Preserved For the Future: Cape Hatteras Lighthouse

The 4,830 ton lighthouse was moved 2,900 ft southwest of its original location to preserve it from the encroaching sea.

U.S. NATIONAL PARK SERVICE, CAPE HATTERAS NATIONAL SEASHORE, ALL

FEW SPOTS ON THE EASTERN seaboard of the United States are as treacherous as the Diamond Shoals, which extend up to 20 mi off the coast of the Outer Banks of North Carolina. The shoals run along part of the razor-thin, 70-mi long Cape Hatteras National Seashore near Cape Point. This stretch of sandbars has more than lived up to its nickname as the "graveyard of the Atlantic." The shoals are dangerous because they are the point of convergence of two major currents—the Labrador Current and the Gulf Stream. According to Jami Lanier, the cultural resource manager of the Cape Hatteras National Seashore, part of the U.S. National Park Service (NPS), the turbulence resulting from this convergence creates shallow, shifting sandbars beneath the ocean surface.

It is therefore a fitting site for America's tallest lighthouse, charged with protecting this challenging coast since the beginning of the 19th century. "Often shrouded in fog and mist, the low trees and dunes of Hatteras Island offer few visual landmarks to warn crews of their proximity to the shoals, and ships can slip all too easily into the shallows," wrote author Dawson Carr in his history of the Cape Hatteras Lighthouse (*The Cape Hatteras Lighthouse: Sentinel of the Shoals*. Chapel Hill: The University of North Carolina Press, 2000). "Barnacle-encrusted skeletons of wrecked ships still rest there, attesting to the fact that, once trapped, there is little chance of escape."

Accounts vary as to the number of ships lost over the last few centuries, from as low as a few hundred to as high as a few thousand.

First completed in 1803, then rebuilt in 1870, Cape Hatteras Lighthouse is, at just under 199 ft, one of the largest in the world. It has safeguarded ships rounding the Outer Banks across three centuries, surviving hurricanes and earthquakes as well as a perilous half-mile move in 1999 (read "Back from the Brink," *Civil Engineering*, October 1999, pages 52–57).

Protecting ships that must navigate dangerous coastlines has preoccupied human societies for millennia. Ptolemy II commissioned the first great light-

house, in Alexandria, Egypt, in the early third century, B.C. That lighthouse, Carr wrote, took 19 years to build and rose 450 ft (though other estimates put it closer to 350 ft), and its signal fire could be seen for nearly 30 mi.

Safe shipping routes were a significant concern to the young American colonies as well: the first American lighthouse, Boston Light, dates to 1716, and 10 other colonial-era lighthouses soon followed.

According to a report by the Historic American Buildings Survey (HABS) on a survey completed in 1989 by historian Catherine C. Lavoie, who is now the chief of the HABS, local communities built and maintained these early structures, which were often funded by fees levied on ships according to their weight when entering the harbor. Once Congress was established in 1789, it took over the work of building "aids to navigation," according to Lavoie's report.

Five years later Congress authorized a lighthouse at Cape Hatteras, and construction began in 1799; the 90 ft tall structure was lit in 1803. But the tower proved too short to adequately warn ships of the shoals, and, according to an NPS website devoted to the structure, its "unpainted sandstone blended in with the background," and the light, powered by whale oil, "was not strong enough to reach mariners." In 1853, Congress approved a 60 ft addition to bring the height up to 150 ft. The larger lighthouse was also painted "red on top of white," the site explains, to make the structure more visible during the day.

To make the structure easier to see at night, the tower was equipped with a Fresnel lens of the first order, the largest and most powerful type. Named for French inventor Augustin-Jean Fresnel, the "Fresnel lens revolutionized lighthouse technology," according to Lavoie's report. "The lens consisted of an assemblage of prisms around a single lamp. The prisms both magnified and refracted the light outward, greatly increasing the intensity of the light."

For its time, the lens was a powerhouse, but the building itself—not very well constructed to begin with—was on its last legs. In 1868, construction began on a new tower at Cape Hatteras. But the local soil made building a foundation difficult. According to the NPS, high groundwater levels along the Outer Banks meant that when workers began digging the pit for the foundation, it filled with water. Additionally, the HABS survey stated that the sand was "so compact that the piles could not be made to penetrate more than six feet and a sounding rod no farther than nine feet."

The solution was developed by the superintendent of construction on the project, Dexter Stetson. According to the NPS, Stetson used a "floating foundation," which consisted of layered 6 by 12 ft yellow pine timbers. These were "laid crossways in the foundation pit below the water table," the NPS site states. "Granite plinths (rock layers) were placed [onto] the top of the timbers."

