Bravo Consultants

Final Design Report

Pasadena Recplex – AE Consultants

Bravo Consultants

April 3, 2013

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April 3, 2013

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Subject: Pasadena Recplex Final Report

Dear Ms. Hancock;

Please find the enclosed Final Design Report for the engineering design and structural cost analysis of the Pasadena Recplex. The final report is a requirement of Engineering 8700 and has been prepared to facilitate the prerequisites of the course.

This report is an overview of all design concepts used for the Pasadena Recplex. It includes the steel and concrete design members for the entire building using calculated design loads. You will also find structural drawings and a Class C cost estimate for the final design attached. A cost comparison between different design methods is also included to confirm that this design is the most economically efficient option.

Should you have any questions regarding this final report, please feel free to contact the undersigned.

Regards,
Bravo Consultants

Jillian Butt	Matthew Alexander
Ryan Coady	Matthew Doyle

Attached: Pasadena Recplex Project Final Report
CC: Dr. Bruneau, Dr. Hussain, Mr. Skinner

Pasadena Recplex Final Report

April 3rd, 2013

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Summary

The Pasadena Recplex is a proposed fitness center for the town of Pasadena, Newfoundland and Labrador. AE Consultants selected Bravo Consultants to complete the design for the structural system of building. This report presents the final design for the conventional steel structure as well as all concrete required for the foundation and floor slab.

All design loads have been calculated to the National Building Code of Canada standard. These loads were then used to determine the structural members of the building. The steel is designed according to CSA Standard S16-09 and the concrete foundation and slab on grade are designed according to CSA Standard A23.3-04.

During the design process, two different design alternatives were evaluated for their cost effectiveness. The first was a CANAM Joist girder and a conventional steel truss. The truss was found to have a lighter gross weight, but a larger depth and greater cost according to RS Means. This confirmed Bravo's decision to choose CANAM joist girders for their design.

Bravo Consultants also compared the cost of a simply supported frame to that of a moment resisting portal truss for lateral load resistance. It was determined that a simply supported frame and cross bracing with diaphragm action in the roof, was more cost effective than using a moment resisting frame for the major buildings.

A Class C estimate is provided using RS Means to provide material and construction costs for the conventional steel building. The cost of the conventional steel and design, with allowances, is $1,008,708.31. AE Consultants also required a Butler Pre-Engineered Building Budget Estimate for the three main building sections, which is $1,293,921.39. This is compared to the conventional steel total of $564,091.91, which excludes all concrete, Lobby and Mezzanine costs.

The major deliverables for this project include structural calculations, a set of working drawings, a Class C estimate and Butler Pre-Engineered Building Estimate. These deliverables are included in the report appendices.

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1.0 Introduction

1.1 Project Description

The Pasadena Recplex is located in the town of Pasadena, Newfoundland. AE Consultants has retained Bravo Consultants to complete the structural design work for the Fitness Center, as well as a cost estimate for the design. Figure 1 shows the location of the Recplex.

Figure 1: Aerial View of the Project Location

The project consists of a one story building with three main components: a Gymnasium with a full size basketball court, a Fitness centre and a Multipurpose area with folding partitions. Figure 2 shows the basic architectural layout of the structure. The Gymnasium is standard size, roughly 730 m^2 while the other two main sections are 360 m^2. All three main structures are joined by a common lobby area.

Since the main areas of the building are large and rectangular in shape, the client has requested a cost comparison of pre-engineered buildings versus a conventional steel system. This will allow the client to make a decision on which construction method they should choose to provide the most economically efficient solution.

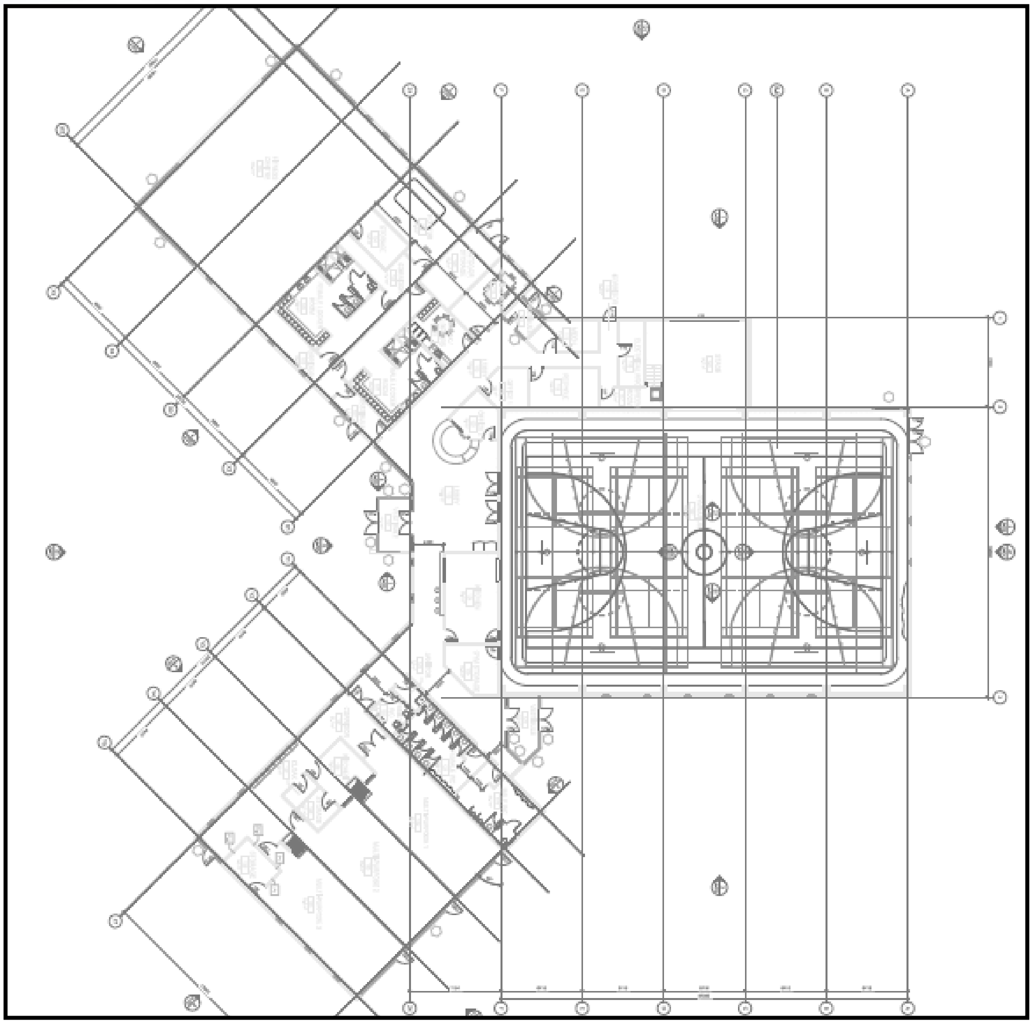


Figure 2: Main Floor Architectural Floor Plan

1.2 Project Requirements

Bravo Consultants will work directly with the engineers at AE Consultants to design a new Recplex center for the town of Pasadena. In order to achieve the desired result, the client has listed the following requirements:

- Calculate the snow, wind and all other dead/live loads on the designed structural frame to ensure the building will withstand all the elements.
- Design of the concrete foundations and slab on grade.
- Design a conventional steel structural frame to resist all possible loading on the building.
- A "Class C" estimate is to be conducted upon completion of the frame design.
- A comparison to pre-engineered building for the Recplex will be required after the conventional steel estimate is prepared for comparison..

1.3 Project Work Plan

A project work plan was completed and submitted to AE Consultants, and the course instructors. The plan contained the project scope, a breakdown of tasks and deliverables, the consultant's methodology, and the initial schedule.

1.3.1 Schedule

A design schedule was prepared for the Pasadena Recplex using Microsoft Project 2010. This schedule was based on the project requirements stated in section 1.2. Bravo Consultants attempted to follow the schedule order but were subjected to fluctuations in the order they were initially applied.

