Coppin State University
Physical Education Complex

Baltimore, MD

Technical Assignment 2

12/04/07

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Structural Option

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Executive Summary:

The purpose of this assignment is to analyze the existing floor system along with 4 possible alternative floor systems for the Coppin State University Physical Education Complex. This report will provide supporting information on each system and outline whether or not these systems are a viable alternative to the existing system.

The existing structural floor system of the Coppin State University Physical Education Complex is composed primarily of composite steel beams with a concrete slab, typically 3.25" lightweight concrete on a 3"x20ga. galvanized composite metal deck reinforced with 6x6-W1.4x1.4 W.W.F. The floor system supporting the SCUP rooms use a 5"x18ga. galvanized composite metal deck reinforced with #4@12" o.c. in direction of deck span and 6x6-W1.4x1.4 W.W.F. All concrete in the superstructure uses an f'c = 4000psi. The beams are typically spaced at 10' intervals (with few exceptions due to vertical openings) to eliminate shoring during construction. Supporting girders are spaced typically at 30'. There is not much conformity of W shape sizing throughout the building due to its odd shape are different loading and spanning conditions. The building contains 3 expansion joints (see Appendix A), basically subdividing it into 4 separate buildings: Facilities Management, Arena, Physical Education North, and Physical Education South. The analyses performed use these sub-divided buildings rather than the structure as a whole. For simplicity of analysis, my report will explore the structural system of facilities management with standard loading conditions. Typical bays in this area are 24'8" x 31'0" and 34'2" x 31'0". The columns fall between corridor walls, so moving them would not be a great alternative for this report.

My initial view on the current framing system was that it was adequately designed and seemed to be the best fit for a recreation center. With this in mind, I tried to pick a wide range of alternate systems to prove the existing composite structure was adequate. Thus, a variety of systems were chosen for my analysis, but several were ruled out by inspection. Four systems seemed to stand out as possibilities for alternative framing. The four alternatives analyzed in this report are: 1) a composite deck on open-web steel joist system, 2) a flat slab system, 3) hollow-core precast planks on a steel frame, and 4) a girder-slab system.

Several factors were considered when analyzing the five floor systems. Critical factors include cost, weight of system, depth of system, construction time, constructability, vibration issues, fireproofing issues, and overall changes to the existing architectural system. The most important factor is obviously cost, but all of the factors are important and must be considered. These factors are all taken into account and the overall system feasibility is thus determined. The comparison is outlined in the following report.

Building Description

Architecture: This state of the art recreation and physical education complex at Coppin State University combines the beauty and sophistication of red brick alongside the sleek appearance that steel and glass construction provides. The building sprawls in several directions at several heights from the hub of the building, the new 2600 seat arena. The arena contains a fully functional basketball court that can be changed to incorporate other sporting events when needed. Probably the most dramatic features would be the exposed steel trusses supporting the roof of the arena. A variety of spaces are all contained within the complex in addition to the arena including an 8-lane swimming pool, racquetball courts, classrooms, and management facilities. The building uses several heights ranging from 30' to 60' which brings an exciting look to the exterior. Alongside the building, tennis courts and other outdoor facilities are being developed, and because the building extends in several directions, greenspaces can be easily incorporated as well. The building actually surrounds a soccer and training field. Canopies stationed around the perimeter also provide a nice gathering spot for young college students. The complex has a good chance of bringing new light and rejuvenating the surrounding area.

Foundation: The foundation is comprised of spread footings and slab on grade. The spread footings use strengths of 3000psf, 6000psf and 10000psf allowable bearing pressure depending on loads and geotechnical data. The spread footings around the columns range from 4'x4' to 20'x20'. Typical footings are 12" thick, but various thicker footings exist in areas of especially high load such as under the soccer scoreboard. The typical floor slab is 8" thick concrete slab-on-grade reinforced with 6x6 W2.1x2.1 W.W.F. on waterproofing and 6" compacted granular fill. The concrete used is normal weight and has a minimum compressive strength at 28 days as follows:

Footings: 4000psi
Caisson Caps: 4000psi
Caissons: 4000psi
Walls + Piers: 4000psi
Grade Beams: 4000psi
Slab-On-Grade: 3500psi

The reinforcement bar strength is fy=60ksi for all areas.

Columns: The Columns of the Coppin State University Physical Education Complex are mostly W shapes. W12's are the most common, but W10's and W14's are also used. Square HSS shapes are also used as columns but rarely. The building uses steel gravity columns as well as moment framed columns. Because the building is only 4 stories maximum, there is only one splice maximum per column line, which generally occurs on level 3. Splicing is specified as 4' above the finished floor which makes the longest column 34'. The lightest W shape used is W10x33 and the heaviest is W14x257. All columns are ASTM GR 50.

Lateral Force Resisting System: The building is essentially 3 buildings side by side. A 3" expansion joint on both sides of the arena runs the entire length of the building in the N-S direction that in effect divides the building. The large trusses composed of W14x120 as top and bottom chords and HSS8x8x1/2 diagonal members along with the roofing material of the arena acts as a diaphragm and shifts the wind loads out to the moment frames along the expansion joints. Other smaller trusses composed of W12x53's as top and bottom chords and HSS6x6x1/2 as diagonal members oriented in the E-W direction act in a similar manner on the eastern part over the classrooms, auxiliary gym, and swimming pool areas. Moment frames and vertical trusses composed of W shapes are widespread throughout the building in both directions.

Arena Trusses: The Coppin State University Physical Education Complex makes use of several trusses supporting the roof structure of the arena. The span of these trusses is 166'6". As noted before, W14x120's make up the top and bottom chords and HSS8x8x1/2's make up the diagonal members. The depth of the trusses is 10'7". The trusses do not span the 166'6" continuously, but rather the adjacent trusses meet about 45' from each end forming a triangle section (see XXXX). The trusses are generally flat with a small slope for water runoff. Special connections are required at the midspan and intersection of the end triangle pieces.

Codes:

Building Code: International Building Code (IBC), 2003 edition

Steel Design: American Institute of Steel Construction LRFD (AISC) 9th Edition
AWSD1.1 Rev. 5

Concrete Design: ACI 301-99, ACI 318-02, ACI 315-99

Loads:

Dead and Live Loads: The building uses several floor systems. The most common is the standard floor, but the SCUP area(area supporting the cooling towers), and mechanical rooms have a larger load. Other areas such as the canopy and the roof areas take a smaller load. These loads are outlined in the following table.

Dead and Live Loads:					
Dead Load Description	Standard Floor	SCUP	Roof	Canopy	Mech. Floor
Concrete Slab	51	79			51
Metal Deck	2	2	2	2	2
M/E/C/L	7	10	16	6	7
Membrane			1.5	1.5	1.5
Roofing			3	3	3
Insulation			2.5	2.5	2.5
Total DL:	60	91	25	15	67
Live Load:	100	300	30	30	55

* Does Not Include Weight of Steel Members
*Live Load Reduction Taken Into Account

System Analysis Overview

Many systems could have been used for the initial analysis of the Coppin State University Physical Education Complex, however, the four chose represent a wide variety of systems. The building is expansive (spanning over 600' in both directions), but it is not very tall (only 4 floors maximum), and there are many odd angles where the floor system merges. Three expansion joints divide the building into 4 smaller buildings: facilities management, arena, physical education north, and physical education south. The building has a wide range of uses and supports many different loads including standard classroom loads, corridor loads, mechanical room loads and dance floor loads. For these reasons, conformity among the members is hard to find. Additionally, if a change were to be implemented in the structural system of the building, the modifications might not carry over to other areas or other floors. For this reason I have chosen 4 systems that seem to be the most different from the existing system and from each other. The existing system is composite steel beams and girders and the four alternative systems are 1) a composite deck on open-web steel joist system, 2) a flat slab system, 3) hollow-core precast planks on a steel frame, and 4) a girder-slab system. A typical section of the Facilities Management area was selected for analysis for all the systems, see Figure 1. This is just a simple analysis done for preliminary investigation that will be used to see whether any system deserves further insight. The five systems are outlined below.

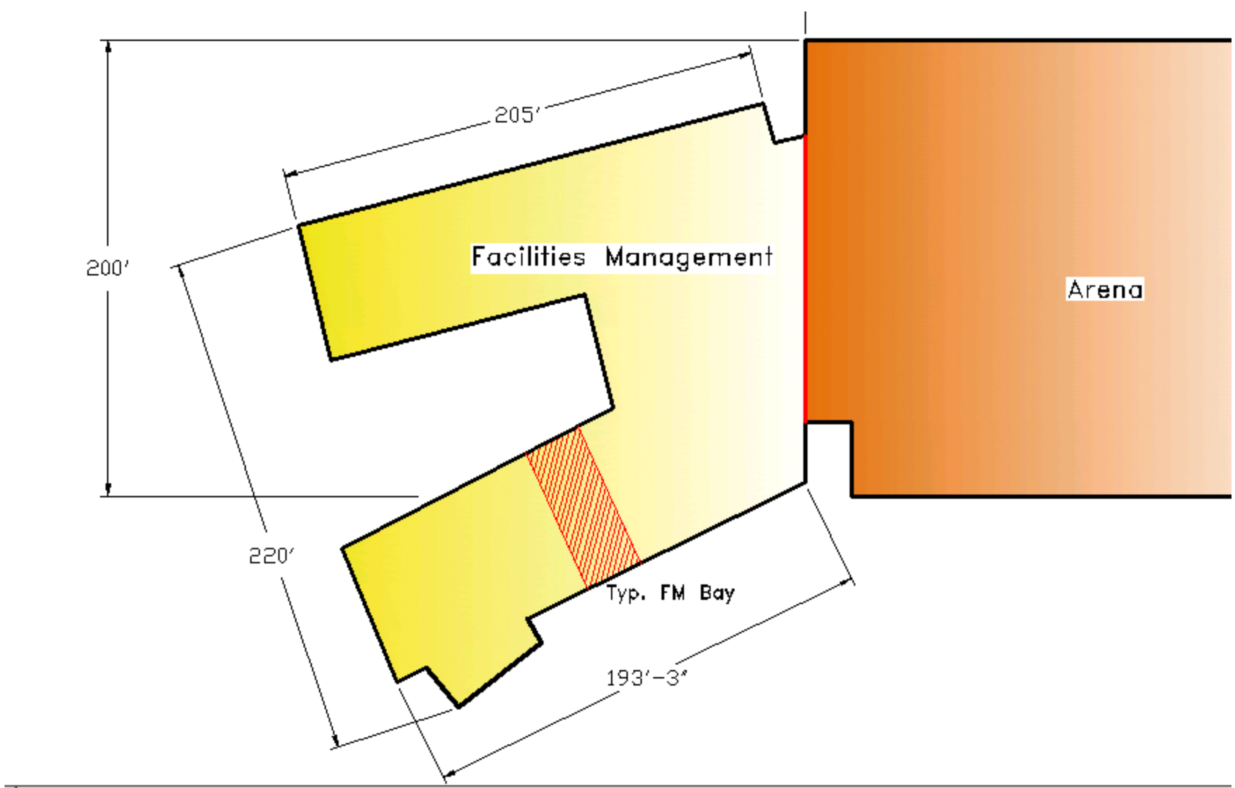


Figure 1 – Location of FM Typical Bay

Existing System: Composite Beam System

As mentioned above, the existing floor system is a composite beam and girder system. The bay analyzed is shown in Figures 1 and the result is shown in Figure 2 below. The loading in this area is standard and the spans are 25'8" and 34'2" in the N-S direction and 31' in the E-W direction.

