To Repair or Replace: Structural Assessment of Damage at the Steeplechase Pier

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Fig. 1: Aerial view of Steeplechase Pier, Coney Island, Brooklyn, NY @ 2003 Pictometry (Reproduced with permission)

Steeplechase Pier, located in Coney Island, Brooklyn was damaged by Hurricane Sandy in late 2012. During reconstruction of the pier in 2013, the mooring "spud" of a construction barge failed and the barge rammed into the pier, seriously damaging it. This article outlines the response to investigate the damage and develop repairs, talks about the challenges of completing an investigation that determined the condition of the piles, and discusses how the aggressive schedule to reopen the pier ultimately determined the chosen repair scheme.

Background

Steeplechase Pier was originally built as part of Steeplechase Park, the largest and most successful of the original amusement parks at Coney Island. Steeplechase Park opened in 1897 and the pier opened in 1904. The pier was built to allow ferries to easily bring crowds of patrons to the amusement park. Steeplechase Park closed permanently in 1964. The pier was later acquired by the City of New York and placed under the management of the Department of Parks and Recreation for use by the general public.

Steeplechase Pier is cross-shaped in plan and extends from the Coney Island Boardwalk southward into the Atlantic Ocean. The main portion of the pier extends perpendicular to the shoreline out from the boardwalk for 1,100 ft (335 m). The crossing portion, 220 ft (67 m) in length, consists of an east and west extension extending parallel to the shore, and is centered on the main portion 200 ft (61 m) from the southern tip. The pier deck is typically 23 ft (7 m) wide for the majority of its length, however, portions of the pier nearer to the shore are either 33 ft (10 m) or 44 ft (13.4 m) wide. Prior to the 2013 reconstruction, the last major work on the pier occurred in 1994 (Fig. 1).

The primary pier structure consists of 16 in (406 mm) square prestressed concrete piles and precast, conventionally-reinforced beams that span across the piles and cantilever out slightly at each end, creating frames. The frames have three configurations: three-pile (overall length of 26 ft-8 in [8.1 m]), four-pile (overall length of 36 ft-8 in [11.2 m]), and five-pile (overall length of 46 ft-8 in [14.2 m]), in which the piles are spaced at 10 ft (3 m) along the center of the beam. The beams are 2 ft-6 in (0.8 m) wide and 2 ft-2 in (0.7 m) deep, and include block-outs for connections to the piles that were later filled with concrete. Prior to the 2013 reconstruction, the walking surface of the pier consisted of wood decking supported by wood joists atop the frames (Fig. 2).

Hurricane Sandy struck New York City on October 29, 2012. The storm brought severe and widespread devastation to low-lying and coastal areas throughout the city and region. Compared to Hurricane Irene, which hit New York City in the prior year, precipitation was relatively light and winds were more severe. However, the timing of high tide combined with the more-severe winds created a storm surge that increased the sea level by an additional 10 ft (3 m) and created shallow water waves as large as 32 ft (9.8 m)[1]. This inundated low-lying areas, especially tunnels and basements, and completely destroyed many coastal structures such as seawalls, piers, and boardwalks.

Steeplechase Pier suffered extensive damage to the wood decking and framing, but the concrete frames (piles and beams) emerged from the storm relatively unscathed. The storm surge and waves displaced, detached, or completely removed the wooden decking and framing throughout the pier. The post-Sandy repair scheme for the pier consisted of completely removing and rebuilding elements of the structure atop the existing precast concrete frames.

On April 12, 2013, a construction barge that was stationed adjacent to the southern tip and west extension of the pier suffered a failure of the "spud" mooring system and began to take on water in rough seas. The barge began to sink and rotate horizontally on the water surface and list (tilt), with the southern end of the barge sinking and the northern end raising up. By April 14, 2013, the majority of the barge had submerged. The sinking, rotating, and listing combined with wave action from rough seas caused the barge to impact the pier at two locations—one at the southern tip and one at the west extension. By April 17, 2013, the barge had completely sunk away from the pier and came to rest on the mudline below (Fig. 3).

Field Investigation

The original reconstruction project had an aggressive schedule, even before the barge unexpectedly damaged portions of the pier, as the City of New York wanted to reopen the pier for the Independence Day fireworks. The investigation assessed if the damaged piles and beams could be repaired or if they needed to be replaced—an executable design was developed for these two scenarios. To expedite the initial repair design while the investigation work was ongoing, an initial assumption was made that the affected piles were only damaged at the top near the beams and could be repaired. The piles were assumed to be in good condition below the waterline and the mudline. This initial assumption would be subject to change pending the findings from continued field investigations.

