Hershey Research Park Building One

Final Report

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Hershey Research Park Building One

General Information

Building Type: Research Facility

Building Size: 80,867 SF

Height: 50 ft

Construction: April 2006 - May 2007

Cost: $10.7 Million

Delivery Type: Design-Bid-Build

Architecture

- Located across the street from the Penn State Milton S. Hershey Medical Research Facility
- Brick, glass, and metal panel facade
- Home to multiple medical and chemical research companies including some departments of Penn State Hershey's College of Medicine
- First of twelve planned buildings in the research park

MEP

- Lighting fixtures consist of 120/277 fluorescent and compact fluorescent lamps
- 150 kW 480/277V 3 phase, 4 W generator
- Two 7,500 CFM AHU's located on roof both are VAV units

Structure

- Concrete piers and spread footers make up the foundation of the building
- Ordinary steel moment frame construction as the main lateral force resisting system
- Composite steel deck floor system, 3 inch deep deck with 4 1/2 inch topping
- Three 14 ft 8 inch stories, with mechanical suite on roof

Project Team

Owner: Wexford Science and Technology, LLC

Architect: Ayers/Saint/Gross Inc.

Engineers: Brinjac Engineering

CM: Whiting - Turner Construction

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Acknowledgements

I would like to start off by thanking all the people that made this year possible. First off I would like to thank Wexford Science and Technology, LLC for allowing me to use their building for my thesis.

Secondly I would like to thank they engineers at Brinjac Engineering and the architects of Ayers, Saint, and Gross. Without their help no of this would be possible. They provided me with the drawings needed to complete the analysis.

Finally I would like to thank the entire AE staff along with the rest of my AE friends. We have gone through many things, both good and bad, over the last few years. Their support kept me going each year.

Special Thanks to:

Professor Parfitt
Professor Holland
Dr. Linda Hanagan

Executive Summary

Hershey Research Park Building One is a three story building located in Hershey, Pa, across the street from Penn State Hershey Medical Center. The building is a research facility focusing on chemical research, and is home to many well-known chemical companies.

This thesis focuses on redesigning the current structural system of the building. The original design is a steel framed building with composite metal deck. The new, redesigned system will be a one way concrete slab with beams and girders. The lateral system of the building was changed from a steel moment frame to a concrete moment frame design. The new system was adequate for supporting the applied loads of the building and met all serviceability issues. It was determined that the original steel frame design was the more practical structural system.

Along with the structural depth, two breadths were also studied. The two breadths chosen were sustainability and mechanical. These two breaths are closely related which helped make the analysis easier. Both the sustainability and mechanical breadths revolved around the addition of a green roof to the building.

The sustainability breadth analyzed the LEED aspects involved in the addition of a green roof. Two different green roof options, TectaGreen and LiveRoof, were compared for the analysis. They were compared on their ability of receiving LEED points. The LiveRoof standard green roof system was picked as the better option of the two. This system has the potential of receiving over 20 LEED credits which is half way to be LEED certified.

In the mechanical breadth, the energy saving ability of the green roof was analyzed. Using the Cooling Load Temperature Difference method learned in HVAC Fundamentals, the amount of energy saved by installing the green roof was determined. It was found that the energy cost savings were not great, but there are still other financial benefits to adding a green roof. Federal tax credits reduce the upfront cost of the green roof, and if LEED certification can be obtained by adding a green roof, even more tax credits can become available for the building. Therefore, adding a green roof to Hershey Research Park Building One would be beneficial.

Building Introduction

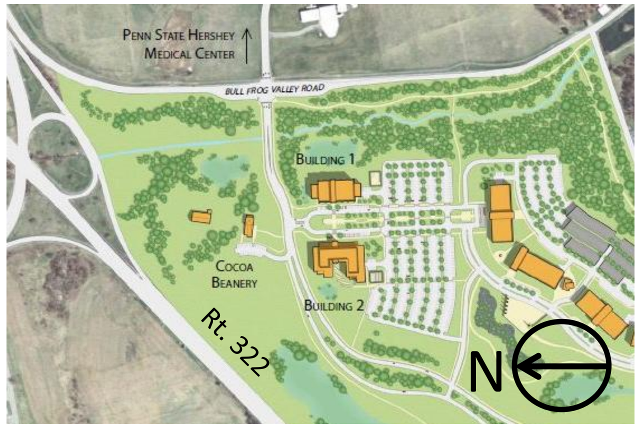

Figure 1: Site Master Plan

The Hershey Research Park Building One (HRPBO) is a research facility located in Hershey, Pa., directly across the street from the Penn State Milton S. Hershey Medical Center. It was designed by Ayers/Saint/Gross Inc. with the engineering done by Brinjac Engineering and the construction by Whiting – Turner Constructuion. Building One is the first building to be finished of a twelve building research park known as the Hershey Center for Applied Research or HCAR for short. Completed in Spring 2007, HRPBO is a state of the art research lab home to various medical and chemical research companies. They include Apeliotus Vision Science, Apogee Biotechnology, and vivoPharm along with some departments of Penn State Hershey's College of Medicine. The building has 80,867 square feet of rentable space and cost approximately $10.7 million dollars total to build. It was designed using the 2003 edition of the International Building Code and its supplements along with ASCE 7-02. Building One consists of a steel moment frame with brick, glass, curtain wall and metal panel façade.

The foundation is drilled steel piles system with concrete pile caps. The main superstructure is composite steel floor deck supported by steel beams, girders and columns. Also some parts of the first floor and basement levels are just slab on grade. The roof system is galvanized roof deck with insulation and water proofing placed on top of the beams. The Hershey Research Park Building One is designed to with stand wind gusts up to 90 mph and is seismic use group II along with a seismic site class of "D". The lateral resisting system is an ordinary steel moment frame which resists both the seismic and wind loads on the building. Even though Building One is not LEED certified there are still multiple forms of sustainability integrated into the building. Regional recycled steel was used in the building which reduces cost as well as waste by reuse. The roof system incorporates an efficient thermoplastic that helps reduce the energy used by the HVAC system, leading to overall reduced costs and emissions. Stones for the excavation of the site were reused for landscaping purposes. Also there is a storm management system integrated with green roof technology. The research center developers, Wexford Science and Technology, are planning on achieving a silver LEED certification on building two of the research park.

Structural Overview

Hershey Research Park Building One sits on a combination of footings and piers. Due to problems with the soil, footings are not enough to support the building. Other than a small portion of the basement, the building is composite steel deck spanning between steel beams. The lateral system utilizes a flexible steel moment frame throughout the entire building.

Foundation

Testing Service, Inc. performed geotechnical testing of the soil before the construction of Building One. The test consisted of nine different borings located throughout the footprint of the building with depths ranging from 25 feet to 38 feet. The results of their tests found three types of layers: residual soil with few rock fragments, residual soil with significant rock fragments, and decomposed limestone. In addition, groundwater was observed in seven of the nine borings after drilling was completed.

TSI recommended certain types of foundations to be used for Building One based on the results of their tests. Their recommendation was to use a shallow spread footing to support the building. In the report TSI also found that the proposed area of Building One was prone to sink holes. Keeping this in mind the engineers decide to use piers with concrete caps. Using a deep foundation like this added more support just in case sinkholes began to develop.

Floor System

The main superstructure is composite steel floor deck which is comprised of 4 ½ inch concrete slab on top of 3 inch deep 18 gage, galvanized composite steel floor deck reinforced with welded wire frame mesh. In addition, ¾ inch diameter, 6 inch steel studs are placed evenly across the beams. Also some parts of the first floor and basement levels are just 4 inch thick slab on grade. The concrete is 4000 psi with the reinforcement being grade 60 steel (F_y = 60ksi). On the structural steel side of things, the wide flange steel is A992 steel. Figure 2 is a typical floor section showing the composite metal deck sitting on top of the steel beam.

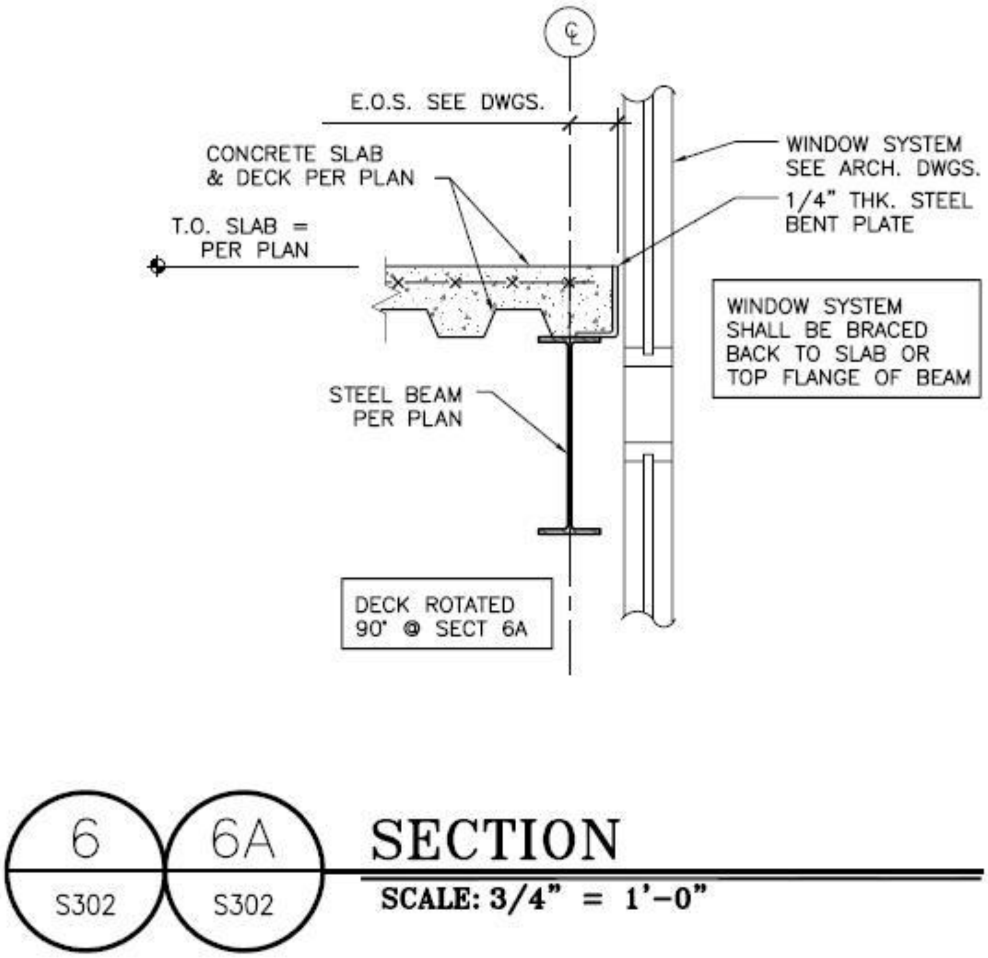

Figure 2: Typical Floor System

Framing System

The framing system of Hershey Research Park Building One is a basic one. It has a steel frame with composite metal deck on top. Beams frame into girders while the girders then frame into the columns which then transfer the forces to the foundation, the basic load path for any building. Figure three shows a basic floor framing plan with a zoomed in view of a typical bay. The numbers within the brackets next to the beam sizes refers to the number of evenly spaces steel studs. The area surrounded by the red box shows where the moment connections are within the frame. The small black arrows are the designator to show which connections are the moment connections. It is also important to note that the 2nd and 3rd floor framing plans are the same. The roof is slightly different.

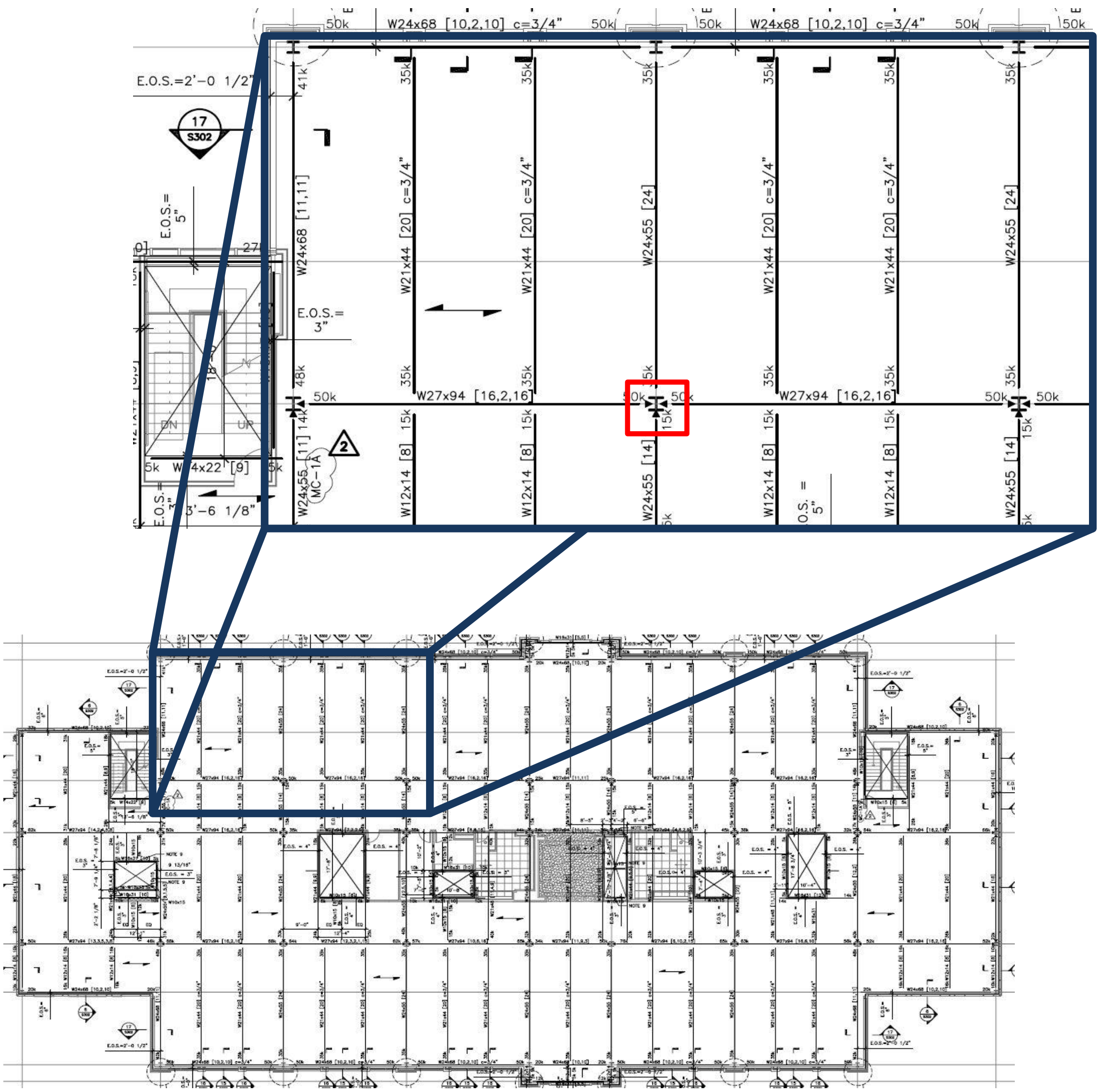

Figure 3: Second Floor Structural Plan with Spot Check Area

Structural Materials Used

Here is a list of all the structural materials as noted in the general notes section of the structural specifications.

Structural Steel Properties	
Material Shape	**ASTM Standard**
Wide Flange	ASTM A992
Tubes	ASTM A500, Grade B
Pipes	ASTM A53
M/S/Channel	ASTM A572, Grade 50
Angles and Plates	ASTM A36
High Strength Bolts	ASTM A325
Reinforcing Steel	ASTM A615, Grade 60
Welded Wire Fabric	ASTM A185
Embedded and Misc.	ASTM A36

Table 1

Structural Concrete Properties	
Type	**f ' c (psi)**
Caissons	3000
Slab on Grade	4000
Elevated Slabs	4000
Stairs	4000
Foundations	4000
Piers	4000
Walls	4000

Table 2 - Note: All exterior exposed concrete is air entrained.

Metal Deck Properties		
Deck Type	**Gage**	**Depth**
Roof	22	1 ½ in
Floors (Composite)	18	3 in

Table 3 - Note: Both types are galvanized steel deck.

Design Codes and Standards

The Hershey Research Park Building One was designed to the following codes.

