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Building Engineering Feasibility Study: Herreshoff Marine Museum

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Building Engineering Feasibility Study

Community Partner: *The Herreshoff Marine Museum - Bristol, RI*

Academic Partner: *School of Engineering, Computing & Construction Management*

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HERRESHOFF MARINE MUSEUM

Team Roger Reliance [P5]

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Abstract

The Herreshoff Marine Museum, bordering Narragansett Bay in Bristol, Rhode Island, is best known for housing an unequaled collection of pristine yachts and ship replicas built by the Herreshoff staff. These ships are on display accompanied by “storyboard” picture exhibits depicting the life of each. The next addition to the museum is an astonishing $1/6^{th}$ scale replica of the famous 1903 America’s Cup winner *Reliance.* The goal of this project is to make this model the cornerstone display and center of attraction for the museum. Since the museum would like to display as many exhibits as possible, a proposed addition to the existing building is necessary to house the new *Reliance* exhibit. Along with an enhanced visitor experience, based on the interior function and flow, the new design must encompass an exterior aesthetic fitting to the Bristol Historic District while also having *Reliance* visible to attract passersby on Hope Street.

Our design team was supplied with a dozen architectural designs from the students of the Roger Williams University Architectural School. After discussing the strengths and weaknesses of each our team was able to narrow our choices down to one base design to conduct our feasibility and structural integrity analysis. Currently, the structural integrity of the proposed building addition has been examined by determining the wind and the snow loads, the green roof requirements, and the column and beam loads. The feasibility of the chosen design was assessed by researching Bristol zoning regulations and developing a path through the required zoning variances, which will help in the construction phase.

Table of Contents

List of Tables

List of Figures

List of Acronyms

FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
HMM	Herreshoff Maritime Museum
TA	Tributary Area
Zone M	Manufacturing zone

Introduction

The Herreshoff Marine Museum/Americas Cup Hall of Fame (HMM) is dedicated to the education and inspiration of the public through presentations of the history and innovative work of the Herreshoff Manufacturing Company and Americas cup competition. Over the past decades HMM has collected various models of beautiful Herreshoff yachts, they just recently embarked on a new strategy to empathize a more comprehensive range of maritime and Americas Cup exhibits. The Reliance project is perhaps the most ambitious of their Americas Cup models. The museum is currently building a 1/6th scale replica of the famous 1903 Americas Cup winner “Reliance” which will become the cornerstone display and source of related museum exhibits. This model will be 33’ in length and more than 37’ in height.

For this design project our general goal is to help run a number of analysis’ and evaluations which ultimately decide on a final architectural design that helps properly display the model Reliance. The structural additions were supplied by a dozen of Roger William’s architecture students. In this project our clients, Larry Lavers, chief operating officer, and Sandy Lee, Reliance Project Manager, are asking our design team to conduct three tasks. For the first task, to develop a brief engineering project plan to include statement of objectives, scope, resources, tasks, schedule, and cost estimate of HMM to review and approve. For the second task, conduct an engineering study to determine the structural integrity, the feasibility and complexity of design that impacts cost, risk and beneficial use, and to identify the elements for improvement, whether materials, structure, aesthesis. Lastly, for the third task, complete a cost estimation and risk assessment activities. In addition, critique whether the design optimizes beneficial use of the design for One Burnside.

Specifications

This Engineering Study Project was organized by the Herreshoff Marine Museum (HMM). This museum also includes America’s Cup Hall of Fame. We have two clients for this project, Sandy Lee the HMM Board of Directors and Larry Lavers the HMM Chief Operating Officer. Recently HMM has been trying to improve an emphasis on their America’s Cup exhibits. One of their most ambitious endeavors is The Reliance project. This 1/6th scale model is being built at the museum and will eventually be put on display in the building’s hopeful new exhibit. In addition to the Reliance exhibit, HMM would also like a new formal entrance and a cafeteria. They would also like to enlarge the multi-use room and bathroom. Not only is there going to be interior renovations, but also the exterior will also be revamped. The architecture’s designs need to take into consideration the Town of Bristol’s historic charter. The design should be aesthetically pleasing while also incorporating “ship-like” materials.

As engineers, we will also assess the architecture's designs. This will include feasibility and structural integrity analysis, a check for elements of improvement and a cost and risk analysis. Since the existing building does not meet a height large enough to actually fit the Reliance model, there will have to be investigating into sinking the models cradle into the ground while also taking into consideration the town of Bristol's 35 ft. height restriction. We will also make sure the proposed new building design is structurally sound against hurricane and floods conditions that may come about in Rhode Island weather. We will determine beneficial materials to use in this design that are affordable.

At the end of this Engineering Study Project we will need to meet a few desired outcomes. Since Bristol is a tourist attraction, HMM would like this new design to attract more visitors. This museum will be competing against other marine museums and we would like HMM to be a successful museum that attracts people internationally to Bristol. Lastly we will need to meet a budget of $1.3 million. This is an amount the museum hopes to fund by donations, fundraisers, admission etc.

Alternative Design Solutions

For our design selection we took the top 3 choices chosen by our clients, Larry Lavers and Sandy Lee, each of the 3 designs had unique interior and exterior aesthesis. Our clients stressed to us which features they liked best about each architectural plan. For Design 1, Marc Sullivan's, they were pleased with his overall exterior look and how it resembled a sailboat, they also liked his green roof aspect and his plan to excavate down in order to fit the Bristol Town height restrictions. For Design 2, Kate Ford's, they favored her interior flow of the museum and her addition of an upstairs café and terrace facing the waterfront. For Design 3, Nate Carden's, they thought his exterior design of the tall cables representing a mass and the addition of a possible copula were very interesting. For the selection process we made a list of the crucial characteristics based off of our design requirements and put them into a radar chart where we ranked each design on a scale from 1 to 5 on how they met these characteristics; the radar chart can be viewed on Appendix A. Once that was completed we choose the design on the radar chart with the largest area, meaning it covered the most design requirements. Our final chosen design was Design 1, Marc Sullivan's.

Project Planning

The design goals set forth for this semester were intended to narrow design choices to conduct a feasibility study on a base design that our clients agreed on. Schedule organization was important for a successful semester study because tasks can be tracked and planned. The final version of the Gantt Chart based upon a CPM diagram for this semester is shown in Appendix B.

Engineering Analysis

Wind Load Analysis

It is important to look into Herreshoff's structural integrity in this feasibility analysis since their components need to be designed to withstand the code-specified wind loads. In this analysis we used the textbook "Principles of Structural Design (Wood, Steel, and Concrete)" by Ram S. Gupta for a basis of all of our wind and snow load calculations. The table below shows the factors that were needed in order to calculate the wind loads, the tables used from the textbook can be found in Appendix C. The adjustment factor (ʎ) was selected based off the location of the museum, which is along the coast making the region hurricane prone. The importance factor (I) was decided upon the type of occupancy of the museum, we choose high occupancy for best case scenario of the museum being very populated. The wind speed of Bristol, RI was determined using the MWFRS Figure in the text, also viewed on Appendix C.

Wind pressure=Ps=(ʎ)(k)(I)(Ps30)			
ʎ=	Category 'C' (Hurricane Prone)		
	Mean Roof Height = 35 ft		
	From Table 4.3		
ʎ=	1.45		
k=	Topographic Factor=		1
I=	Category '3', High Occupancy=		1.15
Ps30	90 mph according to MWFRS Figure		
	Wind Speed	**Angle**	
	90mph	0°-5°	

Table 1 Factors determined in needing to calculate wind loads

For the traverse wind direction on the horizontal wind pressure of the wall and roof projection, a table was set up below to easily calculate the loads at the roof angle. Since our roof slope is very minimal we choose the smallest category of 0-5 degree angle. We then used those factors on Table 4.4, Simplified Wind Pressures, referenced in Appendix C, to locate the correct horizontal and vertical pressures at different zonings on the wall and roof. Shown below are the tables with the values.

Zone	Roof angle		Ps=1.15Ps30
A. End zone wall	12.8	=Ps30	14.72
B. End zone roof	-6.7		-7.705
C. Interior wall	8.5		9.775
D. Interior roof	-4		-4.6

Table 2 Horizontal wind pressure on wall and roof projection

For the vertical wind pressures on the roof, a table calculation was set up. It contains a minimum pressure of 10 psf since the calculated pressures computed to be negative numbers and do not comply with the rule for components and cladding, "the positive pressure, p_{net}, should not be less than +10 psf and the negative pressure should not be less than -10 psf."[1]

Zone	Roof angle		Ps=1.15Ps30	Min Ps
A. End, windward	-15.4	=Ps30	-17.71	10
B. End, leeward	-8.8		-10.12	10
C. Interior, windward	-10.7		-12.305	10
D. Interior, leeward	-6.8		-7.82	10

Table 3 Vertical wind pressure on the roof

The horizontal total load at roof level is shown below in Table 4. It is separated into the following four pressure zones, end zone of wall, end zone of rood, interior zone of wall and interior zone of roof. "The dimensions of the end zones A and B are taken equal to '2a,' where the value of 'a' is smaller of the two values, 0.1 of the horizontal dimension or 0.4 times the rood height." [2] The tributary area was necessary to be calculated for each of the height and width to find the areas. The pressure was then computed in order to find the resulting load in pounds. The two negative pressures in zone B and D are to be treated as zero.

