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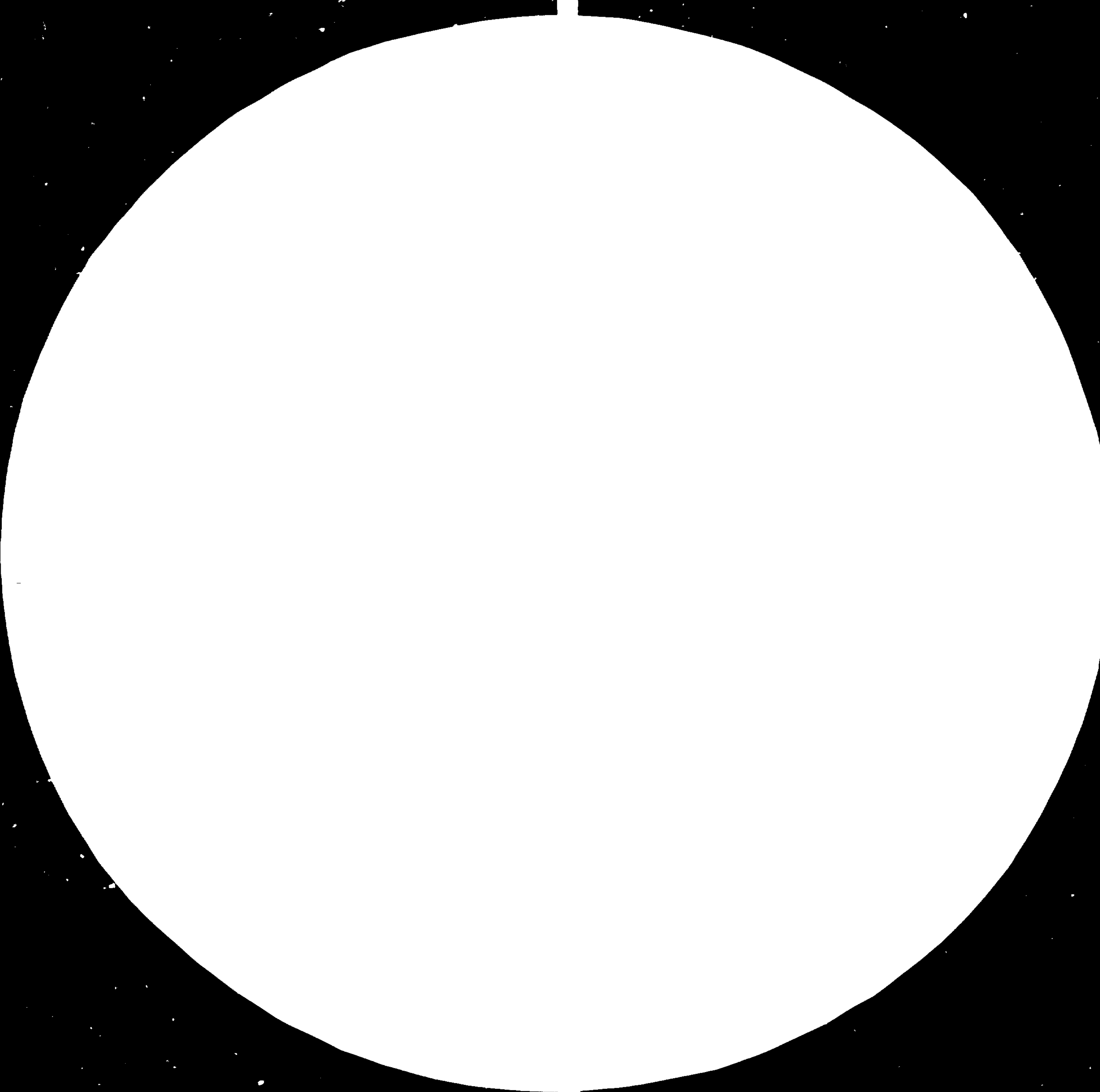

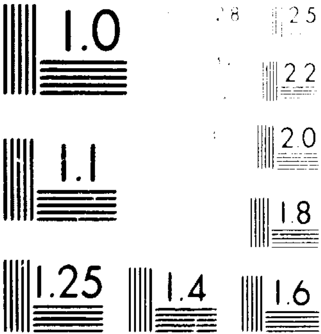
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DP/ID/SER.A/322
2 November 1981
English

DEVELOPMENT OF NEW TIMBER PRODUCTS

DP/KEN/77/007

KENYA .

Technical report: Glulam bridges for developing countries*

Prepared for the Government of Kenya
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of C.R. Francis, Timber engineer

United Nations Industrial Development Organization
Vienna

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C O N T E N T S

1 - Introduction

Developing countries have many problems in common. These include

- Lack of roads;
- Shortage of hard currency to pay for imports;
- Surplus of unskilled labour.

Many developing countries have substantial forest resources, either indigenuous or plantation and in some cases exports of forest products, after varying degrees of processing, may form a substantial part of the economy. This paper suggests a way in which modern timber bridging may help solve the roads construction problem with a minimum drain on foreign exchange reserves.

1.1 History of Timber Bridges

The use of timber as a bridge construction material goes back into antiquity. Julius Caesar's celebrated military bridge across the Rhine was a timber trestle and beam structure. More recently the nineteenth century railway boom in England resulted in the construction of numerous large timber viaducts. The colonization of much of the world by Europeans resulted in countless thousands of timber bridges from culverts up to massive truss spans.

The invention of cheap ways of manufacturing mild steel and later of reinforced concrete gave bridge builders materials which were not subject to the size limitations of forest trees, did not require skilled and time consuming carpentry techniques and which were much more durable than timber in most circumstances. The use of timber as a bridge material dropped rapidly except in a few countries where large strong durable timbers were readily available such as Australia and the West Coast of the USA. Generations of bridge engineers passed who never considered timber as a potential material.

1.2 Timber Technology Developments

Two branches of timber technology have combined to bring timber back into the running as a bridge construction material - preservation and adhesives. The search for methods of increasing the durability of timber has been proceeding for centuries. Insects, fungi and marine borers are the principal agents which attack timber. If it is kept free from these timber will last for centuries.

Modern preservation techniques consist of filling the pores in timber with poisonous chemicals. Large numbers of organic and inorganic chemicals are in use for this purpose but in general the vacuum pressure process using creosote or copper chromium arsenic (CCA) salts is most wide spread. Size has always been a limitation on the use of timber and a fair proportion of the carpenter's craft consists of simply increasing the length or cross section of his raw material. Glueing has always been used. The ancient Egyptians used casein glue, some of which still survives. Around the turn of the century structural sized members were made by glueing boards together and the concept of glued laminated timber or glulam was born.

Glulam was initially very restricted in its use because the protein based glues (casein, blood, gelatine) were not resistant to weathering. In the 1930's new types of synthetic resin glues were invented which were completely resistant to deterioration from damp or weather.

The potential now existed for the manufacture of structural timber in sizes limited only by handling capacity and of very high durability. Engineers particularly on the west coasts of Canada and the U. S. A. were quick to realize this potential for bridge building and numerous pressure treated glulam bridges, some of considerable size now exist.

