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- Lewisburg, PA
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- Structural Report II, Alternative Floor Systems

Executive Summary

A Composite Slab/Deck on a Composite Beam System was designed for the majority of the floor framing for the New Arena/Gymnasium in the Bucknell Athletic Center (BAC). The structural design team at Ewing Cole (Philadelphia, PA) was able to entertain some other framing ideas, such as the alternative floor systems explored in this study; Composite Slab/Deck on Steel Framing, Flat Slab with Drop Panels, Open Web Steel Joist with Concrete Slab, One-Way (Pan) Concrete Joist. The typical floor frame chosen for schematic design is located on the main concourse level of the arena, alongside the east corridor of the facility. From that area, spectators can enter the basketball seating tiers, congregate, visit the restrooms, travel to adjacent building, or continue around the concourse. It has the potential to be a heavily traveled area.

Each system had a few different options to investigate. Although it may have to due with a complex transfer of loads from the floors & roof above, some attention was given to the over-design of flexural steel beams and the repetitive placement of many shear studs. The Flat Slab System (with Drop Panels) produced higher shear capacities, but altered the neighboring column spacing and ceiling heights. Open Web Steel Joists Systems can replace Wide Flanged Members and eliminate the use of some interior columns. The Pan Joist Concrete (One-Way) System produces the greatest amount of added floor area due to the absence of certain columns (See CL17.5, refer to existing frame - pg. 2&3).

When each of the proposed systems were compared to one another, the Open Web Steel Joist with Concrete Slab had the best qualities in three out of the four areas of consideration; Available Resources, Constructability, Effect of the Architectural Scheme/Aesthetics, and Cost. Cost is usually the overbearing factor in the building industry. Cost is the greatest advantage of the most open web joist systems.
All diagrams were inserted from MS Excel, or Exported from ACAD 2002.
All calculations have been entered in MS Word format, although backups are available upon request.

Existing Floor Framing System

A Composite Slab/Deck System exists with Shear Studs welded to the Wide Flanged Steel Beam, an entirely composite floor system. The typical framing panel consists of a 4 ½ inch concrete slab, 20 gauge galvanized *composite* metal deck with 6 X 6 – W2.9 X W2.9 Welded Wire Fabric. Equally spaced ¾ inch diameter X 5 inch long headed shear studs are welded to the centerline of the top of the flange of the beam. The ridges & edges located throughout the pans and/or ribs of the decking promote composite action between the concrete (topping) and the metal floor deck, the shear studs promote composite action between the floor system (concrete slab & metal floor deck) and the supporting wide flange steel beams.

Normal weight concrete was selected because of the use of the spaces in these buildings (occupancy). The spaces in the gymnasium are *public* spaces with high activity levels. As a result, floor vibrations were in need of concern. Increasing the mass of the system is one way to help control floor vibrations. So, normal weight concrete (approx. 150 pcf) will help to control floor vibrations compared to light weight concrete (approx. 110 pcf). There are many drawbacks from implementing a heavier floor slab. A heavier floor slab results in heavier steel framing, steel columns and foundations. However, increasing the floor mass is one of the best ways to control floor vibrations. Finally, it was determined that using normal weight concrete in this type of structure would produce a premium framing system.

The floor construction provides a two-hour fire rating which was the code requirement for this type of assembly. The UL (Underwriter's Laboratory) design number for the floor construction is UL 916. Generally, increasing the amount of concrete is generally cheaper than fireproofing, especially when the impact, direct or indirect, on the schedule (fireproofing is generally on the critical path), on the subcontractors, and on the reapplication is after removal.

