Root Pile Support of Vancouver's Hollow Tree Parallels to Wind Turbine Foundations

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Abstract

One of Vancouver's famous landmarks, the over 1000 year old Hollow Tree in Stanley Park, was condemned to be taken down after a severe hurricane force storm made this 40 ft (circumference) tree tilt into a dangerous position of tipping over (Figure 1).

Figure 1

A proposal to give the tree a new (artificial) root system using Micro Piles was accepted by the Parks Board after long political discussions.

This paper will give some input on the history of the tree and how the project was executed, working inside the tree and connecting it to the new Foundation System. The Paper will conclude with adopting this idea to a Deep Foundation System for Wind Turbine Towers.

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Hollow Tree Location in Vancouver Stanley Park

The northern tip of the park was devastated by hurricane force winds which fell over 3000 trees and tilted the Hollow Tree dangerously in December 2006.

LOCATION PLAN

Figure 2

History of the Hollow Tree

As quoted by the Vancouver Heritage Commission Subcommittee Hollow Tree:

“The Stanley Park Hollow Tree is a unique and famous gathering place where, for generations, people from all over the world have stood inside its unforgettable, yet intimate, natural hollow to be photographed, to marvel at the grandeur and to reflect on our relationship to the environment, the past and our future”.

Figure 3

Figure 4

The Restoration and Conservation Project

Two proposals were originally considered by the Vancouver Parks Board.

The first was, **Keep the tree standing or knock it over!**
Move the leaning tree back into its vertical position and install permanent exterior braces. This idea was heavily criticized by the public on its unaesthetic looks.
Lay the tree down, this one was opposed by the Vancouver Heritage Commission which wanted to keep the tree standing.

The Heritage Commission explained their case as follows:

"In forestry terminology the Hollow Tree is a snag (a standing tree that is no longer living) - a part of the forest with an ecological significance quite distinct from so called deadfall - a tree lying on the forest floor. From this perspective, the question is, should we artificially convert a natural snag into a deadfall? From a heritage perspective, the height, stature, hollow core and view up to the sky are all character defining elements. These features can be retained only by keeping the tree upright. The soundness of the wood, revealed by the wood strength analysis, showed that the tree is sufficiently strong to support itself, with suitable reinforcement, for many years to come. These factors all clearly favor keeping the Hollow Tree standing."

The second proposal was, **Replicate the tree!**
The physical analysis indicated that conservation is indeed feasible, so replication was ruled out.

Keep the Tree standing, with a new Root Pile Foundation was accepted.

The problem was that the access to the tree is very limited and stringent environmental restrictions prohibited large equipment from being brought into the park. This opened the opportunity to suggest the use of Hollow Core Micro Piles which can be installed under those conditions; they can even be installed using hand held drifters which became the solution for working inside the Hollow Tree.

Funding for this work was also a problem. It was only after a supplier and contractor offered to donate the material and the labor, that the Vancouver Parks Board agreed and matched the value of the donations, to fund the project.

Restoration Stages

1. Righted to vertical position

Braces with a hydraulic jacking system were successfully used to push the tree to its original position before the Micro Piles were installed (Figures 5 & 6).

Figure 5

Figure 6

2. Installation of Micro Piles

The design specified 15 micro piles type Titan 40/16 with a rating of 2 tons each (compression and tension) grout injection bored, to be drilled to a depth of 5.25 meters; 7 piles outside and 8 inside the hollow tree (Figure 7).

(The wet trunk weight is 13 tons)

