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TRANSACTIONS (TM)

MULTICORE UNDERSEA PIPELINE TECHNOLOGY

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Multicore Undersea Pipeline Technology

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SYNOPSIS

There is an increasing demand for more than one pipe along the same route for oil, gas, power and communications which for convenience can be installed in a common bundle. A multicore pipeline is economically and technically superior to a series of individual lines. The design of multicore pipelines has a number of unusual aspects such as buckling, bending, thermal expansion and insulation, installation and repair. The authors discuss the advantages and disadvantages of the various construction methods in relation to design.

INTRODUCTION

In many subsea systems, more than one pipeline follows the same path. For instance, a pipeline carrying gas from platform A to platform B might be accompanied by a second line carrying injection water from B to A, separated condensate, oil, or methanol for hydrate suppression.

A line from a remote wellhead might be accompanied by hydraulic control lines, by methanol injection, or by a second line to facilitate pigging. Some of the lines might be thermally insulated, and some might be heat-traced or cold-traced.

Parallel to them, there might be power cables, or electric cables, fibre-optic cables or waveguides for control signals or data transmission. As the sophistication of subsea systems increases, so does the range of possibilities.

Sometimes the correct design solution is to install all the pipelines and cables separately. More often, however, there are compelling technical and economic arguments for constructing them together as a continuous bundle.

In this paper we examine the technical and economic factors that enter the design process.

DESIGN

One approach is to design each individual pipeline separately and then to construct them as an open bundle, by strapping them together, perhaps with spacers [Fig. 1(a)]. An instance is the 5200 m Cobia to Halibut pipeline in the Bass Strait, which consists of a 4 in (114 mm) fuel gas line, strapped to a 12.75 in (324 mm) oil line.[1] Both lines had polyethylene coatings, the 10.75 in line under a concrete weight coating.

These lines were installed by bottom tow, but the same technique can be used for lines laid from barges or reelships.

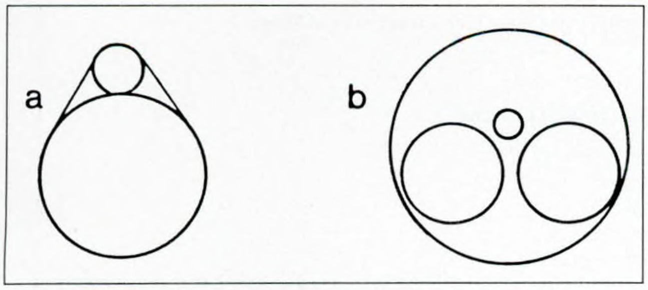

FIG. 1: (a) Open bundle and (b) closed bundle

When two or more lines are tied together in this way, the strapping system must be able to resist the forces induced during installation. If the bundle is bent severely, these forces are often large. The engineer must decide whether the strapping is intended to be permanent, remaining in place through the operating life of the pipeline, or whether it can be allowed to corrode, once the line is in place.

If the strapping is permanent, the two lines can be designed so that their weight together is enough to stabilize the bundle against hydrodynamic forces, but the strapping needs to be cathodically protected and that is awkward and costly. If the strapping is allowed to corrode, the lines must be stable, both as a bundle in the short term, and separately in the long term.

If the two lines have different operating pressures and temperatures, relative thermal expansion needs to be investigated, since the hotter line can less readily relieve expansion by snaking than it could on its own. In practice, a modest and acceptable amount of snaking between straps relieves longitudinal expansion stresses. Lateral instability is not a problem except in unusually hot lines. Relative expansion at end connections does need to be examined thoroughly, as it does for single lines, since constrained lines can exert very large forces.

Cased bundle

As an alternative to an open bundle, the components can be constructed together in a carrier pipe, as a cased bundle [Fig. 1(b)]. This is often a better choice, especially if the bundle is complex. The advantages of a cased bundle are listed below.

Corrosion protection

In an open bundle, each line is exposed to the sea and must be individually protected against corrosion; and the anti-corrosion coating has in turn to be protected against mechanical damage by concrete or by a barrier coating. In a cased bundle, on the other hand, the carrier pipe can be left filled with air, or with an inert gas such as nitrogen. The lines inside the carrier then need only a minimal anti-corrosion coating, or perhaps no coating at all.

The anti-corrosion coating on the internal lines needs no resistance to mechanical damage, except during fabrication of the bundle.

Alternatively, the carrier can be filled with water (to which corrosion inhibitors and oxygen scavengers have been added), with oil, with thermal insulation or with a heavy fluid such as drilling mud. In each instance, anti-corrosion requirements for the internal lines are undemanding.

The carrier pipe for a cased bundle will require corrosion protection but the requirement is less critical than for the individual lines. In service, the carrier protects the internal lines against mechanical damage but does not usually have to carry a large pressure differential. Although it is good practice to design the carrier's corrosion protection system so as to protect it throughout the operating life of the system, corrosion damage to the carrier would not threaten the overall secure operation of the internal lines.

