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Pennsylvania Judicial Center

Harrisburg, PA

Technical Report #2-
Alternate Floor System Analyses

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Executive Summary

The purpose of this report is to research possible alternatives to the steel composite floor system of the Pennsylvania Judicial Center. This is a nine-story, 425,000 square foot building project currently under construction in Harrisburg, PA. This $95 million building will house the Pennsylvania Unified Judicial System, and features courtrooms, conference rooms, and offices.

A total of nine possible floor systems, including the current system, were considered for this project. Of these nine systems, four were deemed unsuitable and eliminated outright because they were not a good match for the building's geometry and/or loading. The one-way concrete system was eliminated because the majority of the bays in the building are square or rectangular with an aspect ratio < 1.5, which means the whole column grid would need to be redesigned. The building was designed for 125 psf live load and 30 psf superimposed dead load and has spans of up to 42 feet. For two-way concrete systems, those heavy loads and long spans make flat plates and flat slabs with drop panels an uneconomical choice. The floor slabs would have to be very thick and heavily reinforced to get a flat slab system to work; however, a waffle slab works well for the same conditions. Finally, precast floor systems were worthy of consideration, but hollow-core planks were eliminated because they were unable to support the high loads and long spans.

This leaves five floor systems for an in-depth comparison: steel composite (the current system), steel non-composite, open-web steel joists, concrete two-way joists a.k.a. waffle slab, and precast, prestressed double T shapes. A three-bay representative system was selected from the construction documents. It features two 38' spans and one 30' span; all three bays are 30' wide. The three steel systems were analyzed using RAM Structural System software, while the waffle slab and precast systems were sized using tables from the CRSI Handbook and the PCI Design Handbook, respectively.

It is important to note that this is a preliminary analysis in which certain assumptions and estimates are used. While an honest attempt was made to keep the calculations as accurate as possible, this is just to provide an overall glimpse to determine if any alternate systems are a viable alternative to the existing system. All five systems were compared based on thirteen criteria; see the spreadsheet for an overview.

In conclusion, it has been determined that the steel noncomposite system and the open-web steel joist system are not good alternatives to the current system while the waffle slab and precast double T's could be possible alternatives that merit further exploration. The two alternative steel systems can be eliminated because they are basically variations of the existing system, but they are less economical and provide inferior performance. In the case of the noncomposite system, unless there is a good reason, it is better to have the steel and concrete work together, and the depths stretched the limits of practicality. An inherent problem with open-web steel joists is achieving the necessary fire rating; this effort should be made only when the joist system provides the most economical solution. The waffle slab is an intriguing solution because it provides the shallowest depth by far over the other systems; however, its drawback is that it is more labor intensive than the rest of the systems. The Double T system was the best choice for the most important criterion, cost, but there are concerns about the depths of the members and, in general, the use of double T's in a building with aesthetic considerations rather than a parking garage.

Structural System Overview

Floor system:

The typical floor is supported by a composite system. The concrete is lightweight (110 pcf dry unit weight) and has a minimum 28-day strength of 4000 psi. There is 3½" of concrete above a 3" 18-gage galvanized composite cellular metal deck, which makes a total slab depth of 6½". Typical reinforcement is welded wire fabric, 6x6-W2.9xW2.9. The slab is supported by steel beams with typical sizes ranging from W16x36 to W24x68. Typical spans run as long as 42 feet, and the widest spacing between beams is typically ten feet. Composite action is created by ¾" diameter shear studs with 5½" length.

Roof system:

The flat roof system is identical to the typical floor system. The sloped monitor roof on the ninth-floor tower has a 3" 20-gage galvanized metal deck. The roof is supported by sloped beams ranging from W8x10 to W12x19, with spans no longer than 25 feet and a 9' maximum spacing. The monitor above the main atrium features the same deck, but it is supported by bent W30x90 beams spanning 56' and spaced at ten feet o.c.

Lateral system:

The structure is laterally supported by concentrically braced steel frames in both the N-S and E-W directions. These frames consist of the wide flange columns, wide flange beams at each story and two HSS (hollow structural section) diagonal braces between each story. The geometry of the diagonal members vary, and this has an impact on their relative stiffnesses. This lateral system features no moment connections, and relies on concrete floor and roof slabs to act as rigid diaphragms and distribute the lateral loads accordingly.

Foundation:

The slab on grade concrete is normal-weight (145 pcf dry unit weight) and has a minimum 28-day strength of 5000 psi. The slab on grade is fiber-reinforced at not less than 1.5 lb/yd^3 in some areas and is reinforced with #3 bars @ 18" c/c in the rest of the slab. Typical slab thicknesses are 5" with 6" drainage fill and 8" with 8" drainage fill. Column loads of up to 1,000 kips can be supported using concrete piers with diameter of up to eight feet end bearing on rock. Larger column loads are supported by socketed caissons with diameters up to 4.5 feet with up to 18' depth. The piers will bear on grey limey shale bedrock with a bearing capacity of 30 ksf. The median core depth to reach bedrock was 9.5 feet, and bedrock depth is relatively uniform throughout the site. The concrete basement foundation walls will be supported by continuous wall footings.

Columns:

The columns are ASTM A992 Grade 50 wide flange steel shapes laid out in a mostly rectangular grid. In this system the columns are acting as the primary gravity resistance members. The columns that are attached as braced frames are also the main lateral resistant force members. The braces between columns are ASTM A 500 Grade B HSS shapes ranging in size from 8x8x1/2" to 12x12x5/8". The largest column is a W14x550, though most of the columns are on the order of about 300 lb/ft at the ground floor.

Loads

Floor Live Loads:

Load Area	Building Design Load	Minimum Load, ASCE 7-05
Corridors	125 psf	100 psf, first floor 80 psf, all other floors
Offices	125 psf	50 psf
Courtrooms	60 psf + 20 psf partition	60 psf, if seats are fixed
Lobbies and Stairs	125 psf	100 psf
Storage Rooms	125 psf	125 psf for light storage (warehouse)
Archive Storage Room	250 psf	250 psf for heavy storage (warehouse)
Conference Center	125 psf	100 psf (assembly area)
Library (Stacks)	150 psf	150 psf
Cafeteria	100 psf	100 psf (assembly area)
Mechanical Rooms (fans only)	125 psf	n/a
Mechanical Penthouse	250 psf	n/a
Exterior Plaza	100 psf	100 psf (assembly area)
fire vehicle access area	300 psf	n/a
Parking Garage	100 psf	n/a
Loading Dock	250 psf	n/a

Roof Live Loads:

Item	Design Value	Code Basis
Roof Live Load	20 psf min	ASCE 7-05
Ground Snow Load (Pg)	30 psf	IBC Figure 1608.2
Flat-roof Snow Load (Pf)	21 psf + drift	IBC Section 1608.3
Snow Exposure Factor (Ce)	1.0	IBC Table 1608.3.1
Snow Importance Factor (I)	1.0	IBC Table 1604.5
Thermal Factor (Cf)	1.0	IBC Table 1608.3.2
Rainwater Ponding Load	30 psf (avg. of 6”)	n/a

Dead Loads:

Item	Design Value
Concrete Slab, Typical Floor	50 psf
Superimposed Dead Loads	
Mechanical, Electrical, Sprinkler	20 psf
Ceiling Finishes	5 psf
Floor Finishes	5 psf
Steel Structure	Varies
Other Dead Loads	Where applicable

System Analysis Overview

Steel composite floor:
Designed using: Existing construction documents, RAM Structural System

This is the existing system, so it serves as the base to which the rest of the systems are compared. Even though all of the designer's beam sizes were available on the blueprints, a RAM model was created in an attempt to get matching results. As many of the same assumptions as possible about the floor system were used (see Structural System Overview on page 4), and all of the shapes matched the design beams within a size or two. Most of the shear stud values from the RAM model were less than what was used in the construction documents; a possible cause of this is a discrepancy between minimum percent of composite action. The RAM model for this report assumed 25% minimum composite action

Steel noncomposite floor:
Designed using: Existing beam locations, RAM Structural System

The design of this system used all of the same variables as the base system except that no composite action was permitted. Predictably, there was a significant jump in both the required weight and depth of the steel members over those in the composite system. Also, almost all of the beams and girders required a camber; very few members needed cambered in the composite system.