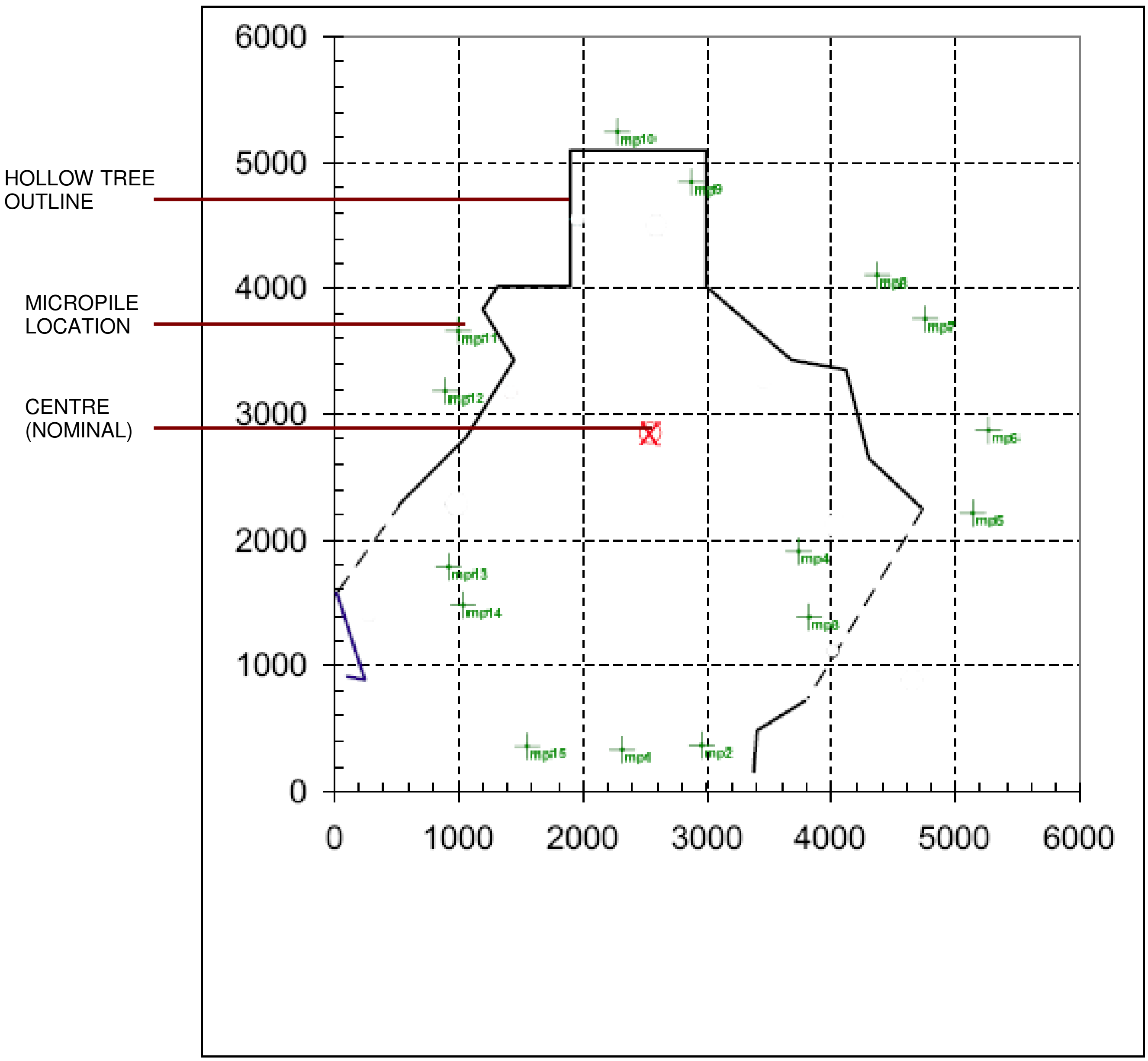

Figure 7

The Contractor decided to use a small hand held air drifter to drill the ROOT PILES inside and outside the Hollow Tree. A separate flushing head was connected to the striker bar of the drill (Figures 8 & 9). A grout plant was used equipped with two high speed/ shear mixers, one for the flushing mix with a W/C 0.7 and the other for the final grout mix W/C 0.45.

Figure 8

Figure 9

The observation of the constant grout outflow during drilling indicates good grout coverage over the hollow Titan bars. This was also confirmed by excavating around the upper portion of the piles for placing the concrete pile cap (Figure 10).

Figure 10

All 15 piles were installed without problems and tested successfully to 200% of the design load.

An average 46 cm Reinforced pile cap was placed with doubled thickness where the above ground tree support steel pipes are embedded in the concrete (Figures 11 & 12).