Design Codes	
Name	**Description**
IBC 2003	International Business Code – Minimum Design Loads
ASCE 7-02	American Society of Civil Engineers – Minimum Design Loads
ACI 318/301	American Concrete Institution – Reinforced Concrete Construction (318) / Structural Concrete for Buildings (301)
ASTM	American Society for Testing and Materials - Various standard use throughout the building
AISC	American Institute for Steel Construction – Specifications for Steel Buildings
NEC	National Electric Code – Specifications of Electrical Components
IMC 2003	International Mechanical Code – Specifications of HVAC Requirements

Table 4

Design Loads

Dead Loads

All the dead loads for the building were designed using IBC 2003 Section 1606. The superimposed dead loads are as shown in the table below. The floor framing dead load is based on the floor deck used and also super imposed dead load. The floor deck used has a weight of 75 psf, and the super imposed load was determined to be 10 psf.

Dead Loads	
Slab on Grade	50 psf
Floor Framing	85 psf
Stair Framing	85 psf
Roof Framing	15 psf

Table 5

Live Loads

Live loads determined through IBC 2003 section 1607, which was the version that was used by the engineers on this project. Compared to the values in the IBC, the design live load numbers were more conservative.

Live Loads	
Slab on Grade	100 psf
Lab	100 psf
Office	100 psf
Mechanical	150 psf
Roof Framing	30 psf

Table 6

Lateral System

The original lateral force resisting system consists of moment frame construction. This type of resisting system transfer the moments in the beams and girders to the columns which then transfer them to the foundation. The moment frame is not the entire framing system. Only certain connections are moment connection. The interior core of the building is what makes up the laterals system. Figure 3 shows which beams and girders are part of the lateral system. Building One uses two different types of moment connections between the columns and beams. These two types are shown in figures four and five.

The lateral system has been broken down into 12 separate frames. There are nine frames spanning in the “Y” direction and three in the “X” direction. Using a 1 kip applied load at the top of the frame, the stiffness of each frame was determined. Using the data found from this analysis the relative stiffness of each frame was also determined. Also the “X” direction is equivalent to the N-S direction and the “Y” direction is E-W.

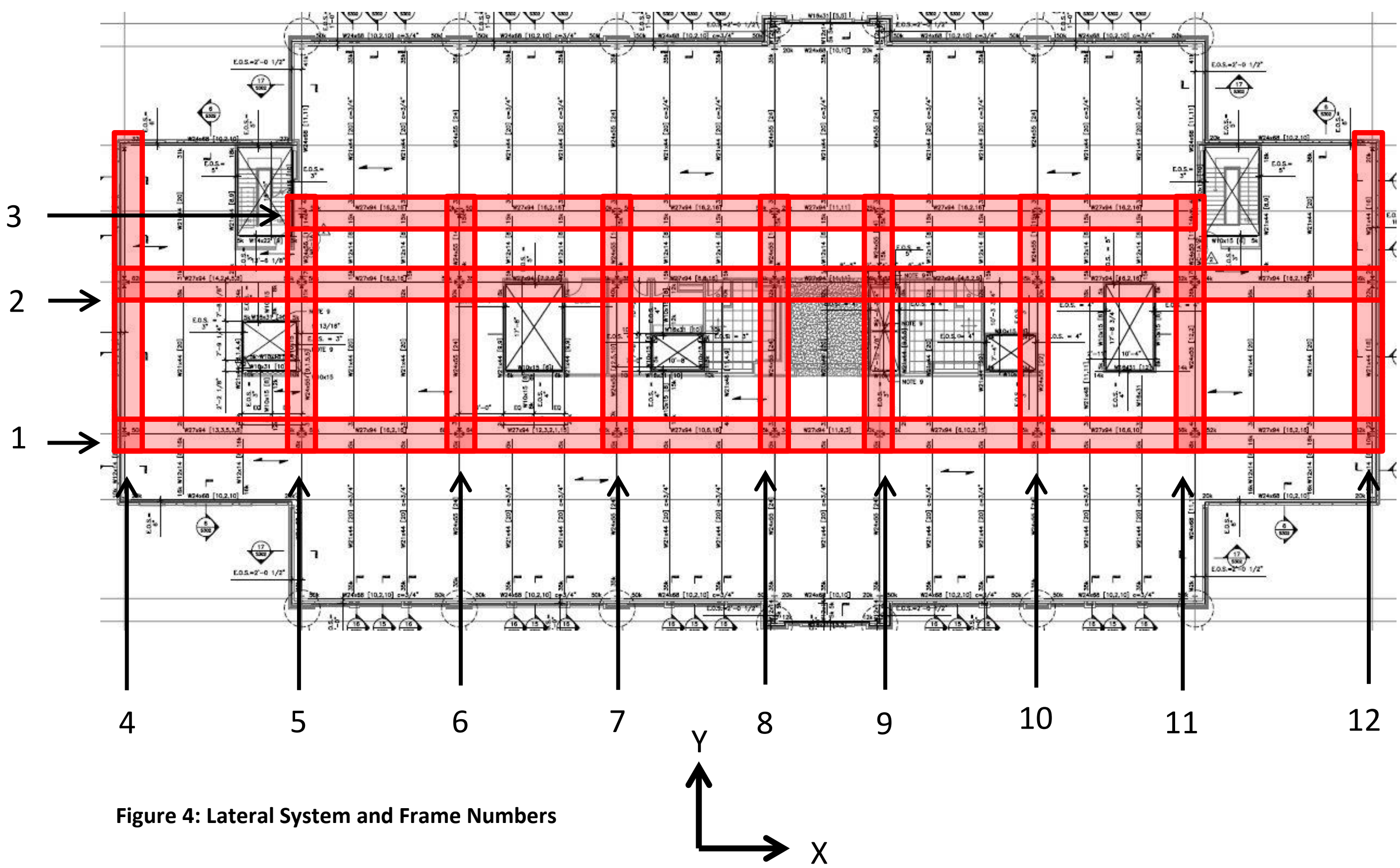

Figure 4: Lateral System and Frame Numbers

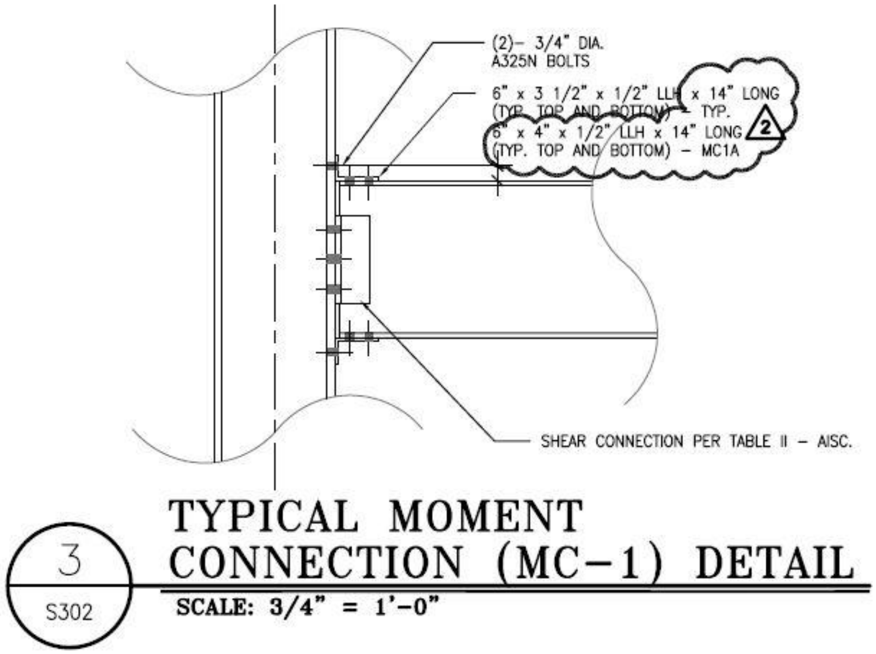

Figure 5: Connection Detail

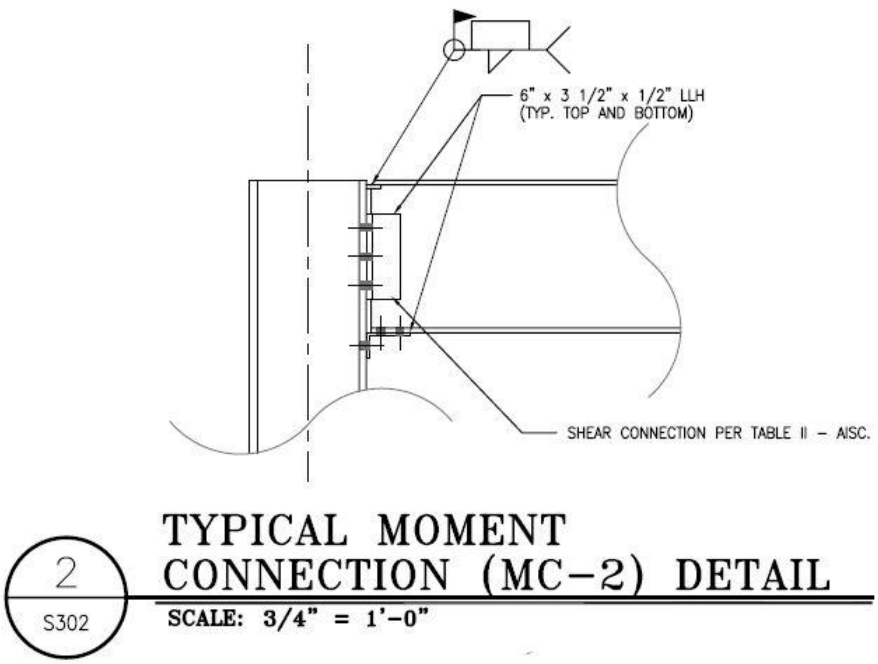

Figure 6: Connection Detail

Proposal Objectives

Depth Topic

The main object of the depth is to redesign the structure system of Hershey Research Park Building One. The current system has been described in the previous sections. It has a steel moment frame as its superstructure with composite metal deck. The new system will be redesigned using concrete. The beams, girders, and columns will all act together as a moment frame to resist lateral loads. With this being the case, no extra lateral resisting system will be needed. To check this assumption the new design will be analyzed using RAM Structural. There are many advantages to using a concrete system over a steel system. One advantage is material cost, concrete for the most part is cheaper than steel. Another advantage is fireproofing. Unlike steel concrete does not have as many fireproofing concerns. Lastly, the column layout will not have to be changed. With the column layout staying the same, the design of the new system will be simplified. The main goal of the structural depth is to design a working concrete system, the will support all loads applied to it.

Breadth One: Sustainability

The first breadth topic will study the advantages and disadvantages of adding a green roof to the building. The addition of the green roof with help to gain LEED certification which is a desire of owner. The owners of the building park want all of their future buildings to be LEED certified even though Building One is not LEED certified. The study of the green roof will also focus on its structural effects on the building. Larger beam, girder, and column sizes will be needed to support this bigger load. The goal of the sustainability breadth is to obtaining LEED certification by focusing on the benefits of adding a green roof. To more points possible, the more successful this will be.

Breadth Two: Mechanical

To go along with the sustainability breadth, the mechanical breadth was also selected to further investigate the effects the green roof has on the building. There are many LEED credits that are associated with green roofs, but one aspect is the heat island effect. Adding the green roof will help to reduce the indoor temperature of the building. This leads to a reduced load on the buildings mechanical system. Through the mechanical breadth, the energy saving ability of the green roof will be analyzed along with its effect on the current mechanical systems. Alternative HVAC systems will also be studied to further increase the energy efficiency of the building. The goal of the mechanical breadth is the study the mechanical aspects of the green roof added to the roof. The more money that can be saved by adding the green roof, the more successful it will be.

Structural Depth

For the structural depth of this report, the steel based structural system will be redesigned using concrete, more specifically a one way slab system. Both of these materials have their own advantages and disadvantages. In this analysis, the column grid was kept intact to keep the existing floor layout unchanged. Due to the relatively small size of Hershey Research Park Building One, a special lateral system will not be needed. The new concrete system will be able to resist the lateral loads applied on it without the help of any extra shear walls. The innate lateral resisting ability of the concrete will create a concrete moment frame that will be adequate for any wind or seismic loads.

Gravity System

Design Loads

The design live loads were determined using the same loads applied to original steel structure. The live loads applied to the structure were not reducible. For simplicity, a constant live load was applied throughout the building. Since there are many different areas in the building that would have different loading, a conservative 100 psf was applied everywhere.

For the dead loads, specific material weights were used to determine the loads. In addition, a superimposed dead load was applied to the structure. The superimposed dead load is there to take into account the elements that are fastened to the superstructure of the building.

Design Loads	
Live Load	100 psf
Super Imposed Dead Load	25 psf
Normal Weight Concrete	150 pcf
Snow Load	30 psf
Roof Live Load	30 psf
Green Roof Weight	35 pf

Table 7

Slab Design

As said before, the new structural system will be a one way slab concrete design. The design process started with the design of the slab, then the beams, girders, and columns. The minimum slab depth was determined to be 5.5" using a reinforcement ratio of 0.005. The weight of this size slab is about 70 psf, and must span a distance of 10.67' between the beams of the one way system. Top and bottom reinforcing is also required. The final design has #4 bars at both the top and bottom spaced at 12". In addition, there is transverse reinforcing to deal with shrinkage and temperature effects. The transverse reinforcing is also #4 bars, but the spacing is 18".

Slab Design Details	
Slab Thickness	5.5"
Flexural Reinforcement (Top and Bottom)	# 4 Bars @ 12"
Transverse Reinforcement	# 4 Bars @ 18"
System Weight	68.75 psf

Table 8

Beam Design

The beams were designed with the same loading as the concrete slab, and run perpendicular to the span of the slab. The beams are evenly spaced throughout the building. A typical bay size was used in the design of the beams. The most common bay size in the building is 32' x 32.5' which is also the largest bay size. This means that the beam sizes that will work for this bay size will work for every other bay. For simplicity and ease of construction the same size beams were used for each bay. The beam layout calls for two beam in between each column, with beams at the columns as well. This means the tributary width for each beam will be 10.67'. Also the span of the beams will be 30.5' which is the clear distance of the beams.

The design of the beams started with an estimate of the beams depth. This was done using table 9.5(a) of ACI 318-08. From this table the minimum depth of the beam was determined to be 22". To be conservative the beams depth was take as 28" and the width was determined to be 16". Through hand calculations it was determined that this beam size along with the proper reinforcement was adequate for the applied loads.

The reinforcing it the beams are different depending on the beams location. The exterior spans do not require as much reinforcing as the interior spans. All of the beams contain the same shear reinforcing which are #3 bars. A deflection check was also performed to make sure the beams were adequate. The details and calculations can all be found in the appendix.

Beam Design Details	
Beam Section Size	16x28
Exterior Span Reinforcing	(3) #7 Bars
Interior Span Reinforcing	(4) #7 Bars
Beam Weight	375 plf
f'c	4000 psi
fy	60000psi

Table 9

Girder Design

The design process of the girder was very similar to that of the beams. One big difference is the loading. Since the girders run parallel to the span of the slab and perpendicular to the beams, the girder sees different loading. The girder has two point loads placed at the third points. These point loads come from the beams. The load path goes from the beams to the girders, then from the girders to the columns. Along with the point loads from the beams the girder also must support its own self weight.

The final designs of the girders in the building have a section of 20"x28". Due to the increased load the girders they must be bigger than the regular beams. With the bigger size of beams that means there must be more reinforcing. These girders require four #7 bars at the midspan as well as five #7 bars at the supports. The deflection check of the girder confirms that this size and reinforcing is adequate for supporting the applied loads.

Girder Design Details	
Beam Section Size	20”x28”
Midspan Span Reinforcing	(3) #7 Bars
Supports Reinforcing	(5) #7 Bars
Beam Weight	563 plf
f’c	4000 psi
fy	60000 psi

Table 10

Column Design

When designing the columns some simplifications were made. First off, all columns on each level were designed to be the same size. For construction simplicity as well as continuity of the design, the columns will all be the same size. The columns will be 20”x20” with twelve #10 bars for reinforcing along with a 2.5” clear cover. These columns were designed with design aids by Alsamsam and Kamara which are based on ACI 318-08. This design was conservative. There are many reasons why such a large column size was chosen. With the addition of the green roof the structure of the building the columns would need to hold a bigger load which is reason for such big columns. With these bigger columns a very wide range of green roof options could be used. Also this helps if new mechanical need to be installed. Being that the building is a research facility a wide variety of equipment may need to be moved into the building. The larger columns will also help with that.

Column Design Details	
Column Section	20”x20”
Steel Reinforcement	(12) #10
f’c	4000 psi
fy	60000psi

Table 11

System Advantages

There are many advantages the new design has over the old design. The biggest advantage this design has is its simplicity and continuity. With the beams, girders, and columns sizes being repeated throughout the building, it would be easy to construct. Also, the types of reinforcement were kept simple. Most of the beams contain #7 bars as the flexural reinforcing, with just different amounts put in each beam depending on the load that needed to be supported. This is also true for the other types of reinforcing in the building. Number four bars are used as the shear reinforcing in the beams, girders, and columns as well as in the flexural reinforcing in the slabs. The only other bar size used were #10s. This size is used in the beams supporting the roof loads as well as in all of the columns. Using only a few different types of reinforcing bars will greatly reduce the overall cost of the project.

