Introduction

Increased marine borer activity in urban waters as a result of recent clean-up efforts has caused major economic and safety impacts on old waterfront structures. Significant portions of these structures were built on timber piles when there was little or no risk of marine borer attack. Many of these structures are still in use today. This paper depicts the inspection, evaluation, partial collapse as a result of marine borer attack, and subsequent replacement of a 193 meter long timber pile supported low-level relieving platform in New York Harbor. The example is particularly important because the critical condition of the dock was assessed and documented by an inspection team of professional engineers and engineer-divers prior to the collapse. Shortly after the submittal of the inspection report to the client, one-third of the dock collapsed. Fuel-oil unloading at the dock was immediately terminated after the
collapse, imposing a major economic burden on the power generating station that was dependent on receiving oil via the dock.

In the following sections, a general description of the dock, the inspection results and subsequent structural evaluations, and the post-collapse field inspection evidence to describe the partial collapse mechanism are given. Then, the fast-track design effort to replace the dock and the accelerated construction schedule are discussed.

**Description of the Dock**

The low-level relieving platform type dock was constructed in the late 1920’s. It was 12 m wide, 193 m long, and supported on approximately 2,200 timber piles. Photo 1 shows an overall view of the dock in the late 1980’s and Figure 1 depicts a typical cross-section. The distance between the mudline to pile caps in front of the dock ranged from 6.0 m to 7.6 m. The pile bents were typically spaced at 1.2 m on center in either direction. The piles framed into 305 mm by 305 mm timber pile caps which supported a 380 mm thick concrete deck slab. Earth fill was placed above the concrete deck to raise the elevation to the design elevation. A massive concrete fascia wall along the offshore face of the dock retained the fill. Inland of the dock, a timber sheet pile bulkhead was constructed to retain earth. The area behind the timber bulkhead was filled with imported construction debris and large rock fragments excavated from New York City subway tunnels at that time. The dock diagonally abutted another low-level relieving platform on its eastern end, which was similar in construction.

The dock was inspected prior to the addition of two marine unloading arms (MUAs) in the late 1980’s to offload No. 6 fuel oil from barges and tankers for the power generating plant. The majority of the timber piles in the first two offshore rows were found to be deteriorated, and were subsequently repaired by cutting the deteriorated timber pile tops and adding timber posts. The splice was then strengthened by fishplates on both sides of the post. Timber pile caps were amputated at these locations and the bearing of the repaired piles on the concrete deck was provided by means of timber wedges.

A small reinforced concrete loading platform at the center of the dock and two breasting dolphins were added to the dock later. The 6 m long platform was cantilevered 3.7 m off the concrete fascia wall. Berthing of tankers and barges was accommodated by means of the breasting dolphins. They were supported on 4.6 meter concrete caissons and located at approximately 30 m on either side of the loading platform. The concrete caissons were 5.3 m in front of the fascia wall and were equipped with panel fenders. The navigational water depth at the fender line was 9.8 m at mean low water (MLW). The remainder of the dock was protected from small vessel impact by timber fender piles. Bollards mounted on the fascia wall served for mooring of berthing vessels.
**Inspection and Condition Evaluation**

Initially, inspection of the dock at the loading platform area was requested by the client when the plans were being developed to install two more MUAs for the new power plant that was under construction in 2002. It was advised to the client, however, that marine borer attack on old waterfront structures in New York Harbor, like this dock, could suffer significant damage to the load bearing system and it would be better to inspect the whole dock to assess the overall safety. As a result of this recommendation, the scope of inspection was increased to cover the entire dock area.

The degree of marine borer infestation, remaining element sizes, structural connectivity between element, and signs of overstressing of the reinforced concrete deck were visually checked during the inspection. Section measurements were taken for all of the piles and pile caps that were accessible to the engineer-divers. The diameters of the piles were measured below the pile cap, midway between MLW and the mudline, and approximately 0.5 m above the mudline.

