Erie on the Park

Chicago, IL

TECHNICAL ASSIGNMENT 2

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Executive Summary

It is the intent of this report to analyze alternative floor system designs and determine whether or not they are sensible alternatives to the current open-web steel joist system.

Current Floor System

The current floor system consists of a 2” concrete slab on metal deck diaphragm spanning across 14K6 open-web steel joists, which in turn span 26’ between W12 steel beams.

Alternative Systems

The following alternative floor systems were compared to one another and to the original system based on a number of different criteria. These criteria are system weight (PSF), overall depth, potential for vibration problems, fire protection, constructability, and the cost of materials and installation.

1. Concrete Continuous Span Joists
2. Concrete Flat Plate
3. Concrete Flat Slab with Drop Panels
4. Lightweight Precast Concrete Double-Tees
5. Composite Deck and Composite Steel Beams

Conclusions

When investigating the alternative floor systems I realized that the concrete systems have an inherent resistance to fire which is a benefit during construction because spray-on fire proofing is not needed for these types of floors. The greater weight of the concrete systems is a benefit when considering induced vibrations, but it requires a more substantial foundation to support the increased dead loads. The precast and composite steel system provide a decrease in labor costs because the pieces are easily assembled and there is little to no formwork needed on site, unlike the cast-in-place systems which are heavily reliant on formwork. In the end two systems were eliminated from the list of viable alternatives: the concrete joist system because it was very costly to install and the flat slab with drop panels because it did not provide any significant advantages over the flat plate system. The remaining systems would require further investigation to determine the final candidate for an alternative floor system.

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Existing Structural System

Introduction

Erie on the Park is a 25 story condominium complex that was erected in 2002 under the Chicago Building Code. This code references the American National Standards Institute's minimum design loads for buildings and other structures. This code assigns a live load of 40 PSF to the dwelling units and the corridors serving these units along with a 15 PSF load for partitions. Superimposed dead load the engineer used was 13 PSF for the units and the corridors serving the units. This includes 10 PSF for ceiling and mechanical systems and 3 PSF for the finished floors. These loads will be used in the following analysis of alternative floor systems for the residential floors of this building.

Existing Floor System

The existing floor system, of the residential floors, is an open-web steel joist system. In this system 14K6 open-web steel joists span 26' between W12x87 steel beams. The beams, in turn, span 26'-4" between columns. A 0.6C26 non-composite steel deck spans the joists and supports 2" of normal weight concrete with 6x6–W1.4xW1.4 welded wire fabric. The overall depth of the floor system omitting the finished floor and ceiling systems is 16". This is only increased by a couple of inches when the floor and ceiling are included because the open-web joists allow the ventilation ducts to weave between the bars of the trusses instead of hanging below the joists.