The work schedule started on February 3, 2013 and ran until April 4, 2013. Originally, Bravo planned to work on each building section separately, but as the project progressed several changes were made to the schedule. The design team realized that the three primary structures were so similar it would be more efficient to complete the design for them concurrently. For example, instead of calculating all steel members for the Gymnasium before moving on to the next building, it was easier to calculate the steel members for each at the same time. This caused our schedule to shift but did not negatively affect the duration of the project timeline.

The schedule was followed and updated within Microsoft Project 2010 on a weekly basis to accommodate any changes in scope or change in anticipated task durations. Progress made and any changes were reported weekly in hard copy on Mondays at the regularly scheduled progress meeting.

The schedule for this project can be found in Appendix A.

1.3.2 Scope Changes

The hot tub was removed from the scope due to budgetary constraints from the owner. This change had no impact on the design schedule.

1.4 Project Deliverables

The requirements for the project that were specified by the client both prior to commencement of the design and during the design process are listed in Table 1.

Deliverable	Report Location
Structural Calculations	Appendix B (Loads) Appendix C (Steel) Appendix D (Concrete)
Structural Drawings: • Roof Plan with Beams • Foundation Plan and Details • Mezzanine Plan and Details • Floor Slab Plan and Details	Appendix E
Quantity Take off and Cost Estimate for the Steel Structure, Foundation and Floor Slab	Section 5.1 Appendix G
Budget Estimate for Pre-Engineered Buildings	Section 5.2

Table 1: List of Project Deliverables and Report Location

2.0 Design Loads

All Design Loads in the following sections were calculated according to NBC 2010 Structural Commentaries (Part 4 of Division B). Snow and wind loads were calculated using data from Corner Brook, NL due to its proximity to Pasadena.

2.1 Dead and Live Loads

The dead load is the sum of the various structural members' weight and the weight of any other permanent object that are attached to the structure. Hence, for this building, the dead load includes the weight of the roofing, steel deck, insulation, and the joists. Initially, to determine the roof deck sections, a dead load of 0.33 kPa was assumed (using average deck and insulation weights found in CISC Handbook of Steel Construction). Once the roof deck design was determined, Bravo Consultants decided to increase the dead load to 0.55 kPa in order to be more conservative.

Live loads are temporary loads placed in a structure. It is not typical for a roof to have many live loads acting on it but a minimum is required as a safeguard to ensure any maintenance personal, etc. are accounted for in the design. The minimum live load on a roof as specified in table 4.1.5.3 NBC 2010 is 1.0 kPa.

2.2 Snow Loads

The snow loads were calculated using Commentary G of the NBC, which uses the formula:

$$S = I_s\{S_s(C_bC_wC_sC_a) + S_r]$$

The Gymnasium, Multipurpose Room and Fitness Center are all similarly shaped and therefore designed using the same snow load, which is listed in Table 1. The Lobby Roof had multiple loading cases due to its irregular shape. These were calculated separately for each different shape and drift factor, and the governing snow load was chosen for design.

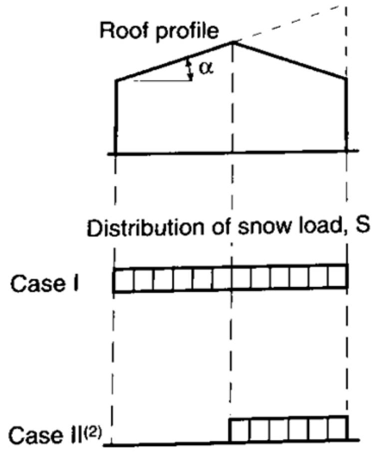
Factor	Description	Value	Comments	Design Loads
I_s	Importance Factor for Snow Load	**1.0**	Importance Factor (Normal)	**Case I: 3.36 kPa** **Case II: 3.89 kPa**
S_s	1-in-50 Ground Snow Load in kPa	**3.70**	From Corner Brook Data	
C_b	Basic Roof Snow Load Factor	**0.8**	Commentary G Par.10 (NBCC 2010)	
C_w	Wind Exposure Factor	**1.0**	Commentary G Par.17 (NBCC 2010)	
C_s	Roof Slope Factor	**0.89**	Slippery Unobstructed Roofing System (metal)	
C_a	Shape Facror (Case I) Shape Factor (Case II)	**1.00** **1.25**	Commentary G Fig. G-1 Case II (NBCC 2010)	
S_r	Associated Rain Load in kPa	**0.60**	From Corner Brook Data	

Table 2: Snow Load Summary for Major Building Sections

An Importance Factor (I_s) of 1.0 was used in this design after discussing the function of the building with the client. The Town of Pasadena does not need this building for an emergency situation, as they have enough emergency rated buildings. Therefore the building is rated as normal importance to be more cost effective.

The Basic Snow Load Factor (C_b) and Wind Exposure Factor (C_w) were chosen to be 0.8 and 1.0 respectively. Although the building is large and located on an existing sports field, they still fell in the range for typical factors in both categories. The Roof Slope Factor (C_s) was chosen based on the material of the roof (metal, slippery).

In order to calculate the snow load on these buildings, two calculations were needed to account for the two Shape Factor cases in Figure G-1 of NBC 2010 (shown in Figure 3). Both cases were calculated separately, and governed for different aspects of the design. The column and joist girders were designed using the Case 1 load of 3.36 kPa, due to a higher moment and reaction on these members. Case 2 was used for the steel roof deck and open web steel joists.



Load case	Roof slope α	Factors		
		C_w	C_s	C_a
I	0° ≤ α ≤ 90°	1.0[3]	f (α)[1]	1.0
II	15° ≤ α ≤ 20° 20° ≤ α ≤ 90°	1.0 1.0	f (α)[1] f (α)[1]	0.25 + α/20 1.25

EG00948A

Figure 4: Snow Distribution and Snow Loading factors (Figure G-1 of NBC 2010)

The Lobby roof section was calculated separately due to its irregular shape. The design also had to account for a drifting factor because this section is lower than the other buildings. This resulted in variable snow loads throughout the lobby. The load profile for a particular section of the lobby is shown in Figure 4 (Section 7, 8), with a maximum load of 3.47 kPa and 3.23 kPa on the rest of the roof section. Detailed snow load calculations are provided in Appendix B.

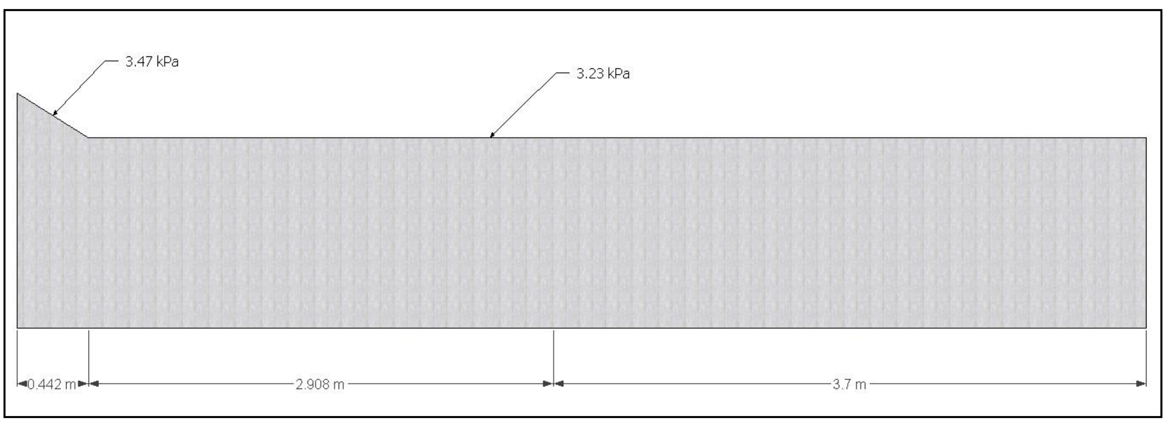


Figure 3: Lobby Roof Snow Load Profile (not to scale)

2.3 Wind Loads

The main supporting elements of the Recplex are designed to withstand pressure and suction caused by wind loads. The wind loads act differently on each section, and use separate calculation tables from NBC. The External Wind Pressure was calculated using Commentary I of the NBC, which uses the formula:

$$P=I_wqC_eC_gC_p$$

Where:
I_w = Importance Factor
q = 1/50 year hourly wind pressure (kPa)
C_e = Wind Exposure Factor
C_g = Wind Gust Factor
C_p = External Pressure Coefficient

The Importance Factor and hourly wind pressure were chosen as 1.0 and 0.55 kPa, respectively. The wind exposure factor was calculated using the formula for rough terrain, however it did not meet the minimum of 0.7. Therefore, 0.7 was the factor used for the Recplex. The Wind Gust Factor and External Pressure Coefficient were calculated based on Figure I-7 of NBC 2010 (shown in Figure 5), and calculated values for each building face are listed in Table 3. The Detailed calculations can be found in Appendix B.

