PRT GROUP

ENGINEERING SERVICES

Structural
Geotechnical
Project Management

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April 5, 2010

Mr. Jonathan Walsh, P. Eng.
Tiller Engineering Inc.
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Dear Mr. Walsh,

RE: Final Report

Please accept the accompanying Final Report.

This report is a requirement of course Civil Project ENGI 8700 which is due on April 5, 2010. This report is an overview of the design methodology of all work completed. You will find enclosed in the report the project description, statement of project requirements, methodology of completed design, cost analysis and a summary of the results. The summary includes a detailed table highlighting the design completed and refers to the enclosed AutoCAD drawings. Attached in the appendix of the report you will also all relevant hand and excel base calculations. You will also find enclosed with the report a soft copy of all excel files, S-Frame files and PDF documents.

Sincerely,

PRT Group

Vanessa Pynn	Ashley Rex	Edwin Tsui

cc: Dr. Steve Bruneau

CIVIL ENGINEERING PROJECT

FINAL REPORT
FOR
DESIGN OF MONOPOLES

PRT GROUP

April 5, 2010

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Summary

This report encompasses the work performed by the PRT Group for the Tiller Engineering Design of Monopoles project. This report includes an introduction and background to the project, the design methodology used by the group, the results of software analysis, a cost comparison between different types of poles, and the group's conclusions and recommendations based on the results obtained. The client requested that the information be summarized in a tabular format; the group has summarized their results in a table and a group of CAD drawings for quick reference use.

The appendix section includes all of the hand calculations and checks performed by the group for the design of the poles, rock anchors and foundations, as well as the calculations performed with the aid of computer software such as Excel and S-Frame.

Table of Contents

1.0 Introduction

This report includes an overview of the project that was undertaken by PRT Group. It consists of the generic design and analysis of 30 – 130 foot monopoles in 10 foot intervals. A design proposed for three different materials was conducted with steel, Douglas fir wood, and fiber reinforced polymer (FRP) composite material. Included with this design is a foundation, design of guy wires, rock anchors. For final deliverables to this project a table organizing our design is provided, included a cost estimate of the poles, and any applicable AutoCAD drawings.

Along with the final report from PRT Group a presentation will be delivered on Tuesday April 6, 2010 in the time slot of 2-5pm. The hard copy of this presentation is included in Appendix A of this report.

2.0 Project Description

The project for the client Tiller Engineering is a structural design project for monopoles. Tiller is expecting to be faced with the challenge of having to design multiple monopoles for their clients, the cellular companies. These companies need to provide cellular service to remote rural areas by regulations being pushed by the Canadian government. The choice of monopoles and point-to-point microwave transmission has been chosen for carrying cellular service to these areas; as it often compares very favorably with cabled systems such as fibre, which require right-of-way, trenching, conduit, splicing, etc. This system known as a microwave hop uses microwave communications channel between two stations with directive antennas that are aimed at each other. There is a transmitting antenna (microwave dish) that focuses the radio beam on the receiving antenna which collects the incoming signal. Additionally, each antenna must be within line of sight of the next antenna. As the antennas have a limited distance between them the need for multiple monopoles in a microwave hop are usually required.

With the expected inflow of monopole design Tiller Engineering has approached our company with the project of creating a monopole “look up” chart for various heights of 30-130 ft. The purpose of this table is to provide a building block and starting point for Tiller Engineering when beginning the design of site specific monopoles for this high demand period and for future reference. The table shall include three different types of materials for the monopole which consist of wood (Douglas fir), steel, and FRP composite material. Our study will examine the analysis and design of a series of antenna pole structures of various heights from 30 ft to 130 ft in 10 ft intervals using CSA S37-01. This will include 11 designs for each material for a grand total of 33 monopoles. Included in the design of the pole will be the design of the foundations for rock and normal soil conditions, rock anchors, guys, and guy connections. It shall be noted that the monopoles shall only be guyed if absolutely necessary. A typical AutoCAD drawing will be produced for the foundations, rock anchors, and guy connections. To help aid in the choice between selecting different monopoles in design a cost estimate will be provide based on the cost of the material used. All the information stated above will be compiled into a quick look-up table that Tiller Engineering can use as a reference when designing their site specific monopoles.

The work for this project as begun on Monday January 11, 2010, and will be completed on Tuesday April 6, 2010. The project shall have a midterm progress report and presentation completed on Tuesday February 16, 2010. At final result of this project will include a final report, a look up chart organizing all design and cost information, AutoCAD drawings, and a softcopy of S-Frame files.

Figure 2.0 Steel Monopole with Dish

3.0 Statement of Project Requirements

The end result for our project is a design look up chart. This required multiple tasks, analysis, and design to be calculated, compiled and organized in an easy view format. As this is not a site specific project the analysis shall be run with constant parameters provided by the client or assumed. A list of information requirements for the table is listed below.

- Research and select (2) two Andrew 4ft dish to use in analysis.

- Design steel poles from 30-130 ft at 10 ft intervals for a total of 11 poles.
- Design wooden poles (Douglas Fir) from 30-130 ft at 10 ft intervals for a total of 11 poles.
- Research and Design FRP composite material poles from 30 – 130 ft at 10 ft intervals for a total of 11 poles.
- Design guy wires for applicable poles above.
- Design connections
- Design (3) three rock anchors each at different capacities.
- Design (3) three foundations for rock and soil conditions for (3) selected heights for each material.
- AutoCAD typical drawings for foundations, rock anchors, and connections.
- Cost Estimate for all 33 poles, foundations, guys, connections, and rock anchors.

When designing the poles the antenna selected was the heaviest antenna that can be located as manufactured by Andrews. This antenna along with the pole will be used in calculating wind, ice, and dead loads on the pole structure. The loading on the microwave dish was calculated using software from Andrew called ANTwind. These loads were analyzed in S-Frame and an appropriate pole section was chosen. As FRP composite material poles are very new to the industry research was conducted to ensure an accurate analysis and design. Based on deflections of the monopole guy wires were required at a certain height. When required, they were designed for all the applicable poles. Typical connections will be used for wood and steel poles; however an effective analysis and design will have to be performed on the connection for the composite poles. For this project three (3) rock anchors were designed at three capacities based on the loads calculated in the guys. As this is not a site specific project three of each type of foundations (rock and soil) were designed for the monopoles at (3) three heights for each material type. As there is no geotechnical data the design was completed based on normal soil conditions as specified by the client. When all design is completed a cost estimate was conducted for the structural components of the monopoles.

4.0 Methodology of Design

This section includes the process of the design, codes, specifications used, assumptions made and reasons for the design choice.

4.1 Calculation of Loads on Dish

The first task that was undertaken by the Group was the selection of the Andrew 4 foot dish. The Andrew Company and a size of 4 feet was specified by the client. As this is a generic design of monopoles the heaviest 4 foot dish was selected. The choice was a high performance parabolic shielded antenna type: HP4-71 similar to the figure below. This was chosen from the Andrew online Catalog and the specifications sheet was obtained.

For calculating the wind loads on the dish the group used a software program ANTwind. ANTwind software provided for free from the Andrew Company. Using this program the group completed analysis on all heights ranging from 30ft-130ft and applied the wind force from 180 degrees to -180 degrees to determine the maximum force applied on the dish. This ensured that the completed analysis was designing for the worst case scenario. We used 2 inch thick ice all over the dish which we attained from the CSA 37-01.

The only other load to calculate on the dish would be the dead load of the dish and we also calculated that load with and without ice as well. We used 2 inch thick ice all over the dish which we attained from the CSA 37-01. This designed the poles for the worst case scenario and the largest load the dish will cause.

Fig. 4.1 Typical Parabolic Shielded Antenna

4.2 Calculation of Loads on Tower

To design any pole the calculation of multiple loading cases were required. As this is a repetitive tasks all loads would have to be recalculated more than once for each 33 poles if the design check didn't pass, so a spread sheet was created. The spreadsheet includes all loads, factored and un-factored, and a hand check for overturning moment and shear at the base of the tower, to compare with the S-Frame results. It is also used to calculate the distributed local load to input into S-frame. To get new results into the table the input required is the outer diameter at the base, the outer diameter and the tip, and the thickness of the monopole.

The loads on the tower have been calculated using CSA-S37-01. [1]. The loads have been calculated for all steel towers as follows below however wood and composite have followed the exact procedure with a few minor adjustments to the spreadsheet/calculations.

Section 4.0 deals with loads; specifically dead, ice and wind loading on the pole. The dead weight has been calculated as per section 4.1 it includes the weight of the steel tower. The weight for the tower has been calculated by breaking the tapered tower up into sections calculating the section volume and multiplying it by the density of steel. This can be seen in Appendix B.

Section 4.2 covers the ice loading to be considered this includes the weight of glaze ice formed radially on the pole. These calculations can also be seen in Appendix B and were also formed by breaking the pole up into sections. The density of ice is taken as 900 kg/m^3. The minimum glaze ice thickness was supplied by the client as 50mm.

Section 4.3 is for the design wind pressure, P, which is the pressure of the undisturbed flow independent of the drag factor. The equation used is $P=qC_eC_gC_a$. The reference velocity pressure, q, was provided by the client as 1000pa. The gust effect factor, C_g , was taken as 2.5 and the speed up factor, C_a , was taken as 1.0. The height factor, C_e is equal to (=) $(H_x/10)^{0.2}$, and $0.9 <= C_e <= 2.0$.To calculate the wind pressure on the tower it was broken down into sections that did not exceed 6m. In our design our largest section was 4.95m, and all poles were broken down into 8 sections. The pressure was calculated at the centroid of each tapered tower section.

