An Innovative Design for the Flood Protection System of a Riverside Development

The use of steel barrier gates raised by cranes, counter-flooding and an early warning system combine to provide reliable and cost-effective flood protection.

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Located on approximately 3.5 acres along the shores of the Potomac River, Washington Harbour is a development with shops, restaurants, an office building and condominium complex, and a 580-car underground parking garage — all sharing a common foundation (see Figure 1).

One of the most innovative features of the development's design, and vital to its success, is virtually invisible to the casual observer. There are 50 floodgates hidden in vertical pockets beneath Washington Harbour's plaza. These retractable, watertight floodgates protect its people and property without obstructing its scenic view or public access to the river. During major floods, a counter-flooding system balances the hydrostatic uplift that accompanies the rising water.

Project Requirements

Even during the planning and approval process for the development, flood protection was a primary concern. A well-organized opposition, intent on preserving the site as a waterfront park, made flood protection issues the cornerstone of their objections to the development. They argued that it would be effectively impossible to isolate the development, and the people it was intended to attract, from a rising Potomac.

In addition, a geotechnical investigation of the site revealed an aquifer running to the Potomac beneath the proposed development. In the event of a major flood, the hydrostatic uplift forces that would develop would exceed the dead weight of Washington Harbour's structures and would, in effect, cause the complex to float.

As a result, the developers were required to perform an extensive hydraulic study that en-

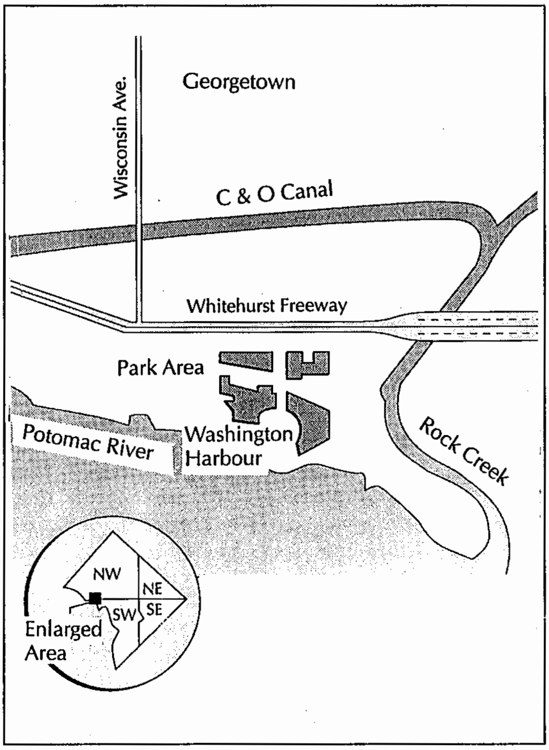

FIGURE 1. Location of the development.

compassed the following:

- Established the 100-year flood level;
- Devised measures to protect the complex and its occupants against a 100-year flood and determined the types of flood barriers and their location;
- Developed a system to neutralize the effects of hydrostatic uplift; and,
- Designed a flood warning system that would provide enough time to make the flood barriers operational.

Study Phase

Working with the civil engineering consultants for the development and Dr. Ron Steinberg of the University of Maryland and using a combination of riverine flow and tidal surge data, consulting engineers for the project determined the elevation of a 100-year flood to be 17.25 feet (MSL). This conclusion was relayed to the Federal Emergency Management Administration. Based on information provided by river gages upstream of the development, this study to establish the 100-year flood level also revealed that, given the configuration of the Potomac River basin and the location of the development, there would be a warning of at least eleven hours of an impending flood.

Flood Barrier Design

Washington Harbour's design called for its retail facilities to be located at the plaza level. Taking this siting into consideration, the engineers worked with the development's architects to define areas where elements of the building could be sited above the 17.25-foot flood elevation. Doing so permitted the building wall to serve as its own flood barrier and ensured that the public would have immediate access to the water — there would be no intervening barriers between the building and the river.

During periods of high water, the complex becomes an island. As Figure 2 illustrates, flood barriers were required for such access points as Virginia Avenue, the entrance to the parking garage, service entrances, and for the decorative windows and main entrance fronting "K" Street.