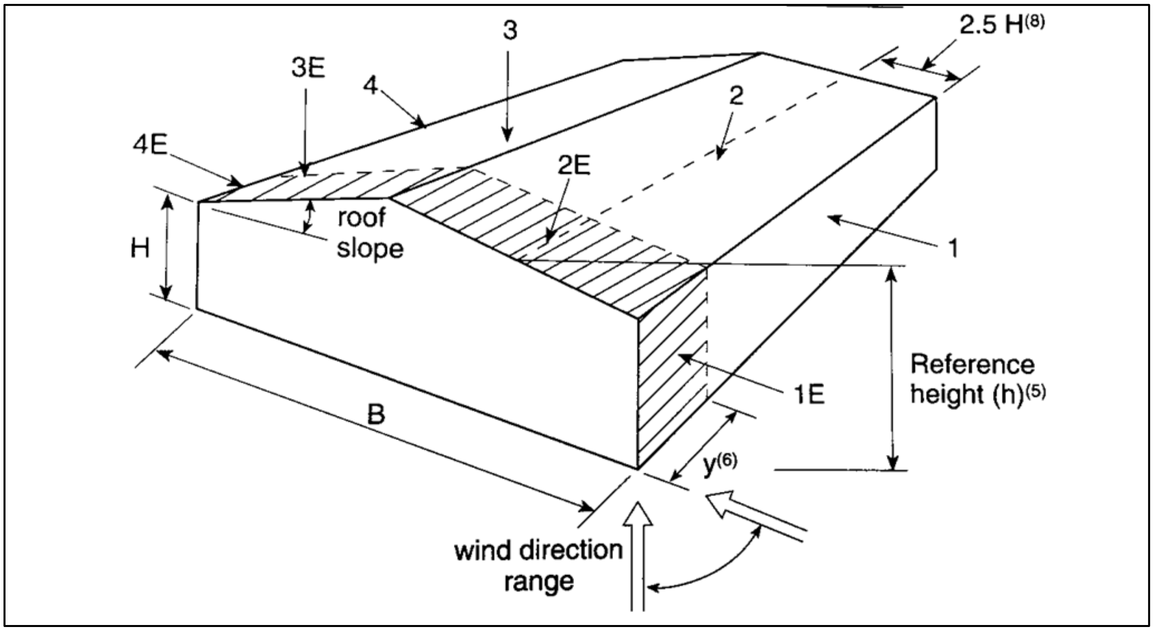


Figure 5: Primary Structure Wind Load CpCg Calculation (Figure I-7 of NBC 2010)

	Building Surfaces							
	1	1E	2	2E	3	3E	4	4E
CpCg Value	1.0	1.5	-1.3	-2.0	-0.9	-1.3	-0.8	-1.2
Wind Pressure (P)	0.289	0.443	-0.5	-0.77	-0.27	-0.385	-0.212	-0.308

Table 3: Primary Structure CpCg and Wind Pressure

Wind Loads on a building can also cause interior pressure and suction forces. The formula for internal pressure is similar to external, except it uses the internal pressure coefficients: C_{gi} and C_{pi}. C_{gi} is 2.0, and C_{pi} is chosen based on the purpose of the building and whether it has large open doors. Since the Recplex does not have large doors the C_{pi} was chosen to be 0 and -0.15. Therefore, the Recplex was designed with an internal suction of -0.1155 kPa.

For the OWSJ's and roof decking, the C_pC_g Values were calculated using Figure I-8 of NBC 2010 (Figure 6 of this report). These differ for each building since the values depend on the area of the roof. The detailed calculations for this are located with the OWSJ and decking calculations in Appendix B.

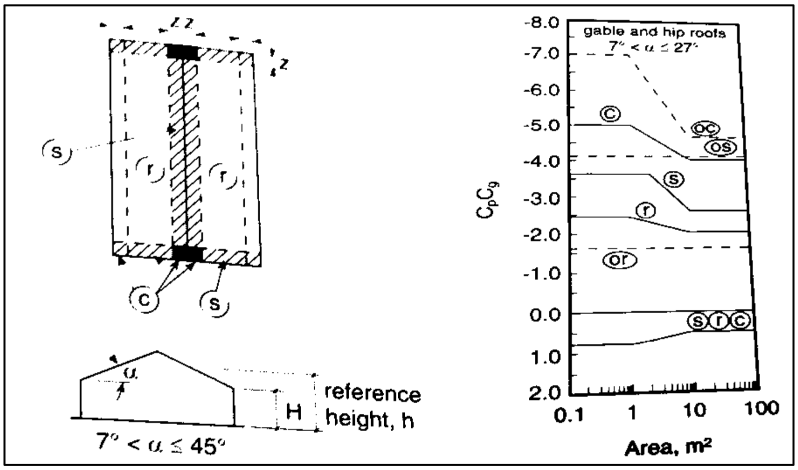


Figure 6: Wind Pressure Coefficients for Gabled Roof (Figure I-11 of NBC 2010)

2.4 Load Combinations

In order to determine the governing load on the building, Bravo Consultants followed the load combinations as defined in the NBC. These loads are shown in Table

4 of this report. In total, 26 different load cases were analyzed for each section of the building, and two governing cases were chosen. This is due to having analyzed 3 separate snow load scenarios, as well as two wind load scenarios. The two governing cases were 1.25*D + 1.5*S_1 + 0.5*L and 1.25*D + 1.4*W_1 + 0.5*S_2 for each building.

Case	Load Combination	
	Principal Loads	Companion Loads
1	1.4*D	
2	(1.25*D or 0.9*D) + 1.5*L	0.5*S or 0.4*W
3	(1.25*D or 0.9*D) + 1.5*S	0.5*L or 0.4*W
4	(1.25*D or 0.9*D) + 1.4*W	0.5*L or 0.5*S
5	1.0*D + 1.5*E	0.5*L + 0.25*S

Table 4: NBC Load Combinations

Where: D = Dead Load
L = Live Load
S = Snow Load
W = Wind Load

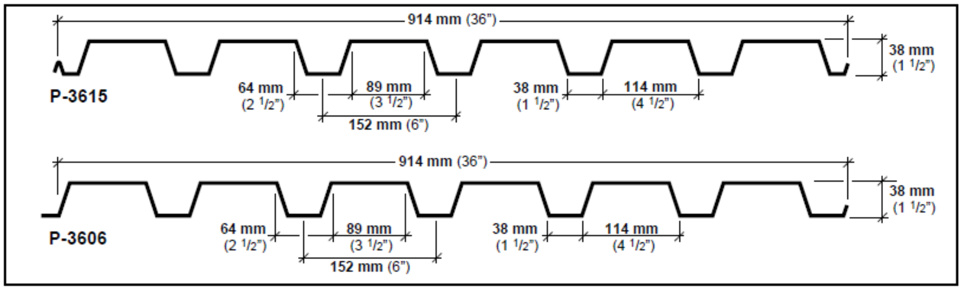
3.0 Conventional Steel Design

All steel members were designed using the CSA S16-09 standard, as well as NBCC 2010. This design included the structural design of rigid frames, roof deck, and lateral bracing. All member connections are to be designed by the steel fabricator. All detailed calculations are located in Appendix C while a list of members and quantities are located in Appendix F.

