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Structural Option
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Whiteland Village
Exton, PA
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AE 481W

Structural Technical Report 2
Structural Study of Alternate Floor Systems

Executive Summary

This report is intended to be a detailed description and preliminary analysis of the structural design of Whiteland Village in Exton, PA. Whiteland Village is a 1,320,000 sq. ft. sprawling retirement community, which is slated for completion by November 2008. The physical components of the first phase of the complex include three 5 story residence buildings, a commons building, and a healthcare facility. The entire footprint has a basement level, which serves as covered parking and utility spaces. The master plan for the site is included in the report as Appendix A. The phase one construction will be on the west side of the campus, including U-1 (renamed R-1), U-2 (renamed R-4), and the J building (renamed R-2). The other buildings will go into planning as soon as Whiteland Village becomes profitable, and will be connected with a pedestrian link.

The residence buildings, designed by Dever Architects, were intended to resemble large typical suburban single family homes with the use of mansard roofs with asphalt shingles and a central exhaust system to limit the amount of roof-mounted equipment and roof penetrations. Each condominium includes a balcony or patio.

In order to complete a thorough analysis, the scope of this report only includes the most current design of the three residence buildings. It is intended to be a preliminary analysis of alternate floor systems for the project. In addition to a brief description of the existing loading conditions, each alternate is analyzed and compared on the basis of constructability, fire protection, weight (in regards to footings), noise transmission, depth, cost, and impact on lateral resistance systems. Whiteland Village is predominately a CMU bearing wall system with a single steel framed section, supporting precast plank. In addition to investigating the current system, Girder-Slab composite, composite, one-way void slab, and ribbed slab flooring systems were also researched. As a result, the ribbed slab was deemed too deep a system, and has been removed from consideration of further investigation. For more thorough insight into the various alternates, sketches of floor plans, sections, and details have been included. The appendix material includes first floor plans of each building and calculations for each floor system.

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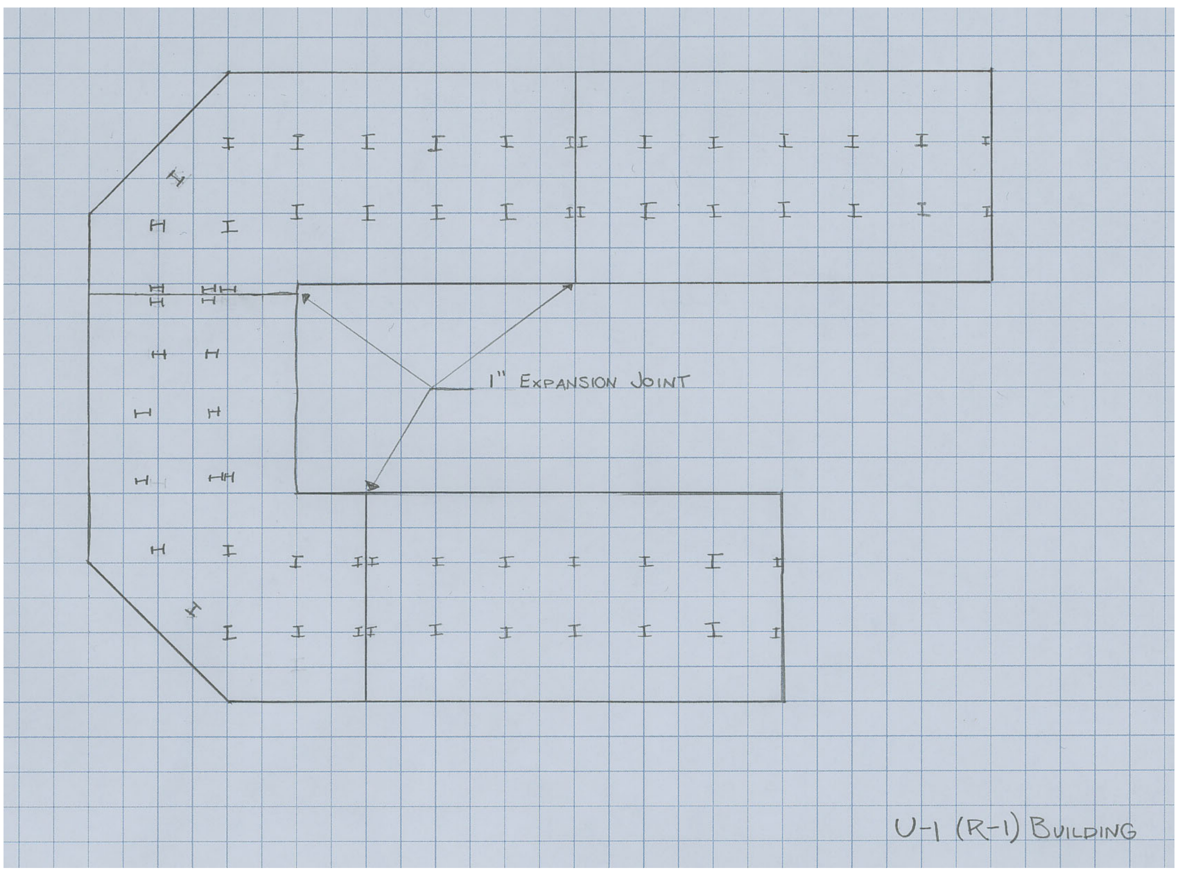
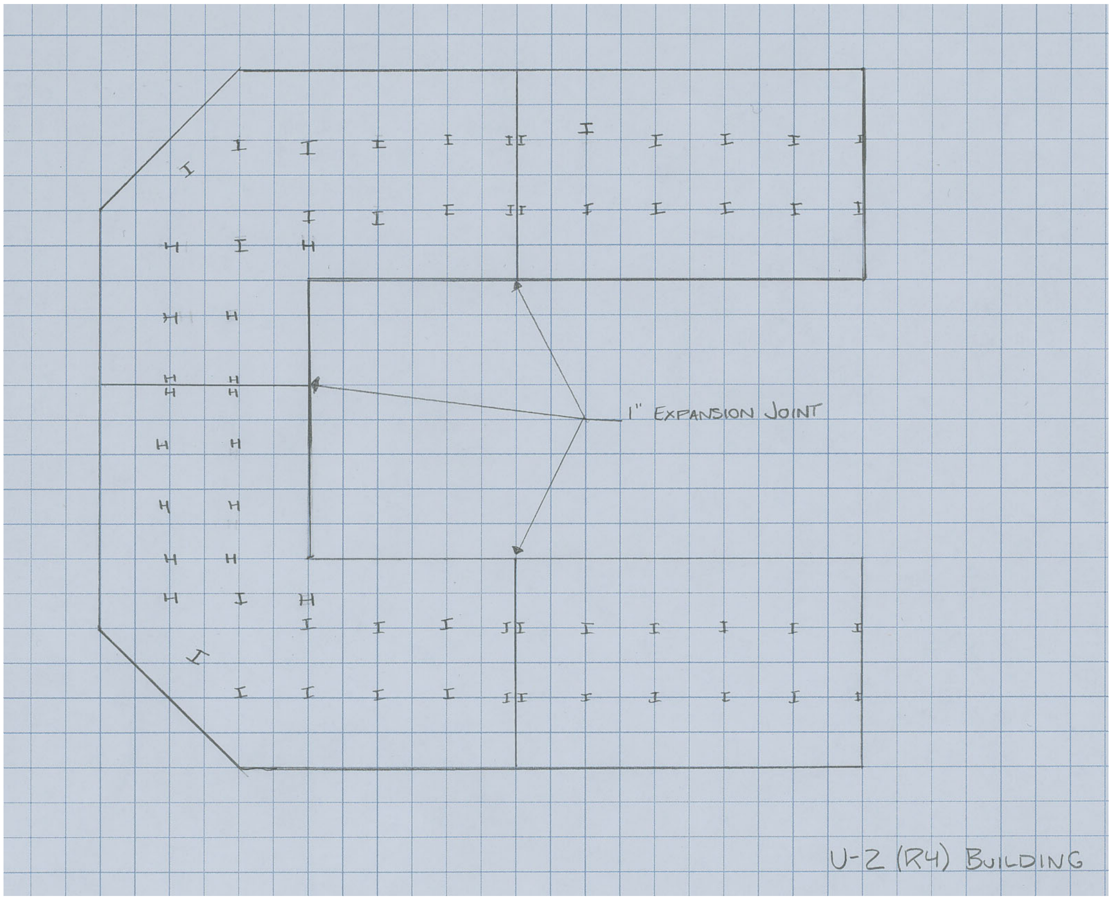
Description of Existing Structural System

