

Artificial Frond System for Seabed Scour Control at Wind Farm Platforms in Nantucket Sound, Massachusetts

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Introduction

This paper describes the underwater installation and monitoring of artificial frond mats around the pile supports of a scientific data monitoring tower in Nantucket Sound. The purpose of this investigation is to verify the effectiveness of the mats to reduce and / or prevent scour around offshore monopile structures proposed for the Cape Wind Project, located on the outer continental shelf approximately five miles off the coast of Massachusetts.

The artificial frond mats contain overlapping continuous lines of fronds composed of buoyant, high tensile strength material that provide an unbroken viscous drag layer above the seabed. The viscous drag layer induced by the fronds reduces water velocities exerted by tides, currents, and waves, thereby minimizing the transport of sediments along the bottom and eliminating scour.

In October 2003, engineer-divers installed two Seabed Scour Control Systems (SSCS) Type-12 Frond Mats at the base of southwest mono-pile of the tower. Follow-up inspections to monitor the performance of the system were conducted by engineer-divers in the summer of 2004.

Project Background

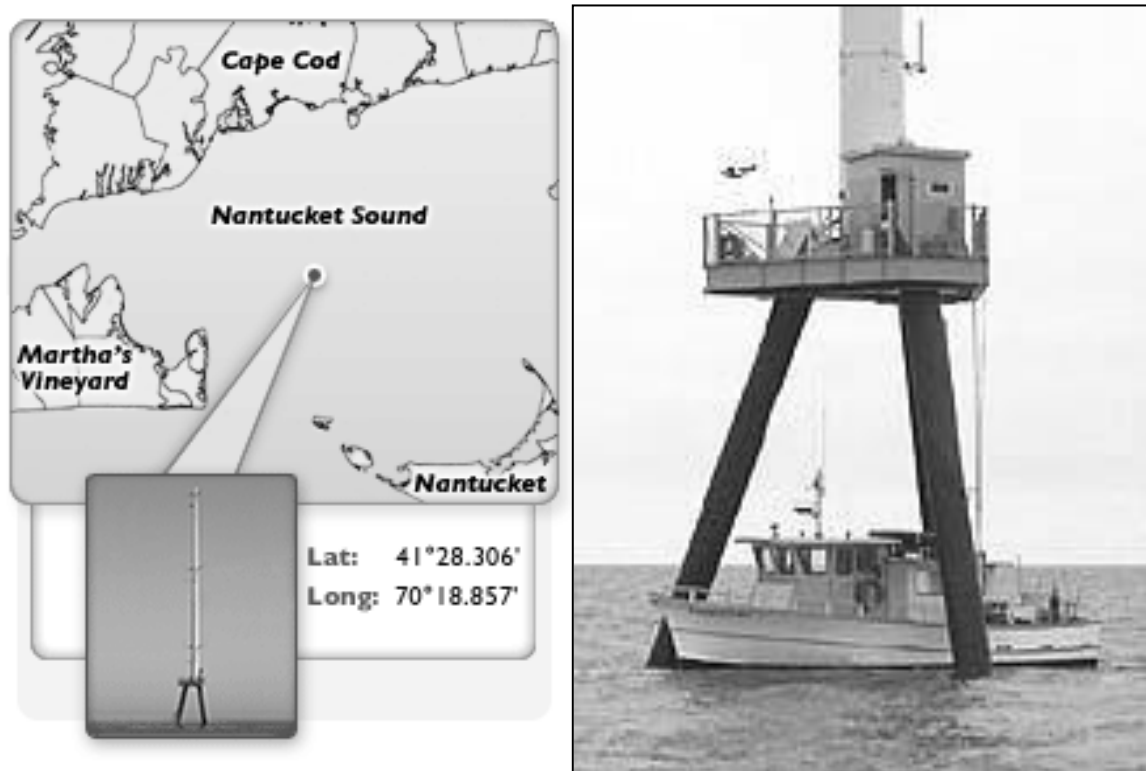
America's first offshore wind farm, the Cape Wind Project, will consist of 130 wind turbines spread across a 24-square mile area of open water on Horseshoe Shoals in Nantucket Sound. Located outside Massachusetts State waters approximately 5 miles off the coast of Cape Cod, the Shoals provide an ideal site for the project; with strong and consistent winds, shallow water depths outside of major shipping channels and aircraft flight lanes, and close proximity to landfall for power transmission and electrical interconnections. The hub of each wind turbine will be 260 feet high, with the blades reaching approximately 420 feet above the water surface. Each turbine will be individually supported by a monopile structure situated in approximate water depths of 15 to 25 feet.