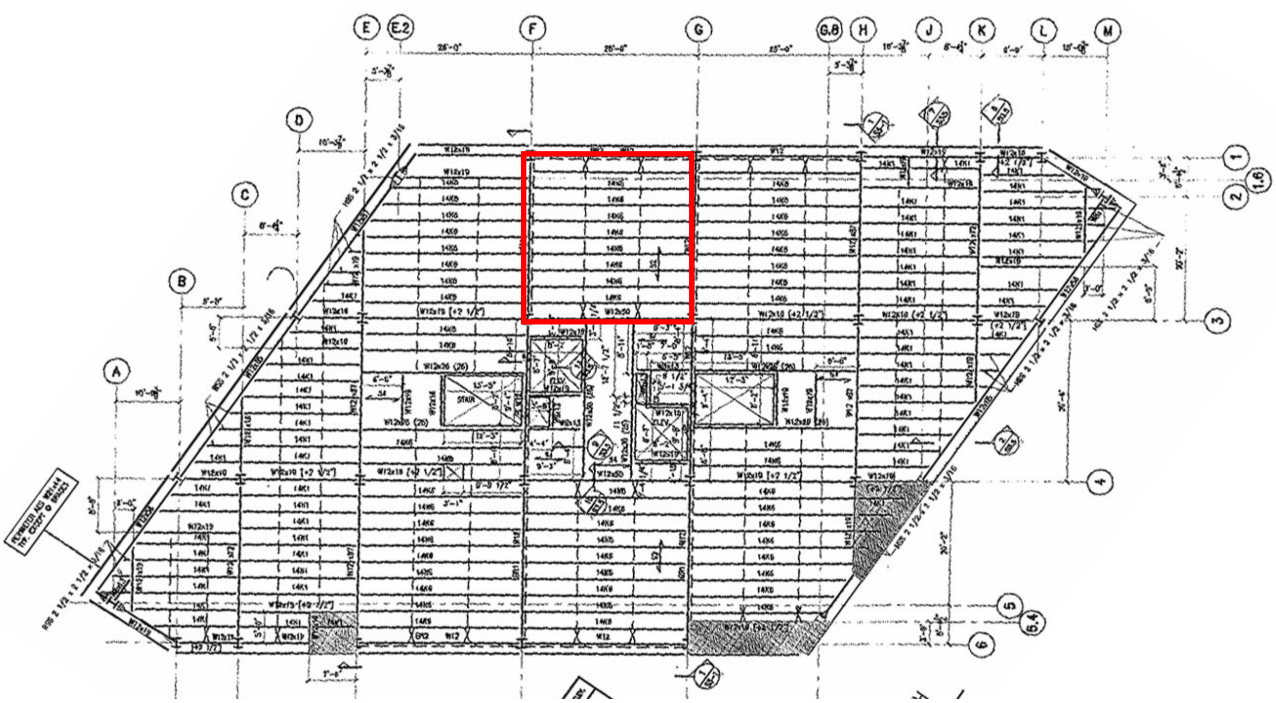


Figure 1: Typical Floor Plan with typical bay highlighted

Alt. 1: Concrete Joists

The continuous concrete joist system is the concrete counterpart to the steel joist system. Unlike the steel joist system this system has inherent fire proofing qualities, and does not require spray-on fire proofing. This system weighs much more than the building's current open-web steel joist system, 85 PSF compared to 30 PSF. This additional weight affects the size of the columns and ultimately the size of the foundation. The added diaphragm weight also alters the seismic design of this building. The increase in weight could help the floor system, too, by greatly decreasing the chances of floor vibrations. The overall depth of this system is 18.5", and there is room in between the joist ribs for the MEP systems to run their conduit and ducts. These would have to be bent around the girders to go from one bay to another which would increase the necessary ceiling to floor distance. This system requires more time and labor during construction in the way of forming the joists and waiting for the concrete to cure enough to remove the forms and support its own weight.

