GEOTECHNICAL ASPECTS OF SUBMARINE CABLES

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ABSTRACT

The network of submarine cables circling the globe connects most of the major population centres. This network is growing, driven by increasing international telecommunications and the internet. For reliability of service, geotechnics form an important consideration. Clearly hazards such as submarine landslides must be avoided, but also consideration is given to burial and the degree of protection afforded by burial. This paper discusses the threats to a cable and the use of ploughs for burial. Investigation techniques for cable routes are discussed and soils which prove hardest to plough are tentatively identified from cone penetration tests.

1. INTRODUCTION

There is an extensive network of submarine cables throughout the world. The network is continuing to grow rapidly, driven by an increasing demand for telecommunications and the internet. Submarine cables are at risk from both natural and human activities. To ensure continuity of service, some form of protection must be provided. Burial has proven to be an effective and economic method for protection. The various threats and protection afforded by burial are described.

An essential part of the planning process is an understanding of the seabed geology, and its associated geotechnical properties. The various methods used for investigation are discussed, including Cable and Wireless Marine's C-BASS cable route investigation tool. Both C-BASS and standard investigations rely heavily on cone penetration testing, however few correlations have been made between cable plough performance and CPT data. A study has recently been performed for Cable and Wireless to assess the possibility of using CPT data for the prediction of plough performance and the main findings are discussed.

2. THE CABLE NETWORK

The international submarine cable network is growing at a rapid pace, fuelled by demand for telecommunications by industry, government and the Internet. Table 1 summarises the growth of this industry and shows almost 350,000 km of cable scheduled for installation between 1997 and 2003. The privatisation of many of the national telecom companies and deregulation of the market has allowed new players into the market. Time is sold to the

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telecom companies and competition is fierce to capture market share. A prime example is Project Oxygen, who plan 275,000km of cable (this is in addition to Table 1 figures) linking 175 countries with a US$14billion investment dedicated to the Internet. A short time scale from conception to initiating service is particularly important as contracts are placed on entering service, and if late, or a competitor enters service first, significant revenue is lost.

Region	**Cables installed to 1996 (km)**	**Cables scheduled, 1997-2003 (km)**	**Cables planned but not scheduled (km)**
Atlantic	93,201	70,470	45,518
Pacific	78,320	105,731	38,400
South East Asia	59,765	37,954	28,355
Mediterranean	29,547	7,798	8,118
Caribbean	19,037	4,935	7,650
Northern Europe	14,698	8,259	1,815
Interregional	17,790	115,850	34,250
Total	312,378	345,997	164,106

Table 1 : Subsea Fibre-Optic Cable Systems (after Rampal 1998)

3. GEOTECHNICAL ASPECTS

For many years cables were simply laid on the seabed and geotechnical aspects of the installation where not of great importance. As such the geotechnical aspects of the selection of a cable route where largely limited to identifying potential hazards such as:-

- Submarine landslides which could break the cable
- Areas of rock where movement or vibration due to currents (strumming) could wear the cable armouring and result in a breakage
- Submarine volcanoes

However a cable is exposed to a wide variety of other risks, largely man made and including fishing and anchoring. Cables were normally protected by armouring in high risk areas. As the fishing industry moved into deeper waters and started to use more powerful ships the incidence of damage to cables increased, to the extent that in the 1970's interest grew in the possibility of providing additional protection by burial into the seabed. The benefits of burial have been illustrated by Shapiro et al (1997) (Figure 1) who found fault rates declining from an average of 3.7 per 1000km per annum between 1959 and 1979 to 0.44 faults per 1000km after 1985. The sharp decrease between 1979 and 1985 is indicative of a direct benefit of burial of existing and new systems.

A further advantage of burial is enabling armouring to be reduced and cost savings to be made in the manufacturing of cable. Cost savings by this means can be of the order of US$10,000's per kilometre.

