Moving an Historic Lighthouse

Using an intricately phased process that required careful planning, this lighthouse structure was moved 450 feet across "soft" terrain and was saved, for the foreseeable future, from the effects of severe coastal erosion.

PETER PARAVALOS &
WAYNE H. KALAYJIAN

Highland Lighthouse is located above 140-foot bluffs in North Truro, Massachusetts, and lies within the Cape Cod National Seashore. It is also known as Cape Cod Light, and since it is the oldest on the cape it is listed on the National Register of Historic Places. When first situated in 1797, Highland Light stood more than 500 feet from the edge of the imposing cliffs. By the early 1990s, however, beach erosion from severe winter weather had claimed 400 feet of this shoreline — 40 feet in the last seven years alone (see Figure 1). This alarming progression was a serious concern to its owners, the United States Coast Guard, as well as local citizens' and civic groups, which as a consequence actively campaigned to rescue the lighthouse from impending danger. These efforts paid off in 1994, when a joint decision was made by the National Park Service and the Coast Guard to move the beacon inland from the fast-eroding bluffs. As a result, the U.S. Congress instructed the Coast Guard to direct and oversee relocation operations of this historic structure. (The Federal government has played a long-standing role in maintaining navigation safety along coastlines in the U.S. During George Washington's day, administration of lighthouse facilities fell within the jurisdiction of the Treasury Department. By 1800, the Federal government had gradually assumed responsibility for maintaining the operations of all existing lighthouses, completing the construction of lighthouses already under construction within the 13 states and erecting new lighthouses as required.)

The lighthouse was actually the third one to be constructed on the Truro Highlands. The site has been ideal for a beacon since the commanding height of the cliffs permits the placement of a relatively low and, therefore, inexpensive lantern that would be visible from a considerable distance at sea. The first Cape Cod Light had been a simple timber lattice structure with protective glass panels at the lantern deck. When two other lighthouses were built along the shore in Massachusetts Bay in the early 1800s, however, nighttime navigation soon became difficult since these beacons could not be distinguished from each other. In response, Cape Cod Light was differ-

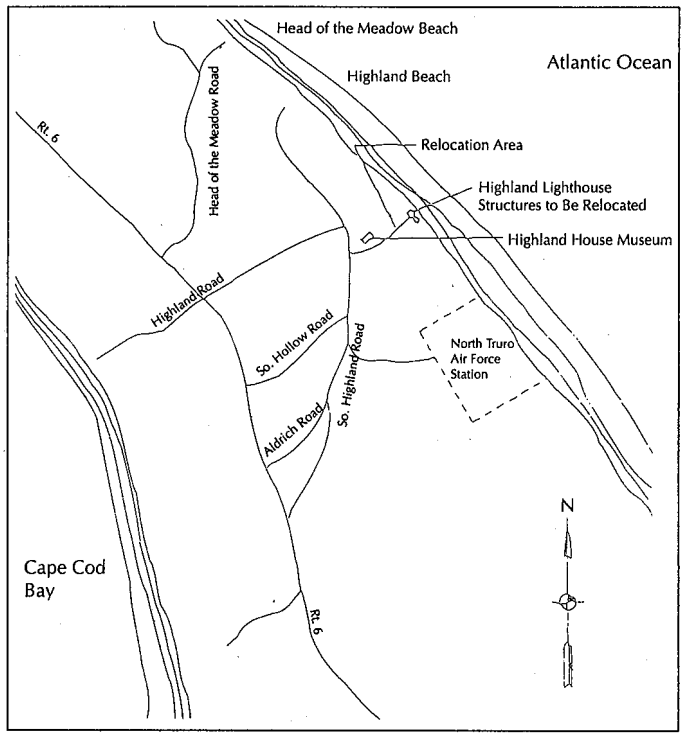

FIGURE 1. Location of the lighthouse on Cape Cod.

entiated by use of an eclipser lantern (a blind that passed in front of the light source once each minute). By the late 1840s this wooden lighthouse was nearing the end of its useful life and it was rebuilt in 1853 out of brick and stone. However, because its lantern was not entirely visible to southern-approaching ships, Highland Lighthouse had to be rebuilt a third time four years later on the site where it has stood for the last 140 years.

In 1994 the New England Division of the U.S. Army Corps of Engineers, under an Indefinite Delivery Contract, issued the lighthouse relocation design to an engineering firm which would perform all the civil and structural work associated with the final site conditions:

