SELECTING APPROPRIATE CABLE BURIAL DEPTHS A METHODOLOGY

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1 INTRODUCTION

The worldwide network of submarine cables continues to grow, driven by increasing international telecommunications and the internet. While the reliability of the internal system components is exceptionally high, this can easily be negated if insufficient care is taken in the planning of the route and preparation of a protection strategy. A recent ISCPC report (Drew and Hooper, 1999) indicates total cost of cable repair can be as much as US$1m even in relatively shallow water depths after taking into account repair, loss of revenue and costs associated with rerouting traffic.

Either lying on, or buried into the seabed, a cable is subject to a wide range of risks ranging from human hazards such as anchoring and fishing, to natural hazards such as sediment mobility, submarine slides and rock outcrops. It is common in the cable industry to specify a constant burial depth for a cable without regard to the strength of the seabed soils and hence the protection provided, and with only minimal regard to the level of threats present.

This paper describes how a protection strategy can be developed and discusses how the different risks to a cable can be assessed. This data, together with a study of the seabed geology and its associated geotechnical properties, can be combined to produce a route specific burial protection index.

Use of a properly engineered burial protection index offers many advantages to both the system purchaser and the cable installer. With care, it ensures that the level of protection provided by the seabed is sufficient to protect the cables from the actual threats to it's integrity and enables burial operations to be optimised.

2 THE NEED FOR CABLE PROTECTION

A submarine cable system requires a significant financial commitment from the system purchasers. For this to be viable the system must be able to demonstrate a clear financial return over it's operating life and have a technological advantage for as long as possible.

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To achieve this, while assuring the financial backers of the integrity of the system, requires the route to be engineered and the optimum method and level of protection to be provided. This can only be achieved by a careful route study that forms an integrated part of the engineering process. All too often the route study is viewed as a box that needs to be ticked off. Lack of time for this study and an inflexible approach to the route prevents the route being optimised and the potential for cost and time saving is lost.

A properly planned route requires consideration of the following geotechnical/ geological aspects:

- An understanding of the seabed geology and its geotechnical properties
- Knowledge the different types of fishing gear and how they interact with the seabed
- An assessment of sediment mobility
- Experience of the capabilities of cable burial tools.

With input from the above disciplines, a route can be selected which ensures the cable can be protected.

3 METHODS OF CABLE PROTECTION

The two primary methods of protection of a cable are by armouring or by burial. A third method is rock dumping or placing flexible concrete mattresses. However the cost and logistics of such methods generally limit their use short areas of particular concern such as crossing postitions.

Armouring is normally applied to a cable by adding further layers of wire strands. These can have a high or low lay angle to give either increased longitudinal strength or improved abrasion resistance. However, for cable handling reasons it is difficult to significantly increase the flexural rigidity of the cable. As exceeding the allowable bend radius quickly develops into damage to the fibre optic strands, it is relatively easy for a cable to be damaged by snagging without being parted.

The adding of each layer of wire armouring results in a further pass through the cable factory. This is a time consuming and expensive process. For example, double armour cable costs almost twice as much as single armour.

The most reliable form of protection is generally considered to be by cable burial. This may be demonstrated by fault histories since 1960 (Figure 1). Widespread burial was first adopted in the late 1970’s and early 1980’s. Figure 1 clearly shows the significant improvement in cable fault histories with the growth of burial.