1.3 Timber

Glulam can be made from almost any timber. In practice, softwoods are more generally used, since they are more easily worked than hardwoods, dry quicker and with less distortion. They are generally more easily impregnated with preservatives. However, there are numerous successful glulam operations based on the use of hardwoods.

A few softwoods and rather more hardwoods are difficult to wet with glue. Trials should be done on the species proposed to be used and in cases of doubt the advice of the glue manufacturer should be obtained. There are numerous formulations of glues for laminating and a suitable formulation for most circumstances can usually be supplied.

Most plantation grown softwoods are suitable for glulam manufacture. For bridge work, the ability of the timber to absorb preservatives is a major consideration.

The overall quality of the timber is not as important as might be thought. For bridges of the type recommended only a small proportion of the timber needs to be of high grade and most of the timber is relatively lightly stressed.

Before a bridge manufacturing programme is started a thorough survey of sawn wood stress grade distribution from various sources should be undertaken. This should extend over all seasons of the year since log sources may vary depending on the weather. The quality of timber from different terrains even in the same forest may be markedly different.

The detailed design should ideally reflect the availability of various grades from the proposed source of timber.

The dimensional accuracy of the timber as supplied by the sawmill should be checked. Glulam manufacture requires that the glued surfaces should be 100% planed. If thickness varies greatly then there will be excessive work and waste of wood to achieve this condition.

2 - Glue[1/]

The glue universally used for exterior glulam is phenol resorcinol formaldehyde (PRF).

This is a dark reddish black liquid which is mixed with a powder hardener. It is sold under various trade nams such as "Aerodux", "Penacolite", etc.. When cured, this glue has a shear strength well in excess of that of most timber. It is a petrochemical and consequently is subject to rapid price increases as oil prices rise. Alternative glues with equivalent properties have been under investigation for some years. Most promising are glues made from the naturally occuring phenolic compounds present in tannin. Tannin is available from various sources, including wattle, pine and mangrove bark and cashew nut liquid. Several countries already manufacture tannin formaldehyde for use in their plywood and particleboard industries and its use as a laminating glue is being investigated.

All indications are that TF is just as durable as PRF. Its use could help to reduce the cost of one of the most expensive items in glulam manufacture. Mixing of glue must be done in suitable conditions with adequate weighing and measuring facilities. Ample water and equipment for cleaning up are required. Mixing of resin and hardener should be done by machine. A baker's dough mixer is very suitable for this purpose. PRF glue is sensitive to temperature and its pot life is short in warm conditions. Refrigeration is frequently necessary to obtain adequate pot life. This need be no more than a domestic refrigerator in which are stored buckets of resin premeasured ready for the day's glue requirements. In some cases the storage chambers of spreading equipment are jacketed for chilled water. In some climates the problem of high temperatures may be overcome by doing all glueing at night.

[1/] See Also UNIDO publication ID/233, Doc. No. ID/WG.248/17/Rev.1; "Adhesives Used in the Wood Processing Industries".

3 - Hardware

There is a significant amount of hardware in any glulam structure. Some of this is rather specialized. Nuts, tie rods, plate washers, etc. are standard items stocked by merchants or easily fabricated in light machine shops.

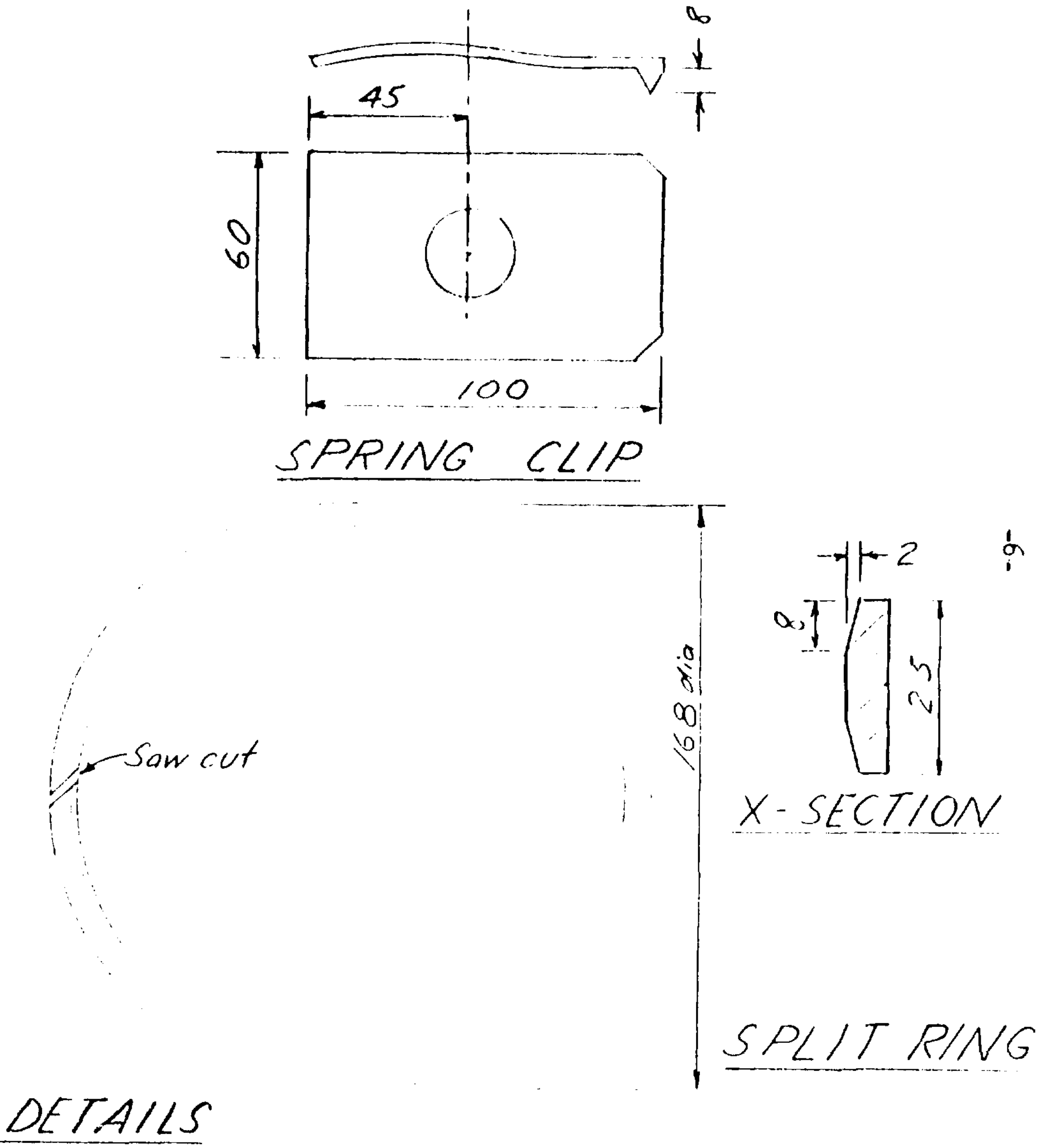
Special hardware includes split rings, mushroom head bolts and spring clips. These items are detailed in Figure 1. Some effort may be involved in locating manufacturers who can make these items and bulk purchase contracts will probably have to be arranged.