Mechanical protection

Small-diameter pipelines are subject to impact damage from fishing gear and can be hooked by trawl boards and beam trawls. They can also be damaged by cables dragging across the bottom during construction operations. Properly designed large-diameter lines, on the other hand, are less subject to such damage, and it is generally accepted that lines more than 16 in (406.4 mm) in diameter do not need to be trenched for protection against fishing; although it may be desirable to trench them for other reasons.

It follows that it will often be unnecessary to trench a cased bundle, because of the protection given by the carrier, whereas it would be necessary to trench the individual lines. This can be a major economy.

Thermal insulation

Thermal insulation is often desirable, to maintain the temperature of waxy crude, to reduce the viscosity and increase the hydraulic efficiency of oil flow, to prevent ice formation on the pipeline due to Joule–Thomson cooling in gas,[2] and to stop hydrate formation. Insulation technology is advancing rapidly. Some materials have closed cells, impermeable to water and strong enough mechanially to resist external pressure and mechanical damage during installation, but these materials are relatively expensive.

The insulation on internal lines in a cased bundle needs hardly any structural strength and can be a light and economical, open-cell foam.

Heat tracing

Except over very short distances, heat tracing is generally electrical. It is plainly easier to construct an efficient heat tracing system in a dry environment within a carrier. This applies equally to conventional resistance heat tracing and to skin-effect current tracing (SECT).

SECT was first used offshore in an Arctic flowline system, described later in this paper. A small-diameter steel tube is welded to the pipeline. Through it passes a cable carrying an alternating current, connected to the tube at the end remote from the power supply. Electromagnetic induction modifies the current density distribution in the tube and concentrates it in a thin surface layer. Heat is generated in that layer, and is conducted to the pipeline.

Differential expansion

Design of a cased bundle is in some ways simpler than that of individual lines, because the functions are to some extent decoupled. The carrier withstands external pressure and impact during construction and operation, and has an external coating which protects it against corrosion. It may also increase its weight to stabilise it on the sea bed. The internal lines must resist internal pressure and withstand internal corrosion from the contents. Cables are subject to the usual electrical requirements and must not overheat.

Whatever spacer system is used to support the internal lines within the carrier must be compatible with the fabrication technique. The design must allow for differential thermal and pressure-induced expansion between individual internal lines and between the internals and the carrier. This can be a serious design problem but it is an advantage of a cased bundle that the carrier can resist the expansion of the internal lines, if they are anchored together.

A designer can take further advantages of the carrier by pretensioning the internal lines against the carrier in compression.

The bundle as a whole must have a submerged weight large enough for stability and small enough to be compatible with the installation method. Some installation methods allow only a narrow tolerance on submerged weight and this can be difficult to achieve, particularly as the weight tolerances on the bundle components tend to accumulate.

Table I lists examples of submarine pipeline bundles.

FABRICATION AND INSTALLATION

Laybarge method

Most submarine pipelines are constructed by the laybarge method. Lengths of pipe are brought to an anchored barge and welded to the end of the previously completed section of the line, on a ramp extending the length of the barge. As the barge advances on its anchors, one pipe length at a time, the pipeline leaves the barge over the stern. It runs over a floating pontoon ('stinger'), and is lowered to the bottom in a long suspended curve, touching down some distance behind the barge. Except in shallow water, the curvature in the suspended span is controlled by a tensioner.

In general, the laybarge method is not well suited to bundles. It can be applied if a small-diameter line is to be strapped ('piggy-backed') to a large line, by constructing the small line in one length, winding it onto a reel, unwinding it along a parallel ramp, and strapping it after the larger line has passed through the tensioner.

At the cost of modifications to the laybarge, it could also be used to lay two lines of equal size, by welding joints on two parallel ramps and bringing them together after a modified tensioner system. More complex bundles would delay the laying process because of the number of welding operations necessary and the impossibility of conducting them all simultaneously.

Reelbarge method

Some pipelines are laid from reels.[3] Reelbarge construction is generally a method for single lines and can be rapid and economical. Small lines can again be piggy-backed from an auxiliary reel, and strapped on after the straightener.

Table I: Examples of submarine pipeline bundles

Field	Length (m)	Open (O) pr closed (C)	Outside diameter of carrier (mm)	Number of lines	Diameter of largest line (mm)	Maximum depth (m)	Installation method	Reference
Drake	1200	C	457	7	168.3	55	Bottom pull	9
Cobia	5200	O		2	324	80	Bottom tow	1
Murchison	1970	C	324	4	88.9	155	Mid-depth tow	6
Cormorant	3350	C	660	1	219	155	Mid-depth tow	7
Gulf test	610	C	324	10	88.9	100	Surface tow	8