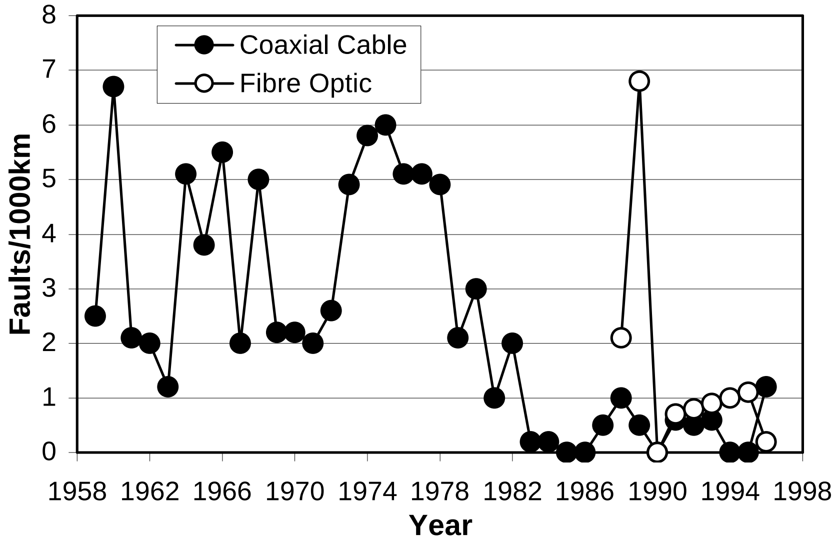

Figure 1 : Cable faults per annum in less than 1000m water depth. (after Shapiro et al, 1997)

(Fibre optic faults in 1989 occurred in eastern Atlantic in area of moving sand waves)

At the same time, the development of offshore oil fields and consequent improvement in subsea technology had the effect of providing the skills to enable design of equipment to achieve cable burial. Burial techniques developed included ploughs and jet tools. Ploughs have some particular advantages including being essentially passive equipment, therefore requiring minimum on board power and able to run for considerable distances and times between recovery. An example of an early cable plough was described by Hata (1979). Jet tools also have advantages, including an ability to bury a cable already laid on the seabed and able to operate close to existing installations with minimum risk of damage.

With the desire to bury cables, it became necessary to investigate the seabed to determine geotechnical properties and make an assessment of the burial which could be achieved.

4. SELECTION OF BURIAL DEPTH

Cables can be damaged by both natural faults (eg landslides and earthquakes) or human activity. However less than 9% of cable faults are due to natural events (Shapiro et al, 1997) and the major human threat, usually arises from fishing. In certain areas, particularly shallow water, anchoring may also pose a potential hazard. In general, relatively shallow burial is adequate for protection from fishing activity and for many years the industry standard burial depth was 0.6m. Fishing activities which pose a threat include trawling by both beam and otter boards. While these types of fishing gear do not, in theory, penetrate the seabed, they do scrape the seabed and can and do hook cables laid on the seabed.

Much more aggressive is shellfish dredging. Fishing gear designed for this purpose positively engages the seabed to chase the bottom living fish into the nets. It is relevant to note that scallop dredging on the Grand Banks was one of the prime driving forces behind universal cable burial. Other types of shellfish dredging disturb the seabed by water jets, again to chase the fish into a net, but potentially expose a cable over time. Another type of fishing which poses a major risk to cables is stow net fishing. This is performed in areas of relatively shallow water, with high currents. Rather than trawl, the fishing vessel anchors and casts its nets. The fish are then carried into the nets by the current. The anchors required to hold the fishing boats are thus disproportionately large. In recent years this type of fishing has necessitated the burial of a power cable to 4m depth.

The nature of the seabed soils clearly plays an important part in the depth to which anchors and fishing gear will penetrate. Clearly there will be additional costs associated with installation if the cable is buried to depths greater than necessary. In recognition of this, Cable and Wireless Global Marine (Mole *et al,* 1997), have developed the concept of a 'Burial Protection Index' (BPI) as shown in Figure 2. This recognises the resistance of different seabed soils to penetration by anchors and fishing gear. It has been based on typical soil types encountered during cable installation, however it must be stressed that such soil mechanics is an inexact science. A BPI of unity has been scaled such that good protection may be anticipated from trawling and fishing gear with an appropriate factor of safety included. Selection of higher BPI values would be justified in areas of higher risk such as anchoring or aggressive fishing techniques.