Open-web steel joists:
Designed using: SJI Standard Specifications, RAM Structural System

Originally, this analysis was to be done using the same beam grid as the two systems above. However, from the error messages in RAM and the load tables in the SJI Standard Specifications, it was clear that the joists were unable to safely support the loads at that spacing. Based on the available strength from the load tables, the maximum spacing for a 30' span is about 4'-4". Therefore, the new joist grid was created based on uniform spacing as close to 4'-4" as possible, and it was found that a series of 24LH09 would be necessary to support the loads.

Two-way concrete joists (Waffle slab):
Designed using: CRSI Handbook

As mentioned in the Executive Summary, after a quick glance at the CRSI Handbook tables it was evident that a standard flat slab system would be insufficient for the floor's structural requirements. Waffle slabs, on the other hand, only become economical over flat slabs for long spans and heavy loads. 30"x30" voids were chosen over 19"x19" because they provided the necessary capacity and use a little less material. The capacity needed was 255 psf superimposed, using the 1.4D+1.7L combination on which the table is based. The smallest system in the table capable of supporting this load at a 39' span has a 4½" slab and 14" ribs. See Appendix for reinforcement. Since the table values are to limit deflections in a square bay, the reinforcement and concrete will probably be a little conservative. Also, the slab will need to be changed to 5" in order to achieve the desired 2-hour fire rating.

Precast Double T's:
Designed using: PCI Design Handbook

In the PCI Design Handbook, there are several pages of load tables that can be used to select the members. Rather than simply going in the manual and selecting the first precast double T capable of supporting the load (155 psf superimposed service load), the members were selected based on several criteria, especially depth and deflection. A 2" slab topping was essential for this project in order to get a smooth floor finish. Precast double T's were selected for several different spans; a big advantage double T's have over the other systems is that they can achieve very long spans (60'+) under this loading, which could enable a reduction of the amount of columns in the building. See the table for the selection of members at various spans. Note: a sketch for this system was not performed because the column grids will need to change and the Double T's will likely be designed to extend beyond the grid.

Floor System Comparisons

Now that the systems have been designed, either using a computer model or load tables from design manuals, a comparison of the systems is needed. Comparing all five systems for each criterion would be the most effective way to determine each system's strengths and weaknesses. Once the strengths and weaknesses are all known, one is able to use judgment to determine if the system is a possible solution for the building or not. Since it is still just a preliminary analysis, though, it is unlikely that one can say with certainty that one system is clearly the best choice over all the rest.

Thirteen factors have been selected for this comparison: cost, fire rating, lead time, constructability, deflection, vibration, slab width, total depth, weight, aesthetics, durability, column grid changes, and lateral system effects. Some criteria hold much more significance than others, but all of the factors come together to show overall how viable each system is for use in the Pennsylvania Judicial Center.

Cost:

Out of all the criteria that can be considered when selecting the most appropriate floor system for this project, the cost of the system is arguably the most significant variable. The structural system that usually will be selected for a project is the cheapest system that can safely support all of the design loads. Most of the floor systems in this project will be designed to be architecturally invisible, hidden from view inside the floor-ceiling sandwich. Therefore, an owner is likely to be in favor of whatever type of system is most economical.

To help with the cost analysis, a RAM model was prepared using a three bay representative system. These bays have varying spans, so the model provides a decent insight into the effects of different systems for a quick analysis. Since the same assumptions for depth of concrete, loading, etc. were made in each model, a cost comparison can be made based on the relative weights.

RAM Weight Comparison:

Composite: 20,496# steel shapes + 643 shear studs + 6½" concrete + 3" deck
Noncomposite: 32,371# steel shapes + 0 shear studs + 6½" concrete + 3" deck
Open-web joists: 16,380# joists + 11,304# girders + 6½" concrete + 3" deck

A reasonable approximation for relative cost of a shear stud to the cost of steel members is that each shear stud is equal to the cost of ten pounds of steel. Converting the shear studs in the composite system to weight, the composite system will have an effective weight of 26,926#, still considerably less than the 32,371# for the noncomposite system. The composite system is also more economical than the open-web joist system, which weighs just slightly more (27,684#), but will need to be designed and fabricated by the joist company, which adds more cost.

The difference between the composite and noncomposite system is 2.72 tons for just three bays; if this was extrapolated to the whole nine-story building, the savings of using a composite system over noncomposite could be drastic. A March 2005 report by the American Institute of Steel Construction put the cost of steel at almost $600/ton. Considering moderate inflation, I will assume $600/ton as the cost of steel for this comparison. The area used in analysis was 3000 sq. ft. If savings is assumed to be constant for the entire 425,000 sq. ft. building, then the cost difference between composite and noncomposite becomes:

$600/ton * 2.72 ton/3000sqft * 425,000sqft = **$231,200 savings**

Next, the R.S. Means Assemblies Cost Data book will be used to compare concrete and precast systems to composite steel. This analysis was done using the CostWorks program for Harrisburg, PA in the year 2005:

System	Material/sq ft	Labor/sq ft	Total/sq ft	Total
Composite Steel	15.55	8.05	23.60	**$10.03 million**
Waffle Slab	10.50	10.25	20.75	**$8.82 million**
Double T w/ 2" Topping	6.70	3.39	10.09	**$4.29 million**

The waffle slab provides a relatively large savings over the composite steel system of approximately $1.2 million, but the cost of the Double T system is significantly less than both. As a matter of fact, it is less than half the cost of the composite system! This is a very big benefit for the precast system.

Fire Rating:

For the Pennsylvania Judicial Center project, a 2 hour fire rating is required for all floors. Concrete will automatically provide adequate fire protection if the minimum slab depth of 5" is achieved. This means that the waffle slab alone is sufficient fire proofing. The three structural systems have adequate concrete depth for fireproofing, but the steel members and metal deck must be sprayed with cementious material or enclosed in another way to achieve the 2 hour rating. Spray-on fireproofing will not work for open-web steel joists, it will need to be enclosed in concrete or other material to achieve the rating. This is a big negative against the use of the steel joists; having to build protection around the joists just to achieve a fire rating is not an economical solution when compared to the other systems. For precast double T's, there are several UL setups that are capable of providing a 2 hour rating for the 4" thickness that was designed. Most, but not all, of these systems require the system to be restrained to achieve this rating.

Lead time:

Lead time is not a big issue for this project. It is not on a fast-track by any means; the design was completed well before the project was bid out to subcontractors so there would be plenty of time to order material for whatever system was chosen. Also, while obviously the owner would like the building operational as soon as possible, since it is not a commercial building, there is no concern about lost profits due to slower construction. However, it should be noted that lead time for poured concrete systems is almost non-existent, while steel and precast systems each have about the same lead time for delivery. Fabrication could up to 10 weeks, and counting the shop drawing phases, etc. the total lead time could be up to five months.

Constructability:

None of these systems would be unreasonably challenging for a skilled contractor. The easiest systems to construct would be the steel composite and noncomposite systems. The procedure is simply set the beams, lay out the deck, and pour the concrete. The joist system could be more difficult because of afore mentioned fire protection requirements. The precast system is considered a very easy system to construct; a large area of floor can be placed with every crane lift. However, the fact that this is a "tight" site, bordered closely on three sides by other buildings, could pose some logistical problems for crane placement requirements to lift the massive members. The waffle slab is a medium difficult system. It requires extensive formwork and is more labor intensive than the other systems.

