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Multipurpose Health Science Center

[TECHNICAL ASSIGNMENT 2]

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Executive Summary

This technical report begins with a description of the structural system, followed a list of applicable building codes, the loading criteria of the building, and the analysis of possible alternative floor systems for the building, which is the primary purpose of this report.

This analysis proceeded in four steps, revealing a plank on girder system as the most attractive design solution, with the other systems remaining as other plausible alternatives.

The first task was to determine the criteria which would be used to make the analysis. Cost, and construction time were the most critical, especially since the project is fast track, design-build. Since lead time, fire protection, and constructability all have a modifying effect on cost and schedule, they were included in the analysis. The other main criteria included the depth of the systems and the serviceability, which is broken down to deflections and vibrations. All three are of significant importance since the building has many laboratory spaces which have sensitive laboratory equipment, as well as large HVAC systems

The second task was to choose the various systems. CIP systems were eliminated due to the high expense of formwork for the buildings many curved areas and openings. Non-composite, steel joist, plank on girder, and precast systems were selected, because they seemed to be the most promising alternative system types. These systems were then designed using the AISC and PCI manuals, as well as the Vulcraft and United Steel Deck institute product design guides.

The fourth task was to take these systems and compare them to the original. For the sake of comparison, the original system was slightly modified and simplified to make it more "typical." RS Means 2008 cost data was then used to perform cost and scheduling analyses. The remaining areas of comparison were either subjectively judged or had already been calculated. It was found that the modified original and precast systems were too expensive and took too long to build, but may still be a plausible alternatives in the face of further scheduling and owner requirement details. The Steel joist, non-composite, and plank on girder systems were more cost effective and had shorter schedules than the previous two systems; however, the plank on girder performed better in terms of depth and serviceability, making it the stand-out system.

Structural System - Foundation

General

The geotechnical survey justified a hybrid foundation system for the site. The upper layer of soil, between 19’to 35’, consists of medium to very compact micaceous silty fines to coarse sands and varying gravel. Deeper soils, between 24’ to 50’, consist of more compact micaceous silty fines to coarse sands and gravel with borings terminating at intact mica bedrock. The building’s excavation is between 78’ to 83’ with street level at approximately 100’, placing the majority of the foundation between these two layers.

The expected column loadings are around 3,100 kips for the braced frame columns and about 1,000 kips for the majority of the columns. The higher bearing capacity of the lower layer of soil coupled with the required bearing of the capacity of the columns justified a hybrid system with braced frame columns resting on caissons.

The concrete used is 28-day, normal weight concrete at f’c=4000 psi for most areas, with the primary exception being concrete exposed to weather-for example, the truck ramp- which should be air-entrained, normal weight at f’c=5000. Reinforcing is grade 60.

Figure 1: View of structural systems

Slab

The typical basement slab consists 6” of concrete over a vapor barrier and 4” of crushed stone, with 6”x6” W4.0xW4.0 WWF. The primary areas where exceptions occur are underneath the library, mechanical and electrical equipment, the loading docks, and areas underneath the auditorium. Slab thicknesses in these areas are either 8” or 12”.

Footings

The shallow foundation system consists of steel columns sitting on concrete piers and footings, which are connected by grade beams. Footing thickness ranges from 1’4” to 4’4”, with most in the 1’10” to 2’4” range. Sizes generally range from 4’x4’ to 9’x9’.

Caissons

The deep foundation system consists of steel columns sitting on concrete piers, caps and caissons. Sixty-six of the one-hundred thirteen basement columns rest on these caissons, which vary in diameter from 36” to 96”. The top of the basement slab is at either 78’ or 83’ elevation, with caisson estimated bearing elevations ranging between 45’ to 70’, with the most around 60’.

Structural System – Columns

The framing system consists primarily of ASTM A992 Grade 50 rolled W-shapes with depths of 12” and 14”. There are several 10” deep W-shapes in the basement through fourth floors and some HSS shapes in the auditorium. Sizes vary greatly with upper floor columns in the 100-120lb range, and lower floor columns in the 200lb range. The columns are spliced 4’ above floor level and span two floors with lengths typically at 25’ to 30’.

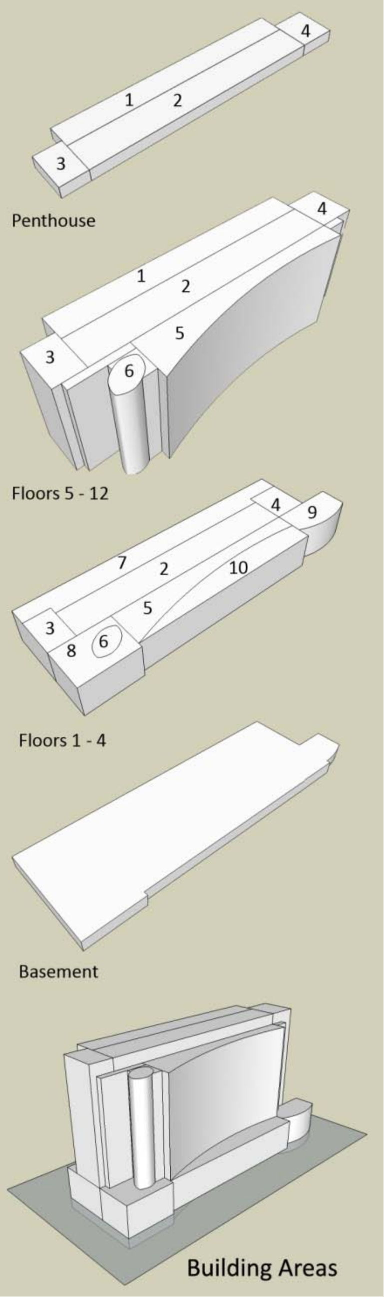


Figure 2: Building Areas

Structural System – Floor System

Given the irregularities of the buildings shape, I decided to describe the framing system by dividing up the building into typical areas, which are schematically represented in figure 2 to the right. A simplified framing plan can be seen in figure 3 on the next page. Floor systems for the various areas are then described.

Slabs are typically 2.5”, f’c=4,000 psi, NWC on 3”deep, 20 gage, galvanized composite steel deck, with 6x6-W2.9xW2.9 WWF. Decking is applied perpendicular to beams and parallel to girder. The primary exception is penthouse mezzanine and roof level, where the slab is thinner.

This building also has three transfer trusses which take column point loads from above and redistribute them to offset columns at a lower level. Two of these trusses are located between the first and second floors, are 15’4” deep, and span 46.5’ in order to clear space for the loading dock below. A third truss is located between the 5th and 6th floors, is 14’8” deep, and spans 62’ in order to relocate columns for corridors on lower levels.

Area 1 typically has 25’x31’ bays with beam sizes ranging from W12x14 to W21x14, with the most common size being the W21x14 and W18x40. The most common girder size is W24x68 and W21x50.

Area 2 contains an elevator core and riser openings. It typically has 38’x31’with beam sizes in the range of W24x44 to W24x94 spanning girders of a similar size.

Areas 3 and 4 contain greatly varying framing sizes due to openings. Area 3 contains openings for mechanical equipment and stairwells, while area 4 also contains an elevator core.

Area 5 contains the framing for the dramatic curved east façade. The curve itself is composed mostly of W21x44 or W24’s members of various sizes with the curved bays typically spanned by W12x19’s. Longer spans range from W14x22 to W24x84.

Area 6 is the oval tower, which is framed by a hexagon of W12 and 16 girders and beams. C shapes round out the shape of the oval. At the 4th floor and below, this area frames into area 8 which member sizes ranging from W14-W24.

At the 4th floor and below, area 1 becomes the larger area 7, with 25’x31’ bays with W18x40 beams spanning W24x55 girders.

Area 9 is the auditorium with 44LH14 shapes spanning curved walls of W16, 18 and 21 girders to form the roof deck. The floor is framed by sloped W30x90 beams for the seating area and W16 girders underneath the stage.

Area 10 is the atrium space with, which extends from the curved façade to form a straight edge facing the street. Beams varying from W16 to W24x68 span the curve girders to the straight W24x55 girders for the floor and roof.

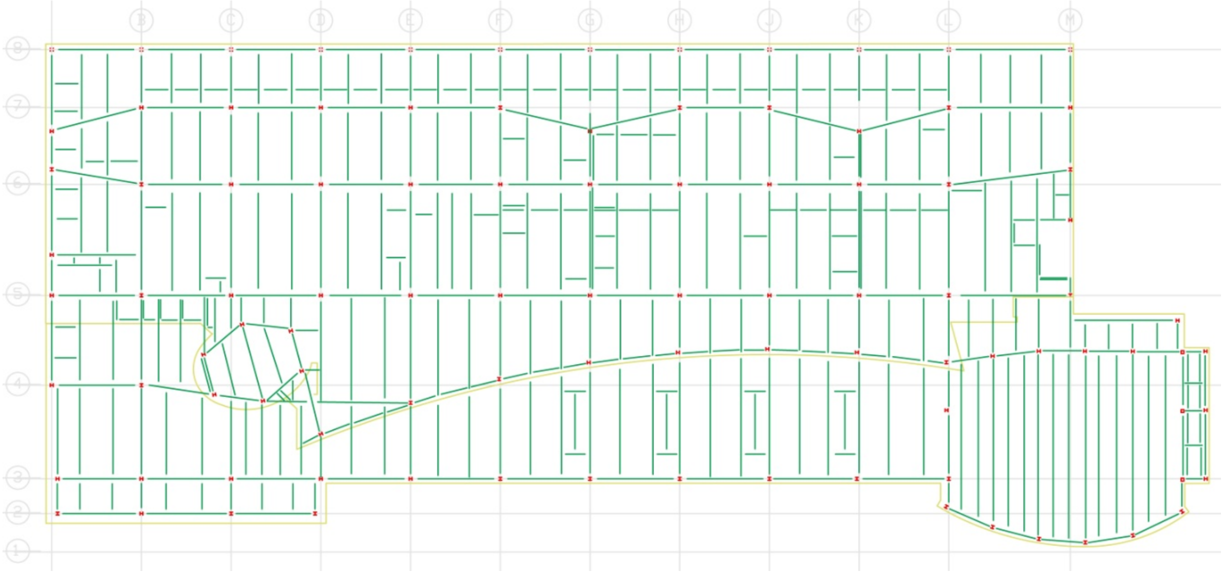


Figure 3: Simplified Framing Plan

Structural System – Lateral System

Due to the slender shape of the building lateral resistance is primarily needed in the East-West direction. This resistance is provided by four sets of braced frames which run the full height of the building. A review of detailed drawings of the connections did not indicate the use of moment connections. The vertical members range from W14x109 at the top to W14x550 at the bottom. Horizontal members are typically W24x55 but range from W21x44 to W27x161. Diagonal members range from W10x49 within the upper four floors to W12x190 at the bottom.

Three sets of North-South braced frames appear from the 12th, 13th mezzanine, and 13th penthouse levels in one line, with an additional set appearing in another line for only two levels. The member sizes are similar with the exception that diagonal members are comprised of 5x5L shapes.

