# Evolution of power plant foundations in Nova Scotia

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ABSTRACT
Power plant foundations are designed based on the geotechnical conditions of the site to withstand the heavy equipment and environmental loads imposed throughout the planned life of the plant. A series of thermal plants were constructed in the province of Nova Scotia from 1960 to the present time. This paper discusses the rationale for the selection of the various types of foundations including designs that incorporated new technology available at the time for effective solutions. The Tufts Cove Generating Station at Dartmouth consisting of five power generating units exemplifies these principles and will be the focus of this paper.

RÉSUMÉ
Les fondations des centrales électriques sont conçues selon les conditions géotechniques du terrain pour résister aux équipements lourds et aux charges environnementales imposées pour la durée de vie prévue de la centrale. Plusieurs centrales thermiques ont été construites en Nouvelle-Écosse de 1960 jusqu'au présent. Cet article examine les fondements sur lesquels repose la sélection des divers types de fondations, y compris les designs ayant incorporé les nouvelles technologies sur le marché à l'époque, pour arriver à des solutions efficaces. La centrale électrique de Tufts Cove à Dartmouth, qui compte cinq unités de production d'énergie, illustre ces principes et sera le thème central de cet article.

## 1 HISTORY BACKGROUND

With bedrock not far from ground level, almost all the major thermal steam plants in the province of Nova Scotia including the first 3 units of Tufts Cove Generating Station were constructed with foundations founded on bedrock and are located close to the sea for easy access to cooling water. Very often the whole footprint of the turbine hall, the boiler house and the chimney is excavated to the bedrock. The massive turbine foundation and other equipment foundations, can be constructed along with the building foundations of column, beam and wall footings. This is usually followed by the installation of circulating water pipes and the construction of pits, duct banks; and trenches and then the placement of floor slabs. Granular backfills are placed in stages to different levels to facilitate the concrete construction.

The above construction sequence results in a construction site open to view which enhances the safety, inspection and quality control programs. This arrangement also results in overall cost effectiveness and flexible foundation construction.

Tufts Cove Generating Station is a power plant located in an urban setting. The back end (boiler house end) of the powerhouse and the chimneys of the first three steam units were constructed on land reclaimed from Halifax Harbour with cellular cofferdams serving as seawalls as well as to house part of the circulating water pump houses. The 100MW Unit No. 1 was commissioned in1965 followed by the 100MW Unit No. 2 in 1972 and the 150MW Unit No. 3 in 1976. From1999 to 2000 all three units were modified from being oil-fired only to allow the burning of natural gas as well.

Recently Unit No. 4 & 5 were added to Tufts Cove Generating Station. These high efficiency units are natural gas fired combustion turbine units to be operated initially as stand alone simple cycle plants. Once through steam generators (OTSG) and a steam turbine are presently being added to generate additional electricity from the exhaust of the combustion turbines of Unit No. 4 & 5. At the completion of the new Unit No. 6 steam turbine unit, together with Unit No. 4 & 5 would form the first combined cycle power plant in Nova Scotia for a total capacity of 150MW. Both Unit No. 4 & 5 and the future No. 6 are located in the south yard of the site. A large part of the south yard was used as a disposal site for the construction of Units No. 1, 2 & 3. The depth of fill on top of the native till varies from about 1m to 3.6m at the site and this consists of sand and gravel fills from excavation with the presence of construction debris. The locations and the years commissioned of Tufts Cove Unit No. 1 to Unit No. 5 are shown on Figure 1.

## 2 TRADITIONAL DESIGN

Tufts Cove Generating Station Unit No. 1, 2 & 3 have building foundations consisting of columns and walls with spread footings founded on bedrock. Unlike other steam plants with slab on grade floors, the ground floors of these three units are beam and wall supported structural slabs. Major equipment foundations such as turbine/condenser foundations, boiler feed pump foundations and fan foundations are concrete block foundations or frame