3.1 Roof Decking

The roof decking was designed to resist exterior roof loads as well as transfer loads to the open web steel joists. Each building had a different load due to the load combinations calculated in Section 2. Once the load was determined, the roof deck was selected from the CANAM decking catalogue. Due to the spacing of our open web steel joists, P-3615 Type 22 triple span decking was chosen to be the most suitable for the three main structures. Figure 7 shows the profile for this section.

Dimensions



Physical Properties

Type	Nominal Thickness	Design Thickness	Overall Depth	Weight	Section Modulus M+	Section Modulus M−	Moment of Inertia for Deflection
	mm (in.)	mm (in.)	mm (in.)	kg/m² (lb/ft²)	mm³ (in³)	mm³ (in³)	mm⁴ (in⁴)
22	0.76 (0.030)	0.762 (0.0300)	37.4 (1.47)	8.50 (1.74)	9 529 (0.1772)	10 081 (0.1875)	202 228 (0.1481)
20	0.91 (0.036)	0.909 (0.0358)	37.5 (1.48)	10.07 (2.06)	11 558 (0.2150)	12 005 (0.2233)	254 750 (0.1865)
18	1.21 (0.048)	1.217 (0.0479)	37.8 (1.49)	13.26 (2.72)	15 813 (0.2941)	15 994 (0.2975)	363 493 (0.2662)
16	1.52 (0.060)	1.511 (0.0595)	38.1 (1.50)	16.34 (3.35)	19 786 (0.3680)	19 786 (0.3680)	452 472 (0.3313)

Recplex Roof Deck

Figure 7: CANAM Steel Decking Profile for P-3615

3.2 Open Web Steel Joists

Bravo Consultants chose Open Web Steel Joists as the system to resist service and ultimate loading from the roof loads. These joists then transfer the loads to the truss system. All OWSJ depths were selected using CANAM's joist catalogue. In order to select OWSJ's, the ultimate and service loads of each roof were calculated and a selection table like the one in Figure 8 was used. The % of service load to produce a deflection of L/360 was checked to ensure the design was efficient. Detailed calculations for the OWSJ's are located in Appendix C while the quantities are listed in Appendix F.

METRIC

XXX : Mass of Joist (kg/m)
xxx : % of service load to produce a deflection of L/360

Span (m)	Joist Depth (mm)	Factored load (kN/m) / Service load (kN/m): 4.5 / 3.0	6.0 / 4.0	7.5 / 5.0	9.0 / 6.0	10.5 / 7.0	12.0 / 8.0	13.5 / 9.0	15.0 / 10.0	16.5 / 11.0	18.0 / 12.0	19.5 / 13.0	21.0 / 14.0	22.5 / 15.0
3	200	8.2 / 200	8.2 / 192	8.2 / 154	8.2 / 128	8.2 / 110	8.2 / 96	8.2 / 86	8.2 / 77	9.5 / 85	9.8 / 81	10.2 / 75	10.6 / 72	12.0 / 79
	250	8.4 / 200	8.4 / 200	8.4 / 200	8.4 / 200	8.4 / 178	8.4 / 155	8.4 / 138	8.4 / 124	8.6 / 113	8.6 / 104	9.8 / 116	9.8 / 108	9.8 / 101
	300	10.1 / 200	10.1 / 200	10.1 / 200	10.1 / 200	10.1 / 200	10.1 / 200	10.1 / 200	10.1 / 200	10.1 / 200	10.1 / 186	10.1 / 171	10.1 / 159	10.1 / 149
	350	10.3 / 200	10.3 / 200	10.3 / 200	10.3 / 200	10.3 / 200	10.3 / 200	10.3 / 200	10.3 / 200	10.3 / 200	10.3 / 200	10.4 / 200	10.4 / 200	10.6 / 200
	400	10.5 / 200	10.5 / 200	10.5 / 200	10.5 / 200	10.5 / 200	10.5 / 200	10.5 / 200	10.5 / 200	10.5 / 200	10.5 / 200	10.6 / 200	10.8 / 200	10.8 / 200
	450	10.6 / 200	10.6 / 200	10.6 / 200	10.6 / 200	10.6 / 200	10.7 / 200	10.7 / 200	10.8 / 200	10.8 / 200	10.9 / 200	10.9 / 200	11.0 / 200	11.1 / 200
	500	10.7 / 200	10.7 / 200	10.7 / 200	10.7 / 200	10.7 / 200	10.8 / 200	10.8 / 200	10.8 / 200	10.9 / 200	11.1 / 200	11.1 / 200	11.2 / 200	11.3 / 200

Figure 8: Example of CANAM Joist Catalogue Selection Tables

3.3 Joist Girders

Joist girders are primary structural components of building design. They generally support the roof OWSJ's and transfer the weight of the roof and OWSJ's to the columns. Joist girders are typically composed of parallel top and bottom chords that are held in place by web members.

During the design process, Bravo Consultants initially decided to use CANAM catalogues to determine the joist girder sections for each main building. This was thought to be the most efficient and economic design for the building. In order to confirm this, Bravo Consultants designed a typical truss from conventional steel to perform a cost analysis. The following subsections outline the design of a CANAM joist girder as well as a conventional steel truss design.

3.3.1 CANAM Joist Girder

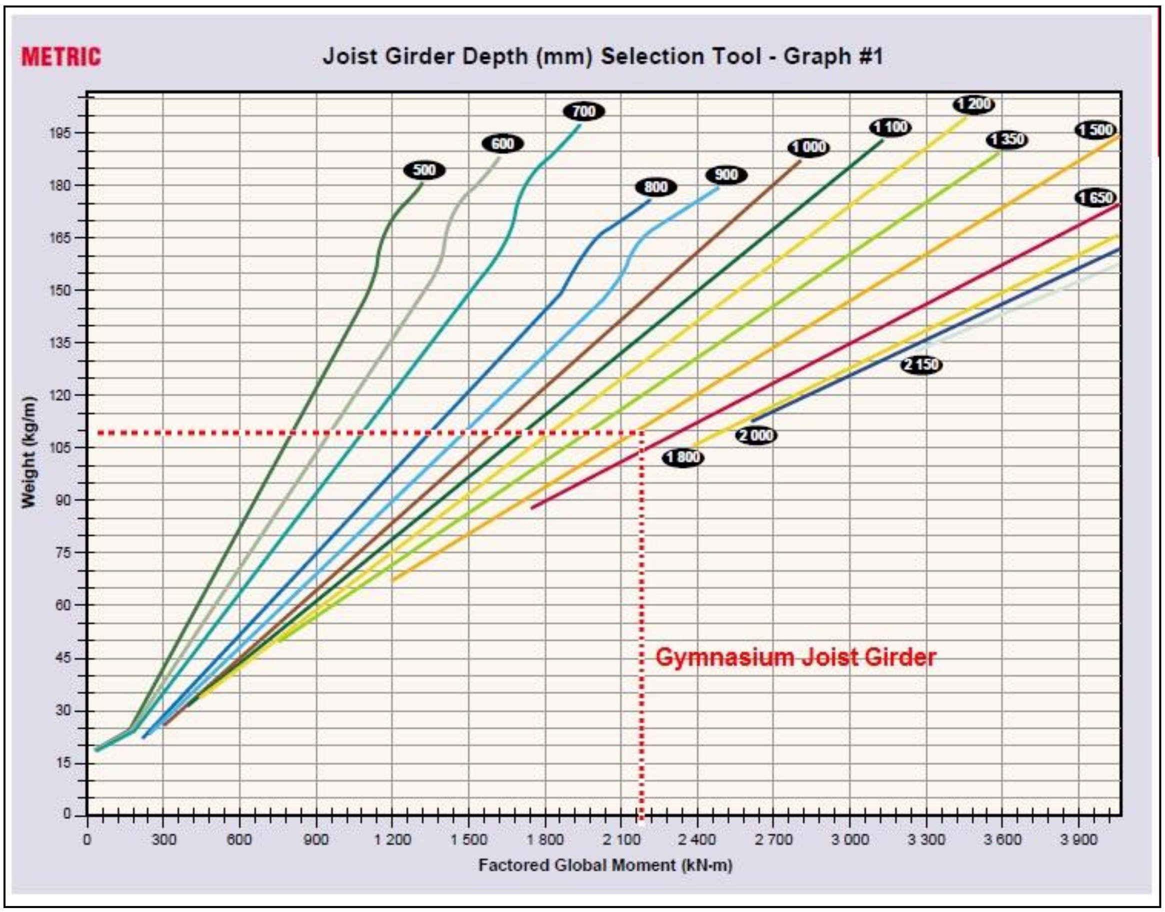


Figure 9: CANAM Joist Graph for member selection

The factored moment of the joist must be calculated in order to choose the weight and depth of a CANAM joist girder. According to the CANAM catalogue, it is unnecessary to calculate the bending moment of the concentrated loads of the joists bearing on the girder as an equivalent uniform load is sufficient. Once the moment was calculated, the graph shown in Figure 9 was used to determine the depth and weight of the girder. As an example, the Gymnasium had a factored moment of 2351 kN-m. The red dotted line shows the selection of a 1500 mm deep, 110 kg/m joist girder. The shape of the girder is a non standard shape (Figure 10), and therefore Bravo Consultants decided to mark up the price of the joist girder.

