MARINE PIPELINE PROTECTION WITH FLEXIBLE MATTRESS

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Abstract

Development of oil and gas fields offshore presents new problems in the design of the civil engineering works since in many cases little is known about prevailing conditions on the bed of the sea over the considerable lengths involved. Movement of pipelines after construction, is, therefore, not uncommon and may result in the failure of the line. Consequent losses can be considerable.

Pipelines are also vulnerable to mechanical damage by anchors and by fishing activities, the latter giving rise to political problems where the pipelines are laid across existing fishing grounds. To give protection to oil and gas pipelines as well as to marine outfalls and cables a method of protection has been developed using the well known concept of rock filled wire mesh or gabions.

To adapt this method to use in underwater works another well proven material, sand mastic asphalt, has been combined with the gabion mattresses to give the required qualities of strength, durability, flexibility together with sufficient weight to restrain movement in the pipeline.

INTRODUCTION

Although pipelines have been built in the tidal zone and for short distances offshore for many years, earlier work has been largely in the sewage disposal and cooling water outfall sectors. In works of these types failures, although serious, are generally capable of repair by conventional means.

Offshore pipelines for oil and gas transmission have now been laid in much deeper water and for many miles at considerable depths. In addition, in areas such as the North Sea, work can only be carried out for a few months per year and failures therefore become extremely serious even before production losses are calculated.

Sea bed conditions over the lengths of these new pipelines are by no means uniform or consistent, nor is survey information as complete as the designers would like. Over undulating terrain pipelines laid on the surface may well bridge across many of the valleys.

Strong currents can lead to major movements of pipelines while in service, unless suitably anchored, and can also give rise to vibrations which may shorten the life of the pipes. Similar protection methods used to anchor pipelines may also be employed to protect against mechanical damage by trawls or by dragging anchors. Since pipelines may cross valuable fishing grounds it is necessary to ensure that these protective measures do not cause additional damage to the trawls and nets.

Although more familiar as a river defense system the use of wire-enclosed riprap, gabions, has been adapted to marine structures of many types. The main change is the addition of a PVC sleeve to the galvanized wire mesh to give resistance to corrosion in salt water. Gabions have been pre-filled and used for outfall protection, jetties in inshore waters and various coastal defense projects worldwide.

A method of protection and anchorage has been developed known as the Sarmac mattress which combines this ancient and well proven gabion method of construction with sand mastic asphalt grout to give a dense yet flexible mattress capable of being placed over a relatively small diameter pipe without failure. The units can be made with sufficient length on either side of the pipeline so as to give considerable protection against scour since they fold down to accommodate changes in bed levels over the service life of the pipeline.

Considerable care has to be taken in the design of the sand mastic asphalt mix since the required flexibility may have to be maintained over a large temperature range between that at the assembly yard and that at laying depth.

Methods of placing are also critical in view of the high cost of employing divers. For a recent project in the Mediterranean special lifting frames were developed by the subcontractor, Ing. Sarti Giuseppe S p A of Ravenna. This enabled placing to be carried out in deep water by remote control methods using a remote control vessel guided by television cameras. To date Sarmac mattresses have been placed satisfactorily at depths of up to 600 metres.

MATERIALS & METHODS

With the introduction of the Sarmac mattress into the offshore pipeline protection inventory there has been an interesting combination of ancient and very modern methods of construction.

Gabions are of considerable antiquity having origins in military uses several centuries ago and, it is thought, in hydraulic works in China, much, much earlier. Of course these early gabions were not made with metal but used wicker work filled with stones, soil and turf. From these origins gabions were developed using steel wire in the form of cylinders of mesh, filled with rock, used for emergency river protection. Later it was realized that it would be possible to manufacture the gabions in rectangular form thus enabling much larger and more uniform structures to be built.

