Hershey Research Park Building One

Technical Report 2

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Executive Summary

The objective of Technical Report Two is to study alternative floor systems, and compare them to the existing floor system of the Hershey Research Park Building One. The existing floor system consists of a composite deck supported by composite beams. The three alternative designs being analyzed are a non-composite beam system, a precast hollow core plank system, and a one way slab with beams concrete system. They will all be analyzed using the same bay, sized at 32.5’ x 32’, which is the most common bay size throughout the building.

After each alternative system is designed, these three systems will all be compared to the existing system as well as each other. Through this analysis, it was found that two of the three alternative systems would be feasible to be used in place of the existing system. Both the non-composite system and the one way slab with beams system were chosen as viable solutions for an alternative design for the building. These systems had advantages that outweighed their disadvantages which made the worthy for further exploration.

The hollow core plank system was the one system not chosen as a practical alternative because it has too many disadvantages. The cost and weight of the hollow core plank system were the biggest of these disadvantages. The weight of this system was considerably higher than the existing system which would call for a change in the foundation of the building which would lead to a higher overall cost.

By analyzing the different possibilities for alternative floor system designs, it was determined that non-composite beams and one way slab with beams systems were both viable alternatives to the existing composite beams currently in place in the Hershey Research Park Building One.

Building Introduction

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.

Figure 1: Site Master Plan

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. preformed 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.

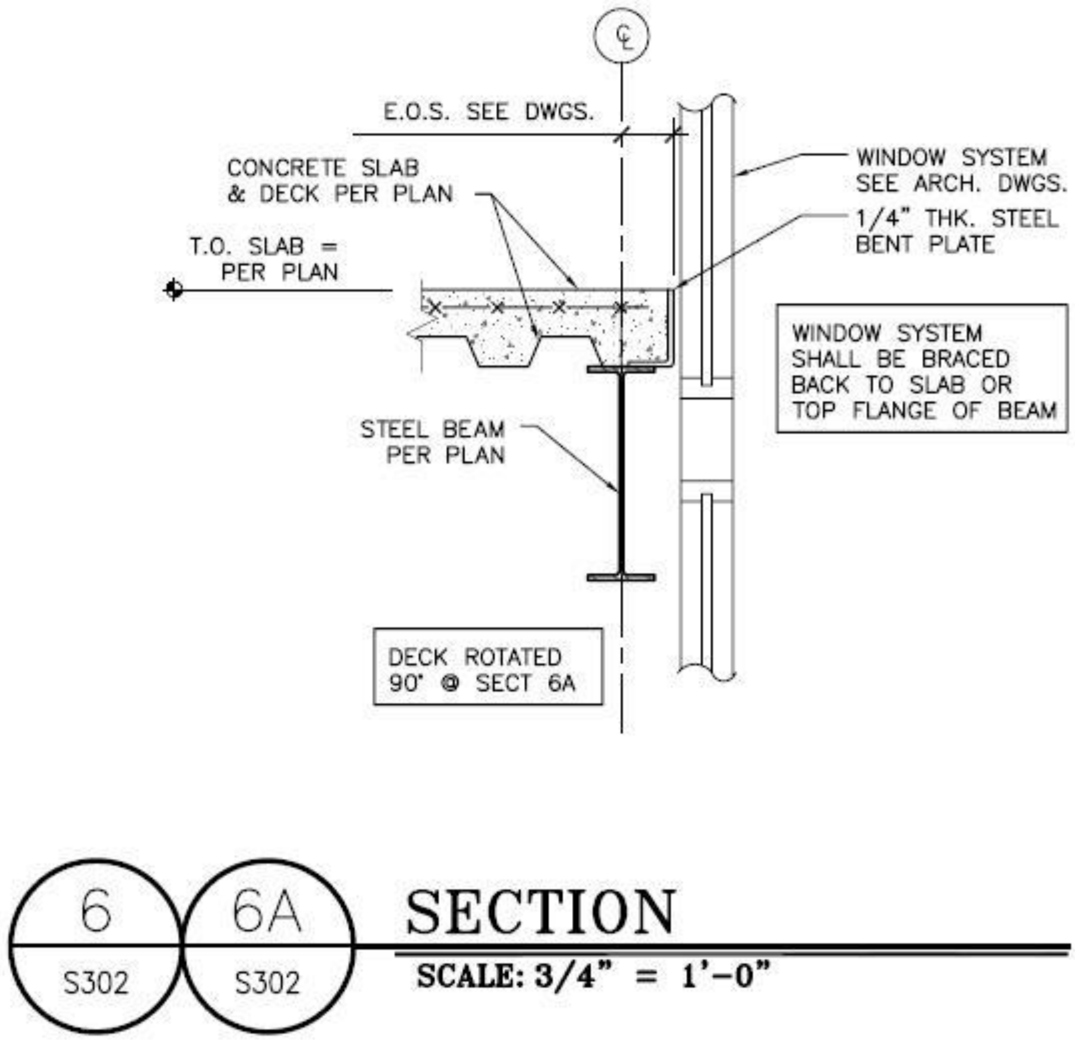


Figure 2: Typical Floor System

Lateral System

The lateral force resisting system is an ordinary 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. Building One uses two different types of moment connections between the columns and beams. These two types are shown in figures three and four.

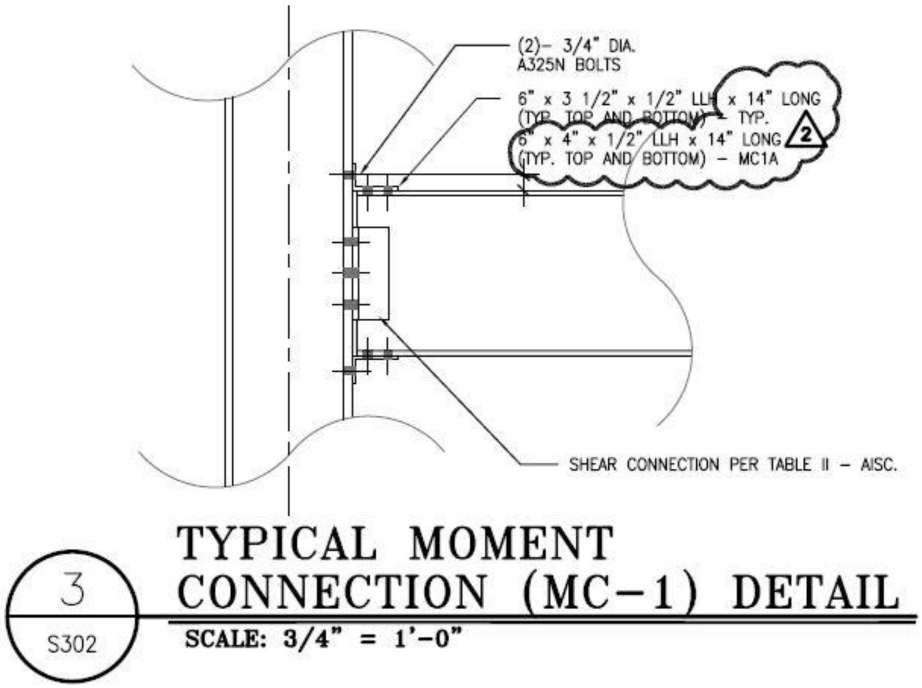


Figure 3: Connection Detail

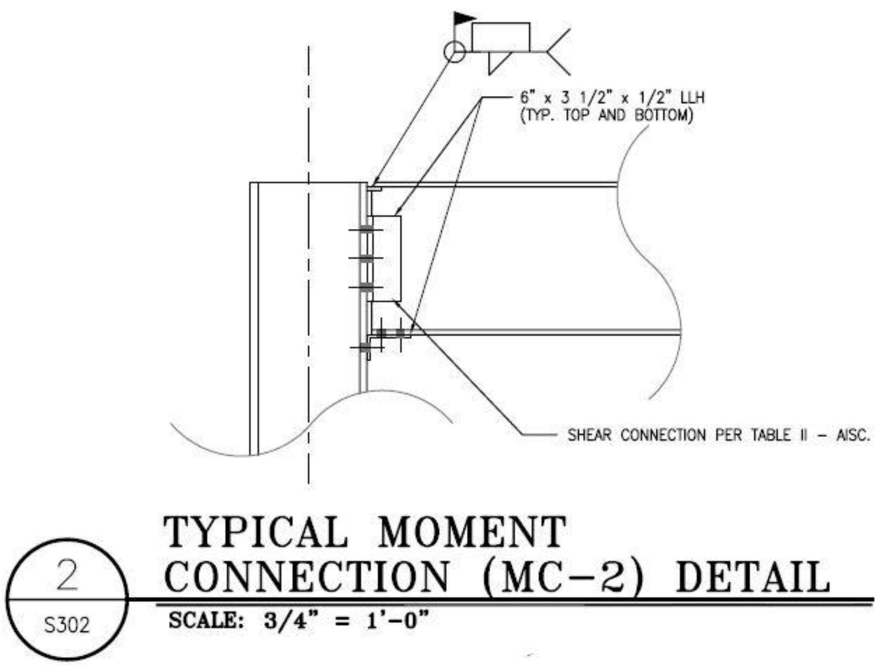


Figure 4: Connection Detail

Framing System

The framing system of Hershey Research Park Building One is a very 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 five 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.

