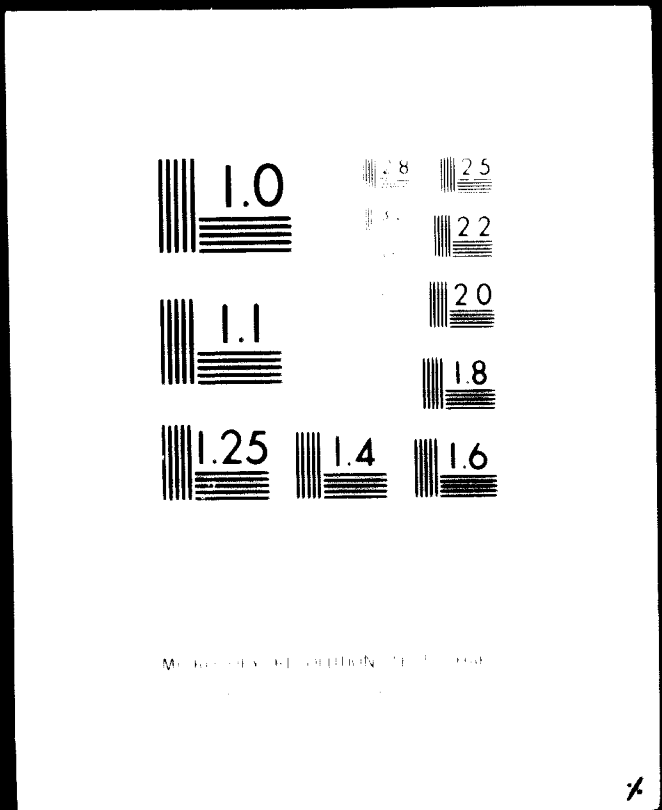
1 OF 1



24x

E

02133

Distr.
LIMITED

ID/WG.248/10
11 October 1977

ENGLISH

United Nations Industrial Development Organization

Workshop on Adhesives used in the
Wood Processing Industries

Vienna, Austria, 31 October - 4 November 1977

FORMULATION AND INDUSTRIAL APPLICATION OF SYNTHETIC RESIN ADHESIVES IN THE GLUELAM BEAM AND TIMBER ENGINEERING INDUSTRY 1/

by

H. Kolb*

* Director, Amtliche Forschungs- und Materialprüfungsanstalt für das Bauwesen "Otto-Graf-Institut" Abteilung Holz-und Holzverbindungen.

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

id.77-7343

TABLE OF CONTENTS

1. Timber engineering, their products and present stage of adhesive application

1.1. Historical development

In Europe the invention of glued laminated timber is usually attributed to the carpenter Hetzer in Weimar. It was Hetzer who acquired the first useful patent for the production of casein adhesive by which he glued boards together in a larger section. The boards were butt-jointed in the longitudinal direction and staggered when connecting different board layers. Up to now the name "Hetzer" - is still used for such beams in countries where the German language is spoken.

As Steinhaus shows (1), the American engineer Remington has scarfed and glued boards in 1850, according to a report of Prof. Culman, using a mixture of linseed oil and marine glue for a bridge near Montgomery, Ala. A similar wood bridge has already been built in 1848 near Stafford in England by Earl Talbot. The bridge has a clear span of 45 m.

During the years between both world wars the commercial glued laminated timber engineering grew up as an independent branch of industry in the United States of America as well as in Europe, especially in Sweden, Switzerland, the Netherlands and Germany. Until 1937 casein adhesive was the only one to be used. In this year a separate manufacturing plant was established for the production of "Kaurit" adhesive, the first urea adhesive developed by the BASF in Ludwigshafen. This adhesive was said to be water-proof and mould-resistant and in this superior to the casein adhesive. Soon, however, it turned out that its strength only fitted to the thinnest glue lines, in thicker ones the adhesive decayed within a short time. Only by the tests of H. Klemm (2) it was possible to make urea adhesive gap-filling by adding a filler in form of ground and cured bakelite. Thus it was possible to use this first synthetic resin for the production of larger structural components where glue-lines with a thickness up to 1 mm may occur.

In Germany the synthetic resin adhesive named "Kaurit-Leim WHK" displaced more and more the casein adhesive. After 1950 this adhesive was no longer used for glued laminated timber. In the USA and other countries casein adhesive were largely used for structural components even in the late sixties. From 1940 to 1950 successful tests were made by CIBA AG in Switzerland to fill the urea adhesive with flour extenders. By this method, it was possible to provide the adhesive with gap-filling qualities.

From 1940 to 1955 the resorcinol glues and phenolic resorcinol glues were developed for timber engineering. They were applied when high quality glue joints were required. Although they are much more expensive than urea adhesives, their application is steadily growing. In the USA and Scandinavia all structural components are glued today with resorcinol adhesives, but in Germany it is not more than 20 per cent at present.

When from 1970 to 1974 resorcinol adhesives run short all over the world, one looked for substitute adhesive and remembered the melamine adhesives or adhesive mixtures out of urea and melamine resins known since a long time. A cold-setting adhesive out of this group is more and more used for glued laminated timber. It is especially appropriate if heat can be added to the curing of the glue-line, for instance in a high frequency alternating field. Regarding the growing importance of environmental protection, waste-removal of resorcinol adhesives becomes more and more difficult. Seen from this point of view the urea melamine adhesive has an advantage.

The growing importance of the engineering of gluing timber described with the example of Germany. This is very easy because since 1935 the construction supervision requires a strict control of all firms producing glued structural components. While before the end of the second world war about 17 factories were producing glued structural components, in 1950 only three firms were left. Figure 1 represents the development of the number of firms which since 1950 up to now have proved their qualification for gluing bearing structural components.

The factories gluing laminated timber in Germany are divided into four groups. The firms of group A are allowed to produce structural components in unlimited length. In group B the length of the glued structural components is limited to 1[illegible] m. Firms of group C are only manufacturing special structures as e.g. finger joints for construction timber; the firms of group D are gluing pre-fabricated wall and roof panels for house construction. Only in 1956 the building trade in the field of timber construction and recovered in such a way that considerable investments for timber engineering could be afforded. Since that time up to now we state a permanent increase of the number of the firms of group A. The firms of group B reached a climax in 1963, but then decreased steadily until today in favour of the firms of group A. Between 1956 and 1959 the special structural components had their boom. Only in the last years the number of these firms increased again since finger-jointed timber is more and more produced in Germany. The firms of group D had their boom 1974. Since that time a consolidation has taken place.

The picture shows only the development of the number of timber gluing firms. It does not tell anything about the production. Since many years there is an annual icnrease of the consumption of glues for timber construction of 10 to 20 per cent. According to a rough approximation about 150,000 m3 of glued laminae were produced in 1975 from10 to 14,000 m3 of beams and girders by the largest factory. Thus Germany is ahead in Europe. In the USA the same development took place. However, one or two American firms are able to produce as much glued members as all German firms together. In other West-European countries a a boom in glued laminated timber can also be stated, however, with some delay and variable intensity. In some countries, the strong recession of the building trade has a disadvantageous influence on glued laminated timber whereas in other countries the orders are no matter of complaints. I do not want to speak about prices now.

A special development occured in the countries of Eastern Europe. Some years ago glued laminated timber played a very subordinate role and was sometimes forbidden. Sawn timber was a valuable export article which brought foreign exchange. In the last three to four years some countries especially the Soviet Union, Poland, the German Democratic Republic, Czechoslovakia and Hungary are making great efforts to establish timber engineering factories and to promote the production of glued beams and girders. A good co-operation developed especially with German firms supplying production plants and the "know-how".

Briefly we can say that the production of glued structural components will permanently grow in the next years and an end of the extension is not yet expected.

1.2. Glued end joints

Square timber and boards which are supplied by the saw mills have only a limited length. Nowadays boards are sold in Europe in lengths between 3 and 5 m. The production of larger members depends on the production of end joints with a high tensile and compressive strength between the members. Owing to the great importance of these joints in timber engineering detailed information will be given in the next chapter.

Until 1944 the boards were exclusively connected by scarf-joints. The scarf-joint relation (board thickness : scarf-joint length) was between 1 : 12 and 1 : 4 so that often different scarf-joint relations were used in the tension or compression zone of bending beams. In the USA large machines were developed for producing scarf joints scarfing the ends, often with a notch in the middle of the scarf-joint or with a glued small dowel in order to prevent a displacement of the ends of the baords during the pressing cycle.

Between 1944 and 1952 the finger joint was developed by K. Egner in Stuttgard (3) which rapidly displaced the scarf-joint. Since 1956 no factory in Germany uses scarf-joints in engineering. In the USA the change from scarf-joints to finger joints took place from 1965 to 1972.

According to the German standard DIN 1052 which regulates the production of load bearing timber structures in Germany, load bearing longitudinal joints must be executed by scarf-joints with a slope of the gluing area of 1 : 10 or by finger joints according to DIN 68140 which covers profile details of the fingers as well as the machining of finger-joints.

Figure 2 represents some forms of finger joints with one piece timber elements. All countries where timber is bounded appropriate standards.have been established.

While in former times, the finger had a length of 40 to 50 mm, the length of the fingers could be reduced in the course of time because the tool industry could offer appropriate cutters. Today the shortest fingers allowable in Germany have a lenth of 7,5 mm.

Normally the fingers are cut into the wood by adequate tools. It is also possible according to a method of Stricler (4) to press the fingers into the wood by means of a matrix under the influence of temperature. By means of the applied heat the curing time of the glue is accelerated.

Finger joints are not only used for joining boards or cants but also glulam beams or beam components. By this method it is possible to machine angular finger joints for framed construction see also 1.3.1.

Nowhere the development of new machines with better performance developed in such a way as in the field of finger joint machines. They possess a key position in timber engineering.

Especially for finger joints the curing cycle is shortened by applying both high frequency or contact heat.

1.3. Products of the timber engineering industry

1.3.1. Glued-laminated timber

The oldest and most important product of timber engineering is the so-called glued-laminated timber. This is a member made by laminating boards.

The most important glulam beams are the horizontally laminated beams (fig. 3a). Besides that there are vertically laminated beams (fig. 2c and 3c) and cross-laminated beams (fig. 3d). The different countries do not agree about how much layers a glulam beam must have in order to be classified under the term "glued laminated timber". The German standard DIN 1052 does not say anything about this. The Dutch standard NEN 3852 requires at least four layers for horizontally laminated beams, at least three layers for vertically laminated beams and at least four layers for cross-laminated beams in order to start the calculations from higher allowable stresses than for solid timber.