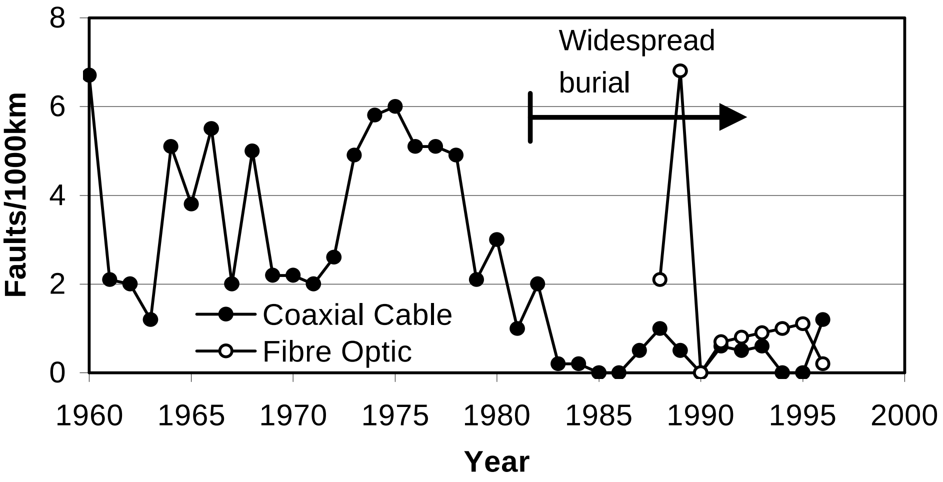

Figure 1 : Trawler and other net fishing faults in less than 1000m water depth (after Shapiro et al 1997)

There are a number of other advantages associated with burial as the primary means of cable protection. It is relatively rapid when the seabed conditions are suitable for ploughing and it is cost effective when compared to armouring. It is often cost effective to adopt a slightly longer route than increase armouring.

4 THREATS TO A SUBMARINE CABLE

4.1 Sources of Threats

A cable route study should be performed to identify a preferred route. This should identify the various threats to a submarine cable and the nature of the seabed soils. The route engineering and the nature of threats to a cable have been discussed on several occasions by previous workers (eg Ing, 1997 and Shapiro et al, 1997). The threats to a cable can be divided into two broad categories of natural and human threats. The main threats are listed below:

- Natural threats
    - Submarine landslides
    - Sediment mobility
    - Seismic activity
    - Iceberg scour
- Human threats
    - Trawling and other net fishing
    - Shell fishing
    - Anchoring
    - Dredging

Natural threats such as submarine landslides and seismic activity are difficult to predict and the route engineering should either investigate alternate routes, or include a risk assessment of their occurrence during the lifetime of the cable. Sediment mobility is a continuous process and can be difficult to avoid in some areas such as the southern North Sea.

The seabed is a shared resource used for a number of purposes. It is important that this is recognised at route planning stage. Some uses, such as dredging, are incompatible with a cable and any areas where they are performed should be avoided. However the seabed must be shared with other widespread users such as the fishing industry. This is possible with proper planning of the cable.

4.2 Fishing Gear

Human threats are the biggest cause of damage to cables. The depletion of fish stocks is resulting in moves towards deeper and deeper water. While trawl gear is designed to skim the surface, large deep water trawl boards can weight more than 4 tonnes and be operating in water depths greater than 1000m. The weight of such a trawl board is sufficient to cause sinkage into the seabed, particularly in soft or firm clays. The bearing pressure of such a trawl board on the seabed can easily be 500kPa. Pressures of this magnitude will sink into firm clays (40-75kPa), and could potentially to sink to quite substantial depths in very soft clays (<20kPa).

The larger fishing boats have a line pull of around 28 tonnes and the impact of trawl boards on a cable can be several times the weight of the board as a result. For these heavy boards, the impact loading can easily be 10 tonnes or more. While this may be insufficient to part an armoured cable, the bend produced by the impact may damage the fibre optic wires.

Beam trawls up to 10 tonnes in weight are now in use. Towing speeds of 4 knots are common and can be up to 7 knots. They are designed with sole plates to support the beam on the seabed. However they will have a tendency to stir up sand as they pass and in areas of undulating seabed, such as sand waves and megaripples, they may ‘dig in’ as they come to slopes.

Shellfish dredging, while a relatively aggressive form of fishing, does not penetrate the seabed to significant depths and is normally limited to depths of 50 to 100m in European waters and 200m in North America.

SEtech are currently involved in a EU research contract with the fishing industry to investigate interaction shellfish dredges with the seabed. The work performed to date has included monitoring the depth of penetration of toothed scallop dredges common in UK waters, and the depth of fluidisation of Italian turbo soffrianti hydraulic dredges as they were pulled across the seabed.

