Aberfeldy Bridge
– an advanced textile reinforced footbridge

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Aberfeldy Bridge - an advanced textile reinforced footbridge

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The footbridge completed recently at Aberfeldy in Scotland combines several advanced technologies into a very practical demonstration of what can be achieved with the use of new materials.

Linksleader project.

The initial enquiries about the bridge came from the golf club in the small town of Aberfeldy, which lies on one side of the River Tay in the Scottish Highlands. The existing 9 hole golf course lay on the town side of the river, but the club owned sufficient land for another 9 holes on the far side. Unfortunately, the only route across the river was via an old hump-backed bridge that was barely wide enough for a single lane of vehicle traffic and was very dangerous for pedestrians, even when not encumbered with golfing paraphernalia.

The club therefore sought a cheap bridge to cross the river in a convenient location in the middle of the course. They approached Prof Harvey at Dundee University to see if this was suitable for a student project, but he realised that a main span in excess of 60 m would be required. This would clearly require serious civil engineering support, but he was anxious to retain student involvement if at all possible. He was aware of the work of Maunsell Structural Plastics [1] both in developing a structural system using glass reinforced plastics, and also in producing a limit state design approach for these materials which allowed them to be properly assessed by certifying authorities.

After various negotiations, the 'Linksleader Project' was formed. The design of the bridge was carried out by Maunsell with assistance from the students, and a civil engineering contractor, O'Rourke, was brought in to manage the contract, in particular with respect to site safety. Maunsell also had a resident engineer on site. The final form of the bridge is a main span of 63 m, within an overall length of 113 m and a width of 2.23 m. Two towers, each 17.5 m high, support the deck with a total of 40 cables, arranged in two planes (Figure 1).

The deck and towers are made from interlocking cellular GRP units, and the stay cables are Parafil ropes made from the aramid fibre Kevlar. The only 'conventional' materials (steel and concrete) are in the foundations and in the connections between the cables and the GRP, where high concentrated loads have to be carried.

Construction.

The bridge was built by students from Dundee during the summer vacation. Two engineers, one from Maunsells and one from O'Rourke, supervised the work, which took approximately 8 weeks on site. The erection method is unique for a cable stayed bridge and was only made possible by the use of lightweight materials.

The GRP pultrusions for the deck structure were assembled on site in a tented ramp structure on one side of the river. A daily cycle of preparation, trial assembly and bonding was carried, which allowed the deck for the main span to be completed within two weeks. Each tower leg (weighing 1.25 tonnes only) was fabricated at GEC Reinforced Plastics works in Preston, and brought to the site by road, where they were bonded together, pinned to the prepared foundation, and rotated into their final position. The light weight meant that the lifting could be carried out without the need for cranes on the site.

The GRP cross beams, which are connected to the stay cables and on which the deck rests, were assembled on site, attached to the Parafil cables, and then held in position across the river by means of temporary wires (Figure 2). This then provided a framework across which the completed main-span deck could be launched, being pulled across by means of a winch on the far bank of the river.

Once the main span was completed, the side spans were assembled, and the entire deck lowered to engage the cross beams in slots left in the deck structure. GRP handrails were added, and the temporary longitudinal cables used for erection were removed (Figure 3). Finally, a wear resistant deck surfacing was added to prevent damage by spiked golfing shoes.

Some technical aspects of the project deserve further consideration.