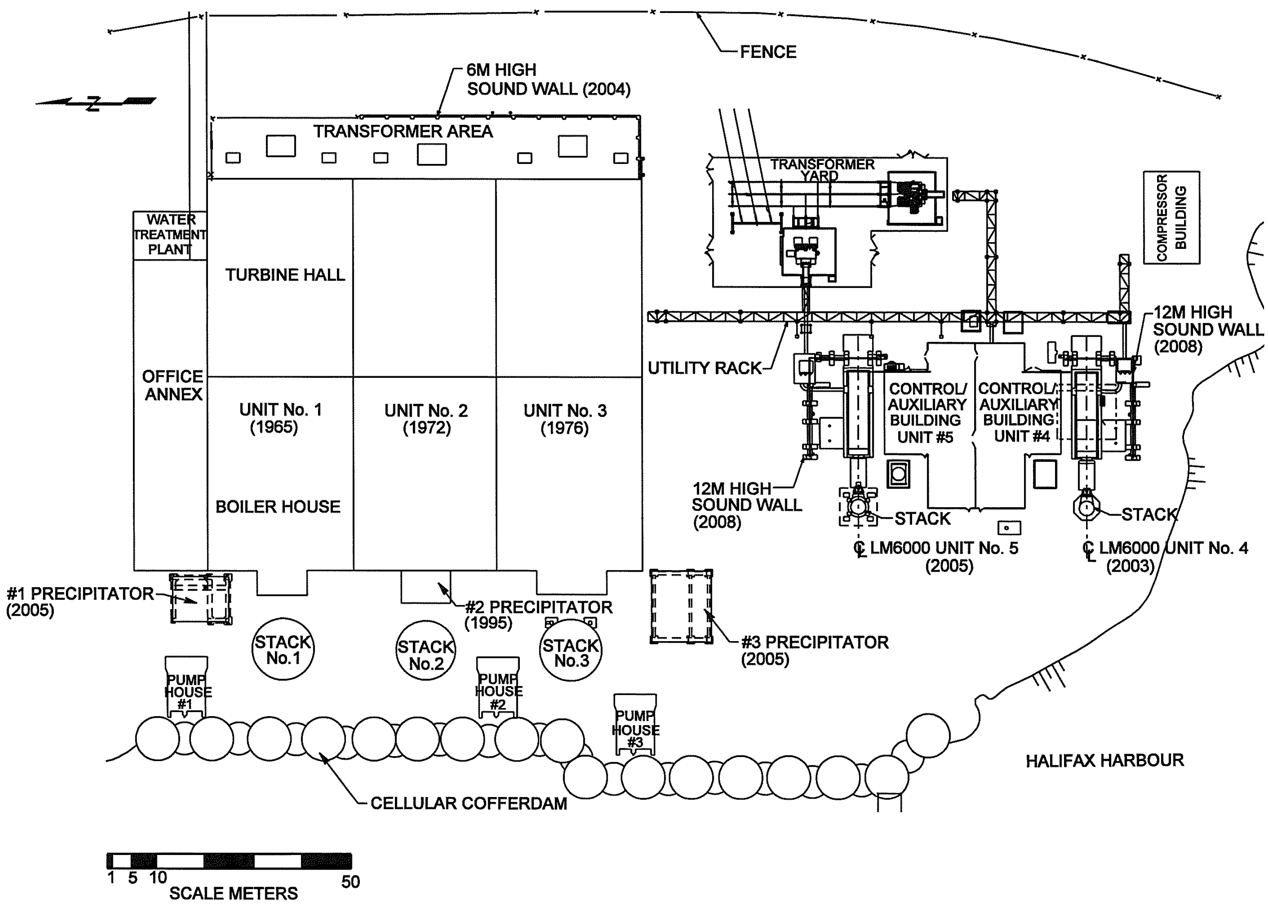


Figure 1. Tufts Cove Generating Station plan

foundations (Dunham 1962) founded on bedrock. The chimney foundations are ring wall foundations with spread footings on bedrock. Due to the close proximity to the harbour, de-watering of the excavated area was required.

For Tufts Cove Unit No. 1, 2 & 3, the bedrock slopes from about 3m below grade at the front of plant to about 7.5m at stacks near the water's edge. In order to allow access to bedrock, a watertight cellular cofferdam was constructed to seal off harbour waters from the construction site. Water was pumped out and overburden was removed to expose bedrock to the entire work area. The cofferdam was constructed in two phases, Phase 1 in 1962 for Unit No. 1 and Phase 2 in 1969 for Unit No. 2 & 3.