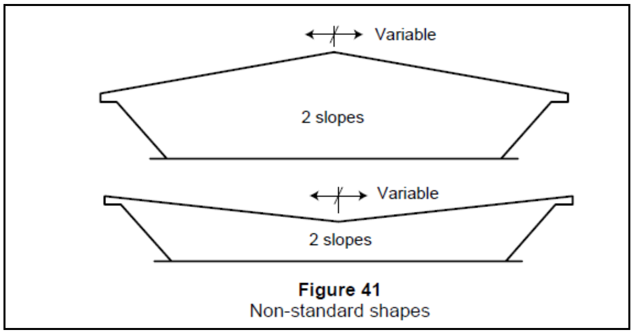


Figure 10: Chosen CANAM Joist Girder Shape

3.3.2 Conventional Truss Design

The conventional steel truss was designed as a pratt truss, using S-Frame and analysed in S-Steel for the most economical sections. According to Building Construction Illustrated, pratt trusses are generally more efficient due to the longer diagonal members being held in tension whereas the shorter vertical members are in compression. The compression members are governed by their buckling resistance which reduces with length and therefore it is more efficient to keep compression members as short as possible.

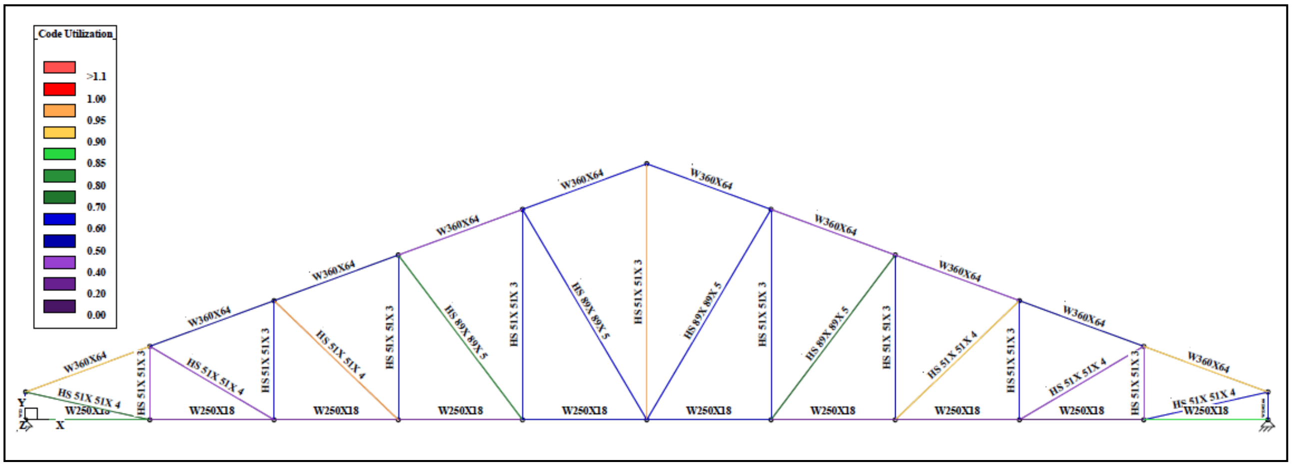


Figure 11: Conventional Steel Truss S-Frame Model

As seen in Figure 11, the truss consists of W sections for the chords and HSS sections for web members. This will reduce the weight since HSS sections resist buckling better than W sections. The weight of the truss is 2388 kg with a maximum depth of 4.6m, which is compared to the Gymnasium joist girder at 2475 kg and 1.8m. There can be advantages and disadvantages of each design based on size; conventional trusses should be used when weight is the constraining factor and depth is not an issue. In the following a cost comparison between the two designs is performed.

3.3.3 Cost Comparison

The joist and truss cost comparison was conducted using information from RS Means. Each member of the truss was individually priced for material cost only, while the joist girder was priced as a similar pre-assembled deep span joist of the same depth and weight.

It may be more conservative to factor up the cost of the Joist Girder due to its non-conventional shape, however the factor may not make up difference between the two. It is clear from this analysis that a Joist Girder system will be more economical than a steel truss.

CANAM Joist Girder

Description	Section	Length (m)	Material Unit Cost	Total Material Cost
Joist Girder	1800x110	22.5	280.61	$6,313.73
			Total Cost	**$6,313.73**

Steel Truss

Description	Section	Length (m)	Material Unit Cost	Total Material Cost
Truss	W530x66	1	252.14	$252.14
	W250x18	22.5	69.16	$1,556.10
	W360x64	23.95	247.25	$5,921.64
	HSS 51x51x4	16.037	101.23	$1,623.43
	HSS 51x51x3	25	101.23	$2,530.75
	HSS 89x89x5	16.234	226.8	$3,681.87
			Total Cost	**$15,565.92**

Table 5: Joist Girder and Truss Cost Comparison

3.4 Columns

Columns transfer the load from the roof structure to the foundations, and also aids in transferring the lateral load to the cross bracing. The columns of this building were designed according to CSA S16-09. In order to determine which section to use for each column, the applied loads and unbraced lengths were used to design against possible buckling. Each column was assumed to have a pinned connection at the base. W sections were selected for the exterior columns since they have good bending resistance and perform well as beam-columns.

The exterior columns were initially designed with the governing loading case of 1.25D+1.5S+0.5L. This load case generated the highest axial compressive force expected in the column. This force was used to choose the specific members from CSA S16-09. The columns were then checked against the highest expected lateral wind loads, to confirm that the initial design did in fact govern.

3.4 Beams

Beams are needed to transfer loads from the joists to the columns. All beams in the Recplex are W-sections that are simply supported. Tributary area method was used to calculate the design load on irregularly loaded beams. It was determined from discussion with the client not to use beams less than W310x28 for construction efficiency. In order to achieve efficiency in the beam design, most span lengths were less than 9 meters to prevent deflection from governing the design. However, due to the Lobby's irregular shape, some spans had to be greater than 9 meters.

3.5 Lateral Load Resisting

Design requirements for buildings have to include lateral wind load resistance structures. These members are able to transmit the lateral loads to the columns, foundations and eventually the soil. Bravo Consultants decided to design the Recplex using simply supported portal frames. These frames are pin supported and rely on other building members to make them stable, as they are statically indeterminate on their own.

Lateral bracing is needed to ensure the building will not collapse in the presence of wind loading. Cross bracing was the lateral bracing method chosen to transfer lateral loading to the foundation and soil. These cross braces are located on each exterior wall of the main buildings. Due to limitations from windows and doors, two 'K' brace sections were used; one on the Gymnasium and one in the Multipurpose building.

Since there is only cross bracing, Bravo Consultants has designed the roof to undergo diaphragm action. As wind blows on the side of the building, the top of the exterior wall will apply a horizontal force on the roof (diaphragm). The roof is then supported by the cross-bracing, which then transfer the lateral loads to the foundation by shear and bending on the exterior beams. This is the most common and economically efficient way of stabilizing an open plan building.