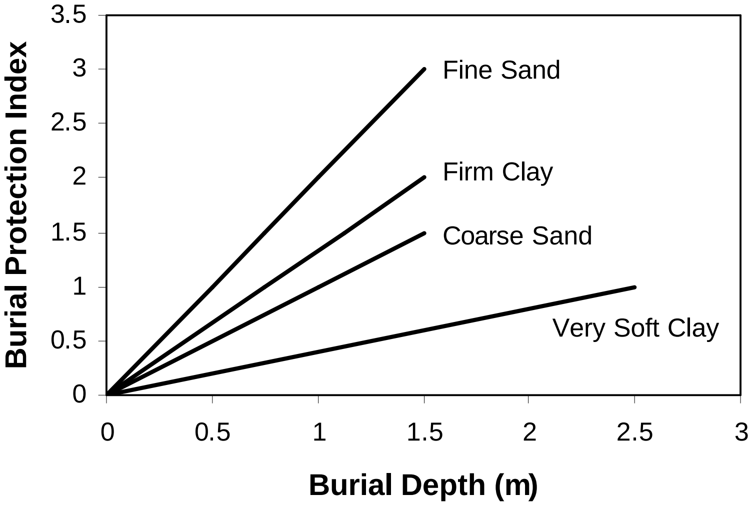

Figure 2 : A Burial Protection Index (after Mole et al, 1997)

While the concept of a burial protection index is becoming accepted by the cable industry, there remains a tendency in the industry to specify a certain burial without due regard for the protection provided by the geology and the associated risks.

As the fishing industry has become more aggressive in it's exploitation of fish stocks, water depths have increased. It is now common practice to bury cables to 1000m water depth, however cable damage associated with fishing are being reported at depths of 1200m. To counter this the cable industry is now being asked on some projects to achieve burial in water depths up to 1500m.

Faults can and do occur with cables. Should a fault occur, the cable is normally recovered with a grapnel. Such grapnels are designed to penetrate the seabed to a depth greater than the original burial depth. Once caught on the cable they cut and hold the cable to allow it to be recovered to deck to enable a repair. Therefore, while burial offers protection, there is a need to identify an optimum depth which both protects the cable but enables recovery to be achieved.

It may be seen that optimising the burial depth offers many advantages. The selection process should assess the various potential threats to the cable including fishing, anchoring and geological, while also assessing the protection provided by the seabed. Use of the Burial Protection Index concept will permit significant savings in installation cost with no increase in risk to the cable. Adoption of such a concept requires a knowledge of the seabed geology and a thorough investigation of the threats along the route.

5. BURIAL EQUIPMENT

To achieve the required cable burial a number of machines have been developed to suit the different conditions. The most widely used method is a cable plough. The plough has several advantages including:-

- The plough is pulled by the cable lay ship thus enabling laying and burial in a single operation.
- It is essentially a passive tool, this reduces the number of moving components and simplifies replacement of wear parts.
- It gives good, rapid and controlled burial with minimal disturbance to the seabed.

The principal limitations on ploughing are at landfalls with normal minimum water depths of 15m governed by the draught of the cable ship and in very deep water where the energy stored in the tow line catenary can make control difficult.

Growth of interest in burial by ploughing in the 1970's led to the development of what became the industry standard plough. This plough, illustrated as Figure 3 has a depth capacity of 1.1m giving an ability to bury cables to the requires depth of 1.0m. The plough is relatively light at 14tonnes in air and incorporates a number of features to improve operation. It is capable of operating in soft clays with undrained shear strengths as low as 4kPa and incorporates a novel method of cutting a wedge of soil, placing the cable and allowing the soil to fall back on top of the cable. The face of the share is essentially vertical and designed to cut a wedge of soil in conjunction with an inclined rotating disc. The geometry of the plough is such that it does not have a high self penetration capability. From a cable installers perspective, and to lesser extent from a cable owners point of view, this has the advantage of the plough running at a depth consistent with the tow force and reducing the tendency to become stuck. (Becoming stuck presents the probability that a bight of cable will be left on the seabed for subsequent burial by post lay trenching). Thus the plough runs at a depth dependant on both soil conditions and trenching speed. However the tendency to ‘ride out’ of the seabed is potentially a significant disadvantage as burial specifications are more rigidly enforced and deeper burial forms a specification requirement.