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During the initial planning stages of the Cape Wind Project, a scientific data monitoring station (MT tower) was constructed on Horseshoe Shoals in 2002 to gather site-specific meteorological and oceanographic data used for the performance evaluation and design of the offshore wind turbines (see Figure 1). The station is located in water depths of approximately 13 ft below the Mean Lower Low Water (MLLW) datum, and consists of a 196-foot high tower and platform supported by three, 36-inch O.D. steel mono-piles.



**Figure 1: Scientific Monitoring Station (MT Tower) on Horseshoe Shoals.
(Images courtesy of Cape Wind Associates, LLC.)**

Seabed Scour

Seabed scour is a natural phenomenon that occurs when currents flow around submerged structures placed in loose sedimentary material. As illustrated in Figure 2, the flow of water around or through the structure causes local increases in water velocity together with eddies and vortices. These flow characteristics increase shear stress on the seabed such that sediment is gradually lifted into suspension and washed away from the localized area around the structure.

Scour may be a slow gradual process or very rapid depending on the characteristics of the site (i.e. site depths; hydrodynamic shape and orientation of the structure; velocity and direction of currents, tides and waves; sediment particle size and specific gravity). In shallow waters, wave induced effects can add significantly to the lifting of sediment into suspension. Due to the similarity in water depths, the MT Tower on Horseshoe Shoals, serves as a

physical model for likely seabed scour that may occur around the larger mono-pile structures for the wind farm turbines.

Seabed scour is of particular concern to the Cape Wind Project, because the turbine operating frequencies are close to the natural frequencies of the turbine support structure. Any significant increase of the exposed pile lengths due to scour around the monopile platforms could therefore create the potential for structural failure due to resonance.

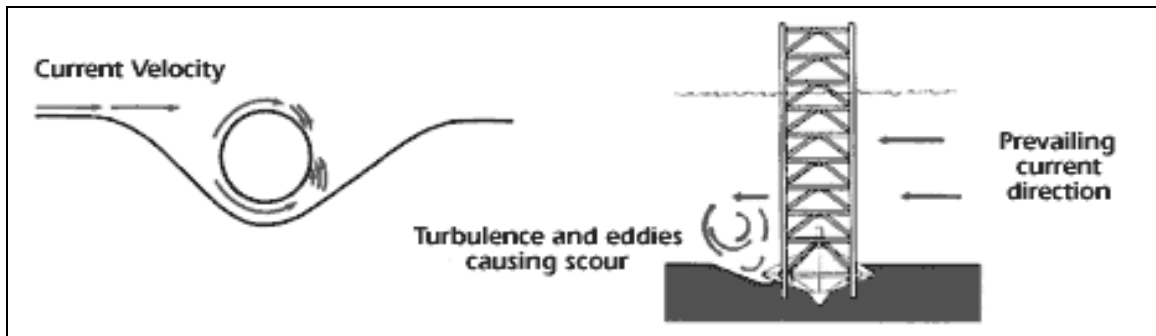


Figure 2: Scour induced at pipelines and structures (courtesy of SSCS, Ltd.).

Scour Mitigation Techniques

Traditional scour countermeasures in U.S. engineering practice has generally taken the form of armoring the seabed around a structure by dumped gravel or rock, sandbagging, gabions, or articulated concrete mattresses placed to fill existing scour pits or prevent future scour from forming. Most of these approaches are costly and time consuming. Traditional methods only act to increase the profile of the structure; in many cases causing severe edge scour and faster settling and displacement of the cover material. These methods therefore also require additional “operational” costs for periodic inspection and maintenance.