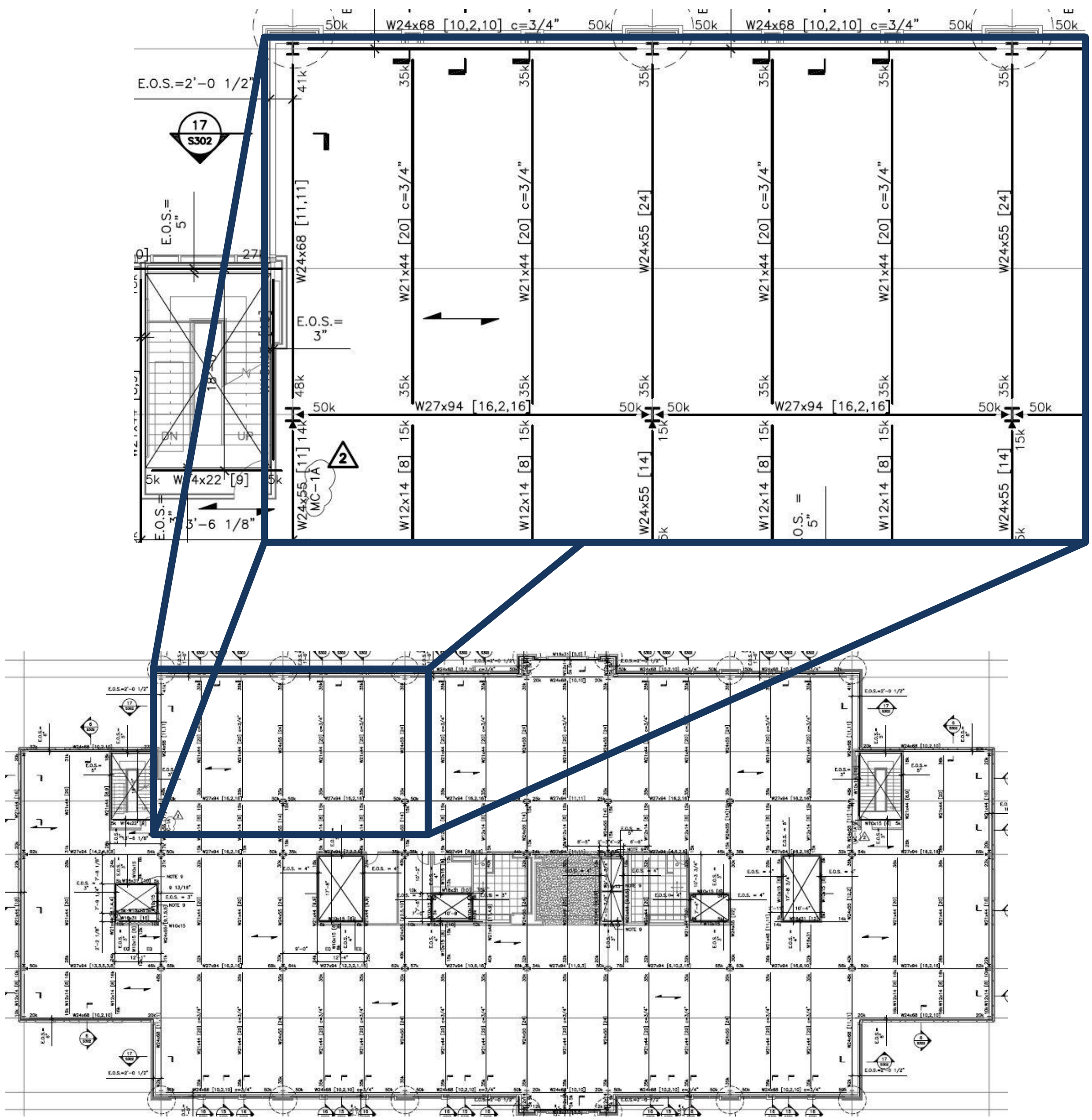


Figure 5: Second Floor Structural Plan with Spot Check Area

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.

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

Alternative Floor System Analysis

The main purpose of this report is to compare different types of floor systems and compare them to the existing system. The comparison will be made by using a pro con analysis to see the different aspects of each system. The existing system consists of composite deck with supporting composite beams. This system will be compared to three alternative designs, deck on non-composite beams, pre-cast hollow core planks on steel girders, and one way flat slab with beams. The typical bay size in which all the analysis was preformed was a 32.5' x 32' which is the most common bay size throughout the building. This analysis was only done using gravity loads and does not include any sort of lateral loads. Further analysis will have to be conducted to take these loads into account.

Composite Deck on Composite Beams

Description:
The existing system is a composite deck on top of composite beams. The deck is a three inch deep 18 gage composite metal deck with normal weight concrete. In the Vulcraft Deck Catalog it is known as 3VLI18 deck, the topping 4 ½ in thick which makes the total thickness 7 ½ in. Through spot checks done in Technical Report 1, which have been referenced for this report, the was found to be sufficient for unshored construction and has a two hour fire rating even when unprotected.

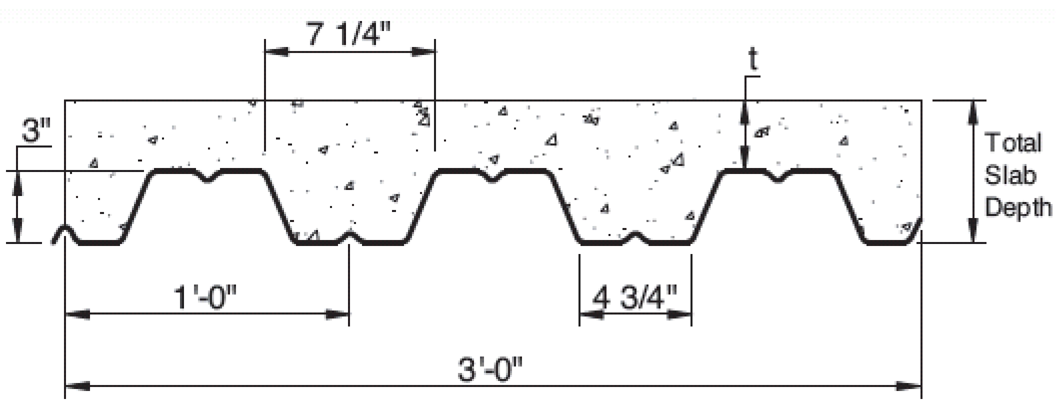


Figure 6: Cross Section of Existing Deck (VULCRAFT 3 VLI) Courtesy VULCRAFT Deck Catalog

The supporting floor assembly is composite W21x44 beams equally spaced between columns that frame into the W21x94 composite girders. In a typical bay, the center to center spacing between the beams is 10'-8". The beams and girders are then tied into the composite deck system using ¾ inch diameter, 6 inch long shear studs spaced evenly along the length of the beam. The analysis showed the beams and girders were adequate for carrying the required loads and had acceptable defection limits.

Advantages:
The advantages of using a fully composite system are the ease of construction, and that the deck and the beams will work together, helping each other carry the required loads. During construction, the concrete is poured directly on the deck and does not require any shoring, both of these factors lead to a fast and efficient construction which would also cut down the cost.

The composite action between the beams and deck allows for smaller beam sizes compared to non-composite beams. In the composite system, the beams analyzed were designed to be W21x44 compared to W21x55 in the non-composite system analysis. The girders differed in size as well. They were W27x94 in the composite system and W30x90 in the non-composite system. The difference in sizes is not very substantial when looking at just one bay, but will still make a difference when looking at every bay on each of the floors.

