MONONGALIA GENERAL HOSPITAL

1200 J.D. ANDERSON DRIVE, MORGANTOWN, WEST VIRGINIA

PRO-CON STRUCTURAL STUDY
OF ALTERNATE FLOOR SYSTEMS REPORT

TECH TWO

THE PENNSYLVANIA STATE UNIVERSITY
DEPARTMENT OF ARCHITECTURAL ENGINEERING
SENIOR THESIS 2008-2009

SUBMITTED: OCTOBER 24, 2008

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Executive Summary

Purpose

The Pro-Con Structural Study of Alternate Floor Systems Report (Tech 2) studies the feasibility of four different floor systems. The floor systems include: flat slab (existing), girder-slab system, composite floor system, and post-tensioned slab system. These floor systems were analyzed under gravity loading alone, and compared to each other for practicality.

Building Description

The Monongalia General Hospital is a 405,994 square feet hospital located in Morgantown, West Virginia. The building project includes a 280,000 square feet addition as well as a 60,000 square feet renovation to the existing structure. The building envelope is a brick façade tied to structural concrete walls with openings for punch windows and curtain wall systems. Aluminum curtain wall systems can be seen all around the Hospital, oriented around lobbies and other major openings on plan. The system consists of insulated tempered spandrel glass framed by aluminum mullions which is tied into the concrete structural system. The main structural system of the Hospital consists of two-way flat slab supported by columns that follow a typical grid and edge beams located in the perimeter of each floor. The loads carried by the columns are transferred to the foundations. The lateral loads are resisted by twelve shear walls of varying height and width located in various portions of the building.

Pro-Con Structural Study

One existing floor system and three alternate floor systems were analyzed for Tech 2 and compared for feasibility when implemented for the Monongalia General Hospital. The existing flat slab system though the analyses seems to be the most viable floor system for the Hospital. On the other hand, the girder-slab system seems to be the least viable floor system, primarily due to its tendency for vibration as well as its short span, requiring more columns to be placed on the plan. The other two floor systems analyzed, the composite floor system and the post-tensioned slab system require further design iterations to develop a better understanding of how these systems can benefit the Hospital. Through the analysis of Tech 2, the composite floor system decreases the floor to floor height and there is still a high possibility of floor vibrations. On the other hand, the post-tensioned floor system could possibly increase the bay widths but for construction, this system is the most expensive.

Monongalia General Hospital

1200 J.D. Anderson Drive
Morgantown, WV

Pro-Con Structural Study of Alternate Floor Systems Report

Introduction

The Pro-Con Structural Study of Alternate Floor Systems Report (Tech 2) studies the feasibility of four different floor systems. The floor systems include: flat slab (existing), girder-slab system, composite floor system, and post-tensioned slab system. These floor systems were analyzed under gravity loading alone, and compared to each other for practicality.

The Monongalia General Hospital

The Monongalia General Hospital is located on 1200 J.D. Anderson Drive, West Virginia (Photograph 2 for aerial view, Photograph 3 for façade). The current project the Hospital is going through is a 340,000 square foot expansion and renovation named the Hazel Ruby McQuain Tower, this new addition will provide more various facilities and departments to the Hospital. The construction started on June of 2006 and is scheduled to be completed on May of 2009 with a design-build contract with a guaranteed maximum price set at an estimated $69,000,000 by the Turner Construction Company. The Tower has been designed by Freeman White, Inc. from North Carolina and the structure designed by Atlantic Engineering Services from Pittsburgh. (See Appendix A for Project Team Directory)

The Monongalia General Hospital's plan can be divided into four different quads, A, B, C, and D (Figure 1). The first floor of the Monongalia General Hospital occupies 92,086 square feet and houses a boiler/chiller room, electrical rooms, doctors' offices, labs, nurse stations, storage spaces, and a dining space equipped with a food services kitchen. The second floor follows a similar layout but provides more space for examination rooms as well as a gift shop and café on the southern face of Quad A. The third floor mainly consists of patient rooms with the central part of the plan dedicated to operation rooms. The third floor has a reduced square footage compared to those of the floors below with an area of 80,882 square feet; the western section of Quad D does not continue up to the third floor as patient room spaces but provides housing for two air handling units. The fourth floor sees an even less square footage on plan at 53,833 square feet, with the western section of Quad D no longer existing at this elevation. This floor only houses private patient rooms, each equipped with a private toilet and shower. The square footage of the fourth floor continues up to the fifth, housing more private patient rooms as well as a Labor, Delivery, Recovery, and Postpartum (LDRP) rooms in Quad B and C. The sixth floor sees nearly a fifty percent reduction in square footage from the fifth floor with only Quads B and C serving rooms for private patients. The rooftop at Quad A is located at this elevation and houses five air handling units. Acoustic ceiling systems are utilized on each floor to provide acoustic insulation. The rooftop of the Monongalia General Hospital is used primarily to house mechanical equipment. Two different types of roof systems are utilized: an adhered roof system and a ballasted roof system. The ballasted roof system is only present on the rooftop of Quad A and all other roofs utilize the adhered roof system. (Refer to Figure 2 for building cross section)

The exterior façade of the Monongalia General Hospital is a brick façade tied to 8" structural concrete walls with openings for punch windows and curtain wall systems. Windows are typically aluminum punch window units and located where there are offices and patient rooms, located on the third floor and up. Aluminum curtain wall systems can be seen all around the Hospital, oriented around lobbies and other major openings on plan (Photograph 1 and 3). The system consists of insulated tempered spandrel glass framed by aluminum mullions which is tied into the concrete structural system. Two inch rigid insulation is provided all around the building for insulation.

Structural System

Introduction

The primary structural system of the Monongalia General Hospital is reinforced concrete with several composite floor systems present in parts of the building where appropriate (i.e. canopy/wall junctions, canopy fascia, etc.). The concrete used for the Hospital ranges from 3000 pounds per square inch (psi) to 5000 psi depending on its use. All concrete, as specified by ASTM C150; is normal weight concrete with a minimum weight of 144 pounds per cubic foot, and the reinforcement used are all ASTM A615 – Grade 60 steel reinforcement bars.

Foundation and Columns

Concrete foundations are placed below every column located at a minimum depth of 3'-6" below grade and utilize 3000 psi cast in place concrete. The columns that transfer the loads to these foundations are all 24 inches by 24 inches utilizing 5000 psi cast in place concrete. A total of 100 columns are present in the structure ranging in height from 11'-6" (supports one floor) to the full height of the building 58'-5". There are six columns in the structure in which the column's material changes from concrete to steel. These columns support the canopy in Quad A as well as used as corner columns for the stair towers.

Slabs

The slab on grades are 5" thick normal weight concrete and the slabs used in floors above are two-way flat plate slabs that utilizes 4000 psi normal weight concrete and are used as the primary floor system with the exception of a few in Quad C where an emergency energy plant is present: a composite concrete-steel floor system is used. The two way slab system is 8 inches thick and transfers its load to the columns and concrete edge beams present in the perimeter of each floor.

Beams

The beams are all variable in size although the dominant cross section is an 18 inch by 24 inch beam usually spanning 27' from column to column. Like the columns, the concrete used for the beams are 5000 psi normal weight concrete framed in by the two way slabs. As mentioned earlier, beams in this Hospital are all edge beams with an exception around openings in plan for elevator shafts, stairs, as well as for the energy plant located in the northern part of Quad C.

Shear Walls

There are twelve lateral force resisting shear walls present in the Hospital (Figure 3). All of these are variable sizes ranging in height and width, the most representative shear wall being a 52'-9-1/8" x 70' wall with two sets of eight #5 bars used at each floor level.

Building Design Loads

Gravity Loads

For the structural analysis, gravity loads were determined as per ASCE 7-05, AISC 13th Edition, IBC 2006, and other relevant publications. The construction documents were also referenced to provide a better perception of code compliant loads. On the following page is a table listing the loads by type and material.

Floor Loads			
Type	*Material/Occupancy*	*Load*	*Reference*
Dead Load	Normal Weight Concrete	145 PCF	Drawing G1-2
	Steel	Per shape	AISC 13th Edition
	Brick Masonry	40 PSF	MSJC
	Partitions	20 PSF	Drawing G1-2
	Superimposed	10 PSF	*
Live Load	Public Areas	100 PSF	IBC 2006
	Lobbies	100 PSF	IBC 2006
	Corridors (1st Floor)	100 PSF	IBC 2006
	Corridors (Above 1F)	80 PSF	IBC 2006
	Operation Rooms	60 PSF	Drawing G1-2
	Patient Rooms	40 PSF	Drawing G1-2
	Mechanical	150 PSF	Drawing G1-2
	Stairs	100 PSF	Drawing G1-2
Roof Loads			
Dead Load	Normal Weight Concrete	145 PCF	Drawing G1-2
	Steel	Per shape	AISC 13th Edition
	Brick Masonry	40 PSF	MSJC
	Superimposed	10 PSF	**
Live Load	Roof Live Load	20 PSF	Drawing G1-2
	Mechanical	150 PSF	Drawing G1-2
Snow Load	Flat Roof Load	24 PSF	ASCE 7-08
Rain Load	Rain Load	21 PSF	ASCE 7-08

*Includes electrical and telecommunications wiring, ductwork, drop ceiling
**Includes ballasting, waterproofing, insulation

Snow drift loads were to be considered as a loading condition as per ASCE 7-08 however this type of loading was determined to be beyond the scope of this report and therefore neglected and will be discussed in future reports.

Analysis of Floor Systems

Four different floor systems were analyzed on a portion of the plan (see Figure 4) as a part of Tech 2; these floor systems include one existing floor system and three alternate systems. The existing system is a flat slab system which is seen in all areas of the Hospital with the exception of those mentioned in the Structural Systems section of this report. Three alternate systems were analyzed: girder-slab, composite floor deck, and post tensioned slab.

Existing System: Flat Slab (Figure 6)

The Hospital's architectural strength lies in an open plan with columns placed every thirty or twenty seven feet apart (See Figure 4 and 5), providing many spaces for rooms and hallways. This is made possible by the use of a flat slab system. The Monongalia General Hospital's flat slab is an eight inch thick slab that spans in between the columns. Flat slab systems allow for larger floor to floor heights as well as it's durability against fire is a great advantage. The density of concrete provides great resistance against floor vibrations and is relatively easy to erect on site.

