CABLE SECURITY IN SANDWAVES

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1. INTRODUCTION

Sandwaves is the generic term that is often used to describe a range of seabed features or bedforms. They are encountered throughout the world and present particular problems for cable engineers. European examples of sandwave fields include the southern North Sea and Western Approaches, both areas crossed by an extensive network of submarine cables. Cables crossing these areas must be properly engineered if they are to be secure and not suffer from faults during their lifetime.

Bedforms have been studied extensively in the past as part of the science of sediment mechanics. Cable engineering can benefit substantially from this work and, with the right input, substantial improvements to cable security are possible. Particular aspects of cable engineering are associated with bedforms. These include the effect of lay tension and the burial methods that must be considered if a cable is to be buried and remain free of suspensions. These can be input in a burial protection index, which enables the protection to the cable to be quantified (Allan, 1999).

This paper discusses the nature and nomenclature of bedforms, the mechanics behind their formation, development and movement, and the effect of bedforms on cable lay and lifetime integrity. The nature of the bedforms is largely dependant on metocean conditions and the sediment characteristics. With knowledge of these parameters, it is possible to predict the likelihood of sediment mobility and the conditions under which it will occur. Differences between different bedforms are indicated, highlighting their relevance to cable burial operations and long-term system security – related, and yet often not complimentary, targets.

Typical tools used to bury cables through areas of bedforms include ploughs and post lay jet tools. The suitability of the different methods, and the operations which may be desirable prior to installation, are described.

It is shown that, with care, action can be taken to minimise the risk to the cable and ensure a secure system installation. This can be achieved with little more information than normally obtained as part of a typical cable route burial assessment survey, yet the savings in maintenance and availability for service can be significant.

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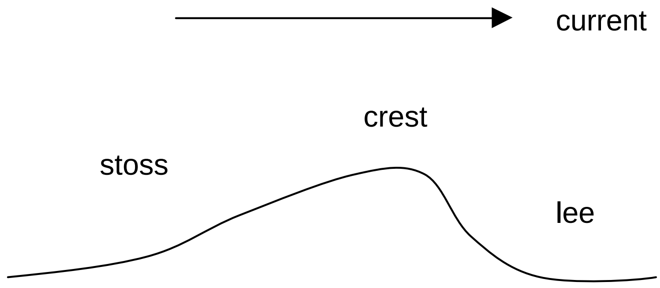
2. TERMINOLOGY

The expression sandwave is commonly used to cover a wide range of seabed features from small ripples of a few centimetres height to large sandbanks of tens of metres height. In sediment mechanics, these are collectively referred to as bedforms. It should be noted that the expression 'dunes' is sometimes used in sediment mechanics to cover both seabed bedforms and the more usual use as shoreline or desert features. Various systems have been published covering the nomenclature of bedforms. In general bedforms are classified on the basis of wavelength and height (or amplitude). There is no uniform standard for the nomenclature of bedforms. In the absence of such a nomenclature, that published by Gass *et al* (1984) is recommended for use in preparation of survey reports. This is summarised below.

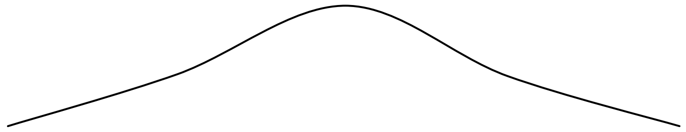
Name	**Relief**	**Wavelength**	**Length**
Ripples	Typically less than 100mm	Function of grain size and bottom orbital velocity	May be continuous or form a complex network
Megaripples	0.4m to 1.5m	0.6m to 30m	Tens to hundreds of metres
Sandwaves	1.5m to 25m	Typically 30m to 500m, but 1km or more possible	Hundreds of metres to tens of kilometres
Sandbanks	5m to 50m	Single distinct feature or as a series	

Table 1: Nomenclature for Bedforms (Gass *et al,* 1984)

In cross section, bedforms may be symmetrical, with both flanks having a similar slope profile. This is generally taken to be indicative of a stable bedform. Asymmetrical bedforms have a steeper slope on one side than on the other. This is generally taken as indication of a more mobile feature. Typical bedform geometries are shown as Figure 1.