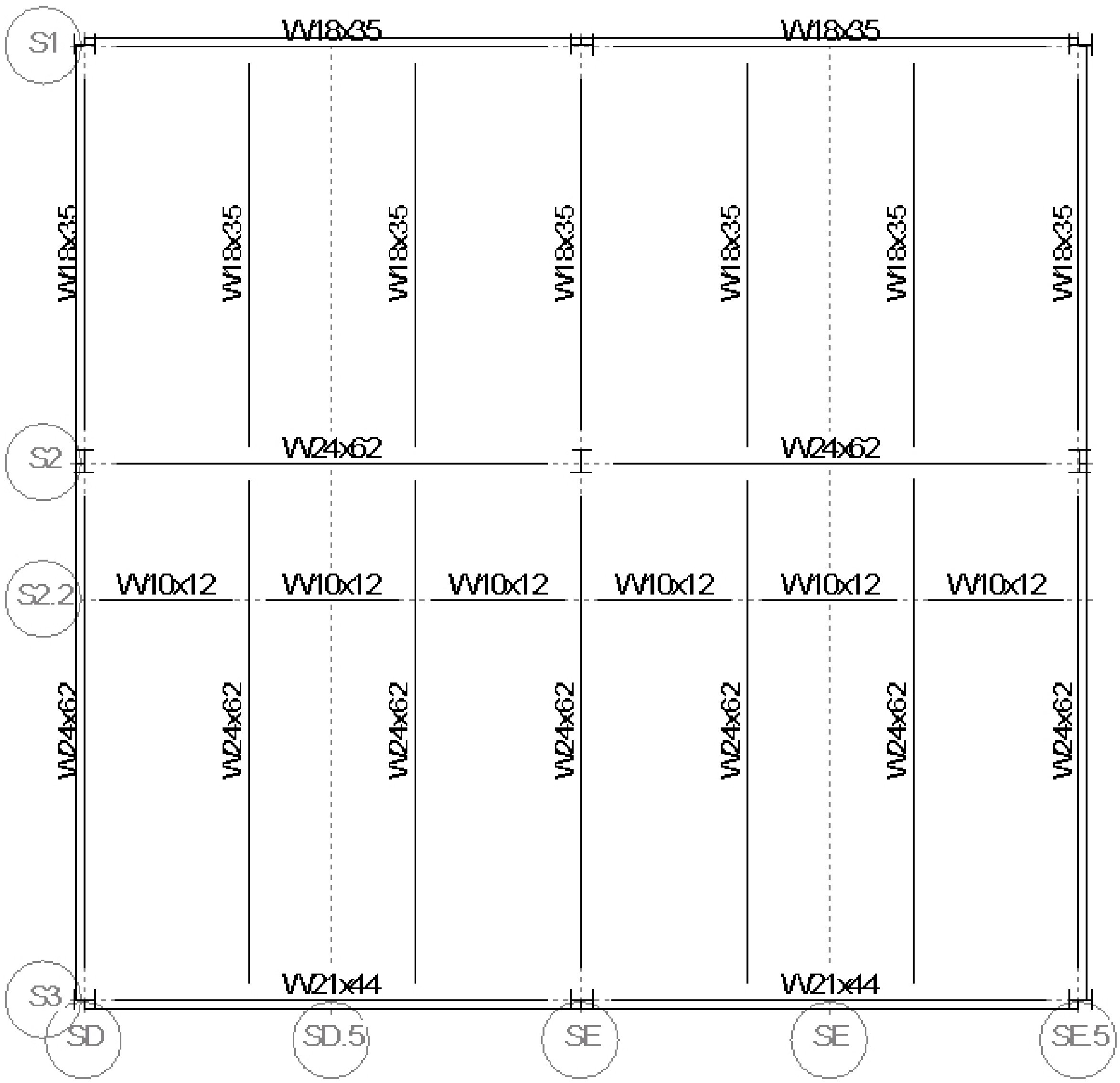


Figure 2 – FM Typical Bay

Alternative System 1: Composite Deck on Open-Web Steel Joists

The first alternative I explored was composite deck on open-web steel joists. The main advantage of this system is that it's light and relatively easy to install under the right circumstances. A drawback could be vibration or connection issues. The longer spans in the building also present a problem for joist construction. Longspan(LH) joists will have to be used, rather than cheaper K-series. This system most closely resembled the current system, so this investigation was done with the same basic grid but with joists spaced at 5'2" rather than beams at 10'. The 5'2" dimension was chosen to divide the 31' span evenly into 6 spaces. Initial analyses were done with RAM Structural System and then checked with hand calculations (see Appendix B). For the typical bay, 24LH09's were chosen for the 34'2" span, 18LH07's were chosen for the 25'8" span, and a typical interior girder was a W24x62(see Figure 3). An additional check for vibration is provided for the 24LH09's using design guide 11. For a full analysis of the system see Appendix B.

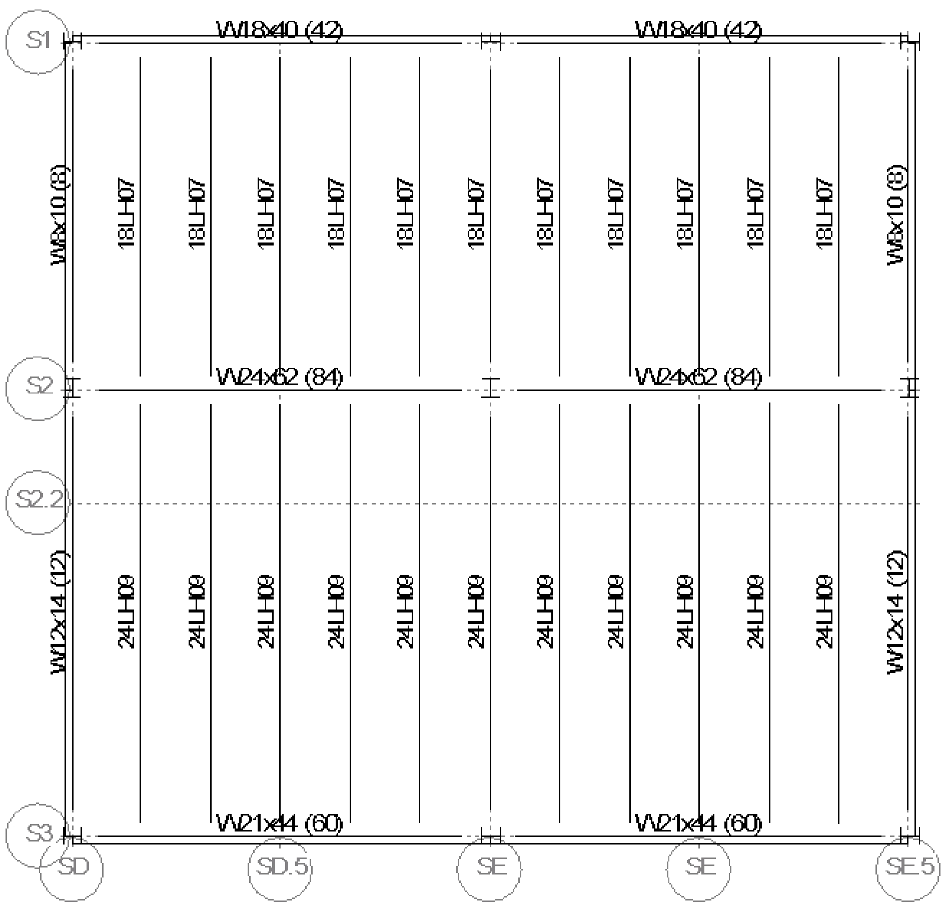


Figure 3 - Typical Composite Open-Web Joist Bay

Alternative System 2: Hollow-core precast plank on steel frame

The second system analyzed was a hollow-core precast plank on a steel frame. Precast members can be easily placed and avoids costly formwork the cast-in-place construction requires. This system is advantageous when spans and loadings are consistent, along with typical bay sizes. I carried my analysis out using the PCI Handbook-6th Edition. I chose a 2" NWC topping and kept the columns in the same location. I chose the provider Ultra Span when choosing particular members. A 12" hollow-core with 2" topping was required for the 33'2" span and to keep things consistent, a 12" hollow-core with 2" topping was chosen for the 25'8" span also. The only difference is the amount of stands in each precast member. The total depth of the system with supporting beams included was 41" which is a bit larger than the existing system, so adjustments would need to be made if this system was selected. A typical bay is shown in Figure 5, and Appendix B provides a complete analysis.

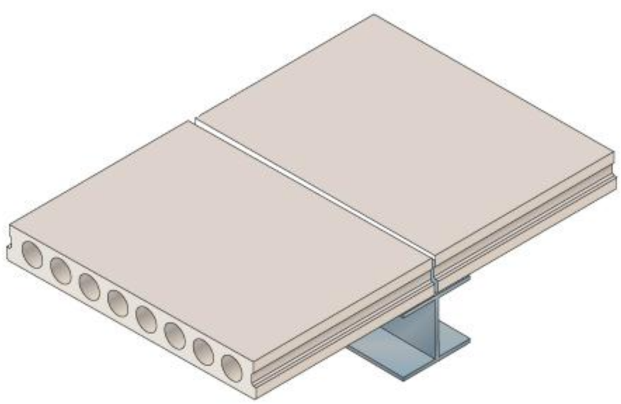


Figure 4 - Typical Hollow-core Precast Plank on Steel Frame

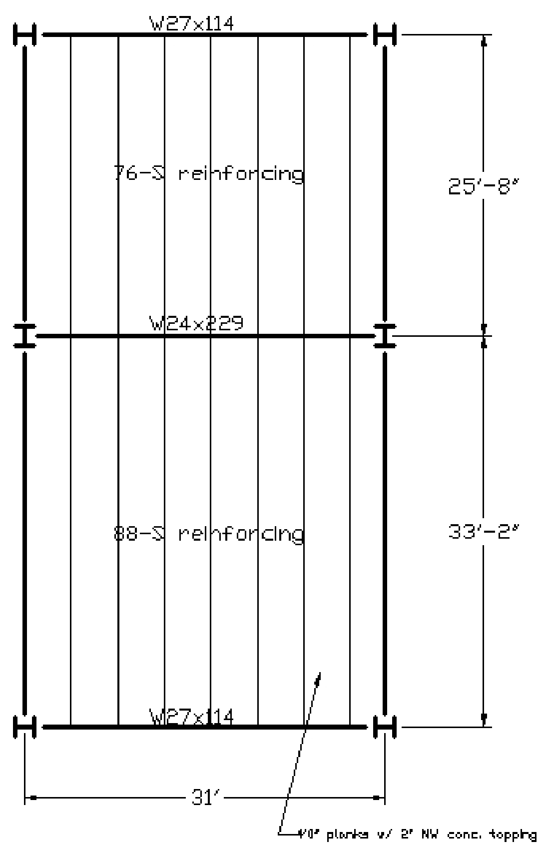


Figure 5 – Typical Hollow-core Precast Plank Bay

Alternative System 3: Flat Slab

The third alternative system I analyzed was the flat slab. I chose to run the analysis with both a flat slab system with drop panels and a waffle flat slab system. The analysis was done using the CRSI handbook-2002 Edition. There are areas with long spans in the Coppin State University Physical Education Complex, so the waffle slab system works better (see Figure 6). I simplified the analysis by using square bays, when in fact most of the bays are rectangular. I used a conservative approach by using the longer dimension as both dimensions. If this system shows feasibility, a further more in-depth approach would be needed. In additional to the capabilities of long spans, the waffle flat slab system does not require additional fireproofing, which could save money. The drawback is the formwork requirements. Especially at odd intersections and at changing loading conditions, the additional placement of formwork will be complex and costly. Figure 7 shows specifications for a typical bay in the facilities management area. See Appendix B for both of the flat slab systems analyses, calculations and details.

