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Shoring Design For Pier 27 On The Shorelines Of Toronto, Ontario

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ABSTRACT

Pier 27 is a world-class waterfront condominium development located right on the shoreline of Lake Ontario at the foot of Yonge Street in downtown Toronto. The original Lake Ontario shoreline was located approximately along Front Street. The area from Front Street to the current shorelines was backfilled with landfill in order to create new piers and industrial development. Toronto shoreline's main uses were for waste disposal, fuel storage, and heavy manufacturing.

In 1972, Canada's Prime Minister, Pierre Trudeau announced the seizure of the south industrial lands from Bathurst Street to York Street West through the new Harbourfront Project. The project would convert the land into residential and cultural districts for Toronto including performance stages, art galleries, parks, and boating areas. In 1986, the Toronto Harbour Commission (now the Toronto Port Authority) sold the industrial property east of Yonge Street to private developers. The land has since been converted into Pier 27, a series of condominium towers, overlooking the Harbourfront Project and Lake Ontario.

During Phase 1 and 2 of the development, many costly setbacks were encountered during the shoring installation including water issues, drilling of lateral supports into the timber dock wall, and soil issues related to the backfilled landfill including the discovery of a military artillery cartridge.

The following paper will highlight the issues with developing the downtown Toronto shoreline, a brief history of the shoreline, the shoring design for Pier 27, the challenges encountered during below grade construction, and the recent and future developments.

1 INTRODUCTION

One of the newest world-class waterfront condominium developments in downtown Toronto is Pier 27. It is located right on the shoreline of Lake Ontario at the corner of Yonge Street and Queens Quay. Pier 27 is comprised of two sets of two twelve-storey glass and steel towers with a three-storey bridge connecting the towers at the top. An architectural rendering of Pier 27 is shown below in Figure 1.

Figure 1: Architectural Rendering of Pier 27 (Source: http://www.pier27.ca/)

Historical maps dating back to 1867 indicates that the original Lake Ontario shoreline was located approximately along Front Street. In 1911, backfilling had begun along the shoreline with landfill in order to create new piers and industrial development. By 1913, a new street along Lake Ontario was created called Lake Street (now known as Lakeshore Boulevard). By 1964, the shoreline had moved almost a kilometre (km) from Front Street to just past the street that is now known as the Queens Quay.

The federal government created the Toronto Harbour Commission (THC) in 1911. The THC was responsible for improving decades of poor development on the shorelines. Prior to 1911, Toronto's shoreline was mainly used for the transportation of goods by railroad. Once backfilling began, the shoreline's main uses were for waste disposal, fuel storage, and heavy manufacturing. The backfilling of the shoreline was heavily supported by older wholesale and retail businesses, the service industries, and manufacturing. This support was evident as a result of Toronto's largest source of employment being in the manufacturing sector with approximately 65,000 workers.

During the First and Second World Wars, production on the shorelines began to increase as a result of the demand for war. As a result, these companies started dumping their waste into the lake. By the earlier 1950's, the majority of backfilling of the shorelines was completed to its current location. A section of map showing the approximate shorelines' expansion from 1911 (solid line) to 1964 (dashed) is shown below in Figure 2.

