Sandwaves and seabed engineering; the application to submarine cables

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Abstract

Sandwaves are frequently observed in estuaries, coastal regions and offshore on the continental shelf. The presence of sandwaves can pose specific challenges to subsea engineering projects. The migration and changing characteristics of sandwaves can influence the design bed level for a structure, present a hazard to navigation and expose pipelines and cables, increasing the risk of damage. This paper examines the current understanding of the behaviour of sandwaves in relation to the practicalities of cable laying operations. The three important questions in relation to cable laying operations are:

1. How deep must the cable be buried in order to avoid future re-exposure?
2. What rate of re-cover can be expected post trenching?
3. What survey data should be collected to assess this?

These questions are addressed, some recommendations of the way to assess and account for the influence of sandwaves are made and some suggestions for further work are put forward to enhance the pre-operational planning.

1-Introduction

Sandwaves are frequently observed in estuaries, coastal regions and offshore on the continental shelf. They are characterised by a wavelike form in fine, medium and coarse grained sandy sediments, and usually indicate a very mobile seabed and an abundant supply of sediment. The growth and migration of sandwaves on the seabed can:

- influence the design bed level for a structure
- present a hazard to navigation
- expose pipelines and cables, increasing the risk of damage
- influence the tidal flow, through the contribution to bed roughness
- indicate sediment mobility and transport pathways

Hence, they can exert an influence on the following aspects of marine engineering:

- ports and harbour engineering
- dredged channels and trenches
- pipeline and cable engineering
- offshore structures

The specific aim of this paper is to assess the existing, available knowledge of the behaviour of sandwaves in relation to one of these aspects, that of cable laying operations. Cables laid on the seabed are prone to damage by fishing trawl gear or by anchors. One of the only ways to protect cables is to bury them beneath the seabed but they may experience periods of burial and exposure as the seabed level changes, this is especially the case in areas of mobile sandwaves and other bedforms. Overburial of cables can also present problems as it may become difficult to lift a faulty cable for repair without causing further damage (Langhorne, 1978). The review addresses three important questions relating to cable laying:

How deep must the cable be buried in order to avoid future re-exposure?

1. What rate of re-cover can be expected post trenching?
2. What survey data should be collected to assess this?

The aim is not to give an exhaustive review of sandwaves in general but to provide focussed answers to these questions.

The paper is structured in the following way. Firstly, a brief introduction to bedforms is given. Next the potential mobility of sandwaves and the required depth of cable burial is examined. Following this the issue of post-trenching recovery is dealt with. The important question of which survey techniques are appropriate for obtaining a better understanding of sandwaves along a particular route is discussed. Finally, some recommendations and suggestions for future work are made.

2-Bedform types

Bedforms are frequently observed in estuaries, coastal regions and offshore on the continental shelf. Whilst they usually indicate a mobile seabed and an abundant supply of sediment, they can also be geological relics (Stride, 1982). This makes it important to determine whether a seabed feature is mobile or immobile when planning the installation of a cable along a chosen route.

To summarise, a hierachy of bedforms exists on the seabed. These can be characterised as follows but are not mutually exclusive:

Sandbanks length 1 km to many 10's of km, width 0.5 km up to 10 km, height 10's of m

Sandwaves wavelength 30 m to several 100 m, height 1-2 m to 10-15 m

Megaripples wavelength 0.3 to 1 m, height 0.05 to 0.2 m

Ripples wavelength about 0.3 m to 0.6 m, height up to 0.05 m

Sandwaves are characterised by a wavelike form in the seabed sediments. They are formed in fine, medium and coarse grained sands and the cross-section shape provides an indication of the net direction of sediment transport. Their crest to trough height can be as large as one-third of the local water depth, although exceptions do occur, the wavelength (horizontal distance crest to crest) increases with the increase in height (vertical distance trough to crest). Also a distribution of heights is found in any sandwave field due to natural variability.

Bedforms exist under a range of current speeds and the type, shape and size varies with the strength of the current. Where sandwaves are found in areas with higher currents they can move as individual features over a gravel or rocky substrate. The sorting of sediment as it is moved by the currents and the avalanching down the lee slope can effectively mean the bedform lays its own "carpet" of coarser material. Where the current is especially high, a gravel bed can form gravel waves.

