Parafil ropes – from development to application.

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Parafil ropes were first developed in the mid-1960s by Linear Composites Ltd. to meet a requirement for mooring a series of floating platforms in deep-water in the North Atlantic, which had to be in accurately fixed positions. The depth of water ruled out steel as a mooring line, and the position keeping necessitated a material which had as high a stiffness as possible. In normal rope construction, individual fibres follow a serpentine path through the rope, and a significant proportion of the fibre stiffness is lost in the rope structure. In the event, the development of satellites removed the need for the platforms, but by that stage, production techniques had been perfected.

Parafil ropes contain a core of yarns within a thermoplastic sheath. The technology can be applied to a variety of core yarns; the most commonly used are polyester and aramid (Table 1), although other yarns such as Nylon have also been used for particular applications.

One of the most important aspects of the Parafil rope system was the development, at an early stage, of a termination system, which consists, at its simplest, of a spike and conical barrel (Figure 1). The profiles of the two parts are carefully chosen to provide a uniform force across the annular fibre pad. This ensures that every fibre is gripped, as opposed to those systems with external wedges which only grip the outer fibres (Figure 2), and also means that the transverse stress on the fibres is kept to allowable values. The result is a termination system that can develop the ***full*** strength of the rope; this has been shown in a large number of tests to failure where rupture takes place outside the termination. ***No*** additional fibre is needed to cope with stresses set up within the termination.

Structural Applications

The earliest applications of the ropes were as guys for radio antennae. In addition to the strength properties of the material, these make use of the non-conducting nature of the ropes to do away with conventional insulators. The first installations used polyester ropes, but since the development of aramid fibres, and with the communications industry using arrays of masts which have to be accurately placed with respect to one another, the stiffer aramid ropes are now being used more extensively.

Moorings for floating systems, such as buoys, have been extensively used (Figure 3).

These often have floats, weights, and other equipment attached at the top and bottom ends, with the bulk of the length of the mooring being provided by Parafil.

Other early uses of Parafil as replacements for steel wire followed. Such uses have included standing rigging in ships, where the smooth sheath has been found to provide the added advantage that ice can easily be shaken free; supports for overhead wires in trolley-bus systems (again making use of the electrical insulation), and in safety rails around the deck of ships. Many of these systems are in use by military authorities around the world.

During the Australian Bicentennial celebrations in 1988, a touring exhibition was mounted, which consisted of a series of tented exhibition stands mounted on trucks (Figure 4). These were moved around the country and erected many times at different locations. Parafil ropes were used as the main supporting cables for the tents.

A rope has recently been removed from the earliest guyed mast application, in order to study the rope after about 20 years in service. No deterioration was found. Similarly, ropes have been recovered in excellent condition after many years immersion in sea water on mooring lines.

Developments in prestressing

In about 1980, when the first ropes had been made with the newly developed aramid fibres, it became clear that the ropes would be suitable for structural applications, so research programmes were set up, first at Imperial College in London, and more recently at Cambridge University, into the relevant properties of the ropes. This work has resulted in many publications, and is continuing; the aim is to provide practising engineers with material properties that can be used with confidence.

One of the most obvious application is in prestressed concrete. Prestressing tendons are the most highly stressed structural components; steel tendons are typically stressed to 70% of their ultimate strength. Increasing concern is being felt about the condition of steel tendons, due to the possible ingress of water into incompletely grouted ducts. The fact that Parafil tendons will not corrode means that this is no longer a problem.

Test beams have been built at Imperial College (Figure 5), and circumferential prestressing has been installed at the top of three badly cracked cooling towers at Thorpe Marsh Power Station in Yorkshire. This work was carried out about three years ago and the Parafil ropes are performing well. Figure 6 shows a typical prestressing sequence.

More recently, a small bus station has been completed in Cambridge; this has a roof supported by Type G Parafil ropes (the stiffest version) (Figure 7). There are four masts, each supporting a pair of forestays and a pair of backstays. This is a sensible precaution, seen from the client's point of view, when using new materials; one of the ropes in each pair can be replaced at a time, without affecting the use of the bus station.