The tapered outer wall of the lighthouse was 46.75 in. thick, and its inner wall was a 20 in. thick cylinder. The two walls merged about 134 ft above the ground. The walls were joined by 12 "hidden, full-length vertical ribs," according to the NPS; these stiffened both the inner and outer walls. "They act like the flying buttresses in gothic cathedrals," the site states, while the "double-walled design helps keep the tower rigid and the center of gravity low."

The new structure was completed and lit in 1870, its exterior clad in 1.25 million bricks. The original lighthouse was demolished early the next year. In 1873, the new lighthouse got its iconic black-and-white striped paint scheme. According to the NPS, each stripe circles the tower 1.5 times; the stripes narrow as they rise. No one knows exactly how the geometry of the stripes was determined; the NPS speculates that it was a combination of "pre-calculated dimensions, plumb bobs, and taut lines."

Push jacks, clamped to a track, pulled the frame forward 5 ft at a time.

Temporary shoring beams replaced the lighthouse's foundation as it was prepared for its move.

A new lamp assembly, meanwhile, had been designed by the French watchmaker Augustin Michel Henry-Lepaute: "The twenty-four-sided frame of bronze contained the individually ground Fresnel lenses and prisms," Carr wrote. They were "arranged like a giant beehive made of glistening glass and metal, and they had a jewel-like appearance even when... turned off."

According to the NPS, 2,500 lb of bronze and glass, including more than 1,000 prisms, composed the 12 ft assembly. "The original lens assembly, which rotated on a chariot at 1/2 rpm, was turned by three 150 pound iron weights suspended on a cable and dropping down the center," the site states. "The cable was wound around a drum in the clockwork mechanism beneath the lens, which worked much like a grandfather clock."

Lighthouse keepers lived on-site and operated and maintained the grounds as well as the tower. At dusk, they could set the light in motion with a push of the hand; the weight would slowly descend to the bottom of the tower. But the next morning, the weight would have to be cranked back up by brute strength. According to the NPS, the "keeper had to manually rewind the clockwork apparatus each day. The Fresnel lens usually took 12 hours for a complete cycle."

As if that was not enough work, the keepers also had to carry the lamp fuel up roughly 260 steps to the lens room atop the lighthouse. They also had to regularly clean and polish the lenses as well as "vast amounts of brass fittings and tools," host visitors and inspectors, and keep records. One family, the Jennettes, served as keepers of the lighthouse from 1843 through 1936.

While the Fresnel lens from the 1853 addition to the original lighthouse had burned whale oil, by the 1870s overhunting of sperm whales meant that the U.S. Lighthouse Board, which oversaw the nation's lighthouses from 1852 to 1910, needed new sources of fuel. It experimented with a range of alternatives, from colza oil (from wild cabbage or rapeseed) to porpoise oil. Ultimately, the Fresnel lens in the new lighthouse would run on some form of kerosene for the next 50 years.

In 1935, fears of erosion along the island led the Bureau of Lighthouses (which later merged with the U.S. Coast Guard) to decommission the lighthouse. Its beacon was mounted atop a steel tower a few miles south. A year later, the NPS took control of the light station (including the lighthouse and keepers' quarters), and in 1953 Cape Hatteras was designated the country's first national seashore.

Beginning in the 1930s, the U.S. Coast Guard built the first of a series of sheet-pile walls, or groins, between the tower and the shore. According to Carr, a key incident in 1946 hastened the recommissioning of the lighthouse. That year, a yacht had set its course during the day by the lighthouse, and at nightfall its captain "assumed the flashing signal was from the tower he had seen earlier," and not from the steel tower 2 miles away. The yacht ran to ground and was destroyed. By 1950, Cape Hatteras Lighthouse had been reactivated.

In subsequent decades, as the island continued eroding westward, other attempts to stabilize the coast were initi-

ated, including the construction of three new groins. But these fixes were inadequate. The original 1803 lighthouse had been built 1 mi from the shore. In 1980 a storm washed away its foundation, and it seemed clear that the current lighthouse was next. Sited 1,500 ft from shore when it was built in 1870, by 1980 it was only 50 ft inland.

Scientists, Lanier says, "were primarily concerned that seawater and the erosion of sand [were] going to compromise the foundation of the lighthouse." The freshwater into which the original timber mat foundation was submerged had served to preserve the mat. "However, if seawater infiltrated the submerged foundation, it would begin to deteriorate the timbers. They were really concerned that it would start deteriorating from the foundation up, and [that would] topple the whole thing."

