EVALUATING CONSTRUCTION METHODS FOR AN ELECTRICAL TRANSITION COMPOUND

A Major Qualifying Project

for Stantec Consulting Ltd.

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Abstract

This project, completed in conjunction with the Dartmouth, NS office of Stantec Engineering, evaluated various construction methods including: Cast in Place Concrete, CMU, ICF, Precast Concrete, and Structural Steel for the construction of an Electrical Transition Compound. The compound will transition underground electrical cables to overhead transmission lines. Evaluation criteria included cost, construction duration, environmental impact, durability, maintenance, and availability of labor and materials. The final report contained a recommendation and an alternative for the construction of the Transition Compound.

Acknowledgments

We would like to thank Professor LePage and Professor Hart for all their help during our preparation for this MQP project and during the project as well. The success of this project could not have been achieved without the knowledge and resources of Stantec Consulting Ltd. We would like to extend our gratitude to Jean Peinsznski, Bill Pay, Joshua Pidgeon, Nathaniel Dimock, and Brian Hines for their individual efforts that guided us to a successful project and a great learning experience. Thank you to all the Stantec Consulting Ltd. employees for making this experience enjoyable and educational.

Authorship

Throughout the course of this project work was completed both together and separately. All work during the research of this project was conducted as a team. The individual sections of this report have one individual author but all sections have been reviewed by both group members. Both group members of the team contributed equally to the success of this project.

Capstone Design Statement

The Accreditation Board of Engineering and Technology (ABET) mandates that all accredited engineering programs are supplemented by a Capstone Design Experience. Undergraduate engineering programs at Worcester Polytechnic Institute satisfy this ABET requirement through the Major Qualify Project (MQP). The American Society of Civil Engineers (ASCE) states that the said Capstone Design Experience must include aspects of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political.

Design Problem

This Major Qualifying Project met the requirements specified by both the ABET and ASCE by carrying out a "design process" which evaluates five different construction methods with several of the factors mentioned above and recommends the best construction method for the installation of an electrical Transition Compound in the Province of Nova Scotia, Canada. The five construction techniques include Concrete Masonry Units (CMU), Insulated Concrete Forms (ICF), Pre-Cast Concrete, Reinforced Concrete, and Structural Steel. Utilizing previous project experience of Stantec Consulting Ltd., research of local and regional standards of construction, cost-estimates, and building schedule approximations, the feasibility of each construction technique was evaluated and the best option selected. The construction techniques were assessed in terms of cost, construction time, manufacturability (constructability), environmental impact, health and safety, social opinions, and political influence. An Unbiased evaluation criteria was developed to decipher the most viable construction technique which was be subsequently recommended to the Dartmouth office of the Stantec Consulting Ltd. for the construction of a coastal electrical Transition Compound.

Engineering Standards and Realistic Constraints

As mentioned above, Capstone Design Experience must include aspects of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. The following sub-sections will briefly explain how the Major Qualify Project covered the necessary considerations of a Capstone Design Experience.

Economic

The evaluation of five alternative construction methods for the construction of an electrical Transition Compound involved economic considerations because of the cost-estimating procedures used to evaluate each different construction methods. The preliminary cost-estimates produced individual economic analyses of the five different options. One of the most important assessment criteria was the monetary cost of applying the building method for the construction of the Transition Compound.

Environmental

The evaluation of five alternative construction methods for an electrical Transition Compound involved environmental considerations by including the environmental impact of each of the methods into the assessment criteria for selecting the most feasible construction method. The environmental impact of building methods has increased significance because of the Transition Compounds site, which is set in a remote environment.

Manufacturability (Constructability)

Assessing the manufacturability of each method was a necessary step in both the cost-estimating and scheduling procedures. The overall degree of constructability of each building method was a measurement which combines both cost-estimating and scheduling.

Constructability was weighed heavily in the assessment criteria because it represents the ability to build the Transition Compound on-time and within the budget. The evaluation of this also took into consideration the availability and transportation for the materials and labor necessary for each specific the construction method.

Health and Safety

The evaluation of five alternative construction methods for the construction of an electrical Transition Compound included health and safety considerations into the assessment criteria for the selection of the most feasible building method. The preliminary scheduling evaluations were required to take into consideration how quickly the Transition Compound could be built using the construction methods without sacrificing the health and safety of the workers. Attention to health and safety was increased because of the dangers related to the high-voltage electrical equipment which is being housed within the Transition Compound. Concerns for human health and safety did not end with the completion of the Transition Compound. A number of safety and security features must be installed and maintained on the Transition Compound site. Because of the high voltage environment, fences and security systems were included into the construction of Transition Compound to protect against trespassers.

Social and Ethical

The evaluation of five alternative construction methods for the construction of an electrical Transition Compound included social and ethical considerations into the assessment criteria for the selection of the most feasible building method. The assessment process included criteria which represents the Social and Ethical impact of the building methods. Additionally, this project strictly followed the American Society of Civil Engineers (ASCE) Code of Ethics which requires engineers to "uphold and advance the integrity, honor, and dignity of the engineering profession (Code of Ethics, 2009).” Construction methods which would ease social and ethical tension, along with reducing construction time, had increased feasibility.

Political

The evaluation of five alternative construction techniques for the construction of an electrical Transition Compound included political considerations into the assessment criteria for the selection of the most feasible building method. As stated above, the installation of the Transition Compound in Cape Breton is rather controversial because of various political issues between the region’s citizens, governmental officials, and the electrical company. Diplomacy with local Aboriginal populations, which reside along the path of the Electrical Transmission Line, is be essential to the pending success of the project. While there are no Aboriginal groups which hold verified rights in Newfoundland region directly affected by the project, the Mi’kmaq tribe of Nova Scotia possess significant political authority . The Mi’Kmaq people are the original inhabitants of Nova Scotia and are the most substantial Aboriginal group within Nova Scotia with 13 Mi’Kmaq First Nation Communities, five of which reside in Cape Breton. The Electrical Transmission Line project will work closely with Mi’Kmaq leadership throughout the entire project.

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1.0 Introduction

The Overhead Transmission Line to Underground Cable Transition Compound will be constructed on the peninsula of Point Aconi, located just outside the city of Sydney, Cape Breton. The proposed Transition Compound will convert underground electrical cables to overhead transmission lines for the Electrical Transmission Project. The Electrical Transmission Project is a 500 Megawatt high voltage transmission system which will transmit electricity generated from a new hydroelectric dam in Upper Churchill Falls, Newfoundland to electrical grids of both Newfoundland and Nova Scotia. The project will not only supply Nova Scotia with large amounts of renewable energy, but also connect the Island of Newfoundland to the North American power grid.

Electricity generated by the hydroelectric dam will travel from Upper Churchill Falls, Newfoundland to Cape Ray, Newfoundland on overhead transmission lines. In Cape Ray, the electricity will be transitioned to underground cables and converted from AC to HVDC (High Voltage Direct Current) on land before being transmitted on two subsea cables which will span the 180 km Cabot Strait which separates Newfoundland and Nova Scotia. The subsea transmission cables will make land fall in Point Aconi, Nova Scotia, where the HVDC electricity will be converted to DC before being transitioned from underground cables to overhead transmission lines.

The Overhead Transmission Line to Underground Cable Transition Compound in Point Aconi is currently being designed by Stantec Consulting Ltd. (Stantec). The Transition Compound will be an approximately 295 Square Meter rectangular structure standing 3 meters tall. The site is in a relatively remote area and will require the construction of an access road. The main purpose of the building is to protect the sensitive transition equipment from the elements.

The Transition compound is currently in the preliminary design phase and the final construction method for the structure is still undecided. Because the structure will be simplistic, with minimal amenities, the construction method for the Transition Compound is the most influential aspect of the construction budget and schedule.

Due to the construction method's degree of importance, several design options have been outlined for the project. They include Cast-in-Place Concrete, Insulated Concrete Form (ICF), Structural Steel, Concrete Masonry Unit (CMU), and Pre-Cast Concrete. While all of the construction methods listed above were plausible options for the construction of the Transition Compound, great consideration was made into deciphering which method would not only be the cheapest but also the quickest to build, among other factors.

This Major Qualifying Project (MQP) consisted of working with Stantec to analyze the viability of the five construction methods listed above and subsequently suggest the optimal design option. Preliminary cost estimates and construction schedules were completed for each of the five construction methods. The final Evaluation Criteria for the design options included Cost, Schedule, Environmental Impact, Duration and Lifespan, Operation and Maintenance, Availability of Labor, and Availability of Supplies.

2.0 Background

The proposed Electrical Transmission Project will connect the provinces of Newfoundland and Nova Scotia. This project is a proposed new 500 MW +/- 200 to 250 kV High Voltage Direct Current (HVDC) transmission system. This will involve two 180km subsea cables across the Cabot Strait, close to 50km of overland transmission in Nova Scotia, and approximately 300km of overland transmission on the Island of Newfoundland (see figure 1). HVDC is the most efficient way to transmit electricity because there is less energy loss over long distances compared to High Voltage Alternating Current which is used primarily to deliver electricity to businesses and residences. With the completion of this project, Newfoundland will be connected to the North American transmission system, and Nova Scotia will have access to more renewable energy and become less dependent on existing carbon-based generation facilities. By 2020, Nova Scotia is required to supply at least 40 percent of its electricity by renewable energy (Emera Newfoundland & Labrador, 2012). The renewable energy will be supplied by the Lower Churchill Hydroelectric Generation Project which is scheduled to supply power in 2017 with the completion of Phase 1 in Muskrat Falls, Newfoundland (Nalcor Energy, 2013). This project uses a large-scale dam to harness the river's energy to produce a renewable source of electricity.

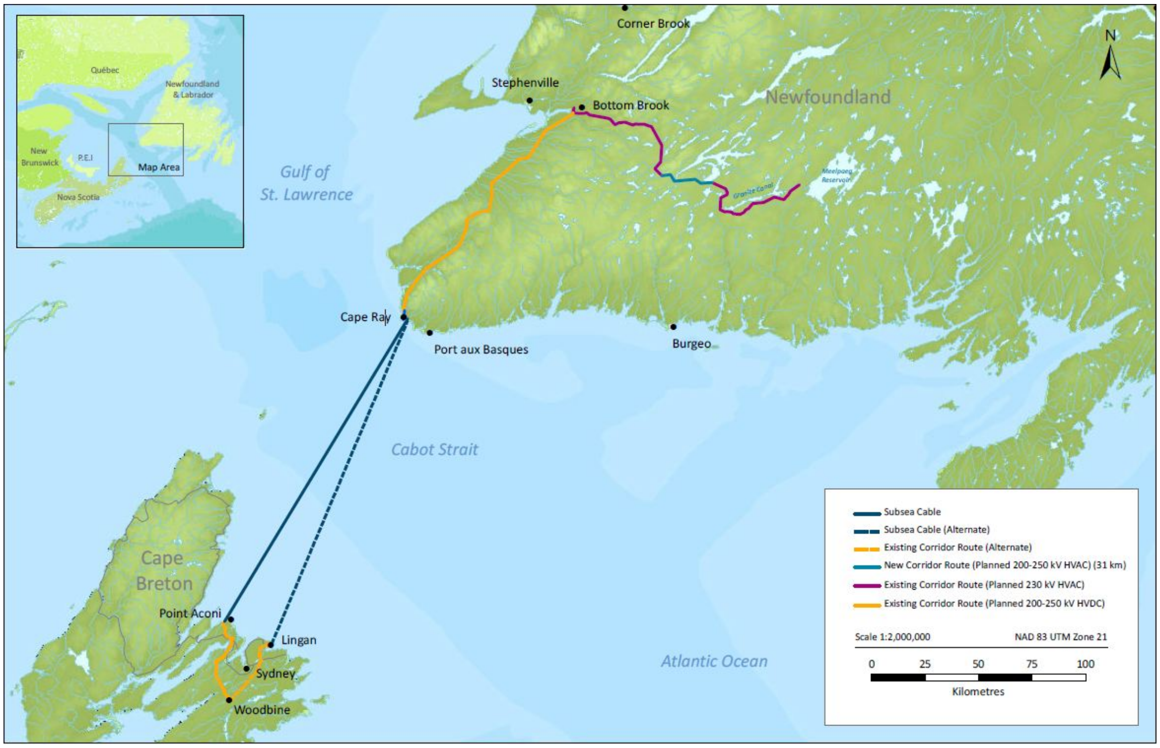

Figure 1: Proposed Route of Electrical Cables (Emera Newfoundland & Labrador, 2011)

The three main areas affected by this project include Newfoundland, the Cabot Strait, and Nova Scotia. In Newfoundland, a new transmission line along existing transmission corridors will be created between Cape Ray and Bottom Rock, and Bottom Rock to Granite Canal. The Cabot Strait will be used to host the two subsea cables spanning from Cape Ray, Newfoundland to Point Aconi, Nova Scotia. In Nova Scotia, a new transmission line will be created between Point Aconi and Woodbine.

This project includes the use of subsea cables, shore grounding facilities, two converter stations and adjoining substations, transmission corridors, two transition compounds, and other possible infrastructure that may be required. Activities included during the construction process are as followed: accessing and clearing of right of ways and sites, distribution of materials, construction of high voltage converter stations, tower installation, stringing of conductors, installation of grounding facilities, installation of landfall sites to bring subsea cables on shore, and laying of the subsea cable (Emera Newfoundland & Labrador, 2011).

The primary objective of the Electrical Transmission Project is "to provide a direct, safe, reliable and cost effective connection between the electrical system of Nova Scotia and the electrical system in southwestern Newfoundland. Secondary objectives include planning, designing, building and operating the Project with minimal adverse environmental, economic, social and cultural effects, and to create and economic cooperation between Nova Scotia and Newfoundland and Labrador, once the connection is completed (Emera Newfoundland & Labrador, 2011)."

2.1 Environmental Assessment

This project spans close to 530km and runs through many different eco-regions. Assessing environmental impact, although a secondary objective, is being conducted by the company proposing the project. Issues concerning wildlife, sea life, and Aboriginal communities have been provoked in several of the areas affected by the transmission lines.

2.1.1 Newfoundland

The project footprint in southwestern Newfoundland encompasses three eco-regions; the Long Range Barrens, the Western Newfoundland Forest, and the Maritime Barrens (see figure 2). These different eco-regions vary in wildlife and environmental conditions. These conditions may include numerous lakes, ponds, and short fast-flowing rivers. In addition, wildlife species that have received provincial and/or national conservation status may inhabit the area covered by the Project. These species may include: American marten, piping plover, rusty black bird, red crossbill, short-eared owl, harlequin duck, Eskimo curlew, gray-cheeked thrush, red knot, banded killifish, American eel, and boreal felt lichen (Emera Newfoundland & Labrador, 2011). There are no Aboriginal groups that currently possess and treaty rights on the island portion of the province (Emera Newfoundland & Labrador, 2011).

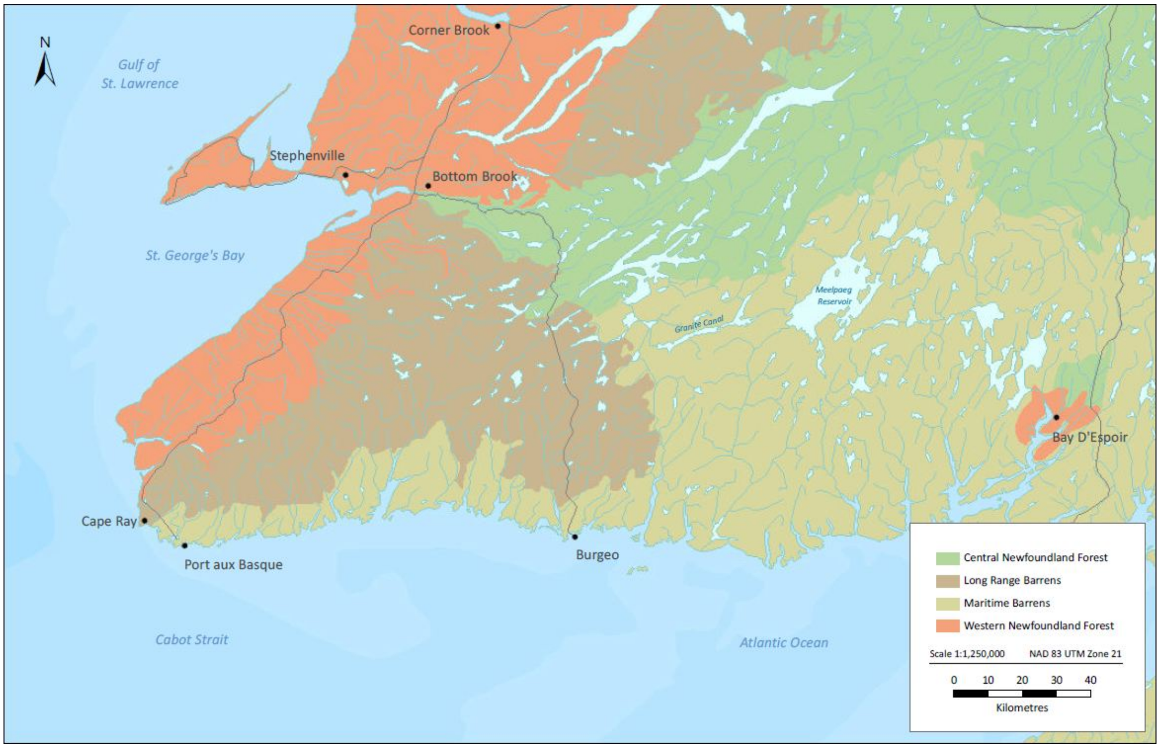

Figure 2: Ecoregions of Southwestern Newfoundland (Emera Newfoundland & Labrador, 2011)

2.1.2 Cabot Strait

The Cabot Strait has significant permanent and/or migratory populations of groundfish, whales, seals, turtles, shorebirds and seabirds. Several species are of conservational concern including: North Atlantic right whale, killer whale, humpback whale, fin whale, blue whale, harbor porpoise, Atlantic salmon, Atlantic cod, Atlantic sturgeon, wolfish (Atlantic, northern, and spotted), American eel, white shark, cusk, and leatherback turtle (Emera Newfoundland & Labrador, 2011). The Cabot Strait is a significant fishing area, waterway, international shipping route, and is crossed by Atlantic ferries. It is important to ensure the placement and design of the subsea cables do not affect the species listed prior in a harmful way, or pose any danger to the shipping and fishing industries of the area.

2.1.3 Cape Breton

Cape Breton is inhabited by a wide variety of wildlife and significant coastal species. Species that may be covered by the project area which have provincial and/or national conservation status include: American marten, Canada lynx, piping plover, harlequin duck, Bicknell's thrush, Atlantic salmon, American eel, jutta arctic butterfly, Quebec emerald butterfly, and yellow lamp mussel (Emera Newfoundland & Labrador, 2011). The area covered by the Electrical Transmission Project in Cape Breton is located in the Bras d'Or Lowlands (see figure 3).

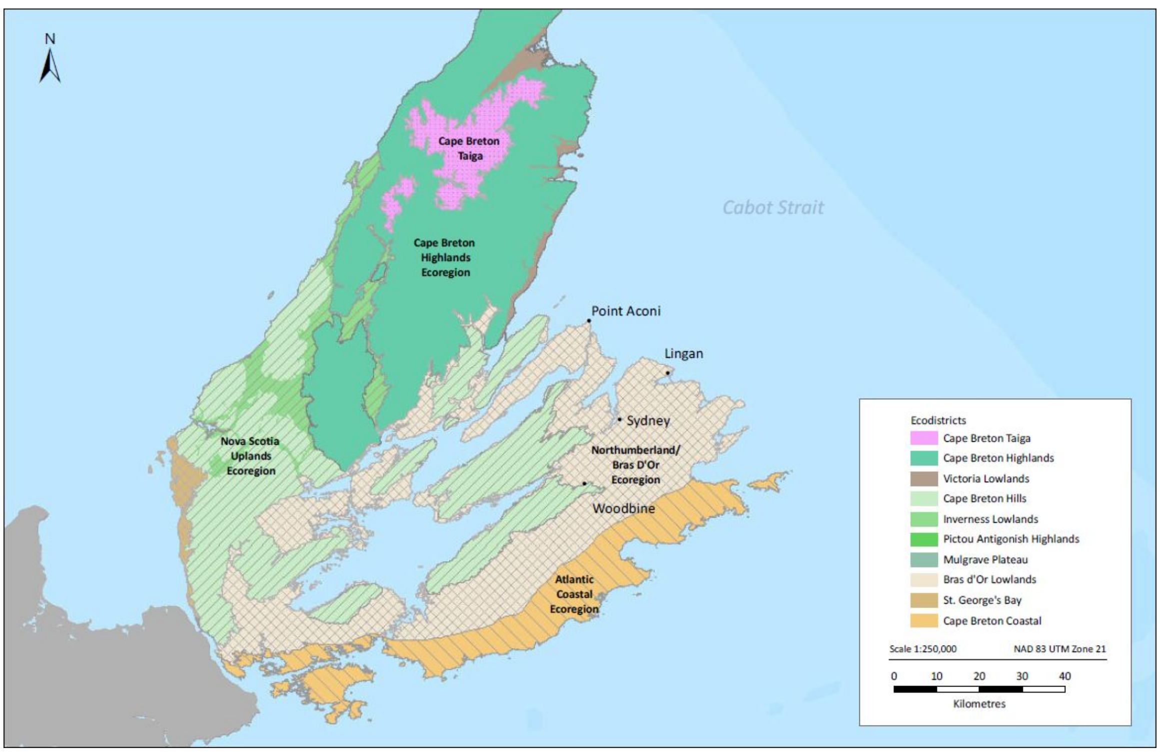

Figure 3: Ecoregions of Cape Breton, Nova Scotia (Emera Newfoundland & Labrador, 2011)

There is also strong Aboriginal presence of the Mi'kmaq Nation in Nova Scotia (see figure 4). There are currently five Mi'kmaq communities in Cape Breton which include:

Eskasoni, Membertou, Wagmatcook, Waycobah, and Potlotek/Chapel Island (Emera Newfoundland & Labrador, 2011). The company has been in contact with representatives of the Mi'kmaq First Nation in Nova Scotia to conduct negotiations and to ensure their areas of interest are not disrupted in a harmful manner.

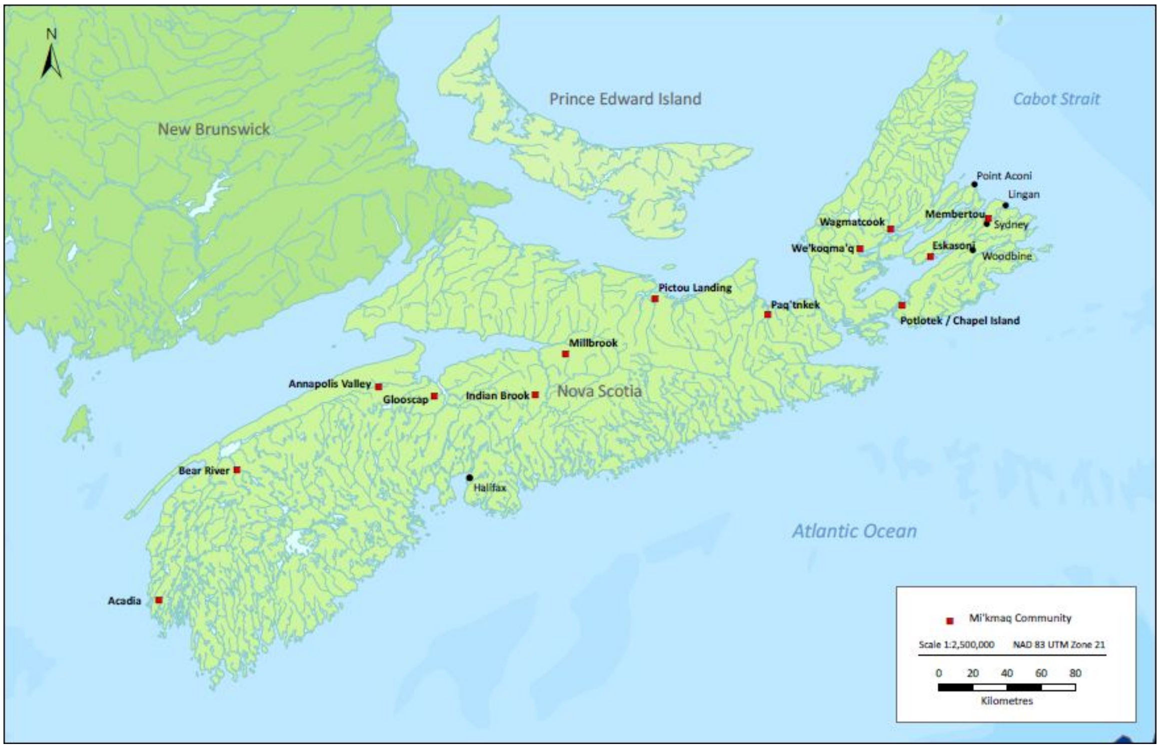

Figure 4: Mi'kmaq Communities in Nova Scotia (Emera Newfoundland & Labrador, 2011)

2.2 Transition Compound

The Electrical Transmission Project requires the use of two Transition Compounds. These Transition Compounds convert the underground subsea cables to overhead transmission lines. These buildings are fairly simple in terms of their structure and will be built in remote locations. They are post disaster buildings, which mean they must be able to withstand extreme forces. The Transition Compounds are involved with extreme electrical currents and equipment, so they must be secured and are also climate controlled while maintaining positive building pressure. These buildings will undergo regular inspection, repair and vegetation management, and decommissioning is not contemplated. The Electrical Transmission Project, including the Transition Compounds, is expected to be in operation for an indeterminate time period (Emera Newfoundland & Labrador, 2011). This means that the building materials used and the quality of construction must be exceptional in order to last a very long time. The location of the proposed Transition Compound in Point Aconi, Nova Scotia can be seen in figure 5 below.