Several alternatives were considered during the process of developing the design approach to the flood barriers. These alternatives included steel barrier gates, mechanized lift gates, swing gates, inflatable rubber dams, and such conventional measures as stop logs and sand bags. Steel barrier gates proved to be the best alternative since they offered a number of advantages:

- They could be unobtrusively stored in vertical pockets immediately below the surface and encased in a decorative cover;
- They could be sited at the precise location in which they would be needed in the event of a emergency;
- Their operation would be simple and reliable — unlike the horizontally-stored mechanized gates that were also considered but rejected as too complex; and,
- Comparatively little manpower would be required to get them in position.

Adapting technology from nuclear containment plants and working with a floodgate manufacturer, the engineers developed an in-

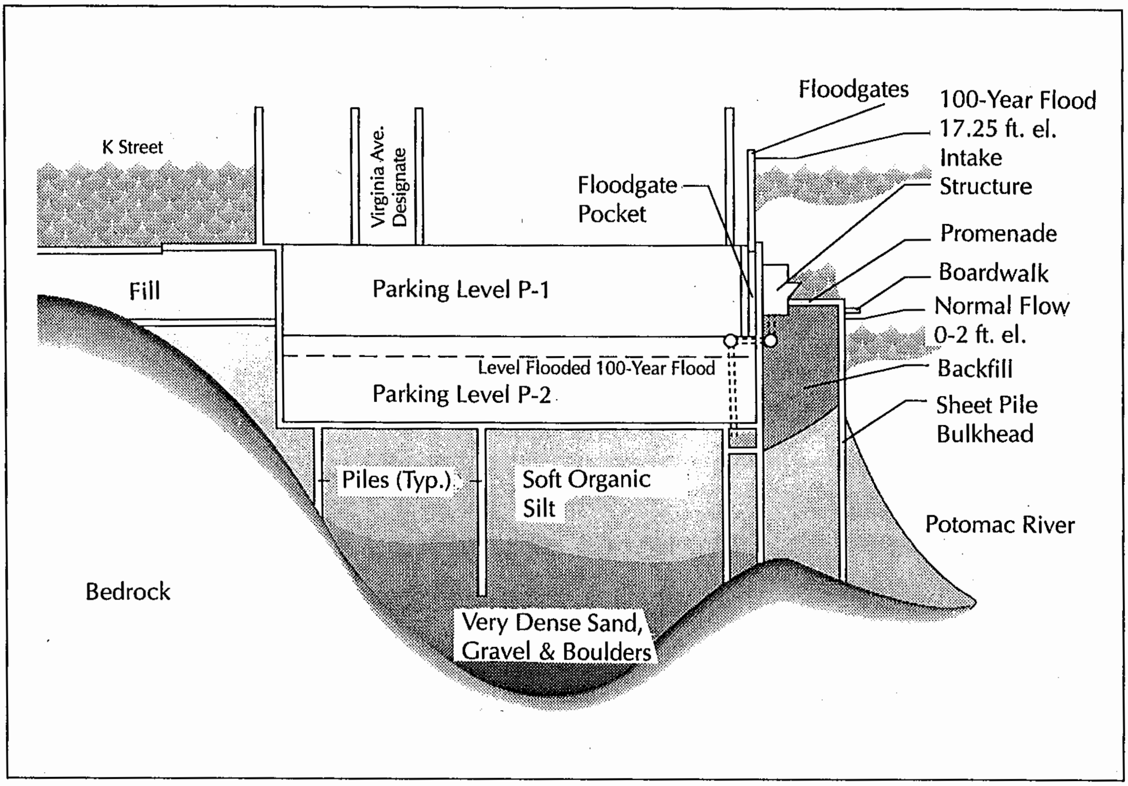

FIGURE 2. Cross section of the development's flood protection system.

novative design solution for Washington Harbour's floodgates. The prototype gate is equipped with two inflatable seals, each designed to withstand the pressures of a 100-year flood. Running continuously around the edges of the gate, these seals provide a watertight barrier when the gate is in its raised position and the seals are inflated. The force of the water on a third P-seal on the back side of the gate effectively ensures that no water whatsoever can get through the floodgate to reach the land side of the development. The water presses the gasket against a steel plate. The steel seal locking device for the floodgate is shown in Figure 3.