For flat slab systems, its advantage is also a great disadvantage. The dense nature of the floor system leads to a heavier building in effect increasing the risk of damages against seismic action. Also, the construction of thicker slabs call for a high number in reinforcement in turn increasing the construction costs.

The flat slab system designed for the Monongalia General Hospital in Tech 2 is 8 inches thick utilizing #5 bars for all column and middle strips (while the author recognizes the need for more iteration regarding reinforcing bar size selection). At most twenty five #5 bars were used during the design of the slab in the column strip, and at least three #5 bars were used during the design of the slab in the middle strip. Further investigation is required for a more efficient use of steel reinforcement in this floor system. Refer to Appendix E for calculations.

For the Monongalia General Hospital, the flat slab system is very well suited for its function. As mentioned earlier, the flat slab allows for larger floor to floor heights, retards vibrations as well as provides an open plan to maximize the number of rooms that can be placed on each floor. Furthermore, with the limitation of the Hospital floors' square footage, the flat slab system allows for a maximum utilization of the open plan.

Alternate System: Girder-Slab (Figure 7)

The first alternate system that was analyzed was the girder-slab system. This system is most commonly used in mid to high rise residential buildings for its efficient use for steel and concrete hollow core planks (See Figure 7). The planks naturally being hollow can be used to run wiring, reducing the cost of raceways and conduits for lighting and electrical systems. Also, naturally these planks are lightweight compared to other concrete flooring systems, in effect reducing the overall building weight if implemented in the Hospital. The floor system, being precast concrete, allows for faster construction under any weather conditions.

On the other hand, the girder-slab system has significant design limitations on its span to depth ratio. The D-beams (dissymmetric beams) have a very short effective span length and is highly controlled by deflection (i.e. heavy loads over long spans will not work under this system). Due to this physical limitation of the beam, the bay sizes are required to be shorter than its alternatives. The lightweight nature of the floor system makes it vulnerable to floor vibrations which is a major issue for any type of building, let alone a hospital where not only people are temporarily housed but also major operations take place on a daily basis.

The girder-slab system designed for the Hospital makes use of DB9x41 beams and 8 inch hollow core concrete planks (See Appendix E for calculations). For this design, the bay size was decreased to 30'-4" by 15', in effect placing more columns on the plan and reducing the amount of usable floor area. If the bay size was to be kept constant, the D-beams available for design would have a larger depth, affecting floor to floor heights. Also, the design load had to be decreased to allow the use of this system. As such, the girder-slab system proved to be a nonviable alternate.

Alternate System: Composite Floor (Figure 8)

The 30'-4" by 30'-4" bay was analyzed for the feasibility of a composite floor system as an alternate floor system (see Figure 4 and 5). Composite floor systems are capable of carrying larger loads over larger spans and are usually a viable alternative to the existing flat slab system. This floor system is fast and relatively easy to construct on the field and allows for wider bay sizes, in effect allowing for more open space on plan. This floor system also allows for an effective acoustic barrier as well as a high fire safety rating.

The greatest problem with the composite floor system is floor vibrations and the possible decrease of floor to floor heights. Floor vibrations, as mentioned in the introduction of the girder-slab system could be a major issue when present in a hospital, and is a very expensive problem to solve and in many cases, almost impossible. To counter possible vibrations, the steel members could be designed to have a higher moment of inertia however this will affect the floor heights. Also, this system is a rather heavy floor system which adds a significant amount of weight on the building.

As mentioned earlier, the 30'-4" by 30'-4" bay was analyzed (see Appendix E for calculations). The floor system will be consisted of a 4.5" slab, 18 GA, 2" LOK-Floor with a two hour fire rating. On each square bay, the concrete and decking will be carried by two W14x26 beams spanning 30'-4" from the W18x175 girders on the edges of the bay. For this design, there is minimal effect on the floor to floor heights however the girder design was highly affected by deflection and the design process called for either a deep girder (a W30 shape) or a heavy and shallow girder. In the interest of floor to floor heights, a W18x175 was picked and the deflection limit was cleared. Also, having a heavier and stiffer beam will provide ample damping against floor vibrations.

Alternate System: Post-Tensioned Slab (Figure 9)

The third alternate floor system that was analyzed was a Post-Tensioned Slab system. Like the flat slab system, this floor system allows for relatively large bay sizes and thin floor thicknesses. With this in mind, this floor system can provide higher floor to floor heights, and significantly reduce the overall building weight. The floor system can also easily achieve ample fire rating.

On the other hand, there are major drawbacks to this floor system. The construction of this floor system is relatively expensive and time consuming. There are high risks during construction due to faulty anchoring of the strands and the damages are extremely hard to fix, delaying the project's schedule.

A one by three bay was analyzed for the feasibility of this system (see Figure 4) and calculations can be found in Appendix E. 1/2" diameter, 7 wire strands were used as the PT cable and a 9.5" thick slab was assumed. Further iterations in the design could be addressed to acquire a wider bay size. Also, through the calculations reinforcement was also required in addition to the PT cable. #8 and #4 bars were used to resist moments at the spans and the supports. The beauty of this floor system is its capability of making a thin yet durable floor. However considering that the floor system is to be implemented in a hospital, the cost for its use may seem a bit too excessive.

Conclusion

One existing floor system and three alternate floor systems were analyzed for Tech 2 and compared for feasibility when implemented for the Monongalia General Hospital. The existing flat slab system though the analyses seems to be the most viable floor system for the Hospital. On the other hand, the girder-slab system seems to be the least viable floor system, primarily due to its tendency for vibration as well as its short span, requiring more columns to be placed on the plan. The other two floor systems analyzed, the composite floor system and the post-tensioned slab system require further design iterations to develop a better understanding of how these systems can benefit the Hospital. Through the analysis of Tech 2, the composite floor system decreases the floor to floor height and there is still a high possibility of floor vibrations. On the other hand, the post-tensioned floor system could possibly increase the bay widths but for construction, this system is the most expensive. Below is a table summarizing the findings of the four floor systems.

Comparison of Floor Systems

	Flat Slab	*Girder-Slab*	*Composite*	*Post-Tensioned*
Depth	8"	9"	22.5"	9.5"
Weight	97 PSF	85 PSF	100 PSF	97 PSF
Story Height	-	Decreased	Decreased	Increased
Vibrations	Minimal	Significant	Moderate	Minimal
Cost (Relative)	Low	Low	Moderate	High
Feasibility	Existing	No	Yes	Yes

MONONGALIA GENERAL HOSPITAL

PRO-CON STRUCTURAL STUDY
OF ALTERNATE FLOOR SYSTEMS

APPENDIX A

PROJECT TEAM

Owner	**Monongalia General Hospital** 1200 J.D. Anderson Dr. Morgantown, WV 26505	Phone: 304-598-7690 Fax: 304-598-7693 Website: http://www.monhealthsys.org/
Architect and Interiors	**Freeman White, Inc.** 8025 Arrowbridge Blvd. Charlotte, NC 28273-5665	Phone: 704-523-2230 Fax: 704-523-2235 Website: http://www.freemanwhite.com/
Civil Engineer	**Alpha Associates, Inc.** 209 Prairie Ave. Morgantown, WV 26502	Phone: 304-296-8216 Fax: 304-296-8216 Website: http://www.alphaaec.com/
Construction Manager	**Turner Construction Company** Two PNC Plaza, 620 Liberty Ave., 27th Floor Pittsburgh, PA 15222-2719	Phone: 412-255-5400 Fax: 412-255-0249 Website: http://www.turnerconstruction.com/
Geotechnical and Environmental Consultant	**Potesta Engineers and Environmental Consultants** 125 Lakeview Drive Morgantown, WV 26508	Phone: 304-225-2245 Fax: 304-225-2246 Website: http://www.potesta.com/
Mechanical, Electrical, and Plumbing	**Freeman White, Inc.** 2300 Rexwoods Dr., Suite 300 Raleigh, NC 27607	Phone: 919-782-0699 Fax: 919-783-0139 Website: http://www.freemanwhite.com/
Structural Engineer	**Atlantic Engineering Services** 650 Smithfield St., Suite 1200 Pittsburgh, PA 15222	Phone: 412-338-9000 Fax: 412-338-0051 Website: http://www.aespj.com/

