelastic fracture mechanics models and cumulative damage theories for the prediction of the influence on strength of duration-of-load combined with different defects such as initial cracks. Papers on such theoretical models should certainly be of interest for the seminar.

2.5 Environmental effects

The environment defines the "working conditions" for timber structures. The air humidity is of special importance both for the strength and stiffness of timber. In recent years, however, there have been several studies, mainly in Canada, showing that for lumber in structural sizes, which has certain defects the influence of high moisture content is much less than for clear wood. Therefore, it should be of great interest to find methods for basic understanding of moisture migration and accumulation in different timber structures used in different situations such as wall and roof structures.

A special problem is created by changing humidity. Often the resulting moisture content variation in the wood is of a periodic nature. Some earlier studies show that certain types of moisture cycling cause a more rapid accumulation of creep deflection than other types. For this problem there is quite a lot of more research to be carried out before we are able to tackle all typical moisture change patterns. The basic mechanism of moisture cycling effects has to be understood first.

3. CONNECTIONS

3.1 Fasteners

Some new types of fasteners such as screws, bolts, nails and staples have been developed in recent years. They are designed to give better and more reliable joints, although many of them are only suitable and economic for certain applications. In some of these cases the new fasteners are only variants of existing types and the actual difference is not great.

A deeper knowledge of the behaviour of different types of fasteners is needed for example for single fasteners, rows of fasteners, for short term and long term loading etc. The influence of moisture content and moisture cycling, especially in combination with creep, are of great interest for the behaviour of mechanical fasteners. A special question concerns fasteners in parallel laminated veneers.

3.2 Metal plate connections and special connections

The metal plate connectors used as nail plates and nailing plates for trusses and similar structures are well known. For special applications different prefabricated special metal plates have been developed for different simple connections such as beam-to-beam connections, see Fig.1, beam-to-column connections and simple moment resistant joints. In some of these connections the plates are nailed through predrilled holes, in others it is a joint with plates and dowels.

For column footings the behaviour of traditional types of cast-in-place rolled steel profiles such as channel section connections has not been investigated properly. New developments include such wood-to-concrete column connections, where glued steel bars are penetrating into the column end and cast into the concrete.

3.3 Glued joints

Some new types of glue are still appearing on the market. Some of them show certain advantages in different applications. The basic knowledge of gluing and glue joint strength, i.e. how to make a reliable and strong glue joint is still unsatisfactory.

The widespread use of finger joints has certainly lead to a better use of timber resources. The knowledge of the behaviour of such joints under long term loading and in varying moisture conditions is still incomplete.

See further the more comprehensive review on timber connections by E.Gehri in section 3 of his report to the 11th Congress |1|.

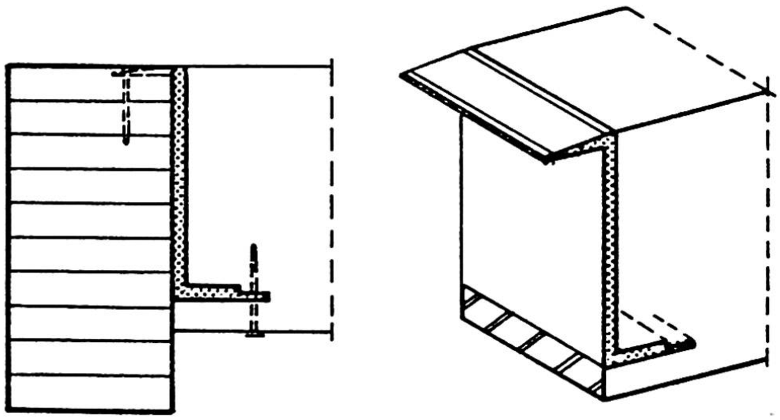


Fig.1
Special metal (aluminium) connector for a beam-to-beam connection.