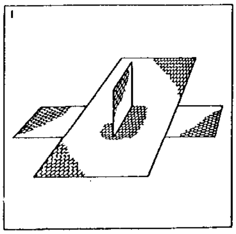
A further development came in the use of woven mesh with a double twist for added security. From these rectangular forms were developed mattresses which were simply gabions with thicknesses relatively small compared with their length and width. Galvanized wire may have a limited life expectancy in highly corrosive conditions and the addition of a PVC sleeve extruded onto galvanized wire enable the mesh to be used in coastal and offshore locations.

For use in the tidal zone investigations have been carried out on the use of PVC coated woven wire mesh mattresses used as continuous revetments by a number of researchers in Canada, Australia and elsewhere, (2), with generally favorable results. In one case design rules have been formulated giving equations for eventual failure by downslope sliding, buckling and uplift (3).

For sloping revetments wire enclosed riprap or mattresses are not normally laid at inclinations greater than IV to 2H or 26° where downrush waves limit the stone size. This has been described by Stephenson who has listed comparisons with rounded rock, angular rock and also concrete units (4).

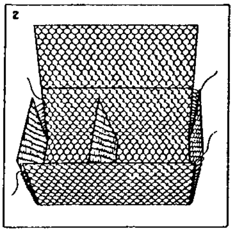
Proprietary concrete block systems have been tested in the wave zone along with other "low-cost" systems including gabions and mattresses in a comprehensive study by the U.S. Army Corps of Engineers (5).

FIGURE 1



GABION BEFORE ASSEMBLY

FIGURE 2



ASSEMBLY OF GABION

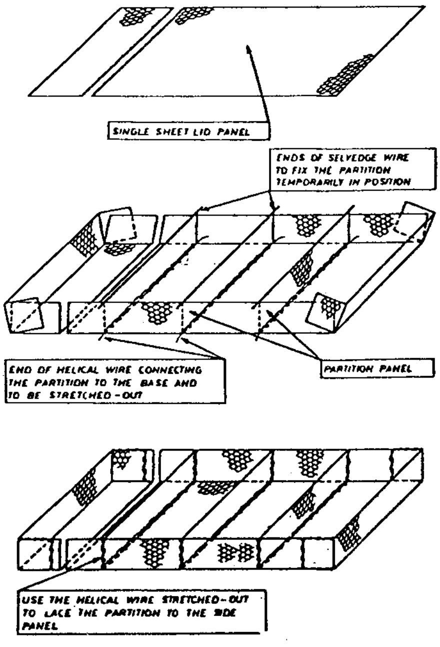


FIGURE 3 MATTRESS TYPE GABIONS

At one location, Ninilchik, in Alaska the gabions were filled by means of filter cloth bags which were themselves filled with a combination of beach gravel, cobbles and concrete rubble. However both this structure and a second at Kotzebue also in Alaska had a rock riprap toe protection which was displaced during the test period. In general this is not a good practice since the riprap can be thrown against the mesh causing damage. However the report on these trials and a third at Oak Harbor, Washington was very favorable.

Gabions and mattresses have also been used for many years to form groynes as a method of countering beach erosion in the United Kingdom, Italy and elsewhere (3). Sand mastic asphalt grouted riprap groynes have also been used with limited success in some locations but giving rise to problems when extended beyond the low water mark (6)(7).

These materials have been combined in revetments and groynes for coastal defenses and have been suggested for a number of related uses such as offshore breakwaters or headlands.

The use of pre-filled gabions for underwater structures had been developed over many years from the original use of cylindrical gabions to fill breaches in river defenses and scour holes around bridge piers and in similar emergency situations.

It was soon realized that modern rectangular gabions could be used in a similar fashion and gabions have subsequently been used pre-filled to form many types of structures (Fig.4). Examples included a large landing stage or jetty at Pula Langkawi in Malaysia, sea walls in Helsingfors Harbor, in Finland (Fig.5). A structure was built some five or six metres high to provide a quay for dhows at Ruweis in Qatar, the gabions having been pre-filled out in the desert and trucked to the site.

These structures employed cranes to place the units either from dry land or pontoons or barges but in recent years placing has even been carried out using helicopters.