Deflection:

All of the systems designed meet or exceed requirements based on L/360 live load and L/240 total load deflections. While this requirement is considered what is necessary for serviceability, it can be said that the less deflection, the better, so a comparison of deflections of members of the system could be useful.

Maximum deflections of each system:

Steel composite:	1.72" total load Δ, 0.89" live load Δ
Steel noncomposite:	1.53" total load Δ, 1.17" live load Δ
Open-web steel joists:	1.11" total load Δ, 0.65" live load Δ
Waffle slab:	??? total load Δ, ??? live load Δ
Precast double T:	0.07-0.67" total load Δ, live load Δ n/a

The precast double T obviously have better deflection numbers than the rest of the system because the members are cambered so that under full loading, it will deflect to a horizontal position. Precast could have a deflection problem in the positive direction when the loading is insufficient to deflect it downward toward horizontal. That is why for this project, 2" slab topping is essential, because it can create a level floor surface even if the members are bowed slightly upward.

Vibration:

The relative vibrations are approximately proportional to relative stiffnesses and depths of the systems. Therefore, it can be hypothesized that the precast double T will have by far the best vibration attenuation, while the steel systems would not perform as well in vibration prevention. A much more in-depth analysis is necessary to take a more accurate look at the vibration of the system, but vibration is not a key factor in floor selection for this project.

Slab width:

The slab width variable on its own does not have much effect on the system selection. However, slab width is directly related to cost, weight, structural depth, deflection, and vibration, so it is important to note. The 6½" slab thickness used in the structural system is the same thickness used by the design professional. This thickness is necessary to achieve the composite action, but it may be possible to get away with a thinner slab for the other steel systems. The systems were kept at 6½" for uniformity, but cost savings could be achieved with a thinner slab.

Slab Widths of Designed Systems:

- Composite Steel – 6½"
- Noncomposite Steel – 6½"
- Open-web Joists – 6½"
- Waffle Slab – CRSI lists options of 3" or 4½". 5" required for 2-hr fire rating.
- Precast – 4" (2" thick flange on double T + 2" CIP topping)

Total depth:

Total depth is a very important criterion in floor system design. It is a direct inhibitor to the architectural goals because every extra inch of structure in the floor-ceiling sandwich is one less inch of height that can be used in the occupied space. This building is not height-controlled, so it is not the crucial issue, but system depth should still be minimized. It should be noted that the composite and noncomposite steel systems are optimized by weight, and their depths can therefore be reduced. However, this would come with an increase in steel weight, making the system less economical.

- Composite Steel – 30.5" (W24 + 6½" concrete)
- Noncomposite Steel – 36.5" (W30 + 6½" concrete)
- Open-web Joists – 30.5" (24LH09 + 6½" concrete)
- Waffle Slab – 19" (5" slab + 14" joists)
- Precast – 26-34" (24-32" double T's + 2" topping)

Weight:

For this preliminary analysis, weight was not deemed to be a critical issue except as it relates to cost. For this project, weight will not have much impact on foundation design because most of the foundation system bears on rock with a 30 ksf bearing capacity. At most, the piers would have to be a slightly wider or deeper. It is also not much of a factor for lateral analysis, since it affects the seismic calculations but wind controls. It will only become a factor in lateral load calculations if the structural weight increases so drastic that it makes seismic design control. This is perhaps a possibility for the heavy double T system, or maybe even the waffle slab. More analysis will need to be done at a later date.

Aesthetics:

Necessary depth of the structural system can be a direct inhibitor to aesthetic features wanted in a building. It can be reasonably assumed that the depth of the current composite steel system allows for the aesthetic freedom that the architect desired. Higher ceilings are desirable when possible. A waffle slab would theoretically provide the best aesthetics because it has a short depth, and it allows recessed lighting in the voids. There are serious aesthetic concerns if specifying the precast double-T, which is typically used in parking structures, not a building in which aesthetics is a primary consideration. The steel joists would also be counter-aesthetic and feel inappropriate in a courtroom setting if left exposed. Also for steel joists, the extra fireproofing needed could limit the architect's options for the ceiling design. These structural systems would need to be designed to be "invisible" to order to be a viable solution.

Durability:

There are no significant durability issues with any of these issues. Steel has the possibility to fatigue over time, concrete may spall if not installed properly, and the precast double T's lose some prestress capacity over time, but these should not be issues because these factors are accounted for in design.

Column grid changes:

Obviously, no column grid changes are necessary for the steel composite and noncomposite systems. Open-web joists would probably not require a column grid change, but the beam grid would need altered as shown on the plan of the typical bays for joists. The concrete systems will probably necessitate a change to concrete columns. The precast system may require slight alterations to the column grid to get the even numbers necessary for precast spans, or they may require major alterations based on the span lengths and direction chosen. Also, due to the very long spans achievable with the double T system, it is possible that some columns can be removed altogether. It also appears that in certain bays columns will need to be moved in order to get proper ratio for two-way action.

Lateral system effects:

No lateral system changes will be necessary for the two alternate steel systems; however, the use of moment frames will be examined in Technical Report #3. For the concrete base floor systems, the lateral system will probably become a shear wall system. It is possible that some of these shear walls could move to the exterior to make some exterior walls structural walls. This will take advantage of some of the heavier walls that are already present and can help to open area in the interior spaces.

COMPARISON SPREADSHEET

	Composite	Noncomposite	Steel Joist	Waffle Slab	Double T
Cost (millions)	$10.03	$10.26	>$10.03	$8.82	$4.29
Fireproofing	Spray-on	Spray-on	Special detail reqd.	None extra reqd.	None extra reqd.
Lead Time	Up to 5 months	Up to 5 months	Up to 5 months	0-2 weeks	Up to 5 months
Construct-ability	Easy	Easy	See fireproofing	Expensive to form, labor intensive	Possible crane issues
Deflection	1.72”	1.53”	1.11”	???	0.07-0.67”
Vibration Resistance	Average	Average	Above Averaage	Above Average	Excellent
Slab Width	6.5”	6.5”	6.5”	5”	4”
Total Depth	30.5”	36.5”	30.5”	19”	26-34”
Weight	Base	Slightly heavier	Same as base	Heavier than base	Heaviest
Aesthetics	Relatively deep system	Very deep members cause problems	Relatively deep system	Small depth, lights in gaps?	“Ugly”, intended for parking garage
Durability Issues	Steel fatigue	Steel fatigue	Steel fatigue	Concrete spalling	Release of prestress
Column Grid Changes	n/a	None	Beam grid altered	Only to achieve two-way action	Could be minor or drastic
Lateral System Effects	n/a	None	None	Change to shear wall	Change to shear wall
Viable solution?	**Yes**	**No**	**No**	**Yes**	**Yes**

Conclusions:

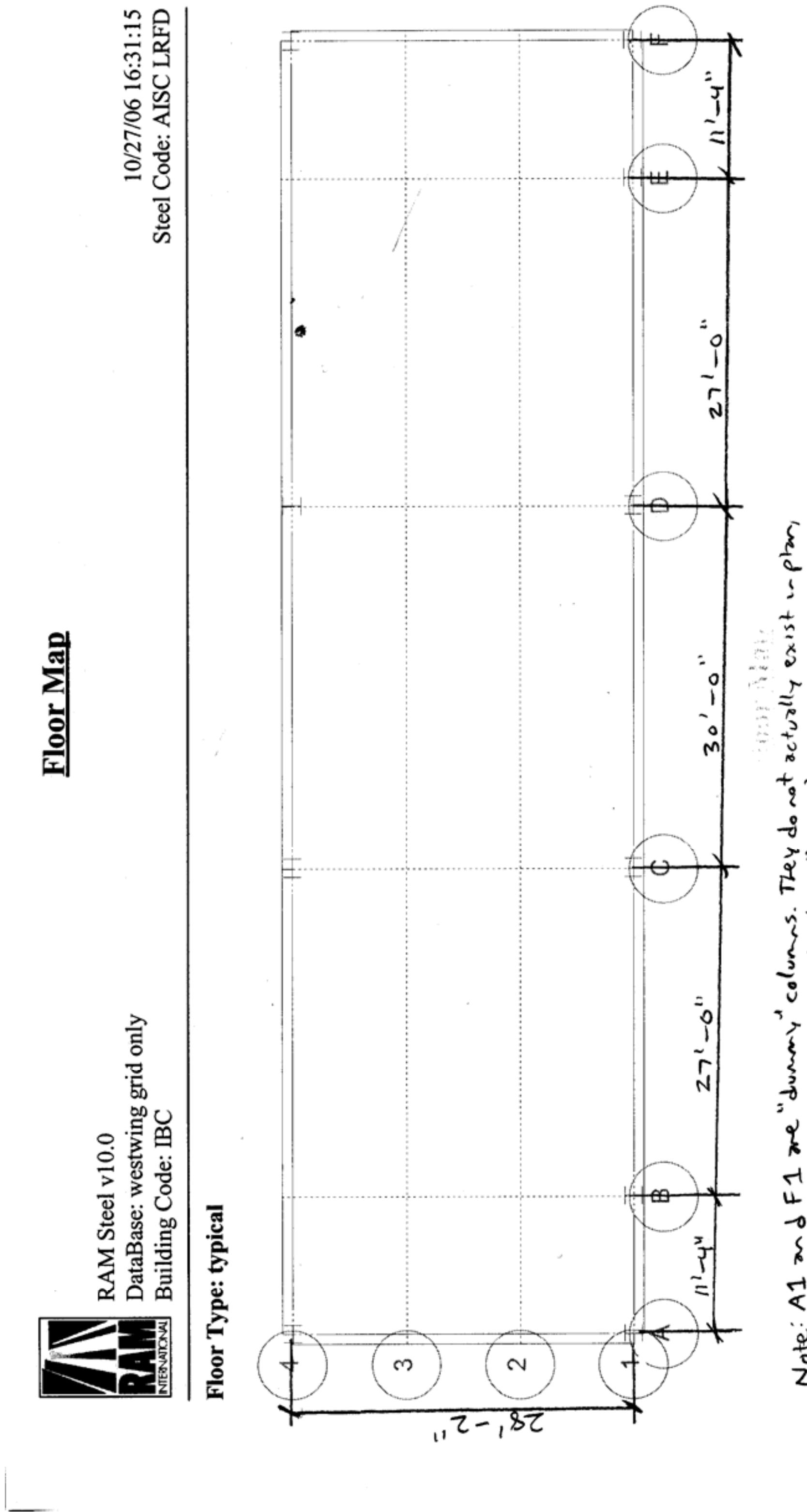
-Composite system, despite having a higher cost than the concrete systems, is still a quality choice and merits consideration

-Noncomposite system and open-web steel joist system are simply inferior variations to the composite system for this project and do not merit further study.

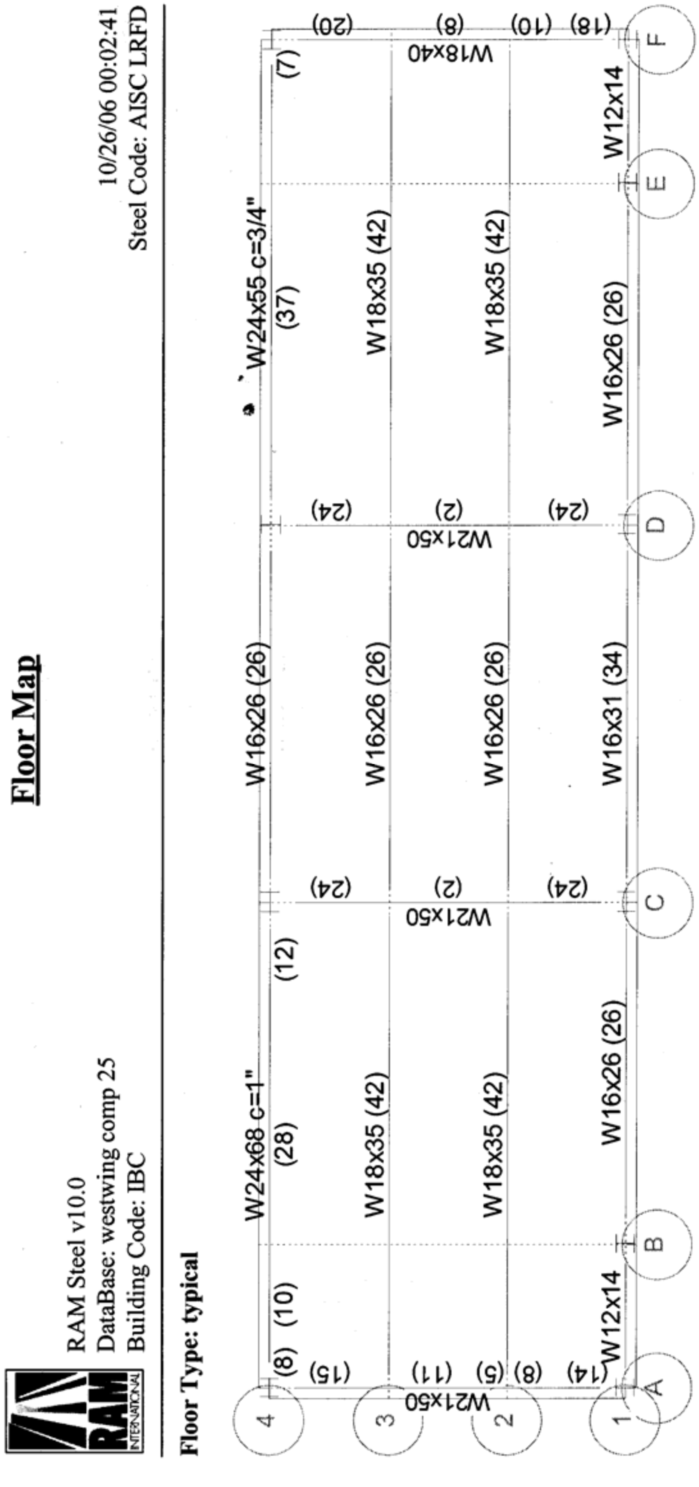
-Waffle slab is a possibility due to its relatively low cost and its aesthetic qualities.

-Precast double T is very cheap compared to the other systems, but aesthetics are a concern. However, the cost alone merits it further consideration.