Diaphragm action is easier to achieve in buildings with flat roof systems. Since the Recplex has three large sections with sloped roofs, Bravo Consultants modelled the building in S-Frame and used S-Steel to determine the cross bracing members for adequate diaphragm action. (See Figure 12)

3.5.1 Moment Resisting vs. Simply Supported Frame

Bravo Consultants initially designed the building to have a moment resisting frame, which resisted all lateral loads as well as the vertical loading on the building. After consultation with the client, a simply supported frame was determined to be the preferred design. Although moment resisting structures have smaller joist girders, they have larger columns that are harder to conceal in walls. Simply supported portal frames are known to be cheaper than moment resisting frames. In order to determine the most cost effective design, Bravo Consultants performed a cost comparison on a single frame in the Gymnasium. The results are shown in Table 5.

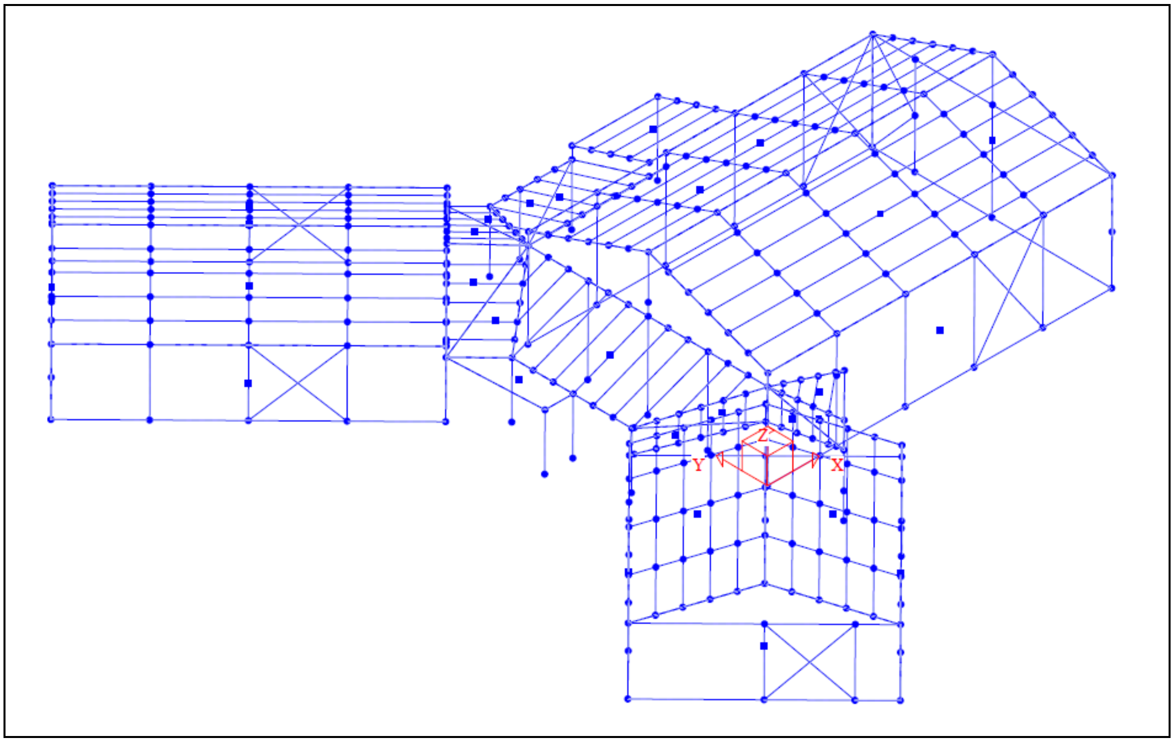


Figure 12: S-Frame Model of Building with Cross Bracing

Moment Resisting Frame vs. Simply Supported

Description	Section	#	Length (m)	Material Unit Cost	Total Material Cost
Columns	W530x150	2	9.15	581.4	$10,639.62
Truss	1350x65	1	22.5	163.39	$3,676.28
			Moment Resisting Cost		$14,315.90

Description	Section	#	Length (m)	Material Unit Cost	Total Material Cost
Columns	W200x71	2	9.15	275.4	$5,039.82
Truss	1800x110	1	22.5	280.61	$6,313.73
			Simply Supported Cost		$11,353.55

Table 6: Moment Resisting Frame vs. Simply Supported

The moment resisting frame is shown in Figure 13, the code checks and S-Frame output are included in Appendix H. The cost analysis confirms that the simply supported frame is the cheaper option, with a difference of $2,962.35 in bare material costs. Applying a savings of 26% to the rest of the building, Bravo Consultants was able to save almost $28,000 in material costs by using a simply supported design.

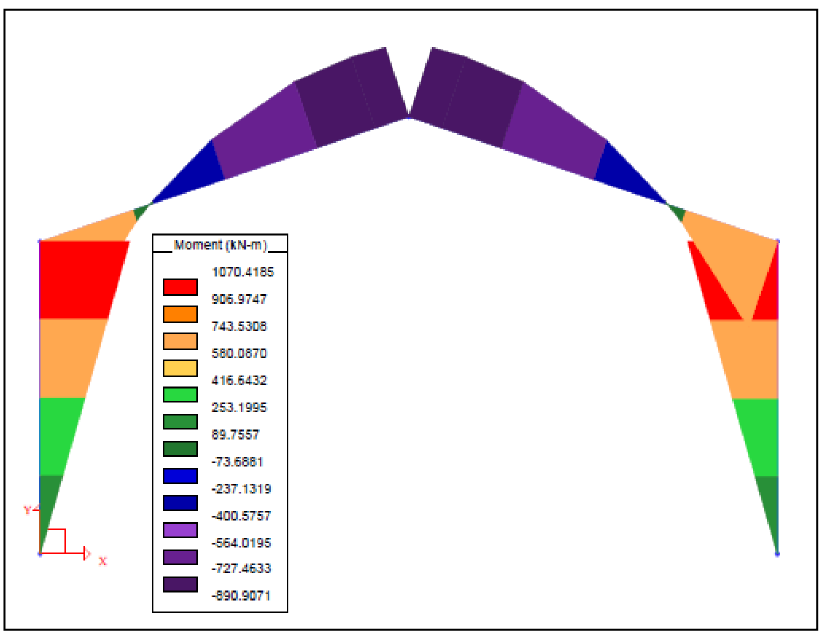


Figure 13: Moment Resisting Frame S-Frame Model

3.7 Lobby Design

The design of the Lobby section of this building was more complex than the rest of the building sections (Figure 14). With the consideration of using pre-engineered buildings for the Gymnasium, Multipurpose and Fitness center, the Lobby has to be conventional steel due to its irregular shape. The column and beam locations were confirmed with the client prior to design of the members.

In order to effectively design the specific members, the lobby was split into sections. Each section had different snow and wind loads based on its location, which caused the design to consist of multiple OWSJ's and beam sections. In order to make the design more efficient for construction, three governing OWSJ sections were chosen to use throughout the entire Lobby.