An alternative approach is to reduce the current velocity, and thus the mass transportation rate, in the vicinity of the structure. Since the 1960's, researchers have recognized that seaweed plays an important role in retaining sand along coastlines due to the natural drag forces of the marine vegetation, which reduces shear stresses exerted by tides, currents and waves on the seabed. During the 1970's, various forms of artificial seaweed, or “viscous drag” systems were tested by Dupont in the United States; Royal Dutch Shell (with Nicolon and Rijkswaterstaat) in the Netherlands; and later by ICI's subsidiary company, Linear Composites Limited (LCL) in both Norway and the United Kingdom (SSCS, 2004). As research and development progressed, artificial seaweed systems achieved a degree of success and proved the viscous drag creation capability of the fronds. A study performed in Trondheim, Norway demonstrated that the fronds reduced flows at a height of 0.1m above the seabed by as much as 74 percent in constant flow trials, and by nearly 92 percent in variable flow trials (SSCS, 2004). The main engineering problem encountered, however, was how to provide adequate anchorage of the systems to the seabed.

Viscous Drag Systems

Viscous drag systems use artificial fronds to reduce the current velocities close to the seabed. This immediately prevents scour from occurring, and the reduction in current velocity causes suspended sediments to drop into the froned area, as shown in Figure 3. This sedimentation acts to back-fill scour pits and forms a permanent fiber-reinforced sandbank over and around the froned area. The rate of build up of sediment depends upon the size of particulates, the speed of tidal flow, predominant wave heights, and the shape of the structure being protected. SSCS reports that in past installations, the time for final build up to be achieved has varied from up to 28 days after a violent storm; to more than 210 days for a much more benign site in Norway (Partridge, 2004).

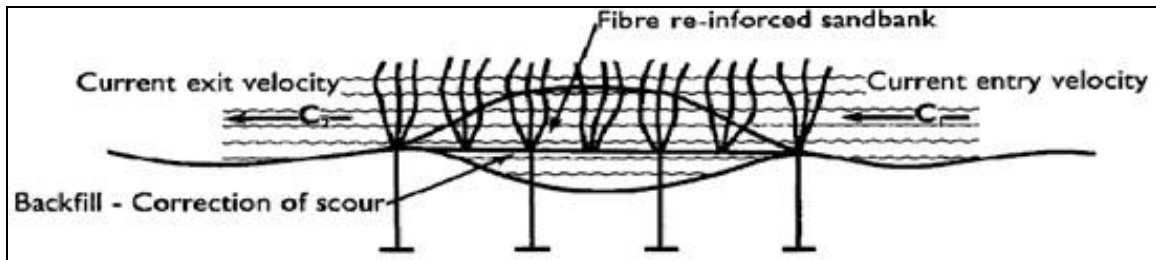


Figure 3: Scour Prevention using Viscous Drag Systems (courtesy of SSCS, Ltd.).

The build-up of sediment within the froned area is non-linear. The greatest viscous drag effects occur during initial deployment, when the full length of the fronds is exposed. This causes an initial infill (typically 200mm to 300mm high) to occur quickly in normal conditions, given the typical sediment sizes likely to characterize scour susceptible sites. As the sediment bank forms, the exposed frond length is reduced; the mat therefore creates less viscous drag and the rate of bank formation slows until a steady state is reached. The sediment bank created is considerably denser, and therefore more stable, than the natural surrounding seabed; as it will have been consolidated by the vibratory movement of fronds during the sedimentary period. As depicted in Figure 4, the fully developed sediment bank is permanently reinforced by the frond material.

Test Installation

To evaluate the effectiveness of an artificial frond mat system to prevent scour at the Cape Wind Project site, Ocean and Coastal Consultants, Inc. (OCC) has installed mats at MT Tower. The selected system, SSCS Type-12, is composed of buoyant, high tensile strength, UV stabilized Polypropylene fronds. The buoyant fronds, each 4.10 feet in length, are attached to the base webbing members in successive continuous rows providing substantial and unbroken overlap of fronds to those in the neighboring rows. Each SSCS Type-12 mat is 16.4 feet (5.0 m) by 8.2 feet (2.5 m).