## 3 FROST PROTECTED SHALLOW FOUNDATIONS

Frost-protected shallow foundations (FPSF) involve the construction of the foundations with bottom of the perimeters above the frost depth and are slab foundations most of the time. Often FPSF require less amount of excavation and concrete than the conventional foundations with frost walls (Robinsky and Bespflug 1973, Burn 1976).

### 3.1 Point Tupper Unit No. 2 Precipitator Foundation

The first major FPSF constructed for Nova Scotia Power was the new precipitator foundation for the Unit No. 2 of Point Tupper Plant, located in the Strait of Canso area This unit was converted to coal/oil dual fired plant from an oil fired plant in 1985. Because a precipitator is a very heavy piece of equipment subject to heavy ash and environmental loads, the use of shallow foundations was not an easy decision considering all the previous precipitator foundations were built on concrete beam and walls founded on bedrock. After careful evaluation, a frosted protected shallow foundation (FPSF) alternative was selected as the foundation for the precipitator.

The 200mm thick slab on grade was thickened to 1.0m for the center row of columns and 0.8m for the two outside row of columns. This slab foundation was constructed in an area of engineered fill at the back end of the reconstructed boiler house. The thickened parts of the slab form structural beam foundations for the column loads. Where the bottom elevations of the slab foundation edges are above the frost line, 50mm thick rigid insulation was placed below the slab and extended 1.2m horizontally from the exposed perimeter edges of the slab foundation to prevent frost heave as shown on Figure 2.

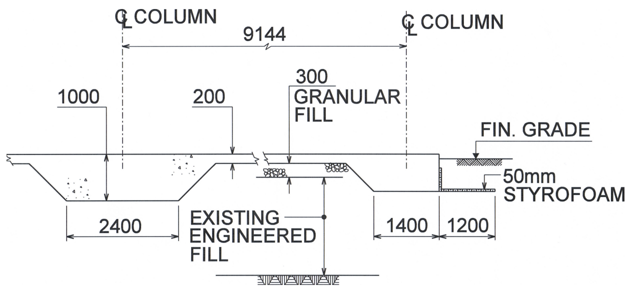


Figure 2. Point Tupper No. 2 precipitator foundation, a frost protected shallow foundation (FPSF)

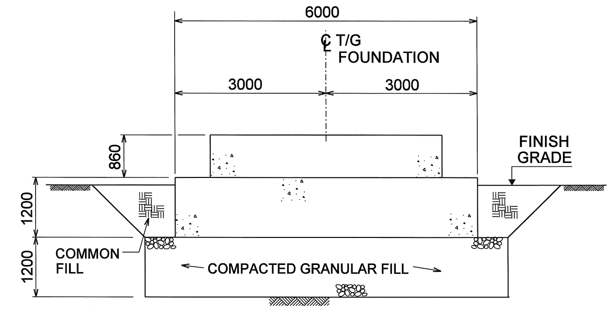


Figure 3. Combustion turbine foundation

## 3.2 Tufts Cove Unit No. 4 & 5 Building Foundations

The heart of both Tufts Cove Unit No. 4 & 5 is a 47.3MW GE LM6000 combustion turbine unit which is designed and manufactured as a module power plant. A weather enclosure is optional but not necessary for the turbo-generator unit. For the balance of the plant, only a single story building is required to house the auxiliary equipment, electrical room and control room. The foundation for the beam and column steel building was a frost protected concrete slab foundation. The use of frost protected shallow foundation (FPSF) is common for commercial and light industrial buildings. It was an ideal application for the control/auxiliary/electrical building. Being a part of the power plant facility, it was conservatively designed for structural rigidity, durability and ability to be modified to allow for heavier equipment to be installed.

# 4 BLOCK/MAT EQUIPMENT FOUNDATIONS

Tufts Cove Unit No. 4 & 5 are located in the south yard of the Tufts Cove site, with subsurface conditions less than ideal. Soil improvement work was performed, as described in Section 5, on all the major equipment such as turbines, compressors and stacks and were founded on relative shallow block/mat foundations.

## 4.1 Tufts Cove Unit No. 4 & 5 Turbine Foundations

Tufts Cove Unit No. 4 and Unit No. 5 are both 47.3MW combustion turbine units. Unlike steam plant units, combustion turbine units are basically jet engines attached to generators for the generation of electricity. Similar to the foundations of their predecessors, combustion turbines of an older generation used as peak plants; the new turbine foundation was designed as a simple concrete rectangular footing with a rectangular block on the top for the unit to sit on as shown on Figure 3. In contrast, the turbine foundation for a steam plant unit would need to have footings well below grade and complicated massive concrete or steel turbine table to support the turbo-generator set and to accommodate associated equipment such as condenser and circulating water piping etc.