The wind load on the tower was calculated as stated in section 4.8.2 as $W=P*A_{proj}*C_d$ when wind and ice is acting the projected area shall included the area of the radial ice. To calculate the wind load as a distributed load in KN/m for the use in S-Frame W (KN/m) =P*(average diameter of the section)* $C_{d.}$

The drag factor, C_d , was calculated as outlined in 4.9.2 for pole structures. Refer to table 2 on pg 18 for more information. The pole shape picked for design was an 18 sided pole structure therefore the value of 0.65 for the drag factor was used for all steel calculations. However in the top section of the tower there are expected to be dishes mounted, through observation of the area of exposed dish and the area of exposed pole for all our top sections PRT Group have concluded that section b) always applies. Here an effective drag factor is used, $C'_d = 1.3\ C_d$.

The analysis of the pole structure is covered in section 5.0 of the CSA-S37-01 code [1]. The load combinations that were considered in this section are Dead + Wind (with no ice), and Dead + Wind (with ice) + Ice. Factored loads for ultimate limit state design was used. The reliability class for the design was class I, in which an importance factor of 1.0 was used. This class was suggested to the Group by the client. For calculating deflections un-factored loads were used.

Included in the load calculation spread sheet is the forces at the base of the tower which include; the factored overturning moment, the shear force (the sum of the wind force), and the axial force which is the total dead load and ice load if applicable. This is used as a check the output of the S-Frame software.

The above description is also applicable for wood and FRP poles. However, a drag factor, C_d = 0. 5 for round poles was used. These calculations can also be seen in Appendix B.

4.3 Steel Monopole Design

The steel monopoles were all evaluated in S-frame for deflection checks. It was determined that no guys were need for the design. All design is based on a monopole structure, with an analysis of the steel pole as a cantilever beam. This section includes a description of the S-Frame analysis, capacity checks, foundation and base plate design. For a full summary of our design refer to section 6.0.

4.3.1 Analysis of Steel Towers in S-Frame

After completing the loads on the tower and the dish and putting all the data into a spreadsheet the group began the analysis of the steel poles in S-Frame. An analysis was ran for all the steel poles from 30-130ft using both the factored and un-factored wind loads calculated earlier for all load cases. For calculating the deflections only service loads were applied to the pole, which consisted of the un-factored wind loads. The analysis was run to ensure it passed the 2^o deflection criteria.

The steel poles that were selected for each height had a bottom trial diameter of X inches and a top trial diameter of X inches with a constant taper all the way up the pole. After completing the analysis on all the steel poles the group came to the conclusion that the monopoles up to 70ft passed the deflection check but the poles above failed. So it was determined the diameters and thicknesses of the poles above 70 ft in height were to be increases and determined if the poles would pass the deflection check. So after increasing all the diameters it was determined that all the steel poles from 30-130 ft passed the deflection check without needing to attach guys. These results can be seen in Appendix C.

4.3.2 Capacity Check for Steel Poles

The steel pole capacity check was completed by analyzing the pole as a cantilever beam. This was done for all poles from 30 – 130 ft. The code used for the design checks was completed in accordance to CSA S16-01 as found in the Handbook of Steel Construction [2]. The moment of resistance was calculated using Cl 13.5, $M_r = \phi S F_y$. F_y used was 345 MPa. This was calculated at 8 sections of the pole and compared to the actual moment, to ensure that $M_f/M_r \leq 1.0$. The shear was also checked as per Cl 13.4.2 to ensure that $0.66\phi F_y \geq$ factored max shear stress. Max shear stress was calculated for the 8 sections of the pole using tmax = (VQmax)/(It). These calculations can be seen in Appendix D. All the poles past for the capacity check however for the 60ft pole it is suggested to use a greater thickness at the base as Mf/Mr is closer to (1) one. However this does not affect our wind loads on the pole and therefore the rest of our groups design.

4.3.3 Foundation Design

The foundations were designed based on the max moment that is expected at the base of the tower. As requested by the client two types of foundations were designed for (3) three different heights of the steel poles. The foundation types designed where a foundation for normal soil conditions, and bedrock. For a summary of the design please see section 6.0.

4.3.3.1 Normal Soil Foundation

The design for soil foundations for the steel poles was completed using the geotechnical information provided by the client. The relevant properties include: The unit weight of compacted dry till of 20.6 kN/m2, allowable bearing pressure of 250 kPa, groundwater level at the surface, frost penetration of 1.2m and a drained angle of internal friction of 38 degrees.

The soil foundations were designed based on the equations in The Principles of Geotechnical Engineering by Braja M. Das [3]. The methods consist of analyzing the pole as a structure with both moment and tension loads acting on it. This consisted of a very large moment causing a vertical uplift force on the pole. Due to the fact that no steel beams needed guy wires, the group decided on the use of pier footings for the soil foundations to counteract these large moments. .

In the design of the pier footing the total axial load was calculated using the weight of the footing and the weight of the soil above the two piers, because the axial force of the pole alone was negligible when compared to the moment at the base of the pole. Then q_{max} was calculated making sure it was below the maximum allowable pressure the size of the footing was determined. After determining the size of the footing it was designed for both failure in shear and flexure, where the size and amount of rebar was calculated for both the footing section and the column section. Also the foundation was designed for the number of anchor bolts needed, and then the foundation was checked for both pull out and breakout resistance. All concrete design was completed in accordance to the Concrete Design Manual [4]. Refer to Appendix E for all relevant hand calculations.

4.3.3.2 Bedrock Foundation

The design for bedrock foundations was completed with the geotechnical rock information as provided by our client. The relevant properties include; a unconfined compressive strength of 65 MPa, a design water level of 2.0 meters below the surface, an estimated RQD=70% (fair quality rock), depth to sound rock of 1.0 meters, and a specific gravity of 2.5 (therefore rock density of 24.5 kn/m^3)..

The bedrock foundations were designed based on the principles as described in Foundations on Rock by Wyllie [5]. The methods consist of analysis the pole as a structure with combined moment and tension loading. This consists of a moment and a vertical uplift force applied to the structure which is anchored with a group of bolts arranged in a circular pattern around the base. The moment applied to the structure is resisted by a force couple composed of tension and compression forces. The tensile force is mobilized by the rock anchors. The stability of the structure is calculated from the weight of the cone of rock mobilized in the foundation, and the strength of the rock on a portion of the cone surface that is subjected to uplift [5]. The weight of this cone was calculated as per equation 9.20 and the surface area of the cone was calculated was per equation 9.21 in Wyllie [5]. The resisting force generated on the surface area (fr') is equal to the tensile strength of the rock on the surface of the cone multiplied by the surface area. Therefore the load capacity of the tower foundation is equal to the weight of the mobilized rock mass plus the resisting force (fr') divided by a factor of safety. The factor of safety used was (2) two. From table 3.5 in Wyllie the rock type used was coarse grained polymінerallic igneous and metamorphic crystalline rocks i.e. granite. The above theory was used to calculate the embedment depth of the anchor bolts in the bedrock foundations. The calculations for these foundations can be found in Appendix E.

The bolt forces were determined as suggested in "Design of Monopole Bases" [6]. It is suggested that most modern monopole base plates are not grouted. As grouting of the plate can learn to corrosion problems if means are not provided to allow for drainage of condensation that can develop with the pole. Also, once grouted, the pole can no longer be adjusted for any out-of-plumb conditions since the leveling nuts will be encased with grout. Some manufactures have specific warranty disclaimers if the pole is grouted. For those above reason the group has determined to design an ungrouted base the monopole structures.

Here the bolt pattern around the bases was chosen was an equally spaced, symmetrical bolt circle with all bolts the same size. Here the maximum bolt force was determined by Fmax = $(P/n) + (My_{max}/I)$. Where n is the number of bolts. The shear in the bolt is suggested to be V = 2V/n for a base plates with a central hole. The max force was then calculated and a treaded anchor bolt was chosen from Williams Engineering Corporation from their 150 KSI all threaded rod [7]. This rod was chosen to conform to Cl 25.2.2.1 and Cl 25.2.3.3 of the steel handbook [2]. Fu was taken as 1030 Mpa as specified by the manufacture. Part no used were R71-08 and R71-10. These calculations can be found in Appendix E.

4.3.4 Base Plate

The base plate for the steel pole was designed for flexure and analyzed like a cantilever between the tributary are supported by the bolt and the axial force applied to the area by the pole. The moment as the force in the bolt times, the distance from the centre of the bolt to the location of the pole wall. The equation of Mr = ϕSFy [2] was used to determine the thickness of the plate. Stiffeners (gusset plates) were then added to help transfer the forces due to the axial and bending moment to the pole. This configuration can be seen in the figure below.

AASHTO recommends that the min thickness of the plate be equal to (1) one bolt diameter. They also suggest that the distance from the bottom leveling nut to the foundation not be greater than (1) one bolt diameter [6]. The calculations for the base plate can be found in Appendix E included with the foundation design.

Fig. 4.3.1 Monopole Base Plate

4.4 FRP Composite Pole Design

The FRP pole dimensions were selected from the pole data sheets as supplied by RS Technologies [8]. The FRP monopoles were all evaluated in S-frame for deflection checks. It was determined that no guys were needed at the heights of 30, and 40 feet. For heights greater than this guys were added at 5 feet below the tip of the structure. All non guyed design is based on a monopole structure, with an analysis of the pole as a cantilever beam. Guyed structures were analyzed as a beam column. This section includes a description of the S-Frame analysis, capacity checks, foundation design. For a full summary of our design refer to section 6.0.

