UBC Botanical Gardens Revitalization Project

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University of British Columbia

CIVL 446

April 04, 2014

2014

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GROUP 18 – PROJECT 5
APRIL 4 2014

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Executive Summary

To enhance the visitor experience at the UBC Botanical Gardens BAMS Engineering proposes the construction of a weather-protected picnic structure. The structure will be approximately 5m by 6m and contain four picnic tables to seat 24 people comfortably. We propose that this amenity be constructed adjacent to the existing Garden Pavilion, near the Great Lawn. The location maximizes the benefit to both the Botanical Gardens and its visitors.

The picnic structure has six columns supported on concrete spread footings. The columns are made from glulam and the building has a green roof complete with skylights. The seating area is a non-structural concrete slab. Further to the Botanical Garden's mission, this amenity achieves numerous sustainability goals for the garden. Our engineering team hopes that this structure can help the Botanical Garden further its education goals as well.

BAMS Engineering has undertaken a site assessment, geotechnical investigation and structural analysis. Detailed footing, column member and column-base connection design drawings have been prepared. In addition a comprehensive construction management plan has been prepared including cost and schedule estimates.

The picnic structure can be built in less than one month, for an estimated total cost of less than $25,000. This structure is an easy to build, cost effective way for the UBC Botanical Garden to improve the overall visitor experience.

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1.0 Introduction

This project proposes a picnic shelter to provide a sustainable community amenity within the UBC Botanical Garden. The main challenge for this project was to keep the budget low and the benefit high. Concepts put forward in the original design proposal included picnic shelters, a wharf, pond redesign, improved walking paths, a playground and water storage cisterns. After much deliberation and multiple design options, the picnic shelter was determined to best meet the criteria. The shelter provides a great focal point for the gardens for a relatively low cost and can address three major engineering disciplines. The main discipline decided on was structural engineering with geotechnical engineering and construction management in supporting roles. The main goal of this project is to increase attendance and therefore revenues to the gardens, while prescribing to the garden's values and vision. The following sections will describe the design, location, benefits, construction management, geotechnical aspects and structural requirements.

2.0 Design, Location and Benefits

This section will introduce and explain the design and describe location justifications as well as discuss benefits of the project with respect to the client, the public and the environment.

2.1 Design Concept

The picnic structure design concept was based on the premise that an architecturally interesting structure would draw more attention than a plain structure. Bryce Gauthier reinforced this concept in a Civil 446 guest lecture. Mr. Gauthier explains how visitorship of architecturally interesting recreation centers has been seen too far exceed that of traditional, simple and inexpensive (usually cinder block) centers (Gauthier, 2014).

Figure 1: Rendering of Picnic Shelter In-Situ

The vision for the structure was a blend of post and beam construction and design queues from the Garden Pavilion. As the Garden Pavilion is directly adjacent to the picnic structure, it was important the design complement the existing structure. It was also important the structure blend in with the existing garden surroundings. The post and beam inspiration is seen in the columns and column connections where oversized glulam columns have been used. In the column base connections, intentionally exposed bolts are used with a steel knife plate that is also oversized and intentionally exposed. In the roof, joists support a central section of 6 skylight panels surrounded by a green roof section. The joist and skylight pattern concept was mimicked from the Garden Pavilion, as seen below in Figure 2, Figure 3 and Figure 4.


Figure 2: Joists and Skylights Seen in Existing Garden Pavilion

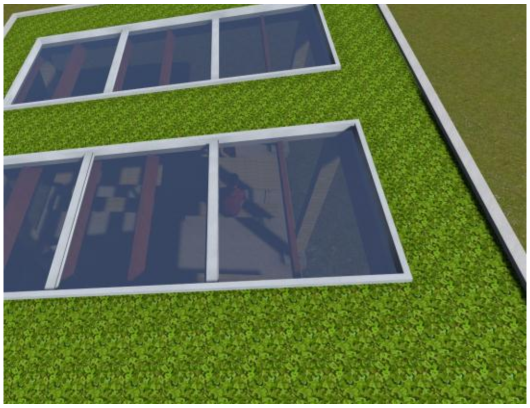
Figure 3: Green Roof with 6 Panel Skylight Inset


Figure 4: Oversized Joists Support Skylight Panel


Figure 5: Glulam Columns with 4 Bolt Knife Plate Connection

2.2 Development Site Selection

The location for the picnic structure was selected based on a second site visit on January 31st, a multi-criterion decision matrix (MCDM) as well as an impromptu interview with a group of UBC horticulture students. The location selected is the small grass field west of the Garden Pavilion, north of the existing swale and is shown below on Figure 6 and Figure 7.

Figure 6: Picnic Structure Location West of Garden Pavilion

Figure 7: Picnic Structure Location North of Existing Swale

The MCDM allowed for rating of each location on various criteria, as well as weighting of each criterion. The MCDM, with the actual criteria and locations evaluated, is shown below in Table 1: MCDM Used In Determining Ideal Development Location. The area referred to as "West of Garden Pavilion" was not originally identified as a development location, but was added to the MCDM during the site visit on the recommendation of a group of UBC horticulture students working in the garden. The selected site is central in the garden and equidistance to the main entrance and amphitheater. Neighbouring the Garden Pavilion, the existing washrooms can easily be accessed and caretaking services for the Garden Pavilion, such as waste and recycling removal, can easily be increased to service the new structure. The swale near the chosen location is currently a natural play site for children and a resting spot for families. Finally, the selected development location is not near any delicate garden collections.

Table 1: MCDM Used In Determining Ideal Development Location

		Location Ratings, 5 High 1 Low						
Criterion Importance	Criteria	Grassy Knoll	Near FOGS Fence	Near Carolinan Forest	Near Physic Garden	Great Lawn (south)	Access Road (Great Lawn north)	West of Garden Pavilion
3	Space Available	4	3	2	2	5	5	4
2	Distance from Entrance	2	1	2	4	3	2	4
2	Proximity to Existing "Anchors"	3	3	3	3	3	3	4
4	Existing Site Conditions	1	4	2	4	4	4	3
3	Proximity to Washrooms	1	1	2	3	3	2	5
2	Visability	3	2	3	3	5	4	4
5	Proximity to Delicate Collections	1	4	1	2	4	4	5
	Sum of the Products	40	60	41	61	82	75	88

INPUT
OUTPUT

2.3 Social, Client and Environmental Benefits

Benefits of this project to the client, UBCBG, can be divided into two categories: public/social benefits and private benefits. Public benefits are those that will impact garden visitors, and private benefits are those that will help UBCBG with internal workings. Environmental benefits are also discussed.

2.3.1 Social Benefits

The picnic shelter has been strategically located in an area that is already a natural resting spot for families. Enhancing and defining this natural resting location will be a welcoming gesture to visitor and provide a sense of community inclusion. The addition of a weather shelter, tables, benches, rubbish cans, recycling containers and informational signage will improve the visitor experience for visiting families as well as encourage more families (currently an under-represented visitor demographic) to visit the gardens. Path improvements local to the picnic shelter and the concrete floor of the structure itself will also aid to visitors with mobility difficulties.

2.3.2 Client Benefits

Internally to UBGBG, the picnic structure will provide a covered outdoor space with permanent tables, an amenity currently not available for programs in the gardens. Providing a covered, outdoor space available for educational and training programs will allow UBCBG to expand and improve on their goal of being a leader in horticulture training and education. The structure's location does not conflict with Apple Fest facilities, but is located close enough to the event to be used as an eating area rather than the rented tents which are currently provided. If UBCBG proceeds with the brick pizza oven planned for the Community Garden, the picnic shelter is located close enough to support this endeavour by providing a food preparation and eating area. This interaction between facilities will help both projects be successful anchors which will in turn drive patronage and interest in the gardens. Finally, the picnic shelter will be visible from Marine Drive and is essentially "self-advertising".

2.3.3 Environmental Benefits

With UBCBG's sustainability mandate in mind, the picnic structure has been designed featuring wood products. Wood products come from a renewable source and provide a major benefit to many British Columbian businesses and families. Furthermore, glulam has been used for the major structural system. Glulam wood products can be manufactured from smaller trees and from sections of wood not suitable (due to knots or other defects) for other applications. Lastly, the green roof and informational signage aims to education visitors about the importance of sustainable options and how being "green" doesn't have to have a negative impact on the way structures are designed and built.

3.0 Site Background

This site is located in north section of the UBC Botanical Gardens and is centered on the latitude and longitude of 49°15'12.06"N and 123°14'51.17"W respectively. The total area of the botanical gardens is approximately 44 hectares and the site is 250 feet above sea level. Our chosen development location is not currently being used for any active purposes. It is a grassy area with adjacent pathways to the north and east and rocky swale directly to the south. The surrounding land use includes a multipurpose building to the east, a roadway to the west and the surrounding, though not immediately adjacent, collections of the gardens.

UBC utilities include water distribution, natural gas distribution, steam distribution, storm drainage, sanitary sewers powers and power utilities. Investigation into this area revealed that a storm drainage system was located to the north of the site, however there is no evidence to suggest any of these systems are present on the current site. There is no drainage, heating, or lighting infrastructure in the surrounding area to provide evidence for underground utilities. Some local underground sprinklers may be present, but these systems are low risk and have low repair costs.

The UBC Botanical Gardens is located on Canada's most south-west climate region. As described by the Köppen−Geiger Climate Classification program, Vancouver is a warm temperate climate with fully humid precipitation and warm to hot summers. The gardens maritime climate has yearly average temperatures of over 10 degrees Celsius and accumulations of over 1000 mm of rain (Whiting & Lai, 2008).

4.0 Geotechnical Investigation and Foundation Design

The purpose of the geotechnical site investigation is to determine the predicted ground conditions and their design properties.