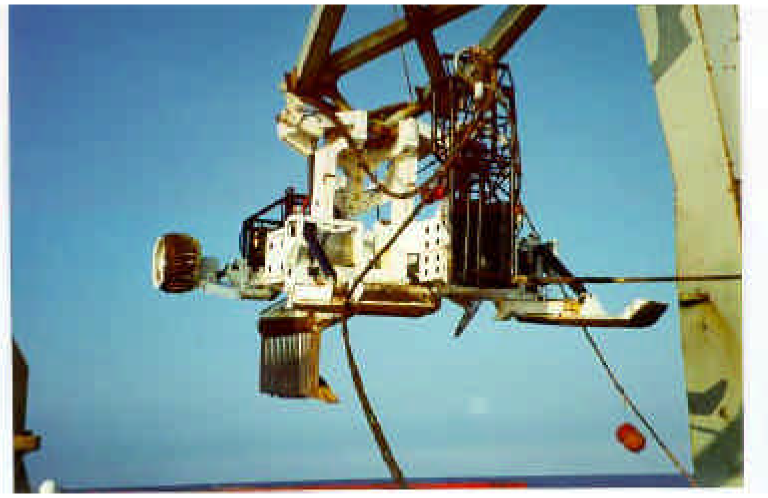

Figure 3 : Standard Cable Plough

In recognition of this need, manufacturers are developing new ploughs capable of routinely burying cables to depths in the range 1.0m to 3.0m, depending on the seabed conditions. To achieve this the share geometry has had to be redesigned to incorporate a high self-penetration. A prime example of this is the ETPM plough Advanced Cable Plough (ACP), built in 1996 for the Cheju Strait crossing. This plough achieved burial depths of 4m in soft and firm clays and also showed a good ability to penetrate rock in other areas to give maximum protection to the cable.

While ploughing is normally the preferred method, there is a requirement for other trenching techniques including jetting and trenching by chain or wheel cutter. Jetting is widely used for burial of cables near crossings of existing pipelines and cables, as well as in very soft clays which may not be able to support a plough. This may be particularly important below the continental shelf where plough operation on steeply sloping, soft seabeds is particularly hazardous. Risks include the plough running away and inducing slope instability in addition to overburial of the cable.

Figure 4 : ETPM's 4m Cable Plough

Use of chain and wheel is normally restricted to areas of exposed rock or other hard strata as the process tends to be comparatively slow with a high risk of cable damage occurring. However such machines are capable of trenching moderately strong rocks (up to 20MPa uniaxial compressive strength) at moderate depths (0.8m).

6. GEOTECHNICAL ASPECTS OF BURIAL

As a direct result the growth in cable burial, the importance of the geotechnical aspects of burial has increased. Knowledge of the geotechnical properties of the seabed is required if a meaningful risk assessment is to be performed. Equally important is the correct selection of the burial equipment and the confidence that it will work and achieve the burial specification. As burial has become standard practice for all cables on the continental shelf, specifications has been applied more rigorously, with neither over burial nor under burial acceptable to cable owners. For the installation contractor, data is required to assist estimation of timescales for the work and planning operations including recoveries and deployment of the burial tool.

For prediction of plough performance, it is necessary to know whether the soil is cohesive or cohesionless. If a soil is cohesive, reasonable estimates of plough performance may be made based on the undrained shear strength. One factor often overlooked is the need to assess accurately the strength of very soft clays. Most cable ploughs can operate on soils with strengths as low as 4 or 5kPa. Below this threshold, excessive sinkage can occur with loss of stability of the plough and uncontrolled over burial of the cable. Similarly a post lay burial operation on soft clay may require use of a free swimming ROV, while stiffer clays may need the stability of a trackbase.