MONONGALIA GENERAL HOSPITAL

PRO-CON STRUCTURAL STUDY
OF ALTERNATE FLOOR SYSTEMS

APPENDIX B

FIGURES

Figure 1: Hospital Divided in Four Quads

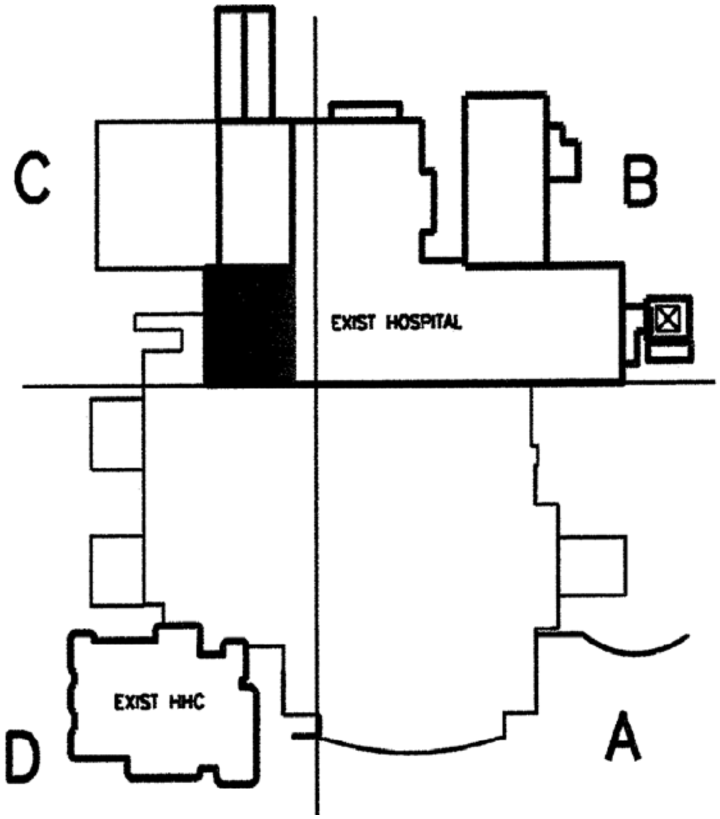
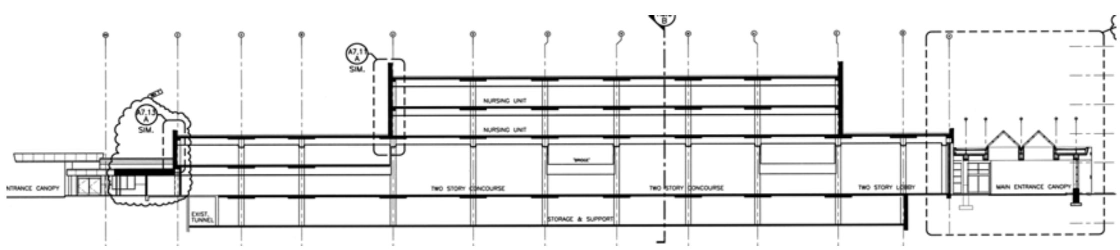
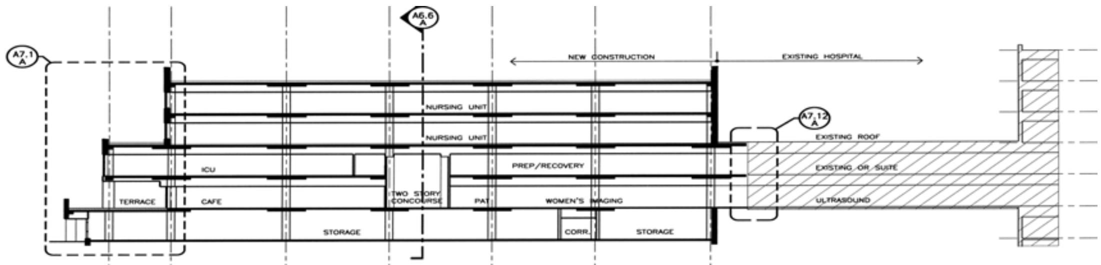


Figure 2: Cross Section of the Monongalia General Hospital



West Section



South Section

Figure 3: Location of Shear Walls (Colored in blue)

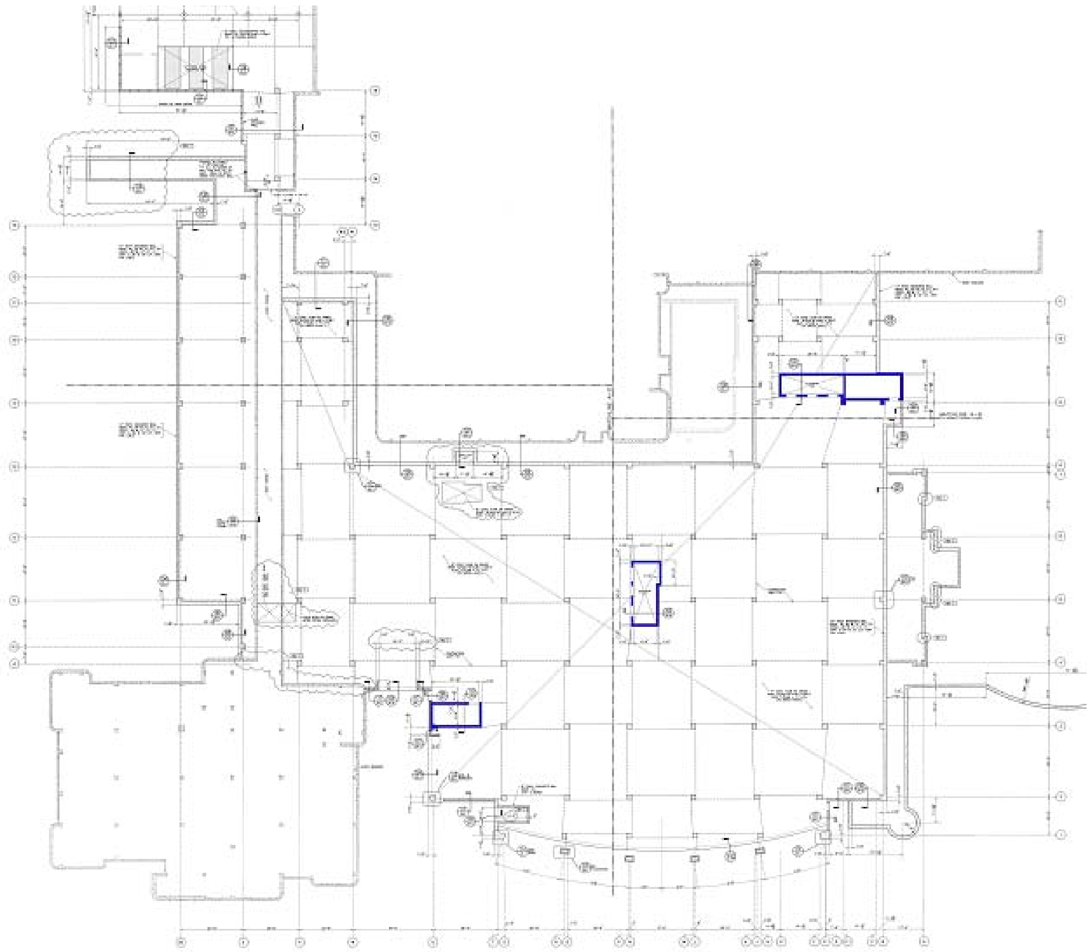


Figure 4: Typical Framing Plan (Taken from Quad A)

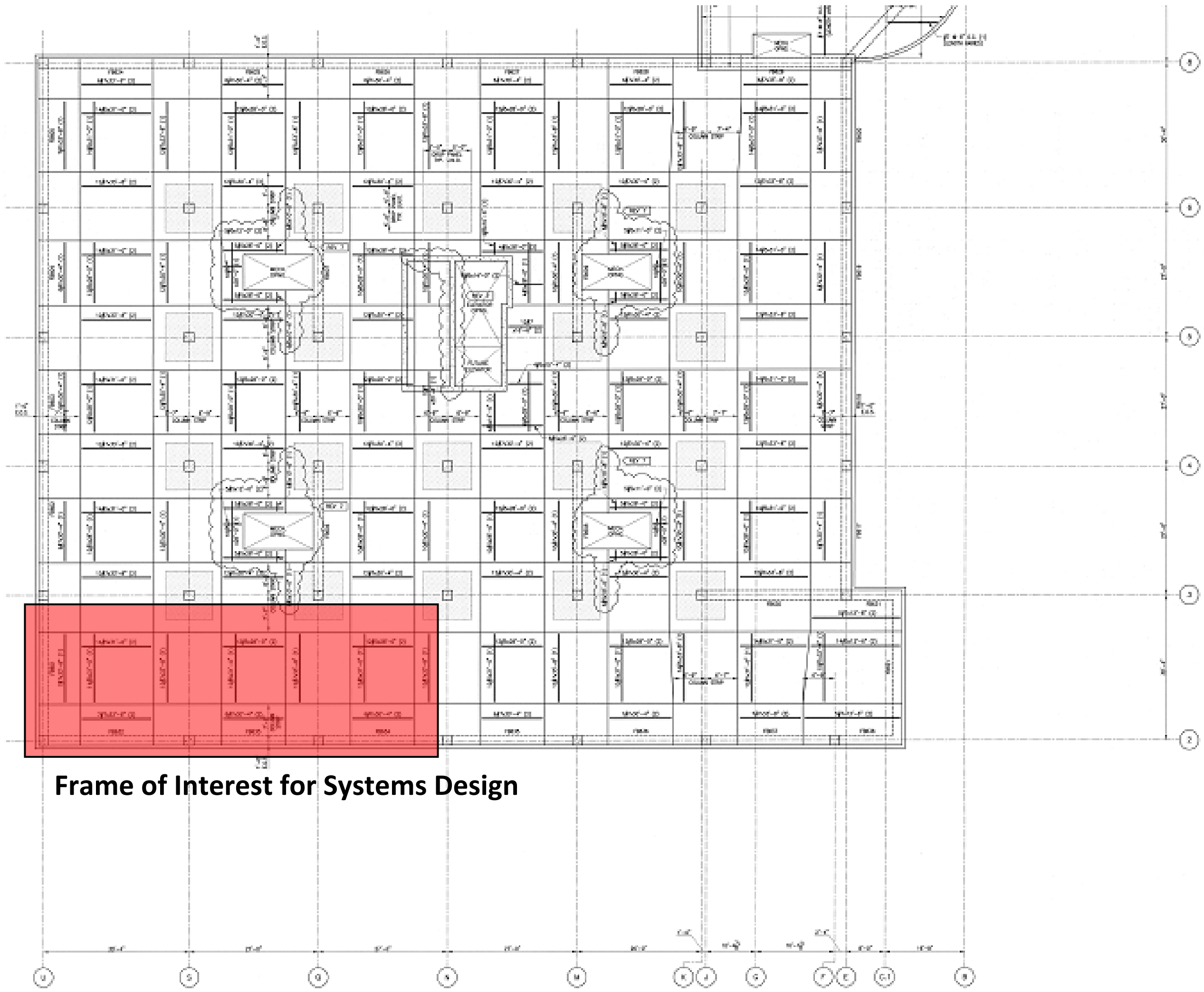


Figure 5: Typical Framing Plan (Taken from Quad A)