4.1 Surface and Subsurface Conditions

The area in consideration for this design is coved in grass and sawed. There are no major obstacles such a large rocks or trees. The surface layer is expected to be approximately 0.3 m in depth and can easily be removed with a shovel and wheelbarrow. Beneath the top soil, till-like conditions are expected for the rest of the excavation depth (Piteau Associates Engineering Ltd., 2012). The till material consists of a grey sand, fine to medium grained, with some silt and some gravel. The development area has not seen any major development in the past, it is expected that no engineer fill is deposited. The groundwater level is expected to be about 40 meters deep and subsequently does not need to be considered in design. The prediction of ground water depth is based on the findings of three surrounding geotechnical site investigations (Piteau Associates Engineering Ltd., GeoPacific Consultants Ltd. and GeoPacific Consultants Ltd.). Both the ground water table and soil stratification can be seen in Figure 10: Geotechnical Cross section B-B' . This location was the closest proximity to the site and therefore most relevant.

Figure 8: Location of Cross Section B-B'

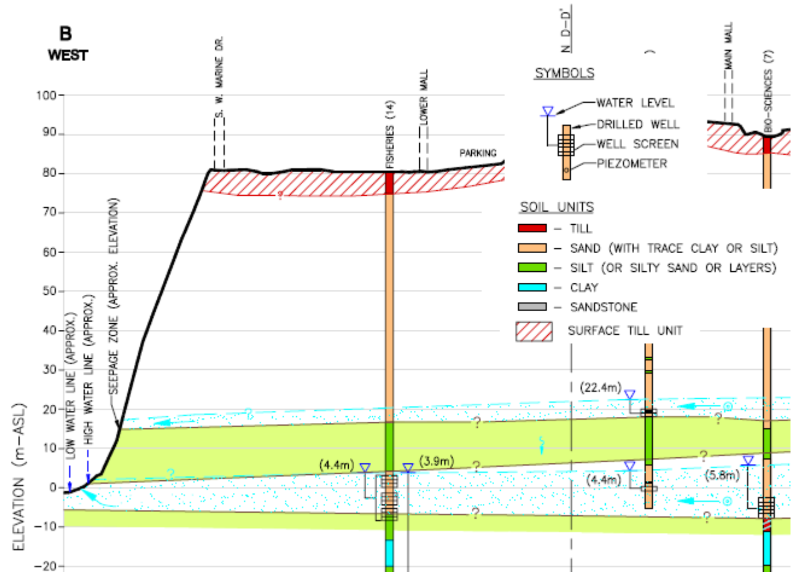

Figure 10: Geotechnical Cross section B-B' **(Piteau Associates Engineering Ltd., 2012)**

4.2 Foundation Design Considerations

4.2.1 General Comments

In order to meet self-drainage requirements, the soil surface will need to be sloped 1:50. Since this area is assumed to be native till, the compaction requirements for construction should be sufficient and not require any further work (Klohn, 1965). As for seismic considerations, this till material is very low risk for any type of liquefaction or major settling.

4.2.2 Location of development

The picnic shelter will be located at the northwest side of Garden Pavilion. Further rationale for selecting this location is given in section 2.2 Development Site Selection. However from a geotechnical viewpoint, this site has been selected for its surface flatness with the aim of reducing the amount of foundation work required. Figure 9 shows the overview of the selected area for development. Elevation profiles used are shown in Figure 10 and

Figure **11** where the footprint of the shelter is shown.

Figure 9 Overview of Selected Shelter Location

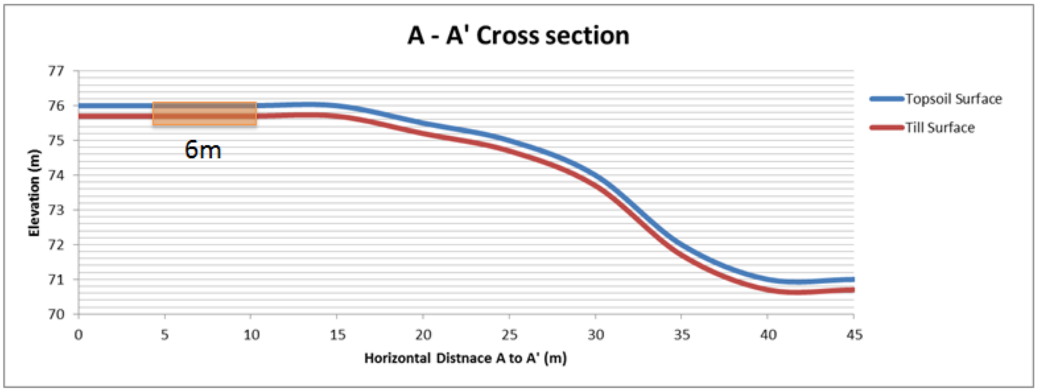

Figure 10: Elevation Profile for A-A' Cross Section

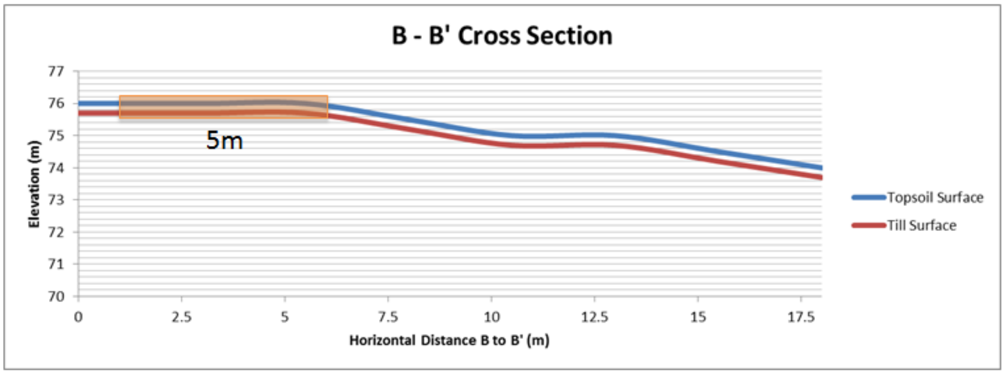

Figure 11: Elevation Profile for B-B' Cross Section

4.2.3 Footing Recommendations

Conventional square footings are recommended to be used to support each column. The design is required to satisfy the ultimate limit states and serviceability limit states. The ultimate limit state requirement is defined by the maximum column loading case of 32.6kN, which resulted from the structural analysis of the picnic shelter (see section 5.1 Design Loads). The footings need to have an allowable bearing capacity greater than the maximum loading. The serviceability limit state requirements are defined by the maximum settlement of 25mm for individual footings and the maximum differential settlement of 1/250 for the structure. (Budhu, 2011)

The ground water table is expected to be well below design foundation levels so any ground water effects are negligible for design considerations. Frost penetration at site is assumed to not exceed 150 mm and footings must be placed below the frost penetration limit.

Based on the evaluation of expected soil condition, ground surface flatness, and structural loading, a retaining wall to stabilize slope surface is not required at this site.

4.2.4 Excavation and Backfill Requirements

The topsoil material is assumed to be 300 mm deep from the surface and this layer is expected to be fully excavated. In the unexpected case where the topsoil deposit exceeds the expected depth, excavation is required until suitable bearing soil is reached. The site will be backfilled with fill to 75.5 m ground elevation once foundations are installed. A clean sand to sand and gravel backfill is to be compacted in 300 mm loose lifts to a minimum standard of 98% of its Standard Proctor. Moisture content should be within 2% of its optimum for compaction. (GeoPacific Consultants Ltd., 2013) Non-structural slab on grade will finish the backfilled surface.

4.3 Detailed Foundation Design

The detailed design of the footings system is presented in this section. Calculation methods and results are presented along with assumptions and justifications. The final foundation system is shown Figure 12 and complete drawings are found in Appendix A: Foundation System Figures.

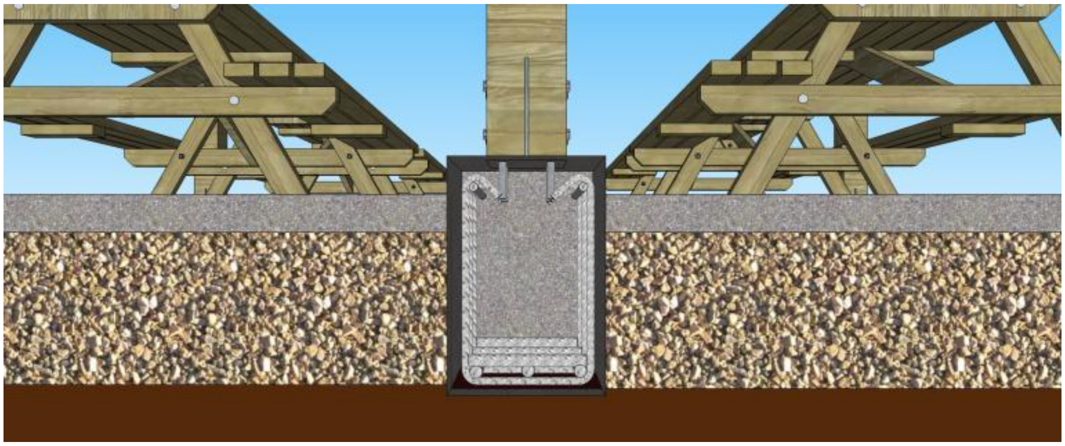

Figure 12: Foundation System

4.3.1 Soil Parameters

The picnic shelter foundations are to be built on the dense glacial till after excavation of the organic layer. Technical references are reviewed and soil input parameters are extracted from Klohn's paper on Canadian dense glacial till. Input values are summarized in Table 2. (Klohn, 1965) Peak friction angle and elastic modulus are adjusted consistent with recommendations made by Budhu to ensure conservative design. (Budhu, 2011) The adjusted values are summarized in Table 2.

Table 2: Soil Input Parameters

	Klohn	Adjusted
Peak friction angle (°)	39	35
Dry unit weight (kN/m^3)	23.2	23.2
Elastic modulus (MPa)	145	80
Poisson's ratio	0.3	0.3

4.3.2 Foundation Size Analysis

Footing settlements on the dense glacial till deposit are expected to be minimal because of the competency in the compact soil and the low loading conditions. The sizing of the foundation is assumed to be governed by bearing capacity limits. An iterative approach is used for the footing size selection by estimating allowable bearing capacity for various test footing dimensions. The effective stress analysis (ESA) method is applied to determine ultimate bearing capacity of each test footing size. The allowable stress design (ASD) method with a factor safety of 3 is then applied to determine the allowable bearing capacity for the test footing size. The analysis determines that a square footing of 400 mm by 400 mm is best suited to carry the maximum column load. The foundation settlements are then estimated with Gazeta's method and checked to determine if serviceability state limits have been met. Summary of analysis results are provided in Table 2: Geotechnical Analysis Outputs. Calculation details are provided in Appendix B: Foundation Design Calculations.