Sandwaves and megaripples can:

- travel over the seabed due to the influence of tidal flow (e.g. Figure 1)
- alter their shape and size as the tidal flow changes from spring to neap tides and seasonally
- have their dimensions significantly reduced during a storm (by wave action; Langhorne, 1978)

- occur on the flanks of larger features such as sandbanks

The sandbanks being larger volume features move relatively slowly in comparison with the sandwaves. They also tend to be flow parallel in tidal environments. Sandbanks on the continental shelf and in the coastal region have recently been the subject of an in depth state-of-the-art review by Dyer and Huntley (1999).

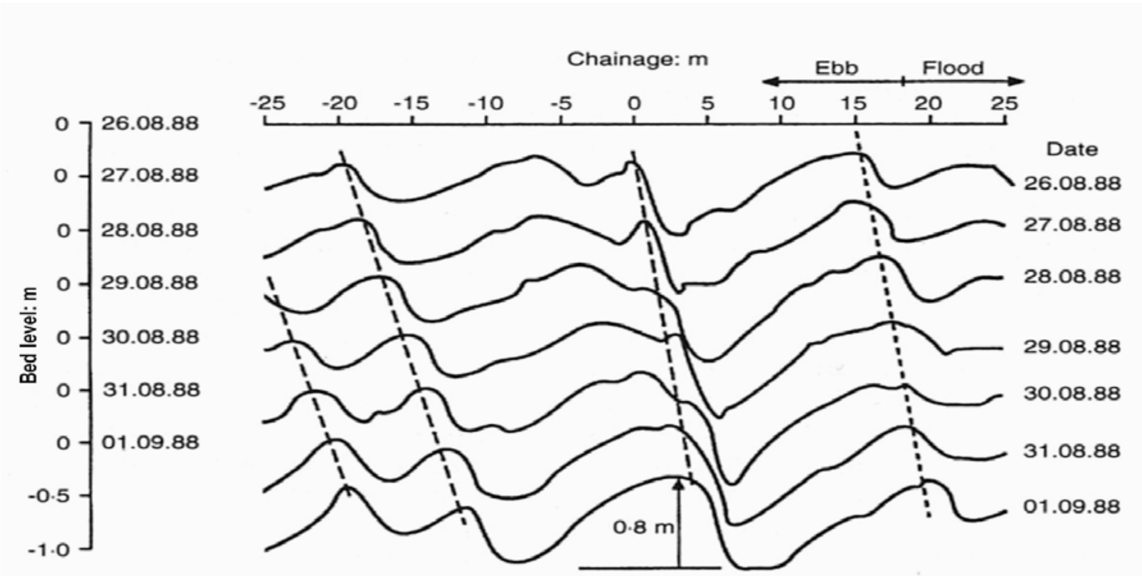


Figure 1 Sandwave migration in a sandy estuary (from Soulsby, 1997), by permission of Thomas Telford Ltd, London

3-Sandwave mobility and cable burial

3.1- Cable installation context

For routing of cables it is often not possible to avoid sandwave fields. Furthermore, when routing through sandwave fields it is not in general possible to stipulate that the cable should be laid parallel or transverse to sandwave crest lines. Current guidance on sandwaves used by cable companies is provided largely by the Society for Underwater Technology publication by Langhorne (1978). More recently, the book by Whitehouse (1998) provides a summary of information on the interaction of pipelines with the seabed in general as well as sandwaves. Given the limited amount of information available it is of interest to explore some generic guidelines for dealing with sandwaves, especially in relation to issues such as depth of burial and rate of recovery of sandwaves after trenching, and risk of re-exposure.

A typical cable is armoured and has a diameter of 50 mm. It is laid with fairly low levels of slack (< 0.5%), and typically has a minimum permitted bending radius of 1.5 m. The main cost is not the cable itself but the repeaters at typically every 50km cable length. The cable design life is typically 25 years, although in practise transmission technology obsolescence may reduce this to perhaps 15 years. The peak of faults with a cable occurs typically within the first year after laying, whilst other seabed users become acquainted with the location of the cable. To reduce the risk of damage to cables the cable industry likes to publicise where cables are laid, cable routes are shown on Admiralty Charts and on charts distributed by cable companies.

Existing current practice (Featherstone, personal communication, 1999) is to bury cables up to 1 metre deep into the seabed using a towed plough simultaneous with the cable lay. In some areas, for instance around Calais deeper burial to a depth of 1.5 to 2 m may be required.