Codes Applied

Below are listed the codes used by the original designers.

- IBC 2003 (Philadelphia building code)
- ASCE7-02
- Concrete:
  - ACI 318 “Building Code Requirements for Structural Concrete”
  - ACI 316 “Manual of Standard Practice for Detailing Concrete Structures”
  - ACI 301, 302, 304, 305, 306, 308, 311, 318, 347
- Steel:
  - AISC “Specifications for Design, Fabrication and Erection of Structural Steel for Buildings”
  - AISC “Code of Standard Practice for Steel Buildings and Bridges”
  - American Welding Society (AWS) D1.1 “Structural Welding Code – Steel.”
  - American Welding Society (AWS) D1.1 “Structural Welding Code – Steel.”
  - ASTM A6 “General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use.”
  - ASTM A325 “Specifications for Structural Joints”
  - Steel Deck Institute “Design Manual for Composite Decks, Form Decks, and Roof Decks”

For my design and analysis I used IBC 2006 and ASCE7-05

Loads: Live & Dead

The loads in tables 1 and 2 were determined by reviewing the building documents and noting the loads used by the original designers, who based their loading off of the IBC 2003, the adopted building code of Philadelphia, Pennsylvania.

Design dead loads, found in table 3 were not presented in the building documents, so material unit weights and ASCE 7-05 Minimum Design Dead Loads were used to make dead load assumptions.

Table 1: Live Loads

Area	Load (psf)
Slab on Grade	150
Truck Drive Aisle	300
High Density Storage Area	300
Elevated Frame Slabs	150
Office/corridor	100
Library	150
Roof	30
Penthouse	150

Table 2: Snow Loads

Flat-roof snow load	22 psf
Snow Exposure Factor	0.9
Snow Load Importance Factor	1.1
Thermal Factor	1.0

Table 3: Dead Loads

	Load (psf)
Decking	50.1
Girders & Beams	7
Subtotal	60
Mech/Elec	20
Partitions	8
Ceiling	1
Floor	1
Total	90

System Comparison Process

Comparison Criteria

The first step in this comparison process was to decide which comparison criteria to use, rank them in terms of importance, and then choose appropriate structural systems to use. Below are the comparison criteria, listed in order of importance for this project.

- Cost - Since the owner of the project is most likely relying on alumni donations and investments, the budget is probably a critical factor in the determination of a building system. This assumption is supported by the fact that the project is fast tracked, which is aimed at keeping costs down.
- Construction time/lead time - Due to the fast tracked construction process, the amount of time spent on site will be critical in choosing a system, with careful planning needed to insure that lead time does not interfere with the construction schedule. Also having a system that is quickly assembled on site is best to allow the other trades to come in.
- Constructability - Several irregularities such as the curved façade, oval tower, and transfer trusses, as well as large openings for up to four different vertical circulation areas will prove challenging to the design (in terms of detailing and fabrication), and construction processes, modifying the initial cost and schedule estimate.
- Fire protection – The amount needed, as well as the difficulty in applying fire protection may have significant affects on cost and schedule as well.
- Serviceability - The vibration and deflection of the various systems is of importance since the building contains many laboratory areas which may hold sensitive equipment.
- Depth – Despite the 14’8” ceiling heights, the depth of the floor system is still of a concern due to the heavy HVAC and plumbing requirements of the laboratory spaces.
- Strength Requirements - Due to the interaction of the requirements for member sizes and the actual availability of the members, some of the systems may be less efficient than others, resulting in considerable price difference.

Other areas for comparison which were not critical in choosing a design are listed below.

- Durability – Issues concerning rust, fire proofing, spalling, and cracking were not considered due to the types of systems considered and the fact that they are to be used for the interior framing of the building.

- Foundation –Despite the solid bedrock located at fairly shallow depths, the precast system will require stronger foundations. Since the other systems are similar in weight, this exception will be discussed in the conclusion.
- Seismic – Is not a critical issue, due to the low activity in the Philadelphia area.
- Wind – Although this is a significant issue due the large EW façade, altering the floor systems should have minimal effect on the lateral system since it consists of braced frames and the floors can be modeled as diaphragms.
- Staging area – There is a large staging area at the north end of the site with plenty of vehicular access and space for large items such as precast members.

Floor System Selection

Various floor systems were considered for analysis, but a few systems were eliminated fairly early one. Cast in Place concrete was not considered due to the irregularities in the building shape, which would drastically increase construction and labor costs, especially in terms of formwork. Post tensioned CIP and precast post tensioned were not further considered due to the difficulty of tightening the post tensioning strands with irregular patterns and floor openings.

Since the original design was a composite floor system, it was decided to first compare this with a non-composite system in order to gain a better understanding of the original designer's intentions and to be able to compare the two systems, especially in terms of cost, and serviceability.

The next system choice was steel joists supporting a non-composite deck and framing into W-shape girders. Steel joists are a fairly cost effective system, but may experience issues concerning depth and serviceability. Once again, it would be interesting to see how these varying pros and cons would interact.

A plank on girder system was designed in order to provide an alternative to the decking material used in the previous systems. Perhaps economy could be obtained by using these precast elements instead of using so many site assembled materials.

Lastly, a precast prestressed concrete system was provided as a completely alternative building material. An advantage of this system over the others is that there would potentially be less individual pieces to be assembled, decreasing construction time.

Analysis Process

The frame in column lines 6-7/F-G from the original drawing set was used for the comparison because it was fairly typical in size and shape, and did not contain any openings. In the original design this frame is next to a cantilevered frame, which resulted in some variations from the other frames, so for the sake of comparison this frame was further simplified. This "modified original composite steel floor system" was then used to compare with the alternative floor systems, which maintained the same dimensions as the modified original.

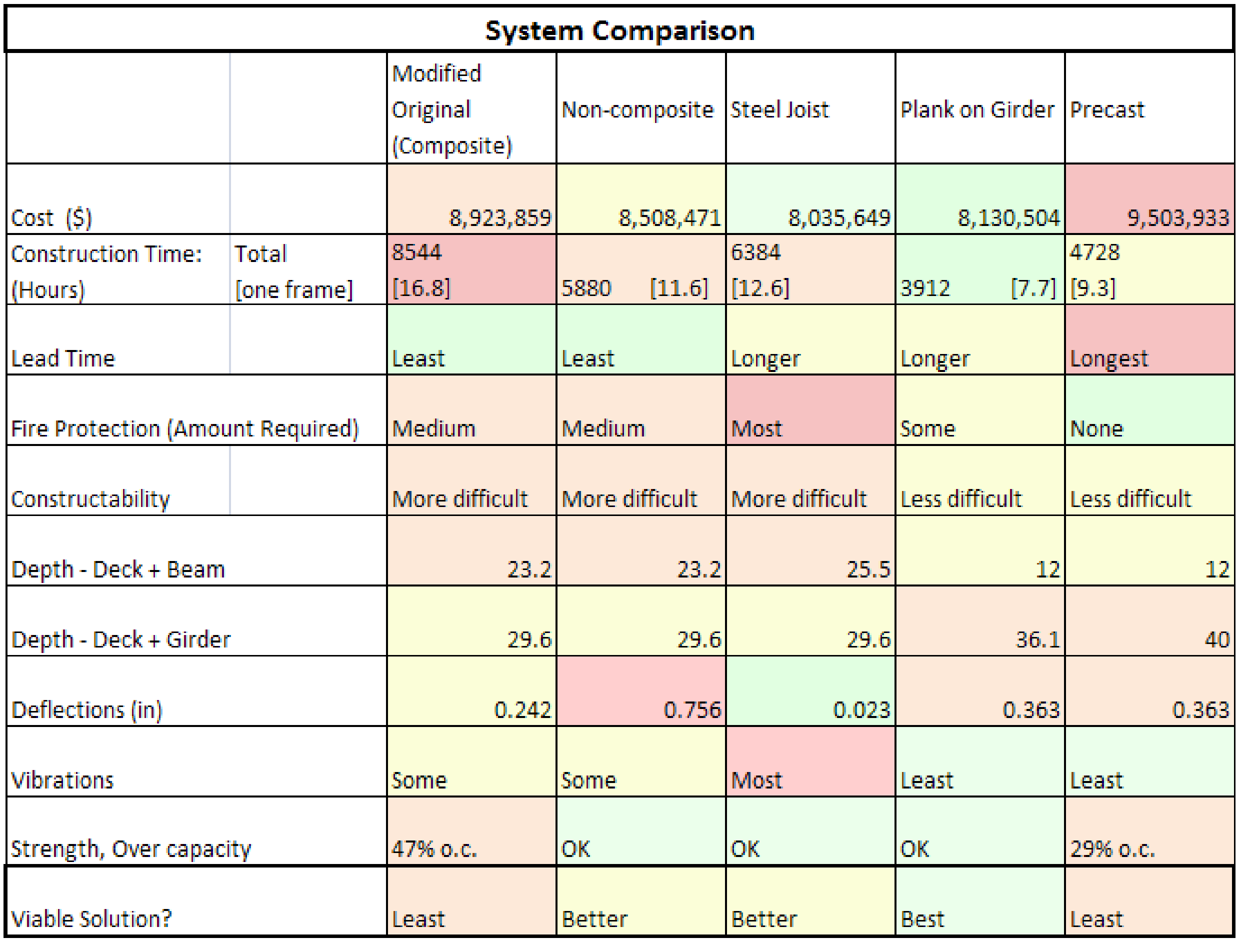
Then, the various systems were designed for strength and serviceability using the AISC steel construction guide, United Steel Deck design guide, Vulcraft design manual, and the PCI design guide. Since much of the building will contain laboratories, and the locations of the future laboratories are not predefined in the shelled floor levels, a fairly large service load accounting for laboratory equipment was used in the analysis, even though this number may be high for the office areas. With this said, the sizing of the modified system was comparable to the original design.

Due to the loading used to size the floor systems, flexure ended up controlling all of the designs. Live load deflections were then calculated for the designs and compared.

After the designs were completed, the 66th Edition, 2008 RSMeans Building Construction Cost Data guide was used to estimate the cost and construction times for the various systems. It is important to note that since a simplified framing plan was used, there should be expected increases in cost and construction time for all of the systems. The remaining criteria were able to be subjectively judged.

System Comparison

This section uses the various comparison criteria to analyze the modified original, non-composite, steel joist, plank & girder, and precast floor systems, and to draw conclusions about which systems are the most plausible alternative. Table 4, appearing below, is a summarization of the findings.