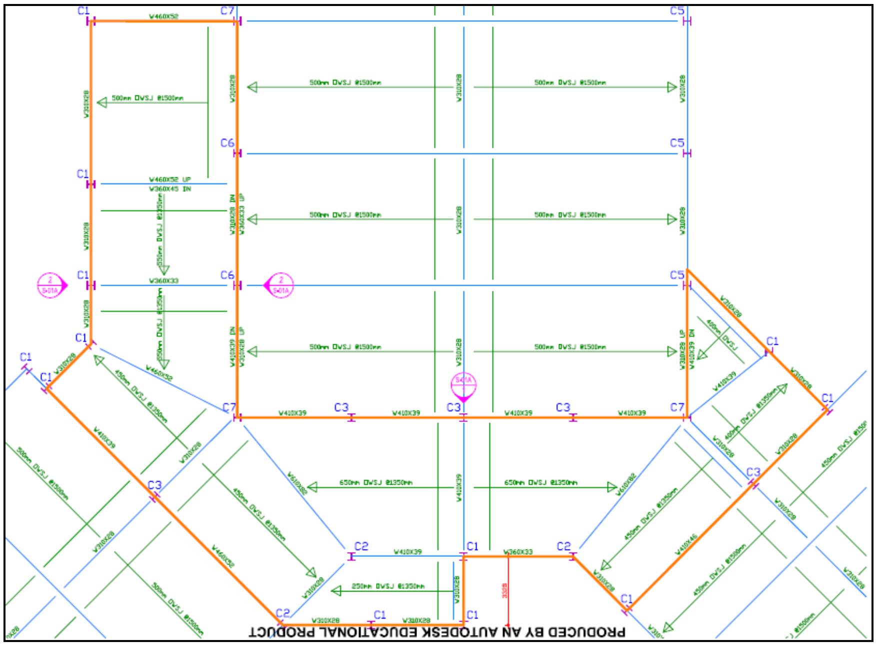


Figure 14: Lobby Design and Sections (Outlined in Orange)

3.8 Mezzanine Design

There were two Mezzanine areas required in the Recplex design which are located in the Multipurpose and Fitness Center (Figure 15). These areas are required for mechanical equipment (HVAC, etc.). Typically, a load of 3.6 kPa is used for mechanical equipment areas as per NBCC 2010, however a load of 4.8 kPa was provided by the client for design. In practice, mechanical equipment is determined by a subcontractor and can weigh more than the standard load.

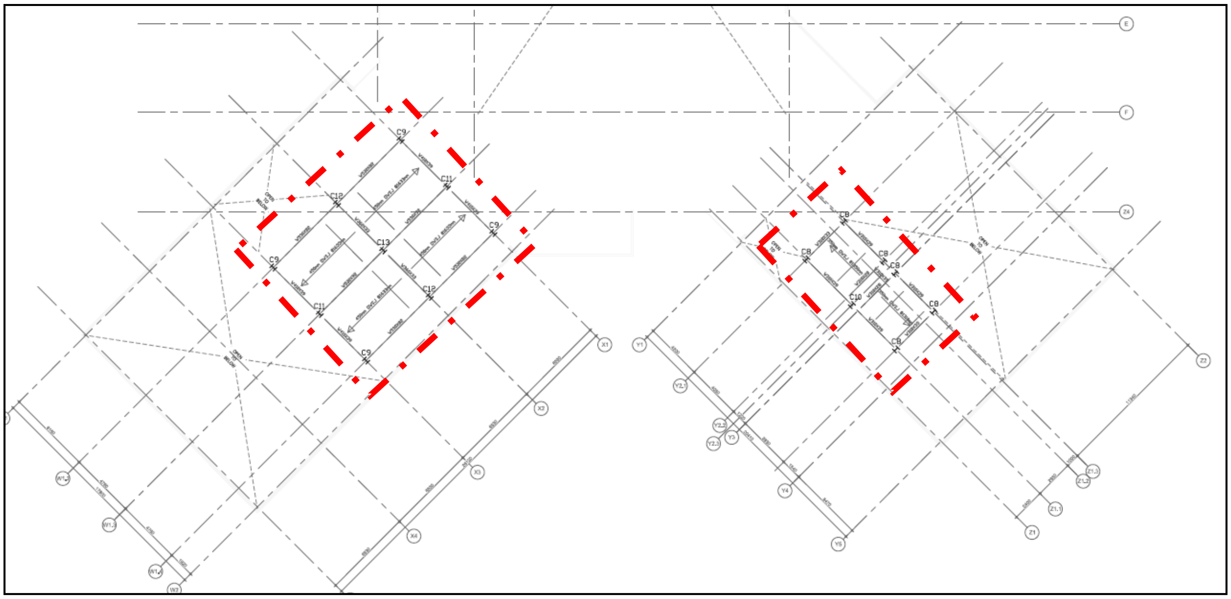


Figure 15: Mezzanine Locations

Figure 16 illustrates the different design components of the Mezzanine. Type 16 P-3615 Composite decking was chosen for the floor, which consists of a steel deck and a 90mm concrete topping. Hollow Structural Sections (HSS) were selected for the columns in both mezzanine areas. These sections were selected higher resistance to buckling are easier to conceal in the partition walls on the main floor.

The architectural drawings show perimeter walls around both mezzanine areas however, the drawings did not indicate what type of wall this was. Bravo Consultants designed the walls as 4 meter masonry walls to get the worst case loading on the structure. This was done to ensure that the design was adequate and will cover any extra weight that could be added to the areas during construction.

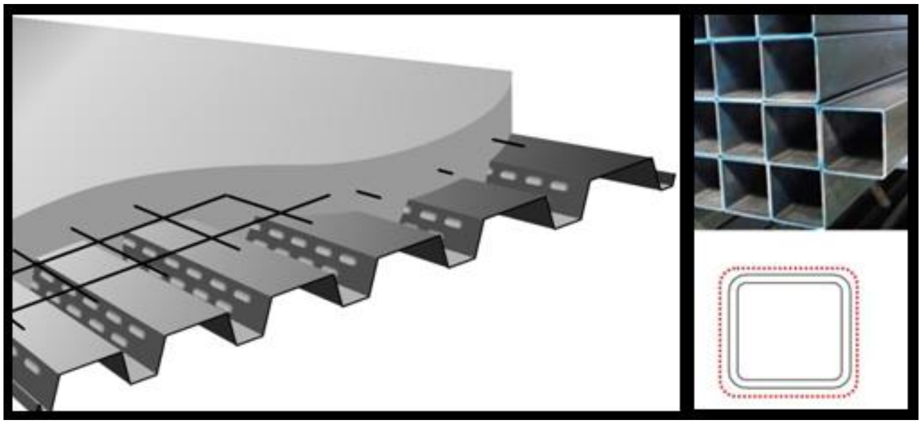


Figure 16: Mezzanine Design Components

4.0 Concrete Design

All Concrete designed in this section is normal weight, 25 MPa. Detailed calculations are included in Appendix D.

4.1 Foundation

Foundations are necessary to transfer loads from the structure to the underlying soil. According to the geotechnical report provided by the client, the soil has a maximum net allowable bearing pressure of 200 kPa.

Concrete footings were needed for all columns in the Recplex; the final design is shown in Figure 17. Footings evenly distribute the column load over a larger area of soil. The weight of the soil was taken to be 20 kN/m^3. The footing area was calculated using allowable stress design.

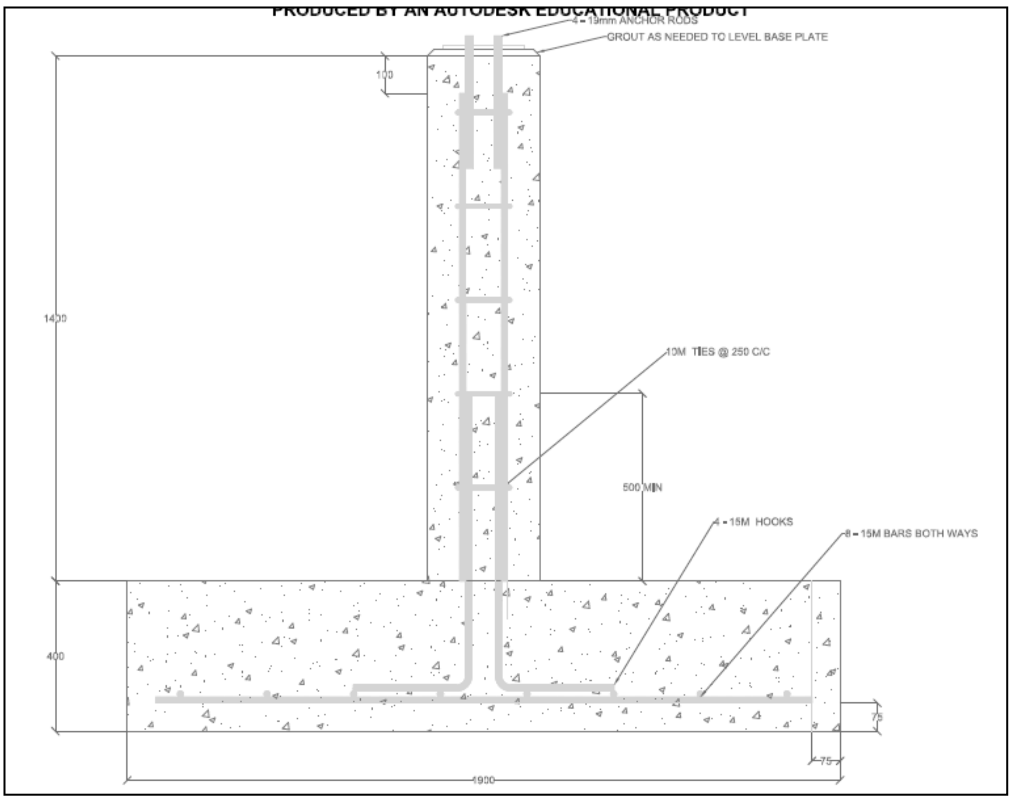


Figure 17: Foundation Footing Detail

The concrete footings and piers were then designed using limit states design, according to CSA A23.3-04. The concrete pier area was calculated by dividing the factored load by half of the compressive strength of concrete. The minimum area of steel was calculated using the equations:

$$A_{s,min} = 0.005A_g \text{ (Footing)}$$
$$A_{s,min} = 0.01A_g \text{ (Pier)}$$