Very soft clays are common in deep water environments and on the slope from the Continental Shelf to the Abyssal Plain. In such very soft clays, tow forces may be very low, (less than 5 tonnes). On steeper slopes the plough can run away uncontrollably, or in deep water, tow line catenary effects become significant. In such instances, burial by plough may not be practical.

Sands, particularly fine silty sands, can be apparently hard to plough with tow forces up to 35tonnes are regularly experienced. To maintain the required burial depth, it may be necessary to reduce the tow speed. This may be explained by the development of pore ‘suctions’ created as the sand dilates during shearing. The resultant increase in effective stress gives the sand a high shear resistance until the pore pressures equalise. The rate at which pore pressures equalise is dependant on the permeability of the sand. With small changes in particle size distribution giving changes of orders of magnitude in permeability, this parameter can govern plough performance.

One problem, which is often encountered, is determining from conventional investigations whether a particular soil will exhibit granular behaviour, with dilation occurring during shearing, or as cohesive material with plastic failure. The difference can be highly significant with a loose sandy silt ‘hard’ to plough and a clayey silt very easy to plough.

The presence of rock at seabed generally results in insufficient burial by ploughing to give adequate protection. In such cases the plough may either skid over the surface of the rock or ‘snag’ and give intermittent high tow tensions.

7. GEOTECHNICAL INVESTIGATION TECHNIQUES

When reviewing techniques used by the cable industry for geotechnical investigation it is important to be aware that the engineering associated with a cable is very much less critical than a pipeline. For example upheaval buckling considerations do not figure and there are no significant environmental considerations associated with a broken cable, in contrast to an oil pipeline which could cause widespread pollution. Investigations for cable routes may not be as detailed and the challenge facing a geotechnical engineer is to make the best of the available information.

The geotechnical data required for a cable route is largely used to assess burial depths and speeds which may be achieved by burial equipment. The main interest is the uppermost 1m of the seabed, with information below this depth being largely incidental. One approach has been to use a scaled down and simplified plough, designed specifically for the purpose of surveying. These tools have a generic name of BAS tools (burial assessment survey). With proper interpretation the data was very useful as an investigation of the whole route was possible and results could be correlated directly with plough performance. The use and interpretation of BAS tools has been discussed by Noad (1993). However they suffered from being designed for operation from a (relatively) expensive cable ship with a large A frame and high bollard pull capability. Further as they are operated by cable installation companies rather than survey companies, they do not easily fit into the main survey contract.

As a result, recent years have seen a trend in the cable industry away from BAS tools and towards cone penetration testing (CPT) and sampling. While both give an indication of soil type they have some major disadvantages.

In the case of a CPT the following disadvantages are apparent:-

- A typical lateral spacing of 1000m and penetration depth of 2m represents a horizontal vertical ratio of 500:1. Significant variations can occur in soils over this distance
- The volume of soil failed is much smaller than that by a plough (approximately 1:100 for a standard $10cm^2$ cone) and the direction of failure is rotated through 90°
- Adding lateral spacing to volume gives an investigation volume to ploughed volume of 1:50,000.
- A standard cone is advanced at 2cm/sec, compared to a plough speed normally in excess of 28cm/sec (1km/hr). Slow speed and small volume significantly reduce effects of dilation and permeability.

Sampling is normally by pushed cores from a CPT frame, or gravity cores. These frequently do not achieve the specified burial depth and are often logged and photographed with little or no laboratory testing performed.

Recognising the short comings of both BAS tools and conventional geotechnical investigation techniques, Cable and Wireless Global Marine have developed C-BASS. This is a towed sledge device and incorporates a CPT capable of 5m penetration depth with geophysical equipment designed to permit extrapolation of strata between locations and with the opportunity to interpret data in real time and enable decisions to be made regarding location for CPT. Included are a resistivity spread and a sub-bottom profiler. The resistivity spread potentially offers the greatest advantage as the resistivity is related to the porosity and hence the moisture content. As undrained shear strength of a clay and relative density of a sand are dependant on moisture content, it is hoped that direct correlation may be possible with plough performance. The equipment has been described in detail by Lewis and McGinnis (1997).