- Designing the new foundations for the relocated Highland

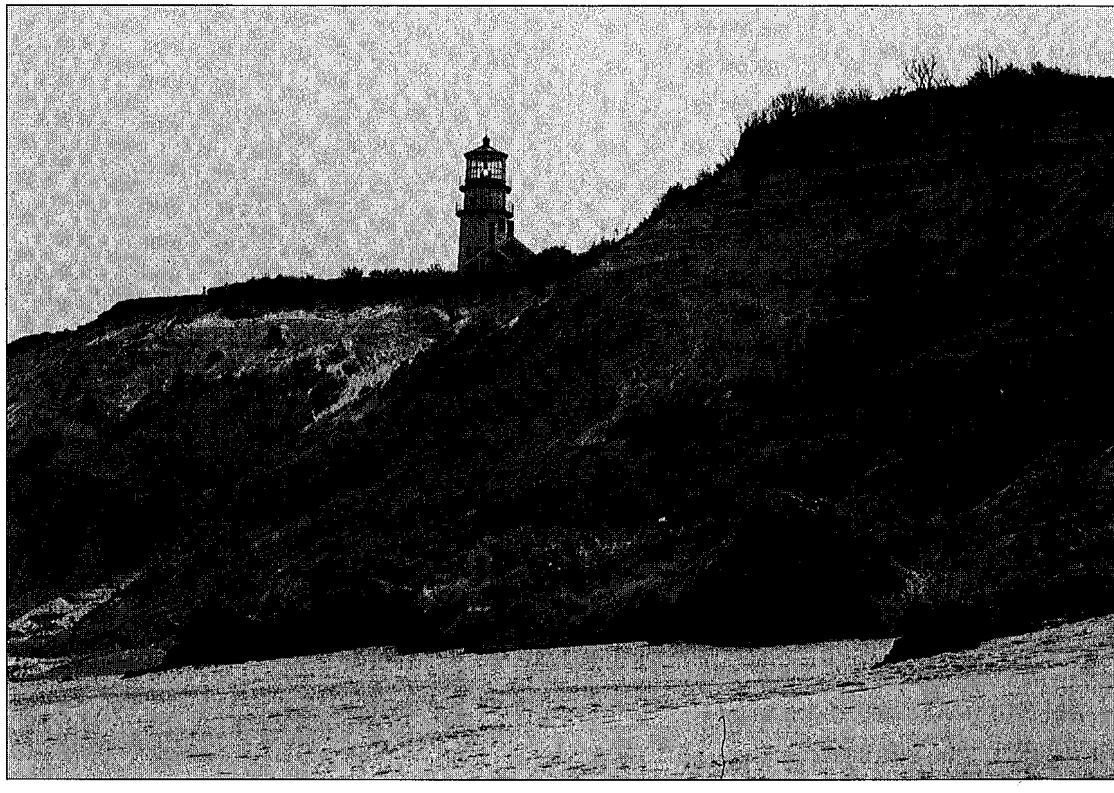

FIGURE 2. A view of the lighthouse from the beach.

FIGURE 3. A view of the lighthouse and adjacent buildings.

Lighthouse and adjoining keeper's dwelling;

- Adding public restrooms adjacent to the nearby Highland House Museum;
- Grading and paving an expanded parking facility; and,
- Improving pedestrian access and circulation.

Those tasks limited to moving the lighthouse and its adjoining buildings would be entirely contractor-designed.

Project Conditions

Site. The lighthouse sat at the end of Highland Road overlooking the Cape Cod National Seashore (see Figures 1 and 2). It consisted of a tower that was equipped with an unmanned beacon, a one-story equipment room and connector building, as well as a two-story keeper's dwelling (see Figures 3 and 4). The complex was immediately flanked on the north and south by a nine-hole golf course that is maintained by the National Park Service.

Relocation plans called for the lighthouse to be moved 450 feet west and 12 feet south to a site that required minimal regrading and alteration of the existing topography. This move would place the building in a rather unusual position: it would be within 10 feet of the golf course's seventh fairway. Consequently, shatter-proof glass had to be installed at the lantern deck and trees planted at the base of the tower to protect the beacon from stray golf balls. The new focal plane elevation of the lantern would be 120 feet above mean sea level, or 10 feet lower than its current height. Prior to the move, the lighthouse beacon could be seen 30 miles at sea. Its new elevation would translate to a reduction in visibility of barely a mile, which was acceptable to the Coast Guard.

Geotechnical. A test pit had been excavated at the base of the lighthouse tower by the U.S. Army Corps of Engineers in September 1994 to expose the existing foundation system and to determine its composition and condition. The soil profile at the pit consisted of a 6-inch layer of topsoil underlain by reddish-brown me-

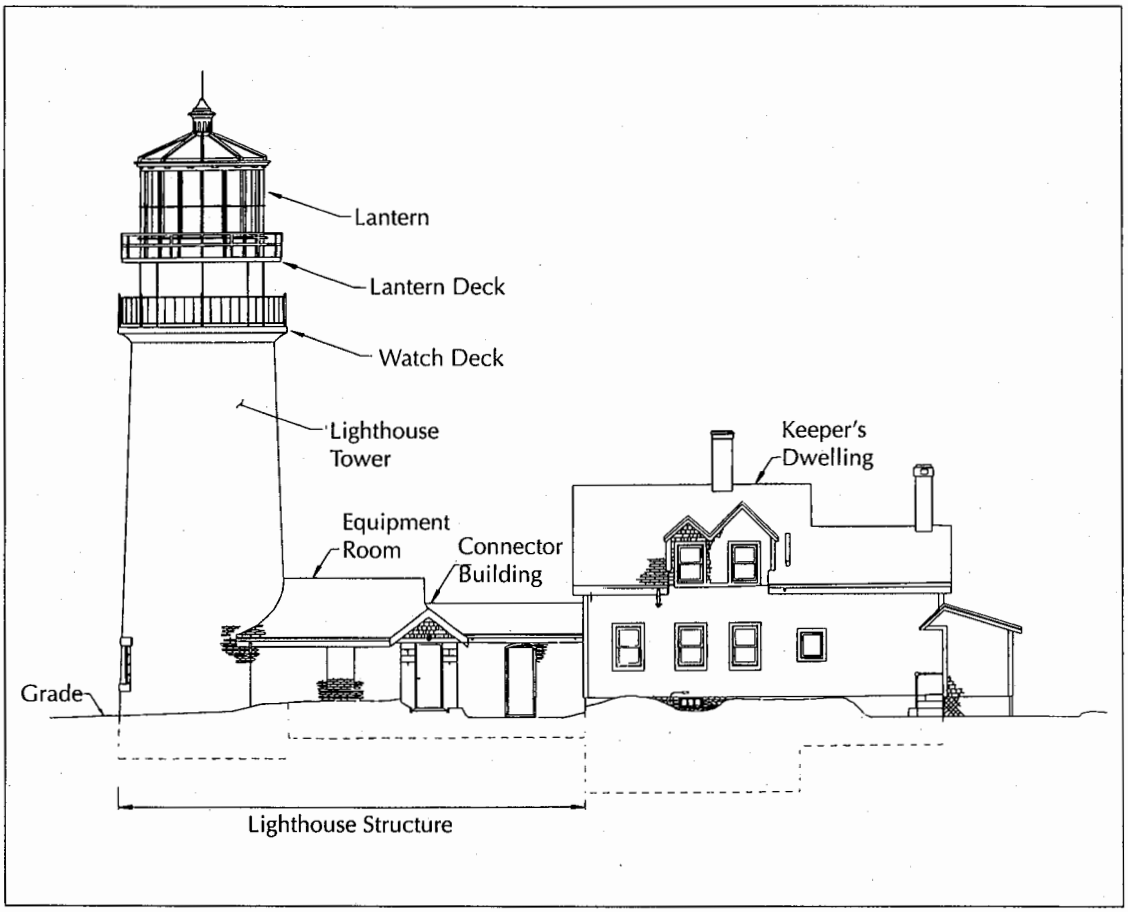

FIGURE 4. The Highland Lighthouse — east elevation.