For safety reasons, the gates were designed to be locked into place at full height (see Figure 4). The gates slide on channels hidden in decorative pylons, similar to casement windows. Construction of the channels and pressure plates must be exact since the tolerances are small.

Building walls serve as a flood barrier wherever possible (as Figure 5 shows). The walls and the floodgates together provide a 960-foot floodwall around Washington Harbour. In one area, a gate runs continuously for 590 feet. Ranging from four to 26 feet wide and four to 12 feet high, the floodgates are some of the largest and heaviest ever installed anywhere.

To preserve the architectural aesthetics of the development, the gates are hidden between concrete pylons disguised as ornamental columns. When a flood warning is issued, a crane lifts the gates from their concealed pockets, sliding them up within channels in the pylons. Once the gates are raised, their seals are inflated by a portable compressor.

Counteracting Hydrostatic Uplift

At six feet above the flood stage, the hydrostatic pressure created by the rising water is enough to float the dead weight of the Washington Harbour development. Several alternative methods of counteracting this condition were considered.

Slurry Wall. The first alternative considered was to reduce groundwater intrusion by con-

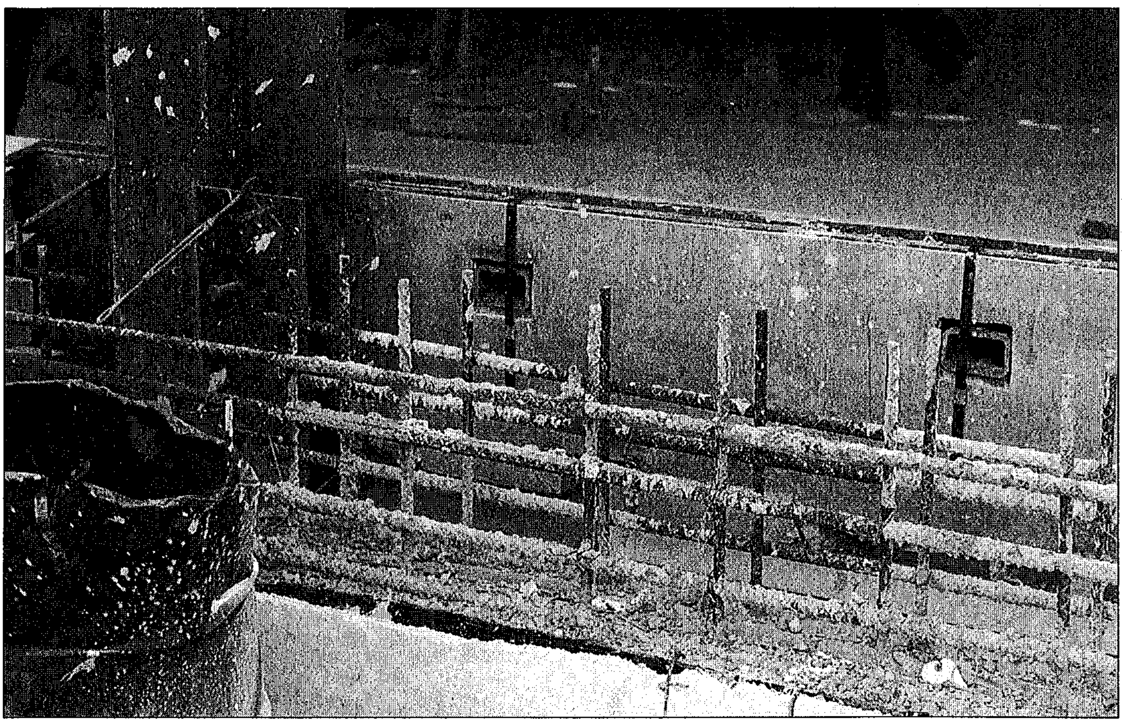

FIGURE 3. A view of the steel seal locking device for the floodgate.