Since several years "glulam", a sub-committee of FEMIB (European Federation of Manufacturers of Industrialized Building Joinery) is dealing with the establishment of a special "European Standard Specification for Glued-Laminated Timber Structural Members". In Part I - Specification of Materials and Design Considerations - the number of layers for glulam beams vary from 4 to 100. This European Standard Specification shall become a part of a new ISO-Standard "Timber Structures". The preliminary session of the Committee ISO-TC 165, at Copenhagen was in September 1976.

The horizontally laminated beams have two essential advantages: the manufacture of beams and girders can largely be mechanized and automated. The production includes straight and bent members of all shapes and sizes. This work is not dealing with the production of glued-laminated timber with the corresponding machines and equipment (fig. 4). Examples of glued-laminated components: three-hinged frames (fig. 5) for span widths from 15 to 35 m, and arched frames (fig. 6) for span widths from 25 to 100 m and more. But not only joists, rafters or girders can be made from straight glued laminated beams but also three-hinged girders by means of finger-joints all over the beam section. Special machines are required for cutting and joining finger jointed beams. Figure 7 shows a three-hinged beam of this type, the span varies between 15 and 25 m. Although these constructions are up-to-date in shape, it has to be stated that the grain direction of the adjoining fingers are not parallel to each other thus only small compression stresses and therefore bending moments can be transmitted (5, 6).

Figure 8 shows a quite different application possibility of glued laminated timber. As it can be seen, even high-voltage beams can be fabricated. In this case the lower part which is in the soil has been reinforced by glueing on two further glulam beams.

Another new method for manufacturing glued-laminated timber has been developed by scientists of the Forest Products Laboratories, Madison, USA (7). The new product is called Press-Lam Lumber and is assembled by veneer plies. Fig. 9 represents the fabrication of Press-Lam. The principal features that distinguish the Press-Lam process from conventional plywood manufacture are the following: peeling 1/4-inch (6,35 mm) veneer, using stored heat from veneer drying for curing thermosetting adhesives in a continuous non-heated laminating-press (not yet available for use in industry) linked with cross cut saws and gang rip saws. This continuous process has a capacity of 4-feet (120 cm) wide panels made of veneer-laminae. The endless laminae panel is crosscut and ripped according to preselected dimensions.

1.3.2. I-beams and box beams

I-beams and box beams can be completely manufactured from glued-laminated timber, but normally only the flanges are made from glued-laminated timber and the webs from wood derived panel products, viz: chipboards, fibreboards and plywood. The "Kämpf-web-beam", an I-beam has a web from crossed board layers according to fig. 3. I-beam are manufactured in view to minimize waste. Their production is more expensive than producing glue laminated beams of square cross section. I-beams can be produced as beams only. Box beams will meet special stiffness requirements. It has to be stated that the fire-resistance of box beams with plywood webs is much more unfavourable than for beams with a rectangular section.

The following corrugated web beams, grid system beams and Trigonit beams belong to the I-beams.

1.3.3. Corrugated web beam

The corrugated web beams are composed (fig. 10) of a plywood web and solid wood flanges. At both web edges are chamfered and glue spread before driven into the grooved flanges. The beams are automatically fabricated by a special machine. Besides a great load capacity they have a low weight and can especially be used for flat roof beams and trusses (8).

1.3.4. Grid system beam (DSB-beam)

As the corrugated web beam the grid system beam (DSB) is an invention of the architect Hanns Hess (9). It is a glued timberwork construction of which the struts are inter-linked with the flanges by tenoned joints into the mortise.(fig. 11). The parallel tenons inter-link each other when driving into the mortise, by means of a "sliding glueing" action. Those assemblies can only be applied when the surfaces engaged are of small size.
As the web is of the grid system a good ventilation is guaranteed also when several girders are mounted adjacent to each other. The field of application of this beam is similar to the corrugated web beam. There are some varieties of this beam, especially with respect to the assembling of the struts into the flanges. Those special constructions are largely used for temporary work in the building trade.

1.3.5. Trigonit-beam

The Trigonit-beam is a glued I-beam similar to the DSB-beam. However, the struts are not glued into the flanges but connected at their ends by finger joints. The flanges are nailed on both sides through jointed fingers, see fig. 12. This beam has also been invented by the Swiss carpenter Kämpf (10). The Trigonit glued beam is very easy to manufacture as the finger jointed struts are only assembled and glued together. These struts have to be kiln dryed. The flanges can be nailed in an air-dry condition.

1.3.6. FJC wood truss system

FJC means finger joint connected. This system has been developed by Hoyle and Strickler of the Washington State University Pullman, Wash. (USA) (11). The nodal points of solid wood truss members are finger jointed. This system transmits strut forces directly, develops primarily compression and shear stresses on the finger joints, and avoids or minimizes tensile forces components perpendicular to the grain. Both flat and ptiched trusses can be designed with this connection system. The finger size used was: length 6,35 mm (0,25 inch), pitch 2,54 mm (0,1 inch), tip thickness 0,38 mm (0,015 inch) and slope 1: 7.

2. Characteristics which outline the application of adhesives in timber engineering

There is no adhesive available satisfying all requirements necessary for glue joints on load bearing timber members. However, many adhesives satisfy the requirements which wood adhesives must meet. Hereafter the minimum requirements which syntehtic resin adhesives have to fulfill:

a) high dry bond strength (higher than the timber strength)
b) permanent stability long term durability
c) water-resistant bond
d) gap-filling quality and stability of glue-line strength
e) cold-curing

Adhesives which do not cover these five features are not suited for glued timber structures. In order to determine these properties, the German standard DIN 68141 "Timber joints; testing of glues and glued connections for load bearing timber structures; quality specifications" is based on many results of applied research work. As the testing of adhesives is subject of another document reference is made to those paragraphs of the standard dealing with minimum requirements:

ad a) This requirement must be made in every case. It is especially applied to softwood. But even hardwood failures must have a sufficient percentage of wood fibres at the gluing joints. For the testing of plywood, for instance, the wood fibre portion of a split glue-joint is an essential criteria for the quality of the glue bond.

ad b) It has not to be mentioned that an adhesive must be permanent in stability proving the long-term strength of glued joints. Research work of long term cycles has to be done. In this connection reference is made to the article of Mr. Raknes (12).

ad c) It has to be mentioned that the term "waterproof" has never been standardized or defined in any way. Nevertheless it is frequently mentioned, and this is done here, because everybody knows what it means. Animal adhesives and casein adhesives are not waterproof. They absorb water, swell and loose their strength. The requirement "waterproof" is applied for members exposed to weather conditions (exterior use); for roof members (interior use) it is a precautionary measure only for a possible exposure against water or high humidity.

ad d) On very small members and joinery work the glue line may be thin (glue coat thickness 0,1 mm) but the wood surfaces have to be planed. This is not the case for big members as they are used in timber engineering. Adhesives are gap-filling if they are stable until a thickness of 1 mm and if the joints reach high strength values.

ad e) "Cold" will here be a temperature of at least 20°C. Higher temperatures often applied accelerate the curing process of the adhesive. Nevertheless an adhesive should cure at 20°C in order to guarantee a regular curing.

Apart of these main adhesive properties, a number of other features are required or at least desirable.

f: weather-resistant
g: long pot life
h: short curing times
i: easy preparation of ready to use glue blend
j: good applicability
k: preventing unhealty hazards
l: anti-pollution of environment
m: curing by R-F heat
n: low priced

ad f) The expression "weather-resistant" has neither been standardized nor defined in any way. But everybody knows what is required: an adhesive which can be applied to members used out doors or under wet conditions without influencing the bond strength of the adhesive.

ad g) For binding big members only an adhesive with an extended pot life is suited.

ad h) It is desirable to have short curing times and, therefore, a short clamping cycle. But in most cases a short pressing cycle of an adhesive adequates a short pot life.

There is a reciprocal action between g and h. Short pressing cycles can be influenced through both a hardener or heating the glue joint.

ad i) All synthetic resin adhesives need at least two components: the resin and the hardener. In case a filler is added, there are three components, or four when adding water. A poor adhesive blend influence by various additives will cause bond failures. This danger can be minimized by controlled mixing equipment about which we will talk later on. The applicability depends on how the adhesive has to be spread on to the component surfaces (manually, roller-coating, curtain coating, spraying).

ad j) Synthetic adhesives are not hazerdeous to health but it is recommended to wear protection clothes and gloves while handling adhesives. During the summer season or in hot climates formaldehyde vapors are causing inconvenience. It is recommended to exhaust these vapors by ventilators. Human reacting allergic against synthetic resin vapor should not work within the gluing section.

ad k) Because of pollution problems it is no longer allowed to lead polluted water into rivers or other places. Therefore, water purification systems are necessary to be installed.

ad l) Curing cycles of adhesives can be accelerated by heat. The glue line can be heated by contact (heated plantes) hot air or by radio frequency. The application of radio frequency curing is not suitable for all adhesives.

ad m) The price of the adhesive amounts to 2,5 through 12,5 per cent of the material costs of a glued-lam-beam. As competition impacts the German timber engineering industry, glue costs will finally influence glulam beam prices, but the rate will differ on certain special constructions in timber engineering.

3. Synthetic resin adhesives - qualities and application in timber engineering

As we have already stated in chapter 2, only synthetic resin adhesives which have fulfilled the requirements of DIN 68141 may be used in Germany. All adhesives which have passed the test and are available on the market are listed on page 34 and 35. These are 18 resorcinol or phenol-resorcinol resins, viz.: 1 phenol-melamine-urea-formaldehyde adhesive and 6 urea adhesives.

Every resin is mostly accompanied by several types of hardeners; thus more than 40 ready-to-use adhesive blends are available. In Scandinavia and other countries there are similar lists which have, however, been established on the basis of other testing and quality standards.

In 1954 only four resins were available. The actual great variety of adhesives is due to the rapid increase of the adhesive consumption in timber engineering, the adaption of special qualities to consumer's requirements and, last but not least, the competition among the producers.