Table 2: Geotechnical Analysis Outputs

Maximum Column Load (kN)	32.6
Qult (kN)	119.3
Qa (kN)	40.7
Settlement (mm)	1.12

4.3.3 Foundation Depth Considerations

The footings have a total depth of 600 mm. The footings depth has been chosen to be 400 mm below grade to satisfy frost penetration considerations and to ensure footing to be built on the dense glacial deposit. The footings extend 200 mm above grade to provide wooden columns protection at base and to add aesthetic values.

4.3.4 Reinforcement Design

Reinforcing steel in the footings is designed following the CSA A23.1 standards. The shear and flexural effects are expected to be minimal based on the footing shape. Reinforcement design is assumed to be governed by the minimal steel requirements. The design considers a compressive concrete strength of 25 MPa and reinforcing steel yield strength of 400 MPa. Stirrups details and steel spacing are also considered to meet the standards. The designed details are presented in Figure 13. Detailed calculations can be found in Appendix B: Foundation Design Calculations.

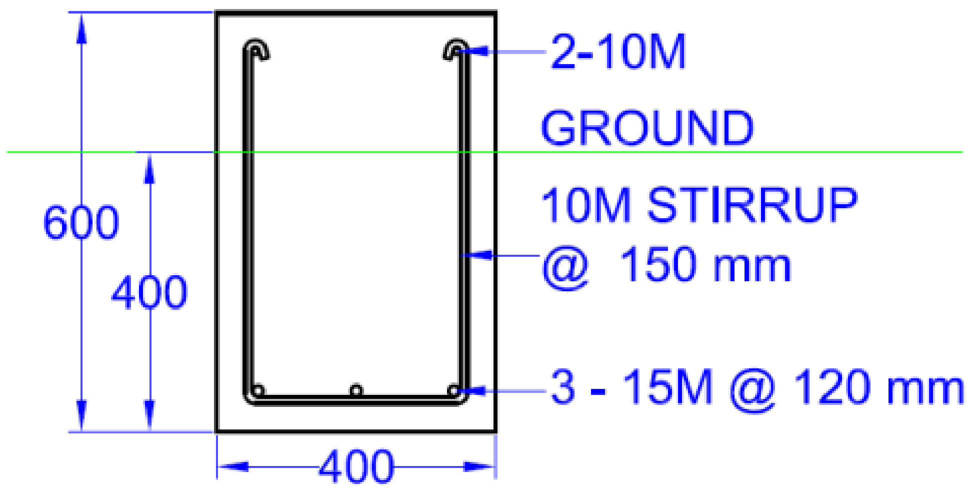

Figure 13: Reinforcement Design for Square Footing

5.0 Structural Analysis and Design

A structural analysis of the structure has been completed with NBCC design loads and the structural analysis software "RISA 2D". With this information, columns and column-foundation connections have been designed based on the Canadian Wood Council's Wood Design Manual (2010).

5.1 Design Loads

Dead, live, snow and wind load were considered for the design of the structural system. Load data for the snow and wind loads have been taken from the UBC Building Operations Technical Guidelines on Building, Structural & Snow Load Design (UBC Building Operations, 2014). The National Building Code of Canada (2010) was consulted for determining load cases and when calculating the snow load. The total dead load of the structure was determined via a material take-off from the as-designed structure.

The governing load case has been found to be: $1.25\text{D} + 1.5\text{S} * I_s + 0.4\text{W} * I_w$. Calculations can be found in Appendix D: Load Combination Calculations.

5.2 Structural Model

The structure has been modeled in RISA 2D. Interior columns and exterior columns have been assigned 3/14 and 2/14 the total roof loads, respectively. Column base connections were modeled as fully moment resisting. The interior column section has been used to determine the worst-case forces and the model of this case can be found in Appendix C: Structural Analysis.

5.3 Column Design

The column members are to be 175x190 Spruce-Pine 20f-ex. For aesthetics and ease of construction, all columns will be of the same type and size. A summary of calculated resistance vs. highest demand (as determined in the RISA model) is shown below in Table 3. Detailed calculations of member resistance, done in accordance with the Canadian Wood Council's Wood Design Manual (2010), can be found in Appendix E: Member Design Calculations. The columns are subject to both axial load and moment, thus combined loading has been checked. Utilization for the highest demand column is compared to the calculated resistance. Shear and axial utilizations are low, however the member selected was chosen based on architectural look, not structural efficiency in accordance with the design goals.

Table 3: Column Resistance and Demand Values

	Resistance	Max Demand	Utilization
Shear (kN)	33.5	8.9	27%
Axial (kN)	279.8	32.6	12%
Moment (kN-m)	21.6	17.7	82%
Combined Loading	OK	n/a	n/a

5.4 Column-Foundation Connection

The column-foundation connection designed is a fully moment resisting, 4-bolt knife plate connection. The knife plate is ½" steel and is assumed to not be limiting. Again, all six columns are to have the same connection detail. Detailed connection drawings can be found in Appendix F: Connection Details. Connection resistance calculations can be found in Appendix G: Connection Calculations and have been carried out in accordance with the Wood Design Manual. Calculations for transforming the applied moment (found in the RISA model) to an equivalent shear and axial force (and thus the force demands) can be found in Appendix H: Connection Force Transformation Calculations. A summary of connection demand, as determined via these calculations, versus connection resistance is shown below in Table 4. As this connection is not subject to tension loads, the likely failure mechanism is splitting perpendicular to the grain, or potentially yielding of fasteners. Thus, these two mechanisms have been reviewed. Utilization for this connection is low as the design has been governed by aesthetics and has not been calculated.

Table 4: Connection Resistance and Demand Values

Failure Mechanism	Demand (kN, maximum)	Resistance (kN, minimum)
Splitting	2.3	24.9
Fastener Yielding	8.2	60.0

6.0 Construction Management

6.1 Construction Risks and Worker Safety

Even though this project is small in scope and will not occupy many workers for a particularly long time, worker safety while on the site is still of paramount importance. Every project must have a well thought out risk management framework and emergency management plan. Workers must know the protocols that are to be implemented in an emergency situation, as well as the location of the nearest emergency response crews. Figure 14 below outlines the locations of the closest hospital, fire hall, and police station. In the event of an emergency all workers must know the specific site address to correctly instruct dispatchers to the scene of the accident.

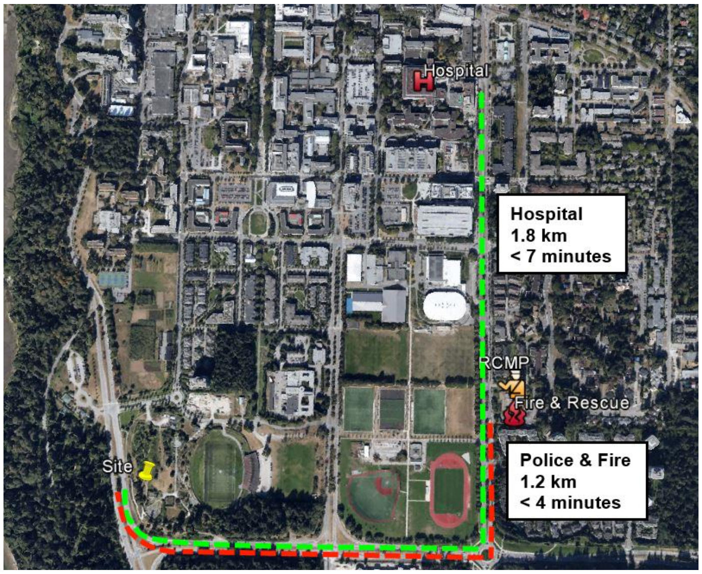

Figure 14: Location and Routes to the Closest Hospital with Emergency Service, Fire Hall and RCMP Detachment

Table 5 below outlines the top six hazards that might be encountered by workers on the UBCBG picnic structure construction site. Risks should be assessed by both likelihood of occurrence, and severity of consequence when determining if a mitigation strategy is required. Once a project superintendent/project manager is selected it is recommended that he or she go through the risk assessment planning process again.

Table 5: Summary of Construction Hazards Most Likely to Apply During the Construction of the UBCBG Picnic Structure

HAZARD	SEVERITY	LIKELIHOOD	MITIGATION STRATEGY
Fall from Height	Medium	Medium	Provide fall protection and appropriate training for workers, if no tie off points exist rent scissor lift for elevated work
Crushing Hazard	Medium	Low	N/A
Chemical Burn (from wet concrete)	Low	Low	N/A
Injury from Hand/Power Tools	Medium	Medium	Ensure proper training with tools before use, ensure adequate supervision during construction, no workers to work alone on site
Injury by Heavy Equipment	High	Low	Ensure Personal Protective Equipment is worn at all times, ensure workers are properly trained to work around heavy equipment
Musculoskeletal Injury	Medium	Low	N/A

Appropriate documentation should be prepared and on site prior to the undertaking of this work to ensure that all steps are taken to protect workers on the site. With such a small job there are no excuses for any lost-time injuries that occur.

6.2 Site Plan

The location chosen for the construction of the picnic structure is very good for the structure's intended use. It is not ideal for construction access, but it can be made to work. The most important consideration is delivery of construction materials. There is easily accessible worker parking, and material storage area (shown in dark blue in **Figure 15**) in the current work yard. This is acceptable for delivery of materials, but moving materials from here to the actual build location may be slightly more challenging. There are two routes shown in **Figure 15**, both of which are wide enough to accommodate a small bobcat, a pickup truck, or a small Zoom-Boom telehandler.