Other advantages of this design are that fireproofing will not be needed and formwork will be able to be reused since many of the beams are the same size. This means that construction time will be faster and easier, and money will be saved by not having to add fireproof. Another advantage this design has is that the column layout remains unchanged. By not changing the locations of the columns, the architecture floor layout will not be affected. All the room and spaces within the building can stay the same.

System Disadvantages

Although there are many advantages to the new design, there are also a few disadvantages. Even though the building has good continuity with each bay containing the same size beams and girders, this conservative design will lead to high costs. The design is capable of supporting the loads applied but some bays are over-designed. The basis of the design was off the most common bay size, which is also the largest bay size. This means that the smaller bay sizes will be over-designed; they will be designed to hold much more load than what is being applied to them. This design decisions will lead to higher material costs, but the continuity will help with construction time. There are only a few bays smaller than the one used for the design, which is why such a decision was made.

Lateral System

The lateral system of the new design is concrete moment frame instead of a steel moment frame that was originally designed. The innate moment resisting ability of the concrete makes the design unchanged in order to resist the lateral loads. The addition of any shear walls will not be necessary. With the gravity system being over-designed as mentioned before, it should have no problems with resisting the extra moment placed on it due to the wind and seismic loads. This assumption still must be checked. This analysis was done using RAM structural, which is the same program used for the analysis of the original steel moment frame in Technical Report Three.

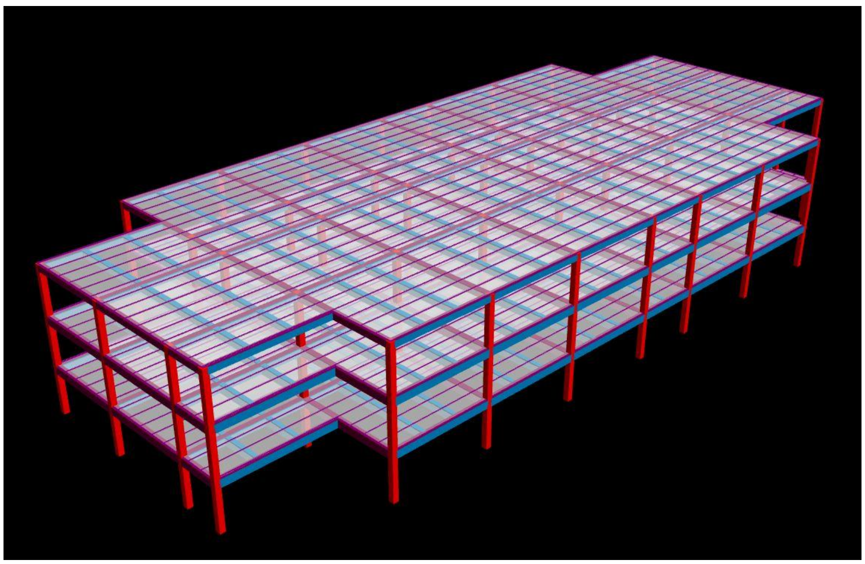

Figure 7 – RAM Model

Wind Loads

The wind analysis was performed using ASCE 7-10 to determine the amount of load on the building due to the wind. The hand calculations for the wind design loads can be found in the appendix. Additional analysis was done through RAM Structural. The Hershey Research Park Building One is located in the 90 mph wind velocity section of figure 6-1 of the code, and also the fundamental frequency for the building is greater than one. In section 26.9.2 of ASCE 7-10, when determining the gust factor on the building, it is permitted to consider a low-rise building as rigid. Hershey Research Park Building One is define as a low-rise building since is mean roof height is under 60 ft. Being rigid that leads to a gust factor of 0.85. In plan view, the building geometry is not exactly a rectangle, but a simplifying assumption was made to change the geometry to a rectangle with the dimensions of 256.66 ft by 95.2 ft.

Once the wind loads were found the base shear, as well as the overturning moment were determined. The allowable story drift was found using h/400, where h is the story height. The allowable story drifts were then compared to the actual drifts due to the loading. The actual drifts were taking from the RAM Structural analysis from the controlling load cases which was determined to be 1.2D + 1.0L + 1.0W. The following tables show the details of the calculations of the wind loads along with a comparison of the story drifts to allowable drifts.

East-West Wind									
Floor	Elevation (ft)	z	kz	qz	qh	Windward (psf)	Leeward (psf)	Trib. Area (ft^2)	Force (kip)
1	409.25	0	0.7	12.34	14.28	8.39	-6.07	1881.30	27.20
2	423.916	14.66	0.7	12.34	14.28	8.39	-6.07	3762.60	54.40
3	438.58	29.33	0.7	12.34	14.28	8.39	-6.07	3934.6	56.88
Roof	454.6	45.35	0.785	13.84	14.28	9.41	-6.07	2589.7	40.08
High Roof Framing	458.6	49.35	0.81	14.28	14.28	9.71	-6.07	536.4	8.46
								Total	187.02
								Overturn Moment	9229.48

Table 12

North-South Wind									
Floor	Elevation (ft)	z	kz	qz	qh	Windward (psf)	Leeward (psf)	Trib. Area (ft^2)	Force (kip)
1	409.25	0	0.7	12.34	14.28	8.39	-3.64	697.8	8.39
2	423.916	14.66	0.7	12.34	14.28	8.39	-3.64	1385.6	16.67
3	438.58	29.33	0.7	12.34	14.28	8.39	-3.64	1459.4	17.56
Roof	454.6	45.35	0.785	13.84	14.28	9.41	-3.64	960.6	12.53
High Roof Framing	458.6	49.35	0.81	14.28	14.28	9.71	-3.64	199	2.66
								Total	57.81
								Overturn Moment	2853.05

Table 13

Wind Calculation Variables	
Kz	0.7 (0-30 ft), 0.785 (45 ft), 0.81 (50 ft)
Kzt	1.0
Kd	0.85
V	90 mph
I	1.0
G	0.85

Table 14

Wind Pressure Diagrams

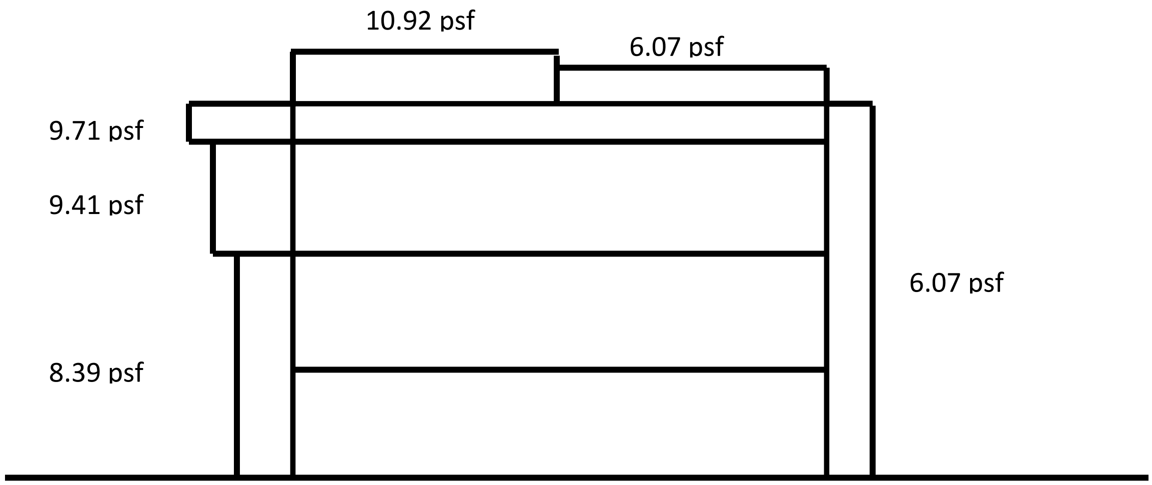

Figure 8: Wind Pressure E-W

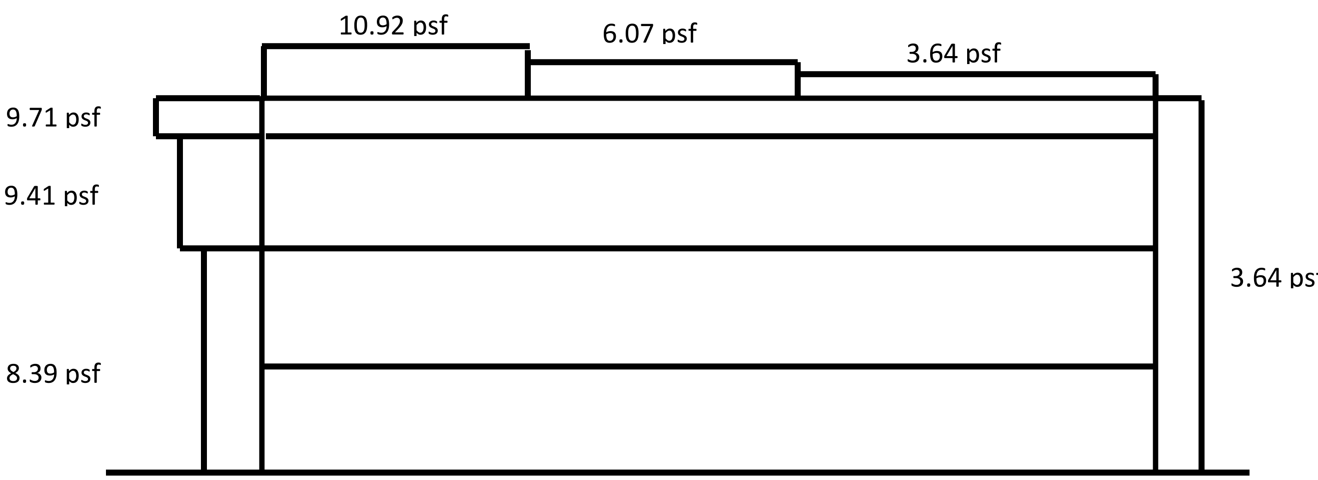

Figure 9: Wind Pressure N-S

Earthquake Loads

For the seismic analysis of the design, ASCE 7-10 chapter 12 was referenced. The equivalent lateral force method was used to find the base shear. The base shear was found to be 997 kips, which is much larger than the base shear found in the original building. This makes sense since the original building was a steel frame. The new concrete building is much heavier, and this is why the base shear is greater. The details of the base shear calculations can be found in the appendix.

RAM Structural was also used when doing the seismic analysis. Through RAM Structural, the story drifts were found from the controlling seismic load case. This load case was determines to be 1.2D + 1.0L + 1.0E. The new concrete structure was found to be adequate for this load case. The allowable story drift for the seismic is equal to 0.015 x the story height. The comparison of the allowable drift to the actual drift can be found in the table below.

Seismic Calculations					
Floor	Height (ft)	Total Weight (kip)	w*h^K	Cvx	Fx (k)
2	14.66	3975.23	69857.1	0.158	157.9
3	29.32	3975.23	146406.3	0.332	330.9
Roof	49.35	3501.51	224822.3	0.510	508.2
Totals		11451.97	441085.7		997.0
Base Shear	997				
		Overturning Moment =	37100 k-ft		

Table 15

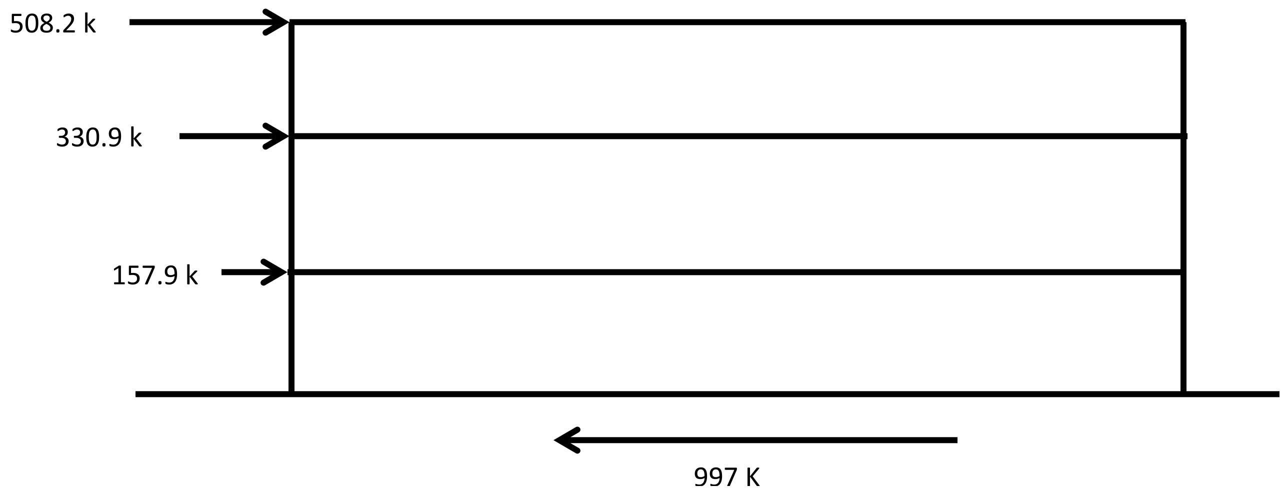

Figure 10 – Vertical Distribution of Story Forces

Controlling Seismic Load Case 1.2D+1.0L+1.0E					
Floor	X Delfection (in)	Y Delfection (in)	X Drift (in)	Y Drift (in)	Allowable Drift (in)
Roof	0.51621	-0.019	0.1492	0.0008	2.64
3rd	0.36698	-0.00981	0.2005	0.0059	2.64
2nd	0.16647	-0.00424	0.1664	0.0045	2.64
			0.5161	0.0112	
Controlling Wind Load Case 1.2D+1.6L+1.0W					
Floor	X Delfection (in)	Y Delfection (in)	X Drift (in)	Y Drift (in)	Allowable Drift (in)
Roof	0.059	0.02152	0.0124	0.01	0.44
3rd	0.04666	-0.01148	0.0231	0.0066	0.44
2nd	0.0236	-0.00485	0.0236	0.0049	0.44
			0.0591	0.0215	

Table 16

Breadth One: Sustainability

One major objective the owners of the building park have for the future buildings is for them to be LEED certified. Building One has a few sustainable aspects but was not LEED certified. To get closer to being LEED certified a green roof will be added to the roof of the building. Obtaining LEED certification is the main goal of this breadth by focusing on the benefits of adding a green roof. Adding a green roof has become a trend in current building construction. It has plenty of advantages that outweigh its disadvantages. Its only disadvantage is cost. Most owners want to get the cheapest possible building, which is the main reason not to have a green roof on the building. This disadvantage is twofold. For one the cost of the actual green roof along with installation and maintenance is a big factor, but also it adds a considerable amount of weight to the roof. This extra weight is not only from the plants, but also from any rainwater that gets absorbed into the system. This weight of the green roof means that the roof structure must be larger than normal.

With this being said the additional upfront costs of the green roof are easily outweighed by the lifetime cost of the system. This comes from money saved in energy costs. The money saved due to decreased energy usage will be covered in the second breadth. These two breadths go hand in hand with each other to help improve the building and achieve LEED certification.

For this analysis two different green roof systems will be compared. The two green roof options to be compared are LiveRoof and TectaGreen. Both of these types of green roofs are modular units that can be easily installed. Therefore is will be easy to compare the two with one another. As said before, achieving LEED certification is the main objective for this breadth. By comparing multiple types of green roof options, one can be chosen to give the greatest benefit. The goal is to gain as many possible LEED points possible.

The proposed design for the green roof will cover as much as the roof area as possible. The roof of the building is flat everywhere so installation should be easy. The one problem with the roof of the building is that there are some mechanical units located there. With that said, some area of the roof will not be able to take advantage of the benefits of the green. Another design aspect of the green roof is that it will not be open to the tenants of the building. Due to this fact, an extensive system will be used.

Selecting the system which will be used on the roof is the next step of the design process. Both have their advantages and disadvantages. First the advantages and disadvantages of the TectaGreen system will be discussed. The extensive TectaGreen has a total depth of 6" with a saturated weight of 35 psf. This system has the ability to achieve up to 9 LEED points. These points are received through a variety of different ways shown in the table below.

TectaGreen System		
LEED Category	**Credit Abbreviation**	**Credits Possible**
Storm Water Design	SS 6.1	1
Heat Island Effect	SS 7.2	1
Water Efficient Landscaping	WE 1.1	1-2
Optimize Energy Performance	EA 1	1-8
Recycled Content	MR 4.1	1-2
Regional Materials	MR 5.1	1-2

Table 17

The main disadvantage of the TectaGreen system is the lack of variety. They only offer one size of modular system, which is 2'x2'x4.4". On the other hand there is the LiveRoof system. The benefits of this design seem to outweigh those of the TectaGreen system. First off, there is a much bigger amount of LEED points available with this design. According to the LiveRoof website, it is possible to achieve over 20 points using their design. The same LEED point received by using TectaGreen system can be achieved using the LiveRoof system, plus some addition credit possibilities. There are also other advantages to the LiveRoof system. One is the seamless integration of the modules. This means the plants will all grow together and make the roof look like a meadow; there are no noticeable modules.