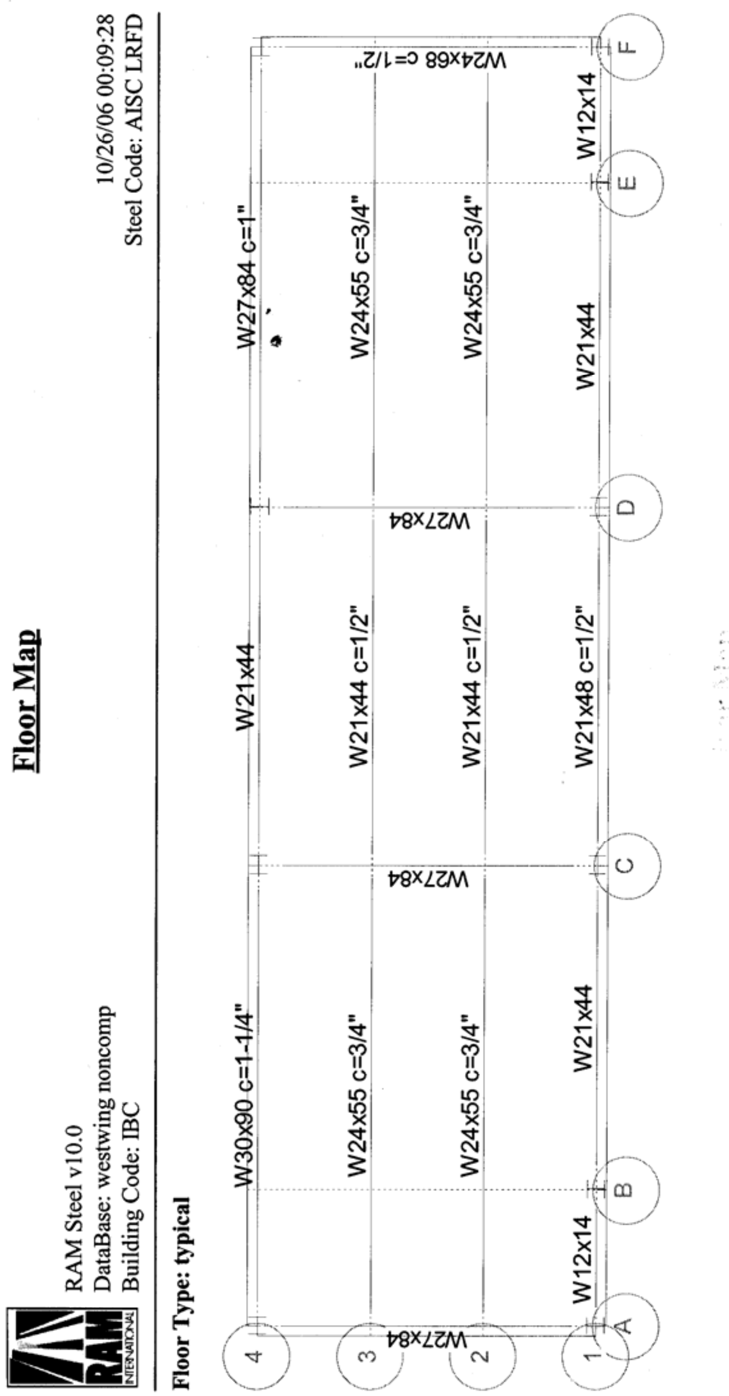
System Sketches -
Grid Dimensions



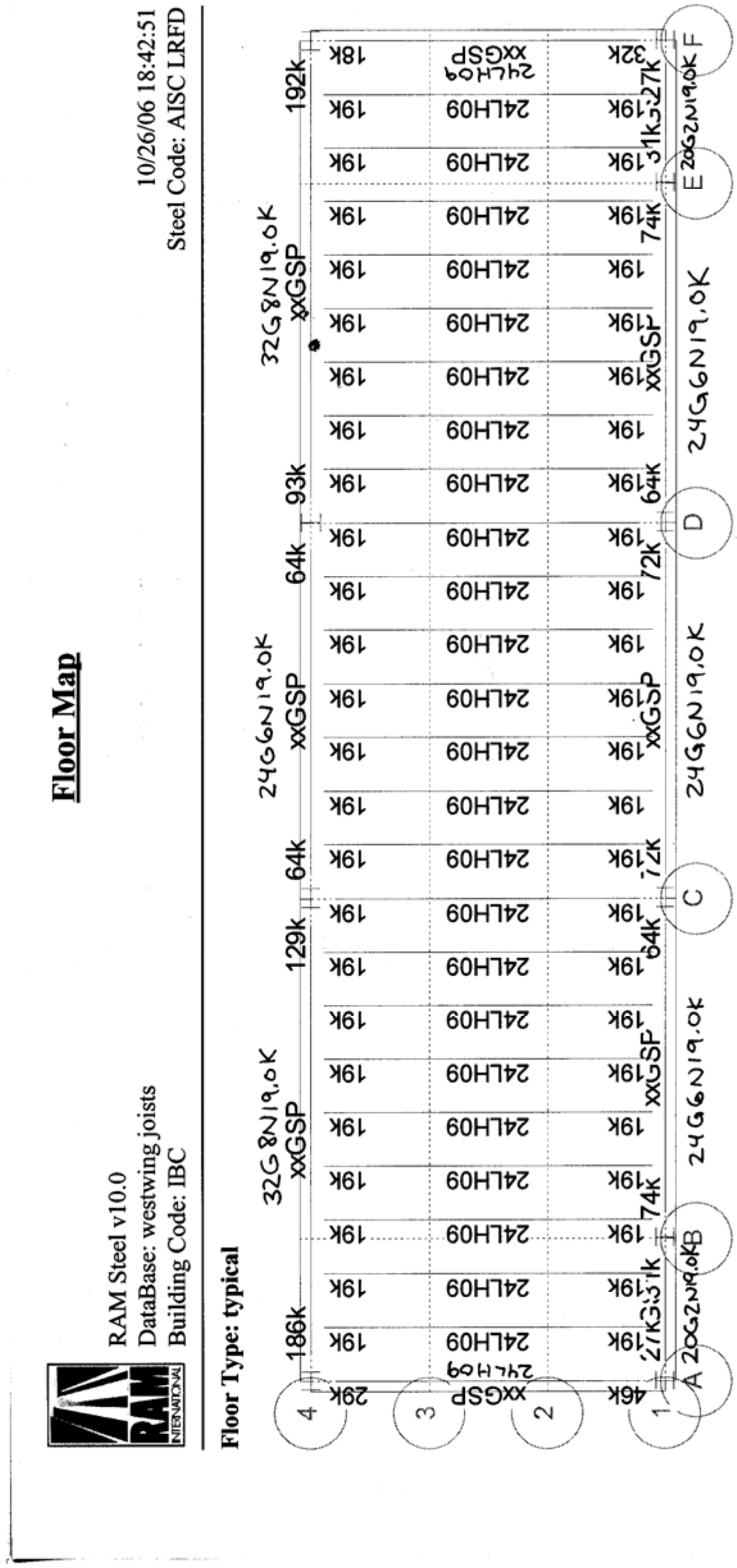
System Sketches -
Composite Steel System