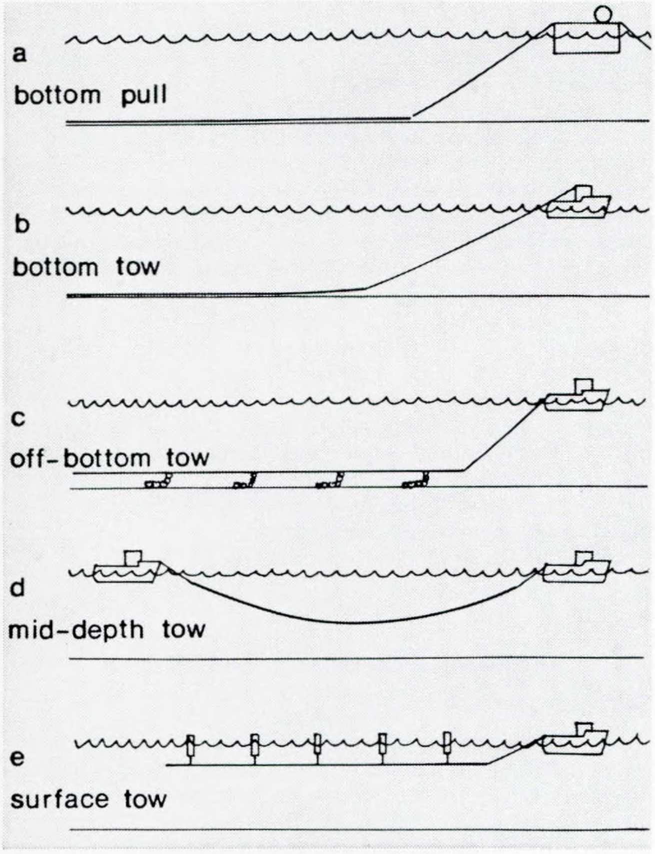

FIG. 2: Different towing methods

Tow and pull

It is almost always better to separate the operations of fabricating the bundle and installing it in place. Tow and pull construction techniques do this, and lend themselves particularly well to the construction of bundles of any degree of complexity. The bundle is first fabricated onshore in the stable, and essentially weather-independent, circumstances of an onshore fabrication site.

The individual lines and the complete bundle can then be inspected minutely, the thermal and electrical insulation can be checked, and the whole line can be hydrotested. The bundle is then towed or pulled to its final position and connected in place.

A major advantage of this scheme is that the make-up operations and tests can be carried out unhurriedly, in factory conditions. Make-up is decoupled from offshore installation. The tow is completed in a relatively short time, often no more than a day or two, and can be planned so as not to conflict with other operations offshore. The experience and resources of land pipeline contractors can be brought to bear and this helps to generate competitiveness and increase local work content.

Bottom pull

There are several distinct modes of tow and pull. One method is to pull the line from an anchored barge or from fixed winches on an opposite shore [Fig. 2(a)]. Lengths of up to 30 km have been installed by this method, which is often used for river and estuary crossings and for loading lines.

A more flexible alternative, and one more suitable for pipelines at some distance from shore, is to tow the pipeline from the make-up site to its final location. A number of large tugs have bollard pulls of 1.8 MN or more: taking a typical submerged weight of 300 N/m (30 kgf/m, 20 lbf/ft), and supposing the pipeline is to be pulled along the bottom with a conservative longitudinal starting friction factor of 1, a single tug can then pull a 6000 m long bundle.

There is an extensive requirement for bundles of this length or less, which are typical of North Sea development schemes based on one or two platforms and bundled connections to remote subsea wells. As development moves into deeper water, more and more schemes are of this type, because of the high costs of deep-water platforms. An example is the planned development of the extensive Troll field in more than 300 m of water.

Bottom tow

The modern development of bottom tow [Fig. 2(b)] springs from a tow test in 1975, when a 610 m length of pipe was made up at Tananger, Norway, towed through the Norwegian trench, across the plateau on the western side, through the trench a second time, and back to Tananger, after covering 450 km in all.

The test confirmed that the pipeline could be towed without damage and that it could be accurately positioned. A number of papers[1,4,5] describe the technique in more detail. It has major advantages of security and weather-independence: the pipeline is always continuously in contact with the bottom, and if the sea-state worsens so that the tow can no longer continue, the tug can release the cable and resume the tow later.

Abrasion to concrete coating is within acceptable limits and recent developments in polymer-modified concrete give the designer more freedom to choose the optimal weight coating thickness.

Off-bottom tow

An alternative is off-bottom tow [Fig. 2(c)], where the pipeline is buoyed so that it floats one or two metres above the bottom, held down by chains that drag on the bottom. At the final location, the buoys are released after the end connections have been made, and the pipeline settles to the bottom. In comparison with bottom tow, the pipeline is less affected by bottom roughness and does not have to have an abrasion-resistant coating. But rigging is more complex and expensive.