# 5 SOIL IMPROVEMENT

Prior to the construction of Tufts Cove Unit No. 4 & 5, a geotechnical investigation of the south yard revealed the presence of old construction debris and other materials not suitable as foundation materials, as shown on one of the bore hole and test pit logs indicated in Figure 4. It was decided to excavate 1.2m below the bottom of the turbine footing and backfill with compacted well graded granular material to form a firm substrate for the concrete foundation. The excavation and backfill of this 1.2m thick gravel substrate was the key to the success of new turbine foundation. Figure 3 also illustrates the extent of earthwork for the turbine foundation.

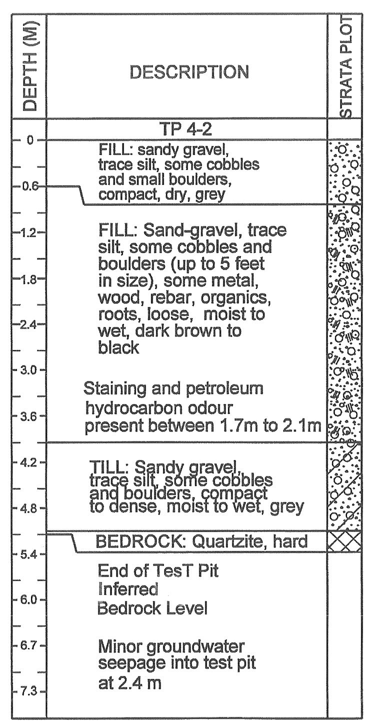


Figure 4. Test pit TP 4-2 data

### 5.1 Earthwork

The construction of Tufts Cove Unit No. 4 and Tufts Cove Unit No. 5 foundations, especially the turbine foundations posed several challenges but one of the main ones was that the excavations were influenced by the tidal waters of the nearby Halifax Harbour. It was determined during the preconstruction phase through the geotechnical work that the excavations would be influenced by the tidal waters and therefore construction activities would be affected. Contractors were informed about this condition during the bidding process.

Work shifts and related activities had to be scheduled around the rising and falling of the local tides. Even with this scheduling normal excavating and backfilling techniques could not be followed. During the excavation of the majority of foundations, the excavation would be taken down to an elevation approximately 150mm above the grade for sub-base gravels. At which time the excavation would be discontinued due to rising water levels since pumps were not able to keep up with the in rush of tidal waters. Once a tidal cycle was complete the remaining 150mm of material, which was now disturbed due to the flooding by the tidal water, would be excavated. Proof rolling of the area was conducted (static roll) to indentify any soft areas and seal the surface.

Vibratory rollers could not be used at this stage of the backfilling sequence due to the wicking of water to the surface, which would leave the entire sub-base spongy and soft. A layer of well graded gravel would then be spread and rolled. Sometimes, this entire process would take place over the course of 2 or 3 days due to the short durations between acceptable tidal water levels which allowed for the proper compaction of the material and provided acceptable compaction results.

For deeper excavations such as the excavation for the turbine foundation, the same process was used, however the first layer of sub-base material needed to be a 25mm or 50mm clear stone to eliminate the wicking effect of water during compaction activities. Once this layer of stone was placed and compacted, a layer of geotextile membrane would be installed to eliminate the displacement of any fines from the well graded material into the clear stone layer of the sub-base. The remainder of the sub-base gravels were then placed and compacted.

Figure 5 and Figure 6 illustrate the influence of the tidal water and many tasks to be performed simultaneously between the tidal cycles.

*Excavation to about 150mm above sub-base grade for turbine foundation with tidal water table clearly in sight*

Figure 5. Tufts Cove Unit 5 foundation excavation

*Activities performed between tidal cycles: Excavator was carrying out excavation, one dump truck was hauling away excavated materials, the dump truck followed was hauling in structural fill for the excavator to place the fill, and roller compactor was compacting the fill in layers.*

Figure 6. Activities performed between tidal cycles for the soil improvement for Unit No. 5 turbine foundation

### 5.2 Contaminated materials

During the preconstruction phase of the Unit No. 4, it was realized through geotechnical work that the soils in the south yard were contaminated as indicated in Figure 4 with the presence of hydrocarbons on the test pit data.