However for offshore structures of some size other methods were adopted with gabions wired together into the form of a raft constructed above low water mark and subsequently floated into position using buoyancy supports of several types. Several outfall structures handling cooling water from nuclear power stations were so protected.

While methods of placement for standard gabions were being developed similar attention was being paid to enable Reno or Revet Mattresses to be pre-filled for placing underwater in river and canal projects. Although lifting frames similar to those used for placing filled gabions were employed, other methods were also initiated. These included launching from pontoons which at first were simple fixed decks (Fig. 6).

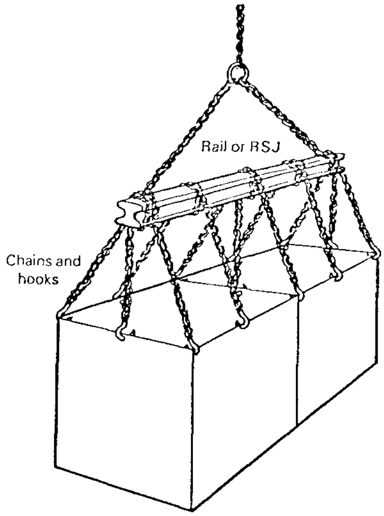


FIGURE 4
SIMPLE LIFTING METHOD

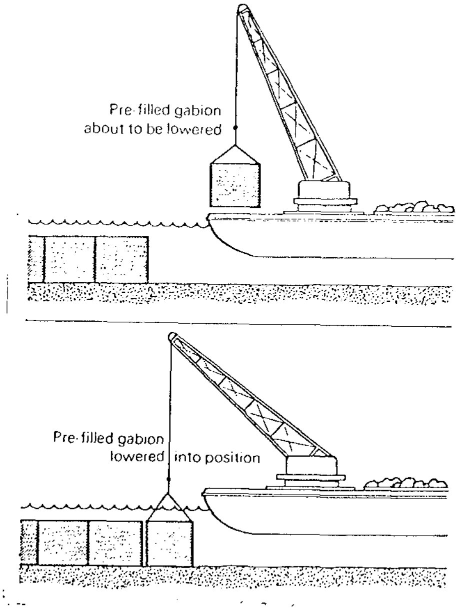


FIGURE 5
PLACING GABIONS BY CRANE

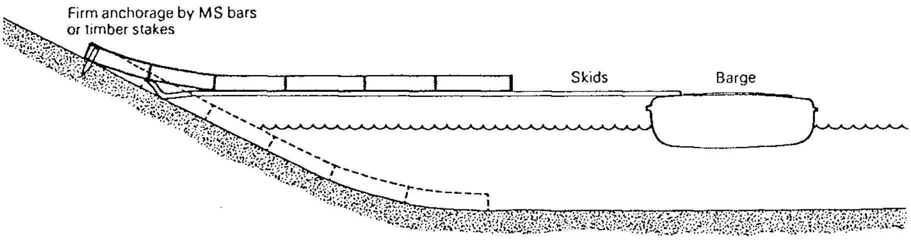


FIGURE 6

PLACING PREFILLED MATTRESSES FROM A SIMPLE PONTOON

Pontoons were then developed with tilting decks upon which mattresses could be built and then launched, the inshore ends being securely anchored to the bank.

This form of bank protection was also used in areas where impermeability was necessary. For this purpose, of course, gabion mattresses were unsuitable if used alone.

The addition of a sand mastic asphalt grout provided the necessary impermeability whilst retaining the essential flexibility of the revetments.

The use of pre-filled and grouted mattresses for underwater applications where construction in the dry was not feasible employed pontoons as developed for regular mattresses with the grouting operation actually carried out with the mattresses already in position on deck. When used with a grout the thickness employed could be reduced for some structures.

Pre-filled mattresses could also be placed by crane when grouted with sand mastic asphalt since the stone fill was held in place by the grout and not permitted to fall to the bottom of each cell as would happen if an ordinary mattress was so lifted (8)(9)(10). For offshore works gabion and Reno Mattresses had been used frequently since methods of placing were relatively expensive requiring the use of divers in many cases.