Parafil ropes have been used in a development of the armoured vehicle launched bridge system by the Defence Research Agency, RARDE at Christchurch. During deployment, the scissoring action means that the bridge components act as cantilevers, with all the tension being carried by the Parafil ropes (Figure 8); these forces are high due to the small lever arm. It is expected that the system will be adopted by the army in the near future.

Future applications

As experience with the material builds up, more applications, on a larger scale, will come into use.

It is clear that Parafil will start to find more widespread use as a non-corroding prestressing tendon. Repair of structures by the use of external tendons will become more common, and the use of unbonded, replaceable tendons is likely to become the norm for all structures in the near future. Structures, such as water towers, which often have poorly protected steel prestressing and a high incidence of corrosion, are currently being studied with a view to their repair with external Parafil tendons. A number of bridges with suspect prestressing tendons are also being identified by the current bridge assessment programmes; these would make useful demonstration sites for new materials as the new tendons would be adding an extra margin of safety, rather than providing the primary stressing.

Offshore, as exploration for oil and other minerals moves into ever deeper water, the arguments for using mooring lines with almost neutral buoyancy become more persuasive. Structures can be moored in 300 m of water using steel, but not in 3000 m. Virtually all the major oil companies have conducted studies into the use of lightweight mooring lines; when economics dictate that such structures be built, Parafil ropes, or similar systems, will undoubtedly be used (Figure 9).

Similarly, as bridge spans increase, the use of lightweight stiff materials becomes more economic. The excellent fatigue behaviour will also be seen to be important. The Eurobridge proposal to cross the English Channel with 7 spans of 4.5 km was probably 20 years ahead of its time, and had some conceptual flaws. Nevertheless, such large spans are only going to be possible if new materials are used.

Other applications will make use of the non-magnetic nature of the material; applications such as de-Gaussing facilities for ships, or as strength elements in members carrying important communications, (such as railway signalling and control equipment), can also be envisaged.

From development to application

The subject of this symposium is directed at the way new materials move from development to application, and the experience with Parafil is probably typical. The first question asked by most people is "Where else has it been used?" No one wants to be first. This is a circular process that it is difficult to break. First uses have to be in fields where failure would not be critical; radio masts have multiple stays, so failure of one is not going to bring the whole mast down.

The next set of applications will be those for whom the new material answers a problem for which there are no conventional solutions; the cooling tower application falls into that category. The bus station use can be seen as a case where the client wished to gain experience with a material which would receive other uses elsewhere.

The role of research is fundamental to this sort of application. No sensible designer would use a new material without some reassurance about the material's properties. Not just the short term, but the long term properties must be understood, and sufficient tests must be carried out to understand the degree of variablity in the properties. This is of increasing importance as designers get a better understanding of limit state principles, and are prepared to apply the methods underlying limit state codes even when the codes themselves have not yet been written.

Finally, there is some responsibility on national client authorities to permit the use of new materials in an experimental way. Some of the new materials will show the best economic return when used in very large structures where weight is important, but no one will build a large structure until a small one has been built first; thus the consent of clients to the building of smaller "prototype" structures is important.

Parafil ropes have been in use for about 25 years. Their properties are well understood as a result of extensive research; knowledge about them is growing, as a result of publicity in national and international journals. Experienced gained with early applications is giving confidence to those considering new applications. There is no doubt that the next few years will see a rapid increase in the use of these materials in a wide range of structural applications, both onshore and offshore.