		Tributary Area				
Location	**Zone**	**Height(ft)**	**Width(ft)**	**Area(ft²)**	**Pressure**	**Load(lb)**
End	**A**	17.5	18.4	322	14.72	4739.84
	B	0	18.4	0	-7.705	0
Interior	**C**	17.5	141.6	2478	9.775	24222.45
	D	0	141.6	0	-4.6	0
Total						28962.29

Table 4 Horizontal force at the roof level

The horizontal force at the second floor level calculations can be viewed in Table 5 below, this is a separate table found when the pressures above were treated as zero. The total load comes out to be 28,962.3 lbs.

[1] Pg. 67 of Principles of Structural Design (Wood, Steel, and Concrete)
[2] Pg. 53 of Principles of Structural Design (Wood, Steel, and Concrete)

		Tributary Area				
Location	**Zone**	**Height(ft)**	**Width(ft)**	**Area(ft²)**	**Pressure**	**Load(lb)**
End	**A**	17.5	18.4	322	14.72	4739.84
Interior	**C**	17.5	141.6	2478	9.775	24222.45
Total						28962.29

Table 5 Horizontal force at the second floor level

The vertical forces on the roof are likewise separated into the following four zones; end zone of windward roof, end zone of leeward roof, interior zone of windward roof and interior zone of leeward roof. The minimum pressures from Table 3 are used to calculate the loads. The final vertical windward and leeward force on the roof are 128,000 lbs.

		Tributary Area				
Zone		**Length(ft)**	**Width(ft)**	**Area(ft²)**	**Pressure**	**Load(lb)**
Windward	**End**	80	18.4	1472	10	14720
	Interior	80	141.6	11328	10	113280
	Total					128000
Leeward	**End**	80	18.4	1472	10	14720
	Interior	80	141.6	11328	10	113280
	Total					128000

Table 6 Vertical force on the roof

Snow Load Analysis

Snow load is a controlling roof load in about half of all the states in the United States. It is a cause of frequent and costly structural problems, so it is importance for us to evaluate Herreshoff's structure integrity once the snow load is applied. The equation below in Table 7 is the basic snow load to which a structure is subjected to. To determine those factors, tables were used on Appendix D, to best fit the situation of HMM. The importance factor remained the same from the wind load analysis; the thermal factor was in the thermal conditioning of "just above freezing or well insulated, ventilated roofs," [3] the exposure factor for the snow load fell into Category C, which was fully exposed and on a waterfront property, and lastly the roof slope remained in the cold roofs category since our thermal factor was 1.1 and since we have a very low sloped roof.

[3] Pg. 34 of Principles of Structural Design (Wood, Steel, and Concrete)

ps=0.7CsCeCtIpg		
pg (the ground snow load)=	30	lb/ft2
I (importance factor)=	1.1	Category III High occupancy structure
Ct (Thermal Factor)=	1.1	Just above freezing, well-insultated, ventilated roofs
Ce (Exposure Factor)=	0.9	Terrain C, Fully Exposed
Cs (Roof Slope Factor)=	1	Cold Roofs (Ct=1.1, θ=0°-10°)
ps =	22.869	lb/ft2
Add rain-on-snow surcharge		
an extra load of 5 lb/ft2 has to be added due to rain on snow		
pb=	27.869	
since roof slope is <2.4° there is no unbalanced drift snow load		

Table 7 Snow Load factors and calculations

The final calculated snow load computed to be 22.9 lb/ft^2 and "an extra load of 5 lb/ft^2 has to be added die to the rain on snow for locations where our roof slope is very low. This extra load is only for the balanced snow load case and should not be used in the partial, drift, and sliding cases."[4] Also since our roof slope is less than 2.4 degrees there is no unbalanced drift snow load. Overall our final rain on snow surcharge computed to be 27.89 lb/ft^2.

Green Roof Load Analysis

Green Roofs:[5]

Green roofs offer significant long-term economic and environmental advantages that justify the higher cost than a typical bare roof:

Aesthetic. Green roofs are visually attractive and the wild plant life is much more appealing than a typical stark roof surface.

Energy-Efficient. The thermal mass of the soil reduces heat gain and loss by averaging temperature extremes. This aspect would be beneficial to the quality upkeep and maintenance of the ships on display.

Reduce Storm water Runoff. Typically, the green roof will retain up to three-quarters of the annual rainfall and redirect the remaining runoff.

[4] Pg. 35 of Principles of Structural Design (Wood, Steel, and Concrete)
[5] Conservation Technology, Inc. published Green Roof Handbook. Appendix F

Permanent. The waterproofing is shielded from the sun and temperature swings are reduced. This allows the synthetic membrane to last more than 50 years.

Although the anatomy of a green roof remains constant in its eight required functional layers (sturdy roof structure, reliable waterproofing membrane, root-barrier/ponding membrane, tough protection mat, water-storing drainage layer, non-clogging separation fabric, engineered soil, and appropriate plant life), the type of drainage system varies based on the structural components of the building in question as well as the availability of labor and expenses. The combination of the drainage type and nominal thickness determines the structural load, allowable slope, type of vegetation, and rainwater retention characteristics.

The nominal thickness is the approximate total height of the soil and drainage components of the green roof system. The variation in thicknesses of the green roof supports the different types of plant life that can be brought to the environment of the building. The four different thickness types include:

- Type 1 (3” to 4”), supports sedums and herbs
- Type 2 (5” to 7”), supports sedums, herbs, and perennials
- Type 3 (8” to 11”), supports perennials, grasses, and shrubs
- Type 4 (12” +), supports grasses, shrubs, and trees

The 3 different types of drainage systems include:

1. *Drainage Plates.* Drainage plates are waffled plastic sheets that retain water within pockets on the upper sides and allow excess water to flow through small holes and over the edges to be carried off the roof. This drainage system is the most popular choice because it is lightweight, easy to install, and recommended for a roof slope less than 1:12.

	P1	P2	P3	P4
Typical Plants	Sedum, herbs	Sedum, herbs, perennials	Perennials, herbs, shrubs	Grasses, shrubs, trees
Nominal Thickness	4”	7”	10”	14”
Dry Weight	13 lbs/ft^2	21 lbs/ft^2	34 lbs/ft^2	51 lbs/ft^2
Saturated Weight	21 lbs/ft^2	34 lbs/ft^2	53 lbs/ft^2	78 lbs/ft^2
Water Retention	50%	60%	70%	80%

Table 8 Drainage Plates Specifications

2. *Granular Drainage.* Granular drainage consists of a base layer of lightweight, inorganic, granular media. The granular media should contain a large percentage of porous material, such as heat-expanded rock, with slotted plastic drainage conduits embedded within. Compared to other drainage systems, granular drainage is heavy, labor-intensive to install, and recommended for roofs with slopes less than 1:12. Positively, granular drainage provides an optimal environment for plant root growth.

	G1	G2	G3	G4
Typical Plants	Sedum, herbs	Sedum, herbs, perennials	Perennials, herbs, shrubs	Grasses, shrubs, trees
Nominal Thickness	4”	6”	10”	14”
Dry Weight	16 lbs/ft^2	24 lbs/ft^2	40 lbs/ft^2	56 lbs/ft^2
Saturated Weight	23 lbs/ft^2	36 lbs/ft^2	58 lbs/ft^2	82 lbs/ft^2
Water Retention	50%	60%	70%	80%

Table 9 Granular Drainage Specifications

3. *Drainage Mats.* Drainage mats are multi-layer fabric mats that combine soil separation, drainage, and protection functions. Compared to the other drainage systems, drainage mats are the fastest, easiest, and lightest to install. However, this system is primarily used for buildings with a roof slope greater than 1:12 (residential green roofs).

	M1	**M2**
Typical Plants	Sedum, herbs	Sedum, herbs, perennials
Nominal Thickness	3”	5”
Dry Weight	13 lbs/ft^2	21 lbs/ft^2
Saturated Weight	20 lbs/ft^2	32 lbs/ft^2
Water Retention	50%	60%

Table 10 Drainage Mats Specifications

The Design:

Marc Sullivan’s design encompasses several different sustainable features including a Green Roof, Heating/Cooling Mass, Double Envelope Glass, and use of local materials. The Green roof in this design is meant to provide added insulation for the building, create a natural wildlife habitat, and collect and redirect rainwater.