Disadvantages:
One disadvantage of a composite system is the depth on the floor system. The thick deck combined with the depth of the steel beams makes for an overall taller building if a certain floor to ceiling height needs to be obtained. The current floor to ceiling height is 14'-8" which is much larger than a typical office building. Hershey Research Park Building One is a research lab, so some large equipment needs to be able to fit in each floor. The combination of the floor system depth and the desired floor to ceiling height, lead to an overall taller building which means higher costs.

Another disadvantage to a composite system is the cost of construction. Even though this type of system is simple to construct, the cost of labor and the shear studs drive up the cost. Also during construction, fireproofing must be added to the exposed metal deck along with the framing, adding more to the overall cost.

Non-Composite System

Description:

The first alternative floor system analyzed was a non-composite system. This type of system is similar to the existing composite system, but still has its own pros and cons. The system make up consists of a 3 inch deck with a 2 inch topping, 18 gage. This deck is the same type used for the composite system, but has a different topping depth. The deck is supported by the beams and girders, same as the existing composite system. The bay size and the beam spacing were not altered at all for the analysis, so the maximum span for the deck remains 10'-8". The analysis showed that unshored construction would be able to be utilized since the maximum allowable span was 15'-1", well under the largest span. Since the overall weight of the non-composite system is slightly different from the composite system, the effects it has on the existing foundation would need to be further studied. Most likely, the majority of the elements making up the foundation would have to be resized.

Advantages:

A non-composite system has similar advantages as the composite system. It is easy to construct since no formwork is required, unlike a concrete floor system. Another advantage this system has over a concrete floor system is the overall weight of the system. Similar to the composite system, the non-composite system also allows for larger spans between columns. This means more floor area will be available for use that can be rented out.

Disadvantages:

The non-composite system also has similar disadvantages the existing composite system. The main disadvantage between the non-composite system and the existing system is bigger steel beams and girders. When compared to a concrete system, the main disadvantage would be the need for fireproofing. Concrete requires minimal fireproofing compared to a steel system. In the non-composite system, both the underside of the deck and the steel framing would have to be fireproofed.

Precast Hollow Core Planks on Steel Girders

Description:
The second alternative floor system selected was precast hollow core planks placed on steel girders. The hollow core planks are normally 4' wide and can span up to about 50'. The planks will be oriented to span the same direction as the beams in composite and non-composite system, and the same size bay, 32.5'x32', will be analyzed. The planks will be spanning perpendicular to the 32' side of the bay which means the bay will not need to be resized; 8 equal 4' wide planks will perfectly fit in the bay.

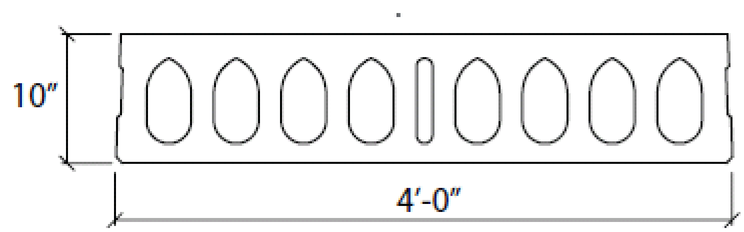


Figure 7: Typical Cross Section of Hollow Core Plank. Courtesy SPANCRETE

The design of the planks was done by referencing the design load tables in SPANCRETE's precast hollow core planks catalog, which was found on their website. Through the analysis, a 4' wide by 10" deep, standard hollow core plank with 1 ¾ inch strand cover was chosen to hold the required load. These planks also contain a 2" thick structural topping.

After the appropriate hollow core planks were pick, the girders were size with new loading. Since the bay being designed was an exterior bay, both an exterior and an interior girder were sized. The exterior girder was sized as a W24x76, and the interior girder was sized as a W30x90. The system weight of the hollow core planks along with the weight of the girders makes for a very heavy building compared to the composite and non-composite systems. This would call for a larger foundation to carry the addition weight of the structural elements.

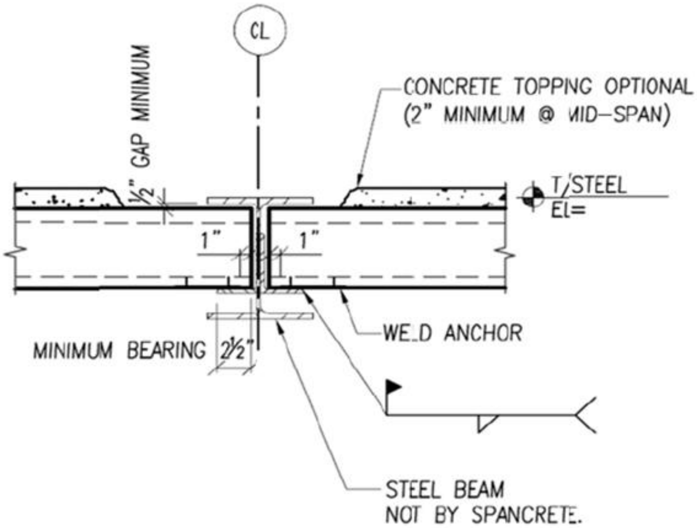


Figure 8: Typical Connection for Hollow Core Plank to Girder. Courtesy SPANCRETE

Advantages:

The biggest advantage of using the SPANCRETE Precast Hollow Core Planks is the construction time. Since the planks are fabricated beforehand at a precast concrete plant, the construction time would be greatly reduced. Also during the construction process, shoring would not be required. The voids in the planks help reduce sound and heat transfer, and the weight of the system, but it is still heavier than most systems.

Disadvantages:

The main disadvantage of using this system is the fact that each plank is 4' wide, so any bay size that is not divisible by 4 will have to either be altered to fit with the standard size of the planks, or the planks will have to be specially made to fit into an irregular bay size. This has multiple negative effects on the building. If the bay sizes must be changed to fit with the standard 4' wide planks the architecture of the building may be effected. Also if the pla **Figure 10: Typical Hollow Core Plank Connection to Steel Girder. Courtesy SPANCRETE** nd may also affect the performance of the planks.

One Way Flat Slab with Beams

Description:

The third alternative floor system design is a one way flat slab with beams. This is a reinforced concrete system that uses the same bay size the other designs used, which is 32.5'x32'. The thickness of the slab was determined using ACI table 9.5(a), and the design was done using the Concrete Reinforcing Steel Institutes (CRSI) design handbook. The handbook help to determine the size of the slab, beams, and girders, as well as the reinforcement need for each. The slab thickness was determined to be 4" thick, the beams are sized at 22" deep by 12" wide, and the girders are 22" deep by 18" wide. More details about the reinforcing can be found in the calculations section.

Advantages:

The biggest advantage for using a concrete system is the total cost of construction. Both the labor and material costs for a concrete system are lower than what they would be with a predominantly steel building. There is less skill involved in construction a concrete building compared to steel.

Disadvantages:

The disadvantage of using a concrete structural system is the construction time. Cast-in-place concrete takes time to set and cure so it can gain strength. This time problem could affect the overall cost of the building because the longer it takes to construct, the longer the owner must wait to receive rent from their tenants. Another drawback of a concrete building is that it weighs more than a steel based building. The added weight will have an effect on the lateral systems of the building along with the foundation. The foundation would need to be altered to handle all the added weight.

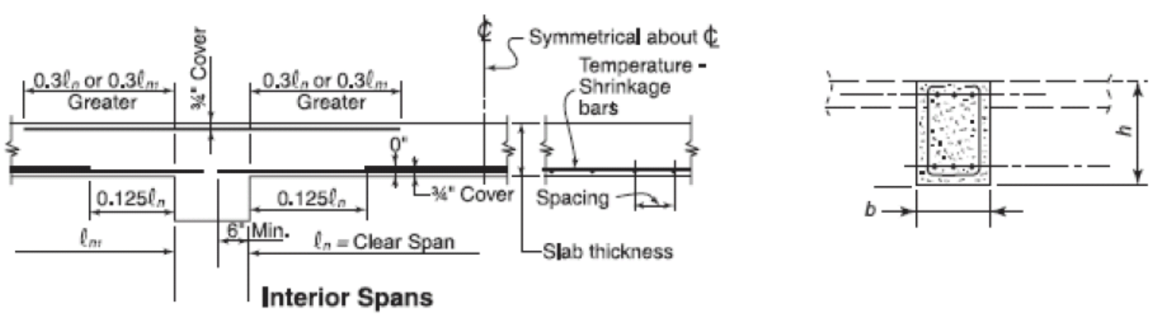


Figure 9: Typical Reinforcement Layout. Courtesy CRSI

Floor System Comparison

The table below shows a quick comparison between the existing floor system and the three alternative designs. Cost data was taken from 2012 RS Means Assemblies Cost Data. These numbers do not take into account some factors such as location so a more in depth analysis must be done.