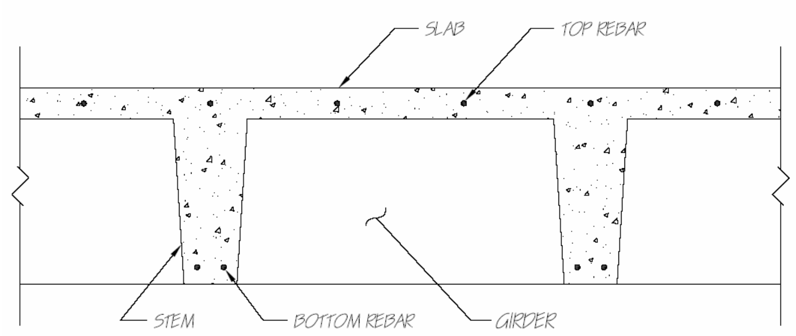


Figure 2: Cross-Section of a Concrete Continuous Joist System

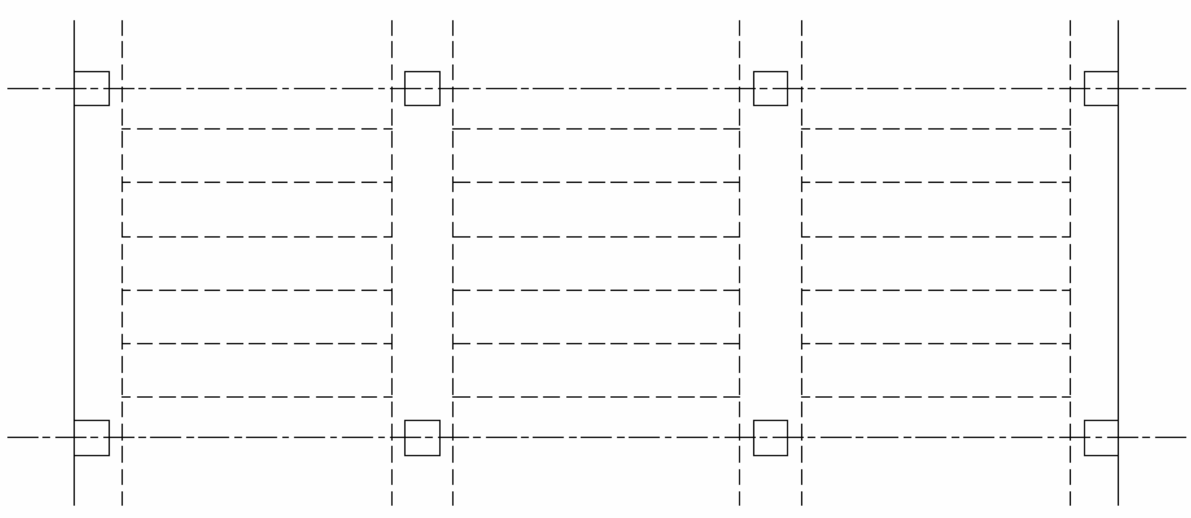


Figure 3: Continuous Concrete Joist Plan

Using the CRSI 2002 Design Guide to find a concrete joist system I determined that 40" skip joist system with 8" ribs was an efficient system for this bay size. The depth of this floor system is 18.5”, which includes a 4.5” slab and 14” deep ribs. The girder required for this system is 26” wide and the same depth as the joist ribs.

Alt. 2: Concrete Flat Plate

The flat plate design is an alternative the open-web steel joist system for a number of reasons. The bay dimensions are relatively square which lends itself to a two-way concrete system such as the flat plate. There are many attributes of this concrete system that would benefit this building. For instance, this system provides a fire proofing barrier with a very high rating between the floors, thus there is no need for spray on fire proofing and the associated labor. This is a heavy floor system, typically greater than 100 PSF, therefore there will not be any walking vibration issues. The flip side, though, is that the foundation would have to be increased greatly to accommodate the extra dead load of the floors. The lateral systems would also have to be strengthened due to the increased seismic loads attributed to the heavier floor system. This is a thin system, with an overall depth of 9”, which allows room for mechanical, electrical, and plumbing within the ceiling cavity. During construction, this is an easy system to form and the forms could be reused from floor to floor.