The recommended green roof design for the new Herreshoff Marine Museum addition is composed of the drainage plate green roof system with the 4” nominal thickness (P1). Drainage plates are ideal for this type of structure because of the minimal roof slope, low nominal thickness, and the ease of installation. A cross-sectional view of the green roof design for this structure is shown in Figure 1. The thickness of the materials is important for this design because the Herreshoff building is in the Historic District of Bristol and there is a height restriction of 35 feet in place. Granular and Drainage Mats were not considered for this design because granular drainage consists of a base layer fo granular media which is too heave and labor-intensive to install for this structure. Also, drainage mats are mainly intended for buildings with a steep roof slope.

The dry and saturated weights of the proposed green roof system are 13 lbs/ft^2 and 21 lbs./ft^2, respectively. Including the existing structure, the roof square footage of the new design is approximately 20,112 square feet. Therefore, the extra dry and saturated loads on the roof will be approximately 261,456 lbs. and 422,352 lbs., respectively.

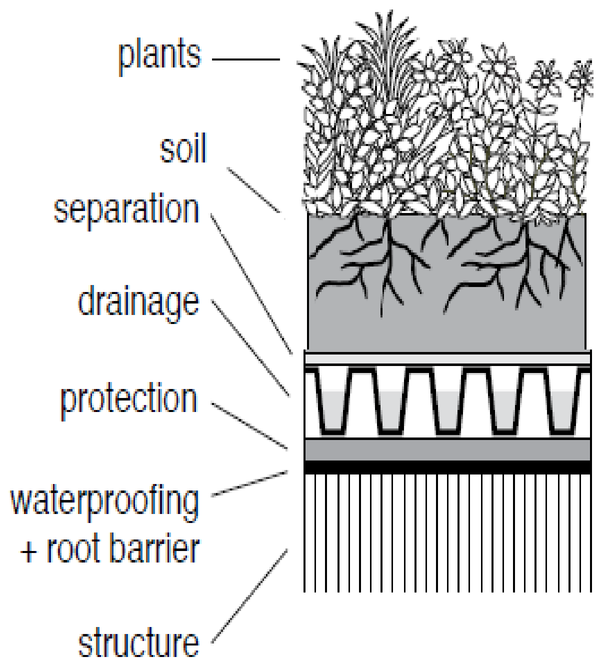


Figure 1 Proposed Green Roof Design

Column and Beam Design Loads

We used Principles of Structural Design (Wood, Steel and Concrete) by Ram S. Gupta for a basis for the beam and column analysis. To begin the column and beam load analysis we took a look at the newly designed floor plan. As show in Figure 2 the new addition is outlined in red. The existing floor plan is in blue. From this layout, one column and one beam was chosen to be analyzed (the column in black and the beam in green).

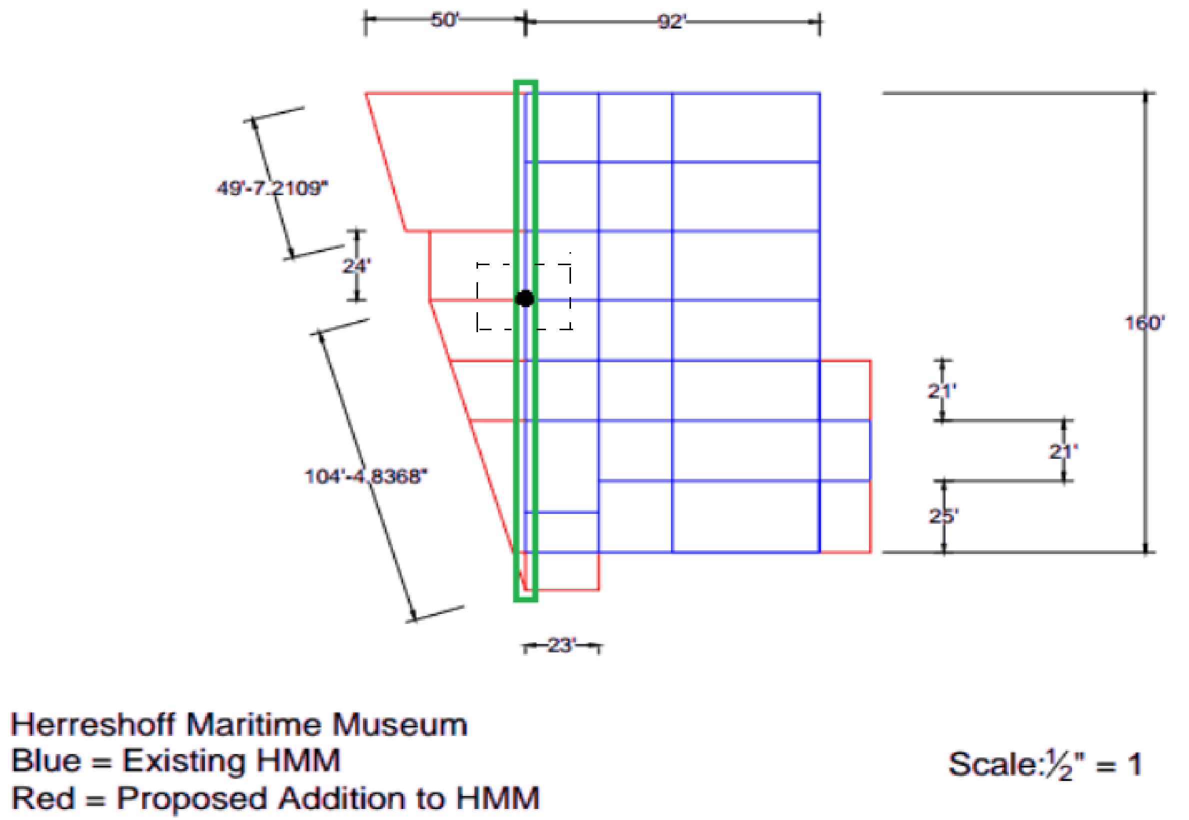


Figure 2 Selected column and beam chosen for analysis

The analysis started off by collecting the load values being placed upon the structure. As found previously, the snow load with addition of saturated rain is 27.9 psf and the wind load is 10 psf. In addition, the proposed design will include a green rood that places a 21 psf load on the roof. This 21 psf load will be added into the original dead load of 20 psf, making the dead load a final 41 psf. The last load need is the live load. This was found from Table 2.1 in our book, Principles of Structural Design (Wood, Steel and Concrete) by Ram S. Gupta, which is listed in Appendix E.[6] A basic design load of 100 psf was chosen from this table. The 100 psf load was determined because the structure is a museum, which is a public place carrying a heavy traffic from many people.

With all of the possible loads now determined, we began to find the load combination that would best suit a distributed load placed upon the structure. Three equations were used from The Combination of Loads listing found in Appendix E. After plugging in the load values, three distributed loads, Wu, were determined. From these three, a final Wu was found to be 193.84 psf. Here are the calculations for the distributed loads:

[6] Appendix A shows Table 2.1 from Principle of Structural Design (Wood, Steel and Concrete) by Ram S. Gupta

Combinations of loads:

DL = 41 psf
LL = 100 psf
SL = 27.9 psf
WL = 10 psf

1.2(DL)+1.6(SL)+LL = **193.84 psf**

1.2(DL)+1.6(SL)+WL = 103.844 psf

1.2(DL)+1.6(WL)+LL+0.5(SL) = 179.15 psf

Now that the distributed load was determined we have a load that will be placed upon both the column and beam. To being the column analysis we needed to find the area this load was going to be placed upon. The tributary area around the column was found to be 596.25 ft^2. We then assumed the weight of the column and with the expected height of 17.5 ft. we were able to find the factored weight of the column. This weight was added to the distributed load to find a concentrated load, Pu, of roughly 120 kips exerted upon the column.

TA = 596.25 ft^2
P_u = TA · W_u = 596.25 ft^2 · 193.84 psf = 115,580 lbs.

Assume weight of column to be 50 lbs/ft
Length of column is 17.5 ft.
Weight of column =50 lbs/ft·17.5 ft.= 875 lbs.
Factored weight = 1.2 · 875 lbs. = 1050 lbs.

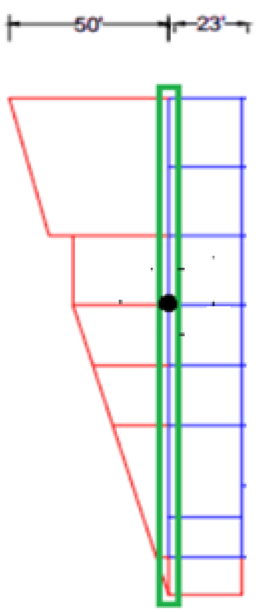
P_u = 115,580 lbs. + 1050 lbs. = 116,630 lbs. = 116.6 k

For the beam analysis, we started off finding the triangular and rectangular loads place upon the column from the tributary area. Figure 3 depicts this. These loads were incorporated with the distributed load found earlier to find a concentrated load of roughly 7 k/ft. placed upon the length of the beam. Next semester, we will analyze and create all of the columns in the new addition and will create continuous beams that will be able to withstand the long length of the building.