A key issue for viscous drag systems is the need to maintain the mats in a stable position. Previous uses of artificial frond mats have failed due to failure of the anchoring system and not the viscous drag concept. The SSCS Type-12 mats utilize “Safe Anchors” to maintain stability on the seabed. “Safe Anchors” are zinc-plated steel anchors which are

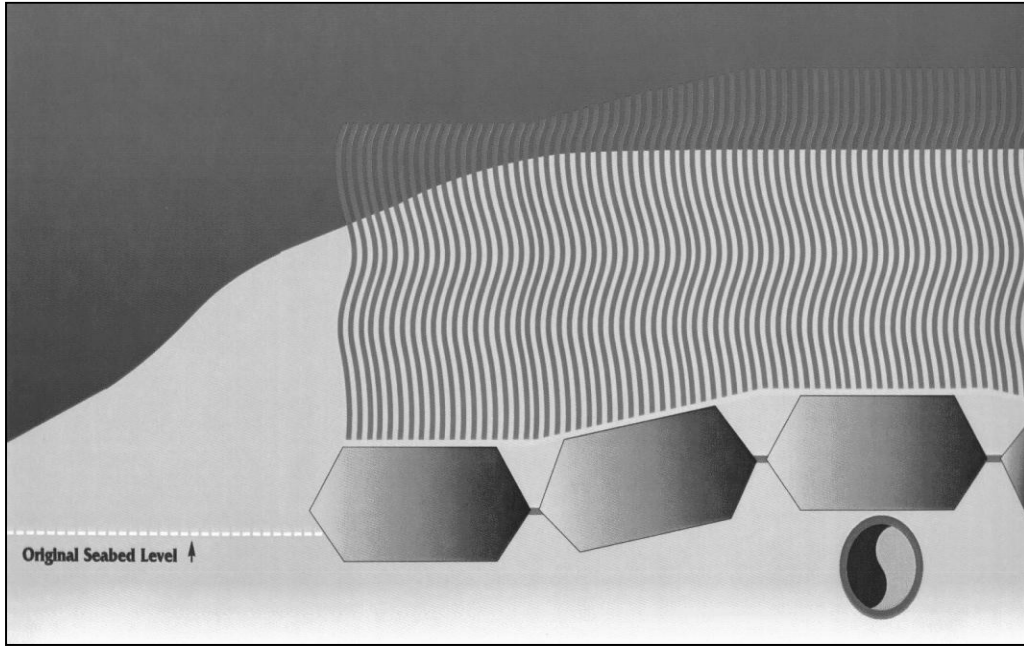


Figure 4: Fully-developed sediment bank is fiber-reinforced and permanent.
 (image courtesy of SSCS, Ltd.)

pre-attached to the rolled mats in lines of anchors spaced at regular intervals, totaling eight (8) anchors per mat. The anchors are driven to a depth of 3.2 feet below existing grade by a diver operated hydraulic hammer fitted with an anchor drive spigot. When driven the pullout strength is typically 1 ton at 3.2 feet of depth in sand. As demonstrated in Figure 5, on withdrawal of the drive spigot, elasticity in the strap pulls on the anchor plate to erect it at a near right angle to the strap.