However protection was given to the cooling water outfall at a nuclear power station on the southern coast of England using a raft of Maccaferri Gabions floated into position and then lowered around the mouth of the outfall which was built in tunnel out from the power station, but this method was not applicable to most types of undwater structure.

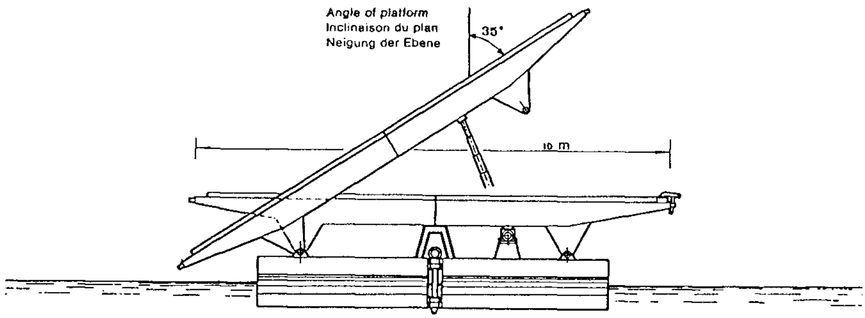


FIGURE 6

SAND MASTIC ASPHALT

Sand mastic asphalt has been used increasingly in gabion and mattress structures of various types ranging from canal linings, power station outfalls, protection of the upstream face of earth dams and for spillways. When used for canal linings the combination of the two products, gabion and sand mastic asphalt, enabled considerable reductions in thickness to be made in some cases. The design of the sand mastic asphalt mix varies according to the required design characteristics. Information on such applications is well documented (11).

		WEIGHT OF BITUMINOUS MASTIC	
TYPE	THICKNESS INCH	SURFACE GROUTING LBS/SQ. FT.	COMPLETE PENETRATION LBS./SQ.FT.
Revet Mattress	0' - 4"	14 - 15	22 - 26
	0' - 6"	16 - 18	26 - 28
	0' - 9"	20 - 25	28 - 30
Gabions	1' - 0"	27 - 30	37 - 40
	1' - 6"	30 - 40	50 - 60
	3' - 0"	50 - 70	80 - 120

TABLE 1 WEIGHTS OF GROUT

SARMAC MATTRESSES

From these origins was developed the Sarmac mattress which combined the strength and flexibility of the Reno or Revet Mattress form of construction with the addition of the weight and impermeability given by the addition of the sand mastic asphalt grout and while retaining the necessary flexibility of the mattress concept.

When used for hydraulic structures such as river and coastal defenses, dams and canals the design of the mastic asphalt mix was subject to rather less vigorous constraints than when applied to the Sarmac technique. It is only necessary that the asphalt can penetrate and flow through the gabions or riprap to the design depth and remain in place without further movement should ambient temperatures increase from those experienced during the construction period. The range of temperature during which such grouting takes place and to which the completed works are exposed is usually well documented and the range not too great to make additives necessary. When mastic grouted mattresses are placed from pontoons or by crane their thicknesses are relatively small and flexibility remains good.

With the new possibilities presented by the construction of offshore pipelines of considerable length and size, the techniques described in the preceding paragraphs were combined to give a material with the require characteristics and, as important, the ability to be placed economically at considerable depths.

At the design stage of such pipelines it has often been necessary to place reliance on climatic data and tidal information from available sources which was not always comprehensive enough for the purpose. In particular, although information might well be applicable for surface conditions, this did not apply to those existing on the sea bed where strong currents could be met. These could result in scouring around and under pipelines laid on the surface.

As a result of such scouring action pipelines may well become entirely unsupported and this can even occur where initial construction was as buried pipelines. The resulting effects arising from unsupported lengths on fatigue life have been assessed in a number of studies(1).

Experience gained in the design and construction of pipelines has resulted in the development of a method of both anchoring and protecting such pipelines. The method was also capable of use in the construction of supports under the pipes which could thus reduce the length of unsupported spans and could reduce vibratory effects.