In a medium to large size project it may be worthwhile considering the setting up of a steel manufacturing shop as an adjunct to the main glulam factory. The machines and equipment required for the full range of hardware manufacture would be:

Power hacksaw;
Screw cutting machine - 25mm capacity;
Drill - 30mm dia capacity;
Forge and swages for bolt and spring
clip manufacture;
Furnace for spring clip manufacture;
Short bed lathe, for split ring manufacture.

Whether or not such a shop is established would depend on the capabilities of the local light engineering industry.

Hardware will require protection from corrosion. In marine atmospheres hot dip galvanizing will be required to give an economic service life to hardware. Otherwise shop priming and painting will normally provide sufficient protection. After erection is completed steelwork should be touched up where damage to paint has occured.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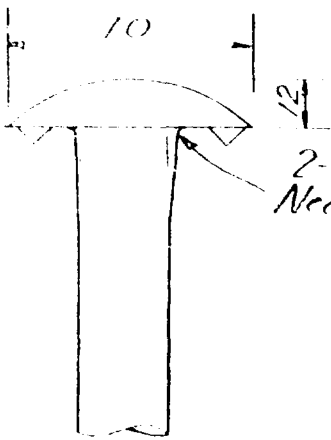
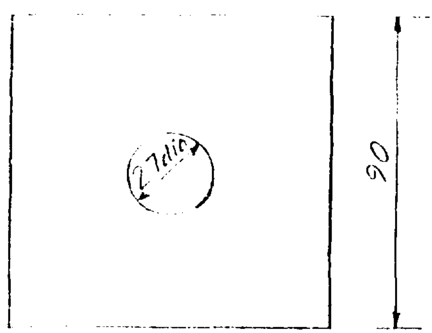


25 DIA MUSHROOM-HEAD BOLT



12 THICK SQUARE WASHER

Figure 1

HARDWARE

4 - Manufacture

4.1 Glulam Manufacture

Glulam manufacture is fairly labour intensive, not over expensive in capital and requires a moderate level of skill but no advanced technology. These factors make it a very suitable process for a developing country.

The exact processes carried out in a glulam factory depend on the degree of processing available from the sawmilling industry. If it is possible to purchase treated dry planed timber then these operations are not required in the glulam factory. In the following description it is assumed that green sawn timber is purchased and all processing is done on site. This makes the operation more complex and in some cases less economic since some items of plant will not be used to capacity.

The order in which processes are carried out also depends on which preservation method is used, and on the dimensional accuracy of the sawn timber. In this description all possible processes are described. In favourable circumstances one or more of these may be omitted. The order in which some of the operations are performed may also vary.

The steps in glulam manufacture from green sawn timber are:

(1)	Dry;	(7)	End joint;
(2)	Plane to dimension;	(8)	Plane faces;
(3)	Pressure treat;	(9)	Spread glue;
(4)	Redry;	(10)	Assemble in jig and clamp;
(5)	Grade;	(11)	Plane or sand faces free of glue;
(6)	Cut out defects;	(12)	Cut to length,drill.notch, etc..

These processes are now described in detail:

(1) Timber to be CCA pressure treated must be dried to about 25% maximum moisture content. In most climates this can readily be achieved by air drying either in the open or under open-sided sheds. In humid climates dipping in an anti-sapstain solution, preferably at the sawmill, may be required as an initial step to avoid sapstain developing.

(2) This planing operation performs several functions. It reduces to a minimum the volume of wood to be treated with expensive preservatives and minimizes the volume of treated waste to be disposed of. A planed surface is much easier to grade correctly and shows up undersize material which can not be used for glulam manufacture. Finally, the uniform thickness permits better stacking during subsequent drying with less possibility of warp occuring due to lack of restraint of thinner than average boards. The planer should be a long bed five-head machine.

(3) Pressure treatment has already been described in section 1.2. Close control must be maintained for it is on this operation that the durability of the bridge depends.

(4) Drying after treatment for glueing is a more demanding operation than the initial drying. The final moisture content required is lower - about 14% average, 18% maximum. These moisture contents may vary slightly depending on timber species and glue formulation. In many climates air drying will not lower the moisture content sufficiently and all or some of this operation will have to be done in a kiln.

(5 and 6) Up to this stage all the timber have been handled in bulk. Grading will sort out:

-- Undersize material;
-- High quality timber for use in highly stressed zones;

-- Selected lengths for deck units;
-- Pieces requiring the removal of gross defects and undersized ends.

Ideally, grading will be done on a chain conveyor from which the various selections are pulled into their respective stacks. Pieces to be defected should be sent to the cross cut saw and after defecting returned to the grading conveyor for resorting.

(7) There are various forms of end joint which have been used for glulam. It is possible to use no special joint at all, merely closely butted square cut ends. However, such joints weaken timber out of proportion to the unjointed cross section and uneconomically large sections must be used to compensate.

Scarf joints cut at slopes of 1 in 8 to 1 in 12 were the first to be used. Despite their simplicity they are quite difficult to cut accurately and even more difficult to glue. They are also very wasteful of timber and for some years the trend has been away from scarf joints to finger joints of one form or another. Fingerjointing is a science on its own and the variables are complex. Most finger jointing machines now on the market have large outputs, are highly automated and are difficult to maintain. There are a few available which have lower outputs and are simpler than average. The choice of a fingerjointer with the right characteristics remains a difficult problem. Fingerjointing consists of:

-- Cutting the profiles;
-- Coating the fingers with glue;
-- Aligning the ends and squeezing together.

The first and last operations must be done mechanically but glue spreading may be done by hand.

(8) After pressure treatment, a thin film of salts will remain on the surface of the timber which will prevent a strong glue bond from forming. Also, alignment after fingerjointing is rarely perfect and hardened glue will be smeared round the joints, which prevents good bonding in the laminating process. The faces at least of all timber must therefore be planed again before glueing. It is desirable but not essential that the edges should be planed also. This depends largely on the quality of lateral alignment of finger-joints and to some extent on the amount of crook developed during the second drying operation.

The replaning may be done through a four-sided planer or through a single sided thicknesser, passing the timber through it twice. The writer has seen a thicknesser mounted on a turntable so it could rotate 180°. This neatly avoided the need to return long heavy planks back to the infeed side of the machine.

(9) Glue spreading may be done by means of a roll spreader or a curtain coater. Double sided spreading, that is spreading on both faces of the boards, is preferable particularly if a moderately resinuous timber is being used. A curtain coater is simpler to operate and adjust than a roll spreader but can only coat on the upper surface, so two passes through it or two coaters in line are required.

Glue is spread at a rate of about 300gm per square metre of double glue line, i. e. 150gm per square metre of single surface if double spreading is used. This is quite a light spread and difficult to achieve if hand spreading is used. Hand spreading is possible but uses more glue than is necessary. Glue will generally be imported at considerable expense - around US$10 per kg. and the cost of a curtain coater or roll spreader and the associated conveyors will generally be recouped in quite a short period.

(10) Once the hardener is mixed with the glue, spreading and assembly must take place during the relatively short pot life of the glue. A well drilled team of workers using the best available equipment is essential. Glueing pressures are quite high, around 700 kPa. The most usual means of applying this pressure is by screw clamps spaced at 400mm intervals. These are tightened with an air powered impact wrench to a preset torque. A steel jig which aligns the glued boards and provides the reaction for the clamps is used.