4.4.1 Analysis of FRP Poles in S-Frame

The dimensions and loads upon the poles were calculated in an excel spreadsheet, and then modeled in S-Frame in a similar fashion to the steel poles Analysis was performed on towers ranging from 30 to 120 ft using both the factored and un-factored wind loads calculated earlier for all load cases. For calculating the deflections only service loads were applied to the pole, which consisted of the un-factored wind loads. Towers greater than 50ft required guy wires to ensure that the location of the dishes on the poles deflected less than 2^{o}. Where applicable, 3 Guy wires were attached 5ft from the tip of the poles (to account for the dish height), and angled downwards at a 45^{o} angle. 3/8” guy wires were selected for all the poles, and the guy wires are located 120^{o} apart. The client provided material properties for FPR Composite which was used to create a custom material type for the tapered, hollow poles (10mm thick). All guy wires were prestressed to 10% of their breaking strength (6.005 MPa) and non-linear analysis was performed in the software to determine the deflections, axial force, shear force, and associated moments for the pole based on the dish and environmental loading.

4.4.2 Capacity Check for FRP Poles

The FRP pole capacity check was completed by analyzing the pole as a cantilever beam for all poles not guyed, 30 and 40 ft. This was done as described in section 4.3.2. A Fy for FRP was taken as 300 MPa as suggested by Dr. Steven Bruneau. As there are no codes for FRP available the procedure described in the Handbook of Steel Construction was followed.

The poles that were guyed from 50 – 120 ft were analyzed as a beam column. The axial compression was calculated by following the clause 13.3.1 of the steel handbook [2]. A value of n=1.34 was used, k was taken as 0.8 as was done for the wood poles, Fy used was 300 Mpa, and E was taken as 4x10^6 psi (27579 MPa) as specified by the client. The section used for calculating Pr was the average of the tip dimensions and the bottom dimensions. The combined (Pf/Pf) + (Mf/Mr) were checked to be greater than 1 for all poles at various heights. This can be seen in Appendix E.

4.4.3 Foundation Design

The foundations were designed based on the max moment, and axial force that is expected at the base of the tower. As requested by the client two types of foundations were designed for (3) three different heights of the FRP poles. The foundation types designed were a foundation for normal soil conditions, and bedrock. For a summary of the design please see section 6.0.

4.4.3.1 Normal Soil Foundations

The soil foundations were designed with the same procedure as described in section 4.3.3.1 for the steel foundations. As the moments for the guyed towers were smaller and the axial forces were larger, block foundations were used. The block foundation provided the resistance needed due to the help from the guy wires.

For the shorter poles 20M rebar was used but for the 90 ft and higher 25M rebar was used. The axial force was taken as (weight of the pole + weight of ice + axial force on column from guys).

4.4.3.2 Bedrock Foundations

The bedrock foundations were designed with the same procedure as described in Section 4.3.3.2 for the steel foundations. As the moments experienced by guyed towers are smaller they have smaller embedment depths for the rock anchors. This was expected in the design procedure.

A treaded anchor bolt was chosen from Williams Engineering Corporation from their Grade 75 all threaded rebar [7]. This rod was chosen to conform to Cl 25.2.2.1 and Cl 25.2.3.3 of the steel handbook [2]. Fu was taken as 698.4 Mpa as specified by the manufacture. Part no used were R61-08 and R61-06.

These calculations can be found in Appendix E.

4.5 Wood Pole Design

The wood pole dimensions were selected from the CSA dimensions for Coastal Douglas Fir Poles as provided by Guelph Utility Pole Company Limited [9]. The wood monopoles were all evaluated in S-frame for deflection checks. It was determined that all poles required to be guyed; this was governed by buckling of the pole and the capacity of the poles. Height of 30 – 60 feet required one set of guys 5 ft from the top, and 70- 100 ft required 2 sets of guys at top and half height of the pole. These structures were analyzed as a beam column. This section includes a description of the S-Frame analysis, capacity checks, foundation design. For a full summary of our design refer to section 6.0.

4.5.1 Analysis of Wood Poles in S-Frame

The spreadsheet used for steel and FRP was modified to aid with the design of the solid wooden poles. Analysis was performed on towers ranging from 30 to 100 ft using both the factored and un-factored wind loads calculated earlier for all load cases. Guy wires were attached 5ft from the tip of the poles (to account for the dish height), and angled downwards at a 45^{o} angle. 3/8" guy wires were selected for all the poles, and the guy wires are located 120^{o} apart (3 guys per layer). All towers required guy wires for either deflection or buckling checks, and poles exceeding 70 feet required two layers of guy wires (the second layer located at the midpoint of the monopole and sharing the same rock anchor as the first set of guy wires). The group used the default Douglas fir material properties included in the software for the tapered, solid wooden poles. All guy wires were prestressed to 10% of their breaking strength (6.005 MPa) and non-linear analysis was performed in the software to determine the deflections, axial force, shear force, and associated moments for the pole based on the dish and environmental loading.

4.5.2 Capacity Check for Wood Poles

The capacity check for wood poles was analyzed as a beam column as per CSA 086 Clause 12 [10]. The constants used are all listed in the enclosed calculations that can be found in Appendix E. As per clause 12.5.2.6 an effective diameter was used to calculate the axial compression resistance for a tapered section. For calculating the moment of resistance an equivalent square section was used as per clause 12.5.3. The pole was checked to ensure that (Pf/Pr) + (Mf/Mr) < 1. The shear resistance of the section was also calculated and checked.

4.5.3 Foundation Design

The foundations were designed based on the max moment, and axial force that is expected at the base of the tower. As requested by the client two types of foundations were designed for (3) three different heights of the wood poles. The foundation types designed were a foundation for normal soil conditions, and bedrock. For a summary of the design please see section 6.0.

4.5.3.1 Normal Soil Foundations

The soil foundations were designed with the same procedure as described in section 4.3.3.1 for the steel foundations. As the moments for the guyed towers were smaller and the axial forces were larger, block foundations were used. The block foundation provided the resistance needed due to the help from the guy wires.

For the shorter poles 20M rebar was used but for the 90 ft and higher 25M rebar was used. The axial force was taken as (weight of the pole + weight of ice + axial force on column from guys).

4.5.3.2 Bedrock Foundations

The bedrock foundations were designed with the same procedure as described in Section 4.3.3.2 for the steel foundations. As the moments experienced by guyed towers are smaller they have smaller embedment depths for the rock anchors. This was expected in the design procedure.

A treaded anchor bolt was chosen from Williams Engineering Corporation from their Grade 75 all threaded rebar [7]. This rod was chosen to conform to Cl 25.2.2.1 and Cl 25.2.3.3 of the steel handbook [2]. Fu was taken as 698.4 Mpa as specified by the manufacture. Part no used were R61-08 and R61-06.

These calculations can be found in Appendix E.

4.6 Rock Anchors

The rock anchors were designed in accordance to the steel handbook [2], and as suggested by Wyllie [5] in Foundations on Rock under tensions foundations. The rock cone method was used in determining the tension resistance of the rock anchor. The rock data was as specified in section 4.3.3.2.

There are two possible failure modes for anchors loaded in pure tension. First is the rock-grout or the grout-steel interface. The bond between the rock and the grout interface was checked as per equation 9.8 [5]. The second step is to check the steel-grout interface this was done in accordance to equations 9.11 – 9.15 [5]. Second, a cone of rock may fail. A simplified assumption can be made that the apex of angle is 90 degrees. When using this method the pull out cone was assumed to start at the tip of the bond zone as suggested by Williams Engineering Corp [7]. The counteracting force of the cone is the weight of the cone, plus the resisting force on the surface area of the failure cone. The weight of the cone was calculated as per equation 9.17 and the resisting force developed on the curved surface area of the cone was calculated as per equation 9.18 [5]. A factor of safety of 2 was used in calculation of the required embedment depth.

A rod of R61 Grade 75 all treated rebar from Williams Engineering Corporation was chosen. This rod was chosen to conform to Cl 25.2.2.1 and Cl 25.2.3.3 of the steel handbook [2]. Fu was taken as 698.4 Mpa as specified by the manufacture. Part number R61-06.

The steel in the rock anchor was designed and checked as per the Steel hand book. Steel used was 350W with a Fy of 345 MPa. All bolts used were A325 ½” bolt with a Fu of 825 MPa. The plates and bolts of the tension members were checked in accordance with Cl. 13.2, 13.11, and 13.12.

See appendix F for detailed calculations and refer to section 6.0 for details on the design of the rock anchors.

5.0 Cost Analysis

The cost analysis for this project was completed with information provided by RS Means [11], Tessco [12], Trylon TSF [13], and other internet sources. Six costs were developed for each tower type (wood, steel, and FRP) for the tower heights in which foundations were considered. The costs for the rest of the tower heights were interpolated.

The costs of the poles were developed based on list prices provided for a similar design of monopoles provided by Tessco [12]. The cost of their towers was graphed with weight of the tower vs. the cost as seen below. The cost of our Groups design was then calculated by using the graph constructed with the weight of our poles. This graph can be seen below. The costs of the wooden poles were provided by Bell Lumber and Pole Co. by Mark VonGrey [14]. The cost of the FRP poles using RS Means was interpolated from the comparison of the cost of a steel flagpole to a fiberglass flagpole of similar size. Other structural components were analyzed and compared such as HSS, and plate steel versus fiberglass. It was determined that FRP was 1.8 times more expensive than steel on average. This was used to determine the cost of our FRP poles. The installation of the pole was determined using a crew for a communications tower in RS Means [8]. The group made a judgment for the steel monopoles installation to take 7 days for the 50 ft, 10. 5 days for the 90 ft, and 14 days for the 130 ft. A similar process was determined for the wood and FRP. Any heights in between were interpolated through a trend line. This can be seen in Fig. 5.2.

The base of the steel monopole was determined using a steel price of plate from Speedy Metals [15]. The price per weight of plate was calculated and determined to be \$1.7 per pound. The group made a decision on welding time for each base, and a welder’s rate as determined from the RS Means [11]. The base plate was for 50, 90, and 130 foot was determined and the other heights were interpolated as seen below in Fig. 5.3.