System Comparison

		Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Cost ($)		8,923,859	8,508,471	8,035,649	8,130,504	9,503,933
Construction Time: (Hours)	Total [one frame]	8544 [16.8]	5880 [11.6]	6384 [12.6]	3912 [7.7]	4728 [9.3]
Lead Time		Least	Least	Longer	Longer	Longest
Fire Protection (Amount Required)		Medium	Medium	Most	Some	None
Constructability		More difficult	More difficult	More difficult	Less difficult	Less difficult
Depth - Deck + Beam		23.2	23.2	25.5	12	12
Depth - Deck + Girder		29.6	29.6	29.6	36.1	40
Deflections (in)		0.242	0.756	0.023	0.363	0.363
Vibrations		Some	Some	Most	Least	Least
Strength, Over capacity		47% o.c.	OK	OK	OK	29% o.c.
Viable Solution?		Least	Better	Better	Best	Least

Table 4

Cost

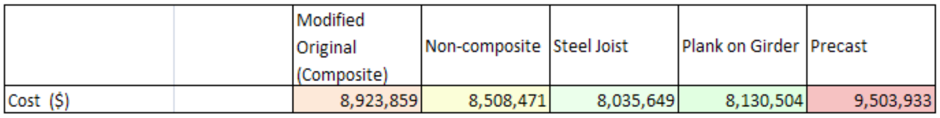
The 66th Edition, 2008 RSMeans Building Construction Cost Data guide was used to estimate the costs for the various building systems, which were modified with the city index factor. Since individual connections were not designed, a 10% allowance per RSMeans recommendation was included in the beam and girder estimates. These and other assumptions and calculations are included in the appendix.

The most expensive system was the precast concrete system at $9.5 million, which is more than the modified original (composite) system's cost of $8.9 million, a 7% increase. This makes the all precast system non-viable.

By making the floor system non-composite, approximately $400,000 in savings can be obtained over the original with a final cost of $8.5 million, a 4% reduction. The savings come entirely from the removal of shear studs which were used on the modified original, as well as the original, on the beams as well as the girders, with 24 studs per beam and an average of 26 studs per girder.

A further cost reduction is achieved by the plank on girder system at $8.1 million. Although hollow core planks are a more expensive item, by combining the function of decking and beams into one member they are cheaper than the non-composite and modified original system, with a 9% savings.

The steel joist system was the cheapest at $8 million, which is about $900,000 less than the modified original a 10% savings. Despite the fact that more joists were needed to support the calculated loads, their inherent lightness and cost efficiency, still made them the cheapest system.



		Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Cost ($)		8,923,859	8,508,471	8,035,649	8,130,504	9,503,933

Table 5

Construction Time

The 66th Edition, 2008 RSMeans Building Construction Cost Data guide was used to estimate the construction time of the various building systems. The estimate was made by summing the construction times of the individual elements for one frame and then multiplying the total by a square footage ratio to estimate the total time of construction required for the floor systems.

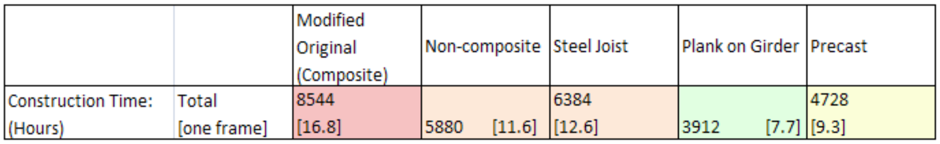
Since the construction time typically depends on the complexity of the system, the modified original took the longest to assemble at 16.8 hours per frame, which translates to

8544 hours for the whole project. This was caused by the high number of separate components that needed to be assembled.

By eliminating the shear studs for the decking, both the non-composite and steel joist system greatly decreased construction time by approximately 28%. However, due to the increased time of assembling seven joists instead of four beams and adding the bracing in between joists, the steel joist system took one hour longer to construct per frame than the non-composite system, which only took 11.6 hours per frame. This may not seem like much but over the course of the project this equaled a 504 man-hour time difference, which equals another 63 days of construction.

The precast system, at 9.3 hours per frame – 4728 total - offered an even more significant time savings of 45%. This is due to the limited number of individual elements that need to be assembled: 4 for the precast, vs. 6 with the steel joist, and 7 with the modified original.

The plank on girder system was the quickest at 7.7 hours per frame – 3912 total – with a 54% savings over the original. Despite having the same number of elements needing assembly, the plank and girder system offered further time savings, most likely due to the greater ease in moving the light steel girder as opposed to the very heavy precast girder.



		Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Construction Time: (Hours)	Total [one frame]	8544 [16.8]	5880 [11.6]	6384 [12.6]	3912 [7.7]	4728 [9.3]

Table 6

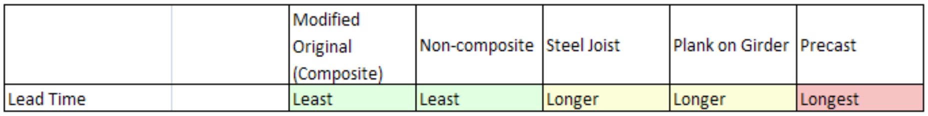
Lead Time

This analysis is a subjective due to the difficulty in obtaining an accurate and generalized estimate on the lead time of the different systems. With this said, a few relative assumptions can be made for the sake of comparison.

The precast system will probably have the longest lead time, since many of the elements, although in standard lengths and sizes, will need to be fabricated and are less likely to be in stock. The openings in the floor system, as well as the many curved shapes will have a significant impact on the lead time of the hollow core decking since these members will need to be detailed in advanced, and be specially formed and prestressed; however, due to the vertical repetition in the buildings, it may be possible to use the same forming and prestressing techniques for repetitive members, which may negate some of the extra time spent on detailing.

The plank on girder system will most likely see similar problems with the hollow core decking, but have less of a problem with the steel girders. The lead time for steel can be decreased by designing for shapes that can be ordered in-stock using standard lengths and common shape sizes from the fabricator, as opposed to designing for ones that need first to be milled. The coordination involved in using separate steel and hollow core fabricators may be difficult and lead to delays.

The steel joist, modified original (composite), and non-composite systems can take full advantage of fabricators with in-stock w-shapes, making it probable that these systems will have the least lead time. Similar coordination problems as with the plank and beam system may occur with the steel joist system however, which means there is a higher chance this system will face a longer lead time over the other two systems.



	Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Lead Time	Least	Least	Longer	Longer	Longest

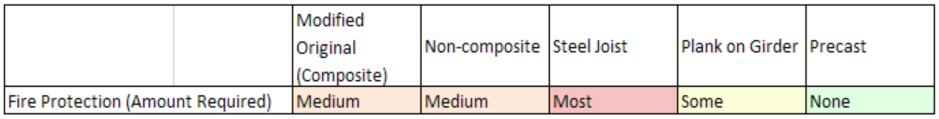
Table 7

Fire Protection

The requirement of extra fire protection can have a significant impact on cost and construction time and should be considered in this comparison. It is assumed that spray on fireproofing will be used since it is the most affordable.

Steel joists are the most difficult to protect against fire due to their open webs. Fireproofing sprays through the open webs, and laborers spend a lot of time trying to cover all of the surfaces; therefore, fire proofing will a significant negative effect on this system’s cost and scheduling.

By contrast, the modified original (composite), and non-composite systems have fairly flat surfaces, which make it much easier and more economical to spray on protection. The hollow core planks of the plank and girder system do not require spray on proofing, but the girders will still require some. The precast system does not require any extra protection due to the fire resistant qualities of concrete; therefore, fire proofing will not have any negative effect on this system’s cost or scheduling.

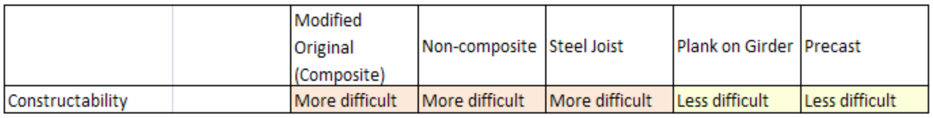


	Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Fire Protection (Amount Required)	Medium	Medium	Most	Some	None

Table 7

Constructability

Due to the building's irregularities such as the curved façade, oval tower, and the typical floor openings, the relative constructability of the various systems will significantly affect the cost and scheduling of the project. The effect will be greatest on systems where a lot of assembly happens onsite; therefore the modified original (composite), non-composite, and steel joist systems will probably experience the most difficulty, since the decking consists of a poured slab on steel decking. Not only will all of the decking material and reinforcement need to be cut for the specific areas, but that slab edges will have to be specially detailed and formed onsite. This will modify the expected construction time and cost. In comparison, the plank on girder system and precast system's hollow core planks will not require nearly as much on site assembly, thereby limiting this increase.



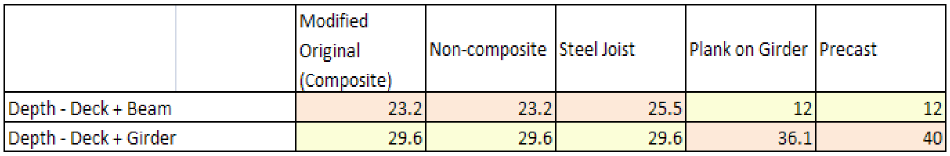
		Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Constructability		More difficult	More difficult	More difficult	Less difficult	Less difficult

Table 8

Depth

Although the floor to floor heights should be sufficient to fit any of the structural systems and the mechanical system, it is important to take note of which systems will be the most restrictive. Looking at the mechanical system, it seems that most of the ducts are around 16" depths, and run in both the N-S and E-W directions. The larger supply and return ducts are around 20-24" and run in the E-W direction.

The modified original (composite), non-composite and steel joists, are fairly similar in depth with approximately 23" depth for the deck and beam, and 29 ½" depth for the deck and girder. The precast and the plank on girder systems lack beams and therefore have a very shallow decking of 12" but have 36" and 40" girder depth, respective to the two systems. These girders run perpendicularly to the larger 20-24" ducts which may make the plenum space tight for those ducts. On the other hand, the 12" deep deck area has significantly more room, allowing plenty of plenum space mechanical equipment in the laboratory areas. In order to correctly asses the best systems in terms of depths, a thorough analysis of the mechanical system should be made, which is out of the scope of this technical report. Therefore, it is possible to weigh all of the systems fairly equally in terms of depth.



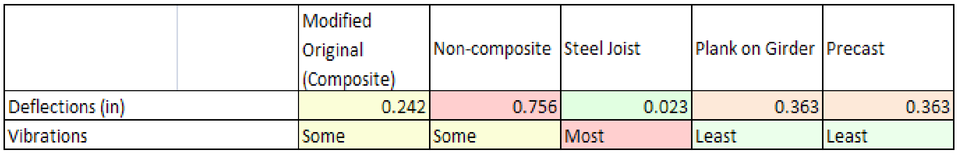
	Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Depth - Deck + Beam	23.2	23.2	25.5	12	12
Depth - Deck + Girder	29.6	29.6	29.6	36.1	40

Table 9

Serviceability

Since this building contains many laboratory areas with sensitive equipment, it is important to limit the deflections and vibrations occurring in the spaces. All of the systems were designed to meet live load deflection requirements, but many exceeded this requirement by virtue of the flexural design. The non-composite system had the highest deflections at 0.756”, which is significantly higher than the original modified (composite) system’s 0.242” deflection. The precast and plank on girder systems deflections were only controlled by the hollow core planks, which experienced 0.363” deflection. Surprisingly the steel joist system, experience the least live load deflection at 0.023”.