The main trenching technique is through ploughing. However for post lay burial, and post repair burial an ROV (Remote Operated Vehicle) with jet burial tool is used, and the cable industry is now interested in the potential use of hydrodynamic excavation tools.

3.2-Mobility of bed features

The key issue with relation to burial of a cable is to identify which part of the seabed and/or the bedforms is actually mobile. The large features (heights of order of magnitude 10 m and wavelengths of order of magnitude 100 m) will move relatively slowly, or flex their crests with successive flood and ebb tides, whereas the smaller sandwaves and megaripples found on the seabed, or on the flanks of bigger features tend to be more mobile. This is because the volume of sediment moved in bed load transport by waves and currents is relatively large in terms of the smaller features, but less so for the larger.

One approach that might be adopted is that it is not necessary to bury cables to the base of the bigger features since they are relatively immobile on the time scales of a cable design life (15 to 25 years). Therefore burial analysis should concentrate on the mobile features, with the objective of defining the depth of the troughs and using this (possibly with an additional factor of safety) to define the depth for cable burial.

A number of scenarios can be envisaged where cables might need to be trenched in mobile seabed areas:

1. through sandwaves or megaripples formed in an otherwise flat seabed:

1a. sediment abundant: fully formed bedforms

1b. sediment sparse: sandwave or megaripple crests moving over e.g. gravel pavement

2. through megaripples or small sandwaves on the flank of a larger sandwave or sandbank

The scenarios are sketched in figure 2. A further scenario could be envisaged where the Scenario 2 bedform exists as an isolated feature on a hard surface, with gravel or rock substrate between successive features.

The sandwaves or megaripples change their dimensions in relation to the tidal currents (spring-neap and seasonal timescales) and can migrate over the seabed. The sandbanks shift more gradually through time and on top of this slow movement the changes produced in the sandwaves or megaripples can lead to changes in seabed level on the monthly to annual timescale. This means a different approach might need to be taken in each scenario as the bedform dynamics are somewhat different.

From an operational viewpoint the implication is that it may not be necessary to bury the cable to the trough of larger, relatively immobile features (height H_2, Scenario 2, see figure 2). Instead it may be sufficient to bury the cable to a level beneath the trough levels of the smaller mobile features height H_1, viz. megaripples or small sandwaves. Hence the buried cable will follow the contours of the larger feature. The saving in terms of removed material during trenching could be significant. In order to adopt this approach it is of course important to know the dynamics of the particular field of bedforms.