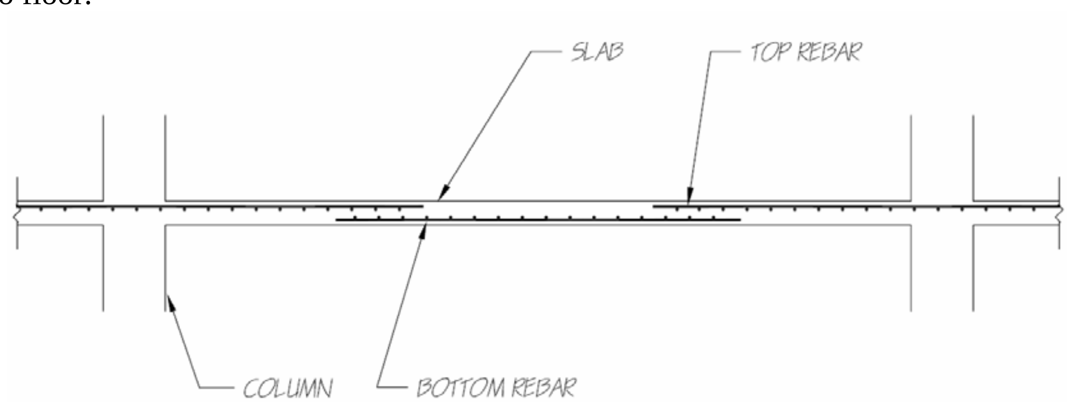


Figure 4: Cross-Section of Flat Plate System

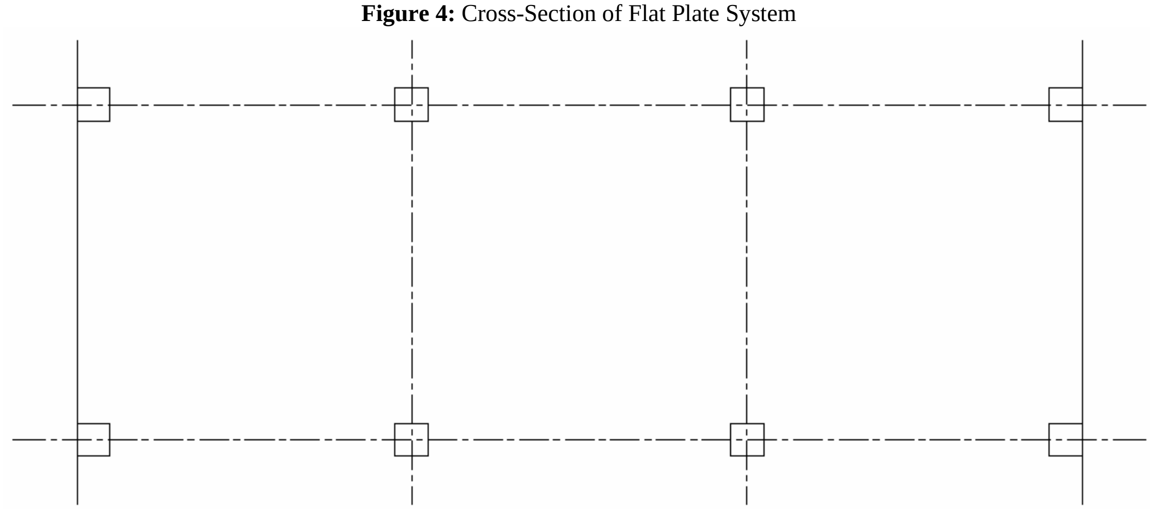


Figure 5: Flat Slab Plan

This system was sized from tables in the 2002 CRSI handbook and it was found that a 9” flat slab with 31” x 31” columns worked for this bay size. It would be advantageous to later check if using post-tensioning this system could reduce the column sizes and the thickness of the slab.

Alt. 3: Concrete Flat Slab with Drop Panels

A concrete flat slab with drop panels is a possible alternative to the steel joist floor system because the typical bays are square (26' x 26'). This system provides inherent fire proofing between each of the residential floors. The inherent weight of this system nullifies any concerns pertaining to walking vibrations. This added weight raises concerns related to the foundation as well as the lateral system, though. The lateral system would have to be re-evaluated for the seismic loads because of the increase in the weight of the floor diaphragms and the foundation would have to be strengthened to account for the additional weight. This system allows for room in the ceiling cavity for the mechanical, electrical, and plumbing systems without dramatically increasing the overall height of the building. This system provides a challenge during construction because of the formwork for the drop panels, but it is possible to reuse the formwork due to the similarity of each of the floors.