LiveRoof System		
LEED Category	**Credit Abbreviation**	**Credits Possible**
Protect or Restore Habitat and Maximum Open Space	SS 5.1/5.2	1 each (2 total)
Storm Water Design	SS 6.1/6.2	1 each (2 total)
Heat Island Effect	SS 7.1/7.2	1 each (2 total)
Water Efficient Landscape	WE 1.1/1.2	2/4 (6 total)
Optimized Energy Performance	EA 1.1-1.19	1 each (19 total)
Construction Waste Management	MR 2	1 to 2
Recycled Content	MR 4.1/4.2	1 to 2
Regional Materials	MR 5.1/5.2	1 to 2
Rapidly Renewable Materials	MR 6	1

When trying to decide the best choice of the three options its best to look at the goals of the breadth. As stated earlier the more LEED points possible. That makes the decision very clear. The green roof option selected will be the LiveRoof system. Through this system it is possible to receive 38 points, but with most of those points coming from the Optimized Energy Performance, it is not likely to receive the full amount of points from the green roof alone.

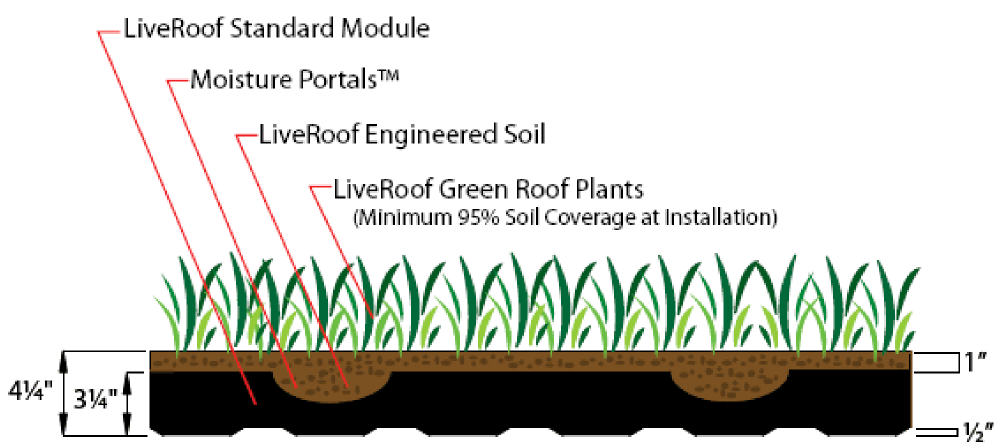

Figure 11 – Green Roof Details. Courtesy www.liveroof.com

Even though all of the energy saving credits cannot be achieved through only the green roof, the other LEED credits should all be able to be obtained. The categories that credits can be obtained in are sustainable sites, water efficiency, and materials and resources.

Sustainable Sites

Protecting animal habitats and maximizing open space both account for one credit each. The green roof will act as a habitat for many different insects as well as birds. The LiveRoof system can also help with storm water control. The green roof can retain water as well as filter out any pollutants contained in the storm water. This adds two more LEED credits by controlling the quantity and the quality of the water moving through the system. Next is the heat island effect. This is the heat given off in urban areas by building and other things that attract heat, like pavement used for parking lots and roads. Of the two possible points available this category, one will be gained by the addition of the green roof.

Water Efficiency

The category of water efficiency has a possible six LEED credits to be obtained. The first two points can be obtained by reducing the water usage by 50%, and the next four points are achieved by requiring no irrigation for the system. Due to the types of plants used in the LiveRoof system, they require much less water than normal green roof systems. With both of these water efficient abilities of the green roof, an additional six credits will be gained.

Materials and Resources

There are four different sections of the material and resources category in which credits can be obtained by the addition of the green roof. First is the construction waste management. The LiveRoof system only contains one object considered as waste. This is the soil elevator that helps the soil sit in the module evenly before being installed. Once installed it will be removed from the module and the site and by doing this two credits will be gained. Two more credits can be gained by using recycled materials. The LiveRoof modules are made of 100% recycled polypropylene. An additional two credits will be achieved by using regional materials. The plants that make up the LiveRoof system are all grown by local nurseries close by the construction site. There are many nurseries in the area near Hershey that are certified growers. The last section of the materials and resource category LEED credits can be gained from is rapidly renewable resources. The plants grown in the LiveRoof system can be harvested and reused making it possible to achieve the one point from this section.

Figure 12 – Sample LiveRoof System. Courtesy www.liveroof.com

Structural Effects

The figures above show more of the details of the design of the LiveRoof system. The standard module show above shows that to total depth of system is 4.5” which when fully saturated equals a weight of about 30 psf. When designing the roof structure that must hold the green roof a weight of 35 psf was used to be conservative. The detailed calculations of the roof structure can be found in the appendix.

When designing the roof structure the extra weight of the green roof is the only extra load that needed to be considered. There is 30 psf of live load which would account for any maintenance workers and their equipment. This would be for maintenance workers for the green roof as well as for the mechanical systems.

The design process of the roof structure was similar to the design process for the rest of the building. The slab thickness was determined to be the same as the other floors of the building which is 5.5”. The reinforcement within the slab is also the same which is #4 bars spaced at 12” for flexural reinforcement along with #4 bars spaced at 18” for transverse reinforcement.

Roof Slab Design Details	
Slab Thickness	5.5”
Flexural Reinforcement (Top and Bottom)	# 4 Bars @ 12”
Transverse Reinforcement	# 4 Bars @ 18”
System Weight	68.75 psf
f’c	4000 psi
fy	60000 psi

Table 18

The loading of the roof is less than the loading on the other floors even with the green roof on it, so the beams and girders will be slightly smaller than the other floors. The beams were determined to be 12”x22”. The reinforcement of the beams will be (3) #7 bars in the first exterior span and (2) #10 bars in every other span. This design also includes #4 stirrups.

Roof Beam Design Details	
Beam Section	12”x22”
Flexural Reinforcement (Exterior Spans)	(3) #7 Bars
Flexural Reinforcement (Interior Spans)	(2) #10 Bars
Beam Weight	206 plf
f’c	4000 psi
fy	60000psi

Table 19

The girders of the roof system were designed the same as the girders on the lower floors, just with different loading. The section was determined to be 18”x22”. The reinforcement consists of (3) #7 bars at the midspan and (5) #7 bars at the supports. Through strength checks the slab, beams, and girders all can support the applied loads including the extra load from the green roof.

Roof Beam Design Details	
Beam Section	18"x22"
Flexural Reinforcement (Midspan)	(3) #7 Bars
Flexural Reinforcement (Supports)	(5) #7 Bars
Beam Weight	310 plf
f'c	4000 psi
fy	60000psi

Table 20

Conclusion

With all of these LEED credits possible from installing the LiveRoof system a total of 18 points can be obtained. To be considered LEED certified a building must accrue 40 points. These 18 points alone will not make the building LEED certified, but it is a very good start. The only disadvantages of adding a green roof is that the entire roof will not be able to be covered, and bigger roof structure required to hold the extra load. There are some mechanical units already placed on the roof that take up valuable green roof space. Also it is possible that new mechanical units will need to be installed in the future. This is because to the nature of the building type. It is a chemical research facility, and the tenants may require special equipment to perform their research. All this being said the addition of the green roof would still be a welcome addition to the building. The LEED points possible from the addition make it very useful. The effects the green roof has on the mechanical systems will also lead to additional points making it even easier to become at least LEED certified. These mechanical aspects of the green will studied further in the second breadth.

Breadth Two: Mechanical

One big aspect the addition of the green roof can do for the building is reduce the overall energy usage. Depending on the amount of energy saved by the green roof, additional LEED credits can be awarded. Not only are these extra LEED points obtained, the energy saved leads to money also being saved. The LiveRoof acts as an extra layer of insulation which will keep the internal temperature cooler in the summer. This mechanical breadth will further study the effect the green roof has on the mechanical loads of the building by using methods learned in HVAC Fundamentals. The analysis will be completed using the Cooling Load Temperature Difference or CLTD method.

The main equation used for this method is q = U x A x CLTD. In this formula, q is the solar heat gain, U is the heat transfer coefficient, A is the area of the green roof, and CLTD is the cooling load temperature difference. The first step for implementing this equation is to figure out the make-up of the roof. Once each component is determined, their U value can be found by taking the inverse of that components R value. The roof assembly is made up of five parts, the concrete slab, insulation, roof board, waterproofing membrane, and finally the green roof. The R value for each material can be found in the following table. The values were taken from Appendix E of Mechanical and Electrical Equipment for Buildings, 10th edition.

Roof Assembly R – Values	
Material	**R – Value**
Concrete Slab (5.5”)	0.4125
Insulation (6”)	22
Roof Board	1.09
Water Proofing Membrane	0.12
LiveRoof Standard Green Roof System	2

Table 21

With this building assembly, a total R value of 25.62 is obtained, and a U value of 0.039. The next step of this process is to determine the area of the roof in which the green roof will be applied. The total roof area is approximately 27,700 square feet. Due to the fact that some mechanical units need to be placed on the roof, some of that area will not be able to be used. An area of 5000 square feet will be reserved for the current and any future mechanical equipment leaving a total usable roof area of 22,700 square feet.

Now that the amount of green roof area is determined, the final step can begin. The final step is to determine the CLTD values. To obtain these values chapter 28 of the ASHRAE handbook will need to be referenced. The first step of this process is to determine the roof number for the roof assembly using table 28.31. The roof number for this assembly is 14. This number is needed to find the CLTD values to be used in the calculations. There is a different CLTD value for each hour of the day.

Cool Load Calculations					
Hour	A (ft^2)	U	CLTD	CLTD(corr)	q (BTU/hr)
1	22700	0.039	35	36	31871
2	22700	0.039	32	33	29215
3	22700	0.039	30	31	27444
4	22700	0.039	27	28	24788
5	22700	0.039	25	26	23018
6	22700	0.039	23	24	21247
7	22700	0.039	21	22	19477
8	22700	0.039	20	21	18591
9	22700	0.039	19	20	17706
10	22700	0.039	20	21	18591
11	22700	0.039	22	23	20362
12	22700	0.039	24	25	22133
13	22700	0.039	28	29	25674
14	22700	0.039	32	33	29215
15	22700	0.039	36	37	32756
16	22700	0.039	39	40	35412
17	22700	0.039	42	43	38068
18	22700	0.039	44	45	39839
19	22700	0.039	45	46	40724
20	22700	0.039	45	46	40724
21	22700	0.039	44	45	39839
22	22700	0.039	42	43	38068
23	22700	0.039	40	41	36297
24	22700	0.039	37	38	33641
				Total	704,699
				Annual Total	128,959,880
				60% Reduction	77,375,928

Table 22

The total reduction of 77,375,928 BTU of the cooling load is possible with the installation of the green roof. The 60% reduction is the assumed amount of solar heat gain absorbed by the green roof. As a conservative estimate the cooling load season was determined to 183 days, which is half the year. Using the Energy Efficiency Rating of the air handling units, a rough estimate for energy cost saving can be found.

Cost Analysis

The EER of the air cooled chiller used to cool the air is 9.7. This number is used to compare the energy needed to cool the room to the amount of electricity needed. Once the amount of electricity is found, the cost of this electricity can be used to find the total savings of the green roof. The amount of electricity needed to remove this load from the building is 7978 kWh. By assuming cost of electricity of $0.06 per kWh, that leads to a total savings of $478.68 per year. This number is much lower than expected. The cost per foot of the LiveRoof green roof system is approximately $29 per square foot, which gives a total cost of $658,300. Although the not much money can be save due to energy savings, there are many other cost incentives of a green roof.

There are federal regulations that give tax credits for buildings with green roofs. To be eligible for this tax credit the green roof must take up more than 50% of the roofs area. In this case, the building would meet this requirement. The regulation states that 30% of the upfront cost of the green roof can be recouped as a tax credit. Residential construction is limited to a maximum of $5000, but since Hershey Research Park Building One is a commercial construction, there is no limitation to the amount of tax credit obtained. This would return $197,490 to the owners of the building, reducing the total cost of the green roof to $460,810.

Another cost advantage from the green roof is from the LEED tax credits. Similar to the tax credits from the federal regulations, it is possible to gain even more tax credits for having a LEED Certified building. One LEED credit not discussed in the sustainability breadth was optimized energy performance. This category has the potential of 19 LEED credits. The addition of the green roof will reduce the amount of energy needed in the building approximately 8% which is enough for one more credit. With the addition of energy efficient mechanical units the amount of energy saved would increase and help to achieve even more LEED points. This would mean the building could become LEED certified and receive even more tax credits.

Conclusion

The green roof addition to the roof has many different advantages. One big advantage is the effect the green roof has on the buildings mechanical systems. The green roof will reduce the amount of stress on the buildings mechanical systems. Another advantage is the cost reduction to the building along with the possible tax credits. The total cost of the green roof can be reduced giving it more incentive to be built. Due to the reduction of energy needed in the building as well as the cost benefits, it would still be useful to add the green roof to the roof. The advantages of the LiveRoof system outweigh its disadvantages.

Conclusion

The main goal of this report was to compare the advantages and disadvantages of changing the structure system of the Hershey Research Park Building One. The original design done by Brinjac Engineering was a steel framed building with a composite metal deck. The redesign proposed was to change to a concrete based building.

The goal was to have a working design able to support the loads acting on the structure. The redesign was determined to be one way slab with beams and girders. The slab was determined to be 5.5” deep with the beam and girder sizes varying. The beams were sized at 16” x 28” and 20” x 28” depending on their location with the girders also being 20” x 28”. As for reinforcing, only a few different size bars were used. They were # 4 bars used in the slabs and for stirrups, # 7 bars used in the majority of the beams and girders, and # 10 bars used in the girders and columns. The new design was simple but had its advantages. One example is that concrete is cheaper than steel, and the continuity of the design we lead to fast construction. The concrete system also had disadvantages like larger floor thickness as well as longer construction time. With both designs have different advantages and disadvantages it is hard to decide what the more feasible option is. All things considered, the steel frame is the superior design.

The second part this report was to study two breadth topics. The first breadth was sustainability. The goal of this breadth was help make the building LEED certified by adding a green roof. Two different green roof systems were compared, TectaGreen and LiveRoof. These two systems were compared on their ability to obtain LEED credits. The LiveRoof design was picked because it made it possible to achieve more than 20 credits. Once this system was determined to be the better option, its effect on the structure of the building was check, and the roof was designed for this extra load.

The second breadth chosen was mechanical. This was picked because it went hand in hand with the sustainability breadth. For the mechanical breadth the ability of the green roof to save energy was studied further. It was found that the green roof will not save very much in energy costs, but by its addition, many different tax credits would be available to reduce the cost of the green roof as well as future energy bills. Overall, the addition of the LiveRoof green roof system would greatly benefit Hershey Research Park Building One.