3.1. Urea adhesives

The urea adhesives are mainly interior-type adhesives. They are suited only for roofed members not exposed to weather conditions although the test includes immersion in water. No doubt that bonding failures cancause trouble more often on urea glued joints than on resorcinol glued joints but the high price difference of these adhesives is decisive in favour of urea in most factories of Central Europe. The price relation between urea adhesives and resorcinol adhesives with regard to the ready-to-use blend is 1 : 5. The aversion against urea adhesives is probably due to the fact that bad experiences have been made with plain urea adhesives or insufficiently filled adhesives. The tests made by Klemm (2) both with cured bakelite powder and with special flours (13) have shown that it is possible to produce a gap-filling urea adhesive. The latest unpublished tests in the Otto Graf Institute Stuttgard on approx. 20 years old members showed no strength decrease compared to strength values of recently glued members.

Compared to other syntehtic resins urea adhesives can be delivered in powdered as well as in liquid form. The powdered adhesive is for small consumers; large consumers preferably receive liquid adhesive on lower costs by tank trucks. Fillers must be blended separately before adding water; the glue blend is then ready for use including four components. Two of the adhesives mentioned include fillers either blended to the resin or the hardener which renders a wide range of the blend influencing the pot life and the pressing cycle. At 20°C and humidity of 65 per cent the pot life is rated by 45 minutes to six hours, the pressing cycle ranges from 8 to 13 hours. Low temperatures causing shorter pot life. At a curing temperature of 30°C (glue line temperature!) the pot life decrease varies between two hours and 15 minutes while the pressing cycle varies between 8 to 4 hours. This shows how important it is for assembly bonding to maintain a uniform climate, (balanced humidity). If the air is too dry it causes a pre-curing resulting in insufficient final curing during the clamp cycle. To shorten the press cycle curing can be accelerated by R-F-heating which is very economic; urea adhesives are better suited for this process than resorcinol adhesives. Some adhesives have been specially developed for the curing by radio frequency.

Urea adhesive waste water is less hazardous than that of resorcinol adhesives, thus the waste water clarifying is easier, when using urea adhesives.

3.2. Phenol adhesives

For a short period, between 1950 and 1952, cold-setting phenol adhesives have been used in Germany. The strength values obtained were good, but the p_H-value of 1 and less was rather critical. In numerous investigations in the USA and Germany it could be shown that the adhesive and especially the acid hardener will decompose the adjacent fibre bond. As some damages could be observed on structural members by using cold-setting phenol adhesives, thus the application in timber engineering in Germany is not allowed, however to a certain extent, they are used in Eastern Eruope (Czechoslovakia, USSR, Pland, GDR) instead of resorcinol resins. In Western Europe nobody will risk to use these adhesives, as resorcinol adhesives are available to a large extent.

3.3. Resorcinol adhesives

Plain resorcinol adhesives have excellent qualities and are certainly the best adhesives for glued laminated timber. But unfortunately, they are very expensive and can only be used today for special purposes.

3.4. Phenol-resorcinol adhesives

Almost all resorcinol adhesives which are used for bodning constructional timber are in reality phenol-resorcinol mixtures. Nothing is known about the relation phenol to resorcinol; this is a well kept production secret. In fact some adhesive producers have reduced, under the pressure of competition, the resorcinol proportion because resorcinol is much more expensive than phenol. A further measure to decrease the adhesive price is the addition of fillers, viz: coconut shell flour (Kokonit) or kaolin powder. These fillers have also their disadvantages. The addition of kaolin powder causes rapid tool edge wear effected by the polymerized glue lines.

Besides their high quality the phenol-resorcinol adhesives, called hereafter PR-adhesives, have another advantage, because there are two compounds only (adhesive and hardener). Most hardeners are powdered only the hardener 501 is liquid, and mixed with Aerodux 500 at a ratio 1 : 1. The liquid hardener tends to settle, therefore, it is necessary to stir up before use.

By the appropriate choice of the hardener it is possible to determine not only the usable life but also the viscosity of the adhesive. The glue coating system of the adhesive viz.: roll coating, curtain coating or spraying, requires a different viscosity. By adding "Aerosil 200" and curtain coating board edges the thread like glue coat will not run of the rim.

In comparison to the urea adhesives PR-adhesives are less affected by production defects. Good bonding strength can be obtained when the board moisture content is high. At 20°C and 65 per cent humidity the pot life ranges from 1 to 4 ½ hours and the clamping cycle ranges between 9 and 20 hours.

While the standard PR-adhesives can be applied up to 1 mm glue line thickness, Weyerhaeuser in Seattle, Wash. (USA) has proved that the adhesive WCO 87 B with a special filler will hold up to 1,5 mm glue line thickness. This adhesive permits to glue up beam parts ("side layup") applied in the production of glue lam poles according to fig. 9 (15).

3.5. Urea-melamine adhesives

Urea-melamine adhesives, usually used for gluing chipboards, have gained application in the field of timber engineering. In the years of resorcinol shortage (1970 and 1971) the BASF has developed an adhesive type called Kauramin 545 which has fulfilled the requirements for timber adhesive and can be regarded as a substitute for the resorcinol adhesives.

The curing behaviour of this adhesive in the high-frequency field or heated presses is very good; good results have been obtained in the production of wall paneling for prefab houses or at a curing temperature of 20°C for glued laminated timber. A disadvantage is the short usable life of 3 months within which the viscosity is increasing permanently. Besides that, the glueing equipment cannot be cleaned only by water, but a leaching solution has to be added. The prices of the adhesive mentioned under 3.1.; 3.5.; 3.4. are comparing as follows:

UF-glue : melamine glue : PR-glue = 1 : 3 : 5

But recently Kreibisch (16) has risen objections against cold-curing urea-melamine adhesives. He supposes that at 20°C only the urea component is curing but not the melamine component. Therefore, if specimens are first stored in cold water and than in boiling water, the melamine combination is composed by the first process, and during the second process the urea combination and the remaining strength is zero.

The result of these tests show insufficiency of long-term strength. This has not been stated with Kauramin 545. Probably this is due to the fact that Kauramin 545 does not only contain urea and melamine resin but also phenolic resin. Anyway a lot of research work has still to be done in this field.

3.6. Epoxy-resin adhesives

Because of their difficulty in use and the high cost these adhesives are normally not used for bonding timber. However, there are some applications where the use of such adhesives is desirable especially because of their durability in thick glue lines (mm to cm). This adhesive is especially employed for gluing broken timber elements or assembling steel members with wood. Glued steel pieces can serve as a reinforcement to timber members or as a connection to the ground (support) or to other elements. In general epoxy resins are less resistant to humidity and heat. However, a formulation has been designed by which these disadvantages can be avoided. At present an epoxy resin adhesive is tested in the Otto-Graf-Institute which promises to achieve the same qualities as the resorcinol adhesives. By adding asbestos flour its viscosity can be adjusted and the adhesive can be sprayed or poured. These resins have certainly a great future in the field of bonding elements for special purposes.

3.7. Other adhesives for glued laminated timber

Because of the high cost of the PR-adhesives and of the vulnerable resorcinol market (great shortage of resorcinol in 1970) many research laboratories make the attempt to replace the PR-adhesives by similar adhesives. The cold-setting phenol and melamine adhesives, for instance, can be regarded as a substitute. Further investigations have been made by the National Timber Research Institute of the CSIR, Pretoria, South Africa. Laboratory research and industrial test runs have been carried out with a modified tannin-formaldehyde adhesive made from an extract of wattle-bark (acacia mearnsii). It was shown that sufficiently strong glue lines can be obtained provided that a glue line temperature of at least 75°C can be applied to the center of the beam. The adhesive is called "TRU-link" and fulfills the requirements demanded by the South African standard SABS Specification 1089-1976.

4. Problems in adhesive technology arising through the use of wood preservatives

In Germany wood preservation is regulated by DIN 68800, wood protection in building construction. Part 3 of this standard stipulates that all timber members having bearing functions must be protected by wood perservatives. When brush, spray or dip treatments are used, the minimum quantities of perservatives are exactly determined.

For the pressure process the instructions of the producer must be followed. All preservatives must have a special test certificate given by the Institut für Bautechnik, Berlin and are submitted to a quality control. All preservatives admitted at present are published in the so called "wood preservatives list" (17). Regulations abroad are not as strong as in Germany. Other countries content themselves with protecting only elements exposed to weather or getting into contact with the foundation, for instance foundation for prefabricated houses, refering then to the pressure impregnation process which guarantees an optimum protection all-over the whole wood section. Unfortunately the pressure process is only effective for fir wood, but not for pine wood. Even the Cellon-process of which the industry thought to be of great success, used in the USA for impregnating poles, could not be applied in Germany because it does not guarantee a thorough impregnation of pine wood. As in Germany 90 per cent of construction wood used is of pine an intensive surface treatment is required. Good bonding can only be obtained on dried and planed lumber. The preservative treatment must be applied to timber elements before glue coating, because a later machining of the lumber (planing) would remove the whole protective layer. Consequently, in timber engineering a protective treatment can only be done by oil-preservatives which do not influence the moisture content of lumber.

At this stage one has to question whether the preserved surface will influence the bonding strength. This question was studied in detail and results are subject of standard DIN 52179 investigating good natured properties of glue preservative features. It is not possible to investigate whole groups of preservatives at once. However, it is necessary to investigate every preservative separately in comparison to the three adhesive groups UF, PR and melamine. Those preservatives having passed the test, are listed. Among the great number of oil-preservatives there is a water-soluble salt (Boliden-salt K 33) which is applied by the pressure process. The committee CEN 38 (wood preservatives) a European-Standardising Group is preparing the outlines of good natured adhesive/preservatives.

If the glue lines have polymerized the later applied preservatives have no influence on the bond strength of the glue. But after bonding a glue lam preservation should not follow within two or three days so that the glue lines can harden completely in a heated hall.

The question has not been solved how great preservative quantities should be applied on glued timber. According to DIN 68800, part 3, the following minimum quantities have to be applied by brush, spray or dip treatments:

wood exposed to rain	300 ml/m2 oil
wood not exposed to rain	350 ml/m2 oil

Such great quantities can only be applied to planed glued-laminated timber in four or more stages, but between the operations 24 hours drying time is necessary.

This method is unfeasible in practice. On the one side investigations are made to use smaller preservative quantities for glued timber and on the other side the preservative industry tries to find more effective preservatives, perhaps a feasible compromise can be found from the one or other side.