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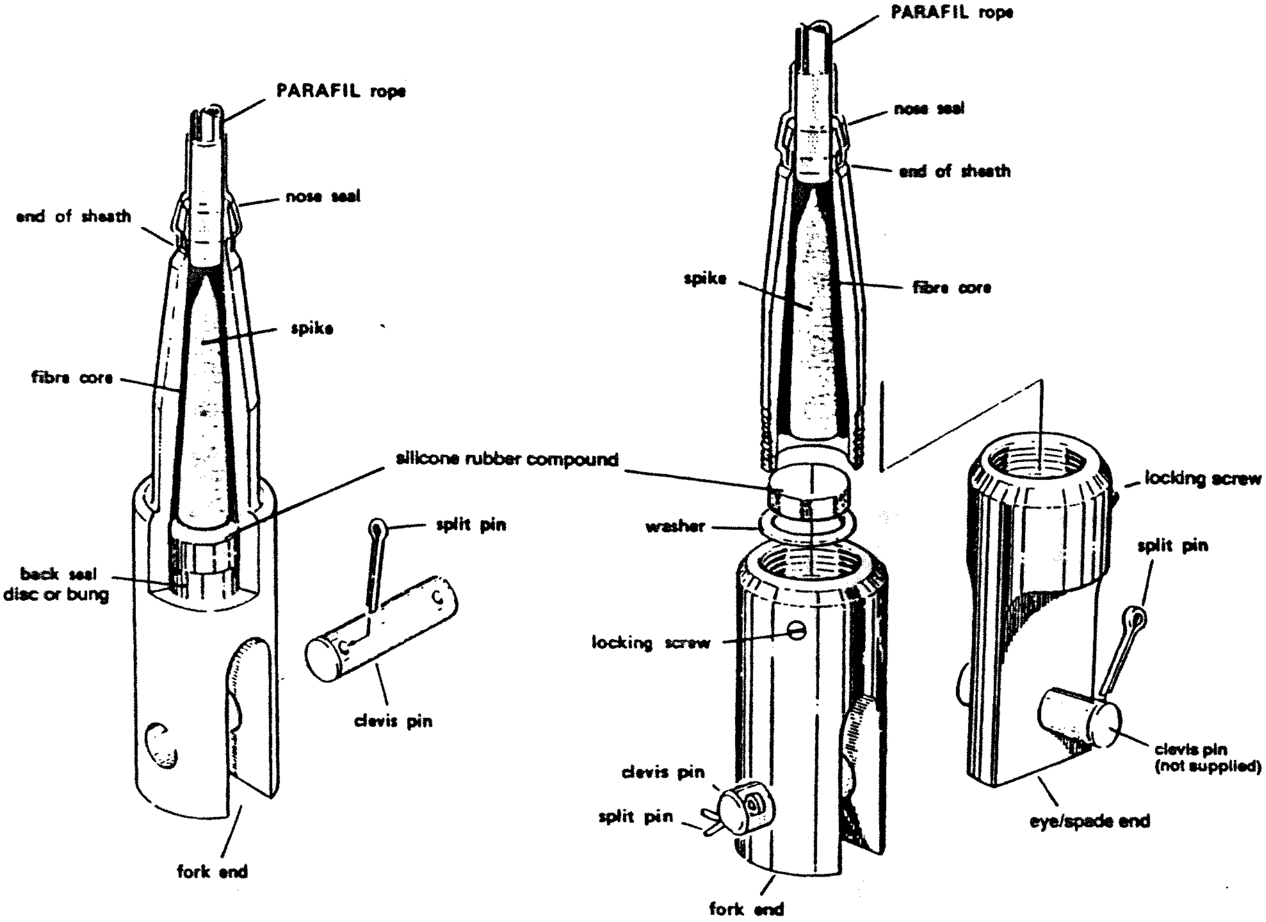
Designation	Material	Strength N/mm²	Stiffness kN/mm²
Type A	Polyester	617	12.0
Type F	Kevlar 29	1926	77.7
Type G	Kevlar 49	1926	126.5

Table 1. Tensile properties of Parafil Ropes
(Manufacturer's data)



One Piece Terminal
(fork end only)

Two Piece Terminal
(choice of fork or eye/spade ends)

Figure 1. Typical Parafil Terminals. Details vary according to application.