Once this was determined several procedures had to be developed to deal with the health hazards, the contaminated waste and the contaminated soil. A safe work practice was developed to protect the workers from all the health hazards. Three containment cells were constructed to temporarily store all the excavated materials during testing. All three cells were constructed with a poly liner. During the actual construction phrase, a geotechnical person was on site at all times during excavation work to determine what material was to be placed in what cell. Once the results were obtained the non-impacted soil was transported to a common landfill. The hydrocarbon impacted soil was transported to an appropriate landfill for an additional cost. All the water collected in the containment cells had to be captured and pumped to the waste water treatment plant for treatment prior to release. This work was closely monitored by Nova Scotia Department of Environment.

## 6 PIPE PILE SUPPORTED FOUNDATIONS

In 1994, a precipitator was added to Tufts Cove Unit No.2. The new precipitator had to be squeezed in the narrow space between the boiler house and the 150m tall concrete stack. This area was part of the reclaimed land formed during the original plant construction. The fill materials in the area were random fills ranging from loose fill to compact silty sand with gravel and contained boulders at various levels. The site is also subject to tidal effects. The ground water level tends to be high with the incoming rising tides yet lag behind for the recessing falling tides. The bedrock is about 7m below.

Because of the site conditions, the construction of a column and wall footing foundation on bedrock would involve extensive excavation and a difficult dewatering operation. A mat foundation on a site with random fill is not suitable unless substantial soil improvement can be performed. The presence of boulders within the fill layer was also a problem for driving piles in place. In the end it was decided to install steel pipe piles in holes drilled through the fill with boulders and penetrated into bedrock. Re-bar cage was lowered to the bottom and the pipe piles were then filled with concrete with 1.8m socket into the bedrock as shown on Figure 7. The reinforced concrete pile caps, connecting beams and 300mm slab completed the precipitator foundation. No batter piles were installed. Lateral load resistance is provided by the rigid frame system consisting of the 16 steel/concrete columns embedded in the bedrock at the bottom and are tied together by concrete beams and slab at the top. The lateral resistance of the piles (Dunham 1962, Tschebotarioff 1973) and the vertical resistance of the piles are checked for the imposed loads.

## 7 MICRO-PILE SUPPORTED FOUNDATIONS

In 2004 micro-piles were used first time at Tufts Cove site for the water treatment plant expansion project. A drilled micro-pile system supplied by Dywidag (GEWI Pile), was used for the existing concrete foundation walls extension.

These micro-piles were installed with double corrosion protection (Dywidag 2000). Each pile consists of a 57mm diameter threaded bar (grade 60, Fy = 60ksi) engulfed in pre-grouted corrugated plastic sheathing. The assembled unit was installed and centered in the 150mm drill hole by a centralizer and surrounded by grout. The grout body encasing the threaded bar unit providing a corrosion protection and enables the load transfer into the bedrock, as well as providing a stabilization element against buckling in weak soil layers. The double corrosion is important for a pile with a relative small steel core area in a marine environment. The micro piles are slender and are less invasive as the conventional steel piles or concrete piles. They have; however, strong axial load carrying capacity with about 3m socket into the bedrock Figure 8 illustrates a typical micro-pile. The overall 150mm diameter concrete/steel bar assembly provide good buckling capacity for the micro-pile surrounded by the soil such that the micro-pile capacity is dictated by the strength of the threaded bar and the friction between the grout and the bedrock.