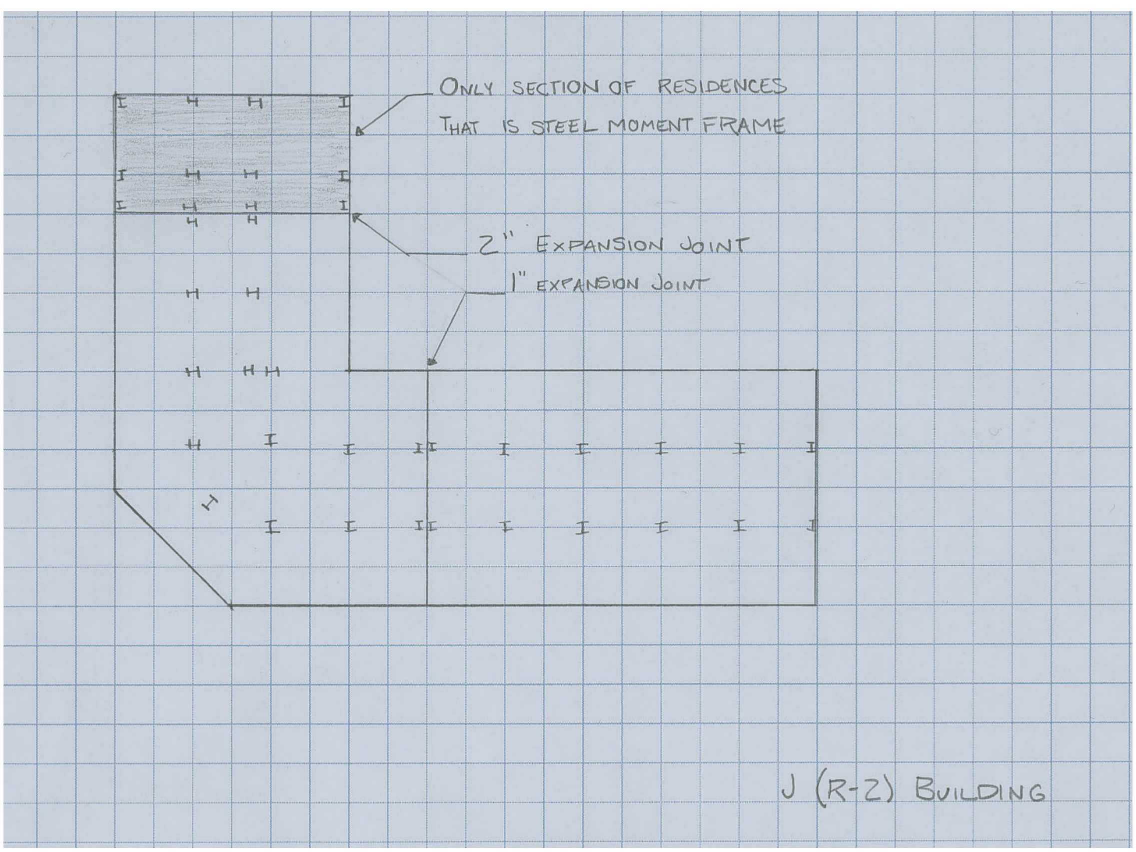
Foundations

The foundation system of Whiteland Village consists of a 5" slab on grade, reinforced with 6x6 – W2.9xW2.9 welded wire fabric, on top of 4" of drainage fill, with a continuous spread footing around the entire perimeter and under all interior foundation level walls. This spread footing is typically 3' wide when supporting exterior walls, and 6' wide when supporting interior wall sections. Interior columns are supported by spread footings, which range in size from an 8' square to a 12'x19'. The footings are spaced approximately in a 30'x30' grid running through the center of the building. There are thickened slabs below all elevator shafts. The foundation system is very shallow, with the top of the deepest footing only 3'-4" below the top of the slab. All reinforced concrete in the foundation is 3000 psi, and is reinforced with 60 ksi rebar. The reinforced CMU exterior foundation walls are designed to withstand 68 PCF of equivalent fluid pressure from the surrounding soil, as dictated by the geotechnical report of the site.

Following are some rough sketches showing the column layout in each residence building.

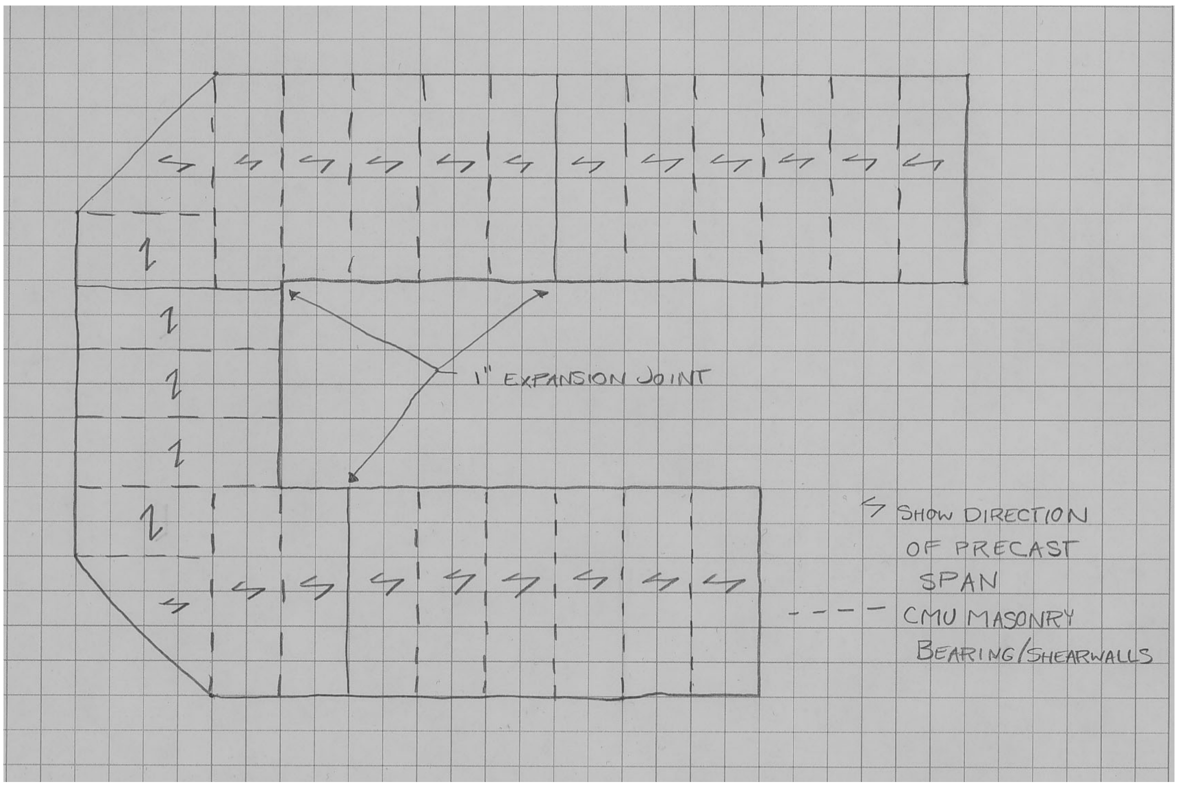



1" EXPANSION JOINT
U-2 (R4) BUILDING


ONLY SECTION OF RESIDENCES
THAT IS STEEL MOMENT FRAME
2" EXPANSION JOINT
1" EXPANSION JOINT
J (R-2) BUILDING

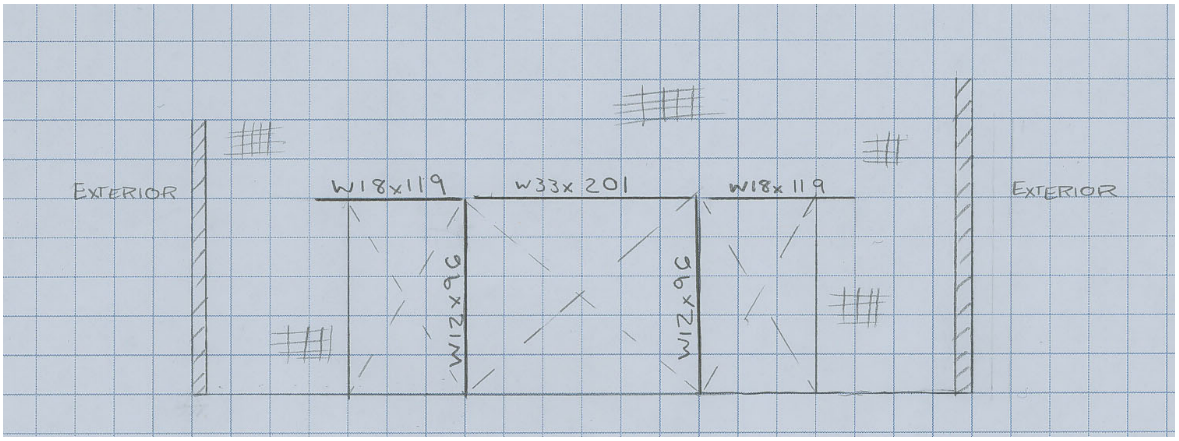
Framing and Lateral Load Resistance

Gravity loads are taken into the overall building structural system by 8" hollow core precast plank spanning approximately 30' at each level. The planks will be designed by the precast contractor to have the required capacity. Both bearing plank ends frame into a 12" CMU wall that runs from the 5th floor ceiling to the 1st floor. These reinforced masonry walls also act as shearwalls for the system, transferring lateral loads from the higher floors to the first floor. The following is a sketch of the masonry shear walls and plank spans for a typical intermediate floor.



Grade A997 wide flange steel beams are positioned under the 5 story walls to pick up the loads, so the basement can have the open space necessary to allow vehicular traffic. These beams range from a W18x50 to a W36x359, with spans of 7'4" to 30'0".

The typical basement section is seen in the sketch below. It consists of two W12x96 columns with a W33x201 spanning between and a W18x119 spanning from the column and bearing on the masonry wall below.



At the first floor, additional masonry shearwalls around the building exterior, with both horizontal and vertical reinforcing, are included to resist lateral loads. Due to their high relative stiffness, lateral loads are redistributed at the first floor to the building perimeter. This results in the previously discussed basement columns only being required to resist gravity loads. In design, this means the basement columns can be smaller and be attached with simpler pin connections to the first floor framing.

There is one section of the residence buildings which differ from this basic plan. In the J Building (R-2), the first section between the commons (separated with a 2" expansion joint) and the 2" expansion joint within the building footprint is 8" hollow core precast plank, spanning 15' and 30'. On the top 2 floors, the plank bears on a 12" CMU wall. At the third floor, the precast is supported by a wide flange A992 steel frame. Framing members range from a W30x90 to a W36x194 beam size. To resist lateral loading, the third floor framing is braced with W8x31 knee braces. The second floor has no framing because it is part of a 2 story atrium. At the first floor, the steel framing is connected with moment connections to resist lateral load, ranging in size from W24x49 to W24x131. The location of this section is indicated with shading on the previous sketch of the J Building.