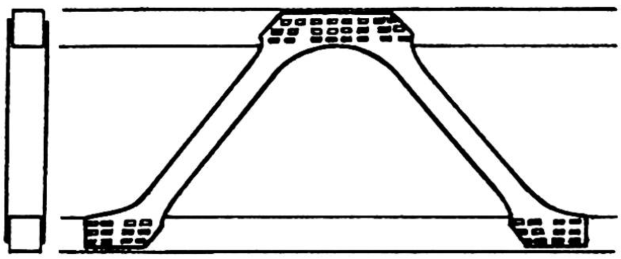


Fig.2
Truss beam with cold-formed steel plate diagonals integrated with nail plate connections.

4. BASIC ASPECTS ON WOOD DESIGN

4.1 Statistical aspects on the strength and stiffness of wood, fasteners and structures

For the practical application of probabilistic theories and for other purposes statistical data on wood strength and stiffness are needed. The basis for these data is of course an extensive testing. Simulation studies using good mathematical models of detailed structural behaviour may, however, show the influence of changes in different parameters. Since the scatter in statistical data for timber and wood based materials is mostly very large, many specimens have to be tested to give reliable estimates for the desired strength and stiffness properties. Computer simulations may therefore be an attractive alternative for economical reasons. With such simulation models the influence of different types of structural defects may be studied.

It is a well-known fact that the strength of a timber structural member is reduced when the size of the member increases. The basis for the study of size effects is the Weibull theory, which was established by the Swedish researcher Waloddi Weibull in the late 1930's. It is desirable that this class of methods is made into a practical tool for engineers.

The behaviour of timber structures under service loading conditions has not attracted as much attention from the research engineers as the ultimate limit state. It is important, however, to make the design engineer aware of the statistical aspects on the stiffness of timber structures, such as load sharing between members in floors etc.

4.2 Reliability of timber structures

There have been some efforts towards a reliability-based design for timber structures. Papers which show applications of safety concepts and probabilistic methods to wood structures are welcome. It is especially desirable that the work is brought forward to a state, which makes the methods usable for the practising engineer. New developments include the so called Load and Resistance Factor Design (LRFD).

For a proper use of reliability concepts in wood structure design, a sufficient amount of basic data for statistical distributions of engineering properties is needed for different structural materials and elements such as gluelam beams, round timber poles etc.

4.3 Computer aided design (CAD) of timber structures

The computer has - at least to some extent - been introduced as a tool for the design of timber structures, for example in the form of some drafting systems. However, systems where design and drafting are integrated seem to have been developed only to a limited extent, for example in some special applications such as roof trusses. A rather fast development of computer aided design and manufacturing (CAD/CAM) applied to the field of timber construction is expected. This will mean that for a housing project a computer and a common data base will support both the design and the automatic drafting of trusses and timber framing as well as the manufacturing of the components. There is also a trend from component design to a complete 3-dimensional design. Therefore, papers that describe integrated CAD/CAM- or CAD-systems using interactive computer graphics for timber structures are most welcome.

5. STRUCTURAL COMPONENTS

5.1 Lumber and gluelam

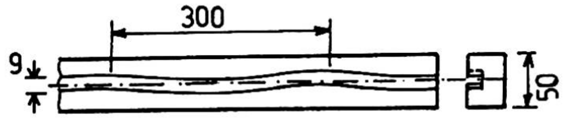
Machine stress rating for structural lumber is now established in the timber industry of several countries.

For gluelam there has been a tendency in some countries to increase the thickness of the laminations. For example in Sweden there has been a recent increase from 33 mm thickness to 45 mm. Some attention has been drawn to special design problems such as gluelam beams with holes of different shapes and to different other stress concentration problems at sections where an abrupt change in beam depth occur.

5.2 Built-up beams and stressed-skin elements

Much effort is still spent to acquire better knowledge of the behaviour of different types of structural elements of wood or wood products, also for elements where the wood material is combined with other materials such as steel or lightweight concrete. Many such composite elements have been developed during the last decade. The majority of these elements are beams of different material combinations. Other important components belonging to this category are stress-skin elements intended for use for either walls, floors or roofs. A study of composite elements should include the influence of duration of load, moisture content and moisture content variation. Both the static and the dynamic performance is of interest for some of these elements. In the developments of new types of composite structural elements it is of vital importance to try to select the material in an optimal way, taking the special properties of each material into consideration.