Vibrations were assessed subjectively based on information obtained in the general information sections of the materials used to design the various systems. Vibration is mostly dependent on span and dampening, so the AISC code recommends analyzing vibration based on acceleration. It can be expected that lighter systems which can more easily accelerate will be more susceptible to vibration. Therefore, it is expected that the steel joist system will have the highest potential for vibration issues, with the modified original (composite) and the non-composite systems experiencing less vibration, and the heavy precast and plank on girder system experiencing the least.

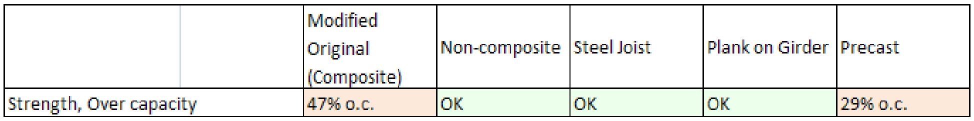


	Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Deflections (in)	0.242	0.756	0.023	0.363	0.363
Vibrations	Some	Some	Most	Least	Least

Table 10

Strength

All of the systems were designed to meet flexural strength requirements, but it is important to note two discrepancies. The first is that the modified original (composite) system has a 47% over capacity in terms of flexural requirements. This is due to the high number of shear studs present, and may be for vibration control issues. The second discrepancy occurs with the precast system. The girders here have a 29% flexural overcapacity, which is due to the types, sizes and shapes of precast girders available. Two members were found during the precast design: one closely matched the flexural requirements but was very deep, while the other was shallower but overly exceeded the flexural requirements. The latter was decided on for the sake of depths requirements; however, this resulted in an overdesigned and heavier system.



	Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Strength, Over capacity	47% o.c.	OK	OK	OK	29% o.c.

Table 11

Conclusion

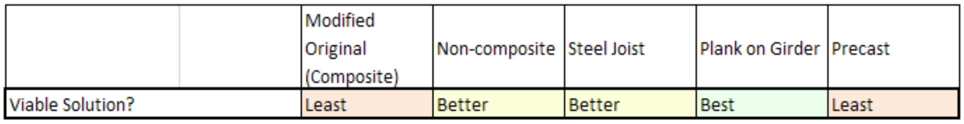
Since cost and construction time are critical issues, an initial conclusion to be drawn from this analysis is that the steel joist and plank on girder systems are the most viable solutions, with the plank on girder system being the best. The non-composite and especially the modified original systems seem to be less viable due to their higher cost and construction time. The precast system was over a half million more than the modified original system, which may appear to make it a completely non-viable system; however, when one considers that $0.5 million is only 0.3% of the $150 million budget and that the construction time is half that of the original system, then this systems remains a viable choice.

When the modifying effects of lead time, fire protection and constructability are considered, it is likely that the precast and plank on girder systems will probably see almost no price increase, the modified original and non-composite will have a slight price increase, and the steel joist system will see a significant increase.

At this point, the whole cost and scheduling picture becomes clearer and it seems that the non-composite, the steel joist and plank on girder designs are good choices in terms of cost and scheduling, with the latter two being the best. Unless substantial benefits can be found by the short construction schedule, the high cost of the precast system -despite its constructability and fire protection benefits- makes it a non-viable solution. Similarly, the original modified system is significantly more expensive than the other systems and will most likely have a higher cost due to added fire protection and constructability issues.

The depths of the non-composite, steel joist, and plank on girder systems are relatively close to each other; however, the plank on girder system stand out because of the very shallow floor area of 12”, which will allow plenty of room for equipment, especially in the laboratory areas. Once serviceability is considered, this system becomes even more attractive due to the combination of relatively small deflections and minimal vibrations. The steel joist system, on the other hand, runs the risk of high vibrations, while the non-composite section had large deflections.

When all of these separate areas for analysis are considered, the plank and girder system remains the most attractive system for its cost, short construction time, and serviceability; however, the other systems are still viable solutions to be considered, especially if more details about the construction schedule and the owner requirements become known.



	Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Viable Solution?	Least	Better	Better	Best	Least

Table 12

Appendix

Floor System Design

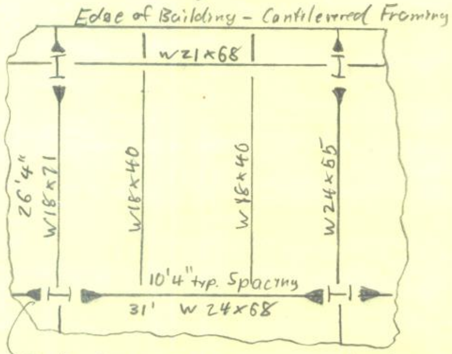
Modified Original Composite Steel

1.

Frame in col. line 6-7 / F-G was picked for analysis because it is the most typical. Also no penetrations and no curves are present in this frame simplifying the analysis.

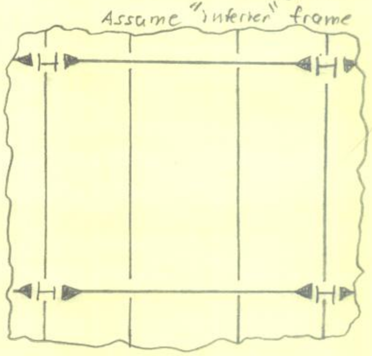
A modification to the original was made to the original in order to create a simplified and more typical frame for comparison purposes. This modified original was used to compare the various possible structural system.

Original



Indicates Moment connection direction.
Top Moment connection at North Columns for cantilever.

Modified Original



Assume Moment direction just for girders.
Columns reoriented in E-W direction

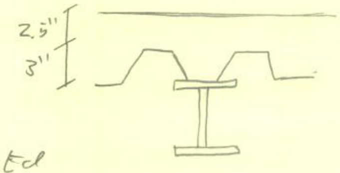
- Effective width beam:

$$b \le \begin{cases} 1/8\,(26.333') = 3.31' & \text{controls} \\ 1/2\,(10.333') = 5.163' \\ \text{distance to edge of slab} \end{cases}$$

- Loading
  $P_L = 90\text{psf}$ (incl sw)
  $L_L = 100\text{psf}$

  $1.2(90) + 1.6(100) = 268\text{psf}$

  $w = 268\text{psf}(10.333') = 2.769\text{ klf}$



- Composite Beam Design – AISC 13th Ed
  - Initial sizing:
    Since floor system will be unshored during construction, beam needs to carry all applied loads per AISC I3.1C
    - $M_u = w\ell^2/8 = 2.769\text{ klf}(26.333')^2/8 = 240\text{ kft}$
    - Decking provides full lateral bracing use Table 3-2
      W18x35 $\phi M_n = 249\text{ ft k}$

  - Decking properties:
    Decking ⊥ to beams, 2.5", $f'_c = 4{,}000$, NWC, 3/4" ϕ studs, 3" deep galvanized 20 gage deck.

    Find ΣQ_n
    table 3-2
    26' 6" span, 24 studs, $12'' = w_r \Rightarrow$ 1 stud/rib
    Assume weak stud
    $\Rightarrow Q_n = 21.5\text{ k}$

    $\Sigma Q_n = 21.5(24\text{studs}) = 516\text{ k}$

  - Use initial beam size with deck properties to find PNA + therefore flexural capacity. table 3-19

    - Smallest of: ① $A_s f_y = (10.3\text{in}^2)(50\text{ksi}) = 515\text{k}$
      ② $0.85 f'_c A_c = 0.85(4\text{ksi})(3.39' \times 12)(2.5'') = 345.78\text{ k}$
      ③ $\Sigma Q_n = 516\text{ k}$

      * Since ⊥ decking, neglect A_c below top of ribs

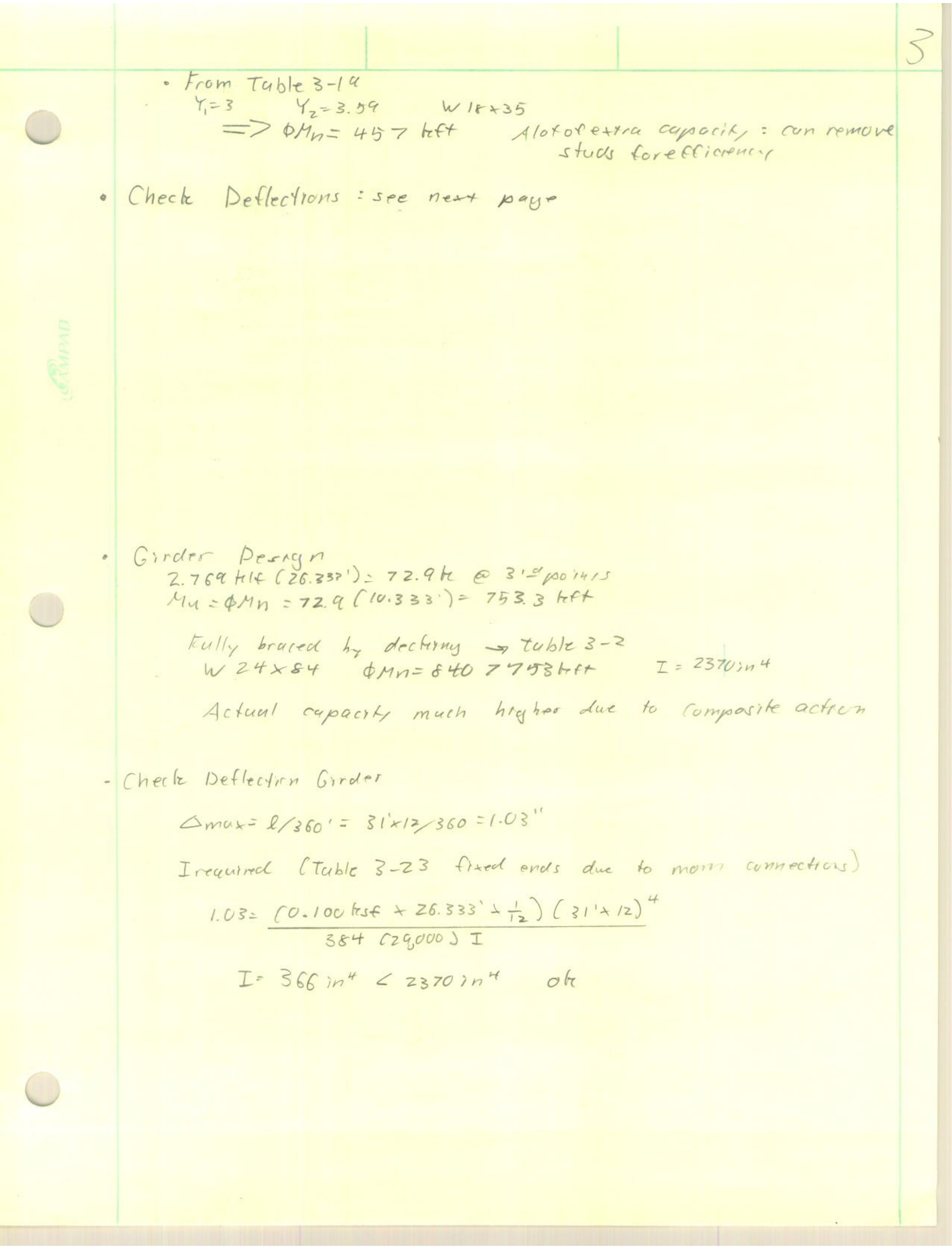
    Case ② controls PNA in flange
    Since $\Sigma Q_n >$ ① or ② fully composite action
    TO control vibration?