Code Requirements and Design Theory

Due to the size and the location of Whiteland Village, it is being designed to be acceptable to both the West Whiteland Township Building Code, as well as the East Whiteland Township Building Code. Both codes are based off of the 2000 International Building Code (IBC), which is published by the International Code Council and heavily reference ASCE 7. In addition, the municipalities have accepted the 1997 Fire Prevention Code, put together by the National Fire Protection Association (NFPA).

In the design of Whiteland Village, the American Institute of Steel Construction's (AISC) Manual of Steel Construction, ASD Method, was utilized. This is the accepted industry standard for steel construction. The Building Code for Reinforced Concrete published by the American Concrete Institute (ACI) as well as the Precast/Prestressed Concrete Design Handbook (PCI) were referenced during design as industry standards.

Gravity Loads

The gravity loads for this project were based on IBC 2000, which references ASCE 7. The loads below are based off of ASCE 7-00, except as noted.

Live Loads (PSF)

- Dwelling Areas – 40
- Corridors – 100
- Stairs – 100
- Storage – 125
- Snow – 27 + drift
- Vehicular Traffic – 50
- Min. Roof – 15

Dead Loads (PSF)

Floor

- 8" Hollow Core Plank – 60
- HVAC – 5
- Ceiling – 2
- Partitions – 10
- Misc. – 3

Total - 80

Roof

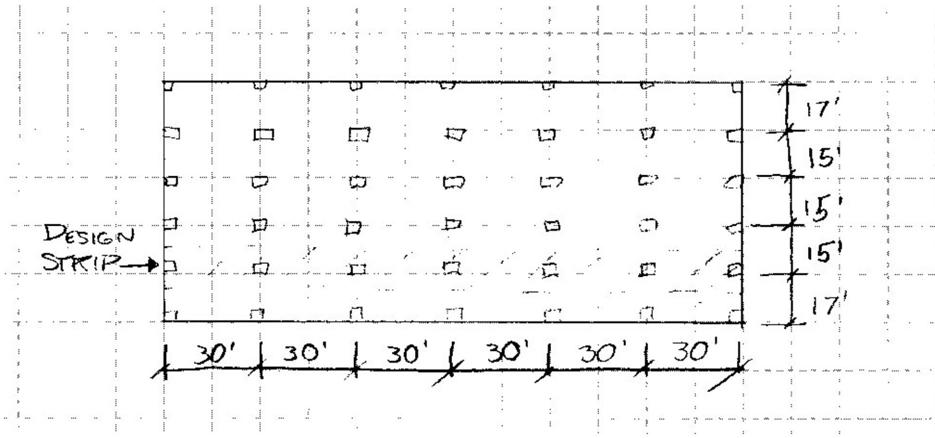
- Roofing – 2
- HVAC – 3
- Ceiling – 2
- Insulation – 3
- Precast Plank – 60
- Misc. – 5

Total - 75

Preliminary Analysis Criteria and Standards

Preliminary analysis into alternate floor systems is a crucial initial step in changing the structure of a building. Different floor systems can limit the use of certain lateral-resistance systems, or create an opportunity to use others. Whiteland Village has a very restrictive height limitation of 65'. Therefore, it is critical that all viable alternate floor systems have a maximum depth of 1'-8", with the possibility of deeper members at the existing, stacking masonry walls. Coupled with the typical bay of 30'x17', it is a challenge to find systems that are viable. To determine viability, floor systems were compared on the basis of constructability, fire protection, weight (in regards to footings), noise transmission, depth, cost, and impact on lateral resistance systems. All cost data was taken from RS Means 2002 Assemblies Cost Data and adjusted for location.

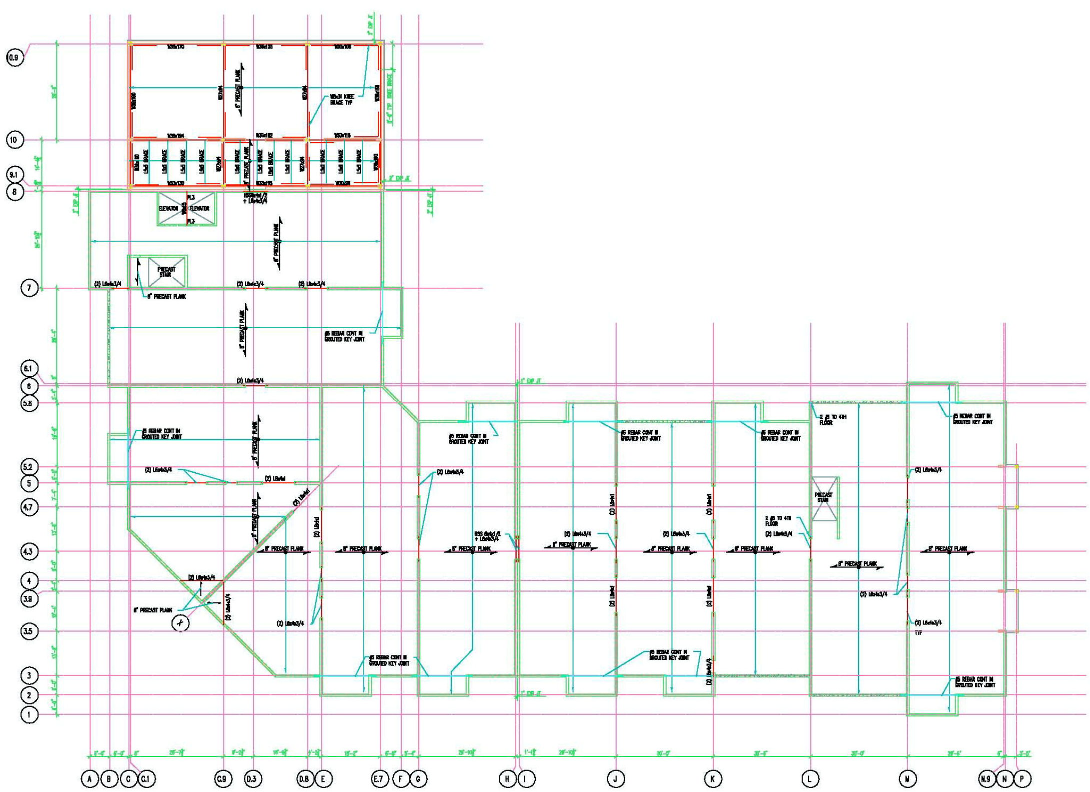
The following is the column layout for intermediate floors that was assumed for all floor systems, since none existed in the existing structure. The typical bay studied was 30'x17'. Initially, two-way flat slab, steel joists, and wood were considered, but disregarded due to issues with deflection, strength, and sound transmission. For a more thorough preliminary analysis, Slab-girder composite, traditional composite, one-way void slab, and ribbed slab were the floor systems investigated.

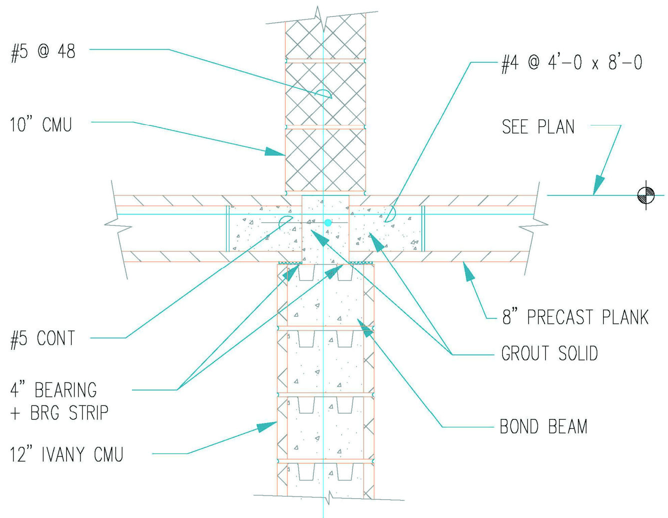


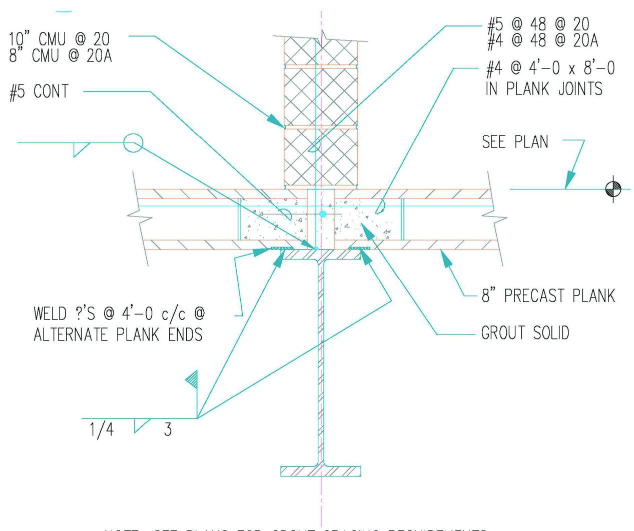
Floor System Analysis

Hollow Core Precast Plank Bearing on CMU: Existing System

The current floor system in Whiteland Village is 8" hollow core precast plank, spanning approximately 30' and bearing on 12" CMU shear walls. Using the (6) ½" strand pattern, 8" plank can resist superimposed loads of 90 PSF in flexure, making it able to resist the 80 PSF required in a typical bay (See Appendix C). A sketch of the current framing plan and the typical sections detailing the connections used in the current system follow.