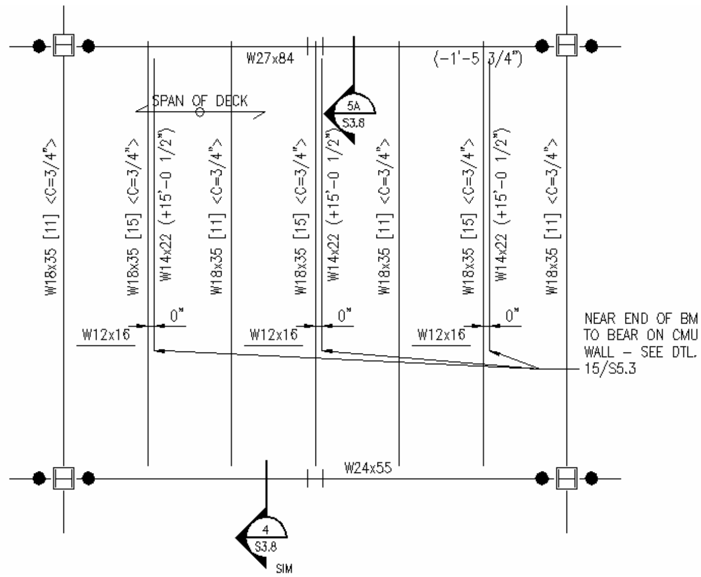
The panel that is analyzed, as typical, is part of the Gymnasium Concourse Level Framing Plan. It is located along the east side of the building, between Column Lines 17, 17.5, 18 & B, C. Columns acting through bays in this section are prismatic up to the top of the Mezzanine Level - Floor # 3 (except for 17.5; Top of Event Level - Floor #1). The One-Way floor deck/slab spans N-S, in the "Short Span" direction.

*See next page for Schematic Images & Section Details.

Typical Floor Panel:

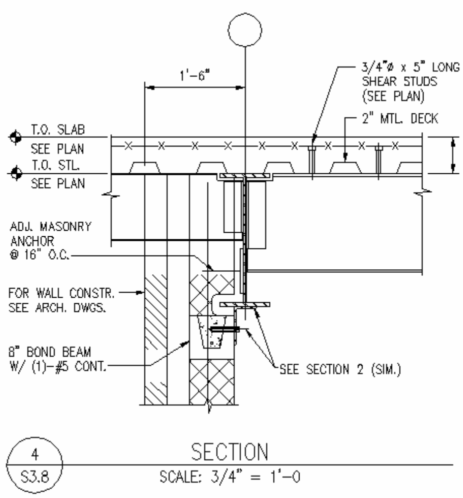
- Moment Connections At All Beam/Column Joints Are Indicated.
- <C=…>, Indicates Beam Camber, In Inches, At The Midspan.

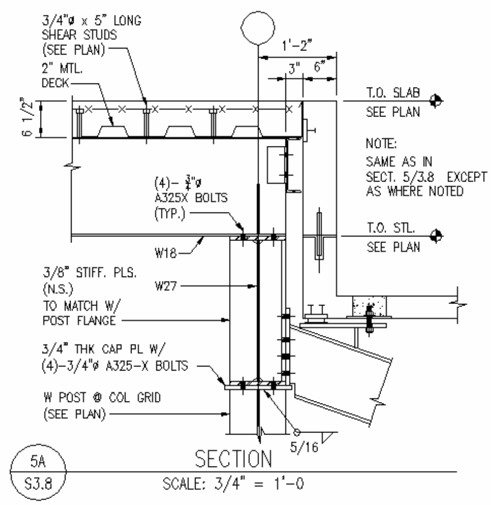
→ N



Typical Section Details:

- Top of Slab EL. = 489'-3" (20'-0" above Ground Floor)
- Top of Steel EL. = 488'- 8 ½" (6 ½" Total Slab Thickness)





Preliminary Sizes of the Framing Members & Slabs :

Column Sizes (Foundation Tie/Pedestal → Mezzanine Level)		
B-17&18:	W10X49	(10"X10", Nominal)
C-17&18:	W14X90	(14"X14.5", Nominal)
Column Sizes (Foundation Tie/Pedestal → Mezzanine Level)		
B-17.5:	W12X53	
C-17.5:	W12X79	
Typical **Girder Spans**		
N-S / Longitudinal / Short Span		E-W / Transverse / Long Span
19' - 6", C/C		33' - 6", C/C
≈ 19' - 0", CLR		≈ 32' - 6", CLR
Typical **Beam Spans**		
E-W / Transverse / Perpendicular to Span of Deck		
33' - 6", C/C		
≈ 32' - 6", CLR		

Stress & Deflection Criteria

$W_u = 1.2(DL) + 1.6(LL)$; Self-Weight Considered

$\Delta = (5wl^4)/384EI$ $\Delta max = l/360$

$I_x = (5wl^4)/(384*\Delta max*E)$

*Interior Beams are Pin Connected, See 4/S3.8 - pg. 3

$M_u = (wl^2)/8$

$\Phi M_p > M_u$; Load Factor Design Selection Table (Φ=0.90, F_y=50 ksi)

W18 X 35 (Typ.) :