The results indicate depths of penetration typically up to 50mm as shown in Figure 2. While this may not appear significant, it should be noted that both methods pass repeatedly over the same area and this will result in a gradual removal of sediment from the area. This is compounded, in the case of the turbo soffrianti, by the use of a relatively large anchor with a minimum fluke penetration of 600mm. It is also noted that larger fishing gear exists (eg the toothed scallop dredges on the Atlantic coast of North America and the hydraulic scallop dredges used in French waters).

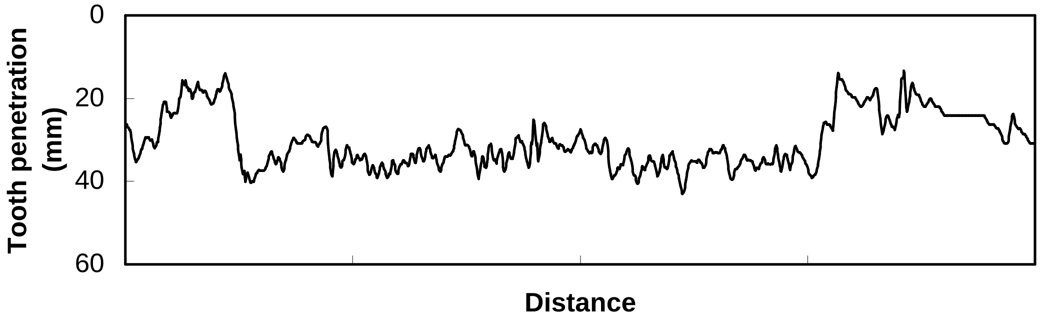

Figure 2a : Measured Penetration of a Toothed Scallop Dredge.

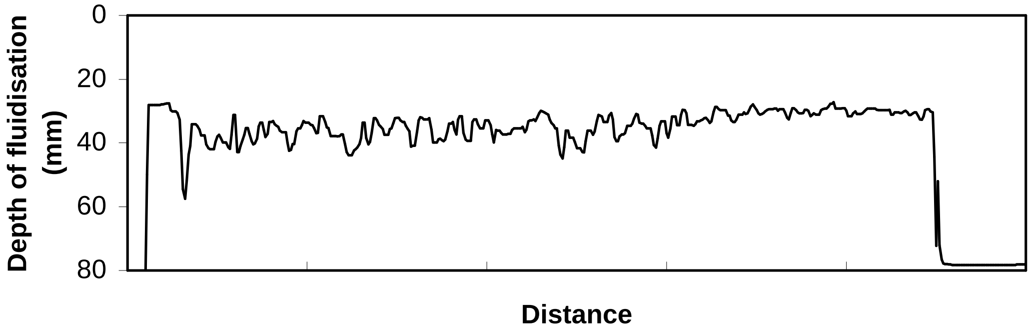

Figure 2b : Depth of Fluidised Sand With a Turbo Soffanti Dredge.

4.3 Anchoring

Anchors are particularly damaging to cable systems, being designed to penetrate the seabed much more aggressively than fishing gear. There are many types of anchor available to suit different applications. Modern high holding capacity anchors can penetrate to depths of 20m in very soft clays and have holding capacities of 600 tonnes. However such anchors are almost exclusively placed as part of a planned and engineered operation to secure an offshore installation. As such they are not a threat that needs to be considered in detail.

All ships are fitted with anchors that may be deployed either as a temporary mooring, or for safety, should the ship be out of control for any reason. Anchor size requirements are based on the Lloyds Regulations for the Classification of Ships.

Anchors fitted to ships are much less aggressive than the high holding power anchors, with stockless anchors being a common choice. These have the advantage of stowing flat, being easy to deploy and having a reasonable holding power to weight ratio. As an anchor is pulled across the seabed, the flukes pivot and engage into the seabed soil. In hard soils, the flukes will open, however the shank will prevent deep penetration. Only in soft soils is there a tendency for the anchor to penetrate to deep depths.