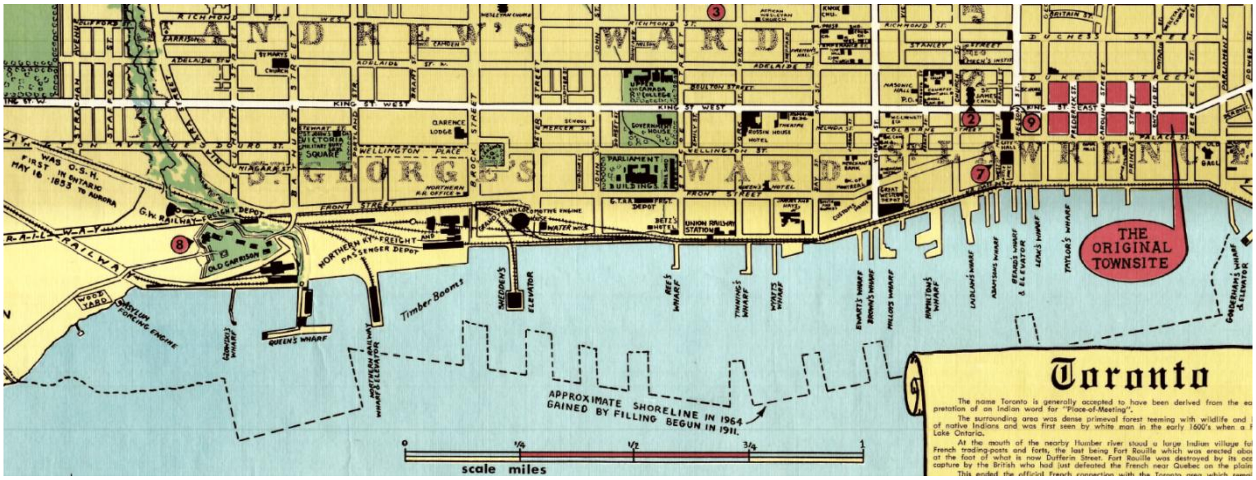

Figure 2: Shorelines From 1911 (Solid Line) To 1964 (Dashed Line) (Source: Ted Chirnside)

After the Second World War ended, no one wanted to live in downtown area of Toronto especially near the shorelines. Society's upper classes began moving north to the cleaner suburbs in order to escape the slums of the industrial core. Once pricing began to drop on automobiles, most of Toronto's downtown residents moved to the outskirts of the City into Mississauga and Scarborough. As a result of these population movements, new major roads and highways were needed to supplement traffic congestion for workers commuting into the industrial downtown.

The new major highway that was needed came when construction started in segments in 1955 on the Frederick G. Gardiner Expressway, otherwise known as the Gardiner Expressway and had finished in 1966. During this time period, most highways were built around the perimeters of cities and if the cities had a large water source nearby, then the highway was built on or near this source. So for Toronto, some sections of the Gardiner Expressway were built right on the shoreline while other sections were built up to 700 metres (m) away from it. This highway spanning from the east end of Toronto to the west end, effectively blocked the public from accessing Lake Ontario.

2 TORONTO SHORELINE FROM 1972

While Toronto began to prosper, the downtown area was finally able to start redeveloping. The industrial companies along the shorelines began to searching in the suburbs for cheaper land. As a result of their moves, the shorelines became known as heavily polluted sites with industrial waste and hydrocarbons.

As most major cities around the world began to redevelop their shorelines into magnificent destinations, Toronto lagged behind. Over multiple decades, many individuals, groups, and other interested parties had good intentions to redevelop the shorelines but their ideas never gained traction. Though, one effort succeeded with the development of the Harbourfront Centre in 1972 by Canada's Prime Minister, Pierre Trudeau. He seized the south industrial lands from Bathurst Street to York Street West for the project. The Harbourfront Centre converted the land into residential and cultural districts for Toronto including performance stages, art galleries, parks, and boating areas. Other than this development, everything completed up to 1972 was just planning, reports, and recommendations with no action.

After Trudeau's accomplishment, the CN Tower's construction began when the old railway lines just north of the shorelines was converted for redevelopment in 1972. The CN Tower development allowed for other developments to begin including the Skydome (now Rogers Centre), Toronto Convention Center, many office buildings, and an abundance of residential condominium towers. All these new developments occurred north of the Queens Quay and therefore, the shorelines still remained undeveloped.

In 1986, the THC sold the industrial property east of Yonge Street to private developers. This began the long battle for development of this area with the citizens of Toronto as many people opposed losing the view of the lake to more condominium towers. Many people were still upset with the Gardiner Expressway and this development was another nail in the coffin for the view of the lake. After many attempts to gain traction from public outcry and government interference, Pier 27 was finally given the green light to start construction in 2007 after the developers granted the public free access to the shorelines with new nature parks and recreational areas.

3 PIER 27 SHORING DESIGN

Shoring design in geostructural engineering consists of shoring systems and lateral support systems. The systems are designed using geotechnical reports and design parameters based on the lateral earth pressure coefficient (K), unit weight of soil (γ), depth of excavation below grade (H), and any surcharge loads (q), water issues, sensitive structures or utilities, and other design specific concerns or issues.