. **Bibliographie**

[1] Steinhaus, M.: Remington's wood bridges
Civil Engineering - ASCE, March 1968, p.60

[2] Klemm, H.: Neue Leimuntersuchungen mit besonderer Berücksichtigung der Kalt-Kunstharzleime, Verlag von R. Oldenbourg, München und Berlin 1938

[3] Egner, K.: Schäftzinkung von Bauhölzern
Mitt.d.Fachausschusses für Holzfragen beim VDI und DFV, Heft 32, 1942, S.87 bis 110

[4] Strickler, M.D.: Impression finger jointing of lumber
For.Prod.J. 17, 10, 23-28 (Okt.1967)

[5] Informationsdienst Holz: Hallen 3, Entwicklungsgemeinschaft Holzbau in der DGfH, Arbeitsgemeinschaft Holz e.V., Füllenbachstr. 6, 4 Düsseldorf 30

[6] Informationsdienst Holz: Konstruktionsblätter, Arbeitsgemeinschaft Holz e.V., Füllenbachstr. 6, 4 Düsseldorf 30

[7] Harpole, G.B.: Assessing a Continuous Precess to Produce Press-Lam Lumber, For.Prod.J. 26, 8, 51-56 (August 1976)

[8] Gerlach, H.: Wellsteg-Träger Handbuch, Gerco Industriebüro GmbH, München, 1974

[9] Handel, P.: Konstruktionsgrundsätze und Bemessungstabellen für den Dreieckstrebenbau, Wilhelm Ernst & Sohn, Berlin-München-Düsseldorf, 1970

[10] Czerny - v.d.Westen: Trigonit Holzleimbauträger, Ph. Schröder oHG, D 6361 Burgholzhausen, 1972

[11] Hoyle, R.I., Ir., M.D. Strickler, R.D. Adams:
A Finger Joint Connected (FJC) Wood Truss System, For.Prod.J. 23, 8, 17-26 (August 1973)

[12] Raknes, E.: Langtidsbestandigket av lim baerende trekonstruksjoner, Norsk Skogindustri Nr. 11-1971

[13] Eger, K. u. P. Jagfeld: Untersuchungen über die Verwendung von Streck- und Füllmitteln bei der Verleimung von tragenden Bauteilen. Berichte aus der Bauforschung, Heft 33 (1963), S. 45 bis 66, Verlag Wilhelm Ernst & Sohn, Berlin

[14] Egner, K. und H. Sinn: Beiträge zur Frage der Faserschädigungen durch sauer ausgehärtete Kunstharzleime. Holzzentralblatt 79.Jg. (1953) Nr. 156/157, S. 1679/81

[15] Coster, R.W., Gillern and Howell: A Gap-Filling Phenol-Resorcinol Adhesive for Laminating, For.Prod. J. 23, Nr. 11, S. 55-59 (1953)

[16] Kreibisch, R.E.: Preliminary Experiments with a Melamine/Urea-Formaldehyde Wood Adhesive, Adhesive Age, Oktober 1976, S. 27-29

[17] Institut für Bautechnik: Verzeichnis der Prüfzeichen für Holzschutzmittel, Erich Schmidt-Verlag, Berlin, April 1976