Route 1 and route 2 as proposed are 165m and 183m respectively. Both routes go through the garden and pose a risk to the collection, though Route 2 would likely affect less significant and easier to repair areas of the garden, namely the Great Lawn. This route must cross the pond drainage swale though, which could be a problem when transporting materials. Using a power buggy concrete could be moved to the job site via either route (The Aberdeen Group, 1960). Also, concrete could be pumped horizontally from SW Marine Drive (the location shown in green in **Figure 15**) as the distance is only approximately 42m, which is within the range of a number of large mobile concrete pumps (Camridge/Granite Concrete Pumping, 2009)

Figure 15: Potential Layout of the Construction Site for the UBCBG Picnic Structure

6.3 Schedule

To determine the project duration and schedule the project was first broken down into a set of construction tasks. Examples of tasks are: form and pour non-structural slab-on-grade, install bituminous roofing membrane, or installation of timber framing connection plates. Specific quantities per task were calculated from the model (the quantity calculation can be found in the Appendix). Using RS Means productivity data the approximate task time for each component of the project was determined, and a schedule was prepared in MS Project. The schedule can be found in Appendix I: Cost Analysis and Construction Schedule, labelled as Figure 19.

With a crew of 2 full time workers and one part time worker when necessary, the whole project will be completed in approximately 3.5 weeks. The site work and footings will take about 7 days (including curing time), the framing will take around 2.5 days, and the installation and planting of the green roof and skylights will take about 5 days.

7.0 Cost Evaluation

Using the same basic methodology as used to determine the schedule, unit cost data was applied to the project-specific quantities to develop a basic cost estimate for the picnic structure. Some efficiency and cost values were adjusted based on issues particular to this project (crew size, location, etc.). Figure 17 and Figure 18 in Appendix I: Cost Analysis and Construction Schedule show the basic cost estimates for the project with and without overhead and profit. If UBC is able to employ its own workers for this project there is a potential for a 22% saving compared to employing a non-UBC crew.

Total construction cost for the picnic structure is estimated to be $19,500 when overhead and profit are excluded, and $25,000 when overhead and profit are included.

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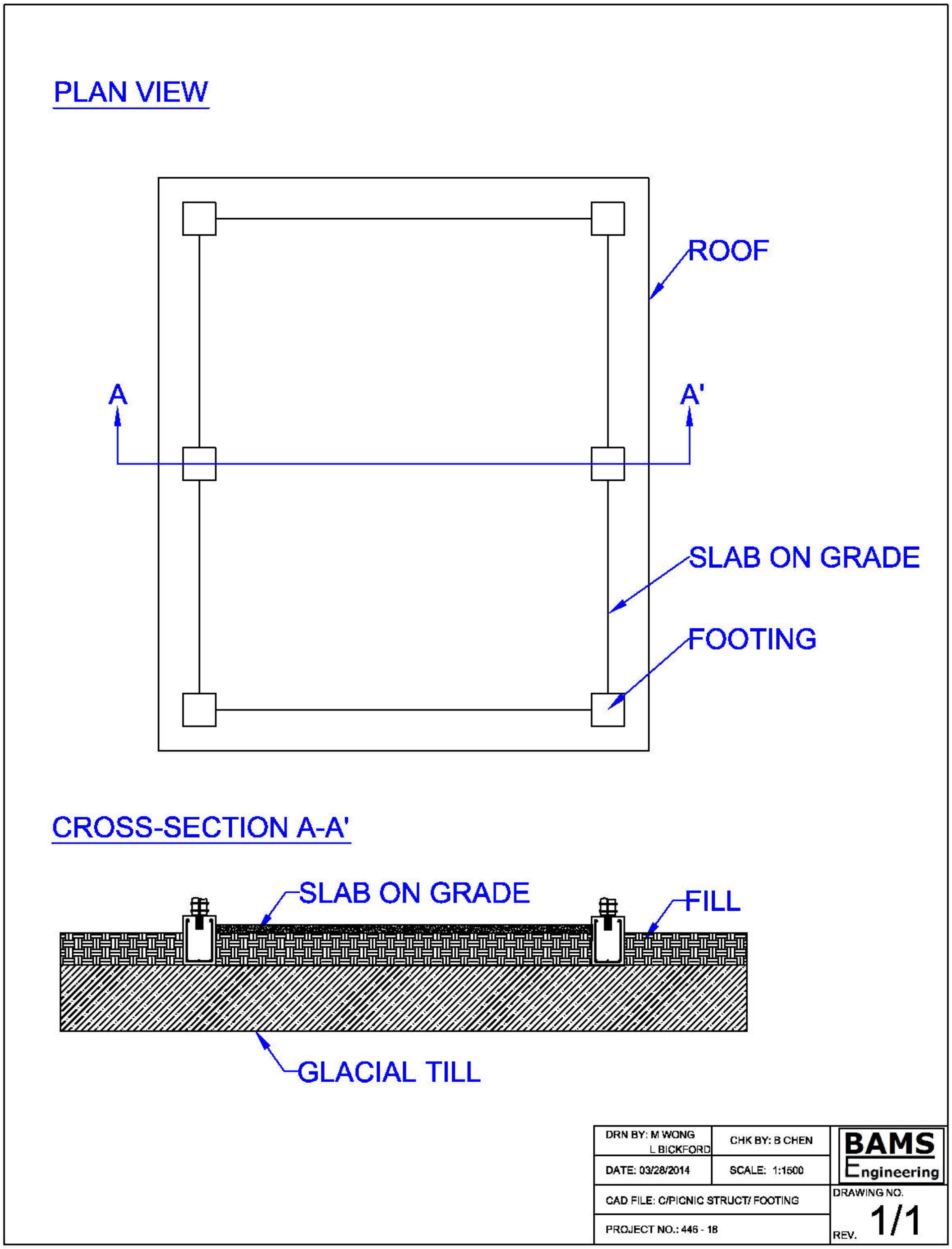
Appendix A: Foundation System Figures



Appendix B: Foundation Design Calculations

Foundation Sizing - Bearing Capacity Calculations

Inputs
Outputs

Material Layer		Start Depth (m)	End Depth (m)	Soil Type
	1	0	0.3	top soil
	2	0.3	10+	Glacial Till

Footing Parameters

Footing Width	B	0.4	m
Footing Length	L	0.4	m
Peak Friction angle	ϕ'p	35	deg
Footing Depth	Df	0.4	m

Assumptions

Not water table effects
Depth of footing must exceed topsoil depth and frost penetration depth
No lateral loads
No eccentric loading

- VERTICAL CENTRIC LOADS

TSA:

$$q_u = 5.14 s_u s_c d_c r_c$$

ESA:

$$q_u = \gamma D_f (N_q - 1) s_q d_q r_q w_q + 0.5\gamma B' N_\gamma s_\gamma d_\gamma r_\gamma w_\gamma$$

Bearing Capacity = ESA Method:

qu	736.28	
γ	23.00	kN/m2
Df	0.40	m
Nq	33.30	
sq	1.70	
dq	1.25	
rq	1.00	
wq	1.00	
B'	0.40	m
Nγ	37.13	
sγ	0.60	
dγ	1.00	
rγ	1.00	
wγ	1.00	
φ'p	35.00	deg
L	0.40	m
Ir	20.97	
Dr	100.00	%

Allowable Bearing Capacity = ASD Method:		
qult	745.48	kN/m2
qa	254.63	kN/m2
Qa	40.74	kN

Foundation Settlement Calculation

Inputs	(blue)
Outputs	(orange)

Notes:

- Design to minimize settlement and satisfy total settlements of 25mm
- Design maximum distortion due to differential settlement between columns is 1/5250 (0.004)
- Design must be safe against shear failure
- Design foundations for maximum loading cases

Inputs

Column Loading

Shelter Max	32.6	kN
Shelter Min	24.45	kN
Footing Dead	2.6	kN
Total load max	35.2	kN
Total load min	27.1	kN

Shelter Dimensions

W	5	m
L	6	m

Column Spacing

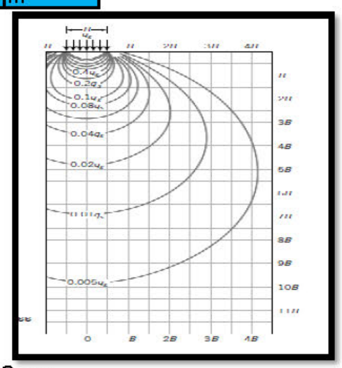
	5	m

Footing dimensions

B	0.4	m
L	0.4	m
h	0.7	m
density	2400	kg/m3
Df	0.4	m

Dense-Very Dense Glacial Till Properties

dry unit weight	23	kN/m3
peak friction angle	35	degrees
E'	80	Mpa
v'	0.3	



Foundation Size

B 0.4 m

Elastic Settlements Calculation: **Gazetas et al. (1985) Method**

Equation (12.35): $$\rho_e = \frac{P(1-\nu_u^2)}{E_u L}\mu_s \mu'_{emb}$$

$$I_s = 0.62 \ln(L/B) + 1.12$$

$$\mu_s = 0.45\left(\frac{A_b}{4L^2}\right)^{-0.38}$$

$$\mu_{emb} = 1 - 0.04\frac{D_f}{B}\left[1 + \frac{4}{3}\left(\frac{A_b}{4L^2}\right)\right]$$

$$\mu_{wall} = 1 - 0.16\left(\frac{A_w}{A_b}\right)^{0.54}$$

Maximum Loading Case			Minimum Loading Case		
µwall	1		µwall	1	
µemb	1		µemb	1	
Is	1.12		Is	1.12	
Pe	1.12	mm	Pe	0.86	mm

Total Settlements from maximum loading

1.12 mm < 25mm **ok**

Total Settlemtns from minimum loading

0.86 mm < 25mm ok

Check for differential Settlement Requirements

Differential settlement: 0.2595775 mm

Distance between columns: 5 m

Differential settlement between columns

0.0000519 < 0.004

(1/250)

Differential settlement is less than service requirements, design is safe!