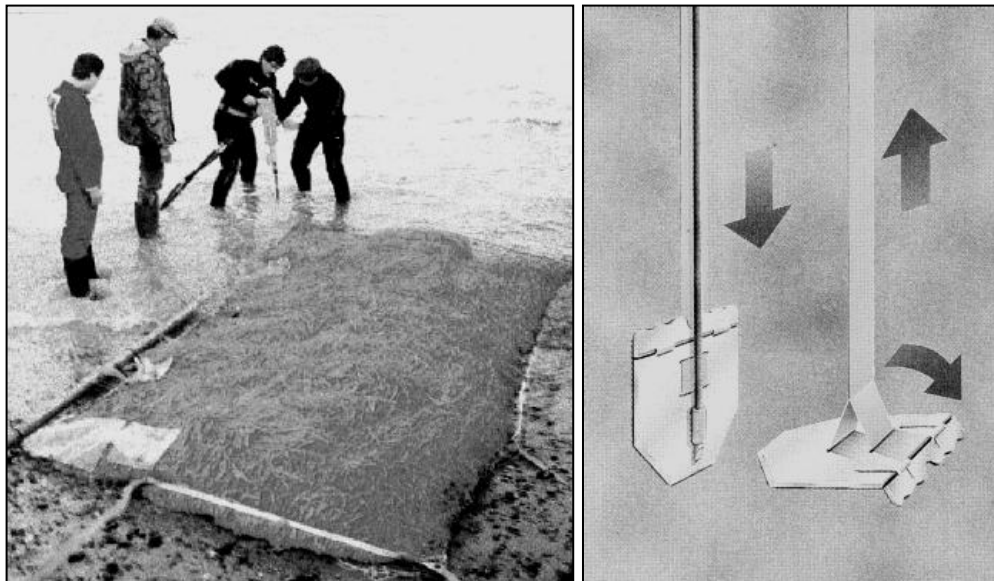


Figure 5: Anchor Installation and Schematic (Courtesy SSCS, Ltd.)

On October 17, 2003, a two-man dive team installed two SSCS Type-12 scour mats around the southwest pile of Cape Wind's MT Tower. Refer to Figure 6 for a diagram of the mat installation plan. Before installing the mats, the OCC divers reported evidence of scour, approximately 6-inches deep to the west of the southwest pipe pile. The divers characterized the seabed as consisting of sandy material. The currents were reported as "evident but not severe" (OCC, 2003).

A nylon line anchored by a large danforth anchor was deployed for use as a down-line to guide the mat to the seabed. Shortly thereafter, the first mat was lowered by the topside crew to the seabed. The installation began on the west side of the pile, due to the direction of the current on the ebb tide. In accordance with the manufacturer's standard installation procedure, the divers placed the edge of the mat approximately 1.1 feet (0.35m) from the pile. The first row of anchors (located adjacent to the pile) was then installed to depth with a hydraulic hammer. After installation of the anchors, the banding straps were removed and the divers unrolled the mat. The mat was then pulled tight, and the second row of anchors was installed to depth. Installation of the second mat on the east side of the pipe pile occurred in similar fashion.

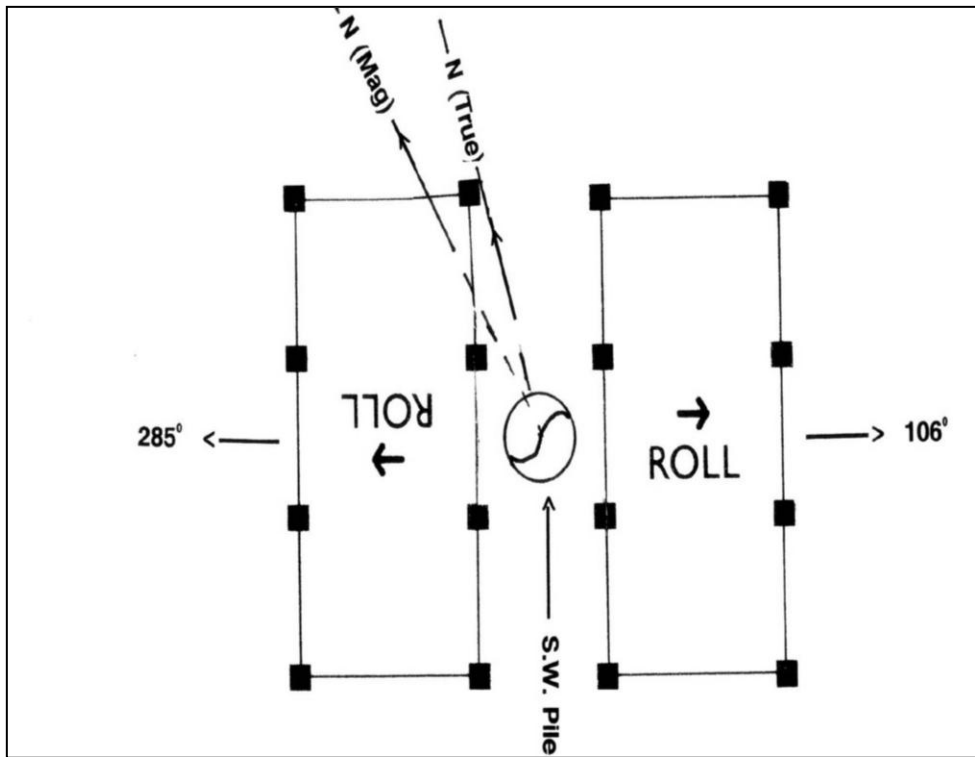


Figure 6: Artificial Frond Mat Installation Diagram

In order to monitor the level of scour and/or accretion of sediments at the site, the divers also installed reference markers (nylon ratchet straps) at 48 inches above the seabed at the

southeast (control) and southwest piles. The entire installation was completed in approximately 1.5 hours, exclusive of the time required to travel to and from the site.