Shoring systems include soldier pile and lagging, caisson wall, shotcrete, or sheet piling. Lateral support systems are commonly used to provide lateral support to the shoring system by using tiebacks, soil nails and rock pins, walers, rakers, corner braces, and struts. The testing of tiebacks, soil nails and rock pins, and the preloading of walers, rakers, corner braces and struts are typically completed to confirm design conformance.

Pier 27's shoring design used caisson wall as the shoring system and two rows of tiebacks, walers, and corner braces as the lateral support systems. Caisson wall is a shoring system that is similar to soldier pile and lagging. Caisson wall is vertically drilled interlocking shafts that have I-beams installed in one shaft with a concrete 'toe' and typically one to two fillers. All the shafts are typically filled with four megapascal (MPa) concrete and the interlock is typically 300 millimetres (mm). Fillers are drilled to the top of the concrete 'toe' elevation using an auger normally drilled first to ensure that the concrete toe is not damaged during the drilling typical caisson wall detail used for Pier 27 is shown below in Figure 3.

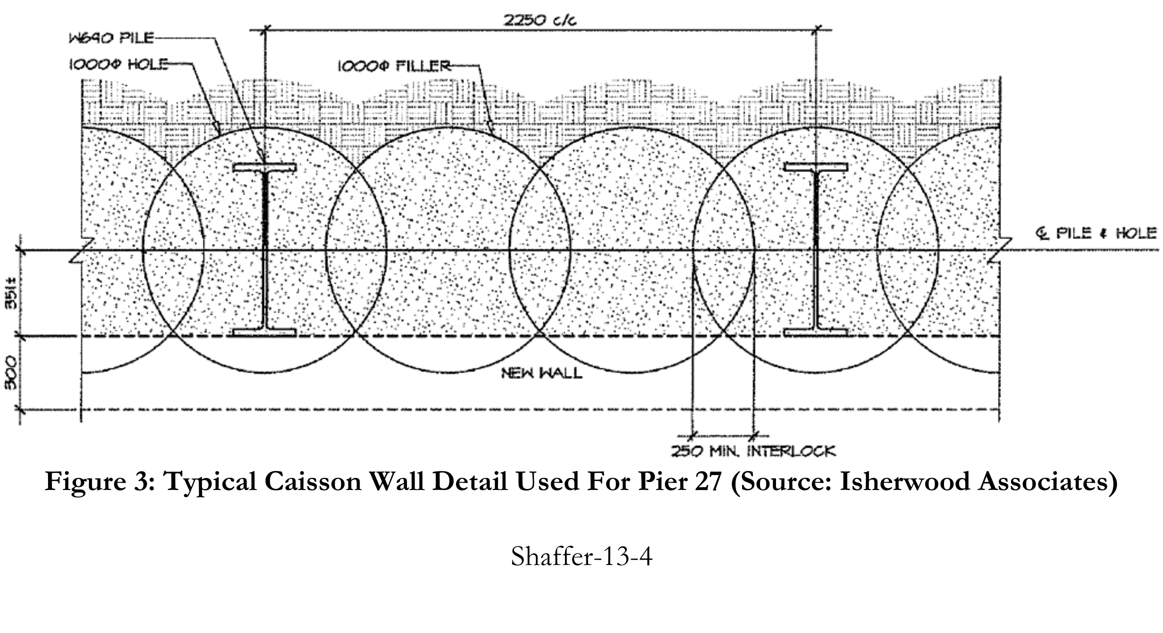

Figure 3: Typical Caisson Wall Detail Used For Pier 27 (Source: Isherwood Associates)

Tiebacks are used as a lateral support system to control the lateral movement of the shoring walls. Tiebacks are installed by drilling a hole at a specified angle and diameter using a line drill or auger. Holes for tiebacks are drilled using appropriate techniques and diameters to suit the geotechnical conditions and shoring design requirements. The anchor zone is filled up with grout and a certain number of strands, depending upon the design load, are placed into the hole. Depending upon the type of tieback, the free zone may be filled up with grout, if a sleeve is used, or bentonite. Also, other certain elements may be installed with the tieback such as a manchette, a half inch polyvinyl chloride (PVC) tube with three valves that break at a minimum pressure of 200 pounds per square inch, or a grout bag; a bag attached to the free zone of the tieback that is filled with grout to prevent water leakage into site.