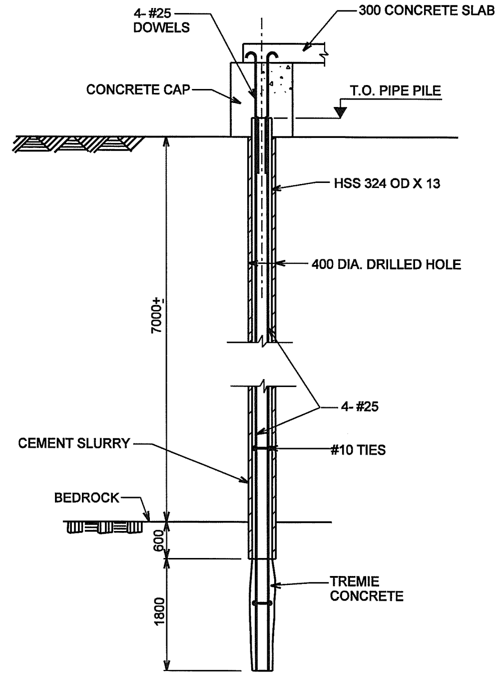


Figure 7. Socket steel pipe pile

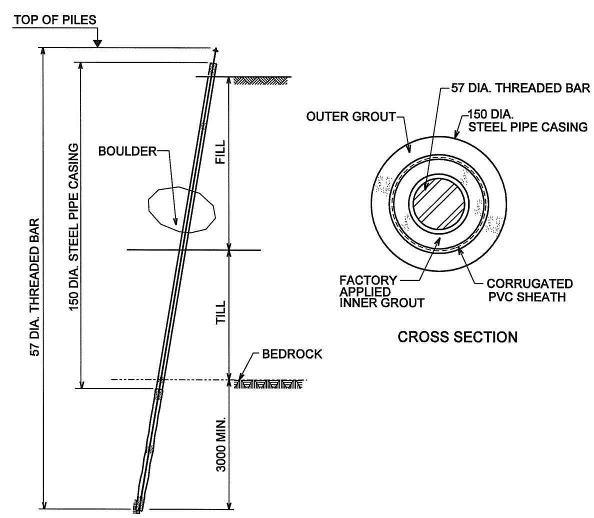


Figure 8. A typical micro-pile

### 7.1 Tufts Cove Unit No.1 &3 Precipitator Foundations

Recently, electrostatic precipitators were installed to replace old non-functioning equipment for Tufts Cove Unit

No. 1 and Unit No. 3. Foundations for both precipitators were concrete beams supported by micro-piles and were completed in early 2005.

For the foundations of the two new precipitators, Williams Form Engineering Corp. was awarded the job of supplying a similar double corrosion protection micro-pile system, multiple corrosion protection anchors (MCPII), with the 57mm threaded bars of grade 75 steel (Fy = 75ksi) (Williams 2004). The higher strength of the threaded bars provided an additional safety factor for the design loads. The new precipitator foundations needed to accommodate the existing circulating water pipe, the pump houses and manholes along with several buried services. The high capacity slender micro-piles are installed in small drilled holes that allowed the use of economic drilling methods. The small overall pile assemblies also allowed flexibility in selecting pile locations and installation of batter piles which is a substantial advantage in a congested site.

A conventional piling design such as H-piles or pipe piles most likely would be much more costly and difficult to install, and would have taken a longer time to complete.

7.2 Tufts Cove No.4 & 5 sound wall foundations

Noise studies were conducted on the overall Tufts Cove Plant operation after Unit No. 4 and 5 were completed and operational. The studies indicated the need to implement various noise abatement programs. In 2004, acoustical weather hoods were added to the turbine hall louvers, acoustical overhead doors installed to replace the existing south overhead doors of Unit No. 1, 2 & 3 building and a 6m tall sound barrier wall was erected for the transformers of Unit No. 2 &3.

In 2008, the most challenging noise abatement project was completed, the Unit No. 4 & 5 sound wall project. The 12m tall insulated metal sound walls were designed to be installed as close to the turbo-generator unit as possible to be effective in noise reduction. The sound barrier walls consisted of insulated metal panels spanned between 610mm wide flange vertical steel columns. The column foundations had to be capable of resisting the large horizontal shear and overturning moment loads imposed by the wind. For a site that was already crowded with equipment and buildings, pile bents consisting of concrete pile caps supported by micro-piles, tied together laterally with concrete beams was evaluated as the best solution.

The micro piles are strong in resisting axial loads both as compressive and tensile loads but are not strong in resisting bending moments. Therefore micro-piles were treated as rods or links in the structural analysis. Most of the pile bents were supported by two batter piles and were tied to the adjacent concrete foundations for a horizontal reaction point. The structural system is shown on Figure 9.

For pile bents without the benefit of this additional horizontal support, a third pile is needed to ensure the structural stability of the bents. Figure 10 is a photograph showing micro-pile installation for both pile bents with two piles and three piles. Dywidag's GWEI piles were used for the sound wall foundations.