dium to fine sands. The sand layers contained traces of coarse sand and fine gravel. This profile was similar to the kind of soils that had been investigated at the proposed lighthouse site.

Lighthouse Structure & Keeper's Dwelling

Lighthouse Tower. The tower contained five levels: the ground slab at grade, the half-deck, weight-deck, watch-deck and lantern-deck. All of these decks were of steel plate construction. A cast-iron spiral staircase was bolted to the interior face of the tower wall and was the sole means of ascent to the lighthouse lantern. The inside diameter of the tower was approximately 11 feet and the top of tower stood at nearly 66 feet above grade (see Figure 4). Tower walls measured 3.5 feet thick and consisted of three brick masonry courses separated by two 6-inch wide cavities. These cavities had been infilled with cobblestone, mortar and brick fragments. The base of the tower extended 4 feet below grade, bearing on the sandy soils as well as a thin layer of leveling mortar. At the lantern deck, clear plexi-glass within an aluminum frame and panel system protected the lighthouse beacon.

Equipment Room & Connector Building. The equipment room and connector building was a 32-foot long, single-story brick masonry structure with an asphalt shingle roof. It served as an intermediate link between the tower and the keeper's dwelling. Exterior walls measured 12 inches thick, and consisted of two brick courses separated by a 3-inch cavity, which was filled in a manner similar to the tower. The bottom of the foundation was approximately 3.5 feet below grade, 6 inches shallower than the tower. Altogether, the

weight of the lighthouse structure — tower, equipment room and connector building — was estimated at 450 tons.

Lighthouse Keeper's Dwelling. The keeper's dwelling was a two-story wood-framed cottage with an attached porch. The foundation walls were constructed of 12-inch thick brick masonry. A crawl space existed below the first floor kitchen, with a full basement under the remainder of the cottage. First floor framing consisted of wood planking supported on timber floor joists and beams. Brick foundation walls and two intermediate steel pipe columns provided vertical support.

The Movers

The $1.5-million lighthouse relocation contract was awarded to a firm that would perform all of the construction services associated with the relocation contract. To assist with the actual move of the Highland Light, the firm subcontracted with another company with much experience moving structures.

In 1993, the construction contractor and subcontractor mover partnered to orchestrate the 360-foot move of the Southeast Lighthouse on Block Island (located in Rhode Island Sound). The Block Island project had been a "soft" move, where the lighthouse had traveled over unreinforced earth. The construction contractor anticipated that it would use a similar technique at the North Truro site. (In contrast, a rival contractor had unsuccessfully proposed a "hard" move approach for the Highland Light project. This method would have required pouring a concrete travel-way over which the buildings would have rolled.) Figure 5 shows the construction sequence for moving the lighthouse tower.

Shoring the Structure

The moving team's initial task was to lift the keeper's dwelling and move it safely aside to a temporary staging area in order to improve construction access to the lighthouse structure. First, both masonry chimneys were shored, windows boarded over and door jambs stabilized. Five-foot deep trenches were excavated around the cottage perimeter and small square holes were cut in the foundation walls just below the fourth brick course at 4-foot intervals. W10 steel beams were then threaded through these holes to support the floor framing system. After that the connection with the adjoining connector building was severed, and the keeper's dwelling was jacked 8 feet vertically in the air and rolled 30 feet to the north (see Figure 6).

The second preparatory phase consisted of stabilizing the lighthouse tower and the equipment room/connector building, which would be moved as a monolithic unit. This phase required repointing the mortar in the brick walls, blocking over all windows with timber studs and wrapping the exterior of the tower with corsets consisting of 2- by 4-inch vertical timbers spaced at 3-foot intervals and wrapped together with wire (see Figure 7). Next, a 5-foot deep continuous trench was excavated around the base of the entire structure, thereby exposing the foundation walls (see Figure 5a).

To support the lighthouse structure for the duration of the move, the moving subcontractor developed an intricate temporary steel framing system (see Figure 8). To install this framework, twelve square openings were precisely cut around the circumference of the tower foundation wall using a diamond-impregnated cable-saw. Next, two W14x342 cross beams were threaded through the east and west wall openings in the tower foundation. Each of these beams were supported on two stacks of oak cribbing located 5 feet from the tower face (see Figure 5b). To ensure that lifting pressures would be uniformly distributed onto the flanges of the W14 cross beams throughout the jacking process, oak lintels were installed at the top of each wall opening, and any remaining voids across the opening were grouted solid.