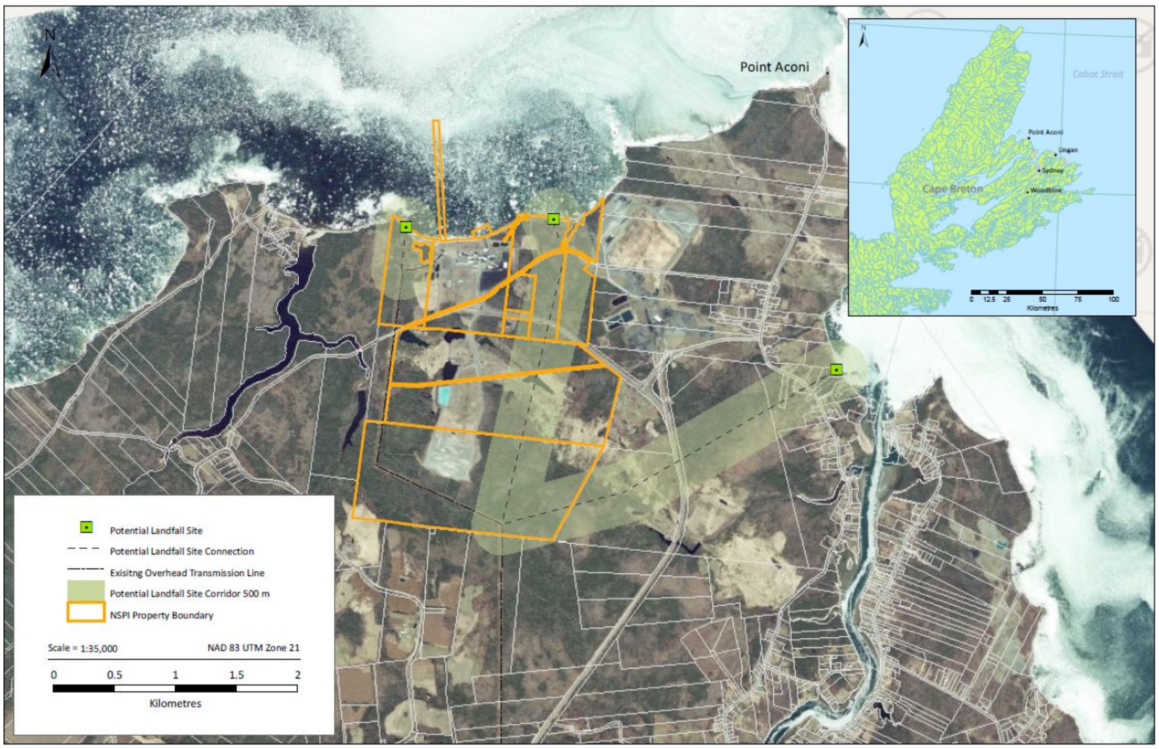

Figure 5: Proposed Locations of Transition Compound in Point Aconi, Nova Scotia (Emera Newfoundland & Labrador, 2011)

2.3 Construction Methods

There are a variety of construction methods that can be used during the construction process. There are five different methods that are possible for the construction of the Transition Compound in Point Aconi, Nova Scotia. These construction methods include Cast in Place Concrete, Concrete Masonry Walls (CMU), Insulated Concrete Forms (ICF), Precast Concrete, and Structural Steel.

2.3.1 Cast in Place Concrete

Cast in place concrete or reinforced concrete is one of the most common building materials used in construction. Reinforced concrete is a mixture of water, cement, sand, gravel, and reinforcing steel rods or rebar. The process of creating a reinforced concrete structure involves the usage of forms and steel cages. Reinforcing steel cages are built using rebar and steel mesh and forms are constructed around the steel creating the specified width and length and height of the walls/columns/beams etc. The concrete mixture is then poured into the form and set to cure. Concrete is extremely useful in handling compression forces but not in tension forces, which is the reason for the reinforcing steel. The concrete and steel are bound together during the curing process, which allows for the concrete to support the structure under compression loads and the steel to support the tensile loads (Britannica).

2.3.1.1 Cost & Schedule

Cast in Place Concrete is a very economical form of construction. Most of the cost that is involved with this method is due to the formwork that is required. Formwork for this method can be made from reusable forms or non-reusable (one use) forms. Reusable forms allow for quicker assembly of the formwork and less waste is produced using them. Unfortunately, reusable forms are more expensive and may also have to be made custom for parts of each specific job, also adding to the cost. One use forms, which are typically made out of plywood, are less expensive but are also more labor intensive and produce much waste. It takes longer to construct formwork using plywood, but it allows for more customization during construction.

Cast in Place Concrete is a relatively fast form of constructing large structures but you may only pour sections at a time, about eight or nine feet, depending on the size of the structure. Also time is needed to allow the concrete to cure and time to strip the forms off. This impacts construction schedules and typically all tasks involved with Cast in Place Concrete are part of the critical path. One possible issue involved with this method is that all work is done on site and is subject to weather conditions.

2.3.1.2 Environmental Impact

The method of cast in place concrete, if using one use forms, produces a lot of construction waste because after those forms are used they are thrown away. The material used in the cast in place method such as concrete also has major environmental impacts.

Concrete has many pros and cons in terms of its environmental impact. Most of the negative impact caused by reinforced concrete comes from the manufacturing of the product and the waste cause by excess material. During the production of cement, there are almost equal amounts of CO_2 emitted for every part of cement produced. For example, with every ton of cement produced there is almost a ton of CO_2 emitted (Bremner, 2001). Waste water is also produced from the excess concrete, because the inside of the delivery trucks must be cleaned out so that the concrete does not set. Recycling of the excess concrete also requires much water. Now, in the US, both of these processes must manage the waste water and treat it properly.

Reinforced concrete also has added environmental features. Low maintenance and high durability are features that not only reduce costs over time but material used to maintain it as well. The design of cast in place concrete allows for low energy consumption during the life span of the building. Concrete has a relatively lower R-value but it is a single solid surface making it harder for heat to escape. Excess concrete may also be recycled by combining fresh concrete with the water from washing the truck to create fine aggregate that can be used as soil conditioner or as roadbed material (Bremner, 2001).

2.3.2 Concrete Masonry Unit (CMU)

Concrete Masonry Unit (CMU) or concrete block as it is commonly called, is a mixture of Portland cement, gravel, sand, and water. This mixture can also include air-entraining agents, coloring pigment, and water repellent (Portland Cement Association). Concrete blocks are made by forming this mixture into its desired shape and curing it by heating it at a high temperature in a special chamber. Concrete blocks allow for the ability to create economical, energy efficient, and fire-resistant structures that involve minimal maintenance (Portland Cement Association).

Concrete blocks can be used to construct both small and large structures. The most common uses of concrete block include retaining walls, chimneys, fireplaces, and fire-rated shaft walls, elevator shafts, and storage vaults (Portland Cement Association). The different types of concrete masonry units include split-face concrete blocks, patented slotted concrete blocks, and glazed concrete blocks.

Concrete block walls can also be reinforced using different gauge wire reinforcement and rebar. Metal wire, welded together to form the shape of a truss, is used horizontally between courses to provide lateral strength. This technique resists “bowing” due to earth, wind, and seismic loads. Vertical rebar can be placed inside the openings in the block and filled with concrete-like grout. The rebar is spaced evenly throughout the wall, accommodating for larger vertical and lateral loads (University, 2008).

2.3.2.1 Cost & Schedule

Concrete block structures are versatile and allow for many different design concepts. Although this method of construction is relatively cheap, it is very labor intensive. Labor and material costs are low for this method but it takes much longer to construct projects on a larger scale than alternative methods. For projects that are on a tight schedule this would not be a suitable option.

2.3.2.2 Environmental Impact

Concrete blocks have many of the similar characteristics of the concrete used during the cast in place method. The production of concrete blocks also produces large amounts of CO_2 emissions. Another major environmental impact is cause from the extraction of aggregates. Most of the aggregates are derived from a land base source, with 20% of sand and gravel being dredged from the seabed (Greenspec). Using cement substitutes such as ground granulated blast furnace slag (GGBS) or pulverized fuel ash (PFA) can aid in the reduction of the amount of cement used to produce concrete blocks (Greenspec). Recycling aggregates is a way to reuse construction site waste in a positive way.

2.3.3 Insulated Concrete Forms (ICF)

Insulated Concrete Forms (ICF) have been around for quite a while but is still unheard of or rarely used in many parts of North America. ICF's can be made from different types of insulation but one in particular manufactured by NUDURA, is made from a polystyrene foam. ICF's are pre-made forms and are chosen based on concrete thickness: 4", 6", 8", etc. The typical form size is 1' 6" x 8' 0", and they also produce 90^{o} and 45^{o} corners, custom radius forms, and T-forms (Stantec, 2013). ICF is a very similar process to that of cast in place concrete, except these forms are much easier and much faster to construct compared to cast in place forms. The pre-made forms are delivered from the manufacturer and pieced together on site, similar to building with Legos. Reinforcement bars are clipped in horizontally as each level is built and vertical rebar is placed down through the top of the finished formwork. Also, another key advantage is that the forms do not need to be stripped off after the concrete has been poured and had a chance to cure. The insulated foam stays in place and acts as a thermal, vapor, and water barrier. A 6" concrete wall has a performance value of thermal resistance, or R-value, ranging from 30 – 40 (Stantec, 2013). This includes the insulated forms and the concrete. These walls also have a Sound Transmission Class (STC) rating of 52 (Stantec, 2013). The inside of the walls are covered with standard gypsum board and the exterior can be finished with anything from brick to stucco to siding. The assets of this product make it a prime solution for residential and low-rise commercial construction.

2.3.3.1 Cost & Schedule

ICF has many advantages in regards to cost and schedule for construction. ICF building cuts down on construction time, which saves money. The process of building with these forms is less labor intensive, which also saves money. ICF also has a very high level of energy efficiency. A high R-value, with no thermal gaps and minimal air leaks all lead to cost savings over time. One area where ICF can become more expensive than alternative options is door and window openings and corners or radius walls. The cost goes up with the more of these occurrences there are.

ICF is quicker to build than cast in place and much stronger than traditional wood framed construction. The only limited factor is the amount of concrete you can pour at one time. Finishes on the inside and outside or the building gain from ICF construction as well. Piping and electrical can carve into the insulating form work and drywall can directly fasten their boards to the wood joists already manufactured in the formwork.

2.3.3.2 Environmental Impact

ICF construction is considered environmentally friendly by using recycled materials, reducing construction waste, mold resistant, and energy efficient. The durability of ICF also adds to reducing its environmental impact. The insulated forms make use of recycled materials which is a much “greener” option than cast in place concrete, which does not use recycled materials and involves a lot of construction waste. Since ICF has a mold resistant quality, it is not only environmentally friendly but adds an additional safety feature to the occupants of the building. The use of concrete in this method is one negative impact on the environment. Although it has many great qualities, ICF still use concrete which produces a lot of CO_2.

2.3.4 Precast Concrete

Precast Concrete is a relatively new construction technique that has many advantages. Precast concrete is designed and manufactured off site. This allows for a more predictable manufacturing time because it is produced in a controlled environment. A great advantage of precast is the quick assembly on site when the precast pieces arrive. Piecing together precast concrete is much like piecing together a puzzle. Using this process allows the ability to reduce construction waste and debris on site as well as provide a stronger load capacity and longer possible spans. These increased load capacities are possible because precast concrete is much like reinforced concrete except that the manufacturing process off site allows for the ability to “pre-stress” the reinforced steel (Sustainability and Precast Concrete).

2.3.4.1 Cost & Schedule

Precast concrete is a rather expensive construction method. It requires very precise design in order for the pieces to go together correctly when it arrives on site. The skill level required for this method is costly, as well as, shipping costs and installation costs. Precast makes up for cost in the time it takes for the structure to be built. This method is a great solution for projects than have a flexible budget but require extremely fast construction times. Precast concrete also allows for finishes to be added to the concrete panels offsite, reducing construction time even more.

2.3.4.2 Environmental Impact

The use of precast concrete is considered a green type of building material (Sustainability and Precast Concrete). Since precast concrete is made off site it reduces construction waste and debris on site. Also, most factories that produce precast will be able to produce exact amount of concrete needed, which eliminates excess material and excess CO_2 emissions (Sustainability and Precast Concrete). Just like precast is designed to be assembled on site it can also be easily disassembled, which can be extremely helpful when attempting to add on to the current structure. Also, members that are disassembled can also be reused again in the future if needed. Precast concrete can also contain recycled steel reinforcement and materials such as fly ash, slag, and silica fume, which would otherwise be disposed of in a land fill, to reduce the amount of cement needed. Precast concrete is also typically made using re-useable formwork. Although precast has many great qualities is still uses concrete which produces harmful CO_2 emissions.

2.3.5 Structural Steel

Structural steel is the most popular framing material for non-residential buildings in the United States (American Institute of Steel Construction). Structural steel is used to construct the skeleton of the building which will support all the other components that will be added to the building. There are two processes used to create structural steel, they are Electric Arc Furnaces (EAF) and Basic Oxygen Furnace (BOF). The EAF process uses mostly recycled material that is melted down to a liquid allowing for easy forming. The BOF process uses iron ore and coke (a processed form of coal) and less recycled metal than EAF (American Institute of Steel Construction). The main reason for choosing structural steel is for the speed of construction. Just like precast concrete, structural steel is manufactured off site and once delivered the speed of construction is reduced greatly. Structural steel is also constructible in all seasons of the year and almost all weather conditions.

2.3.5.1 Cost & Schedule

Structural steel is a cheaper form of construction compared to precast concrete. Most of the costs affiliated with steel are from the fabrication and erection processes. Structural steel is manufactured off site and it can be a rather quick process depending on the complexity of the design. The erection process is very similar to precast concrete and construction time is very quick. Structural steel is a very good method for projects that have both time and budget constraints.

2.3.5.2 Environmental Impact

Structural Steel is considered a very "green" form of material for structural use. The main reason why steel is so highly regarded in that context is because it is 100% recyclable (Coskun). Unlike most other materials, steel can be recycled over and over again without losing its quality. Steel construction is also very fast and reduces onsite debris because the steel is fabricated off site and delivered to the site and is assembled piece by piece, similar to precast panels. Any waste that is produced during that process is also recyclable. Steel does emit CO_2 emissions during the production process, but it is lower than that of concrete. For one ton of steel produces about 0.73 tons of CO_2 is produced (American Institute of Steel Construction).

3.0 Methodology

3.1 Approach

The goal of this project was to select the most viable construction method for the Overhead Transmission Line to Underground Cable Transition Compound project, located in Point Aconi, Nova Scotia. The five construction methods: Cast in Place Concrete, Insulated Concrete Form (ICF), Structural Steel, Concrete Masonry Unit (CMU), and Pre-Cast Concrete were assessed based upon a weighted, evaluation criteria rubric. The design option which scored the highest in the rubric was selected for the construction of the Transition Compound. The following sections explain more thoroughly how each phase was performed in order to complete this MQP.

3.2 Research

The first phase of this project was to research the basic requirements of an electrical transition compound and review the preliminary design documents submitted by Stantec. These preliminary documents included the SK-1: Ground Floor Plan & Roof Plan, SK-2: Elevation Plan, SK-3: Site Plan, and Design Criteria. Additional information was collected through conference calls with the senior engineers at Stantec who are managing the project. This phase of the project was crucial in writing the MQP's Scope of Work Document which outlined what the final report was to address.

3.2.1 SK-1: Ground Floor Plan and Roof Plan

The document SK-1: Ground Floor Plan and Roof Plan, provided a more detailed view of the Transition Compounds structure. The document provided dimensions and structural information which would become crucial when performing preliminary cost estimates. SK-1 illustrated that the Transition Compound was a relatively simple structure on the interior with two large "Pole

Rooms" and one smaller "Electrical Room." The "Pole Rooms" titled "1" and "2," are identical in shape and equipment configuration. These rooms, which are approximately 13.00 meters long by 10.00 meters wide, will house the sensitive electrical equipment which will transition the Overheard Transmission Lines to Underground Cables. The "Pole Rooms" are symmetric, with exterior access doors, motorized vertical lift doors, interior access doors to the electrical room, and roof hatches all located in the same relative position. The symmetry of the interior can be seen in Figure 6 below. This will streamline certain aspects of the design phase while slightly shortening the construction schedule and reduce the cost. The smaller "Electrical Room" is positioned between the two "Pole Rooms" and has two interior access doors and one exterior access door. The document SK-1 illustrated that the interior of the Transition Compound possesses no formal utilities, such as bathrooms or a kitchen, which would increase the complexity and therefore duration and cost of the project.

While the Ground Floor Plan illustrated that the interior layout of the Transition Compound was minimal, the Roof Plan of SK-1 outlined several components which will increase the complexity of the project. The specialty electrical equipment positioned on the roof, which will connect to overhead transmission lines, will require the installation of additional roof trusses and bracing thus increasing the construction cost and elongating the building schedule.

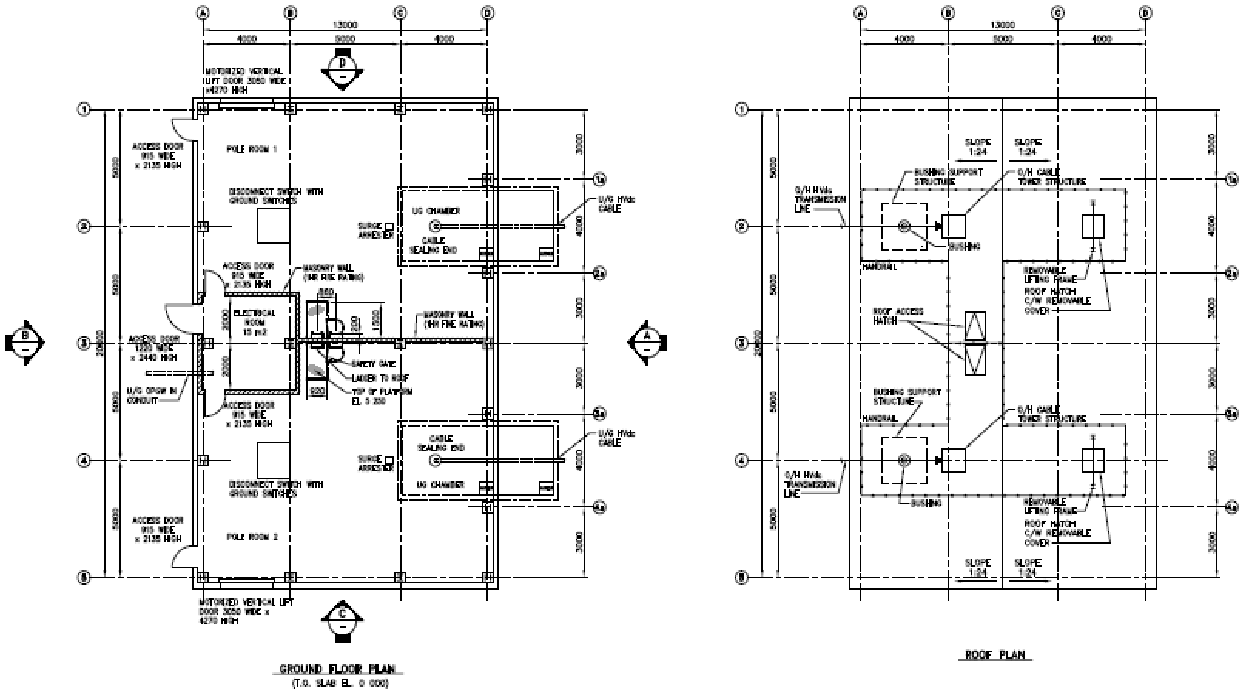

Figure 6: SK-1: Ground Floor Plan and Roof Plan

3.2.2 SK-2: Elevations

The document SK-2: Elevations illustrated the height and exterior finish of the Transition Compound. SK-2: Elevations states that the structure will stand 8.00 meters high, thus presenting several logistic issues. While the Transition Compound is only one level, the building will stand nearly three stories high. This will require scaffolding and additional bracing to construct the structures exterior walls, adding substantial time and cost to the project. SK-3 illustrates that the structure will have no exterior windows or openings other than the three access doors and two motorized vertical lift doors. All exterior points can be seen below in Figure 7. The lack of exterior openings will slightly offset the complexities presented by the substantial height of the Transition Compound.

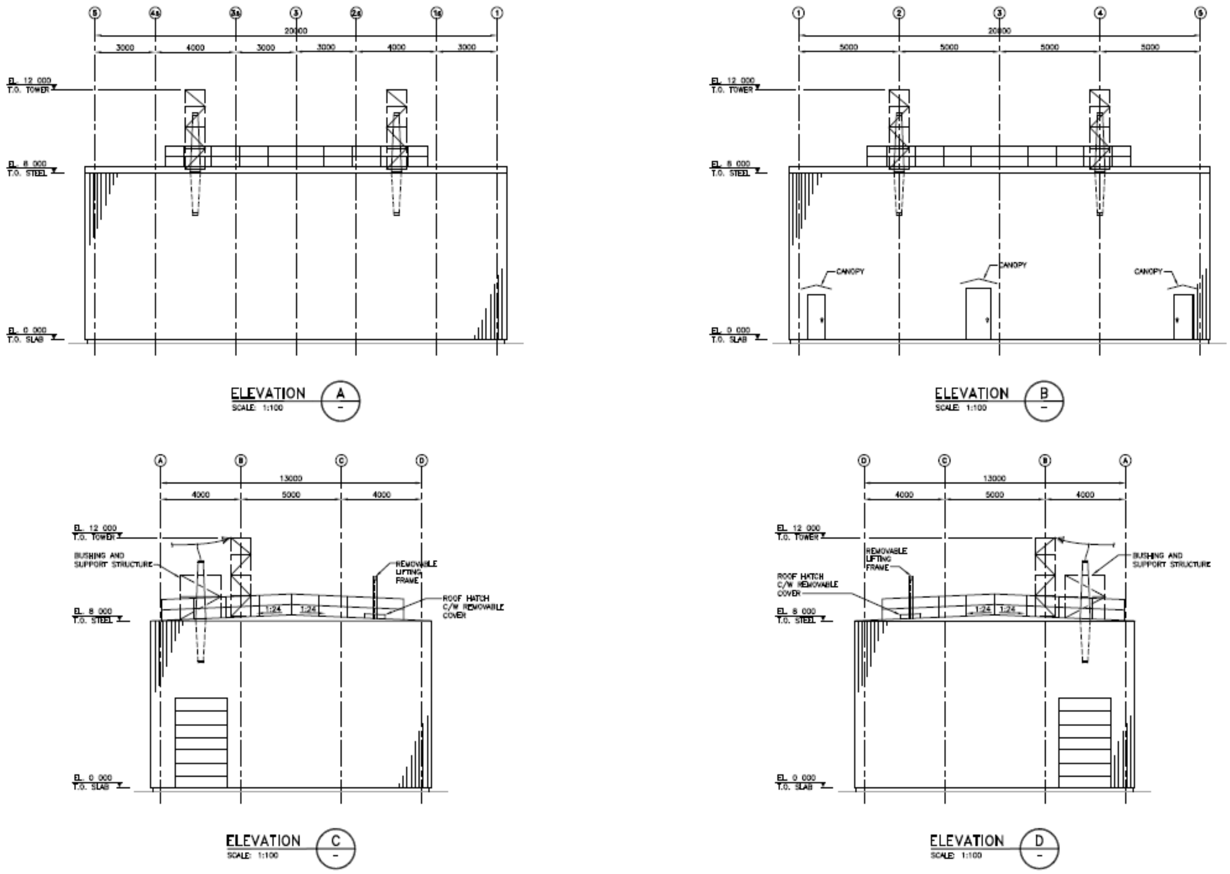

Figure 7: SK-2: Elevations

3.2.3 SK-3: Site Plan

SK-3: Site Plan, provided a preliminary view of the location where the Transition Compound would be constructed. Because the Electrical Transmission Project is a sensitive political issue, the exact location of the Transition Compound could not be revealed to the MQP team until Confidentiality Agreements were signed. However the document SK-3: Site Plan illustrated the general configuration of the site where the Transition Compound will be constructed including an access road, security measures, environmental management measures, and the approximate dimensions of the Transition Compound itself. All of these aspects of the project are illustrated below in Figure 8. The site plan exposed that the Transition Compound was a rectangular shaped structure, 20.95 meters long by 13.95 meters wide. The site plan also provided information directly related to aspects of the project's construction management plan including scheduling and estimating. SK-3 illustrated that the Transition Compound would be located in a relatively remote and forested area, which increases the complexity of the planning and construction phase of the project. The characteristics of the construction site will require special considerations for both scheduling and estimating. The site requires additional tasks that include clearing and grubbing, site grading, and large-scale drainage efforts. Another unique aspect of the design phase is the climate in which the structure will be constructed. The Transition Compound will be located on less than a kilometer from the ocean on a large peninsula, known as Point Aconi in Cape Breton, Nova Scotia. The proximity to the ocean requires the design address climate issues such as corrosion, flooding, and coastal storms. The site plan was important in evaluating the environmental, site-specific complexities of the Transition Compounds location which would need to be taken into consideration when producing preliminary schedules and cost estimates.

