APPENDIX VII:

Archaeological Monitoring of the Dredging for the Immersed Tunnel, Oslo, Norway. Rescuing Archaeological Heritage.

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Backdrop and Location

The city of Oslo, the capital of Norway, is situated in the innermost part of the Oslofjord, on both sides of the small river Akerselva. On the eastern shores of the harbour, a small town emerged at the end of the Viking era. After a large fire wiped out the whole town in AD1624, the town was rebuilt on the other side of the harbour. Today, the modern city of Oslo incorporates areas far beyond the earlier city limits, and both the 'old' and 'new' town are located within the city centre. Even if the settlements on land have moved through time, the main harbour basin itself has been the same for more than 1000 years.

At the turn of the last millennia, a new immersed tunnel through the central harbour was planned. The tunnel would connect to already existing tunnels on each land side, and had to cross through open water, jetties and quays (Figure 1). The water depth in the tunnel line varied from two to 16 metres and the trench for the tunnel had to be excavated down to around 22 metres the whole way. In all, the excavation of the tunnel trench included the dredging of 1,000,000 m^3 of harbour sediments from an area also expected to be rich in archaeological remains (Figure 2).

Figure 1: The planned immersed tunnel in Bjørvika, Oslo (Norway)
Source: Norwegian Road Administration

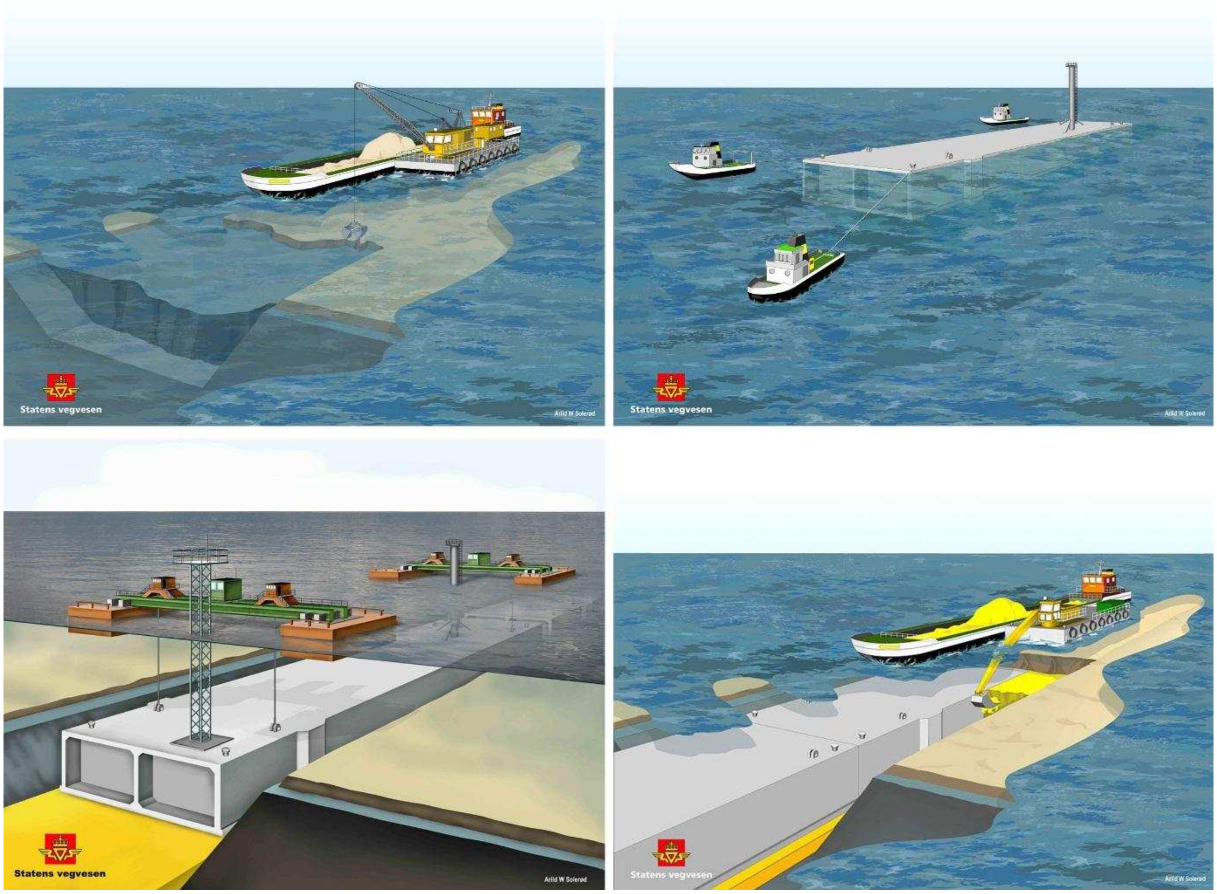

Figure 2: Method. Constructing the immersed tunnel
Source: Norwegian Road Administration