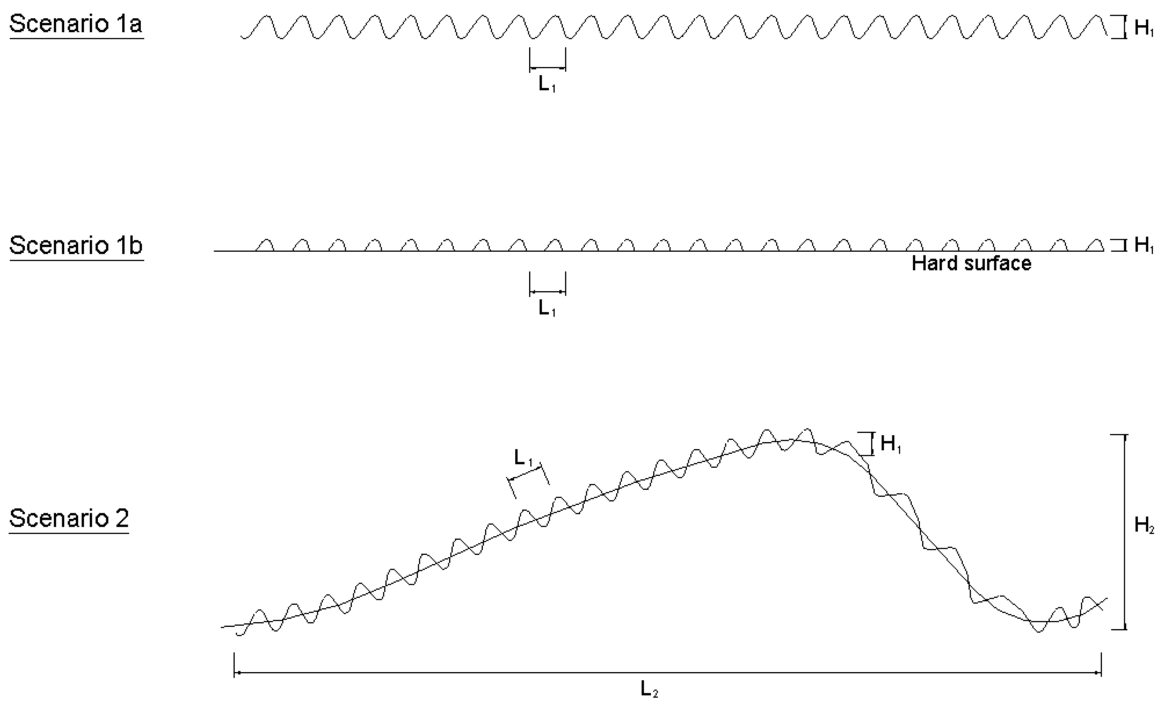


Figure 2 Scenarios for mobile seabed areas – schematic only

Of course it is always possible that the cables may settle into the seabed due to their own weight aided by scouing of sediment from around the cable by waves and currents. How much protection can this provide? The cables are of a sufficiently high density (2.8 to 4.2 kgm^{-3}) to self-bury into the sediment. However, the self-burial by scour is of the order, say, one to three times the cable diameter (Whitehouse, 1998), i.e. relatively small but at least this can help reduce the risk of damage. In practice, the only way to achieve significant self-burial is if the overall bed-level falls then rises - the cable will not follow the bed level upwards and will become covered with sediment. On the other hand the bed could of course go down again and re-expose the cable.

3.3-Analysis of mobile features

In terms of analysing the mobile bedforms a probabilistic analysis of trough depths, for example a 'peaks over threshold' method (POT) may enable a quantification of the risk of cable exposure for a given burial depth. Such a tool would help decide upon a target burial depth on the basis of accepted risk of exposure, for example a burial depth for a given operation could be defined as the depth at which there is less than 0.1 % probability of re-exposure based on the available data.

Essentially the POT method (or a similar statistical method) requires the following steps:

1. identify the shape of the mobile features. In relation to the previous arguments this may entail a 'filtering' of the seabed profile in order to remove the influence of large scale potentially immobile features,

2. identify a reasonable threshold trough level. This could be for example the mean trough depth but that would have to be ascertained for each data set,

3. determine the probability distribution for the trough depths exceeding the threshold level.

The analysis methodology has been sketched in figure 3. The figure is only indicative - it is intended merely to illustrate the principles stated above.

On the basis of this estimated distribution it could be possible to determine, and operate with, exceedance levels for trough depths. For example the probability of the exposure of a cable initially buried at a given depth below a certain datum can be estimated. The above method requires ample, high quality data for the sandwave field(s) encountered along the cable route. However, it was recognised that the observed distribution of crest heights and trough depths T1, T2, T3 etc. would be dependent on the most recent forcing conditions from waves and tides. The analysis becomes more robust if a larger dataset is available for say winter as well as summer bedform profiles, or if sufficiently accurate historic data is available.

Exceedance of a certain trough depth also depends on whether Scenario 1a., 1b. or 2. in Section 3.2 is prevalent, i.e. how much loose sediment is available. In some areas the sandwave troughs may be "armoured" with coarser material and in areas of low sediment abundance the sandwaves may be travelling over a gravel pavement. The underlying bed level in these areas is likely to be more stable.

To apply this approach it is necessary to obtain high quality survey data that truly represents the amplitude and wavelength of the mobile features. With poor quality data, the distortion on the echo sounder trace (or swath sounder output) due to ship motion may equate with the height of the megaripples and small sandwaves.

In order to exploit the techniques mentioned above it is relevant to discuss burial scenarios. It is obviously important to determine whether burial through sandwave fields needs to be to a uniform depth beneath the chosen sandwave trough level or whether a "profiled" approach can be adopted placing the cable at a fixed depth beneath the local bed level. Clearly different approaches will be required depending on the scale of the bed features. Some more research is necessary in this area to assess the applicability of a "profiled" (i.e. variable) burial depth approach but taking into account the capability of the trenching tool.

