

Fussgängerbrücken in Brettstapelbauweise

Stress-laminated arch construction for foot-bridges

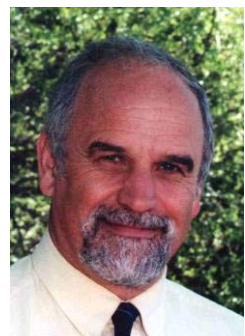
Ponti pedonali con una struttura di pannelli di tavole accostate „Brettstapel“

Passerelles piétonnières en lamellé-collé

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Arched stress-lamination of timber for the construction of footbridges was developed in 2002 in a collaborative research between Napier University of Edinburgh and the UK's Forestry Civil Engineering, Forestry Commission. The aim of the collaboration was focused on using stress-lamination technique to utilise the UK grown small-sections of low-grade timber to form strong low cost sustainable structures. The main advantages of this form of lamination are the lateral distribution of load, the dispersement of defects in the timbers and the use of timber in compression, while being low cost and employing less early capital. The very low cost of the first arch bridges built as a result of this development was offset by the relatively expensive installation/erection costs; so ways of reducing these costs were examined. For large span bridges, modular construction is considered an effective way of reducing scaffolding costs; whereas, for the short-span ones, complete manufacture of bridges in the workshop is found to be the best way of reducing site costs. During this research over 6 years nearly 40 permanent bridges have been built throughout the UK.

1. Introduction

Stress-lamination of timber is a form of construction designed to utilise the timbers of small and low quality softwood that are typically available from the UK forests. The first use of modern stress-lamination took place in Canada and the USA, driven by the need to repair old timber bridges and to replace many others. This was followed by parallel work in Australia and Scandinavia throughout the 1990s. Further developments around the world concentrated on flat-deck construction, using timber in bending. These initiatives were forced, by the need to increase spans to something greater than the capability of the largest cross-section of timber, to develop cellular box or 'T' beam composite structures. When such forms of timber construction were explored, they were found to be unsuitable for use in the UK due to entrapping moist air and creating a rot problem and so the development was focused on maximising the performance of stress-lamination by utilising the strength properties of timber in an arching action, which contributes significantly to the overall strength and stiffness of the structures.

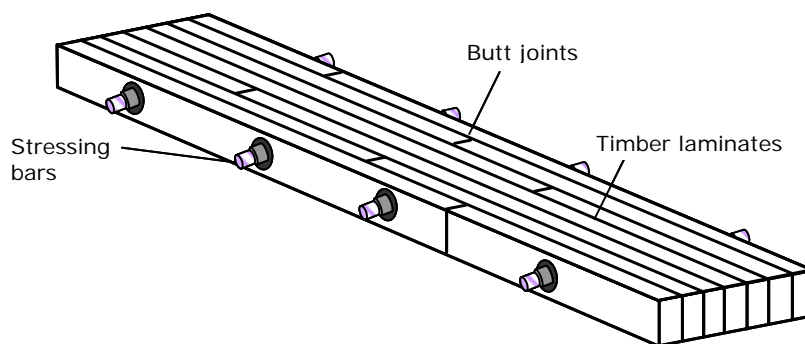


Figure 1: Stress-laminated timber plate/deck

Mechanical stress lamination of timber is a technique whereby a number of individual sawn sections of timber are compressed together using high yield steel (HYS) bars to form a large load sharing member, or orthotropic plate (Figure 1). The HYS bars are passed through pre-drilled holes in the wide face of the timbers, which are laid side by side on their narrow faces. The bars are jacked against anchors on the outside timbers, which need to be hardwood in order to sustain the very high local bearing stresses. Load is transferred from one laminate to the next by friction forces between them. This converts the whole into a solid load-bearing timber deck with the ability to transfer load laterally and longitudinally. The natural variability and defects found in timber are responsible for the reduced allowable stresses in whole timber. However, with stress-lamination the defects and natural variability are dispersed and the efficiency of the system is greatly enhanced. This form of construction utilises a low cost sustainable material with the minimum input of quality control and production energy. The resultant life cycle carbon footprint is very low compared with other bridge construction materials.

2. Development work

2.1. Laboratory and field tests

Examination of the use of stress-laminated timber decks in arched form began at Napier University, Edinburgh, some 6 years ago with a trial arch of 6m span and 100x50x1000mm timber laminates. It comfortably sustained 50kN at mid span and failed with over 30kN under a quarter-point loading (Figure 2).