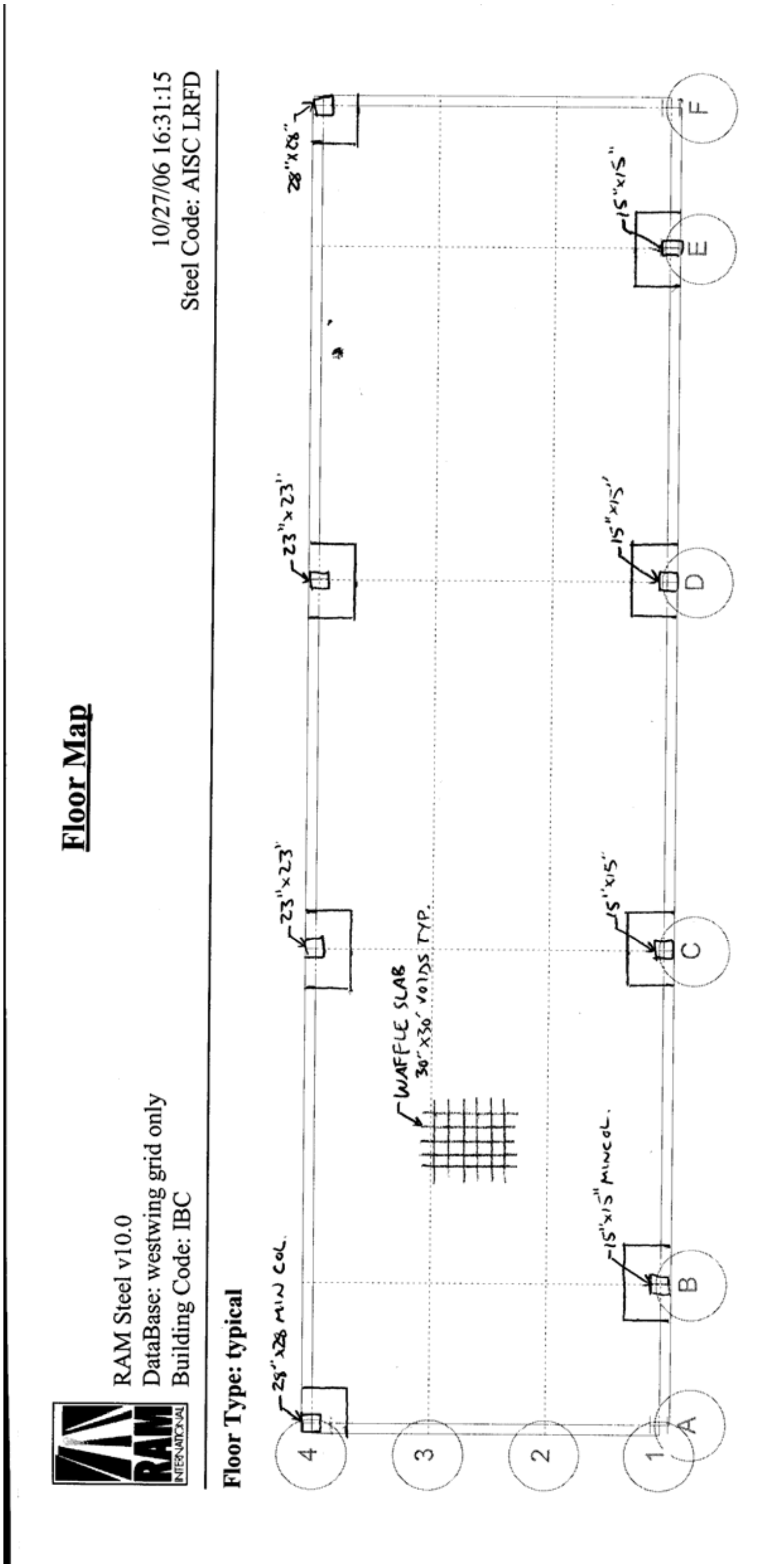
System Sketches -
Noncomposite Steel System



System Sketches -
Open-web Steel Joist System



System Sketches -
Two-way Joist (Waffle Slab) System



System Designs by Table -
Two-Way Joist System (Waffle Slab)

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

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

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

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Edge Column $c_1 = c_2$ (in.)	Square Edge Column γ_f	Square Edge Column (2) Stirrups	Column Strip Top Edge No.-size +	Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size	−M Edge (ft-k)	+M Bot. (ft-k)	−M Int. (ft-k)
39'-0" D=15.500 RIB NOT ON COLUMN LINE 0.904 CF/SF	50	2.63	19	0.812		29-#5+ 4	6	2-#7	35-#5	7	#5	#5	12-#5	398	796	1071
	100	3.04	19 *	0.872		29-#5+ 8	6	1-#7 and 1-#8	30-#6	7	#5	#6	14-#5	487	973	1310
	150	3.82	19 *	0.922		29-#5+13	6	1-#8 and 1-#9	27-#7	7	#6	#7	12-#6	575	1151	1549
	200	4.51	21 *	0.631		29-#5+ 8	6	1-#9 and 1-#10	24-#8	7	#7	#7	14-#6	661	1437	1780
	300	5.52	28 *	0.626		35-#5+ 8	6	2-#10	24-#9	7	#7	#8	13-#7	817	1763	2199
42'-0" D=15.500 RIB NOT ON COLUMN LINE 0.888 CF/SF	50	2.99	21 *	0.829		31-#5+ 6	6	1-#7 and 1-#8	31-#6	8	#5	#6	14-#5	492	984	1325
	100	3.65	21 *	0.894		31-#5+12	6	1-#8 and 1-#9	28-#7	8	#6	#6	12-#6	603	1206	1623
	150	4.24	22 *	0.630		31-#5+ 7	6	2-#9	26-#8	8	#6	#7	15-#6	712	1424	1916
	200	5.01	27 *	0.626		35-#5+ 8	6	2-#10	29-#8	8	#7	#7	13-#7	813	1671	2190
45'-0" D=15.500 RIB NOT ON COLUMN LINE 0.876 CF/SF	50	3.36	22 *	0.868		34-#5+10	6	1-#8 and 1-#9	38-#6	9	#5	#6	13-#6	603	1207	1624
	100	4.20	23 *	0.917		34-#5+17	6	1-#9 and 1-#10	28-#8	9	#6	#7	15-#6	738	1476	1987
	150	4.93	27 *	0.626		38-#5+ 9	6	2-#10	32-#8	9	#7	#7	18-#6	867	1734	2334
48'-0" D=18.500 RIB ON COLUMN LINE 0.898 CF/SF	50	3.85	24 *	0.896		36-#5+19	7	1-#8 and 1-#9	34-#7	9	#6	#7	15-#6	738	1476	1987
	100	4.72	27 *	0.922		39-#5+24	7	1-#9 and 1-#10	32-#8	9	#7	#7	19-#6	898	1796	2418
	150	5.55	34 *	0.622	4 S 6 1	33-#6+ 8	7	2-#10	30-#9	9	#7	#8	17-#7	1046	2093	2817
51'-0" D=18.500 RIB ON COLUMN LINE 0.886 CF/SF	50	4.39	26 *	0.912		38-#5+24	7	1-#9 and 1-#10	32-#8	10	#6	#7	18-#6	880	1761	2370

SQUARE INTERIOR PANELS

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

Span c.-c. Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Interior Column $c_1 = c_2$ (in.)	Square Interior Column (2) Stirrups	Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size
39'-0"	50	2.33	19		6	1-#5 and 1-#6	32-#5	7	[illegible]	[illegible]	[illegible]
	100	2.70	19	4 S 6 1	6	2-#6	28-#6	7	[illegible]	[illegible]	13-#6
	150	3.38	19 *	4 S 6 1	6	2-#7	33-#6	7	[illegible]	[illegible]	[illegible]
	200	3.99	19 *	4 S 6 1	6	1-#7 and 1-#8	29-#7	7	[illegible]	[illegible]	[illegible]
	300	5.17	23 *	4 S 6 2	6	1-#8 and 1-#9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42'-0"	50	2.69	21		6	1-#6 and 1-#7	40-#5	[illegible]	[illegible]	[illegible]	13-#6
	100	3.31	21 *	4 S 6 1	6	2-#7	35-#6	8	[illegible]	[illegible]	[illegible]
	150	3.95	21 *	4 S 6 2	6	1-#7 and 1-#8	31-#7	8	[illegible]	[illegible]	[illegible]
	200	4.61	21 *	4 S 6 2	6	2-#8	[illegible]	8	[illegible]	[illegible]	[illegible]
45'-0"	50	3.01	22	4 S 6 1	6	2-#7	35-#6	9	[illegible]	[illegible]	16-#5
	100	3.69	22 *	4 S 6 2	6	1-#7 and 1-#8	32-#7	9	[illegible]	[illegible]	14-#6
	150	4.50	22 *	4 S 6 2	6	1-#8 and 1-#9	29-#8	9	[illegible]	[illegible]	[illegible]
48'-0"	50	3.47	24 *	4 S 6 1	7	2-#7	32-#7	9	[illegible]	[illegible]	14-#6
	100	4.31	24 *	4 S 6 1	7	2-#8	30-#8	9	[illegible]	[illegible]	15-#6
	150	5.20	25 *	4 S 6 2	7	1-#8 and 1-#9	29-#9	9	[illegible]	[illegible]	16-#7
51'-0"	50	4.06	25 *	4 S 6 1	7	2-#8	38-#7	10	[illegible]	[illegible]	17-#6

See the notes on Page 11-19.