To facilitate installation of the temporary steel system, trenches on the east and west sides of the tower were deepened another 3 feet. Soil at the bottom of these deepened trenches was then compacted and covered with a layer of transverse timbers. Three longitudinal rows of W6 jack beams were then laid side-by-side on the timbers. These jack beams, in turn, would continuously support a pair of 70-foot long W24 "duplex" girders. Each duplex girder would be integrally outfitted with thirteen hydraulic jacks, and it was these jacks

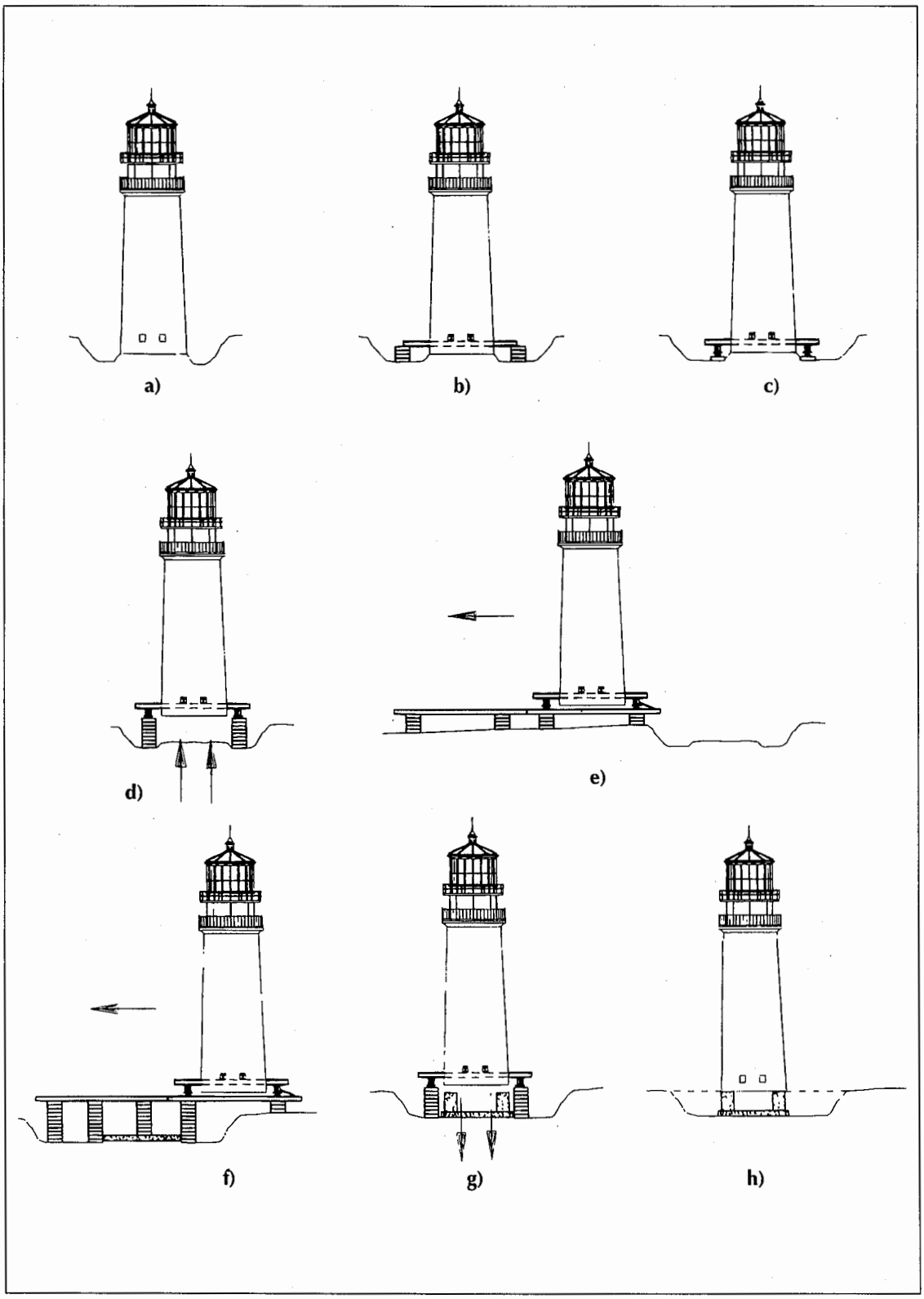

FIGURE 5. The construction sequence for moving the lighthouse structure.

FIGURE 6. A view of the jacked keeper's dwelling.

that would lift the lighthouse structure (see Figures 5c and 9).

At this point the remaining temporary steel shoring could be installed. This phase required the placement of additional W14 cross beams and radial beams through the tower foundation, as well as W10 cross beams under the equipment room and the connector building. Because of the shallower foundations at the equipment room and connector building, steel beams could be inserted directly underneath this portion of the structure without puncturing the walls.

The Lifting Process

Lifting the lighthouse structure required the use of a unified hydraulic jacking machine. The unified machine supplied hydraulic fluid so that each jack within the duplex beams could be independently adjusted at any time during the jacking sequence. This ability to make independent adjustments was very important, since it ensured that uniform lifting pressures would be maintained and that the structure would remain plumb throughout the move. Every jacking cylinder housed a 5-inch diameter piston, extending to a maximum length of 16 inches, and had a lifting capacity of 30 tons. The system was highly redundant: jacks were each tied to a separate hydraulic circuit, and failure in any single jack would not induce pressure-loss among the others.

The unified machine contained eighteen hydraulic feeds, but by using "splitter blocks" it could be expanded to provide eight additional lines. Valves on the splitter blocks were calibrated to accommodate the three different kinds of anticipated loading conditions:

- *Unified mode* would be used when vertical jacking was underway;
- *Zone mode* when moving the structure laterally, and,
- *Individual mode* when additional pressure was required at isolated jacks.

With temporary shoring in place, jacks in the duplex beams were independently pressurized

FIGURE 7. A view of the lighthouse tower with corsets.

to eliminate the effects of uneven cribbing and localized ground settlement. All jacks were then switched into unified mode and fourteen of the twenty-six jacks (seven on each side of the tower) began the initial lift. To compensate for the structure's asymmetrical massing, jacks closest to the tower exerted between 3,500 to 4,000 psi. Jacks nearer to the equipment room exerted between 1,200 to 1,500 psi. Once the structure had been raised one full stroke (16 inches), the fourteen extended jacks were temporarily locked into zone mode, and additional cribbing was shimmed under the twelve remaining jacks that had not been used during the initial lift. With new cribbing in place, these twelve jacks then lifted the lighthouse structure another full stroke. This technique was repeated until the building had been lifted 5 feet, at which point workers could access its underside and wrap the masonry base with steel banding in order to maintain its structural integrity (see Figure 5d).