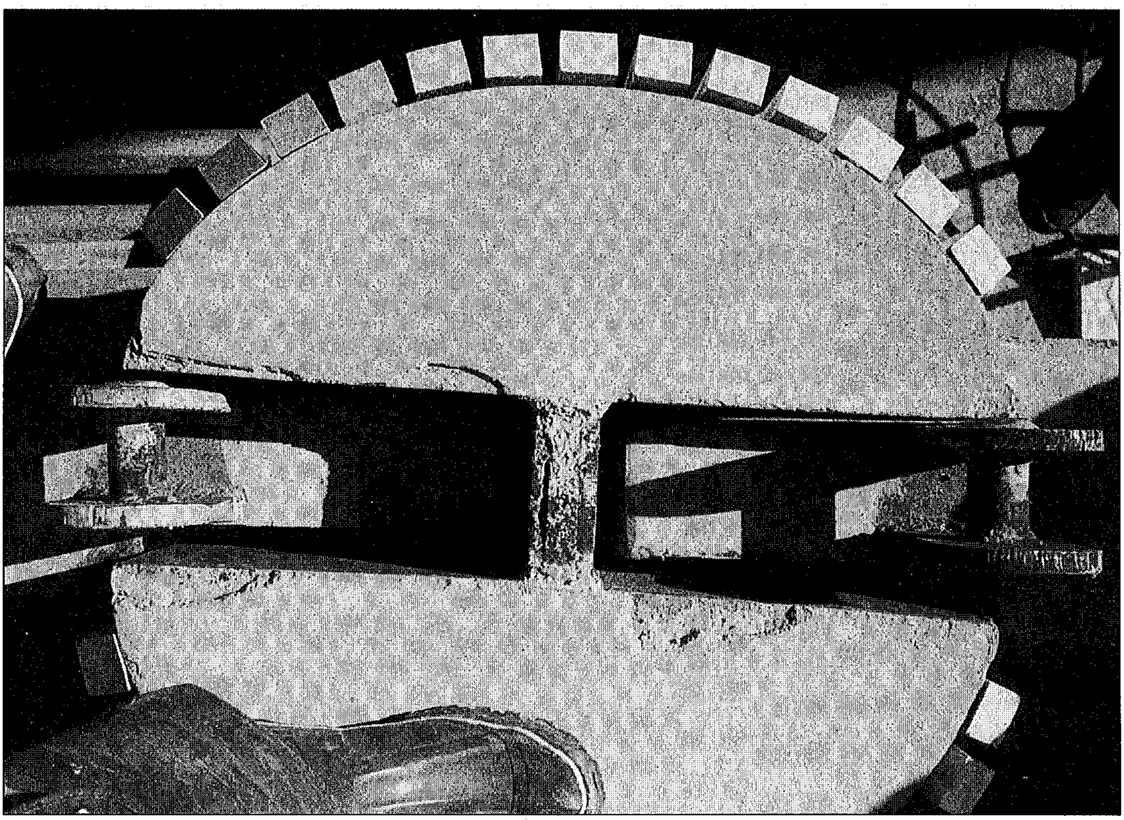

FIGURE 4. A view of the floodgate pylon with the gate in locked position.

structing a slurry wall surrounding the development to isolate it from the river. It was estimated, however, that this alternative would escalate the project budget beyond acceptable limits and delay the schedule by at least nine months since no other work could begin until the slurry wall was in place.

Tie Downs. The use of tie downs, anchored and tensioned in the bedrock, in combination with piles was also considered. This approach was rejected because it was discovered that a "bedrock canyon" ran underneath the site. This feature increased the number of piles that would be needed to resist tie down tension. Moreover, maintaining uniform tension during major floods in an area where rock depths varied from 25 feet to more than 90 feet presented very significant problems.

Relief Wells and Subdrains. A third approach to neutralizing hydrostatic pressure under the development consisted of installing a series of two-foot diameter wells with 12-inch diameter casings and ten feet of well screen designed and constructed to accommodate groundwater flows generated by a 100-year flood. These wells were to be connected to five sump pumps constructed in the lower basement level of the development: three on the river side, and one at each corner on the "K" Street side. As groundwater rose, it would be concentrated at the wells, drained to the sumps and pumped off. While the system would have been reliable, it would have demanded taking steps to mitigate settlement that could have occurred adjacent to the building.