Because of the limited time available, makeshift equipment can not be used for clamping up and full production equipment is required. This part of the equipment at least must be available even for a pilot project, including a compressor and receiver of sufficient capacity to operate at least two impact wrenches continuously. Details of a suitable jig are shown in Figure 2. This can be made as long as required.

(11) When the glue has cured, the wide faces of the members will be a mess of squeezed out glue and the edges of the boards will be uneven. This must be cleaned off and the faces made reasonably flat. Various tools can be used for this purpose.

In very high volume factories single or double sided planers of a throat capacity large enough to take the whole member are installed. Slower, but just as effective are heavy duty floor sanders using coarse grit paper. Heavy duty portable planers may also be used. The aim of this operation is to remove the glue and to provide flat surfaces for accurate fits. The quality of finish is not important. Removal of the glue is especially important if the members are to be creosoted as the glue forms a barrier to the penetration of the creosote.

(12) Finishing work is done with heavy duty power tools. Maintenance of accuracy is assured by the use of sheet metal templates. Squares long enough to cover the widest piece in one pass should be made and checked regularly. Even roofing squares are not large enough for use on glulam. The drilling of deep holes accurately perpendicular to the face is best done by portable drills working in heavy duty guides. Many electric drill manufactures make suitable auxilliary equipment.

Pneumatic tools are preferable to electric since they can be stalled without damage. If electric tools are used then care should be taken to fit accurately adjusted overlad cut outs to protect the motors from over heating.

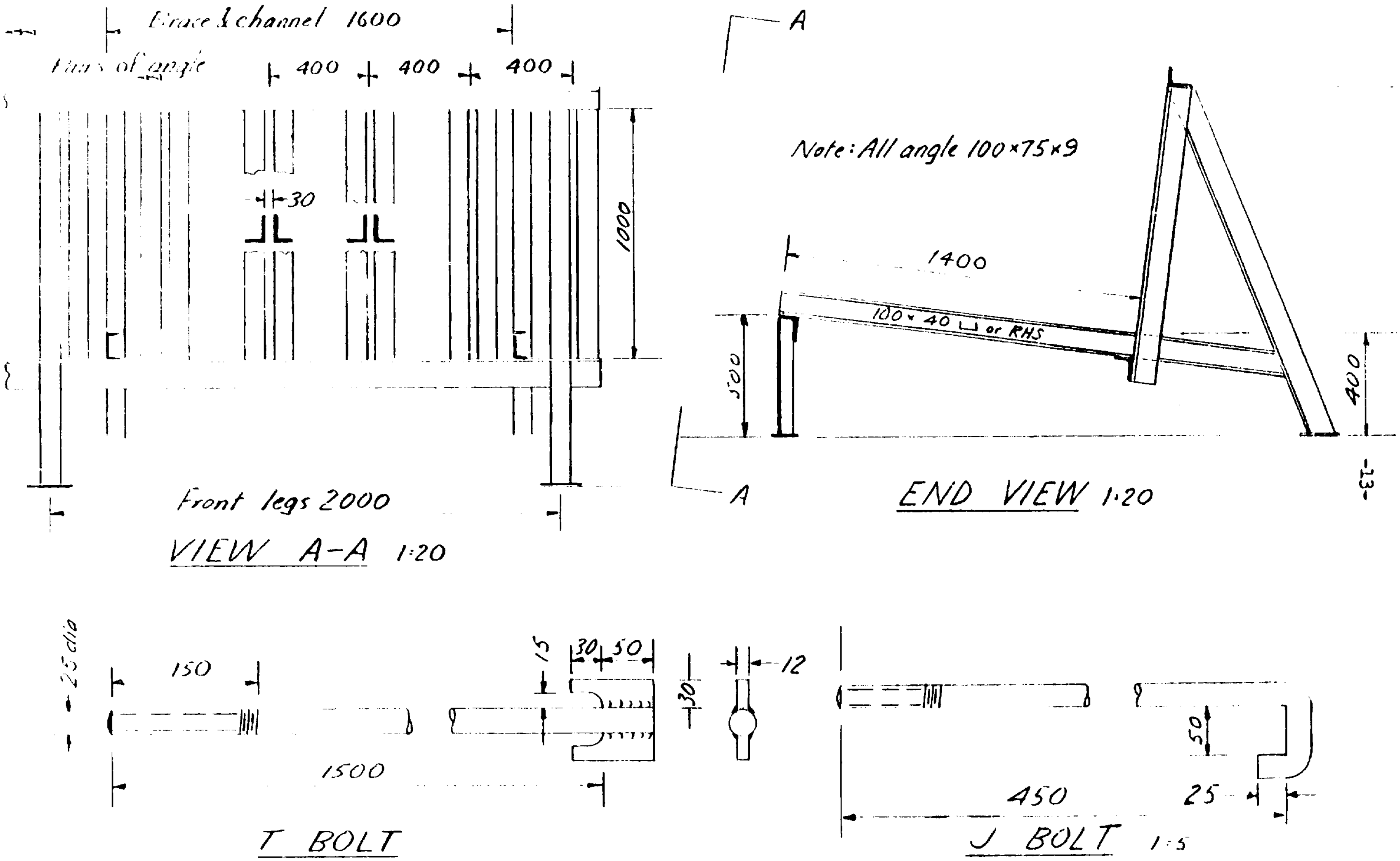


Figure 2 GLULAM JIG & BOLTS

4.2 Glulam Equipment and Its Use

The major item of laminating equipment is the jig and its associated clamping bolts. Details of the jig can vary but the design shown in Figure 2 has been found to be suitable. It should be made reasonably rugged since over its life it will be subject to considerable abuse from heavy timbers and continued placing of bolt, etc.. Also it will get covered in hardened glue which can only be removed with a hammer and chisel.

It must be carefully aligned and firmly bolted down. Note that the bed should slope backwards so that laminations do not tend to fall on their flat scattering glue and wasting time while they are righted. Two clamping systems are required. The primary system which puts the required pressure on the glue lines consists of pairs of bolts at 400 to 500mm centres. These should be about 24mm (1 inch) diameter. Ordinary coarse threads are satisfactory. Acme or similar threads are not necessary. Standard hexagon nuts may be used but because of the wear experienced in service, double length nuts are preferable. Wooden clamping blocks and washers complete this system.

The secondary system is for aligning the laminations laterally. This consists of steel channel sections which a[illegible]ted down to the front and rear of the jig at about 1.2 to 1.6 me[illegible] centres. The exact spacing depends on the amount of crook normally present in the laminations.

A compressometer is required. This is a hollow hydraulic cylinder fitter with a pressure gauge and completely filled with oil or brake fluid. It is used to set the torque on the impact wrenches used for tightening the clamping bolts. It can be made by any competent precision engineering shop. Exact dimensions and details will depend on the hydraulic seals available. The glue spreader may be of the roller or curtain coater type. Roller spreaders are available from various specialist manufacturers. Curtain coaters may also be purchased or manufactured locally.