NOTE: SEE PLANS FOR GROUT SPACING REQUIREMENTS

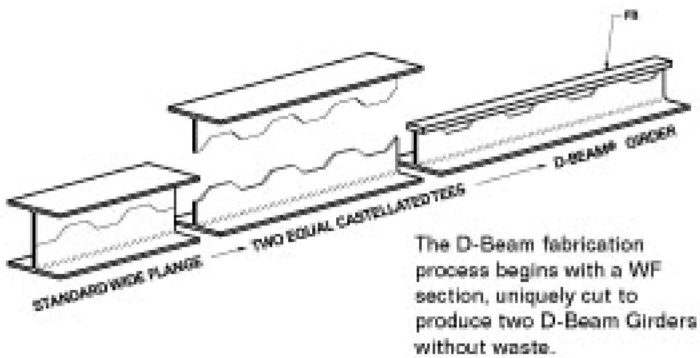
Precast plank has distinct benefits that are easily utilized in the Whiteland Village project. The floor systems are limited to a maximum depth of 1'-8" due to the zoning restriction on height as previously mentioned. In addition to allowing more plenum space for mechanical systems, a shallower floor system allows for higher ceilings in the condominiums. The very shallow precast system also has other benefits, including ease of construction.

Because it arrives on site ready to assemble, erection is considerably quicker than other flooring systems. An experienced crew can erect 10,000 ft^2 of floor per day. Plant manufacturing means on-time delivery that can be easily sequenced and controlled. Since construction of the residence buildings is slated to begin in February 2007, it is conceivable that some of the flooring systems will be installed in winter months. While this would potentially pose problems for a steel or concrete system, inclement weather conditions do not affect precast installation.

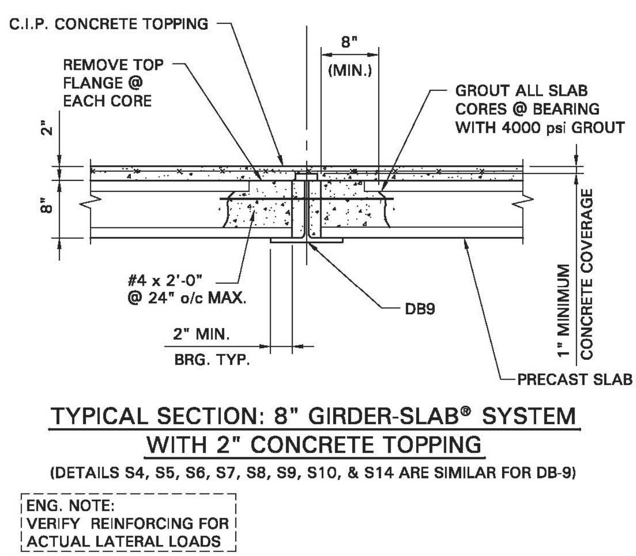
In addition to having one- and two-hour assembly ratings available, the combination of hard concrete and hollow cores provide excellent sound attenuation of both airborne and low-impact noises. Lateral loads are resisted by the masonry shear walls, so the precast merely needs to act as a diaphragm to distribute shear loads at each level. Using RS Means, the expected cost of this system is \$8.44 per ft^2.

Girder-Slab Composite Precast and Steel System

The Girder-Slab system is a steel and precast hybrid that removes the disadvantage of increased floor to floor heights when bearing precast on steel. It is the first patented system to create a monolithic structural slab assembly using precast with an integral steel girder. Open-web dissymmetric beam (D-Beam), produced as seen below, are used as girders.



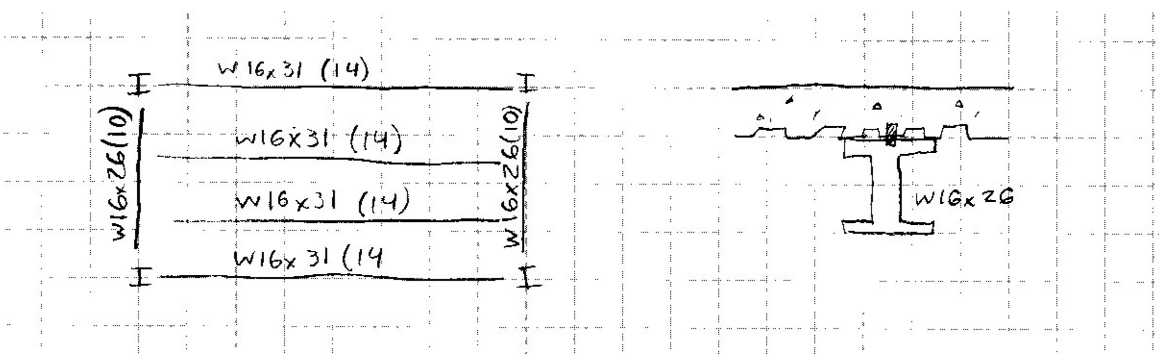
The larger bottom flange of the D-Beam is used for bearing the individual planks, while the openings in the web provide space for reinforcing between the spans. At least 8" of the top flange of each core is removed to allow for the placing of reinforcing and subsequent grouting. This system specifies using grout with a compressive strength of 4 ksi. Calculations are located in Appendix D. The typical section for the 10" Girder-Slab system is included below.



Obviously, many of the benefits of the existing precast system are the same for the Girder-Slab system: ease of construction, limited weather impact, sound attenuation, and fire protection. However, there are some distinctions between the two. Lateral loads are resisted by a steel moment frame, consisting of D-Beams and standard wide-flange shapes, as opposed to shear walls. Because of the use of steel framing as opposed to masonry, there is also a reduced building weight, reducing the seismic base shear and the size of the spread footings.

Composite Concrete Slab

In order to maintain a shallow floor system, a composite system was considered. For this option, a 1.5VL20 deck with a total slab depth of 4" and 6x6-W1.4xW1.4 welded wire fabric were selected for the 4 ksi concrete slab. The maximum considered depth of beam was W16. After completing calculations on both flexure and deflection criteria, W16x31 were selected as filler beams with 14 shear studs and W16x26 with 10 shear studs for girders (See Appendix E). Below is a sketch of a typical bay for the required framing, as well as a section.

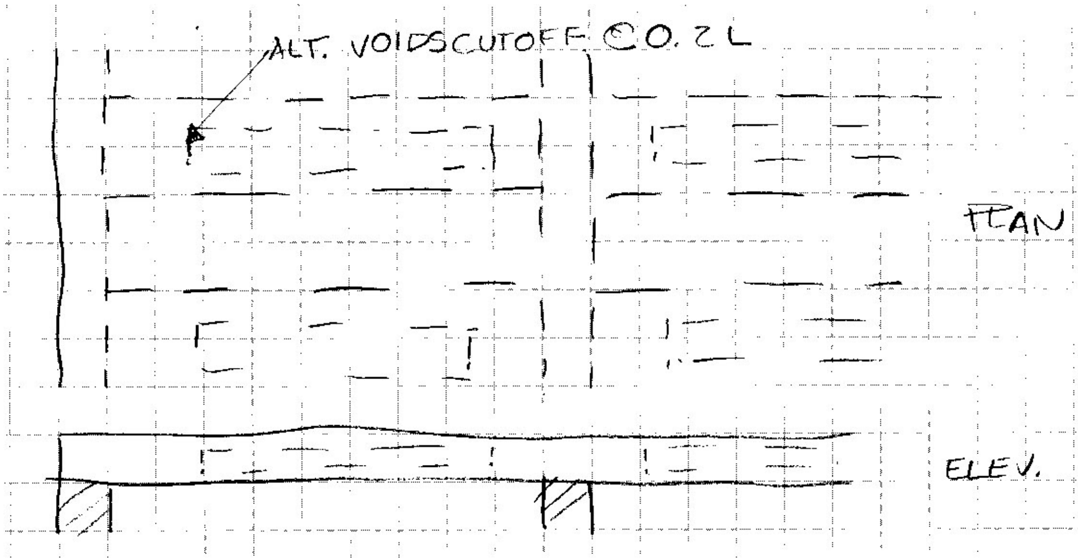


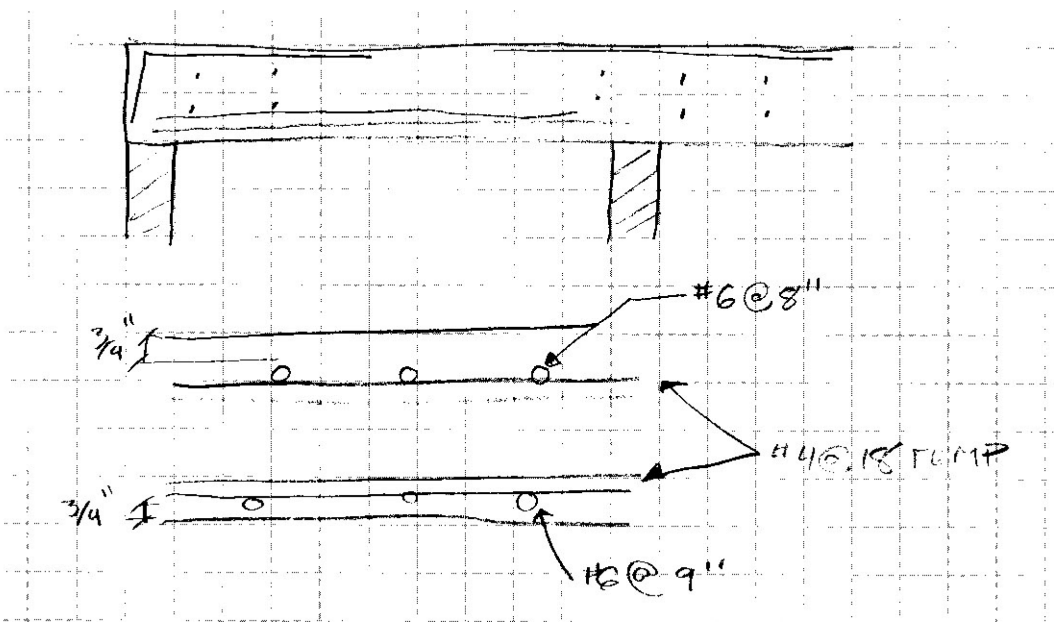
Composite systems are almost always deeper than precast because of the depth of both the slab and supporting beam. This system is at the allowable maximum depth of 20", an obvious disadvantage. Unlike precast, the composite system is affected by inclement weather, which can delay both pouring and curing. In addition, cold weather construction is more challenging, and may require space heating to promote proper curing. Sound and vibration transmission are also more likely to be an issue with composite over precast. To increase fire protection, the steel would most likely require spray fireproofing.