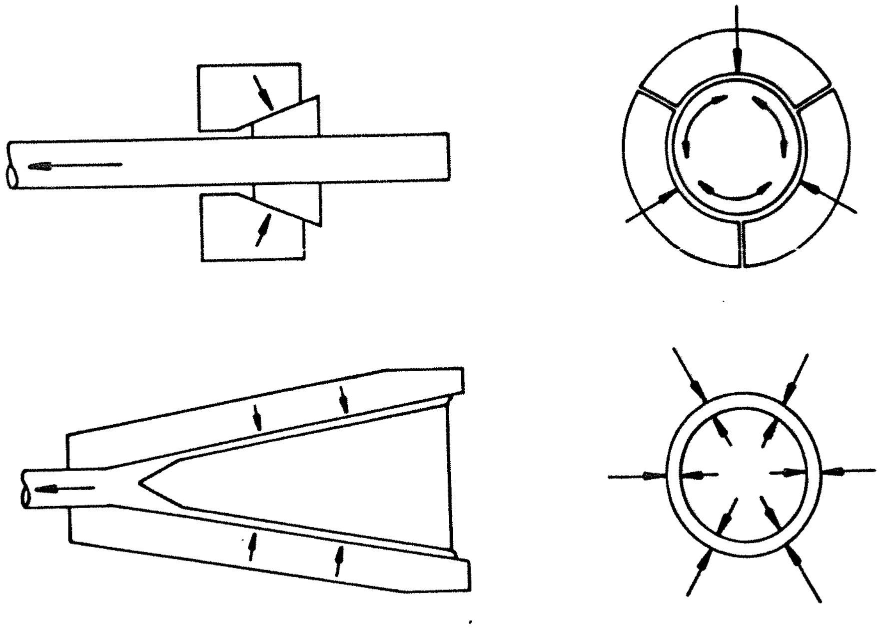


Figure 2. Comparison of effect of external wedges, which sets up hoop compression in outer fibres, and internal spike which grips all fibres uniformly.

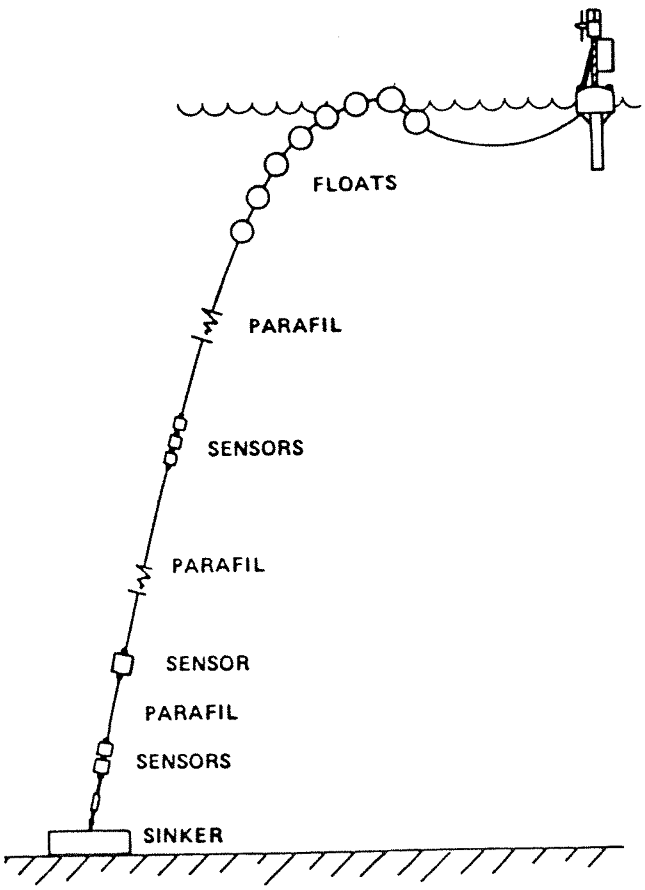


Figure 3. Radio navigation buoy installed in 6000m water depth in 1975, with Type F Parafil mooring line.