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Appendices

Appendix A: Structural Plans

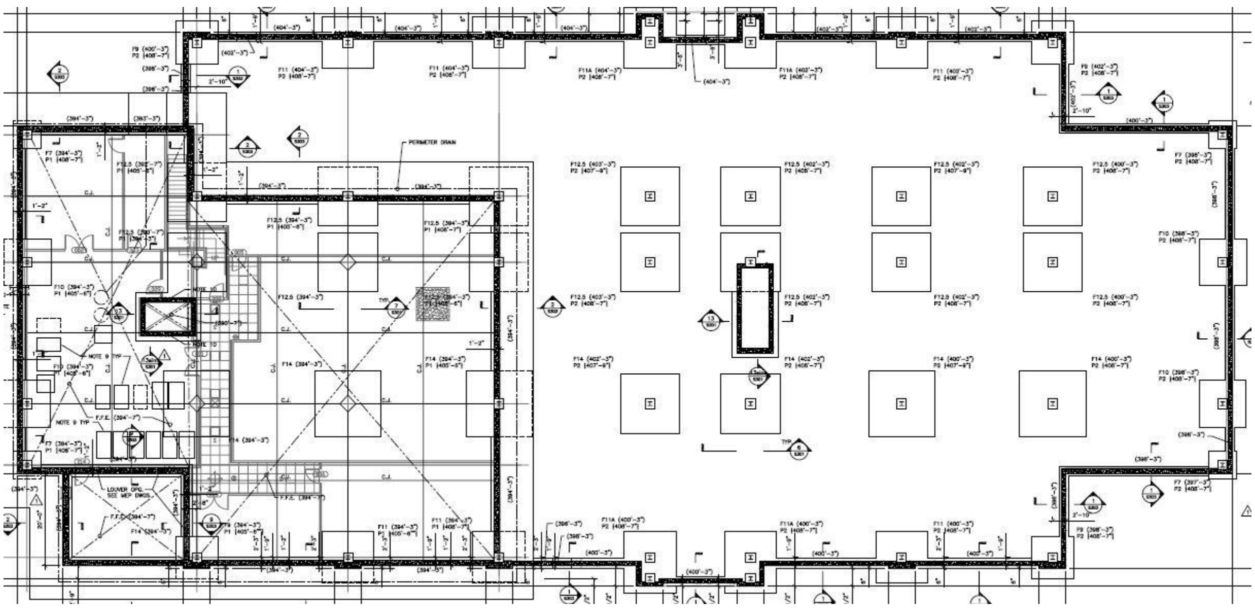


Figure 13 – Basement/Foundation Structural Plan

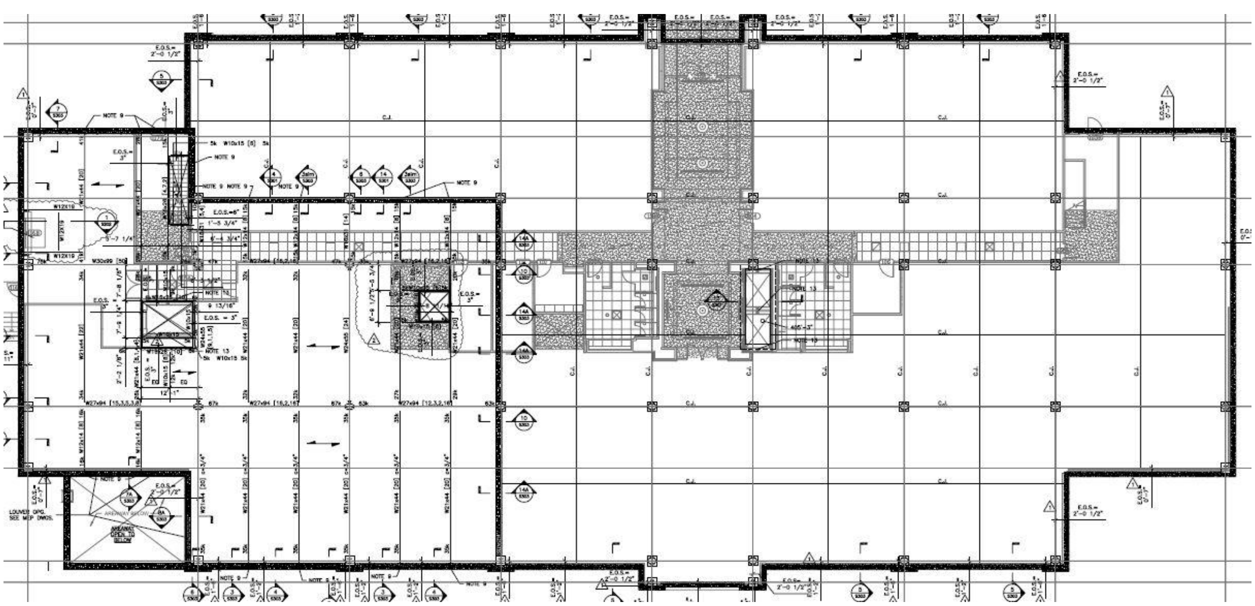


Figure 14 – First Floor Structural Plan

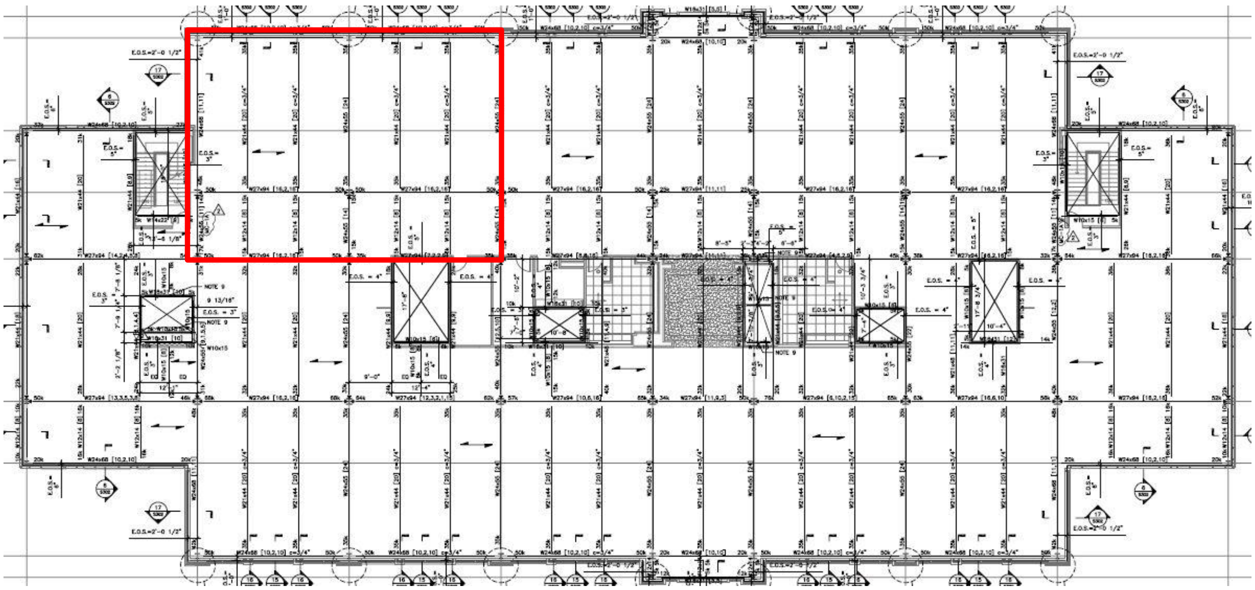


Figure 15 – Second Floor Structural Plan

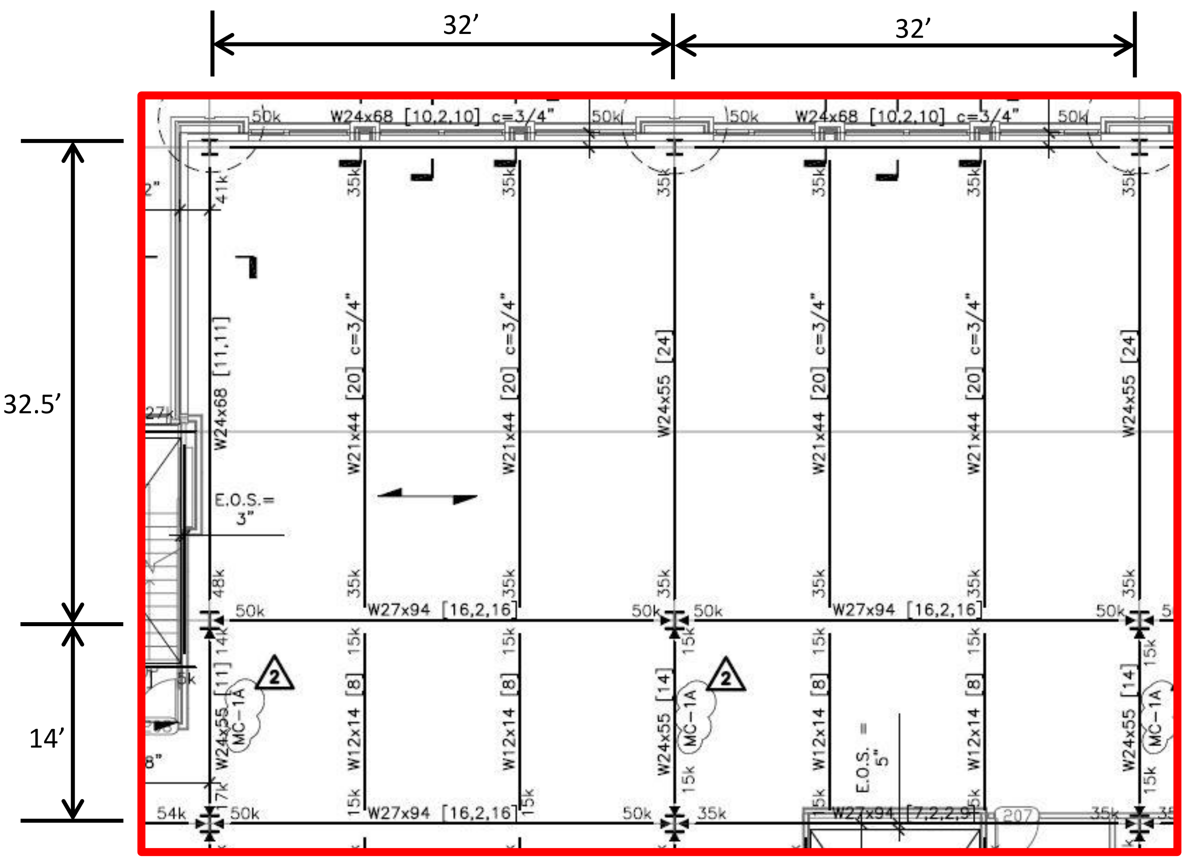


Figure 16 – Spot Check Area

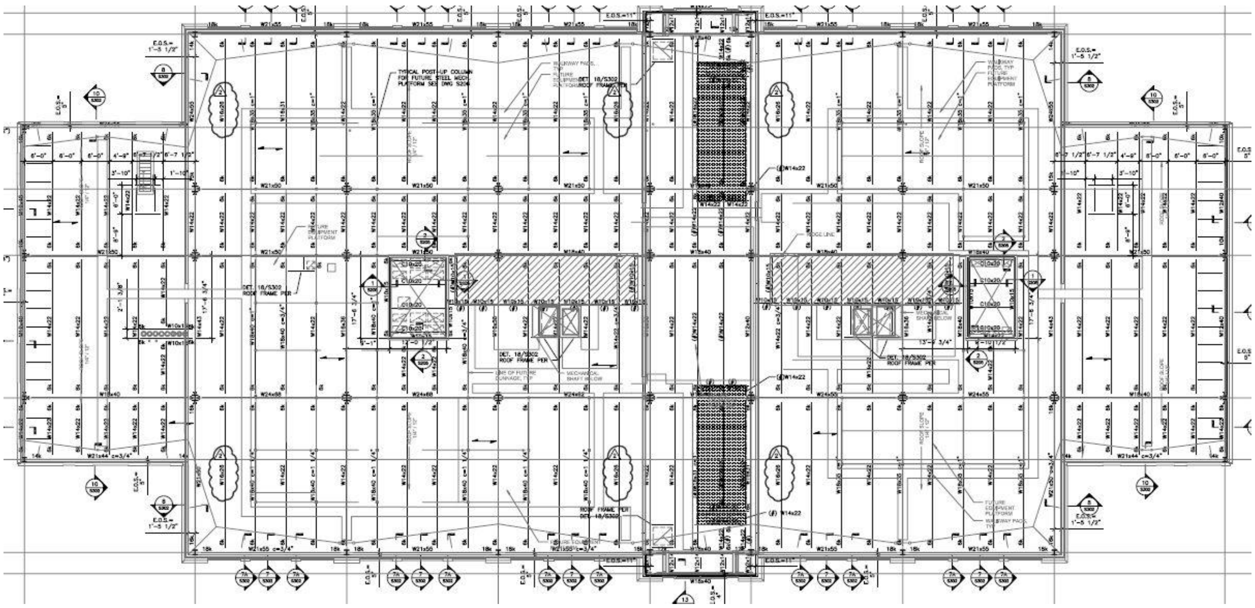


Figure 17 – Roof Structural Plan

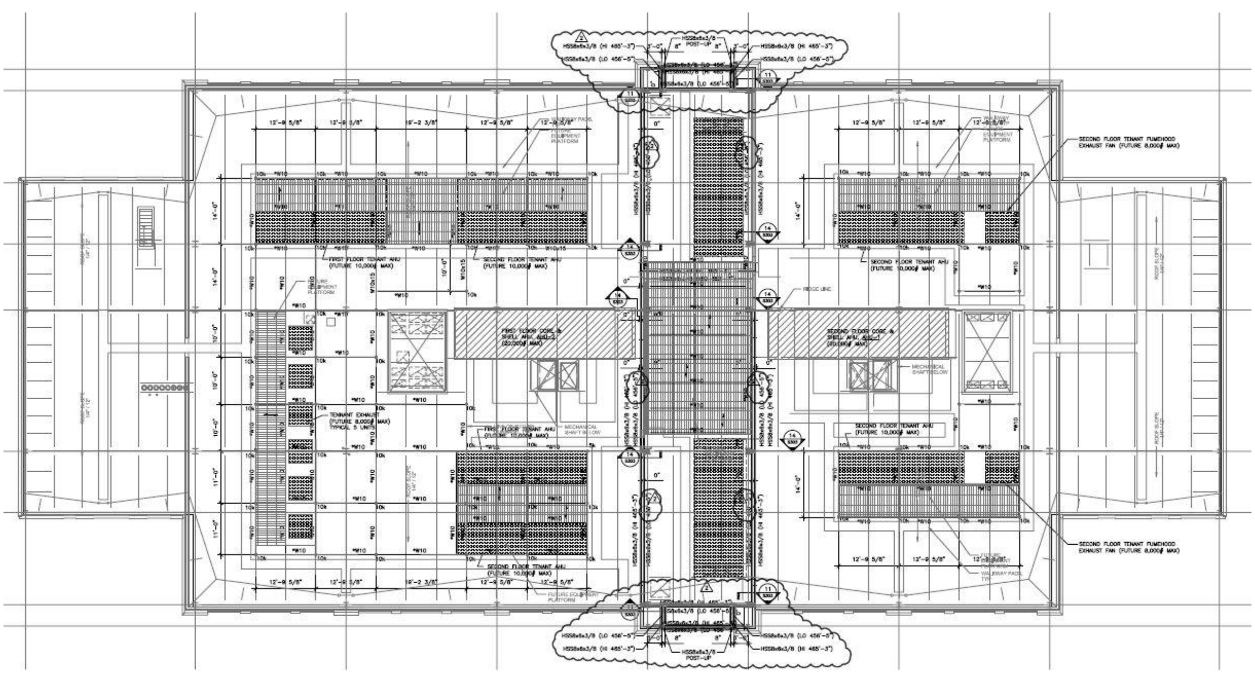


Figure 18 – High Roof Structural Plan

Appendix B: Hand Calculations

Jon Krepps AE Senior Thesis Wind Calcs - pg 1

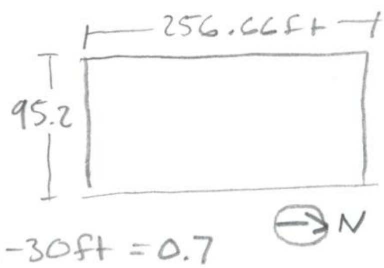
Basic wind Speed = 90mph = V (Figur 6-1)

Occupancy Type II (Table 1-1)

Importance Factor $I_w = 1.0$ (Table 6-1)