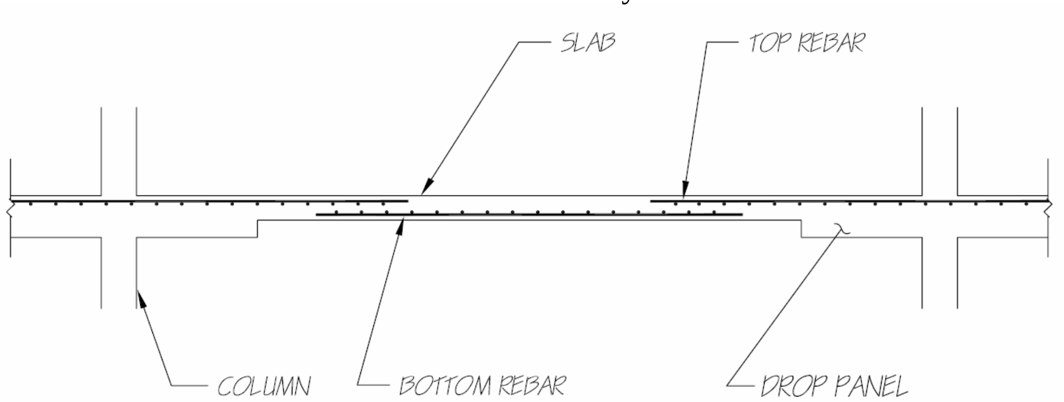


Figure 6: Cross-Section of Flat Slab with drop panels

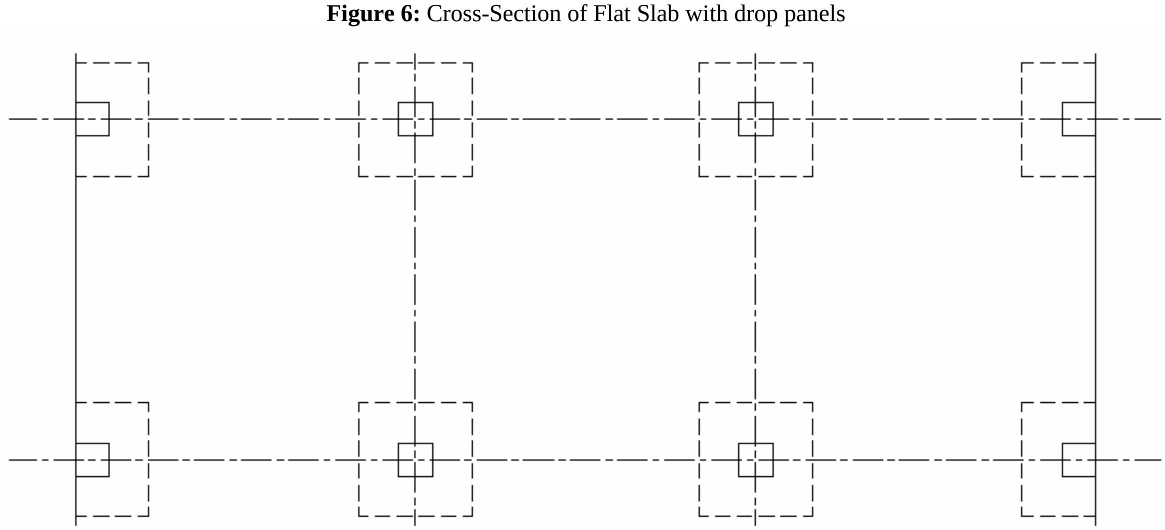


Figure 7: Flat Slab Plan

This system was sized using the CRSI handbook. The system that best fit the bay size was a 9" thick slab with 7" drop panels that are 8'-8" square. The columns are significantly smaller than the flat plate system at 15" x 15".

Alt. 4: Precast Concrete

A precast concrete system would be another concrete alternative to the steel joist system. This system would have many of the same advantages as the other concrete systems: inherent fire proofing, greater weight alleviates vibration concerns, and it provides a ceiling cavity for the MEP systems. Like the other concrete systems, this system is heavier and would require a redesign of the columns, foundation, and a second look at the lateral system under seismic loadings. This system is more like steel during construction in that it requires more crane time to lift the pieces into place and the erection time is usually shorter. Also like steel, though, precast pieces are a long lead item and you would have to order them earlier in the design process.

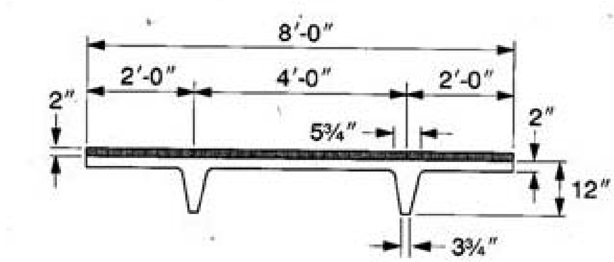


Figure 8: Cross Section of Precast Double-Tee

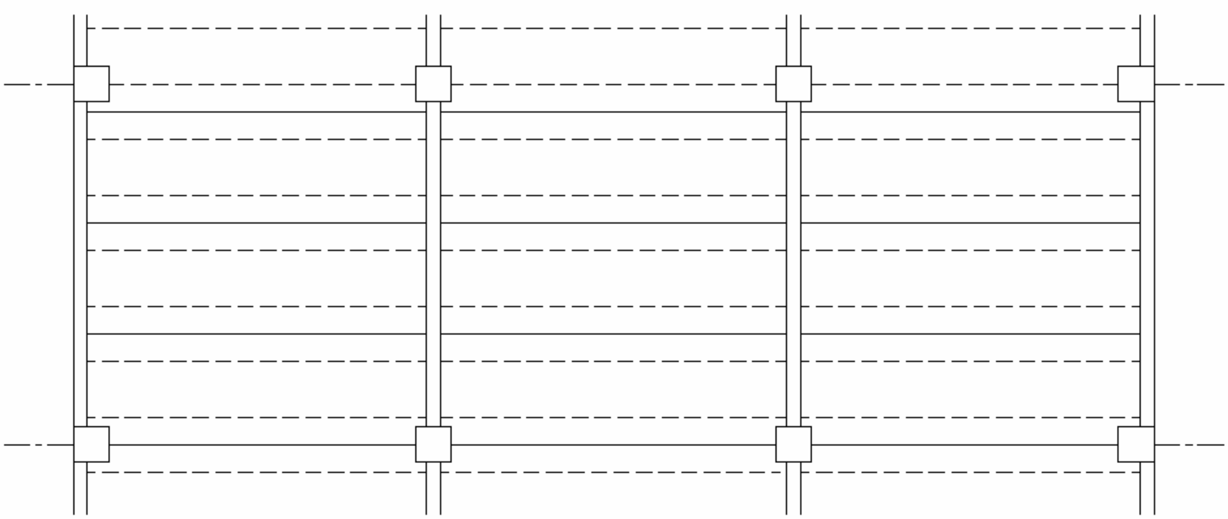


Figure 9: Precast Double-Tee Plan

Looking at the PCI Design Handbook it was determined that a 12” double-tee with a 2” topping layer is adequate for this bay size. This double-tee is made of lightweight concrete to save on overall weight of the system. Precast, inverted tee beams with a depth of 20” support the double-tees.