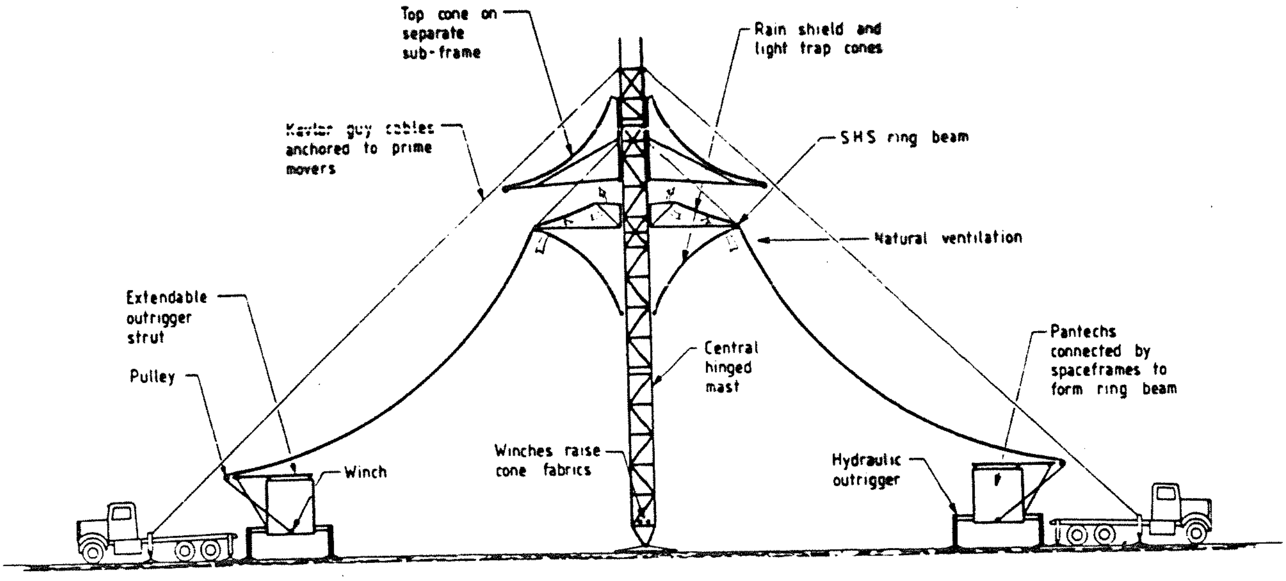
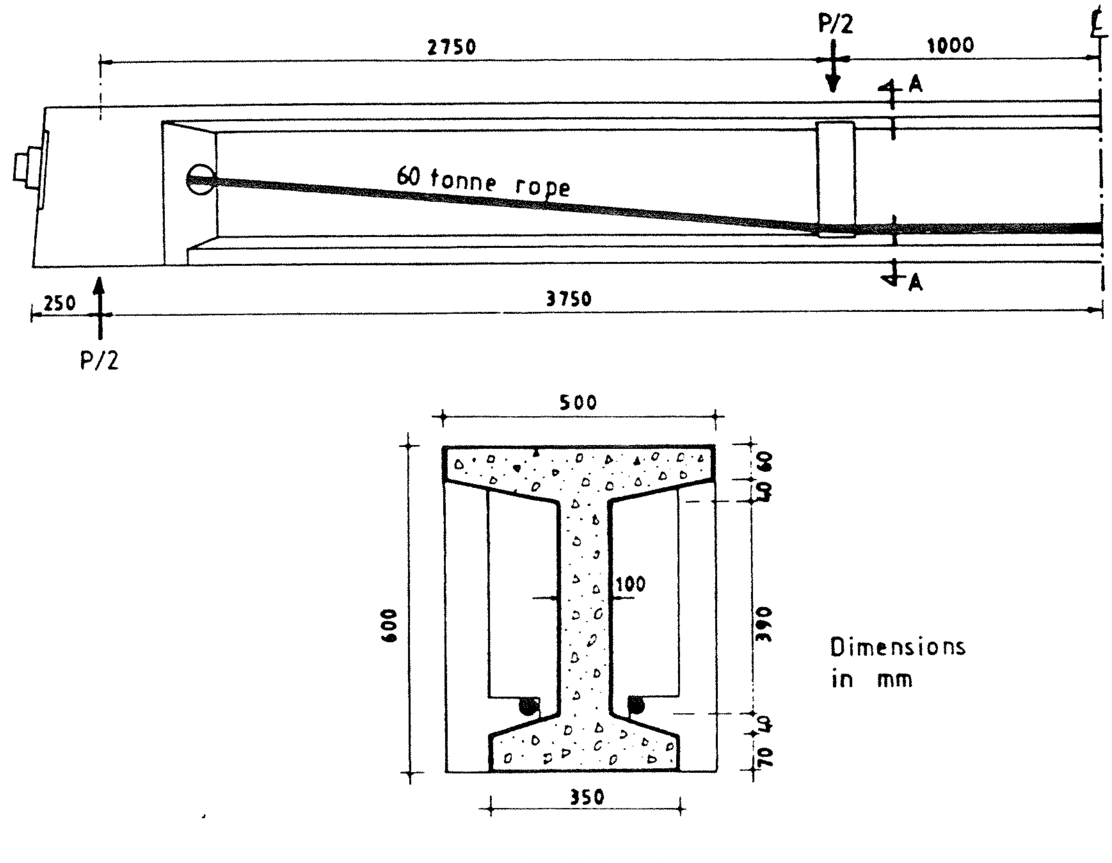