Based on these principles a number of different standardized ('pre-engineered') composite beams have been developed during the last few years. Some are variants of earlier types of I-beams or box-beams with hardboard or plywood web and flanges of lumber or laminated veneer, Fig.3. A new type of small box-beam (or column) recently presented in Sweden has hardboard web and flanges of cold-formed thin-walled steel plate.



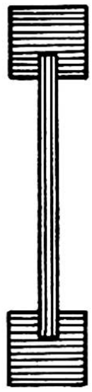


Fig.3 I-beam with corrugated web and flanges of laminated veneer.

Small standardized truss-beams with parallel flanges of lumber and falling and rising diagonals of steel rods were introduced in Sweden a couple of years ago. The steel rod is bent in a zig-zag pattern and placed in slots cut into the middle of the flanges. The product is marketed under the name of Wirewood and is intended to be used as wall studs, roof beams for small spans etc.

Another recent pre-engineered truss-beam with lumber flanges is shown in Fig.2. The diagonals are of thin-walled steel plate, cold-formed to give a cross section which is stiff enough to give sufficient safety against buckling. The ends of the diagonals are shaped as nail plates (tooth-plates) and the whole set of two diagonals and integrated nail plates shown in Fig.2 is pressed into the lumber flanges.

The following list of different stressed-skin elements, where timber and wood based materials work in complete, or partly, composite action with steel or concrete, just gives some examples :

- Joists of timber or of built-up (wood and wood based panel) beam sections <u>and</u> steel plates,
- Timber joists and concrete plate(s),
- Thin-walled, cold-formed steel sections (trough or C-shape) in composite action with panels of wood based materials such as plywood or chipboard. Glued or screwed steel-to-panel connections.
- Profiled steel joists pressed into chipboard flanges.

5.3 Columns

Some developments have been made that shed more light on the behaviour of simple columns. The influence of different inherent defects on column strength should be an interesting theme for a paper at the Congress.
For larger buildings built-up columns are sometimes used. The most popular column type for such buildings is the glued laminated column.

5.4 Trusses

Because the roof truss is a structural element which is mass produced for small houses a tremendous amount of work has been carried out in order to find better forms of truss design, especially concerning the joints. Research towards better understanding of the behaviour of a typical roof truss is still underway in different countries. This research concerns the full behaviour up to failure load. The computer has been introduced as a rather common design tool for this type of components.

Different trusses have been designed with combination of steel and wood, e.g. where some or all diagonals are steel rods or steel tubes. Some of these types are the small standardized roof trusses discussed in section 5.2.

5.5 Arches and frames

For larger halls and industrial buildings several types of arches and frames have been used for special purposes, thus showing the possibilities which the material offers the designer. Many of these buildings, but not all, are of gluelam.

5.6 Shells and other three-dimensional elements

Different types of folded plates and shells were reviewed by Möhler |1|. Among the structures of this category are space trusses which, although used quite a lot in structural steel, are less common for timber structures.

6. BEHAVIOUR OF STRUCTURAL SYSTEMS

There have been some recent developments in structural wood systems such as pre-engineered buildings and standardized framed buildings. A good designer should make use of the special advantages of wood (and wood based materials) as a structural material and try to minimize the influence of the disadvantages.

6.1 In-service behaviour

As mentioned in section 4.1 there has been a trend in recent years to pay more attention than before to the serviceability limit state. In earlier days the main interest in this state was for deformations under long term loading. The development of lighter and more efficient structures, however, has led to a situation, where problems concerning the dynamic behaviour of structures occur more frequently. Since the stiffness of the structure then becomes an important parameter, the static interaction between different components will be of great interest as a means of reducing the deflection. Design criteria which only contain 'static' parameters such as stiffness, however, can only be regarded as tentative until a complete dynamic criterion with parameters such as damping and mass has been etablished.

For example for light-weight, long span floors — both in small houses and for other applications — the vibrational behaviour due to different kinds of dynamic loads has been the object of recent investigations, see references in |7|. The dynamic performance of such floors is of interest with respect to the comfort or discomfort felt by the user |7|.