The excavation of the tunnel trench started autumn 2005, and lasted until winter 2008, with continuous work, summer as winter. In the most work-intensive periods, two dredgers and four excavators were working parallel in three different parts of the trench.

The spoil consisted of a mixture of highly polluted harbour sediments, sawdust from several hundred years of the saw mill industry in Oslo, natural sediments from the rivers and ocean, modern garbage and waste, jetty and quay constructions on top of land fillings, an old shipyard and a machine factory – and archaeological remains [Falck and Gundersen, 2012]. In addition, the tunnel is located at the outlet of the river Akerselva where a combination of natural and man-made sedimentation has been a challenge for the users of the harbour for centuries. Attempts to control the sedimentation by forcing the stream of the river to reach deeper waters and restricting the dumping of ballast to specific areas, was supplemented by man-powered dredging until the first steam-powered dredgers came into use in the 1860’s. In all, the combination of continuous sedimentation and everlasting efforts to keep the harbour deep enough for its users, has altered the original sea floor tremendously over the centuries.

To understand why the Norwegian Maritime Museum came to monitor the process, a short introduction to the legal framework for the protection of cultural heritage in Norway is important. The Norwegian Cultural Heritage Act (1978, § 14) protects underwater archaeological remains older than 100 years (shipwrecks and its cargo). It also states that the developer has a duty to consider whether the project will affect protected archaeological sites or monuments (§§ 9, c.f. 14), before the construction work begins. If it is found that a project will affect archaeological remains, the Directorate for Cultural Heritage ('Riksantikvaren') decides if and on what conditions the project can be carried out. Such conditions might typically be archaeological excavations and/or documentation of the protected remains before the construction work can begin. Furthermore, the act (§ 10) also states that the developer has to pay for any means necessary to fulfil these conditions, including excavations. In the immersed tunnel project this was the Norwegian Public Roads Administration (NPRA).

In Oslo the methods for detecting archaeological remains embedded in the sea bed, in advance of the construction work, *was not fit* for delimiting areas with potential for archaeological remains. This resulted in a situation where the Directorate for Cultural Heritage determined that the archaeological investigations should be conducted parallel to the construction work.

The experiences from Oslo show that, despite the difficulties involved, the mapping of underwater cultural heritage prior to the construction work *should have been given higher priority* [Laugesen et al., 2011]. This would probably have given better archaeological results and it would potentially have restricted the areas the archaeologists would have had to monitor. Even considering the relatively high costs of doing adequate mapping, it is claimed that such investigation would pay off, considering the process and the project as a whole.

Attempts of Mapping and the Definition of Potential for Archaeological Remains

The standard method of first-hand mapping of the seabed in Norwegian underwater archaeology is using a Scuba-diver, alternatively an ROV, making a visual detection of the sea floor. Using side-scan sonar and high-resolution multi-beam echo sounders has also become regular during recent years. While many underwater sites we know of are discovered by amateur divers, more and more sites are now being detected by professional maritime archaeologists using high technology equipment doing surveying. Taking into account the massive sedimentation rate in the Oslo harbour, it was clear that these methods were unsuitable for finding archaeological remains. All objects of interest would be embedded in the seabed, covered by younger sediments and not visible on the surface of the sea floor.

Attempts were therefore made to try to analyse the contents of the seabed with (acoustic) sub-bottom profiler. However, the high organic contents of the sediments, mainly caused by the sawdust from the saw mill industry in the 17th to 19th century, gave unexpected problems. The decaying sawdust produces hydrogen sulphide gas (H_2S) which is captured in the sediments. The highly gas-rich sediments reflected the acoustic signals in a manner which, in practice, shadowed all other anomalies and made the method useless for locating objects or structures of archaeological interest. What the sub-bottom profiler did show, however, was that the sea bottom still contained large volumes of sawdust and thus that more than 100 years of power-driven dredging still had not removed all the sediments from the periods of archaeological significance.