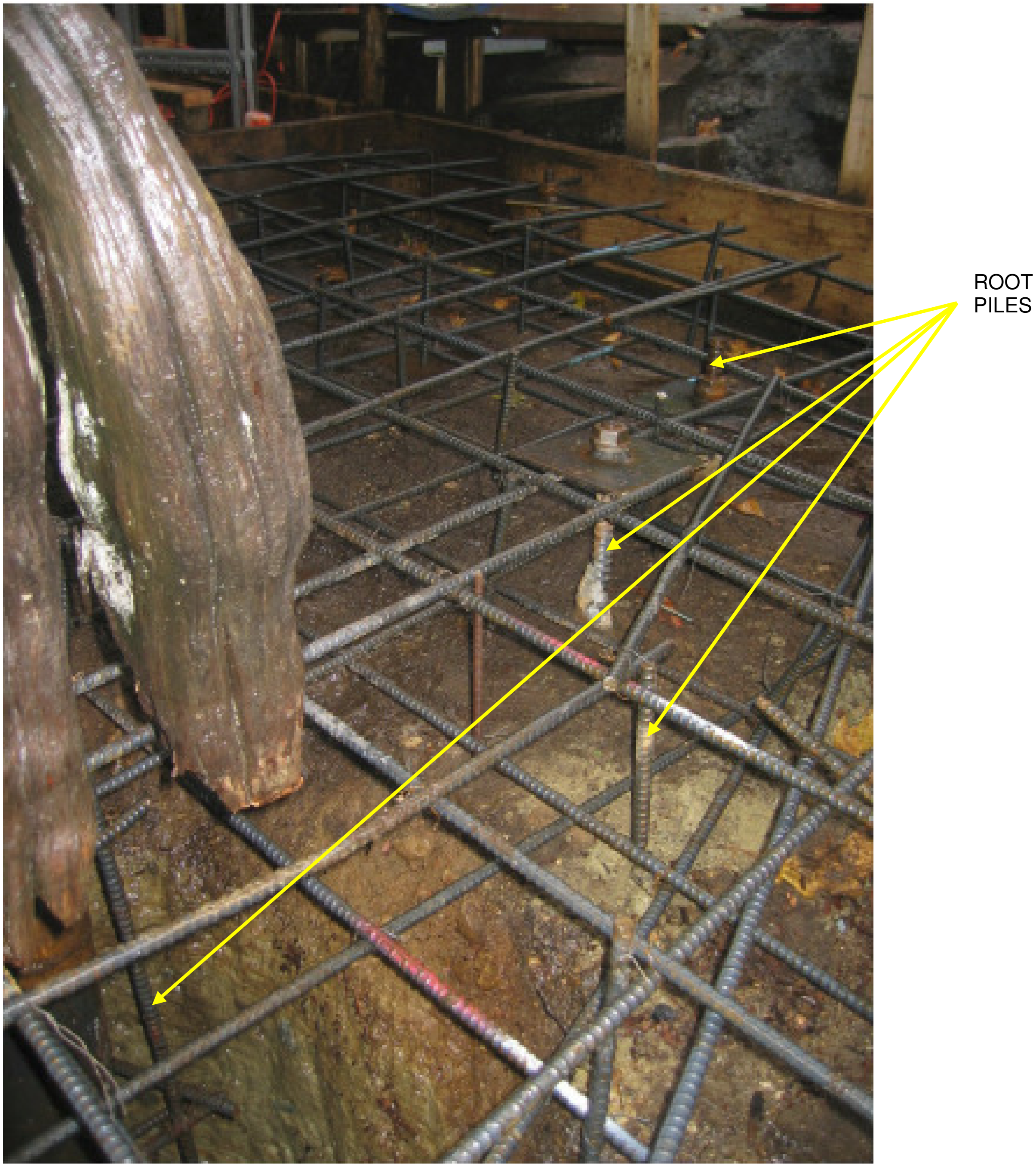

Figure 11
Showing hollow bar root piles and reinforcing steel in pile cap

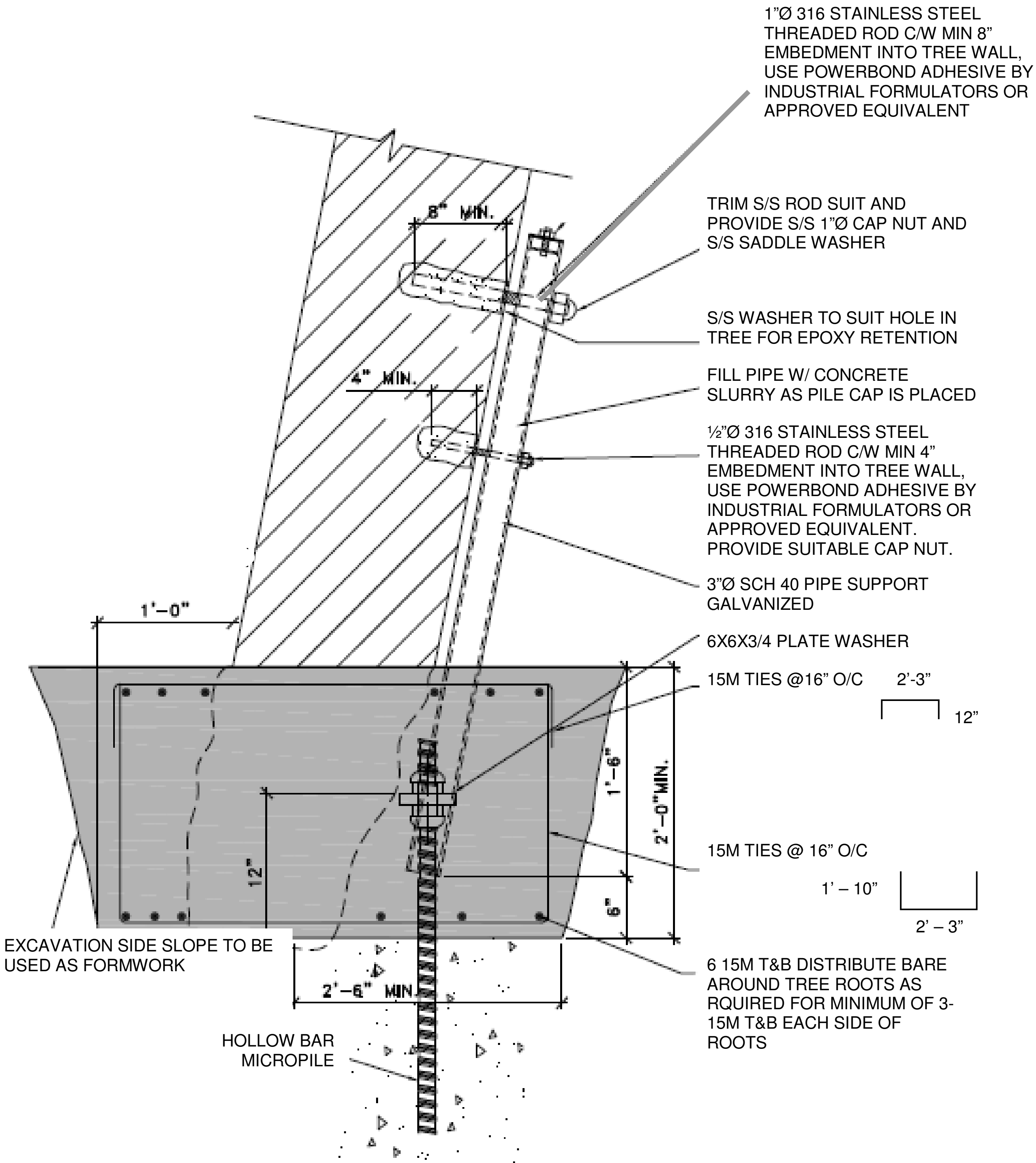

Figure 12

MICRO PILE TO PILE CAP AND TREE CONNECTION

3. Connecting the Hollow Tree to the foundation

The steel support system connected to the inside face of the Hollow Tree consists of a Tripod of steel pipes, 6 meters (18’) high, 150mm (6”) diameter, schedule 40 (Figure 13).