Mid-depth tow

A further alternative is mid-depth (or controlled-depth) tow.[6,7] The pipeline is towed clear of the bottom [Fig. 2(d)], suspended between two tugs, one pulling the line forward and the other applying a holdback tension. The line configuration

Table II: Design of Drake F-76 bundled flowline

Line	Outside diameter (mm)	Wall thickness (mm)	Minimum yield (MPa)	Operating pressure (MPa)	Coating
Carrier	457.0	9.53	290	0.552 External	Polyethylene Undercoat 0.18 mm Main coat 1.35 mm
Production 1	168.3	10.97	290	12.07	Epoxy zinc-rich prime Vinyl/urethane SECT heat tracing
Production 2	168.3	9.53	290	12.07	Epoxy zinc-rich prime Urethane foam Polyethylene Thermon heat tracin
Annulus access	60.3	5.54	241	12.07	Extruded polyethylen
Methanol injection	33.4	4.55	241	12.07	Extruded polyethylen
Hydraulic control (3 off)	33.4	4.55	241	20.69	Extruded polyethylen

is now determined by the interaction between the weight and flexibility of the bundle, the tension applied by the tugs and the hydrodynamic forces induced by motion through the water.

On arrival at the final location, the tension is released slowly and the pipeline settles to the bottom (or to an intermediate position just above the bottom, as in off-bottom tow, from where it can be deflected into alignment for connection).

Since this method frees the pipeline from interaction with the bottom, it can be used if the tow route crosses very rough bottom topography or very deep water. On the other hand, mid-depth tow requires very precise control of the bundle's submerged weight, implies complex rigging, is weather-sensitive and needs rigorous monitoring of the delicate tow and lowering operations. It appears to be limited to a maximum length of about 5 km.

Mid-depth tow has been used to install a number of pipeline bundles in the North Sea, the longest of them 3350 m long. In that installation there were two bundles, each an 8.625 in (219 mm) flowline, insulated within a 14 in (355.6 mm) steel sleeve, in a 26 in (660 mm) carrier, pressurised with nitrogen to balance the external water pressure. The bundle was towed 380 km, from a make-up site near Wick to the Cormorant field.

Sub-surface tow

Yet another alternative is sub-surface tow [Fig. 2(e)]. The bundle is towed some 10 m below the surface, suspended from spar buoys, and lowered or drawn down into its final position. In a trial in the Gulf of Mexico[8] this method was used to install a flowline bundle 600 m long in 100 m of water. It can be applied to longer pipelines than mid-depth tow.

Connections

The cost of connections can be a major part of the total construction cost of a submarine pipeline and has attracted a great deal of research and development. The available methods include flanged connections completed by divers, hyperbaric welding, mechanical connectors, one-atmosphere welding, explosive welding, and memory-metal sleeves: the first three of these are widely used. The same techniques can be used to connect bundles.

Electrical connections have been a source of unreliability in subsea systems but have improved greatly. Inductive coupling systems can transmit higher power than formerly, and fibre-optic couplings are available.

An example of a bundled flowline system

Some of the possibilities of bundled pipelines are illustrated by the Drake F-76 flowline system, constructed at Melville Island in Arctic Canada. As part of a program to demonstrate the feasibility of production from the Drake and Hecla gas-fields, which extend offshore from the Sabine Peninsula to a water depth of 400 m, a subsea wellhead was connected to shore by a bundled flowline system.

Environmental conditions in the area are severe in the extreme: the sea is frozen for ten months of the year and in the winter construction season (January through May) the sea ice thickness reaches 2 m.

Figure 3 is a cross-section of the bundle, which consisted of two 6 in (162 mm) flowlines, one insulated and both heat-traced, and five smaller lines. Details of these lines are given in Table II, which is taken from a paper[9] describing the project as a whole. The bundle included instrumentation cables leading to thermistors just before the wellhead: there was no requirement for an electrical connection to the wellhead but one could have been added without difficulty.

The bundle was fabricated onshore, pulled into position and connected by the first application of the deflect-to-connect technique. The schedule required it to be fabricated in mid-winter, when darkness is continuous and air temperatures fall to − 50 °C, often accompanied by high winds and driving snow.

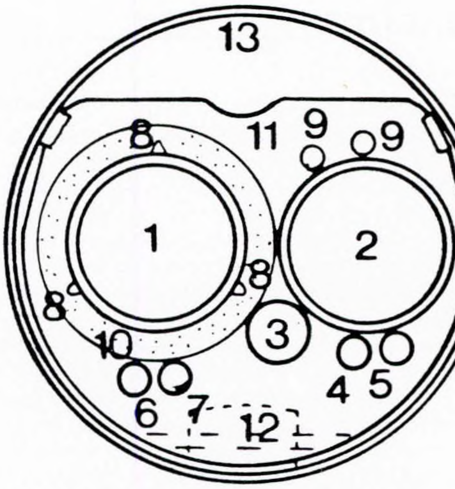

FIG. 3: Cross-section of a bundle. 1 and 2, flowlines; 3, annulus access line; 4–7, methanol and hydraulic control lines; 8, Thermon heat tracing; 9, SECT heat tracing; 10, insulation; 11, spacer; 12, spacer roller; 13, carrier

To have fabricated the bundle in the open and to have tried to maintain high welding quality there would have been almost impossible. Instead all fabrication was in a heated tent, close to the shore, at the end of a roller launchway which extended 1200 m onto the island. The carrier was fabricated first, and winched onto the launchway joint by joint. The bundle followed, and was pulled into the carrier on wheeled spacers. A connection manifold was welded to the leading end of the bundle which was then pulled into position by a winch on the sea ice.