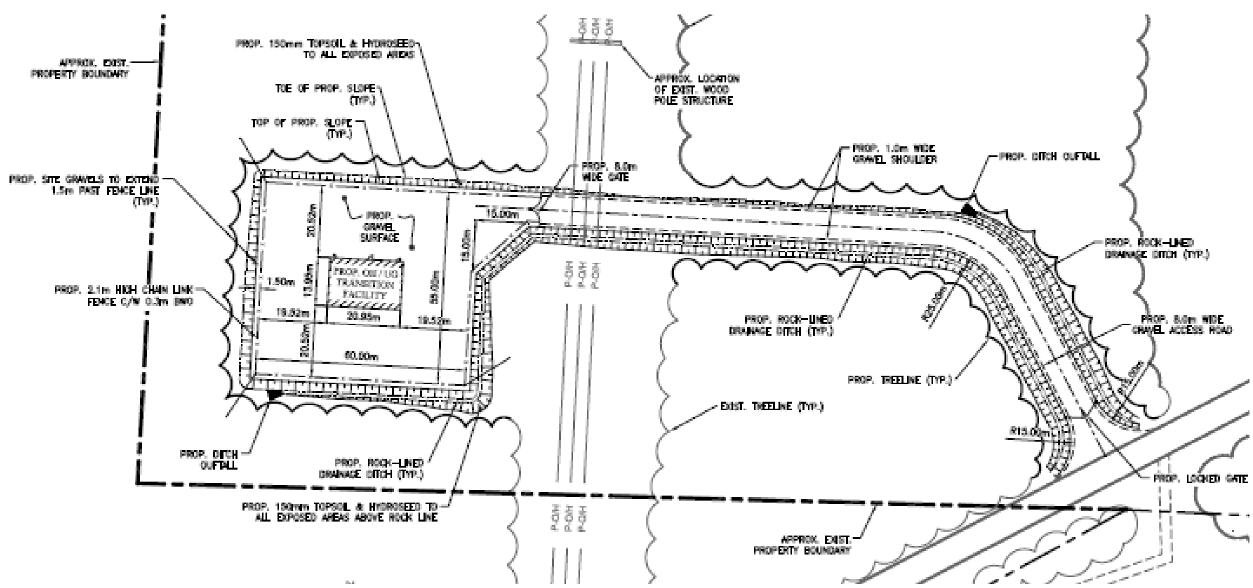

Figure 8: SK-3: Site Plan

3.2.4 Design Criteria

Review of the Design Criteria package for the Transition Compound provided a multitude of crucial information for nearly every facet of the MQP Report. The Design Criteria was divided into nine major sections: “Scope,” “Major Equipment,” “Units of Measure,” “Codes,” “Climatic and Seismic,” “Geotechnical Design Parameters,” “Materials of Construction,” “Civil,” and “Structural.” The sections which were most pertinent to this MQP were “Materials of Construction” and “Civil.” The “Materials of Construction” section outlined every material which was to be used in the construction of the Transition Compound. This information on the construction materials would become crucial when fabricating preliminary schedules and calculating cost estimates because it outlined exactly what was necessary to build the Transition Compound. The “Civil” section detailed the measures which must be taken when preparing the site including “Site Preparation,” Erosion and Sediment Control,” “Access Roads and Parking,” “Site Grading,” “Stormwater,” “Water Supply,” “Sanitary Sewage,” and “Fencing and Security.” The “Civil” Section contained information that helped outline the list of task for the construction phase which subsequently assisted in the creation of the preliminary construction schedules and cost estimates.

3.3 Design Option Selection

The next phase of the MQP was to select the construction methods for the Transition Station, which would be evaluated. The review of the preliminary construction sketches and the Design Criteria helped reduce the number of options. Some building materials could be eliminated from consideration because of the Transition Compound’s unique specifications. Wood based construction methods were deemed irrelevant because of durability and maintenance restrictions. While traditional red brick building method is frequently used in the construction industry, there is no need for the structure to have an aesthetic exterior. The two materials which were most realistic for application in this project were concrete and steel. The three major construction methods which utilize concrete are Cast-in-Place Concrete, Concrete Masonry Unit, and Pre-Cast Concrete. While the three concrete building techniques listed above may be the accepted industry standard, Stantec Senior Engineer Bill Pay recommended that Insulated Concrete Form also be evaluated. The preliminary sketches utilized a structural steel design and therefore structural steel was added to the list of possible methods. By the end of this phase of the project, the finalized list of construction methods was complete and contained five options: Cast-in-Place Concrete, Precast Concrete, Concrete Masonry Unit (CMU), Insulated Concrete Form (ICF), and Structural Steel.

3.4 List of Tasks

Once the five construction methods had been selected, the Pre-Construction and Construction stages of the project had to be divided into individual tasks which would be handled by separate entities. The Design Phase was not taken into consideration during this phase of the MQP because Stantec is already nearly complete with the finalized design for the transition compound. The individual tasks of Pre-Construction would all be handled by the general contractor or construction management firm in charge. Individual tasks of the Construction phase of the project would be handled by separate sub-contractors who would have to bid on the project.

3.4.1 List of Tasks: Pre-Construction

The Pre-Construction phase of the project consisted of four major tasks: Land Acquisition, Project Tendering, Awarding Contracts to Sub-Contractors, and Permitting. Land Acquisition is the act of researching and purchasing the site on which the Transition Compound will be built. In the case of the Point Aconi Transition Compound, once the trajectory of the sub-sea cables was set, there was only a small region of land where the Transition Compound could actually be located. Occurring simultaneously with Land Acquisition, Project Tendering is a two stage activity which includes both sending submittal requests to sub-contractors and reviewing the subsequent bids which they submit. Once the bids have been thoroughly reviewed, thus marking the end of the Project Tendering task, the winning sub-contractor is awarded the project. Occurring simultaneously to these tasks is the Permitting Process which can have a variable duration. As mentioned in the previous section, all of the Pre-Construction activities would be handled by the same entity, a General Contractor or Construction Management firm, depending upon the specific format of the project. Each of the four tasks remained consistent for the five methods.

3.4.2 List of Tasks: Construction

The Project Tendering task, described above, would divide the Construction phase into individual tasks which would be handled by separate sub-contractors. Based on the Preliminary Design sketches and Design Criteria, the Construction Phase of the Transition Compound was divided into fourteen distinct trade categories including: Site Preparation, Excavation, Foundation & Concrete, Structural Steel, Interior Partitions, Specialty Electrical, Plumbing, General electrical, HVAC, Fire Protection, Building Exterior, Roofing, and Permanent Fencing and Security.

Each of the trade categories listed above was then broken down into individual tasks which must be completed. Figure 9, which can be found below, contains all of the generic individual construction tasks. The majority of the individual tasks were specific to its corresponding trade. Many of the trade categories had individual tasks which followed the same pattern. The first task for the majority of the trade categories was “Submittals and Shop Drawings,” where the entitled documents were exchanged and reviewed by both engineers and sub-contractors. The next task represented the offsite fabrication of any necessary components for the specific trade. Fabrication of offsite components was followed by “Shipment and Delivery of Materials and Equipment.” The final task in this common pattern for the majority of the trade categories was the instillation of necessary components.

While the five construction methods had the same fourteen trade categories, each one had unique task, primarily in the “Foundations and Concrete,” “Structural Steel,” and “Exterior Siding” sections. The trade sections which remained consistent for all five of the Design Options included: “Site Preparation,” “Excavation,” “Interior Partitions,” “Specialty Electrical,” “Plumbing,” “General Electrical,” “HVAC,” “Fire Protection,” “Roofing,” and “Permanent Fencing & Security.”

Figure 9: Non-Construction Method Specific List of Tasks

Task Name
Land Acquisition
Project Tendering
Awarding Contracts to Subs
Permitting
Site Preparation
Mobilization of Materials & Equipment
Clearing & Grubbing for Access Road & Site
Environmental Management
Construct Access Road
Temporary Security & Fencing
Set up Field Office
Excavation
Underground Services
Site Grading
Foundation & Concrete
Submittals & Shop Drawings
Concrete Sub Mobilization
Construct Strip Footings
Construct Formwork for Foundation Walls
Pour Concrete for Foundation Walls
Install Weatherproofing for Foundation
Slab on Grade
Install Rebar for Roof Slab
Pour Concrete for Roof Slab
Structural Steel
Submittals & Shop Drawings
Fabrication of Structural Steel
Steel Sub Mobilization
Installation of Structural Steel Columns
Installation of Structural Steel Beams
Installation of Open Web Joists
Installation of Roof Decking
Interior Partitions
Shipment & Delivery of Materials & Equipment
Partition Layout
Construction of Masonry Wall
Specialty Electrical
Submittals & Shop Drawings
Fabrication of Specialty Electrical Equipment
Temporary Electrical
Shipment & Delivery of Materials & Equipment
Installation of Specialty Electrical Equipment
Connection of Overhead to Underground Electrical
Testing of Equipment
Plumbing
Submittals & Shop Drawings
Shipment & Delivery of Materials & Equipment
Roughing for potable water systems and/or fire protection systems
General Electrical
Submittals & Shop Drawings
Shipment & Delivery of Materials & Equipment
Installation of General Electrical Equipment

HVAC
Submittals & Shop Drawings
Fabrication of Specialty Equipment
Shipment & Delivery of Materials & Equipment
Installation of HVAC Equipment
Testing of Equipment
Fire Protection
Submittals & Shop Drawings
Fabrication of Specialty Equipment
Shipment & Delivery of Materials & Equipment
Installation of Fire Protection Equipment
Testing of Equipment
Building Exterior
Submittals
Shipment & Delivery of Materials & Equipment
Install Weatherproofing for Building Exterior
Install Exterior Metal Siding
Roofing
Submittals & Shop Drawings
Shipment & Delivery of Materials & Equipment
Installation of Two-Ply Modified Roofing System
Permanent Fencing & Security
Submittals
Shipment & Delivery of Materials
Installation of Chain Link Fence & Barbed Wire
Installation of Double Swinging Chain Link Gates
Installation of Alarm System

3.5 Preliminary Construction Schedules

Creation of the Preliminary Construction Schedules was in fact a continuation of the MQP's previous phase. This stage of the project was multifaceted, involving three major activities. The first step was to assign durations to each individual task of the five construction methods. Subsequently, start dates had to be established for both the pre-construction and construction phases of the Transition Compound project. Finally, the individual trades had to be coordinated most efficiently to reduce the total duration of the construction phase. A computer program called SmartSheet was used to organize and order the construction activities. In SmartSheet, the start date and duration for a specific task was plugged in and an end date was subsequently produced. Once all the construction activities were assigned start dates, end dates, and durations, the computer program produced a Gant chart which is a visual display of a construction schedule.

3.5.1 Estimating Durations

The first step of this phase involved estimating the duration of time which a specific construction activity would take. This requires large amounts of field experience and members of the Stantec Staff, especially Bill Pay, were great assistance in recommending approximate time frames for construction tasks. The durations were calculated in workdays and not calendar days. Once the estimated durations were complete, the estimating program CostWorks was used to compare values. CostWorks assigns unit costs and estimated labor hours per unit for specific construction tasks. While not every construction activity in the List of Tasks for the Transition Compound is found in CostWorks, the durations for all related ones in the program were compared to the initial estimate durations.

3.5.2 Estimating Start Dates

Once the durations for the construction tasks had been finalized, start dates for both the pre-construction and construction phases were set. With the design phase of the Transition Compound beginning its third and final stage, there is not enough time to complete all the work necessary for construction to begin in the 2013 Canadian building season (May to December). Because of this pre-construction will begin on January 1, 2014, at the beginning of the 2014 fiscal year. This start date has its financial benefits because the total cost of the project can be distributed between two fiscal years with design and the pre-construction cost being included in the 2013 fiscal budget and construction costs being included in the 2014 fiscal budget. The pre-construction phase will last from January 1, 2014, beginning with Land Acquisition, and end in late February with the awarding of contracts to sub-contractors. The pre-construction phase is independent of the five construction methods and therefore the duration remained constant.

The time period between the end of pre-construction in late February and the beginning of construction in early May is crucial to the pending success of the project. This time period (March & April, 2014) represents the "Lead Time" of the project when the project engineers provide submittals to sub-contractors, who subsequently shop-drawings which are in turn reviewed by the project engineers. It is also during this "Lead Time" period that any necessary offsite fabrication for specific trades is completed. While the amount of offsite fabrication varied, the "Lead Time" remained consistent for all five construction methods

Because of the climate of the Transition Compound's location, the construction phase cannot begin until May 1, 2014. The accepted building season for Atlantic Canada is from May to December, but it ultimately depends on when the ground thaws. Therefore the start date for the construction phase was set as April 30, 2014.

3.5.3 Schedule Coordination

With the construction activity durations and start dates finalized, the last step of the preliminary construction phase was the coordination and sequencing of subcontractors. In order to perform this task efficiently, one must imagine the exact order in which a structure is completed. This order of tasks that directly affect the project end date is known as the "Critical Path" of a project's schedule. Before scheduling all secondary activities, the "Critical Path" of the Transition Compound was determined. In sequential order, the "Critical Path" of the project was set as followed: "Site Preparation," "Foundation & Concrete," "Structural Steel," and finally "Specialty Electrical." All secondary trades were scheduled subsequently to accommodate for the "Critical Path." The "Critical Path" of the structural steel construction method is illustrated in red in Figure 10 below.

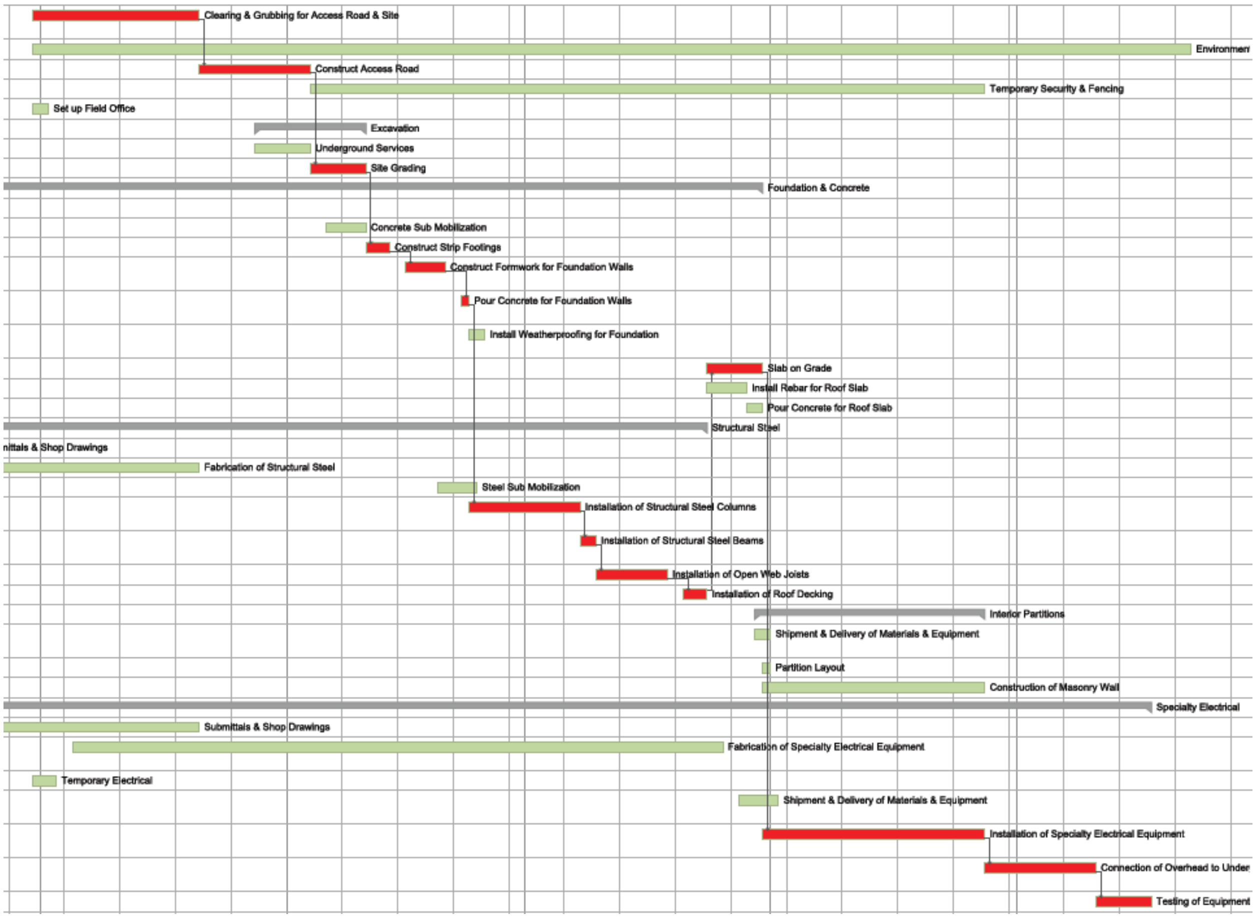

Figure 10: Critical Construction Schedule Path for Structural Steel

3.6 Preliminary Cost Estimates

With the preliminary construction schedules finalized, the next phase of the project was to conduct preliminary cost estimates for each of the five construction methods. Therefore, a number of sources were utilized to most accurately estimate the costs of construction activities for the Transition Compound, including the computer program CostWorks, Hanscomb Yardsticks for Costing (2012), and sub-contractor quotes compiled through research by Stantec. Before these sources could be used, exact material quantities for the Transition Compound had to be calculated. Quantities were calculated using the dimensions outlined in the preliminary design sketches and materials specified in the project's Design Criteria document. With quantities having been determined, unit prices were taken from the three sources mentioned above, and the two corresponding values were multiplied to obtain a cost estimate for the given construction activity. Cost values for individual tasks were compiled, producing sub-totals for each trade, and finally a total for each of the five construction methods were calculated. Figure 11 is a template of the cost estimating sheets which were used to calculate the total cost estimate for each construction method. For the majority of the major construction activities, cost estimate values were produced using both CostWorks and sub-contractor quotes provided by Stantec. A comparison process similar to the one outlined in the Preliminary Construction Scheduling section was used to evaluate the validity of these contradicting cost estimates.

Cost Estimate Template						
Task	**Description**	**Quantity**	**Units**	**Cost per Unit**	**Total**	**Subtotal**
Site Preparation						
Clearing and Grubbing of Site	Removal of Trees and Vegatation on Site and Access Road		Square Meters	$ 6.00	$ -	
Soil Stripping	Removal of Existing Top Soil		Square Meters	$ 6.00	$ -	**$ -**
Environmental Management						
Rip-Rap Ditching	Gravel Lining of Drainage Ditch		Cubic Meters	$ 85.00	$ -	
Ditch Geotechnical Fabric	Lining of Drainage Ditch		Square Meters	$ 4.20	$ -	
Flow Checks	Outtake of Drainage Ditch		Each	$ 360.00	$ -	
Rip-Rap Discharge Apron	Gravel Area Surrounding Discharge of Drainage Ditch		Square Meters	$ 85.00	$ -	
Topsoil and Hydroseed	Planted Vegatation on Banks of Drainage Ditch		Square Meters	$ 8.40	$ -	
Silt Fencing	Fencing System to Reduce Run-off and Erosion		Meter	$ 13.50	$ -	
Temporary Cut-Off Ditches	Drainage Ditches Feeding Temporary Filtration System		Meter	$ 15.00	$ -	
Temporary Sedimentation Pond	Area Designed to Collect Excess Sediment		Lump Sum	$ 10,000.00	$ -	
Temporary Pumping	Filtration system		Lump Sum	$ 20,000.00	$ -	**$ -**
Access Road						
Class A Gravel	Top Layer of Access Road (NLDTW Class A/NSTIR Type 1)		Cubic Meters	$ 60.00	$ -	
Class B Gravel	Base Layer of Access Road (NLDTW Class B/NSTIR Type 2)		Cubic Meters	$ 40.00	$ -	**$ -**
Excavation						
Foundation Excavation & Backfill	Excavation of Compound's Footprint		Cubic Meters	$ 17.50	$ -	
Surge Rock Allowance	Drainage Assistance		Cubic Meters	$ 70.00	$ -	
Class A Gravel	Top Layer of Site Surface (NLDTW Class A/NSTIR Type 1)		Cubic Meters	$ 60.00	$ -	
Class B Gravel	Base Layer of Site Surface (NLDTW Class B/NSTIR Type 2)		Cubic Meters	$ 40.00	$ -	**$ -**
Foundation & Concrete						
Strip Footings	Furnish & Install Strip Footings with reinforced concrete		Cubic Meters	$ 1,100.00	$ -	
Foundation Walls	Furnish & Install Foundation Walls with reinforced concrete		Cubic Meters	$ 2,100.00	$ -	
Ground Floor Walls	Furnish & Install Ground Floor Walls with reinforced concrete		Cubic Meters	$ 2,100.00	$ -	
Slab on Grade	Furnish & Install Slab on Grade		Square Meters	$ 150.00	$ -	
Roof Slab	Furnish & Install Roof Slab of reinforced concrete		Cubic Meters	$ 2,100.00	$ -	**$ -**
Structural Steel						
Columns	Furnish & Install (2) Structural Steel Columns		Kg	$ 5.65	$ -	
Beams	Furnish & Install (4) Structural Steel Beams & Girders		Kg	$ 5.65	$ -	
Open Web Joists	Furnish & Install (28) Open Web Joists (350 x 10.1)		Kg	$ 5.65	$ -	
Open Web Joists	Furnish & Install (14) Open Web Joists (400 x 10.6)		Kg	$ 5.65	$ -	
Roof Decking	Furnish & Install Roof Decking		Square Meters	$ 20.00	$ -	**$ -**
Interior Partitions						
CMU Wall	Furnish & Install Concrete Masonry Block Wall		Square Meters	$ 90.00	$ -	**$ -**
Electrical						
Plumbing						
HVAC						
Fire Protection						
Building Exterior						
Exterior Wall Cladding	Furnish & Install Outer Sheet w/ Insulation & Liner Sheet		Square Meters	$ 280.00	$ -	**$ -**
Roofing System						
Two-Ply Insulated System	Furnish & Install Two-Ply Modified Roofing System		Square Meters	$ 290.00	$ -	**$ -**
Permanent Fencing & Security						
Chain Link Fence	Furnish & Install Chain Link Fence w/Barbed Wire Overhang		Meters	$ 140.00	$ -	
Double Swing Gates	Furnish & Install Double Swinging Gates (8.0m wide)		Each	$ 5,000.00	$ -	
Vehicle Restriction Gate	Furnish & Install Vehicle Restriction Gate		Each	$ 4,200.00	$ -	**$ -**
Total						**$ -**

Figure 11: Template of Cost Estimate Sheet

3.7 Design Option Evaluation Criteria

The next step in the project was to evaluate the five construction methods based upon their construction schedule overall end date, their cost estimate total cost, environmental impact data, and availability factors. In order to perform this analysis most objectively, a design option evaluation criteria was created. The evaluation criteria consisted of a weighted, rubric system. The five construction methods were ranked one through five for each of the criteria's seven categories which included: "Cost," "Schedule," "Environmental Impact," "Durability and Lifespan," "Required Maintenance," "Availability of Labor," and Availability of Supplies." The two categories which were assigned a weight factor because of their increased significance were "Cost" and "Schedule."