The important point about either machine is that it must be capable of easy disassembly and thorough cleaning.

Glueing and clamping must be carried out in a well planned manner by a well drilled team. The flow pattern of the timber must be arranged so that there is minimum handling and carrying to cause delay. Long laminations are heavy and may require 4 or 5 men to carry and place them, especially when they are slippery with wet glue. Clamping bolts and nuts, previously oiled, should be placed on the jig in their positions, clamping blocks set out, and impact wrenches tested.

Laminations should be stacked in order next to the glue spreader. Once all is ready the first batch of glue is mixed and spreading and layup may start. The glue hand should stand by the glue spreader making any necessary adjustments and also carrying out a glue spread test. When the glue is running low he mixes another batch so that spreading is not delayed. Layup in the jigs proceeds until completed, then all hands except the glue hand turn to positioning the bolts and clamping up. Meanwhile the glue hand is ready with hot water to clean the glue spreader and conveyors.

Glue spread is checked by passing a weighed and measured piece of cardboard through the glue spreader on a lamination. This is reweighed and from the weight increase and the area of the cardboard the spread rate can be calculated A fairly precise balance is required since total weights of only 20 or 30gm are involved and the net weight of glue will be in the order of only 10gm.

Adequate spreading, tight clamping, and ungelled glue are indicated by a uniform bead of squeezed out glue along the glue line. An experienced laminator can tell from the look of this alone whether all has been done properly. Faults are indicated by:

No squeeze out or hardly any:

-- insufficient glue

Squeeze out satisfactory in some areas, absent in others:

-- insufficient pressure

Squeeze out adequate on last laminations placed but absent on the first ones placed:

-- pot life of glue exceeded before clamping up.

About half an hour after the initial clamping all nuts should be retorqued to take up the creep which will have occurred through squeeze out and compression of the wood.

4.3 Clamping

The key operation in glulam manufacture is clamping. The various processes leading up to it and the subsequent finishing operations are all standard techniques but clamping is peculiar to glulam and unless done properly, all the other work is wasted. The pressure required on the glueline for good bonding is quite high, at least 700 kPa (100 p. s. i.). This pressure must be maintained until the glue has cured.

Various hydraulic and pneumatic clamping systems have been tried, but the bulk of all glulam is clamped by means of long bolts tightened in pairs. While uniform tension is what is actually required, in practice, the nuts are tightened to a uniform torque using pneumatic impact wrenches whose torque can be adjusted by varying the air pressure.

Impact wrenches consume most air when running free. When impacting their air consumption is relatively low. In order to limit compressor and receiver sizes two sizes of impact wrench should be used. The small tool is used to run the nuts down the bolts and lightly tighten the assembly. At this stage any lateral misalignment of the laminations is corrected with the lateral clamps and J bolts. The nuts are then tightened with the large tool. Not only is air saved but the work is faster since the small tools generally spin faster than large ones.

If only one pair of wrenches is available work should start at one end of the lay up and proceed to the other. If two pairs are used, work should start at the centre and proceed to both ends simultaneously.

4.4 Finishing

Glued components can be removed from the clamps about 12 to 16 hours after clamping up depending on temperature and glue formulation. They should be handled carefully as curing of the glue is not complete for several days.

Finishing includes removal of squeezed out glue and surfacing the faces of members, cutting to length, drilling bolt holes and cutting grooves for split rings and clips. This work is best performed by heavy duty power tools. Pneumatic tools are preferable to electric since they may be stalled without ill effect.

If prefabricated components are to be assembled on site without problems then accurate shop work is essential. The best way to ensure this is by the use of templates for the marking out of all holes, etc.. Templates should be used for marking out only, not for guidance of cutting tools. Most accuracy is required in cutting grooves for split rings. Any inaccuracy here will make it almost impossible to fit beams and diaphragms together in the field.

A major source of inaccuracy in glulam manufacture is variations in thickness of laminations during final surfacing. This is not so bad in beams and diaphragm where all dimensions are measured from the upper face, but it can lead to problems in the deck slab. The length of the deck is the sum of the lamination thicknesses and a variation of a fraction of a millimetre in lamination thickness results in a deck length variation of several centimetres. There are several ways of overcoming this problem:

(1) All deck slabs are made slightly over design size, then planed back to exact width. This involves a considerable amount of shop work but allows for interchangeability of deck slabs on site. Any slight variations in width can be adjusted on site by making the clip grooves two or three cm longer than actually required. If the centre slab is fixed first then the variation from true length will be divided between the two ends.

(2) A shop assembly of the deck is made and the last slab is adjusted to give the correct length. This method needs a workshop large enough to take the full area of the bridge and also requires that the slabs shall be coded and kept together so that they are erected in the same order. This should be quite acceptable on a relatively small scale operation of about one bridge per week.

5 - Bridge Design and Detailing

5.1 Bridge Type

The bridge type recommended for short spans (up to say 12-15m) consists of heavy glulam deck baulks resting on glulam beams. The beams are separated by diaphragms which resist lateral buckling and also act as load sharing members. Handrails, posts and kerbs are also made from glulam. The arrangement of a typical single lane span is shown in Figure 3.

All members are made the same thickness of 200mm. This leads to great economy in the manufacturing operation since only one size of timber is purchased and stocked. The deck is constructed of baulks which span the full width of the bridge. Because of their thickness and the relatively close beam spacing no shear connections are required between them. Experience in U. S. A. has shown that when deck baulks of this thickness are used the relative deflections between them are so small that asphalt topping does not crack. Also the stresses in decks of this thickness are very low so high grade timber is not required. This provides a useful outlet for the low grade timber which inevitably comprises much of a sawmill's outjout.

An alternative deck type uses thinner baulks keyed together with steel dowels.[1/] This type of deck may use only half the volume of timber compared with the heavy deck, but these savings must be offset against the need for an additional size of timber and the higher grade requirements for it. Also the holes for the dowels must be bored very precisely if the baulks are to be keyed together and site construction not made more complicated.

The deck is clipped to the sides of the beams by spring clips sitting in short grooves routed in the face of the beams. This has major advantages over the traditional construction of spiking or screwing the deck to the top face of the beams. The most important is that the prime cause of beam decay is eliminated. Spike or screw holes in the top edge of a beam form water traps, ideal places for decay to start. In creosoted timber, such holes are certain to penetrate the creosote envelope unless the holes pre pre-drilled.

This can hardly be done without a shop assembly. Vibration from traffic inevitably causes loosening of deck spikes or screws. In CCA treated timber this vibration results in the loosening of the oxide layer on the steel, leading to accelerated corrosion of the fastenings which have bare metal exposed to damp acid wood. Finally, if the deck has an asphalt wearing surface this must be removed to maintain any loose fastenings.

[1/] Described in "Simplified Design Procedure for Glued-Laminated Bridge Decks" by William L. McCutcheon and Roger L. Tuomi, USDA Forest Service Research Paper FPL 233, US Forest Products Laboratory, Madison, Wisconsin, 1974.

The system of clips avoids all these problems. The clips maintain a constant clamping force which must be overcome before vibration can cause relative movement between components. The nuts are accessible if tightening is required and the tightness of the fastening does not depend on the wood fibres tightly gripping the spikes or screws.