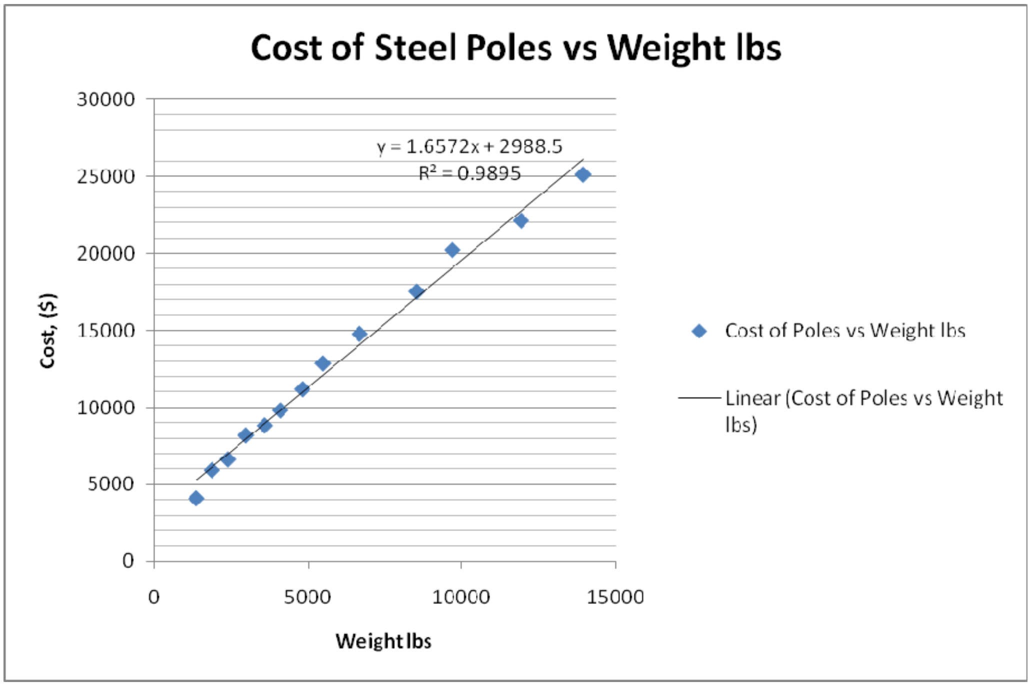


Fig. 5.1 Cost of Steel Poles vs Weight

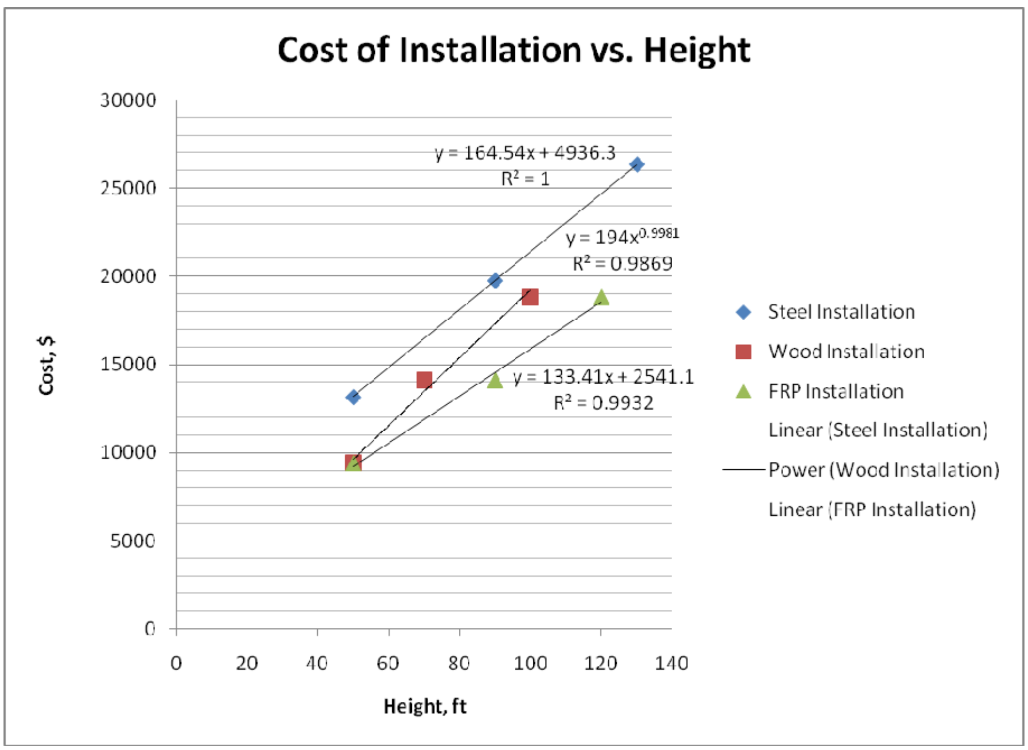


Fig. 5.2 Cost of Installation vs. Height

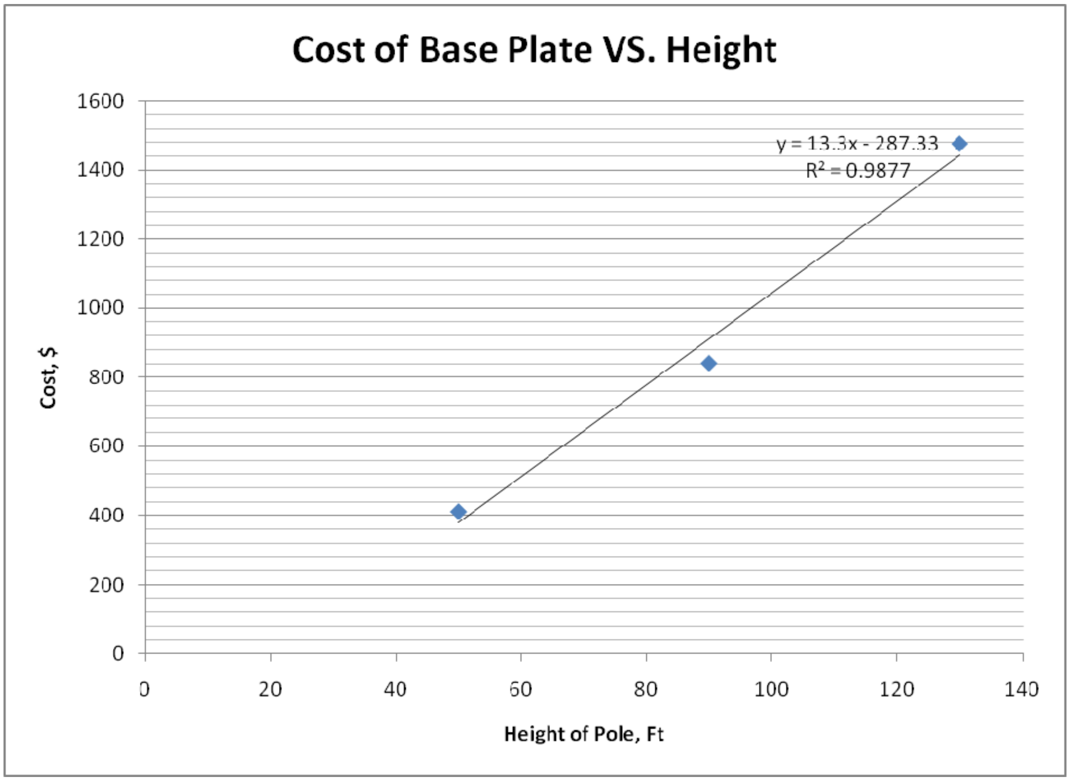


Fig. 5.3 Cost of Base Plate vs. Height

The soil foundations at 3 selected heights were determined using the values provided by the RS Means [11]. The cost for the concrete was taken as $120 per cubic yard, the reinforcement was determined for each type of footing individually having a different cost for the column and footing. From the RS Means $1550 per ton of concrete for the 25M bars and $2105 per ton of concrete for the 20M bars. For the column the costs determined was $2000 per ton of concrete for 25M bars. The cost for placing the concrete was determined as $68 per cubic yard for the column and $19.95 per cubic yard. The anchor bolts the group needed were the 12 inch and the 18 inch which were determined as $2.76 and $3.44 per bolt. The cost of excavation was determined using $23.50 per cubic yard and backfill as $1.12 per cubic yard. All other heights were interpolated based on Fig. 5.4.

The bedrock foundation costs were also determined using RS Means [11]. The drilling of the rock bolts was taken as $8.45 per foot, and the anchor bolts were interpolated from RS Means as $4.00 per foot. The cost of grout was calculated based on a list price provided by Capital Ready Mix [16] at $215 per cubic meter. The cost of grouting the bolts was determined by the group as one laborer at $45.00 per hour [11] with it expected to take 0.5 hours to grout one rock anchor. This was calculated at our three selected tower heights for each material and the rest of the foundations cost was interpolated based on Fig. 5.5.

The rock anchors were bolts and drilling were calculated as the same procedure as above. The cost of the above ground steel anchor assembly was judged by a cost of plate taken from Speedy Metals [15] as $1.40 per pound.