Wind Exposure Factor B

PLAN VIEW



$q_z = 0.00256\, K_z K_{zt} K_d V^2 I$

K_z = varies with height

↳ Table 6-3 Exposure B Case 1 = 0-30ft = 0.7
45ft = 0.785
50ft = 0.81

$K_{zt} = 1.0$

$K_d = 0.85$

$q_z = 0.00256(K_z)(1.0)(0.85)(90)^2(1.0)$

$V = 90$ mph

$q_z = 12.34$ psf → 0-30ft

$q_z = 13.84$ psf → 45ft

$I = 1.0$

$q_z = 14.28$ psf → 50ft

Structure is Rigid so $G = 0.85$

↳ $f > 1$

Internal Pressure Coefficient

$GC_{pi} = \pm 0.18$

Design Pressures for MWFRS Wind - pg 2

$P = qGC_p - q_i(GC_{pi})$

$q = q_z$ = Windwart walls
↳ variable

$q = q_h$ = leeward walls = 14.28psf
↳ constant

$G = 0.85$

C_p = External Pressure coefficient

$q_i = q_h = 14.28_{psf}$, for enclosed building

$GC_{pi} = \pm 0.18$

$C_p = 0.8$ windward wall Pressure

$= -0.7$ side wall pressure

$= -0.5 \rightarrow L/B = 0.37$, leeward pressure normal to 256.66ft

$= -0.3 \rightarrow L/B = 2.7$, Leeward pressure normal to 95.2ft

Wind ward Pressure

$P = 12.34(0.85)(0.8)$

$= 8.39$

$P = 13.84(0.85)(0.8)$

$= 11.98\,psf \rightarrow$ Roof

$P = 14.28(0.85)(0.8)$

$= 12.28\,psf \rightarrow$ High Roof

Leeward Pressure East-West Wind - pg 3

$P = 14.28(0.85)(-0.5)$

$= -6.07$

Leeward Pressure North-South

$P = 14.28(0.85)(-0.3)$

$P = -6.21$ psf → constant

Roof Pressure

$C_p = -0.9$ 0 to h

$= -0.5$ h to 2h

$= -0.3$ >2h

$P = 14.28(0.85)(C_p)$

$= -10.92$ → 0-50ft

$= -6.07$ → 50-100ft

$= -3.64$ → >100ft

Jon Krepps AE Senior Thesis Snow load - pg 1

$P_f = 0.7\, C_e C_t I P_g$ $P_g = 30\text{psf}$

$C_e = 1.0$

$P_f = 0.7(30)$ $C_t = 1.0$

$P_f = 21\text{psf}$ $I = 1.0$

Drift $\gamma = 0.13 p_g + 14 = 0.13(30) + 14 = 17.9 < 30$ ✓

Find drift height → Roof Projection, use figure 7-9 ASCE 7-02

$P_g = 30\text{psf}$

Chart value $h_d = 1.7\text{ft}$

$l_u = 27\text{ft}$

From §7.8 $h_d = 0.75 h_d$ ⇒ From Figure 7-9

$h_d = 0.75(1.7) = 1.275\text{ ft}$

$P_d = (1.275)(17.9) = 22.8\text{ psf}$ → Roof snow load w/drift

$22.8_{psf} > 21_{psf}$ ✓

Seismic Base Shear

Equivalent Lateral Force Method

Base shear

$V = C_s W$ $\quad$ C_s = Seismic Response Coefficient
$\quad$ W = Building Weight

$W = 11{,}452^k$ => Take from RAM Structural

$C_s = S_{DS} / \left(\frac{R}{I_e}\right)$ $\quad$ $I_e = 1.25$
$R = 3.0$
$S_{DS} = 0.245$

$$C_s = \frac{0.245}{\left(\frac{3.0}{1.25}\right)} = 0.1021$$

$$C_s < \frac{S_{D1}}{\left(\frac{R}{I}\right)(T)}$$

$S_{D1} = 0.112$

$T = C_T h_n^x$ $\quad$ $h_n = 49.5'$
$C_T = 0.016$
$x = 0.9$

$T = 0.016(49.5)^{0.9}$

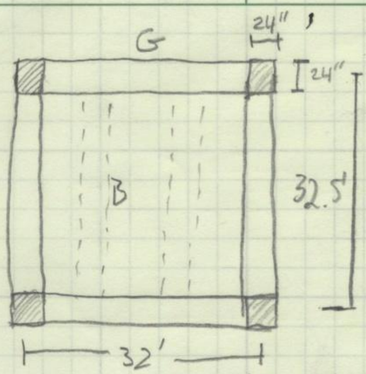
$T = 0.536 < T_L = 6$

$$C_s < \frac{0.112}{\left(\frac{3}{1.25}\right)(0.536)}$$

$C_s = 0.0871 < 0.1021$

$V = 0.0871(11452) = 997^k$

Roof Design w/Green Roof 1/8



*10.67' Spaces

$f'_c = 4000\,psi$ $f_y = 60000\,psi$

Roof Live Load = 30psf

SDL = 25psf

Green Roof = 35psf

Snow = 30psf

$1.2D + 1.6(L_r \text{ or } S)$

$= 1.2(25+35) + 1.6(30) = 120\,psf$

Slab Depth

$= 1/24 = \frac{10.67(12)}{24} = 5.33 \Rightarrow$ Use 5.5"

Assuming #4 Bars, 3/4" CLR cover

$d = h - 3/4" - \frac{d_b}{2} = 5.5 - .75 - \frac{0.5}{2} = 4.5"$

Slab self weight $= \frac{5.5}{12}(150) = 68.75\,psf\,(1.2) = 82.5$

$W_u = 82.5 + 120 = 202.5\,psf$

Try Beam width = 12"

$l_n = 10.67' - 2(\frac{12}{2})/12 = 9.67'$

Slab Reinforcement

$M_u = \frac{w_u l_n^2}{10} = \frac{202.5(9.67)^2}{10} = 1.9\ \frac{k\text{-}ft}{ft}$

$A_s \geq \frac{M_u}{\phi f_y (d - a/2)}$ $a = \frac{A_s f_y}{0.85 f'_c b}$ Try $jd = 0.95d$, $jd \approx (d - a/2)$

$= \frac{1.9(12)}{0.9(60)(0.95)(4.5)} = 0.099\ in^2/ft$

Roof Design W/Green Roof 2/8

Shear Check

$$\frac{1.15 w_u l_n}{2} = \frac{1.15(202.5)(9.67)}{2} = 1.13 \text{ k/ft}$$

$$\phi V_c = 0.75(2\lambda\sqrt{f'_c}\, b_w d) = 0.75(2)(1.0)\sqrt{4000}(12)(4.5)$$

$$= 5.12^k > 1.13$$

Transverse Reinforcement

$$\rho = 0.0018 \quad \rho = \frac{A_{s\,min}}{bh} = 0.0018(12)(5.5) = 0.119$$

$$\text{Spacing} = \min \left| \begin{array}{l} 5h = 5.5(5) = 27.5\text{in} \\ 18\text{in} \Rightarrow \text{Controls} \end{array} \right.$$

Design Details

Slab Thickness = 5.5"

Flexural Reinforcement

= #4 @ 12" Top and Bottom

Transverse (Shrinkage/Temp)

= #4 @ 18"

Roof Design w/Green Roof 3/8

Beam Design

Try $B = 12\,in$ $\quad h \approx \frac{l}{18}$ to $\frac{l}{12} = 21.67'' - 32.5''$

Try $h = 22\,in$

$w_{beam} = \frac{(22-5.5)(12)}{144}(150) = 206\,plf$

$w_{LL} = 30(10.67) = 320\,plf$

$w_{slab} = \frac{(5.5)(10.67)(12)(150)}{144} = 734\,plf$

$w_{GR} = 35(10.67) = 373.5\,plf$

$w_u = 1.2(206 + 373.5 + 734) + 1.6(320)$

$w_u = 2.09\,klf$

$l_n = 30.5'$

First Ext

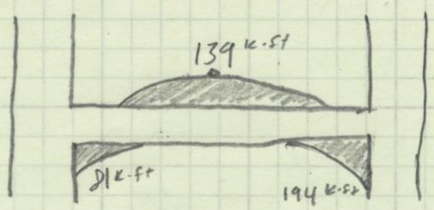
$\frac{-w_u l_n^2}{24} = \frac{-2.09(30.5)^2}{24} = -81\,k\text{-}ft$

Midspan

$\frac{w_u l_n^2}{14} = \frac{2.09(30.5)^2}{14} = 139\,k\text{-}ft$

First Int

$\frac{-w_u l_n^2}{10} = \frac{-2.09(30.5)^2}{10} = -194\,k\text{-}ft$



$d = 22 - 1.5 - \frac{0.5}{2} - \frac{1.0}{2}$

$d = 19.75$

@First Ext

$M_u = -81\,k\text{-}ft$ $\quad A_s = \frac{M_u}{4d} = \frac{-81}{4(19.75)} = 1.0\,in^2$ $\Rightarrow$ Try (2)#7 $A_s = 1.2\,in^2$

$\rho = \frac{A_s}{bd} = \frac{1.2}{12(19.75)} = 0.005$

@Midspan

$M_u = 139\,k\text{-}ft$ $\quad A_s = \frac{M_u}{4d} = \frac{139}{4(19.75)} = 1.75\,in^2$ $\Rightarrow$ Try (3)#7 $A_s = 1.8\,in^2$

$\rho = \frac{A_s}{bd} = \frac{1.8}{12(19.75)} = 0.0076$

Roof Design w/Green Roof 4/8

@ First Int

$M_u = 194^{k\cdot ft}$ $A_s = \frac{194}{4(19.75)} = 2.5 in^2 \Rightarrow$ Try (2)#10 $A_s = 2.54 in^2$

$\rho = \frac{A_s}{bd} = \frac{2.54}{(12)(19.75)} = 0.0107$

Strength Check

@ First Int

$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{1.2(60)}{0.85(4)(12)} = 1.76$ $c = \frac{a}{\beta_1} = 2.08$

$\varepsilon_s = \frac{d-c}{c}(0.003)$

$\phi M_n = 0.9(1.2)(60)(19.75 - \frac{1.76}{2})/12$

$\varepsilon_s = 0.025 > 0.005$

$\phi M_n = 102^{k\cdot ft} > 81^{k\cdot ft}$ ok $A_{s,min} = \frac{200bd}{f_y}$

$= \frac{200(12)(19.75)}{60000} = 0.79 < 1.2 in^2$ ok

@ Mid Span

$a = \frac{1.8(60)}{0.85(4)(12)} = 2.65$ $c = 3.11$ $\varepsilon_s = 0.016 > 0.005$

$\phi M_n = 0.9(1.8)(60)(19.75 - \frac{2.65}{2})/12 = 149^{k\cdot ft} > 139^{k\cdot ft}$ ok

@ First Ext

$a = \frac{2.54(60)}{0.85(4)(12)} = 3.7$ $c = 4.39$ $\varepsilon_s = 0.01 > 0.005$

$\phi M_n = 0.9(2.54)(60)(19.75 - \frac{3.7}{2})/12 = 204^{k\cdot ft} > 194^{k\cdot ft}$ ok

Shear Check using #4 stirrups

$V_u = \frac{w_u l_n}{2} = \frac{2.09(30.5)}{2} = 31.9^k$ $V_c = 2\sqrt{f'_c}\,bd$

$= 2\sqrt{4000}(12)(19.75)$

$V_s = 2A_s f_y d/12 = 2(0.2)(60)(19.75)/12$ $= 30^k$

$V_s = 39.5^k$

$\phi V_n = \phi(V_s + V_c) = 0.75(30 + 39.5) = 52.1^k > 31.9^k$ ok

Roof Design w/Green Roof 5/8

Deflection Check

$w_L = 320\text{ plf}$ $w_{TL} = 1634\text{ plf}$

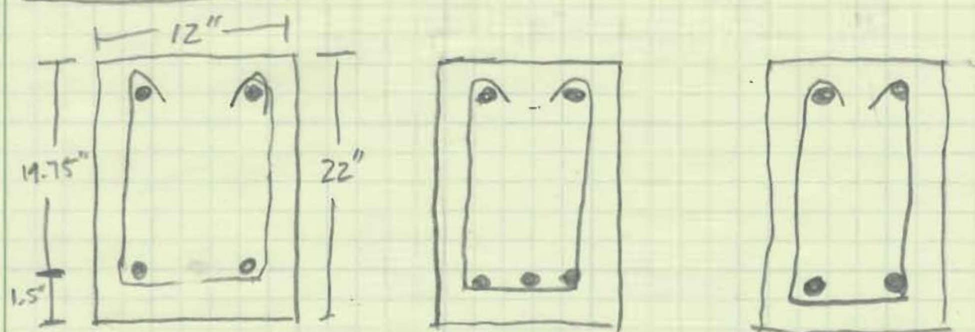
$$\Delta_{LL} = \frac{5 w_L \ell^4 (12)^3}{384 EI} = \frac{5(320)(30.5)^4(1728)}{384(57000\sqrt{4000})(\frac{1}{12}(12)^2(22)^3)} = 0.162$$

$$\Delta_{LL} < \frac{\ell}{400} = \frac{30.5(12)}{400} = 0.915\text{ in} > 0.162\text{ in} \quad \underline{ok}$$

$$\Delta_{TL} = \frac{5(1634)(30.5)^4(1728)}{384(57000\sqrt{4000})(\frac{1}{12}(12)(22)^3)} = 0.83\text{ in}$$

$$\Delta_{TL} < \ell/280 = 1.31'' > 0.83\text{ in} \quad \underline{ok}$$

Beam Details



(2)#7 Bars (3)#7 Bars (2)#10 Bars

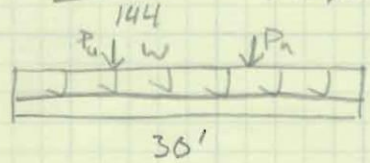
@First Int @Mid Span @First Ext

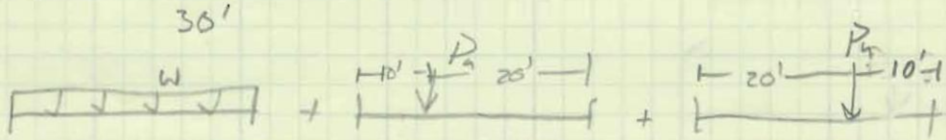
Roof Design W/Green Roof 6/8

Girder Design

Try $h = 22in$ to match beams
$b = 18in$ $\quad l_n = 30'$

$w_{G} = \frac{(22-5.5)(18)}{144}(150) = 310\ plf \quad P_u = 31.9^k$





$M^- = \frac{wl^2}{12} = \frac{0.31(30)^2}{12}$
$= 23.25^{k\text{-}ft}$

$M^+_{@x} = \frac{w}{12}(6lx - l^2 - 6x^2)$
$= 7.75^{k\text{-}ft}$

$V = \frac{wl}{2} = \frac{.31(30)}{2}$
$V = 4.65^k$

$M^- = \frac{Pa^2b}{l^2} = \frac{31.9(10)^2(20)}{30^2}$
$= 70.9^{k\text{-}ft}$

$M_{@P} = \frac{2Pa^2b^2}{l^3} = \frac{2(31.9)(10^2)(20)^2}{30^3}$
$= 94.5^{k\text{-}ft}$

$V = \frac{Pa^2}{l^3}(a+3b)$
$V = 8.27^k$

$M = \frac{Pa^2b}{l^2} = \frac{31.9(20)^2(10)}{30^2}$
$= 142^{k\text{-}ft}$

$M_{@P} = \frac{2Pa^2b^2}{l^3}$
$= 94.5^{k\text{-}ft}$

$V = \frac{Pa^2}{l^3}(a+3b)$
$V = 23.63^k$

$V_{max} = 4.65 + 8.27 + 23.63 = 36.55^k$

$M^-_{max} = 23.25 + 70.9 + 142 = 236^{k\text{-}ft}$

$M^+_{max} = 7.75 + 94.5 + 11.8 = 114^{k\text{-}ft}$

$M_{@x=10}$, $P @ x=20$

$R_1 x - \frac{Pab^2}{l^2} = 8.27(10) - \frac{31.9(20)(10)^2}{30^2}$

$M = 11.8^k$

Roof Design w/Green Roof 7/8

@Midspan

$d = 19.75$

$M_u = 114^{k\cdot ft}$ $A_s = \frac{M_u}{4d} = \frac{114}{4(19.75)} = 1.44\ in^2$

↳ Try (3) #7

$\rho = \frac{A_s}{bd} = \frac{1.8}{18(19.75)} = 0.005$ $A_s = 1.8\ in^2$

@Supports

$M_u = 236^{k\cdot ft}$ $A_s = \frac{236}{4(19.75)} = 2.98\ in^2$

↳ Try (5) #7

$\rho = \frac{3.0}{18(19.75)} = 0.008$ $A_s = 3.0\ in^2$

@Midspan

$a = \frac{A_s f_y}{0.85 b f'_c} = \frac{1.8(60)}{0.85(18)(4)} = 1.76$ $c = 2.08$

$\varepsilon_s = 0.025 > 0.005$

$\phi M_n = \phi A_s f_y (d - a/2)$

$\phi M_n = 0.9(1.8)(60)(19.75 - \frac{1.76}{2}) = 153^{k\cdot ft} > 114^{k\cdot ft}$ ok

$A_{s,min} = \frac{200(18)(19.75)}{60000} = 1.18\ in^2 < 1.8\ in^2$ ok

@Supports

$a = \frac{3.0(60)}{0.85(4)(18)} = 2.94$ $c = 3.46$ $\varepsilon_s = 0.014 > 0.005$

$\phi M_n = 0.9(3)(60)(19.75 - \frac{2.94}{2})/12 = 247^{k\cdot ft} > 236^{k\cdot ft}$ ok

$A_{s,min} = 1.18 < 3.0\ in^2$ ok

Roof Design W/Green Roof 8/8

Deflection Check:

$$\Delta_{max} = \frac{PL^3 \, 12^3}{28EI} + \frac{5 w_L \ell^4 \, 12^3}{384EI}$$

$$\Delta_{LL} = \frac{7.8(30)^3(1728)}{28(57000\sqrt{4000})(\frac{1}{12})(18)(22)^3} + 0 = 0.23\text{in}$$

$$\Delta_{LL} = \frac{\ell}{400} = \frac{30(12)}{400} = 0.9\text{in} > 0.23\text{in} \text{ ok}$$