Post-Installation Assessment

On June 13, 2004, OCC performed an underwater investigation at the MT Tower to visually inspect the mat performance after nearly eight months. The two scour mats were observed to be in the installed position at the southwest pile. In addition, all of the mat anchors were noted as securely anchored in the seabed.

Divers verified that approximately 0.82 feet (0.25 meters) of sand had accumulated in various areas of the mats. The accumulation appeared to be in sporadic locations with no consistent pattern and in areas of no sand accumulation the mat webbing was exposed. The exposed webbing does not show signs of tearing or any other damage. The seabed was measured to be approximately 43 inches below the previously installed reference marker on the south side of the pile, which indicates 5 inches of infilling had occurred since the mat installation. The sand surface was virtually level with no scour depression. North of the pile, the mat-to-mat bottom sand area was slightly dished with a scour depression approximately 12 inches deep. This scour extended out from the circumference of the pile 3 feet where the bottom became level and flat (other than sand waves of 2 foot period and 4 inch wave height). Since pre-existing scour was observed during the installation of the mats, this measurement could represent infilling if pre-existing scour was greater than 1 foot.

The reference marker installed on the south side of the southeast pile was 48 inches above the bottom. Measurements taken during the June 13, 2004, investigation, reflected a height above bottom of 6 feet. This implies additional scour after installation of 2 feet during the period of October 2003 to June 2004.

Measurements of scour pockets on the southeast pile of 3 feet over 6 feet on the west side and 2 feet over 6 feet to the north and east were measured. This indicates a scour depression of 15 feet across and a maximum depth of 3 feet on this non-protected pile. Similar measurements, with respect to scour depth and width, were taken on the north pile. The width and depression depth were nearly identical to the southeast pile.

As reflected by Figure 7, A significant amount of marine life was observed nested in the scour mats. Dozens of spider crabs, moon snails, juvenile tautog (*tautoga onitis*), juvenile cunner (*tautogolabrus adspersus*), juvenile sea bass (*entopristes striatus*), kelp and algae were present in the nest of the mats fronds. Extensive barnacle and mussel and anemone bio-fouling on the pipe piles made the finding of the ratchet strap buckles a challenge.



Figure 7: Spider Crabs nested with Artificial Frond Mats

Summary

Artificial frond mats provide an efficient means for controlling seabed scour. Today over 10,000 SSCS viscous drag mats have been installed throughout the world. These systems offer low installation costs, zero maintenance costs (the mats are self maintaining), immediate cessation to scour, progressive accumulation of sediment, and an environmentally acceptable alternative.

Over an observation period of eight months, the test installation of two SSCS Type-12 mats at the Scientific Monitoring Station (MT Tower) on Horseshoe Shoals has presented positive results. Installation of the mats required a limited installation effort, two-man dive team. Measurable sediment accumulation was observed on the surface of the mats. In addition, marine habitat development was observed.

References

Ocean and Coastal Consultants, Inc. (OCC), “*Rapid Assessment Report of Findings – Seabed Scour Control System Test Installation.*” Unpublished report for Cape Wind Associates, LLC dated June 13, 2004.

Ocean and Coastal Consultants, Inc. (OCC), “*Field Report – Cape Wind SSCS Installation.*” Unpublished report for Cape Wind Associates, LLC dated October 17, 2003.

Partridge, D.J.,”*Environmentally Acceptable Solutions to Scour.*”

Seabed Scour Control Systems, Ltd. “SCIENTIFIC DEVELOPMENT OF FRONDED SCOUR & EROSION CONTROL SYSTEMS”.

SSCS “SCOUR CONTROL MATS - MATERIAL SPECIFICATIONS

Seabed Scour Control Systems Limited - SEABED SCOUR CONTROL MATS
Performance Specification – Rolled Mat Installation Requirements

SSCS Website; Mat specifications; presentations; etc.

Cape Wind website