    - $T_s = (515 - 345.78)/2 = 84.61\text{ k}$

      $$PNA = \frac{84.61\text{k}}{(50\text{ksi})(b_f = 6'')} = 0.282''$$

    - $t_f = .425''/4 = 0.106''$
      $3(0.106) = 0.318 < 0.282''$ Conservative
      $Y_1 = 3$

    - $$Y_2 = 5.5'' - \frac{1}{2}\frac{\Sigma Q_n}{0.85 f'_c b} = 5.5 - \frac{1}{2}\frac{516}{0.85(4)(3.31 \times 12)} = 3.59$$



3

- From Table 3-19
  $Y_1 = 3$ $Y_2 = 3.59$ W 18×35
  $\Rightarrow \phi M_n = 457$ kft A lot of extra capacity : can remove studs for efficiency

- Check Deflections : see next page

- Girder Design
  $2.769 \text{ klf} (26.333') = 72.9\text{k}$ @ 3^{rd} points
  $M_u = \phi M_n = 72.9(10.333') = 753.3$ kft

  Fully braced by decking → table 3-2
  W 24×84 $\phi M_n = 840 > 753$ kft $I = 2370 \text{ in}^4$

  Actual capacity much higher due to composite action

- Check Deflection Girder

  $\Delta_{max} = \ell/360' = 31' \times 12/360 = 1.03''$

  I required (Table 3-23 fixed ends due to mom connections)

  $$1.03 = \frac{(0.100 \text{ ksf} \times 26.333' \times \frac{1}{12})(31' \times 12)^4}{384(29{,}000)I}$$

  $I = 366 \text{ in}^4 < 2370 \text{ in}^4$ ok

4

Extra Capacity = Can remove studs for efficiency

Check deflections

$\Delta_{max} = l/360 = (26.333' \times 12)/360 = 0.88$

$I_{eff} = I_{tr} \times 0.75$

	A	Y	AY	$\bar{I}$	d	$\bar{I} + Ad^2$
Concr	99.3	1.25	~~124.13~~	53.6	1.875	489.99
W18×35	10.3	13.6"	~~140.08~~	510 in⁴	10.6"	1667.31
						2157.3

effective width

$A_c = 39.72'' \times 2.5'' = 99.3 \text{ in}^2$
$Y_c = 2.5''/2 = 1.25''$
$\bar{I} = 39.72''(2.5'')^3/12 = 53.6 \text{ in}^4$
$d = \bar{Y} - Y = 3'' - 1.25'' = 1.875 \text{ in}$

$A_s = 10.3''$
$Y_s = 5'' + 17.7/2 = 13.6''$
$\bar{I}_s = 510 \text{ in}^4$
$d = Y - \bar{Y} = 13.6 - 3 = 10.6''$

$$\Delta_{actual} = \frac{5wl^4}{384EI}$$

$$= \frac{5\,[(0.1)(10.333')(\tfrac{1}{12})]\,(26.333' \times 12'')^4}{384\,(29{,}000\text{ ksi})\,2157.3 \text{ in}} =$$

$= 0.242 \text{ in} < 0.88$

Steel Noncomposite - Strength + Serviceability

Using same framing layout. for Col line 6-7/F-6
Use AISC 13th Edition

- Loading

  $W_u = 1.2D + 1.6L = 1.2(90\,psf) + 1.6(100\,psf) = 268\ psf$

- Typical Beam

  $M_u = \phi M_n = wl^2/8 = 0.268(10.333)(26.333')^2/8 = 240.0\ kft$

  Table 3-2 (decking provides full lateral support)
  W18x35 $\phi M_n = 249$ $I = 510\,in^4$

- Typical Beam Deflection

  $\Delta_{max} = l/360 = 26.333' \times 12/360 = 0.88\ in$

  $\Delta_{actual} = 5wl^4/384EI$ (Table 3-23 Shear connection)

  $$= \frac{5(0.100\,ksf \times 10.333ft \times \frac{1}{12})(26.333' \times 12)^4}{384(29{,}000\,ksi)(510\,in^4)}$$

  $= 0.756\ in < 0.88$

- Girder Design
  $2.769\ klf\,(26.333') = 72.9k$ @ 3rd points
  $M_u = \phi M_n = 72.9(10.333') = 753.3\ kft$

  Fully braced by decking → table 3-2
  W 24x84 $\phi M_n = 840 > 753\ kft$ $I = 2370\,in^4$

- Check Deflection Girder

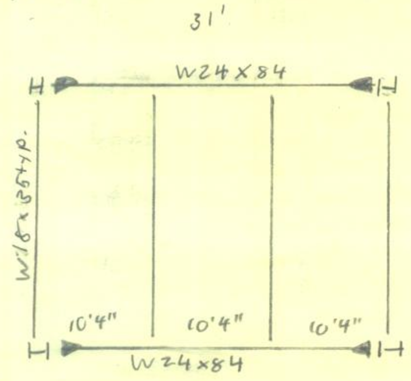
  $\Delta_{max} = l/360' = 31' \times 12/360 = 1.03''$

  I required (Table 3-23 fixed ends due to moment connections)

  $$1.03 = \frac{(0.100\,ksf \times 26.333' \times \frac{1}{12})(31' \times 12)^4}{384(29{,}000)I}$$

  $I = 366\,in^4 < 2370\,in^4$ ok

- Layout



Girders have moment connections to columns
Beams have shear connections to girders

Same bay size and column orientation as modified original design

Same decking without sheer studs as modified original

Joist System

1

- Use Vulcraft Joist Guide.

- Loading

  DL = sw = 50.1 psf for decking other sw incl in Tables
  MEP, etc = 30 psf
  81 psf
  LL = 100 psf

  $1.2D + 1.6L = 1.2(81) + 1.6(100) = 257$ psf

  Convert to ASD to use Joist Guide
  $w_{SSJ} = \frac{w_{LRFD}}{1.65 \times 0.9} = 173$ psf

- Joist Design using Economical Joist Guide pg 108 in 26'4" span

  Try 6 Joists 6'2" spacing = 1072 plf
  NOT Economical

  Try 7 Joists 5'2" spacing = 899 plf
  20 LH 9 (17 plf s.w) 903 plf capacity

  9 designation
  6" min bearing length
  14" max bridge spacing
  need 23 bridges

  ☆Try 8 Joists 4'5" spacing = 766 plf
  20 LH 6 (15 plf sw) 791 plf capacity
  ↰ 20" depth "longspan"

  6 designation
  6" min bearing length
  12" max bridge spacing
  need 26 bridges

- Joist Deflection Check: see next page

- Girder Design

  257 psf (26.333') = 6.767 klf (Assume cont loading b/c so many closely spaced joists)
  $M_u = wl^2/8 = 6.767(31')^2/8 = 813$ k-ft

  Fully braced by decking Table 3-2

  W24×84 $\phi M_n = 840$ 7753 k-ft $I = 2370$ in⁴

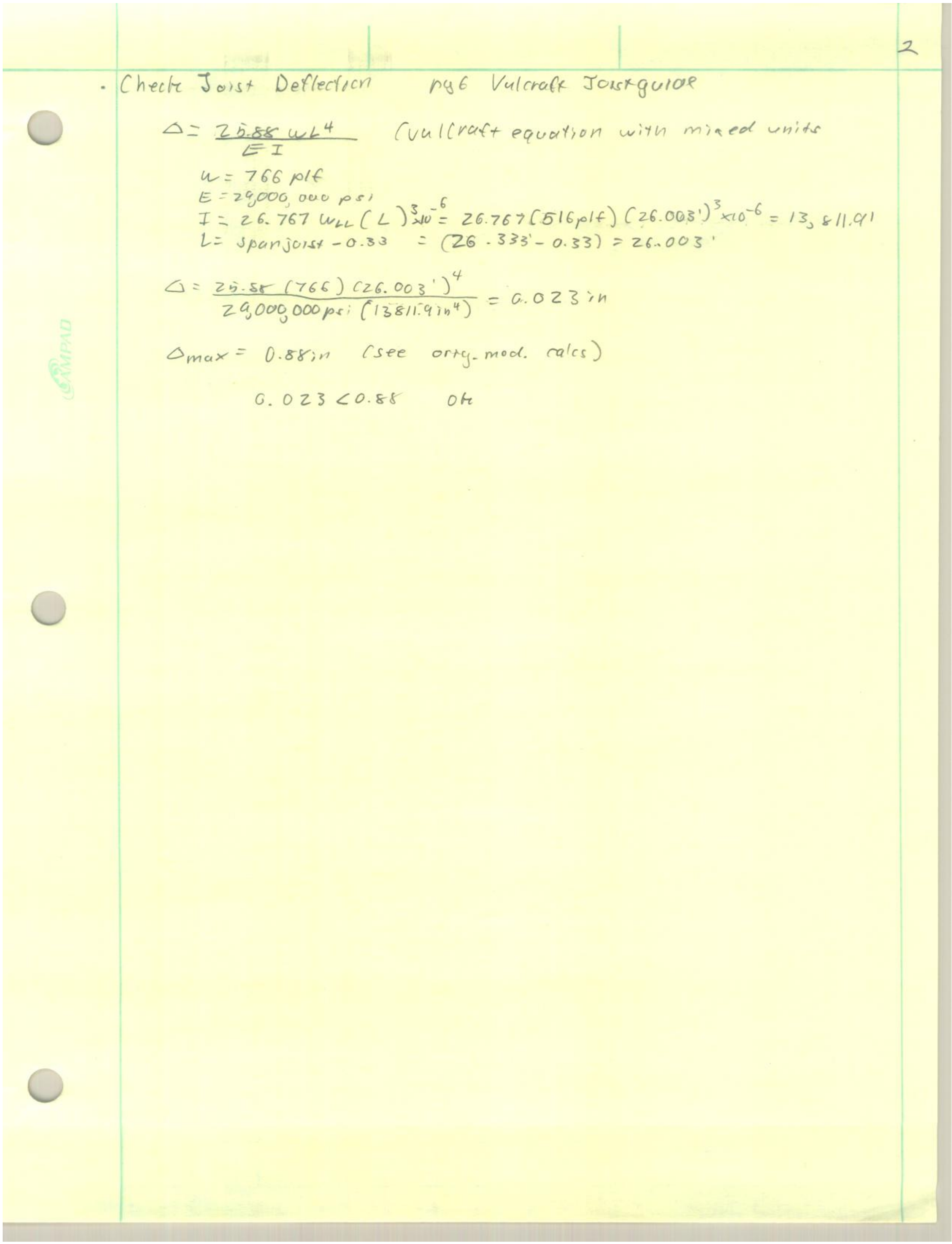
- Check Deflection Girder

  $\Delta_{max} = l/360' = 31' \times 12/360 = 1.03''$

  I required (Table 3-23 fixed ends due to mom connections)

  $$1.03 = \frac{(0.100\text{ ksf} \times 26.333' \times \frac{1}{12})(31' \times 12)^4}{384(29{,}000)I}$$