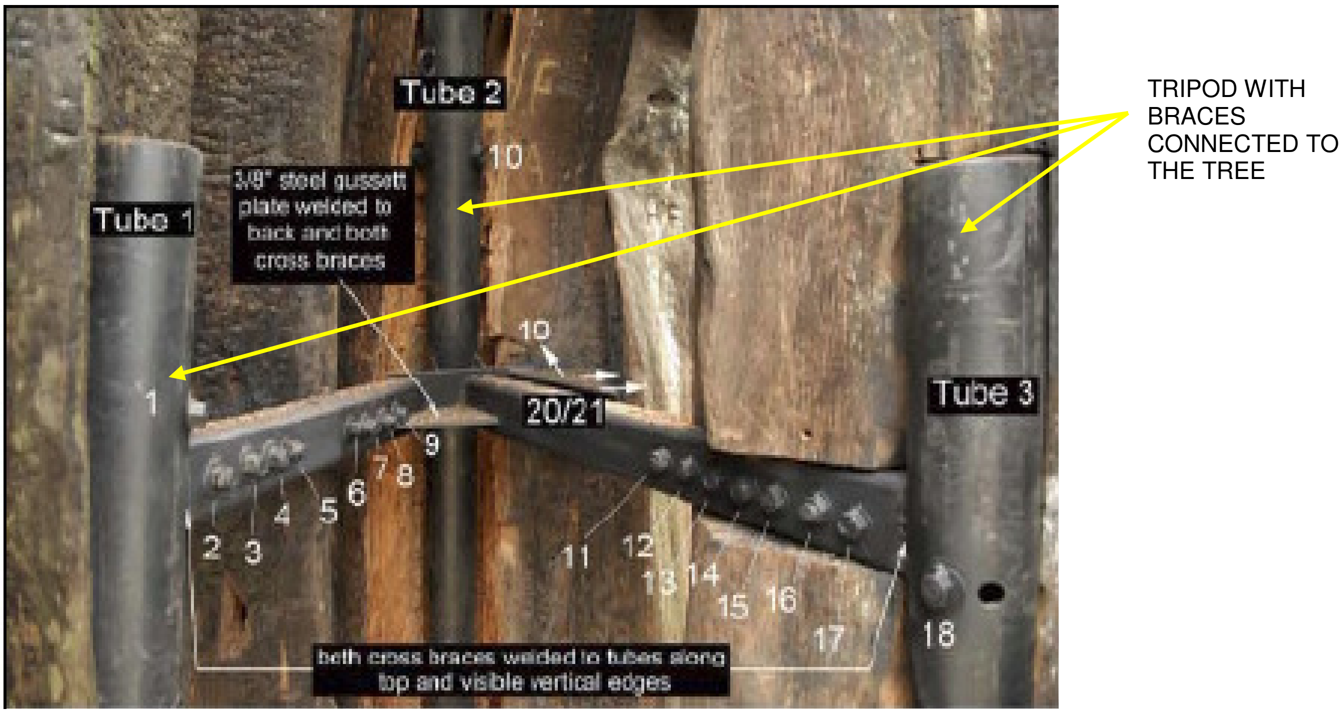

Figure 13

Five additional steel tubes each about 2 meters (6') high, 75mm (3") diameter schedule 80 were also connected to the tree, hidden inside grooves of the tree (Figure 14).