Instead of ranking the five construction methods for each of the seven categories one through five, the options received rating scores. The most optimal option received a rating score of five while the least optimal option received a rating score of one for each of the seven specific category. A total score was calculated for the five options by adding up their rating scores for each of the seven categories. Finally, the options were ranked one through five based upon their total score, with the highest scoring construction method being ranked number one and the lowest scoring option being ranked number five.

			Cast in Place Concrete	Precast Concrete	Structural Steel	Insulated Concrete Form (ICF)	Concrete Masonry Unit (CMU)
Criteria	**Score Range**	**Weight Factor**					
Cost	1-5	2					
Schedule	1-5	2					
Environmental Impact [1]	1-5	1					
Durability and Life Span [2]	1-5	1					
Required Maintenance [3]	1-5	1					
Availability of Labor	1-5	1					
Availability of Supplies	1-5	1					
Total Score	1-5	1					
Ranking	1-5	1					

Figure 12: Template of Design Evaluation Criteria

3.8 Selection of Optimal Design Option

The final phase of the project was the selection and implementation of the optimal design option. The construction method which received the highest ranking in the evaluation criteria was not necessarily selected as the optimal design option. The information and data collected to this point in the project was presented to the supervisors at Stantec and the client's needs were taken into special consideration. A recommendation was then made to the client based on an educated decision derived from evaluating our results.

3.9 Final Deliverables

The final deliverables for this project contained a detailed report outlining the best construction method for the construction of a Transition Compound for the Electrical Transmission Project.

[1] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria
[2] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria
[3] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria

A secondary report, called a project package, was produced specifically for the staff at Stantec which presented the findings and recommendations of this MQP in a more streamlined form. A formal presentation was made to the Stantec staff illustrating all of our final conclusions and relevant data. A capstone design addressing the economic, environmental, manufacturing, health and safety, social, and political aspects of the five construction methods was included in the final report that was submitted to both Stantec and WPI. A final poster was produced, summarizing the methodology, data, and conclusions made during this project.

4.0 Results

4.1 Design Evaluation Criteria for Transition Compound

In order to successfully choose the best construction method for this project, design evaluation criteria were created. These criteria evaluated cost, schedule, environmental impact, durability and life span, required maintenance, and availability of labor and materials as key elements for each construction method. Below is a template of the design evaluation criteria which illustrates the general organization of this aspect of the project.

			Cast in Place Concrete	**Precast Concrete**	**Structural Steel**	**Insulated Concrete Form (ICF)**	**Concrete Masonry Unit (CMU)**
Criteria	**Score Range**	**Weight Factor**					
Cost	1-5	2					
Schedule	1-5	2					
Environmental Impact [4]	1-5	1					
Durability and Life Span [5]	1-5	1					
Required Maintenance [6]	1-5	1					
Availability of Labor	1-5	1					
Availability of Supplies	1-5	1					
Total Score	1-5	1					
Ranking	1-5	1					

Figure 13: Template of Design Evaluation Criteria for Transition Compound

[4] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria
[5] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria
[6] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria

4.1.1 Construction Schedule Estimates

Table 1: Table of Estimated Construction End Dates

Construction Method	Total Construction Duration	Estimated Construction End Date	Rating
Structural Steel	20 weeks	September 17, 2014	5
Precast Concrete	22 weeks	October 1, 2014	4
Insulated Concrete Form	23.5 weeks	October 13, 2014	3
Cast in Place Concrete	24.5 weeks	October 20, 2014	2
Concrete Masonry Unit	31 weeks	December 2, 2014	1

The construction schedule estimates were produced using the computer program, SmartSheet, which utilized the Gant Chart method to illustrate the construction schedules. All five of the construction methods had consistent start and end dates for the pre-construction phases and the same start date for the construction phase of the project (April 29, 2014). It was crucial that all of the construction methods start the construction phase of the project on the same date to ensure continuity and allow the ability for their scheduling values to be compared. The construction methods were evaluated based on the end date of their construction phase. The construction method with the earliest end date was structural steel. Structural steel was estimated to finish on September 17, 2014. It was the only design option to end construction in the month of September, 2014 with the construction phase lasting twenty weeks. Ending two weeks after structural steel, precast concrete was estimated to finish on October 1, 2014 with a construction phase duration of twenty-two weeks. Insulated concrete form and cast in place concrete have estimated end dates within a week of each other, finishing on October 13, 2014 and October 20, 2014, respectively. The insulated concrete form design option had a construction duration of twenty-three and a half weeks while cast in place concrete lasted a week longer, ending after twenty-four and a half weeks. The last design option to finish the construction phase of the project was concrete masonry unit, ending on December 2, 2014, over a month after cast in place concrete. CMU had a construction length of thirty-one weeks, taking over one and a half times longer to build the Transition Compound than the structural steel method.

4.1.1.1 Comparison of Estimated Scheduling Values

Table 2: Comparison of Estimated Construction Durations from CostWorks

Task	Duration (Estimated)	Duration (CostWorks)	Difference
Foundation & Concrete			
Strip Footings	3 Days	3 Days	
Formwork for Foundation Walls	5 Days	11 Days	-6 Days
Pour Concrete for Foundation Walls	5 Days	1 Day	+4 Days
Formwork for Stage 1 Walls	5 Days	49 Days	-44 Days
Pour Concrete for Stage 1 Walls	2 Days	4 Days	-2 Day
Formwork for Stage 2 Walls	5 Days	49 Days	-44 Days
Pour Concrete for Stage 2 Walls	2 Days	4 Days	-2 Day
Slab on Grade	5 Days	7 Days	-2 Days
Elevated Slab	5 Days		
Insulated Concrete Form			
Formwork for Foundation Walls	3 Days	3 Days	
Pour Concrete for Foundation Walls	5 Days	1 Day	+4 Days
Formwork for Stage 1 Walls	3 Days	13 Days	-10 Days
Pour Concrete for Stage 1 Walls	2 Days	4 Days	-2 Day
Formwork for Stage 2 Walls	3 Days	13 Days	-10 Days
Pour Concrete for Stage 2 Walls	2 Days	4 Days	-2 Day
Precast Concrete			
Erection of Precast Wall Panels	5 Days	72 Days	-67 Days
Structural Steel			
Columns (18)	15 Days	4 Days	+11 Days
Columns (2)	2 Days	1 Day	+1 Day
Beams (4)	2 Days	1 Day	+1 Day
Open Web Joists (28)			
Open Web Joists (14)	7 Days	4 Days	+3 days
Roof Decking	3 Days	3 Days	
Concrete Masonry Unit			
Reinforced CMU Walls	42 Days	86 Days	-44 Days
Interior Partitions			
CMU Wall	10 days	29 Days	-19 Days
Building Exterior			
Exterior Wall Cladding	10 Days	65 Days	-55 Days
Roofing System			
Two-Ply Modified Insulated System	10 Days	11 Days	-1 Day
Permanent Fencing & Security			
Chain Link Fence w/ Barbed Wire	12 Days	13 Days	-1 Day
Double Swing Gates	2 Days	3 Days	-1 Day

The table above illustrates the discrepancies between initial construction time estimates and those calculated using the CostWorks program. Comparisons were not available for every specific construction activity because CostWorks did not possess scheduling information for every task included in this project. Therefore Table 2 is a representation of only certain elements of the entire estimated construction schedules. The initial construction time estimates were produced subjectively with recommendations by Bill Pay. The CostWorks durations were based upon the specific construction activity and the quantities involved. The values in the column entitled "Difference" of Table 2 represent the duration difference, in working days, between our original estimates and the estimates derived using CostWorks. The largest discrepancies can be found in the areas of concrete formwork, erection of precast concrete, the construction of concrete block walls, and the installation of exterior wall cladding. The time difference shown by CostWorks for the forming or Stage 1 and Stage 2 of the building for both cast in place and ICF was quite significant, forty-four and ten days respectively. Erection of precast walls showed a sixty-seven day difference and the construction of reinforced CMU walls and interior CMU walls showed a difference of forty-four and nineteen days respectively. The installation of exterior wall cladding showed a discrepancy of fifty-five days.

4.1.2 Construction Cost Estimates

Table 3: Table of Estimated Overall Construction Cost

Construction Method	Estimated Construction Cost	Rating
Concrete Masonry Unit	$895,957.10	5
Insulated Concrete Form	$898,601.70	4
Structural Steel	$929,674.85	3
Cast in Place Concrete	$990,457.10	2
Pre-Cast Concrete	$1,147,957.10	1

The estimated construction costs for the construction of the Transition Compound were calculated using three primary sources which included the computer program CostWorks, Stantec sub-contractor quotes, and Hanscomb Yardsticks for Costing (2012). The least expensive construction method, with an overall construction budget of $895,957.10, was concrete masonry unit. Insulated concrete form was the second least expensive design option with an overall cost of $898,601.70, less than three thousand dollars more expensive than the concrete masonry unit method. Structural steel was the third most costly construction method with an overall construction cost of $929,674.85. The second most expensive design option with an overall construction cost of $990,457.10 was cast in place concrete. Precast concrete was the only design option with an overall cost which exceeded a million dollars. The estimated construction cost was $1,147,957.10. The overall construction cost to build the Transition Compound ranged from $895,957.10, using concrete masonry unit, to $1,147,957.10, using precast concrete.

4.1.2.2 Comparison of Estimated Construction Costs from CostWorks

Table 4: Table of Comparison between Initial Estimated Costs and CostWorks Values

Structural Steel					
Task	**Cost (Estimated)**	**SqFt Cost (Estimated)**	**Cost (CostWorks)**	**SqFt Cost (CostWorks)**	**Difference**
Foundation & Concrete					
Strip Footings	$6,930.00	$30.13	$3,080.37	$13.39	$+3,849.63
Formwork for Foundation Walls	$22,470.00	$32.57	$6,761.35	$9.80	$+15,708.65
Pour Concrete for Foundation Walls					
Slab on Grade	$44,100.00	$27.79	$12,451.37	$7.85	$+31,648.63
Roof Slab	$61,740.00	$19.45	$16,940.56	$5.34	$+44,799.44
Structural Steel					
Columns (18)	$109,836.00		$26,117.74		$+83,718.26
Beams (23)	$30,255.75		$21,114.04		$+9,141.71
Open Web Joists (28)	$10,588.10		$6,532.86		$+4,055.24
Open Web Joists (14)					
Roof Decking	$5,880.00	$1.85	$8,911.40	$2.81	$-3,031.40
Interior Partitions					
CMU Wall	$18,000.00	$8.36	$19,206.37	$8.92	$-1,206.37
Building Exterior					
Exterior Wall Cladding	$156,800.00	$25.25	$71,480.33	$11.51	$+85,319.67
Roofing System					
Two-Ply Modified Insulated System	$85,260.00	$26.86	$8,006.16	$2.52	$+77,253.84
Permanent Fencing & Security					
Chain Link Fence w/ Barbed Wire	$34,300.00	$5.33	$49,527.26	$7.70	$-15,227.26
Double Swing Gates	$5,000.00		$3,112.10		$+1,887.90
Total	$591,159.85		$253,241.91		$337,917.94

The table above illustrates the discrepancies between initial construction cost estimates and those calculated by CostWorks. All cost values above take into consideration materials, labor, and transportation. Comparisons were not available for every specific construction activity because CostWorks did not possess costing information for every task included in this project. Therefore Table 4 is a representation of only certain elements of the entire construction cost estimates. The initial construction cost estimates were produced by utilizing sub-contractor quotes provided by the Stantec office and costs values for additional activities were taken from the Hancomb Yardstick for Costing (2012) index. The CostWorks cost values were based upon the specific construction activity, the quantities involved, and the location of the site. The values in the column entitled "Difference" of Table 4 represent the initially estimated costs minus the CostWork's cost for a specific construction activity. A lot of discrepancies were found between our estimates and the estimates derived using CostWorks. For example, the erection of structural steel was estimated to cost $109,836.00 and CostWorks estimated it would cost $26,117.74. This is a difference of $83,718.26. Comparisons for all other construction methods can be found in Appendix H.

4.1.3 Environmental Impact

Table 5: Environmental Ratings for Construction Methods

			Cast in Place Concrete	**Precast Concrete**	**Structural Steel**	**Insulated Concrete Form (ICF)**	**Concrete Masonry Unit(CMU)**
Criteria	**Score Range**	**Weight Factor**					
Environmental Impact	1-5	1	2	3	5	4	1

The third evaluation criteria was the "Environmental Impact" for each of the five construction methods. The category "Environmental Impact" includes all aspects of the specific construction method, from the manufacturing of the products utilized by the process to the installation of the products. Decommissioning of the building was not taken into consideration as specified by the Preliminary Design Criteria document. Structural Steel received the highest environmental impact rating followed by ICF, precast concrete, cast in place concrete, and CMU.

4.1.4 Durability and Life Span of Construction Methods

Table 6: Table of Durability and Life Span Ratings for Construction Methods

			Cast in Place Concrete	Precast Concrete	Structural Steel	Insulated Concrete Form (ICF)	Concrete Masonry Unit(CMU)
Criteria	**Score Range**	**Weight Factor**					
Durability and Life Span	1-5	1	3	3	5	4	4

The "Durability and Life Span" evaluation criterion was included to assess the robustness of each construction method against the elements of a harsh coastal climate. Each design option was analyzed to determine the approximate life span of a structure built using the construction method in question. Structural Steel received the highest "Durability and Life Span" rating of the five methods. Insulated concrete form and concrete masonry unit both received ratings of four, while cast in place concrete and precast concrete both received ratings of three for the "Durability and Life Span" evaluation criteria.

4.1.5 Required Maintenance for Construction Methods

Table 7: Table of Required Maintenance Rating for Construction Methods

			Cast in Place Concrete	Precast Concrete	Structural Steel	Insulated Concrete Form (ICF)	Concrete Masonry Unit(CMU)
Criteria	**Score Range**	**Weight Factor**					
Required Maintenance	1-5	1	4	4	3	5	4

The fifth evaluation criteria, “Required Maintenance,” assessed the necessary amount of upkeep required to keep the Transition Compound online and functioning. The category of “Required Maintenance” has increased importance for the Transition Compound project because is intended to remain in Point Aconi for an indefinite amount of time. Insulated concrete form received the highest “Required Maintenance” rating while cast in place concrete, precast concrete, and concrete masonry unit all received a rating of four. Structural Steel received the lowest rating of three.

4.1.6 Availability of Labor for Construction Methods

Table 8: Rating of Availability of Labor for Construction Methods

			Cast in Place Concrete	**Precast Concrete**	**Structural Steel**	**Insulated Concrete Form (ICF)**	**Concrete Masonry Unit (CMU)**
Criteria	**Score Range**	**Weight Factor**					
Availability of Labor	1-5	1	5	4	5	4	5

The evaluation criteria “Availability of Labor” gauged the accessibility of the workforce in the region required to complete each of the five construction methods. “Availability of Labor” is an important factor in the construction phase because of the remote site on which the Transition Compound will be located. Structural steel, concrete masonry unit (CMU), and cast in place concrete all received a rating of five. Insulated concrete form and precast concrete both received a rating of four.

4.1.7 Availability of Materials for Construction Methods

Table 9: Rating of Availability of Materials for Construction Methods

			Cast in Place Concrete	Precast Concrete	Structural Steel	Insulated Concrete Form (ICF)	Concrete Masonry Unit (CMU)
Criteria	**Score Range**	**Weight Factor**					
Availability of Materials	1-5	1	5	5	5	5	5

The final evaluation criteria "Availability of Materials" assessed the obtainability of building materials which are utilized in the five construction methods. "Availability of Materials" is a pertinent factor in evaluating the viability of construction methods because the location of the construction site for the Transition Compound presents several restrictions and logistical complexities. All five of the construction methods were given a rating of five.

4.2 Final Design Evaluation Criteria Scores

Table 10: Final Design Evaluation Criteria Scores

			Cast in Place Concrete	**Precast Concrete**	**Structural Steel**	**Insulated Concrete Form (ICF)**	**Concrete Masonry Unit (CMU)**
Criteria	**Score Range**	**Weight Factor**					
Cost	1-5	2	4	2	6	8	10
Schedule	1-5	2	4	8	10	6	2
Environmental Impact [7]	1-5	1	2	3	5	4	1
Durability and Life Span [8]	1-5	1	3	3	5	4	4
Required Maintenance [9]	1-5	1	4	4	3	5	4
Availability of Labor	1-5	1	5	4	5	4	5
Availability of Supplies	1-5	1	5	5	5	5	5
Total Score	1-5	1	27	29	39	36	31
Ranking	1-5	1	**5**	**4**	**1**	**2**	**3**

The table above contains all of the rating scores which the five construction methods received for each of the seven evaluation categories. The second to last row is comprised of total score values for each of the five design options which were calculated by adding up the individual rating scores for each of the seven evaluation categories. Structural steel received the highest total score with 39 points followed by insulated concrete forms with a score of 36, concrete masonry unit with a score of 31, precast concrete with a score of 29, and finally cast in place concrete with a score of 27. The last row in the table is a final ranking of the five construction methods. Because structural steel received the highest overall score, it was ranked number one and therefore was deemed the most viable construction method for the construction

[7] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria
[8] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria
[9] Consultation with Nathan Sarapas aided in the results of this portion of the Evaluation Criteria

of the Transition Compound. Insulated concrete form (ICF) which received the second highest overall score was ranked number two and was suggested as an alternative to structural steel.

5.0 Discussion

The research and evaluation of these five methods allowed for great insight on the different construction methods available, and allowed for taking this information and implementing it into a practical situation. Different aspects of the construction management process such as scheduling, cost estimating, organizing, and time management were used to successfully choose the best option for the Transition Compound. The development of the design evaluation criteria allowed for all the methods to be accurately compared to one another.

5.1 Cost

Evaluating the cost of each construction method required the use of many resources. Previous sub-contractor bids were supplied by Jean Peinsznski, which allowed us to price most of the tasks accurately in today's market. Due to the fact that the bids were based off of the preliminary design of the Transition Compound, bids for alternative methods were not provided. In order to obtain pricing for the alternative construction methods, CostWorks and Hanscomb's Yardsticks for Costing were used. Sub-contractor bids allowed for a more exact price to the Compound's specific site while CostWorks provided an average price based on years prior in Sydney, Nova Scotia which is an area approximately twenty-three miles away from the location of the site. Yardsticks was able to provide an average price based on years prior in Halifax, Nova Scotia which is significantly further away (approx. 250 miles).

Pricing this project was completed by using the assembly cost method. This method is provides a price to construct a certain task. For example, the price to construct a 6" cast in place concrete wall. This price includes all formwork, reinforcement, bracing, scaffolding, and labor and materials required to build that type of wall per unit (sq. ft. or sq. m.). Quantities were derived from the three sketches of the Transition Compound (SK 1, 2, & 3).

After the completion of our estimates for each method, a system of check and balances was used to ensure that pricing was accurate. This was done by using at least two different sources of pricing for each task. After all comparisons were made, discrepancies arose in a few areas as stated in the results section of this report. After analyzing all of the discrepancies it was evident that CostWorks and Yardsticks were not as accurate in estimating construction costs for this project. Large price differences were found in a few tasks and we concluded that it was due to three factors. These factors are profit, location, and building type. We concluded that CostWorks did not include a large enough percentage for profit, taken by the contractor for providing his/her services. Location was also a factor in the discrepancies because the prices were an average of years past from a major area closest to the site that we could find. Our site is in a very remote location and this will require additional costs. Our building is rectangle in shape and fairly simple but it is twenty-four feet tall, which requires additional scaffolding and bracing. The final cost estimates for each construction method can be found in Appendix G and the final cost comparisons can be found in Appendix H.

Changes to our original estimates were not made and our group concluded that the cost estimating software is a very useful tool but only in the stages of project evaluation. We believe that during the preliminary or final design phases more accurate estimates can be obtained from contractors in order to assess the economic feasibility of a certain project.

5.2 Schedule

The schedule for each construction method is a very important part of evaluating a project. In the instance of this project, it was the ultimate reason why structural steel was chosen. Our preliminary schedule estimates were produced using information and knowledge provided by Bill Pay from Stantec Consulting Ltd. In order to check our estimated durations for each task we used CostWorks. Using the unit costs feature in CostWorks to derive durations for tasks using quantities we were able to make comparisons to our original estimates.

Using CostWorks to compare task durations from our original estimates allowed for us to take into consideration certain aspects of each task that we originally had left out. For instance we estimated that it would take five working days to construct the formwork for the first stage of cast in place concrete. CostWorks estimated that it would take forty-nine days to complete this task. After analyzing the data we concluded that five days was not enough time for this task but forty-nine days was certainly too long. We realized that due to the size of this building and the square footage that it entailed, the task would take an additional five working days. This process was used to compare stage two construction of cast in place concrete as well and stage one and two of ICF. This is why changes were made to all tasks to allow for a more accurate duration to complete the tasks. Stage two of both methods was given additional time because of the additional scaffolding and bracing required due to the height of the building.

CostWorks gave seventy-two days for the precast panels but we concluded that this included fabrication time and no change was made to the duration. During the comparison process we found that we had overestimated the time it took to construct the building with structural steel. Five days were taken off the duration for erecting the steel columns but all other durations were kept because we concluded that CostWorks was too aggressive in estimating the amount of time it took to erect steel. Concrete block walls also showed discrepancies when comparing our original estimates to CostWorks estimates. After analyzing the results, we concluded that time needed to be added to both the reinforced CMU walls and the interior partitions because of the time needed to construct scaffolding because of the height of the building. Originally we estimated that it would take ten working days to install the exterior wall cladding, but after comparing it with CostWorks the task duration was change to fifteen days. CostWorks estimated that it would take sixty-five days to complete the task but it was concluded that the estimate was extremely conservative. The final schedules for the construction methods can be found in Appendix I and the final time comparisons can be found in Appendix H.

5.3 Environmental Impact

The environmental impact of each of the construction methods is a factor in the decision because this structure is intended to remain in a remote location for an indeterminate period of time. There is an abundance of wildlife in the area along with a very densely forested area. Minimizing the environmental impact is an important evaluation criterion to consider. Structural steel scored the highest in this area because it is a recyclable material and is manufactured offsite which minimizes onsite construction debris. Steel was followed by ICF, precast, cast in place, and CMU. ICF scored second highest because of its added values in the area of life cycle costing. The added values of great insulation, water barrier, vapor barrier, and thermal barrier reduce costs over time. Precast is manufactured offsite which allows for more accuracy in the amounts of materials used and the use of reusable forms. Cast in place edged out CMU because it is less labor and material intensive and has less onsite construction debris. Steel scored above all concrete options because of the amount of carbon emission that are emitted in the making of concrete. The scores of each material can be found in the design evaluation criteria in Appendix F.

5.4 Durability and Lifespan

The durability and lifespan of the chosen construction method is an important criterion to consider because of the time it is intended to be in commission and the harsh weather conditions it will have to withstand. Structural steel scored the highest in this area as well due to its strength and durability. Steel is also known to have a very long life span, especially when the correct precautions are taking to prevent it from rusting. ICF and CMU received equal scores because CMU is a very durable form of concrete and has relatively low maintenance while ICF has the permanent insulated forms to protect the concrete from the harmful conditions it may face. Cast in place and precast concrete scored the same because the concrete is in direct with the exterior conditions and are less durable than CMU and ICF. All of the concrete options typically had the same lifespan if built the correct way. The scores of each material can be found in the design evaluation criteria in Appendix F.

5.5 Required Maintenance

Due to the Transition Compound's remote location, required maintenance is an important criterion to consider. Limiting the level of maintenance required on the building would reduce costs over the life cycle of the building. ICF scored the highest in this area because the permanent insulating forms provide protection to the structural components of the building, reducing maintenance. All of the other concrete options (precast, cast in place, CMU) scored the same in second place because of the weatherproofing required to maintain the structure. These options have exposed joints that require additional maintenance to ensure they are sealed and structurally sound. Structural steel scored the lowest in this area because of the maintenance required to keep it from rusting due to the possible weather conditions such as freezing temperature, rain, wind, and snow. The scores of each material can be found in the design evaluation criteria in Appendix F.