4-Rate of recovery after trenching

The rate at which sandwaves recover after having been modified by trenching is mainly dependent on the sediment transport rate and the supply of sediment. As far as we know the work by Langhorne (1977) is the only systematic study available on this subject of sandwave recovery. This work reported on the post-storm recovery of small sandwaves (4 m wavelength) on the flank of a much larger sandwave in the Thames Estuary (cf. Scenario 2. in Section 3.2). The storm resulted in the production of much smaller sandwaves and megaripples, the sandwaves became established again through the tidal processes, taking 14 days or more to recover their pre-storm configuration.

It is feasible to use existing models for predicting trench infill to provide rough estimates of the time taken for infilling of the trenched area (e.g. Soulsby, 1997). If the prevailing current is perpendicular to the crests of the sandwaves, and the cable lies in the same direction, the techniques for calculating the infill of dredged navigation channels (e.g. Fredsøe, 1978) can be used with some modifications.

The infill, or sandwave recovery, rate is mainly dependent on the local sediment transport rate, the size of the bedforms, and the sideslopes of the trench.

5-Survey techniques

The survey techniques presently available to provide the information necessary to perform the analyses mentioned above are:

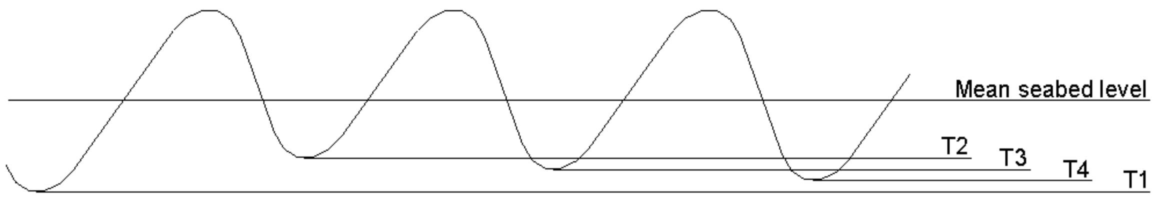
1. echo- or swathe-sounding with sub-metre positional accuracy and the necessary attitude and vessel motion compensation,

2. cone penetration testing (CPT) of seabed sediments,

3. grab sampling of seabed sediments, and

4. current measurements in the water column (e.g. by vessel mounted Acoustic Doppler Current Profiler), these do not need to be taken in the vicinity of the sandwave crest to make estimates of sandwave mobility.

The use of accurate sounding techniques to map the seabed along the cable route is the first, and most important, step as this indicates where sandwaves exist. The second step is to quantify their size parameters from the survey record, height H1, wavelength L1 (figure 2) and trough levels T1 etc. (figure 3).



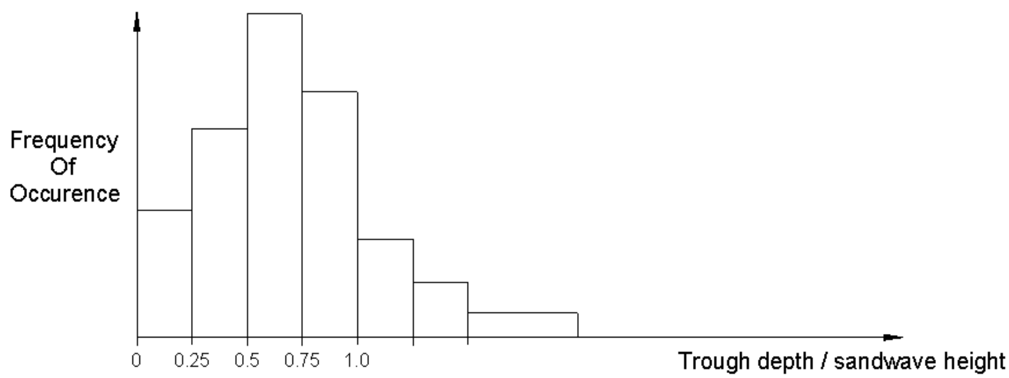


Figure 3 Probabilistic analysis of trough depths

CPT measurements can be used to get semi-quantitative data for the sub-seabed soil consistency and that, in turn, may indicate whether there is an immobile layer underneath mobile smaller features. CPT results can be used to derive soil design conditions for the top 0.1 to 1 m of the seabed although corrections may need to be applied to produce accurate results (Lunne et al., 1997). This can be complemented with grab sampling of the seabed surface sediments.