Asymmetrical



Symmetrical

Figure 1: Typical Bedform Geometry

3. FORMATION OF BEDFORMS

The formation of bedforms arises from the flow of a fluid over a bed of soil. The fluid may be either air or water. Much research has been performed to investigate the movement of dunes in desert areas and this has been transferred to subsea environments with appropriate changes to the physical properties of the fluid.

To consider how bedforms are formed, it is most logical to start with a flat seabed and to consider the physical process that causes the individual soil particles to move on the seabed. This is then placed in the context of the various soil types that may be present on the seabed.

While a seabed may be notionally perfectly smooth, the individual soil grains have a roughness. This roughness creates turbulence as water flows over the soil surface. The drag on the soil particles gives an uplift force, which if greater than the gravitational pull, can then cause the particle to be moved along the seabed. This phenomenon is illustrated as Figure 2 (from Leeder, 1982). Factors that affect the propensity of a soil particle of a particular size to move are the roughness associated with its diameter and the force required to lift it out of the seabed.

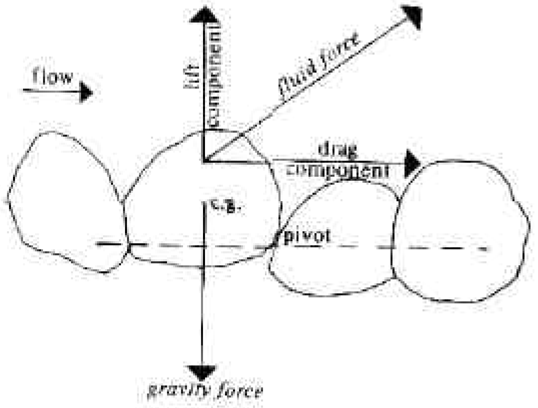


Figure 2: Forces on a Soil Bed in Flowing Water (Leeder, 1982)

Soil types are characterised by size and classified as clays, silts, sands and gravel. Taking clay soils first, the small grain size results in a potentially very smooth surface profile. Therefore little turbulence is created in the flowing water and the uplift force exerted on the clay particle is small. In addition, clay soils exhibit cohesion. This enables the soil particles to ‘stick’ together as a plastic material. Thus clay soils have very little propensity to move on the seabed and may often be very stable, despite being soft.

Sands create some turbulence in the flowing water and are relatively small in diameter, and hence weight. Relatively slow flow speeds can therefore generate sufficient turbulence to move the sand particles on the seabed. While the larger size of gravel particles create additional turbulence, and hence uplift, the weight of the particles also increases. In practice the weight of the particles increases at a faster rate than the uplift force and hence gravel particles are relatively more stable on the seabed.

This is neatly summarised in the Hjulstrom Curve, as shown in Figure 3. The Hjulstrom curve gives a very useful first indication of when particles will become mobile, and also their tendency to be transported in flowing water.

It can be seen from Figure 3 that the particle size most easily moved is a fine or medium grained sand, hence the tendency for mobility and bedforms to be most commonly associated with sand. More accurate forms of this curve (e.g. Soulsby and Whitehouse, 1997) are available. These include functions that allow for waves and current flows. Once particles become mobile they reach an equilibrium at which the net deposition and mobility balance each other. This is referred to as bedload transport.

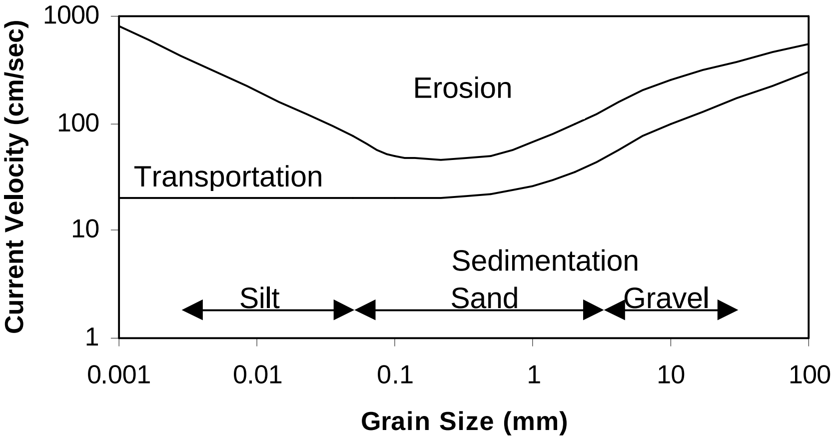


Figure 3: Hjulstrom Curve

For a bedform to form, some other factor must apply. This may be a change in the current regime, for example a slowing of the tidal stream as it enters a wider channel or deeper water. As the flow slows, soil particles will tend to fall, or settle, out of suspension. This then creates a small sand bar. The sand bar can create an eddy current as the main water current flows over it (Figure 4).