Sequential vertical jacking and shimming continued to lift the lighthouse structure to a total of 15 feet above grade. To stabilize the building in its temporarily raised position, stacks of cribbing were shimmed under twelve of the jacks. Once this was accomplished, steel "roll" beams and "crawler dollies" were inserted under the remaining fourteen jacks, which would enable the lighthouse to slide laterally across the site (see Figure 10). Each dolly assembly consisted of eighteen steel cylinders (1 inch in diameter and 3 inches long) that were encased in a housing box that resembled the tread configuration of a Sherman tank. The roll beams were then braced with steel tubes in order to maintain their horizontal alignment, while the flanges and webs of the duplex beams were also braced to the cross beams above with diagonal W6 steel sections (see Figure 11).

The Move

After the bracing was completed the lighthouse was ready to move to its new home. The roll beams that had been installed were very similar in concept to those of railroad tracks: the difference being that the lighthouse struc-

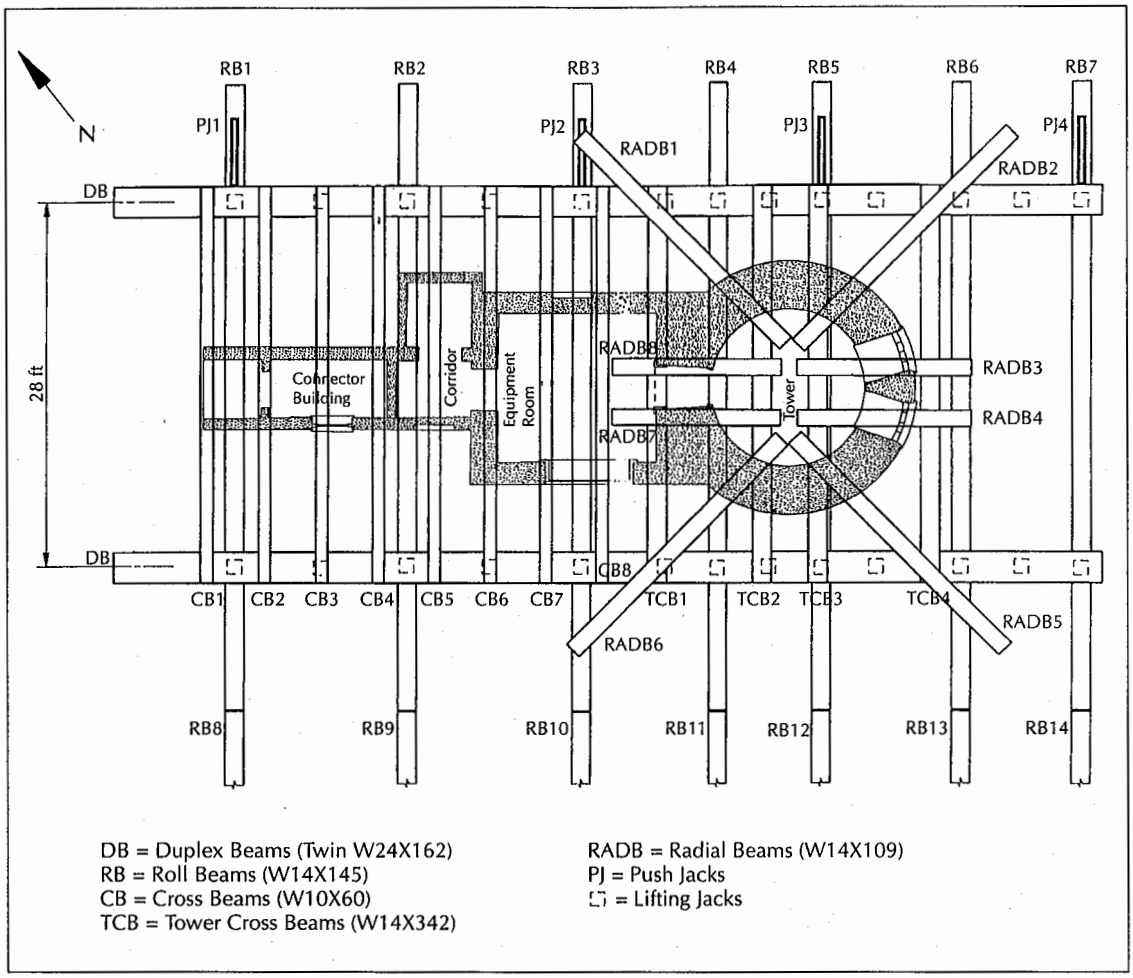

FIGURE 8. A plan view of the temporary steel frame lifting system.

ture would travel on seven rails rather than two (see Figure 12). Each rail consisted of two 40-foot long W14x140 sections connected end-to-end. These girders were detachable, so that as the lighthouse structure crept toward the end of one section, the other could be maneuvered to swing around and re-attach to form a continuous rail system. To provide a smooth and firm rolling surface, a horizontal ¼-inch thick steel plate was welded to the top flange of each beam. The bolted connections between the roll beams were designed to transfer substantial shear stress as the lighthouse structure travelled from one W14 section to the next (see Figure 5e).

Four "push rams," each with a 30-ton bearing capacity and a 5-foot piston stroke, were bolted to the ends of the roll beams and connected to the duplex beams (see Figure 13). Prior to the first horizontal push, all hydraulic lines were checked against blockage, and household soap applied to all roll beams. The soap would lubricate the roll beams while also producing a greasy film among the rollers. Using the soap would make the lighthouse structure easier to maneuver along its serpentine route.