However, composite does not limit the options of lateral resisting systems like the precast systems outlined above. Moment frame, staggered truss, shear wall, and partially restrained composite connections are all viable options when using the composite system. With the additional options comes an additional cost; the anticipated cost per square foot is $19.61.

One-way Concrete Void Slab

Void slabs are a viable alternative when longer spans are required than are feasible or economical to do with a solid one-way concrete slab. Using information from the Concrete Reinforcing Steel Institute (CRSI), it was determined that using 4 ksi concrete and 60 ksi steel, the slab would need to be 12" thick with No. 6 bars at 8" spacing on top and No. 6 bars at 11" spacing on the bottom, with No 4. temperature bars at 18" for interior spans (See Appendix F). All tubes would be full length. Sketches of the void slab system are included below.



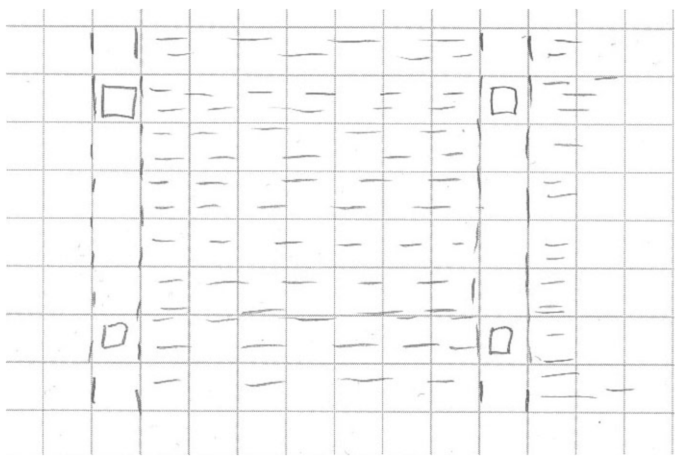


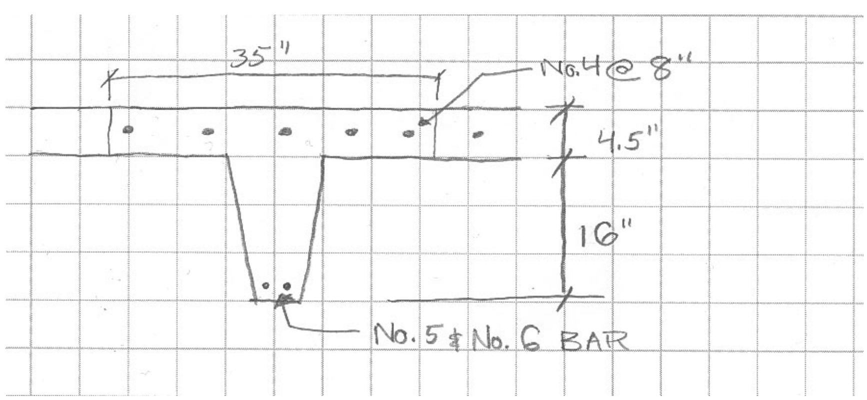
Placing the concrete and reinforcing properly is one of the challenges with this system. The one-way void section is extremely similar to that of hollow core precast plank, which is created in controlled conditions. Logically, it makes sense that the cast-in-place version is deeper and consequently weighs more. This would mean reworking the foundation design for the additional gravity loads, and possibly increased lateral loads as well. Lateral resistance would need to be provided by shear walls or frames.

Similarly to the composite system, the one-way void slab is affected by inclement weather. It is also more difficult to place because the section is considerably more complicated. Most likely, additional shoring would be required, adding more time and expense to construction. Because it is a concrete system, though, fireproofing is not as major a concern. Due to its similarities with concrete, one-way void slabs are assumed to have similar noise and vibration transmission properties to precast plank. Although not priced in RS Means, it can be surmised that the complexity of this floor system would make it similar in cost to a waffle slab, which is \$15.16 per ft^2.

One-way Concrete Joist Construction (Ribbed Slab)

Concrete joist construction consists of a monolithic combination of regularly spaced joists (ribs) and a thin cast-in-place slab. The floor system then forms an integral unit with its supporting beams, columns, or walls. Reduced dead weight and less required steel are two reasons this slab type was developed. Using the CRSI, it was determined that this application requires 6"x16" deep rib at 36" c/c with 4.5" top slab for a total depth of 20.5". Top bars are No. 4 at 8" spacing, with a No.5 and No. 6 bar at the bottom of the joists. These values were determined using 4 ksi concrete and 60 ksi steel, and can be reviewed in Appendix G. Sketches of the system follow.





One of the benefits of this system over other concrete floors is the simplified formwork involved. Both the joist and beam soffit are formed with the same deck, and it is simple to form beam sides with the ends of removable forms. To enable contractors to use the same forms for the entire project, beam widths are adjusted to allow for irregular spans. Because it is cast-in-place concrete, there are still major constructability concerns with weather conditions. The system is also slightly over 20” deep, making it too deep to work in this project.

This system would also be heavier than the others considered due to its cross-section. Foundations would need to be increased and the changes in seismic load considered. While noise transmission may be a concern with this system, it is unlike that vibration would be an issue considering its weight. The anticipated cost of this floor system is \$14.47 per ft^2.

Summary Comparison Chart

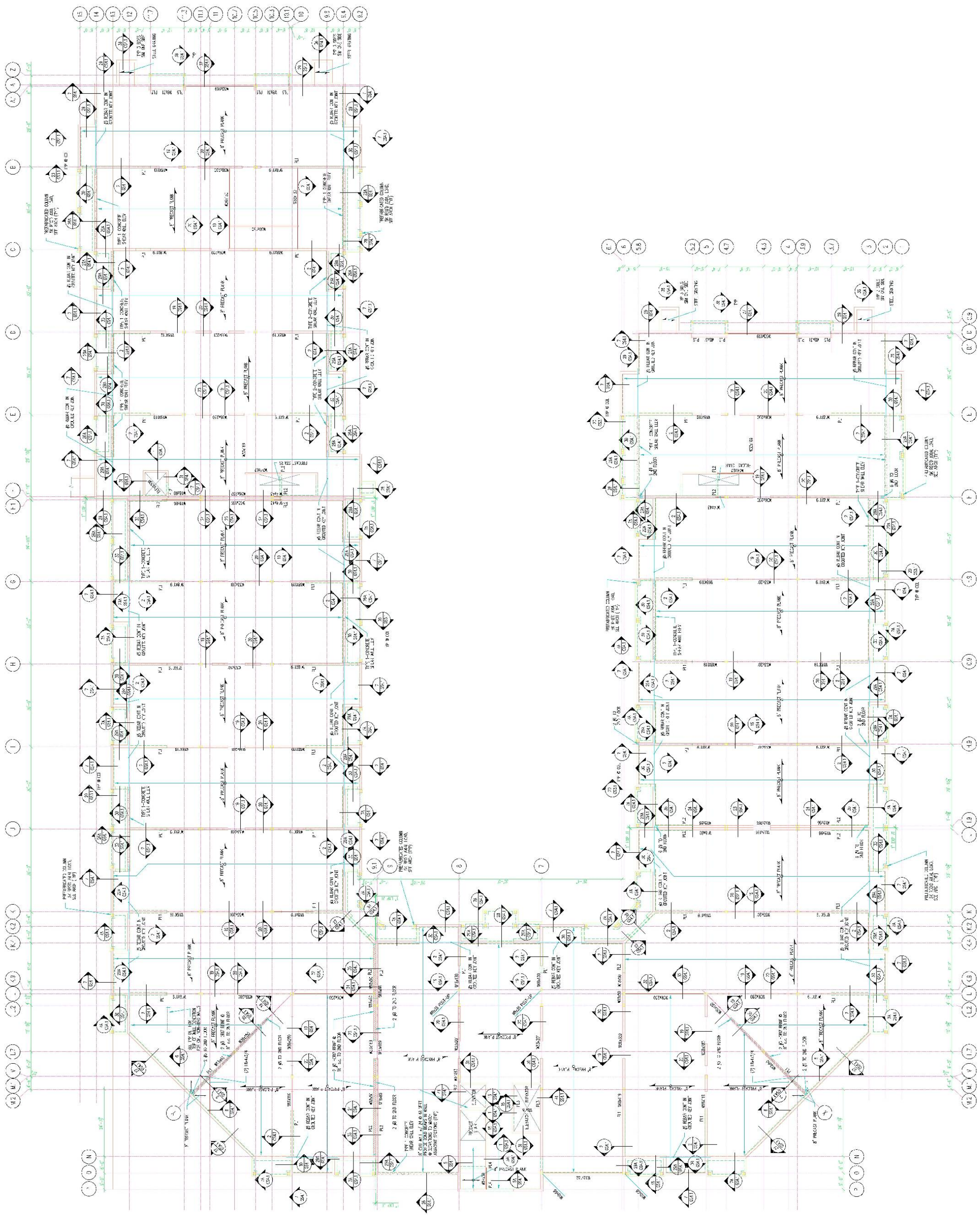
Floor System	Depth (in)	Constructability	Fire Protection	Relative Weight	Sound and Vibration Transmission	Impact on Lateral Load Resistance Systems	Cost/ft^2	Potential for More Investigation
Hollow Core Precast (Existing)	8	Not impacted by weather Easy to sequence and control Ready to assemble when it arrives on site	Easily achieve necessary rating		Excellent sound attenuation	Uses masonry shearwalls	\$8.44	Yes
Girder-Slab Composite (Precast and Steel)	10	Not impacted by weather Easy to sequence and control Ready to assemble when it arrives on site	Need to spray exposed steel	Lighter than existing	Excellent sound attenuation	Uses steel moment frame		Yes
Composite (Concrete and Steel)	20	Cast-in place Slowed by curing Impacted by weather	Need to spray exposed steel	Lighter than existing	Needs to be considered	Could use steel moment frame, staggared truss, or partially restrained composite connections	\$19.61	Yes
One-way Void Slab	12	Cast-in place Sequence lowed by curing Impacted by weather Complicated section	Easily achieve necessary rating	Heavier, need to look at foundations	Similar to hollow core	Higher seismic loads, resist with shearwalls or frames	\$15.16	Yes
Ribbed Slab	20.5	Cast-in place Sequence slowed by curing Impacted by weather Simple formwork	Easily achieve necessary rating	Heavier, need to look at foundations	Vibration not a major concern	Higher seismic loads, resist with shearwalls or frames	\$14.17	No