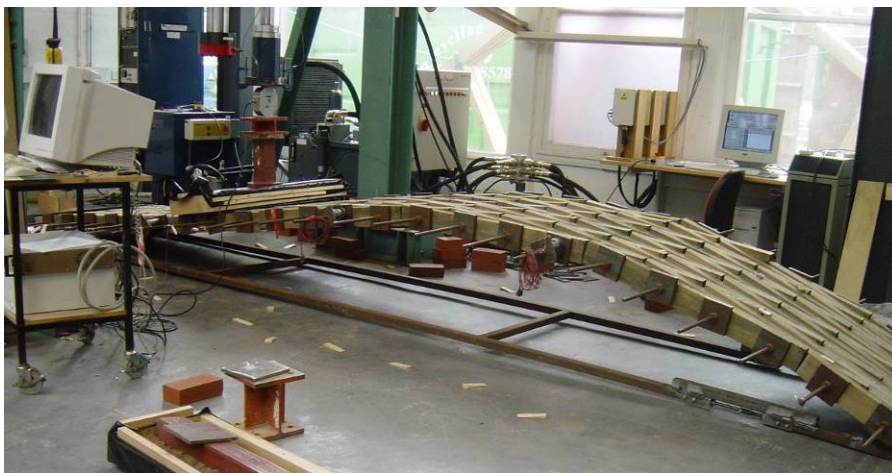


Figure 2: 6m span test bridge

The results were beyond expectations and the structure displayed a true arch behaviour so a 15m span, of similar geometry, was built and load tested [1]. The results confirmed the findings of the previous test so a number of 2.1m span bridges of variable rise were constructed in the laboratory and tested for load and friction effects with differing tensions to further understand their arching effects [2].

Encouraged by the results, a 20m span arch bridge was designed and constructed, first for demonstration at the Royal Highland Show in Edinburgh (June 2004) and then transported for testing to the Glentress Forestry Commission site near Peebles, Scotland in August 2004. The bridge was then subjected to a series of static and dynamic loads evaluating its response to crowd and vandal loadings, (Figures 3 & 4).

Further research [1, 2, 3] investigated the performance characteristics of stress laminated timber arches in detail. The significant findings include the ability of the structures to sustain large deformations and the redistribution of resulting stresses and also the effectiveness of the arching action which contributed to their stiffness and strength characteristics.

The arch shape allowed the timbers to take forces in compression parallel to the grain through the friction between the laminates and end-bearing. Unlike a masonry arch, which would fail as a result of a very small shape change, the stress-laminated timber arch can sustain large deformations, is very good in bending and recovers on load removal. All load tests to failure over a 4 year period resulted in ductile (slow plastic) failures which would give plenty of warning in a real structure.



Figure 3: Bridge at Glentress during construction



(a) Field static tests

(b) Field dynamic tests (crowd walking)

Figure 4: Arch structure during testing (20m span at Glentress).

The study showed that it is possible to make a good prediction of structural performance using a step-wise elastic linear analysis based on large-deformation concept. Semi-empirical models were also developed to assist engineers with the analysis-design process, taking into account many possible boundary conditions.

2.2. Markets and Uses

Since the development of stress-lamination technique in arch form in the UK, in 2002, some 40 commercial bridges have been commissioned and built throughout the UK. These bridges are mostly arches for pedestrians but there are some short-span flat decks for 44 tonne lorries. This year the first long span arch and flat deck combination will be built for 44 tonne lorries. Commissions have also been received to design a 40m span railway arch and flat deck combination and a 40m span Leonardo double arch footbridge.



Figure 5: Examples of a stress laminated arch structures built in the UK.

Stress-laminated arches have also been used for roofs, though there is still much development required, and there is great interest in the use of the technique for industrial floors. There are also plans to build tall towers using stress laminated legs and bracing panels stressed between legs to provide the lateral restraint. Also, there is a new market in Forestry for temporary bridges for forwarders and harvesters which are large machines with total weights up to 40 tonnes. Because they have a very high ratio of strength to weight, the forest machine can carry its own bridge without the need for a crane.

However, the biggest market will be for footbridges. In the UK there is a need for at least 2000 replacement bridges in rural areas. Development of these kinds of bridges, made in factories and light enough to be transported to site complete and lifted into place, will be in demand.

3. Modular construction

Recent development has focused on determining the viability, dimensional limits and the type of fixings that would be required to produce self-supporting modules to take construction loads. The modules need to span the full distance from abutment to abutment and be of a weight that could be easily lifted. The aim was to produce modules weighing less than one tonne so that an excavator (often available on site for other purposes) can lift easily. This means that there will be no need to hire a crane, so keeping cost down. It was therefore decided to start with 400mm wide modules which would keep even the longest spans under a tonne in weight.

The laminates were temporarily fixed by nails or screws to one another to form the modules. The modules would then be lifted into position and laid side by side, while being temporarily supported laterally, and stressed together to form the permanent bridge deck.