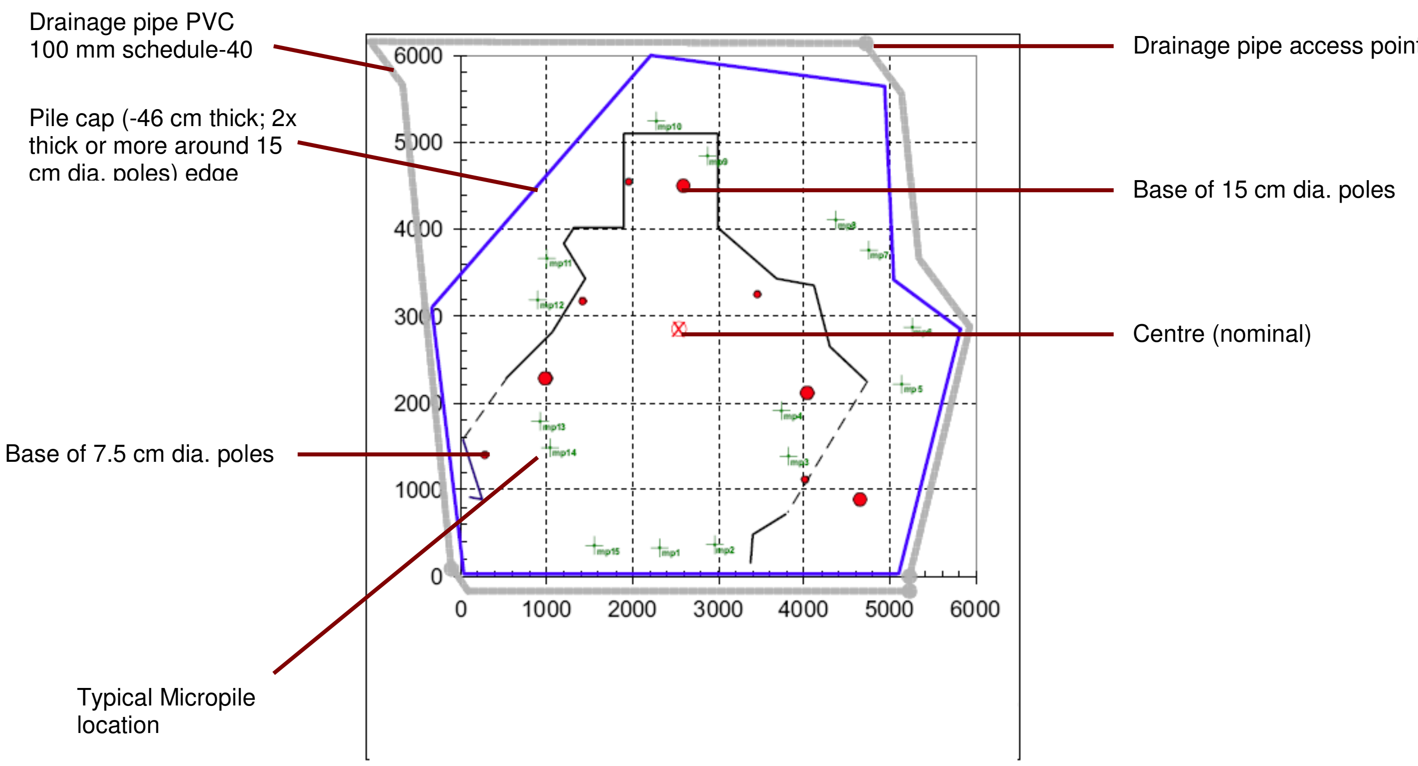

Figure 14

The Hollow tree is connected to the Root Piles and the Landscaping around it can be completed (Figures15 &16).