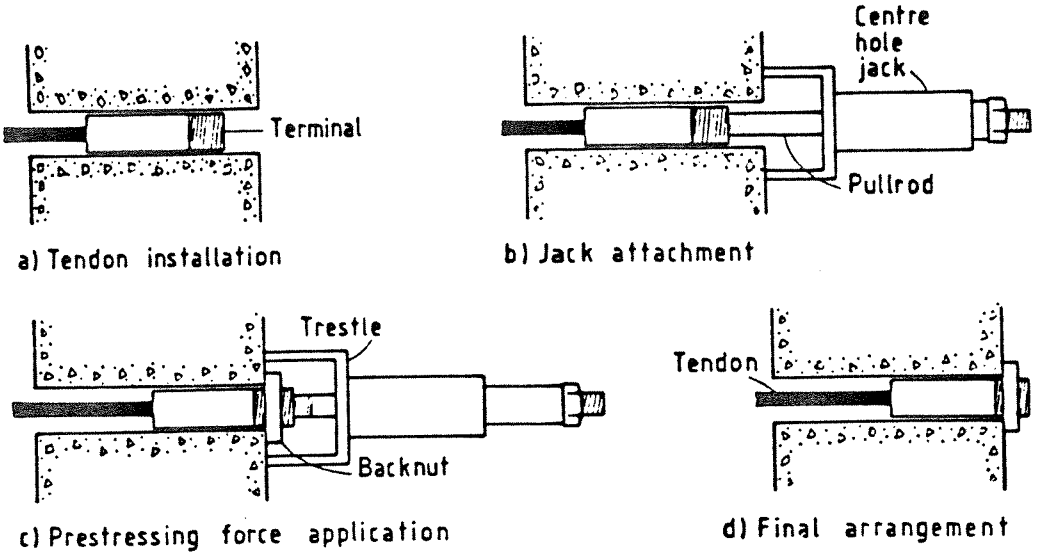