3.1. Timber species

The stress lamination research in the UK aimed to explore the possibilities of using locally grown species such as Sitka spruce, a low-grade plantation timber, for large structures. However, as Sitka spruce is not durable and is very difficult to treat with preservative, other home-grown species such as Scots pine, Larch or Douglas fir are preferred for high value bridges, as they are either more durable or take preservative easily.

For these tests, a relatively dense Douglas fir from the Scottish Borders was used. This resulted in some difficulty with nailing but provided useful comparisons with the timber used for other tests.

3.2. Fixings

The module fixings are temporary and as such they need to be low cost provided that the required stiffness and strength are achieved.



Figure 6: Assembly of a 12m span test bridge module in the laboratory.

The first trial was to make a roof for a Royal Highland Show exhibit. The laminates were nailed using 3mm diameter \times 90mm long ridged nails fired from a gas powered gun. These modules were 4m span and they held together well but it soon became clear that greater rigidity would be required for larger modules.

To align the holes for stressing bars, plastic tubes were inserted through the holes. Nails were driven in approximately 50mm from each side of every hole which amounted to 8 nails per laminate.

3.3. Module types and sizes

The experimental work was designed to examine a range of different sizes of modules and spans to determine the viability and dimensional limits of modules that could be made. Our study [1, 2, 3] on stress-laminated arch bridges concentrated mostly on span to rise ratios of 12:1 and 6:1 so it was decided to maintain these ratios so that test results could be compared to previous experimental work and provide some valuable cross-referencing.

As design had shown that a 100mm deck depth is strong enough to withstand pedestrian loading over a span of 6m, 150mm over a span of 12m and 200mm over a span of 18m, it was decided to construct and test two replicate modules of each of these three spans with two different rises. The rises of these arches were 0.5m and 1m for the 6m span, 1m and 2m for the 12m span and 1.5m and 3m for the 18m span.

4. Structural performance

Prior to static load tests, each module was raised up and then lowered by a crane. This was to allow the module to hang down (sag) from a crane sling as well as being subjected to a small impact under its own weight and allowed for its ends to slide apart.



Figure 7: A 12m span nailed bridge module during lifting and under quarter-point load test.

This was repeated a number of times aiming to simulate a range of possible stress conditions that might occur during lifting and assembly on site. Then, each module was placed under the laboratory loading machine, supported at each end by a steel channel, held together and prevented from spreading apart by two 20mm diameter treaded rods, in series with load cells which recorded the horizontal thrust at the springing points of the arch. The modules, after a regime of bedding-down loads, were first subjected to four-point loading of up-to half their service design load (to avoid damage), then by a line load at mid-span before being loaded at a quarter span position to failure. The load was applied through a bed of sand to exert uniform pressure across the laminates. Deformation of the arch was recorded at various positions along the span using displacement transducers (Figure 7).

The sagging shape of the arches, when lifted at their centre point by crane, was taken as the empirical test of handling capacity. The 6m spans were very robust but it became clear when lifting the 12m spans that the nail jointing was at near capacity and that an 18m span would require connectors with larger diameter and length penetrating two or more laminates and this was out of the range of the gas powered nail gun.

5. Factory production

The production of a number of demonstration and commercial bridges had shown that factory production of whole, small span, bridges was in most cases a more efficient production method than making modules and assembling on site. The method would require a small crane and provided that access was possible the cost saving of total factory production would be substantial. As an example, the building of Arran Golf Course Bridge, shown in Figure 8, demonstrated that factory production of a 12.6m bridge would lead to total installed cost of £20k for 30m² of bridge which is very competitive.



Figure 8: Arran Golf Course Bridge during installation (top) and after completion (below).

6. Summary

The project began by making and testing modular units with a view to reducing the site costs of building stress-laminated timber arch bridges. The tests on the 400mm modules of up to 12m span, using 8 nails of 3mm diameter 90mm long per laminate, showed that they were strong enough for all temporary and construction loads. The use of plastic tubes to facilitate the insertion of stressing rods also contributed to the shear capacity of the connection medium.

It was shown that this modular approach with nails was limited to 12m span. Larger nails for longer span modules would need to be shot fired which could be too costly, so screws and glue were considered as alternatives. The use of screws and glue for manufacture of smaller bridges without the need for stressing bars was also examined and it was found that they can be viable construction systems as they exhibit adequate structural performance as well as being factory manufactured at low cost.

Stress lamination of timber, as an engineering concept, has a useful future in construction and should provide many opportunities to utilise the low-grade UK timber – a readily available lightweight material, excellent in compression yet good in bending. That combination will particularly encourage its use.

7. References

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