Foundation reinforcing steel design

Inputs	
Outputs	

Footing Dimensions

B	0.4	m
L	0.4	m
h	0.6	m
applied load	32.6	kN

Material Properties

f'c	25	Mpa
fy	400	Mpa

Shear and flexural requirements are to be minimal and can be neglected (dimension size)
Design of reinforcment required for minimum rebar reinforcement

cover	30	mm
stirrups	10	mm
db	16	
d	344	mm

Design required steel reinforcment = As minimum

Asmin = 0.002 Ag

Ag	240000	mm2
Asmin	480	mm2/m

Spacing Check

B	400 mm		
bars	16 mm		
side cover	30 mm	Table A.2	
spacing	136 mm	Smax < 500mm (ok)	

select:	**3-15M bars @ 120 mm spacing**
As	600 mm2/m

check flexural requirements

pb	0.022
p	0.00436
p<pb	**ok!**

$$\rho \le \rho_b$$

where

$$\rho = \frac{A_s}{bd}$$

Table A.4 Balanced reinforcement ratio (for grade 400 steel)

f_c'	25 MPa	30 MPa	35 MPa	40 MPa
ρ_b	0.022	0.027	0.030	0.034

Stirrups

stirrup size	10M
hooks	135 degrees

Stirrups: 10M @ 150mm

Add 2-10M @ 250mm at top for stirrup

Key Tables from CSA A23.1

Table A.1 Properties of deformed reinforcing bars

Nominal bar size	Nominal dimensions: Diameter (mm)	Area (mm^2)	Perimeter (mm)	Mass per unit length (kg/m)
10M	11	100	36	0.8
15M	16	200	50	1.6
20M	20	300	61	2.4
25M	25	500	79	4.0
30M	30	700	94	5.5
35M	36	1000	112	8.0
45M	44	1500	137	12.0
55M	56	2500	177	20.0

Table A.2 Concrete cover requirements

Table A.2 Concrete cover requirements

	Exposure class		
Exposure condition (see Table 2.1)	N	F-1, F-2, S-1, S-2	C-XL, C-1, C-3, A-1, A-2, A-3
• Cast against and permanently exposed to earth	—	75 mm	75 mm
• Beams, girders, columns, and piles	30 mm	40 mm	60 mm
• Slabs, walls, joists, shells, and folded plates	20 mm	40 mm	60 mm
• Ratio of cover to nominal bar diameter	1	1.5	2
• Ratio of cover to nominal maximum aggregate size	1	1.5	2

(*Source:* CSA A23.1-04 Table 17, reproduced with permission by the Canadian Standards Association)

Table A.3 Thickness below which deflections must be computed for nonprestressed beams or one-way slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections

Appendix C: Structural Analysis

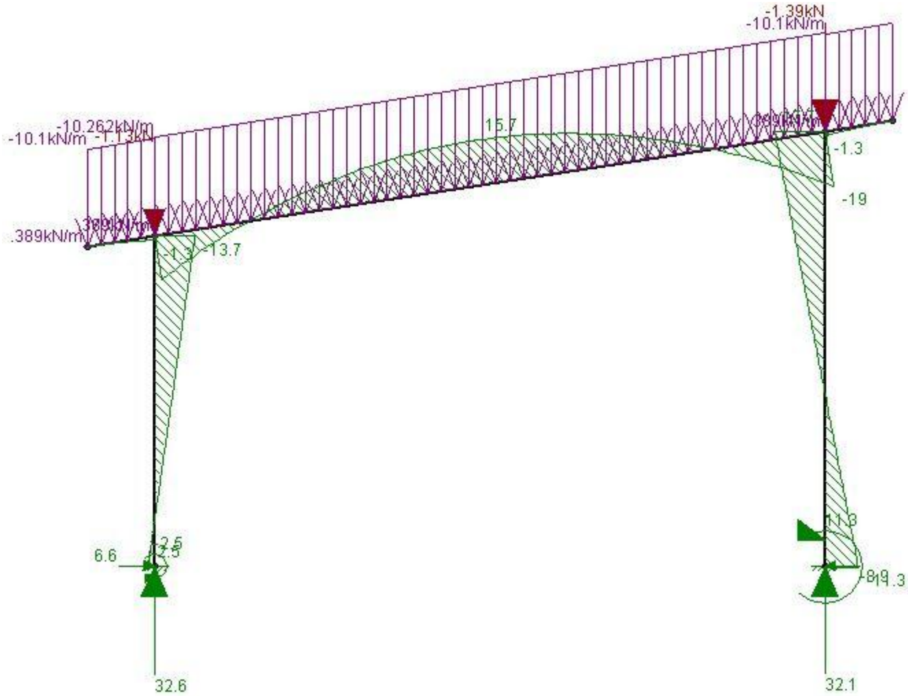


Figure 16: Bending Moment and Shear Diagram

Table 6: Reactions in Columns and Base Reactions in the Connection

		Short Column	Long Column	Base Connection
Max Moment	(kNm)	13.7	17.7	11.3
Max Shear	(kN)	6.6	8.9	8.9
Max Axial	(kN)	32.6	32.1	32.6

Appendix D: Load Combination Calculations

	TEAM	18
CIVL 446	DATE	03/18/2013
Load Calculations for Model	TIME	6:51 PM

DESCRIPTION

Rise	4-2.5	0.78	
Run	5	5.00	
Slope		0.16	
Angle	ARCTAN(1.5/5)	0.15	RAD
Legnth of Girder		7.00	m
Length of Beam	6/cos(angled)	5.06	m
Area		35.42	m2
Exterior Tributary Area	(1.5+0.5)/7 x 3/6	0.14	
Interior Tributary Area	(1.5+1.5)/7 x 3/6	0.21	

Notation

(yellow)	For Total Load Calculation
(blue)	For Model Calculation

Snow

1-in-50 Snow Load		Ss	1.9	kPa	UBC
1-in-50 Rain Load		Sr	0.3	kPa	UBC
Basic Roof Snow Load		Cb	0.8		4.1.6.2.2
Wind Exposure Factor		Cw	0.75		4.1.6.2.4
Slope Factor		Cs	1		4.1.6.2.6
Shape Factor		Ca	1		4.1.6.2.8
Snow Load	Ss*(Cb*Cw*Cs*Ca)+Sr	S	1.44	kPa	4.1.6.2
Total Snow Force	S * Area		51.0	kN	
Exterior	63.24 x 0.14/(7/cos(17)/2)		1.44	kN/m	
Interior	63.24 x 9/42/ (7/cos(17)/2)		2.16	kN/m	

Wind

1-50 Wind Load	0.48

Building Dead Load

Roofing				
Sheathing	PLY or OSB	1-3.6	lb/ft2	(Boise Cascade Company, 2014)
Roofing		1.0-3.0	lb/ft2	(Boise Cascade Company, 2014)
Total(lb/ft2)		2-6.5	lb/ft2	(Boise Cascade Company, 2014)
Total (kg/m2)		9.75 - 31.7	kg/m2	
Total (kPa)		0.31	kPa	
Green Roof		1.50	kPa	Optigreen
Distributed Load on Roof		1.81	kPa	
Total Roof Load	7/cos(17) m x 6m	64.15	kN	
Roof on Exterior Beams	13.658 kN x 0.14 / (7/cos(17))	1.81	kN/m	
Roof on Interior Beams	13.658 kN x 9/42 / (7/cos(17))	2.72	kN/m	
Roof - Glulam Beams				
Material	Glulam Weight	550.00	kg/m^3	
Length of Beam	5/cos(angled)	5.06	m	
Height of Beam		0.30	m	
Width of Beam		0.08	m	
Weight of Single Beam	Material Weight x Volume	66.80	kg	
Load of Single Beam	3300 kg *9.81 /1000	0.66	kN	
Number of Beams		3.00		
Total Load from Beams		1.97	kN	
Roof - Glulam Joist				
Material	Glulam Weight	550.00	kg/m^3	Canadian Wood Council
Length of Joist	=6-3*0.2m	2.70	m	
Height of Joist		0.24	m	
Width of Joist		0.10	m	
Weight of Single Joist	Material Weight x Volume	35.64	kg	
Load of Single Joist		0.35	kN	
Number of Beams		4.00		
Total Load from Beams		1.40	kN	

Columns - Short Column				
Material	Glulam Weight	550.00	kg/m^3	Canadian Wood Council
Height of Short Column		2.57	m	
Cross section height		0.18	m	
Cross section width		0.19	m	
Weight of Single Short Column	Material Weight x Volume	47.00	kg	
Load of Single Short Column		0.46	kN	
Number of Short Columns		3.00		
Total Load from Short Columns		1.38	kN	
Columns - Tall Column				
Material	Glulam Weight	550.00	kg/m^3	Canadian Wood Council
Height of Tall Column		3.35	m	
Cross section height		0.18	m	
Cross section width		0.19	m	
Weight of Single Tall Column	Material Weight x Volume	61.26	kg	
Load of Single Tall Column		0.60	kN	
Number of Tall Columns		3.00		
Total Load from Tall Columns		1.80	kN	

Total Load

Total Roof Load		64.15	kN
Total Load from Beams		1.97	kN
Total Load from Joist		1.40	kN
Total Load from Short Columns		1.38	kN
Total Load from Tall Columns		1.80	kN
	Total Dead Load	70.70	kN

Calculations for Model — Interior Section

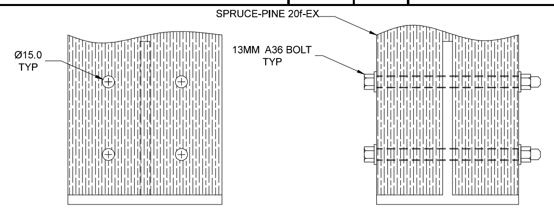
Dead Load				
Factor		1.25		NBCC 2010 Table 4.1.3.2 A
Roof				
Tributary Area of Strip	(2 x 3m/2)/ 7 m	0.43		
Total Roof Load		64.15		
Roof Load on Strip		27.49		
Length of Strip		6.00		
Distributed Load on Beam - Roof		4.58	kN/m	
Factored		5.73	kN/m	
Beam				
Load of Single Beam		0.66	kN	
Length of Beam		5.06	m	
Distributed Load of Beam		0.13	kN/m	
Factored		0.16	kN/m	
Joist				
Load of Single Joist		0.35	kN	
Tributary Area		0.50		
Point Load on Column From Joist	2x0.34963 kN/2	0.35	kN	
Factored		0.44	kN	
Columns				
Short Column		0.55	kN	
Factored		0.69	kN	
Tall Column		0.76	kN	
Factored		0.95	kN	