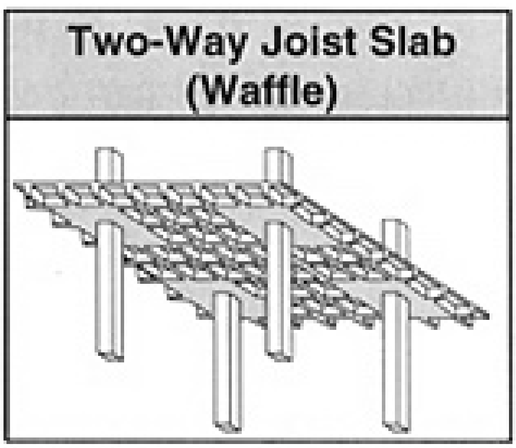


Figure 6 – Typical Waffle Flat Slab System

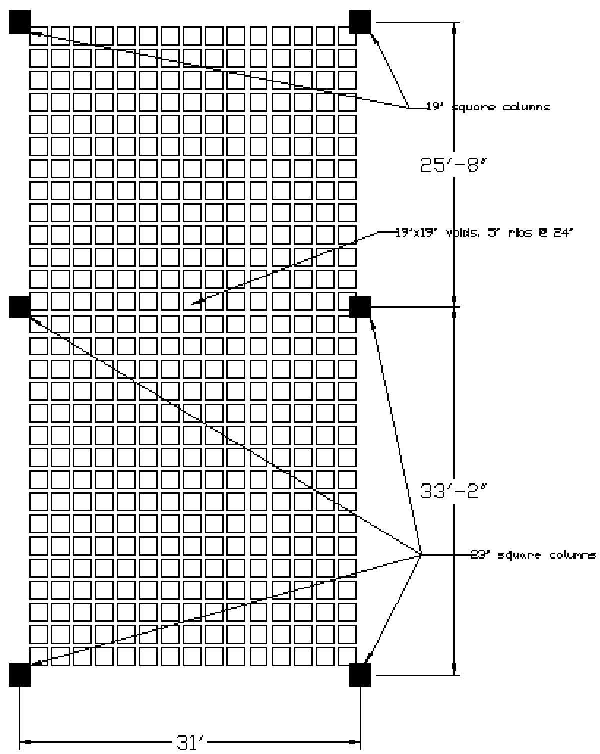


Figure 7 – Typical Waffle Flat Slab Bay – see Appendix B for reinforcement details

Alternative System 4: Girder-Slab System

The last alternative I chose to analyze was the Girder-Slab system. The depth of the existing system was average, so I decided to explore the possibilities of a small depth to see if it could have significant savings or merit further investigation. The main advantage of this system is its simplistic nature and minimal depth. The Girder-Slab system consists of an interior girder (known as a D-Beam) and precast hollow-core slabs connected with cementitious grout. Installation is fairly simple with typical spans. Contractors can simply place grout through web openings and into the slab cores and after curing develops composite action. For a complete guide of the uses and applications of Girder-Slab systems, see www.Girder-Slab.com. The section chose for my analysis was DB9x46 which is an 8" precast slab with 2" concrete topping. The details for this system can be seen in Figure 8, originally printed by www.Girder-Slab.com, and a typical bay can be seen in Figure 9. Specific D-Beam properties for DB9x46 are in Appendix B. A major drawback of the system is the permitted span. Spans over 30' are not frequently used in conjunction with heavy loads because of the deflection and/or section modulus becomes an issue. The fact that the Coppin State University Physical Education Complex has some large spans and typically 100psf live load does not make it an ideal candidate for the Girder-Slab system, but if column changes or architectural changes are permissible, the system could become viable.

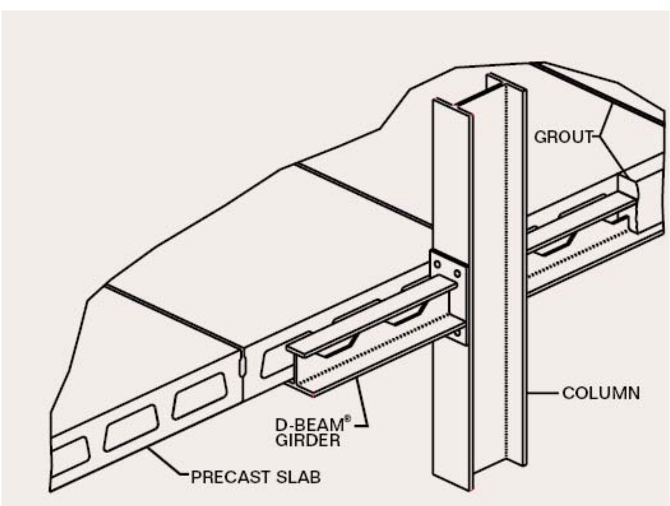


Figure 8 – Isometric View of Girder-Slab System

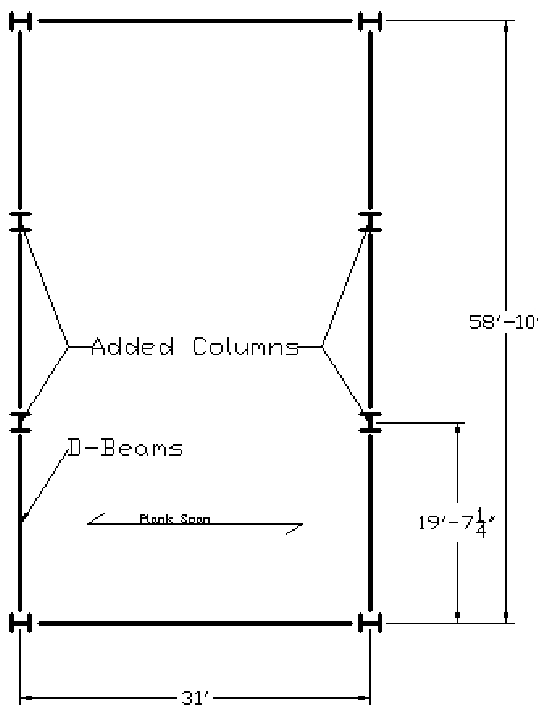


Figure 9 – Girder-Slab Typical Bay

Floor System Comparisons

Cost:

Cost is probably the most important factor in determining which system to use. Basic cost analysis can be taken from RSMeans catalogues, but it should be noted that these are just approximations. Many factors go into the overall cost, so it is important to consider everything that needs to be designed and built. These factors include connections, formwork, constructability, shoring needs, contractor issues, availability of materials, and many more. An assembly estimate, rather than detailed unit pricing works best for preliminary estimations.

I used the same criteria when evaluating every system. Since the bays in the facilities management area are typically 31'0"x25'8" and 31'0"x33'2", I chose an average 30'0"x30'0" for the analysis of all systems. I tried to keep the total load as close to each other as possible. The total load specified in the tables varied between 168psf and 204psf, so the comparisons are quite similar. The pricing information is as follows:

Existing composite system (TL=168psf)…………………………………………………….$20.05/s.f.
Alt. 1-Steel joists on conc. slab on steel columns and beams (TL=172psf)……….$21.55/s.f.
Alt. 2-Hollow-core precast plank w/2" topping(TL=180psf)……………….…………$13.08/s.f.
Alt. 3-Waffle Slab (TL=204psf)……………………………………………………………………$21.80/s.f.

The value for Alternative 4-Girder-Slab is not listed in RSMeans, but it can be assumed to be comparable to hollow-core or even a little cheaper. The best buy for typical square bays of 30' length seems to be hollow-core precast or girder-slab systems. This pricing only deals with typical bays however, and since the Coppin State University Physical Education Complex has many odd angles, differing loading conditions and column locations, the cost of these systems will rise dramatically. Of the three remaining systems, the best buy seems to be the existing composite system, but they are all relatively close.

Weight of Materials:

Dead load accounts for a large portion of the total load on any structure. The live load for the Coppin State University Physical Education Complex is high already at 100psf, but the dead load still carries importance. The existing system has 60psf dead load, but if other systems are used that value could increase dramatically. The flat slab system and hollow-core precast plank system both have extremely high material weights. This not only affects the floor system, but column sizes, foundation sizes and even seismic loads. Typical system weights are listed below. It should be noted that only system weights are shown, e.i. no superimposed loads are included.

Existing composite system…………………………………………………………………………...59psf
Alt. 1-Steel joists on conc. slab on steel columns and beams ……………………………49psf
Alt. 2-Hollow-core precast plank w/2" topping…………………..………………………..……171psf
Alt. 3-Waffle Slab……………………………………………………………………………….……….137psf
Alt. 4-Girder-Slab…………………………………………………………………………………………..85psf

This shows that the lightest systems, and therefore the smallest columns, foundation and seismic loads are found in the composite system and the steel joist system. The concrete systems are heavier, and thus the columns and foundation will be heavier and more expensive.

Construction Time:

Construction time was not a major issue for this project, but nevertheless it did play a role. This project is located on a college campus which already has a physical education complex, albeit one that's not in the greatest shape, but it is functional. Excavation for this project just began in September of 2007 and the building is due to open in 2009, so it has obviously not been fast-tracked. There will not be much revenue coming from the building, so having it functional earlier does not help on that regard, however students on the campus would appreciate having it open as soon as possible. Composite steel typically takes longer because of the small detailed steel fabrication drawings and erection time. Additionally, scheduling issues can arise because of the longer time period. Precast is typically good with timing issues because the members can be easily designed and dropped into a building relatively easy if the bays are alike and the manufacturer is somewhat close. The Girder-Slab system is also good with timing issues, but the problem that arises is that because it is a relatively new system, experienced contractors might be hard to find. The process seems easy enough on the website, but problems could still arise. Cast-in-place systems would be faster in a high-rise situation where the formwork can be reused over and over again, but with the atypical bays and odd angles, it might not save that much time in the field.

Constructability:

Any experienced contractor should be able to build and install any of the systems designed. Steel erection, especially with detailed connections could take additional time, but laying a lot of formwork and rebar could take a long time as well. The precast panels and girder-slab systems could be very tough to install because of all the odd angles in the building.

Vibration:

Vibration is typically a problem with steel systems, with either W-shapes or joists. Joists typically suffer more from vibration problems because they are very light. Typically vibration problems arise from large spans in conjunction with heavy or dynamic loads. Unfortunately because this is a physical education complex, dynamic loads are abundant. There is a dance floor on the second floor that could cause problems. There are the basketball and racquetball courts that could cause problems. Also there is a high probability for bouncing balls or people running in the corridors. These issues are currently addressed with the aid of many interior masonry walls, but if switching to a lighter system, the masonry walls could fall short of providing adequate dampening. A typical steel joist bay is analyzed in Appendix B. The analysis does not address the masonry walls. Vibration is typically not an issue with a concrete flooring system, so the flat slab, hollow-core, or Girder-Slab are better in this regard.

Fireproofing:

The concrete waffle slab system requires no additional work relating to fireproofing. The rest of the systems have exposed steel that must be dealt with. According to code, a 2 hour rating is required at all major sections, except the roof ceiling assembly (1 hour). Spray-on fire protection is required for the 4 systems that have exposed steel. The toughest to coat would probably be the composite steel or composite joist systems because they have the most steel, and the joists have many small tendons.

Lateral System Changes:

The current lateral system is composed of moment frames and braced frames. The members used are W-shapes and HSS members. In order to use some of the other systems analyzed, the lateral system would need to be either modified or completely redesigned. The steel joist system could manage with just a modification to areas where joists are used instead of beams. The concrete floor systems would need to be redesigned to incorporate either a core system, which would be difficult since the structure is subdivided into 4 buildings, or utilize a series of shear walls. Braced frames and moment frames seem to be the best solution for a lateral system on a short, sprawling building.