Studies concerning the interaction of the main parts of the whole 3-dimensional structural system of a building are still rare. For 2-dimensional subsystems such as walls, floors and roofs subjected to in-plane loading there is, however, some knowledge concerning deformations and deflections under service load, cf.Fig.4.

6.2 Ultimate limit state

Apart from the improvement of traditional knowledge concerning the failure loads of wood structures subject to static loading there have been some trends also to look into the load carrying capacity under dynamic loading such as earthquake loading. Here questions concerning energy absorption may be of interest. The problem area ought to be touched upon at the congress, because earthquake resistant design is of such vital importance for many countries.

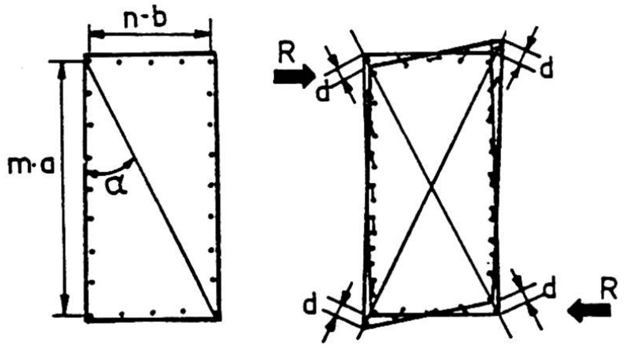


Fig.4

Nailed wall element of lumber and board plates. Deformations due to racking load.

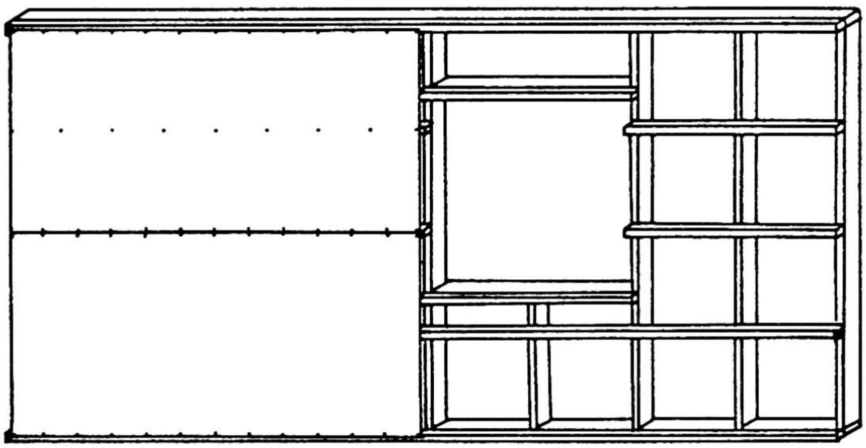


Fig.5

Timber-frame wall for low-energy consumption house.

6.3 Light-weight framing

There is an increasing need for better, low-energy consumption houses. This leads to a partly changed design also for wood houses. The 'energy efficiency' of the building becomes more important, which leads to a more general approach to the overall design problem including a systems approach to 'environmental design'.

A typical wall structure for a low-energy timber house is shown in Fig.5. Apart from the ordinary wall studs there are a number of horizontal battens to which plates of chipboard, hardboard, plywood or gypsum board are nailed. In this example wood material panels are used acting as a stressed-skin which stiffens the building against wind loading (wall-racking case). If the stressed-skin action is used both in walls, floors and roofs the weight of the building will be reduced. The stressed-skin elements may alternatively be designed as sandwich structures with a thick core of insulating material in composite action with the skin as was shown in a contribution to the 11th Congress |2|.

Another way of creating an efficient structure for a small house is by a series of parallel light-weight stiff timber frames, a system recently improved by developments at the US Forest Products Lab.

7. NEW STRUCTURES

Many interesting developments are continuously made in structural design utilizing the special properties of wood and wood based materials. These new designs are found in different types of structures in buildings, halls, bridges etc, Fig.6. What is wanted for the seminar are presentations of really new concepts and new solutions that deserve special attention from the practising structural engineer. Examples of new projects with structures of exciting new forms are found in buildings of a special character and buildings with long spans (halls for sport etc, churches, shopping centres, industrial buildings etc) and in bridges. Innovative designs may, however, also be found in small buildings like one-family houses, cf. section 6.3, or in simple small buildings like pole buildings, Fig.7.