8. PLOUGH PERFORMANCE FROM CPT DATA

C-BASS has now been used as part of the investigation for several cable routes. Plough data from these routes is becoming available as they are installed and Cable and Wireless Global Marine have commissioned studies to investigate correlations between plough performance and C-BASS. Some tentative findings regarding prediction of plough performance based on the results of CPT from C-BASS have been made.

As noted above, the particular requirements of the subsea cable industry are not as geotechnically rigorous as that for a pipeline. Due to the long nature of the routes and the approximate nature of burial required, it is desirable not to develop detailed mathematical relationships. A preferable approach is to take data directly from the survey and to apply this to give a plough performance in terms of depth, speed and tow tension via an empirical correlation factor. However the development of these empirical correlation factors must include an appreciation of the geotechnics of the burial process. Standard plough burial is relatively shallow (up to 1m typically) and variations in the soil may not be as significant as for a pipeline plough, required to form a trench of up to 2m depth.

The first stage in the interpretation process must therefore be to determine the soil type. For CPT, Robertson and Campanella (1983) have provided an indication of soil type. Reference to this chart shows that soil type is a function of both cone resistance (q_c) and friction ratio (R_f). For plough performance, the first step must be to determine whether the soil will behave as a clay or a sand. In a clay, good correlation may be developed based on the interpreted undrained shear strength. In sands, the dynamic component is the most significant component of tow force. For example a change in angle of internal friction a over normal range would represent less than 20% of the total tow force and frictional resistance a further 20% to 30%. The dynamic component of the tow force is accounted for by dilation of the sand on shearing and the permeability which governs the rate at which water fills the increased void space. Volumetric dilation on shearing may vary from 0% to say 30%, while the change in permeability may be several orders of magnitude. Thus permeability is the dominant factor. Permeability is in turn related to the particle size distribution of the soil.

Using Robertson and Campanella's chart, it has been possible to develop a basis for empirical constants. While the data set is still limited, it has been found that lines of constant empirical factor follow the trend lines established by Robertson and Campanella. These are shown as Figure 5. Further data is required before full confidence can be placed, however the results analysed to date are encouraging. While not presently applicable to pipeline ploughs, it is considered probable that the trends shown in Figure 5 will be of assistance in determining the behaviour of the soil and hence give guidance on whether a clay or sand plough performance model will be most appropriate.

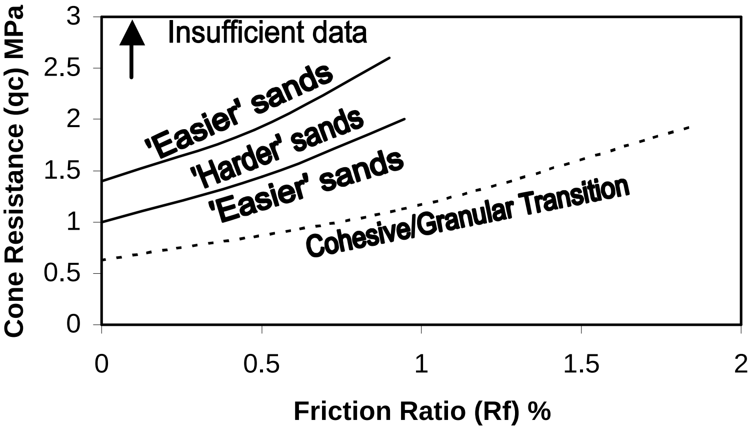

Figure 5 : Tentative Plough Performance Interpretation Based on CPT

The main features which should be noted from Figure 5 are the zone of 'harder' sands and the transition from cohesive to granular behaviour. In particular the fact that the relative density of sands (as indicated by q_c) is less significant than the grading, and hence permeability, of a sand when estimating plough performance should be noted.

9. CONCLUSIONS

This paper has described some of the geotechnical aspects of submarine cable routes. Most significant is the ease with which the cable can be buried and the protection afforded by such burial. At the planning stage, it is essential that an investigation is performed reliable burial predictions are made to enable correct cable armouring to be identified and enables the installer to plan his burial programme. Conventional geotechnical sampling and testing forms the basis for investigation of many cable routes. While further work is required, data available to date suggests there is potential for prediction of plough forces from CPT tests.

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