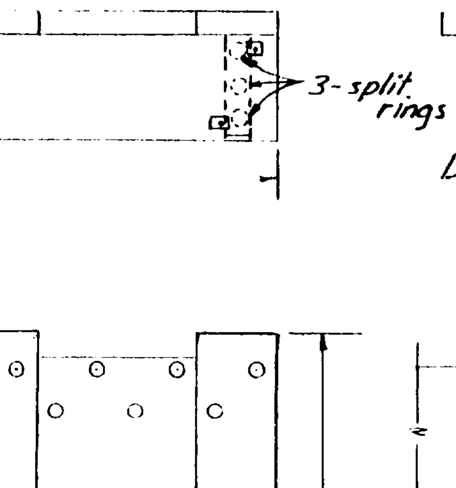
5.2 Beam Design

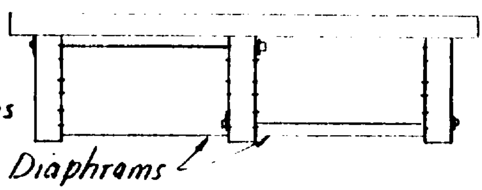
Beams are designed according to normal engineering principles. Detailed rules for the distribution of loads to beams are given in AASHO "Standard Specifications for Highway Bridges" (U. S. A.) and Canadian Standard S6 "Design of Highway Bridges".

It should be noted that neither of these standards makes allowance for glue laminated deck slabs, the nearest approach being nail laminated slabs which are much more flexible. Research from various sources shows that with glulam deck slabs a much greater degree of load distribution takes place than with nailed laminated decks. While the writer would not suggest exceeding the distribution factors given in the above standards, they can be used to the full in the knowledge that they are conservative for a glulam deck.

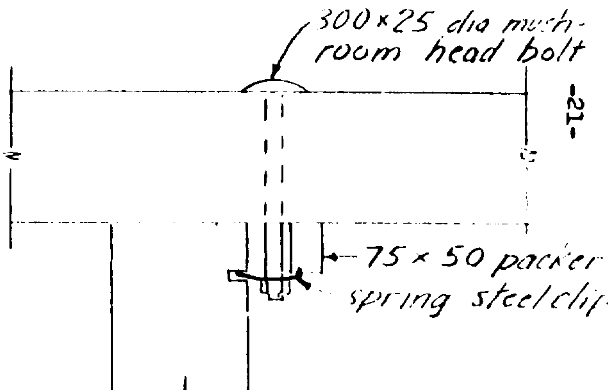
It should be noted that Canadian Standard S6 prefers that load distribution should be performed by elastic analysis. Several computer programmes are available for the analysis of the grid system formed by this type of bridge. The national policy on bridge loadings and geometrical standards should be followed, if one exists, but in any case it is recommended that the load distribution requirements of either of the above codes as they apply to glulam should be used.

Where no bridge standards exist it is recommended that bridges should be designed for loads of not less than HS20 (American) or MS200 (Canadian). Highway loads in developing countries are increasing rapidly and it is not recommended that any loading lighter than HS20 should be used.





END VIEW 1:50



DECK FIXING DETAIL 1:10

Note: Handrails kerbs etc not shown. See "Modern Timber Bridges" for suitable details.

SPAN BRIDGE

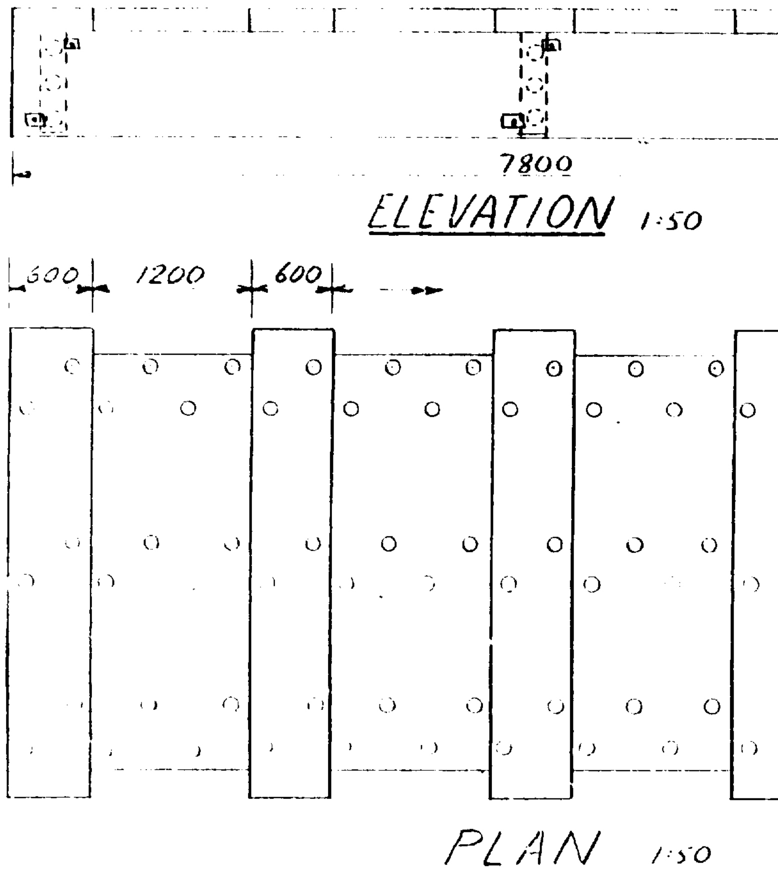


Figure 3 TYPICAL 7.8M

In a single lane two-beam bridge of minimum width between kerbs, and with a typical cross section arrangement, the extreme lateral position of the design load will impose a load about 20% greater than the wheel loads on the edge beam.

Deflections in the deck slabs become relatively high. As the bridge width is increased proportionally more load is imposed on the edge beam and the slab deflections increase markedly.

If three beams are used, the load on the edge beam is limited to the wheel load and the slab deflections are negligible. If four beams are used, elastic analysis of a perfectly elastic structure with load distribution through the central diagram will give a load reduction of about 30% in the edge beam. However the split ring joints between beams and diaphragms may have a slip of about 1mm before full load transfer takes place, and this combined with lack of fit reduces the effect so that very little load reduction in the edge beam may actually take place. Economy commensurate with the cost of a fourth beam is not gained. It is therefore recommended that three beams should be adopted as a standard construction for single lane bridges. This limits individual beam loads to the wheel loads and provides about 50% overload capacity provided the overweight load is located centrally on the bridge centreline.

5.3 Geometrical Standards

In the case where national geometrical standards have been promulgated these must be followed. If no national standards exist, then the engineer should follow a set of standards appropriate for his country and for the anticipated density of traffic which will cross the bridge in its lifetime.

A suitable code to follow is "Geometric Design Standards for Canadian Roads and Streets" published by the Roads and Transportation Association of Canada.

Many rural roads have very light traffic and the expense of a two-lane bridge cannot be justified. In this case the following dimensions are recommended:

3.0m minimum, 3.7, maximum between kerbs;
3.7m minimum between handrails.

Agricultural vehicles may be considerably wider than heavy trucks, and the choice of type and dimensions of handrails should be made after consideration of the actual vehicles using the road and the clearance to any overhanging portions of the vehicle.