Alt. 5: Composite Steel Beams

Steel beams are an alternative to the open-web steel joists. Using composite beams and decks reduces the overall depth of the floor system because you are able to use lighter beams and girders. This allows for space in the ceiling cavity for mechanical equipment and ducts. Since it is a lighter system there is the possibility of having issues with vibration. Spray-on fire proofing would have to be applied since the steel is exposed below the concrete slab. Though this system is lighter than a concrete system it is still heavier then the joist system, thus the columns, foundation and lateral systems would have to be reevaluated under the larger load. This system is relatively easy to construct and the metal deck provides a temporary staging area. What is going to be very labor intensive is welding the shear studs to the beams.

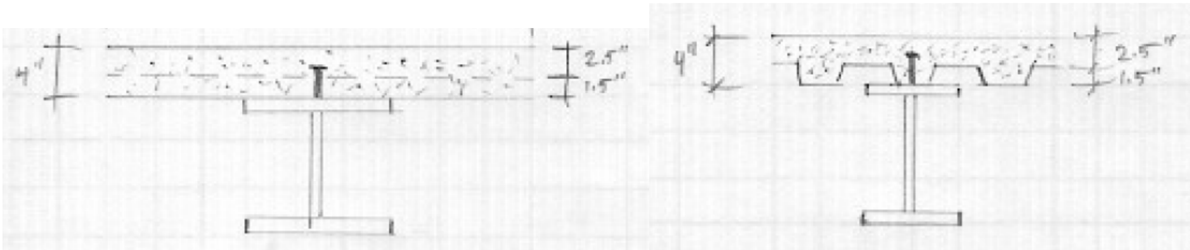


Figure 10: (Left) Section through Beam. (Right) Section through Girder

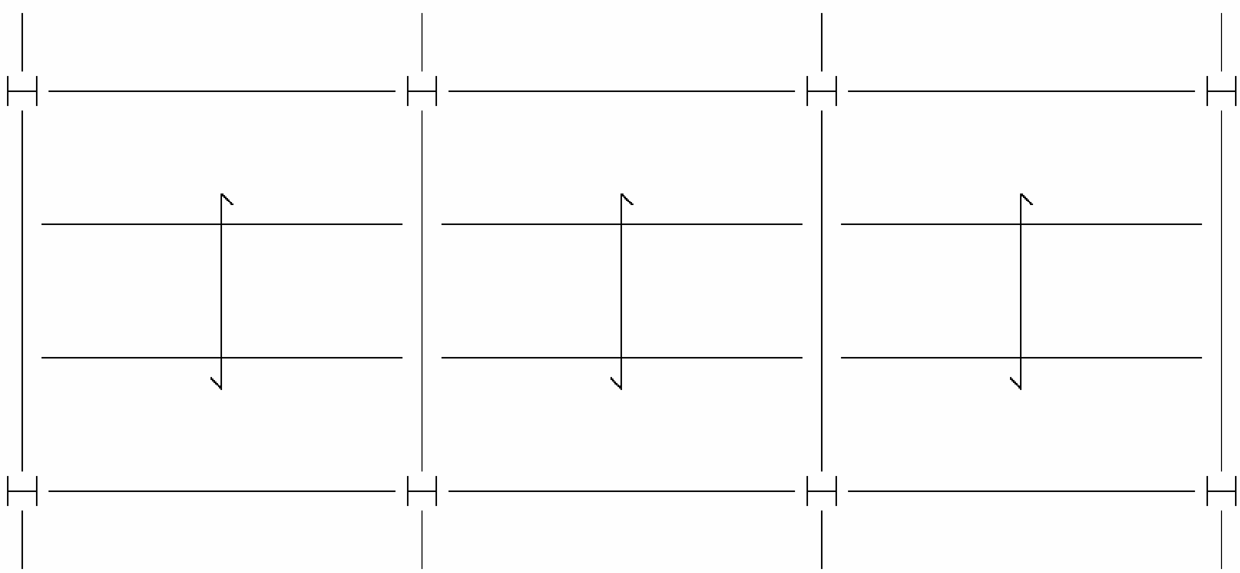


Figure 11: Composite Slab/Beam Plan

These bays were designed with two beams 8'-8" O.C. per bay. To support a 1.5" metal deck with 4" of normal weight and the superimposed loads a W10x15 with 18 shear studs along its length was utilized. Two of these W10 beams frame into a W14x30 girder with 44 shear studs along its length. All the connections in this system were assumed pinned.