Architectural Changes:

Even though there are some long span conditions with the Coppin State University Physical Education Complex, most of the alternative systems can work with the existing column grid. The only system that presents a problem is the Girder-Slab system. This system works best with shorter spans and since there is 100psf live load throughout the building, the existing spans will not work with this system. This has an extreme impact on architectural features, because the new columns fall in usable and planned space.

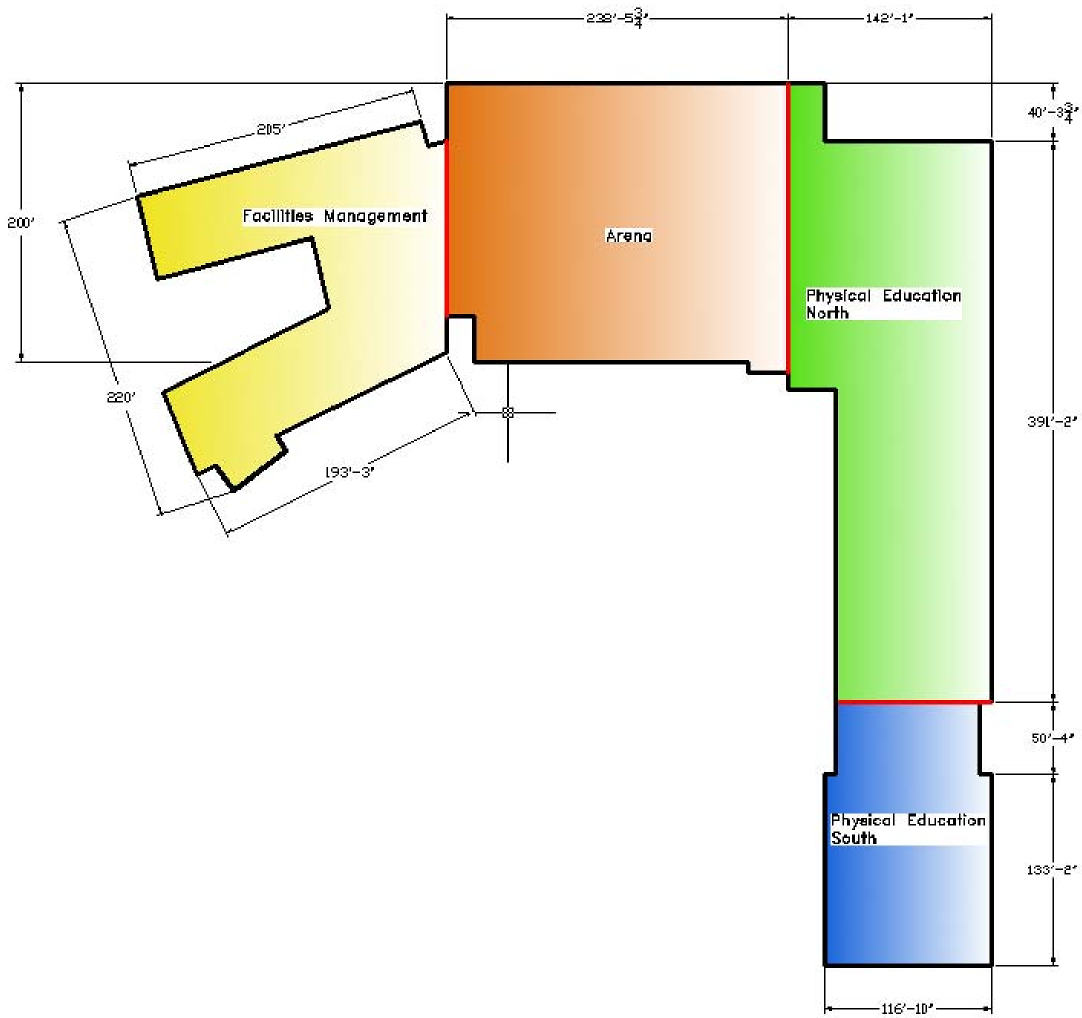
Comparison Summary

Cost is the most important consideration when selecting a flooring system, but several other factors also need to be considered. The building is an odd shape, (see Appendix A) so constructability is a concern for this project. With the existing system of composite beams and girders, an issue that must be dealt with is the construction of some of the difficult connections at the odd intersection areas. Larger girders that lie in some of the intersecting areas help in this by giving a firm place to weld or bolt into, however the beams still must be cut and placed accurately. This was a key issue to be dealt with any alternative system. After comparing and contrasting each system to the existing system, several observations were made. All the analyzed systems have their advantages and their drawbacks. Simply looking at cost projections from RSMeans will not give an accurate reading; other factors must be considered. The building has many odd angles and projections along with differing loading conditions which plays an important role in selecting a system. For this reason, the first systems eliminated were the Girder-Slab system and Hollow-core precast plank system. Construction would be too difficult and the savings from RSMeans would quickly be evaporated in this process. The steel joist system seems like a viable alternative because it is lighter and less deep; however the possible vibrations issues and connection details could be very troublesome. Savings made by selecting this cheaper, lighter system will probably be dissolved in extra vibration control equipment or connection materials. The flat slab system seems like the best alternative of the four alternatives analyzed. The system can probably be designed and implemented in the building, however the cost of placing rebar and formwork, especially at odd connections and angles would be difficult. The system is also heavier, so larger columns will need to be used and the foundation will need to be looked at. Everything considered, the existing composite steel system seems to be the best option for the Coppin State University Physical Education Complex. A benefit to using this system is the flexibility of changing beam and girder size with relatively low additional construction costs compared to the formwork required for differing slab thicknesses and column capitals in a concrete structure. The overall depth of the current system is 30" in this bay due to large W24's making up girder members. The depth was not a major factor since the building is only a few stories high, so changing the floor system to try and squeeze in an extra floor would not be possible or desirable for the buildings use. Additional fireproofing will be needed for the exposed steel, but the cost of the fireproofing is minimal with respect to the total cost of the building. A spreadsheet comparing the 5 systems is shown below.

Floor System Comparison					
System	Existing Composite	Girder Slab	Open-web Steel Joists	Flat Slab (Waffle Slab)	Hollow-core Precast Planks
Cost	$20.05/s.f.	Not Available	$21.55/s.f.	$21.80/s.f.	$13.08/s.f.
Depth of System	30"	10"	24"	14.5"	41"
Weight of Materials	59psf	85psf	49psf	137psf	171psf
Construction Time	Long	Short	Long	Short	Short
Constructability	Easy	Easy	Easy	Hard	Easy
Vibration	Average	Average	Poor	Good	Good
Fireproofing	Additional Materials Req'd	Additional Materials Req'd	Additional Materials Req'd	None	Additional Materials Req'd
Lateral System	Moment/ Braced Frames	Moment/ Braced Frames	Moment/ Braced Frames	Shear Walls/ Core	Shear Walls/ Core
Other Engineering Issues	Difficult Connections	Longs Spans, Atypical bays	Difficult Connections	Formwork, Rebar Issues	Atypical Bays, Splicing
Architectural Changes	None	Additional Columns Req'd	None	None	None
Feasible Solution	Yes	No	No	Maybe	No

Appendix A

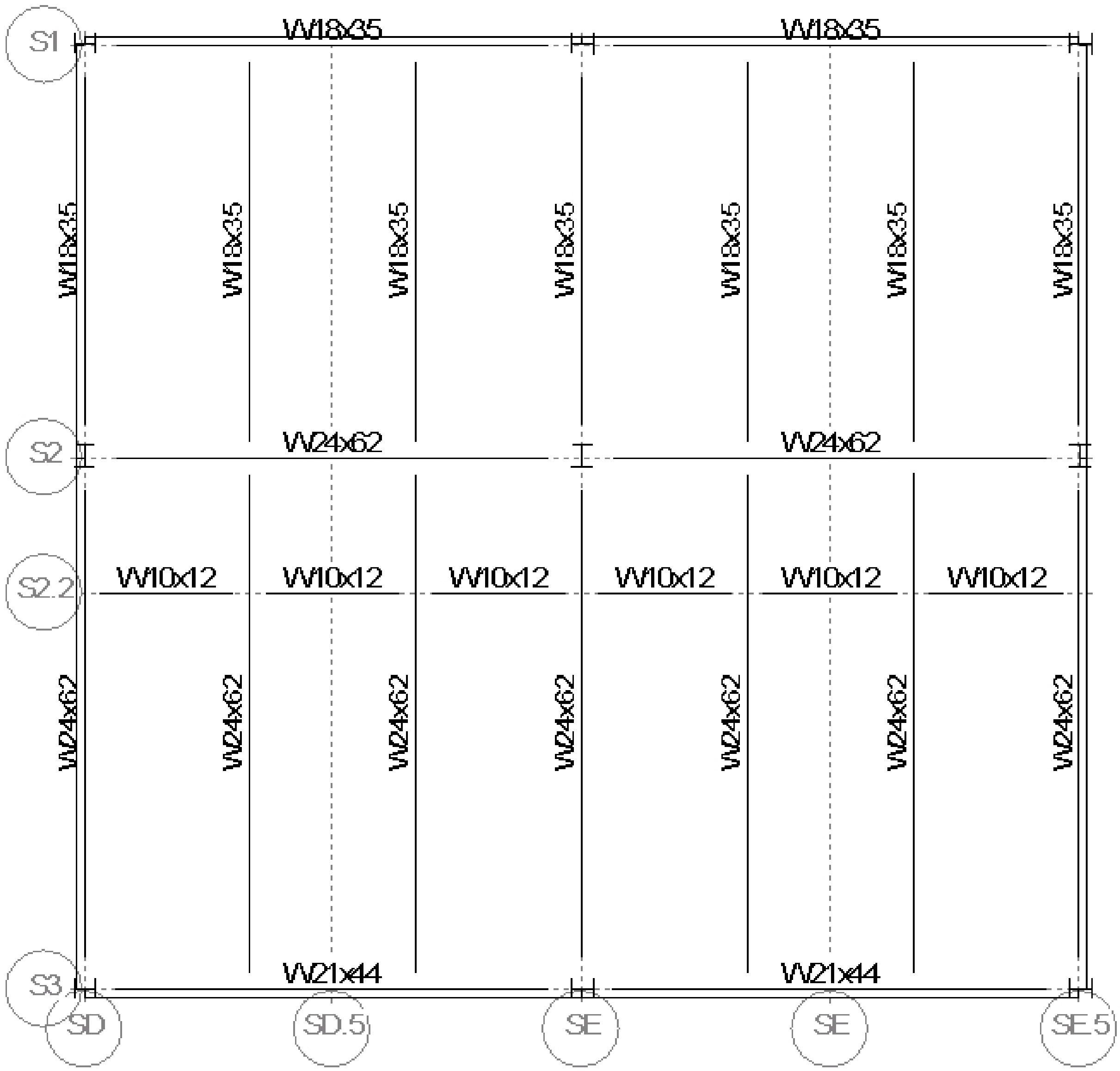
General Floorplan:



*Expansion joints shown in red

Appendix B

Existing System: Composite Beam System



Alternate System 1: Composite Deck on Open-web Steel Joists

Alternative System #1 - Composite Deck on open-web Steel Joists

Standard Floor Loads

DL = 60 psf assumed

LL = 100 psf (non-reducible)

Load Combination

$w_u = 1.2D + 1.6L = 232\text{ psf}$

spans = 25'8", 33'2"

try 5'2" spacing, 3.25" conc. topping

1.5" Lok-Flooring → see USD Catalog ⇒ total conc = 4.75"

22 Ga → 2 span max unshored length = 6.39' for 4.75" depth
3 span max unshored length = 6.47' for 4.75" depth

max service LL = 400 psf > 100 psf ok for 4.75" depth

wt = 37 psf + 10 psf superimposed = 47 psf

$w_T = 1.2(47) + 1.6(100) = 216.4\text{ psf} \times 5'2" = 1118\text{ plf}$
↑ for even spacing for 31'0" span

unfactored → $w_L = 100(5.166) = 516.6\text{ plf}$

33'2" span 24LH09 TL = 1212 (@ 33') > 1118 ok
LL = 530 > 517 ok

use 24LH09 for 33'2' span

25'8" span 18LH08 TL = 1264 (@ 26') > 1118 ok
LL = 534 (@ 26') > 517 ok

use 18LH08 for 25'8" span

Floor Map

RAM Steel v11.0
DataBase: Bay Analysis joists2
Building Code: IBC

12/03/07 14:42:55
Steel Code: ASD 9th Ed.