The question then, was how much of the older sediments, and possible archaeological remains were still present, and how much had already been removed and destroyed by earlier dredging. An effort to answer this was done by analysing core samples.

In 1996 the Norwegian Maritime Museum, in collaboration with the University of Oslo, delivered a feasibility study of the sediments in Bjørvika (west harbour) and Bispevika (east harbour) to identify any presence of intact sediments from the medieval and early modern times [Nævestad, 1996 ; Dale, 1996a, b]. It recorded a total of ten sediment cores and a reference sample from the Sørenga jetty. The core samples were examined visually for the presence of sawdust and sequences of samples were taken for analysis of spruce pollen and dinoflagellate cysts. The composition of pollen and cysts are influenced by climatic change, and assays could detect sediments from the medieval warm period around AD 1000-1300 [Dale, 1996a]. The presence of such a layer in the sediments would strengthen the possibility that the layers also could contain archaeological remains. The results showed that sediments from the medieval period were present in four of the samples from Bjørvika and in three of the samples of Bispevika (Figure 3).

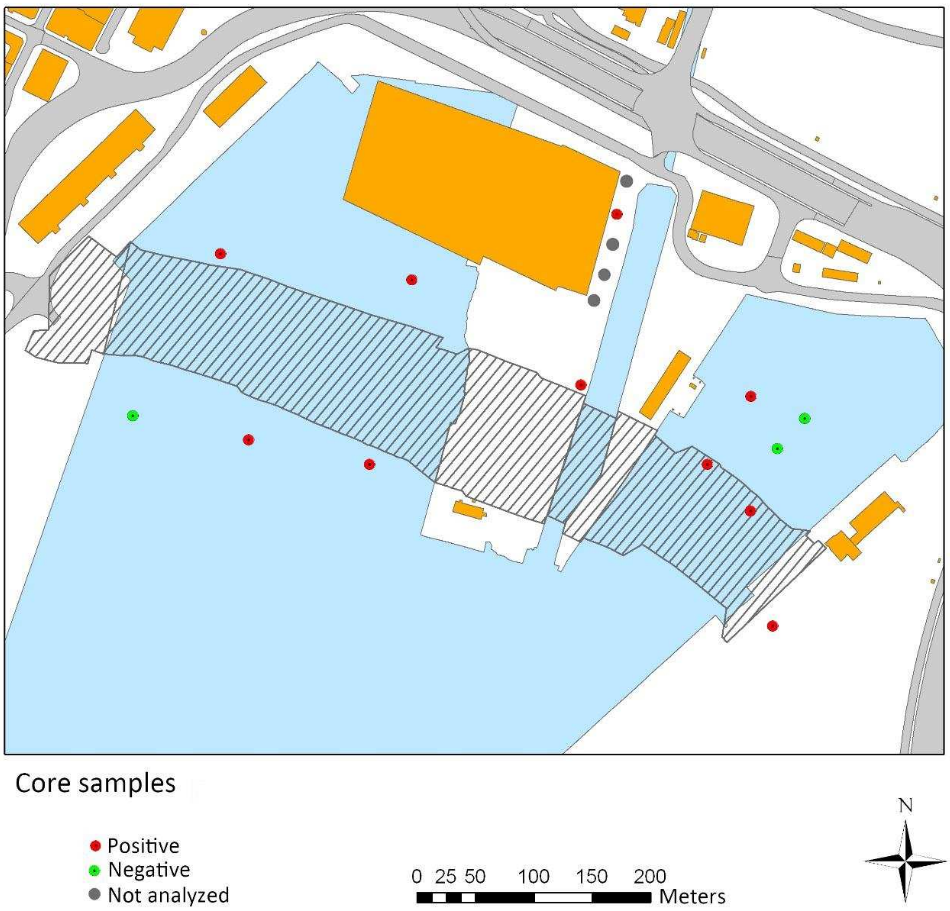

Figure 3: Scoping and planning the archaeological investigation.
Core samples analysed for the precence of dinoflagellate cysts and spruce pollen.
Map: K. Løseth/Norwegian Maritime Museum.