A lateral force of 500 psi was exerted by each ram, pushing the building one full stroke (5 feet), at a rate of about 20 feet per hour. After each stroke the rams were reset (which meant that they were disconnected, retracted and rebolted to the roll beams to prepare for the next push). In this fashion, the lighthouse structure was moved to its new location in ninety push strokes (see Figure 5f).

FIGURE 9. A view of the jacks lifting the lighthouse structure.

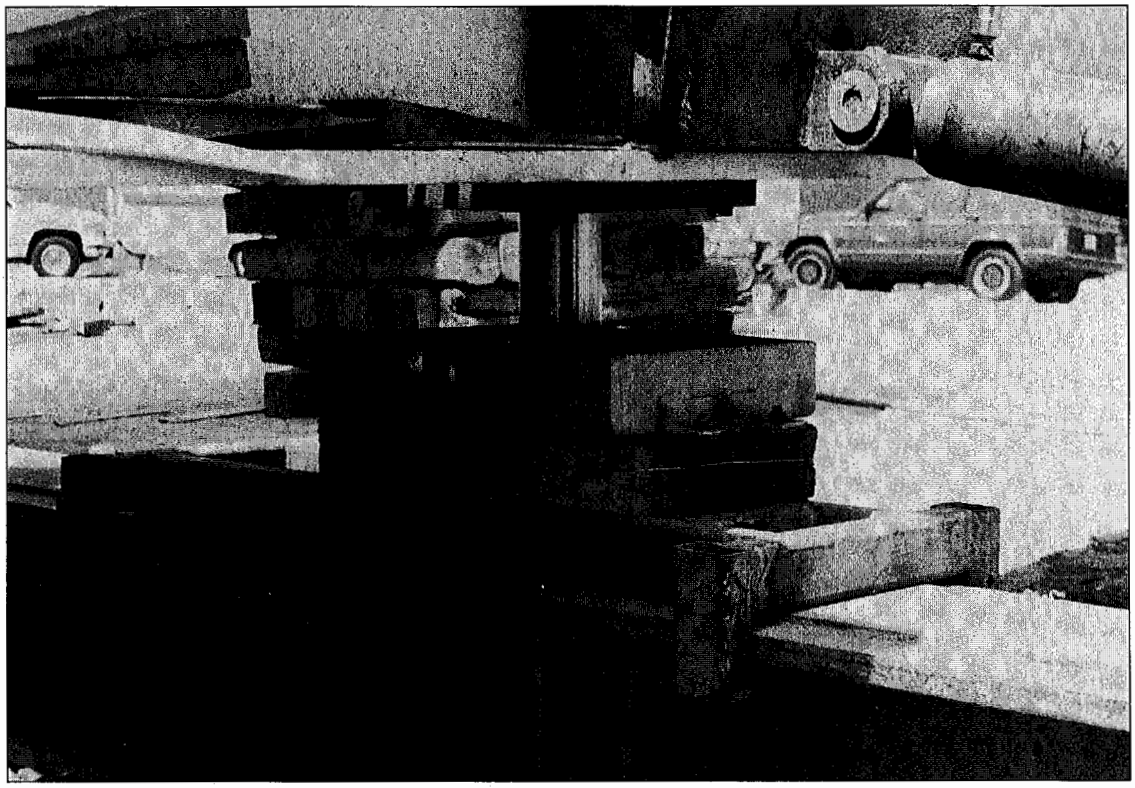

FIGURE 10. Roll beam and crawler dolly under a jack.

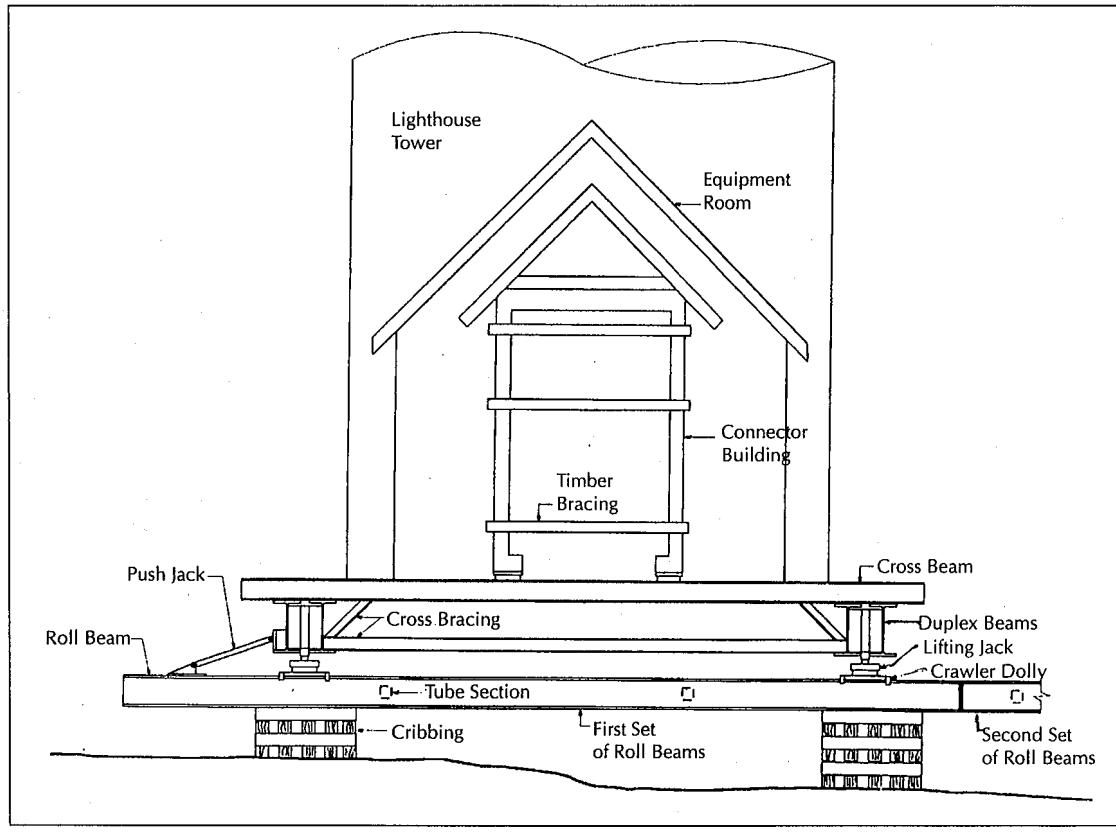

FIGURE 11. A schematic of the moving system.