Floor Type: FLOOR

Beam Summary

RAM Steel v11.0
DataBase: Bay Analysis joists2
Building Code: IBC

12/03/07 14:42:55
Steel Code: ASD 9th Ed.

STEEL BEAM DESIGN SUMMARY:

Floor Type: FLOOR

Bm #	Length ft	+M kip-ft	-M kip-ft	Seff in3	Fy ksi	Beam Size	Studs
1	33.17	69.8	0.0	26.8	50.0	W12X14	12
11	31.00	360.7	0.0	133.0	50.0	W21X44	60
2	25.67	41.5	0.0	15.9	50.0	W8X10	8
8	31.00	572.9	0.0	210.6	50.0	W24X62	84
3	31.00	288.1	0.0	106.8	50.0	W18X40	42
18	31.00	360.7	0.0	133.0	50.0	W21X44	60
19	31.00	572.9	0.0	210.6	50.0	W24X62	84
15	31.00	288.1	0.0	106.8	50.0	W18X40	42
16	33.17	69.8	0.0	26.8	50.0	W12X14	12
17	25.67	41.5	0.0	15.9	50.0	W8X10	8

* after Size denotes beam failed stress/capacity criteria.
# after Size denotes beam failed deflection criteria.
u after Size denotes this size has been assigned by the User.

Beam Summary

RAM Steel v11.0
DataBase: Bay Analysis joists2
Building Code: IBC

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12/03/07 14:42:55
Steel Code: ASD 9th Ed.

JOIST SELECTION SUMMARY:

Floor Type: FLOOR

Standard Joists:

Joist #	Length	WDL	WLL	WTL	Joist
34	33.17	310.0	516.7	826.7	24LH09
39	25.67	310.0	516.7	826.7	18LH07
35	33.17	310.0	516.7	826.7	24LH09
40	25.67	310.0	516.7	826.7	18LH07
36	33.17	310.0	516.7	826.7	24LH09
41	25.67	310.0	516.7	826.7	18LH07
37	33.17	310.0	516.7	826.7	24LH09
42	25.67	310.0	516.7	826.7	18LH07
38	33.17	310.0	516.7	826.7	24LH09
43	25.67	310.0	516.7	826.7	18LH07
55	33.17	310.0	516.7	826.7	24LH09
54	25.67	310.0	516.7	826.7	18LH07
49	33.17	310.0	516.7	826.7	24LH09
44	25.67	310.0	516.7	826.7	18LH07
50	33.17	310.0	516.7	826.7	24LH09
45	25.67	310.0	516.7	826.7	18LH07
51	33.17	310.0	516.7	826.7	24LH09
46	25.67	310.0	516.7	826.7	18LH07
52	33.17	310.0	516.7	826.7	24LH09
47	25.67	310.0	516.7	826.7	18LH07
53	33.17	310.0	516.7	826.7	24LH09
48	25.67	310.0	516.7	826.7	18LH07

* after Size denotes joist is inadequate.
u after Size denotes this size has been assigned by the User.

Beam Deflection Summary

RAM Steel v11.0
DataBase: Bay Analysis joists2
Building Code: IBC

12/03/07 14:42:55
Steel Code: ASD 9th Ed.

STEEL BEAM DEFLECTION SUMMARY:

Floor Type: FLOOR

Composite / Unshored

Bm #	Beam Size	Initial in	PostLive in	PostTotal in	NetTotal in	Camber in
1	W12X14	0.150	0.933	1.493	1.643	
11	W21X44	0.038	0.501	0.869	0.907	
2	W8X10	0.110	0.724	1.158	1.268	
8	W24X62	0.029	0.462	0.740	0.769	
3	W18X40	0.047	0.563	0.998	1.045	
18	W21X44	0.038	0.501	0.869	0.907	
19	W24X62	0.029	0.462	0.740	0.769	
15	W18X40	0.047	0.563	0.998	1.045	
16	W12X14	0.150	0.933	1.493	1.643	
17	W8X10	0.110	0.724	1.158	1.268	

Beam Deflection Summary

RAM Steel v11.0
DataBase: Bay Analysis joists2

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12/03/07 14:42:55

STEEL JOIST DEFLECTION SUMMARY:

Floor Type: FLOOR

Standard Joists

Bm #	Beam Size	Dead in	Live in	Total in
34	24LH09	0.591	0.985	1.577
39	18LH07	0.479	0.799	1.279
35	24LH09	0.591	0.985	1.577
40	18LH07	0.479	0.799	1.279
36	24LH09	0.591	0.985	1.577
41	18LH07	0.479	0.799	1.279
37	24LH09	0.591	0.985	1.577
42	18LH07	0.479	0.799	1.279
38	24LH09	0.591	0.985	1.577
43	18LH07	0.479	0.799	1.279
55	24LH09	0.591	0.985	1.577
54	18LH07	0.479	0.799	1.279
49	24LH09	0.591	0.985	1.577
44	18LH07	0.479	0.799	1.279
50	24LH09	0.591	0.985	1.577
45	18LH07	0.479	0.799	1.279
51	24LH09	0.591	0.985	1.577
46	18LH07	0.479	0.799	1.279
52	24LH09	0.591	0.985	1.577
47	18LH07	0.479	0.799	1.279
53	24LH09	0.591	0.985	1.577
48	18LH07	0.479	0.799	1.279

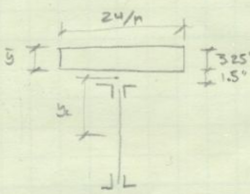
Evaluation of walking vibrations

$M_{all} = \frac{wL_n^2}{8} = \frac{1118(33'2")^2}{8} \sim 153.7'^{k}$

$A_{bot} = \frac{M_{all}}{(d-1.5)(f_{all})} = \frac{153.7(12)}{(24-1.5)(50)} \sim 1.64 in^2$

$A_{top} \sim 1.25 A_{bot} \sim 2.05 in^2$

$A_{chord} \sim 3.69 in^2$



$y_c = 0.75" + \frac{A_{bot}(d-1.5")}{A_{chord}} = 10.75"$

$I_{chord} = A_{top}(y_c - .75)^2 + A_{bot}(d - y_c - .75)^2 = 461.3 in^4$

$n = \frac{E_s}{1.35 E_c} = \frac{29000}{1.35(110^{1.5}\sqrt{3.5})} = 9.95$

$\bar{y} = \frac{\Sigma A y}{\Sigma A} = \frac{(24/9.95)(3.35)(\frac{3.35}{2}) + 3.69(4.75+10.75)}{\frac{24}{9.95}(3.35) + 3.69} = 6"$

$I_{comp} = \Sigma I + \Sigma A d^2 = \frac{24/9.95\,(3.25)^3}{12} + 461.3 + 24/9.95(3.25)(6 - \frac{3.25}{2})^2$

$+ 3.69(10.75 + 4.75 - 6)^2 = 847.4 in^4$

$\frac{L}{d} = \frac{34'2"(12)}{24} = 17'1" < 24$ ok

$C_r = 0.9(1 - e^{-0.28(17'1")})^{2.8} = 0.88$

$\gamma = \frac{1}{0.88} - 1 = 0.138$

$I_j = \frac{1}{\frac{0.138}{461.3} + \frac{1}{847.4}} = 676.5 in^4$

$w_j = 5'2'' \,(\overset{DL}{52} + \overset{LL}{11}) + \overset{self}{21} = 347 \text{ plf}$

$\Delta_j = \dfrac{5 w_j L_j^4}{384 E I_j} = 0.313 \text{ in}$

$w_j = 347 / 5'2'' = 67.1 \text{ psf}$

$D_s = \dfrac{12 d_e^3}{12 n} = \dfrac{12(4)^3}{12(9.95)} = 6.81$

$D_j = I_j / s = \dfrac{676.5}{5'2''} = 130.9$

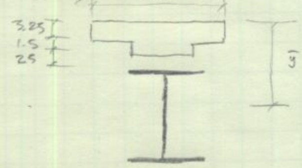
$B_j = C_j (D_s / D_j)^{.25} L_j = 2(6.81/130.9)^{.25}(34'2'') = 32.6'$

$W_j = w_j B_j L_j = 67.1(32.6)(34.16) = 74800 \text{ lbs.}$

Find I_g

Girder W24×55 (40)

$b/n = .4(34'2'')(12) = 164$



$$\bar{y} = \frac{\Sigma A y}{\Sigma A} = \frac{\left[164/9.95\,(3.25) + 164/9.95\,(\tfrac{1.5}{2})\right] 2.375 + 16.2(7.25 + \tfrac{23.6}{2})}{\tfrac{164}{9.95}(3.25) + \tfrac{164}{9.95}(1.5/2) + 16.2}$$

$\bar{y} = 5.66$

$$I_{comp} = \Sigma I + \Sigma A d^2 = \frac{\frac{164}{9.95}(3.25)^3}{12} + \frac{\frac{164}{9.95(2)}(1.5)^2}{12} + 1350$$

$$+ \left(\frac{164}{9.95}\right)(3.25)(5.66 - 1.625)^2 + \frac{164}{9.95(2)}(1.5)(5.66 - 4)^2$$

$$+ 16.2(7.25 + \tfrac{23.6}{2} - 5.66)^2 = 5210 \text{ in}^4$$

$I_g = I_{nc} + (I_{comp} - I_{nc})/4 = 1350 + \dfrac{(5210 - 1350)}{4} = 2315 \text{ in}^4$

Find Δ_g

$w_g = \dfrac{347}{5'2''}(34'2'') + 55 = 2348 \text{ plf}$

$\Delta_g = \dfrac{5 w_g L_g^4}{384 E I_g} = 1.25'' \left(\dfrac{L_s}{B_j}\right) = 1.18''$

W_g calc

$w_g = 2340/5'2" = 37.9$ psf

$D_j = I_j / s = 131$

$D_g = I_g / L_j = 67.8$

$B_g = 1.6 (D_j / D_g)^{.25} L_g = 64.4'$

$W_g = w_g B_g L_g = 75605^{\#}$

$$W = \frac{\Delta_j}{\Delta_j + \Delta_g} W_j + \frac{\Delta_g}{\Delta_j + \Delta_g} W_g = 75436^{\#}$$

$$f_n = 0.18 \sqrt{\frac{g}{\Delta_j + \Delta_g}} = 0.18 \sqrt{\frac{386.4}{.313 + 1.18}} = 2.90 \text{ Hz}$$

↑ girder >> joist ⇒ problematic

Evaluation

$P_o = 65$ lbs - offices
$\beta = 0.03$

$a_o / g = 0.005g$

$$\frac{a_p}{g} = \frac{P_o e^{-0.35 f_n}}{\beta W} = \frac{65 e^{-.35(2.90)}}{0.03(75436)} = 0.0104$$

$\frac{a_o}{g} = 0.005 < 0.0104$ Not Good For Vibrations

Conclusions:

Δ_g seems to be the problem - girder size should be increased to limit Δ_g. A thicker slab would also help. Often this is hard to achieve, matching girders with joists. The spans of the system seem to present a problem. Spans over 30' are tough to design for vibrations, especially w/ joists.