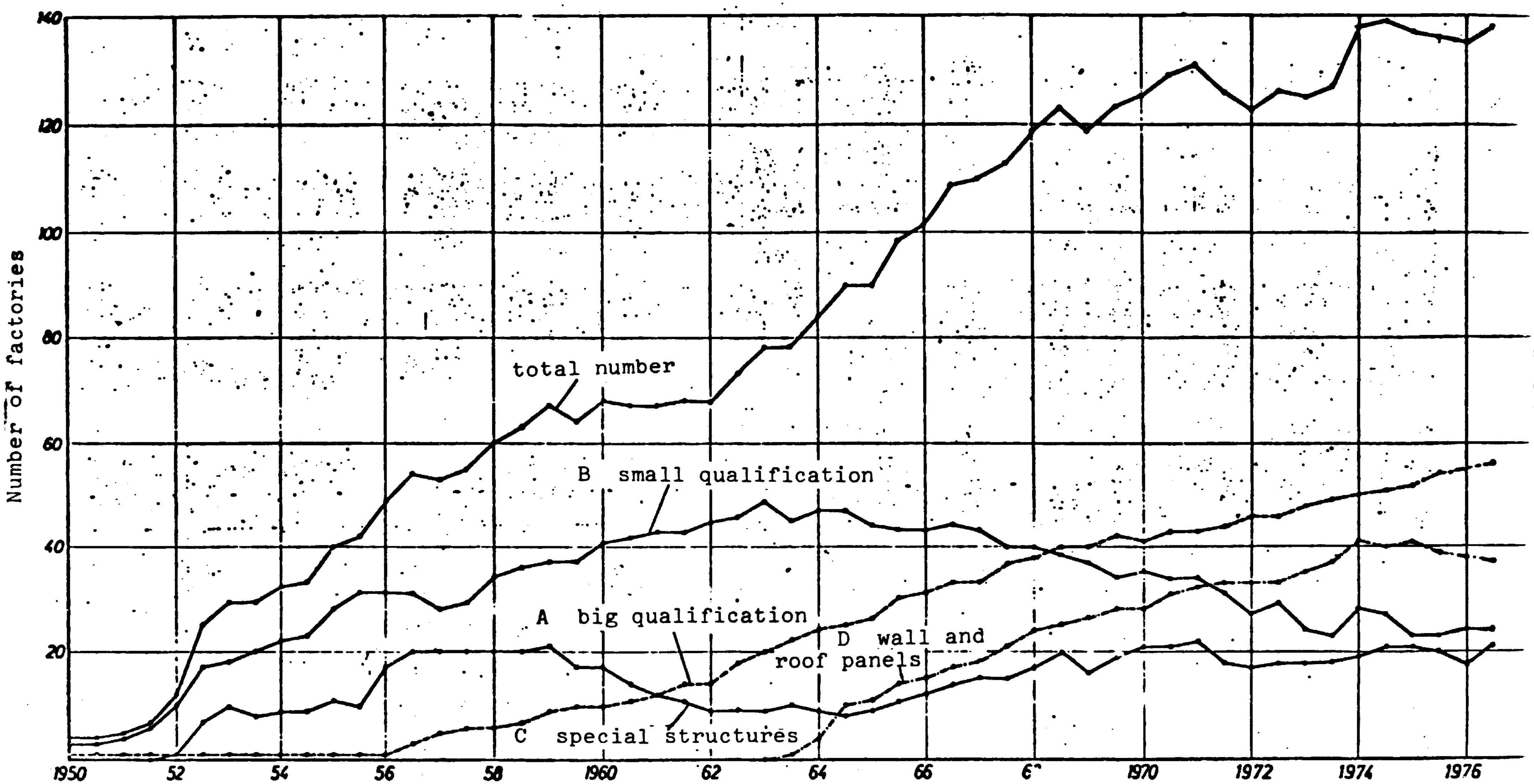


Fig.1 Factories with the qualification for gluing bearing structural components

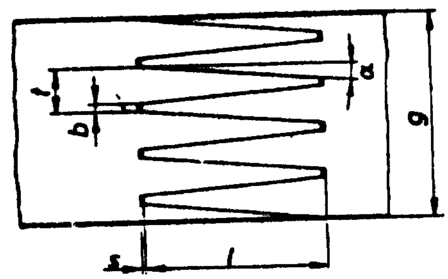


Fig.2a Dimensions of a finger joint
according to DIN 68 140

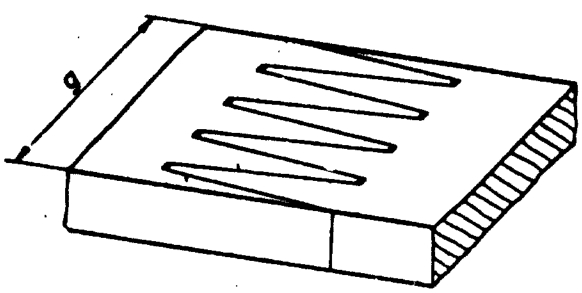


Fig.2b Long fingers, cross cut

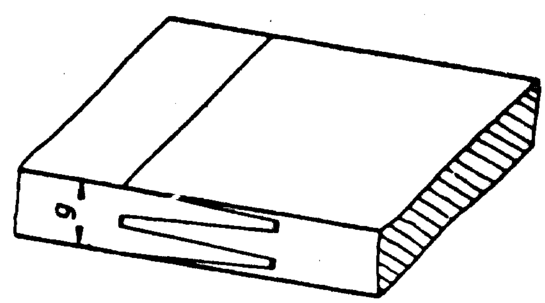


Fig.2c Long fingers, flat cut

Long fingers down to nearley 15 mm

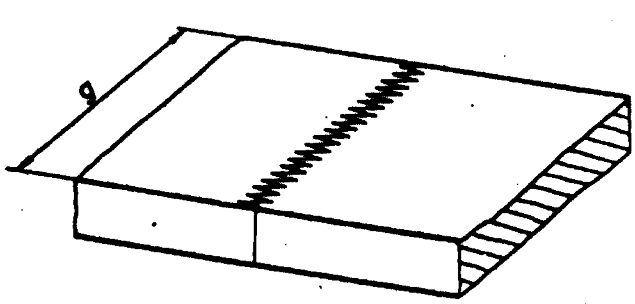


Fig.2d Short fingers, cross cut

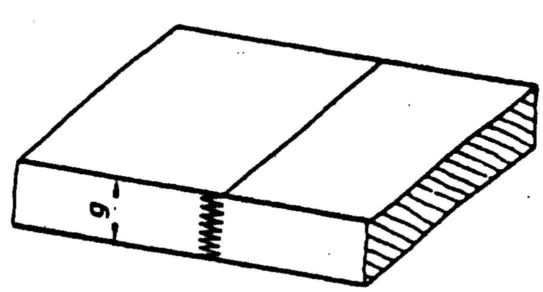


Fig.2e Short fingers, flat cut

Short fingers less than 15 mm

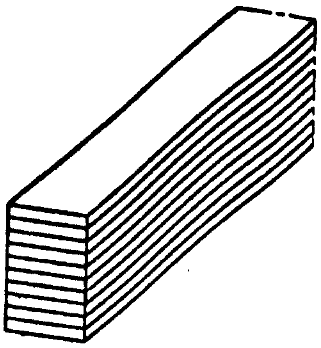


Fig.3a horizontally laminated beam

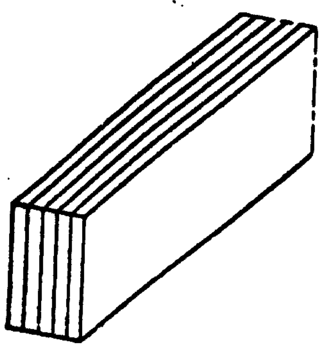


Fig.3b vertically laminated beam

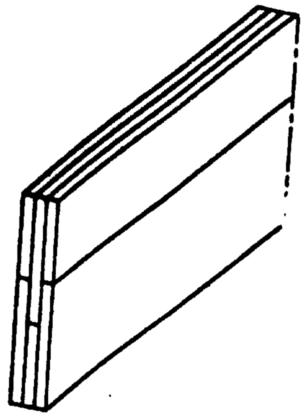


Fig.3c vertically laminated beam, e.g.for webs

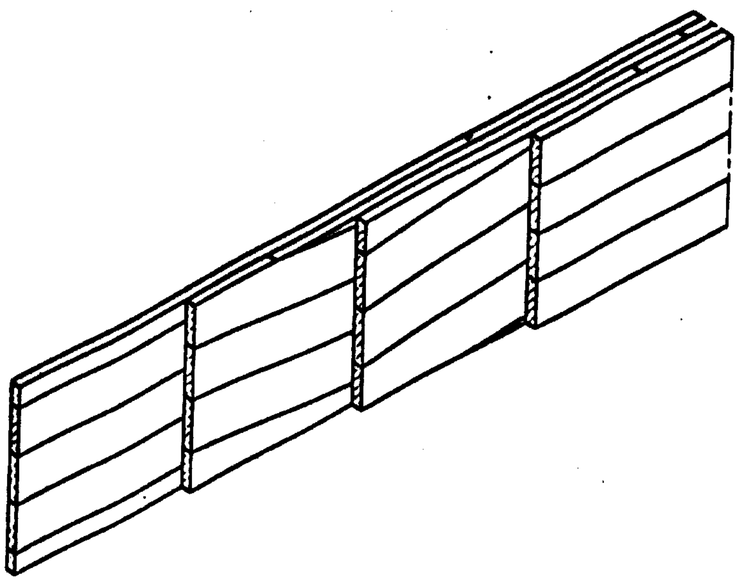
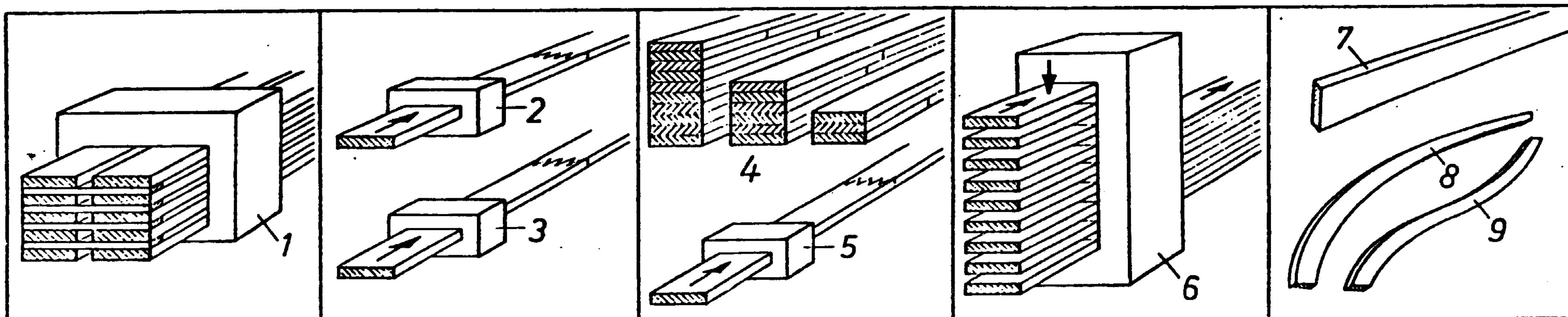


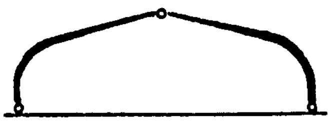
Fig.3d Cross-Laminated beam

Fig. 4 Glued laminated wood is an improved material which is being produced industrially under continuous quality control.



The selected laminations are dried in kilns (1) to a low moisture content; only kiln drying the wood guarantees durable gluing.	Timber boards approximately 5 m long are machine jointed end to end (2) then these laminations are passed through a planing machine (3).	A second grading (4) of the laminations ensures uniformity of quality of the laminated members. In a glue spreading machine (5) the glue is applied in exact quantities.	The laminations, arranged in layers, are cramped in special jigs to produce members of the required shape and length. Intensity of pressure and pressing time are carefully observed.	Cross section, length and shape of laminated structural members may be varied to meet structural requirements. (7) Straight beams (8) and (9) curved and tapered structural members.

Three hinged frame
Glue lam



Bowed frames

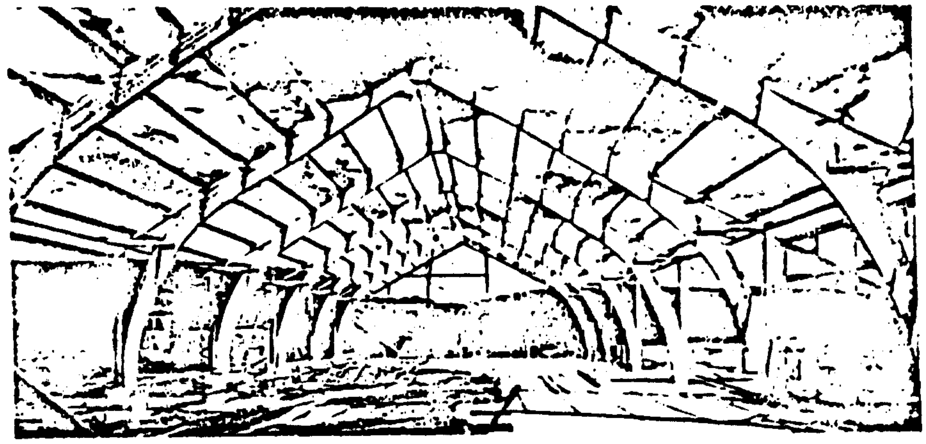
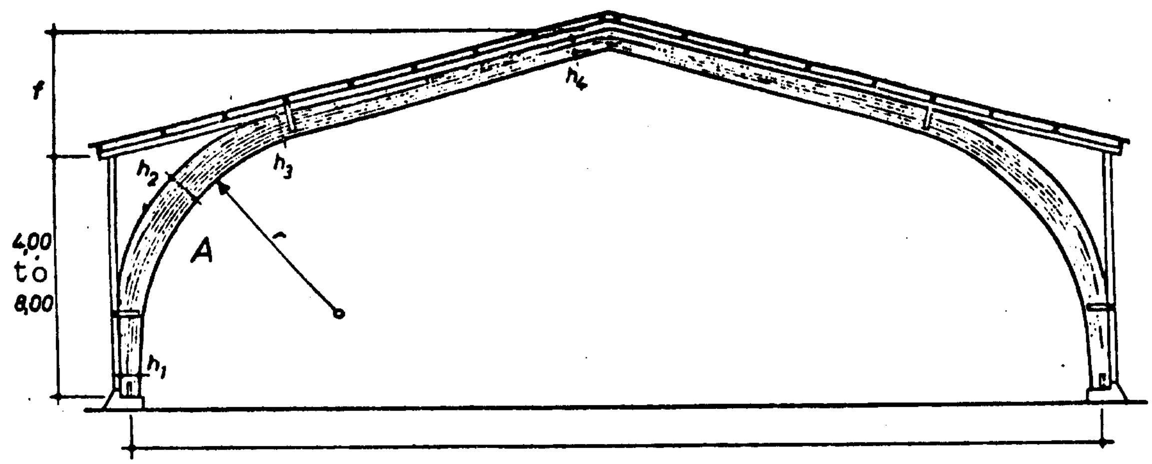
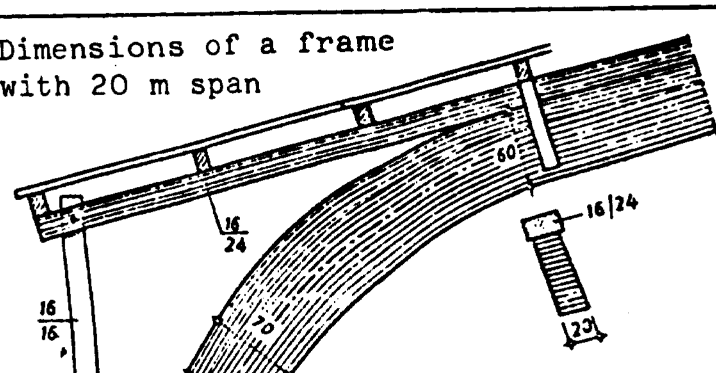


Fig.5



System	Span l m	frame distance e m	Slope of roof α	Dimensions h_1 m	h_2 m	h_3 m	h_4 m	r m
Three Hinged frame Glue lam Bent frame	15,00	5,00 ... 7,50	14°	0,30	0,55 ... 0,80	0,45 ... 0,70	0,25	3,00
	17,50	5,00 ... 7,50	14°	0,35	0,60 ... 0,85	0,50 ... 0,75	0,30	3,50
	20,00	5,00 ... 7,50	14°	0,40	0,65 ... 0,90	0,55 ... 0,80	0,35	4,00
	22,50	5,00 ... 7,50	14°	0,45	0,70 ... 1,00	0,60 ... 0,85	0,40	4,50
	25,00	5,00 ... 7,50	14°	0,50	0,75 ... 1,10	0,65 ... 0,90	0,45	5,00
	27,50	5,00 ... 7,50	14°	0,55	0,80 ... 1,20	0,70 ... 0,95	0,50	5,50
	30,00	5,00 ... 7,50	14°	0,60	0,85 ... 1,30	0,75 ... 1,00	0,55	6,00
	35,00	5,00 ... 7,50	14°	0,70	1,00 ... 1,40	0,85 ... 1,10	0,65	6,50

