CEMENTED HARDGROUNDS ON THE NORWEGIAN CONTINENTAL SHELF AND THEIR IMPACT ON SUBMARINE CABLE INSTALLATION

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ABSTRACT

The Enicom North fibre optic cable was installed in 2001 to provide broadband communication facilities to platforms at the Troll, Veslefrikk, Oseberg, Huldra, Kvitbjørn, Gullfaks and Snorre Fields in the Norwegian Sector of the North Sea. There had previously been many investigations for subsea developments in this region including for the platforms themselves and a number of export pipelines.

A detailed desk study of the proposed fibre optic cable route was undertaken using the available geodata from these previous investigations. This indicated that there might be some local hardground but it was unlikely to present a hazard on a significant scale; the phenomenon had been identified only at a few locations on the Norwegian Continental Shelf. A route-specific geophysical survey was also undertaken but acoustic sub-bottom profiling was not expected to be capable of detecting very shallow hardground. A limited amount of geotechnical testing was carried out.

During the installation works the trenching tool experienced widespread resistance to excavation in areas of otherwise relatively soft silts and sands. This had a significant impact on the speed of burial operations and the depth of burial achieved. Following a detailed review of the installation records, in particular ROV video tapes of the trench, extensive cemented sediments/hardgrounds were identified.

This paper discusses the nature of the hardgrounds and their impact on the installation works. Suggestions are made for avoiding similar problems on future cable projects.

INTRODUCTION

Gas-cemented hardground (GCH) has previously been described from the Norwegian Continental Shelf by a number of authors (e.g. Hovland et al. 1985, Hovland et al. 1987, Lien 1988) but it was thought to be of only local lateral extent. The phenomenon is encountered at very shallow depths below seabed and is hence a potential hazard to seabed engineering work.

During the installation of the Enicom North fibre optic cable in the Norwegian Sector of the North Sea in 2001, GCH was extensively encountered. Considerable problems were experienced during the trenching works with the hardground having significant impact on both the speed of burial operations and the depth of burial achieved.

Post-lay ROV video records of many kilometres of trench were examined. The generally excellent quality images provide a comprehensive and detailed visual database that reveals a variety of hardground development stages and forms the basis for this paper. The presence and degree of GCH can be correlated with the trenching performance and an assessment made of its impact on the installation works.

CABLE ROUTE

The Enicom North cable was installed to provide fibre optic communications between a number of oil and gas developments in the Norwegian Sector of the North Sea. The cable route runs E-W from Troll A in the middle of the Norwegian Channel to the Veslefrikk platform on the upper Western Slope, with a spur S to Oseberg, which lies on the Central Plateau. The main route then heads NW from Veslefrikk following the upper/middle zone of the Western Slope to Huldra, Kvitbjørn and Gullfaks C, finally turning N to descend once more to the floor of the Channel to reach Snorre TLP. Water depths lie within the range 100 to 330 m. The route is shown in Figure1.

A desk study and route-specific survey were undertaken as part of the cable route engineering by the turnkey installation contractor. They indicated a largely unproblematic route. Numerous pockmarks were present in the fine-grained deeper water soils and rare encounters with hard or cemented soils reported from the upper Western Slope of the Norwegian Trench and on the Plateau east of Oseberg. Although there was some concern that the cemented soils were very difficult to detect, experience from earlier pipeline construction suggested that the main areas would probably be located away from the proposed route.

A post-lay ROV survey was subsequently undertaken along the entire route, with the central camera pointing ahead and down into the trench itself and the two flanking cameras looking diagonally from each side across the trench and the far shoulder. The centre tape and either the port or starboard one were usually viewed together when examining the trench for geological detail.

GAS-CEMENTED HARDGROUNDS

Regional Setting

Previous studies of cemented hardgrounds have found them associated with gas seepages in pockmarks (e.g. Hovland and Sommerville 1985). Pockmarks are local depressions which form in soft, very fine grained sediments (silty-clayey) when gas or liquid is released. It has been suggested by Hovland et al. (1987) that the hardgrounds are formed by either methane oxidation in aerobic conditions or sulphate reduction in anaerobic conditions, producing a carbonate cement. The diagenetic conditions may fluctuate between the two, resulting in a complex cement stratigraphy.