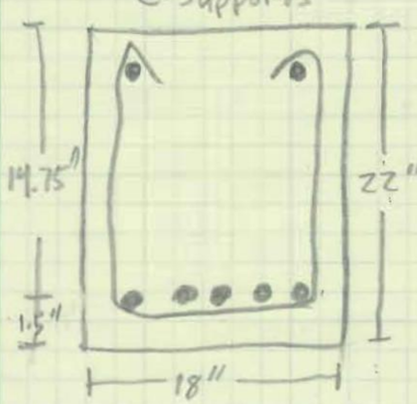
$$\Delta_{TL} = \frac{31.9(30)^3(1728)}{28(57000\sqrt{4000})(\frac{1}{12})(18)(22)^3} + \frac{5(0.31)(30)^4(1728)}{384(57000\sqrt{4000})(\frac{1}{12})(18)(22)^3}$$

$$= 0.9 + 0.1 = 1\text{in}$$

$$\Delta_{TL} = \ell/280 = \frac{30(12)}{280} = 1.29 > 1.0\text{in} \text{ ok}$$

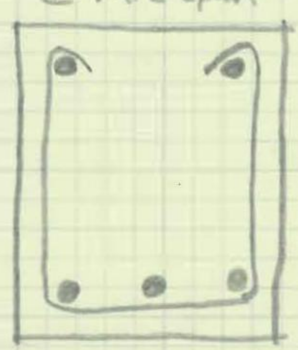
Design Details

@ Supports



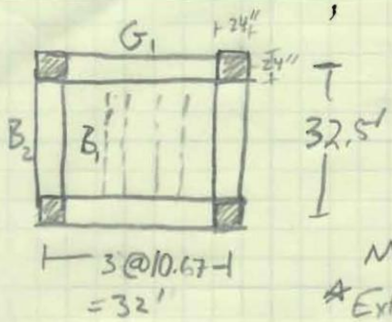
(5) #7 Bars

@ Mid span



(3) #7 Bars

One Way Slab Design 1/3



$f'_c = 4000$

$f_y = 60000$

$LL = 100\,psf$

$SDL = 25\,psf$

Min Slab Thickness From Table 9.5(a)

*Exterior Bay One end continuous

$= \ell/24 = \dfrac{10.67'(12''/ft)}{24} = 5.335'' \approx 5.5''$

use 5.5" Thick slab

Assume #4 bars w/ 3/4" CLR Cover

$d = h - \frac{3}{4}'' - \frac{d_b}{2} = 5.5'' - 0.75 - \frac{0.5}{2} = 4.5''$

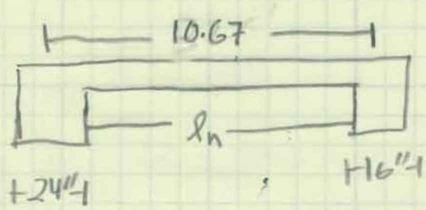
Load $= \quad W_D = \left(\frac{5.5}{12}\right)(150) = 68.75\,psf + 25\,psf$

$= 93.75\,psf$

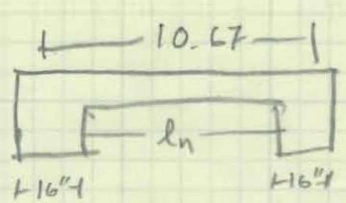
$W_L = 100\,psf \Rightarrow$ Unreducible

$W_u = 1.2(93.75) + 1.6(100) = 272.5\,psf$

Try $b_1 = 16''$, $b_2 = 24''$



Exterior Span



Interior Span

$\ell_n = 10.67 - \frac{12}{12} - \frac{8}{12} = 9'$

$\ell_n = 10.67 - \frac{16}{12} = 9.33'$

2/3

Use Larger $\ell_n \doteq 9.33'$ => Conservative

Using Moment Coefficient Method

First Interior Support $M_u = \frac{w_u \ell_n^2}{10} = \frac{272.5(9.33^2)}{10} = 2.37 \frac{k\text{-}ft}{ft}$

Second Interior Support $M_u = \frac{w_u \ell_n^2}{11} = \frac{272.5(9.33)^2}{11} = 2.17 \frac{k\text{-}ft}{ft}$

Slab Reinforcement

↳ low reinforcement ration

$A_s \geq \frac{M_u}{\phi f_y (d - a/2)}$ $\quad a = \frac{A_s f_y}{0.95 f'_c b}$ $\quad$ Try $jd = .95d$
$jd \approx (d - a/2)$

$= \frac{2.37 \times 12}{0.9(60)(0.95)(4.5)} = 0.123 \ in^2/ft$ $\quad a = \frac{0.123(60)}{0.85(4)(12)} = 0.18 \ in$

$A_s \geq \frac{0.123 \times 12}{0.9(60)(4.5 - \frac{0.18}{2})} = 0.007 \ in^2/ft$

$\rho = \frac{A_s}{bd} = \frac{0.007}{12(4.5)} = 1.30 \times 10^{-4}$ $\quad A_{s,min} = 1.3 \times 10^{-4} \times bh$
$= 0.0078 \ in^2/ft$

Shear Check

Shear in end Member at face of first interior Support

$= 1.15 w_u \ell_n / 2 = 1.15(272.5)(4.33)/2 = 1.46^k/ft$

$\phi V_c = 0.75(2\lambda\sqrt{f'_c}\, b_w d) = 0.75(2)(1.0)\sqrt{4000}(12)(4.5)$
$= 5.12^{k/ft} > 1.46$ ok

Beam Design 1/4

Beam B1

$b = 16''$ $\quad h \approx \frac{l}{18}$ to $\frac{l}{12} = 21.67 - 32.5$

Try $h = 28''$ $\quad w_{beam} = \frac{(28-5.5)(16)}{144}(150) = 375\,plf$

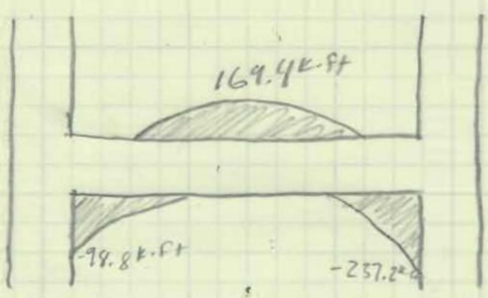
$W_{slab} = \frac{(5.5)(10.67 \times 12)(150)}{144} = 61.3\,plf$ $\quad w_{SDL} = 25psf(10.67) = 266.75\,plf$

$w_{LL} = 100(10.67) = 1067\,plf$

$w_u = 1.2(375 + 61.3 + 266.75) + 1.6(1067) = 2550\,plf$

$l_n = 32.5 - \frac{24}{12} = 30.5'$

First Ext	Midspan	First interior
$-\frac{w_u l_n^2}{24}$	$\frac{w_u l_n^2}{14}$	$-\frac{W_u l_n^2}{10}$
$= \frac{-2.55(30.5)^2}{24}$	$= \frac{2.55(30.5)^2}{14}$	$= \frac{-2.55(30.5)^2}{10}$
$= -98.8\,k\cdot ft$	$= 169.4\,k\cdot ft$	$= -237.2\,k\cdot ft$



2/14

$b_{eff} = \min \begin{cases} \frac{1}{4} \text{ span} & = \frac{1}{2}(30.5)(12) = 91.5 \Rightarrow \text{Cont.} \\ b_w + 16h_f & = 16 + 16(5.5) = 104 \\ b_w + 2(\frac{1}{2} \text{ CLR Dist}) & = 16 + 2(\frac{1}{2}(9.33)) = 128 \end{cases}$

$b_{eff} = 91.5''$ use $f'_c = 4000 psi$, #4 stirrups

@ First Exterior

Assume #8 Bar

$M_u = -98.8^{k\cdot ft}$ $A_s = \frac{M_u}{4d}$ $d = 28 - 1.5'' - \frac{0.5}{2} - \frac{1.0}{2}$

$d = 25.75''$

$A_s = \frac{98.8}{4(25.75)} = 1.0$ use (2) #7 Bars

$A_s = 1.2 in^2$

$\rho = A_s/bd = \frac{1.2}{16(25.75)} = 0.0029 < 0.0125$

@ Midspan

$M_u = 169.4^{k\cdot ft}$ $A_s = \frac{M_u}{4d} = \frac{169.4}{4(25.75)} = 1.64$

use (3) #7 Bars $A_s = 1.8 in^2$

$\rho = A_s/bd = \frac{1.8}{16(25.75)} = 0.0043 < 0.0125$

@ First interior

$M_u = -237.2^{k\cdot ft}$ $A_s = \frac{237.2}{4(25.75)} = 2.3$ use (4) #7

$A_s = 2.4 in^2$

$\rho = A/bd = \frac{2.4}{16(25.75)} = 0.0058 < 0.0125$

Now $d = 28 - 1.5 - \frac{0.5}{2} - \frac{0.875}{2} = 25.8 in$

3/4

Strength Check

@First Exterior

$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{1.2(60)}{0.85(4)(16)} = 1.32$

$c = a/\beta_1 = 1.55$

$\varepsilon_s = \left(\frac{d-c}{c}\right)\varepsilon_u$

$= \left(\frac{25.8-1.55}{1.55}\right)0.003$

$= 0.047 > 0.005$

$\therefore \phi = 0.9$

$\phi M_u = \phi A_s f_y (d - a/2)/12$

$= 0.9(1.2)(60)(25.8 - \frac{1.32}{2})/12$

$= 135.75^{k\cdot ft} > 98.8$ ok

$A_{s,min} = \max \begin{cases} \frac{3\sqrt{f'_c}\, b d}{f_y} \\ \frac{200bd}{f_y} = 1.376 > 1.2 \end{cases}$

Change to (3) #7 Bars $A_s = 1.8 in^2$

↳ Strength will still work w/ More Bars

@Midspan

$a = \frac{1.8(60)}{0.85(4)(16)} = 1.99$ $c = 2.33$ $\varepsilon_s = \left(\frac{25.8-2.33}{2.33}\right)0.003$

$\varepsilon_s = 0.03 > 0.005$

$\phi M_u = 0.9(1.8)(60)(25.8 - \frac{1.99}{2})/12$

$= 201^{k\cdot ft} > 169.4^{k\cdot ft}$ ok

$A_{s,min} = \frac{200bd}{f_y} = 1.376$

$1.376 < 1.8 in^2$ ok

@First Interior

$a = \frac{2.4(60)}{0.85(4)(16)} = 2.65$ $c = 3.11$ $\varepsilon_s = 0.022 > 0.005 \Rightarrow \phi 0.9$

$\phi M_u = 0.9(2.4)(60)(25.8 - \frac{2.65}{2})/12$

$\phi M_n = 264.33^{k\cdot ft} > 237.2^{k\cdot ft}$

$A_{s,min} = 1.376 < 2.4 in^2$ ok

4/4

Shear Check

$$V_u = \frac{w_u l_n}{2} = \frac{2.55(30.5)}{2} = 38.9^k$$

$$V_c = 2\sqrt{f'_c}\, bd$$
$$= 2\sqrt{4000}(16)(25.8) = 52.2^k$$

$$V_s = 2A_s f_y\, d/12 = 2(0.2)(60)(25.8/12) = 51.6^k$$

$$\phi V_n = \phi(V_c + V_s) = 0.75(52.2 + 51.6) = \underline{77.85^k > 38.9^k}$$
ok

Deflection Check

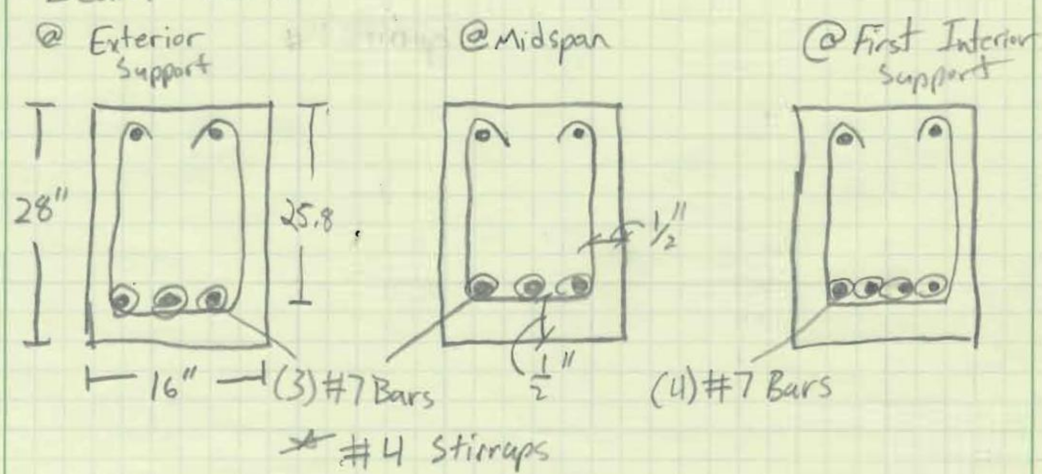
$$\Delta_{LL} = \frac{5 w_L l^4 (12^3)}{384 EI} = \frac{5(1.067)(30.5)^4(1728)(1000)}{384(57000\sqrt{4000})(\frac{1}{12}(16)(28)^3)}$$

$$\Delta_{LL} = 0.197'' < l/480 = \frac{30.5(12)}{480} = 0.7625''\ \underline{ok}$$

$$\Delta_{TL} = \frac{5(2.55)(30.5^4)(1728)(1000)}{384(57000\sqrt{4000})(\frac{1}{12}(16)(28)^3)} = 0.47''$$

$$\Delta_{TL} = l/280 = \frac{30.5(12)}{280} = 1.31'' > 0.47''\ \underline{ok}$$

Beam Details



Beam Design 1/4

Beam B2 Design:

$B = 20''$ $\quad h = \frac{\ell}{12}$ to $\frac{\ell}{18} = 21.67$ to 32.5

Try $h = 28''$

$$w_{beam} = \frac{(28-5.5)(20'')}{144}(150) = 468.75\,plf$$

$$w_{slab} = \frac{(5.5)(10.67)(12)(150)}{144} = 61.3\,plf$$

$$w_{SDL} = 25\,psf\,(10.67) = 266.75\,plf$$

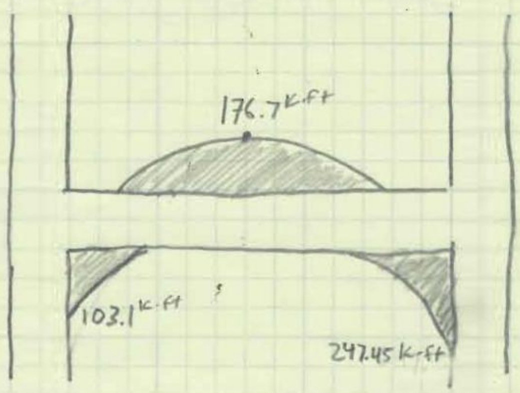
$$w_{LL} = 100(10.67) = 1067\,plf$$

$$w_u = 1.2(468.75 + 61.3 + 266.75) + 1.6(1067)$$

$$w_u = 2.66\,^{KLF}$$

$$\ell_n = 30.5'$$

First Ext	Midspan	First Interior
$\frac{-w_u \ell_n^2}{24}$	$\frac{w_u \ell_n^2}{14}$	$\frac{-w_u \ell_n^2}{10}$
$= \frac{2.66(30.5)^2}{24}$	$= \frac{2.66(30.5)^2}{14}$	$= \frac{2.66(30.5)^2}{10}$
$= -103.1^{k\cdot ft}$	$= 176.7^{k\cdot ft}$	$= -247.45^{k\cdot ft}$



2/4

$$b_{eff} = \min \begin{cases} 1/4 \text{ span} & = \tfrac{1}{2}(30.5)(12) = 183 \\ b_w + 16h_f & = 20 + 16(5.5) = 108 \\ b_w + 2(\tfrac{1}{2} \text{ CLR Dist}) & = 20 + 2(\tfrac{1}{2})(4.33)(12) = 132 \end{cases}$$

$b_{eff} = 108''$ Use $f'_c = 4000$ #4 stirrups

@ First exterior

$M_u = 103.1$ $A_s = \frac{M_u}{4d}$ $d = 28 - 1.5 - \frac{0.5}{2} - \frac{1.0}{2} = 25.75$

$A_s = \frac{103.1}{4(25.75)} = 1.0$

$\rho = \frac{A_s}{bd} = \frac{1.2}{20(25.75)} = 0.0023 < 0.0125$ Use (2) #7 Bars $A_s = 1.2 \text{ in}^2$

@ Mid span

$M_u = 176.7^{k \cdot ft}$ $A_s = \frac{M_u}{4d} = \frac{176.7}{4(25.75)} = 1.7 \text{ in}^2$