Dimensions of a frame
with 20 m span



Point A

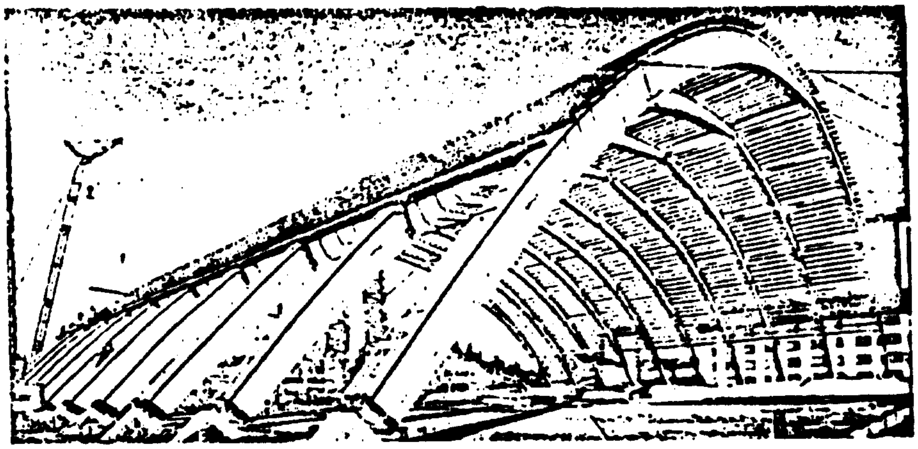
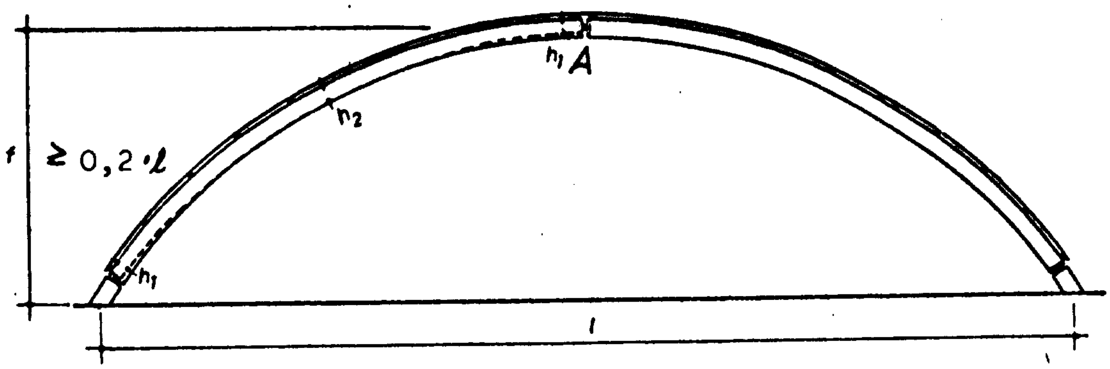
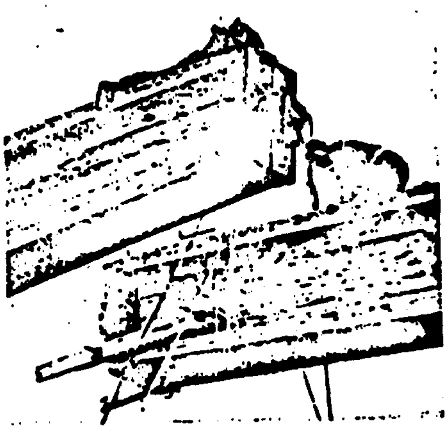
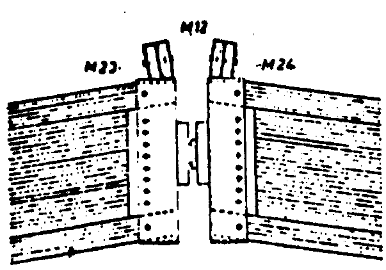


Fig.6

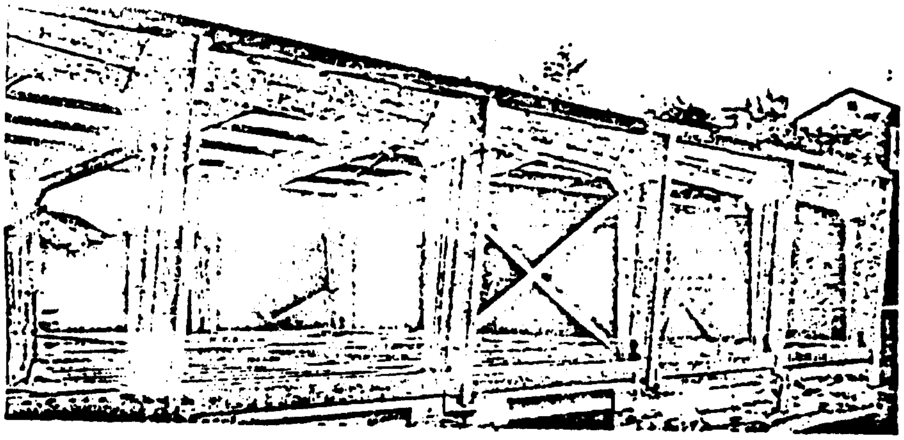




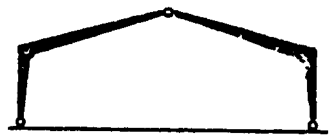
System	Span l = m	frame distance e = m	Dimensions h1 m	h2 m	f m
Arched Glue lam frame	25,00	5,00 ... 7,50	0,25	0,50	6,25
	30,00	5,00 ... 7,50	0,30	0,60	7,50
	35,00	5,00 ... 7,50	0,35	0,70	8,75
	40,00	3,50 ...15,00	0,80	0,80	10,00
	45,00	3,50 ...15,00	0,45	0,90	11,25
	50,00	3,50 ...15,00	0,50	1,00	12,50
	60,00	3,50 ...15,00	0,60	1,20	15,00
	80,00	3,50 ...15,00	1,60	1,60	20,00
	100,00	3,50 ...15,00	1,00	2,00	25,00



Point A

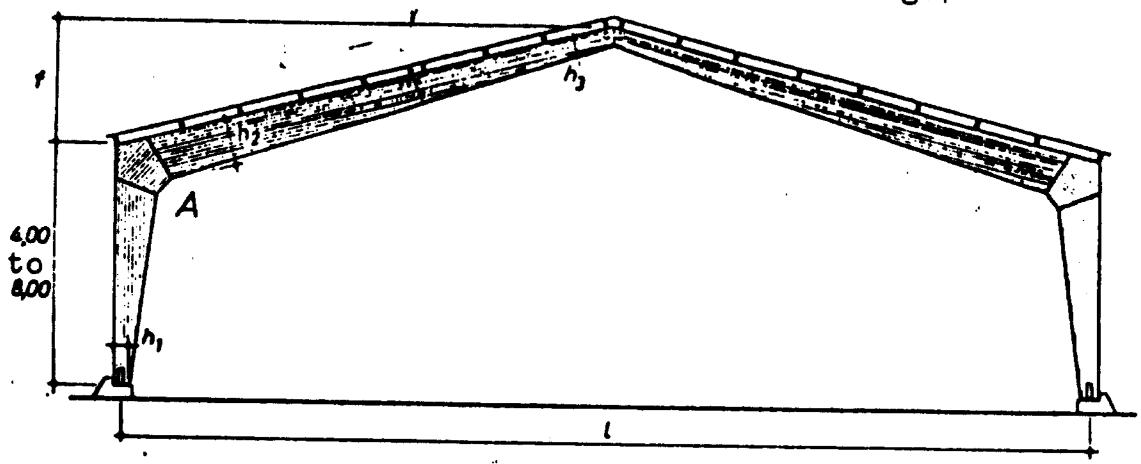


Three hinged frame
Glue lam



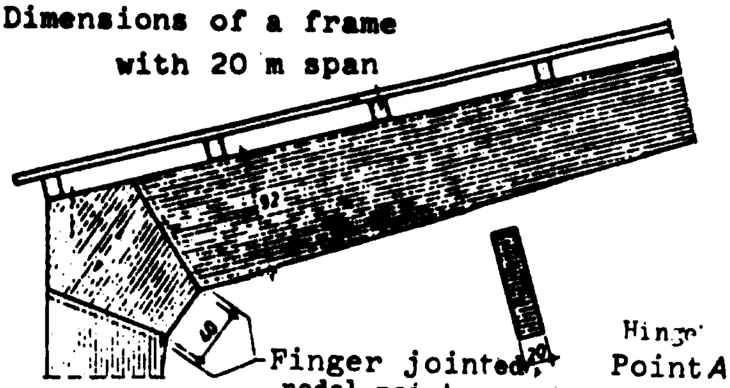
frame with finger joints

Fig.7



System	Span l m	frame distance e m	Slope of roof α	Dimensions h_1 m	h_2 m	h_3 m
Three hinged frame Glue lam	15,00 17,50 20,00 22,50 25,00	5,00 ... 7,50 5,00 ... 7,50 5,00 ... 7,50 5,00 ... 7,50 5,00 ... 7,50	14° 14° 14° 14° 14°	0,30 0,35 0,40 0,45 0,50	0,70 ... 0,82 0,78 ... 0,90 0,85 ... 1,00 0,93 ... 1,10 1,00 ... 1,20	0,25 0,30 0,35 0,40 0,45

Dimensions of a frame with 20 m span



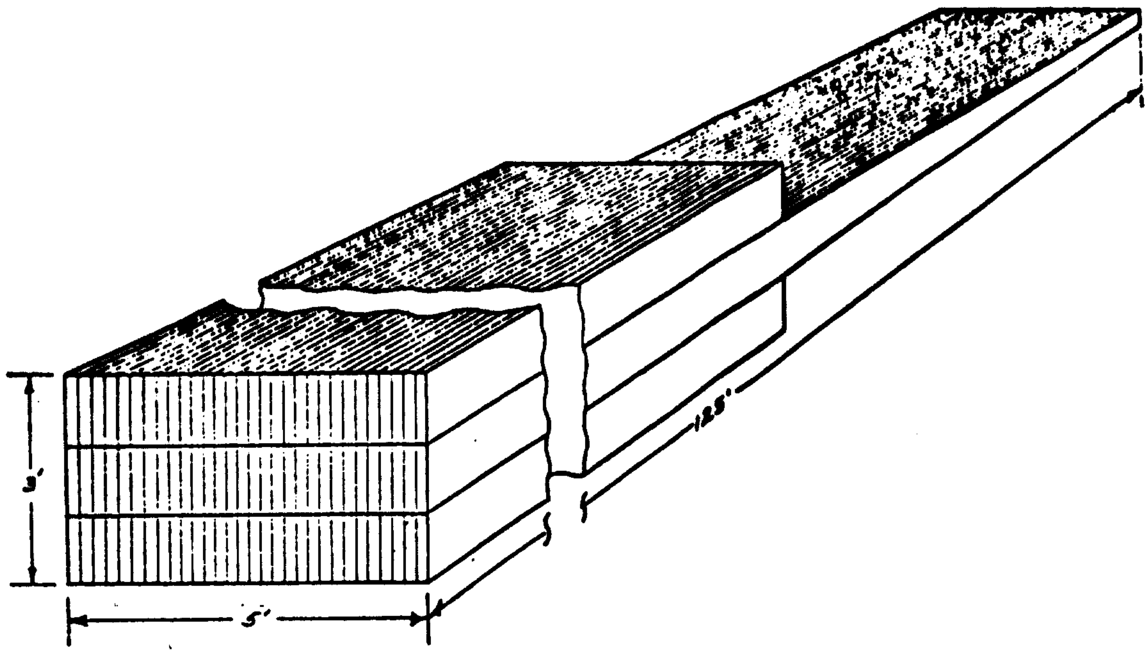


Fig. 8 Diagram of a laminated wood high voltage power transmission pole.