W_u = 193.84 psf

Rectangular Load = 11.5 W_u= 4846 lbs.
Triangular Load = 25 W_u= 2229.16 lbs.

Total Load = 4846 lbs./ft. + 2229.16 lbs./ft.
= 7075.16 lbs./ft. = 7.075 k/ft.



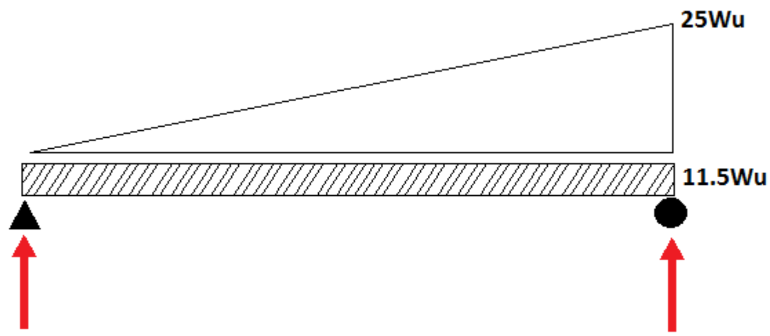


Figure 3 Rectangular and Triangular Loads on beam

Beam Selection

In order to reduce the maximum moment acting on the beams of the addition, diagonal knee braces are to be added to provide additional support to the beam at approximately 0.2L from each column. The moment diagram for a 24 ft beam can be reduced from 330 kip·ft to 240 kip·ft.

Using the reduced moment, suitable beams were selected using the equation:

$$M_p = \sigma_y Z$$

Where M_p is the maximum moment stated above, σ_y is the yield stress of A36 steel and Z is the plastic section modulus of the beam. The calculation yields a Z requirement of at least 80 in^3. The following table lists several beams sufficient for this design:

Shape	Z_{actual} [in^3]	Depth [in]	Area [in^2]	Weight [lb/ft]
W10x68	85.3	10.4	20.0	67.2
W10x77	*97.6*	*10.6*	*22.6*	*75.9*

W10x88	113.0	10.8	25.9	87.0
W12x58	86.4	12.2	17.0	57.1
W12x65	96.8	12.1	19.1	67.2
W14x53	87.1	13.9	15.6	52.4
W14x61	102.0	13.9	17.9	60.15

For this design, **W10x77** beams will be used because it provides a sufficient plastic section modulus combined with a minimum depth, as to not take up any extra space.

Column selection

Using the loading outlined in the *Column and Beam Design Loads* section for the second floor columns and adding 25.63 psf for the first floor columns, the column was designed using the following formulas:

$$P_u = \phi F_y A_g$$

Where P_u is the load capacity, φ is a load reduction factor equal to 0.9, F_y is the yield stress of A36 steel and A_g is the gross area of the column. The equation yields a required A_g of 3.70 in^2 for the first floor and 4.19 in^2 for the second floor. The following table lists columns suitable for this design:

Shape	**Area [in^2]**	**Weight [lb/ft]**
W10x17	4.99	16.77
W10x19	5.62	18.88
W10x30	*8.84*	*29.70*
W12x16	4.71	15.83
W12x30	8.79	29.53
W14x22	6.49	21.81
W14x30	8.85	29.74

For this design, W10x30 columns will be used because it provides sufficient gross area for both the second and first floor.

Steel Cost Estimation

The cost estimation of steel was produced using *Walker's Building Estimator's Reference Book.* Using the members listed above, approximately 40 tons of steel will be needed for the addition. An estimation was made for Boston ,MA and Providence, RI using inflation factors for these regions. Providence is probably the most accurate estimation, given its proximity to Bristol, RI.

The estimation includes information on the shop painting on structural steel, structural steel work (including fabrication and transportation), the erection of steel, and the cost of bolting steel. The summarized cost of steel is shown below. For the complete steel estimation, see Appendix:

Providence			Boston		
Price of structural steel, delivered at job	$	155,672.93	Price of structural steel, delivered at job	$	163,583.37
Cost of Erecting Steel	$	60,809.26	Cost of Erecting Steel	$	65,228.13
Cost of Bolting Steel	$	3,835.93	Cost of Bolting Steel	$	4,573.61
Total Cost	$	220,318.12	Total Cost	$	233,385.10

Dimensional Layout

The proposed addition to HMM is shown in Figure 4 and Figure 5. The dimensions of the proposed structure were calculated through a combination of the architect's design, the requested additional space to accommodate HMM's intended use, and maximum conformity to the zoning regulations of Zone M in RI. The proposed structure will provide an addition 4320 square feet, including 2100 square feet to accommodate the *Reliance* display.