5.6 Availability of Labor and Materials

The availability of labor and materials is important because both of these have to be readily available to make the cost stay on budget and the schedule on track. All construction generally scored the same because of this buildings location. The Transition Compound is located about thirty minutes from Sydney, Nova Scotia which is a large city that has all needed materials and contractors available. Precast concrete and ICF scored lower in the area of availability of labor because these construction methods require a more specialized skill set and tools. For these two options a reputable contractor with much experience would be the preferred option, making these harder to obtain compared to the other methods. The scores of each material can be found in the design evaluation criteria in Appendix F.

6.0 Recommendations

For the construction method of the Transition Compound in Point Aconi, Nova Scotia we recommend that structural steel be used. After analyzing the seven different criteria developed in our design evaluation criteria, structural steel scored the highest. We believe that tradeoffs in cost and schedule combined with the assets of lower environmental impact and high durability and life span, makes this the best choice economically as well as environmentally. We believe that structural steel will not only be the a sufficient method for the structure of the building but also its ability to construct the building quicker at a moderate price will allow the client to produce revenue quicker making up for the extra construction cost. If the client is looking for a cheaper option in a reasonable time frame, we recommend ICF as an alternative method that is economically feasible. ICF is a cheaper option but it comes with and extra three and a half week construction time associated with it. This does not allow revenue to be produced as early at structural steel but is still a viable option.

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Appendix A: Proposal

Evaluating Construction Management Techniques for an Electrical Transmission Station

Scope of Work

O'Connor, Christopher

Andrew Canniff

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Introduction

A transmission line connecting Newfoundland and Nova Scotia has been proposed to help ease the strain placed on the region's electrical transmission system. This project will address several construction project management facets associated with the instillation of a transmission station which will service the line. The Transmission Station will convert overhead electrical power lines to underground electrical power lines. The transmission station in question will be located in a remote location on Cape Breton island, Nova Scotia and will house sensitive electrical equipment. The main goal of the project will be to assess the feasible of four major construction methods/materials for the Transmission Station: Concrete Masonry Unit (CMU), Cast in Place Reinforced Concrete, Pre-cast Concrete, and structural Steel. Additionally, the project will conduct a preliminary assessment of both the necessary construction time frame and the cost associated with each of the four techniques. Once the most viable construction technique is selected, the final phase of the project will be to conduct a thorough evaluation of the construction schedule and costs associated with the chosen building method

The final deliverables for this project will include a complete, multi-facet analysis of the potential application of alternative construction management on the transmission station, a final presentation illustrating all work completed at Stantec, a Capstone Design Statement, a poster displaying methodology and conclusions, and a Major Qualifying Project (MQP) report submitted Worcester Polytechnic Institute (WPI).

Project Description

The team for this project will be comprised of two senior, civil engineering students at Worcester Polytechnic Institute: Andrew Canniff and Christopher O'Connor. The project team will be working out of Stantec Consulting Limited (Located in Dartmouth, Nova Scotia) and will work closely with staff there to complete the necessary deliverables. In order to evaluate the most advantageous Construction Method for the Transmission Station, information concerning the financial data, regarding the construction methods, must be collected and analyzed. Information and experiences from previous projects of similar scope will be provided by the Staff of Stantec will be extremely valuable. The collection of information mentioned above will allow the project team to select and subsequently thoroughly apply the most feasible Construction Method for the proposed Transmission Station. The majority of the work for the project will take place in Dartmouth, Nova Scotia between January 10, 2013 and March 1, 2013, while Pre-MQP preparation for the project will be conducted in B-term of the 2012-2013 academic year on-campus at Worcester Polytechnic Institute, under the close supervision of the project's advisors.

Background

Construction Techniques

There are a variety of construction materials and techniques that can be used during the construction process. Our goal is to research multiple combinations of methods and materials and produce possible schedules and preliminary cost estimates to decide what the best option is that meets the needs of both the Transmission Station and the client. The materials that have been selected for our project include masonry walls (CMU), cast in place concrete, and structural steel. Pre-cast concrete will also be researched as a viable construction material.

Concrete Masonry Unit (CMU)

Concrete Masonry Unit (CMU) or concrete block as it is commonly called, is a mixture of Portland cement, gravel, sand, and water. This mixture can also include air-entraining agents, coloring pigment, and water repellent (Concrete Masonry Units). Concrete blocks are made by forming this mixture into its desired shape and curing it by heating it at a high temperature in a special chamber. Concrete blocks allow for the ability to create economical, energy efficient, and fire-resistant structures that involve minimal maintenance (Concrete Masonry Units).

Concrete block can be used to construct both small and large structures. The most common uses of concrete block include retaining walls, chimneys, fireplaces, and fire-rated shaft walls, elevator shafts, and storage vaults (Concrete Masonry Units). The different types of concrete masonry units include split-face concrete blocks, patented slotted concrete blocks, and glazed concrete blocks.

Concrete block walls can also be reinforced using different gauge wire reinforcement and rebar. Metal wire, welded together to form the shape of a truss, is used horizontally between courses to provide lateral strength. This technique resists “bowing” due to earth, wind, and seismic loads. Vertical rebar can be placed inside the openings in the block and filled with concrete-like grout. The rebar is spaced evenly throughout the wall, accommodating for larger vertical and lateral loads (Concrete Masonry Unit (CMU) Construction).

Cast In Place Concrete

Cast in place concrete or reinforced concrete is one of the most common building materials used in construction. Reinforced concrete is a mixture of water, cement, sand, gravel, and reinforcing steel rods or rebar. The process of creating a reinforced concrete structure involves the technique of using forms and cages. Reinforcing steel cages are built using rebar, steel mesh and forms are constructed around the steel creating the specified width and length and height of the walls/columns/beams etc. The concrete mixture is then poured into the form and set to dry or cure. Concrete is extremely useful in compression but not in tension, which is the reason for the reinforcing steel. The concrete and steel are bound together during the curing process, which allows for the concrete to support the structure under compression loads and the steel to support the tensile loads (Reinforced Concrete).

Structural Steel

Structural steel is the most popular framing material for non-residential buildings in the United States (Structural Steel Solutions). Structural steel is used to construct the skeleton of the building which will support all the other components that will be added to the building. There are two processes used to create structural steel, they are Electric Arc Furnaces (EAF) and Basic Oxygen Furnace (BOF). The EAF process uses mostly recycled material that is melted down to a liquid allowing for easy forming. The BOF process uses iron ore and coke (a processed form of coal) and less recycled metal than EAF (How Is Structural Steel Made?). The main reason for choosing structural steel is for the speed of construction. Just like precast concrete, structural steel is manufactured off site and once delivered the speed of construction is reduced greatly. Structural steel is also constructible in all seasons of the year and almost all weather conditions.

Pre-cast Concrete

Precast Concrete is a relatively new construction technique that has many advantages. Precast concrete is designed and manufactured off site. This allows for quick assembly on site when the precast pieces arrive. Piecing together precast concrete is much like piecing together a puzzle. The use of precast concrete is considered a green type of building material (Sustainability and Precast Concrete). Using this process allows the ability to reduce construction waste and debris on site as well as provide a stronger load capacity and longer possible spans. These increased load capacities are possible because precast concrete is much like reinforced concrete except that the manufacturing process off site allows for the ability to “pre-stress” the reinforced steel (Sustainability and Precast Concrete). Often times the material used in precast concrete is material obtained from local companies and local quarries. In terms of scheduling, the offsite manufacturing time for pre-cast is longer, but onsite construction time is reduced greatly.

Schedule

A project schedule for multiple combinations of building materials will be produced that includes such items as projected lead times on materials, estimated transportation duration, and estimated construction time. The schedule for each combination will be combined with a cost estimate of the materials used to produce the best possible options. A construction project schedule is produced because it gives the owner or client an idea of when the project will be substantially completed and it gives the contractor a timeline to track the progress of the project while it is being construction. A project schedule is very important for the success of any construction project.

Cost Estimate

Preliminary cost estimates will be produced for each combination of building materials used. The cost estimates will be used in conjunction with the schedule for the chosen building materials to decide which combination and method is the most efficient in terms of time and cost. The client’s budget determines the materials used and the duration of time available for construction. The designers must adapt to the budget with their design and project managers must ensure the project comes in on budget as best as possible.

Methods

Task 1. Evaluate the Transmission Station Construction Documents

The first step of the project will be to gain a complete understanding of exactly what Stantec's client requires for the transmission station. An electrical station is a relatively unique structure and there will certainly a number of distinctive specifications. While the building will only contain three rooms, the amount of sensitive electrical equipment installed in each will drastically increase the complexity of the construction process. Other factors of the project which will be evaluated during this phase will include the budget, environmental restrictions, scheduling, and political issues. The Stantec Staff will be an essential resource for these activities because they will have experience with construction "status quo" for the Nova Scotia region. Examining previous projects of similar scope to the Transmission Station will not only provide examples of which construction techniques were utilized in the past, but also improve efficiency by identifying the short-comings in these application. Information collected during this phase will be crucial while assessing the feasibility of the four construction techniques.

Task 2. Research Regional Application of the Four Construction Techniques:

While the four major construction techniques in question have relatively uniform standards and applications, the accepted norm for the construction methods in the Nova Scotia region may be slightly different which could alter the data when the preliminary scheduling and cost-estimating are conducted. Becoming familiar with the local building practices and procedures of the region is essential to the accuracy of the project's analysis. The major factors which influence construction management activities such as cost-estimating and scheduling include present labor costs, current building material costs, time frames for the local permit process, the availability of construction supplies, and specialty electrical equipment logistics. The last factor mentioned above, specialty electrical equipment logistics, will be especially crucial to the analysis phase of the project because the equipment necessary for the operation of a transmission station is extremely expensive, sensitive, and requires skilled instillation. The increased complexities caused by the specialty electrical equipment, could dramatically alter the Cost-Estimating and Scheduling evaluations of the construction techniques.

Task 3. Conduct Preliminary Cost Estimating and Scheduling Evaluations for the Four Construction Techniques:

This phase will approximate the overall cost associated and time frame necessary to build the Transmission Station using each of the four major construction techniques. Essentially answering the questions of "how much will it cost?" and "how long will it take?" to construct the

Transmission Station utilizing a given construction technique. Information concerning prices and time frames for the activities associated with each of the four Construction Techniques, collected from Task 2, will be essential to conduct preliminary cost-estimates and scheduling evaluations. While Task 3 will only produce approximate answers to the questions posed above, the estimates calculated during this phase of the project will be crucial in the process of selecting the most viable construction technique for the Transmission Station. Each of the following evaluation criteria should be considered for each of the four construction techniques:

Cost

a. How much does the construction technique cost per a square foot?
b. How much does the labor required for the construction cost per an hour?
c. What additional costs does the construction technique require?

Scheduling

d. How long is the local and provincial permitting process take?
e. How long will the complete design of the transmission station take using the construction technique?
f. How long will the construction phase of transmission station take?
g. Is there any additional time necessary when utilizing the construction technique?
    i. If so, what are they?
    ii. How long will they take?

Availability of Labor

h. Does the region contain sufficient labor capacity required to use the construction technique?
i. Will there be sufficient amount of laborers available at the time of the project?
j. Are skilled sub-contractors required to use the construction technique?
    i. If so, are they available?
    ii. How much do they cost per an hour?
k. Are labor unions a necessary consideration?

Availability of Supplies

l. What supplies doe the construction technique require?
m. Are the required buildings supplies available in the region?
    i. If not, what are the logistics involved with getting them transported to the site?

Task 4. **Compare the Advantages and Disadvantages of the Four Alternative Construction Techniques for the Transmission Station:**

The information collected in Task 2 and the preliminary evaluations performed in Task 3 will be utilized to compare the application of the four construction techniques for the instillation of the transmission station. A uniform assessment criteria will be developed, tailored to the available information, in order to analyze the four construction techniques without bias. Instead of simply selecting the construction technique with the lowest preliminary cost-estimate and the shortest construction schedule, a number of other factors will be taken into consideration including availability of sub-contractors, transportation logistics, obtainability of necessary building supplies, and environmental impact. The assessment criteria will weigh all the factors mentioned above along with the preliminary cost-estimates and building schedules to gauge which construction technique is most viable for the construction of the Transmission Station.

Task 5. **Select Most Viable Construction Technique for the Transmission Station:**

Task 5 represents more of a check point than an activity. At this point in the project, the construction technique which is best applicable for the transmission station will be selected. The title of "most viable construction technique," means that the given building method will provide the Transmission Station with the best opportunity to be completed on-time, within-budget, and within the constraints and specifications of the owner. Deciding which of the four construction techniques in question is the most viable for the instillation of the Transmission Station will be completely objective and based upon the bulk of the work completed in Tasks 3 & 4.

Task 6. **Perform Detailed Cost Estimating and Scheduling Analysis for the Most Viable Construction Technique:**

While preliminary cost-estimates and building schedules were formulated in Task 3, the selection of the most viable construction technique will allow a substantially more detailed cost-estimate and scheduling evaluation for the construction of the transmission station to be conducted. A breakdown of the activities necessary for construction of the transmission station using the chosen building technique will be created. The breakdown of construction activities will include both the estimated cost and time for each activity. Performing the cost-estimate and scheduling evaluations in this manner will produce a much more accurate answers for the questions of "how much will it cost?" and "how long will it take?" to construction the transmission station using the chosen building technique. The cost and time estimates will be generated based off of projects Stantec has completed in the past and current market values of both labor and materials.

Deliverables

The final deliverables for this project will include a detailed report outlining the best construction materials and methods for a Transmission Station under the specified construction project management process. A formal presentation will be made to Stantec showing all of our final conclusions and relevant data. A capstone design addressing the economic, environmental, manufacturing, health and safety, social, and political aspects of construction materials and methods, will be included in a final report that is submitted to both Stantec and WPI. A final poster will be produced, summarizing the methodology, data, and conclusions found during process of completing this project.

Capstone Design Statement

The Accreditation Board of engineering and Technology (ABET) mandates that all accredited engineering programs are supplemented by a Capstone Design Experience. Undergraduate engineering programs at Worcester Polytechnic Institute satisfy this ABET requirement through the Major Qualify Project (MQP). The American Society of Civil Engineers (ASCE) states that the said Capstone Design Experience must include aspects of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political.

Design Problem

This Major Qualifying Project meets the requirements specified by both the ABET and ASCE by carrying out a "design process" which evaluates four major construction methods with several of the factors mentioned above and recommends the most viable construction method for the installation of an electrical transmission station in the Province of Nova Scotia, Canada. The four construction techniques in question are Concrete Masonry Units (CMU), Reinforced Concrete, Structural Steel, and Pre-Cast Concrete. Utilizing previous project experience of the Stantec Consulting Limited, research of local and regional standards of construction, construction method specific cost-estimates, and construction technique specific building schedule approximations, the feasibility of each construction technique will be evaluated and the most viable option will be selected. The construction techniques will be assessed in terms of cost, building time frame, constructability (manufacturability), environmental impact, health and safety, social opinions, and political influence. An unbiased evaluation criteria will be developed to decipher the most viable construction technique which will be subsequently recommended to the Dartmouth office of the Stantec Consulting Limited for the construction of a costal electrical transmission station.

Engineering Standards and Realistic Constraints

As mentioned above, Capstone Design Experience must include aspects of the following considerations: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. The following sub-sections will briefly explain how the Major Qualify Project will cover the necessary considerations of a Capstone Design Experience.

Economic

The evaluation of four alternative construction techniques for the construction of an electrical transmission station will involve economic considerations because of the cost-estimating procedures used to evaluate each of the four construction techniques. The preliminary cost-estimates produced in Task 3 will provide individual economic analyses of the four construction techniques. Finally, one of the major assessment criteria for the selection of the most feasible construction technique will be the economic or monetary cost of applying the building method for the construction of the transmission station

Environmental

The evaluation of four alternative construction techniques for the construction of an electrical transmission station will involve environmental considerations by including the environmental impact of each of the four techniques into the assessment criteria for selecting the most feasible construction technique. As mentioned above, the selection of the most feasible construction technique will not be simply based off of the preliminary cost-estimating and scheduling evaluations. This is because there is a number of other factors which must be taken into consideration when making such a large decision. One of these factors is the environmental impact of the construction techniques in question. The environmental impact of building methods has increased significance because of the transmission stations site, which is set in a remote environment.

Manufacturability (Constructability)

One of the most crucial aspects in the evaluation process of the four alternative construction techniques for the construction of an electrical transmission station is the manufacturability of each building method. Assessing the manufacturability of each technique is a necessary step in both the cost-estimating and scheduling procedures. The degree of constructability of each building method is actually a value which combines both cost-estimating and scheduling. High Constructability will be weighed heavily in the assessment criteria because it represents the ability to build the transmission station on-time and within-budget using a given construction technique. The evaluation of constructability will also take into consideration the availability and transportation logistics for the materials necessary apply the construction technique in question. Finally, the degree of constructability for each of the construction technique will be affected by not only the cost but also the availability of the labor necessary to implement it.

Health and Safety

The evaluation of four alternative construction techniques for the construction of an electrical transmission station will include health and safety considerations into the assessment criteria for the selection of the most feasible building method. The preliminary scheduling evaluations must take into consideration how quickly the transmission station can be built using the construction methods in question without sacrificing the health and safety of the workers. Attention to health and safety must be increased because of the dangers related to the high-voltage electrical equipment which is being housed within the transmission station. Small mistakes can become deadly when working in proximity to the high voltages power lines which run through the transmission station. Concerns for human health and safety will not end with the completion of the transmission station. A number of safety and security features must be installed and maintained on the transmission station site. Because of the high voltage environment, fences and security systems must be included into the construction of transmission station to protect against trespassers.

Social and Ethical

The evaluation of four alternative construction techniques for the construction of an electrical transmission station will include social and ethical considerations into the assessment criteria for the selection of the most feasible building method. The installation of the transmission station in Cape Breton is a rather controversial because of various social issues between the region's citizens and officials. The assessment process of the construction techniques will include a criteria which represents the Social and Ethical impact of the building methods in question. Construction Techniques which ease social and ethical tension will have increased feasibility.

Political

The evaluation of four alternative construction techniques for the construction of an electrical transmission station will include political considerations into the assessment criteria for the selection of the most feasible building method. As stated above, the installation of the transmission station in Cape Breton is a rather controversial because of various political issues between the region's citizens, governmental officials, and the electrical company. The assessment process of the construction techniques will include a criteria which represents the political impact of the building methods in question. Construction Techniques which ease political tension will have increased feasibility.

Eight Week Schedule

Activity	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
	1/9 - 1/11	1/14 - 1/18	1/21 - 1/25	1/28 - 2/1	2/4 - 2/8	2/11 -2/15	2/18 - 2/22	2/25 - 3/1
Acclimization Period								
Move in to Housing								
Orientation of Stantec office and Dartmouth Area								
Background Research								
Identify possible resources								
Identify key Stantec employees								
Review project documents								
Review older related Stantec projects								
Identify site factors related to construction materials								
Identify site factors related to construction methods								
Evaluate Combinations of Construction Materials								
Assess pro's & con's of each material								
Assess the ability to use materials on specified project								
Produce possible schedules for each combination								
Produce cost estimates for each combination								
Implement Most Efficient Choice								
Provide detailed project schedule of project								
Provide detailed cost estimate of project								
Final Report								
Start Final Deliverables								
Analyze results								
Finish final deliverables								
Present to Stantec								