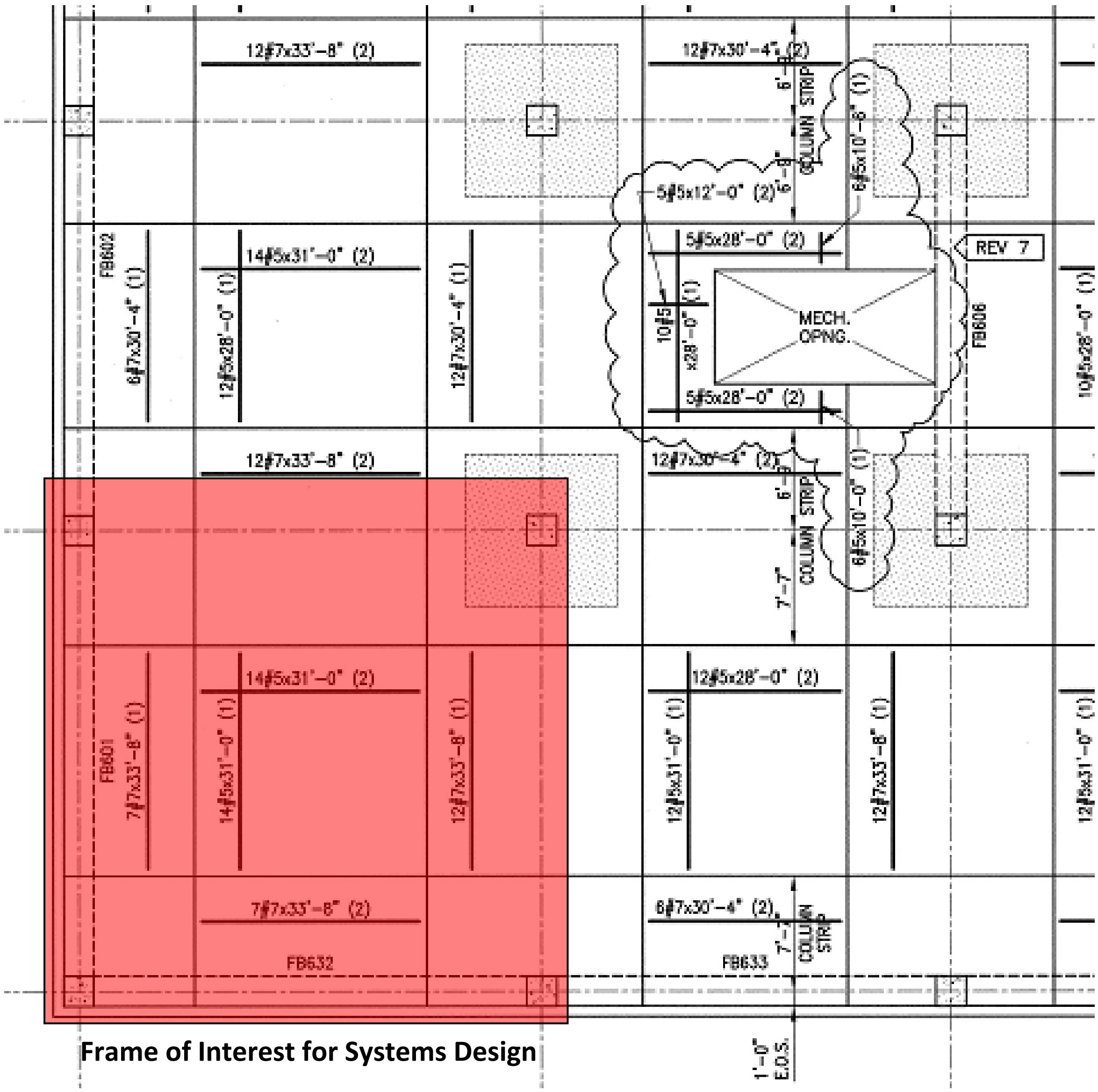
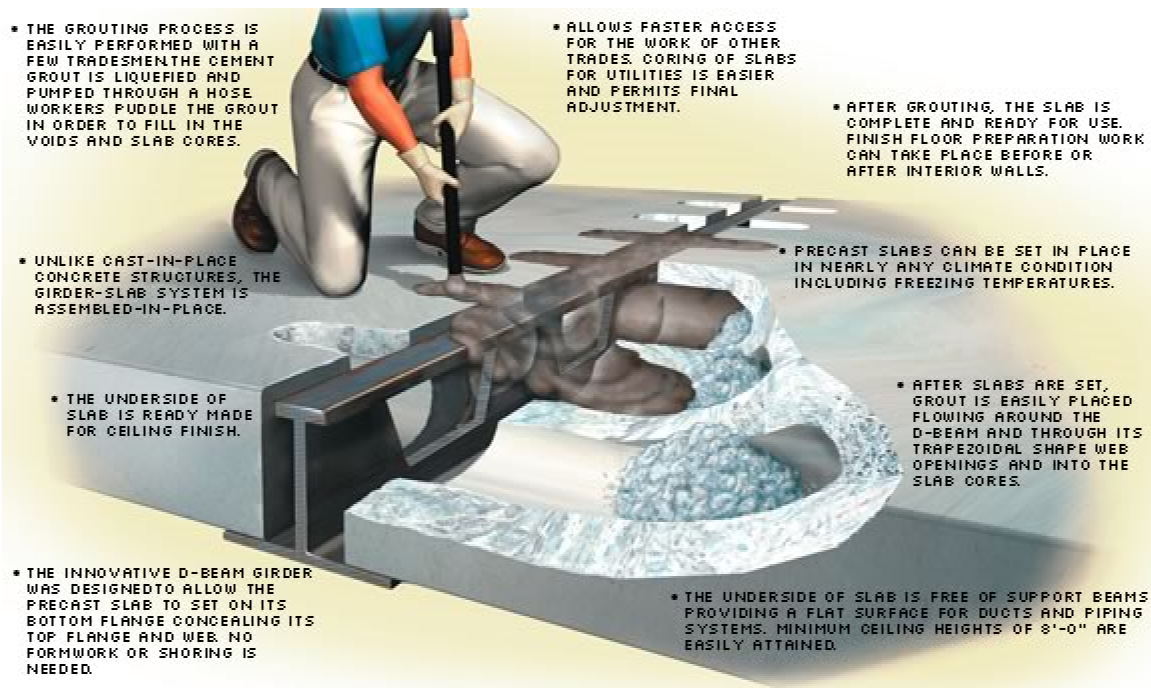


Figure 6: Flat Slab

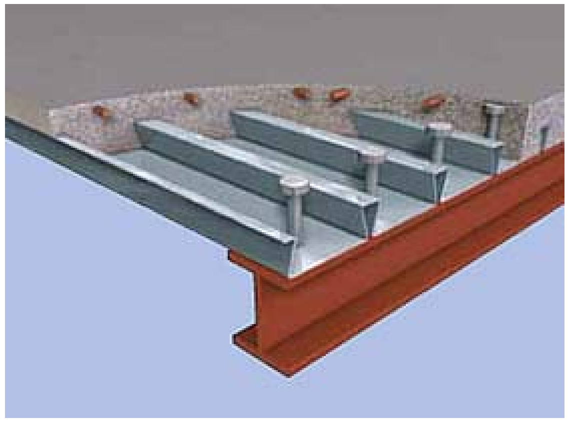
Taken from Interger-Software.co.uk

Figure 7: Girder Slab



Taken from Girder-Slab.com

Figure 8: Composite Floor



Taken from EpicMetals.com

Figure 9: Post-Tensioned Slab

Taken from Suncoast-PT.com

MONONGALIA GENERAL HOSPITAL

PRO-CON STRUCTURAL STUDY
OF ALTERNATE FLOOR SYSTEMS

APPENDIX C

PHOTOGRAPHS

Photograph 1: View from South-East

Photograph 2: Aerial Photo of the Monongalia General Hospital

Photograph 3: View from South-East showing the brick façade and curtain walls

MONONGALIA GENERAL HOSPITAL

PRO-CON STRUCTURAL STUDY
OF ALTERNATE FLOOR SYSTEMS

APPENDIX D

CODES

Type	Designed with	Analyzed with
Building	IBC 2000	IBC 2006
Structural	IBC 2003	IBC 2006
Plumbing	IPC 2000	-
Mechanical	IMC 2000	-
Electrical	NFPA 1999	-
Fire Safety	WV Fire Code 2002	-
Accessibility	ADA 1994	-
Energy	IEGC 2000	-
Fuel Gas	IFGC 2000	-
Sprinkler	NFPA 13	-

Construction Type: 1-A

Primary Occupancy: Institutional I-2

At the point of the project design phase, the building codes that were effective in Morgantown, WV are the ones listed above under the "Designed with" column. Today, the city of Morgantown has adopted the latest codes and ordinances.

The floor systems were designed as per ACI 318-08 and AISC 13th Edition Steel Construction Manual.

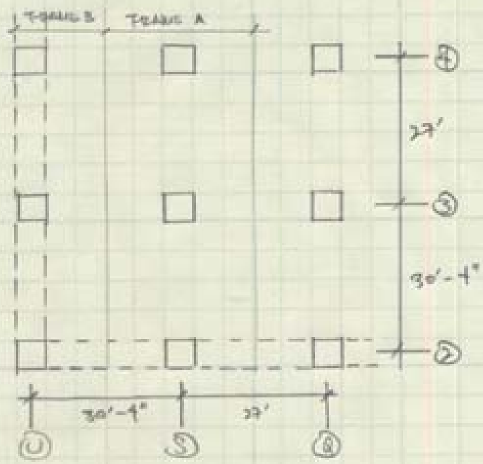
MONONGALIA GENERAL HOSPITAL

PRO-CON STRUCTURAL STUDY
OF ALTERNATE FLOOR SYSTEMS

APPENDIX E

CALCULATIONS

EXISTING SYSTEM ANALYSIS : FLAT SLAB



f'_c = 5000 psi
f_y = 60000 psi

NORMAL WEIGHT CONCRETE
8" SLAB

24" × 24" COLUMNS (TYPICAL)

- SLAB THICKNESS CHECK

$$t_{min} = \frac{l_n}{36}$$

$$\Rightarrow l_n = 30.333' - \left(\frac{24"}{12"/ft}\right) = 28.333'$$

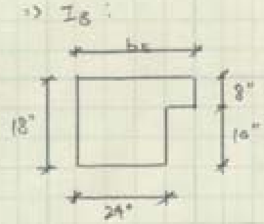
$$t_{min} = \frac{(28.333')(12"/ft)}{36} = 9.44" > 8"$$

⇒ HOWEVER, ACI 318-08, SECTION 9.5.3.2(b), t_{min} = 4" < 8", USE 8" SLAB.

- CHECK $\alpha > 0.8$ (IN LONG DIRECTION)

$$\alpha = \frac{I_B}{I_S}$$

⇒ I_B :



$b_e = b_w + h_w < b_w + 4t$

$= 24" + 10" < 24" + 4(8")$

$= 34" < 56"$ (USE 34")

$$\frac{b_e}{b_w} = \frac{34"}{24"} = 1.417$$

$$\frac{t}{h} = \frac{8"}{18"} = 0.444$$

$$k = \frac{1 + (b_e/b_w - 1)(t/h)\left[4 - 6(t/h) + 4(t/h)^2 + (b_e/b_w - 1)(t/h)^3\right]}{1 + (b_e/b_w - 1)(t/h)}$$

∴ k = 1.18.