Figure 4. Section through demountable theatre in Australian Bicentennial Exhibition.



SECTION A-A

Figure 5. Half views of 8m long prestressed beam tested at Imperial College. Prestressed with two 60 Tonne Type G Parafil ropes.



a) Tendon installation
b) Jack attachment
c) Prestressing force application
d) Final arrangement

Figure 6. Typical prestressing procedure with Parafil ropes.

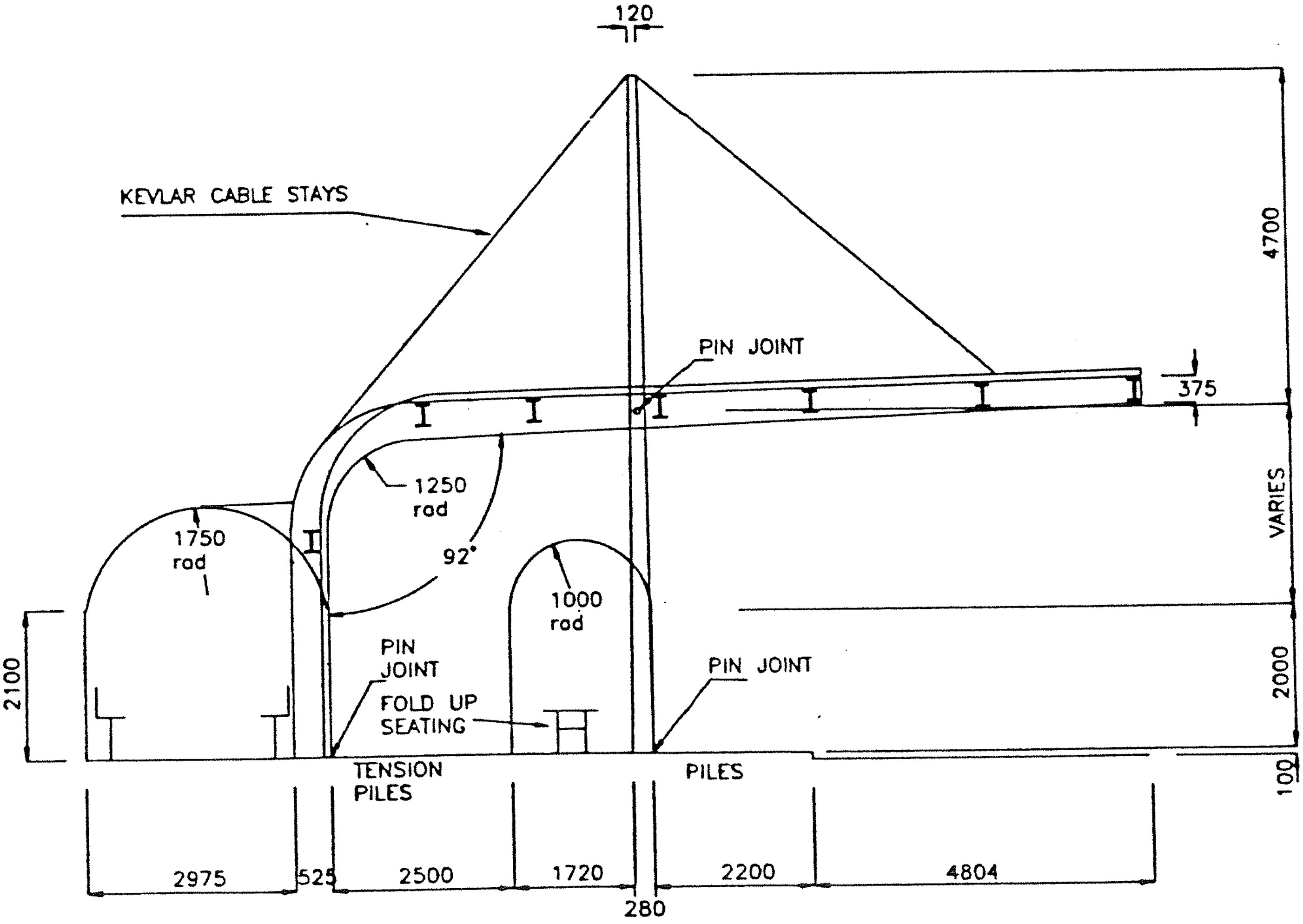


Figure 7. Section through bus station roof, supported by 30 Tonne Type G Parafil cables. *(Cambridgeshire County Council)*

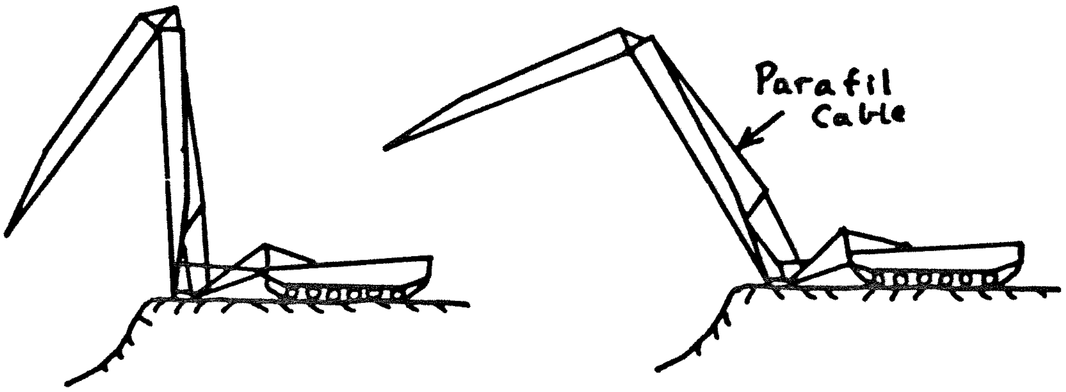


Figure 8. Part of the launching sequence of RARDE tank-launched bridge.