Alternative System 2: Hollow-core Precast Plank on Steel Frame

Alternate System #2 – Hollow-core precast plank on steel frame

Standard Floor Loads

DL = 60 psf

LL = 100 psf (non-reducible)

Load Combination

Service Load = 160 psf

Spans = 25'8", 33'2"

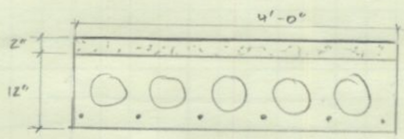
Using PCI handbook – 6th Edition for 33'2" span ⇒ use 33'

12" Hollow-core w/ 2" NWC topping

$f'_c = 5000$ psi
$f_{pu} = 270{,}000$ psi

88-S

allowable service load = 161 psf > 160 ok



Using Ultra Span ⇒ $y_b = 7.43"$ I = 8195 in⁴ wt = 100 psf

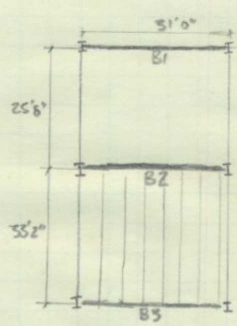
Using PCI handbook – 6th Edition for 25'8" span ⇒ use 26'

for continuity stick w/ 12" hollowcore

12" Hollow-core w/ 2" NWC topping

76-S

allowable service load = 196 psf > 160 ok



check deflections for support beams

$W_u = 1.2D + 1.6L = 1.2(60+100) + 1.6(100) = 352$ psf

middle beam (B2)

$w = 352\left(\frac{33'2" + 25'8"}{2}\right) = 10.35^{KLF}$

worst-case span = 31'

$\Delta \le L/360 = \frac{31(12)}{360} = 1.03"$

$I_{req} = \frac{5(10.35)(31)^4(1728)}{384(29000)(1.03)} = 7203 \text{ in}^4$

$M_u = \frac{wl^2}{8} = \frac{10.35(31)^2}{8} = 1243'^k$

$V_u = \frac{wl}{2} = \frac{10.35(31)}{2} = 160.4^k$

try W36×135 I = 7800

$\phi M_n = 1910'^k > 1243'^k$ ok

$\phi V_n = 576^k > 160.4^k$ ok — W24×229 also works

Use W24×229 as middle beam (B2) (to save 12" vertically)

check end beams (B1 & B3)

worst-case = B3 — keep both same for continuity

$w = 352\left(\frac{33'2"}{2}\right) = 5.84^{KLF}$

$I_{req} = \frac{5(5.84)(31)^4(1728)}{384(29000)(1.03)} = 4064 \text{ in}^4$

$M_u = \frac{5.84(31)^2}{8} = 702'^k$

$V_u = \frac{5.84(31)}{2} = 90.5^k$

try W27×114 I = 4080 in⁴

$\phi M_n = 1290'^k > 702'^k$ ok

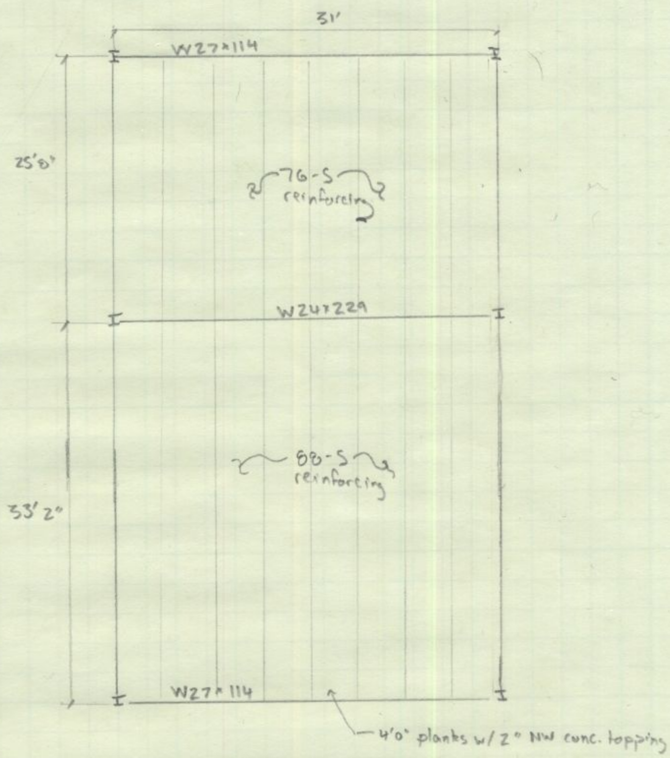
$\phi V_n = 467^k > 90.5$ ok

Use W27×114 as end beams

Use 4'0" x 12" planks w/ 2" NW concrete topping
w/ W24 x 229 as middle beams and W27 x 114 as end beams

Total System weight = $100 + \dfrac{\left[\left[229 + 114(2)\right] \times 31\right]}{58'10" \times 31'}$ = **171 psf**

Total System depth = 12" + 2" + 27" = **41"**



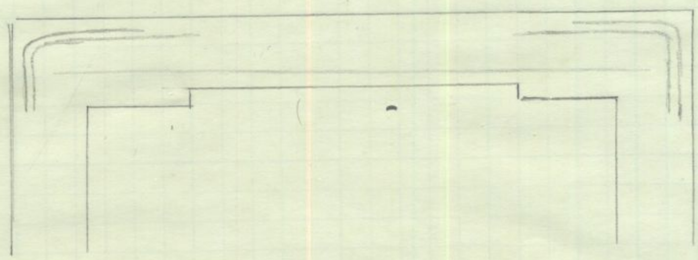
Layout

Existing System 3: Flat Slab (Waffle Slab Chosen)

Alternative System #3a - Flat Slab System w/ Drop Panels

\# Use a conservative Superimposed DL ⇒ 7 psf Mechanical
10 psf partitions
3 psf unaccounted wt
20 psf

SDL = 20 psf
LL = 100 psf (non reducible)
DL = 60 psf + 10 psf = 70 psf



check $\frac{l}{l_2} < 2$ $\frac{31'}{24'8"} = 1.26 < 2$ ok

$\frac{34'2"}{31'} = 1.10 < 2$ ok

2-way system ok

Use f'_c = 4000 psi concrete NW w = 150 pcf

Using CRSI handbook - 2002 edition

Factored Superimposed Load =

w = 1.2(20) + 1.6(100) = 184 psf Both bays are edge bays

⇒ For 31'-0" x 34'-2" bay ⇒ use square bay 34' x 34' for analysis (edge bay)

use flat slab 12" deep

Drop Panel: 11'4" x 11'4", depth = 11"
Edge Panel: f'_c = 4000 psi, f_y = 60 ksi
Column: 17" x 17"

Reinforcing Bars: Column Strip: Top Ex - 17 #5
Bottom - 14 #9
Top Int - 18 #7
Middle Strip: Bottom - 12 #8
Top - 13 #7

Total Steel ~ 4.83 psf
Total depth ~ 23'4"

⇒ For 31'-0" × 24'8" ⇒ use square bay 31' × 31' for simplified analysis

Edge Panel: factored load = 200 > 184 ok   f'c = 4000psi fy = 60ksi

→ use flat slab 12" deep (for conformity

Drop Panel: 10'4" × 10'4", 9" deep

Column: 16" × 16"

Reinforcing Bars: Column Strip: Top Ext: 14 #5
Bottom: 15 #8
Top Int: 15 #7

Middle Strip: Bottom: 11 #7
Top: 13 #6

Total Steel: 3.96 psf
Total depth: 22'4"

f'_c = 4,000 psi
Grade 60 Bars

FLAT SLAB SYSTEM

SQUARE EDGE PANEL — With Drop Panels — No Beams

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	(3) Square Column Size (in.)	γ_f	Reinforcing Bars (E. W.) Column Strip (1) Top Ext. +	Column Strip Bottom	Column Strip Top Int.	Middle Strip Bottom	Middle Strip Top Int.	Total Steel (psf)	Moments Edge (-) (ft-k)	Bot. (+) (ft-k)	Int. (-) (ft-k)
h = 12 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS														
30	100	7.00	10.00	12	0.886	14-#5 3	12-#7	16-#6	15-#5	13-#5	3.10	257.4	514.8	683.0
30	200	9.00	10.00	16	0.787	14-#5 3	15-#7	18-#6	10-#7	11-#6	3.65	329.4	658.8	886.8
30	300	9.00	10.00	19	0.763	15-#5 5	12-#9	22-#6	12-#7	19-#5	4.62	401.5	803.1	1081.0
30	400	11.00	10.00	21	0.661	16-#5 3	17-#8	14-#8	11-#8	12-#7	5.27	473.2	946.3	1273.9
30	500	11.00	12.00	24	0.766	19-#5 6	13-#10	16-#8	13-#8	11-#6	6.20	545.2	1090.4	1467.9
31	100	9.00	10.33	12	0.729	14-#5 2	13-#7	16-#6	16-#5	14-#5	3.12	285.7	571.4	769.2
31	200	9.00	10.33	16	0.766	14-#5 5	13-#8	15-#7	11-#7	13-#6	3.96	364.7	729.3	981.8
31	300	11.00	10.33	19	0.683	15-#5 4	13-#9	16-#7	18-#6	15-#6	4.76	444.4	888.7	1196.4
31	400	11.00	10.33	22	0.749	18-#5 6	19-#8	15-#8	16-#7	18-#6	5.68	522.9	1045.8	1407.8
31	500	11.00	12.40	27	0.755	15-#6 4	16-#9	14-#9	12-#9	12-#8	6.78	599.3	1198.5	1613.4
32	100	9.00	10.67	12	0.794	15-#5 5	11-#8	17-#6	13-#6	15-#5	3.33	314.9	629.9	847.9
32	200	11.00	10.67	16	0.640	15-#5 2	12-#9	15-#7	13-#7	19-#5	4.27	403.4	806.8	1086.1
32	300	11.00	10.67	19	0.757	17-#5 6	18-#8	18-#7	12-#8	13-#7	5.16	490.7	981.3	1321.0
32	400	11.00	12.80	25	0.729	20-#5 5	14-#10	16-#8	11-#9	12-#8	6.21	575.3	1150.7	1549.0
32	500	11.00	12.80	30	0.718	16-#6 4	16-#10	15-#9	13-#9	13-#8	7.14	651.1	1302.2	1752.9
33	100	11.00	11.00	12	0.678	15-#5 1	16-#7	17-#6	14-#6	12-#6	3.44	347.3	694.7	905.1
33	200	11.00	11.00	16	0.743	15-#5 5	13-#9	16-#7	18-#6	15-#6	4.45	443.7	887.5	1194.7
33	300	11.00	11.00	21	0.747	19-#5 5	13-#10	15-#8	22-#6	11-#8	5.56	537.1	1074.2	1446.0
33	400	11.00	13.20	28	0.721	22-#5 6	15-#10	18-#8	12-#9	16-#7	6.55	628.5	1257.0	1682.2
33	500	11.00	13.20	33	0.680	17-#6 3	17-#10	16-#9	11-#10	14-#8	7.47	705.8	1411.6	1900.3
34	100	11.00	11.33	12	0.752	16-#5 4	14-#8	19-#6	12-#7	13-#6	3.74	380.6	761.2	1024.7
34	200	11.00	11.33	17	0.757	17-#5 6	14-#9	18-#7	12-#8	13-#7	4.83	485.4	970.8	1306.8
34	300	11.00	11.33	24	0.699	20-#5 4	17-#9	17-#8	14-#8	12-#8	5.88	584.8	1169.6	1574.5
34	400	11.00	13.60	30	0.700	17-#6 3	17-#10	19-#8	13-#9	14-#8	7.00	681.2	1362.3	1833.9
35	100	11.00	11.67	12	0.795	16-#5 6	12-#9	16-#7	13-#7	14-#6	3.95	415.9	831.9	1119.8
35	200	11.00	11.67	19	0.752	18-#5 6	19-#8	16-#8	16-#7	18-#6	4.98	528.2	1056.4	1422.1
35	300	11.00	11.67	26	0.715	22-#5 6	15-#10	18-#8	12-#9	22-#6	6.24	636.9	1273.8	1714.8
35	400	11.00	14.00	33	0.706	18-#6 5	18-#10	17-#9	14-#9	12-#9	7.34	734.7	1469.4	1978.1
36	100	11.00	12.00	14	0.767	16-#5 6	13-#9	22-#6	14-#7	12-#7	4.17	451.1	902.3	1214.6
36	200	11.00	12.00	21	0.760	20-#5 7	17-#9	16-#8	14-#8	12-#8	5.45	573.5	1147.0	1544.0
36	300	11.00	12.00	29	0.704	17-#6 5	17-#10	16-#9	13-#9	14-#8	6.66	686.8	1373.6	1849.1
36	400	11.00	14.40	36	0.660	27-#5 5	19-#10	18-#9	19-#8	13-#9	7.67	793.0	1586.1	2135.1