Since the sea bed in the vicinity of the pipelines could vary considerably it was advantageous to develop the mattress used for its protection with capability to fold in service to adjust to the changing levels. Flexibility was also necessary to take up the curve of the pipe which could be as small as 500mm diameter.

Considerable weight was also called for in order to function as anchors and therefore the combination of sand mastic asphalt and gabions or mattresses already frequently used in combination in hydraulic structures of several types, was a logical development.

The Sarmac mattress was developed to address several of the problems experienced in the rapid construction of the massive net of oil and gas pipelines that now cross vast expanses of seas and oceans.

Reno or Revet Mattresses are used as the basis of a dense, flexible unit, using stone fill in the usual way but with stone size selected to permit the most suitable penetration by the sand mastic asphalt and to give the required finished weight. Choice of single or double thicknesses is made according to site conditions.

The sand asphalt mix is designed to give the required flexibility at the ambient temperatures in which it is to be placed, but at the same time must not be so soft as to deform or even flow during manufacture or transport to site. It is equally important that it should not become too hard thus losing flexibility in service and risking failure by brittleness. Since pipelines are currently being placed in conditions as diverse as the North Sea and the Indian Ocean, mix designs must be selected with care for each application.

	PENETRATION	R.& B. SOFTENINC POINT	DUCTILITY	VOLATILITY AFTER 5 HOURS AT 322° F
80/100 Pen	.314-.344	125 - 140°F	39,37 inch	0.5%
60/70	.234-.275	115 - 129°F	"	0.2%
40/50 Pen	.157-.196	124 - 136°F	"	0.2%

TABLE 2 BITUMEN SPECIFICATIONS

Having selected the correct mix design and thickness, overall dimensions are designed to suit the conditions of use, i.e. for mattresses used as protection against scour, as anchors where the pipeline is liable to move laterally, as deadweights to constrain the pipeline where it is not laid continuously on the ocean bed and as protection against mechanical damage.

For placing underwater in depths of up to 600 metres or more the use of divers to locate and place the Sarmac units may be impracticable or very expensive and methods have been developed by which the units can be located in position and released by remote control vessels whilst being monitored on close circuit television.

For such underwater structures temperature ranges are often even more restricted. Placing generally takes place during the warmer months although work was recently carried out on a project in Cumbria in North West England during a very cold period from November'81 to January '82 when the temperatures rarely rose above °Selsius and much of the grouting was carried out at much lower temperatures. This required that the temperature at the mixer was at or very near the maximum for the material in order that reasonable flows could be obtained in the very cold mattresses.

Earlier work had in fact been carried out by the French in Antartica many years ago and those experiences have been documented (12).

However initial studies were incorporated in projects sited in less intemperate areas and for the first full scale application this type of construction was used at points along the gas pipeline being built from Algeria to Italy which has 170 kilometres of its total length of 2500 kilometres on the bed of the Mediterranean. This project, which was initially proposed in 1971, was authorized in 1977 following negotiations between the Algerian authority SONATRACH and the Italian ENI company. Design work was carried out with the cooperation of both companies.

Across the Sicily Canal underwater construction was carried out by a consortium of Italian and Algerian companies under the title TMPC. However technical direction was the responsibility of SNAMPROGETTI. The depths at which pipes were laid in this sector exceeded 500 metres and the pipeline was divided into three separate lines for safety reasons.

The Sarmac units designed for this part of the project had overall dimensions of 4 metres by 3 metres. Each unit comprised two separate thicknesses of 200mm each giving an overall thickness of 400mm joined together with steel cables. Double twist mesh mattresses were used to give flexibility reinforced with steel wire ropes for lifting purposes. The units were wrapped in a non woven polyester filter cloth of weight 0.55 kilogrammes per square metre. Polyester was required as other fabrics are unable to withstand the temperatures at which the sand mastic asphalt is placed.

The total weight of the units was 12,000 kgs. or 1,000 kgs. per square metre and the specific gravity 2500 kgs. per cubic metre.