The results indicated that previous dredging in all probability had removed all traces of medieval (and younger) periods in the innermost parts of Bispevika and along the waterfront on the west side of the bay. In the tunnel route, however, it was likely that the sediments from the medieval period and thus possible archaeological remains from the period, were present. The medieval sediment horizon, defined in terms of climatic conditions, was about two metres thick in all positive samples. In Bispevika parts of the horizon was removed and, therefore, the full thickness was difficult to determine. At the deepest, the bottom of this horizon was nearly six metres below the present sea floor, in the area on the west side of the Bjørvika jetty.

In conclusion, the unlevelled vertical distribution of the medieval horizon in the seabed also showed that the layers which could contain protected archaeological remains were to be found both close to present sea floor and several metres down in the seabed[34].

Even with the additional two samples from 2007, a total of 12 samples of an area of altogether 64,000 m^2, is insufficient to say something more convincing and definite on the potential for cultural remains.

Later in the process, actually after the construction work had already started and the decision to monitor the whole process was made, the Norwegian Maritime Museum was invited to join the geophysical mapping of the level of contamination in the sediments (the Norwegian Geotechnical Institute). Regrettably, we were involved so late in the process, that the time schedule and financing of the conduct made true participation with archaeological questions and requests difficult. In retrospect, we believe that a more thorough visual analysis of the core samples from an archaeological point of view could have functioned as a more thorough mapping of the potential for archaeological remains in the harbour. During the period of the dredging we managed to identify large pockets consisting of sand, ballast and artefacts, that most certainly would have shown as defined layer changes in the core samples (Figure 4). These pockets were interpreted as remains that had 'survived' the extensive dredging in modern times. Systematic sampling and detection of the visual archaeological strata, could have worked as a tool for pointing out areas of interest and of special focus.

Figure 4: Dredging from barges in open water.
On the custom made sieve a 19th century anchor has appeared.
Photo: Norwegian Maritime Museum.

[34] In 2007, the Norwegian Maritime Museum conducted a comparable survey along the outlet of the Akerselva river [Falck, 2007 ; Dale and Dale, 2007]. Analysis was done on two of the six core samples and sediments from the medieval period were identified in both samples of between 9 and 13 metres below present sea level.

Due to inadequate mapping in advance, it was concluded that there was a potential for archaeological remains in the whole construction area. This resulted in the archaeological monitoring of the dredging throughout the whole period of the construction work for the planned tunnel.

Monitoring the Dredging: Challenges and Responses

Due to different contents of water, organic matter (sawdust) and pollution, the sediments and spoil from the tunnel trench had to be handled differently after excavation:

- polluted 'modern' harbour sediments and clay was to be disposed in a deep water deposit
- sediments with a high content of organic matter (sawdust) had to be transported to a land deposit by lorries/trucks
- clean marine clay and sediments would be used in the Oslo harbour remediation project [Laugesen et al., 2011]
- fillings from piers and quays were to be transported to a land deposit by lorries/trucks
- modern garbage and timber constructions larger than 1 x 1 m had to be sorted out from the sediments going to the different areas of disposal

The 'destination' of the sediments meant that different methods for excavation and transport were chosen. Furthermore, the monitoring process required *on site visual and if needed, physical contact* between archaeologist and dredged sediments at all times. This was considered a primary requirement if the presence of the archaeologists on site would be of any purpose viewed from an archaeological point of view. Obviously, this presence presented both archaeologists and contractors to challenges they had never before been confronted to. Many of these challenges can also be discussed in relation to the Health and Security management that guides the entirety of the work on such a construction site.

Based on the sediments disposal, different barges and different equipment for dredging and excavation were chosen, which also resulted in different situations for the archaeologists to adjust to:

- polluted 'modern' sediments and clay was dredged with a closed clam shell dredger, into barges *c.* 600 m^3 in size for transportation to a nearby deep water deposit
- sawdust was dredged with a closed clam shell dredger onto a large flatbed barge to 'dewater', before being loaded onto lorries for transportation to a land deposit (Figure 5)

Figure 5: Dredging old sawdust layer.
Photo: Norwegian Maritime Museum.