Typical **Loading Calculations & Deflection Checks**							
N.W. Concrete (pcf):		150					
Slab Thickness (in.):		4.5					
Span (ft.):		32.5					
Tributary Width (ft.):		6.5					
Tributary Area (sf):		211.25					
E (ksi):		29000					
Dead:	PLF	Live:	PSF			Total Loading(w_u):	PLF
S.W. =	35.00	Public Area:	30			Dead:	400.63
Slab =	365.63	S.Imposed:	25			Live:	195.00
						S.Imposed:	162.50
w =	955.25	(lb/ft) =	0.96	(k/ft)			
Δmax =	1.08						
Ix =	763.26	(in^4)	*Calculated				
	510	(in^4)	*LRFD, 4-25				
Mu =	126.12	(ft-k)					
Trial Size:	W12X26						
	ΦMp = 140	(ft-k)	*LRFD, 4-20				
		ΦMp > Mu, Then Good.					
		140 > 126.12, Then OK.					

Alternate System #1; Composite Slab/Deck on Steel Framing
- Variation of Existing Floor System

Typical Floor Panel:
- 3 ½ inch *Light Weight* Concrete Slab on 2 inch – 20 gauge galvanized composite metal deck.
- Total Slab Depth = 5 ½" (Existing Slab Depth = 6 ½")

Typical Details/Differences:
- Decrease in number of Shear Studs & absence of W.W.F.
  - No Composite Beam Action (Just Composite Slab/Deck).
- Less Total Slab Depth.
- N.W. → L.W. Concrete.

Design Concept:
Shear Studs, or Shear 'Connector' Studs, are designated to effectively tie the concrete to steel beams and to resist shear loadings between the concrete slab & steel beam in composite construction. Shear studs may be neglected if composite (beam) action is not necessary (or the number required may be greatly decreased).
*All shear studs include a required ferrule. A ferrule is the bushing placed around the shaft of the shear stud for reinforcement. Most manufactured studs are made of low carbon steel.

Welded Wire Fabric (W.W.F.) may be neglected in thinner slab construction with a change in spacing of the placement of flexural steel. Closer minimum spacing throughout the cross-section of the slab will also provide a means of Shrinkage & Temperature resistance, since the effective depth of the rebar would have to be very near the middle in order to fulfill spacing & cover requirements.

This is an analysis depicting how the *existing* floor design of Shear Studs may be over-conservative. LRFD>Specs&Codes>Chapter I (Composite Members)>I5 (Shear Connectors, pg. 6-67). Shear connectors are evaluated by material, horizontal shear force, stud strength, placement & spacing.

f'c	3500 psi	>>	3.5 ksi	*for all concrete on metal deck
Fy	60 ksi	>>	60 ksi	*60 yield grade
Fu	12 ksi			*specification
Ac	4.5" X 12"		42 in^2	*2", 20-GaugeLok-Floor, pg.28 USD-99
As	0.520 in^2	>>	0.52 in^2	*2"; 20-GaugeLok-Floor, pg.28 USD-99
A_{sc}	10 in ^2			
Ec	29000000 psi	>>	$29E^3$ ksi	*approximation

HORIZONTAL SHEAR FORCE			SHEAR STUD STRENGTH		
0.85(f'c)(Ac) =	124.95 kips,	125 kips	$0.5(A_{sc})\sqrt{[f'c(Ec)]}$ =	50.37 kips,	51 kips
As(Fy) =	31.2 kips,	32 kips	A_{sc}(Fu) =	120 kips	

∑Qn = Sum of Nominal Strengths of Shear Connectors between the Point of Max. Pos. Moment & Zero Moment.
Critical / Total Horiz. Shear = 125 kip

* Check (51 ≤ 120) kip, **OK**

Consider the smallest of the following;
0.85(f'c)(Ac), As(Fy), ∑Qn.
∑Qn = 0.5Asc√(f'c(Ec)) = 86.1 ≤ Asc (Fu), Meets Required Tensile Capacity

LRFD, I5.5, pg. 6-68, Required Number of Shear Connectors;

Total Horizontal Shear Strength / Nominal Strength of One Shear Connector = 125/86.1 = 1.45

LRFD, I5.6, pg. 6-68, Shear Connector Placement & Spacing;

"Except for connectors installed in the ribs of formed steel decks, shear connectors shall have at least on inch of lateral concrete cover."