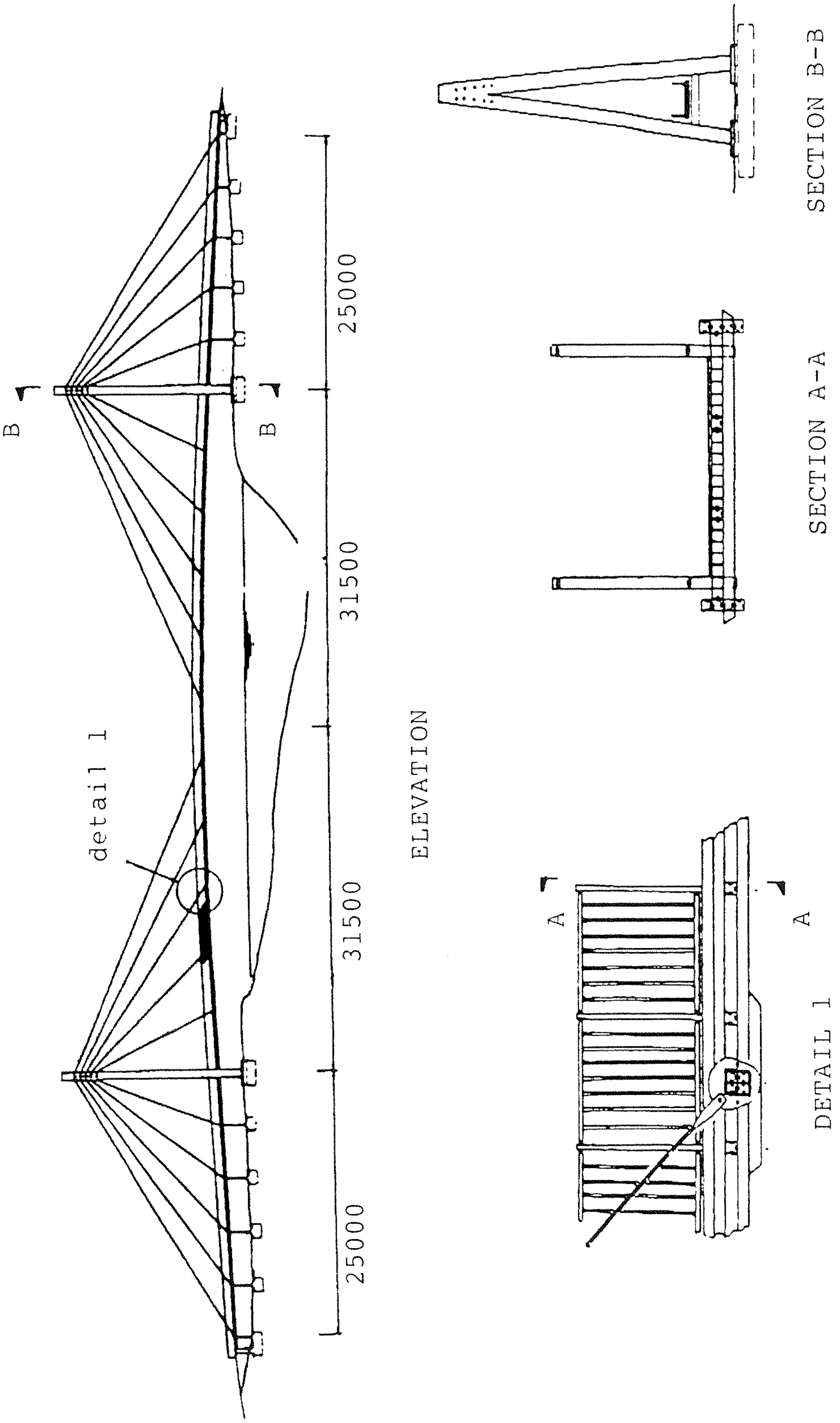

Figure 1. General Arrangement of Aberfeldy Bridge

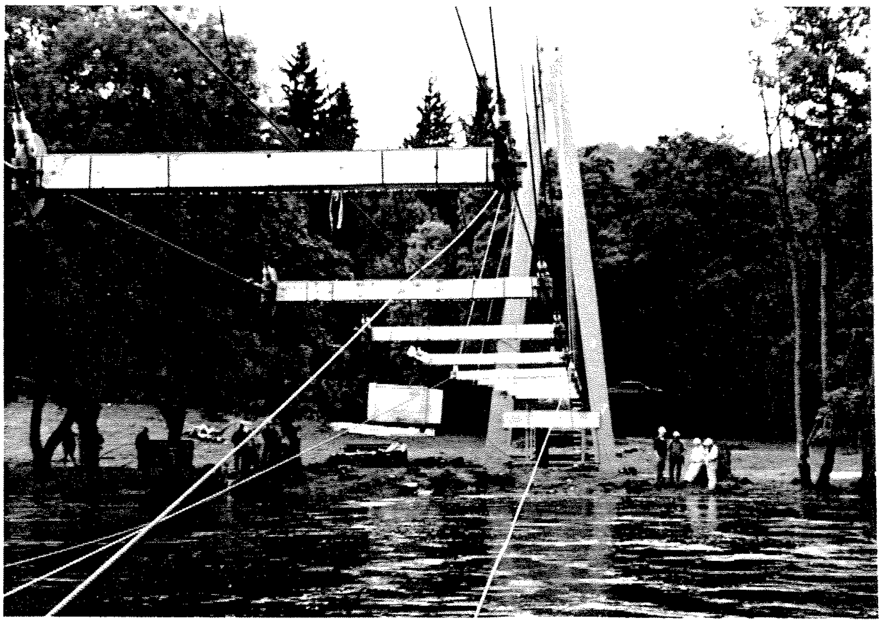

Figure 2. Cross beams suspended from Parafil ropes, ready for deck launch.

GRP Pultrusion system.

The Glass Reinforced Plastic pultrusions used on this project were invented and developed by Maunsell for a variety of structural applications [2]. The basic component is a unit cell, approximately 80 mm square, which features a keyway running down each side. This receives a toggle bar which links the cell to its neighbours. The joint is filled with adhesive to provide a permanent rigid bond between the components. Wider planks, composed of seven cells side by side, form the bulk of the structure, with single cell units being used to provide additional stiffness at edge beams and in the joints between units.

All components are made by the pultrusion process, and incorporate high volume fractions of fibre. Many layers of fibre can be incorporated in this process, with most of the fibres running longitudinally, but with some arranged in the form of ribbons and tapes so that transverse strength can be provided to the cells. Different amounts of fibre can be placed in the different faces of the cells, to reflect the different stresses (axial, shear or flexure) that arise in each face, and extra reinforcement can be provided in areas of high stress concentration, such as the toggle keyways.

Pultrusions thus give the designer additional freedom. Not only is the shape variable, but also the reinforcement that is provided within that shape. Two pultrusions that look superficially the same may well have different strengths. Economic consideration will have an influence here. By far the largest cost associated with pultrusions is in the cost of the die, which has to be very accurately machined from wear resistant chrome steel. There are thus enormous cost penalties associated with changing the *shape* of the structure, whilst it is relatively easy to vary the amounts of reinforcement, which can be altered to suit different applications.