SQUARE INTERIOR PANEL — With Drop Panel(2) — No Beams

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	(3) Square Column Size (in.)	Reinforcing Bars (E. W.) Column Strip Top	Column Strip Bottom	Middle Strip Top	Middle Strip Bottom	Total Steel (psf)	Concrete (cu. ft / sq. ft)
h = 12 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS								
30	100	12	15-#6	15-#5	13-#5	13-#5	2.82	1.065
30	200	19	23-#5	19-#5	15-#5	13-#5	3.16	1.083
30	300	22	15-#7	17-#6	10-#7	15-#5	4.02	1.083
30	400	25	16-#7	11-#8	11-#7	18-#5	4.59	1.102
30	500	27	14-#8	13-#8	10-#8	11-#7	5.31	1.147
31	100	12	20-#5	12-#6	13-#5	13-#5	2.78	1.083
31	200	19	26-#5	11-#7	16-#5	14-#5	3.41	1.083
31	300	23	15-#7	18-#6	14-#6	12-#6	4.10	1.102
31	400	25	14-#8	16-#7	13-#7	14-#6	4.98	1.102
31	500	27	16-#8	12-#9	11-#8	13-#7	5.93	1.147
32	100	12	16-#6	18-#5	14-#5	14-#5	2.90	1.083
32	200	19	26-#5	17-#6	13-#6	15-#5	3.57	1.102
32	300	23	22-#6	15-#7	12-#7	13-#6	4.43	1.102
32	400	26	15-#8	11-#9	11-#8	12-#7	5.37	1.147
32	500	30	17-#8	13-#9	12-#8	18-#6	6.12	1.147
33	100	12	16-#6	14-#6	11-#6	14-#5	2.97	1.102
33	200	19	15-#7	18-#6	14-#6	12-#6	3.82	1.102
33	300	23	18-#7	22-#6	13-#7	11-#7	4.71	1.102
33	400	26	17-#8	12-#9	12-#8	13-#7	5.74	1.147
33	500	33	15-#9	11-#1	13-#8	11-#8	6.52	1.147
34	100	12	18-#6	22-#5	12-#6	15-#5	3.16	1.102
34	200	19	22-#6	15-#7	12-#7	13-#6	4.13	1.102
34	300	23	18-#8	14-#8	14-#7	12-#7	5.15	1.102
34	400	29	18-#8	14-#9	22-#6	14-#7	6.07	1.147
35	100	12	19-#6	17-#6	13-#6	16-#5	3.32	1.102
35	200	19	18-#7	22-#6	13-#7	20-#5	4.31	1.102
35	300	23	17-#8	20-#7	12-#8	13-#7	5.43	1.102
35	400	32	16-#9	18-#8	14-#8	12-#8	6.42	1.147
36	100	12	16-#7	14-#7	20-#5	17-#5	3.58	1.102
36	200	19	37-#5	14-#8	14-#7	12-#7	4.71	1.102
36	300	25	18-#8	17-#8	22-#6	14-#7	5.68	1.102
36	400	34	17-#9	13-#10	12-#9	22-#6	6.84	1.147

NOTES: (1) 50 percent of these bars may be place in the middle third of column strip. (2) Drop panels same size as for edge panels. (3) Same column size above and below slab.

Alternate System #36 - Waffle Flat Slab System

Choose 19" x 19" Voids 5" Ribs @ 24"

⇒ For 31'0" x 34'2" bay ⇒ use square bay 34' x 34' (edge bay) for analysis

$w_u = 1.2(20) + 1.6(100) = 184$ psf (using only superimposed loads)

$w = 200$ psf > 184 ok

Edge Panel : $f'_c = 4000$ psi $f_y = 60$ ksi

Column : 23" x 23"

- see attached CRSI excerpt for reinforcing details

Total Steel = 4.37 psf , Total depth = 14.5"

⇒ For 31'0" x 24'8" ⇒ use square bay 31' x 31' (edge bay) for analysis

$w_u = 184$ psf < 200 psf ok

Edge Panel $f'_c = 4000$ psi $f_y = 60$ ksi

Column : 19" x 19"

- see attached CRSI excerpt for reinforcing details

Total Steel = 3.92 psf Total depth = 14.5"

WAFFLE FLAT SLAB SYSTEM 19" X 19" Voids: 5" Ribs @ 24"

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

Total Depth = 14½ in. Rib Depth = 10 in. Total Slab Depth = 4½ in.

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Edge Column: $c_1 = c_2$ (in.)	Square Edge Column: γ_f	Square Edge Column: (2) Stirrups	Column Strip: Top Edge No.-size +	Column Strip: Bottom No. Ribs	Column Strip: Bottom Bars per Rib	Column Strip: Top Interior No.-size	Middle Strip: Bottom No. Ribs	Middle Strip: Bottom Long Bars	Middle Strip: Bottom Short Bars	Middle Strip: Top Interior No.-size	Moments: −M Edge (ft-k)	Moments: +M Bot. (ft-k)	Moments: −M Int. (ft-k)
30'-0" D=10.417 RIB NOT ON COLUMN LINE 0.784 CF/SF	50	2.37	15	0.817		22-#5+0	6	2-#5	22-#5	9	#4	#4	9-#5	166	333	448
	100	2.52	15*	0.854		22-#5+1	6	1-#5 and 1-#6	24-#5	9	#4	#4	9-#5	207	413	557
	150	3.02	15*	0.914		22-#5+4	6	1-#6 and 1-#7	21-#6	9	#4	#5	9-#5	247	519	655
	200	3.41	16*	0.631		22-#5+1	6	2-#7	24-#6	9	#4	#5	11-#5	286	652	771
	300	4.49	21*	0.626		22-#5+2	6	2-#8	23-#7	9	#5	#6	10-#6	359	855	967
32'-0" D=12.417 RIB ON COLUMN LINE 0.798 CF/SF	50	2.46	16	0.838		24-#5+0	7	2-#5	24-#5	9	#4	#4	10-#5	203	407	548
	100	2.74	16*	0.808		24-#5+4	7	2-#6	29-#5	9	#4	#4	10-#5	252	505	679
	150	3.25	16*	0.631		24-#5+2	7	1-#6 and 1-#7	25-#6	9	#4	#5	11-#5	301	620	811
	200	3.92	19*	0.628		24-#5+3	7	1-#7 and 1-#8	21-#7	9	#5	#5	9-#6	347	778	935
	300	4.51	26*	0.622	3S41	24-#5+4	7	1-#7 and 1-#8	20-#8	9	#5	#6	12-#6	427	854	1151
34'-0" D=12.417 RIB ON COLUMN LINE 0.790 CF/SF	50	2.55	17*	0.857		25-#5+2	7	1-#5 and 1-#6	28-#5	10	#4	#4	10-#5	243	486	654
	100	3.10	17*	0.914		25-#5+6	7	1-#6 and 1-#7	25-#6	10	#4	#5	11-#5	302	603	812
	150	3.49	19*	0.620		25-#5+3	7	2-#7	22-#7	10	#4	#5	10-#6	358	717	965
	200	4.37	23*	0.624		25-#5+5	7	2-#8	26-#7	10	#5	#6	11-#6	412	900	1110
36'-0" D=12.417 RIB ON COLUMN LINE 0.784 CF/SF	50	2.77	18*	0.883		27-#5+5	7	2-#6	34-#5	11	#4	#4	11-#5	288	575	774
	100	3.37	18*	0.629		27-#5+3	7	2-#7	30-#6	11	#4	#5	10-#6	357	714	962
	150	3.94	22*	0.625		27-#5+5	7	1-#7 and 1-#8	27-#7	11	#5	#5	11-#6	423	845	1138
	200	4.47	29*	0.621	3S41	27-#5+5	7	2-#8	23-#8	11	#5	#5	13-#6	478	957	1288
38'-0" D=14.417 RIB NOT ON COLUMN LINE 0.795 CF/SF	50	3.10	19*	0.904		28-#5+9	8	1-#6 and 1-#7	28-#6	11	#4	#5	13-#5	340	680	916
	100	3.77	22*	0.921		28-#5+14	8	2-#7	26-#7	11	#5	#5	11-#6	419	838	1128
	150	4.41	29*	0.621		28-#5+7	8	1-#7 and 1-#8	24-#8	11	#5	#6	13-#6	491	982	1322

SQUARE INTERIOR PANELS

Total Depth = 14½ in. Rib Depth = 10 in. Total Slab Depth = 4½ in.

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Interior Column: $c_1 = c_2$ (in.)	Square Interior Column: (2) Stirrups	Column Strip: Bottom No. Ribs	Column Strip: Bottom Bars per Rib	Column Strip: Top Interior No.-size	Middle Strip: Bottom No. Ribs	Middle Strip: Bottom Long Bars	Middle Strip: Bottom Short Bars	Middle Strip: Top Interior No.-size
30'-0"	50	2.22	15		6	2-#4	22-#5	9	#4	#4	9-#5
	100	2.33	15		6	1-#4 and 1-#5	22-#5	9	#4	#4	9-#5
	150	2.64	15*	3S41	6	2-#5	27-#5	9	#4	#4	9-#5
	200	3.13	15*	3S41	6	2-#6	32-#6	9	#4	#4	10-#5
	300	4.12	17*	3S42	6	2-#7	21-#7	9	#4	#5	9-#6
32'-0"	50	2.37	15		7	1-#4 and 1-#5	24-#5	9	#4	#4	10-#5
	100	2.48	15		7	1-#4 and 1-#5	27-#5	9	#4	#4	10-#5
	150	2.98	16*	3S41	7	1-#5 and 1-#6	23-#6	9	#4	#4	10-#5
	200	3.55	16*	3S41	7	2-#6	27-#6	9	#4	#5	12-#5
	300	4.31	23*	3S42	7	1-#6 and 1-#7	30-#7	9	#4	#5	11-#6
34'-0"	50	2.36	17		7	1-#4 and 1-#5	26-#5	10	#4	#4	10-#5
	100	2.77	17*	3S41	7	2-#5	24-#6	10	#4	#4	10-#5
	150	3.19	17*	3S41	7	1-#5 and 1-#6	25-#6	10	#4	#4	13-#5
	200	3.92	17*	3S42	7	1-#6 and 1-#7	21-#7	10	#4	#5	13-#6
36'-0"	50	2.80	18		7	2-#5	31-#5	11	#4	#4	11-#5
	100	3.05	18*	3S41	7	1-#5 and 1-#6	28-#6	11	#4	#4	12-#5
	150	3.56	18*	3S42	7	2-#6	25-#7	11	#4	#4	15-#5
	200	4.27	22*	3S42	7	1-#6 and 1-#7	23-#8	11	#4	#5	15-#6
38'-0"	50	2.76	19*		8	2-#5	26-#6	11	#4	#4	12-#5
	100	3.48	19*	3S41	8	2-#6	25-#7	11	#4	#4	15-#5
	150	4.14	20*	3S42	8	1-#6 and 1-#7	29-#7	11	#4	#5	13-#6

See the notes on Page 11-19.