Varying degrees of sediment cementation were identified along the Enicom North cable route. However, the main occurrences of well-developed GCH were found chiefly in the shallower water depths (< 175 m) on the upper Western Slope in the Veslefrikk area and halfway to Oseberg across the adjacent Plateau, Figure2. The latter was predicted by Norsk Hydro as a potential area for hardground formation (Per Kjærnes, pers. comm.) but not to the extent or in the concentrations encountered. Cementation observed in water depths down to at least 150 m was seen to be mostly associated with silty to fine sandy beds, in areas of essentially featureless seabed with a sandy or loose silty surficial layer. The seabed thus gave no indication of the problem soils hidden just below the surface.

Pockmarks would not be expected in such relatively coarse and apparently clay-free types of sediment which are sufficiently porous for upward-migrating gas to be able to seep out unimpeded into the water column. Very small, isolated vents can form in sands (seen previously by AR in the Gullfaks area), but these were not observed either. On the Plateau and uppermost Western Slope the surficial sediment is clearly mobile to the extent that small sand ripples are often seen, and this would quickly backfill any small vents. This agrees with observations by Hovland and Judd (1988) at Tommeliten where active gas seeps and enhanced benthic biological activity were discovered, but no pockmarks or exposed carbonates were present. Subsequent work at the site by Hovland (2002) has proved the presence of methane-derived authigenic carbonates covered by a thin veneer of sediment.

The 150-175 m isobath interval near Veslefrikk is transitional from the shallower featureless seabed type to the steeper middle to lower parts of the Western Slope which are characterised by large contour-parallel elongated depressions with pockmarks (Hovland 1983). This development coincides with an increase in the clay content of the sediment with water depth. These depressions give way to great numbers of round and oval shaped pockmarks on the fine silty-clayey floor of the Norwegian Channel. As the cable route is followed downslope from Veslefrikk towards Troll, GCH is increasingly located in pockmarks. Below about 275 m, clouds of fine silt stirred up by the ROV almost totally obscure the view of the trench but patches with hard trenching conditions were generally found to coincide with pockmark depressions defined by the bathymetric survey records.

Since the entire area traversed by the cable route has experienced little net sediment accumulation during the last few thousand years, the ages of pockmarks and hardgrounds are not known. This makes it difficult to assess the extent to which the phenomenon of GCH may still be active or whether the lithified beds are relict features. The process responsible is in any case likely to be very slow so the timing is more of academic than practical interest.

Hardground Observations along the Route

Weak lithification, typically 0.2 to 0.5 m below seabed, was widespread along parts of the route. This has been interpreted as incipient hardground formation and was only discovered from close inspection of the video tapes; it had not had a significant impact on the trenching although it may have slowed progress a little. The interesting aspect was that, unlike the more advanced stages of GCH, it appeared to be almost continuous for hundreds of metres in places. This implies that the presumed gas seepage itself was widespread, but of low intensity or duration. Two models are possible: either the gas spread laterally as it ascended from a deeper lying chimney or it was generated from a relatively shallow but extensive organic-rich deposit such as might exist within a buried channel infill sequence.

Cable trench video reveals a characteristic steepening of the wall profile through the affected sediment depth interval, which in places seemed to extend upwards to the base of the surficial sand layer. Some of the video records give an impression of a dense pattern of fine vertical markings which might be gas seepage passages lined with a chemical precipitate, but as detail was not clearly discernible this remains speculative. However, the existence of discrete seepage ways is supported by the presence locally of small crumbly blocks of jetted material lying in the trench floor or on the shoulders. These indicate that with just slightly more cementation, a weak blocky structure develops, possibly representing gas seepage routes kept open as lithification proceeded.