Counter-flooding. The most cost-effective method of neutralizing hydrostatic pressure proved to be a carefully controlled system for counter-flooding the lower level of the parking garage. This system provides built-in redundancy and a safety factor of two in overall systems. Redundancy is created by using three intake structures instead of just one large structure and by using two 16-inch diameter pipes instead of one 20-inch pipe leading from the intake structures to the P-1 parking level. Control valves on these two 16-inch pipes can be operated either manually or by electric motor and are located for easy access. The piping system leads also to the P-2, or lower garage, parking level and discharges into a trench to dissipate water energy in a controlled flow.

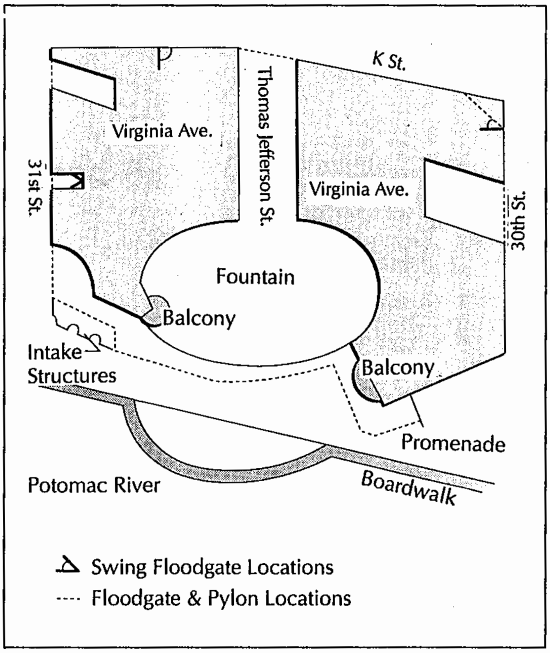

FIGURE 5. Location of building walls and floodgates.

As Figure 6 shows, the intake structures of the counter-flooding system are located below benches outside the floodgates surrounding Washington Harbour. To prevent debris from entering the garage, the intake structures take water from two to four feet below the debris-filled surface of the flood waters. Inflow velocity is low to prevent debris being sucked into the intakes. Standard two-inch catch basin screens help filter out any debris that is caught. The screens are also slanted to allow debris to drop off. Figure 7 shows a detail of the intake structure.

The thickness of the bottom slab of the lower parking garage was sized so that there would be enough dead weight to resist the hydrostatic pressure of flood water rising to the 10-foot elevation. Above the 10-foot elevation, ballast water is introduced into the the lower parking garage in quantities that correspond to the rise of the river. No more water is introduced than is required to balance the flood level of the river. For the last 6.9 feet above the 10.35-foot elevation (up to the 17.25-foot 100-year flood elevation), an inch of water is introduced into the garage for every inch that the river rises.