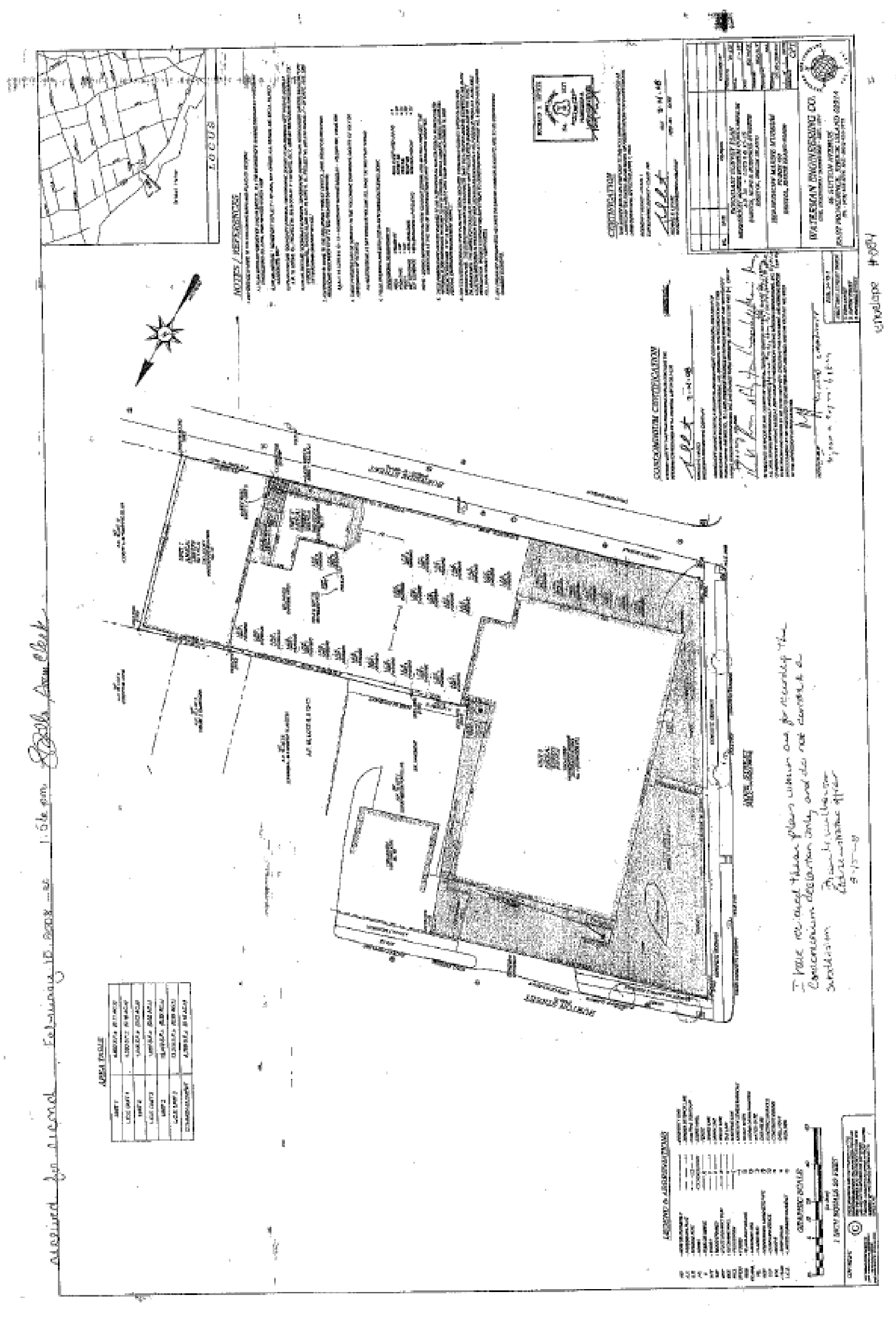


Figure 4 Existing Site Layout

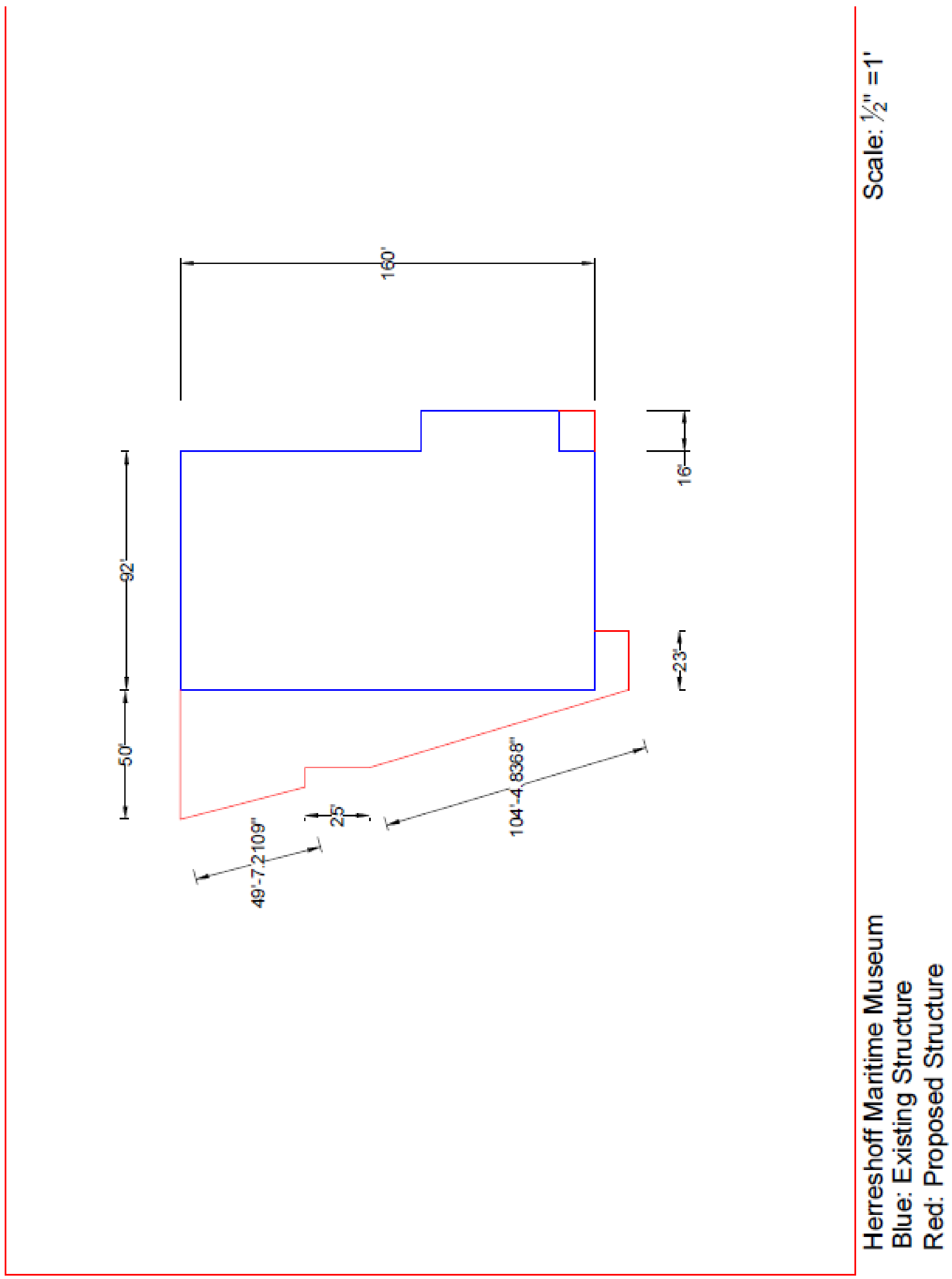


Figure 5 Proposed HMM Addition

Zoning Analysis

The following is the zoning analysis for the proposed addition to Herreshoff Maritime Museum. The analysis was done using the boundary survey plan of Herreshoff Maritime Museum condominium (Lots 8 & 13-15) approved by Richard Lipsitz of the Waterman Engineering Company on 14 February 2008. The survey data is shown in Figure 5. The analysis was done conservatively, assuming worst case scenario. It is important to note that since HMM abuts Burton, Hope and Burnside Street, the lot has to conform to front yard regulations for these three sides. Shown below in Table 11 is the estimated status of zoning compliance/violations of the proposed addition:

<table>
<tr><th>REGULATION</th><th>ZONE M</th><th colspan="2">ACTUAL</th></tr>
<tr><td>MINIMUM LOT AREA</td><td>20,000 s.f.</td><td colspan="2">≈ 47,068 s.f.</td></tr>
<tr><td>MINIMUM LOT AREA/DU</td><td>N/A</td><td colspan="2">N/A</td></tr>
<tr><td>MINIMUM LOT AREA/RU</td><td>N/A</td><td colspan="2">N/A</td></tr>
<tr><td>MINIMUM LOT WIDTH</td><td>100 ft.</td><td colspan="2">140 ft.</td></tr>
<tr><td>MINIMUM FRONTAGE</td><td>100 ft.</td><td colspan="2">150 ft.</td></tr>
<tr><td>MAXIMUM LOT COVERAGE BY STRUCTURES</td><td>50%</td><td colspan="2">≈ 54 %</td></tr>
<tr><td>MAXIMUM LOT COVERAGE BY STRUCTURES & PAVEMENT</td><td>80%</td><td colspan="2">≈ 91%</td></tr>
<tr><td>MAXIMUM FLOOR AREA RATION</td><td>1.0</td><td colspan="2">≈ 1.08</td></tr>
<tr><td>MINIMUM DISTANCE OF STRUCTURE FROM RESIDENTIAL ZONE BOUNDARY</td><td>100 ft.</td><td colspan="2">≈ 100 ft.</td></tr>
<tr><td rowspan="3">MINIMUM FRONT YARD SETBACK</td><td rowspan="3">30 ft.</td><td>Burton</td><td>28 ft.</td></tr>
<tr><td>Hope</td><td>3 – 8 ft.</td></tr>
<tr><td>Burnside</td><td>30 ft.</td></tr>
<tr><td>MINIMUM SIDE YARD SETBACK</td><td>25 ft.</td><td colspan="2">N/A</td></tr>
<tr><td>MINIMUM REAR YARD SETBACK</td><td>20 ft.</td><td colspan="2">N/A</td></tr>
<tr><td>MAXIMUM HEIGHT OF PRINCIPAL STRUCTURE</td><td>35 ft.</td><td colspan="2">35 – 37.5 ft.</td></tr>
<tr><td>MAXIMUM HEIGHT OF ACCESSORY STRUCTURE</td><td>35 ft.</td><td colspan="2">N/A</td></tr>
</table>

Table 11 Zoning Compliance and Violations

Orange denotes areas where a variance may be required or where alterations to the design can avoid seeking a variance. Red denotes areas where a variance will be needed and is unavoidable.

Violating the height limit may be avoided by excavating down enough to ensure that the addition does not exceed the height of the existing structure, while still providing enough clearance for the *Reliance* model. Next semester, the soil conditions and height of the water table will be investigated to conclude whether or not this can be done.

Path through Variances

The path to seek permission to begin construction is outline in Figure 6 and listed below:

1. After the design phase is completed, the proposed design must first be brought to the Historic District Commission of the town of Bristol. The design must conform to the quality and character of the historic area—aesthetically and functionally. The decision of the Historic District Commission is final and there are no variances in this phase. If the design is turned down by the commission, the proposed addition must be redesigned.
2. After approval from the Historic District Commission is granted, the Zoning Board must be consulted. To gain a variance(s), a strong case must be made to assert that the land/structure would be of no beneficial use if relief is not granted. Furthermore, a presentation of the benefits of the addition to the community should be made to the board to state the positive impact the proposed design will have on the community. If the design is viewed as beneficial and meets the requirements for a variance(s), the zoning board will allow the commencement of construction (pending building permits, etc.).

Note: Variances are rarely given in regards to the 35 ft. height restriction.