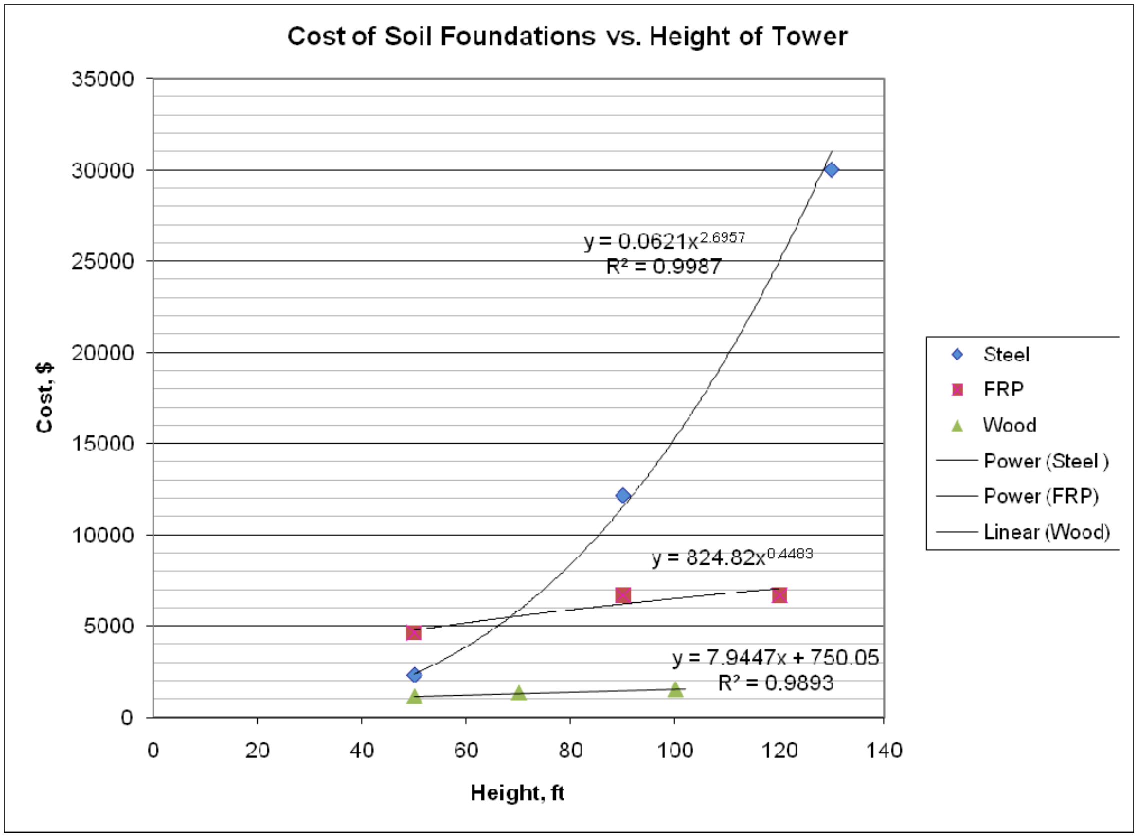


Fig. 5.4 Cost of Soil Foundations vs. Height

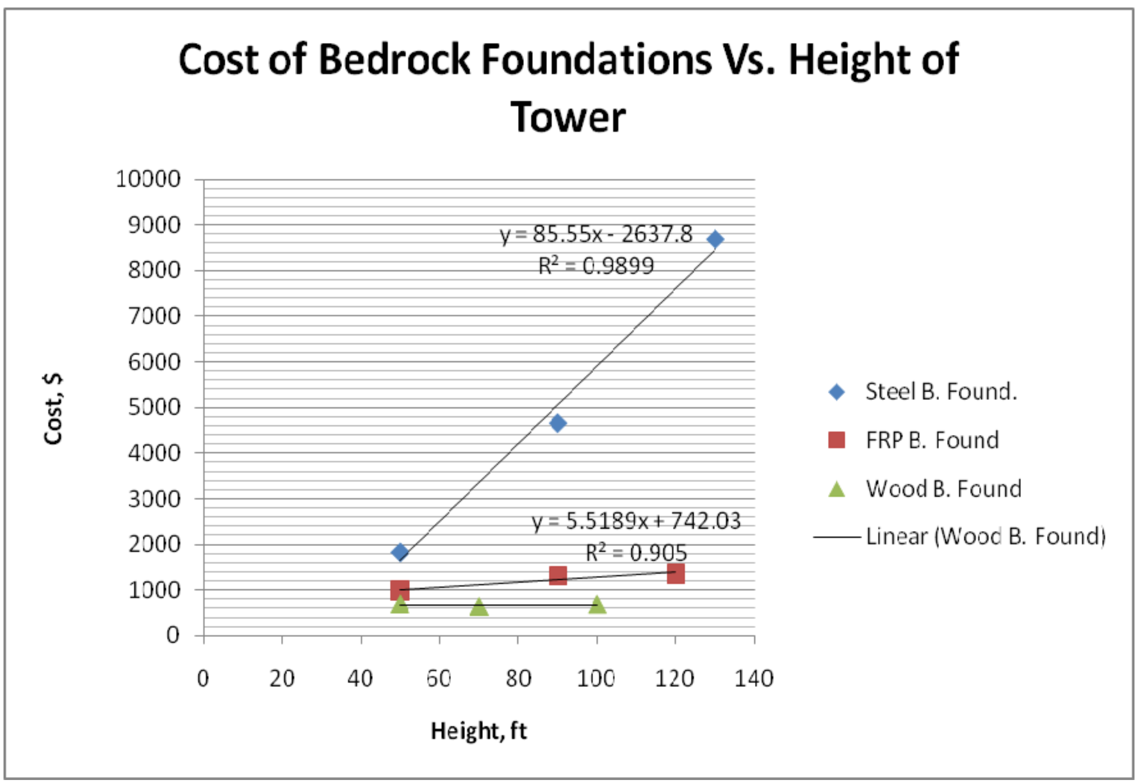


Fig. 5.5 Cost of Bedrock Foundations Vs Height

The cost of the guy wires was determined from an online catalogue provided by Trylon TSF [13]. The cost was taken as $1.50 per foot of guy wire, the guy wire accessories for each was also determined.

The summary of our cost can be can be found in Section 6.0 in the project summary table. For detailed calculations for the cost refer to Appendix G for all hand and excel based calculations.

6.0 Summary of Results

The tabulated results and associated drawings are presented over the following 7 pages of the report.

	Description	Steel Monopole (DWG: ST-01)	Wood Monopole (DWG: ST-01)	FRP Monopole (DWG: ST-01)
30 Ft	Base Diameter (in), D1	16	13.8	18.3
	Top Diameter (in), D2	12	10.6	12
	Thickness (in), t	1/4"	N/A	3/8"
	Foundation with Soil (DWG: ST-02)	Refer to Type S1	Refer to Type W1	Refer to Type S1
	Rock Foundation (DWG: ST-03)	Refer to Type S1	Refer to Type W1	Refer to Type S1
	Monopole Base (DWG: ST-04)	Refer to Type S1	-	-
	Guy Elevation	N/A	25 ft @ < 45 degrees	N/A
	Rock Anchors (DWG: ST-05)	N/A	Type 2	N/A
	Cost ($Soil ($Bedrock))	$16,856 ($17,064)	$9732 ($9388)	$16,527 ($14,059)
40 Ft	Base Diameter (in), D2	17	16.2	24.8
	Top Diameter (in), D3	12	10.6	16.2
	Thickness (in), t	1/4"	N/A	avg. 0.42"
	Foundation with Soil (DWG: ST-02)	Refer to Type S1	Refer to Type W1	Refer to Type S1
	Rock Foundation (DWG: ST-03)	Refer to Type S1	Refer to Type W1	Refer to Type S1
	Monopole Base (DWG: ST-04)	Refer to Type S1	-	-
	Guy Elevation	N/A	35 ft @ < 45 degrees	N/A
	Rock Anchors (DWG: ST-05)	N/A	Type 2	N/A
	Cost ($Soil ($Bedrock))	$20,355 ($19,795)	$12,703 ($12,271)	$20,358 ($16,668)
50 Ft	Base Diameter (in), D2	19	17.5	27.9
	Top Diameter (in), D3	12	10.6	16.6
	Thickness (in), t	1/4"	N/A	avg. 0.42"
	Foundation with Soil (DWG: ST-02)	Type S1	Type W1	Type F1
	Rock Foundation (DWG: ST-03)	Type S1	Type W1	Type F1
	Monopole Base (DWG: ST-04)	Type S1	-	-
	Guy Elevation	N/A	45 ft @ < 45 degrees	45 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A	Type 2	Type 3
	Cost ($Soil ($Bedrock))	$24,516 ($23,994)	$15,410 ($14,906)	$25,512 ($21,488)
60 Ft	Base Diameter (in), D3	20	18.8	34.5
	Top Diameter (in), D4	12	10.6	20.7
	Thickness (in), t	1/4"	N/A	avg. 0.44"
	Foundation with Soil (DWG: ST-02)	Refer to Type S2	Refer to Type W2	Refer to Type F2
	Rock Foundation (DWG: ST-03)	Refer to Type S2	Refer to Type W2	Refer to Type F2
	Monopole Base (DWG: ST-04)	Refer to Type S2	-	-
	Guy Elevation	N/A	55 ft @ < 45 degrees	55 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A	Type 2	Type 2
	Cost ($Soil ($Bedrock))	$29,144 ($27,644)	$18117 ($17,510)	$23,332 ($24,375)
70 Ft	Base Diameter (in), D3	24	19.8	40.8
	Top Diameter (in), D4	12	10.6	25.7
	Thickness (in), t	3/8"	N/A	avg. 0.44"
	Foundation with Soil (DWG: ST-02)	Refer to Type S2	Type W2	Refer to Type F2
	Rock Foundation (DWG: ST-03)	Refer to Type S2	Type W2	Refer to Type F2
	Monopole Base (DWG: ST-04)	Refer to Type S2	-	-
	Guy Elevation	N/A	65 ft @ < 45° / 35 ft @ < 22.5°	65 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A	Type 2	Type 2
	Cost ($Soil ($Bedrock))	$34,727 ($31,982)	$21,995 ($21,275)	$32,685 ($27,832)
80 Ft	Base Diameter (in), D4	30	20.8	40.8
	Top Diameter (in), D5	14	10.6	23.2
	Thickness (in), t	3/8"	N/A	avg. 0.44"
	Foundation with Soil (DWG: ST-02)	Refer to Type S2	Refer to Type W3	Refer to Type F2
	Rock Foundation (DWG: ST-03)	Refer to Type S2	Refer to Type W3	Refer to Type F2
	Monopole Base (DWG: ST-04)	Refer to Type S2	-	-
	Guy Elevation	N/A	75 ft @ < 45° / 40 ft @ < 22.5°	75 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A	Type 2	Type 2
	Cost ($Soil ($Bedrock))	$45,943 ($41,352)	$24,348 ($23,566)	$41,894 ($36,726)
90 Ft	Base Diameter (in), D4	32	21.7	40.8
	Top Diameter (in), D5	14	10.6	20.8
	Thickness (in), t	3/8"	N/A	avg. 0.44"
	Foundation with Soil (DWG: ST-02)	Type S2	Refer to Type W3	Type F2
	Rock Foundation (DWG: ST-03)	Type S2	Refer to Type W3	Type F2
	Monopole Base (DWG: ST-04)	Type S2	-	-
	Guy Elevation	N/A	85 ft @ < 45° / 45 ft @ < 22.5°	85 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A	Type 2	Type 2
	Cost ($Soil ($Bedrock))	$54,366 ($46,095)	$27,472 ($26,603)	$46,429 ($40,503)
100 Ft	Base Diameter (in), D5	38	22.6	40.8
	Top Diameter (in), D6	17	10.6	19.3
	Thickness (in), t	3/8"	N/A	avg. 0.43"
	Foundation with Soil (DWG: ST-02)	Refer to Type S3	Type W3	Refer to Type F3
	Rock Foundation (DWG: ST-03)	Refer to Type S3	Type W3	Refer to Type F3
	Monopole Base (DWG: ST-04)	Refer to Type S3	-	-
	Guy Elevation	N/A	95 ft @ < 45° / 50 ft @ < 22.5°	95 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A	Type 2	Type 1
	Cost ($Soil ($Bedrock))	$64,713 ($54,400)	$30,114 ($29,168)	$54,148 ($48,421)