Snow Load					
Factor			1.50		NBCC 2010 Table 4.1.3.2 A
Importance			0.80		
Factor x Importance			1.20		
Snow Load	S	=	1.44	kPa	
Toal Snow Load			51.01		
Tributary Area of Strip	(2 x 3m/2)/ 7 m		0.43		
Snow Load on Strip			21.86		
Length of Strip			6.00		
Distributed Load on Beam - Roof			3.64	kN/m	
Factored			4.37	kN/m	
Wind Load					
Factor			0.40		NBCC 2010 Table 4.1.3.2 A
Importance			0.80		
Factor x Importance			0.32		
Wind Load	W		0.48	kPa	
Toal Wind Load			17.00		
Tributary Area of Strip	(2 x 3m/2)/ 7 m		0.43		
Wind Load on Strip			7.29		
Length of Strip			6.00		
Distributed Load on Beam - Roof			1.21	kN/m	
Factored			0.39	kN/m	

Appendix E: Member Design Calculations

		TITLE	Timber Connection		DATE	2014-03-31	
		FILE	Civil 446- Wood Design		TIME	5:24 PM	

Title Member Resistance Calculations



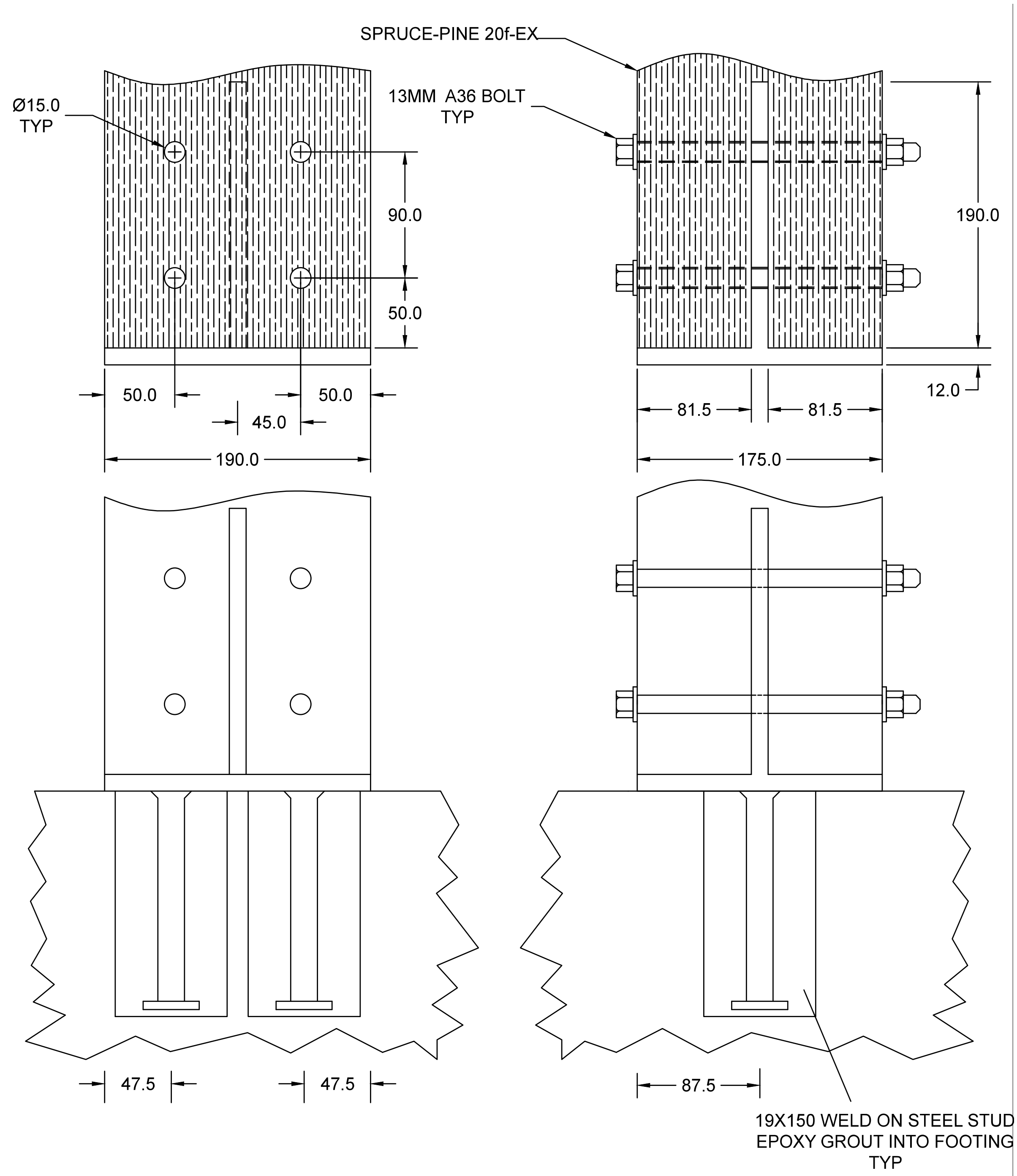
INPUTS

							WDM REFERENCE
phi	phi	=	0.8	=	0.8		6.5.7.2
Modulus of Elasticity	E	=	12700	=	12700	Mpa	Table 6.3
Length, Short	Ls	=	2.5*1000	=	2500	mm	
Length, Long	Ll	=	3.3*1000	=	3300	mm	
Width	b	=	175	=	175	mm	
Depth	d	=	190	=	190	mm	
Gross Area	Ag	=	b*d	=	33250	mm^2	
Section Modulus	S	=	b*d^2/6	=	1052916.667	mm^3	
Moment of Inertia	I	=	b*d^3/12	=	100027083.3	mm^4	
Specified Strength, Shear	fv	=	2	=	2	Mpa	Table 6.3
Notch Factor	Kn	=	1	=	1		6.5.7.2.2
Safety Factor, Duration	Kd	=	1	=	1		6.4.1
Safety Factor, System	Kh	=	1	=	1		6.4.3
Safety Factor, Service in Shear	Ksv	=	1	=	1.0		Table 6.4.2
Safety Factor, Treatment	Kt	=	1	=	1		6.4.4
Specified Strength, Compression	fc	=	30.2	=	30.2	Mpa	Table 6.3
SS, Compression Parallel with Combined Bending	fcb	=	30.2	=	30.2	Mpa	Table 6.3
Equivalent Length Factor	Ke	=	1.5	=	1.5		A.5.5.6.1
Safety Factor, Service in Compression	Ksc	=	1	=	1		Table 6.4.2
Safety Factor, Modulus of Elasticity	Kse	=			1		Table 6.4.2
E05	E05	=	.87*E	=	11049	Mpa	6.5.8.5
Specified Strength, Bending	fb	=	25.6	=	25.6	Mpa	Table 6.3
Safety Factor, Service in Bending	Ksb	=	1	=	1		Table 6.4.2
Safety Factor, Curved Members	Kx	=	1	=	1		6.5.6.5.2
Factored Shear Load	Vf	=	8.9	=	8.9		kN
Factored Moment	Mf	=	17.1	=	17.1		kN-m
Factored Axial Load	Pf	=	32.6	=	32.6		kN

CALCULATIONS

Shear Resistance							6.5.7.2
	Vr	=	phi*Fv*(2/3)*Ag*Kn/1000	=	35.5	kN	
	Fv	=	fv*(Kd*Kh*Ksv*Kt)	=	2.0	Mpa	
Compression Resistance							6.5.8
Factored Compression Resistance	Pr	=	min(Pr_s, Pr_l)	=	279.8	kN	
Compression Resistance, Short	Pr_s	=	phi*Fc*Ag*Kzg_s*Kc_s/1000	=	438.3	kN	
Compression Reistance, Long	Pr_l	=	phi*Fc*Ag*Kzg_l*Kc_l/1000	=	279.8	kN	
	Fc	=	fc*(Kd*Kh*Ksc*Kt)	=	30.2	Mpa	
Equivalent Length, Short	Les	=	Ke*Ls	=	3750	mm	6.5.8.1
Equivalent Length, Long	Lel	=	Ke*Ll	=	4950	mm	6.5.8.1
Slenderness Ratio, Short	Cc_s	=	Les/b	=	21.4		6.5.8.2
Slenderness Ratio, Long	Cc_l	=	Lel/b	=	28.3		6.5.8.2
Kzg, Short	Kzg_s	=	0.68*(d*b*Ls/1000^3)^-.13	=	0.940		6.5.8.4.2
Kzg, Long	Kzg_l	=	0.68*(d*b*Ll/1000^3)^-.13	=	0.906		6.5.8.4.2
Kc, Short	Kc_s	=	(1+(Fc*Kzg_s*Cc_s^3/(35*E05*Kse*Kt)))^-1	=	0.581		6.5.8.5
Kc, Long	Kc_l	=	(1+(Fc*Kzg_l*Cc_l^3/(35*E05*Kse*Kt)))^-1	=	0.384		6.5.8.5
Moment Resistance							
Factored Moment Resistance	Mr	=	MIN(Mr_s, Mr_l)	=	21.56	kN	
	Mr_s	=	MIN(Mr1_s, Mr2_s)	=	21.56	kN	
	Mr_l	=	MIN(Mr1_l, Mr2_l)	=	21.56	kN	
	Mr1_s	=	phi*Fb*S*Kx*Kzbg_s/1000000	=	21.56	kN	
	Mr2_s	=	phi*Fb*S*Kx*Kl_s/1000000	=	21.56	kN	
	Mr1_l	=	phi*Fb*S*Kx*Kzbg_l/1000000	=	21.56	kN	
	Mr2_l	=	phi*Fb*S*Kx*Kl_l/1000000	=	21.56	kN	
	Fb	=	fb*(Kd*Kh*Ksb*Kt)	=	25.6	Mpa	
Lateral Stabilty Factor, Short	Kl_s	=	IF(Cb_s<10, 1, "Check")	=	1		6.5.6.4.4.(a)
Lateral Stabilty Factor, Long	Kl_l	=	IF(Cb_l<10, 1, "Check")	=	1		6.5.6.4.4.(a)
Slenderness Ratio, Short	Cb_s	=	sqrt(Le'_s*d/b^2)	=	5.46		6.5.6.4.3
Slenderness Ratio, Long	Cb_l	=	sqrt(Le'_l*d/b^2)	=	6.27		6.5.6.4.3
Effective Length for Bending, Short	Le'_s	=	1.92*lu_s	=	4800	mm	Table 6.5.6.4.3
Effective Length for Bending, Long	Le'_l	=	1.92*lu_l	=	6336	mm	Table 6.5.6.4.3
Unsupported Length, Short	lu_s	=	Ls	=	2500	mm	6.5.6.4.1
Unsupported Length, Long	lu_l	=	Ll	=	3300	mm	6.5.6.4.1
Kzbg, Short	Kzbg_s	=	1	=	1		6.5.6.5.1
Kzbg, Long	Kzbg_l	=	1	=	1		6.5.6.5.1
Combined Loading							6.5.12
Interaction, Short	Inter_s	=	IF((Pf/Pr')^2+(Mf/Mr)*(1/(1-(Pf/Pe_s)))>1.0, "Check", "OK")	=	OK		
Ineration, Long	Inter_l	=	IF((Pf/Pr')^2+(Mf/Mr)*(1/(1-(Pf/Pe_l)))>1.0, "Check", "OK")	=	OK		
Factored Compressive Load Resistance with Fcb	Pr'	=	phi*Fcb*Ag*Kzg_l*Kc_l/1000	=	280	kN	
(For weaker, long member)	Fcb	=	fcb*(Kd*Kh*Ksc*Kt)	=	30.2	Mpa	
Euler Buckling Load, Short	Pe_s	=	PI()^2*E05*Kse*Kt*I/(Ke*Ls)^2/1000	=	776	kN	
Euler Buckling Load, Long	Pe_l	=	PI()^2*E05*Kse*Kt*I/(Ke*Ll)^2/1000	=	445	kN	