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

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANELS

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

Span c-c Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Edge Column $c_1 = c_2$ (in.)	Square Edge Column γ_f	Square Edge Column (2) Stirrups	Column Strip Top Edge No.-size +	Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size	Moments −M Edge (ft-k)	Moments +M Bot. (ft-k)	Moments −M Int. (ft-k)
[illegible] D=9.500 RIB NOT ON COLUMN LINE 0.8[illegible] CF/SF	50	2.07	12	0.660		18-#5+0	4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5	92	185	248
	100	2.07	12	0.686		18-#5+0	4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5	113	226	304
	150	2.12	12	0.712		18-#5+0	4	2-#5	18-#5	4	#4	#5	7-#5	134	294	360
	200	2.19	12	0.738		18-#5+0	4	1-#5 and 1-#6	18-#5	4	#4	#5	7-#5	154	364	415
	300	2.57	12	0.791		18-#5+0	4	1-#6 and 1-#7	18-#5	4	#5	#6	7-#5	195	496	526
	400	3.00	12	0.843		18-#5+0	4	1-#7 and 1-#8	20-#5	4	#6	#6	7-#5	237	624	637
	500	3.44	12 *	0.612		18-#5+0	4	2-#8	17-#6	4	#6	#7	8-#5	278	751	748
[illegible] D=9.500 RIB NOT ON COLUMN LINE 0.878 CF/SF	50	2.10	13	0.695		20-#5+0	4	2-#5	20-#5	5	#4	#5	8-#5	130	261	351
	100	2.17	13	0.726		20-#5+0	4	1-#5 and 1-#6	20-#5	5	#4	#5	8-#5	160	320	431
	150	2.27	13	0.756		20-#5+0	4	2-#6	20-#5	5	#4	#5	8-#5	189	413	510
	200	2.54	13	0.787		20-#5+0	4	2-#7	20-#5	5	#5	#5	8-#5	219	513	589
	300	3.07	13 *	0.848		20-#5+0	4	2-#8	24-#5	5	#6	#6	8-#5	278	701	748
	400	3.87	13 *	0.640		20-#5+0	4	2-#9	21-#6	5	#6	#7	10-#5	337	884	907
	500	4.49	13 *	0.640		20-#5+0	4	1-#9 and 1-#10	18-#7	5	#7	#7	8-#6	396	1065	1065
[illegible] D=12.500 RIB ON COLUMN LINE 0.913 CF/SF	50	2.10	15	0.706		22-#5+0	5	2-#5	22-#5	5	#4	#5	9-#5	182	363	489
	100	2.17	15	0.742		22-#5+0	5	1-#5 and 1-#6	22-#5	5	#4	#5	9-#5	222	444	597
	150	2.43	15	0.778		22-#5+0	5	1-#6 and 1-#7	23-#5	5	#5	#5	9-#5	262	561	706
	200	2.83	15	0.821		22-#5+1	5	2-#7	26-#5	5	#6	#6	9-#5	302	699	814
	300	3.71	15 *	0.909		22-#5+6	5	1-#8 and 1-#9	24-#6	5	#6	#7	11-#5	383	956	1031
	400	4.57	15 *	0.637		22-#5+4	5	1-#9 and 1-#10	21-#7	5	#7	#8	10-#6	464	1207	1248
	500	5.37	19 *	0.633	4 S 6 1	23-#5+4	5	2-#10	19-#8	5	#8	#8	11-#6	536	1423	1444
33'-0" D=12.500 RIB ON COLUMN LINE 0.892 CF/SF	50	2.30	16	0.746		25-#5+0	5	2-#6	25-#5	6	#4	#5	10-#5	240	480	646
	100	2.49	16	0.788		25-#5+0	5	1-#6 and 1-#7	25-#5	6	#5	#5	10-#5	294	587	790
	150	2.77	16 *	0.839		25-#5+2	5	2-#7	30-#5	6	#5	#6	10-#5	347	730	935
	200	3.33	16 *	0.888		25-#5+5	5	2-#8	25-#6	6	#6	#6	12-#5	401	915	1080
	300	4.51	16 *	0.636	4 S 6 1	25-#5+4	5	1-#9 and 1-#10	24-#7	6	#7	#7	10-#6	509	1256	1370
36'-0" D=12.500 RIB ON COLUMN LINE 0.876 CF/SF	50	2.38	18	0.757		27-#5+0	5	1-#6 and 1-#7	27-#5	7	#4	#5	11-#5	308	617	830
	100	2.76	18	0.809		27-#5+1	5	1-#7 and 1-#8	33-#5	7	#5	#5	11-#5	378	756	1017
	150	3.15	18 *	0.870		27-#5+5	5	2-#8	28-#6	7	#5	#6	13-#5	448	898	1205
	200	3.82	18 *	0.634		27-#5+2	5	2-#9	24-#7	7	#6	#6	15-#5	517	1140	1392

SQUARE INTERIOR PANELS

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

Span c-c Columns $\ell_1 = \ell_2$ (ft)	Factored Super-imposed Load (psf)	(1) Steel (psf)	Square Interior Column $c_1 = c_2$ (in.)	Square Interior Column (2) Stirrups	Column Strip Bottom No. Ribs	Column Strip Bottom Bars per Rib	Column Strip Top Interior No.-size	Middle Strip Bottom No. Ribs	Middle Strip Bottom Long Bars	Middle Strip Bottom Short Bars	Middle Strip Top Interior No.-size
[illegible] D=9.500 RIB NOT ON COLUMN LINE 0.8[illegible] CF/SF	50	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	100	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	150	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	200	2.04	12		4	1-#4 and 1-#5	18-#5	4	#4	#5	7-#5
	300	2.25	12		4	1-#5 and 1-#6	18-#5	4	#4	#5	7-#5
	400	2.55	12	4 S 6 1	4	2-#6	19-#5	4	#5	#5	7-#5
	500	2.97	12 *	4 S 6 1	4	1-#6 and 1-#7	16-#6	4	#5	#6	7-#5
[illegible] D=9.500 RIB NOT ON COLUMN LINE 0.878 CF/SF	50	2.04	13		4	1-#4 and 1-#5	20-#5	5	#4	#5	8-#5
	100	2.04	13		4	1-#4 and 1-#5	20-#5	5	#4	#5	8-#5
	150	2.12	13		4	2-#5	20-#5	5	#4	#5	8-#5
	200	2.23	13	4 S 6 1	4	1-#5 and 1-#6	20-#5	5	#4	#5	8-#5
	300	2.56	13	4 S 6 1	4	1-#6 and 1-#7	22-#5	5	#4	#5	8-#5
	400	3.39	13 *	4 S 6 1	4	1-#7 and 1-#8	19-#6	5	#5	#6	9-#5
	500	4.05	13 *	4 S 6 2	4	2-#8	23-#6	5	#6	#6	8-#6
[illegible] D=12.500 RIB ON COLUMN LINE 0.913 CF/SF	50	2.03	15		5	1-#4 and 1-#5	22-#5	5	#4	#5	9-#5
	100	2.03	15		5	1-#4 and 1-#5	22-#5	5	#4	#5	9-#5
	150	2.12	15		5	2-#5	22-#5	5	#4	#5	9-#5
	200	2.43	15		5	2-#6	24-#5	5	#4	#5	9-#5
	300	3.26	15 *	4 S 6 1	5	2-#7	22-#6	5	#5	#6	10-#5
	400	3.95	15 *	4 S 6 1	5	1-#7 and 1-#8	20-#7	5	#6	#6	9-#6
	500	4.90	16 *	4 S 6 2	5	1-#8 and 1-#9	23-#7	5	#7	#7	10-#6
33'-0" D=12.500 RIB ON COLUMN LINE 0.892 CF/SF	50	2.15	16		5	2-#5	25-#5	6	#4	#5	10-#5
	100	2.26	16		5	1-#5 and 1-#6	25-#5	6	#4	#5	10-#5
	150	2.46	16	4 S 6 1	5	2-#6	28-#5	6	#4	#5	10-#5
	200	2.94	16 *	4 S 6 1	5	1-#6 and 1-#7	23-#6	6	#5	#5	11-#5
	300	4.07	16 *	4 S 6 1	5	2-#8	22-#7	6	#6	#6	10-#6
36'-0" D=12.500 RIB ON COLUMN LINE 0.876 CF/SF	50	2.24	18		5	1-#5 and 1-#6	27-#5	7	#4	#5	11-#5
	100	2.46	18	4 S 6 1	5	2-#6	31-#5	7	#4	#5	11-#5
	150	2.80	18	4 S 6 1	5	1-#6 and 1-#7	26-#6	7	#4	#5	12-#5
	200	3.46	18 *	4 S 6 1	5	1-#7 and 1-#8	30-#6	7	#5	#5	10-#6