Quality control during pultrusion is also critically important. As with reinforced concrete, it is almost impossible to determine how much reinforcement is present without destroying the specimen. In the case of GRP, this can be done by burning off all the resin. Thus, suitable quality standards have had to be produced to ensure that the correct amounts of fibre are put into the pultrusions, in the right place, and that production is done at the correct speed, which can have a great (but opposite) influence on the costs and quality of the product. This is covered by a detailed manufacturing specification prepared by Maunsell for use with their limit state design approach.

The greatest use of the GRP system to date has been in bridge enclosures, most notably on the A19 Tees Viaduct in Middlesbrough. Here, GRP planks, as used at Aberfeldy, were assembled together to form an enclosure around the steel plate girders that support the bridge. The enclosure serves both to protect the bridge from the elements, thus reducing the need for maintenance, and to provide a working platform from which that maintenance can be carried out. A total of 16,000 m of pultrusions, weighing 250 tonnes was used in this application.

The pultrusion construction system has been patented worldwide by Maunsell's, and is now available under the name Advanced Composite Construction System.

Limit state design philosophy.

In the last twenty years, starting (at least in the UK) with the introduction of CP110 for reinforced concrete, codes of practice have been produced based on limit state principles for the design of most structural elements. These codes, in theory, adopt the idea that both materials and loadings are variable, and that we must strive for acceptably low levels of probability of failure. That is difficult to achieve, even when we are dealing with materials such as steel and concrete about which we know a lot and have large bodies of test data on which to base our decisions. But when we come to use new materials, we can find ourselves in a vicious circle where we cannot use the material unless a code is available, the code cannot be produced until the test data is available and the testing will not be carried out until there is a certainty that the material will be used.