Conclusions

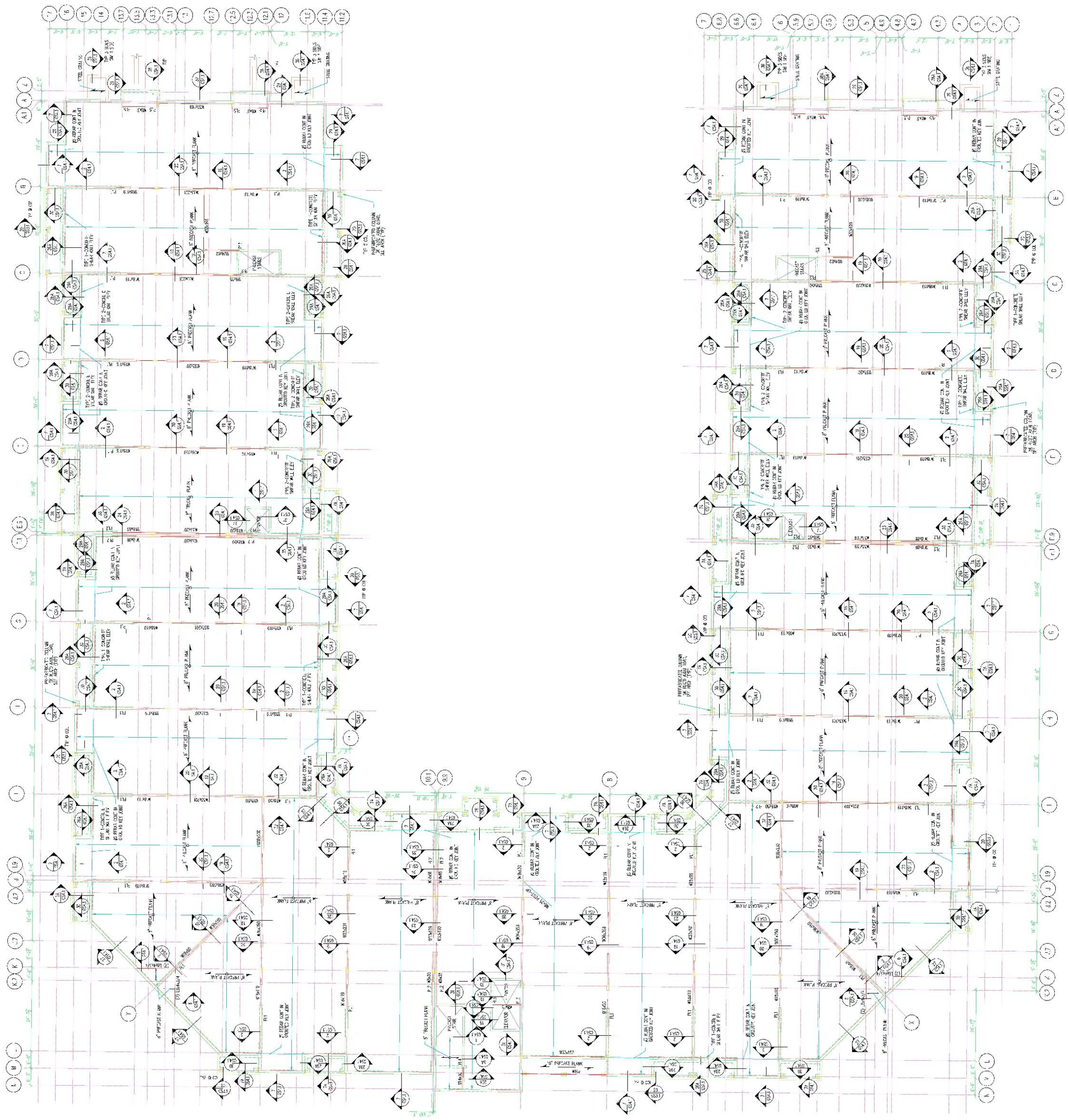
After this preliminary investigation into alternate flooring systems, three of the alternates are still viable alternatives to the existing precast: Girder-Slab composite, composite, and one-way void slab. The ribbed slab did not meet the basic depth requirements for the system, although it did use very simple formwork. Although precast has major benefits in terms of constructability, its use limits the types of lateral resistance systems that can be used on the project. Using the void slab may also require increasing the size of the foundation due to its increased weight, as well as shift the lateral loads to being controlled by seismic forces. Only with continued investigation into the three remaining systems will determine which is the most viable alternate for Whiteland Village.

Appendix A: Master Plan of Whiteland Village

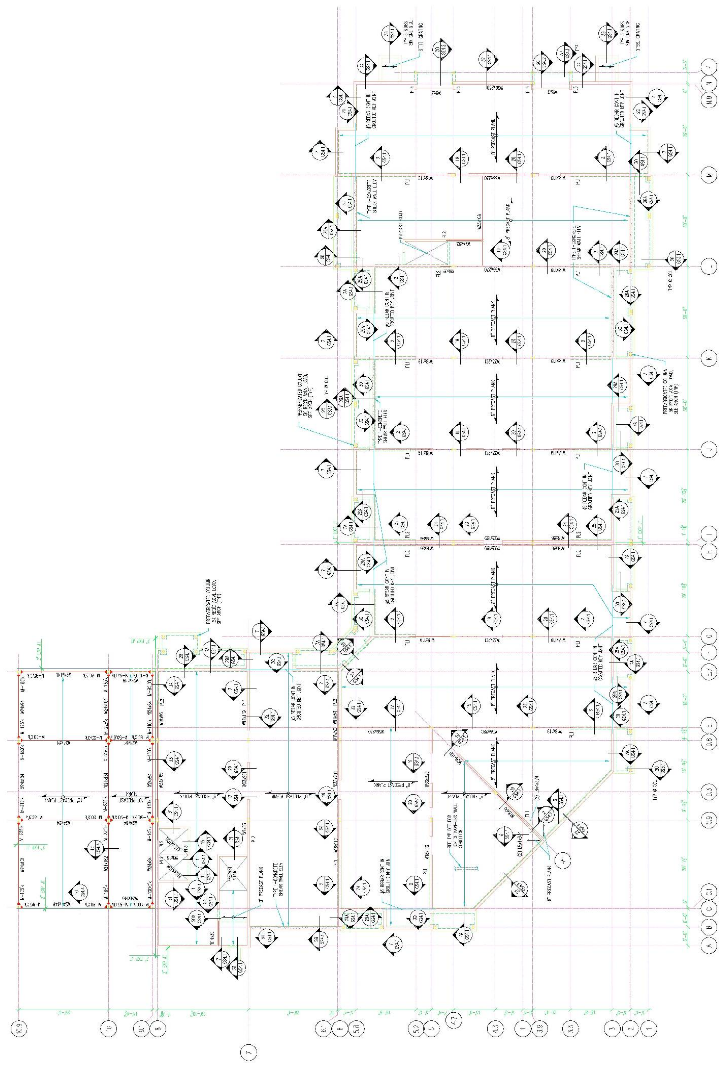
Appendix B: First Floor Plans of Residence Buildings



U-1 (R-1) Building



U-2 (R-4) Building



J (R-2) Building

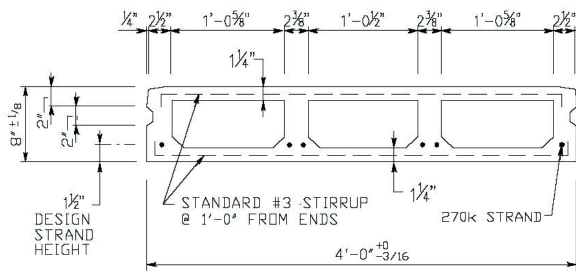
Appendix C: Hollow Core Precast Plank Calculations

Prestressed Concrete
8"x4' SpanDeck–U.L.–J917
(NO TOPPING)

PHYSICAL PROPERTIES

Precast

A = 180 in.^{2}	S_b = 397 in.^{3}
I = 1543 in.^{4}	S_t = 375 in.^{3}
Y_b = 3.89 in.	Wt. = 230 PLF
Y_t = 4.11 in.	Wt. = 57.5 PSF
e = 2.39 in.	



8" SPANDECK CROSS SECTION

UL FIRE RATED J917

DESIGN DATA
1. Precast Strength @ 28 days = 5000 PSI.
2. Precast Density = 150 PCF.
3. Strand = 1/2"ø, 270 K Lo-Relaxation.
4. Strand Height = 1.50 in.
5. Ultimate moment capacities (when fully developed)...
   4 – 1/2"ø, 270K = 74.3'K
   6 – 1/2"ø, 270K = 105.6'K
6. Maximum bottom tensile stress is $6\sqrt{f'c}$ =424 PSI.
7. All superimposed load is treated as live load in the strength analysis of flexure and shear.
8. Flexural strength capacity is based on stress/strain strand relationships.
9. All values in this table are based on ultimate strength and are not governed by service stress.
10. Shear values are the maximum allowable before shear reinforcement is required.
11. Deflection limits were not considered when determing allowable loads in this table.