Of special interest are papers which show the proper use of impregnated wood in different applications. Here, again, developments concerning pole structures ought to form a special subsection.

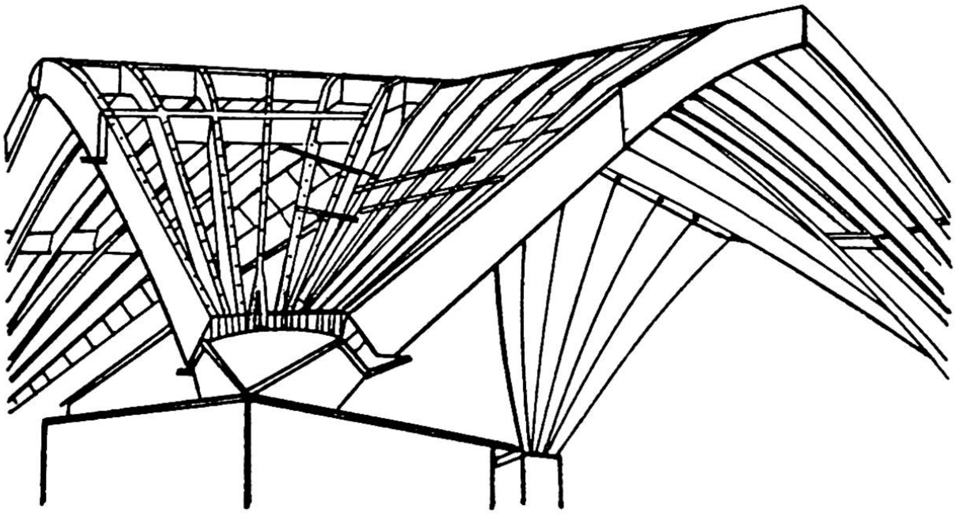


Fig.6 Glued laminated arches for a large hall.