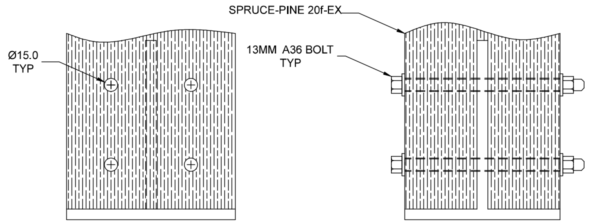
Appendix F: Connection Details



Appendix G: Connection Calculations

PROJECT	Picnic Strucutre	SECTION	1
TITLE	Timber Connection	DATE	2014-03-31
FILE	Civil 446- Wood Design	TIME	5:19 PM

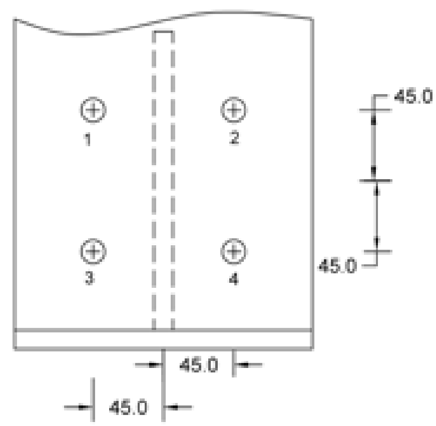
Title Knife Plate Connection for 20f-ex Spruce-Pine Glulam Column (175x190)



								WDM Reference
INPUTS								**WDM REFERENCE**
ASTM A 307 Bolts								
fy	fy	=		310	=	310	Mpa	
fu	fu	=		400	=	400	Mpa	
phi_steel	phi_steel	=		0.67	=	0.67	10.4.4.3.3.2	
phi_y	phi_y	=		0.8	=	0.8	10.4.4.3.3.2	
phi_w	phi_w	=		0.7	=	0.7	10.4.4.7	
Number of Shear Planes	ns	=		2	=	2		
Number of Fasteners in the Joint	nf	=		nr*nc	=	4		
Number of Rows	nr	=		2	=	2		
Number of Fasterns Per Row	nc	=		2	=	2		
Safety Factor, duration	Kd	=		1	=	1		6.4.1
Safety Factor, service for fastenings	Ksf	=		1	=	1		10.2.1.5
Safety Factor, treatment	Kt	=		1	=	1		6.4.4
thickness	t	=		175	=	175	mm	
width	w	=		190	=	190	mm	
Gross Area	Ag	=	w*t		=	33250	mm2	
Inputs for Yeilding Resistance								
Mean Oven Dry Relative Density	G	=		0.44	=	0.44		Table A10.1
Dowel Diamter	df	=	25.4/2		=	12.7	mm	
Embedment Strength of Middle Member (Steel)	f2	=	3*fu*phi_steel/phi_y		=	1005	Mpa	10.4.4.3.3
Embedment Strength of Side Plates (Glulam)	f1	=	50*G*(1-.01*df)		=	19.2	Mpa	10.4.4.3.3
Side Plate Thickness	t1	=	(w-t2)/2		=	89	mm	
Steel Plate Thickness	t2	=		12	=	12	mm	
Geometry Checking								
Edge Distance, loaded	eQ	=		50	=	50	mm	
Edge Distance,unloaded	eP	=		50	=	50		
End Distance, Unloaded	a	=		90	=	90	mm	
Spacing Between Rows	Sc	=	w-eQ-eP		=	90	mm	
Spacing Between Columns	Sr	=			=	90.0	mm	
Edge Distance, both	e_check	=	IF(AND(eQ>=4*df, eP>=1.5*df), "OK", "FAIL")		=	FAIL	**	10.4.3.2 (a)
End Distance, Unloaded	a_check	=	IF(AND(a>=50, a>=4*df), "OK", "FAIL")		=	OK		10.4.3.2 (a)
Spacing Between Rows	Sc_check	=	IF(Sc>=3*df, "OK", "FAIL")		=	OK		10.4.3.2 (a)
Spacing Between Columns	Sr_check	=	IF(Sr>=3*df, "OK", "FAIL")		=	OK		10.4.3.2 (a)
			**eP=50mm ~= 4*df=50.8 m. Rationally, spacing requirement met.					
CALCULATIONS								
Yeilding of Fasteners								10.4.4.3
Find nu for a three member connection	nu	=	MIN(Item_a, Item_c, Item_d, Item_g)		=	9.4	kN	
Item A	Item_a	=	f1*df*t1/1000		=	21.7	kN	
Item C	Item_c	=	0.5*f2*df*t2/1000		=	76.6	kN	
Item D	Item_d	=	f1*df^2*(sqrt(f2*fy/(6*f1*(f1+f2)))+t1/(5*df))/1000		=	9.4	kN	
Item G	Item_g	=	f1*df^2*sqrt(2*f2*fy/(3*(f1+f2)*f1))/1000		=	10.1	kN	
Total Factored Yeild Resistance per 3 Member Unit	Nr	=	phi_y*nu*ns*nf		=	60	kN	
Splitting								10.4.4.7
Splitting Resistance	Qsri	=	phi_w*Qsi*(Kd*Ksf*Kt)/1000		=	24.9	kN	
	Qsi	=	14*t*SQRT(de/(1-(de/w)))		=	35598	N	
	de	=	w-a		=	100	mm	

Appendix H: Connection Force Transformation Calculations

INPUTS		
dx, dy	90	mm
Ip	8100	mm^2
Design Moment, Mf	11.3	kN/m
Highest Shear (x)m Vf	8.9	kN
Highest Axial (y), Nf	32.6	kN
Number of Bolts, n	4	



Bolt	rx	ry	Vx (shear)	Ny (axial)
	mm	mm	kN	kN
1	45	45	2.3	8.2
2	45	45	2.3	-8.1
3	45	45	-2.2	8.2
4	45	45	-2.2	8.2

Where,

$$I_p = 4 * \left(\frac{dx}{2}\right)^2 \; or \; 4 * \left(\frac{dy}{2}\right)^2$$

$$Vx = \frac{M_f * r_x}{I_p} \pm \frac{V_f}{n}$$

$$Ny = \frac{M_f * r_y}{I_p} \pm \frac{N_f}{n}$$

Appendix I: Cost Analysis and Construction Schedule

TASK/COMPONENT	RS MEANS #	CREW	CONVERTED TO METRIC UNITS				PROJECT SPECIFIC		WITHOUT		
			DAILY OUTPUT	UNIT	BARE PRICE	PRICE W. OH	QUANTITY	UNIT	EXTENDED PRICE	TASK DURATION (HRS)	DURATION (DAYS)
SITE WORK AND FOUNDATIONS											
Excavation to bottom of structural footings	312316160200	B2	9.2	m3	$ 62.13	$ 104.64	19.21338	m3	$ 1,193.73	16.75	2.50
Frame, reinforce, pour spread footings	33053403800	C14C	8.6	m3	$ 393.92	$ 537.95	0.576	m3	$ 226.90	0.54	0.50
Backfill up to bottom of SOG	312323130015, 31232313110	A1E	21.4	m3	$ 46.07	$ 76.88	9.31	m3	$ 428.89	3.48	0.50
Frame, reinforce, pour slab on grade	33053404650	C14E	18.6	m3	$ 223.08	$ 283.95	6.21246	m3	$ 1,385.87	2.68	0.25
FRAMING AND STRUCTURE											
Install Column base supports	N/A	2 Carp.	16.0	Ea.	$ 167.00	$ 200.00	6	Ea.	$ 1,002.00	3.00	0.50
Column framing (8"x8" timber framing)	61323100400	2 Carp.	40.0	m	$ 37.86	$ 49.84	17.79	m	$ 673.55	3.56	0.50
Install Beams (8" x 16" single beams)	61323100100	2 Carp.	34.3	m	$ 86.62	$ 105.00	24.72	m	$ 2,141.27	5.77	0.75
Install Framing connectors	60523600100	2 Carp.	50.0	Ea.	$ 46.65	$ 57.75	12	Ea.	$ 559.80	1.92	0.25
Installation of 2"x12" joists	61110101060	2 Carp.	167.6	m	$ 8.46	$ 11.32	26.9	m	$ 227.71	1.28	0.50
ROOFING											
Install plywood roof sheathing	61636100030	2 Carp.	148.6	m2	$ 9.80	$ 13.02	26.5832	m2	$ 260.39	1.43	0.25
Install green roof 4" x 4" edge	73363100400	2 Carp.	121.9	m	$ 8.69	$ 12.30	52.32	m	$ 454.90	3.43	0.50
Install roofing membrane	73363100560	G5	32.5	m2	$ 42.73	$ 72.33	26.5832	m2	$ 1,135.98	6.54	1.00
Install root barrier for planted roof	73363100570	2 Roofers	72.0	m2	$ 12.59	$ 18.94	26.5832	m2	$ 334.79	2.95	0.50
Install moisture retention mat	73363100580	2 Roofers	83.6	m2	$ 29.49	$ 36.71	26.5832	m2	$ 784.03	2.54	0.50
Install planting medium and plants	73363100600	1 Lab.	39.0	m2	$ 61.79	$ 71.04	26.5832	m2	$ 1,642.45	5.45	1.00
Install Skylight panels	84510100020	G3	36.7	m2	$ 406.66	$ 464.47	17.2368	m2	$ 7,009.58	3.76	0.50
								TOTAL	$ 19,461.84	TOTAL DURATION	10.5
											~ 2 WEEKS