5.4 Diaphragms

Diaphragms are fitted between beams and connected with split rings to take a shear load of half a wheel load.

Diaphragms provide stability to the beams and perform an important load sharing function. Diaphragms effectively act only in shear and consequently the grade of timber used for them is not important. They form a useful disposal for short lengths of low grade timber, also for pieces supplied undersize which require thicknessing to less than standard dimension.

5.5 Bearings

Modern practice in bridges is to use elastomeric bearings at beam ends rather than metallic sliding or rolling bearings. Dimensional changes in timber due to temperature are so small that they may be neglected but in longer spans some slight seasonal changes in length may occur due to changes in moisture content.

Purpose manufactured elastometric bearings will probably be difficult or impossible to obtain in a developing country but an excellent substitute may be made from old conveyor belt which is usually readily available.

5.6 Details

An excellent source of details for handrails, scuppers, holding down angles, etc. is "Modern Timber Highway Bridges" published by the Canadian Institute of Timber Construction. These details conform to the AASHO specifications and have the added authority of having been recommended for use by Canadian Standard CS6.

While it is not suggested that these details should be followed slavishly, they provide an excellent starting point for developing standard details for a standard series of bridges.

6 - Erection

It is assumed that the foundations and abutments will have been completed by the time the bridge components are delivered on site.

Erection with a crane is by far the simplest and quickest method of construction. A machine capable of lifting 2 tonnes 6 metres clear of its side supports is required. Using a crane the beams are unloaded as close to the near abutment as possible and the other lighter components are stacked conveniently close. The beams may then be positioned directly.

If a crane is not available then two shear legs must be made. These are manufactured from glulam as shown in Figure 4. The shear legs are erected with their feet 2m back from the abutments. The tops are tied back to 1.5m long log "deadmen" buried 1.5m deep at least 10m back from the shear legs. The tie should be adjusted so that the top of the shear legs is over the face of the abutment. A 1 tonne chain block is hung from each shear legs. The arrangement is shown in Figure 5. The block at the far side of the gap must have an extra long chain - about 8m or a series of slings of varying lengths must be provided. The beams are brought up on rollers on their flat and launched across the gap until they are about one third of the way across. A short choker sling of soft rope is then attached to the overhanging end and the launching continues with the far chain block supporting and pulling the beam.

A tie-back must be attached to the near end of the beam. A steel wire rope sling is attached to the centre diaphragm hole with a deck-bolt and tie rod washers. This in turn is taken back to a sling fixed to the near deadman with a six-part tackle or a small "tirfor" or similar winch.

The weight of the near end can be partly taken by the near chain block. In longer spans of about 10m the weight of the beam will be nearly double the capacity of the near block until it is nearly across the gap. However, taking some weight at the near end will reduce the friction of the rollers and ease the load on the far chain block.

The sling used for lifting at the near end should be positioned in line with the feet of the shear legs - no further back or lifting will tip the shear legs over backwards. The beam is eased forward for 1 metre then this sling must be repositioned. In no circumstances must the near chain approach the vertical in the initial stages of the launch. An unexpected jar at this stage could cause the beam to move forward, its weight on the far chain block raising the near end clear of the ground and so swinging out of control. It is for this reason that the tie back is included. It should be kept just slack as the beam is launched, but always under control of two men.

When the beam is fully across the gap it can be turned upright and moved sideways into its final position.

The outside beam on one side is positioned correctly on its bearings and the adjacent beam is placed about 10cm clear of its final position. The diaphragms have a piece of 200 x 50 timber fixed to their top edges with two 100 x 12 coach screws. The split rings are positioned in the face of the first beam and the diaphragms offered up and seated as far as possible. Split rings are then positioned in the face of the second beam which is then moved sideways on to the ends of the diaphragms. The tie rods are then placed through their holes and tightened to draw the beams home on to the ends of the diaphragms. As the second beam is reaching its final position, it is jacked up to allow the placing of its bearings and holding down angles.

The deck baulks are then positioned, care being taken to see that they are square and closely butted. Although not necessary in the design a more rigid bridge will result if the edges of the baulks are glued together. This is only possible with CCA or creosote treated timber. It is not possible to glue timber which has been treated with heavy fuel oil. With creosote treated timber, the surfaces should be wiped down with petrol and allowed to dry.

Either phenol-resorcinol or neoprene emulsion glue may be used. Natural rubber glues are not suitable for this purpose as tests have shown then to have a relatively short life in exposed conditions. When the deck is completed, kerbs handrails and asphalt screeds are fixed and the asphalt running surface placed.

As much preliminary work as possible should be done in the factory - e. g., attachment of support pieces to diaphragms, drilling of all holes for kerbs in deck baulks, drilling of scupper blocks etc.. Some site work is inevitable such as drilling of kerbs and handrails but this should be reduced to a minimum by careful planning. Factory work is always more efficient and accurate then site carpentry.