→ CONT'D.

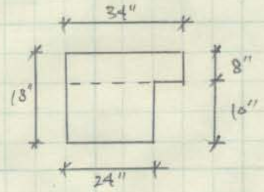
$$I_B = \frac{k(b_w h^3)}{12} = \frac{1.18(24'')(18'')^3}{12} = 13763.5\ in^4$$

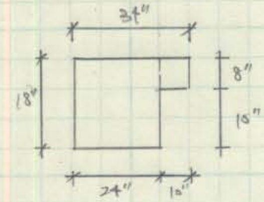
$\Rightarrow I_s$:

$$I_s = \frac{l_2 t^3}{12} = \frac{(30.333'/2)(12''/ft)(8'')^3}{12} = 7765.25\ in^4$$

$$\alpha = \frac{I_B}{I_s} = \frac{13763.5\ in^4}{7765.25\ in^4} = 1.77 > 0.8 \quad \text{(GOOD)}$$

- TORSIONAL CONSTANT.





$$C = \Sigma\left(1 - 0.63\frac{x}{y}\right)\left(\frac{x^3 y}{3}\right)$$

$$C_1 = \left(1 - 0.63\frac{8''}{34''}\right)\left(\frac{(8'')^3(34'')}{3}\right) + \left(1 - 0.63\frac{10''}{24''}\right)\left(\frac{(10'')^3(24'')}{3}\right)$$

$\therefore C_1 = 11098.5\ in^4$

$$C_2 = \left(1 - 0.63\frac{18''}{24''}\right)\left(\frac{(18'')^3(24'')}{3}\right) + \left(1 - 0.63\frac{8''}{10''}\right)\left(\frac{(8'')^3(10'')}{3}\right)$$

$\therefore C_2 = 25713.5\ in^4$ * CRITICAL (FRAME A, B)

- PARAMETERS

- FRAME A

$$I_s^{AC} = \frac{(28.665')(12''/ft)(8'')^3}{12} = 14677.2\ in^4$$

$$\beta_t = \frac{C}{2 I_s^{AC}} = \frac{25713.5\ in^4}{2(14677.2\ in^4)} = 0.741$$

$$\alpha = \frac{I_B}{I_s} = 0$$

$$\frac{l_2}{l_1} = \frac{28.665'}{28.665'} = 1.0$$

$$\frac{\alpha l_2}{l_1} = 0$$

→ CONT'D

- FRAME B

$I_s^{\beta_b} = \frac{(13.167')(12''/ft)(8'')^3}{12} = 7762.25\ in^4$

$\beta_t = \frac{21753.5\ in^4}{2(7762.25\ in^4)} = 1.4.$

$\alpha = 1.77$

$\frac{l_2}{l_1} = 1.0$

$\frac{\alpha l_2}{l_1} = 1.77.$

- TOTAL FACTORED MOMENT AND DISTRIBUTIONS

- FRAME A.

$M_o = \frac{w_u l_2 l_1^2 (1 - \frac{2c}{3l_1})^2}{8}$

$\Rightarrow w_u = 1.2[(8''/12''/ft)(145\ pcf) + 20\ psf] + 1.6(80\ psf) = 268\ psf.$

$M_o = \frac{(268\ psf)(28.665)(28.665)^2(1 - \frac{2(24'')}{(28.665')(12''/ft)})^2}{8} = 682.8\ k \cdot ft$

$M^-_{EXT} = 0.25 M_o = 170.7\ k \cdot ft$ $M^+_{INT} = 0.35 M_o = 238.9\ k \cdot ft$

$M^+_{EXT} = 0.52 M_o = 355\ k \cdot ft$ $M^-_{INT} = 0.65 M_o = 443.8\ k \cdot ft.$

$M^-_{INT} = 0.7 M_o = 477.96\ k \cdot ft$

- SUMMARY:

	355	238.9
170.7	477.96	443.8

- FRAME B

$M_o = \frac{(268\ psf)(15.665')(28.665')^2(1 - \frac{2(24'')}{28.665'(12''/ft)})^2}{8} = 309.1\ k \cdot ft$

→ CONT'D.

$M^-_{EXT} = 0.3M_o = 92.73$ k·ft $M^+_{INT} = 0.35M_o = 108.2$ k·ft

$M^+_{EXT} = 0.5M_o = 154.5$ k·ft $M^-_{INT} = 0.65M_o = 200.9$ k·ft.

$M^-_{INT} = 0.7M_o = 216.4$ k·ft

- SUMMARY.

	154.5		108.2
92.73		216.4	200.9

- DISTRIBUTION TO MS, CS.

  - FRAME A.

    - EXTERIOR NEGATIVE MOMENTS. (ACI 318-08 SECTION 13.6.4.2)

		l_2/l_1 = 1.0
$\alpha(l_2/l_1) = 0$	$\beta = 0$	100
	$\beta = 0.741$	x
	$\beta = 2.5$	75

⇒ INTERPOLATING...

$x = 92.6$

-170.7 k·ft
- 92.6% TO CS (-158.1 k·ft)
- 7.4% TO MS (-12.6 k·ft)

* $\alpha = 0$, NO BEAMS

    - POSITIVE MOMENTS (ACI 318-08 SECTION 13.6.4.4)

355 k·ft
- 60% TO CS (213 k·ft)
- 40% TO MS (142 k·ft)

* $\alpha = 0$, NO BEAMS

238.9 k·ft
- 60% TO CS (143.34 k·ft)
- 40% TO MS (95.56 k·ft)

→ CONT'D.

- INTERIOR NEGATIVE MOMENTS (ACI 318-08 SECTION 13.6.4.1)

- 477.96 k·ft — 75% TO CS (358.5 k·ft); 15% TO MS (119.49 k·ft)   * α = 0, NO BEAMS

- 443.8 k·ft — 75% TO CS (332.9 k·ft); 15% TO MS (110.8 k·ft)

- SUMMARY

	M^-_{EXT}	M^+_{EXT}	M^-_{INT}	M^-_{INT}	M^+_{INT}
TOTAL	-170.7	355	-477.96	-443.8	238.9
CS	-158.1	213	-358.5	-332.9	143.34
MS	-12.6	142	-119.49	-110.8	95.56

- FRAME B

- EXTERIOR NEGATIVE MOMENTS (ACI 318-08 SECTION 13.6.4.2)

$\alpha\, l_2/l_1 > 1$	l_2/l_1	1.0
	$\beta = 0$	100
	$\beta = 0.741$	x
	$\beta = 2.5$	75

⇒ INTERPOLATING … $x = 92.6$

- 92.73 k·ft — 92.6% TO CS (-85.9 k·ft) — 85% TO BEAM (-72.99 k·ft); 15% TO SLAB (-12.9 k·ft)
- 7.4% TO MS (-6.83 k·ft)

→ CONT'D.

- POSITIVE MOMENTS (ACI 318-08 SECTION 13.6.4.4)

154.5 k·ft — 75% TO CS (115.5 k·ft) — 85% TO BEAM (98.18 k·ft); 15% TO SLAB (17.32 k·ft)
154.5 k·ft — 25% TO MS (38.6 k·ft)

108.2 k·ft — 75% TO CS (81.2 k·ft) — 85% TO BEAM (69 k·ft); 15% TO SLAB (12 k·ft)
108.2 k·ft — 25% TO MS (27.1 k·ft)

- INTERIOR NEGATIVE MOMENTS (ACI 318-08 SECTION 13.6.4.1)

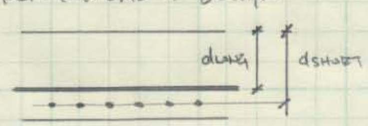
-216.4 k·ft — 75% TO CS (-162.3 k·ft) — 85% TO BEAM (-137.9 k·ft); 15% TO SLAB (-24.35 k·ft)
-216.4 k·ft — 25% TO MS (-54.1 k·ft)

-200.9 k·ft — 75% TO CS (-150.7 k·ft) — 85% TO BEAM (-128.1 k·ft); 15% TO SLAB (-22.6 k·ft)
-200.9 k·ft — 25% TO MS (-50.2 k·ft)

- SUMMARY.

	M^-_{EXT}	M^+_{EXT}	M^-_{INT}	M^-_{INT}	M^+_{INT}
TOTAL	-92.73	154.5	-216.4	-200.9	108.2
CS	-12.9	17.32	-24.35	-22.6	12
MS	-6.83	38.6	-54.1	-50.6	27.1
BEAM	-72.99	98.18	-137.9	-128.1	69.

- REINFORCEMENT DESIGN



$d_{SHORT} = 8" - 0.75" - \frac{1}{2}(5/8") = 6.93"$

$d_{LONG} = 6.93" - (5/8") = 6.31"$

→CONT'D.