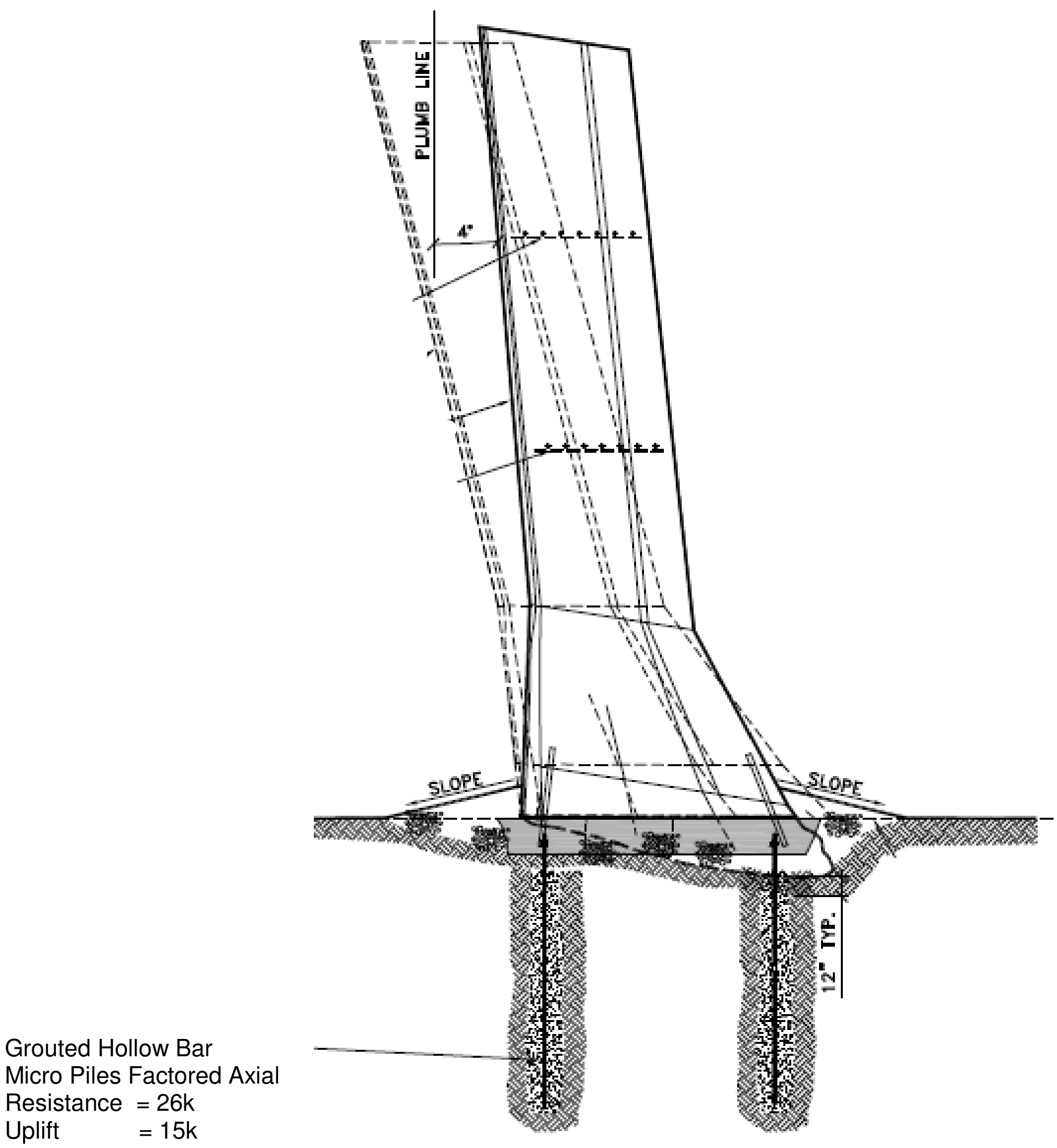

Figure 15
SIDE ELEVATION

Figure 16

4. Capping the Hollow Tree

The final task was to put a sealing cap on top of the tree (Figure 17). A total of four caps were required. The caps with wood preserving oil underneath will extend the life of the wood significantly to match the extended life time given by the Root Piles. The caps will also significantly reduce the overall weight of the trunk as the wood dries out.

Figure 17

The Project was completed just before the opening of the Vancouver 2010 Winter Olympics and used by VANOC, the Vancouver Olympic Committee in their promotional program with the Olympic mascots.

The Vision became Reality.

Root Pile Parallels for Wind Turbines

With the example of catastrophic failures of some wind turbine foundations during hurricane force winds (Figure 18), similar to the storm which endangered the Hollow Tree in the Vancouver Stanley Park, the idea of using a Root Pile (Micro Pile) System became attractive as a Foundation System.

Figure 18

The basic idea of having a post-tensioned pre-tested foundation using post-tensioned Micro Piles or Anchor Piles and a new Groutable Void Form (GVF) is to eliminate these possible failures experienced with conventional mass concrete footings.

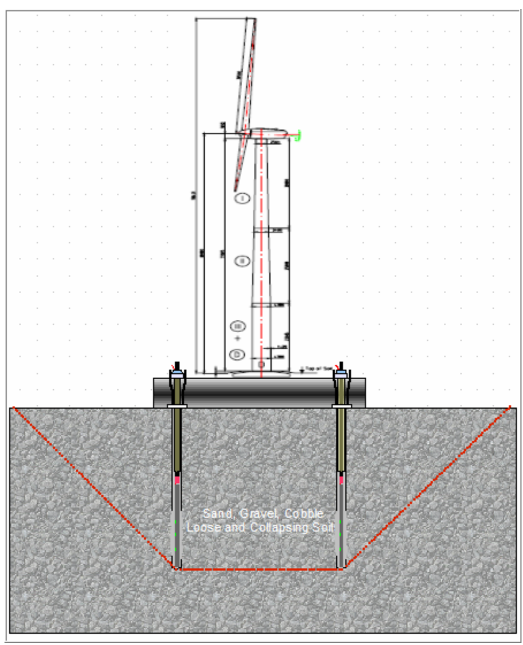

Figure 19

Engaging the rock or soil mass underneath the foundation with post-tensioned anchor piles (Figure 19), improves performance and reduces costs.

For a Micro Pile Foundation, only small drill rigs and excavation equipment is required and the amount of concrete is largely reduced.

Also, the cost of the foundations will be reduced significantly.

Mass concrete foundations require mass excavations. Especially when founded on rock, 10,000 PSI rock is replaced with 3,000 PSI concrete.

Generally:

Slab Foundations are preferred when the top soil layers are strong enough to support all the loads and load conditions.

Deep Pile Foundations with Pile Caps are preferred when the upper soil layers are of a softer quality and the loads must be transferred to larger depth where stronger ground layers are present

Post-Tensioned Anchor Pile Foundations use the ground mass to resist overturning moments.

Types of Tendons used for Post-Tensioning Wind Turbine Foundation Anchor Piles

-Multiple 7 Wire Strands, 270 KSI, Low Relaxation.

-Solid Bars 150 KSI.

-Injection Bore (IBO) Hollow Bar System.

The Key to Post-Tension and Testing Wind Turbine Foundations

Is the use of a Groutable Void Form (GVF) Concept (Figures 20 & 21)
(patent pending). The groutable void form creates a temporary space between the top of the anchor and the bottom of the foundation cap to permit unrestrained movement during post-tensioning. The void is filled with cement grout after the anchor is tensioned and locked-off.