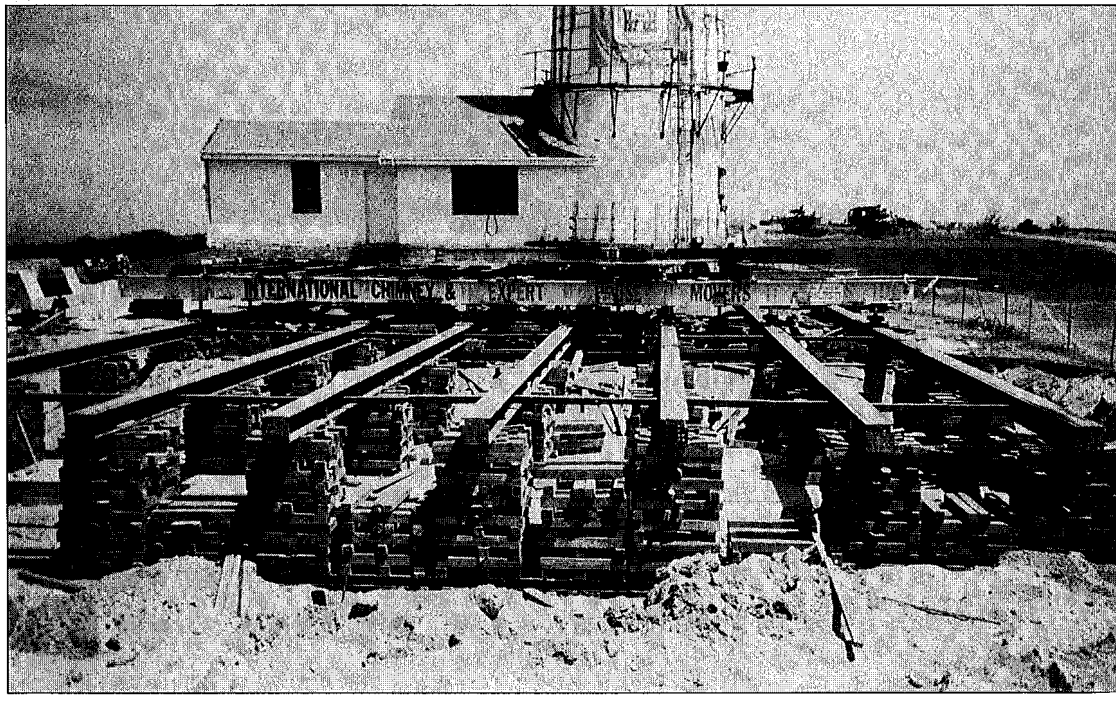

FIGURE 12. The lighthouse structure moved on seven rails.

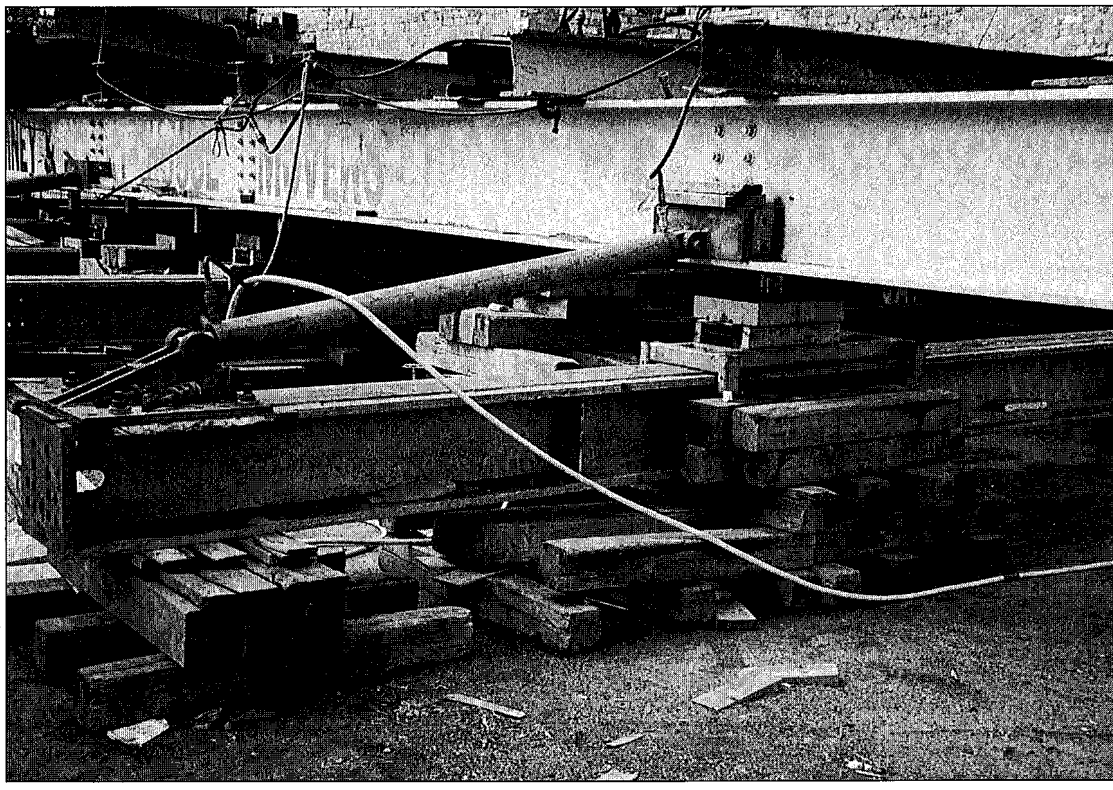

FIGURE 13. A view of the push rams.