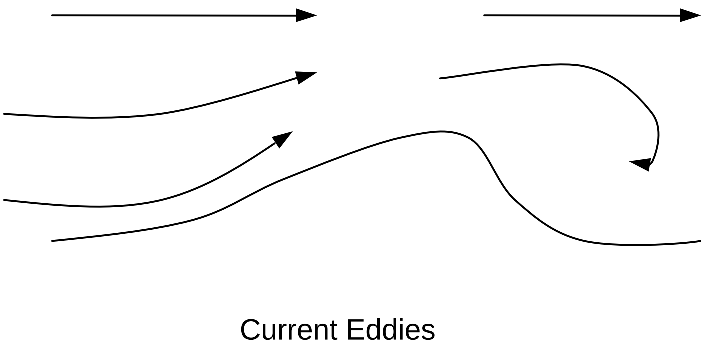


Figure 4: Current Eddy Development

This eddy current then 'pushes' sand back up the downstream slope, while deposition continues on the upstream slope. The net effect is that the bedform increases in size until some equilibrium profile is reached. The asymmetrical form of such bedforms is generally taken to be indicative of a more mobile structure, however this will depend on local factors and some may be relatively stable.

Changing metocean conditions can also result in the reduction in height of a bedform. This is most commonly achieved by wave action. A simplified explanation for this is as follows and is illustrated in Figure 5.