If the tieback is post-grouted, then after approximately twenty-four hours, grout is pumped into the manchette at a high pressure to break the three valves, creating a bulb for a higher soil adhesion.

A tieback performance test is typically completed on two to three tiebacks per row of anchors. A tieback performance test determines whether the assumption of the design adhesion of the soil is accurate. The tieback would normally be tested to two times the design adhesion which is approximately 200% of the design load.

The stressing of tiebacks is typically completed on all tiebacks. Tieback stressing is very similar to a tieback performance test with the exception that the tieback is normally stressed to 133% of the design load in order to ensure that the tieback will hold and for a proper lock in value for the design load. The loading may be halted at a lower percentage as a result of less than desirable adhesion, connection issues, or poor workmanship. A ten minute creep test is held to ensure the tieback is holding. If the creep value is greater than two mm, then the creep test is held an additional ten minutes or longer to determine if the tieback is slowly pulling out.

Pier 27 used two levels of rock anchor tiebacks that were drilled using auger and grout bags to prevent water leakage into site. Two performance tiebacks were completed at Pier 27 and both indicated the design adhesion was adequate.

There are two different types of walers used as a lateral support system; internal and external. Internal walers are normally used for soldier pile and lagging systems where two tiebacks have been drilled in the same lagging bay. The tieback connections are welded to the internal waler for bracing and the internal waler is welded to the piles. Internal walers are also used in corners on soldier pile and lagging to assist the stabilization of the load of the corner piles. External walers are typically used in combination with external supports such as rakers, corner braces, and struts to help transfer the load to the supports. They may also be used when a tieback is unable to attain the desirable design load.

Corner braces are lateral support systems that are installed in the corners of the shoring system where tiebacks are not practical. They are used in compression to transfer the load from neighbouring piles across the corner. Corner braces can also be used to help transfer the load of external walers to a neighbouring shoring wall. Corner braces may be preloaded.

Figure 4 shows five different photos including unshaved caisson wall, shaved caisson wall and stressed upper tiebacks, grout bags, two levels of external walers, and two levels of corner braces.

Figure 4: Pier 27 From Top Left To Bottom Right, Centre: Unshaved Caisson Wall; Shaved Caisson Wall And Stressed Upper Tiebacks; Grout Bags; Two Levels Of External Walers; And Two Levels Of Corner Braces (Source: Isherwood Associates)

4 PROJECT CHALLENGES

There were a number of challenges and issues which arose throughout the shoring of the project until construction reached grade. Due to the large nature of the site, it required the installation and testing of 550 tiebacks. Of the 550 tiebacks, there were 158 along the south wall of the site which neighboured Lake Ontario. Along this wall were previously installed timber support piles. Since the installation of these timber piles was during the early part of the century, their exact locations and depths were unknown. Therefore, during the installation of tiebacks, holes were abandoned if they intercepted these timber piles. It took up to four attempts to install a tieback per pile as the contractor would try each side of the pile and change elevations until the timber piles were avoided. Installation records show that at least 56 tiebacks were abandoned due to the timber members. Also, the tiebacks had to be installed into the lakebed and the contractor had to ensure minimal loss of grout for the tiebacks from entering the lake during installation. If grout was lost, the tiebacks had a high probability of underperforming.

The second challenge was soil conditions. The soil conditions at Pier 27 were poor due to the backfilled landfill and industrial waste. The Geotechnical Investigation reported finding clayey silt, sandy silt, sand, organics, and local rubble including cinders, slag, and pieces of concrete, brick and wood. The drilling of boreholes encountered large obstructions, including old foundations. There was also a strong hydrocarbon odour detected during the drilling which is indicative of oil spills and contamination. The hydrocarbon odour had the potential for combustion and combustion readings had to be continuously monitored with average readings of 500 parts per million (ppm).

The fill on Pier 27 had maximum shear strength of 20 MPa which was rare on the majority of the site. The average shear strength of the fill was less than 10 MPa. If shale bedrock was not located underneath the fill, tiebacks would not have been possible as the tieback adhesion with the soil would be near impossible. The shale bedrock was at an elevation of 62.0 m which was almost fifteen metres below grade. Therefore the tiebacks had to be drilled at a steeper angle with a larger free zone in order to reach the bedrock.