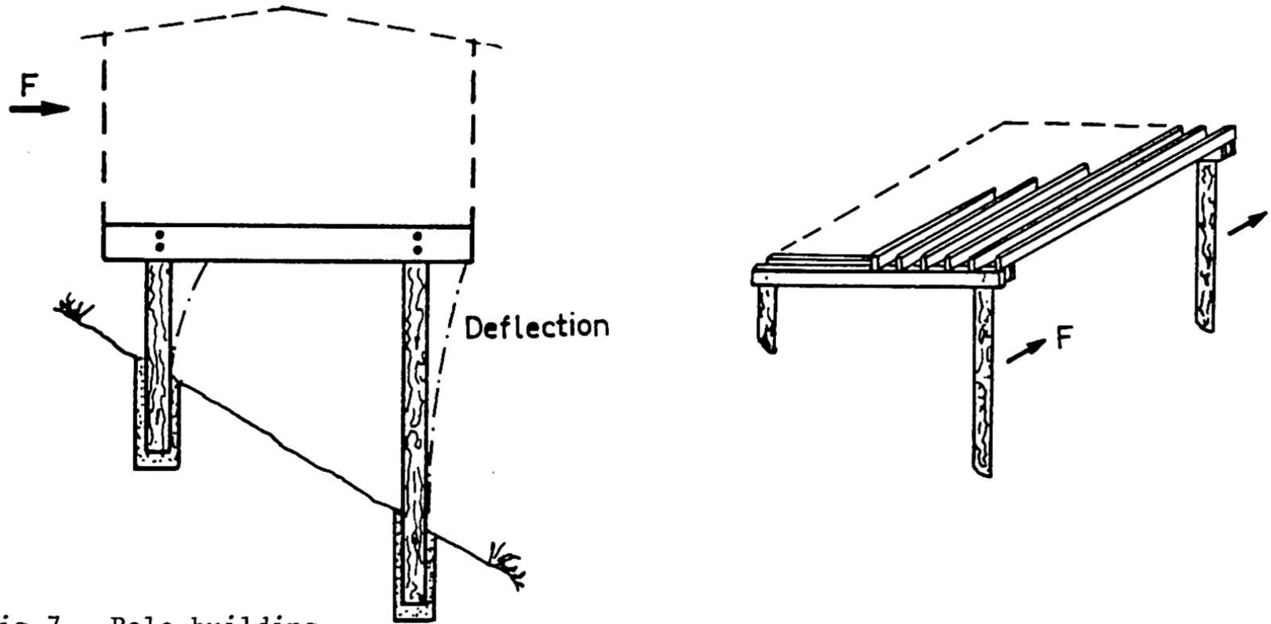


Fig.7 Pole building.

8. WOOD CONSTRUCTION, TRANSPORTATION AND ERECTION

As for the field of design there are continuously new developments concerning more efficient methods for the production, transportation and erection of timber structures. This is necessary in order to make modern timber structures competitive. Due to lack of space we will here only refer to the brief review by Möhler in |1|.

Apart from the construction of new buildings the rehabilitation and repair of existing structures also belongs to the field of wood construction. This kind of work is also of increasing importance to the structural engineer, and it is expected that - although there is an IABSE Symposium in Venice in September 1983 on the strengthening and repair of buildings - there will still remain some special questions within this field concerning timber structures that ought to be touched upon in Vancouver in 1984.

9. PROTECTION AND MAINTENANCE

A considerable amount of research and testing work has been invested on the problem of fire research during the past two decades. Therefore, there is now a basis for design rules for timber structures with respect to fire conditions. These refer both to fire *protection* and the behaviour of structures under fire. Some tentative design rules have been published in the CIB Structural Timber Design Code |5| by the Working Group CIB-W18.
Some special problems that ought to be treated in more detail concern (1) different timber structures under static loading combined with fire loading and (2) safety problems with respect to fire.

As mentioned before, e.g. in section 2.5, moisture performance of structures in different buildings is an important problem. *Impregnation* is one means for timber preservation as indicated above. It is, however, of vital importance that the designer is aware of different aspects of the moisture problem, since he may himself to a large extent contribute to the improvement of the resistance of the structure against fungi attack simply by designing with respect to the way moisture from the environment interacts with timber. The field of knowledge needed here may be called 'design for moisture protection' and it is a field that certainly deserves more attention by structural engineers.

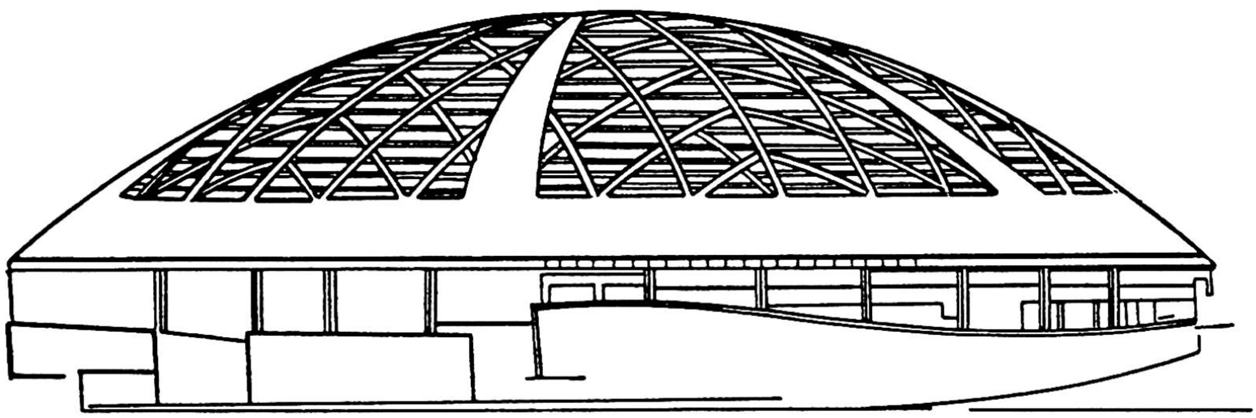


Fig.8 World's largest wooden dome, Tacoma Wash. Diameter just above 160 m.

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