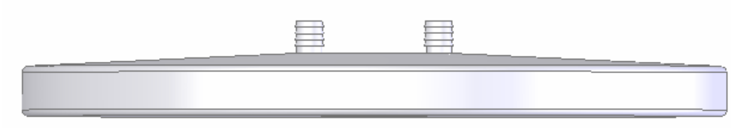

Figure 20

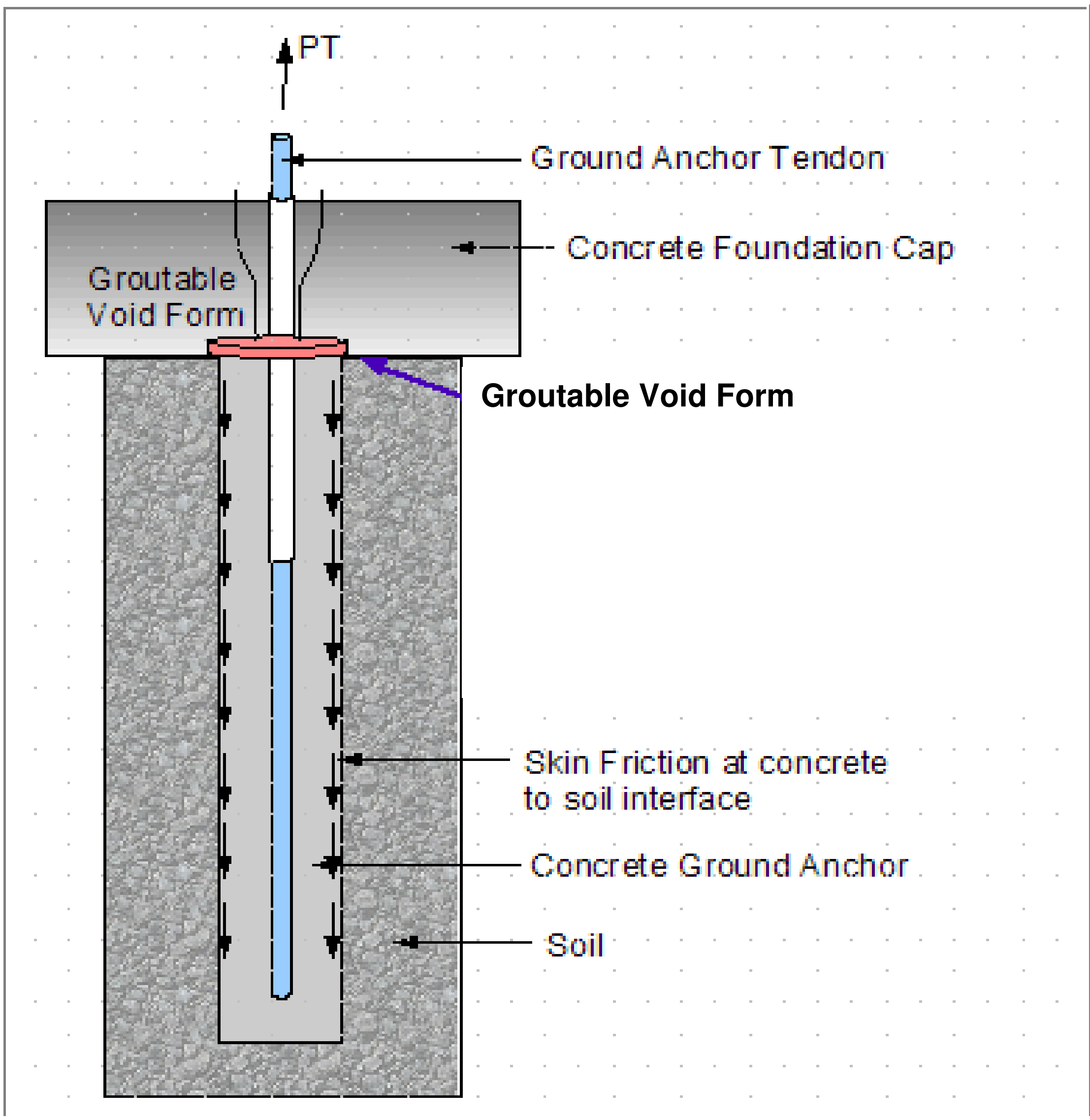

Figure 21

Typical Design of a Con-Tech Systems Groutable Void Form (GVF) Foundation

(Figure 22)