CONCLUSION

Bundle fabrication and installation offer enormous potential in the offshore industry, and the possible applications have hardly begun to be exploited. It is not going too far to say that the designer of a subsea system need not feel himself constrained: whatever he wants, the technology to build it is available.

REFERENCES

1. R. J. Brown, 'Towing and remote connection of single and multiple offshore flowlines', *Oil and Gas Journal*, Vol. 81, pp. 79–83 (1983).
2. F. J. Alexander, 'Frost heave effects from operation of gas pipelines at low temperatures', Proceedings, Offshore Oil and Gas Pipeline Technology Seminar, Amsterdam (1985).
3. R. J. Brown and A. C. Palmer, 'The mechanics of pipeline reeling', Proceedings, Offshore Oil and Gas Pipeline Technology Seminar, Birmingham (1984).
4. A. C. Palmer, 'Bottom tow of submarine pipelines' in *Offshore Oil and Gas Pipeline Technology*, pp. 75–82, Oyez Publishing Limited (1981).
5. W. Abel and R. J. Brown, 'Offloading line made up onshore, towed to site', *Oil and Gas Journal*, Vol. 76, pp. 67–72 (1978).
6. A. W. Morton, 'New concepts used in the Murchison field submerged production system', Proceedings, Thirteenth Annual Offshore Technology Conference, pp. 309–318 (1981).
7. E. J. Rooduyn, 'Transportation of prefabricated flowlines with the controlled depth tow method', Proceedings, Offshore Oil and Gas Pipeline Technology Seminar, Birmingham (1984).
8. J. T. Coleman, K. C. Saliger and I. R. Yancey, 'Method for laying and connecting intrafield flowline bundles in deep water', Proceedings, Fourteenth Annual Offshore Technology Conference, Vol. 2, pp. 479–490 (1982).
9. A. C. Palmer, D. J. Baudais and D. M. Masterson, 'Design and installation of an offshore flowline for the Canadian Arctic Islands', Proceedings, Eleventh Annual Offshore Technology Conference, Houston, Vol. 2, pp. 765–772 (1979).

Discussion

J. COWLEY (Surveyor General, DTp): May I open the discussion by referring to my professional interest in undersea technology. This interest is through the Offshore Safety Section of my Department, which deals, amongst other things, with submersible undersea pipeline repair craft. As part of the initial survey, this Section examines and approves the drawings in the following subjects: hull, power, control, buoyancy, stability, position indicating and all matters relating to life support systems.

The statutory requirements are contained in The Merchant Shipping (Submersible Craft Construction and Survey) Regulations 1981. As manned craft, submersibles obviously have to have high safety standards, as exemplified by the Regulations. However, it is obviously important from commercial and pollution aspects that pipelines should be sufficient for their intended purpose. I would like to know whether the authors' organization had to satisfy the regulatory authorities on whose continental shelf the pipelines were laid as to the engineering philosophy and construction within the closed-bundle pipelines. Were the regulatory authorities concerned with, for example, whether internal failures within the carrier pipe might occur or were they mainly concerned with the strength of the outer enclosing pipeline which would contain the contents and prevent pollution?

The paper referred to the need for the design to allow for pressure-induced expansion between individual internal lines and between the internals and the carrier. What is the relative magnitude of the pressure-induced expansion compared with the temperature-induced expansion in the case of gas and oil pipelines within the closed bundle and how is it estimated and verified? The paper also refers to a hydraulic test of the completed installation. It would be interesting to know the philosophy of this test and the relationship of the test pressure to the working pressure of the system. Is it intended to be merely a leak test or is it a test of the strength of the fabricated installation? If the test pressure is too high in relation to the working pressure, distortion may occur.

My Department's Regulations define a submersible as a manned mobile submersible craft which is designed to maintain some or all of its occupants at, or near, atmospheric pressure. The Regulations therefore exclude systems used to transfer divers (bells) from the surface to the underwater site because the occupants in such cases are kept at the pressure at which they will work when they leave the bell.

However, since the Regulations were written, many developments in underwater engineering have occurred. Items such as wellhead encapsulations, where repair or maintenance teams are able to work in a near shirt-sleeve environment on seabed installations, were not considered. These are outside the scope of the Regulations since they are not mobile. On the other hand, outside the conventional view of submersibles, but falling within the scope of our Regulations, are certain underwater repair facilities. The Offshore Safety Section is at present examining plans and co-operating with the builders of two different such projects.