Figure 17: Cost estimate for the picnic structure excluding overhead and profit

TASK/COMPONENT	RS MEANS #	CREW	CONVERTED TO METRIC UNITS				PROJECT SPECIFIC		WITH		
			DAILY OUTPUT	UNIT	BARE PRICE	PRICE W. OH	QUANTITY	UNIT	EXTENDED PRICE	TASK DURATION (HRS)	DURATION (DAYS)
SITE WORK AND FOUNDATIONS											
Excavation to bottom of structural footings	312316160200	B2	9.2	m3	$ 62.13	$ 104.64	19.21338	m3	$ 2,010.49	16.75	2.50
Frame, reinforce, pour spread footings	33053403800	C14C	8.6	m3	$ 393.92	$ 537.95	0.576	m3	$ 309.86	0.54	0.50
Backfill up to bottom of SOG	312323130015, 31232313110	A1E	21.4	m3	$ 46.07	$ 76.88	9.31	m3	$ 715.79	3.48	0.50
Frame, reinforce, pour slab on grade	33053404650	C14E	18.6	m3	$ 223.08	$ 283.95	6.21246	m3	$ 1,764.05	2.68	0.25
FRAMING AND STRUCTURE											
Install Column base supports	N/A	2 Carp.	16.0	Ea.	$ 167.00	$ 200.00	6	Ea.	$ 1,200.00	3.00	0.50
Column framing (8"x8" timber framing)	61323100400	2 Carp.	40.0	m	$ 37.86	$ 49.84	17.79	m	$ 886.65	3.56	0.50
Install Beams (8" x 16" single beams)	61323100100	2 Carp.	34.3	m	$ 86.62	$ 105.00	24.72	m	$ 2,595.48	5.77	0.75
Install Framing connectors	60523600100	2 Carp.	50.0	Ea.	$ 46.65	$ 57.75	12	Ea.	$ 693.00	1.92	0.25
Installation of 2"x12" joists	61110101060	2 Carp.	167.6	m	$ 8.46	$ 11.32	26.9	m	$ 304.49	1.28	0.50
ROOFING											
Install plywood roof sheathing	61636100030	2 Carp.	148.6	m2	$ 9.80	$ 13.02	26.5832	m2	$ 346.23	1.43	0.25
Install green roof 4" x 4" edge	73363100400	2 Carp.	121.9	m	$ 8.69	$ 12.30	52.32	m	$ 643.73	3.43	0.50
Install roofing membrane	73363100560	G5	32.5	m2	$ 42.73	$ 72.33	26.5832	m2	$ 1,922.87	6.54	1.00
Install root barrier for planted roof	73363100570	2 Roofers	72.0	m2	$ 12.59	$ 18.94	26.5832	m2	$ 503.61	2.95	0.50
Install moisture retention mat	73363100580	2 Roofers	83.6	m2	$ 29.49	$ 36.71	26.5832	m2	$ 975.74	2.54	0.50
Install planting medium and plants	73363100600	1 Lab.	39.0	m2	$ 61.79	$ 71.04	26.5832	m2	$ 1,888.53	5.45	1.00
Install Skylight panels	84510100020	G3	36.7	m2	$ 406.66	$ 464.47	17.2368	m2	$ 8,005.92	3.76	0.50
								TOTAL	$ 24,766.46	TOTAL DURATION	10.5
											~ 2 WEEKS

Figure 18: Cost estimate for the picnic structure including overhead and profit

	Task Name	Duration	Start	Finish
1	**Site Work**	**6.75 days**	**Mon 14-03-24**	**Tue 14-04-01**
2	Excavation	2.5 days	Mon 14-03-24	Wed 14-03-26
3	Spread Footings	0.5 days	Wed 14-03-26	Wed 14-03-26
4	Backfill for SOG	0.5 days	Tue 14-04-01	Tue 14-04-01
5	SOG	0.25 days	Tue 14-04-01	Tue 14-04-01
6	**Framing**	**2.5 days**	**Fri 14-04-04**	**Wed 14-04-09**
7	Column Brackets	0.5 days	Fri 14-04-04	Mon 14-04-07
8	Columns	0.5 days	Mon 14-04-07	Mon 14-04-07
9	Beams	0.75 days	Mon 14-04-07	Tue 14-04-08
10	Framing Plates	0.25 days	Tue 14-04-08	Tue 14-04-08
11	Install joists	0.5 days	Tue 14-04-08	Wed 14-04-09
12	**Roofing**	**4.25 days**	**Wed 14-04-09**	**Tue 14-04-15**
13	Plywood sheathing	0.25 days	Wed 14-04-09	Wed 14-04-09
14	Green roof edge	0.5 days	Wed 14-04-09	Wed 14-04-09
15	Skylights	0.5 days	Thu 14-04-10	Thu 14-04-10
16	Roofing membrane	1 day	Thu 14-04-10	Fri 14-04-11
17	Root barrier	0.5 days	Fri 14-04-11	Fri 14-04-11
18	Moisture retention mat	0.5 days	Mon 14-04-14	Mon 14-04-14
19	Planting medium and plants	1 day	Mon 14-04-14	Tue 14-04-15

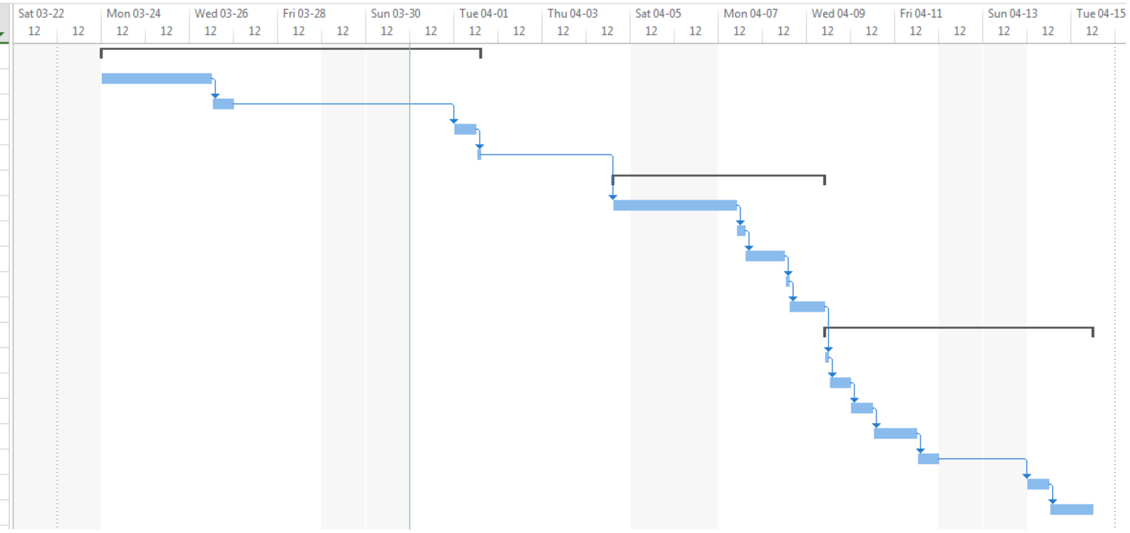


Figure 19: Basic project schedule showing all construction tasks required to complete the picnic structure

CONCRETE FOOTINGS			
Width	Length	Height	Number
0.4	0.4	0.6	6
Area		Volume	
0.96	m2	0.58	m3

CONCRETE SLAB ON GRADE			
Width	Length	Height	
6.17	5.19	0.2	
Area (no footings)		Volume	
31.1	m2	6.21	m3

EXCAVATION/SITE WORK			
Slab Area	Max Depth		
32.0223	0.6		
Volume		Backfill Required	
19.21	m3	9.32	m3

UNIT CONVERSIONS	
$/CY to $/m3	1.308
$/SF to $/m2	10.764
$/LF to $/m	3.281
$/MBF(8x8) to $/LF	0.00533
$/MBF(8x8) to $/m	0.017488
$/MBF(8x16) to $/LF	0.010667
$/MBF(8x16) to $/m	0.034998

GREEN ROOF		
Width	Length	Perimeter
7	6.26	26.52
Area		
26.58	m2	

SKYLIGHTS			
Perimeter		Area	
25.8	m	17.24	m2

TIMBER BEAMS			
Diagonal	Number	Flat	Number
4.64	3	2.7	4
Total Length			
24.72	m		

TIMBER COLUMNS			
Height	Number	Height	Number
3.36	3	2.57	3
Total Length			
17.79	m		

Figure 20: Quantity calculation based on the picnic structure design