Use (3) #7 $A_s = 1.8 \text{ in}^2$

$\rho = \frac{A_s}{bd} = \frac{1.8}{20(25.75)} = 0.003 < 0.0125$

@ First Interior

$M_u = -247.45^{k \cdot ft}$ $A_s = \frac{M_u}{4d} = \frac{247.45}{4(25.75)} = 2.4 \text{ in}^2$

Use (4) #7 $A_s = 2.4 \text{ in}^2$

$\rho = A_s/bd = 2.4/20(25.75) = 0.0047 < 0.0125$

3/4

Strength Check:

@ First Exterior

$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{1.2(60)}{0.85(4)(20)} = 1.06$

$c = a/\beta_1 = 1.25$

$\varepsilon_s = \left(\frac{d-c}{c}\right)\varepsilon_u$

$= \frac{25.8-1.25}{1.25}(0.003)$

$\varepsilon_s = 0.059 > 0.005$

$\hookrightarrow \phi = 0.9$

$\phi M_u = \phi A_s f_y (d - a/2)/12$

$= 0.9(1.2)(60)(25.8 - \frac{1.06}{2})/12$

$\phi M_u = 136.45^{k\text{-}ft} > 103^{k\text{-}ft}$ ok

$A_{s\,min} = \max \begin{cases} \frac{3\sqrt{f'_c}\,bd}{f_y} \\ \frac{200bd}{f_y} \Rightarrow \text{controls} \end{cases} = 1.72 in^2 > 1.2 in^2$

$\hookrightarrow$ Change bars to (3)#7

$A_s = 1.8 in^2$

@ Midspan

$a = \frac{1.8(60)}{0.85(4)(20)} = 1.58$

$c = \frac{a}{\beta_1} = 1.87$

$\varepsilon_s = \left(\frac{25.8-1.87}{1.87}\right)(0.003)$

$= 0.038 > 0.005$

$\phi M_u = 0.9(1.8)(60)(25.8 - \frac{1.58}{2})/12$

$\phi M_u = 202.6^{k\text{-}ft} > 176.7^{k\text{-}ft}$ ok

$A_{s\,min} = 1.72 in^2 < 1.8 in^2$ ok

@ First Interior

$a = \frac{2.4(60)}{0.85(4)(20)} = 2.12$

$c = 2.5$

$\varepsilon_s = \frac{25.8-2.5}{2.5}(0.003)$

$= 0.028 > 0.005$

$\phi M_n = 0.9(2.4)(60)(25.8 - \frac{2.12}{2})/12$

$\phi M_u = 267.2^{k\text{-}ft} > 247.45^{k\text{-}ft}$ ok

$A_{s\,min} = 1.72 in^2 < 2.4 in^2$ ok

4/4

Shear Check

$V_u = \frac{w_u l_n}{2} = \frac{2.66(30.5)}{2} = 40.6^k$

$V_c = 2\sqrt{f'_c}\, b d = \frac{2\sqrt{4000}(20)(25.8)}{1000} = 65.3^k$

$V_s = 2 A_s f_y \, d/12 = 2(0.2)(60)(25.8/12) = 51.6^k$

$\phi V_n = \phi(V_c + V_s) = 0.75(65.3 + 51.6) = 87.65^k > 40.6^k$ ok

Deflection Check

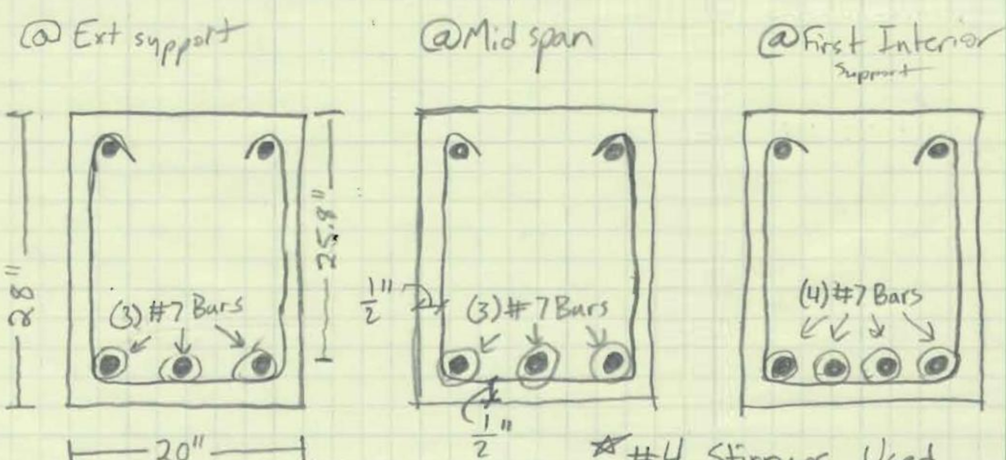
$$\Delta_{LL} = \frac{5 w_L l^4 (12^3)}{384 E I} = \frac{5(1.067)(30.5)^4(1728)(1000)}{384(57000\sqrt{4000})(\frac{1}{12}(20)(28^3))} = 0.158''$$

$\Delta_{LL} = .158 < l/400 = \frac{30.5(12)}{480} = 0.7625''$ ok

$$\Delta_{TL} = \frac{5(2.66)(30.5)^4(1728)(1000)}{384(57000\sqrt{4000})(\frac{1}{12}(20)(28^3))} = 0.393''$$

$\Delta_{TL} = 0.393 < l/280 = \frac{30.5(12)}{280} = 1.31'' > 0.393''$ ok

Final Beam Design Details

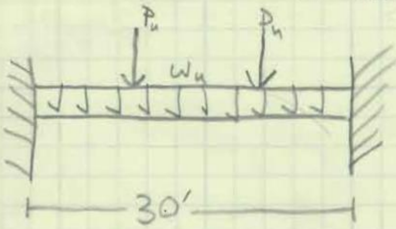


* #4 Stirrups Used

Girder Design 1/4

Girder Design

Assume b = 20" to match Column width
h = 28" to match Beams depth

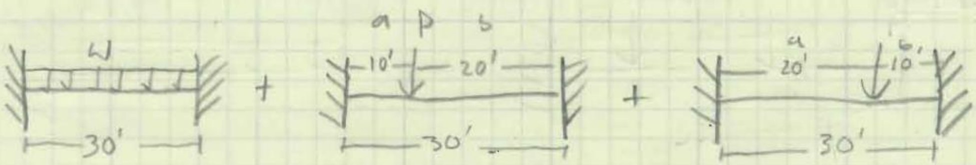


$l_n = 32' - \frac{24}{12} = 30'$

W_u = Girder self weight

P_u = Load from Beams

$W_u = \frac{(28-5.5)(24)}{144}(150) = 562.5\ plf$ $\quad P_u = 38.9^k$



$M = \frac{wl^2}{12} = \frac{0.563(30)^2}{12}$

$M = 42.2^{k\cdot ft}$

$M^+_{@x} = \frac{w}{12}(6lx - l^2 - 6x^2)$

$M^+_{@x} = 14.1^{k\cdot ft}$

$V = \frac{wl}{2} = \frac{0.563(30)}{2}$

$V = 8.4^k$

$M = \frac{Pa^2b}{l^2} = \frac{38.9(10)^2(20)}{30^2}$

$M = 86.44^{k\cdot ft}$

M^+@ Point Load

$M^+ = \frac{2P_u a^2 b^2}{l^3} = 28.8^{k\cdot ft}$

$V = \frac{Pa^2}{l^3}(a+3b) = 10.1^k$

$M = \frac{38.9(20^2)(10)}{30^2}$

$M = 173^{k\cdot ft}$

M^+@ Point Load

$M^+ = \frac{2Pa^2b^2}{l^3} = 28.8^{k\cdot ft}$

$V = \frac{Pa^2}{l^3}(a+3b) = 28.8^k$

$V_{max} = 8.4 + 10.1 + 28.8 = 47.3$

$M^-_{max} = 42.2 + 86.44 + 173 = 301.6^{ft}$

$M^+_{max} = 14.1 + 14.6 + 28.8 = 57.5^{k\cdot ft}$

M @ $x = 10$, P @ $x = 20$

$R_1 x - \frac{Pab^2}{l^2}$

$= 10.1(10) - \frac{38.9(20)(10)^2}{30^2}$

$= 14.6^{k\cdot ft}$

2/4

@ Midspan

$M_u = 57.5^{k\text{-}ft}$ $\quad A_s = \frac{M_u}{4d} = \frac{57.5}{4(25.8)} = 0.557 \text{ in}^2$

use (1) #7 $\quad A_s = 0.6 \text{ in}^2$

$\rho = A_s/bd = \frac{0.6}{(20)(25.8)} = 0.00116$

@ Supports

$M_u = 301.5^{k\text{-}ft}$ $\quad A_s = \frac{301.5}{4(25.8)} = 2.92 \text{ in}^2$

use (5) #7 $\quad A_s = 3 \text{ in}^2$

$\rho = \frac{A_s}{bd} = \frac{3.0}{20(25.8)} = 0.0058$

$$b_{eff} = \min \left| \begin{array}{ll} \frac{1}{4}(30)(12) & = 90'' \Rightarrow \text{Controls} \\ 24 + 16(5.5) & = 112'' \\ 24 + 2(\frac{1}{2}\text{ clr span}) & = 384'' \end{array} \right.$$

$M_{u,TBM} = \phi(0.85)(f'_c)(b_{eff})(h_f)(d - \frac{h_f}{2})/12 = 2909 > M_u$

↳ Use Rectangular Beam Analysis

3/4

@ Midspan

$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.6(60)}{0.85(4)(20)} = 0.529$

$c = a/\beta_1 = 0.623$

$\varepsilon_s = \left(\frac{d-c}{c}\right)(\varepsilon_u)$

$= \frac{25.8 - 0.519}{0.519}(0.003)$

$= 0.121 > 0.005$

$\hookrightarrow \phi = 0.9$

$\phi M_n = 0.9(0.6)(60)(25.8 - \frac{0.444}{2})/12$

$\phi M_n = 69.1^{k\text{-}ft} > 57.5^{k\text{-}ft}$ ok

$A_{s,min} = \max \begin{cases} \frac{3\sqrt{f'_c}\,bd}{f_y} = \frac{189.75d}{f_y} \\ \frac{200bd}{f_y} \Rightarrow \text{Controls} = \frac{200(20)(25.8)}{60000} = 1.72\text{ in}^2 \end{cases}$

$1.72\text{ in}^2 > 0.6\text{ in}^2 \Rightarrow$ Reinforcement Must be changed

Use (3) #7 bars, $A_s = 1.8\text{ in}^2$

@ Supports

$a = \frac{A_s f_y}{0.85 b f'_c} = \frac{3(60)}{0.85(4)(20)} = 2.65$

$c = \frac{a}{\beta_1} = 3.11$

$\varepsilon_s = \frac{25.8 - 2.6}{2.6}(0.003)$

$\varepsilon_s = 0.022 > 0.005$

$\phi M_n = 0.9(3)(60)(25.8 - \frac{2.21}{2})/12$

$\phi M_n = 333.4^{k\text{-}ft} > 301.5^{k\text{-}ft}$ ok

$A_{s,min} = 1.72\text{ in}^2 < 3.0\text{ in}^2$

Use (5) #7 bars, $A_s = 3.0\text{ in}^2$

Design meets spacing and min/max bar requirements

↳ Table A.7 A.8

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Deflection Check

$E = 57000\sqrt{f'_c}$
$= 57000\sqrt{4000}$
$= 3605000$

$I = \frac{1}{12} b h^3$
$I = \frac{1}{12}(20)(28)^3$
$I = 36587 \text{ in}^4$

$$\Delta_{max} = \frac{P L^3 12^3}{28 E I} + \frac{5 w_L \ell^4 12^3}{384 E I}$$

$$\Delta_{LL} = \frac{16.3(30)^3(1728)}{28(3605000)(36587)} + 0$$

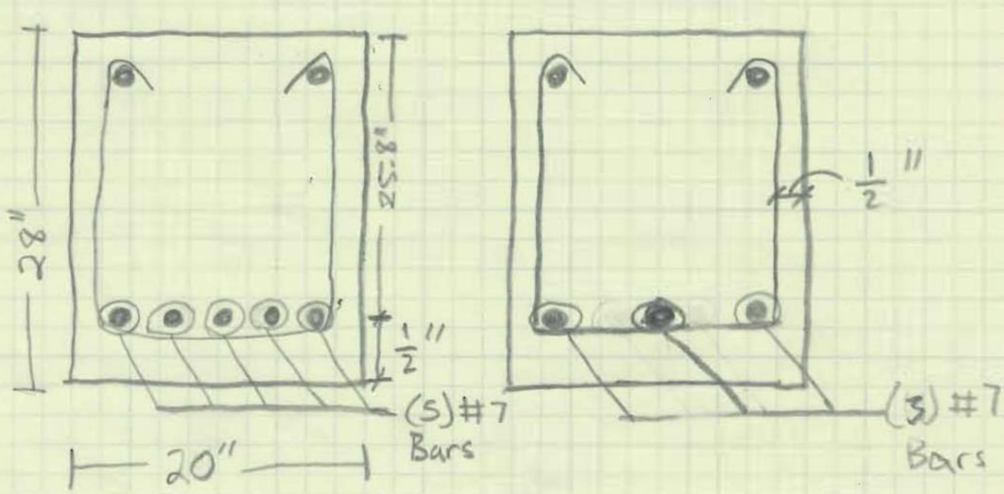
$\Delta_{LL} = 0.206 \text{ in} < \ell/400 = \frac{30(12)}{400} = 0.9 \text{ in}$
→ ok

$$\Delta_{TL} = \frac{38.9(30)^3(1728)}{28(3605000)(36587)} + \frac{5(0.563)(30)^4(1728)}{384(3605000)(36587)} = 0.41 \text{ in}$$

$\Delta_{TL} = 0.569 < \ell/280 = \frac{30(12)}{280} = 1.29 \text{ in}$
→ ok

Final Girder Design Detail

@ Supports @ Mid span



Appendix C: Design Aids

Chapter 5 • Simplified Design for Columns

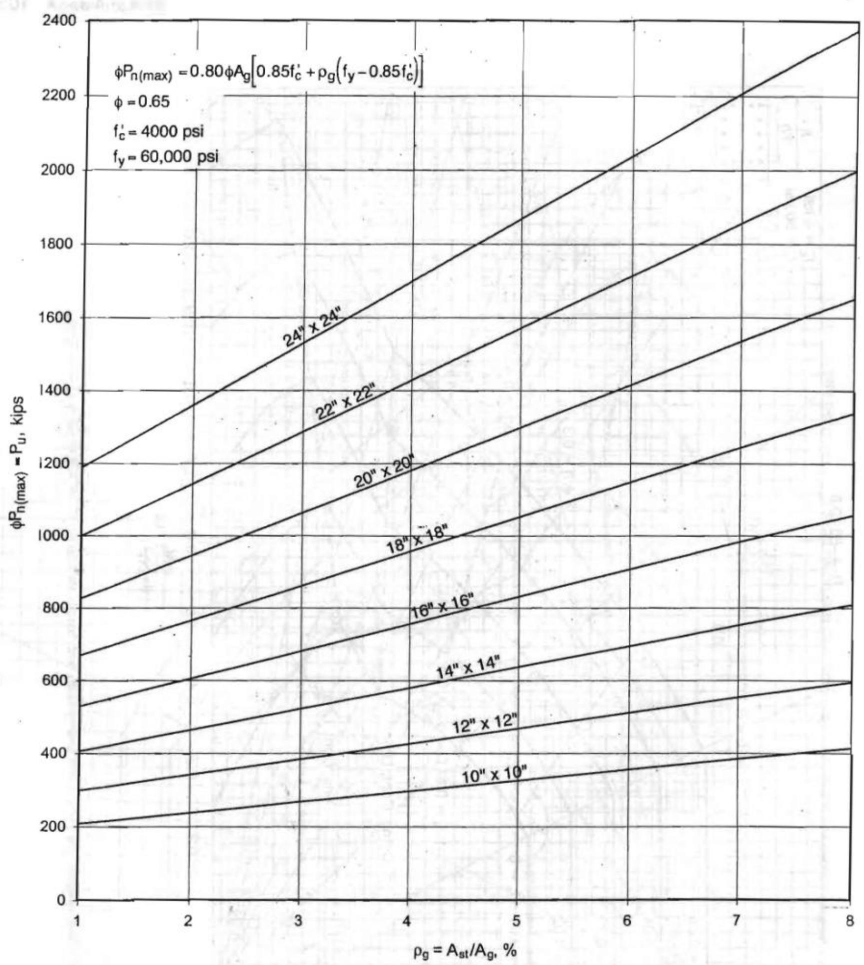


Figure 5-1 Design Chart for Nonslender, Square Tied Columns

SIMPLIFIED DESIGN
(ALSAMSAM & KAMARA, PCA, 2004)