To avoid this situation, Maunsell went back to first principles to produce a limit state design method for the use of the new system [3], and carried out basic testing to provide the strength and variability information necessary to allow the various partial safety factors to be determined.

This allows designs to be produced with sufficient assurance to satisfy certifying authorities, and is likely to form the basis of future codes of practice for new materials generally.

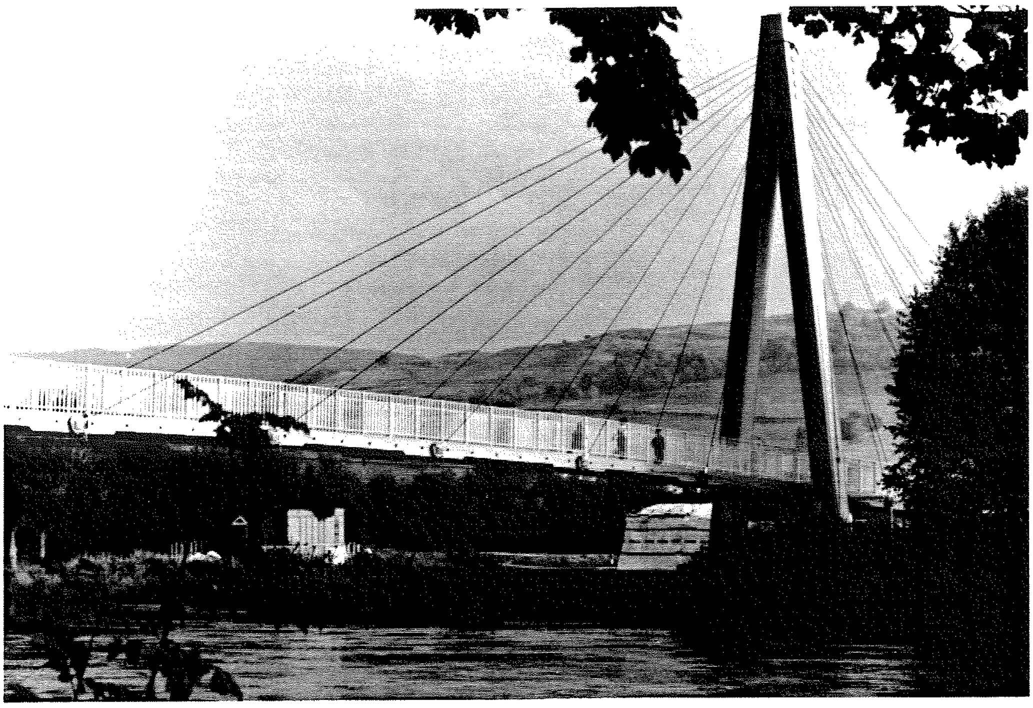

Figure 3. Completed structure.

Parafil Cables.

Parafil ropes have a core of parallel filaments contained within a polymeric sheath. In the case of the ropes used for the Aberfeldy Bridge, Kevlar 49 yarns, with a stiffness of 126 kN/mm^2 and a breaking strength of 1930 N/mm^2 were used. The ropes are fitted with terminals in which the fibres are gripped between a central spike and a matching external barrel (Figure 4). This ensures that all fibres are equally gripped, and tests have shown that the termination achieves the full strength of the rope.