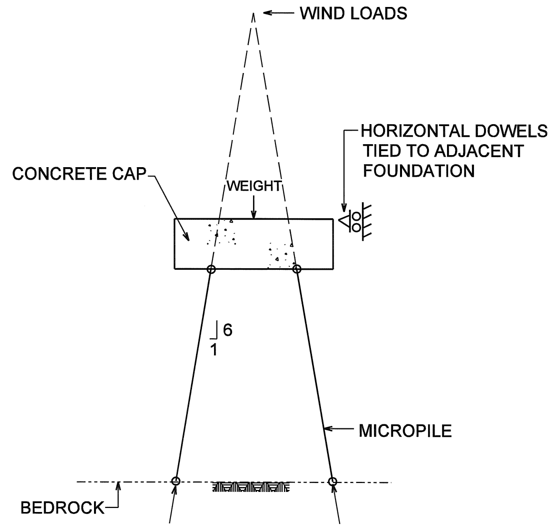


Figure 9. Sound wall pile bent force diagram

*Two piles per bent for the 3 bents in the front with drilled holes for connecting dowels on the right, the bent at the far end has three piles*

Figure 10. Micro-piles for Tufts Cove No. 5 sound wall foundation

7.3 Micro Pile Installation

A small drill rig was employed to drill the hole for the 150mm steel pipe casing. The casing was mounted on drill bit and followed the drill as it worked down through fills, boulders, and bedrock. About 600mm to 1500mm penetration into the bedrock was achieved for the casing to ensure a good water seal. A new smaller drill bit was used to further the hole about 3m into the bedrock. After the hole drilling operation was completed the casings were temporarily capped. The factory assembled anchor assemblies were cut and /or coupled to length to suit the drill hole length. The capped casings were cut off to grade and holes were flushed clean. A grout pipe was inserted to the bottom. The cut to length anchor assembly was inserted in the hole and then grout was pumped to fill the hole for the piles for the precipitator foundations. For the piles for sound wall foundations, the holes were filled with grout first prior to the insertion of the anchor assembly. This method used more grout than needed but was contractor's preferred method. Afterward the cut to length anchor assembly was inserted to the grout filled hole. In both cases the grout was pumped until the consistency of the grout was adequate. Grout cubes were taken as part of the quality program to ensure the strength of the grout. After the grout was set, a 50mm thick square plate complete with double nuts was installed to complete the micro-pile installation.

In general, the drill rig would drill holes through various materials, including boulders, with ease. However the drill bit would deflect from wooden materials, such as rotten timber members from an old wharf, thus prolonged the drilling operation.

Due to the maneuverability of the drill rig, the pile installation contractor was able to perform the pile installation in the close proximity of existing structures and equipment. It is worthwhile to note that the piles for the sound walls were installed while the plant was still operating. The vibration sensors of the combustion turbines did not register anything abnormal during pile installation.

## CONCLUSIONS

Different types of power plant foundations were used by Nova Scotia Power over the past fifty years with success. The traditional column and wall footings on bedrock worked well for steam plant units where bedrock is not that deep down. Where applicable, shallow foundations such as frost protected shallow foundation and mat foundations are good foundation solutions even for heavy construction projects.

Where weak and/or difficult soil condition is encountered and soil improvement is not feasible or cost effective, pile supported foundations may be a better choice. At Tufts Cove, due to the presence of boulders, pipe piles needed to be installed in drilled holes in 1995 for the Unit No. 2 Precipitator foundation. By comparison, the use of micro-piles in 2005 for Unit No. 1 & 3 Precipitators proved to be much easier to install, relatively non-protrusive in congested sites full of buried structures and services. Similarly, for the Unit No.4 & No. 5 sound wall foundations, the high resistance capacities for both downward and uplift loads of the micro-piles embedded deep into the bedrock proved to be very valuable. These tall wall structures are subject to very high wind loads and were constructed at a geotechnical challenged site. It shows the importance to consider all the options and select the alternatives based on structural soundness, constructability and cost for a most efficient solution for the whole project. Often, adopting a relatively new technology can achieve a cost effective result.

It can not be overemphasized that good geotechnical investigation and consultation is the basis for good design and construction of foundation works. The lessons learned from the design and construction of the various power plant foundations described above are applicable to other similar heavy equipment and/or heavily loaded building foundation design and construction.

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