Systems Comparison				
	Existing	Alternative		
Design Concern	Composite Beams	Non-Composite Beams	SPANCRETE Hollow Core Planks	One Way Flat Slab w/Beams
General				
Weight	80 psf	50 psf	105 psf	60 psf
Overall Depth	34”	34.5”	36”	26”
Slab Depth	7”	5”	12”	4”
Assembly Cost	$31.60/sf	$34.55/sf	$26.00/sf	$22.80/sf
Architectural				
Bay Size	32.5’x32’	32.5’x32’	32.5’x32’	32.5’x32’
Fire Rating	2 HR – Spray On	2 HR – Spray On	2 HR - Unrestrained	2HR
Other	Additional Fireproofing Needed for Underside of Deck and Steel Members	Additional Fireproofing Needed for Underside of Deck and Steel Members	Additional Fireproofing Needed for Steel Members May Have Problems with Irregular Bay Sizes	Change From Steel to Concrete Structure
Structural				
Gravity System Changes	N/A	Increase Structural Member Sizes	Increase Structural Member Sizes	Concrete Beams and Girders
Lateral System Changes	N/A	Increase Structural Member Sizes	Increase Structural Member Sizes	Possible Change to Shear Walls
Foundation Changes	N/A	Minimal	Increase Foundation Size Due to Larger Building Weight	Minimal
Construction				
Formwork Required	Minimal	Minimal	Minimal	Yes
Constructability	Moderate	Moderate	Easy	Moderate
Serviceability				
Vibration Control	Moderate	Moderate	Moderate	Good
Feaseability				
	Yes	Yes	No	Yes

Table 7

Conclusion

After analyzing each alternative floor system as well as the existing system, it is clear that The Hershey Research Park Building could have been built differently. The existing system, using composite steel beams, may be the best choice for the structure, but there are other feasible options. The three alternative floor systems, non-composite beams, SPANCRETE Hollow Core Planks, and one way slab with beams, all would be able to carry the loads of the building, but other considerations need to be made like cost and constructability.

The non-composite beam system is similar to the existing system which makes it a feasible solution. The disadvantage is that the non-composite would cost more to construct. The one way slab with beams is another feasible floor system that could be used for this building. The floor system depth is much smaller than the other systems and also costs less compared to the existing system. On the other hand, a concrete building could take longer to build and are generally heavier than steel buildings.

The hollow core planks system is the only one found to not be feasible. The system does have the advantage of being quick and easy to construct, but it still has a downside. The planks are a standard size of 4' wide which may become a problem with irregular size bays. In a bay that the planks would not fit, the planks would have to but specially made to fit which would increase the price and also could have an effect on the performance of the system.

By studying each system's advantages and disadvantages, both non-composite beams and one way slab with beams are viable alternative floor system to the existing composite beam system of the Hershey Research Park Building One.