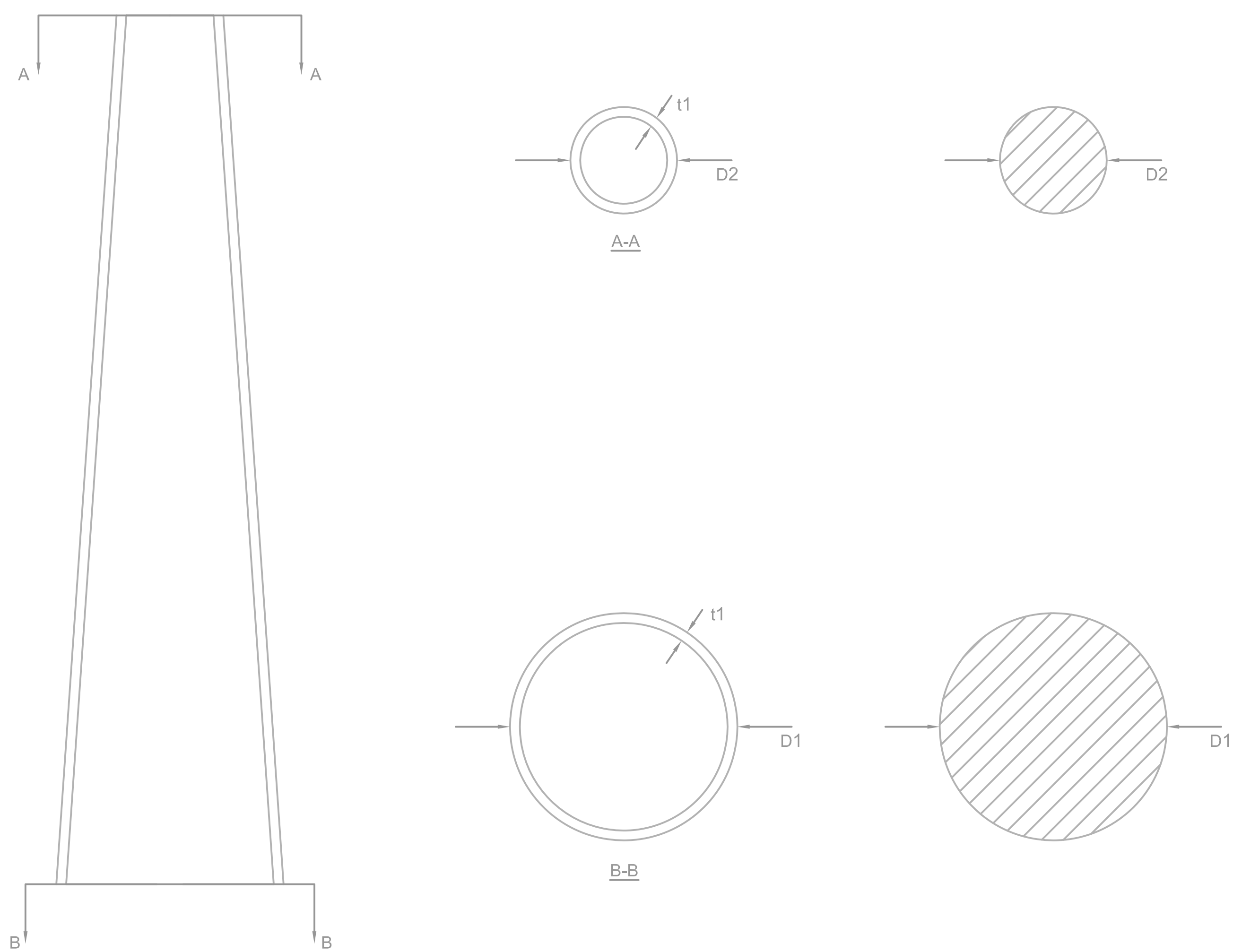
110 Ft	Base Diameter (in), D5	40		40.8
	Top Diameter (in), D6	18		16.8
	Thickness (in), t	3/8"		avg. 0.44"
	Foundation with Soil (DWG: ST-02)	Refer to Type S3	N/A	Refer to Type F3
	Rock Foundation (DWG: ST-03)	Refer to Type S3		Refer to Type F3
	Monopole Base (DWG: ST-04)	Refer to Type S3		-
	Guy Elevation	N/A		105 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A		Type 1
	Cost ($Soil ($Bedrock))	$74,819 ($60,519)		$59,781 ($53,802)
120 Ft	Base Diameter (in), D6	42		40.7
	Top Diameter (in), D7	24		15.3
	Thickness (in), t	3/8"		avg. 0.44"
	Foundation with Soil (DWG: ST-02)	Refer to Type S3	N/A	Type F3
	Rock Foundation (DWG: ST-03)	Refer to Type S3		Type F3
	Monopole Base (DWG: ST-04)	Refer to Type S3		-
	Guy Elevation	N/A		115 ft @ < 45 degrees
	Rock Anchors (DWG: ST-05)	N/A		Type 1
	Cost ($Soil ($Bedrock))	$88,181 ($69,072)		$67,917 ($62,048)
130 Ft	Base Diameter (in), D6	46		
	Top Diameter (in), D7	26		
	Thickness (in), t	3/8"		
	Foundation with Soil (DWG: ST-02)	Type S3	N/A	N/A
	Rock Foundation (DWG: ST-03)	Type S3		
	Monopole Base (DWG: ST-04)	Type S3		
	Guy Elevation	N/A		
	Rock Anchors (DWG: ST-05)	N/A		
	Cost ($Soil ($Bedrock))	$101,086 ($77,613)		