- clean clay was dredged with an open clam shell dredger into small (*c.* 150 m^3) barges for towing and re-deposition in nearby areas with polluted sediments
- fillings from piers and quays were excavated by large excavators into piles on land, before being transported to other deposits (Figure 6)

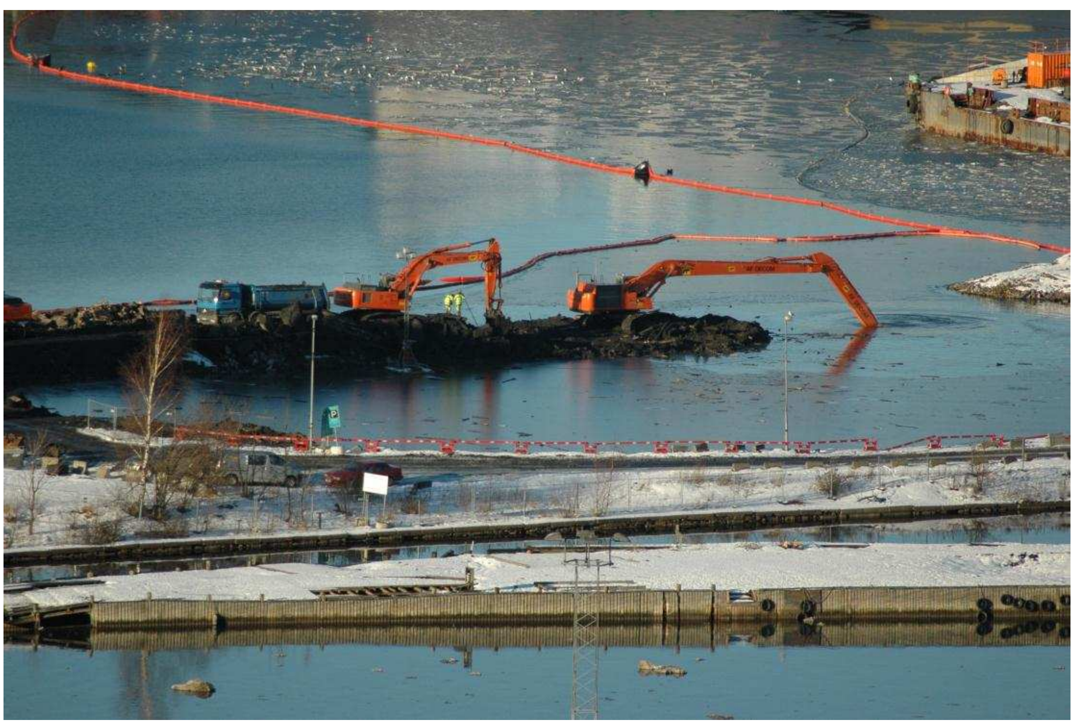

Figure 6: Dredging from the piers.
Photo: Norwegian Maritime Museum.

All dredging of sediments required that the archaeologist were situated directly on the different dredging barges, while the excavation of the piers and quays required that the archaeologist were on-site close to the excavator (Figure 7).

Figure 7: Dredging from barges in open water. Archaeologist on board.
Photo: Norwegian Maritime Museum.

The work took place all year, regardless of temperatures and weather conditions. Especially work during the relatively long and cold Oslo-winters was challenging, considering that the work often required the archaeologist to stay put outdoors on site for hours with little activity to keep them warm. Temperatures below minus 10 degrees centigrade were not unusual during the coldest months. The smell from the polluted sediments though, especially those consisting of H_2S (hydrogen sulphide), was worse during the warm summer days than under cooler conditions.

Considering health and security precautions, the most challenging situations was directly caused by the physical closeness of the archaeologist, both to highly polluted sediments causing potential health risks and the dredging machinery causing risk for physical injury. We experienced that the NPRA took these challenges very seriously. As a small museum, not yet familiar with working on large construction sites, we were introduced to a professional health and security regime. Although the system sometimes failed to meet *all* our requirements, it certainly prevented serious accidents to happen during the whole period of work. The fear of long-term health risks caused by pollution was met by several precautions and procedures. Any skin contact with the sediments was to be avoided, always using gloves and clothing to be fully protected. The archaeologist also carried a gas alarm, signalling when the level of gas (H_2S) reached a certain level and masks were to be put on. All the workers on site were included in a blood surveillance programme, testing for both contamination in the blood and for general changes in health conditions. All in all we were satisfied with the way our presence on site was solved, considering that the need to be close to the actual physical work often was in direct divergence to the recommendations according to the strict health and security regime.

How to Reach a Best Practice – Main Mitigation Measures

Health and security measures were certainly important to make the monitoring process possible and secure. But also the implementations of other mitigation measures were necessary to be able to conduct the investigation with reasonable prospects of fulfilling the task of salvaging cultural heritage.