There was also the surprising discovery of an old military artillery cartridge from one of the World Wars. During excavation, an operator was stockpiling material on site for future hauling when something caught their eye. Once they realized what was exposed, the entire site was evacuated and the bomb squad was dispatched. After several tenses moments, it was determined the cartridge was inactive and posed no danger. As a result, the site was shut down for an extended period of time while crews scanned the site for any other potential hazards.

The third challenge was water infiltrating the site. According to the Geotechnical Investigation, the groundwater infiltration was recorded at elevations of 74.9 to 75.4 m. Lake Ontario's water level was surveyed at an elevation of 75.1 m. The caisson wall fillers had to extend at least 1.5 m into the bedrock shale to prevent the groundwater from entering the site. When the drilling of tiebacks was being completed, grout bags had to be used to prevent water seepage into site and to prevent the water from flushing the grout out of the holes. Many tiebacks underperformed at Pier 27 and it is believed to be due to the water and the grout bags malfunctioning.

The soil conditions discussed in the previous couple paragraphs are also known as poor aquifers and water can easily travel through them once they are disturbed from pile drilling and tieback drilling. Depending upon the dewatering systems efficiency and weather, the soils on site would become saturated and would act like quicksand. Water presence could cause issues with the tieback anchor zones.

A high water level is a problem because it is considered a common issue for poor grout strength in underperforming tiebacks. The grout for the anchor zones can mix with water and lower the grout strength from 25 MPa to nearly zero. Water can also cause the tieback hole to collapse and cause voids and settlement issues. Grout could escape through these voids and not create any adhesion with the tieback and soils.

Dewatering will normally remove the presence of water on site and the tiebacks can be drilled without concern of voids and grouting issues. Pier 27 was dewatered across the entire site from the beginning of construction to the end. There were dewatering pipes at every pile or every three metres. The dewatering system had problems due to the massive size of the site and machinery would also dislodge some pipes, and others would become clogged and freeze in the winter. If a dewatering pipe underperformed, the nearby soil would become a large mud puddle with sinking and suction characteristics which provided a dangerous work environment for the workers and machinery on site.

5 RECENT AND FUTURE DEVELOPMENTS

With Toronto's bid to host the 2008 Summer Olympics, Canada's Prime Minister Jean Chrétien, Ontario's Premier Mike Harris, and Toronto's Mayor Mel Lastman announced a new taskforce to develop a business plan and make recommendations for developing Toronto's shoreline in 1999.

This taskforce determined that regardless of the Olympic bid, the revitalization of the shorelines was necessary, as it would have "a major, positive economic impact on the City, the region and the country." They also stated that it was "an integrated partial solution to the environmental, transportation, infrastructure, housing, economic and tourism challenges confronting the City."

After the failed bid for the Olympics, all the levels of government showed their support by establishing the Toronto Waterfront Revitalization Corporation in order to oversee all aspects of the planning and development of the shorelines in November 2001. In December 2002, Ontario's provincial government passed the Toronto Waterfront Revitalization Corporation Act. On April 1st, 2003, they enacted this new legislature, creating the permanent independent organization for overseeing and leading the renewal of Toronto's shorelines.

As a result of everyone's hard work and commitment, there have been many new developments and upgrades on Toronto's shorelines. The new Billy Bishop Airport upgrades and tunnel under Lake Ontario, the Distillery District upgrades and new condominium towers, George Brown Waterfront College, upgrades to the Redpath Sugar Refinery, and the upgrades and replacements of wharfs and docks shows the commitment while the future redevelopment of the West Don Lands provides a level of confidence and certainty.

6 CONCLUSIONS

It can be seen from this paper that there were many challenges associated with the Pier 27 project and the development along Toronto's shorelines. Through infrastructure uncertainty, poor soil conditions, water infiltration, and an old military artillery cartridge scare, Pier 27 shows that anything can be carefully and thoroughly designed for the construction and development on the shorelines. As long as all levels of government maintain and continue their support of this massive undertaking, especially with the redevelopment of the West Don Lands, the Toronto shorelines will become one of the leading waterfronts in the world.

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