Further cementation leads to the formation of a thin but distinct crust within the affected interval, not necessarily at the top. The crust protrudes slightly in the trench walls and breaks up into small tabular or irregular pieces during jetting. One fragment was recovered from the Plateau area during remedial trenching. This stage of GCH seems to be less widespread than the described incipient lithification but more common than the more competent hardground. If found within an area of the former it would indicate a locally greater flux of seeping gas, while if near the latter it should mark the peripheral zone of a gas chimney.

With increased cementation the most common development seen was the formation of a coarsely porous hardground. The "pores" appeared to be up to 2-3 cm wide with a visually random distribution and orientation, though detailed study might find a more ordered pattern. Such hardground was typically 10-30 cm thick, with a fairly even upper surface and a highly irregular lower surface. This suggests the location of the top of the GCH is primarily determined by a lithological boundary in the shallow sediment sequence, which controls the rate or pathways of gas seepage, the porewater chemistry and the microbial environment.

In some places the GCH appears quite massive, not unlike a slab of beachrock or concrete and again with an even upper surface. The lower surface is less irregular than in the porous variety although it still displays a definite roughness. This implies that cementation of both varieties has "grown" by accretion from an upper limiting boundary within the sediment, in the case of the porous type in a downward direction.

The thickest examples of GCH were composite at some localities, with an upper massive part and a lower porous part. The transition from the one type to the other appeared to be relatively sharp and even, similar to the upper surface of the porous hardground. Comparison with the carbonates described from further south in the Norwegian Sector (Hovland et al. 1987, Hovland and Judd 1988) indicates that this transition is likely to mark the boundary between oxygenated sediments (above) where methane will be oxidised (Hovland and Judd 1988), and anoxic sediments (below) where methane is broken down by sulphate-reducing bacteria (Aloisi et al. 2002). In either case, a by-product is the precipitation of carbonate, which acts as a cement binding the seabed sediment to form the hardground. If the comparison is correct, it implies that massive hardground developed in the oxic zone and the porous hardground in the anoxic zone. Such aspects, including the question of the long-term stability of the boundary between these zones, will be discussed in a more detailed geological review to be published elsewhere.

JET TRENCHING OPERATIONS

Jet trenching tools operate by directing a series of water jets obliquely at the trench face. The jets are mounted in a pair of “swords” either side of the cable to be trenched. The water jets fluidise the soil and the cable either falls through to the base of the trench or is pushed down by a cable depressor.

As previously described above, the GCH encountered along the route was almost entirely associated with silty to fine sandy soils. Jetting can be very effective in fine sands and silts, as they are easily fluidised and remain in suspension for a sufficiently long time for the cable to sink to the bottom of the trench. However, it is widely accepted that where sands and silts are cemented, this will provide significant difficulties to jet tools. The mechanism for jetting cemented soils is very different to that described above. Uncemented sands are most efficiently fluidised by a large volume of water flowing over the trench cross sectional area. The large water volume is required to maintain a sufficiently high upward velocity to lift the sand particles into suspension. In cemented soils, the jet pressure must exceed a threshold value at which the soil can be “cut”. This pressure is related to the mass strength of the soil, taking into account potential zones of weakness or discontinuities.

Once the cemented soil is broken up by the jet pressure, it is either lifted by the surrounding turbulent soil – water suspension or in the case of larger fragments, falls rapidly to the base of the trench. If the coarse cemented fragments do not remain buoyant long enough for the cable to reach the bottom of the trench, reduced burial will occur.

An alternative mechanism for trenching cemented soils and observed along the Enicom North route is the undermining of the hardground by washout of the underlying sediment and then fracturing of the hardground by either the applied water jet pressure or possibly by direct loading with the jet tool swords.