An anchor penetrating into the seabed follows a trajectory with the greatest rate of penetration occurring initially. As the penetration depth increases the resistance of the anchor increases. At some point the load is balanced by the resistance. Using mathematical relationships, it is possible to predict the depth to which an anchor will penetrate, under a given applied load. While the anchor may theoretically continue to penetrate, this depth is limited by the load applied, which in turn will be dependant of factors such as the size of the ship and environmental conditions

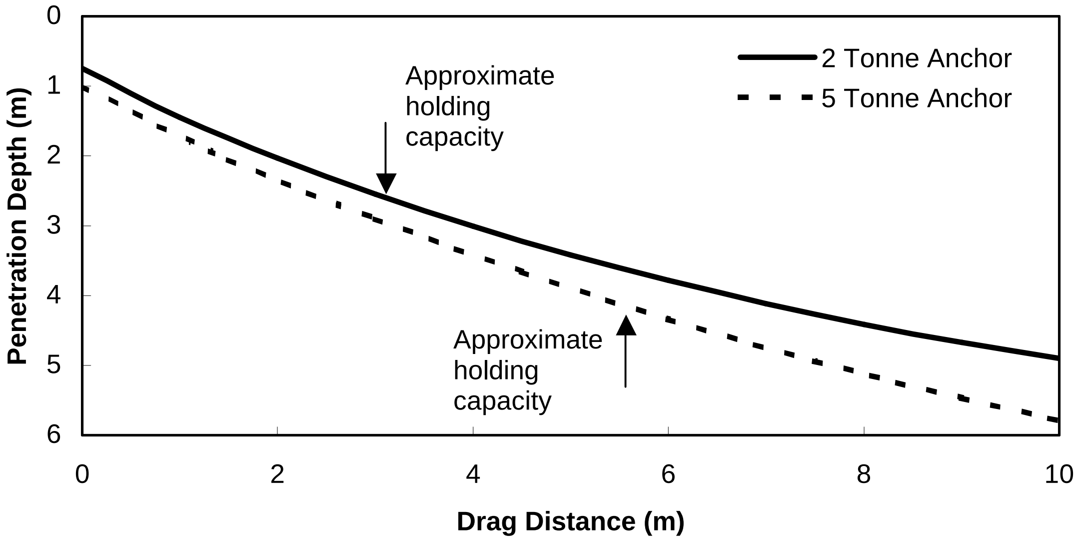

Figure 3 : Typical Anchor Penetration Curve in Very Soft Clay

Using a curve such as Figure 3, it is possible to predict the depth to which anchors are likely to penetrate. To this value, a safety margin may be added and a burial depth determined, which ensures the integrity of the cable.

When assessing the risk of anchor damage, water depths should be borne in mind. Chain lengths carried by ships normally preclude anchoring in deep water and the requirement for anchoring is reduced. Typical maximum water depths for anchoring would be between 100m and 150m.

4.4 Sediment Mobility

Sediment mobility in itself may not be a major threat, however the movement of sediments can have a significant effect on the depth of burial of a cable. This may result in the cable becoming exposed and then being at much greater risk from fishing activity or anchoring. The southern North Sea is a case in point where the mobility of sand waves and megaripples can be a particular problem.