COLUMN STRIP DESIGN FRAME A

Item	Description	Exterior Span			Interior Span	
		M^-_{EXT}	M^+_{INT}	M^-_{INT}	M^-	M^+
1	M_n	-158.1	213	-358.5	-332.9	143.34
2	b_{CS}	182	182	182	182	182
3	d_{eff}	6.31	6.31	6.31	6.31	6.31
4	$M_u = M_n/\phi$	-175.67	236.67	-398.33	-369.89	159.27
5	$M_n(12/b)$	-10.42	14.04	-23.64	-21.95	9.45
6	$R=M_u/bd^2$	-291	392	-660	-613	264
7	ρ	0.00051	0.0068	0.00118	0.00111	0.0045
8	$A_{steel} = \rho bd$	0.59	7.81	1.36	1.27	5.17
9	$A_{s,min} = 0.002bt$	2.91	2.91	2.91	2.91	2.91
10	$N = A_s/(0.31)$	5	25	9	9	17
11	$N_{min} = w_{strip}/2t$	11	11	11	11	11

MIDDLE STRIP DESIGN FRAME A

Item	Description	Exterior Span			Interior Span	
		M^-_{EXT}	M^+_{INT}	M^-_{INT}	M^-	M^+
1	M_n	-12.6	142	-119.49	-110.8	95.56
2	b_{MS}	91	91	91	91	91
3	d_{eff}	6.93	6.93	6.93	6.93	6.93
4	$M_u = M_n/\phi$	-14.00	157.78	-132.77	-123.11	106.18
5	$M_n(12/b)$	-1.66	18.73	-15.76	-14.61	12.60
6	$R=M_u/bd^2$	-38	433	-365	-338	292
7	ρ	0.0007	0.0078	0.0063	0.0057	0.0052
8	$A_{steel} = \rho bd$	0.44	4.92	3.97	3.59	3.28
9	$A_{s,min} = 0.002bt$	1.46	1.46	1.46	1.46	1.46
10	$N = A_s/(0.31)$	2	16	13	12	11
11	$N_{min} = w_{strip}/2t$	6	6	6	6	6

COLUMN STRIP DESIGN FRAME B

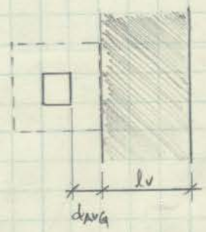
Item	Description	Exterior Span			Interior Span	
		M^-_{EXT}	M^+_{INT}	M^-_{INT}	M^-	M^+
1	M_n	-12.9	17.32	-24.35	-22.6	12
2	b_{CS}	91	91	91	91	91
3	d_{eff}	6.31	6.31	6.31	6.31	6.31
4	$M_u = M_n/\phi$	-14.33	19.24	-27.06	-25.11	13.33
5	$M_n(12/b)$	-1.70	2.28	-3.21	-2.98	1.58
6	$R=M_u/bd^2$	-47	64	-90	-83	44
7	ρ	0.0007	0.0011	0.0015	0.0014	0.00068
8	$A_{steel} = \rho bd$	0.40	0.63	0.86	0.80	0.39
9	$A_{s,min} = 0.002bt$	1.27	1.27	1.27	1.27	1.27
10	$N = A_s/(0.31)$	2	2	4	4	1
11	$N_{min} = w_{strip}/2t$	6	6	6	6	6

MIDDLE STRIP DESIGN FRAME B

Item	Description	Exterior Span			Interior Span	
		M^-_{EXT}	M^+_{INT}	M^-_{INT}	M^-	M^+
1	M_n	-4.5	33.33	-40.83	-37.91	20.42
2	b_{MS}	45.5	45.5	45.5	45.5	45.5
3	d_{eff}	6.93	6.93	6.93	6.93	6.93
4	$M_u = M_n/\phi$	-5.00	37.03	-45.37	-42.12	22.69
5	$M_n(12/b)$	-1.19	8.79	-10.77	-10.00	5.39
6	$R=M_u/bd^2$	-27	203	-249	-231	125
7	ρ	0.0004	0.0034	0.0042	0.0036	0.0021
8	$A_{steel} = \rho bd$	0.13	1.07	1.32	1.14	0.66
9	$A_{s,min} = 0.002bt$	0.64	0.64	0.64	0.64	0.64
10	$N = A_s/(0.31)$	2	2	2	2	2
11	$N_{min} = w_{strip}/2t$	3	3	3	3	3

- CHECK SHEAR

- ONE WAY ACTION.



$$d_{AVG} = \frac{6.93" + 6.31"}{2} = 6.62"$$

$$l_v = \frac{23.665'}{2} - \frac{2'}{2} - \frac{6.62"}{12"/ft} = 12.78'$$

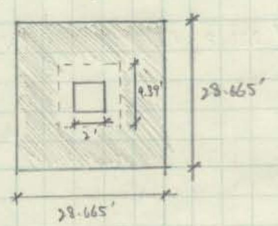
$$V_u = (268\,PSF)(12.78')(28.665') = 98.18k.$$

$$\phi V_n = 0.75(2)\sqrt{f'_c}\, b_w d$$

$$= 0.75(2)\sqrt{5000\,psi} \cdot (28.665')(12"/ft)(6.62" - \frac{6.62"}{4})$$

$$\therefore \phi V_n = 181.14k > 98.18k \quad (GOOD)$$

- PUNCH SHEAR.



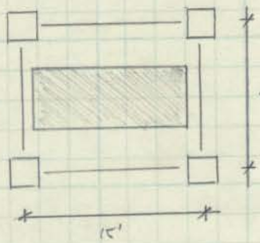
$$V_u = (268\,PSF)(28.665')^2 - (2')^2 = 219.13k.$$

$$V_n \leq \begin{cases} 4\sqrt{f'_c}\, b_o d = 4\sqrt{5000\,psi}\,(4 \times 9.89')(12"/ft)(6.62") = 844.8k \\ (2 + \frac{4}{\beta_c})\sqrt{f'_c}\, b_o d = (2 + \frac{4}{1})\sqrt{5000\,psi}\,(4 \times 9.89')(12"/ft)(6.62") = 1267.25k. \\ (\frac{\alpha_s}{b_o/d} + 2)\sqrt{f'_c}\, b_o d = (\frac{40}{b_o/d})\sqrt{5000\,psi}\,(4 \times 9.89')(12"/ft)(6.62") = 547.7k. * \end{cases}$$

$$\phi V_n = 0.75(547.7k) = 410k > 219.13k \quad (GOOD)$$

END OF ANALYSIS

DESIGN: GIRDER SLAB.



PLANK f'_c = 5000 psi, DL = 60 PSF, $DL_{TOPPING}$ = 25 PSF.
GROUT f'_c = 4000 psi

8" HOLLOW CORE PLANK, 30.333'
SPAN = 15'

- ASSUME LIVE LOAD = 40 PSF
- USE DB 9x41, f_y = 50 ksi

- DEFLECTION LIMIT

$$\Delta_{ALLOW.} = \frac{L}{360} = \frac{(15')(12''/ft)}{360} = 0.5''$$

- INITIAL LOAD (PRECOMPOSITE)

$$M_{DL} = \frac{w l_1 l_2^2}{8} = \frac{(0.06\,ksf)(30.333')(15')^2}{8} = 51.2\,k\cdot ft < 61\,k\cdot ft \quad (GOOD)$$

$$\Delta_{DL} = \frac{5}{384}\cdot\frac{w l_1 l_2^4}{EI}$$

$$= \frac{5}{384}\cdot\frac{(0.06\,ksf)(30.333')(15')^4(12''/ft)^3}{(159\,in^4)(29000\,ksi)} = 0.449''$$

- TOTAL LOAD (COMPOSITE)

$$M_{SUP} = \frac{(30.333')(0.02\,ksf + 0.04\,ksf + 0.025\,ksf)(15')^2}{8} = 72.5\,k\cdot ft.$$

$$M_{TL} = 51.2\,k\cdot ft + 72.5\,k\cdot ft = 123.6\,k\cdot ft.$$

$$S_{REQ} = \frac{M_{TL}}{0.6 f_y} = \frac{(123.6\,k\cdot ft)(12''/ft)}{0.6(50\,ksi)} = 49.5\,in^3 < 62.1\,in^3 \quad (GOOD)$$

$$\Delta_{SUP} = \frac{5}{384}\cdot\frac{(30.333')(0.02\,ksf + 0.04\,ksf + 0.025\,ksf)(15')^4(12''/ft)^3}{(332\,in^4)(29000\,ksi)} = 0.03'' < 0.5'' \quad (GOOD)$$

- COMPRESSIVE STRESS ON CONCRETE.

$$N = \frac{E_s}{E_c} = \frac{29000\,ksi}{57000\sqrt{5000\,psi}} = 7.195$$

$$S_{TC} = NS_T = 7.195(62.1\,in^3) = 446.8\,in^3$$

→ CONT'D.

$f_c = \frac{M_{SUP}}{S_{TC}} = \frac{(72.5k \cdot ft)(12''/ft)}{446.18 in^3} = 1.95 ksi$

$F_c = 0.45f'_c = 0.45(5ksi) = 2.25ksi > 1.95ksi$ (GOOD)

- CHECK BOTTOM FLANGE TENSION CAPACITY

$f_b = \frac{M_{DL}}{S_b} + \frac{M_{SUP}}{S_{bTR}} = \frac{(51.2k \cdot ft)(12''/ft)}{51 in^3} + \frac{(72.5k \cdot ft)(12''/ft)}{77.7 in^3} = 23.2ksi$

$F_b = 0.9(50ksi) = 45ksi > 23.2ksi$ (GOOD)

- SHEAR CAPACITY

$w_L = 145 psf$

$W = (0.145 ksf)(30.333') = 4.398k/ft$

$V = \frac{(4.398k/ft)(15')}{2} = 32.99k$

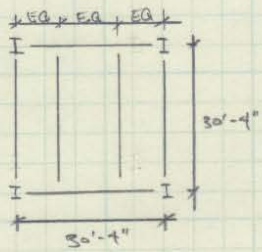
$f_v = \frac{32.99k}{(0.375'')(5.23'')} = 16.7 ksi$

$F_v = 0.4(50ksi) = 20ksi > 16.7ksi$ (GOOD)

∴ USE DB 9x41 AND 8" HOLLOW CORE PLANK

END OF ANALYSIS

DESIGN: COMPOSITE FLOOR



f'_c : 5000 psi
F_y : 50 ksi.

- SLAB DESIGN.
  - TRY 4.5" SLAB, 18 GA, 2" LOK-FLOOR.
    - ALLOWABLE LOAD: 270 PSF > 268 PSF (GOOD)
    - MAXIMUM UNSHORED SPAN; 10.83' > 10.111' (GOOD)

      => DEFLECTION, BENDING, SHEAR CONSIDERED.

- BEAM DESIGN

$$M_U = \frac{(268\,\text{PSF})(10.111')(30.333')^2}{8 \cdot (1000\,\text{lb/k})} = 308.23\ \text{k}\cdot\text{ft}.$$

- TRY W14×26.
  - ASSUME $a = 1.0"$

$$Y_2 = 4.5" - \frac{1.0"}{2} = 4.0"$$

$$b_{eff} \le \begin{cases} \text{SPACING} = (10.111')(12"/\text{ft}) = 121.32" \\ \text{SPAN}/4 = (30.333'/4)(12"/\text{ft}) = 91" \text{ * CRITICAL.} \end{cases}$$

PNA #1

. ϕM_p = 316 k·ft > 308.23 k·ft (GOOD)

ΣQ_N = 385 k.

- CHECK ASSUMPTION

$$a = \frac{\Sigma Q_N}{0.85 f'_c\, b_{eff}} = \frac{385\text{k}}{0.85(5\text{ksi})(91")} = 0.995" < 1.0" \quad \text{(GOOD)}$$

∴ USE W14×26.