Comparison

	Steel Joists	Concrete Joists	Flat Plate	Flat Slab	Precast Double-Tees	Composite Steel Beams
Weight (psf)	30	85	112.5	123	54	40
Depth (in)	16	18.5	9	9 +7	14	14
Vibration	Maybe	No	No	No	No	Maybe
Column Size	W14	20x20	31x31	15x15	20x20	W14
Constructability	Easy	Hard	Medium	Medium - Hard	Easy	Medium
Long Lead	Y	N	N	N	Y	Y
Formwork	N	Y	Y	Y	N	N
Fire Rating (hr)	1.5-2	>2	>2	>2	1.5-2	1-2
Cost (USD)						
Materials	7.85	6.85	5.20	5.80	6.35	8.65
Installation	4.28	9.40	7.05	7.50	1.30	4.49
Total	12.13	16.25	12.25	13.30	7.65	13.14
Viable Alternative	XXX	No	Yes	No	Yes	Yes

Conclusion

All of these systems are possible alternatives to the current open-web steel joist floor system, but some of them are more efficient than others and thus better alternatives. The concrete joist system, I believe, could be ruled out as a viable alternative. This system is much more efficient when the bays have a higher aspect ratio (>2:1). It is also a heavy system that would require a redesign of the foundation, and the labor/installation costs are the highest of all the systems. The flat plate system is still a viable alternative because it is a relatively easy floor system to form, thus reducing the cost of labor, and it is very efficient for square bays. It is a heavy system, which would reduce the possibility of vibration issues, but this also requires a more substantial foundation. Introducing post-tensioning to this system would be advantageous because it would decrease the weight of the system. The flat slab system is also very efficient when used with square bays, but it is a more difficult system to construct and form and it is ultimately heavier than the flat plate system and that is why it is no longer a viable alternative. Light weight concrete double-tees are a viable alternative because they are incredibility inexpensive and easy to install. They are also lighter than any of the other concrete alternatives which means the foundation would not have to be increased as much as with the other systems. Lastly, the composite steel system is a viable alternative because it is the lightest system next to the open-web steel joists and it is relatively easy to install.

Appendix

A1: References

CRSI Handbook, 2002

Manual of Steel Construction LRFD, Third Edition, 2002

PCI Design Handbook, Edition 5, 1999

RS Means Assemblies Cost, 2005

Underwriters Laboratories Fire Resistance – Volume 1, 2001

A2: Floor System Sizing Charts

ALT 1: ONE-WAY CONCRETE JOISTS

LIVE LOADS:

UNITS/CORRIDORS : 40 PSF

PARTITIONS : 15 PSF

SUPERIMPOSED D.L.:

MEP : 10 PSF

FLOORING : 3 PSF

FACTORED LOADS:

1.4(13) + 1.7(55) = 111.7 PSF

@ 48" SPACING

1.4(4×13) + 1.7(4×55) = 446.8 PLF

@ 72" SPACING

1.4(6×13) + 1.7(6×55) = 670.2 PLF

SPACING	36" o.c.	48" o.c.	72" o.c.
PAN SIZE	30"	40"	66"
RIB SIZE	6"	8"	6"
OVERALL DEPTH	19"	18.5"	20.5
WEIGHT (PSF)	71	85	73
TOP BARS EXT SPAN	#4 BARS @ 10" o.c.	#4 BARS @ 9" o.c.	#4 BARS @ 11.5" o.c.
TOP BARS INT SPAN	#4 BARS @ 11" o.c.	#4 BARS @ 10.5" o.c.	#4 BARS @ 10" o.c.
BOT BARS EXT SPAN	2 #5 BARS	2 #6 BARS	1 #6 & 1 #7 BAR
BOT BARS INT SPAN	2 #4 BARS	2 #4 BARS	2 #6 BARS
JOISTS PER BAY	8 1/3	6.5	4 1/3
CHOICE		XX	