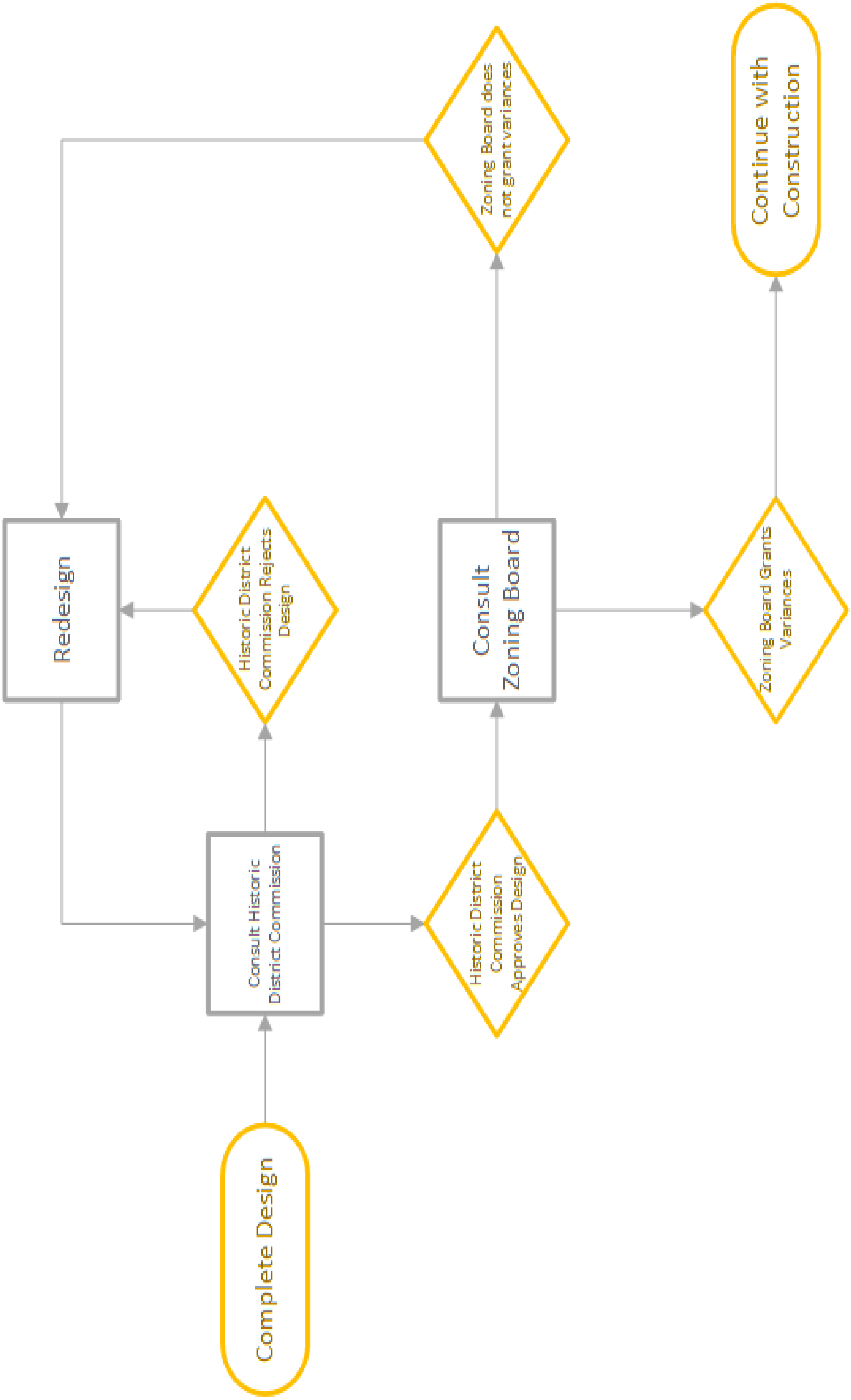


Figure 6 Path Through Variances

Definitions[7]

Buildable lot – a lot where construction for the use(s) permitted on the site under this chapter is considered practicable by the planning board, considering the physical constraints to development of the site as well as the requirements of the pertinent federal, state and local regulations

Building height – the vertical distance from grade, as defined herein, to the top of the highest point of the roof or structure. The distance shall exclude unoccupied decorative spaces or items (i.e. spires, chimneys, cupolas, flag poles, etc.)

Floor Area, gross – the sum of the gross horizontal area of all floors of a building measured from the exterior face of exterior walls but not including interior parking spaces, or any space where the floor to ceiling height is less than six feet

Floor area ration – the gross floor area of all buildings on the lot divided by the area of the lot

Historic District – one or more historic sites and intervening or surrounding property significantly affecting or affected by the quality and character of the historic sites, and has been registered, or deemed eligible to be included, on the state register of historical places

Lot Frontage – portion of a lot abutting a street

Lot width – the horizontal distance between the side lines of a lot measured at right angles to its depth along a straight line parallel to the front lot line at the minimum setback line (i.e. the width of the lot at the minimum setback)

Variance – permission to depart from the literal requirements of this chapter. An authorization for the construction or maintenance of a building or structure, or for the establishment or maintenance of a use of land, which is prohibited by this chapter

> Use Variance – permission to depart from the use requirements of this chapter where the applicant for the requested variance has shown by evidence upon the record that the subject land or structure cannot yield any beneficial use if it is to conform to the provisions of this chapter
>
> Dimensional Variance - – permission to depart from the dimensional requirements of this chapter where the applicant for the requested relief has shown, shown by evidence upon the record, that there is no other reasonable alternative way to enjoy legally permitted beneficial use of the subject property unless granted the requested relief from the dimensional regulations. However, the fact that a use may be more profitable or that a structure may be more valuable after the relief is granted shall not be grounds for relief

[7] Definitions as defined by Municode and clarified by Edward M. Tanner, Principal Planner and Zoning Officer of Bristol, RI

Parking Plan

Currently, HMM has 21 parking spaces (9 ft wide by 18 ft long) in the lot located to the south west of the museum with space for 2-3 more spaces being obstructed by a boat. There is an additional 6 parking spaces of the same dimensions located along the south of side of the museum.

With the proposed addition, the entire HMM complex with have a gross floor area (GFA) of 50,140 s.f. with 38,104 s.f. belonging to the HMM museum. The town of Bristol requires 1 parking space per 500 s.f. of GFA. If the entire complex is taken into account, 101 spaces are to be required. If only the museum is taken into account, 77 spaces are required.

Since the HMM lot will have more than 20 spaces, the painted lines for each parking stall shall be double-line striped, such that there is a minimum of two feet between each stall. This two-foot area shall be included in calculating the overall width of the parking space stall, provided that at least eight feet of width shall be provided between the inner edges of the stall. Up to 25 percent of the spaces may be reduced in size for small cars, provided that such spaces shall be prominently signed for small cars only. The painted lines for each small car parking stall shall also be double-line striped, such that there is a minimum of two feet between each stall. This two foot area shall be included in calculating the overall width of the parking space stall, provided that at least seven feet of width shall be provided between the inner edges of the stall. The overall size of the small car space may be reduced to nine feet wide by 16 feet long.

Flood Study

The flood map of Bristol, RI was obtained from the and it was determined that a portion of the HMM plot is located in Zone X, which is defined as "areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood[8]". The portion of the map showing the concerned property is depicted in Figure 7.

According to Larry Levers, HMM currently does not have flood insurance. Since, the proposed addition will encroach further upon the 0.2% flood zone, a further study will be executed to see if it is prudent for HMM to obtain flood insurance, and what coverage will be provided, what design alterations will be required to qualify for coverage, and what the premium for coverage would be.

[8] As define by FEMA under the Definitions of FEMA Flood zones

Figure 7 Flood Map

Additional Considerations

Economic Impact

Through adding an addition to the museum, which would allow for an expansion and reorganization of the exhibit, the museum is bound to see a growth in customers, resulting in a larger margin for profit. It is expected that the museum, with the *Reliance* display as its crown jewel, will gain much more exposure. Since the museum is a national Hall of Fame, HMM will gain both regional and national exposure. With the growth of patrons visiting the museum, other businesses in Bristol—hotels/motels, restaurants, etc.—will also see growth in business.

Environmental Impact

There is no significant environmental impact anticipated. Apart from standard construction, there is no significant environmental impact of the proposed addition. The proposed structure will not encroach on wetlands, forestry or wildlife. The only impact will be a change in the runoff, and an analysis will be performed next semester if necessary.

Societal Impact

The largest impact the museum will have is on the community of Bristol, specifically the Historic District. The proposed addition must obtain approval from both the Zoning Board and the Historic District Commission. Even when approval is obtained, there will be residents of Bristol that do not like the remodel of the museum, particularly residents who live in the vicinity of the museum. In order to minimize objections, the design was chosen for how well it fits with the character of the neighborhood. The addition is being design with maximum conformity with zoning regulations, particularly the height restriction, to ensure that the addition will not encroach upon or disrupt any of the residents' style of living. Increased patron flow will result in a need for more parking, which could prove problematic if patrons need to park on the street. To avoid this issue, the parking spaces in the existing lot will need to be resized to maximize the amount of cars the lot can accommodate. Additionally, HMM has stated that they own property that can be used for offsite parking and transportation to and from the offsite lot is being considered. All of these issues are being considered to ensure that there is minimal backlash from the community of the Historic District in Bristol.

Political Impact

There is no significant political impact as the museum and its employees have minimal political leverage.

Ethical Considerations

No significant ethical considerations need to be made, apart from standard construction ethics.

Health, Ergonomics, safety considerations

No significant health, ergonomics, or safety considerations apart from standard construction safety, complying with OSHA regulations.

Sustainable Considerations

The museum incorporates a number of green features, including a glazing system that will allow for natural light and temperature control. A green roof is also incorporated in the design to insulate the museum, provide a natural habitat for wild life and reduce the difference in runoff. The sustainable features will be outline more in depth next semester in the material selection process.

Constructability Analysis

To civil engineers, construction of a project is of equal weight to the design as the feasibility analysis. A few features of the construction phase of the HMM addition that should be considered by the engineer to decide if the design is feasible to build include 1) the laydown area plan, 2) the crane and equipment location, 3) installation of the model, 4) the foundation design, and 5) connection of the addition to the existing building.