  $I = 366$ in⁴ < 2370 in⁴ ok



- Check Joist Deflection pg6 Vulcraft Joist guide

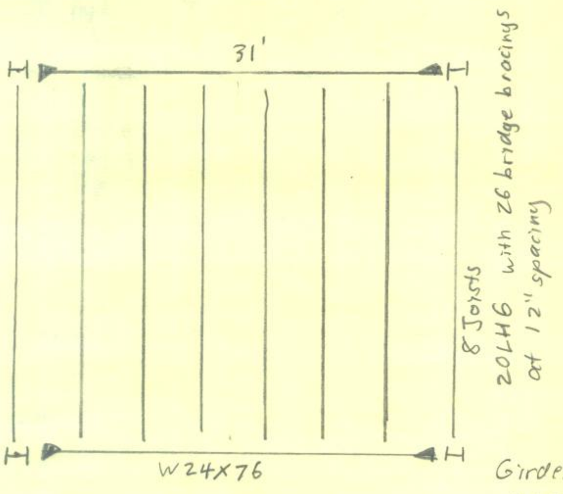
$\Delta = \frac{25.88\, wL^4}{EI}$ (vulcraft equation with mixed units

$w = 766$ plf
$E = 29{,}000{,}000$ psi
$I = 26.767\, w_{LL} (L)^3 \times 10^{-6} = 26.767(516\text{plf})(26.003')^3 \times 10^{-6} = 13{,}811.91$
$L =$ spanjoist $- 0.33 = (26.333' - 0.33) = 26.003'$

$$\Delta = \frac{25.58\,(766)\,(26.003')^4}{29{,}000{,}000\text{psi}\,(13811.9\text{in}^4)} = 0.023\text{in}$$

$\Delta_{max} = 0.88$in (see orig. mod. calcs)

$0.023 < 0.88$ ok



Girders have moment connections to column

Same decking as modified original without shear studs
Same column orientation as mod. Orig.

Plank + Beam

1

- Assumptions
  - Using same 26'4" x 31' bay size although it would probably be more economical to have bays sized for standard sizes
  - Therefore, assume it is possible to cut or premanufacture planks for custom size
  - Planks span E-W (along 31' dimmension) to minimize number of planks
  - Use 1 set of planks rather than dividing span with a girder and using 2 sets of planks
  - Although the last two assumptions will result in deeper members, they should be most economical since they reduce the number of planks, and the amount of time spent lifting planks.

- Loading

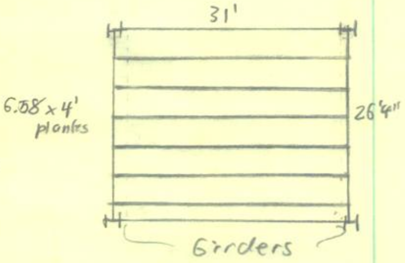
  DL = 30 psf (sw included in design tables)
  LL = 100 psf

  1.2(30) + 1.6(100) = 191 psf

- Plank Design – PCI Handbook 6th Edition

  Pg 2-33: 191 psf, 31' span

  Hollow Core Plank: 4HC10+2 885
  10" plank, 2" topping, 8 7/16"Φ strands, 195 psi



- Girder Design AISC 13th Edition

  DL = 30 psf + 81 psf (Plank sw) = 111 psf x 1.1 (Girder sw) = 122 psf
  LL = 100 psf

  1.2(122) + 1.6(100) = 306 psf
  306 x 31' = 9.498 klf

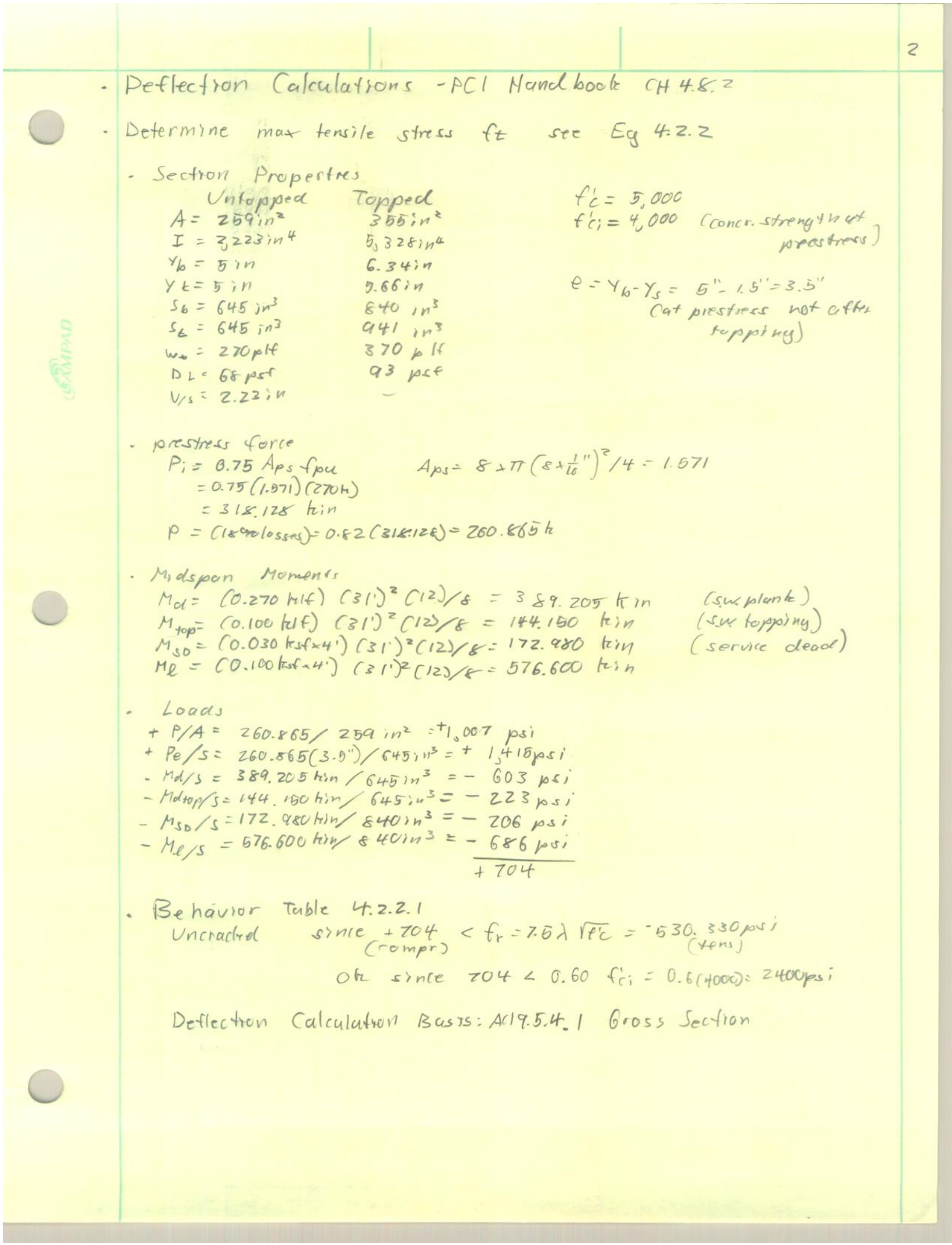
  $M_u = wl^2/8 = 9.498(26.333)^2/8 = 823$ k-ft

  Assume continuously braced use Table 3-2
  W24x84 $\phi M_n = 840$ k-ft $I = 2370$

- Girder Deflection

  2370 > 366

  (See Noncomposite calcs → still ok since Required I will be much smaller since the span is smaller)



2

- Deflection Calculations - PCI Handbook CH 4.8.2
- Determine max tensile stress f_t see Eq 4.2.2
  - Section Properties

	Untopped	Topped
$A =$	$259\ in^2$	$355\ in^2$
$I =$	$3{,}223\ in^4$	$5{,}328\ in^4$
$y_b =$	$5\ in$	$6.34\ in$
$y_t =$	$5\ in$	$5.66\ in$
$S_b =$	$645\ in^3$	$840\ in^3$
$S_t =$	$645\ in^3$	$941\ in^3$
$w =$	$270\ plf$	$370\ plf$
$DL =$	$68\ psf$	$93\ psf$
$V/s =$	$2.22\ in$	–

$f'_c = 5{,}000$
$f'_{ci} = 4{,}000$ (concr. strength at prestress)

$e = Y_b - Y_s = 5'' - 1.5'' = 3.5''$
(at prestress not after topping)

  - prestress force

$P_i = 0.75\ A_{ps} f_{pu}$
$= 0.75(1.571)(270k)$
$= 318.128\ kin$
$P = (18\%\ losses) = 0.82(318.128) = 260.865\ k$

$A_{ps} = 8 \times \pi \left(8 \times \frac{1}{16}''\right)^2 / 4 = 1.571$

  - Midspan Moments

$M_d = (0.270\ klf)(31')^2(12)/8 = 389.205\ k\,in$ (sw plank)
$M_{top} = (0.100\ klf)(31')^2(12)/8 = 144.150\ kin$ (sw topping)
$M_{SD} = (0.030\ ksf \times 4')(31')^2(12)/8 = 172.980\ kin$ (service dead)
$M_\ell = (0.100\ ksf \times 4')(31')^2(12)/8 = 576.600\ kin$

  - Loads

$+\ P/A = 260.865 / 259\ in^2 = +1{,}007\ psi$
$+\ Pe/s = 260.865(3.5'') / 645\ in^3 = +\ 1{,}415\ psi$
$-\ Md/s = 389.205\ kin / 645\ in^3 = -\ 603\ psi$
$-\ Md_{top}/s = 144.150\ kin / 645\ in^3 = -\ 223\ psi$
$-\ M_{SD}/s = 172.980\ kin / 840\ in^3 = -\ 206\ psi$
$-\ M_\ell/s = 576.600\ kin / 840\ in^3 = -\ 686\ psi$
$+\ 704$

- Behavior Table 4.2.2.1

Uncracked since $\underset{(compr)}{+704} < f_r = 7.5\lambda\sqrt{f'c} = \underset{(tens)}{-530.330\ psi}$

ok since $704 < 0.60\ f'_{ci} = 0.6(4000) = 2400\ psi$

Deflection Calculation Basis: ACI 9.5.4.1 Gross Section

- Deflection : Since uncracked, use uncracked moment of inertia of composite section.