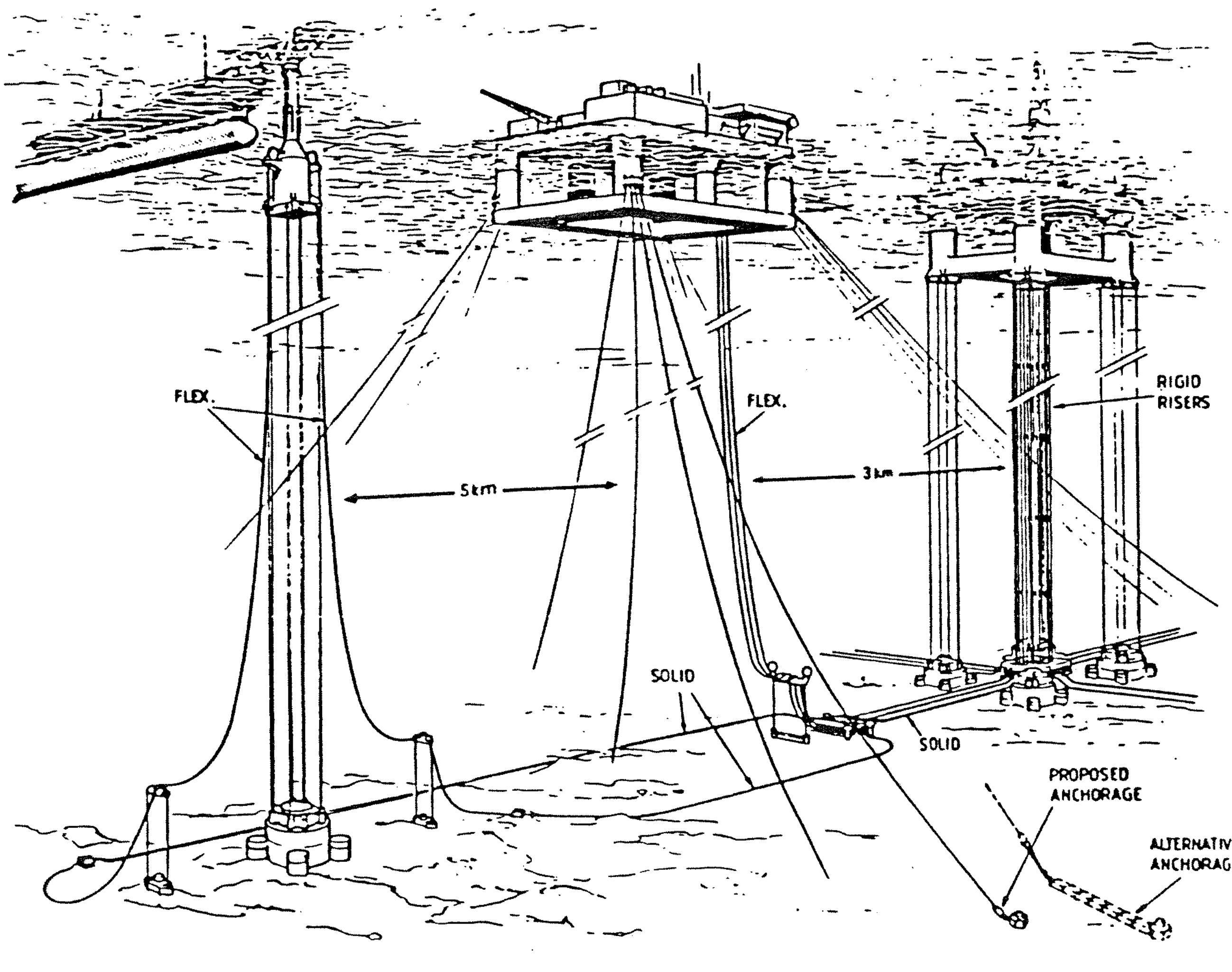


Figure 9. Possible mooring configurations for deep-water offshore platforms.