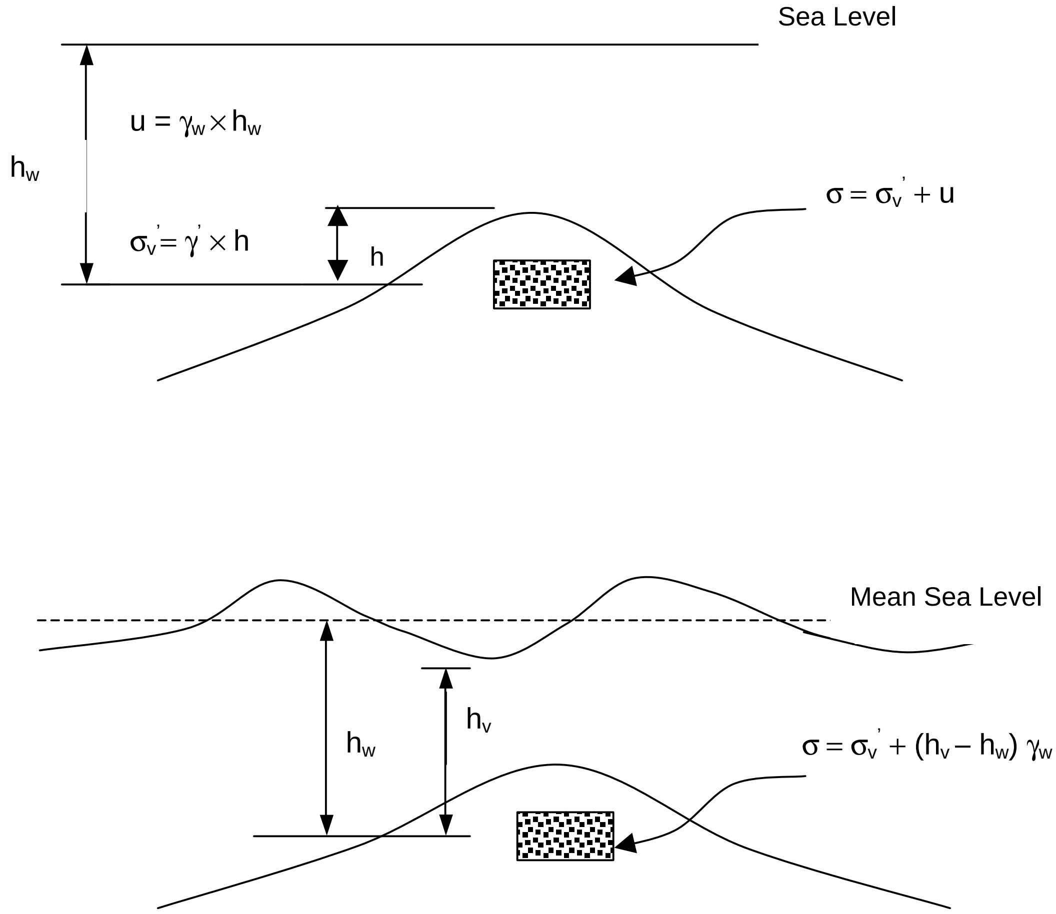


Figure 5: Reduction of Bedforms by Waves

The water pressure in the sand mass increases hydrostatically below the water surface. The contact stress, or effective stress, between the soil particles is a function of the depth of the particle below the soil surface and the submerged weight of the soil. This is the concept of effective stress in soil mechanics, where the sum of the hydrostatic and effective stresses is the total stress. Should a wave pass over, the water level will change from the mean value. As the trough of a wave passes over, the water level reduces and hence the water pressure at a point in the soil mass reduces, 'sucking' the soil particles together. Conversely as the crest of a wave passes, the water pressure increases. As this happens over a very short time period, there is insufficient time for the total pressure to equalise. The net effect is that the hydrostatic pressure goes up, and the effective stress goes down by a similar magnitude. As sand is a frictional material, which gains it's strength from the contact stress between particles, there is a reduction in the strength of the sand, and this will tend to make sand particles run downhill, flattening the height of the bedform.

4. CABLE LAY AND BURIAL OVER BEDFORMS

Effect of Lay Tension

The previous section has discussed the formation of bedforms. With the aid of suitable mathematical models, it is possible to assess the likely mobility of bedforms and the depth profile to which the cable needs to be buried, if it is to be secure. It is noted that the depth of burial may vary according to the form of the bedform. The cable lay and burial operation must be carefully controlled if burial is to be achieved and the cable is to be secure. Factors that need to be considered include the lay tension, and if ploughed, the interaction of the plough with the seabed profile.

For any cable laid with a residual tension, it is possible to calculate the sag in the cable between the two points of suspension. This has been done for a range of tensions, based on the weight of a typical double armoured cable. These are presented as Figure 7. Over the spans of interest, the stiffness of the cable would have a small effect and can be ignored. The most interesting feature of Figure 6 is the way in which the sag increases by the square of the span for any given lay tension.

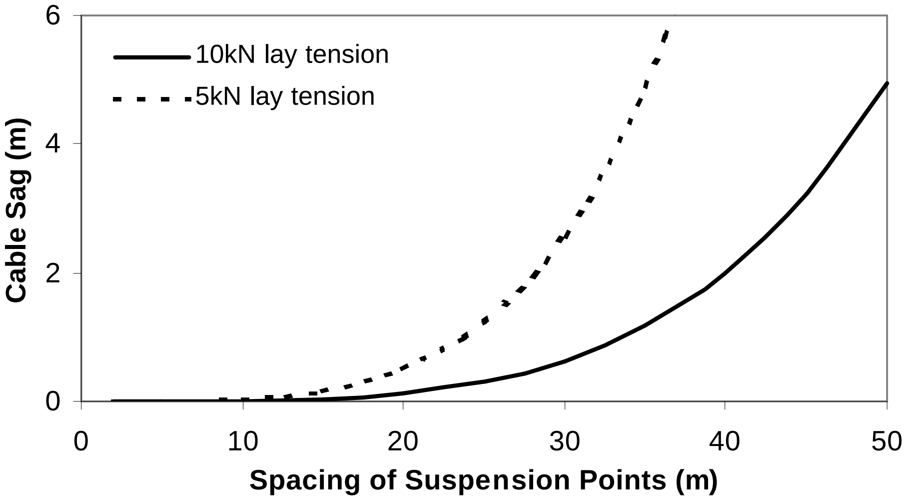


Figure 6: Cable Sag When Suspended Between Two Points

The results of Figure 6 can be applied to a range of bedforms. It can be seen that for the larger features, such as sandwaves of 5m height and a wavelength of 50m or more, the sag of the cable is such that the cable will lie naturally at the depth to which is has been buried. However, for smaller features such as megaripples of only 1m height, and wavelengths less than 30m, a residual tension of less then 10kN will tend to pull the cable out the seabed if the burial depth under the crest is less than 0.5m. Small features such as megaripples are also likely to be the most mobile and hence areas at which the cable is at greatest risk.