Statistical and structural analyses were performed on the collected data. The timber piles and pile caps had lost significant section due to marine borer infestation. The average estimated initial pile diameter of 330 mm was reduced typically to 230 mm. The condition of the timber pile caps was even worse, as illustrated by Photo 2. Ninety percent of the connections between the pile caps and piles were theoretically either marginally capable or incapable of supporting the design load, which was estimated by addition of the dead load and a uniformly distributed live load of 5 kPa. The timber wedges which had been inserted between the repaired piles and the concrete deck were largely deteriorated.

In the structural analyses allowable compressive stress parallel to the grains for treated Southern Yellow Pine was assumed to be 6.9 MPa (AITC, 1994). Typical structural capacity calculations for timber piles can be found elsewhere (e.g., AITC, 1994). The results of the analyses are presented graphically in Figure 2, which reveals that the first three offshore rows of piles were on the verge of exceeding their capacities. The dock was in critical condition and there was a significant possibility of collapse.

The timber sheet pile bulkhead that retained the earth and imported fill material inland of the dock was also severely deteriorated. Large cavities were observed behind the bulkhead at accessible locations. The deterioration of the timber sheet piling was the reason for ongoing sinkhole development upland of the dock, and it was expected that the development of sinkholes would continue.

In June 2002, inspection findings were reported to the client. Understanding the critical condition of the dock, the studies were immediately began to identify the most feasible repair/replacement solution to be implemented in order to minimize the impact to the electricity generating operations.
Partial Collapse of the Dock

On August 28, 2002, the western one third of the dock collapsed at low tide while the parties involved in the project were in a pre-design meeting at the site. The dock was immediately removed from service until the replacement dock could be constructed. On September 4, 2002, an emergency inspection team of engineer-divers inspected the debris field and assessed the condition of the remainder of the dock. Inspection revealed that massive pieces of the collapsed portion of the concrete fascia wall were on the river bottom. Most of the timber piles supporting the collapsed portion of the dock were broken and scattered on the river bottom, as was the earth fill on the dock.

Based on the observed orientation of the concrete fascia wall pieces, it was believed that the collapse was triggered at the western end of the dock due to severely deteriorated piles and pile caps. Crushing of the supporting piles and pile caps caused the western end of the fascia wall to rotate offshore and collapse. Construction joints on the concrete fascia helped the massive wall break into pieces. Progressive collapse was stopped by the restraining effect of the western breasting dolphin caisson, preventing damage to the MUAs and miscellaneous equipment located in their vicinity. The MUAs and miscellaneous equipment were removed from the dock following the collapse to be re-utilized on the replacement dock.

Repair and Replacement Alternatives

The conditions of the dock after the partial collapse necessitated immediate rehabilitation of the dock for continued safe operation. Most of the timber pile caps were already in critical condition and continued marine borer infestation would cause additional section loss which would likely trigger another collapse.

Three alternatives for rehabilitation were being evaluated prior to the partial collapse at the dock. All three included replacement of the existing timber bulkhead. The first alternative involved repair of the timber pile caps and timber piles by encasing them in concrete. Wrapping timbers with impervious sheets was not considered because it was not deemed to be effective if standard polyethylene sheets were used, and would be very costly if special measures and materials were considered. Moreover, periodic inspections of the dock would be required if this alternative were chosen. After the partial collapse of the dock, this alternative was rendered obsolete.

The second alternative involved isolation of the central portion of the dock (where the existing and new MUAs to be located), from the remainder of the structure, and rehabilitation of this section by concrete encasement of deteriorated timber piles and pile caps. The remainder of the existing dock would be demolished, and separate breasting and mooring dolphins would be constructed. A relatively shorter service life and required periodic inspections of the facility after the repair resulted in this alternative also not being implemented.
The third alternative was staged construction of a new T-head pier and complete demolition of the existing dock. The client chose this alternative due to its longer service life and lower life cycle cost.

**Conceptual Design and Permitting Issues**

Figure 3 illustrates a plan of the new dock. It consists of a loading platform supported on steel pipe piles, a steel sheet pile bulkhead to replace the existing bulkhead and retain fill, four mooring dolphins supported on steel H piles inboard of the bulkhead, two upgraded breasting dolphins connected to the bulkhead via steel walkways, new product piping, two refurbished and two new marine loading arms located on the loading platform, a ship to shore gangway, a new oily water collection and treatment system, a new fire protection system, a new steam line, and a new electrical distribution system.