Laydown area, crane/equipment location [still working on this]

- Materials
- Crane location
- Can block the main road from before HMM until right before house after HMM?
- safety

Installation of Model

After studying the design, two options are possible for the installation of the *Reliance* model:

1. Incorporate a moveable door on the North side of HMM to allow for installation of *Reliance* model
2. Install *Reliance* model prior to glazing of front window

Option 1 calls for a slight modification of the design, but would allow for the model to be moved in and out of the museum if HMM ever decided to have the *Reliance* model travel for showcase opportunities. Option 2 would avoid modifying the design and would result in easier installation of the model, as the window space is more than large enough for the model to fit through. Option 2 would prevent the *Reliance* model from being moved for showcase without removing the window. Also, special provisions and protection during construction would have to be implemented to protect the model in the time period between installation of the model and glazing of the front window.

We initially decided that Option 2 is the best fit, as HMM has stated that they have no plans to ever move the *Reliance* model from its place in the museum.

Foundation Design

The design of the foundation must satisfy three general criteria:[9]

1. The foundation must be located properly (both vertical and horizontal orientation) so as not to be adversely affected by outside influences.
2. The foundation must be safe from bearing capacity failure (collapse).
3. The foundation must be safe from excessive settlement.

The factors that have a direct impact on the foundation type choice include depth of water table, susceptibility to flooding, permeability, depth of bedrock or other impervious layers, and steepness of slope. The plot of land that will hold the addition is relatively flat which results in less drainage due to the steepness of slope. Also, Figure 7 makes it clear that a portion of the HMM plot is located in Zone X, which is defined in the previously stated flood study. This is cause for concern with potential flooding because the water table is so close to the ground surface. The permeability of the soil also has an effect on the susceptibility to flooding of this plot of land. The US Soil Conservation service has mapped and classified all of the soils in the state according to their physical and chemical properties and suitability for various uses including agriculture and community development activities. The soil constraints toward development for Bristol are presented in Figure 8.[10] The map shows that the soil on the plot of land that holds the Herreshoff museum has variable constraints as well as a slow percolation. This combination has the potential to add to the flooding and ponding of this land.

[9] *Soils and Foundations* by Cheng Liu and Jack B. Evett

[10] Town of Bristol, RI On-Site Wastewater Management Plan prepared by BETA Group, Inc.

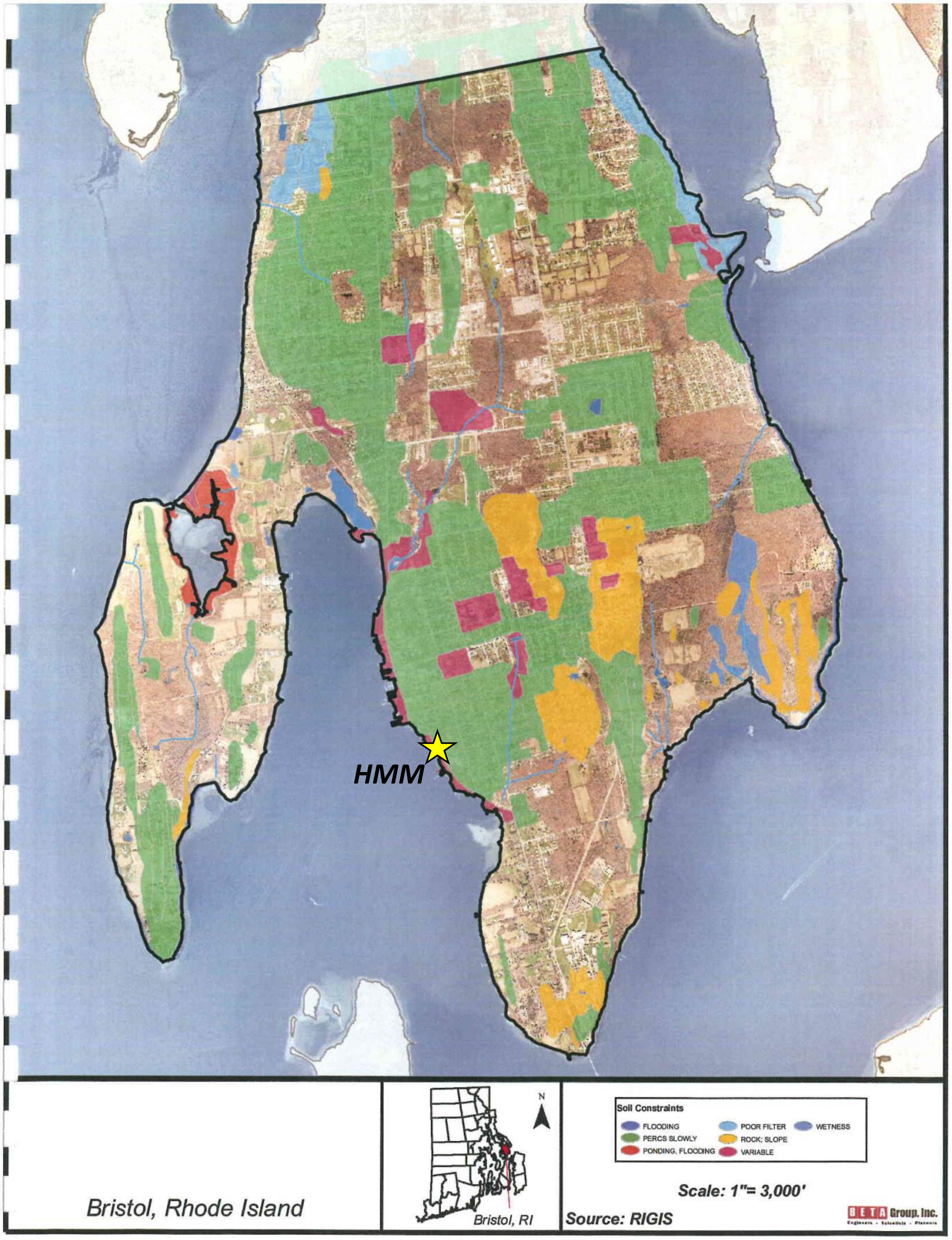


Figure 8 Soil Constraints

Based on the soil and flooding constraints, a raft foundation would be the appropriate choice for this addition. A raft foundation, Figure 9, is a large slab supporting a number of columns that may be stiffened by ribs or beams incorporated into the foundation. This type of foundation is the best choice for this addition because its continuity and rigidity helps in reducing differential settlements of individual columns relative to each other, which may be caused by local variations in the quality of the subsoil. Settlement should be avoided at all costs to prevent interruption of the foundation connection to the existing. They are used to spread the load from a structure over the entire area of the structure and when column loads or other structural loads are close together and individual pad foundations would interact. Raft foundations are also water tight which is very important for the lowered section of the floor that will hold *The Reliance* model.

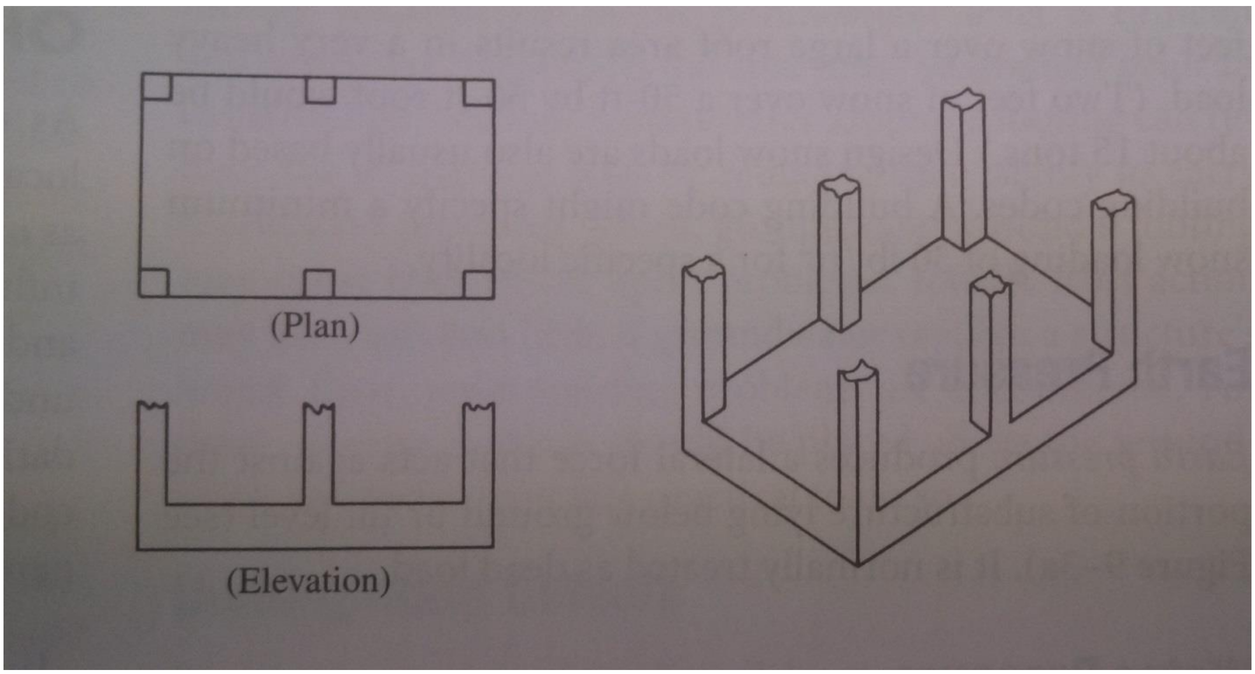


Figure 9 Raft Foundation Diagram

The preliminary design of the foundation was conducted by determining the geometric centroid and the resultant load center of the columns for the museum addition. Table 12 depicts the steps taken to determine the geometric centroid of the shape of the addition. The proposed slab on grade, or raft outline, was broken into multiple triangular and rectangular shapes. The area as well as the *x* and *y* centroid coordinates of each shape in the addition are determined and then multiplied together. The centroid of the total addition shape is determined by dividing the sum of the multiplied values by the sum of the areas. Figure 10 shows the column layout and dimensions necessary to determine the area and centroid of each shape.