Most important was the construction of a custom made steel sieve for each of the barges, which prevented archaeological remains from disappearing into the barge basins (Figure 8). Already during the first week of dredging, it became very clear that the earlier mentioned primary requirement; *on site visual and if needed physical contact between archaeologist and dredged sediments*, could not be met without something stopping the sediments from drowning and disappearing directly in the water filled barges. The sieve made it possible to collect larger archaeological finds (ship timbers and anchors) and to a lesser degree smaller artefacts. It was made with parallel bars only, to let the sediments go through relatively easy. The spacing between the bars was 12 cm, and the bars themselves had the same width. This made it fairly easy to walk on the sieve to retrieve various objects if necessary.

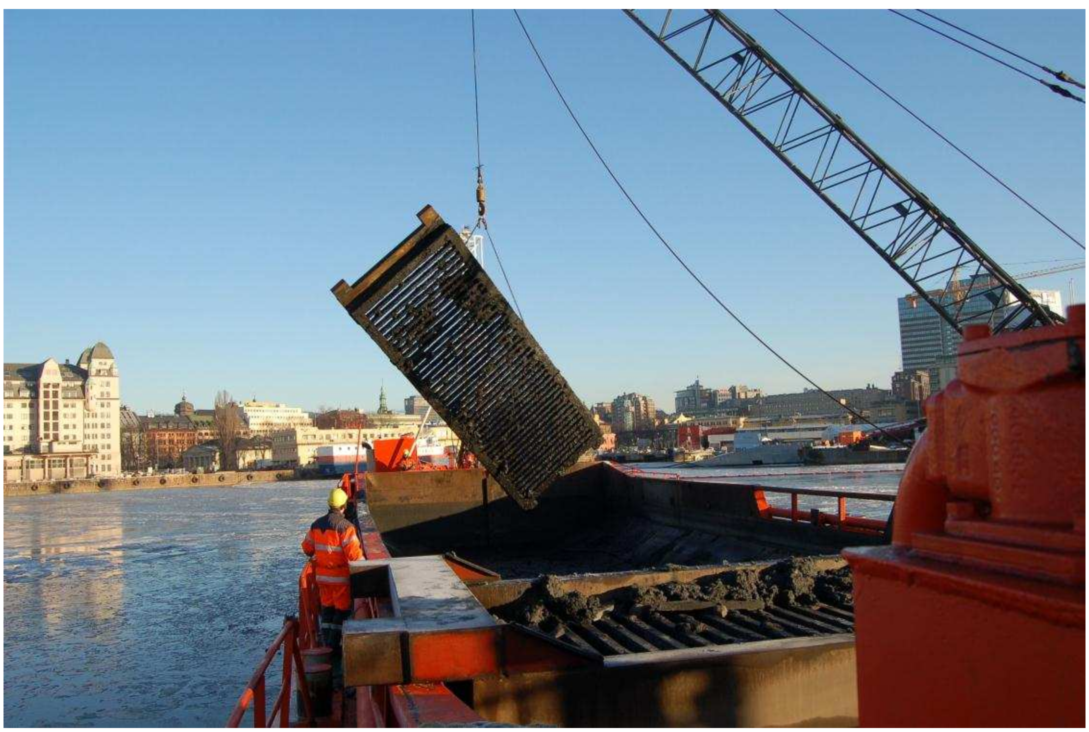

Figure 8: Showing the custom made sieve. The sieve was constructed so that archaeological material would be prevented to disappear into the barges.
Photo: Norwegian Maritime Museum.

Another mitigation measure that deviates from a more ordinary archaeological investigation was the implementation of work shifts. To meet the required progression of the work, the work days on a construction site are long (up to 12 hours), and the archaeologists had to adjust to this and be prepared to work sometimes earlier and other times later than normal. In addition, the project had to accept that the finds that were rescued were partly damaged and therefore also of a poorer scientific source value than they would have had under more ideal conditions.

Yet another very important aspect was the agreement that the dredging could be put on hold, or moved to another part of the tunnel trench, if the archaeologist found it necessary to inspect finds and/or rescue archaeological remains. In practice, this meant that the dredging contractor always had to have a ‘plan B’ for the dredging each day, preferably some hundred metres apart so that any further work would not disturb the working conditions (mainly visibility) for diving archaeologists working at the sea bed. To meet the contractors flexibility, the museum had to have archaeologists being certified to dive at the site every day, even if it could be months between each time it was necessary to dive.