One concerns the repair of underwater pipelines up to 1067

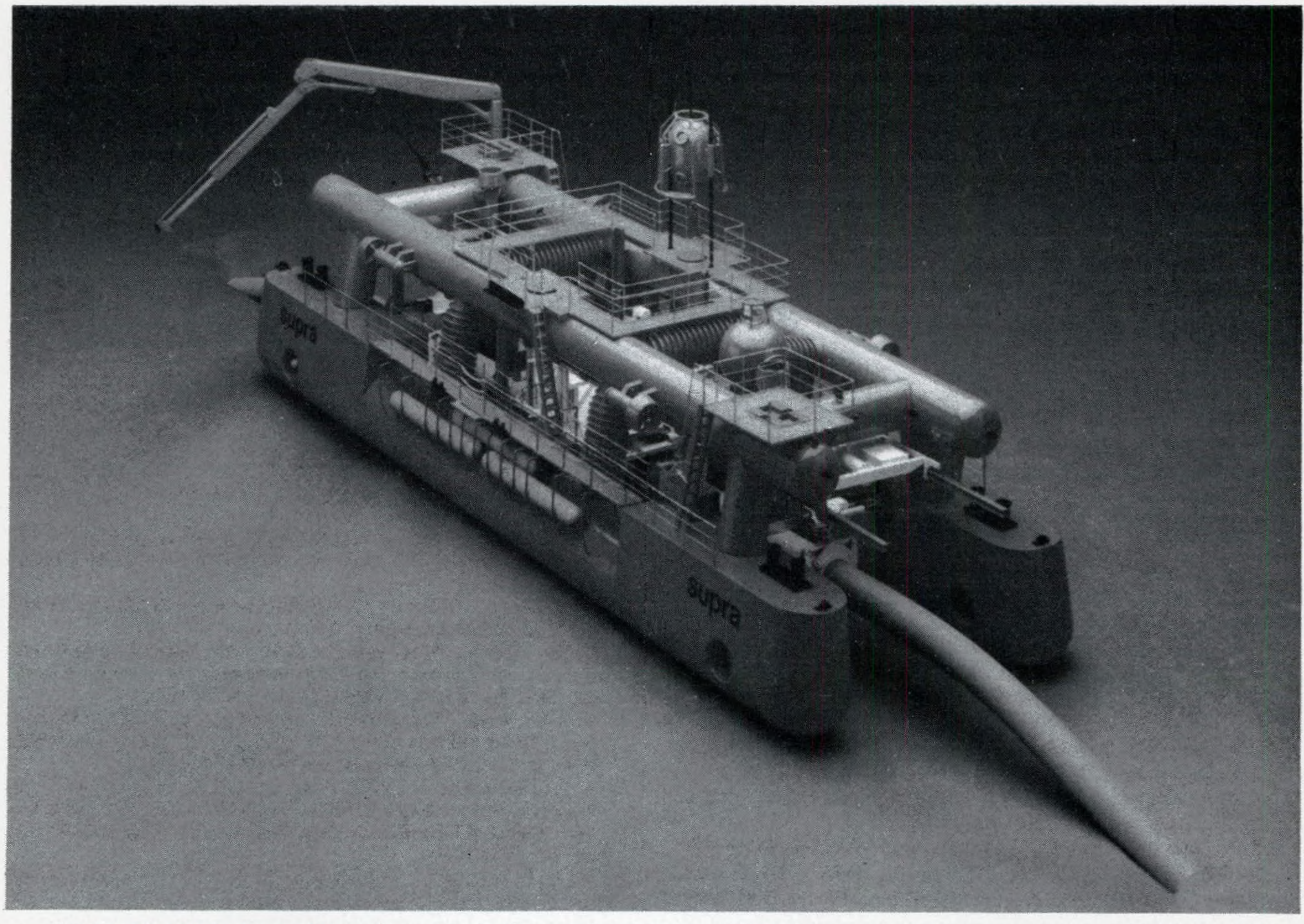

FIG. D1: Model of submersible underwater pipeline repair apparatus, SUPRA (reproduced by kind permission of AGRE SUPRA)

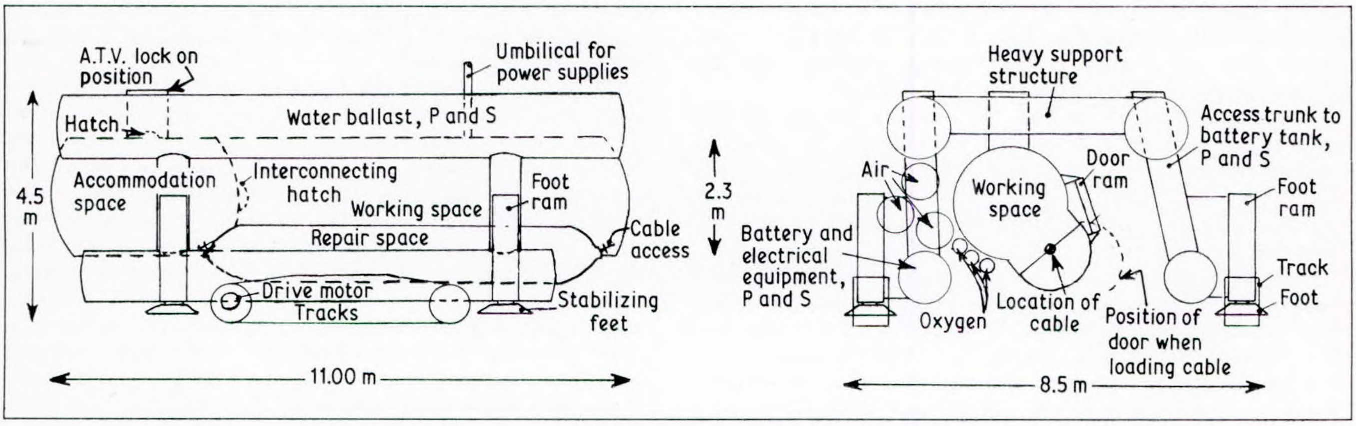

FIG. D2: Longitudinal and transverse sections of proposed Anglo/French power cable repair complex (reproduced by kind permission of CEGB)