Fig. 2: Overview of pier construction (some existing wood decking and framing remains)

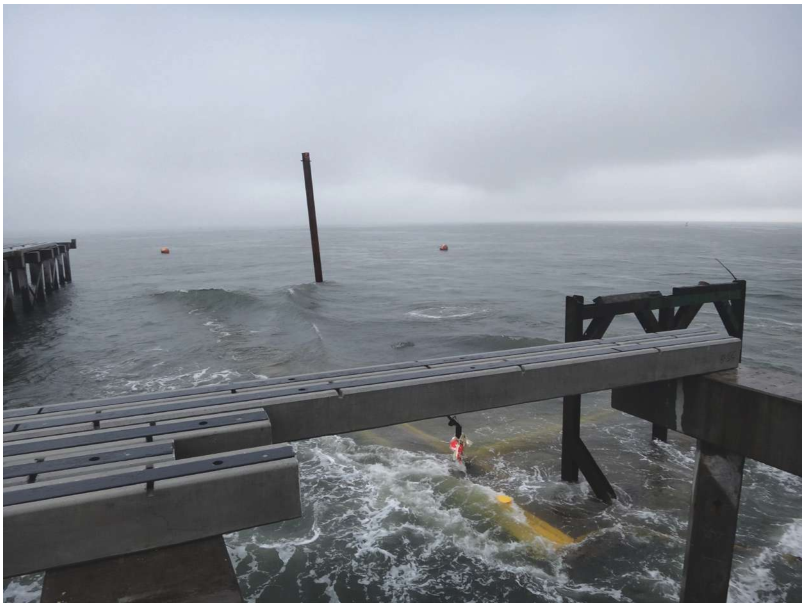

Fig. 3: View of completely-submerged barge (the submerged barge came to rest away from the pier)

On April 15, 2013, the damage that was readily apparent above the waterline was observed and documented. The observations were made from atop the remaining portions of the pier deck and from the top of the partially submerged barge that had temporarily stabilized in calm seas. The barge had severely damaged three of the typical three-pile frames. The damage to the piles immediately below the beams was severe and plainly visible.

The barge lifted one of the beams at a frame at the west extension of the pier. At the other two frames (one at the west extension and one near the

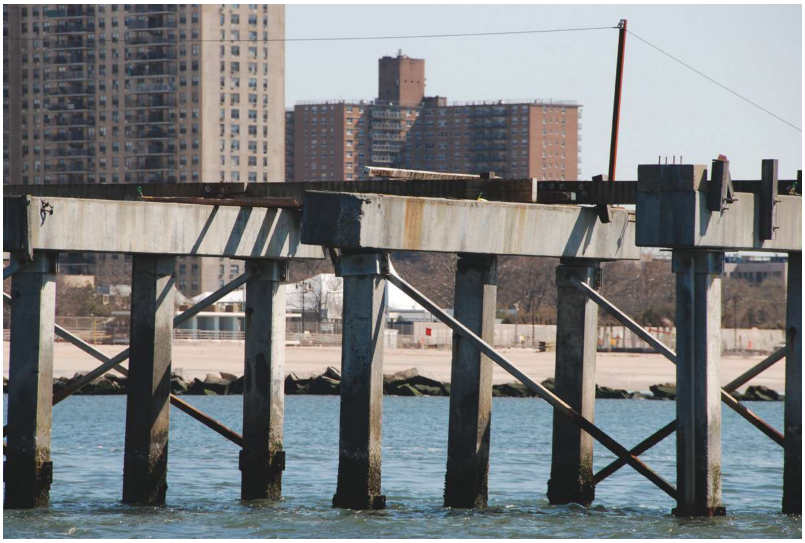

Fig. 4: View of rotated beam at southern tip of pier

Fig. 5a & b: Views of (typical) shear failures at piles

Fig. 6: View of lifted beam at west extension of pier

southern tip), the entire frame assembly was displaced at the top (as seen with the naked eye) from its original position. At all three locations, the impact of the barge imparted large lateral forces on the frames, resulting in lateral displacement and shear failures of the piles in a zone directly below the beam. Large horizontal cracks running completely through the pile cross-section, along with associated concrete spalling and lateral displacement across the pile axis, provided evidence of shear failures. The condition of the piles below the waterline remained unknown (Fig. 4 through 6).

Poor weather and difficulty finding an appropriate boat that could navigate between the piles delayed the investigation until April 25, 2013. While on site, the boat was positioned between and against the piles, making hands-on surveys possible from the deck of the boat. Ground penetrating radar (GPR) determined the locations and typical configurations of reinforcement. GPR results were confirmed, along with the sizes of reinforcement, at the concrete spalls caused by the barge impact. Portions of the piles accessible above the waterline were also sounded to survey for damage or delaminations not visually apparent. This hands-on survey from a boat indicated that significant distress to the piles above the waterline was only at the plainly-visible distressed zones (Fig. 7 and 8).

During the hands-on survey, damage to the piles immediately below the beams was found to be significant, and that any repair scheme would require removing and reinstalling the beams. Following the hands-on survey, the contractor was directed to remove the beams in preparation for repair work.

In parallel with the investigation above the waterline, two independent engineering firms conducted multiple underwater surveys of the potentially-damaged piles. The firms made several dives at the affected portions of the pier to survey the condition of the piles below the waterline. Underwater surveys revealed some abrasion damage to the piles. The divers characterized the abrasions as scrapes 2 ft (0.6 m) long, 2 in (51 mm) wide, and up to 1 in (25.4 mm) deep. However, the abrasions did not expose any reinforcement, and none of the underwater surveys revealed any notable structural damage to the piles. Upon completion of the underwater surveys, the investigations above and below the waterline did not contradict the initial assumption— the affected piles were locally damaged directly below the pile cap but, otherwise, were in good condition.