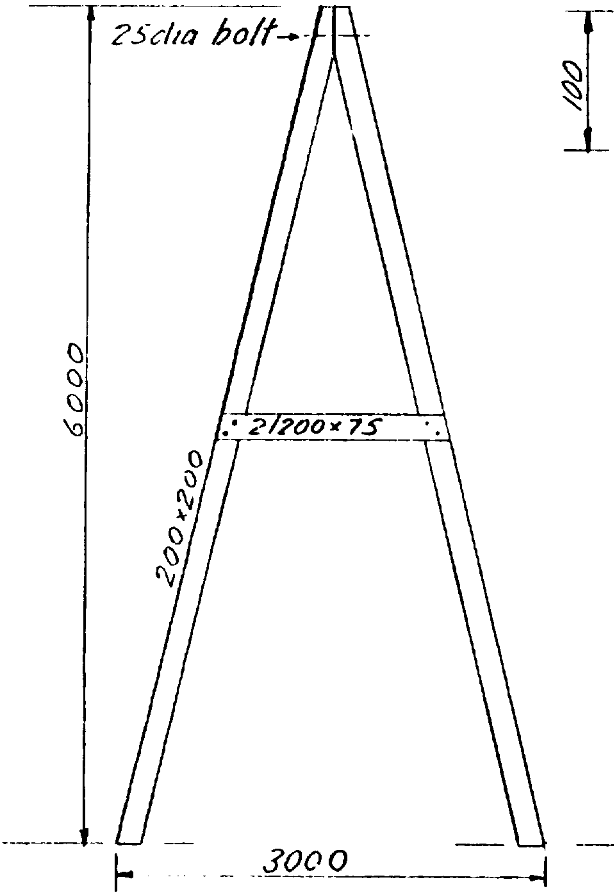
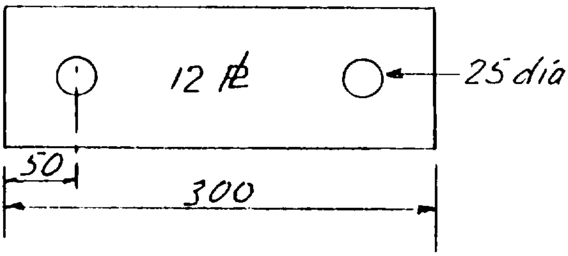
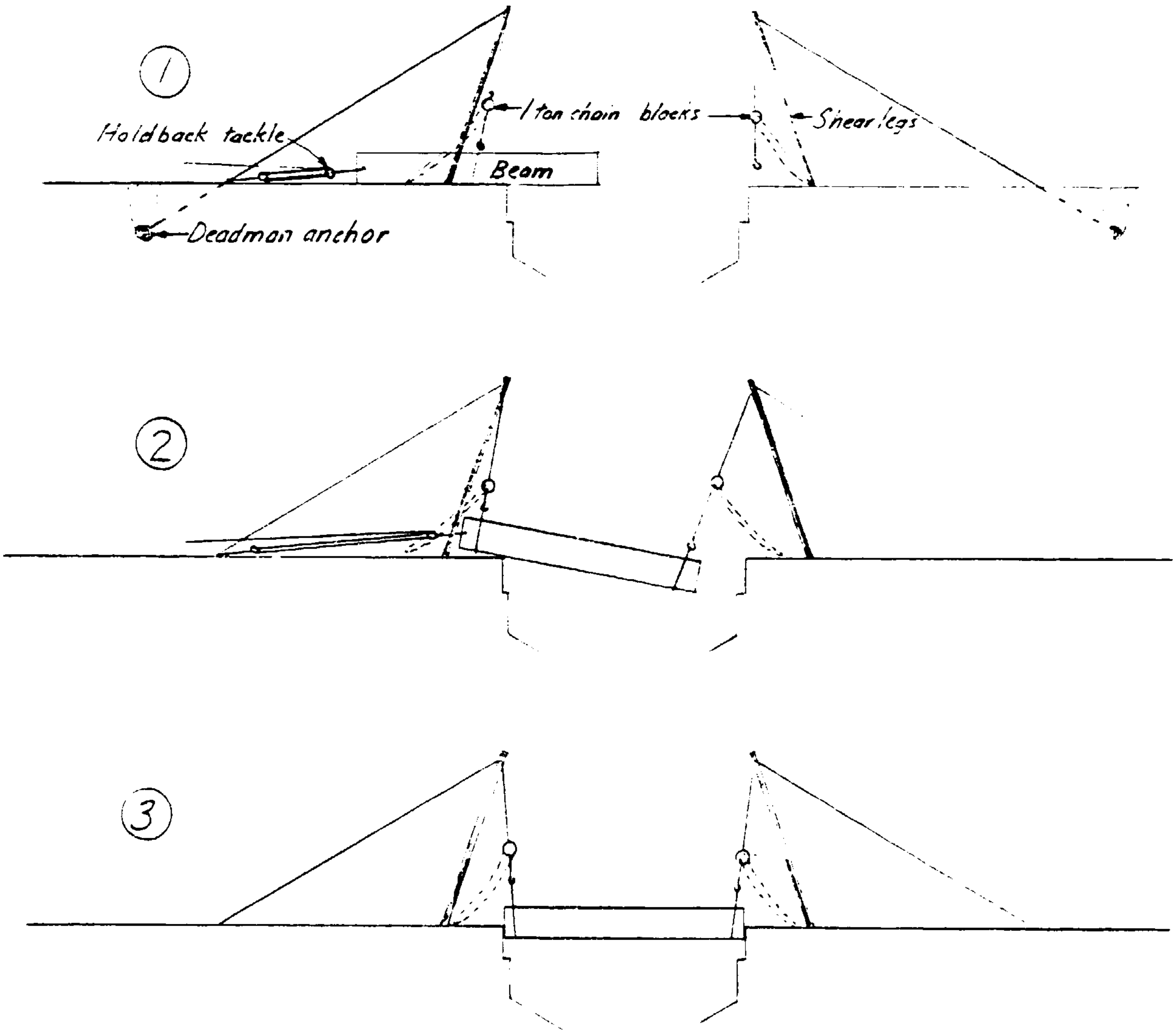


Figure 4

SHEAR LEGS 1:50



HANGER 1:5



LAUNCHING A BEAM USING SHEAR LEGS Figure 5

7 - Economics of Glulam Manufacture

There is no short accurate rule for costing glulam manufacture. Circumstances and the timber industry infrastructure vary so much between different countries. Also the volume of glulam manufactured at a factory will have a significant effect on the cost effectiveness of various of the major machines.

In the following section, a particular set of assumptions is used. For any project a similar analysis using pertinent data must be done.

Assumptions:

Bridge volume:	100 x 8m spans per year
Timber input volume:	$30m^3$ per week
Timber cost:	US\$150 per m^3, treated, planed, wet after treatment
Air drying is satisfactory	
Labour cost:	US\$6 per man per day
Cost of capital:	25% of installed cost (includes insurance and maintenance)
Shipping and installation:	100% of purchase price of machinery
Working capital cost:	13% p. a.
Glue cost:	US\$10 per Kg

Details of quantity calculations are not given here, but if desired may be checked from the data in this report and shown on the drawings.

Costs per year - U. S. Dollars

Fixed Costs:

Building rent	20,000
Electricity, water	2,000
Office expenses and overhead .	8,000
	30,000

Capital Costs:

Drying yard	10,000
Finger Jointer*	35,000
Cross cut saws* 2 at US$3000	6,000
Glue spreader* and conveyors	4,000
Thicknesser*	5,000
Finishing Tools:	
Floor sanders 2 at 12.00	2,400
Portable saws 2 at 9.00	1,800
Portable drills 2 at 10.00	2,000
Misc hand tools	1,000
Glue mixer	800
Tool sharpener*	1,200
Misc equipment	1,500
Impact wrenches 4 at 350.00 . .	1,400
Compressor*	3,500
Jig and bolts	5,500
Crane installation	20,000
	101,100
Shipping and install*-ation items at 100%	65,700
T O T A L	166,800
Annual Cost at 25%	41,700

Materials:

Timber 1500 m^3 at 150.00		225,000
Glue 7000 kg at 10.00		70,000
Steel 18 tons at 1500		27,000
Fillet replacements 12 m^3 at 167		2,000
Sandpaper		5,000
		329,000 vvvvvvv

Labour:

Manager		10,000
2 Foremen at 4000		8,000
Labourers -		
Drying yard	2	
Defecting	1	
Grading	1	
Fingerjointing . . .	2	
Planing	2	
Glue mixer	1	
Laminating	4	
Finishing	5	
Office	2	
	20 at 1500	30,000
		48,000 vvvvvvv

Working Capital:

Timber in drying yard - 3 months stock	56,000
Stock in hand - 1 month's production	38,200
T O T A L	94,200 vvvvvvv
Interest at 15%	14,200

Cost Summary:

Rents, etc.	30,000
Capital charges	41,700
Materials	329,000
Labour	48,000
	448,700
Interest on Working Capital	14,200
T O T A L	462,900
s a y	480,000

Annual production: 100 x 8m = 800m

Cost per metre: US$600

This is a fair cost for a heavy duty permanent bridge with its very simple and quick erection.

In any particular case, a similar study using up to date local costs, interest rates, etc. must be undertaken. A detailed study of all manufacturing operations and the labour required for the production level aimed at must be undertaken.