The largest minimum area of reinforcement generally governs the design. Once the dimensions were determined, each footing was checked for punching shear, one way shear and bending.

The foundation piers were governed exclusively by the geometry of columns above since the anchor bolts required would have to fit into the steel reinforcing of the pier.

The Recplex also needed wall footings to support the exterior walls of the building. These walls were designed per meter length for a height of 1800mm. The thickness was designed to be 250mm thick. Reinforcement for the wall footings is mostly needed for crack control.

4.2 Slab on Grade

A simple slab on grade was required for the building floor, which is supported mainly by the ground beneath it. The slab was designed as per ACI-360R-92 for shrinkage and temperature only, as there are no vehicles or heavy loads on the floor system. After meeting with the client, a thickness of 100mm was chosen to be acceptable. The minimal area of steel for a floor slab according to ACI-360R is calculated as follows:

$$A_s = \frac{FLw}{2f_s}$$

Where:
A_s = cross sectional area in sq. in. of steel per lineal ft.
f_s = allowable stress in reinforcement, psi
F = Friction factor (commonly taken as 1.5)
L = Distance in ft. between joints
w = dead weight of slab in psf

Bravo Consultants decided to use wire mesh as the preferred reinforcement for the slab on grade. Using the Welded Wire Reinforcement Manual of Standard Practice, wire mesh sections were selected at a spacing of 152 mm for each section of the slab. The governing wire mesh section was determined to be 152x152 – MW19xMW15. This section was then used throughout the entire building for more efficient construction. The calculations for this floor slab are in Appendix D.

The floor slab requires control joints for shrinkage or temperature cracks. The joints act as a guide to control where cracks will happen in the slab. These are generally designed from column to column with spans no greater than 9m in each direction. They also have to be cut at 90 degree angles around column bases. The final floor slab details are shown in Figure 18 for both longitudinal and transverse sections.

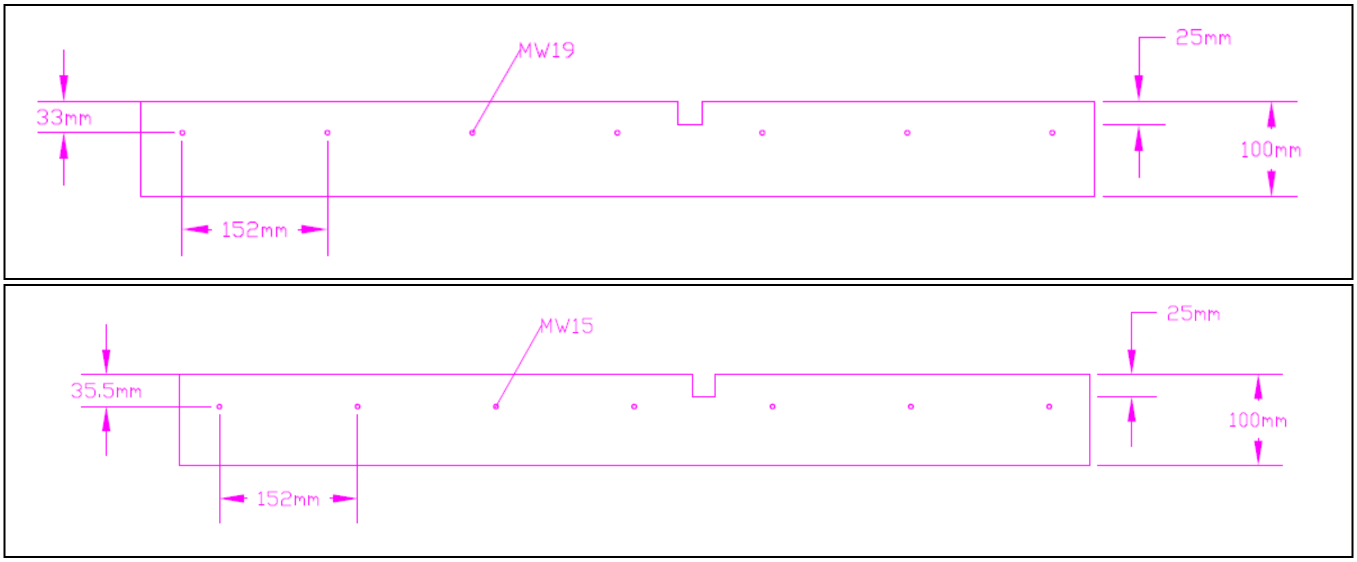


Figure 18: Slab on Grade Details

5.0 Cost Estimates

The client requested a class C estimate for the conventional steel design, as well as a budget estimate for pre-engineered buildings. The following cost estimate was completed using RS means and the material quantities based on the final design.

5.1 Conventional Steel

The Following is a Class C estimate which has been prepared using RS Means. A more detailed cost breakdown is provided in Appendix G. Due to the nature of RS Means, some of the exact steel members were not available. Because of this, Bravo Consultants priced the members based on similar sections.

	Materials	Construction	Section TOTAL
Gymnasium	$147,209.05	$13,467.50	$160,676.54
Fitess Center	$91,163.13	$9,884.14	$101,047.27
Multipurpose	$70,911.09	$9,238.98	$80,150.07
Mezzanine #1	$32,188.56	$4,408.65	$36,597.21
Mezzanine #2	$11,301.02	$2,683.76	$13,984.79
Lobby	$74,901.21	$9,602.49	$84,503.70
Concrete	$109,613.71	$24,765.07	$134,378.78
Sub Totals	**$537,287.78**	**$74,050.59**	**$611,338.37**

Allowances

Scaffolding (15%)	$91,700.76
Fabrication (15%)	$91,700.76
Shipping (10%)	$61,133.84
Contingency (25%)	$152,834.59

GRAND TOTAL:	**$1,008,708.31**

5.2 Pre-Engineered Building

Bravo Consultants contacted Butler Building Systems for a budget estimate on the three main building sections (Gymnasium, Multipurpose and Fitness Center). The representative provided a rough budget estimate of $85/ft^2 over the telephone. Bravo Consultants used this value to calculate the following price:

	Conventional Steel	Pre-Engineered
Gymnasium	$265,116.30	$594,052.64
Fitness Center	$166,728.00	$305,845.02
Multipurpose	$132,247.62	$394,023.73
Totals	**$564,091.91**	**$1,293,921.39**

6.0 Recommendations

Bravo Consultants would like to make the following recommendations based on the findings of this report:

- The final design should include joist girders instead of conventional steel trusses to save money and possibly have a decreased depth and more overhead room.
- Simply supported portal frames with cross bracing and diaphragm action should be used to resist lateral wind loads
- A more in depth Pre-Engineered Building quote should be obtained before the final design decision is made.

7.0 Acknowledgments

- Krista Hancock, AE Consulting Ltd.
- Dr. Steve Bruneau, Memorial University Faculty of Engineering
- Dr. Amgad Hussein, Memorial University Faculty of Engineering
- Justin Skinner, Suncor Energy

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