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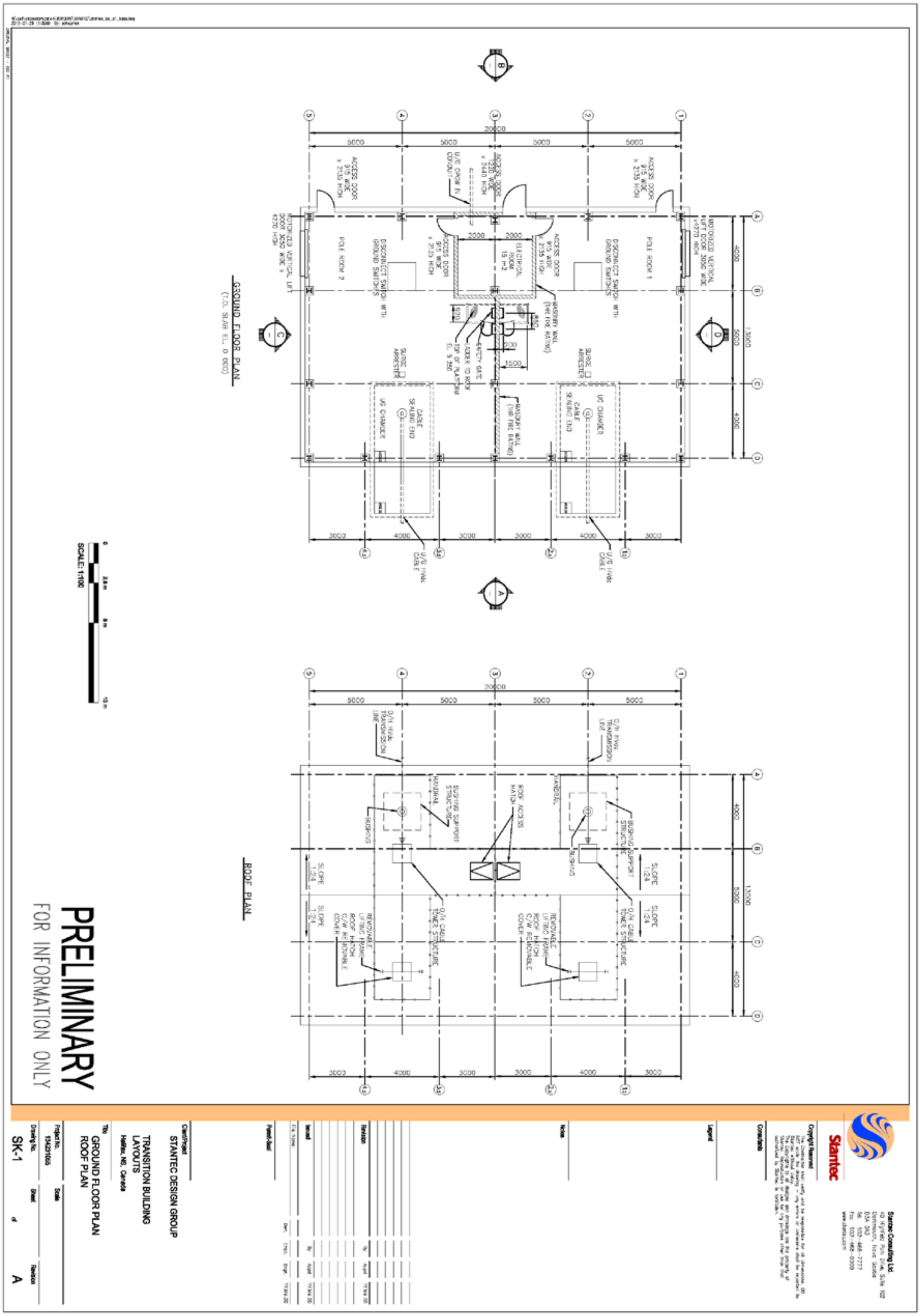
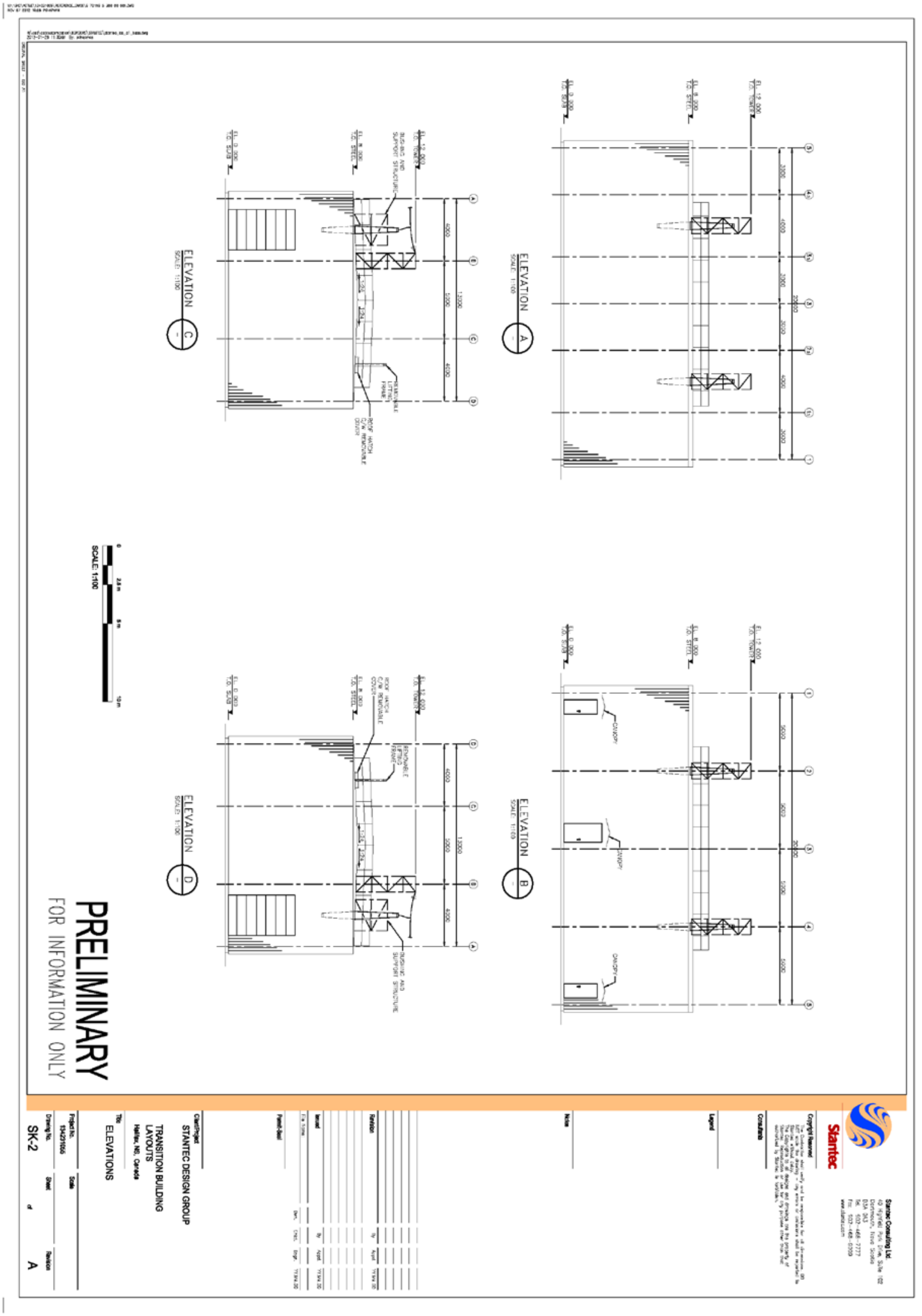
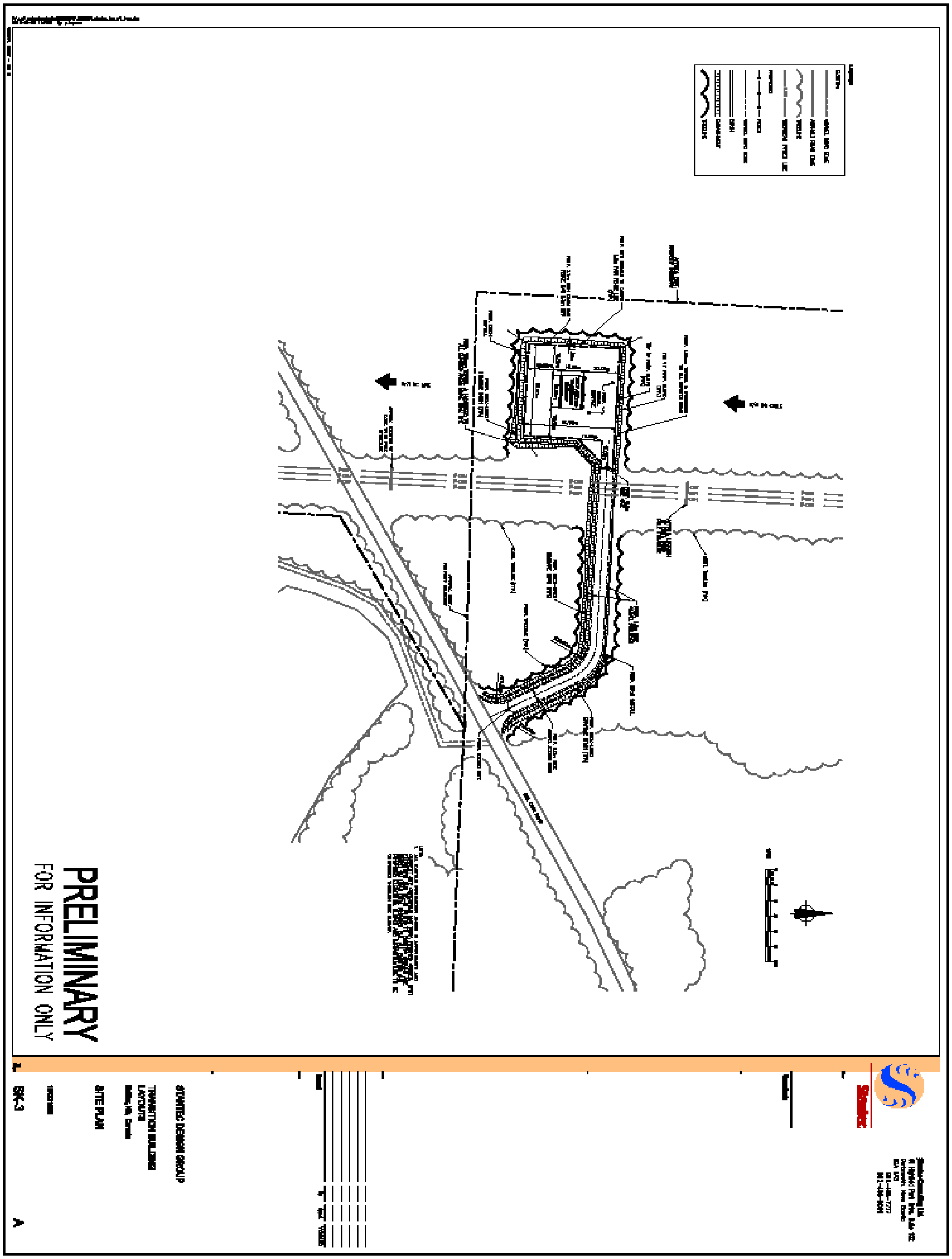
Appendix B: SK-1Ground Floor Plan and Roof Plan



Appendix C: SK-2 Elevations



Appendix D: Site Plan



Appendix E: Design Option Evaluation Criteria

Preliminary Design Evaluation Criteria for Transition Compound Project							
	1:Lowest 5:Highest		**Cast in Place Concrete**	**Pre-Cast Concrete**	**Structural Steel**	**Insulated Concrete Form**	**Concrete Masonry Unit**
Criteria	**Range**	**Weight Factor**					
Cost	1-5	2					
Schedule	1-5	2					
Environmental Impact	1-5	1					
Durability and Lifespan	1-5	1					
Required Maintenance	1-5	1					
Availability of Labor	1-5	1					
Availability of Supplies	1-5	1					
Total Score							
Ranking	1-5		0	0	0	0	0

Appendix F: Final Design Evaluation Criteria

Final Design Evaluation Criteria for Transition Compound Project

	1:Lowest 5:Highest		Cast in Place Concrete	Pre-Cast Concrete	Structural Steel	Insulated Concrete Form	Concrete Masonry Unit
Criteria	**Range**	**Weight Factor**					
Cost	1-5	2	4	2	6	8	10
Schedule	1-5	2	4	8	10	6	2
Environmental Impact	1-5	1	2	3	5	4	1
Durability and Lifespan	1-5	1	3	3	5	4	4
Required Maintenance	1-5	1	4	4	3	5	4
Availability of Labor	1-5	1	5	4	5	4	5
Availability of Supplies	1-5	1	5	5	5	5	5
Total Score			27	29	39	36	31
Ranking	1: Best 5: Worst		5	4	1	2	3

Appendix G: Final Cost Estimates

Cast in Place Concrete Estimate

Task	Description	Quantity	Units	Cost per Unit	Total	Subtotal
Site Preparation						
Clearing and Grubbing of Site	Removal of Trees and Vegatation on Site and Access Road	10050	Square Meters	$ 6.00	$ 60,300.00	
Soil Stripping	Removal of Existing Top Soil	10050	Square Meters	$ 6.00	$ 60,300.00	$ 120,600.00
Environmental Management						
Rip-Rap Ditching	Gravel Lining of Drainage Ditch	95	Cubic Meters	$ 85.00	$ 8,075.00	
Ditch Geotechnical Fabric	Lining of Drainage Ditch	2500	Square Meters	$ 4.20	$ 10,500.00	
Flow Checks	Outtake of Drainage Ditch	2	Each	$ 360.00	$ 720.00	
Rip-Rap Discharge Apron	Gravel Area Surrounding Discharge of Drainage Ditch	20	Square Meters	$ 85.00	$ 1,700.00	
Topsoil and Hydroseed	Planted Vegatation on Banks of Drainage Ditch	2500	Square Meters	$ 8.40	$ 21,000.00	
Silt Fencing	Fencing System to Reduce Run-off and Erosion	245	Meter	$ 13.50	$ 3,307.50	
Temporary Cut-Off Ditches	Drainage Ditches Feeding Temporary Filtration System	120	Meter	$ 15.00	$ 1,800.00	
Temporary Sedimentation Pond	Area Designed to Collect Excess Sediment	1	Lump Sum	$ 10,000.00	$ 10,000.00	
Temporary Pumping and Dewatering	Filtration system	1	Lump Sum	$ 20,000.00	$ 20,000.00	$ 77,102.50
Access Road						
Class A Gravel	Top Layer of Access Road (NLDTW Class A/NSTIR Type 1)	350	Cubic Meters	$ 60.00	$ 21,000.00	
Class B Gravel	Base Layer of Access Road (NLDTW Class B/NSTIR Type 2)	560	Cubic Meters	$ 40.00	$ 22,400.00	$ 43,400.00
Excavation						
Foundation Excavation and Backfill	Excavation of Compound's Footprint	35	Cubic Meters	$ 17.50	$ 612.50	
Surge Rock Allowance	Drainage Assistance	100	Cubic Meters	$ 70.00	$ 7,000.00	
Class A Gravel	Top Layer of Site Surface (NLDTW Class A/NSTIR Type 1)	660	Cubic Meters	$ 60.00	$ 39,600.00	
Class B Gravel	Base Layer of Site Surface (NLDTW Class B/NSTIR Type 2)	1150	Cubic Meters	$ 40.00	$ 46,000.00	$ 93,212.50
Foundation & Concrete						
Strip Footings	Furnish & Install Strip Footings with reinforced concrete	6.3	Cubic Meters	$ 1,100.00	$ 6,930.00	
Foundation Walls	Furnish & Install Foundation Walls with reinforced concrete	10.7	Cubic Meters	$ 2,100.00	$ 22,470.00	
Ground Floor Walls	Furnish & Install Ground Floor Walls with reinforced concrete	85	Cubic Meters	$ 2,100.00	$ 178,500.00	
Slab on Grade	Furnish & Install Slab on Grade	294	Square Meters	$ 150.00	$ 44,100.00	
Roof Slab	Furnish & Install Roof Slab of reinforced concrete	29.4	Cubic Meters	$ 2,100.00	$ 61,740.00	$ 313,740.00
Structural Steel						
Columns	Furnish & Install (2) Structural Steel Columns	2160	Kg	$ 5.65	$ 12,204.00	
Beams	Furnish & Install (4) Structural Steel Beams & Girders	1800	Kg	$ 5.65	$ 10,170.00	
Open Web Joists	Furnish & Install (28) Open Web Joists (350 x 10.1)	1132	Kg	$ 5.65	$ 6,395.80	
Open Web Joists	Furnish & Install (14) Open Web Joists (400 x 10.6)	742	Kg	$ 5.65	$ 4,192.30	
Roof Decking	Furnish & Install Roof Decking	294	Square Meters	$ 20.00	$ 5,880.00	$ 38,842.10
Interior Partitions						
CMU Wall	Furnish & Install Concrete Masonry Block Wall	200	Square Meters	$ 90.00	$ 18,000.00	$ 18,000.00
Electrical						
Plumbing						
HVAC						
Fire Protection						
Building Exterior						
Exterior Wall Cladding	Furnish & Install Steel Outer Sheet with Insulation & Liner Sheet	560	Square Meters	$ 280.00	$ 156,800.00	$ 156,800.00
Roofing System						
Two-Ply Modified Insulated System	Furnish & Install Two-Ply Modified Roofing System	294	Square Meters	$ 290.00	$ 85,260.00	$ 85,260.00
Permanent Fencing & Security						
Chain Link Fence	Furnish & Install 2.4m High Chain Link Fence with Barbed Wire Overhang	245	Meters	$ 140.00	$ 34,300.00	
Double Swing Gates	Furnish & Install 2.4m High Double Swinging Gates (8.0m wide)	1	Each	$ 5,000.00	$ 5,000.00	
Vehicle Restriction Gate	Furnish & Install Vehicle Restriction Gate	1	Each	$ 4,200.00	$ 4,200.00	$ 43,500.00
Total						$ 990,457.10

Concrete Masonry Unit (CMU) Estimate

Task	Description	Quantity	Units	Cost per Unit	Total	Subtotal
Site Preparation						
Clearing and Grubbing of Site	Removal of Trees and Vegatation on Site and Access Road	10050	Square Meters	$ 6.00	$ 60,300.00	
Soil Stripping	Removal of Existing Top Soil	10050	Square Meters	$ 6.00	$ 60,300.00	**$ 120,600.00**
Environmental Management						
Rip-Rap Ditching	Gravel Lining of Drainage Ditch	95	Cubic Meters	$ 85.00	$ 8,075.00	
Ditch Geotechnical Fabric	Lining of Drainage Ditch	2500	Square Meters	$ 4.20	$ 10,500.00	
Flow Checks	Outtake of Drainage Ditch	2	Each	$ 360.00	$ 720.00	
Rip-Rap Discharge Apron	Gravel Area Surrounding Discharge of Drainage Ditch	20	Square Meters	$ 85.00	$ 1,700.00	
Topsoil and Hydroseed	Planted Vegatation on Banks of Drainage Ditch	2500	Square Meters	$ 8.40	$ 21,000.00	
Silt Fencing	Fencing System to Reduce Run-off and Erosion	245	Meter	$ 13.50	$ 3,307.50	
Temporary Cut-Off Ditches	Drainage Ditches Feeding Temporary Filtration System	120	Meter	$ 15.00	$ 1,800.00	
Temporary Sedimentation Pond	Area Designed to Collect Excess Sediment	1	Lump Sum	$ 10,000.00	$ 10,000.00	
Temporary Pumping and Dewatering	Filtration system	1	Lump Sum	$ 20,000.00	$ 20,000.00	**$ 77,102.50**
Access Road						
Class A Gravel	Top Layer of Access Road (NLDTW Class A/NSTIR Type 1)	350	Cubic Meters	$ 60.00	$ 21,000.00	
Class B Gravel	Base Layer of Access Road (NLDTW Class B/NSTIR Type 2)	560	Cubic Meters	$ 40.00	$ 22,400.00	**$ 43,400.00**
Excavation						
Foundation Excavation and Backfill	Excavation of Compound's Footprint	35	Cubic Meters	$ 17.50	$ 612.50	
Surge Rock Allowance	Drainage Assistance	100	Cubic Meters	$ 70.00	$ 7,000.00	
Class A Gravel	Top Layer of Site Surface (NLDTW Class A/NSTIR Type 1)	660	Cubic Meters	$ 60.00	$ 39,600.00	
Class B Gravel	Base Layer of Site Surface (NLDTW Class B/NSTIR Type 2)	1150	Cubic Meters	$ 40.00	$ 46,000.00	**$ 93,212.50**
Foundation & Concrete						
Strip Footings	Furnish & Install Strip Footings with reinforced concrete	6.3	Cubic Meters	$ 1,100.00	$ 6,930.00	
Foundation Walls	Furnish & Install Foundation Walls with reinforced concrete	10.7	Cubic Meters	$ 2,100.00	$ 22,470.00	
Slab on Grade	Furnish & Install Slab on Grade	294	Square Meters	$ 150.00	$ 44,100.00	
Ground Floor Walls	Furnish & Install Reinforced CMU Walls	560	Square Meters	$ 150.00	$ 84,000.00	
Roof Slab	Furnish & Install Roof Slab of reinforced concrete	29.4	Cubic Meters	$ 2,100.00	$ 61,740.00	**$ 219,240.00**
Structural Steel						
Columns	Furnish & Install (2) Structural Steel Columns	2160	Kg	$ 5.65	$ 12,204.00	
Beams	Furnish & Install (4) Structural Steel Beams & Girders	1800	Kg	$ 5.65	$ 10,170.00	
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Roof Decking	Furnish & Install Roof Decking	294	Square Meters	$ 20.00	$ 5,880.00	**$ 38,842.10**
Interior Partitions						
CMU Wall	Furnish & Install Concrete Masonry Block Wall	200	Square Meters	$ 90.00	$ 18,000.00	**$ 18,000.00**
Electrical						
Plumbing						
HVAC						
Fire Protection						
Building Exterior						
Exterior Wall Cladding	Furnish & Install Steel Outer Sheet with Insulation & Liner Sheet	560	Square Meters	$ 280.00	$ 156,800.00	**$ 156,800.00**
Roofing System						
Two-Ply Modified Insulated System	Furnish & Install Two-Ply Modified Roofing System	294	Square Meters	$ 290.00	$ 85,260.00	**$ 85,260.00**
Permanent Fencing & Security						
Chain Link Fence	Furnish & Install 2.4m High Chain Link Fence with Barbed Wire Overhang	245	Meters	$ 140.00	$ 34,300.00	
Double Swing Gates	Furnish & Install 2.4m High Double Swinging Gates (8.0m wide)	1	Each	$ 5,000.00	$ 5,000.00	
Vehicle Restriction Gate	Furnish & Install Vehicle Restriction Gate	1	Each	$ 4,200.00	$ 4,200.00	**$ 43,500.00**
Total						**$ 895,957.10**

Insulated Concrete Form (ICF) Estimate

Task	Description	Quantity	Units	Cost per Unit	Total	Subtotal
Site Preparation						
Clearing and Grubbing of Site	Removal of Trees and Vegatation on Site and Access Road	10050	Square Meters	$ 6.00	$ 60,300.00	
Soil Stripping	Removal of Existing Top Soil	10050	Square Meters	$ 6.00	$ 60,300.00	**$ 120,600.00**
Environmental Management						
Rip-Rap Ditching	Gravel Lining of Drainage Ditch	95	Cubic Meters	$ 85.00	$ 8,075.00	
Ditch Geotechnical Fabric	Lining of Drainage Ditch	2500	Square Meters	$ 4.20	$ 10,500.00	
Flow Checks	Outtake of Drainage Ditch	2	Each	$ 360.00	$ 720.00	
Rip-Rap Discharge Apron	Gravel Area Surrounding Discharge of Drainage Ditch	20	Square Meters	$ 85.00	$ 1,700.00	
Topsoil and Hydroseed	Planted Vegatation on Banks of Drainage Ditch	2500	Square Meters	$ 8.40	$ 21,000.00	
Silt Fencing	Fencing System to Reduce Run-off and Erosion	245	Meter	$ 13.50	$ 3,307.50	
Temporary Cut-Off Ditches	Drainage Ditches Feeding Temporary Filtration System	120	Meter	$ 15.00	$ 1,800.00	
Temporary Sedimentation Pond	Area Designed to Collect Excess Sediment	1	Lump Sum	$ 10,000.00	$ 10,000.00	
Temporary Pumping and Dewatering	Filtration system	1	Lump Sum	$ 20,000.00	$ 20,000.00	**$ 77,102.50**
Access Road						
Class A Gravel	Top Layer of Access Road (NLDTW Class A/NSTIR Type 1)	350	Cubic Meters	$ 60.00	$ 21,000.00	
Class B Gravel	Base Layer of Access Road (NLDTW Class B/NSTIR Type 2)	560	Cubic Meters	$ 40.00	$ 22,400.00	**$ 43,400.00**
Excavation						
Foundation Excavation and Backfill	Excavation of Compound's Footprint	35	Cubic Meters	$ 17.50	$ 612.50	
Surge Rock Allowance	Drainage Assistance	100	Cubic Meters	$ 70.00	$ 7,000.00	
Class A Gravel	Top Layer of Site Surface (NLDTW Class A/NSTIR Type 1)	660	Cubic Meters	$ 60.00	$ 39,600.00	
Class B Gravel	Base Layer of Site Surface (NLDTW Class B/NSTIR Type 2)	1150	Cubic Meters	$ 40.00	$ 46,000.00	**$ 93,212.50**
Foundation & Concrete						
Strip Footings	Furnish & Install Strip Footings with reinforced concrete	6.3	Cubic Meters	$ 1,100.00	$ 6,930.00	
Foundation Walls	Furnish & Install Foundation Walls with ICF	10.7	Cubic Meters	$ 1,242.00	$ 13,289.40	
Ground Floor Walls	Furnish & Install Ground Floor Walls with ICF	85	Cubic Meters	$ 1,118.00	$ 95,030.00	
Interior 1/2" Drywall	Furnish & Install Half-Inch Drywall to Interior Surface of ICF	560	Square Meters	$ 1.42	$ 795.20	
Slab on Grade	Furnish & Install Slab on Grade	294	Square Meters	$ 150.00	$ 44,100.00	
Roof Slab	Furnish & Install Roof Slab of reinforced concrete	29.4	Cubic Meters	$ 2,100.00	$ 61,740.00	**$ 221,884.60**
Structural Steel						
Columns	Furnish & Install (2) Structural Steel Columns	2160	Kg	$ 5.65	$ 12,204.00	
Beams	Furnish & Install (4) Structural Steel Beams & Girders	1800	Kg	$ 5.65	$ 10,170.00	
Open Web Joists	Furnish & Install (28) Open Web Joists (350 x 10.1)	1132	Kg	$ 5.65	$ 6,395.80	
Open Web Joists	Furnish & Install (14) Open Web Joists (400 x 10.6)	742	Kg	$ 5.65	$ 4,192.30	
Roof Decking	Furnish & Install Roof Decking	294	Square Meters	$ 20.00	$ 5,880.00	**$ 38,842.10**
Interior Partitions						
CMU Wall	Furnish & Install Concrete Masonry Block Wall	200	Square Meters	$ 90.00	$ 18,000.00	**$ 18,000.00**
Electrical						
Plumbing						
HVAC						
Fire Protection						
Building Exterior						
Exterior Wall Cladding	Furnish & Install Steel Outer Sheet with Insulation & Liner Sheet	560	Square Meters	$ 280.00	$ 156,800.00	**$ 156,800.00**
Roofing System						
Two-Ply Modified Insulated System	Furnish & Install Two-Ply Modified Roofing System	294	Square Meters	$ 290.00	$ 85,260.00	**$ 85,260.00**
Permanent Fencing & Security						
Chain Link Fence	Furnish & Install 2.4m High Chain Link Fence with Barbed Wire Overhang	245	Meters	$ 140.00	$ 34,300.00	
Double Swing Gates	Furnish & Install 2.4m High Double Swinging Gates (8.0m wide)	1	Each	$ 5,000.00	$ 5,000.00	
Vehicle Restriction Gate	Furnish & Install Vehicle Restriction Gate	1	Each	$ 4,200.00	$ 4,200.00	**$ 43,500.00**
Total						**$ 898,601.70**