8" SPANDECK W/O TOPPING	ALLOWABLE SUPERIMPOSED LOAD (PSF)																						
STRAND PATTERN	SPAN (FEET)																						
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Flexure 4 – 1/2"ø	610	550	499	457	399	341	294	255	222	195	171	151	133	117	103	92	82	72	66	56	49	43	
Shear 4 – 1/2"ø	441	393	354	321	294	270	249	231	215	201	188	177	160	145	132	120	110	101	95	90	82	75	
Flexure 6 – 1/2"ø	885	800	726	667	586	509	437	382	334	296	263	234	208	187	168	151	136	122	111	100	90	81	73
Shear 6 – 1/2"ø	459	411	370	337	308	283	262	243	226	211	197	185	174	164	155	147	139	131	120	111	102	94	87

NITTERHOUSE
CONCRETE PRODUCTS

This table is for simple spans and uniform loads. design data for any of these span–load conditions is available on request. Individual designs may be furnished to satisfy unusual conditions of heavy loads, concentrated loads, cantilevers, flange or stem openings and narrow widths.

2655 MOLLY PITCHER HWY. SOUTH, BOX N
CHAMBERSBURG, PA 17201–0813
717–267–4505 • FAX: 717–267–4518

REVISED 12/93

Appendix D: Girder-Slab Composite Calculations

GIRDER SLAB USING OPEN-WEB DISSYMMETRIC BEAMS
FOLLOWING DESIGN EXAMPLE ON COMPANY WEBSITE
UNTOPPED 8" HOLLOW CORE PLANK
SPAN 30' (PLANK)
D-BEAM SPAN = 17'
PLANK $f'_c = 5ksi$
GROUT $f'_c = 4ksi$

PLANK DL = 60PSF
PARTITION = 20 PSF
LIVE LOAD = 40 PSF

DB9x46

STEEL ONLY (WEB IGNORED)	TRANSFORMED SECTION (WEB IGNORED)
$I_s = 195\,in^4$	$I_t = 356\,in^4$
$S_t = 33.7\,in^3$	$S_t = 68.6\,in^3$
$S_b = 50.8\,in^3$	$S_b = 70.6\,in^3$
$M_s = 84'k$	$b = 5.75"$
$t_w = 0.375\,in$	

ASSUME A DB9x46

$$\Delta_{LL\ ALLOW} = \frac{17(12)}{360} = 0.57\,in$$

INITIAL LOAD - PRECOMPOSITE

$$M_{DL} = \frac{30'(0.06ksf)(17')^2}{8} = 65.0'k < 84'k \quad \therefore OK$$

$$\Delta_{DL} = \frac{5(30')(0.06ksf)(17')^4(1728)}{384(195\,in^4)(29{,}000\,k/in^2)} = 0.60\,in$$

TOTAL LOAD - COMPOSITE

$$M_{SUP} = \frac{30'(0.06ksf)(17')^2}{8} = 65.0'k$$

$$M_{TL} = 2(65.0'k) = 130.1'k$$

$$S_{REQ} = \frac{130.1'k(12)}{(0.6)(50\,k/in^2)} = 52.02\,in^3 < 68.6\,in^3$$

$$\Delta_{SUP} = \frac{5(30)(0.06)(17)^4(1728)}{384(356)(29{,}000)} = 0.33\,in < 0.50\,in \quad \therefore OK$$

CHECK SUPERIMPOSED COMPRESSIVE STRENGTH OF CONCRETE

$$N_{VALUE} = \frac{29{,}000ksi}{57000(4000psi)^{1/2}} = 8.04 \quad \therefore S_{tc} = 8.04(68.6\,in^3) = 552\,in^3$$

$$f_c = \frac{65.0'k(12)}{552\,in^3} = 1.41\,ksi$$

$$F_c = 0.45(4ksi) = 1.80ksi > f_c \quad \therefore OK$$

CHECK BOTTOM FLANGE TENSION STRESS (TOTAL LOAD)

$$f_b = \frac{65.0'k(12)}{50.8\,IN^3} + \frac{65.0'k(12)}{80.6\,IN^3} = 15.4 + 9.7 = 25.1\,ksi$$

$$F_b = 0.9(50ksi) = 45ksi > f_b \quad \therefore OK$$

CHECK SHEAR

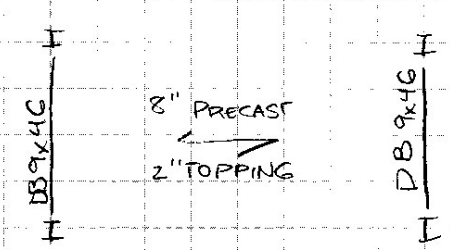
TOTAL LOAD = 120 PSF

$$W = .12ksf(30') = 3.6\,k/ft$$

$$R = \frac{3.6(17')}{2} = 30.6^k$$

$$f_v = \frac{30.6k}{(0.375)(5.75)} = 14.2\,ksi$$

$$F_v = 0.4(50ksi) = 20ksi > 14.2ksi \quad \therefore OK$$



Appendix E: Composite Calculations

4" COMPOSITE SLAB WITH W16 STEEL BEAMS (LRFD)

TRY TO DETERMINE WHAT SPACING IS REQ'D FOR W16x36

W16x36 SPANNING 30'

$f'_c = 4\,ksi$

$F_y = 60\,ksi$

$w_{LL} = 40 + 20 = 60\,PSF$

$w_{DL} = 75\,PSF = (150\,PCF)(4/12) + 3\,PSF + 5 + 2 + 10 + 5 = 75$

$w_U = 1.2(75) + 1.6(60) = 182\,PSF$

LOOK AT CONST. DEFLECTION

$\frac{l}{360} = \frac{30(12)}{360} = 1"$

$1" \geq \frac{5w(30)^4(1728)}{384(29{,}000)(448)}$ $\qquad w_a \leq 0.713\,kLF$

ASSUME 6' SPACING OF FILLER BEAMS

$w = (182)(6') = 1.092\,k/ft$

$M_U = \frac{1.092(30)^2}{8} = 123'k$

$b_{eff} = \frac{30}{4} = 7.5 = 90"$

$= 6' = 72"$ ← CONTROLS

ASSUME $a = 1"$ $\quad Y_2 = 4 - \frac{1}{2} = 3.5"$ $\quad$ TRY LOCATION 7 FOR PNA

$\phi M_n = 331'k$ $\quad \Sigma Q_n = 132^k$

$132 = 0.85(4)(72)a$ $\qquad a = 0.54" < 1"$ $\quad \therefore$ ASSUMPTION OK

$\phi M_P = 240'k$ $\quad$ ASSUME DECK PERPENDICULAR 1 WEAK STUD PER RIB (3/4'

$132/17.2 = 7.7 \Rightarrow 8$ $\qquad$ TOTAL 16 STUDS

WITH CONS. DL $\quad w_{DL} = 75(6) + 36 = .486\,kLF < .713\,kLF$ $\quad \therefore$ OK

LOOK AT LIVE LOAD DEFLECTION

$$\Delta = \frac{5(0.80)(30)^4(1728)}{384(29000)(724)} = 0.69'' < 1.0''$$

LOOK AT OTHER COMPOSITE OPTIONS

SHAPE	ϕM_p	ϕM_n	ΣQ_n	# STUDS	EQUIV. WT (16)
W16x36	240	331	132	16	196
W10x19	81.0	137	122	16	179
W12x19	92.6	150	104	14	159
W14x22	125	177	81.2	10	122 ← DOESN'T MEET Δ CRITERIA

CHECK DEFLECTIONS OF W16x36

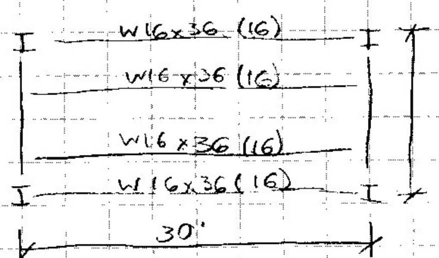
CONST. DEFLECTION

$$\Delta = \frac{5(0.354)(30)^4(1728)}{384(29,000)(448)} = 0.50'' = 1.0''$$

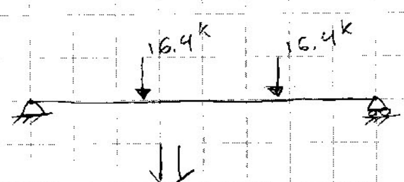
LL DEFLECTION

$$\Delta = \frac{5(0.77)(30)^4(1728)}{384(29,000)(724)} = 0.67'' < 1.0''$$

USE W16x36 WITH (16) ¾" STUDS FOR FILLER BEAMS

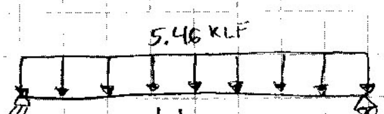


LOOK AT GIRDERS



$$\phi M_n = (16.4^k)(5.7') = 93'k$$

OR



$$\phi M_n = \frac{5.46(17)^2}{8} = 197'k$$

USE $197'k = \phi M_n$

ASSUME $a = 1''$ $Y_2 = 3.5''$ $b_{eff} = \frac{17}{4} = 4.25' = 51''$ ← CONTROLS

30'

TRY W14x22 AS GIRDER

$\phi M_n = 206'k$ $\Sigma Q_n = 157^k$

$\frac{157}{0.85(4)(51)} = 0.91'' < 1.0''$ ∴ ASSUMPTION VALID

$157/21.5 = 7.3 \Rightarrow 8$ (16) SHEAR STUDS

LOOK AT OTHER COMPOSITE OPTIONS

SHAPE	ϕM_p	ϕM_n	ΣQ_n	# STUDS	EQUIV. WT (lb)
W14x22	125	206	157	16	182
W16x26	166	234	96	10	126
W16x36	240	331	132	14	176