Manufacture took place at the SNAMPROGETTI yard in Trapani, Italy by the contractor, Ing. Sarti Guiseppe & Co. and then transported the short distance to the docks. Placing was made from the ship, Saipem Ragno 2, for most of the work.

The application for which the Sarmac units were required in this project was that of anchoring the pipes, by virtue of their weight, to the sea bed across areas where the bed was irregular.

A later use of Sarmac mattresses of similar size and construction but with overall thicknesses of 500mm is by Saipem in a British petroleum field in the North Sea. In this case the application is to protect one pipeline where it is crossed by new work and the total weight per unit and, of course, the specific gravity has been designed to be somewhat lower.

When the requirement is for thicker mattresses of the types used for Sarmac units, typically 40 or 50 cms thick, the composition of the mastic mix is much more difficult to design since the completed mattress must have excellent flexibility if it is to flex around small diameter pipes in deep water.

In addition the units may be manufactured in an area of fairly high ambient temperatures for placing in cold deep seas. If the required flexibility is not maintained, the unit could become brittle and not take up the required curvature in service.

To establish design criteria early experimental work was carried out in the United Kingdom by River and Sea Gabions, Ltd. but at an early stage the work was taken over by Officine Maccaferri S p A in Italy where there had been extensive work with sand mastic asphalt for a wide variety of hydraulic works.

This work proceeded jointly with Ing. Sarti Guiseppe with considerable assistance from Dr. V. Castagnetti of Industria Italiana Petroli of Genova. Much of this work was carried out simultaneously with the development of systems for use in the widening of the Suez Canal (13) (14)(15).

The experimental work not only concentrated on the design of the mix to achieve flexibility but also on completed thicknesses, density and application rates which were themselves variations on those already calculated and used in hydraulic works, see Table 1.

The Sarmac mattress concept also necessitated the development of methods to simplify lifting from the point of manufacture and transportation inland and by sea to the jobsite.

These were, of course, relatively minor problems since there was already a fund of knowledge based on previous uses of pre-filled and grouted mattresses and gabions. However placing underwater had previously involved the use of divers which was not impracticable when only a few units were to be placed in shallow seas.

For gas and oil pipelines the depths at which protection was to be carried out were such that effective diving time per shift would be very limited and costs accordingly very high. It was therefore necessary to develop underwater placing methods using remote control techniques and a lifting frame was devised which could be operated from a remote control vessel.

This has worked satisfactorily and has permitted relatively fast placing times although, unfortunately, detailed data remains confidential to the companies concerned.

A simplification of the construction technique, omitting both the filter cloth envelope and the lifting cables built into the body of the Sarmac units, has been employed for small scale pipeline protection in estuarial areas in the North Adriatic. These units, resembling the standard wire enclosed riprap mattresses used for river defenses, were grouted with a mix also being used to grout a riprap revetment several years old situated a few miles from the mixing plant. Since the application was close to normal water level, the range of temperatures under which the grouted mattresses were to be employed was very limited and the mix design was therefore not formulated specifically for that project.

It should be noted that few filter fabrics are suitable for use as envelopes for grouted mattresses since the melting point of most membranes is at or below the temperature at which the sand mastic is normally poured.

The final product, as used in offshore pipeline work, is very different to early underwater gabion structures such as that for a nuclear power station in the United Kingdom where the gabions were assembled as a raft within Folkestone Harbor at a location between high and low water marks. The raft, supported by steel drums and fastened together by steel rails, was floated into position and sunk on top of the outfall position.

This type of simple construction has therefore evolved into a degree of sophistication not foreseen at that time but still offers a considerable scope for further development particularly in inshore areas and in the immediate vicinity of platforms where complex pipe layouts are to be found.

CONCLUSIONS

Use of these methods of construction to protect parts of the gas pipeline from Algeria to Italy and also a small application in the Magnus Project in the North Sea have shown the effectiveness of this method of construction. The experience gained in earlier underwater gabion work and in the design of sand mastic asphalt for hydraulic works has enabled challenges posed by the new applications to be met thus marrying old and very new techniques in the manufacture and use of the Sarmac Mattress.

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and

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