Appendices

Appendix A: Structural Plans

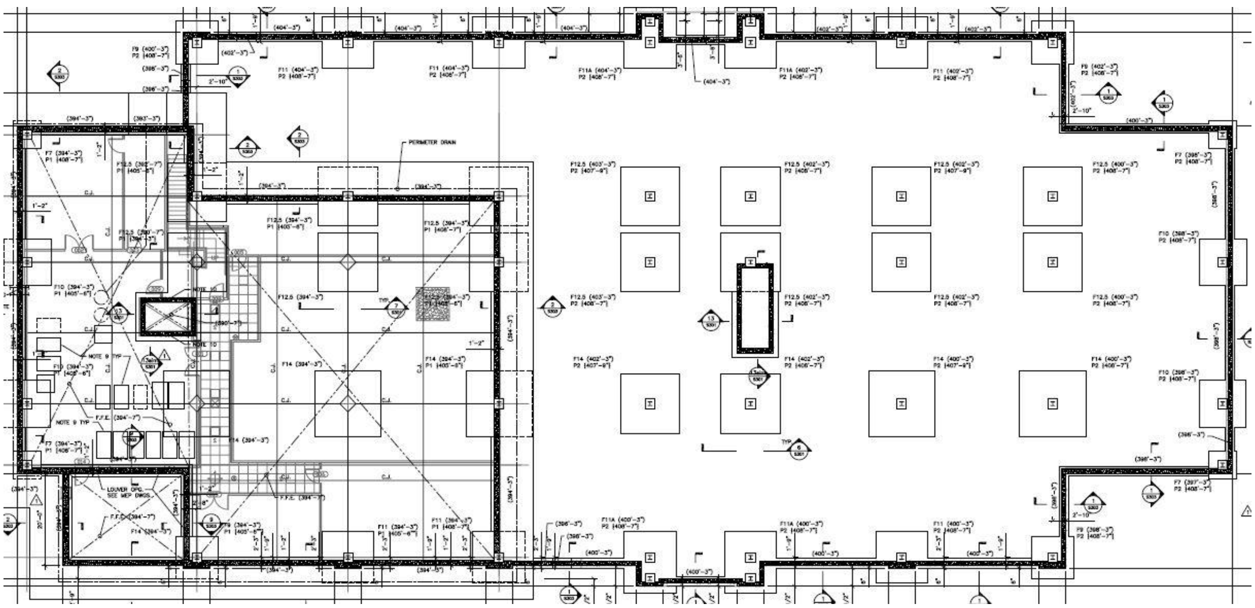


Figure 10 – Basement/Foundation Structural Plan

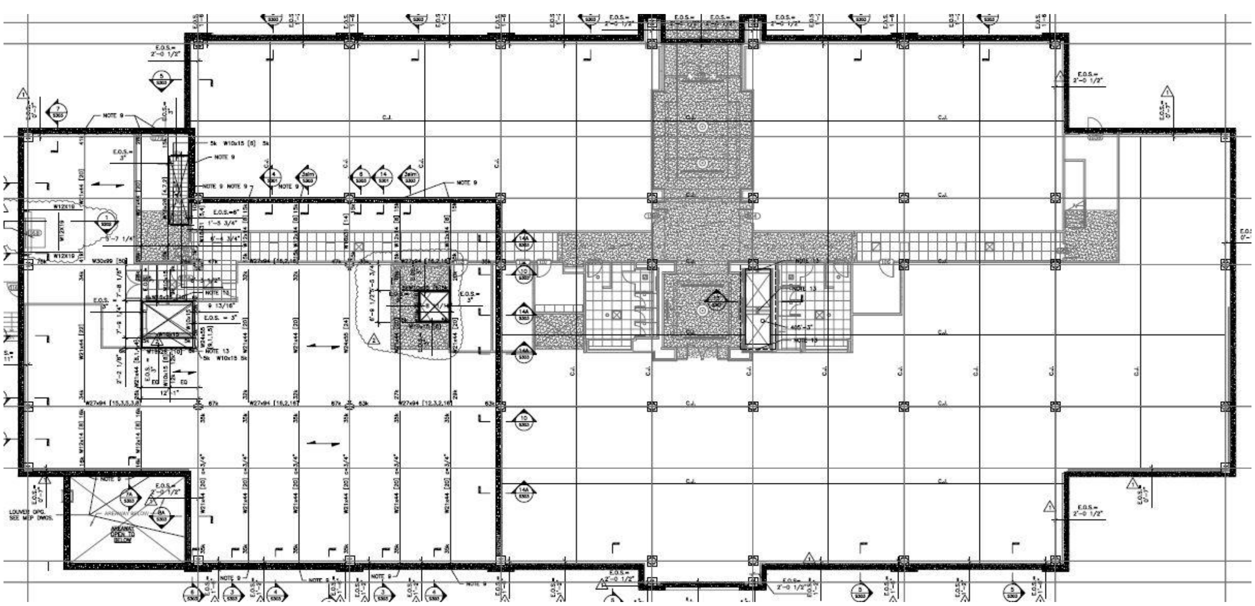


Figure 11 – First Floor Structural Plan

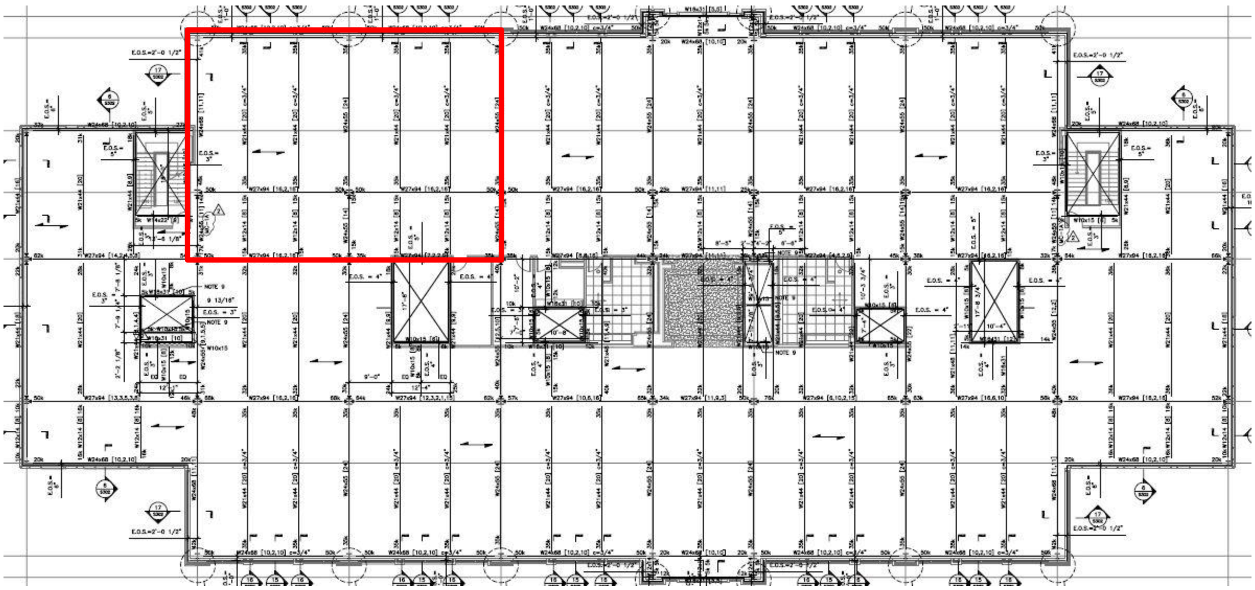


Figure 12 – Second Floor Structural Plan

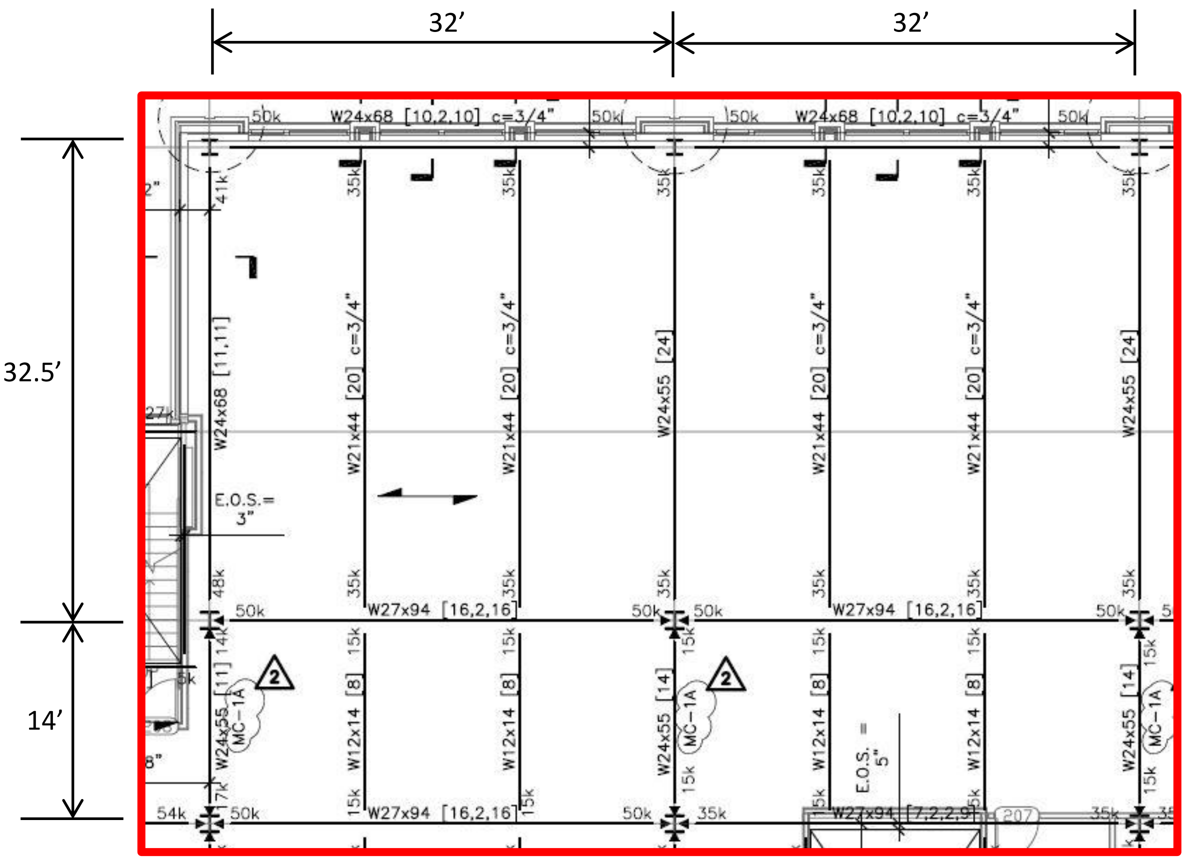


Figure 13 – Spot Check Area

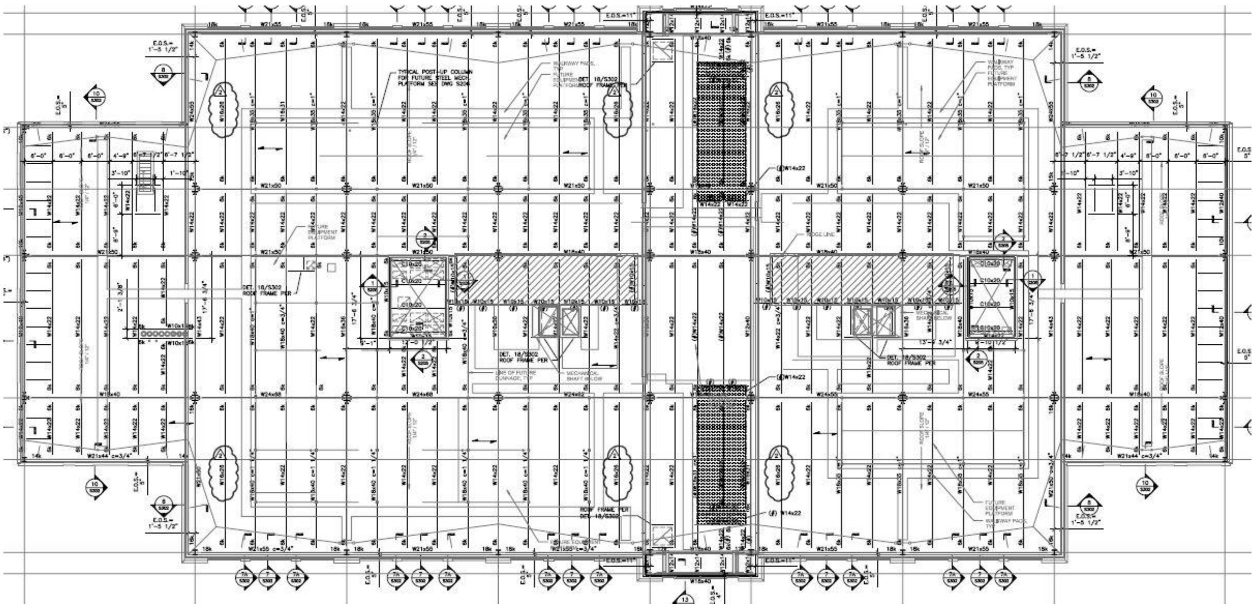


Figure 14 – Roof Structural Plan

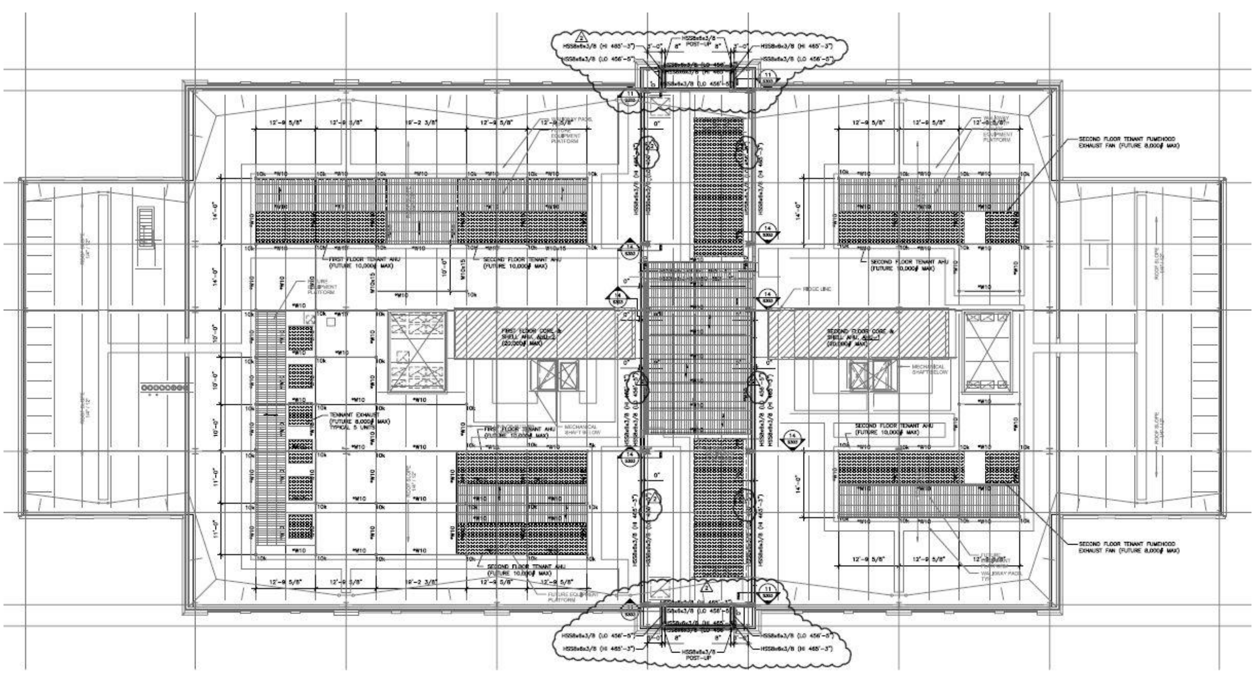


Figure 15 – High Roof Structural Plan

Appendix B: Composite Beams (Existing System)

Jon Krepps AE Senior Thesis SPOT Checks – pg 1

Roof Deck

→ 1½" deep, 22 Gage, Type B

Typical SPAN

= 6.4ft between beams

Total Roof Load

15psf DL
30psf LL
22.8psf Snow

$\left.\begin{array}{l} 15\text{psf DL} \\ 30\text{psf LL} \\ 22.8\text{psf Snow} \end{array}\right\}$ 67.8psf

From VULCRAFT Deck Catalog – pg 7

1.5 B, 22 Gage, 3 or more spans

Allowable load @ 6.5ft spans

= 74psf > 67.8psf ok

Max Construction span

= 6'-11" = 6.917' > 6.4' ok

Spot Checks - pg 2

Floor Deck

-> 3" deep, 18 Gage, Composite Metal Deck

-> Slab thickness = 4½" *NWC

Total thickness = 7½"

Floor Loads

$\left.\begin{array}{l}85\,psf\ DL\\100\,psf\ LL\end{array}\right\}$ 185 psf

VULCRAFT Deck Catalog pg 54

3VLI Deck

Typical Span Length = 10.66 ft = 10'-8"

Using 3VLI18 Total thickness = 7.5"

@ 11' Allowable Load = 210 psf > 185 psf ok

Max Unshored span

3 or more spans = 13'-3" > 10'-8"

ok for unshored construction

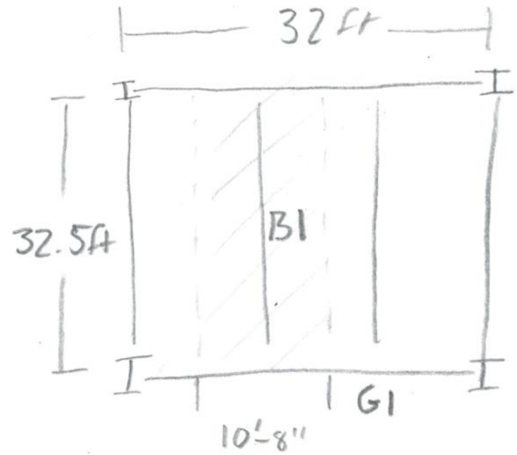
Spot Checks - pg 3

Typical Beam - B1

Loads

85 PSF DL