mm diameter. Those who are familiar with the usual small submersibles in the offshore industry will be surprised at the overall dimensions of this craft, which are of the order of 34.0 × 12.6 × 7.35 m. Figure D1 shows a model of this craft.

The other facility is for any possible repairs of the electric cables of the Anglo-French 2000 MW power sharing scheme. Published data for this project show that it can handle individual solid copper cables of about 125 mm diameter.

In each of these cases the repair vehicle will be too large to be offloaded at sea by the parent vessel, therefore each will be towed to the site. When in the approximate desired position, they will submerge. One craft is designed to be deployed from the surface with occupants who are concerned only with running the craft and not with the repair work. When on the seabed both craft will use their own propulsion systems to manoeuvre to the exact location. In both cases the repair teams will be brought from the surface to the repair habitat of the submersible complex by atmospheric transfer vehicles, guided by wire ropes from the parent vessel and secured to the complex. These transfer vehicles will also fall within the scope of the Regulations and will be treated by the Offshore Safety Section as submersibles.

In both cases arrangements are made to hinge open part of the vehicles and for divers to bring the pipe or cable into the repair habitat. The hinged portion is then closed, the ends made watertight and the habitat pumped dry, ready for the repair team to enter in the dry.

These developments show that undersea repairs of conventional piping systems and cables are a practicable proposition. Do the authors envisage that undersea repairs could be carried out on their closed-bundle system?

The closed-bundle system has overwhelming advantages in the case of the Arctic pipelines as it is inconceivable that conventional welding could be carried out in the cold and hostile Arctic environment. Could the authors comment on the commercial competitiveness of this system in less onerous environmental conditions?

C. F. SMITH (Offshore Safety Section, DTp): Further to the comments of Dr Cowley, I would like to add some notes regarding the developing philosophy of dry underwater cable and pipe repair facilities.

It was not long ago that underwater cables which needed to be repaired in the dry were of necessity pulled to the surface for the repair to be made. Repairs by this method required the insertion of a new length of cable to make up the length of the catenary caused by the cable being brought to the surface. If such a cable had originally been buried then repairs of this type would cause considerable difficulties for burying the increased length of cable with the control of trenching tools then available.

Current needs demand that some repairs must be made on the seabed; whether or not dry, atmospheric conditions are conveniently available. The basic design of the new generation of underwater cable and pipe repair facilities require:

- An environment suitable for the techniques of the repairs. It may be that the techniques developed on land have to be changed to accommodate the best environment that can be provided.
- An environment which supports the humans involved.
- A portable system.
- A rescue capability for the human occupants.

A dry repair environment can be provided by what is known as a habitat. This is cylindrical and has a length-to-repair diameter ratio of about 100 for small cables and down to 30 for 1 m diameter pipes. Care must be taken that the techniques used in repairs do not create conditions hazardous to the crew.

Modifications must be made to the shell of the habitat so that the pipe or cable can be brought into the habitat and subsequently released. A suitable arrangement to cope with this is to have a hinged appendage on the side of the cylindrical habitat. With this hinged appendage open, cables and pipes can be winched up into the habitat by divers or remote control. When the appendage is closed, a water-tight seal is formed round the cable or pipe.

Until the habitat space is dry and ventilated, the repair team can be accommodated in a second, permanently dry habitat, connected to the repair habitat through a single hatch. The repair team is brought from the parent vessel in the first instance by submersible. The submersible, known as an atmospheric transfer vehicle, is dedicated to the repair complex and is guided up and down by diver-attached wires, the whole operation being analogous to a lift in a building. Power to the repair complex is provided from the parent vessel through an umbilical cable.

To arrange mobility and provide support functions, such a habitat is attached to an exostructure, consisting mostly of cylinders, which provides a combination of ballasting, emergency battery storage, propulsion, auxiliary machinery, communications etc., depending on the operator requirements. Propulsion can be by a bottom-crawling arrangement or it is possible to have a system whereby some ballast can be blown, leaving only a little negative buoyancy which can be overcome by vertical thrusters to cause the complex to clear the seabed and maintain a stable depth, whilst horizontal thrusters move it to the next site.

Figure D2 shows the outline of the British CEGB/French EDF combined project for cross-channel power cable repairs. This is being built jointly by SEL, Yorkshire and ACB, Nantes. This is a relatively small design when compared with the one mentioned by Dr Cowley, but does show the essential features and the way the technology is going.