→ CONT'D.

- CHECK NUMBER OF SHEAR STUDS.

$\frac{w_L}{h_L} = \frac{6''}{2''} = 3'' > 1.5'' \Rightarrow q_n = 21.0k.$

- ASSUMING WEAK POSITION

$\#\text{STUDS} = \frac{385k}{21.0k} = 18.33 \text{ STUDS} \Rightarrow \text{USE } 19 \text{ STUDS}$

- CHECK DEFLECTION
  - LIMIT

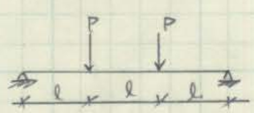
$\frac{L}{360} = \frac{(30.333')(12''/ft)}{360} = 1.01''$

- DEFLECTION

$\Delta_{LL} = \frac{5}{384} \cdot \frac{(0.08ksf)(10.111')(30.333')^4(12''/ft)^3}{(29000ksi)(707in^4)} = 0.743'' < 1.01'' \text{ (GOOD)}$

∴ USE W14 × 26 ⟨19⟩

- GIRDER DESIGN.



$P = \left(\frac{(268 PSF)(15.1665')(10.111')}{1000 lb/k}\right) \cdot 2 = 81.2k.$

- ASSUMING PLASTIC MOMENTS,

$M_u = P \cdot l = (81.2k)(10.111') = 821k \cdot ft.$

$Z = \frac{M_u}{F_y} = \frac{(821k \cdot ft)(12''/ft)}{50ksi} = 197.043 in^3.$

- TRY W24 × 76, $Z = 200 in^3$
  - CHECK DEFLECTION

$\Delta = \frac{1}{28} \cdot \frac{(81.2k)(30.333')^3(12''/ft)^3}{(29000ksi)(2100in^4)} = 2.3'' > \frac{(30.333')(12''/ft)}{240} = 1.5'' \text{ (NO GOOD)}$

→ CONT'D.

- CHECK AGAINST DEFLECTION

$$\frac{(30.333')(12''/ft)}{240} = 1.5''$$

$$1.5'' = \frac{(81.2k)(30.333')^3(12''/ft)^3}{28(29000ksi)(I)}$$

$I \geq 3215.13 in^4$

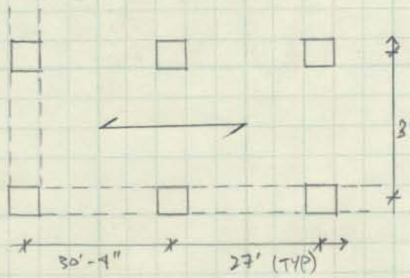
USE W18x175, $I = 3450 in^4$

- SUMMARY

USE: 4.5" SLAB, 18GA, 2" LOK-FLOOR
W14x26 <19> FOR BEAM
W18x175 FOR GIRDER.

END OF ANALYSIS

DESIGN; POST-TENSIONED SLAB.



$f'_c = 5000psi$ 24"×24" COLUMN (TYP.)
$f'_{ci} = 3000psi$
$f_y = 60ksi.$

1/2" Φ, 7 WIRE STRANDS, $A = 0.153in^2$
$f_{pu} = 270ksi.$

- POST-TENSIONING.
  - ESTIMATED PRESTRESS LOSSES = 15ksi.

    $f_{se} = 0.7 f_{pu} - \text{LOSSES} = 0.7(270ksi) - 15ksi = 174 ksi.$

    $P_{eff} = A \times f_{se} = (0.153in^2)(174 psi) = 26.6k/\text{TENDON}.$

- PRIMARY SLAB THICKNESS

  $\frac{l}{36} = \frac{(30.333' - 2')(12''/ft)}{36} = 9.44'' \Rightarrow \text{USE } 9.5''$

- SECTION PROPERTIES

  $A = bh = (30.333')(12''/ft)(9.5'') = 3458 in^2$

  $S = \frac{bh^2}{6} = \frac{(30.333')(12''/ft)(9.5'')^2}{6} = 5475.1 in^3$

- DESIGN PARAMETERS
  - ASSUME CLASS U.
    - AT TIME OF JACKING

      $f'_{ci} = 3ksi$

      $\text{COMPRESSION} = 0.6f'_{ci} = 0.6(3000psi) = 1800psi.$

      $\text{TENSION} = 3\sqrt{f'_{ci}} = 3\sqrt{3000psi} = 164 psi.$

→ CONT'D.

- AT SERVICE

  $f'_c = 5\text{ksi}$

  COMPRESSION $= 0.45 f'_c = 0.45(5000 \text{ psi}) = 2250 \text{ psi}$

  TENSION $= 6\sqrt{f'_c} = 6\sqrt{5000 \text{psi}} = 424 \text{ psi}.$

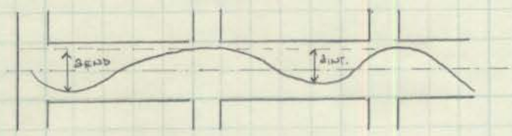
- TARGET LOAD BALANCE

  $$0.75 w_{DL} = 0.75\left[\frac{(9'')(145 \text{pcf}) + 20 \text{psf}}{12''}\right] = 101.1 \text{ psf}.$$

- TENDON PROFILE

  $a_{INT} = 9.5'' - 1'' = 8.5''$

  $$a_{END} = \frac{9.5'' + 4''}{2} - 1.75'' = 8.5''$$



- PRESTRESSED FORCE REQUIRED TO BALANCE 75% SELFWEIGHT

  $$w_B = 0.75 w_{DL,S} = \frac{0.75(145 \text{pcf})(9.5'')(30.333')}{(12''/\text{ft})(1000 \text{ lb/k})} = 2.61 \text{ k/ft}.$$

  $$P = \frac{w_B l^2}{8 a_{END}} = \frac{(2.61\text{k/ft})(30.333')^2}{8(8.5''/12''/\text{ft})} = 423.95\text{k}.$$

- PRECOMPRESSION ALLOWANCE

  - NUMBER OF TENDONS

    $$\frac{423.95\text{k}}{26.6\text{k/TENDON}} = 15.94 \Rightarrow \text{USE 16 TENDONS.}$$

  - ACTUAL FORCE FOR BONDED TENDONS.

    $P_{ACT.} = (16 \text{ TENDONS})(26.6\text{k/TENDON}) = 425.6\text{k}.$

  - BALANCED LOAD

    $$w_{BAL} = \left(\frac{425.6\text{k}}{423.95\text{k}}\right)(2.61\text{k/ft}) = 2.62\text{k/ft}.$$

→CONT'D.

- ACTUAL PRECOMPRESSION STRESS.

$\frac{P_{ACT}}{A} = \frac{(425.6k)(1000 lb/k)}{3459 in^2} = 123.1 psi < 125 psi$ (NO GOOD)

⇒ USE 18 TENDONS.

$P_{ACT.} = (18 \text{ TENDONS})(26.6k/\text{TENDON}) = 478.8k.$

$w_{BAL} = \left(\frac{478.8k}{423.95k}\right)(2.61k/ft) = 2.95 k/ft.$

$\frac{P_{ACT}}{A} = \frac{(478.8k)(1000 lb/k)}{3459 in^2} = 138.4 psi > 125 psi$ (GOOD)

$< 300 psi$ (GOOD)

- INTERIOR SPAN FORCE

$P = \frac{(2.61k/ft)(27')^2}{8\,(8.5''/12''/ft)} = 335k < 423.95k$

⇒ LESS FORCE REQUIRED AT INTERIOR.

$w_B = \frac{(423.95k)(8)(8.5'')}{(27')^2\,(12''/ft)} = 3.3k/ft.$

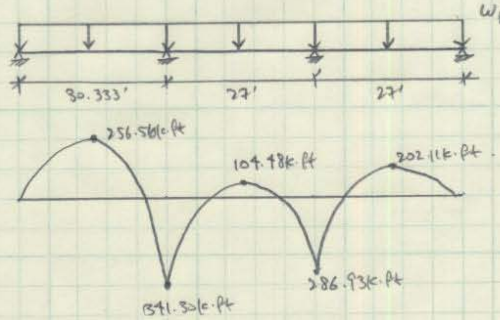
$\frac{w_B}{w_{DL}} = \frac{3.3k/ft}{3.48k/ft} = 94.8\% < 100\%$ (GOOD)

∴ $P_{EFF} = 423.95k.$

- SLAB STRESSES

- DEAD LOAD MOMENTS

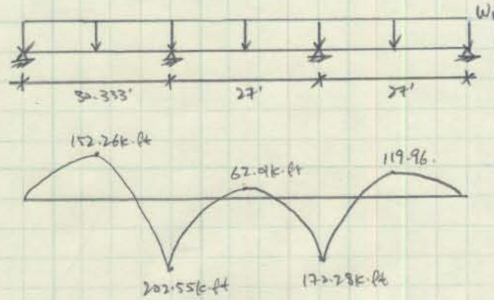
$w_{DL} = \left[\frac{(145pcf)(9'')}{12''/ft} + 20 psf\right](27') = 3.64k.$



→ CONT'D.