CHECK DEFLECTIONS OF W16x26

CONST. DEFLECTION $\frac{L}{360} = \frac{17(12)}{360} = 0.57''$

$$\Delta = \frac{5(1.59)(17)^4(1728)}{384(29000)(301)} = 0.34'' < 0.57''$$

LIVE LOAD DEFLECTION

$$\Delta = \frac{5(3.84)(17)^4(1728)}{384(29000)(499)} = 0.55'' < 0.57''$$

LOOK AT FILLER BEAMS, TRY W16x26 OR W16x31

SHAPE	ϕM_p	ϕM_n	ΣQ_n	# STUDS	EQUIV. WT (lb)
W16x26	166	234	96	10	126
W16x31	203	283	114	14	171

LOOK AT DEFLECTION OF W16x31

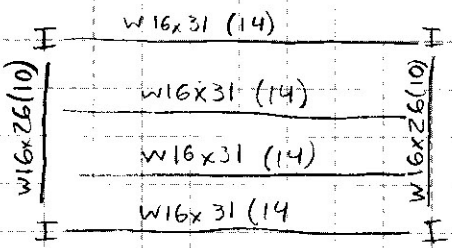
CONST. DEFLECTION

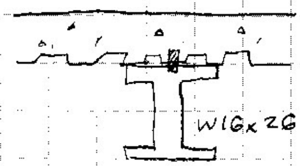
$$\Delta = \frac{5(0.349)(30)^4(1728)}{384(29000)(375)} = 0.58'' < 1''$$

LL DEFLECTION

$$\Delta = \frac{5(0.77)(30)^4(1728)}{384(29,000)(614)} = 0.79" < 1.0"$$

USE W16x31 WITH (14) STUDS





Appendix F: One-way Void Slab Calculations

VOID ONE-WAY SLABS—INTERIOR SPAN $f'_c = 4{,}000$ psi

Top Steel for $-M$ Grade 60 $\rho \approx 0.0050$

Slab Thickness (in.)	12		14		16		18		20		22		24	
Void Dia.	7		9		11		12		14		16		18	
Web Width	3		3		4		4		4		5		5	
Void Spacing c.c.	10		12		15		16		18		21		23	
Top Bar Size	6		6		6		7		7		8		8	
Spacing (in.)	8		7		6		7		6		7		7	
Bott. Bar Size	6		6		6		7		7		8		8	
Spacing (in.)	11		10		8		10		8		10		10	
Temp. Bar Top & Bott.	4		4		4		4		4		4		4	
Spacing (in.)	18		18		18		18		18		18		18	
Steel Areas (in.²/ft) Top	0.660		0.754		0.880		1.029		1.200		1.354		1.354	
Steel Areas (in.²/ft) Bott.	0.480		0.528		0.660		0.720		0.900		0.948		0.948	
Slab Weight (psf)	102		109		121		137		143		155		162	
CLEAR SPAN	**FACTORED USABLE SUPERIMPOSED LOAD (psf)**													
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
15′-0″	490	787	490	766	644	963								
16′-0″	446	728	443	708	584	892								
17′-0″	408	676	403	658	532	829	568	867	574	853				
18′-0″	373	631	368	613	486	774	519	808	522	794				
19′-0″	343	590	337	572	447	724	474	756	476	742				
20′-0″	316	554	310	536	412	680	436	708	436	695				
21′-0″	292	520	285	503	380	639	402	666	400	652				
22′-0″	271	490	263	473	352	602	370	627	368	614	467	745	471	737
23′-0″	252	463	243	446	327	568	342	591	340	578	432	703	435	695
24′-0″	234	435	225	421	304	538	318	558	314	546	400	665	402	657
25′-0″	217	390	209	398	283	509	294	528	290	516	372	629	373	621
26′-0″	202	349	194	377	264	484	273	501	269	488	345	597	345	589
27′-0″	188	313	180	357	245	460	255	475	249	463	321	566	321	558
28′-0″	176	280	167	339	229	436	237	451	231	439	300	538	298	531
29′-0″	164	252	155	322	214	416	220	429	214	417	279	512	278	504
30′-0″	153	225	144	306	200	396	205	408	199	396	261	488	258	480
31′-0″	144	201	134	292	188	378	191	389	185	377	243	465	241	457
32′-0″	134	180	124	278	176	361	178	371	172	359	227	444	224	436
33′-0″	124	159	115	259	164	345	165	354	159	342	212	424	208	416
34′-0″	116	141	107	234	153	330	154	338	147	326	198	405	194	397
35′-0″	109	126	99	212	144	316	144	322	136	311	185	387	181	379
36′-0″	102	110	91	192	134	296	133	308	126	297	172	370	168	362
37′-0″	94	97	84	173	125	270	124	294	116	283	161	354	156	346
38′-0″	87	84	78	155	117	247	115	282	107	270	150	340	145	331
39′-0″	78	72	71	139	109	225	106	270	99	258	140	325	134	317
40′-0″	67	61	66	124	102	205	99	258	90	247	129	312	124	303

(1) = All tubes are full length.
(2) = Alternate tubes are cut off @ .200 × span length to increase shear capacity.

CONCRETE REINFORCING STEEL INSTITUTE

Appendix G: Ribbed Slab Calculations

CONCRETE REINFORCING STEEL INSTITUTE

STANDARD (1) ONE-WAY JOISTS MULTIPLE SPANS	30″ Forms = 6″ rib @ 36″ c.-c. FACTORED USABLE SUPERIMPOSED LOAD (PSF)(2)	f'_c = 4,000 psi f_y = 60,000 psi

Depth	16" Deep Rib + 4.5" Top Slab = 20.5" Total Depth											
TOP BARS Size @	#4 10	#4 8	#5 10.5	#5 9	#6 10.5	End Span Defl. Coeff. (3)	#4 9	#5 11.5	#5 9	#6 11	#6 9	Int. Span Defl. Coeff. (3)
BOTTOM BARS # #	#5 #5	#5 #6	#6 #6	#6 #7	#7 #7		#4 #5	#5 #5	#5 #6	#6 #6	#6 #7	
Steel (psf)	.85	1.04	1.24	1.44	1.71		.93	1.15	1.42	1.70	2.01	
CLEAR SPAN	END SPAN						INTERIOR SPAN					
27'-0"	131 0	185 0	240 0	305 * 306	314 * 373	6.398	184 0	252 0	331 0	359 * 412	368 * 454 *	3.938
28'-0"	112 0	163 0	214 0	275 0	293 * 338	7.400	161 0	225 0	299 0	338 * 373	346 * 423 *	4.554
29'-0"	95 0	142 0	190 0	247 0	274 * 306	8.516	141 0	201 0	269 0	318 * 339	325 * 395 *	5.240
30'-0"	80 0	124 0	169 0	222 0	256 * 277	9.752	123 0	178 0	243 0	300 * 307	306 * 370 *	6.001
31'-0"	66 0	108 0	149 0	200 0	240 * 250	11.119	106 0	158 0	218 0	279 0	289 * 347 *	6.842
32'-0"	54 0	93 0	132 0	179 0	226 * 227	12.625	92 0	140 0	197 0	254 0	273 * 322	7.769
33'-0"	43 0	79 0	116 0	160 0	205 0	14.278	78 0	124 0	177 0	230 0	258 * 295	8.787
34'-0"		66 0	101 0	143 0	185 0	16.089	66 0	109 0	159 0	209 0	244 * 270	9.901
35'-0"		55 0	88 0	127 0	167 0	18.067	54 0	95 0	142 0	190 0	231 * 247	11.118
36'-0"		45 0	76 0	113 0	150 0	20.222	44 0	82 0	127 0	172 0	219 * 226	12.445
37'-0"			64 0	99 0	135 0	22.565		71 0	113 0	155 0	207 0	13.886
38'-0"			54 0	87 0	121 0	25.105		60 0	100 0	140 0	189 0	15.449
39'-0"			44 0	76 0	108 0	27.853		50 0	88 0	126 0	172 0	17.141
40'-0"				65 0	96 0	30.822		41 0	77 0	113 0	157 0	18.967

(1) Gross section properties, Table 8-1.

(2) First load is for standard square end joists; second load is for special tapered end joists.

(3) Computation of deflection is not required above horizontal line (thickness $\geq \ell_n/18.5$ for end spans, $\ell_n/21$ for interior spans).

(4) Exclusive of bridging joists and tapered ends.

*Controlled by capacity in shear.

PROPERTIES FOR DESIGN (CONCRETE .65 CF/SF) (4)

NEGATIVE BENDING STEEL AREA (SQ.IN.) STEEL % (UNIFORM) (TAPERED) EFF. DEPTH, IN. -ICR/IGR	 .72 .49 .30 19.25 .154	 .90 .61 .37 19.25 .184	 1.06 .73 .44 19.19 .208	 1.24 .85 .51 19.19 .234	 1.51 1.04 .63 19.13 .269		 .80 .55 .33 19.25 .168	 .97 .67 .40 19.19 .194	 1.24 .85 .51 19.19 .234	 1.44 .99 .60 19.13 .260	 1.76 1.21 .73 19.13 .300	
POSITIVE BENDING STEEL AREA (SQ.IN.) STEEL % EFF. DEPTH, IN. +ICR/IGR	 .62 .09 19.19 .168	 .75 .11 19.13 .199	 .88 .13 19.13 .230	 1.04 .15 19.06 .265	 1.20 .17 19.06 .302		 .51 .07 19.19 .140	 .62 .09 19.19 .168	 .75 .11 19.13 .199	 .88 .13 19.13 .230	 1.04 .15 19.06 .265	