During the jetting operation, thin patches of weakly cemented or porous hardground were broken up into small pieces and were generally ejected onto the trench shoulders; they looked rather like pieces of coral. Thicker patches, however, proved much more difficult to trench due to their mechanical strength. As described above, these were undermined and then fractured and broken into large tabular blocks. Where these were left resting on the lower trench walls the cable was usually partially or completely buried in the gap between them. However, in some places the hardground rubble also covered the trench floor. The cable then lay somewhere below, in the middle of or on top of the debris.

Massive GCH was a serious obstacle to the lay operation at a number of locations, the trencher unable to break through the GCH and the cable left exposed on the seabed. The strength of these highly cemented blocks is not known as thick samples of massive GCH have never been recovered for laboratory testing.

By correlating the presence of GCH with the trenching performance, a semi quantitative assessment can be made of the impact of GCH on the installation works. Weakly cemented sediments were found to be continuous for hundreds of metres. However, they had no significant impact on the trenching works in terms of speed and depth of burial achieved. As described above, the more competent porous hardground was encountered as discrete blocks. This resulted in variable trenching speeds and in places reduced burial. Trenching speeds were significantly reduced from typically 600 to 800m/hr in uncemented sediments to less than 200m/hr. By undermining the GCH, it was possible to fracture the larger blocks to allow some burial of the cable, however, this was at the expense of trench shape. At some locations, the trencher was also observed to pitch forward and the depth of swords reduced as it passed over the GCH.

Where GCH had reduced the depth of burial achieved, it was necessary to undertake additional remedial trenching works. Where satisfactory burial was still not achieved, for example where massive GCH was encountered, it was also necessary to provide additional protection through rock dump.

CONCLUSIONS AND RECOMMENDATIONS

Based on the experiences of the Enicom North project, gas cemented hardground (GCH) would appear to be much more widespread in the Norwegian Sector of the North Sea than previously thought. Unlike previous discoveries, much of the GCH was not associated with pockmarks and was found in a number of locations as a weakly cemented blanket layer. A number of different stages of GCH development were identified, each type having a differing impact on the trenching operations, Figure3.

GCH would potentially be far less of a problem if it could be detected during pre-lay route surveys and thus avoided, but efforts to date have apparently failed. The upper surface of the cemented interval is typically only 0.2-0.4 m below seabed and although the acoustic impedance contrast to the overlying surficial sediment cover will be high, it is "lost" in the strong seabed reflector generated by the often equally or greater contrast between the water and the seabed sediment. The new generation of powerful Chirp profilers, with their very narrow seabed return pulse, may overcome this problem.

The only tell-tale clue is where local erosion has exposed small patches of highly reflective material which can be seen on side scan sonar records and appear anomalous, i.e. occur in places where other geological data indicates only relatively soft sediments without outcrops or scattered boulders, and where debris is not anticipated. Only a very few sonar contacts which might possibly have been hardground exposures were noted along the route and none would have been picked as hardground during sonogram interpretation as ice-rafted boulders are also present.

Consideration should also be given to the use of alternative profiling techniques such as resistivity survey, which would provide a continuous profile of the seabed. The resistivity is normalised with the water resistivity to provide the Formation Factor. The Formation Factor is related to the porosity of the formation “Archie’s Law” (Archie 1941) and hence is a measure of its density or water content. The Formation Factor for cemented soils will therefore be significantly different to that of uncemented soil.

Where GCH is thought to be present for example after carrying out a resistivity survey, it is recommended that a detailed geotechnical sampling and testing programme is also undertaken. Incidents where cores or CPTs are stopped or repeated due to hard layers or gravel should be carefully checked. Samples should be carefully logged for evidence of cementation and strength tests undertaken when possible. Using a combination of resistivity survey and geotechnical ground truthing, it is likely that different cemented zones could be identified effectively.

Where GCH is identified in future projects and cannot be avoided, careful consideration will need to be given to the trenching techniques selected. Tracked based jet tools may provide sufficient reaction to break through weakly cemented soils, however, ploughing may be more appropriate for more competent strata. Where jet tools or ploughs are considered unlikely to be able to trench through strongly cemented soils, the use of mechanical trenchers will need to be considered.

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