*Please refer to the Existing Typical Floor Frame system to see you many shear studs per beam were originally called out.

Alternate System #2; Flat Slab with Drop Panels

- Introduced New Column → Creates 2-Way Action (possibility)

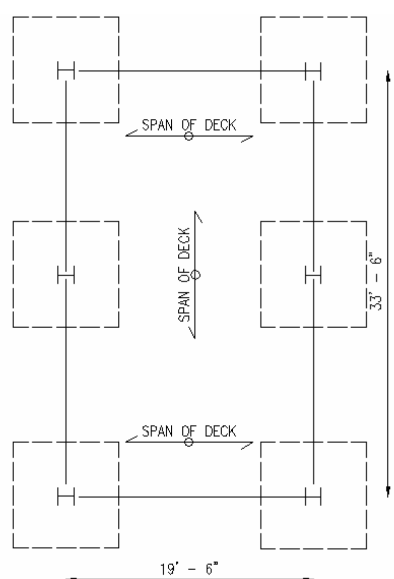
Typical Floor Panel Schematic:

- N.W. Concrete (150 pcf)
- Exterior Dimensions:
  19' - 6" (N-S, Long Direction)   16' - 9" (E-W, Short Direction)
- Column Lines Introduced / Steel Beams Abandoned Within Concrete Spans.
  - Note - Solid Lines (Seen On Diagram) Just Define the Panel Dimensions.
- Minimum Drop Panel Dimensions:
  ACI 13.3.7.1, No less than one-sixth the span length measured from center-to-center of support in the direction.   3'-4" X 2'-10", Typical
- Minimum Slab Thickness: 4" (By Standard Practice)
  By Code, for Interior Panel: ln/36 = (19.5'*12"/')/36 = 6' - 6"   *Critical
  * Deflection (or Minimum Thickness), Thickness/Span Ratios
- Minimum Depth of Drop Panels: 2 ¼"
- Minimum Column Size: 12" - 12"

Floor Panel Notes:

- The thickening of the slab around columns increases the shear carrying capacity at the points of intense shear force.
- Under normal loading conditions, floor loadings are independent of the floor height.
- Materials contained by a Flat Slab are typically controlling the deflection because increasing the slab thickness in a Flat Slab does not affect the limit of deflection.

→ N



Alternate System #3; Open Web Steel Joist with Concrete Slab

- Replaced Wide Flange Members with a series of Bar Joists.

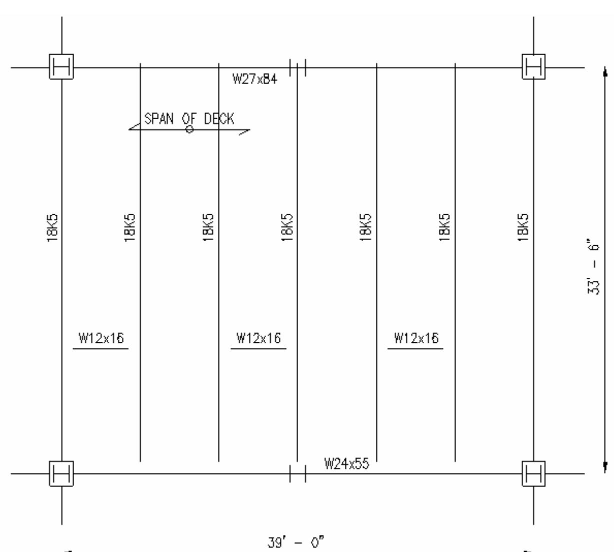
- Eliminates Interior Columns → Bigger Bay Size

Typical Floor Panel Schematic:

- N.W. Concrete (150 pcf)
- Exterior Dimensions:
  39' - 0" (N-S, Long Direction) 33' - 6" (E-W, Short Direction)
  - Note - Same as Existing Layout.
- Decking:
  9/16 inch deep *Form* Deck, USD-99 pg. 52
  - Note - Does *Not* Create Composite Action (Slab/Decking)
- Slab Thickness: Floor Thickness:
  2 ½ inches 3 1/16 inches
- Joist Span & Layout:
  - Note - Floor Live Load in (high traffic) 'Public Area' = 100 PSF
  Floor Dead Load (from Existing Conditions Report) = 45 PSF
  K – Series:
  Span ≈ 34' - 0" Depth = 18" Approx. Wt. = 7.7 lbs/ft
  Joist Designation: 18K5
  Load Carry Capacities, NJC-98 pg. 25;
  D.L. = 214 PLF L.L = 110 PLF
- Deflection:
  l/360 = 1.133" (@ Midspan)
  l/240 = 110 PLF * 1.5 = ((110/7.7)(12"/'))/240 = 0.714" (@ Midspan)

Floor Panel Notes:

- Each joist span should not exceed 24 times the depth of the joist.
- Depending on orientation, horizontal or diagonal bridging may be required.
- The spacing of the joist is related to the floor load magnitude, span capacity of decking, load carrying capacity, and desired floor depth.
- The smaller W-Shapes may still be needed for lateral resistance, as seen in Existing.