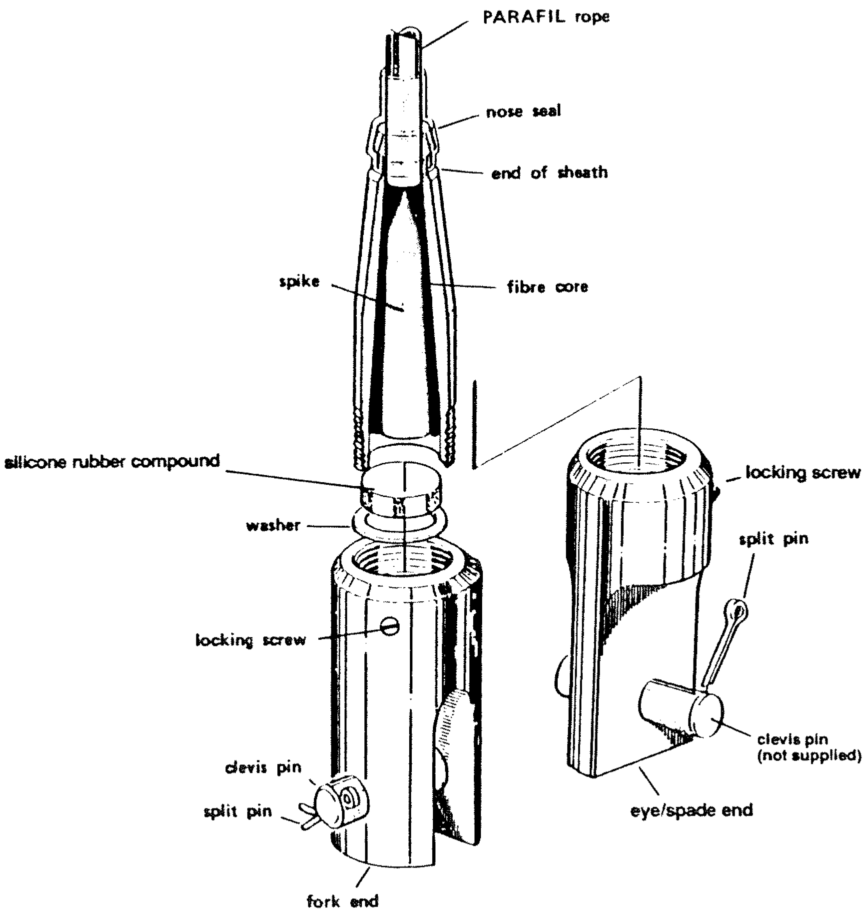

Figure 4. Parafil rope terminations

Parafil was orginally developed for offshore mooring, but the combination of high strength, high stiffness and light weight makes the ropes attractive for a number of structural applications, such as prestressing cables for concrete, ground anchors and, as in this structure, stay cables for bridges and roofs.

One of the first structural applications was the repair of cooling towers at Thorpe Marsh power station in the north of England. Three of the towers had extensive cracking, which was repaired by resin injection followed by circumferential prestressing with Parafil cables. Other applications include stay cables on a bus station roof at Cambridge, which are pretensioned slightly in normal operation, but are primarily designed to resist snow loading on the horizontal roof.

Structural Dynamics.

A lightweight structure such as the Aberfeldy Bridge raises interesting structural dynamic problems. The light dead weight makes the structure very easy to excite. But it is designed to carry a much higher load, which means that weight can be selectively added to the structure, by filling the FRP cells with concrete, to uncouple the flexural and torsional vibration modes. This has the effect of simplifying the analysis of the structure, and also makes it easier to control the magnitude of the oscillations. Results have shown that the structural performance of the materials is highly predictable.

A long-term monitoring programme for the bridge, both for its static and dynamic behaviour, is being undertaken by Dundee University. This will study, amongst other things, the structural damping. The bridge has been subjected to extreme weather conditions since construction, including severe flooding and 140 km per hour winds. It has performed outstandingly well and is aerodynamically stable despite its slenderness and low weight.

Conclusions

The Aberfeldy Bridge demonstrates that new light weight materials can be regarded as serious structural elements. It has been shown that careful selection of material, overall structural form and element design can lead to efficient and elegant structures. It also shows that we must think of these materials in their own right, rather than as replacements, to achieve the best results.

Acknowledgements

The bridge was built with assistance in kind from many companies.

GEC Reinforced Plastic Ltd supplied the composite components.
Scott Bader supplied the polyester resin
Vetrotex (UK) Ltd supplied the glass reinforcement
Ciba Geigy supplied the adhesives
Linear Composites Ltd supplied the Parafil ropes and fittings
O'Rourke were the civil engineering managers.

Kevlar is a trade name of EI Du Pont de Nemours, and Parafil is a trade name of Linear Composites Ltd.

The Advanced Composite Construction System is marketed by Designer Composites Technology Ltd.

Parafil ropes for prestressing applications are marketed by Linear Composites Ltd in association with VSL International Ltd.

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