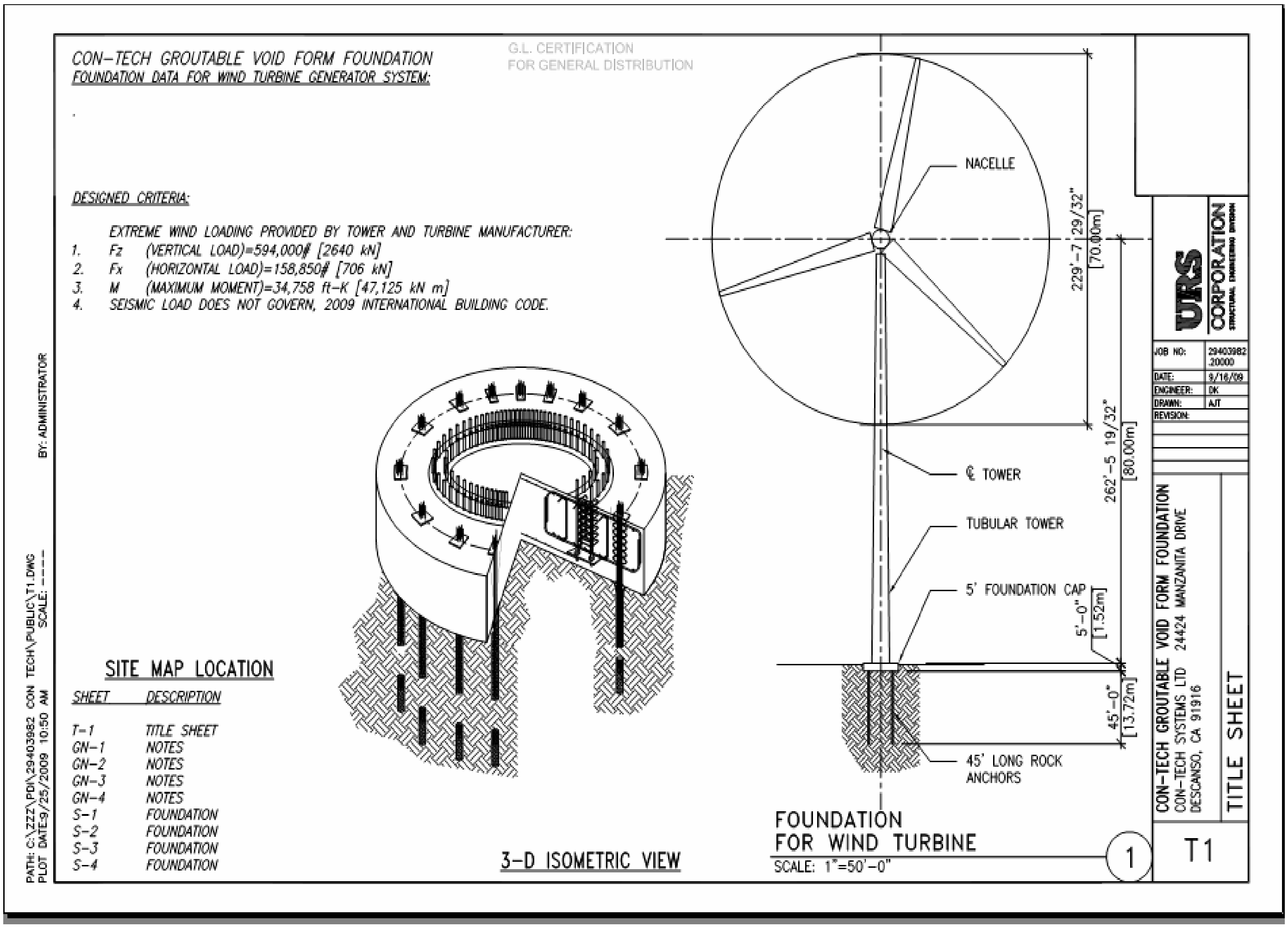

Figure 22

Micro Piles act as stiff springs in Tension and Compression (Figure 23)

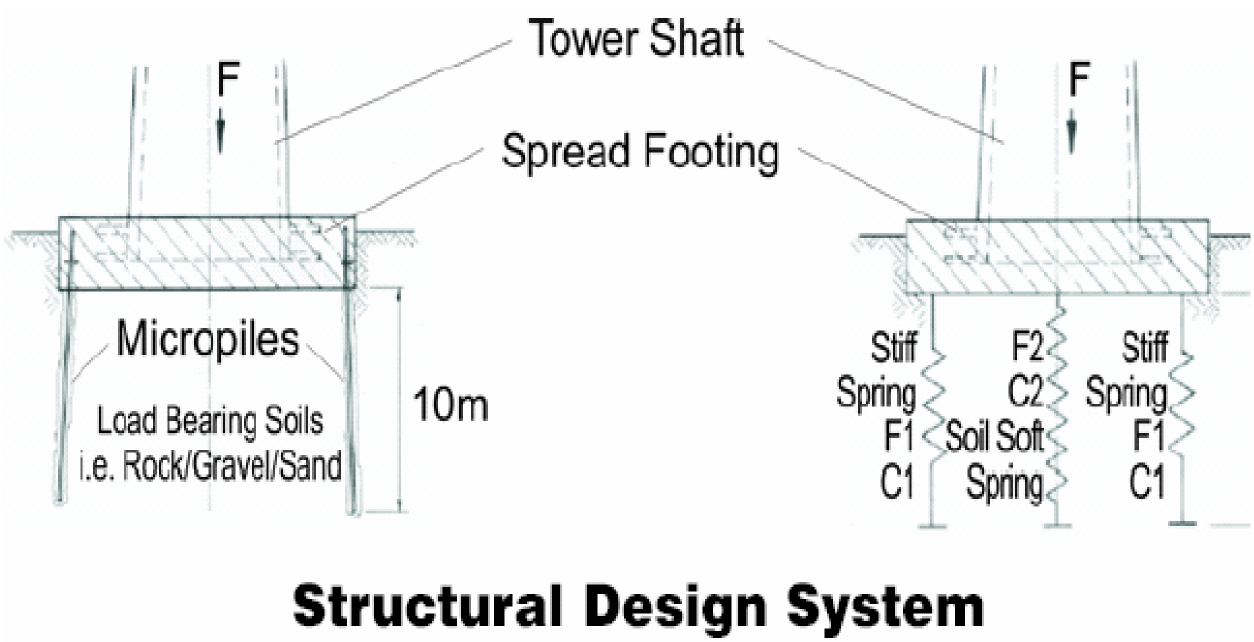

Figure 23

Micro Piles for Wind Turbine Foundations

Typical Case History

Figure 24, Casting of Pile Cap

Figure 25, Drilling of Hollow Core Micro Piles

Figure 26, Observing Grout Outflow

Figure 27, Testing and Post-Tensioning of Hollow Core Micro Piles
(IN PAIRS)


Figure 28, Transporting the tower


Figure 29, Setting the tower

Figure 30, Connecting the tower

Conclusions

-Over 75% reduction in Foundation Area
-Over 40% reduction in concrete consumption
-Over 70% reduction in reinforcing steel consumption
-20% to 30% foundation cost reduction

References

Vancouver Heritage Commission Subcommittee for the Hollow Tree