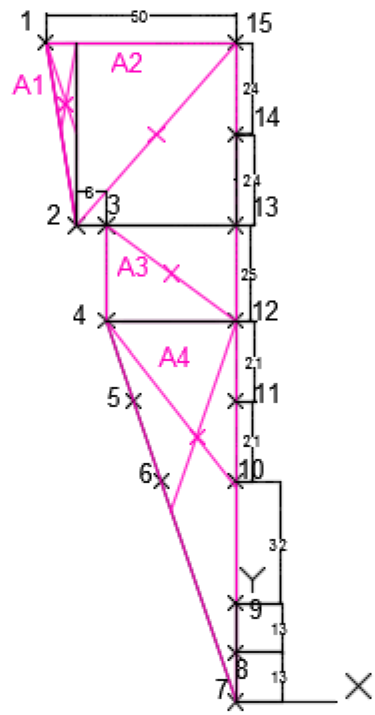


Figure 10 Column Layout

	Area (ft²)	x (ft)	y (ft)	A*x (ft³)	A*y (ft³)
A1	192	-44.67	157	-8576.64	30144
A2	2016	-21	149	-42336	300384
A3	850	-17	112.5	-14450	95625
A4	1700	-10.31	69.69	-17527	118473
Σ=	4758			-82889.64	544626

Table 12 Geometric Centroid

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i A_i}{\sum_{i=1}^{n} A_i} = \frac{-82889.64\ ft^3}{4758\ ft^2} = -17.4\ ft$$

$$\bar{Y} = \frac{\sum_{i=1}^{n} y_i A_i}{\sum_{i=1}^{n} A_i} = \frac{544626\ ft^3}{4758\ ft^2} = 114.5\ ft$$

Similar to the geometric centroid determination, Table 13 shows the results of the load center of the columns of the addition.

Column	x (ft)	y (ft)	Load, P (kips)	x*P (ft*kips)	y*P (ft*kips)
1	-50	173	94.76	-4738.00	16393.48
2	-42	125	51.33	-2155.86	6416.25
3	-34	125	87.43	-2972.62	10928.75
4	-34	100	81	-2754.00	8100.00
5	-26.86	79	63.35	-1701.58	5004.65
6	-19.72	58	50.73	-1000.40	2942.34
7	0	0	8.07	0.00	0.00
8	0	13	28.51	0.00	370.63
9	0	26	23.56	0.00	612.56
10	0	58	50.73	0.00	2942.34
11	0	79	61.77	0.00	4879.83
12	0	100	80.21	0.00	8021.00
13	0	125	82.92	0.00	10365.00
14	0	149	154.33	0.00	22995.17
15	0	173	73.33	0.00	12686.09
		Σ=	992.03	-15322.46	112658.09

Table 13 Load Center of Columns

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i P_i}{\sum_{i=1}^{n} P_i} = \frac{-15322.46\ ft * kips}{992.03\ kips} = -15.4\ ft$$

$$\bar{Y} = \frac{\sum_{i=1}^{n} y_i P_i}{\sum_{i=1}^{n} P_i} = \frac{112658.09\ ft * kips}{992.03\ kips} = 113.6\ ft$$

Figure 11 shows the locations of the geometric centroid and the load center of the columns in regards to the column locations.

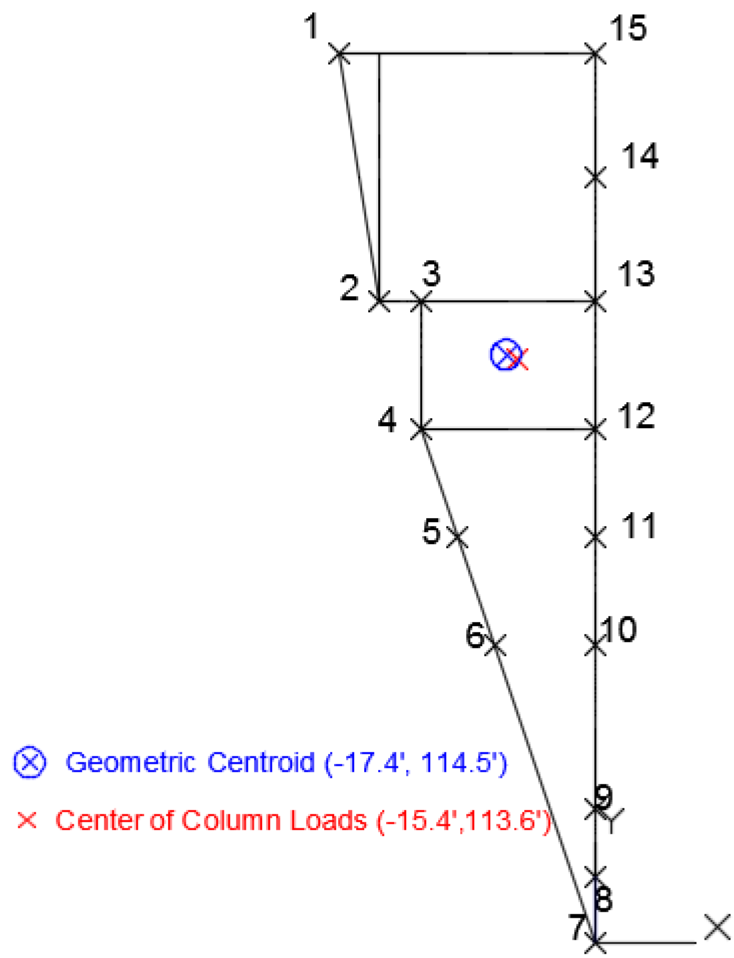


Figure 11 Geometric and Column Load Centroid Locations

The foundation connection from the new addition to the existing building is an important aspect in the feasibility of this design. To prevent movement and settling, steel angle iron should be bolted to the existing. The steel pins and bolts would be encapsulated by the masonry materials that are used to create the new addition. Also, in order to waterproof the connection, waterproofing compounds should be applied to the exterior of the finished foundation. The design will rely mostly on the drainage area around the foundation where the subsurface water will be collected and transported to a low spot on the property.

Cost Analysis

Conclusion

As the semester ends and the first half of our Senior Design Project is complete, we feel confident that our early work has put us in the perfect position to complete our tasks for next semester. We have obtained the plot of land's survey data, we have met with Town Hall employees to sort out zoning data and restrictions and we have created a dimensional layout. Even when obstacles were thrown at us we were able to keep working and solve these problems. An initial problem was not given any dimensions from the architecture plans. We obtained HMM's original plans and went to the museum and surveyed the land. We also have a height restriction we are dealing with. This also has been sorted out by sinking the model into the ground and discussing the matter with Town Halls zoning officials. This semester we have also found all of the loads that will be placed upon this structure and included a green roof design. This has set us up for the structural analysis next semester, as well as the parametric costs, the parking plan, elements of improvements, risk analysis constructability and model installation. We feel confident with where we are ending the semester and are excited to complete the project in the upcoming months.

References

"Green Roof Handbook." ConservationTechnology.com. Conservation Technology, Inc. <http://www.conservationtechnology.com/documents/GreenRoofHandbook1008.pdf>.

Gupta, Ram. *Principle of Structural Design (Wood, Steel and Concrete)*. N.p.: Taylor and Francis Group, 2011. Print.

Short, D. L. (2012). *Building estimator's reference book: a reference book setting forth detailed procedures and cost guidelines for those engaged in estimating building trades* (29th ed.). Lombard, Ill.: Frank R Walker Company

Appendices

A. **Radar Chart**

B. **Gantt Chart**

C. **Wind**

D. **Snow**

E. **Column and Beam**

F. **Green Roof Handbook**

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