Interaction of a Plough With Bedforms

Typical cable ploughs are around 10m in length and are pulled by the cable lay ship. The depth to which the cable is buried is regulated by the height of the front skids on the plough. Over larger scale features, such as sandwaves and sandbanks, the length of the plough is relatively short in comparison with the wavelength of the bedform. No significant problems arise when ploughing over such features. The main factor to consider is the change in the tow force as the plough is pulled up one side of the sandwave and then down the other. The slope effect may change the tow force required by a maximum of between 10 and 15 tonnes.

More significant is the interaction of the plough as it crosses megaripples with a wavelength close to it's own length. This is illustrated as Figure 7, which shows that as the cable plough skids descend into the trough between two megaripples, the rear of the plough, at which point the cable leaves the plough, rises up and the depth of burial achieved by the plough is greatly reduced. If this is combined with a lay tension that tends to pull the cable out of the seabed, the cable can end up exposed on the flank of the megaripple.

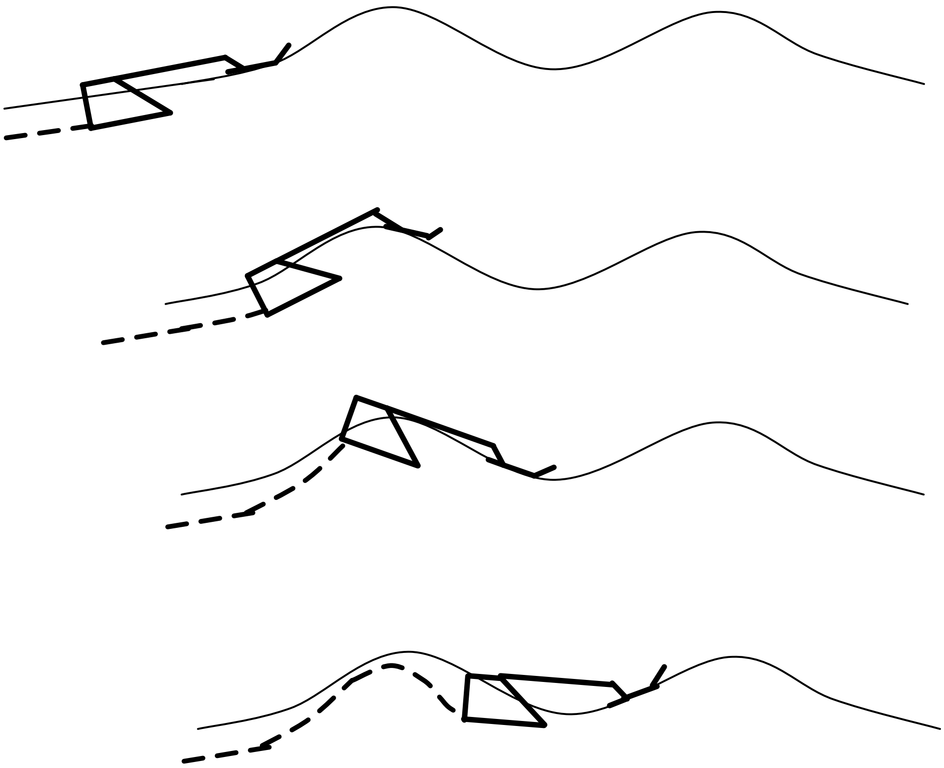


Figure 7: Interaction of a Cable Plough With Megaripples

5. RECOMMENDATION FOR CABLE BURIAL

It is often thought that if a cable is to be secure through an area of sandwaves, it is necessary to remove the sandwave completely. With a little additional data to that normally obtained as part of a cable route survey, it is possible to make an estimate of the depth to which the sand is at risk of being mobile. This study should provide a design depth below the crest and the trough of the bedforms.

Once these depths have been determined, options can be considered for burial of the cable. It may be that the additional depth required can be achieved with a standard cable plough. Should this method be adopted, the maximum acceptable lay tension should be calculated. Alternative methods, which should also be considered, include post lay jetting tools, particularly those with long jet legs. If this is deployed from the cable ship, lay tension can be regulated. If required cable either recovered or paid out to suit the ongoing burial operation.