$I = 5328 \text{ in}^4$

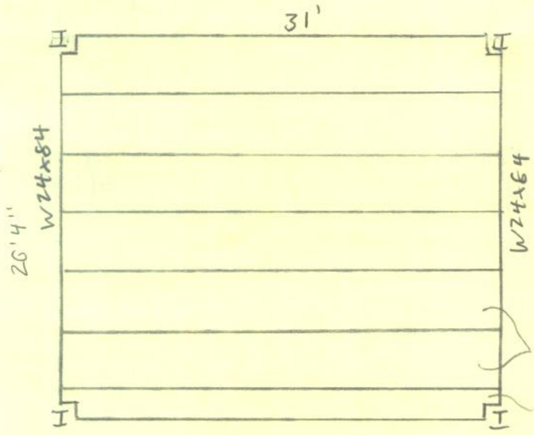
$\Delta_{max} = l/360 \cdot \quad (31' \times 12)/360 = 1.03$

$\Delta = \frac{5wl^4}{384EI} \qquad E_c = 4287\text{ksi for nwc } f'_c = 6000$

$$= \frac{5\left[0.1\text{ksf}(4\text{ft}) \times \frac{1}{12}\right](31' \times 12)^4}{384\,(4287\text{ksi})(5328\text{in}^4)}$$

$= 0.364 \text{ in} < 1.03 \text{ in}$

- Layout



Girders with moment connections to columns

4', 10" planks with 2" topping
8 5/16" strands

Modified plank width

Same bay size as modified original
Column orientation altered from modified original

Precast System

1

- Use PCI Industry Hand book 6th Edition Preliminary design methods.
- Similar Assumptions were made here as for the Plank+Beam design

- Hollow Core Slab Design PCI 2.5

Loads
DL = 30psf (s.w included in design table)
LL = 100psf

$1.2D + 1.6L = 1.2(30) + 1.6(100) = 196$ psf

PCI 2.5 Table : 196 psf, 31' span
4HC10+2, 885
10" plank, 2" topping, 8 $\frac{5}{16}$"ϕ strands, 195psf, wt = 74psf

- Girder Design PCI 2.6

Loads
DL = 30 + 74 psf = 104psf
LL = 100 psf

$1.2D + 1.6L = 1.2(104) + 1.6(100) = 285$ psf

$w_u = 285\text{psf}(26.333') = 7505$ plf

PCI 2.6 Tables : 26'
Best for weight
* 12 RB36, 158-S (Rectangular beam)
b = 12", h = 36", 15 $\frac{5}{16}$"ϕ strands, 7624 plf

20 LB36, 168-S (L-Beam)
b_{base} = 20", h = 36", 16 $\frac{5}{16}$"ϕ strands, 7958 plf

26 LB32, 218-S
b_{base} = 26", h = 32", 21 $\frac{5}{16}$"ϕ strands, 9265 plf

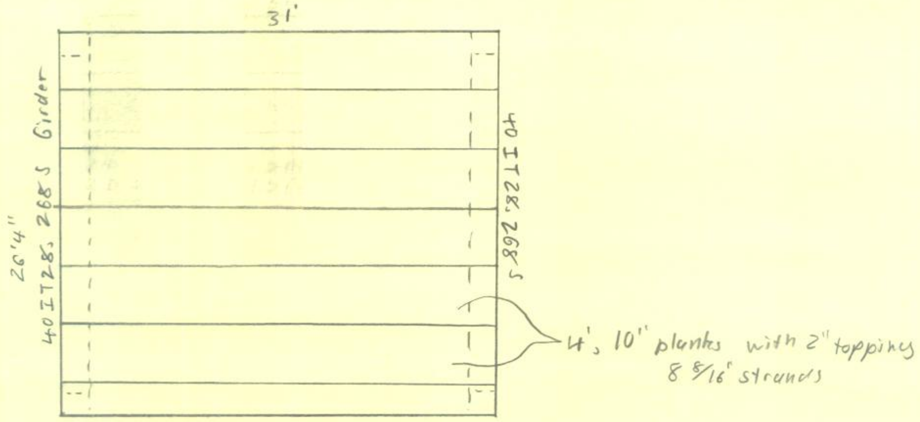
* 40 IT28, 268-S
b_{base} = 40" h = 28", 26 $\frac{5}{16}$"ϕ strands, 9672 plf

Best for depth, use this

- Hollow Core Deflections: same as in planks from previous example

- Girder deflections will be very minimal since the 40IT28, 268-S is so oversized for flexure.

- Layout



Same bay size as modified original
Precast columns

Cost & Schedule Estimate

Modified Original (Composite) Floor System

Item		Quantitiy	Unit	Crew
Steel Deck	05 31 13.50 #5800	816.323	sf	E-4

3" Deep, galv, 20 gauge

Note: 26.333' x 31' = 816.323　　Assume this does not include sheer studs, WWF or concrete.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
816.323	3000	0.27	508	138

Bare Cost						
	Bare Cost Item x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	1.86	816.323	1518.361	508	771327.2762	1.015
Labor	0.46	816.323	375.5086	508	190758.3586	1.309
Equip.	0.4	816.323	326.5292	508	165876.8336	1.309
Total			$2,220		$1,127,962	$1,249,733

Item		Quantitiy	Unit	Crew
WWF	03 22 05.50 #0300	0.816	C.S.F	2 Rodm

6x6-W2.9xW2.9(6x6) 42 lb per C.S.F

Note: C.S.F (hundred square feet) = 816.323sft/100 = .816

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
0.816	29	0.03	508	14

Bare Cost						
	Bare Cost Item x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	20	0.816	16.32	508	8290.56	1.015
Labor	23.5	0.816	19.176	508	9741.408	1.309
Equip.	-	-	-	508	-	-
Total			$35		$18,032	$21,166

Item		Quantitiy	Unit	Crew
Weld Shear Connectors	05 05 23.85 #0600	96	Ea.	E-10

3/4" Ø, 5-3/16"

Note: 3/4" Ø, 5" long shear studs. 24 per beam, 4 beams per frame and 26 per girder, 2 girders per frame

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
148	920	0.16	508	82

Bare Cost						
	Bare Cost Item x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	0.62	148	91.76	508	46614.08	1.015
Labor	0.77	148	113.96	508	57891.68	1.309
Equip.	0.39	148	57.72	508	29321.76	1.309
Total			$263		$133,828	$161,476

Item		Quantitiy	Unit	Crew
Concrete Material	03 31 05.35 #0300	10.078	CY	-

Normal wieght concrete, ready mix, 4000psi

Note: Slab Calculation: (26.333ft x 31ft)(4" avg thickness) = 10.078 CY

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
-	-	-	-	-

Bare Cost						
	Bare Cost Item x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	106	10.078	1068.268	508	542680.144	1.105
Labor	-	-	-	-	-	
Equip.	-	-	-	-	-	
Total			$1,068		$542,680	$599,662

Item		Quantitiy	Unit	Crew
Placing Concrete	03 31 05.70 #1400	10.078	CY	C-20

Elevated Slabs, less than 6" Thick, pumped

Note: Slab Calculation: (26.333ft x 31ft)(4" avg thickness) = 10.078 CY

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
10.078	140	0.07	508	37

Bare Cost						
	Bare Cost Item x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	-	-	-	-	-	
Labor	14.9	10.078	150.1622	508	76282.3976	1.375
Equip.	5.55	10.078	55.9329	508	28413.9132	1.375
Total			$206		$104,696	$143,957

Item		Quantitiy	Unit	Crew
Beams	05 12 23.75 #3300	105.332	L.F.	E-5

W18x35

Note: Quantity = 2 x 31' = 62'　　Total costs include 10% allowance for plates, angles, nuts, bolts, washers, etc.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
105.332	960	0.11	508	56

Bare Cost						
	Bare Cost Item x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	42.5	105.332	4476.61	508	2274117.88	1.015
Labor	3.53	105.332	371.822	508	188885.5557	1.309
Equip.	1.77	105.332	186.4376	508	94710.32112	1.309
Total			$5,538		$2,813,485	$2,947,402

Item		Quantitiy	Unit	Crew
Girders	05 12 23.75 #5700	62	L.F.	E-5

W24x84

Note: Total costs include 10% allowance for plates, angles, nuts, bolts, washers, etc.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
62	1080	0.06	508	29

Bare Cost						
	Bare Cost Item x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	102	62	6324	508	3212592	1.015
Labor	3.14	62	194.68	508	98897.44	1.309
Equip.	1.57	62	97.34	508	49448.72	1.309
Total			$7,278		$3,697,032	$3,800,463

Totals: Modified Original Floor System	Duration Frame (days)	x SF Ratio =	Duration Building	Cost Frame	Cost Building	Cost incl. City Index
	0.70	508	356	$16,610	$8,437,716	$8,923,859

Non-composite Floor System

Item				
		Quantitiy	Unit	Crew
Steel Deck	05 31 13.50 #3360	816.323	sf	E-4

3" Deep, galv, 20 gauge, over 500 squares

Note: 26.333' x 31' = 816.323 Assume this does not include WWF or concrete.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
816.323	3800	0.21	508	109

Bare Cost						
Bare Cost Item	x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	1.85	816.323	1510.198	508	767180.3554	1.015
Labor	0.37	816.323	302.0395	508	153436.0711	1.309
Equip.	0.03	816.323	24.48969	508	12440.76252	1.309
Total			$1,837		$933,057	$995,821

Item				
		Quantitiy	Unit	Crew
WWF	03 22 05.50 #0300	0.816	C.S.F	2 Rodm

6x6-W2.9xW2.9(6x6) 42 lb per C.S.F

Note: C.S.F (hundred square feet) = 816.323sft/100 = .816

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
0.816	29	0.03	508	14

Bare Cost						
Bare Cost Item	x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	20	0.816	16.32	508	8290.56	1.015
Labor	23.5	0.816	19.176	508	9741.408	1.309
Equip.	-	-	-	508	-	-
Total			$35		$18,032	$21,166

Item				
		Quantitiy	Unit	Crew
Concrete Material	03 31 05.35 #0300	10.078	CY	-

Normal wieght concrete, ready mix, 4000psi

Note: Slab Calculation: (26.333ft x 31ft)(4" avg thickness) = 10.078 CY

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
-	-	-	-	-

Bare Cost						
Bare Cost Item	x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	106	10.078	1068.268	508	542680.144	1.105
Labor	-	-	-	-	-	
Equip.	-	-	-	-	-	
Total			$1,068		$542,680	$599,662

Item				
		Quantitiy	Unit	Crew
Placing Concrete	03 31 05.70 #1400	10.078	CY	C-20

Elevated Slabs, less than 6" Thick, pumped

Note: Slab Calculation: (26.333ft x 31ft)(4" avg thickness) = 10.078 CY

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
10.078	140	0.07	508	37

Bare Cost						
Bare Cost Item	x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	-	-	-	-	-	
Labor	14.9	10.078	150.1622	508	76282.3976	1.375
Equip.	5.55	10.078	55.9329	508	28413.9132	1.375
Total			$206		$104,696	$143,957

Item				
		Quantitiy	Unit	Crew
Beams	05 12 23.75 #3300	105.332	L.F.	E-5

W18x35

Note: Quantity = 2 x 31' = 62' Total costs include 10% allowance for plates, angles, nuts, bolts, washers, etc.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
105.332	960	0.11	508	56

Bare Cost						
Bare Cost Item	x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	42.5	105.332	4476.61	508	2274117.88	1.015
Labor	3.53	105.332	371.822	508	188885.5557	1.309
Equip.	1.77	105.332	186.4376	508	94710.32112	1.309
Total			$5,538		$2,813,485	$2,947,402