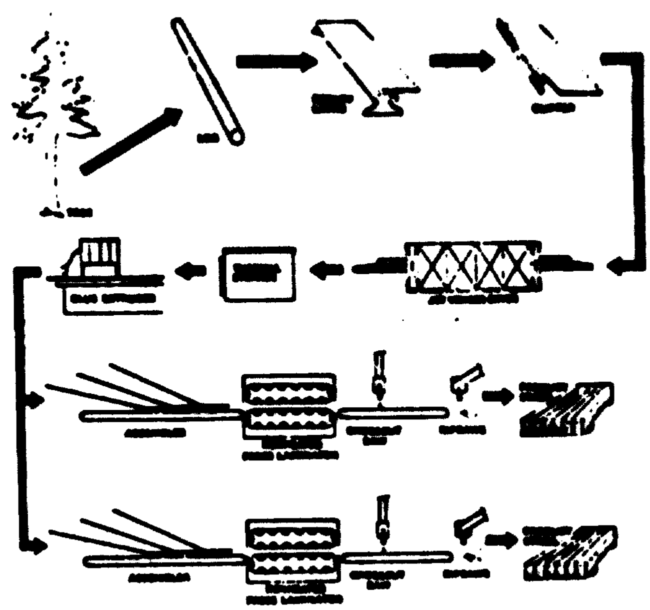


Fig. 9 Principal features of hypothetical Press-Lam processing system.