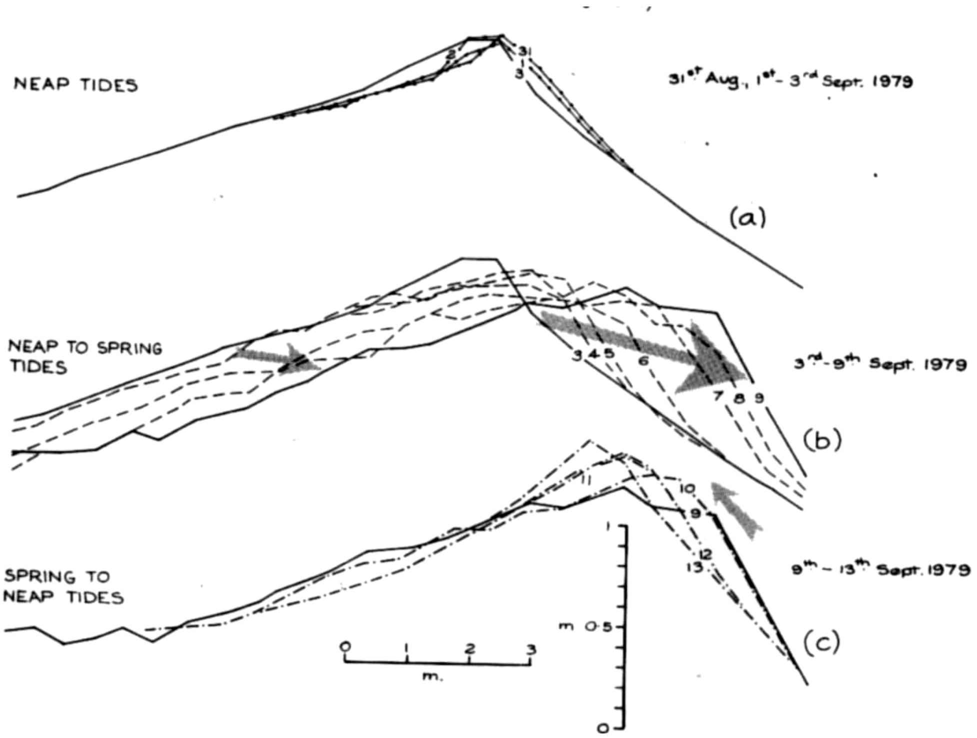

Figure 4 : Example of sandwave mobility (after Langthorne, 1979)

Figure 4 illustrates the mobility of a typical sandwave over a lunar cycle. The depth change can be seen to be approximately 0.5m. This would be sufficient to effectively expose a cable, without considering the possibility that lay tension may tend to pull the cable out of the seabed.

The mobility of sediment is dependant on a number of factors including metocean conditions (current, tides and wave height) and the grain size and relative density of the soil. With little more than routine cable route study and survey data, a good estimate of the potential mobility of a sandwave may be assessed. The basic tool for this is the Hjulstrom curve (Figure 5). This shows the relatively high currents required to erode clay, silt and gravels. From this a first estimate of the likelihood of sediment mobility may be made.

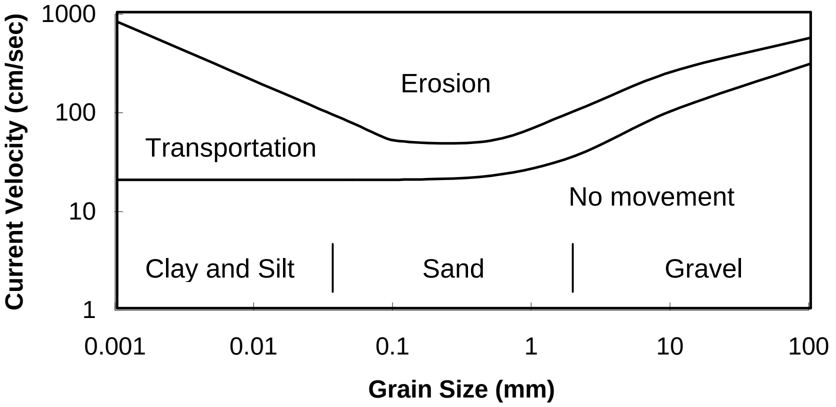

Figure 5 : Hjulstrom curve showing sediment mobility

If sediment mobility is shown to be a problem, then a more advanced analysis is possible with the assistance of a bedform phase diagram, an example of which is shown in Figure 6. From this a prediction may be made of the conditions under which significant sediment movement may occur and the likely form of the of the resulting seabed.