100 PSF LL



$f'_c = 4000\,psi$

$d = 20.7\,in$

W21x44 [20] $A_s = 13\,in^2$ Total Thickness = 7.5

$b_{eff} = \min \left| \begin{array}{l} \frac{32.5(12)}{8} = 48.75'' \checkmark \\ \frac{10.67}{2}(12) = 64'' \end{array} \right.$

Assume $a = 1$

$7.5 - \frac{1}{2} = 7 \Rightarrow Y_2 = 3.5$

$b_{eff} = 48.75''(2) = 97.5''$

$w_u = [1.2(85) + 1.6(100)]\,10.67\,ft$

$w_u = 2.8\,k/ft$

$$M_u = \frac{w_u l^2}{8} = \frac{(2.8)(32.5)^2}{8} = 370\,k\text{-}ft$$

$V = \frac{2.8(32.5)}{2}$

$V = 45.5^k$

$Q_n = 21.5^k$ 3/4 ϕ studs

$\Sigma Q_n = 21.5^k(10) = 215^k$

$$a = \frac{\Sigma Q_n}{0.85(f'_c)(b_{eff})} = \frac{215}{0.85(4)(97.5)} = 0.648$$

$a/2 = 0.324$

$7.5 - 0.324 = 7.176 \Rightarrow 7 = Y_2$

Spot Checks - pg 4

$$x = \frac{A_s f_y - \Sigma Q_n}{2(b_f)(f_y)} = \frac{13(50) - 215}{2(6.5)(50)}$$

$x = 0.67 > 0.45$ Y_1 in web

Through Interpolation

$\phi M_n = 681^{k \cdot ft} > 370^{k \cdot ft}$ ok

Bigger than necessary

Defection

$\Delta_{LL} = l/360 = \frac{32.5(12)}{360} = 1.083 in$ $w_{LL} = 100(10.67) = 1.067^{klf}$

$I_{LB} = 2200 in^4$

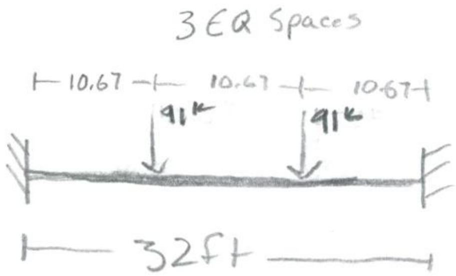
$$\Delta_L = \frac{5(1067)(32.5^4)(1728)}{384(29000)(2200)} = 0.42 in < 1.083 in \text{ ok}$$

$\Delta_{TL} = l/240 = \frac{32.5(12)}{240} = 1.625 in$ $w_{TL} = (85+100)10.67' = 1.97^{klf}$

$$\Delta_{TL} = \frac{5(1.97)(32.5^4)(1728)}{384(29000)(2200)} = 0.775 < 1.625 \text{ ok}$$

Typical Girder - G1

Spot Checks - Pg 5



$G1 = W27\times94$

$$\frac{91^k + 91^k}{32ft} = 5.7^{k/ft} \text{ equivalent uniform load}$$

$$M = \frac{wl^2}{12} = \frac{5.7(32)^2}{12} = 486.4^{k\cdot ft} = \text{Max } M.$$