The grab sampling can shed light on two aspects:

- it provides input data for the seabed sediment characteristics with which to assess and calculate the potential mobility of the sandwaves, and
- the presence or absence of coarser grain 'bands' (armouring or gravel substrate) between the sandwaves that occur in sediment sparse areas.

Measurements of the currents in conjunction with grab samples gives an indication of sediment mobility. Assuming that the rate of recovery is related to sediment transport rate then this aspect is also covered by the above mentioned surveys. Depth mean flow may be better than near bed (say 1m above the seabed) measurements, as the near bed current velocity varies with position between sandwave troughs and crests.

Box coring is judged to be unfeasible for cable laying operations. Without very precise positioning (in relation to crests and troughs) the results that can be obtained relating to the internal structure of the sandwaves may not be particularly meaningful. The use of other forms of coring (e.g. vibrocoring) is considered arduous and time consuming for the relatively small amount of additional information generated if CPT and grab sampling data have been obtained. The positioning of the measurements with respect to crest and trough is of paramount importance. However, at the time of writing we are not aware of research relating CPT measurements to sandwave fabric.

6-Recommendations and future work

A review of available information on sandwaves has been performed as it relates to the operational aspects of laying submarine cables. The recommendations of this paper are as follows.

- apply probabilistic techniques to derive appropriate burial depths and to quantify the probability of cable re-exposure,
- trench infill or bedform recovery rate is largely be dependent on seabed mobility (sediment transport rate) and can be estimated using existing techniques,
- a number of survey techniques can be combined to obtain the information necessary for making a proper assessment of sandwave mobility and determining an appropriate depth of burial.

The paper has identified areas in which further work may be relevant:

Since sandwave mobility and trench recovery rate is intimately linked with sediment mobility, it may be useful to generate a map of sediment mobility covering the regions of interest, such as the North Sea. A seabed mobility map could be produced on the basis of available information on wave climate, current speeds and seabed sediment composition. In some areas there is a lot of information available, in other areas the information is sparser. However it will almost always be possible to make estimates of the important parameters - it is a question of the confidence interval assigned to the mobility estimates for a given location.

In addition, it is hoped that the range of papers presented in the conference will provide additional background information on sandwave dynamics and the application of appropriate survey techniques to assist cable laying operations. For example, it would be interesting to hear about recent investigations of the relationship between CPT readings and the internal structure of a sandwave, or of the recovery of sandwaves after trenching.

Finally, it will be instructive to apply the analysis techniques discussed in this paper to a 'real' data set. This exercise would further establish the applicability of the various techniques discussed and help develop a ‘toolkit’ to aid the planning of cable laying operations in regions of sandwaves.

7-Acknowldgements

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8-References

Dyer, K R and Huntley, D A, 1999, The origin, classification and modelling of sand banks', *Continental Shelf Research*, **Vol. 19, No. 10**, Elsevier.

Fredsøe, J, 1978, 'Sedimentation of river navigation channels', *J. Hydr. Div. ASCE*, **vol. HY2**, New York, 223-236.

Fredsøe, J and Deigaard, R, 1992, 'Mechanics of Coastal Sediment Transport', *World Scientific*, Singapore, 369 pages.

Langhorne, D N, 1977, 'Consideration of meteorological conditions when determining the navigational water depth over a sand wave field', *International Hydrographic Review*, **LIV (1)**, 17-30.

Langhorne, D N, 1978, 'Offshore Engineering and Navigational Problems - The Relevance of Sandwave Research.' *Published by the Society for Underwater Technology in Conjunction with the Institute of Oceanographic Sciences*. 21 pages.

Lunne, R, Robertson, P K, and Powell, J J M, 1997, 'Cone penetration testing in geotechnical practice.', E & FN Spon. 312 pages.

Soulsby, R L, 1997, 'Dynamics of Marine Sands.', *Thomas Telford Publications*, London, 249 pages.

Stride, A H (ed.), 1982, 'Offshore Tidal Sands: Processes and Deposits.', *Chapman and Hall*, 222 pages.

Whitehouse, R J S, 1998, 'Scour at Marine Structures.', *Thomas Telford Publications*, London, 216 pages.

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