WAFFLE FLAT SLAB SYSTEM 30" X 30" Voids: 6" Ribs @ 36"

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

Total Depth = 18½ in. Rib Depth = 14 in. Total Slab Depth = 4½ in.

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Edge Column: $c_1 = c_2$ (in.)	Square Edge Column: γ_f	Square Edge Column: (2) Stirrups	Column Strip: Top Edge No.-size +	Column Strip Bottom: No. Ribs	Column Strip Bottom: Bars per Rib	Column Strip: Top Interior No.-size	Middle Strip Bottom: No. Ribs	Middle Strip Bottom: Long Bars	Middle Strip Bottom: Short Bars	Middle Strip: Top Interior No.-size	Moments: −M Edge (ft-k)	Moments: +M Bot. (ft-k)	Moments: −M Int. (ft-k)
24'-0" D= 9.500 RIB NOT ON COLUMN LINE 0.898 CF/SF	50	2.07	12	0.660		18-#5+ 0	4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5	92	185	248
	100	2.07	12	0.686		18-#5+ 0	4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5	113	226	304
	150	2.12	12	0.712		18-#5+ 0	4	2-#5	18-#5	4	#4	#5	7-#5	134	294	360
	200	2.19	12	0.738		18-#5+ 0	4	1-#5 and 1-#6	18-#5	4	#4	#5	7-#5	154	364	415
	300	2.57	12	0.791		18-#5+ 0	4	1-#6 and 1-#7	18-#5	4	#5	#6	7-#5	195	496	526
	400	3.00	12	0.843		18-#5+ 0	4	1-#7 and 1-#8	20-#5	4	#6	#6	7-#5	237	624	637
	500	3.44	12 *	0.642		18-#5+ 0	4	2-#8	17-#6	4	#6	#7	8-#5	278	751	748
27'-0" D= 9.500 RIB NOT ON COLUMN LINE 0.878 CF/SF	50	2.10	13	0.695		20-#5+ 0	4	2-#5	20-#5	5	#4	#5	8-#5	130	261	351
	100	2.17	13	0.726		20-#5+ 0	4	1-#5 and 1-#6	20-#5	5	#4	#5	8-#5	160	320	431
	150	2.27	13	0.756		20-#5+ 0	4	2-#6	20-#5	5	#4	#5	8-#5	189	413	510
	200	2.54	13	0.787		20-#5+ 0	4	2-#7	20-#5	5	#5	#5	8-#5	219	513	589
	300	3.07	13 *	0.848		20-#5+ 0	4	2-#8	24-#5	5	#6	#6	8-#5	278	701	748
	400	3.87	13 *	0.640		20-#5+ 0	4	2-#9	21-#6	5	#6	#7	10-#5	337	884	907
	500	4.49	13 *	0.640		20-#5+ 0	4	1-#9 and 1-#10	18-#7	5	#7	#7	8-#6	396	1065	1065
30'-0" D=12.500 RIB ON COLUMN LINE 0.913 CF/SF	50	2.10	15	0.706		22-#5+ 0	5	2-#5	22-#5	5	#4	#5	9-#5	182	353	489
	100	2.17	15	0.742		22-#5+ 0	5	1-#5 and 1-#6	22-#5	5	#4	#5	9-#5	222	444	597
	150	2.43	15	0.778		22-#5+ 0	5	1-#6 and 1-#7	23-#5	5	#5	#5	9-#5	262	561	706
	200	2.83	15	0.821		22-#5+ 1	5	2-#7	26-#5	5	#6	#6	9-#5	302	609	814
	300	3.71	15 *	0.909		22-#5+ 6	5	1-#8 and 1-#9	24-#6	5	#6	#7	11-#5	383	959	1031
	400	4.57	15 *	0.637		22-#5+ 4	5	1-#9 and 1-#10	21-#7	5	#7	#8	10-#6	464	1207	1248
	500	5.37	19 *	0.633	4 S 6 1	23-#5+ 4	5	2-#10	19-#8	5	#8	#8	11-#6	536	1423	1444
33'-0" D=12.500 RIB ON COLUMN LINE 0.892 CF/SF	50	2.39	16	0.748		25-#5+ 0	5	2-#6	25-#5	5	#4	#5	10-#5	240	480	646
	100	2.49	16	0.788		25-#5+ 0	5	1-#6 and 1-#7	25-#5	6	#5	#5	10-#5	294	587	790
	150	2.77	16 *	0.839		25-#5+ 2	5	2-#7	30-#5	6	#5	#6	10-#5	347	730	935
	200	3.33	16 *	0.888		25-#5+ 5	5	2-#8	25-#6	6	#6	#6	12-#5	401	915	1080
	300	4.51	18 *	0.636	4 S 6 1	25-#5+ 4	5	1-#9 and 1-#10	24-#7	6	#7	#7	10-#6	509	1256	1370
36'-0" D=12.500 RIB ON COLUMN LINE 0.876 CF/SF	50	2.38	18	0.757		27-#5+ 0	5	1-#6 and 1-#7	27-#5	7	#4	#5	11-#5	308	617	830
	100	2.76	18	0.809		27-#5+ 1	5	1-#7 and 1-#8	33-#5	7	#5	#5	11-#5	378	756	1017
	150	3.15	18 *	0.870		27-#5+ 5	5	2-#8	28-#6	7	#5	#6	13-#5	448	898	1205
	200	3.82	18 *	0.834		27-#5+ 2	5	2-#9	24-#7	7	#6	#6	15-#5	517	1140	1392

SQUARE INTERIOR PANELS

Total Depth = 18½ in. Rib Depth = 14 in. Total Slab Depth = 4½ in.

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Interior Column: $c_1 = c_2$ (in.)	Square Interior Column: (2) Stirrups	Column Strip Bottom: No. Ribs	Column Strip Bottom: Bars per Rib	Column Strip: Top Interior No.-size	Middle Strip Bottom: No. Ribs	Middle Strip Bottom: Long Bars	Middle Strip Bottom: Short Bars	Middle Strip: Top Interior No.-size
24'-0"	50	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	100	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	150	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	200	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	300	2.25	12		4	1-#5 and 1-#6	18-#5	4	#4	#5	7-#5
	400	2.55	12	4 S 6 1	4	2-#6	19-#5	4	#5	#5	7-#5
	500	2.97	12 *	4 S 6 1	4	1-#6 and 1-#7	16-#6	4	#5	#6	7-#5
27'-0"	50	2.04	13		4	1-#4 and 1-#5	20-#5	5	#4	#5	8-#5
	100	2.04	13		4	1-#4 and 1-#5	20-#5	5	#4	#5	8-#5
	150	2.12	13		4	2-#5	20-#5	5	#4	#5	8-#5
	200	2.23	13	4 S 6 1	4	1-#5 and 1-#6	20-#5	5	#4	#5	8-#5
	300	2.56	13	4 S 6 1	4	1-#6 and 1-#7	22-#5	5	#4	#5	8-#5
	400	3.39	13 *	4 S 6 1	4	1-#7 and 1-#8	19-#6	5	#5	#6	9-#5
	500	4.05	13 *	4 S 6 2	4	2-#8	23-#6	5	#6	#6	8-#6
30'-0"	50	2.03	15		5	1-#4 and 1-#5	22-#5	5	#4	#5	9-#5
	100	2.03	15		5	1-#4 and 1-#5	22-#5	5	#4	#5	9-#5
	150	2.12	15		5	2-#5	22-#5	5	#4	#5	9-#5
	200	2.43	15		5	2-#6	24-#5	5	#4	#5	9-#5
	300	3.26	15 *	4 S 6 1	5	2-#7	22-#6	5	#5	#6	10-#5
	400	3.95	15 *	4 S 6 1	5	1-#7 and 1-#8	20-#7	5	#6	#6	9-#6
	500	4.90	16 *	4 S 6 2	5	1-#8 and 1-#9	23-#7	5	#7	#7	10-#6
33'-0"	50	2.15	16		5	2-#5	25-#5	6	#4	#5	10-#5
	100	2.26	16		5	1-#5 and 1-#6	25-#5	6	#4	#5	10-#5
	150	2.46	16	4 S 6 1	5	2-#6	28-#5	6	#4	#5	10-#5
	200	2.94	16 *	4 S 6 1	5	1-#6 and 1-#7	23-#6	6	#5	#5	11-#5
	300	4.07	16 *	4 S 6 1	5	2-#8	22-#7	6	#6	#6	10-#6
36'-0"	50	2.24	18		5	1-#5 and 1-#6	27-#5	7	#4	#5	11-#5
	100	2.46	18	4 S 6 1	5	2-#6	31-#5	7	#4	#5	11-#5
	150	2.80	18	4 S 6 1	5	1-#6 and 1-#7	26-#6	7	#4	#5	12-#5
	200	3.46	18 *	4 S 6 1	5	1-#7 and 1-#8	30-#6	7	#5	#5	10-#6

(Continued on next page)

See the notes on Page 11-19.

Alternate System4: Girder-Slab

D-Beam® Calculator Reference Tool
12/3/2007

Project Name: CSU Physical Education Complex
Job Number:

Design Information

Dead Load =	9 psf
Partition Load =	10 psf
Live Load =	100 psf
Topping Load =	0 psf
DB Span =	19.61 ft
Plank Span =	31 ft
Grout f'c =	5000 psi
Allowable Δ_{LL} = L /	240
Allowable Δ_{LL} =	0.98 in

DB Properties

DB Size ------------> DB 9 x 46

Steel Section		Transformed Section	
I_s =	195 in^4	I_t =	356 in^4
S_t =	33.7 in^3	S_t =	68.6 in^3
S_b =	50.8 in^3	S_b =	80.6 in^3
M_{scap} =	84.0 ft-k		
t_w =	0.375 in		
b =	5.75 in		

Live Load Reduction (IBC 00/03/06)

Include LLR	☑
% Reduction =	31.98 %
Reduced Load =	68.0 psf

Initial Load - Precomposite

M_{DL} =	13.4 ft-k	<	84.0 ft-k	**OK**
Δ_{DL} =	0.16 in			
Δ Ratio = L /	1433			
Camber D-Beam	☐			
D-Beam Camber	1			

Total Load - Composite

M_{sup} =	116.3 ft-k			
M_{TL} =	129.7 ft-k			
S_{REQ} =	51.9 in^3	<	68.6 in^3	**OK**
Δ_{SUP} =	0.78 in	<	0.98 in	**OK**
Δ_{TOT} =	0.94 in	= L/ 249		

Superimposed Compressive Stress on Concrete

N value =	7.20			
S_{tc} =	494 in^3			
f_c =	2.83 ksi			
F_c =	2.25 ksi	<	2.83 ksi	**NO GOOD**

Bottom Flange Tension Stress (Total Load)

f_b =	20.5 ksi			
F_b =	45 ksi	>	20.5 ksi	**OK**

Shear Check

Total Load =	87 psf			
w =	2.70 klf			
R =	26.4 k			
f_v =	12.3 ksi			
Fv =	20 ksi	>	12.3 ksi	**OK**