Where the depth of mobile sand is greater, consideration may be given to use of a larger plough. There are now ploughs available theoretically capable of between 1.5m and 3m. The suitability of such ploughs should be assessed by detailed performance analysis.

Other alternatives include presweeping the route to a defined profile. This can be achieved either by dredging or by a tool such as JetProp. In both cases checks are required to ensure that the design profile is achieved. This creates a corridor through which a conventional plough can pass and burial the cable. A potential risk with such methods is the possibility that sand will be deposited through the corridor, if the cable lay and burial operation is not performed relatively quickly.

6. BEDFORM RISK ASSESSMENT EXAMPLE SOUTHERN NORTH SEA

An area where bedforms are a particular concern is the southern North Sea. This is an area of relatively high sediment mobility, which is crossed by a large number of telecom cables.

The sandbanks within this area are illustrated as Figure 8, (after Kenyon et al, 1981). This shows that the larger banks are orientated at approximately 20° to the direction of flow, not perpendicular to the flow as suggested by the description relating to the formation of sandbanks given above. The map also shows the line of bedload parting and direction of net sand transport.

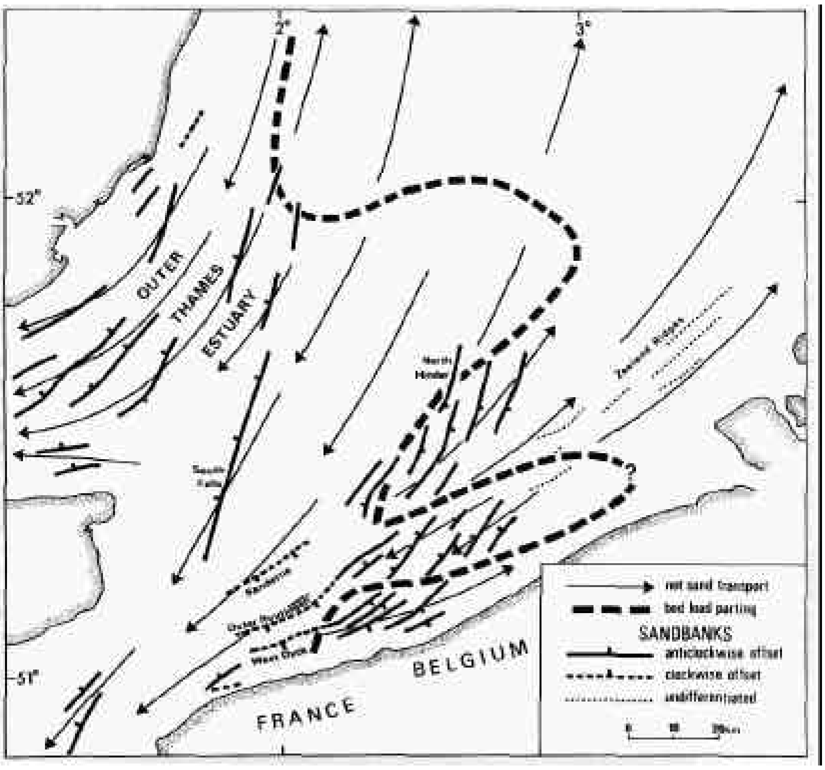


Figure 8: Location of Sandbanks in the Southern North Sea (after Kenyon et al, 1981)

The probable explanation for the angle of the sandbanks lies in the formation of hairpin vortices (Best, 1972). These gradually push a sand ribbon forward at one point leaving sandbanks to either side. Current vortices over the bank create a reverse flow that maintains the downstream side at a steeper angle than the upstream side. The larger banks have reached a stable equilibrium and are essentially static despite having an asymmetric profile. However, superimposed on these banks are smaller ripples that represent the more mobile sands at the seabed. These megaripples run perpendicular to the direction of transport. Kenyon et al prepared a side scan mosaic that illustrates this (Figure 9).