TILLER ENGINEERING MONOPOLES

STRUCTURAL DRAWINGS

PREPARED BY: EDWIN TSUI
PREPARED FOR: TILLER ENGINEERING
DATE: MARCH 26th, 2010

<u>LIST OF DRAWINGS:</u>



DWG. NO.	REFERENCE DRAWINGS

#	DATE	REVISION/ ISSUE	DRN	CHK	APPR

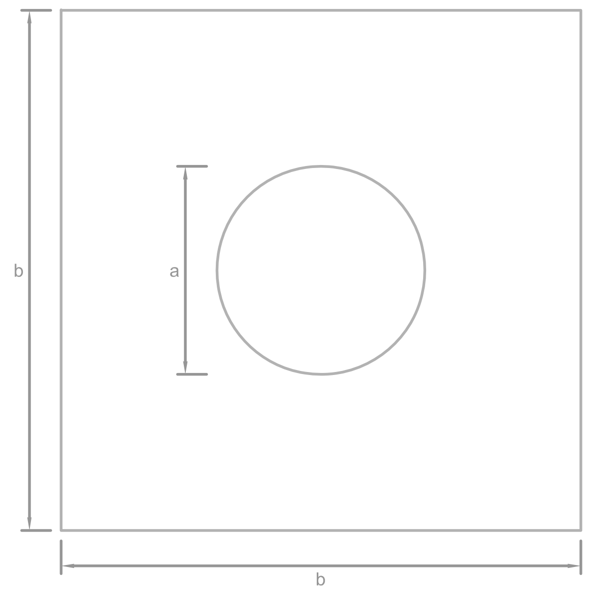
PROJECT

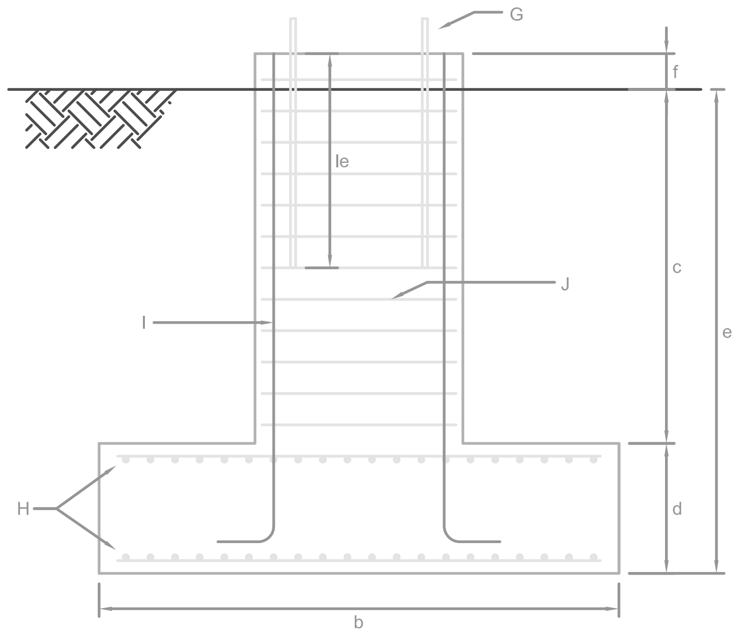
TILLER ENGINEERING MONOPOLES

SUBJECT

TYPICAL MONOPOLE STRUCTURE

	DATE MAR 26, 2010
DESIGNED AR	SCALE NTS
DRAWN ET	CHECKED -
DRAWING NO. ST-01	REVISION NO. A





TYPE	a	b	c	d	e	F	G	H	I	le	J
S1	750	2500	2300	700	3000	300	8-25M	12-20M	9-25M	359	10M@400
S2	1100	3500	1000	1000	2000	300	16-25M	14-25M	20-25M	301	10M@400
S3	1500	5000	1300	1300	2600	300	24-30M	20-25M	43-25M	417	10M@400
W1	600	-	1000	-	-	300	8-25M	-	10-20M	22.2	10M@400
W2	650	-	1000	-	-	300	8-25M	-	7-25M	28.5	10M@400
W3	700	-	1000	-	-	300	8-25M	-	8-25M	39.0	10M@400
F1	1000	-	1500	-	-	300	8-25M	-	16-25M	40.5	10M@400
F2	1200	-	1500	-	-	300	8-25M	-	23-25M	71.6	10M@400
F3	1200	-	1500	-	-	300	8-25M	-	23-25M	79.0	10M@400

NOTES:

1. REFER TO DRAWING ST-03 FOR ANCHOR BOLT DETAIL.
2. ASSUMED A490M ANCHOR BOLTS
3. Fu = 1040 MPa
4. FRP & WOOD FOUNDATIONS HAVE ONLY THE COLUMN SECTION
5. CONCRETE PROPERTIES USED:
   Fc' = 30 MPa,
   Fy = 400 MPa
6. SOIL PROPERTIES USED:
   $\phi' = 34°$
   q_{all} = 250 kPa
   γ_{soil} = 20.6 kN/m2
   GROUND WATER LEVEL = AT SURFACE
   FROST PENETRATION = 1.2m

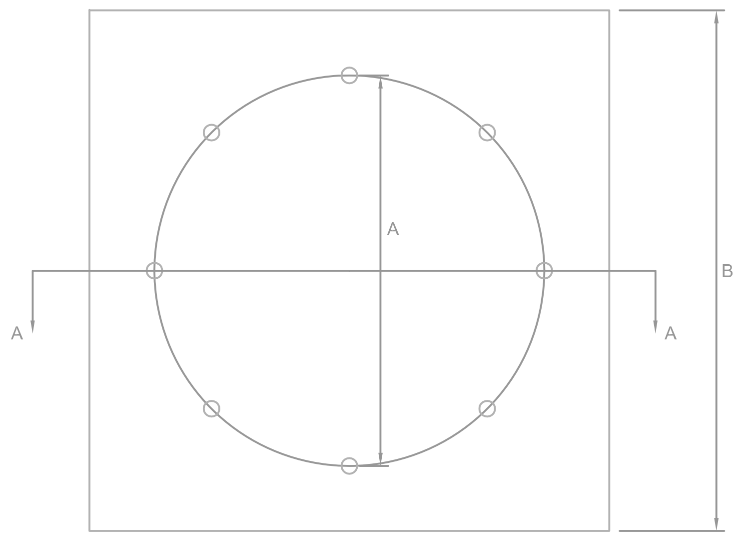
DWG. NO.	REFERENCE DRAWINGS

#	DATE	REVISION/ ISSUE	DRN	CHK	APPR

PROJECT
TILLER ENGINEERING MONOPOLES

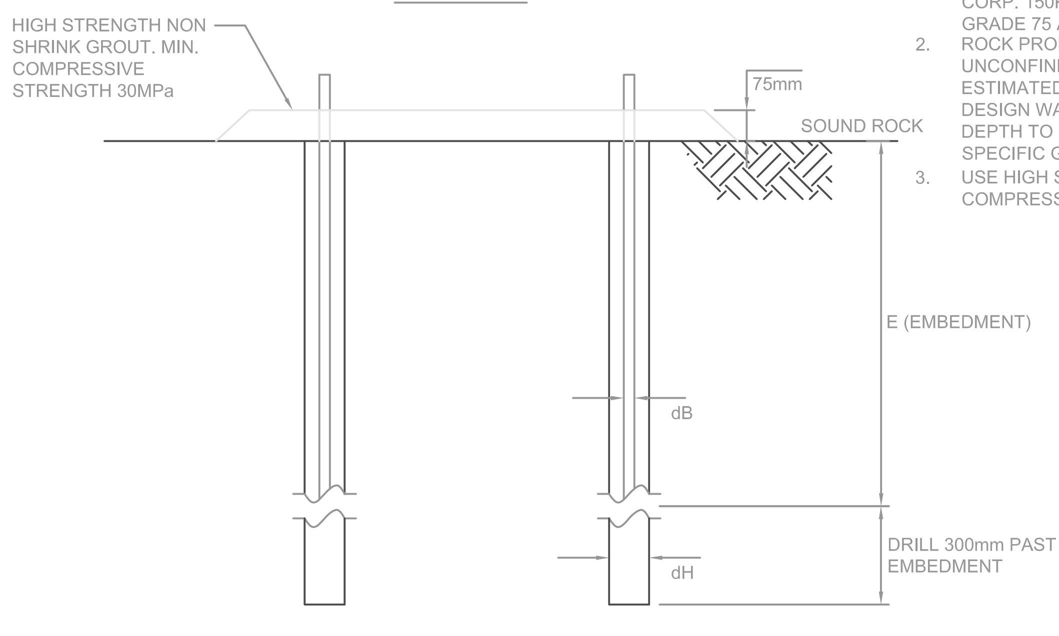
SUBJECT
TYPICAL SOIL FOUNDATION NON GUYED

	DATE MAR 26, 2010
DESIGNED VP	SCALE NTS
DRAWN ET	CHECKED -
DRAWING NO. ST-02	REVISION NO. A



BASE OF POLE

TYPE	A	B	E	dH	dB	No. ANCHOR BOLTS	TYPE ANCHOR BOLT
S1	520	750	4750	50	25	8	PART#: R71-08
S2	850	1100	6250	50	25	16	PART#: R71-08
S3	1213	1450	8000	60	30	24	PART#: R71-10
W1	475	750	1700	40	20	8	PART#: R61-06
W2	533	775	1100	40	20	8	PART#: R61-06
W3	603	850	1250	40	20	8	PART#: R61-06
F1	739	1000	2150	40	20	8	PART#: R61-06
F2	1065	1300	3100	40	20	8	PART#: R61-06
F3	1070	1300	3300	40	20	8	PART#: R61-06



SECTION A-A

NOTES:

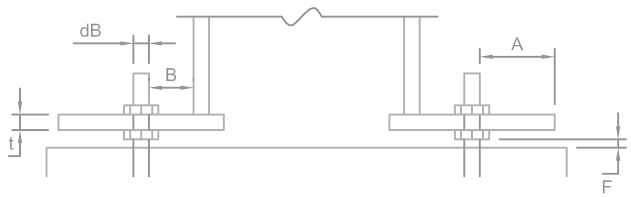
1. ANCHOR BOLTS USED ARE FROM WILLIAMS ENGINEERING CORP. 150KSI ALL THREADED ROD. GRADE 75 ALL-THREAD REBAR (Fu = 698 MPa)
2. ROCK PROPERTIES:
   UNCONFINED COMPRESSIVE STRENGTH = 65 MPa
   ESTIMATED RQD = 70%
   DESIGN WATER LEVEL = 2.0m
   DEPTH TO SOUND ROCK = 1.0m
   SPECIFIC GRAVITY = 2.5
3. USE HIGH STRENGTH NON SHRINK GROUT WITH A MINIMUM COMPRESSIVE STRENGTH OF 30 MPa