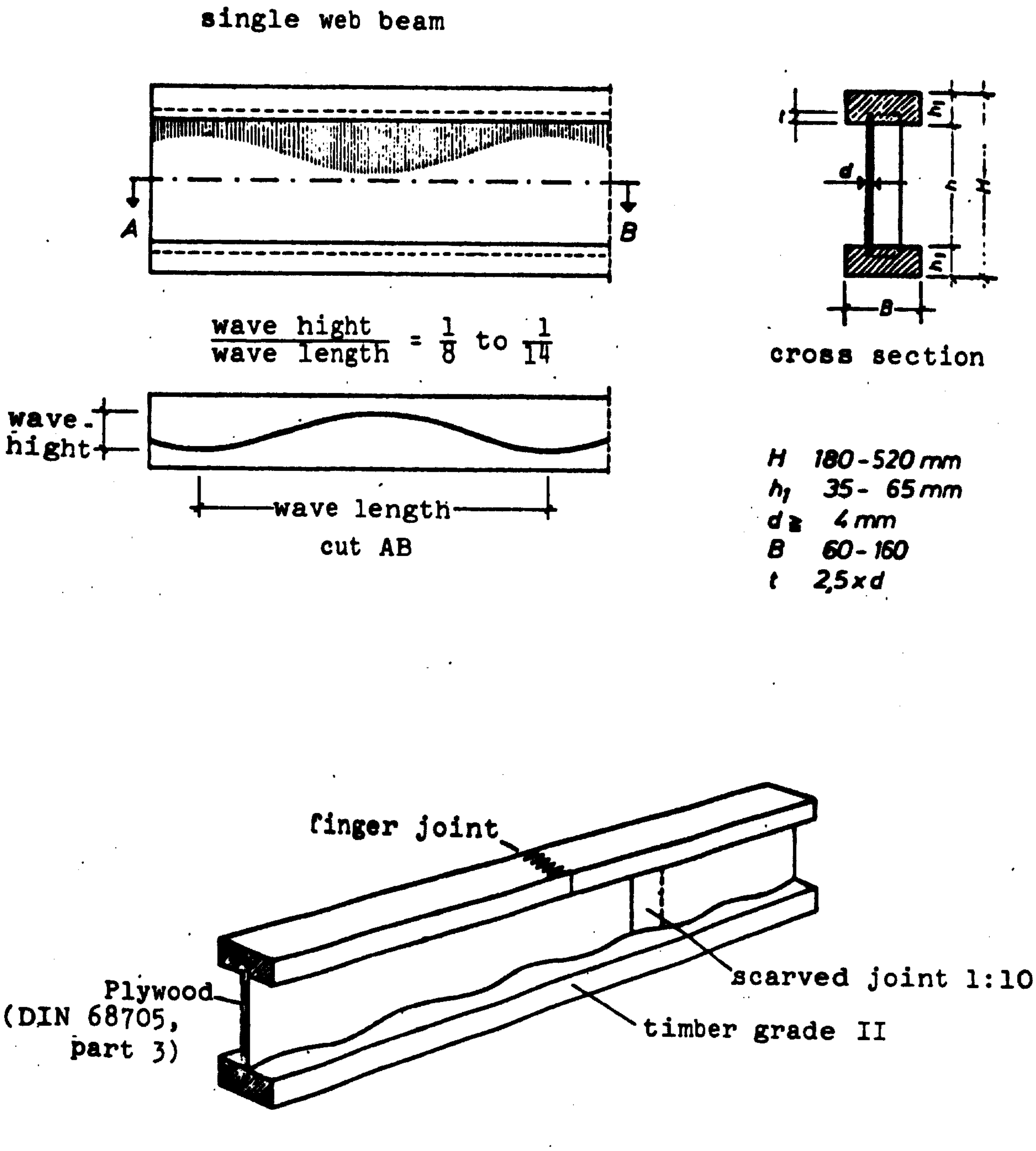


Fig.10 Corrugated Web-Beam

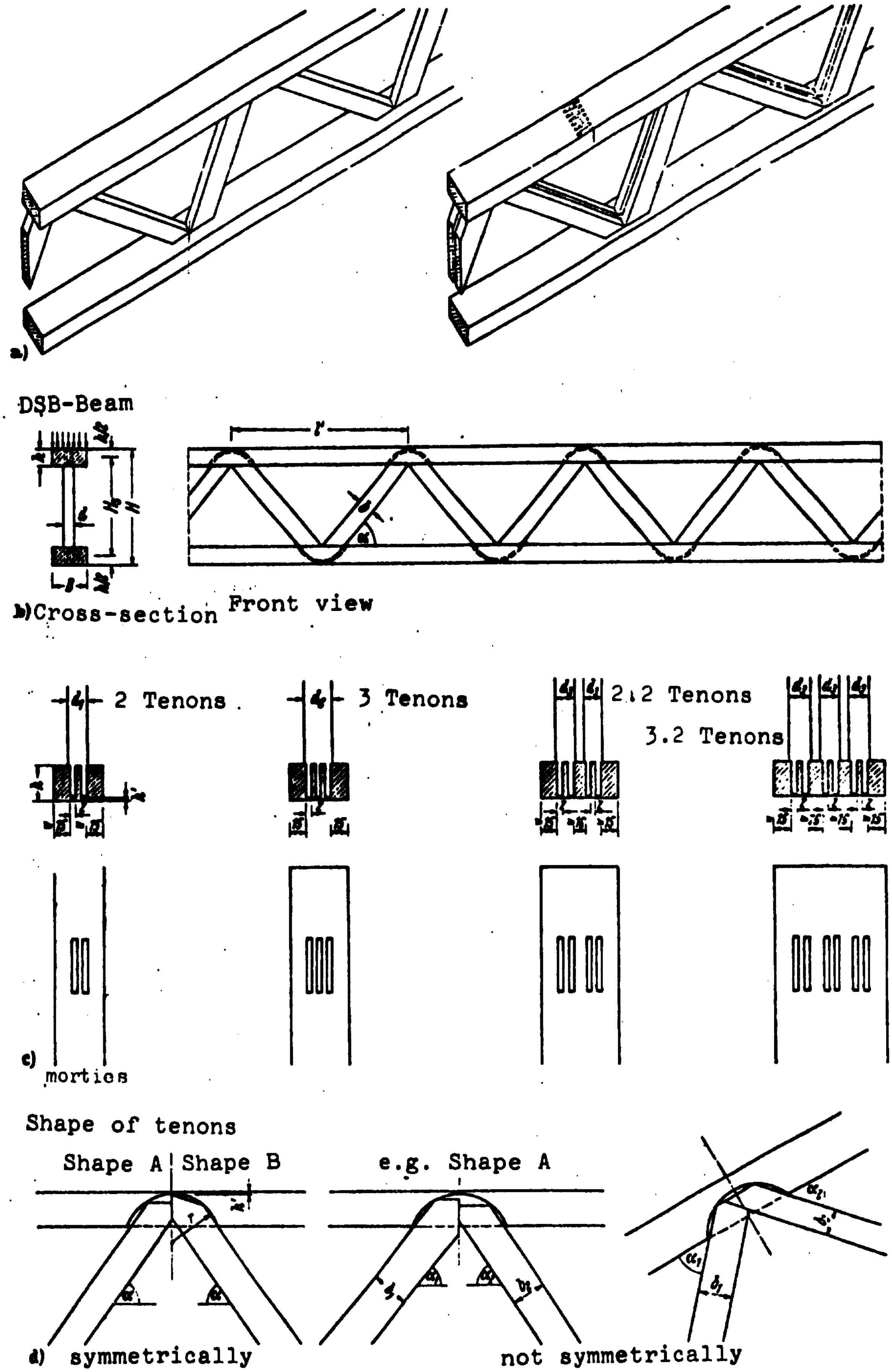


Fig.11 Grid system beams

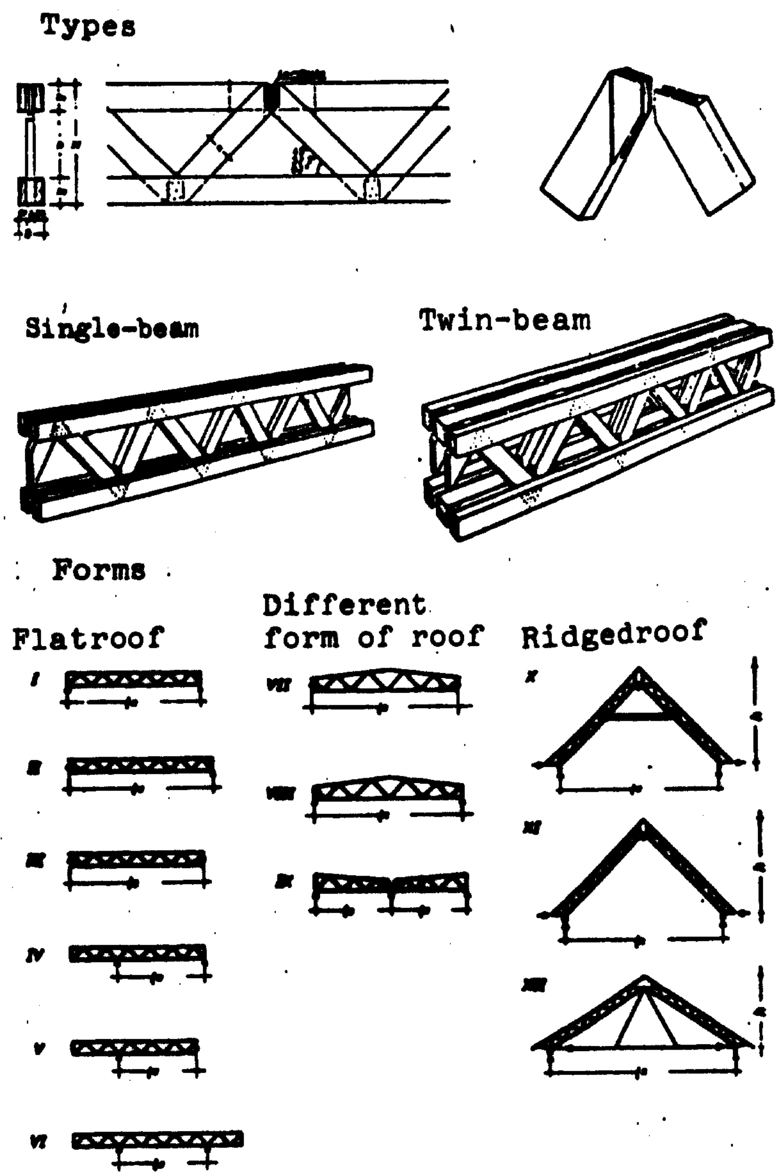
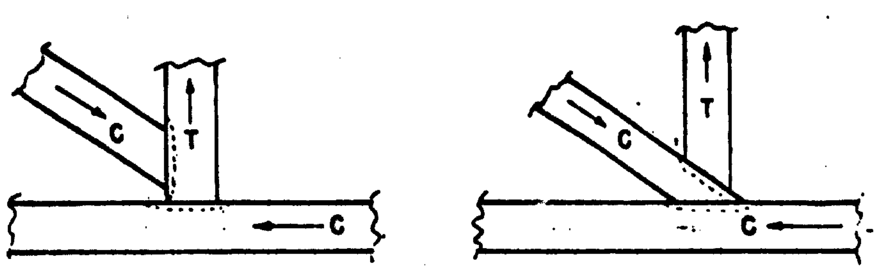


Fig.12 Trigonit-Beam



A. CORRECT DESIGN. JOINTS STRESSED IN COMPRESSION AND SHEAR.

B. INCORECT DESIGN. WEB TO WEB JOINT STRESSED IN TENSION.

Fig.13 FJC Wood Truss System
Two variations of a Howe truss connection

Resorcinol- and Melaminresin adhesives, testet according to DIN 68141 and suitable for gluing of structural timber components

Type of adhesive	Type of Hardener	Filler	Ratio of Mixture Parts of weight				Adress of manufacturer
			Adhesive	Hardener	Filler	Water	
Aerodux 185 D	RF 150,151, 155	-	100	20	-	-	CIBA - GEIGY AG 7867 Wehr (Baden)
Kauresin 440	Kauresin - Härter 444 455, 457	-	100	20	-	-	Badische Anilin- & Soda Fabrik AG 67 Ludwigshafen
Bakelite 283 (Reinhars)	Bakelite - Härter 183 Härter 184	-	100	25	-	-	Bakelite Gesellschaft mbH 4100 Duisburg 12 Postfach 76
Bakelite 284	Bakelite - Härter 184	-	100	25	-	-	
CASCOPHEN RS-240	CASCOPHEN - Härter RXS-1 Härter RXS-10	-	100	20	-	-	Borden-Chemie Deutschland GmbH, 61 Darmstadt, Landskronstraße 46
CASCO / SYNTEKO 1752 Resorcin-harzleim	Härter 2610 oder Härter 2612	- -	100 100	15 20	- -	- -	AB-CASCO Labor für Industrieklebstoffe P.O. Box 1 10 10 S-10061 Stockholm 11 (Schweden)
CASCO / SYNTEKO 1760 Resorcin-harzleim	Härter 2610 oder Härter 2612	- -	100 100	15 15 u.20	- -	- -	
Kauramin 545 [1]	Kauramin-Härter 08 flüssig	Kokonit 300 Pulver	100	3	15	-	Badische Anilin- & Soda-Fabrik AG 67 Ludwigshafen
Strucol RF 9-A-	Strucol RF-9-B- flüssig	Strucol RF 9-C- Pulver	100	20	10	-	Struyck NV Zutphen (Holland)
Dynosol S-199	Härter H-620 H-627 H-628	-	100 100 100	20 20 20	-	-	DYNO Industrier AS Chemical Division P.O. Box 779 Sentrum OSLO (Norwegen)
Aerodux RL 185	HRP 155	Kaolin-Pulver	100	20	30	10	CIBA - GEIGY AG 7867 Wehr (Baden)
Aerodux RL 188	HRP 155	-	100	20	-	-	
Aerodux RL 500	HL 501 flüssig	-	100	100	-	-	
Penacolite Leim G-4422 A	Penacolite Härter G-4400 B	- Aerosil 200 [2]	100 100	20 20	- 1	-	Koppers Company, Inc. Rotterdam 1 Coolsingel 6
Bakelite 284	Bakelite-Härter 186 Härter 188	-	100	25	-	-	Bakelite Gesellschaft mbH 4100 Duisburg 12 Postfach 76
Penacolite Leim G-4411 A	Penacolite Härter G-4400 B	- Aerosil 200 [2]	100 100	20 20	- 1	-	Koppers Company, Inc. Rotterdam 1 Coolsingel 6
PRIHA Resorcin-harzleim RF 30	RF Härter	-	100	15	-	-	E. PRIHA OY Box 80 SF - 49401 Hamina Finnland

1) Melamin-Phenol-Adhesive

2) Additive for a tixotrope adaptation

Resorcinol- and Melaminresin adhesives, testet according to DIN 68141 and suitable for gluing of structural timber components

Type of adhesive	Type of Hardener	Filler	Ratio of Mixture Parts of weight				Adress of manufacturer
			Adhesive	Hardener	Filler	Water	
Bakelite 284	Bakelite Härter 186	Mikrosöhl-Schlämm-kreide	100	25	30	10	Bakelite Gesellschaft mbH 4100 Duisburg 12 Postfach 76
Kaurein-Leim 460	Kaurein-Härter 467	Mikrosöhl-Schlämm-kreide	100	15	-	-	Badische Anilin & Sodafabrik AG 67 Ludwigshafen
			100	20	-	-	
			100	20	30	10	
			100	25	-	-	
CASCO SYNTEKO 1710 Resorcin-harzleim	Härter 2620	-	100	20	-	-	AB CASCO Labor für Industrieklebstoffe P.O. Box 11010 S - 10061 Stockholm 11 (Schweden)
CASCO SYNTEKO 1711 Resorcin-harzleim	Härter 2620	-	100	20	-	-	
	Härter 2623	-	100	25	-	-	

Urea adhesives, testet according to DIN 68141 and suitable for gluing of structural timber components

Type of adhesive	Type of Hardener	Filler	Ratio of Mixture Parts of weight				Adress of manufacturer
			Adhesive	Hardener	Filler	Water	
Aerolite FFD-Plv.	Härter L 38 Plv.	EB-Mehl	100 oder 100	15 / 15	50 / 30	95 / 75	CIBA - GEIGY AG 7867 Wehr (Baden)
Aerolite FFD-Plv.	Härter 200 Plv.	EB-Mehl	100 oder 100	3 / 3	50 / 30	100 / 80	
Kaurit-Leim 270 flüssig	Härter 30 fl.(15:85) Härter 70 fl.(50:50)	Bonit-125 oder EB-Mehl oder Walzit 250	100	10	35	25	Badische Anilin- & Soda-Fabrik AG 67 Ludwigshafen
Kaurit-Leim 234 Plv.	Härter 30 fl.(15:85) Härter 70 fl.(50:50)	Bonit-125 oder Walzit 250	100	15	50	100	
Kaurit-Leim 220 Plv.	Härter 30 fl.(15:85) Härter 70 fl.(50:50)	---	100	14	--	40	
CASCO / SYNTEKO 1209 flüssig Karbamid-harzleim	Härter Plv. HP 2658	---	100	20	--	10	AB - CASCO Labor für Industrieklebstoffe P.O. Box 1 10 10 S-10061 Stockholm 11 (Schweden)
W-Leim 62 flüssig	Härter U Pulver	Bonit [illegible]	100	4	32	12	Kreme Chemie Gesellschaft mbH A 3500 Kreme Hafenstraße 77

.../

18.6.1976 Go/bc

C-902

82.09.27