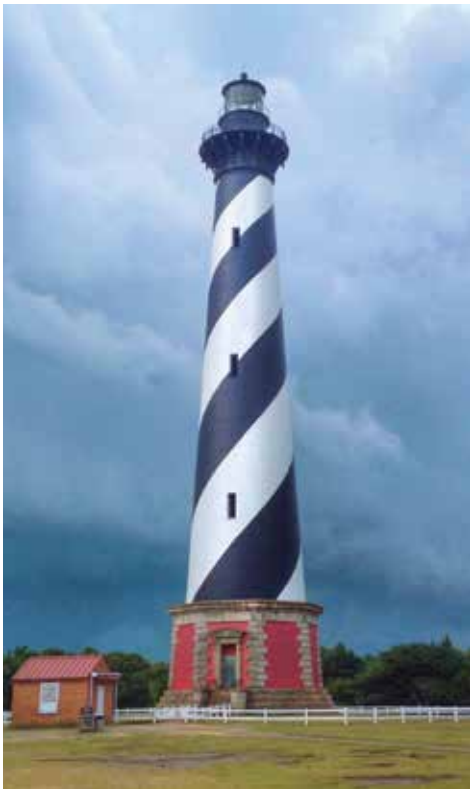
A lengthy planning and debate process began on the future of the lighthouse. Initially, the NPS planned a "concrete and steel seawall revetment that would have protected the lighthouse in place but would eventually have created an island as the coastline receded to the southwest," the NPS site states.

In 1988, the National Academy of Sciences (NAS) issued a report arguing that the lighthouse should be relocated, though no funding was available. In the 1990s the NPS and the U.S. Army Corps of Engineers proposed a plan to build a fourth groin to protect the lighthouse, but state officials rejected the plan, as building "any hardened structures on the North Carolina coast is prohibited by state statutes," the NPS site states. Finally, in 1998, after a North Carolina State University report backed up the NAS plan, Congress approved funds to move the lighthouse.

As the NPS notes, to move the 4,830 ton lighthouse required "lifting it off its foundation, transferring the load to a transport system, moving the tower along a prepared move route, and installing it on the new foundation."

According to Carr, to separate the foundation from the lighthouse, workers pumped water out, "leaving the granite foundation…exposed for cutting. The hard stone was then sliced through by a diamond-edged cable saw, chipped away by pneumatic hammers, and finally removed to allow the insertion of a platform on which the lighthouse would rest for its journey."

Temporary shoring beams replaced the foundation, and then "a steel beam mat was inserted over the timber mat with temporary posts on top," the NPS site states. "As cross beams and main beams were set, the temporary shoring parts and beams were removed."



Cape Hatteras Lighthouse, the tallest lighthouse in America, has protected ships from the dangerous Diamond Shoals on North Carolina's Outer Banks since 1870.

From there, jacks were positioned: "After all jacks were shored, using oak cribbing, the system was pressurized and the jacks began lifting," the site states. "At each lift level, jacks were retracted and shored up in sequence and the system lifted again to 6 feet."

After being lifted onto steel mats, the tower was moved, beginning on June 17, 1999, a total of 2,900 ft to the southwest. According to the NPS, "Three zones of hydraulic jacks kept the lighthouse aligned. Push jacks, clamped to the track, pulled the frame forward 5 feet at a time." As the tower was moved, 60 sensors measured "the transfer of the load, tilt, vibration, and shaft diameter," while a weather station atop the lighthouse tracked temperature and wind speed.

The tower was then placed on its new foundation, which comprised a steel-reinforced concrete pad measuring 60 by 60 by 4 ft plus 5 ft of bricks (147,000 in total), and almost 2 ft of rock. The move took 23 days, roughly a week less than planned, and the lighthouse is now once again 1,500 ft from the ocean.

The complex project, carried out by the NPS, relied on experts from 22 disciplines and was recognized by ASCE as the Outstanding Civil Engineering Achievement of the year.

The shoals, of course, remain a place of danger—for ships and for the lighthouse. Carr notes that despite the presence of the country's tallest lighthouse, 100 ships were still lost along the shoals between 1871 and 1900. Though records are incomplete, the NPS estimates that about 40 hurricanes have hit the Outer Banks since the lighthouse, which has been designated an ASCE National Historic Civil Engineering Landmark, was completed. The structure also survived an 1886 earthquake that hit Charleston; it was estimated at 7.7 on the Richter scale, and the temblor was felt as far away as Chicago.

The Outer Banks remain dynamic. "The barrier islands naturally migrate to the southwest, driven by prevailing water and wind currents," says Lanier. The 1999 lighthouse relocation followed a tradition established in the 19th century, when the U.S. Lighthouse Service moved several lighthouses to protect them from erosion. "We understand," Lanier says, "that we must make informed decisions and adapt to the changing nature of our environment to preserve our cultural resources for future generations."

—T.R. WITCHER

Witcher

T.R. Witcher is a contributing editor to Civil Engineering.