The most important mitigation measures can be summed up as:

- custom made sieve
- overlapping work shifts, always archaeologists present
- ability to put the construction works on hold/move it until findings were checked and rescued (if necessary)

Both the sheer presence of the archaeologist on the construction site, and the actual power to put the work on hold, makes communication between the archaeologists and contractors/project owners of utmost importance. The mutual understanding of each other’s roles and responsibilities in all joints of the work chain can only be reached through good direct, face to face, communication on a personal level. Weekly meetings were held to make sure that consensus of progression plans and delays was maintained. In addition, the day to day communication between the archaeologists and the workers on the barges and excavators was equally important.

Results and Conclusion

We had to accept that the method only would give us a selection of objects and finds from the harbour. Still, all in all, the results are believed to show an approximate average of what the sea bottom in the Oslo harbour consists of. More troubling from an archaeological point of view was the poor control of the depositional and contextual situation of the finds.

Key archaeological results that were delivered: rescuing parts of 13 boat finds, numerous loose parts from boats, anchors and over 7,000 finds of cargo and objects lost from boats, etc. (Figure 9 and Figure 10). The 7,000 artefacts consisted of a range of different pieces of tools, ceramics, clay pipes, shoes and other personal and industrial items. Most of it was fragmented and the dating ranged from late 16th century through the industrial era. The boat finds must also be said to be very fragmented and damaged and we most certainly *lost* parts of boat – maybe even whole boat finds as a result of the monitoring situations. Still, the finds can be claimed to provide knowledge of use for further scientific investigation. We also feel very sure that if there had been a ship of larger size in the tunnel route, we would have detected it. The main conclusion when it comes to achieve best practice is to put more effort into the mapping ahead of the construction work. This would, in the case of the immersed tunnel in Oslo, most certainly have made it possible to make a better priority of the areas of investigation, but also would have provided a better understanding of the depositional and stratigraphic situations that varied from area to area in the tunnel route.

Figure 9: Finding damaged boat parts on the pier.
Photo: Norwegian Maritime Museum.

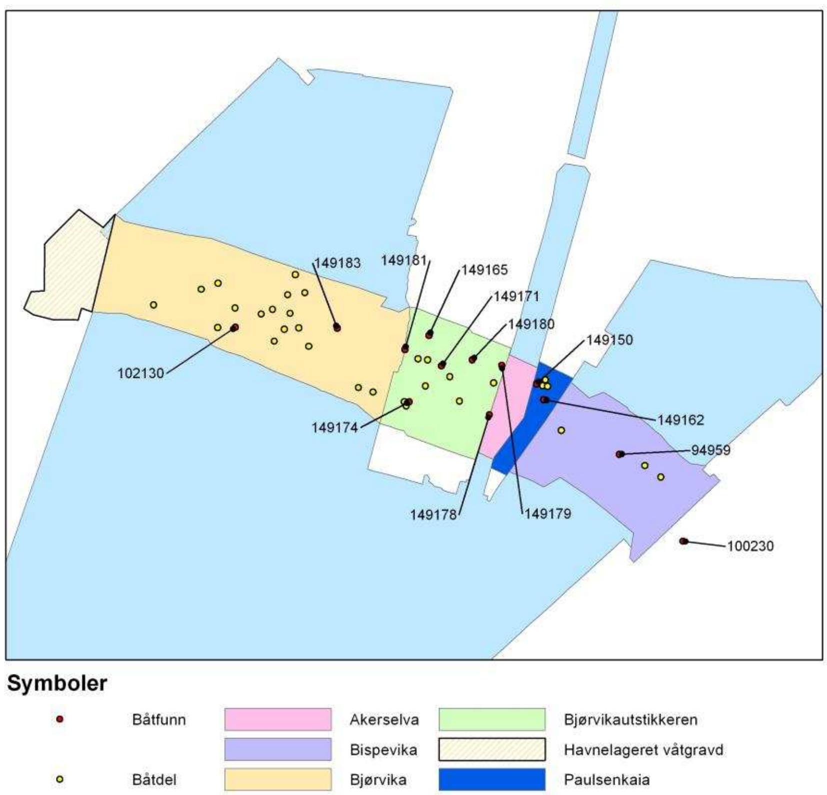

Figure 10: Some results. Boat parts and finds marked on map.
Map: K. Løseth/Norwegian Maritime Museum.

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