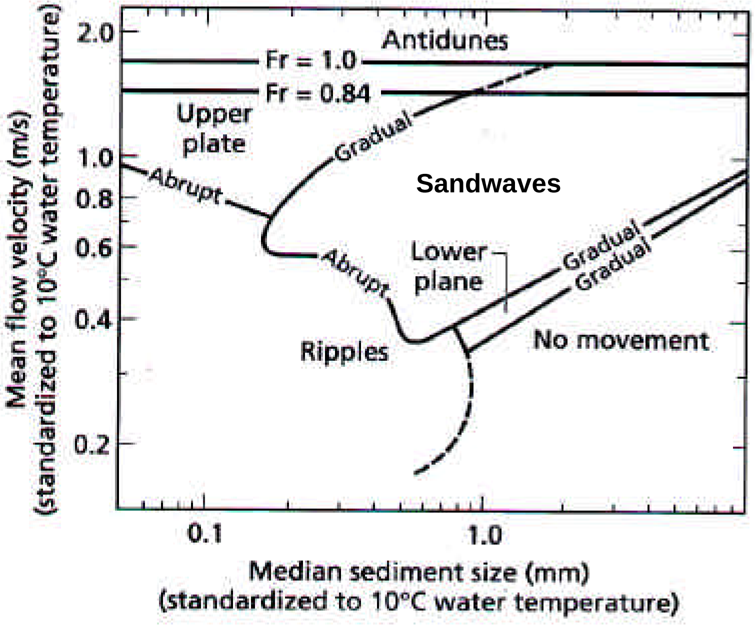

Figure 6 : Example Bedform Phase Diagram (after Ashley, 1990)

5 THE BURIAL PROTECTION INDEX

During the early 1980's, when burial of cables became common practice, a burial depth of 0.6m was selected. This was normally adopted as a blanket specification for a cable without regard to soil strengths and the threats that may be present. Target burial depths have increased and it is now common for 0.9m or even 1.5m to be specified

It has always been recognised that ‘stronger’ seabed soils provide greater protection than a softer soil for a cable buried to a similar depth. Although recognised, it was only in 1997 (Mole et al, 1997) that the concept of a burial protection index was first proposed. This burial protection index (BPI) was scaled such that a value of unity was sufficient to protect against trawling and most common fishing gear in a clay of 40kPa undrained shear strength. This was given a BPI of 1, and a tentative correlation with other soil types is shown. The chart produced by Mole *et al* is shown as Figure 7.

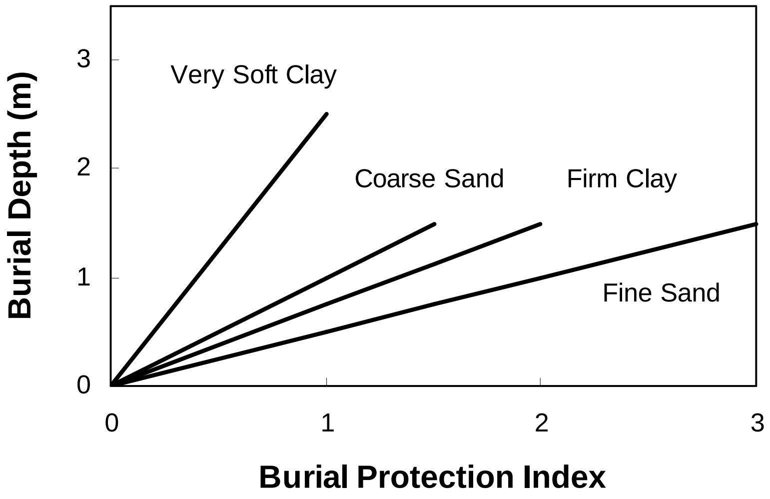

Figure 7 : Burial Protection Index (after Mole *et al* 1997)

For the burial protection index to work properly it is necessary to identify with greater confidence the depth to which threats are likely to penetrate into the seabed and the risk of exposure of the cable with due regard to their probability. It is proposed that this is done on the following basis although this should be adjusted to suit local conditions including method of trenching and nature of any backfill soil:

BPI = 1	Depth of burial consistent with protecting a cable from normal fishing gear only. Would be appropriate to water depths greater than say 50 to 100m, where anchoring of ships is unlikely.
BPI = 2	Depth of burial will give protection from vessels with anchors up to approximately 2 tonnes. This may be adequate for normal fishing activity, but would not be adequate for larger ships (eg tankers, large container ships)
BPI = 3	Depth of burial sufficient to protect from anchors of all but the largest ships. Suitable for anchorages with adjustments made to suit known ship/anchor sizes.