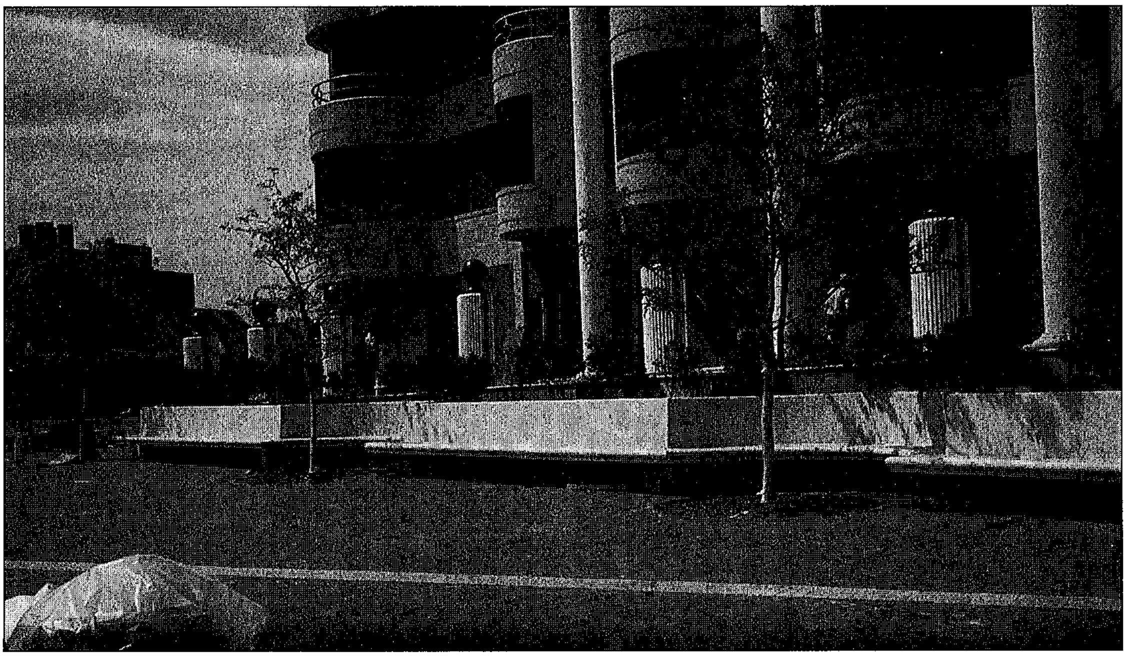

FIGURE 6. A view of the intake structures.

The water ballasting, combined with the 10-foot resistance provided by the oversized bottom slab, yields the 16.9 feet required to resist the hydrostatic pressure of a 100-year flood.

Once the floodwaters have receded, the inundated parking levels are pumped out using two 800-gallons-per-minute pumps located in the southwest corner of the complex. After a 100-year level flood, it will take approximately three and a half days to evacuate the eight million gallons of water needed to offset hydrostatic pressure from the garage.

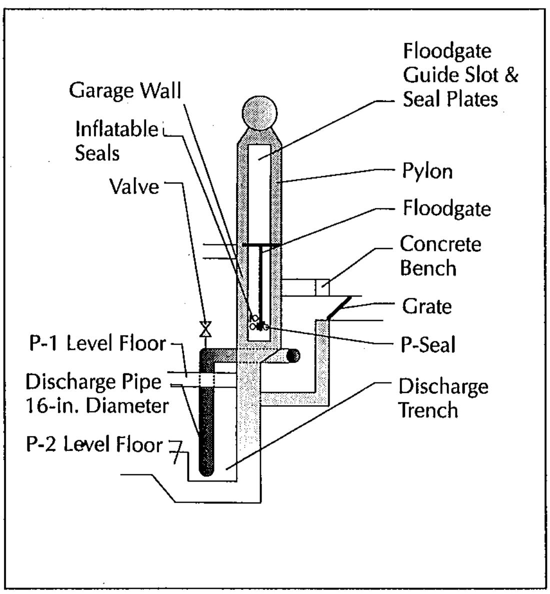

FIGURE 7. Intake structure detail.

Flood Warning System and Operation

Flood Warning System. For Washington Harbour's flood protection barrier to be effective, systems have to be in place in order to provide adequate warning of an impending flood. The National Weather Service (NWS) tracks all storms, predicting their intensity several days before they reach the area. The larger the storm, the longer it is tracked. The NWS also gathers data from numerous gages along the Potomac. These data, along with predicted rainfall within the drainage basin, are used to generate a flood prediction computer model. Warnings are issued to property owners as soon as the computer model indicates that flood water will exceed elevations at given sites.

The effectiveness of the NWS's flood prediction and warning system was demonstrated four times during the construction of the Washington Harbour development. On each occasion the early warning gave the contractor the