<u>Alternate System #4; One-Way Concrete Joist</u>
- Pan Joist System.

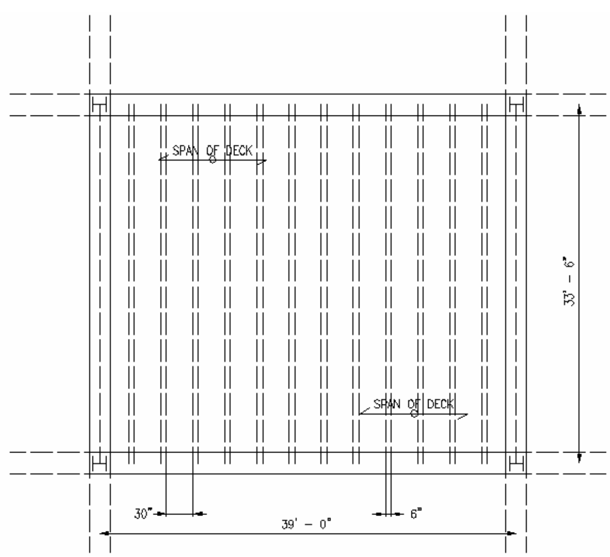
Typical Floor Panel Schematic:

- L.W. Concrete (110 pcf)
- Exterior Dimensions:
  39' - 0" (N-S, Long Direction) 33' - 6" (E-W, Short Direction)
  - Note - Same as Existing Layout.
- Pan Joist System, Section:
  Pan Size = 30" Rib Size = 6" Module = 3' - 0"
  39' = 468", 468"/36" = 13 , Use 13 Pans @ 36" (No Cantilever)
- Minimum Slab Thickness:
  ACI Table 9.5A, l/28 = 36"/28 = 1.29"
  IBC 2000, Requires 3.5" for a 2 hr. Fire-Rating
- Loading:
  ACI 9.2.1, Critical Loading Case: U = 1.2(D.L.) + 1.6(L.L.), Trib. Width = 4'-0"
  - Note - Joist are manufactured in 4' sections.
  D.L. = (D.L.(slab) + D.L.(rib) = D.L. (s.imposed)) X (Trib. Width)
  L.L. = 100 PSF X Trib. Width

Floor Panel Notes:

- One-Way concrete joist construction provides a monolithic combination of regularly-spaced joists (ribs) and a thin slab of concrete cast in place to form an integral unit with supporting beams, columns and walls.
- Joists span in the E-W.
- Slabs span in the N-S (in between the joist; 3ft.).

→ N



Proposed Framing System

- Bar Joist System

An alternative floor system that has shown to be highly effective, for this framing system, is the Open Web Steel Joist with Concrete Slab (Alternative # 3). It is the least expensive system considered in this study. The Open-Web System lessens the necessary thickness of concrete topping, and the mass of the overall floor system. However, there is one major drawback. The strict placement and deep projections bring up a lot of non-structural issues with respect to MEP space requirements in the ceiling. The decreased ceiling height is not that big of a concern. The concourse level the floor system oversees has a floor-to-floor height of 20 feet.

In general, a steel joist floor system is considerably more flexible (less stiff) than a steel beam floor system. Stiffness is another means of controlling floor vibrations. A stiffer floor system provides better vibration *characteristics*. A flexible floor has great amplitude of response (deflection) and a longer period (time it takes to complete a cycle of motion). This causes a more uncomfortable condition for inhabitants compared to a stiffer floor with smaller amplitude of response and shorter period.
Bar Joists exist in other floors in this building, so I think it should be utilized throughout the New Arena.

Floor System Comparison

- Scale: 1 → 5 (1 = Highest Rating, 5 = Lowest Rating)

* See next page for Comparison Chart.