For clay soils a typical classification is shown as Figure 8. The main features to note are the significant depth of burial required to protect from anchor damage in very soft clays. This arises from the tendency of the anchor to penetrate into the seabed, rather than being pulled over the surface. In stiffer clays, the flukes penetrate into the seabed, however the shank supports the anchor and it is dragged along the surface. While flukes have difficulty penetrating into the seabed, this cannot be relied on as there is often a softer layer of soil at the seabed. Once the anchor has opened and the flukes have penetrated into the seabed, the depth will be largely independent of the strength of the clay. The resistance to dragging over the surface of the clay does not increase linearly with the undrained shear strength. This is due to the fissures generated in stiff (>100kPa) clay by their geological formation process.

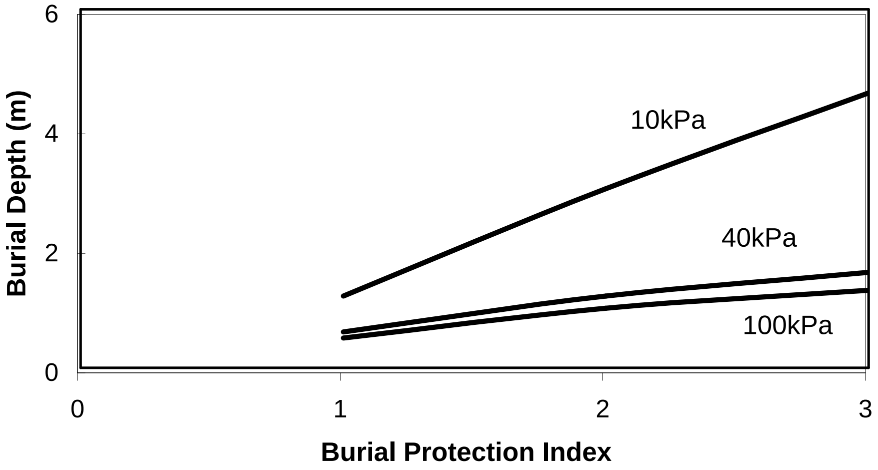

Figure 8 : Example Burial Protection Index in Clay
(Strengths refer to undrained shear strength)

Development of a burial protection index in sands is more complex as the bedform and the mobility of the sediment must be considered. Particular care must be taken where megaripples and sandwaves are present. In addition the geotechnical parameters of relative density and grain size must also be considered.

Taking first the significance of megaripples and sandwaves, it is necessary to consider the possibility of cable suspensions occurring between crests. Ideally the lay tension should be such that the self weight sag of the cable is sufficient to enable the cable to follow the seabed profile. This may be readily calculated for a typical telecom cable as shown in Figure 9.

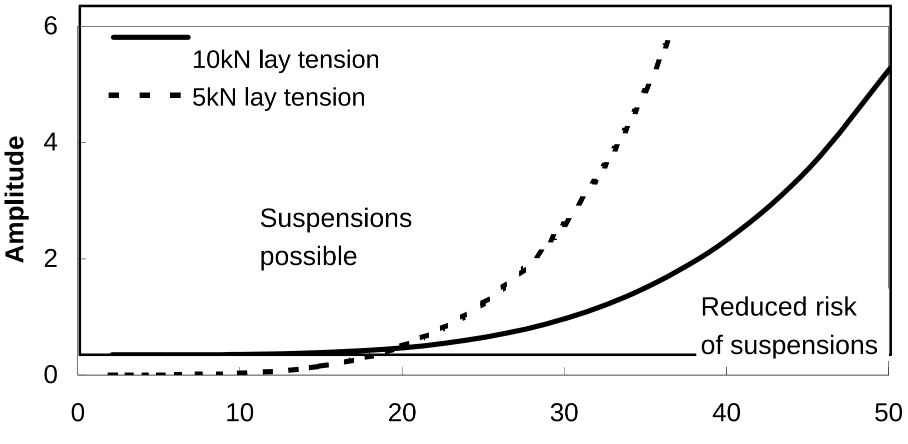

Figure 9 : Sandwave dimensions at risk of inducing cable suspensions for a typical armoured cable.