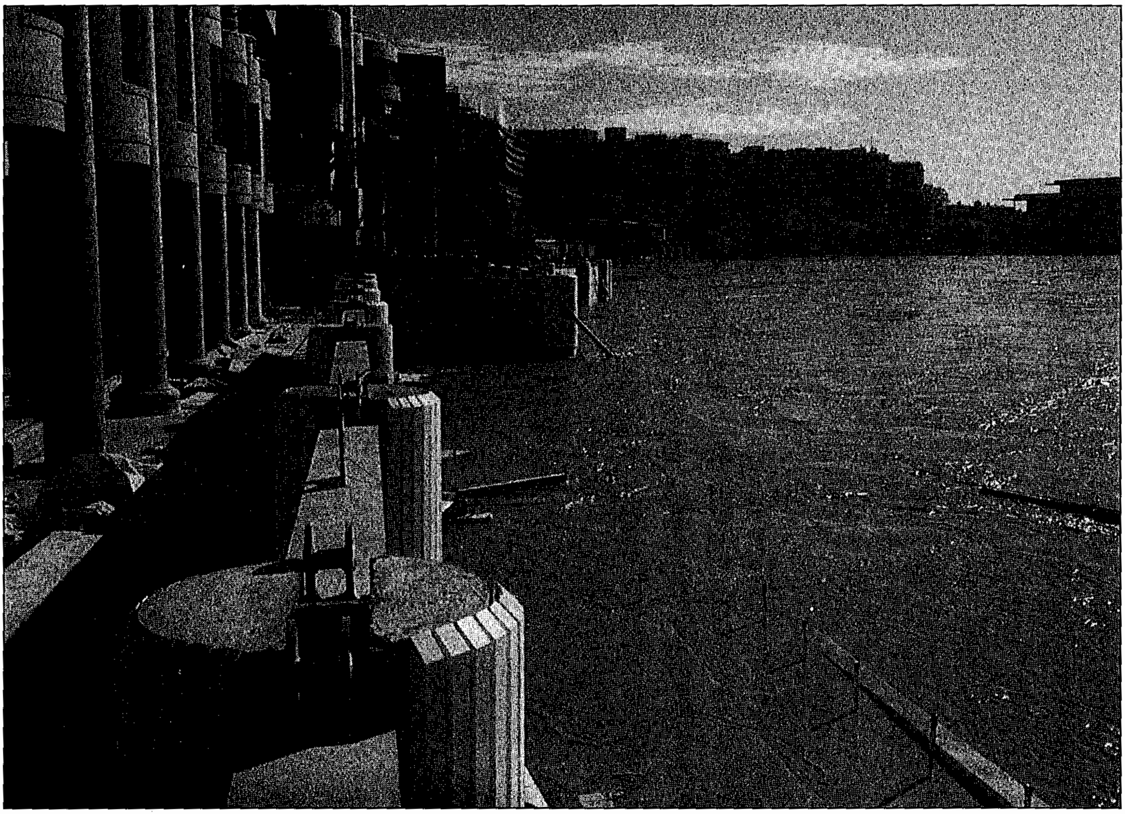

FIGURE 8. A view of the floodgates in operation.

lead time needed to prepare for the floods (Figure 8 shows the barriers in place during one of these instances).

On one occasion, when floodwaters exceeded the 12-foot elevation, the contractor received a warning that gave sufficient time to contact the Washington, D.C., electric company in order to request that Washington Harbour's power supply be isolated from the rest of the city's electric system. Doing so usually takes 24 hours. That the NWS was able to provide flood alerts so far in advance of the event is a testament to the accuracy and effectiveness of the warning system.

Warning System Design and Operation. Based on NWS data, it was established that a six-hour warning would be issued for small tidal surges while riverine flooding would be preceded by a minimum eleven-hour warning. A variety of alternative methods for lifting the flood barriers, inflating their seals, and locking them in place within these times were considered. They included hydraulic systems, permanently installed chain hoists and come-alongs designed to complement the marine theme of the plaza, and crane/fork lift systems.

Hydraulic systems were rejected because their reliability would be adversely impacted by the infrequency of their use. Chain hoists were deemed to be too laborious and too slow to get all floodgates in position in time. Moreover, it was doubtful that chain hoists could keep the gates level as they were being raised to avoid wedging or that, in the event that they did become wedged, they could break them free.

The developers ultimately decided that the most effective way of putting the floodgates in place was to raise them with a crane. Experienced crane operators and riggers can center the hoist to minimize the chances of wedging the gates in their slots while a crane provides sufficient power to dislodge a gate if it does become wedged.

The decision to raise the gates by crane has proved to be a wise one. The crane, which must be stored off site, can be mobilized and then all the gates around Washington Harbour raised within a couple of hours — well within the warning window provided by the NWS.

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