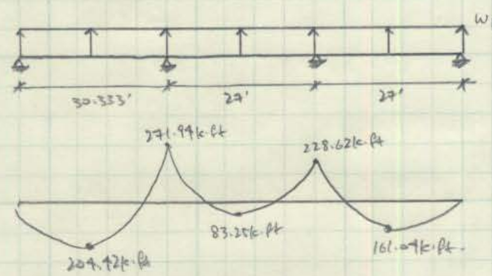
- LIVE LOAD MOMENTS

$$W_{LL} = \frac{(80\,PSF)(27')}{1000\,lb/k} = 2.16\,k/ft.$$



- BALANCED MOMENTS

$$W_{BAL} = \frac{3.64\,k/ft + 2.16\,k/ft}{2} = 2.9\,k/ft.$$



- STRESSES AFTER JACKING (DL + PT)

- INTERIOR SPAN

$$f_{TOP} = \frac{-M_{INT_{DL}} + M_{INT_{BAL}}}{S} - \frac{P_{ACT}}{A}$$

$$= \frac{(-104.48\,k\cdot ft + 83.25\,k\cdot ft)(12''/ft)(1000\,k/ft)}{5475.11\,in^3} - 138.4\,psi$$

$$= 44.1\,psi < 164\,psi \quad (GOOD)$$
(TENSION)

$$f_{BOT} = \frac{M_{INT_{DL}} - M_{INT_{BAL}}}{S} - \frac{P_{ACT}}{A}$$

$$= \frac{(104.48\,k\cdot ft - 83.25\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$$

$$= -320.8\,psi < 1800\,psi \quad (GOOD)$$
(COMPRESSION)

→ CONT'D

- END SPAN

$f_{TOP} = \frac{(-256.56\,k\cdot ft + 204.92\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= -252.7\,psi < 1800\,psi$ (GOOD)
(COMPRESSION)

$f_{BOT} = \frac{(256.56\,k\cdot ft - 204.92\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= -24.12\,psi < 1800\,psi$ (GOOD)
(COMPRESSION)

- SUPPORTS

$f_{TOP} = \frac{M_{INT\,DL} - M_{INT\,BAL}}{S} - \frac{P_{ACT}}{A}$

$= \frac{(341.30\,k\cdot ft - 271.94\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= 13.62\,psi < 164\,psi$ (GOOD)
(TENSION)

$f_{BOT} = \frac{-M_{INT\,DL} + M_{INT\,BAL}}{S} - \frac{P_{ACT}}{A}$

$= \frac{(-341.30\,k\cdot ft + 271.94\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= -290.53\,psi < 1800\,psi$ (GOOD)
(COMPRESSION)

- STRESSES AT SERVICE LOAD. (DL + LL + PT)

- INTERIOR SPAN.

$f_{TOP} = \frac{-M_{INT\,DL} - M_{INT\,LL} + M_{INT\,BAL}}{S} - \frac{P_{ACT}}{A}$

$= \frac{(-104.48\,k\cdot ft - 62.01\,k\cdot ft + 83.25\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= -320.84\,psi < 2250\,psi$ (GOOD)
(COMPRESSION)

→ CONT'D.

$f_{BOT} = \dfrac{M_{INT\,DL} + M_{INT\,LL} - M_{INT\,BAL}}{S} - \dfrac{P_{ACT}}{A}$

$= \dfrac{(107.48\,k\cdot ft + 62.01\,k\cdot ft - 83.25\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= 44.04\,psi < 424\,psi$ (GOOD)
(TENSION)

- END SPAN.

$f_{TOP} = \dfrac{(-256.56\,k\cdot ft - 152.26\,k\cdot ft + 204.42\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^2} - 138.4\,psi$

$= -586.4\,psi < 2250\,psi$ (GOOD)
(COMPRESSION)

$f_{BOT} = \dfrac{(256.56\,k\cdot ft + 152.26\,k\cdot ft - 204.42\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= 309.59\,psi < 424\,psi$ (GOOD)
(TENSION)

- SUPPORTS

$f_{TOP} = \dfrac{M_{INT\,DL} + M_{INT\,LL} - M_{INT\,BAL}}{S} - \dfrac{P_{ACT}}{A}$

$= \dfrac{(341.30\,k\cdot ft + 202.55\,k\cdot ft - 271.94\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= 457.55\,psi > 424\,psi$ (NO GOOD)
(TENSION)

=> MUST INCREASE NUMBER OF TENDONS AND/OR INCREASE f'_c

$f_{BOT} = \dfrac{-M_{INT\,DL} - M_{INT\,LL} + M_{INT\,BAL}}{S} - \dfrac{P_{ACT}}{A}$

$= \dfrac{(-341.30\,k\cdot ft - 202.55\,k\cdot ft + 271.94\,k\cdot ft)(12''/ft)(1000\,lb/k)}{5475.11\,in^3} - 138.4\,psi$

$= -740.9\,psi < 2250\,psi$ (GOOD)
(COMPRESSION)

→ CONT'D.

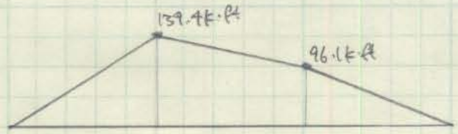
- ULTIMATE STRENGTH
  - PRIMARY PT MOMENT

$$M_1 = P_{ACT} \cdot e = \frac{(423.95k)(3.75'')}{12''/ft} = 132.5k \cdot ft$$

  - SECONDARY PT MOMENT.

$$M_{2_1} = M_{BAL_1} - M_1 = 271.94k \cdot ft - 132.5k \cdot ft = 139.4k \cdot ft$$

$$M_{2_2} = M_{BAL_2} - M_1 = 228.62k \cdot ft - 132.5k \cdot ft = 96.1k \cdot ft$$



  - TYPICAL LOAD COMBINATION.

$$Mu_{MIDSPAN} = 1.2(256.56k \cdot ft) + 1.6(152.26k \cdot ft) + 1.0(139.4k \cdot ft/2) = 621.2k \cdot ft.$$

$$Mu_{SUPPORT} = 1.2(341.3k \cdot ft) + 1.6(202.55k \cdot ft) + 1.0(139.4k \cdot ft) = 873.1k \cdot ft.$$

- DETERMINE MINIMUM BONDED REINFORCEMENT.
  - POSITIVE MOMENT REGION.
    - INTERIOR SPAN

$f_T = 44.04 psi < 2\sqrt{f'_c} = 2\sqrt{5000psi} = 141.4 psi$ (NO REINFORCEMENT REQUIRED)

    - EXTERIOR (END) SPAN

$f_T = 309.59 psi > 141.4 psi$ (REINFORCEMENT REQUIRED)

    - REINFORCEMENT DESIGN.

$$y = \frac{f_T}{f_T + f_c} \cdot h = \frac{309.95psi}{309.95psi + 586.84psi} \cdot (9.5'') = 3.28''$$

$$N_c = \frac{M}{S} \cdot \frac{1}{2} \cdot y\, l_2 = \frac{(104.48k \cdot ft + 62.01k \cdot ft)(12''/ft)}{5475.11 in^3} \cdot \frac{1}{2} \cdot (3.28'')(27')(12''/ft)$$

$$= 193.89k.$$

→ CONT'D.

$A_{S,MIN} = \frac{N_c}{0.5 f_y} = \frac{193.89k}{0.5(60ksi)} = 6.46 in^2$.

$\frac{6.46in^2}{27'} = 0.24 in^2/ft$ => USE #5 @ 12", BOTTOM.

- NEGATIVE MOMENT.

$A_{S,MIN} = 0.00075 A_{CF}$.

- INTERIOR SUPPORTS

$A_{CF} \geq \begin{cases} (9.5")(30.333'+27'/2)(12"/ft) = 3267.98 in^2 & \text{* CRITICAL.} \\ (9.5")(27')(12"/ft) = 3078 in^2 \end{cases}$

$A_{S,MIN} = 0.00075(3267.98in^2) = 2.45 in^2$ => USE (12) #4, TOP.

- EXTERIOR SUPPORTS

$A_{CF} \leq \begin{cases} (9.5")(30.333'/2)(12"/ft) = 1728.98 in^2 & \text{* CRITICAL.} \\ (9.5")(27'/2)(12"/ft) = 1593 in^2 \end{cases}$

$A_{S,MIN} = 0.00075(1728.98in^2) = 1.29 in^2$ => USE (6) #4, TOP.

- CHECK MINIMUM REINFORCEMENT AGAINST ULTIMATE STRENGTH.

- AT SUPPORTS

$A_{PS} = 0.153in^2(18 \text{ TENDONS}) = 2.74 in^2$

$f_{PS} = f_{SE} + 10000 + \frac{f'_c b d}{300 A_{PS}}$

$= 174000 + 10000 + \frac{(5000psi)(27')(12"/ft)d}{300(2.74in^2)}$

$= 184000 + 1970.8d$

$d = 9.5" - 3/4" - \frac{1}{2}(1/2") = 9"$

$f_{PS} = 201737 psi$

$a = \frac{(0.64in^2)(60ksi) + (2.74in^2)(201.7ksi)}{0.85(5ksi)(27')(12"/ft)} = 0.52"$

→ CONT'D.

$$\phi M_n = \frac{0.9\left[(2.64\,in^2)(60ksi) + (2.74\,in^2)(201.7ksi)\right]\cdot\left(9" - \frac{0.53"}{2}\right)}{12"/ft}$$

$= 466.1\ k\cdot ft < 873.08\ k\cdot ft$ (ULTIMATE STRENGTH REINFORCEMENT GOVERNS)

∴ USE (12) #4, TOP, INTERIOR SUPPORTS
(6) #4, TOP, EXTERIOR SUPPORTS.

- AT END SPAN

$d = 9.5" - 1.5" - 1/4" = 7.75"$

$f_{ps} = 174000\ psi + 10000 + 1970.8(7.75") = 199274\ psi$

$$a = \frac{(6.46\,in^2)(60ksi) + (2.74\,in^2)(199.3ksi)}{0.85(5ksi)(27')(12"/ft)} = 0.69"$$

$$\phi M_n = \frac{0.9\left[(6.64\,in^2)(60ksi) + (2.74\,in^2)(201.7ksi)\right]\left(7.75" - \frac{0.69"}{2}\right)}{12"/ft}$$

$= 529\ k\cdot ft < 621.21\ k\cdot ft$ (NO GOOD)

⇒ INCREASE NUMBER OF TENDONS, AND REINFORCEMENT

$$621.21\ k\cdot ft = \frac{0.9\,x\,(7.75 - \frac{a}{2})}{12"/ft}$$

$8282.8 = x(7.75 - a/2)$

⇒ LET $x = A_s f_y + A_{ps} f_{ps}$
$a = 0.85"$

⇒ $x = 1130.8$

⇒ TRY #8 @ 12", BOTTOM.
25 TENDONS.

⇒ $\phi M_n = 1073.7\ k\cdot ft > 621.21\ k\cdot ft$ (GOOD)

∴ #8 @ 12", BOTTOM FOR END SPAN
(12) #4, TOP FOR INTERIOR SUPPORTS
(6) #4, TOP FOR EXTERIOR SUPPORTS
25 TENDONS

* END OF ANALYSIS *

MONONGALIA GENERAL HOSPITAL

PRO-CON STRUCTURAL STUDY
OF ALTERNATE FLOOR SYSTEMS

APPENDIX F

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- Photograph 1 and 3 taken by the Turner Construction Company.

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