The most critical seabed topography for cable suspensions are wavelengths up to 20m where even quite small amplitudes of less than 1m could result in exposure of a cable buried to 0.6m depth. As wavelengths increase, the risk of a suspension falls markedly, particularly if lay tension can be kept low. As wavelengths increase, the amplitude has to increase dramatically for a cable to be suspended. Such combinations of amplitude and wavelength are rare. It can be seen that the greatest risk of a cable suspension is where megaripples (wavelengths <30m, amplitudes <1.5m) are present and not sandwaves.

Due to the variability in these parameters, it is necessary to prepare a chart for each geological section of a route. An example chart is shown as Figure 10. The chart includes an allowance for sediment mobility. If the sediment is known to be mobile, then the depth of this mobile sediment should be ignored. In practice this will be a function of the grain size, currents and wave conditions. The protection is then a function of the relative density of the sand and the grain size.

As in clays, most anchors used on ships will be supported on the seabed by the shank of the anchor and only the flukes will penetrate into the seabed. Full penetration of typical anchors is largely limited to loose sands. Therefore the nominal penetration depths are similar to those for firm and stiff clays. Figure 10 suggests that substantial burial depths would be required where large anchors may be placed and the sand is loose and mobile. Such deep depths would be difficult to achieve and require non-standard burial equipment. In practice, the areas of high currents associated with sand mobility are a poor choice for an anchorage for obvious reasons. However, while unlikely to be a frequent occurrence, anchors may be deployed in such locations in an emergency.

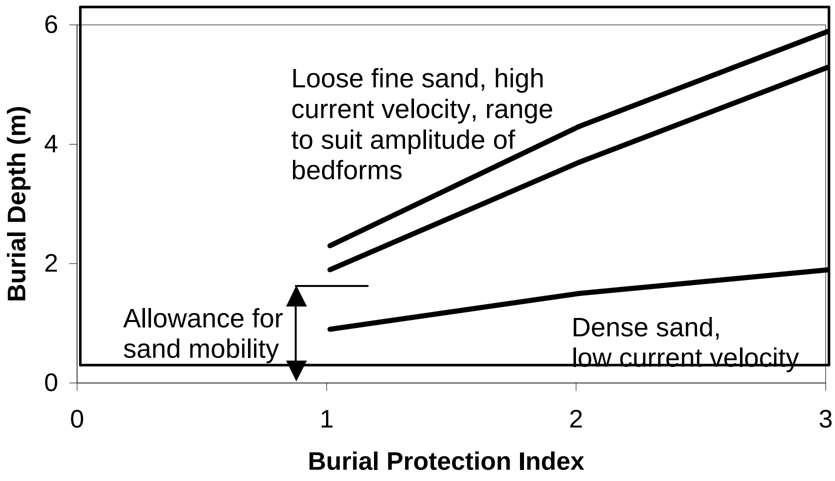

Figure 10 : Example Burial Protection Index in Sand

6 CONCLUSIONS

A submarine cable is a major commercial investment, which is expected to provide a financial return. It is relatively fragile and lies on a seabed that is shared with other users and can only be seen on charts or other reference material. To maximise the return, cable security is of paramount importance. This can only be achieved if the cable is adequately protected.

The two primary methods for protecting a cable are armouring or burial. Burial has been shown to be preferable as it both protects the cable from impact and is cost effective when compared to armouring. For many years cable burial has been stipulated on the basis of a uniform depth, with often minimal regard to the nature of the threat and the degree of protection provided by burial to different depths in different soil types.

The concept of a burial protection index has been developed to include discussion of soil strengths and mobility. With proper engineering at feasibility and survey stages, a route and burial depth can be selected which gives much greater confidence that the cable will remain undamaged.

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