A variety of federal, state, and local agencies were involved in the permitting of the new facility. To expedite the construction schedule, the client initiated the preparation of permit applications during the development of the concept design. All federal, state, and local agencies involved in permitting the new dock were contacted, and their specific requirements were incorporated into the concept design. The types of permits required for this project can be divided into three basic categories - environmental permits, navigation permits, and permits related to public health and safety.

Environmental permits are issued on both the state and federal levels. The key agencies involved were the New York State Department of Environmental Conservation (NYS DEC), U.S. Army Corps of Engineers (USACE), and the New York State Department of State (NYS DOS). The USACE and the U.S. Coast Guard (USCG) have primary responsibility for regulating navigation. Permits related to public health and safety included work permits and other approvals, and are issued on the federal and local levels. The agencies involved included the U.S. Coast Guard, the New York City Department of Business Services (NYC DBS), and the Fire Department of the City of New York (FDNY).

The USACE, NYS DEC and FDNY permits were the most critical in scheduling of the project. The project was viewed as favorable to the USACE and NYS DEC because the footprint of the new dock over the East River was considerably smaller than the footprint of the old dock. Thus, the USACE and the DEC expedited the issuance of permits.

The FDNY, on the other hand, required many additions and alterations to the original scope of the fire protection system proposed for the new dock. The FDNY required that the new fire protection system should cover the entire deck of the largest tanker that would supply oil to the dock. This required special fire monitors with longer reaches to be installed along the new bulkhead. In addition, the FDNY required redundancy in the fire protection system for both the electric power and water source.
As a result of this requirement, a 454 m$^3$ supply water tank and a diesel generator were added to the scope of the project.

**Detail Design and Construction**

In order to continue generating electrical power during the dock downtime, the client managed to secure an arrangement with a neighboring fuel oil company for temporary deliveries via pipeline. In order to expedite the construction of its new facility, a select number of pre-qualified marine contractors were invited to bid on the project as the detail design was evolving. Meetings and site visits were held with each bidder, and they were advised of the scope and schedule constraints. Moreover, long-lead items such as steel sheet piles, new MUAs, the ship access gangway, fire monitors and pumps, fender units, quick release hooks, and the oil containment boom were pre-purchased by the client.

Installation of the new steel sheet pile bulkhead was critical to the project schedule. In addition to a soil boring program, a series of probes was drilled along the proposed new sheet pile bulkhead line. This enabled identification of rocks and boulders which could make the sheet pile driving difficult and have a negative effect on the project schedule. The probe results were incorporated into the contract documents and the bidders were advised that pre-excavation of all obstructions was required prior to the sheet pile installation. This avoided related claims and potential delays during the construction.

A contract was awarded to the lowest bidder who mobilized to the site on May 12, 2003. According to the baseline schedule proposed by the contractor, the new dock would be completed and in service by December 31, 2003. Photos 3 through 7 illustrate the construction work.

**Conclusions**

This paper demonstrates the extent of the threat imposed on urban waterfront structures by marine borers. A significant number of similar structures in New York Harbor and other locations are at risk. However, the level of risk cannot be readily quantified unless a detailed inspection and evaluation is performed, as was the case discussed in this paper. Timely inspection and preparation of contingency plans as a result of this inspection significantly reduced the downtime of the fuel offloading facility which is a vital component of the electricity generating operations.

**References**

Figure 1. Typical Cross Section of Relieving Platform

Figure 2. Current Average Available Capacity of Timber Piles
Figure 3. Plan View of the A-10 Dock Replacement
Photo 1. Overall View of the Dock in the Late 1980s

Photo 2. Typical Extent of Deterioration at the Pile Caps

Photo 3. Completed Sheet Piling and Mooring Structures at Western End of Site
Photo 4. Pile Driving at Loading Platform

Photo 5. Overall View of Upland Work

Photo 6. Loading Platform Deck and Sheet Pile Bulkhead with Fascia Beam