M. ROBERTSON (Offshore Safety Section, DTp): The authors are to be congratulated on this paper and Dr Palmer on his presentation. Although not professing to have any expertise in pipeline technology, I found the paper of immense interest in revealing the complexity of this form of technology, which involves more than just dragging or towing a multicore bundle to some predetermined position on the sea floor.

Could the authors outline the limiting factors in the maximum length of bundle that could be 'bottom towed' or 'pulled'? A typical tug bollard pull of 1.8 MN is quoted. Is this one of the limiting factors or is the limit more related to the stress/strain pattern across the bundle, particularly close to the two attachment point?

The paper describes the various methods of placing the bundle on site but does not suggest a preferred method. Being clear of wave influences and of the seabed, it would seem that the 'off-bottom tow' is the method least likely to damage the bundle, although it is more expensive in terms of rigging required. The 'mid-depth tow' would seem to have its attractions but would no doubt depend on the relative separation of the two tugs being closely maintained. Perhaps the authors could comment.

Tension-leg platforms would seem to be one type of installation gaining favour for the exploration of oil in deeper waters. Are there any particular problems in terms of fatigue when one considers that the cores have to rise up from the sea floor to a non-stationary platform?

Could the authors comment on what thought has been given to in-service surveys? Conventional methods of using submersible craft, remotely operated vehicles or divers to carry out ultrasonic measurements, although adequate for single oil or gas lines, may prove unsatisfactory for multicore lines due to their close proximity. 'Intelligent pigs' would probably be able to examine the larger oil and gas lines but would leave other cores in the bundle still to be examined.

The 'skin effect' current tracing appears to be an attractive concept, so far as heating of the line is concerned. Although it may not be their field of expertise, could the authors comment on the precautions considered necessary when divers operate close to such an electrical field? Presumably a high-frequency supply is necessary to produce an adequate 'skin effect' and the capacitative and inductive effects may also have to be considered. My particular interest in this topic stems from my recent involvement in a Code of Practice for the safe use of electricity underwater where it was recognized that exposure of divers to electrical currents of the order of only a few milliamps for short periods of time could prove hazardous.

Authors' Reply

In reply to Dr Cowley, regulatory authorities almost invariably wish to satisfy themselves about all aspects of a submarine pipeline system, and in the case of a bundle are concerned both with the internal lines and the external carrier. Both thermal and pressure-induced expansion are important, and in most production systems the two effects make roughly equal contributions to the total movement. However, the effects are not simply additive. The question is discussed in detail in ref. (1), which also presents a comparison between the theory and observations in the field.

Hydraulic testing is both a leak test and a strength test, and experience has shown that it is prudent to maintain the test pressure for a reasonably long period, often 24 h. In one recent instance,[2] a rupture of a 20 in oil pipeline occurred after 21 h at 150 bars (15 MN/m^2); the design pressure was 95 bars.

It is certainly more difficult to repair a bundle in a carrier than it is to repair individual lines, although the risk of damage to internal lines is much reduced. In our view, hyperbaric repair of an internal in a carrier is certainly possible, but there will be several difficulties, not least the problem of locating the fault precisely. There is certainly a potential role for submersibles, and we are interested in Dr Cowley's suggestion.

Bundles in carriers have been used several times in the North Sea, and other projects are in progress. In the right context, bundled pipelines are commercially competitive as well as technically attractive. We do, however, want to make clear that bundling is not in any way a proprietary system.

We accept Dr Smith's points about underwater cable connection, which is advancing rapidly in the way pipline connection methods progressed rapidly some 10 years ago.

In reply to Mr Robertson, very long lengths of pipeline can be pulled, and a line more than 30 km long was pulled to Kharg Island in Iran. If the length is extreme, one obviously needs either a very light pipeline or a very large pull force, and it may then be better to pull the line in sections and to make tie-ins. There is no single preferred method of tow, and the choice between bottom, off-bottom, mid-depth and surface tow is a delicate and difficult one, governed by many factors, both technical and commercial.

The question of fatigue in FPS risers is again complex, and there are many papers on the subject; see, for example, Westin.[3] In-service survey is another huge subject, and an account of current good North Sea practice is given by Cryer.[4]

We thank the contributors to the discussion for their interesting remarks.

1. A. C. Palmer and M. T. S. Ling, 'Movements of submarine pipelines close to platforms', Proceedings, 13th Annual Offshore Technology Conference, Houston, Texas, Vol. 3, pp. 17–24 (1981).
2. M. W. Braestrup, J. Packness and P. L. Patient, 'Highlights from the construction of the Danish offshore oil and gas pipelines', Proceedings, Offshore Oil and Gas Pipeline Technology Seminar, Amsterdam, (1985).
3. H. Westin, 'Random analysis of a riser for a floating production system (FPS) in a northern North Sea environment', Proceedings, 15th Annual Offshore Technology Conference, Houston, Texas, Vol. 2, pp. 407–416 (1983).
4. P. M. Cryer, 'Pipeline inspection—one operator's philosophy', Proceedings, Offshore Oil and Gas Pipeline Technology Seminar, Amsterdam (1985).

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