Pre-Cast Concrete Estimate

Task	Description	Quantity	Units	Cost per Unit	Total	Subtotal
Site Preparation						
Clearing and Grubbing of Site	Removal of Trees and Vegatation on Site and Access Road	10050	Square Meters	$ 6.00	$ 60,300.00	
Soil Stripping	Removal of Existing Top Soil	10050	Square Meters	$ 6.00	$ 60,300.00	$ 120,600.00
Environmental Management						
Rip-Rap Ditching	Gravel Lining of Drainage Ditch	95	Cubic Meters	$ 85.00	$ 8,075.00	
Ditch Geotechnical Fabric	Lining of Drainage Ditch	2500	Square Meters	$ 4.20	$ 10,500.00	
Flow Checks	Outtake of Drainage Ditch	2	Each	$ 360.00	$ 720.00	
Rip-Rap Discharge Apron	Gravel Area Surrounding Discharge of Drainage Ditch	20	Square Meters	$ 85.00	$ 1,700.00	
Topsoil and Hydroseed	Planted Vegatation on Banks of Drainage Ditch	2500	Square Meters	$ 8.40	$ 21,000.00	
Silt Fencing	Fencing System to Reduce Run-off and Erosion	245	Meter	$ 13.50	$ 3,307.50	
Temporary Cut-Off Ditches	Drainage Ditches Feeding Temporary Filtration System	120	Meter	$ 15.00	$ 1,800.00	
Temporary Sedimentation Pond	Area Designed to Collect Excess Sediment	1	Lump Sum	$ 10,000.00	$ 10,000.00	
Temporary Pumping and Dewatering	Filtration system	1	Lump Sum	$ 20,000.00	$ 20,000.00	$ 77,102.50
Access Road						
Class A Gravel	Top Layer of Access Road (NLDTW Class A/NSTIR Type 1)	350	Cubic Meters	$ 60.00	$ 21,000.00	
Class B Gravel	Base Layer of Access Road (NLDTW Class B/NSTIR Type 2)	560	Cubic Meters	$ 40.00	$ 22,400.00	$ 43,400.00
Excavation						
Foundation Excavation and Backfill	Excavation of Compound's Footprint	35	Cubic Meters	$ 17.50	$ 612.50	
Surge Rock Allowance	Drainage Assistance	100	Cubic Meters	$ 70.00	$ 7,000.00	
Class A Gravel	Top Layer of Site Surface (NLDTW Class A/NSTIR Type 1)	660	Cubic Meters	$ 60.00	$ 39,600.00	
Class B Gravel	Base Layer of Site Surface (NLDTW Class B/NSTIR Type 2)	1150	Cubic Meters	$ 40.00	$ 46,000.00	$ 93,212.50
Foundation & Concrete						
Strip Footings	Furnish & Install Strip Footings with reinforced concrete	6.3	Cubic Meters	$ 1,100.00	$ 6,930.00	
Foundation Walls	Furnish & Install Foundation Walls with reinforced concrete	10.7	Cubic Meters	$ 2,100.00	$ 22,470.00	
Slab on Grade	Furnish & Install Slab on Grade	294	Square Meters	$ 150.00	$ 44,100.00	
Ground Floor Walls	Furnish & Install Pre-Cast Concrete Load Bearing Walls	560	Square Meters	$ 600.00	$ 336,000.00	
Roof Slab	Furnish & Install Roof Slab of reinforced concrete	29.4	Cubic Meters	$ 2,100.00	$ 61,740.00	$ 471,240.00
Structural Steel						
Columns	Furnish & Install (2) Structural Steel Columns	2160	Kg	$ 5.65	$ 12,204.00	
Beams	Furnish & Install (4) Structural Steel Beams & Girders	1800	Kg	$ 5.65	$ 10,170.00	
Open Web Joists	Furnish & Install (28) Open Web Joists (350 x 10.1)	1132	Kg	$ 5.65	$ 6,395.80	
Open Web Joists	Furnish & Install (14) Open Web Joists (400 x 10.6)	742	Kg	$ 5.65	$ 4,192.30	
Roof Decking	Furnish & Install Roof Decking	294	Square Meters	$ 20.00	$ 5,880.00	$ 38,842.10
Interior Partitions						
CMU Wall	Furnish & Install Concrete Masonry Block Wall	200	Square Meters	$ 90.00	$ 18,000.00	$ 18,000.00
Electrical						
Plumbing						
HVAC						
Fire Protection						
Building Exterior						
Exterior Wall Cladding	Furnish & Install Steel Outer Sheet with Insulation & Liner Sheet	560	Square Meters	$ 280.00	$ 156,800.00	$ 156,800.00
Roofing System						
Two-Ply Modified Insulated System	Furnish & Install Two-Ply Modified Roofing System	294	Square Meters	$ 290.00	$ 85,260.00	$ 85,260.00
Permanent Fencing & Security						
Chain Link Fence	Furnish & Install 2.4m High Chain Link Fence with Barbed Wire Overhang	245	Meters	$ 140.00	$ 34,300.00	
Double Swing Gates	Furnish & Install 2.4m High Double Swinging Gates (8.0m wide)	1	Each	$ 5,000.00	$ 5,000.00	
Vehicle Restriction Gate	Furnish & Install Vehicle Restriction Gate	1	Each	$ 4,200.00	$ 4,200.00	$ 43,500.00
Total						$ 1,147,957.10

Structural Steel Estimate

Task	Description	Quantity	Units	Cost per Unit	Total	Subtotal
Site Preparation						
Clearing and Grubbing of Site	Removal of Trees and Vegatation on Site and Access Road	10050	Square Meters	$ 6.00	$ 60,300.00	
Soil Stripping	Removal of Existing Top Soil	10050	Square Meters	$ 6.00	$ 60,300.00	**$ 120,600.00**
Environmental Management						
Rip-Rap Ditching	Gravel Lining of Drainage Ditch	95	Cubic Meters	$ 85.00	$ 8,075.00	
Ditch Geotechnical Fabric	Lining of Drainage Ditch	2500	Square Meters	$ 4.20	$ 10,500.00	
Flow Checks	Outtake of Drainage Ditch	2	Each	$ 360.00	$ 720.00	
Rip-Rap Discharge Apron	Gravel Area Surrounding Discharge of Drainage Ditch	20	Square Meters	$ 85.00	$ 1,700.00	
Topsoil and Hydroseed	Planted Vegatation on Banks of Drainage Ditch	2500	Square Meters	$ 8.40	$ 21,000.00	
Silt Fencing	Fencing System to Reduce Run-off and Erosion	245	Meter	$ 13.50	$ 3,307.50	
Temporary Cut-Off Ditches	Drainage Ditches Feeding Temporary Filtration System	120	Meter	$ 15.00	$ 1,800.00	
Temporary Sedimentation Pond	Area Designed to Collect Excess Sediment	1	Lump Sum	$ 10,000.00	$ 10,000.00	
Temporary Pumping and Dewatering	Filtration system	1	Lump Sum	$ 20,000.00	$ 20,000.00	**$ 77,102.50**
Access Road						
Class A Gravel	Top Layer of Access Road (NLDTW Class A/NSTIR Type 1)	350	Cubic Meters	$ 60.00	$ 21,000.00	
Class B Gravel	Base Layer of Access Road (NLDTW Class B/NSTIR Type 2)	560	Cubic Meters	$ 40.00	$ 22,400.00	**$ 43,400.00**
Excavation						
Foundation Excavation and Backfill	Excavation of Compound's Footprint	35	Cubic Meters	$ 17.50	$ 612.50	
Surge Rock Allowance	Drainage Assistance	100	Cubic Meters	$ 70.00	$ 7,000.00	
Class A Gravel	Top Layer of Site Surface (NLDTW Class A/NSTIR Type 1)	660	Cubic Meters	$ 60.00	$ 39,600.00	
Class B Gravel	Base Layer of Site Surface (NLDTW Class B/NSTIR Type 2)	1150	Cubic Meters	$ 40.00	$ 46,000.00	**$ 93,212.50**
Foundation & Concrete						
Strip Footings	Furnish & Install Strip Footings with reinforced concrete	6.3	Cubic Meters	$ 1,100.00	$ 6,930.00	
Foundation Walls	Furnish & Install Foundation Walls with reinforced concrete	10.7	Cubic Meters	$ 2,100.00	$ 22,470.00	
Slab on Grade	Furnish & Install Slab on Grade	294	Square Meters	$ 150.00	$ 44,100.00	
Roof Slab	Furnish & Install Roof Slab of reinforced concrete	29.4	Cubic Meters	$ 2,100.00	$ 61,740.00	**$ 135,240.00**
Structural Steel						
Columns	Furnish & Install (18) Structural Steel Columns (360 x 45)	19440	Kg	$ 5.65	$ 109,836.00	
Beams	Furnish & Install (23) Structural Steel Beams & Girders (360 x 45)	5355	Kg	$ 5.65	$ 30,255.75	
Open Web Joists	Furnish & Install (28) Open Web Joists (350 x 10.1)	1132	Kg	$ 5.65	$ 6,395.80	
Open Web Joists	Furnish & Install (14) Open Web Joists (400 x 10.6)	742	Kg	$ 5.65	$ 4,192.30	
Roof Decking	Furnish & Install Roof Decking	294	Square Meters	$ 20.00	$ 5,880.00	**$ 156,559.85**
Interior Partitions						
CMU Wall	Furnish & Install Concrete Masonry Block Wall	200	Square Meters	$ 90.00	$ 18,000.00	**$ 18,000.00**
Electrical						
Plumbing						
HVAC						
Fire Protection						
Building Exterior						
Exterior Wall Cladding	Furnish & Install Steel Outer Sheet with Insulation & Liner Sheet	560	Square Meters	$ 280.00	$ 156,800.00	**$ 156,800.00**
Roofing System						
Two-Ply Modified Insulated System	Furnish & Install Two-Ply Modified Roofing System	294	Square Meters	$ 290.00	$ 85,260.00	**$ 85,260.00**
Permanent Fencing & Security						
Chain Link Fence	Furnish & Install 2.4m High Chain Link Fence with Barbed Wire Overhang	245	Meters	$ 140.00	$ 34,300.00	
Double Swing Gates	Furnish & Install 2.4m High Double Swinging Gates (8.0m wide)	1	Each	$ 5,000.00	$ 5,000.00	
Vehicle Restriction Gate	Furnish & Install Vehicle Restriction Gate	1	Each	$ 4,200.00	$ 4,200.00	**$ 43,500.00**
Total						**$ 929,674.85**

Appendix H: Final Cost & Duration Comparisons

Cost & Time Comparison for Elements in Costworks

Cast in Place Concrete								
Task	Duration (Estimated)	Duration (CostWorks)	Difference	Cost (Estimated)	SqFt Cost (Estimated)	Cost (CostWorks)	SqFt Cost (CostWorks)	Difference
Foundation & Concrete								
Strip Footings	3 Days	3 Days		$ 6,930.00	$ 30.13	$ 3,080.37	$ 13.39	$ 3,849.63
Formwork for Foundation Walls	5 Days	11 Days	6 Days					
Pour Concrete for Foundation Walls	1 Days	1 Day		$ 22,470.00	$ 32.57	$ 6,761.35	$ 9.80	$ 15,708.65
Formwork for Stage 1 Walls	10 Days	49 Days	39 Days					
Pour Concrete for Stage 1 Walls	2 Days	4 Days	2 Days					
Formwork for Stage 2 Walls	15 Days	49 Days	34 Days					
Pour Concrete for Stage 2 Walls	2 Days	4 Days	2 Day	$ 176,400.00	$ 28.41	$ 75,889.51	$ 12.22	$ 100,510.49
Slab on Grade	5 Days	7 Days	2 Days	$ 44,100.00	$ 27.79	$ 12,451.37	$ 7.85	$ 31,648.63
Roof Slab	5 Days	4 Days	1 Day	$ 61,740.00	$ 19.45	$ 16,940.56	$ 5.34	$ 44,799.44
Structural Steel								
Columns (2)	2 Days	1 Day	1 Day	$ 12,204.00		$ 2,916.01		$ 9,287.99
Beams (4)	2 Days	1 Day	1 Day	$ 10,170.00		$ 7,084.81		$ 3,085.19
Open Web Joists (28)								
Open Web Joists (14)	7 Days	4 Days	3 days	$ 10,588.10		$ 6,532.86		$ 4,055.24
Roof Decking	3 Days	3 Days		$ 5,880.00	$ 1.85	$ 8,911.40	$ 2.81	$ (3,031.40)
Interior Partitions								
CMU Wall	20 Days	29 Days	9 Days	$ 18,000.00	$ 8.36	$ 19,206.37	$ 8.92	$ (1,206.37)
Building Exterior								
Exterior Wall Cladding	15 Days	65 Days	50 Days	$ 156,800.00	$ 25.25	$ 71,480.33	$ 11.51	$ 85,319.67
Roofing System								
Two-Ply Modified Insulated System	10 Days	11 Days	1 Day	$ 85,260.00	$ 26.86	$ 8,006.16	$ 2.52	$ 77,253.84
Permanent Fencing & Security								
Chain Link Fence w/ Barbed Wire	12 Days	13 Days	1 Day	$ 34,300.00	$ 5.33	$ 49,527.26	$ 7.70	$ (15,227.26)
Double Swing Gates	2 Days	3 Days	1 Day	$ 5,000.00		$ 3,112.10		$ 1,887.90
Total				**$ 649,842.10**		**$ 291,900.46**		**$ 357,941.64**

Cost & Time Comparison for Elements in Costworks

Concrete Masonry Unit								
Task	Duration (Estimated)	Duration (CostWorks)	Difference	Cost (Estimated)	SqFt Cost (Estimated)	Cost (CostWorks)	SqFt Cost (CostWorks)	Difference
Foundation & Concrete								
Strip Footings	3 Days	3 Days		$ 6,930.00	$ 30.13	$ 3,080.37	$ 13.39	$ 3,849.63
Formwork for Foundation Walls	5 Days	11 Days	6 Days					
Pour Concrete for Foundation Walls	1 Days	1 Day		$ 22,470.00	$ 32.57	$ 6,761.35	$ 9.80	$ 15,708.65
Slab on Grade	5 Days	7 Days	2 Days	$ 44,100.00	$ 27.79	$ 12,451.37	$ 7.85	$ 31,648.63
Roof Slab	5 Days	4 Days	1 Day	$ 61,740.00	$ 19.45	$ 16,940.56	$ 5.34	$ 44,799.44
Structural Steel								
Columns (2)	2 Days	1 Day	1 Day	$ 12,204.00		$ 2,901.97		$ 9,302.03
Beams (4)	2 Days	1 Day	1 Day	$ 10,170.00		$ 7,050.71		$ 3,119.29
Open Web Joists (28) Open Web Joists (14)	7 Days	4 Days	3 days	$ 10,588.10		$ 6,532.86		$ 4,055.24
Roof Decking	3 Days	3 Days		$ 5,880.00	$ 1.85	$ 8,911.40	$ 2.81	$ (3,031.40)
Concrete Masonry Unit								
Reinforced CMU Walls	60 Days	86 Days	26 Days	$ 84,000.00	$ 13.53	$ 75,922.47	$ 12.23	$ 8,077.53
Interior Partitions								
CMU Wall	20 Days	29 Days	9 Days	$ 18,000.00	$ 8.36	$ 19,206.37	$ 8.92	$ (1,206.37)
Building Exterior								
Exterior Wall Cladding	15 Days	65 Days	50 Days	$ 156,800.00	$ 25.25	$ 71,480.33	$ 11.51	$ 85,319.67
Roofing System								
Two-Ply Modified Insulated System	10 Days	11 Days	1 Day	$ 85,260.00	$ 26.86	$ 8,006.16	$ 2.52	$ 77,253.84
Permanent Fencing & Security								
Chain Link Fence w/ Barbed Wire	12 Days	13 Days	1 Day	$ 34,300.00	$ 5.33	$ 49,527.26	$ 7.70	$ (15,227.26)
Double Swing Gates	2 Days	3 Days	1 Day	$ 5,000.00		$ 3,112.10		$ 1,887.90
Total				**$ 557,442.10**		**$ 291,885.28**		**$ 265,556.82**

Cost & Time Comparison for Elements in Costworks

Insulated Concrete Form								
Task	Duration (Estimated)	Duration (CostWorks)	Difference	Cost (Estimated)	SqFt Cost (Estimated)	Cost (CostWorks)	SqFt Cost (CostWorks)	Difference
Insulated Concrete Form								
Strip Footings	3 Days	3 Days		$ 6,930.00	$ 30.13	$ 3,080.37	$ 13.39	$ 3,849.63
Formwork for Foundation Walls	3 Days	3 Days						
Pour Concrete for Foundation Walls	1 Days	1 Day		$ 13,289.40	$ 19.26	$ 4,573.78	$ 6.63	$ 8,715.62
Formwork for Stage 1 Walls	8 Days	13 Days	5 Days					
Pour Concrete for Stage 1 Walls	2 Days	4 Days	2 Day					
Formwork for Stage 2 Walls	13 Days	13 Days						
Pour Concrete for Stage 2 Walls	2 Days	4 Days	2 Day	$ 95,030.00	$ 15.30	$ 40,864.57	$ 6.58	$ 54,165.43
Slab on Grade	5 Days	7 Days	2 Days	$ 44,100.00	$ 27.79	$ 12,451.37	$ 7.85	$ 31,648.63
Roof Slab	5 Days	4 Days	1 Day	$ 61,740.00	$ 19.45	$ 16,940.56	$ 5.34	$ 44,799.44
Structural Steel								
Columns (2)	2 Days	1 Day	1 Day	$ 12,204.00		$ 2,901.97		$ 9,302.03
Beams (4)	2 Days	1 Day	1 Day	$ 10,170.00		$ 7,050.71		$ 3,119.29
Open Web Joists (28)								
Open Web Joists (14)	7 Days	4 Days	3 days	$ 10,588.10		$ 6,532.86		$ 4,055.24
Roof Decking	3 Days	3 Days		$ 5,880.00	$ 1.85	$ 8,911.40	$ 2.81	$ (3,031.40)
Interior Partitions								
CMU Wall	20 Days	29 Days	9 Days	$ 18,000.00	$ 8.36	$ 19,206.37	$ 8.92	$ (1,206.37)
Building Exterior								
Exterior Wall Cladding	15 Days	65 Days	50 Days	$ 156,800.00	$ 25.25	$ 71,480.33	$ 11.51	$ 85,319.67
Roofing System								
Two-Ply Modified Insulated System	10 Days	11 Days	1 Day	$ 85,260.00	$ 26.86	$ 8,006.16	$ 2.52	$ 77,253.84
Permanent Fencing & Security								
Chain Link Fence w/ Barbed Wire	12 Days	13 Days	1 Day	$ 34,300.00	$ 5.33	$ 49,527.26	$ 7.70	$ (15,227.26)
Double Swing Gates	2 Days	3 Days	1 Day	$ 5,000.00		$ 3,112.10		$ 1,887.90
Total				**$ 559,291.50**		**$ 254,639.81**		**$ 304,651.69**

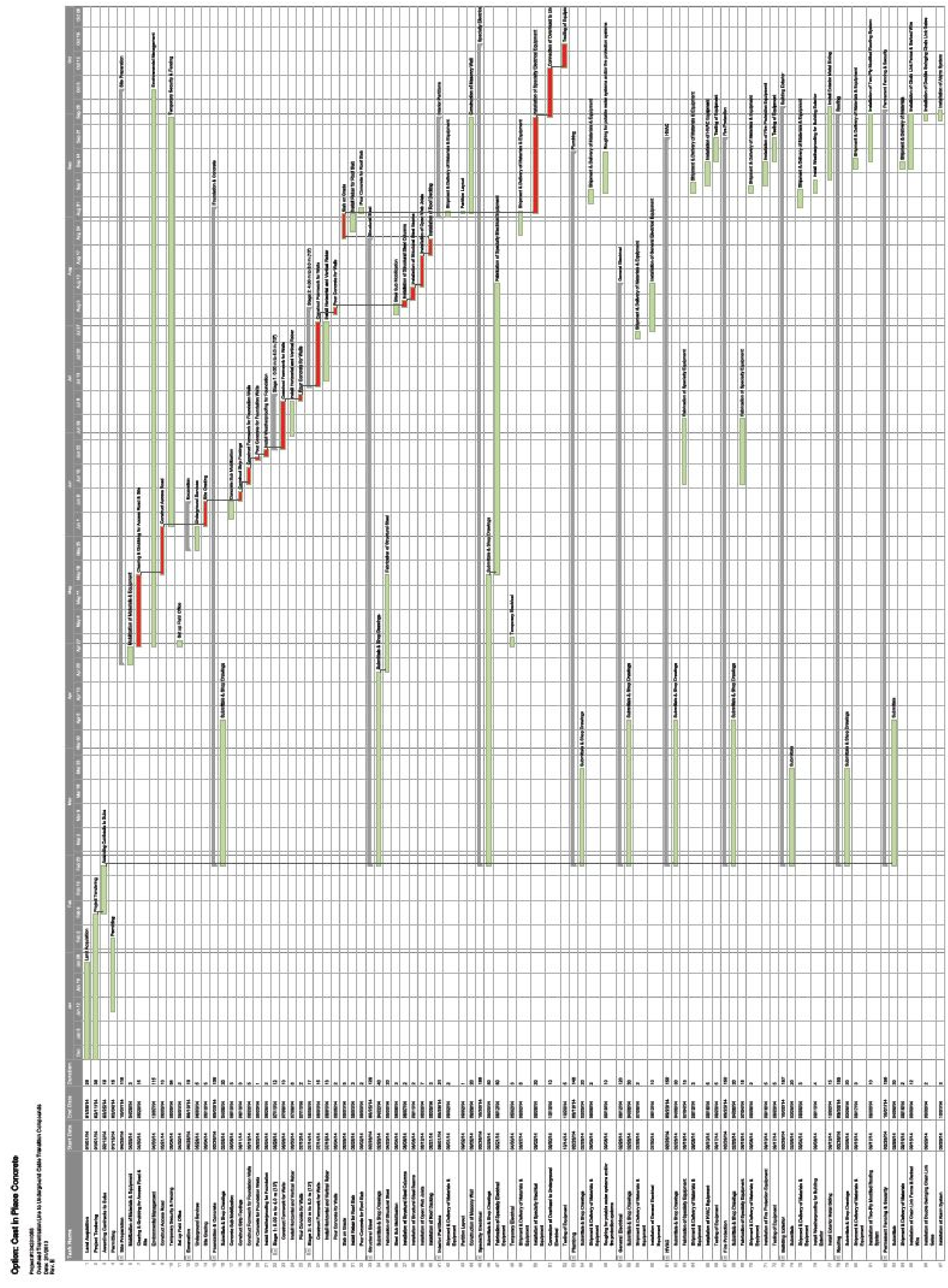
Cost & Time Comparison for Elements in Costworks

Precast Concrete								
Task	**Duration (Estimated)**	**Duration (CostWorks)**	**Difference**	**Cost (Estimated)**	**SqFt Cost (Estimated)**	**Cost (CostWorks)**	**SqFt Cost (CostWorks)**	**Difference**
Foundation & Concrete								
Strip Footings	3 Days	3 Days		$ 6,930.00	$ 30.13	$ 3,080.37	$ 13.39	$ 3,849.63
Formwork for Foundation Walls	5 Days	11 Days	6 Days					
Pour Concrete for Foundation Walls	1 Days	1 Day		$ 22,470.00	$ 32.57	$ 6,761.35	$ 9.80	$ 15,708.65
Slab on Grade	5 Days	7 Days	2 Days	$ 44,100.00	$ 27.79	$ 12,451.37	$ 7.85	$ 31,648.63
Roof Slab	5 Days	4 Days	1 Day	$ 61,740.00	$ 19.45	$ 16,940.56	$ 5.34	$ 44,799.44
Precast Concrete								
Erection of Precast Wall Panels	10 Days	72 Days	62 Days	$ 336,000.00	$ 54.11	$ 335,472.15	$ 54.02	$ 527.85
Structural Steel								
Columns (2)	2 Days	1 Day	1 Day	$ 12,204.00		$ 2,901.97		$ 9,302.03
Beams (4)	2 Days	1 Day	1 Day	$ 10,170.00		$ 7,050.71		$ 3,119.29
Open Web Joists (28)								
Open Web Joists (14)	7 Days	4 Days	3 days	$ 10,588.10		$ 6,532.86		$ 4,055.24
Roof Decking	3 Days	3 Days		$ 5,880.00	$ 1.85	$ 8,911.40	$ 2.81	$ (3,031.40)
Interior Partitions								
CMU Wall	20 Days	29 Days	9 Days	$ 18,000.00	$ 8.36	$ 19,206.37	$ 8.92	$ (1,206.37)
Building Exterior								
Exterior Wall Cladding	15 Days	65 Days	50 Days	$ 156,800.00	$ 25.25	$ 71,480.33	$ 11.51	$ 85,319.67
Roofing System								
Two-Ply Modified Insulated System	10 Days	11 Days	1 Day	$ 85,260.00	$ 26.86	$ 8,006.16	$ 2.52	$ 77,253.84
Permanent Fencing & Security								
Chain Link Fence w/ Barbed Wire	12 Days	13 Days	1 Day	$ 34,300.00	$ 5.33	$ 49,527.26	$ 7.70	$ (15,227.26)
Double Swing Gates	2 Days	3 Days	1 Day	$ 5,000.00		$ 3,112.10		$ 1,887.90
Total				**$ 809,442.10**		**$ 551,434.96**		**$ 258,007.14**