Unbraced length = 10.67ft

For W27x94 @ UBL = 10.67ft

$$\phi M_n = 948^{k\cdot ft} > 486.4^{k\cdot ft} \text{ ok}$$

Bigger than necessary

$$\Delta_{LL} = l/360 = \frac{32(12)}{360} = 1.067 in$$

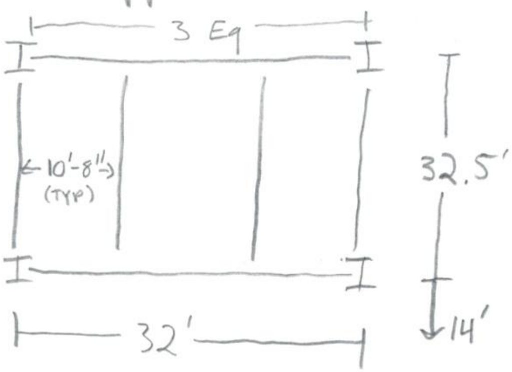
$$\Delta_{LL} = \frac{5(1.067)(32^4)(1728)}{384(29000)(3270)} = 0.265 in < 1.067 in \text{ ok}$$

$$\Delta_{TL} = l/240 = \frac{32(12)}{240} = 1.6 in$$

$$\Delta_{TL} = \frac{5(1.97)(32)^4(1728)}{384(29000)(3270)} = 0.49 in < 1.6 in \text{ ok}$$

Appendix C: Non-Composite Beams

Jon Krepps AE Senior Thesis Non-Composite System pg1



Live Load
100 psf
SIDL
25 psf

3 Spans
10'-8" span length
≈ 11'

= 100 + 25 = 125 psf

No Live Load Reduction

Try 3 VLI 18 w/2" Topping

@11' Allowable Load = 151 psf > 125 psf

Unshored Length

3 span = 15'-1" > 10'-8" ✓

System Weight

45 psf

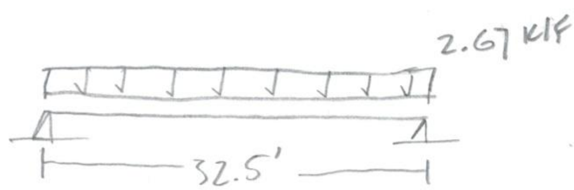
Total Load ⇒ Beam

1.2DL + 1.6LL

Beam weight allowance

1.2(25 + 45 + 5) + 1.6(100) = 250 psf

(250)(10.667)/1000 = 2.67 klf



Non-Composite System pg 2

$$V_u = \frac{wL}{2} = \frac{2.67(32.5')}{2} = 43.38^k$$

$$w_{LL} = \frac{100(10.667)}{1000} = 1.07\text{ klf}$$

$$M_u = \frac{wL^2}{8} = \frac{2.67(32.5'^2)}{8} = 352.5^{k\,ft}$$

$$\Delta_{LL} \le L/360 = \frac{(32.5)(12)}{360} = 1.08\text{in}$$

$$\Delta_{LL} = \frac{5w_{LL}l^4}{384EI} = \frac{5(1.07)(32.5^4)\times 1728}{384(29000)I} = 1.08\text{in}$$

$$I \ge 857.6\text{in}^4$$

$$\Delta_{TL} \le L/240 = \frac{32.5(12)}{240} = 1.625\text{ in}$$

$$w_{TL} = \frac{175(10.667)}{1000} = 1.87\text{ klf}$$

$$\Delta_{TL} = \frac{5(1.87)(32.5^4)(1728)}{384(29000)\,I} = 1.625$$

$$I \ge 996.1\text{in}^4$$

Try W21x55, $I = 1140\text{in}^4 > 996.1\text{in}^4$ ✓

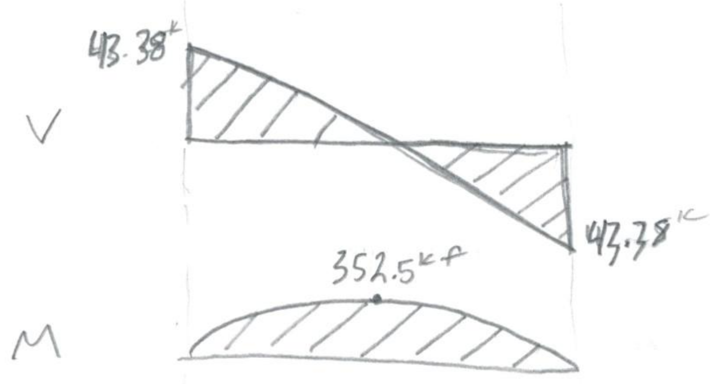
$\phi M_n = 473^{k\cdot ft} > 352.5^{k\cdot ft}$ ✓

$\phi V_n = 234^{k\cdot ft} > 43.38^k$ ✓

Beam SW Check

$55/10.67' = 5.15\text{psf}$

$$W_{TL} = \frac{175.15(10.67)}{1000} = 1.87\text{ klf} \Rightarrow \text{same as above} \therefore \underline{ok}$$

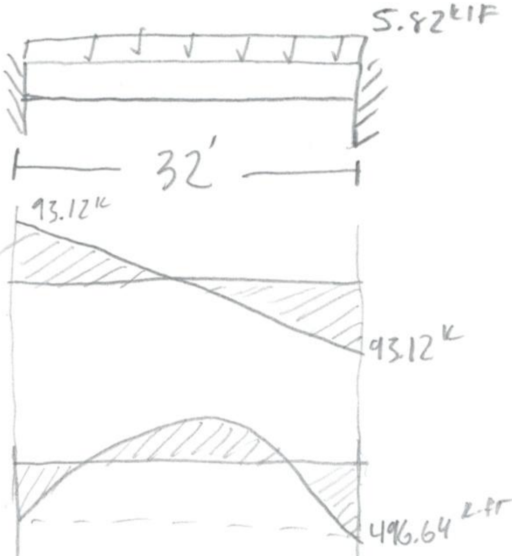


Girder Design

Non Composite System pg 3

$W_u = 1.2(45+25+5.15) + 1.6(100) = 250.2\,psf$

$W_u = 250.2\,psf\left(\frac{32.5+14}{2}\right) = 5.82\,klf$



$M = \frac{wl^2}{12} = \frac{5.82(32^2)}{12}$

$M = 496.64\,k\text{-}ft$

$V = \frac{wl}{2} = \frac{5.82(32)}{2} = 93.12^k$

$W_{LL} = 100\left(\frac{32.5+14}{2}\right) = 2.325$

$\Delta_{LL} = \frac{5(2.325)(32^4)(1728)}{384(29000)I} = \frac{32(12)}{360} = 1.07\,in$

$I \geq 1767.8\,in^4$

$\Delta_{TL} = \frac{5(5.82)(32^4)(1728)}{384(29000)I} = \frac{32(12)}{240} = 1.6\,in$

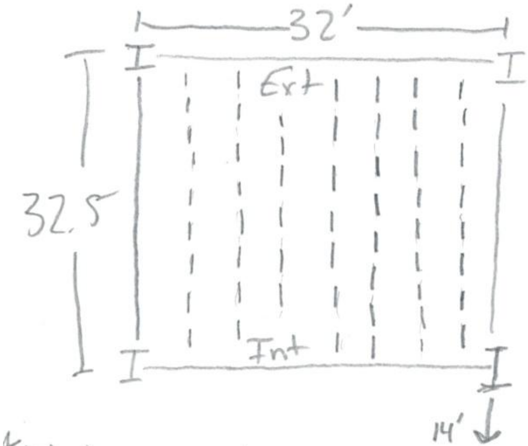
$I = 2959.3\,in^4$

Try W30x90, $I = 3610\,in^4 > 2959.3\,in^4$

$\phi M_n = 1060^{k\text{-}ft} > 496.64^{k\text{-}ft}$ $\quad \phi V_n = 374^k > 93.12^k$

Appendix D: Pre-Cast Hollow Core Planks

Jon Krepps AE Senior Thesis Hollow Core Planks pg 1



Typial Bay Size

= 32.5' x 32'

Loads

$LL + SI_{DL} = 100 + 25 = 125_{psf}$

Note: Planks self weight and Topping Weight are taken into account in tables.