(Continued on next page)

See the notes on Page 11-19.

System Designs by Table - Precast Double T System

Double T Selection from PCI Design Handbook
PCI Design Handbook - Fifth Edition

f'c for all = 5000 psi, f(pu) = 270,000 psi, all topped w/2" NWconc

Span	PCI Page (2-	Width	Depth	Conc Type	I(topped-in^4))	Wt (topped-plf)	Strand Pattern	Load Capacity (service psf)	Long Term Camber (in)	Calc Defl	Real Defl (Camber - Defl)	Notes
30	9	8	24	normal	27720	618	6S-6	175	0.5	0.32	0.18	
30	13	10	24	normal	29396	718	68-D1	168	0.7	0.38	0.32	
38	10	8	24	light	29857	520	88-D1	175	2.4	1.13	1.27	
38	21	10	26	normal	30716	718	108-D1	163	1.6	0.93	0.67	Pretopped
42	15	10	32	normal	77131	891	108-D1	179	0.9	0.55	0.35	
42	16	10	32	light	83019	741	108-D1	192	1.5	0.76	0.74	
42	17	12	28	normal	57323	967	148-D1	171	1.3	0.89	0.41	
42	18	12	28	light	61410	811	108-D1	171	1.5	1.24	0.26	
54	11	8	32	normal	71886	791	148-D1	173	1.5	1.29	0.21	
60	11	8	32	normal	71886	791	188-D1	170	1.9	1.97	-0.07	

Strand Pattern - First No. is No. of strands, 2nd No. is Diameter of strand in 1/16ths, S=straight, D1= one depression point

Geometry:
T's centered at 1/4 and 3/4 span
For 24": bottom of web is 3 3/4" thick and top is 5 3/4" thick
For 32": bottom of web is 4 3/4" thick and top is 7 3/4" thick
Flange always 2", except pretopped = 4"
2" topping not included in depth

Note: Grey boxes denote possible use of member in system.

Member Deflections - Composite Steel System

Beam Deflection Summary

RAM Steel v10.0
DataBase: westwing comp 25
Building Code: IBC

10/26/06 00:02:41
Steel Code: AISC LRFD

STEEL BEAM DEFLECTION SUMMARY:

Floor Type: typical

Composite / Shored

Bm #	Beam Size	Dead in	Live in	NetTotal in	Camber in
1	W21X50	0.642	0.327	0.969	
11	W18X35	0.827	0.892	1.719	
12	W18X35	0.827	0.892	1.719	
2	W24X68	1.397	0.423	0.820	1
9	W16X26	0.435	0.587	1.022	
13	W21X50	0.500	0.441	0.941	
8	W16X31	0.526	0.707	1.233	
15	W16X26	0.528	0.628	1.156	
14	W16X26	0.528	0.628	1.156	
3	W16X26	0.530	0.711	1.241	
16	W21X50	0.500	0.441	0.941	
7	W16X26	0.435	0.587	1.022	
18	W18X35	0.827	0.892	1.719	
17	W18X35	0.827	0.892	1.719	
4	W24X55	1.222	0.591	1.061	3/4
5	W18X40	0.622	0.461	1.083	

Noncomposite

Bm #	Beam Size	Dead in	Live in	NetTotal in	Camber in
10	W12X14	0.139	0.190	0.329	
6	W12X14	0.139	0.190	0.329	

Member Deflections - Noncomposite Steel System

Beam Deflection Summary

RAM Steel v10.0
DataBase: westwing noncomp
Building Code: IBC

10/26/06 00:09:28
Steel Code: AISC LRFD

STEEL BEAM DEFLECTION SUMMARY:

Floor Type: typical

Noncomposite

Bm #	Beam Size	Dead in	Live in	NetTotal in	Camber in
1	W27X84	0.620	0.309	0.929	
10	W12X14	0.139	0.190	0.329	
11	W24X55	1.109	1.170	1.529	3/4
12	W24X55	1.109	1.170	1.529	3/4
2	W30X90	1.643	0.494	0.887	1-1/4
9	W21X44	0.485	0.644	1.129	
13	W27X84	0.522	0.445	0.967	
8	W21X48	0.652	0.862	1.015	1/2
15	W21X44	0.663	0.772	0.935	1/2
14	W21X44	0.663	0.772	0.935	1/2
3	W21X44	0.605	0.795	1.400	
16	W27X84	0.522	0.445	0.967	
7	W21X44	0.485	0.644	1.129	
18	W24X55	1.109	1.170	1.529	3/4
17	W24X55	1.109	1.170	1.529	3/4
4	W27X84	1.307	0.624	0.930	1
6	W12X14	0.139	0.190	0.329	
5	W24X68	0.667	0.482	0.648	1/2

Member Deflections -
Open-web Steel Joist System

Beam Deflection Summary

RAM Steel v10.0
DataBase: westwing joists
Building Code: IBC

10/26/06 18:42:51
Steel Code: AISC LRFD

STEEL JOIST DEFLECTION SUMMARY:

Floor Type: typical

Standard Joists

Bm #	Beam Size	Dead in	Live in	Total in
76	24LH09	0.464	0.645	1.109
77	24LH09	0.464	0.645	1.109
78	24LH09	0.464	0.645	1.109
79	24LH09	0.464	0.645	1.109
80	24LH09	0.464	0.645	1.109
81	24LH09	0.464	0.645	1.109
82	24LH09	0.464	0.645	1.109
83	24LH09	0.464	0.645	1.109
63	24LH09	0.466	0.647	1.113
92	24LH09	0.467	0.649	1.116
93	24LH09	0.467	0.649	1.116
94	24LH09	0.467	0.649	1.116
95	24LH09	0.467	0.649	1.116
96	24LH09	0.467	0.649	1.116
97	24LH09	0.467	0.649	1.116
64	24LH09	0.466	0.647	1.113
84	24LH09	0.464	0.645	1.109
85	24LH09	0.464	0.645	1.109
86	24LH09	0.464	0.645	1.109
87	24LH09	0.464	0.645	1.109
88	24LH09	0.464	0.645	1.109
89	24LH09	0.464	0.645	1.109
90	24LH09	0.464	0.645	1.109
91	24LH09	0.464	0.645	1.109