Item				
		Quantitiy	Unit	Crew
Girders	05 12 23.75 #5700	62	L.F.	E-5

W24x84

Note: Total costs include 10% allowance for plates, angles, nuts, bolts, washers, etc.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
62	1080	0.06	508	29

Bare Cost						
Bare Cost Item	x	Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	102	62	6324	508	3212592	1.015
Labor	3.14	62	194.68	508	98897.44	1.309
Equip.	1.57	62	97.34	508	49448.72	1.309
Total			$7,278		$3,697,032	$3,800,463

Totals: Non-composite Floor System	Duration Frame (days)	x SF Ratio =	Duration Building	Cost Frame		Cost Building	Cost incl. City Index
	0.48	508	245	$15,963		$8,108,983	$8,508,471

Steel Joist Floor System

Item				
		Quantitiy	Unit	Crew
Steel Deck	05 31 13.50 #3360	816.323	sf	E-4

3" Deep, galv, 20 gauge, over 500 squares

Note: 26.333' x 31' = 816.323 Assume this does not include WWF or concrete.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
816.323	3800	0.21	508	109

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	1.85	816.323	1510.198	508	767180.3554	1.015
Labor	0.37	816.323	302.0395	508	153436.0711	1.309
Equip.	0.03	816.323	24.48969	508	12440.76252	1.309
Total			$1,837		$933,057	$995,821

Item				
		Quantitiy	Unit	Crew
WWF	03 22 05.50 #0300	0.816	C.S.F	2 Rodm

6x6-W2.9xW2.9(6x6) 42 lb per C.S.F

Note: C.S.F (hundred square feet) = 816.323sft/100 = .816

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
0.816	29	0.03	508	14

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	20	0.816	16.32	508	8290.56	1.015
Labor	23.5	0.816	19.176	508	9741.408	1.309
Equip.	-	-	-	508	-	-
Total			$35		$18,032	$21,166

Item				
		Quantitiy	Unit	Crew
Concrete Material	03 31 05.35 #0300	10.078	CY	-

Normal wieght concrete, ready mix, 4000psi

Note: Slab Calculation: (26.333ft x 31ft)(4" avg thickness) = 10.078 CY

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
-	-	-	-	-

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	106	10.078	1068.268	508	542680.144	1.105
Labor	-	-	-	-	-	
Equip.	-	-	-	-	-	
Total			$1,068		$542,680	$599,662

Item				
		Quantitiy	Unit	Crew
Placing Concrete	03 31 05.70 #1400	10.078	CY	C-20

Elevated Slabs, less than 6" Thick, pumped

Note: Slab Calculation: (26.333ft x 31ft)(4" avg thickness) = 10.078 CY

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
10.078	140	0.07	508	37

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	-	-	-	-	-	
Labor	14.9	10.078	150.1622	508	76282.3976	1.375
Equip.	5.55	10.078	55.9329	508	28413.9132	1.375
Total			$206		$104,696	$143,957

Item				
		Quantitiy	Unit	Crew
Joists	05 21 16.50 #2260	210.664	L.F.	E-7

Long Span Joist: 20LH6, 40-ton job lots, bolted cross bridging, shop primer

Note: Quantity = 8 x 26.333' = 210.664

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
210.664	1400	0.15	508	76

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	15.9	210.664	3349.558	508	1701575.261	1.015
Labor	2.42	210.664	509.8069	508	258981.895	1.309
Equip.	1.31	210.664	275.9698	508	140192.6787	1.309
Total			$4,549		$2,310,825	$2,474,580

Item				
		Quantitiy	Unit	Crew
Girders	05 12 23.75 #5700	62	L.F.	E-5

W24x84

Note: Total costs include 10% allowance for plates, angles, nuts, bolts, washers, etc.

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
62	1080	0.06	508	29

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	102	62	6324	508	3212592	1.015
Labor	3.14	62	194.68	508	98897.44	1.309
Equip.	1.57	62	97.34	508	49448.72	1.309
Total			$7,278		$3,697,032	$3,800,463

Totals: Steel Joist Floor System	Duration Frame (days)	x SF Ratio =	Duration Building	Cost Frame		Cost Building	Cost incl. City Index
	0.52	508	266	$14,973		$7,606,322	$8,035,649

Plank & Girder Floor System

Item			
		Quantitiy Unit	Crew
Hollow Core Plank	03 41 13.50 #0150	816.323 sf	C-11

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
816.323	3600	0.23	508	115

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	7.65	816.323	6244.871	508	3172394.443	1.015
Labor	0.84	816.323	685.7113	508	348341.3506	1.309
Equip.	0.52	816.323	424.488	508	215639.8837	1.309
Total			$7,355		$3,736,376	$3,958,232

Hollow core Plank 10" thick

Note: Quantity = 26.333' x 31' = 816.323

Assume this does not include topping.

Item			
		Quantitiy Unit	Crew
Topping Material	03 31 05.35 #0300	5.039 CY	-

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
-	-	-	-	-

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	106	5.039	534.134	508	271340.072	1.105
Labor	-	-	-	-	-	
Equip.	-	-	-	-	-	
Total			$534		$271,340	$299,831

Normal wieght concrete, ready mix, 4000psi

Note: Topping Calculation: (26.333ft x 31ft)(2" avg thickness) = 5.039CY

Item			
		Quantitiy Unit	Crew
Placing Topping	03 31 05.70 #1400	10.078 CY	C-20

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
5.039	140	0.04	508	18

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	-	-	-	-	-	
Labor	14.9	5.039	75.0811	508	38141.1988	1.375
Equip.	5.55	5.039	27.96645	508	14206.9566	1.375
Total			$103		$52,348	$71,979

Elevated Slabs, less than 6" Thick, pumped

Note: Topping Calculation: (26.333ft x 31ft)(2" avg thickness) = 5.039CY

Item			
		Quantitiy Unit	Crew
Girders	05 12 23.75 #5700	62 L.F.	E-5

Productivity				
Quantity ÷	Daily Output =	Duration Frame (days)	x SF Ratio =	Duration Building
62	1080	0.06	508	29

Bare Cost						
Bare Cost Item		x Quantity =	Cost Frame	x SF Ratio =	Cost Building	x City Index
Material	102	62	6324	508	3212592	1.015
Labor	3.14	62	194.68	508	98897.44	1.309
Equip.	1.57	62	97.34	508	49448.72	1.309
Total			$7,278		$3,697,032	$3,800,463

W24x84

Note: Total costs include 10% allowance for plates, angles, nuts, bolts, washers, etc.

Totals: Plank & Girder Floor System	Duration Frame (days)	x SF Ratio =	Duration Building	Cost Frame		Cost Building	Cost incl. City Index
	0.32	508	163	$15,270		$7,757,096	$8,130,504

Precast Floor System

Item		Quantitiy	Unit	Crew
Hollow Core Plank	03 41 13.50 #0150	816.323	sf	C-11

Hollow core Plank 10" thick

Note: Quantity = 26.333' x 31' = 816.323

Assume this does not include topping.

Productivity								
Quantity	÷	Daily Output	=	Duration Frame (days)	x	SF Ratio	=	Duration Building
816.323		3600		0.23		508		115

Bare Cost										
Bare Cost Item		x	Quantity	=	Cost Frame	x	SF Ratio	=	Cost Building	x City Index
Material	7.65		816.323		6244.871		508		3172394.443	1.015
Labor	0.84		816.323		685.7113		508		348341.3506	1.309
Equip.	0.52		816.323		424.488		508		215639.8837	1.309
Total					$7,355				$3,736,376	$3,958,232

Item		Quantitiy	Unit	Crew
Topping Material	03 31 05.35 #0300	5.039	CY	-

Normal wieght concrete, ready mix, 4000psi

Note: Topping Calculation: (26.333ft x 31ft)(2" avg thickness) = 5.039CY

Productivity								
Quantity	÷	Daily Output	=	Duration Frame (days)	x	SF Ratio	=	Duration Building
-		-		-		-		-

Bare Cost										
Bare Cost Item		x	Quantity	=	Cost Frame	x	SF Ratio	=	Cost Building	x City Index
Material	106		5.039		534.134		508		271340.072	1.105
Labor	-		-		-		-		-	
Equip.	-		-		-		-		-	
Total					$534				$271,340	$299,831

Item		Quantitiy	Unit	Crew
Placing Topping	03 31 05.70 #1400	10.078	CY	C-20

Elevated Slabs, less than 6" Thick, pumped

Note: Topping Calculation: (26.333ft x 31ft)(2" avg thickness) = 5.039CY

Productivity								
Quantity	÷	Daily Output	=	Duration Frame (days)	x	SF Ratio	=	Duration Building
5.039		140		0.04		508		18

Bare Cost										
Bare Cost Item		x	Quantity	=	Cost Frame	x	SF Ratio	=	Cost Building	x City Index
Material	-		-		-		-		-	
Labor	14.9		5.039		75.0811		508		38141.1988	1.375
Equip.	5.55		5.039		27.96645		508		14206.9566	1.375
Total					$103				$52,348	$71,979

Item		Quantitiy	Unit	Crew
Precast Girders	03 41 05.10 #2300	2	EA	C-11

Inverted T: 40IT28, 268S

Note: Used a Tee single with 30' length and included the RSMeans 20% material cost increase for large inverted tee beams.

Productivity								
Quantity	÷	Daily Output	=	Duration Frame (days)	x	SF Ratio	=	Duration Building
2		16		0.13		508		64

Bare Cost										
Bare Cost Item		x	Quantity	=	Cost Frame	x	SF Ratio	=	Cost Building	x City Index
Material	4620		2		9240		508		4693920	1.015
Labor	190		2		380		508		193040	1.309
Equip.	118		2		236		508		119888	1.309
Total					$10,842				$5,006,848	$5,173,952

Totals: Precast Floor System	Duration Frame (days)	x SF Ratio =	Duration Building	Cost Frame		Cost Building	Cost incl. City Index
	0.39	508	197	$18,834		$9,066,912	$9,503,993

Comparison Spread Sheet

System Comparison

		Modified Original (Composite)	Non-composite	Steel Joist	Plank on Girder	Precast
Cost ($)		8,923,859	8,508,471	8,035,649	8,130,504	9,503,933
Construction Time: (Hours)	Total [one frame]	8544 [16.8]	5880 [11.6]	6384 [12.6]	3912 [7.7]	4728 [9.3]
Lead Time		Least	Least	Longer	Longer	Longest
Fire Protection (Amount Required)		Medium	Medium	Most	Some	None
Constructability		More difficult	More difficult	More difficult	Less difficult	Less difficult
Depth - Deck + Beam		23.2	23.2	25.5	12	12
Depth - Deck + Girder		29.6	29.6	29.6	36.1	40
Deflections (in)		0.242	0.756	0.023	0.363	0.363
Vibrations		Some	Some	Most	Least	Least
Strength, Over capacity		47% o.c.	OK	OK	OK	29% o.c.
Viable Solution?		Least	Better	Better	Best	Least