DWG. NO.	REFERENCE DRAWINGS			
#	DATE	REVISION/ ISSUE	DRN	CHK	APPR

PROJECT: TILLER ENGINEERING MONOPOLES

SUBJECT: TYPICAL BEDROCK FOUNDATION

	DATE: MAR 26, 2010
DESIGNED: VP	SCALE: NTS
DRAWN: ET	CHECKED:
DRAWING NO.: ST-03	REVISION NO.: A

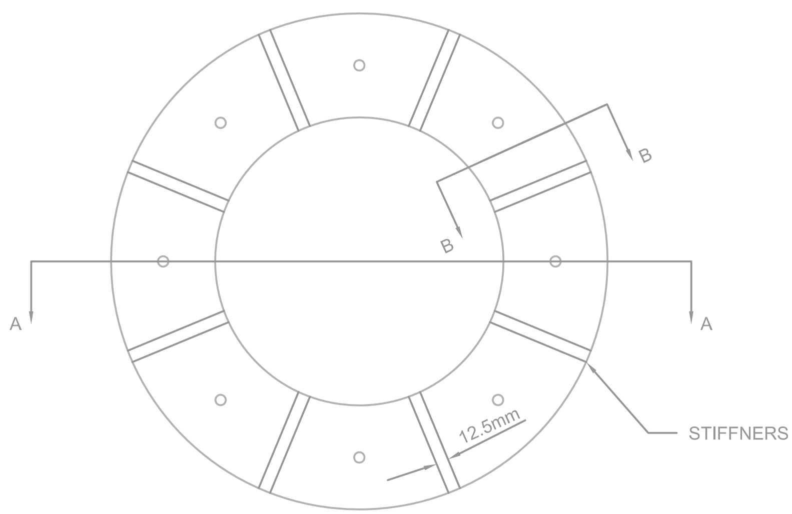


SECTION A-A

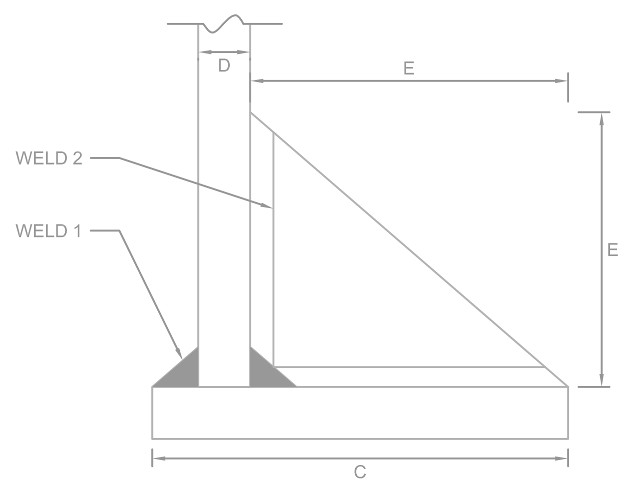
TYPE	A	B	C	E	t	dB	No. BOLTS	E	F	WELD 1	WELD 2
S1	35	25	100	6.35	25	25	8	85	≤25	6mm FILLET	6mm FILLET
S2	35	25	105	9.53	30	25	16	85	≤25	10mm FILLET	6mm FILLET
S3	40	30	120	9.53	40	30	24	100	≤30	10mm FILLET	6mm FILLET

NOTES:

1. STEEL PROPRETIES ARE 350W STEEl, Fy = 345 MPa.
2. WELD PROPERTIES TO MATCH STEEL PROPERTIES



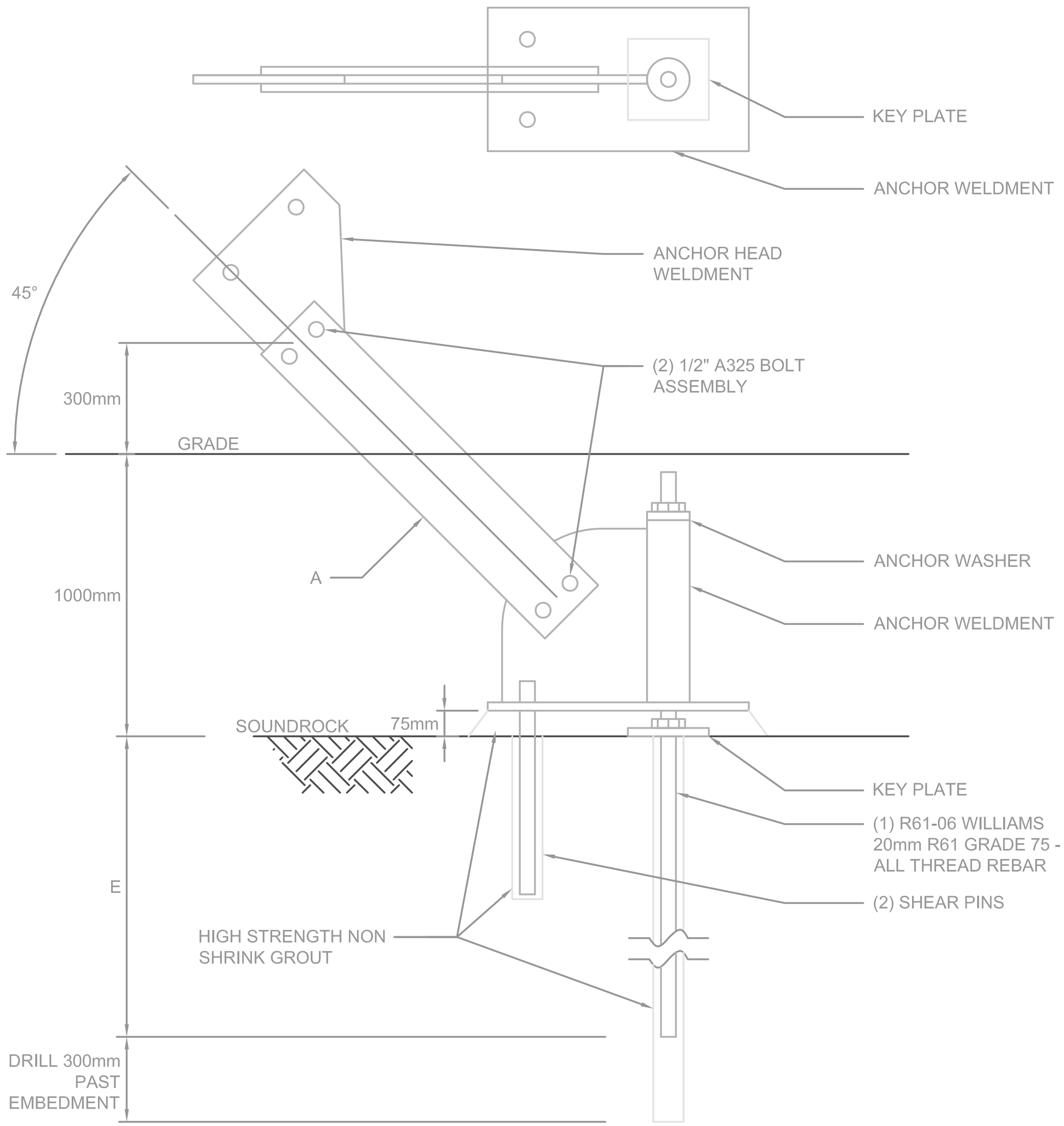
STEEL BASE PLATE



SECTION B-B

DWG. NO.	REFERENCE DRAWINGS			
#	DATE	REVISION/ ISSUE	DRN	CHK	APPR

PROJECT	TILLER ENGINEERING MONOPOLES
SUBJECT	TYPICAL MONOPOLE BASE FOR STEEL OPTION
DATE	MAR 26, 2010
DESIGNED: VP	SCALE: NTS
DRAWN: ET	CHECKED: -
DRAWING NO.: ST-04	REVISION NO.: A



TYPICAL ROCK ANCHOR FOUNDATION
(3) REQUIRED

TYPE	A	E
1	PL5 x 115 x 1626	1300
2	PL5 x 115 x 1626	900
3	PL5 x 115 x 1626	600

NOTES:

1. STEEL IS 350W STEEL, Fy = 345 MPa
2. ROCK PROPERTIES:
   UNCONFINED COMPRESSIVE STRENGTH = 65 MPa
   ESTIMATED RQD = 70%
   DESIGN WATER LEVEL = 2.0m
   DEPTH TO SOUND ROCK = 1.0m
   SPECIFIC GRAVITY = 2.5
3. BOLTS ARE A325, 1/2", Fu = 825 MPa
4. HIGH STRENGTH NON SHRINK GROUT WITH A MINIMUM
   COMPRESIVE STRENGTH OF 30 MPa

DWG. NO.	REFERENCE DRAWINGS

#	DATE	REVISION/ ISSUE	DRN	CHK	APPR

PROJECT
TILLER ENGINEERING MONOPOLES

SUBJECT
TYPICAL ROCK ANCHOR

	DATE: MAR 26, 2010
DESIGNED: AR	SCALE: NTS
DRAWN: ET	CHECKED: -
DRAWING NO.: ST-05	REVISION NO.: A

7.0 Conclusion and Recommendations

Based on our cost comparison, wood is the most cost-effective material for communication poles. However, our comparison does not take into account maintenance or project lifespan. Additionally, it may not always be feasible to use wooden towers due to their guy wire requirements. The foundation design used for wooden towers may also not be optimal for towers of lower heights – it was recommended by the client, but it is typical for wooden poles to simply be driven into the ground.

The steel poles compared were designed based on having no guy wire requirements, and consequently are large at the base and taper off significantly. It would likely be more economical to reduce the section size and use guy wires to reduce the deflection of the poles. The advantage of having unguyed towers is for installation under difficult conditions (i.e on a steep inclined mountain side) where it may be difficult or impossible to set up guy wires. Steel has more flexibility in pole sizing in comparison to wood, and is the most commonly used material for monopoles in the present age.

FPR Composite is not a commonly used as material for monopoles, but may become more commercially widespread in the future. There is a lack of readily available information on the material, and further research should be performed – much of the data used by the group was based on interpolation and based on the limited data provided by manufacturers.

It is important to note that the site conditions will be the primary limitation in selecting which materials are available, and that the quick-reference tables compiled by the group are for a generic design.

8.0 References

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[14] Mark VonGrey. Personal Reference. Bell Lumber & Pole Co. April 1, 2010.

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[16] Capital Ready Mix Ltd. (2009). Capital Ready Mix List Prices. St. John’s.

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APPENDIX A

"Hardcopy of Slideshow Presentation"

APPENDIX B

“Loading Calculations”

APPENDIX C

"S-Frame Results"

APPENDIX D

"Capacity Check Calculations"

APPENDIX E

"Foundation Calculations"

APPENDIX F

"Rock Anchor Calculations"

APPENDIX G

"Cost Analysis Calculations"

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