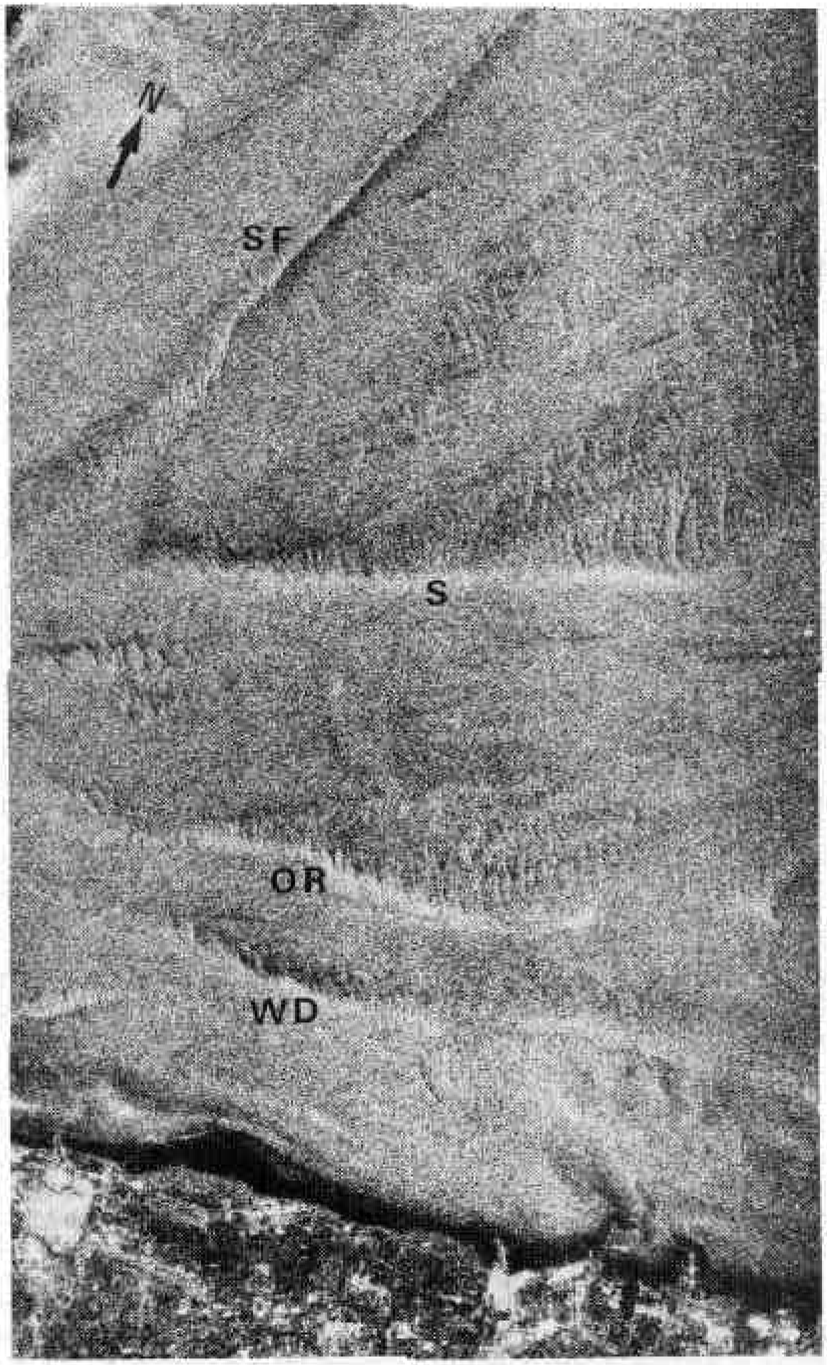


Figure 9: Sidescan Mosaic of Southern North Sea Showing Major Sandbanks and Superimposed Megaripples/Sandwaves (from Kenyon et al, 1981)

It is possible to perform a mathematical study of the rate of movement of the sandbanks, which illustrates the basic stability of these sandbanks within the operational life of a cable. However, it can also be shown that a more mobile surface veneer is present. Protection of the cable can be achieved by burying it below the level of the more mobile seabed.

7. CONCLUSIONS

Mobile sandy seabeds, such as are often associated with megaripples and sandwaves, present several problems to the installation of a secure cable. These include particular requirements to minimise lay tension and to have due regard to the interaction of a cable plough with megaripples of similar wavelength.

Cables can be protected by burying them to moderate depths, as larger features tend to have a relatively high degree of stability. An assessment of the depth that is required to ensure protection can be made with data on metocean currents and wave frequencies, seabed profile and relative density and particle size distribution of the sands. While each location must be considered individually, often moderate burial depths of approximately 2m can provide sufficiently good protection during the design life of the cable.

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