*Planks are 4' wide so they will fit in the 32' direction

↑ Use SPANCRETE Hollow Core Planks

-> Span = 32.5' -> use 33'

-> 2 hr, unrestrained fire rating

-> 2" Topping

-> Loading = 125_{psf}

From SPANCRETE Tables

Use 10" Standard SPANCRETE, 1.75" Strand Cover

-> 2" Structural Topping

@ 33' Span Allowable load =

$= 149_{psf} > 125_{psf}$

System Weight = 101_{psf}

Girder Design

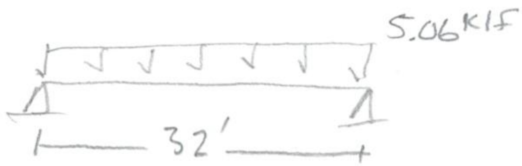
Hollow Core Planks pg 2

*Exterior Girder

$DL = 101\,psf \rightarrow$ Planks
$+\ 25\,psf$
$126\,psf$

$LL = 100\,psf$

$$W_u = [1.2(126) + 1.6(100)]\frac{32.5}{2} = 5.06\,klf$$



$$M_u = \frac{w_u l^2}{8} = \frac{5.06(32)^2}{8} = 647.7^{k\text{-}ft}$$

$$V_u = \frac{wl}{2} = \frac{5.06(32)}{2} = 81^k$$

$$W_{LL} = 100\left(\frac{32.5}{2}\right) = 1.625\,klf$$

$$\Delta_{LL} = \frac{5(1.625)(32^4)(1728)}{384(29000)I} = L/360 = \frac{32(12)}{360} = 1.07\,in$$

$$I_{req} \geq 1235.5\,in^4$$

$$W_{TL} = (126+100)\left(\frac{32.5+14}{2}\right) = 3.67$$

$$\Delta_{TL} = \frac{5(3.67)(32^4)(1728)}{384(29000)I} = L/240 = \frac{32(12)}{240} = 1.6\,in$$

$$I_{req} \geq 1866.1\,in^4 \rightarrow \text{controls}$$

Try W24x76 $I = 2100\,in^4 > 1866.1\,in^4$ ok

$\phi M_n = 750^{k\cdot ft} > 647.7^{k\cdot ft}$ ok

$\phi V_n = 315^k > 81^k$ ok

Hollow Core Planks pg 3

Interior Girder

$DL = 126\,psf \quad LL = 100\,psf$

$$W_u = [1.2(126) + 1.6(100)]\left(\frac{32.5+14}{2}\right) = 7.24^{klf}$$

$$M_u = \frac{wl^2}{8} = \frac{7.24(32^2)}{8}$$

$$M_u = 926.72\ k\cdot ft$$

$$w_{LL} = 100\left(\frac{32.5+14}{2}\right) = 2.33$$

$$V_u = \frac{wl}{2} = \frac{7.24(32)}{2} = 115.84^k$$

$$\Delta_{LL} = \frac{L}{360} = 1.07 = \frac{5(2.33)(32^4)(1728)}{384(29000)I}$$

$$I_{req} \geq 1771.56\ in^4$$

$$w_{TL} = [126 + 100]\left(\frac{32.5+14}{2}\right) = 5.25^{klf}$$

$$\Delta_{TL} = \frac{L}{240} = 1.6 = \frac{5(5.25)(32)^4(1728)}{384(29000)I}$$

$$I_{req} \geq 2669.46\ in^4 \rightarrow \text{Controls}$$

Try W27x84, $I = 2850 > 2669.46$ ok

$\phi M_n = 915^{k\cdot ft} < 926.72^{k\cdot ft}$ NG

Try W30x90, $I = 3610\ in^4 > 2669.46\ in^4$

$\phi M_n = 1060^{k\cdot ft} > 926.72^{k\cdot ft}$ ok

$\phi V_n = 374^{k\cdot ft} > 115.84^k$ ok

☆ USE W24x76 for exterior Girder

☆ USE W30X90 for Interior Girder

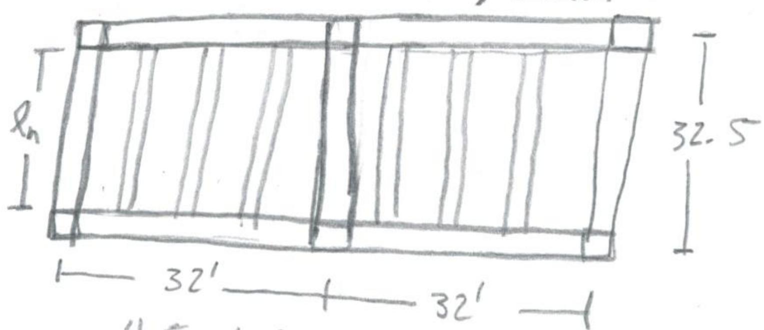
Appendix E: One Way Slab with Beams

Jon Krepps AE Senior Thesis One Way Slab w/ Beam pg 1

Assuming
18" square
Columns

$f'_c = 4000\,psi$

$f_y = 60\,ksi$



Slab

$LL = 100\,psf$

$SI_{DL} = 25\,psf$

$h_{min} = l/24 = \frac{8(12)}{24} = 4''$

Slab DL = $\frac{4}{12}(150) = 50\,psf$

$w_u = 1.2(25) + 1.6(100\,psf) = 190\,psf$

From CRSI Design Tables

@ $\rho \simeq 0.005$, 8' spans, 4" Slab thickness

↳ Factored usable superimposed load

$= 260\,psf > 190\,psf$ ✓

Bottom Bars

↳ #4 spaced @ 12 in

Top Bars

↳ #3 spaced @ 12 in

T-S Bars

↳ #3 spaced @ 11 in

$A_s = 0.200\,in^2$

↳ Bottom

Slab WT = 50 psf

Steel WT = 1.25 psf

Crack Control

1 Way Slab w/ Beams pg 2

$$S = 12\left(\frac{40000}{f_s}\right) = 12\left(\frac{40000}{40{,}000}\right) = 12'' \ \underline{OK}$$

Deflection

$$\Delta = \frac{LL}{W_u}\left(\frac{l_n}{360}\right) = \left(\frac{1.6(100)}{190}\right)\left(\frac{8'}{360}\right) = 0.224 in$$

Beam Design

$$h_{min} = l/18.5 = \frac{32.5 \times 12}{18.5} = 21.1 \Rightarrow 22 in$$

$$W_u = 190_{psf} + 1.2(50_{psf}) = 250 psf = 0.25 ksf$$

$$(0.25 ksf)(8') = 2^{klf}$$

From CRSI Design Tables

$\rightarrow h = 22 in$, $l_n = 32 ft$

@ $b = 12 in$, Load $= 2.04^{klf} > 2.00^{klf}$

Bottom Bars = (2)#8

Top Bars = (2)#10

Stirrups
1536
↳ (15)#3
1@2", 16@9" Each End

Design Moment Capacity
for rectangular Section

$+\phi M_n = 130^{k \cdot ft}$

$-\phi M_n = 199^{k \cdot ft}$

one way slab w/Beams pg 3

Deflection

$C = 583e\text{-}9$ $\Delta = C\,(w/1.4)\,l_n^{\,4}$

$= \frac{583\times10^{-9}(2.00)(31)^4}{1.4} = 0.77''$

Girder

$V = \frac{(2.00)(30.5)}{2}$ $l_n = 32 - 1.5 = 30.5$

$V = 30.5^{k}$ $(30.5)(3)/32 = 2.86$ klf

from CSRI Design Tables

$\rightarrow b = 18''$, $l_n = 32$ft

$h = 22''$ Load $= 3.06^{klf} > 2.86$klf

Bottom Bars
$= (2)\#8$ full length
$(1)\#8$ @ $0.875 l_n$

Top Bars
$= (3)\#10$

Stirrups
153G
$= (15)\#3$
1@2", 16@9" Each End

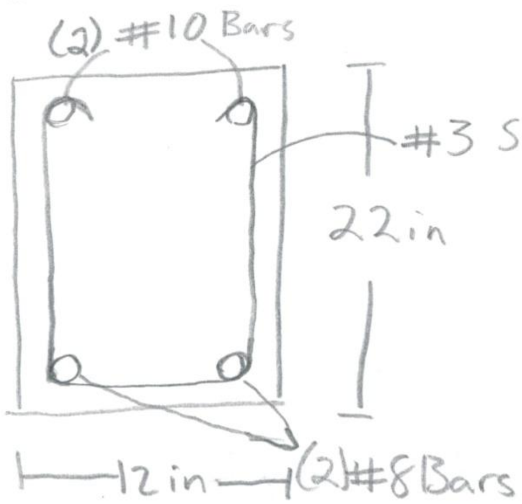
Deflection

$C = 389\times10^{-9}$ $\Delta = 389\times10^{-9}\left(\frac{2.86}{1.4}\right)(30.5)^4$

$= 0.687$in

one way Slab
w/Beams pg4

Beam Cross Section



Girder Cross Section