The condition of the piles below the mudline; however, still needed to be evaluated. Because of the significant horizontal displacement of the piles, the project team recognized that it was possible the piles had been overstressed at their point of fixity somewhere below the mudline.

Non-destructive testing (NDT) was to be used to determine pile conditions below the mudline. The plan was to remove the beams from the affected piles and perform sonic-echo impulse-response testing of the piles. Shortly after removing the first beam, a damaged pile tipped over and sank into the water. Considering that pile damage below the mudline may be more severe than originally suspected, the project team decided not to proceed with the NDT work, and to instead assume that the affected piles were badly damaged below the mudline. The project team also wanted to avoid the risk of delays to the overall project schedule if NDT was inconclusive.

Additionally, shortly after the pile tipped, the owner directed the project team to remove all of the affected piles and physically inspect them on a barge. If the piles were determined to be undamaged, they could be reused, or alternatively, new piles could be installed in their place. Again driven by the project schedule, the project team decided to install new piles. The project schedule no longer had time for the additional inspection, testing, analysis, coordination, and repair that would be required to potentially preserve the affected piles. Design of new piles, with the same or greater capacity as the existing undamaged piles, was chosen as the path forward.

Repair Analysis And Design

The initial analysis was based on visual observations above the water line and assumed that repairs to the piles would need to extend down the prestressed concrete piles several feet below the pile cap. Because the prestressed piles utilized bonded tendons (seven-wire strands) as reinforcement, there was no reliable means to transfer moment through the interface between the new repair and existing pile. Further complicating any repair scheme was the small cross-section of the pile (16 in [406 mm] square), and shear transfer across the interface using added reinforcement bars or dowels would be limited by edge distance. This complicated the transfer of lateral loads and the design of any repair to the damaged piles.

The initial repair design assumed the lower portions of the affected piles could be reused. The repair would consist of connecting the existing beam, using a full-moment connection, to three new stub piles extending down to a point below the shear failures of the existing piles. The tops

Fig. 7: Sounding at affected piles

Fig. 8: Ground-penetrating radar (GPR) at affected piles

Fig. 9: View of damage to affected piles, after removal, below mudline

Fig. 10: Overview of driving new replacement pile

of the existing piles would be selectively demolished and the stub piles would be connected to the existing piles to transfer only shear and axial loads. This initial repair design would effectively shorten the length of the existing piles and upgrade the pile-beam connection from a pinned connection to a full-moment connection. Development of this repair design stopped shortly after an existing pile tipped following removal of the beam. Following the pile failure, and as directed by the owner, the contractor removed and surveyed the affected piles on a barge. At previously-unseen areas below the mudline, the piles exhibited notable damage, such as cracking through the full cross-section, further confirming that the initial repair design would not correct all of the damage (Fig. 9).

New piles and beams were fabricated during removal of the existing piles. Generally, the new piles and beams were designed to be identical to the existing. However, by modifying and implementing some of the detailing planned for use in the initial repair scheme, a precast concrete solution was created to develop the full flexural strength of the new piles at the connection to new beams. The connection used couplers at the end of four threaded No. 10 bars which were cast into the top of each pile. After driving the pile (Fig. 10) and demolishing the tops of the piles to the same elevation, the threaded bars were carefully exposed and couplers used to connect stub lengths of threaded No. 10 bar up through the beam, terminated with nuts and washers atop anchor plates located within the beams. Each pile-to-beam connection was then grouted together using a rapid-strength-gain repair mortar on site, following assembly (Fig. 11 through 13).

Conclusion

The project evolved quickly and the field investigation was complicated, often overridden by coordination and schedule concerns. Because of the aggressive schedule, the decision to forego additional investigations and replace the damaged piles and beams in-kind ultimately proved to be the right choice, especially considering the significant damage to the removed piles. Several technical investigations would have been required to confidently determine the condition of the affected piles and at least several new piles would have been required. The immediate tipping of an affected pile, after removal of its associated beam, provided the most conclusive information, and confirmed the project team's decision and path forward.

Over the course of the project, multiple repair options were designed for various and constantly evolving scenarios. The final design replaced the prestressed concrete piles and precast, conventionally reinforced beams in-kind. However, because of the development of other repair options, improved detailing was implemented and resulted in the final design. ■

Fig. 11: Pile-beam connection prior to assembly

Fig. 12: Pile – beam connection after installation of threaded bars, couplers, plates, washers, and nuts

Fig. 13: Pile – beam connection after grouting with rapid-strength-gain repair mortar

References

1. *Wave Heights—Hurricane Sandy 2012*. Wave Heights—Hurricane Sandy 2012 Dataset, The National Oceanic and Atmospheric Administration, Sept. 26, 2014, Web: January 24, 2018, https://sos.noaa.gov/datasets/wave-heights-hurricane-sandy-2012/.

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