Due to topographical changes, cribbing heights below the roll beams were constantly monitored and adjusted, and use of a surveying transit ensured that the structure remained plumb throughout the move. After the lighthouse had been relocated, the keeper's cottage was then moved in quicker fashion, due to its lower weight and more stable proportions.

New Foundations

Lighthouse Structure. Because of the lighthouse structure's asymmetrical massing, an expansion joint was included to separate the tower's foundation from that of the equipment room and connector building. This configuration would virtually eliminate eccentric soil bearing pressures. The new tower footing was an octagonal, reinforced concrete mat that was 24 feet long and 18 inches deep. The adjoining equipment room and connector building rested on a "tee"-shaped reinforced concrete mat that was also 18 inches deep.

Keeper's Dwelling. The new foundation at the keeper's dwelling provided a full-depth basement beneath the entire building. To provide adequate construction horizontal tolerance while lowering the building into place, the foundation walls were 21 inches thick. The basement floor was a 6-inch slab on grade, with haunched ends to act as footings for the perimeter foundation walls. Isolated spread footings were also poured to accommodate interior columns, walls and exterior porch posts.

Setting the Lighthouse Into Place

Once the base of the lighthouse had been moved and was directly aligned 8 feet above its new foundation, the crawler dollies, rollers and roll beams were completely dismantled. Then the 450-ton structure was slowly lowered by means of reverse jacking until the required beacon focal elevation was reached. To compensate for the difference in elevation between the old and new sites, additional structure was installed under the base of the lighthouse (see Figure 5g) — a 3.5-foot wide

concrete bearing wall cast as a sandwich between the top of mat footing and bottom of the building. Once the concrete had cured, the lighthouse was plumbed, pressure supplied by the jacks was released and the weight of the structure was slowly redistributed onto the new bearing wall and footing (see Figure 5h). As expected, consolidation of the sandy soil was nearly instantaneous, with minor cracking occurring between the tower and the adjoining equipment room.

With the lighthouse and the keeper's dwelling now firmly in place, all timber cribbing and steel cross beams were removed from the underside of both structures. Cross beam openings were then infilled with brick and mortar. A 12-inch wide reinforced concrete "ring" beam was then cast at the base of the inside perimeter of the tower, extending from the ground floor slab to the mat foundation. A similar ring beam was cast along the interior faces of the equipment room walls. These walls would stabilize and anchor the lighthouse structure to its new foundations. The hollow interior of the tower base was then filled with soil, compacted and a slab on grade was cast at what would serve as the ground floor.

The entire relocation process of the Highland Lighthouse and its keeper's dwelling took six weeks. Moving the lighthouse structure alone took the better part of two weeks. The moving team successfully moved the buildings on time, within budget and without incident. Highland Lighthouse now sits 570 feet from the Truro bluffs, safely away from the Atlantic Ocean for another 150 years. The United States Coast Guard will continue to operate the facility in conjunction with the National Park Service, and the Truro Historical Society (along with the National Park Service) will maintain the lighthouse and continue to provide public access.

Lessons Learned

Moving the lighthouse structure 450 feet over soil and pavement was an intricately phased process that required careful planning. Continuous monitoring of the structure's stability and weight distribution played a large role in the success of the project. Variations in existing topography combined with the asymmetrical height and mass of the lighthouse structure required significant engineering judgment in order to permit precise installation of hydraulic equipment and structural framing.

ACKNOWLEDGMENTS — *Sverdrup Civil, Inc., Boston/St. Louis, was the design engineer for the project. International Chimney Corporation, of Buffalo, New York, which was founded in 1941 and which specializes in building repair and moving industrial-sized chimneys, was the construction contractor. Expert House Movers, of Charptown, Maryland, was the subcontractor for the move. The authors thank Sverdrup Civil, Inc., the U.S. Army Corps of Engineers, International Chimney Corporation, Expert House Movers and Hillman Rollers for their support during preparation of this article. Special gratitude to Jerry Matyiko, Pete Friesen and Michael Landen of Expert House Movers for sharing their specialized knowledge and particular insights.*

PETER PARAVALOS *is a structural engineer with Commonwealth Engineers and Consultants, Inc., in Providence, Rhode Island. He received a B.S. in Civil Engineering from Northeastern University in 1992. His experience includes a wide variety of transportation projects, with particular emphasis on bridge structures. He is a member of BSCES and ASCE.*

WAYNE H. KALAYJIAN *is a Project Manager with Sverdrup Civil, Inc. He received a B.S. in Civil Engineering from Tufts University in 1981, an M.S. in Structural Engineering from Stanford University in 1984, and an M.S. in Engineering Management from the Massachusetts Institute of Technology in 1996. He has 16 years of diverse technical and managerial experience with particular emphasis on construction mitigation in urban environments. He is a member of BSCES and ASCE, and is a Registered Professional Engineer in Massachusetts and California.*

BIBLIOGRAPHY

Albee, P.A., Binder, R., & Galland, M., *Highland Lighthouse and Keeper's Dwelling Historic Structures Report*, National Park Service, Building Conserva-

tion Branch, Cultural Resources Center, North Atlantic Region, May 1994.

Curtis, J.O., *Moving Historic Buildings*, U.S. Department of the Interior, HCRC Publication No. 9., 1979.

International Association of Structural Movers, *The Structural Mover*, Vol. 11, No. 3, Lakeside Printing, Inc., December 1994.

International Association of Structural Movers, *The Structural Mover*, Vol. 12, No. 1, Lakeside Printing, Inc., April 1994.