Cost & Time Comparison for Elements in Costworks

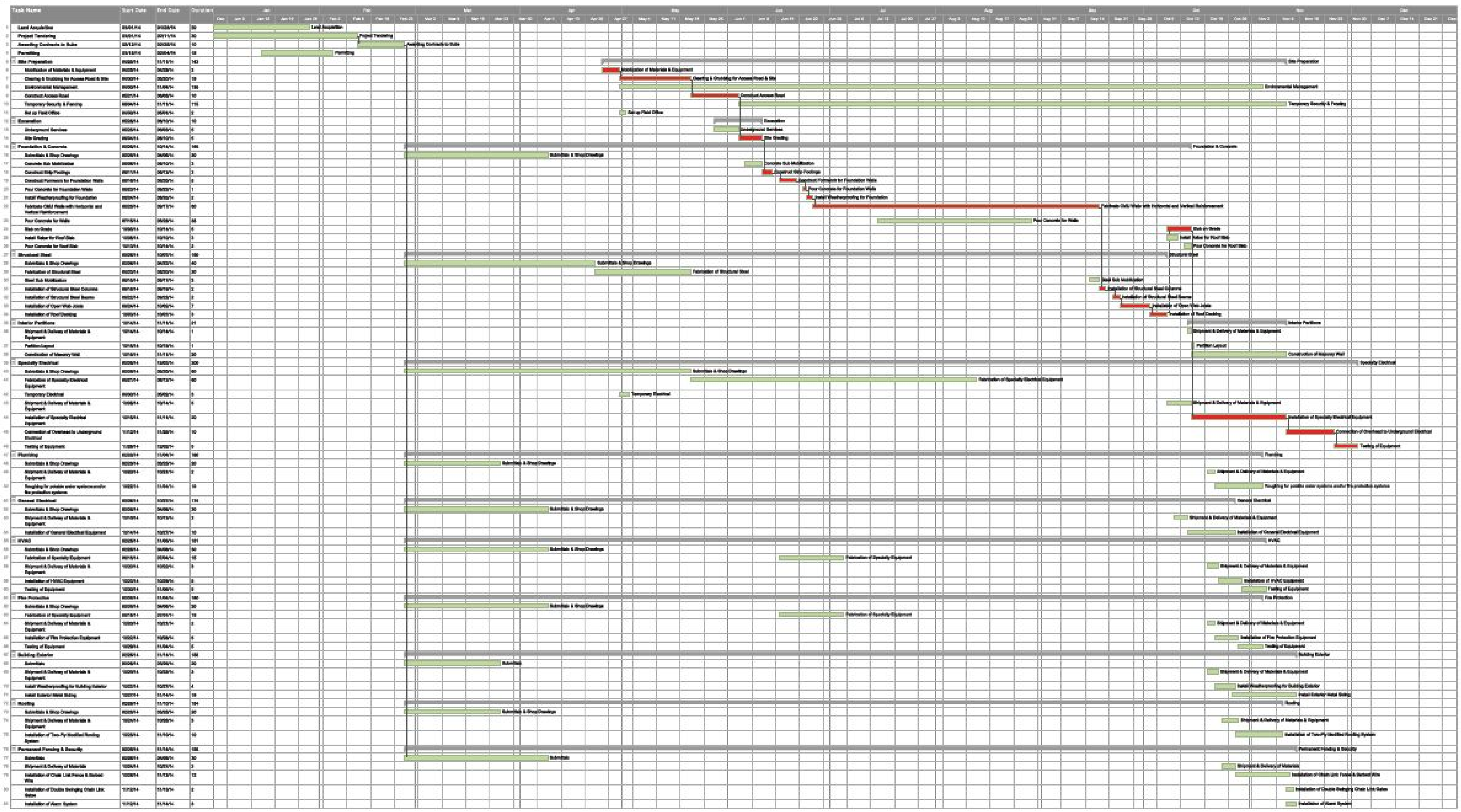
Structural Steel								
Task	Duration (Estimated)	Duration (CostWorks)	Difference	Cost (Estimated)	SqFt Cost (Estimated)	Cost (CostWorks)	SqFt Cost (CostWorks)	Difference
Foundation & Concrete								
Strip Footings	3 Days	3 Days		$ 6,930.00	$ 30.13	$ 3,080.37	$ 13.39	$ 3,849.63
Formwork for Foundation Walls	5 Days	11 Days	6 Days					
Pour Concrete for Foundation Walls	1 Days	1 Day		$ 22,470.00	$ 32.57	$ 6,761.35	$ 9.80	$ 15,708.65
Slab on Grade	5 Days	7 Days	2 Days	$ 44,100.00	$ 27.79	$ 12,451.37	$ 7.85	$ 31,648.63
Roof Slab	5 Days	4 Days	1 Day	$ 61,740.00	$ 19.45	$ 16,940.56	$ 5.34	$ 44,799.44
Structural Steel								
Columns (18)	10 Days	4 Days	6 Days	$ 109,836.00		$ 26,117.74		$ 83,718.26
Beams (23)	2 Days	1 Day	1 Day	$ 30,255.75		$ 21,114.04		$ 9,141.71
Open Web Joists (28)								
Open Web Joists (14)	7 Days	4 Days	3 days	$ 10,588.10		$ 6,532.86		$ 4,055.24
Roof Decking	3 Days	3 Days		$ 5,880.00	$ 1.85	$ 8,911.40	$ 2.81	$ (3,031.40)
Interior Partitions								
CMU Wall	20 Days	29 Days	9 Days	$ 18,000.00	$ 8.36	$ 19,206.37	$ 8.92	$ (1,206.37)
Building Exterior								
Exterior Wall Cladding	15 Days	65 Days	50 Days	$ 156,800.00	$ 25.25	$ 71,480.33	$ 11.51	$ 85,319.67
Roofing System								
Two-Ply Modified Insulated System	10 Days	11 Days	1 Day	$ 85,260.00	$ 26.86	$ 8,006.16	$ 2.52	$ 77,253.84
Permanent Fencing & Security								
Chain Link Fence w/ Barbed Wire	12 Days	13 Days	1 Day	$ 34,300.00	$ 5.33	$ 49,527.26	$ 7.70	$ (15,227.26)
Double Swing Gates	2 Days	3 Days	1 Day	$ 5,000.00		$ 3,112.10		$ 1,887.90
Total				**$ 591,159.85**		**$ 253,241.91**		**$ 337,917.94**

Appendix I: Final Project Schedules



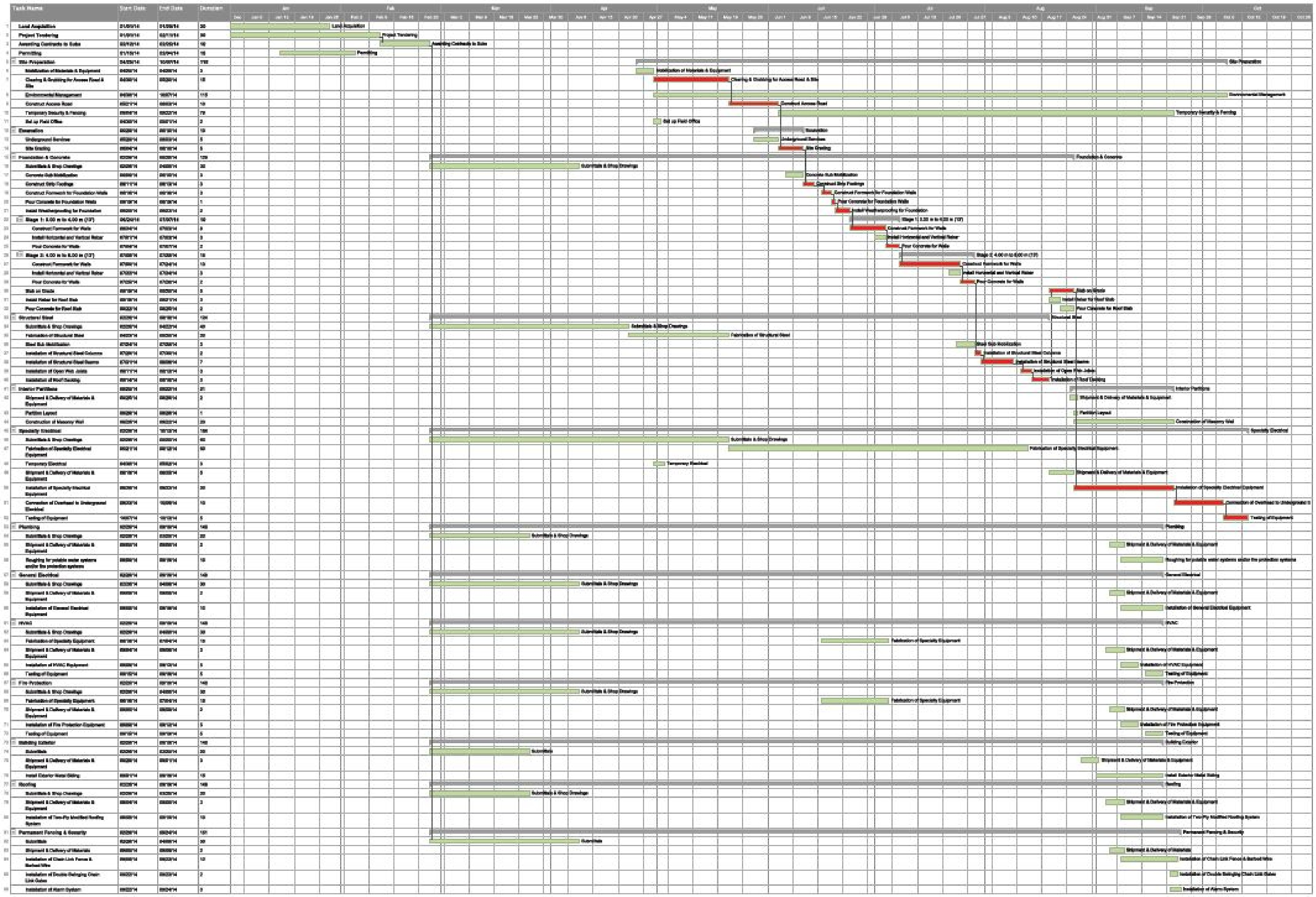
Option: Concrete Masonry Unit (CMU)

Project #[illegible]
Overhead Transmission Line to Underground Cable Transition Compounds
Date:
Rev. D



Option: Insulated Concrete Forms (ICF)

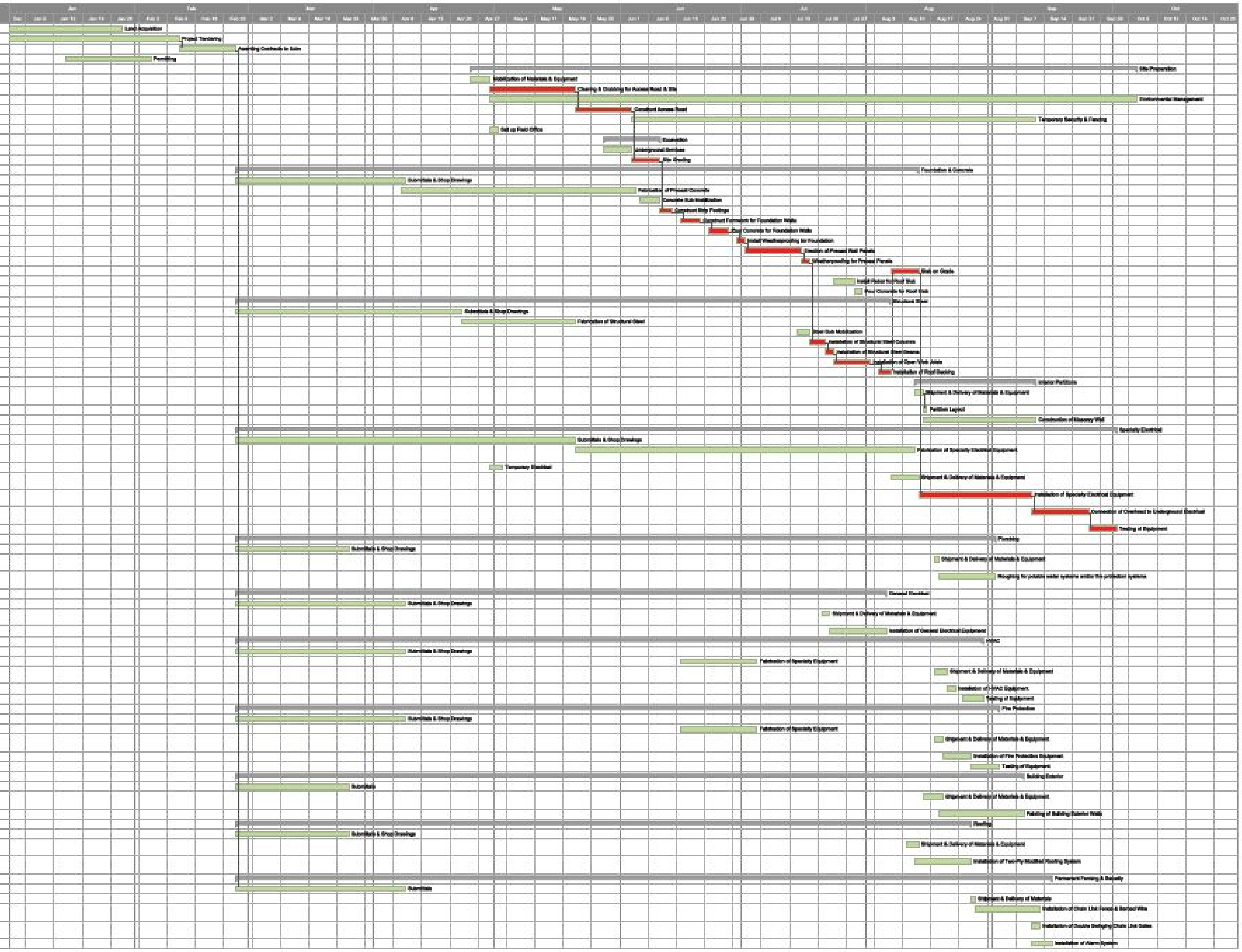
Overhead Transmission Line to Underground Cable Transition Compounds
Rev. D



Option: Precast Concrete

Project #[illegible]
Overhead Transmission Line to Underground Cable Transition Compounds
Date: [illegible]
Rev. D

	Task Name	Start Date	End Date	Duration
1	Land Acquisition	[illegible]	[illegible]	30
2	Project Tendering	[illegible]	[illegible]	30
3	Awarding Contracts to Subs	[illegible]	[illegible]	10
4	Permitting	[illegible]	[illegible]	15
5	Site Preparation	[illegible]	[illegible]	117
6	Mobilization of Materials & Equipment	[illegible]	[illegible]	3
7	Clearing & Grubbing for Access Road & Site	[illegible]	[illegible]	15
8	Environmental Management	[illegible]	[illegible]	114
9	Construct Access Road	[illegible]	[illegible]	10
10	Temporary Security & Fencing	[illegible]	[illegible]	72
11	Set up Field Office	[illegible]	[illegible]	3
12	Excavation	[illegible]	[illegible]	10
13	Underground Services	[illegible]	[illegible]	6
14	Site Grading	[illegible]	[illegible]	6
15	Foundation & Concrete	[illegible]	[illegible]	121
16	Submittals & Shop Drawings	[illegible]	[illegible]	30
17	Fabrication of Precast Concrete	[illegible]	[illegible]	42
18	Concrete Sub Mobilization	[illegible]	[illegible]	8
19	Construct Strip Footings	[illegible]	[illegible]	5
20	Construct Formwork for Foundation Walls	[illegible]	[illegible]	8
21	Pour Concrete for Foundation Walls	[illegible]	[illegible]	8
22	Install Weatherproofing for Foundation	[illegible]	[illegible]	2
23	Erection of Precast Wall Panels	[illegible]	[illegible]	10
24	Weatherproofing for Precast Panels	[illegible]	[illegible]	3
25	Slab on Grade	[illegible]	[illegible]	8
26	Install Rebar for Roof Slab	[illegible]	[illegible]	3
27	Pour Concrete for Roof Slab	[illegible]	[illegible]	2
28	Structural Steel	[illegible]	[illegible]	116
29	Submittals & Shop Drawings	[illegible]	[illegible]	40
30	Fabrication of Structural Steel	[illegible]	[illegible]	20
31	Steel Sub Mobilization	[illegible]	[illegible]	3
32	Installation of Structural Steel Columns	[illegible]	[illegible]	2
33	Installation of Structural Steel Beams	[illegible]	[illegible]	2
34	Installation of Open Web Joists	[illegible]	[illegible]	7
35	Installation of Roof Decking	[illegible]	[illegible]	2
36	Interior Partitions	[illegible]	[illegible]	22
37	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	2
38	Partition Layout	[illegible]	[illegible]	1
39	Construction of Masonry Wall	[illegible]	[illegible]	20
40	Specialty Electrical	[illegible]	[illegible]	[illegible]
41	Submittals & Shop Drawings	[illegible]	[illegible]	60
42	Fabrication of Specialty Electrical Equipment	[illegible]	[illegible]	60
43	Temporary Electrical	[illegible]	[illegible]	3
44	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	6
45	Installation of Specialty Electrical Equipment	[illegible]	[illegible]	20
46	Connection of Overhead to Underground Electrical	[illegible]	[illegible]	10
47	Testing of Equipment	[illegible]	[illegible]	6
48	Plumbing	[illegible]	[illegible]	[illegible]
49	Submittals & Shop Drawings	[illegible]	[illegible]	20
50	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	1
51	Roughing for potable water systems and/or fire protection systems	[illegible]	[illegible]	10
52	General Electrical	[illegible]	[illegible]	115
53	Submittals & Shop Drawings	[illegible]	[illegible]	50
54	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	2
55	Installation of General Electrical Equipment	[illegible]	[illegible]	10
56	HVAC	[illegible]	[illegible]	[illegible]
57	Submittals & Shop Drawings	[illegible]	[illegible]	50
58	Fabrication of Specialty Equipment	[illegible]	[illegible]	15
59	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	3
60	Installation of HVAC Equipment	[illegible]	[illegible]	2
61	Testing of Equipment	[illegible]	[illegible]	6
62	Fire Protection	[illegible]	[illegible]	156
63	Submittals & Shop Drawings	[illegible]	[illegible]	30
64	Fabrication of Specialty Equipment	[illegible]	[illegible]	15
65	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	2
66	Installation of Fire Protection Equipment	[illegible]	[illegible]	6
67	Testing of Equipment	[illegible]	[illegible]	5
68	Building Exterior	[illegible]	[illegible]	[illegible]
69	Submittals	[illegible]	[illegible]	30
70	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	3
71	Painting of Building Exterior Walls	[illegible]	[illegible]	15
72	Roofing	[illegible]	[illegible]	150
73	Submittals & Shop Drawings	[illegible]	[illegible]	30
74	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	3
75	Installation of Two-Ply Modified Roofing System	[illegible]	[illegible]	10
76	Permanent Fencing & Security	[illegible]	[illegible]	144
77	Submittals	[illegible]	[illegible]	50
78	Shipment & Delivery of Materials	[illegible]	[illegible]	1
79	Installation of Chain Link Fence & Barbed Wire	[illegible]	[illegible]	12
80	Installation of Double Swinging Chain Link Gates	[illegible]	[illegible]	2
81	Installation of Alarm System	[illegible]	[illegible]	6



Option: Structural Steel

Project #[illegible]
Overhead Transmission Line to Underground Cable Transition Compounds
Date: 2/1/2013
Rev. D

	Task Name	Start Date	End Date	Duration
1	Land Acquisition	[illegible]	[illegible]	20
2	Project Tendering	[illegible]	[illegible]	30
3	Awarding Contracts to Subs	[illegible]	[illegible]	10
4	Permitting	[illegible]	[illegible]	15
5	Site Preparation	[illegible]	[illegible]	107
6	Mobilization of Materials & Equipment	[illegible]	[illegible]	3
7	Clearing & Grubbing for Access Road & Site	[illegible]	[illegible]	15
8	Environmental Management	[illegible]	[illegible]	106
9	Construct Access Road	[illegible]	[illegible]	10
10	Temporary Security & Fencing	[illegible]	[illegible]	61
11	Set up Field Office	[illegible]	[illegible]	2
12	Excavation	[illegible]	[illegible]	10
13	Underground Services	[illegible]	[illegible]	5
14	Site Grading	[illegible]	[illegible]	5
15	Foundation & Concrete	[illegible]	[illegible]	111
16	Submittals & Shop Drawings	[illegible]	[illegible]	30
17	Concrete Sub Mobilization	[illegible]	[illegible]	3
18	Construct Strip Footings	[illegible]	[illegible]	3
19	Construct Formwork for Foundation Walls	[illegible]	[illegible]	5
20	Pour Concrete for Foundation Walls	[illegible]	[illegible]	1
21	Install Waterproofing for Foundation	[illegible]	[illegible]	2
22	Slab on Grade	[illegible]	[illegible]	5
23	Install Rebar for Roof Slab	[illegible]	[illegible]	3
24	Pour Concrete for Roof Slab	[illegible]	[illegible]	2
25	Structural Steel	[illegible]	[illegible]	106
26	Submittals & Shop Drawings	[illegible]	[illegible]	40
27	Fabrication of Structural Steel	[illegible]	[illegible]	20
28	Steel Sub Mobilization	[illegible]	[illegible]	3
29	Installation of Structural Steel Columns	[illegible]	[illegible]	10
30	Installation of Structural Steel Beams	[illegible]	[illegible]	2
31	Installation of Open Web Joists	[illegible]	[illegible]	7
32	Installation of Roof Decking	[illegible]	[illegible]	3
33	Interior Partitions	[illegible]	[illegible]	21
34	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	2
35	Partition Layout	[illegible]	[illegible]	1
36	Construction of Masonry Wall	[illegible]	[illegible]	20
37	Specialty Electrical	[illegible]	[illegible]	140
38	Submittals & Shop Drawings	[illegible]	[illegible]	60
39	Fabrication of Specialty Electrical Equipment	[illegible]	[illegible]	60
40	Temporary Electrical	[illegible]	[illegible]	3
41	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	5
42	Installation of Specialty Electrical Equipment	[illegible]	[illegible]	20
43	Connection of Overhead to Underground Electrical	[illegible]	[illegible]	10
44	Testing of Equipment	[illegible]	[illegible]	5
45	Plumbing	[illegible]	[illegible]	123
46	Submittals & Shop Drawings	[illegible]	[illegible]	20
47	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	2
48	Roughing for potable water systems and/or fire protection systems	[illegible]	[illegible]	10
49	General Electrical	[illegible]	[illegible]	120
50	Submittals & Shop Drawings	[illegible]	[illegible]	30
51	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	2
52	Installation of General Electrical Equipment	[illegible]	[illegible]	10
53	HVAC	[illegible]	[illegible]	122
54	Submittals & Shop Drawings	[illegible]	[illegible]	30
55	Fabrication of Specialty Equipment	[illegible]	[illegible]	15
56	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	3
57	Installation of HVAC Equipment	[illegible]	[illegible]	5
58	Testing of Equipment	[illegible]	[illegible]	5
59	Fire Protection	[illegible]	[illegible]	120
60	Submittals & Shop Drawings	[illegible]	[illegible]	30
61	Fabrication of Specialty Equipment	[illegible]	[illegible]	15
62	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	3
63	Installation of Fire Protection Equipment	[illegible]	[illegible]	5
64	Testing of Equipment	[illegible]	[illegible]	5
65	Building Exterior	[illegible]	[illegible]	115
66	Submittals	[illegible]	[illegible]	20
67	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	3
68	Installation of Exterior Wall Cladding	[illegible]	[illegible]	15
69	Roofing	[illegible]	[illegible]	155
70	Submittals & Shop Drawings	[illegible]	[illegible]	20
71	Shipment & Delivery of Materials & Equipment	[illegible]	[illegible]	3
72	Installation of Two-Ply Modified Roofing System	[illegible]	[illegible]	10
73	Permanent Fencing & Security	[illegible]	[illegible]	134
74	Submittals & Shop Drawings	[illegible]	[illegible]	30
75	Shipment & Delivery of Materials	[illegible]	[illegible]	2
76	Installation of Chain Link Fence & Barbed Wire	[illegible]	[illegible]	12
77	Installation of Double Swinging Chain Link Gates	[illegible]	[illegible]	3
78	Installation of Alarm System	[illegible]	[illegible]	5