EVEN SPACING, SHALLOWEST

WIDE MODULE (1) ONE-WAY JOISTS MULTIPLE SPANS

40" Forms + 8" Ribs @ 48" c.-c.
14" Deep Rib + 4.5" Top Slab = 18.5" Total Depth
FACTORED USABLE SUPERIMPOSED LOAD (PLF)

f'_c = 4,000 psi, f_y = 60,000 psi

TOP BARS NO	#4	#4	#5	#5	#6	End Span Defl. Coeff. (2)	#4	#5	#6	#6	#6	Int. Span Defl. Coeff. (2)
AT	12.0	9.0	11.5	10.0	11.5		10.5	10.5	12.0	10.5	9.0	
BOTTOM BARS NO	2#4	1#6	1#6	1#5	1#7		2#4	1#6	1#6	1#5	1#7	
BARS NO	1#4	1#6	1#7	2#6	1#8		1#4	1#6	1#7	2#6	1#8	
STEEL (PSF)	.62	.92	1.09	1.20	1.48		.52	.52	.52	.52	.52	
CLEAR SPAN		END SPAN						INTERIOR SPAN				
24'-0" (3)	355	742	963	1177	1441	1.265	745	1306	1629	1940	2325	0.779
STIR	#3-48	#3-65	#3-98	#3-106	#3-117		#3-64	#3-89	#3-85	#3-106	#3-112	
25'-0"	288	645	848	1045	1289	1.490	647	1166	1462	1749	2103	0.917
STIR	#3-45	#3-85	#3-99	#3-108	#3-120		#3-63	#3-90	#3-93	#3-108	#3-114	
26'-0"	228	558	746	928	1153	1.743	561	1040	1314	1579	1906	1.073
STIR	#3-42	#3-85	#3-99	#3-110	#3-110		#3-62	#3-92	#3-100	#3-111	#3-117	
27'-0"	175	481	655	824	1033	2.027	483	928	1182	1428	1731	1.247
STIR	#3-38	#3-84	#3-100	#3-111	#3-118		#3-60	#3-92	#3-103	#3-113	#3-120	
28'-0"	128	412	574	731	925	2.344	414	828	1064	1292	1574	1.443
STIR	#3-33	#3-83	#3-100	#3-112	#3-124		#3-58	#3-93	#3-105	#3-101	#3-123	
29'-0"	85	350	501	648	829	2.698	352	738	957	1170	1434	1.660
STIR	#3-28	#3-82	#3-100	#3-113	#3-126		#3-56	#3-94	#3-106	#3-109	#3-125	
30'-0"	46	294	435	572	741	3.090	296	656	862	1061	1307	1.901
STIR	#3-23	#3-81	#3-100	#3-114	#3-127		#3-54	#3-94	#3-107	#3-116	#3-128	
31'-0"		244	376	504	662	3.523	245	583	775	962	1192	2.168
STIR		#3-79	#3-100	#3-115	#3-129		#3-51	#3-94	#3-108	#3-118	#3-129	
32'-0"		198	322	442	591	4.000	199	516	696	871	1088	2.461
STIR		#3-77	#3-99	#3-115	#3-130		#3-48	#3-94	#3-108	#3-120	#3-114	
33'-0"		156	273	386	525	4.523	157	455	625	789	993	2.784
STIR		#3-75	#3-98	#3-115	#3-131		#3-45	#3-94	#3-110	#3-121	#3-121	
34'-0"		118	228	334	466	5.097	119	400	560	715	906	3.137
STIR		#3-72	#3-97	#3-115	#3-132		#3-42	#3-93	#3-110	#3-122	#3-129	
35'-0"		83	186	287	411	5.724	84	349	500	646	827	3.522
STIR		#3-69	#3-96	#3-115	#3-132		#3-38	#3-92	#3-111	#3-123	#3-135	
36'-0"		51	149	244	361	6.407	52	302	445	583	754	3.942
STIR		#3-66	#3-94	#3-114	#3-133		#3-34	#3-91	#3-111	#3-124	#3-137	
PROPERTIES FOR DESIGN (CONCRETE .60 CF/SF)												
NEGATIVE MOMENT												
STEEL AREA (SQ. IN.)	.80	1.07	1.29	1.49	1.84		.96	1.42	1.76	2.01	2.35	
ACTUAL STEEL %	.508	.678	.826	.950	1.177		.610	.904	1.128	1.289	1.504	
EFF. DEPTH, IN.	16.75	16.75	16.69	16.69	16.63		16.75	16.69	16.63	16.63	16.63	
−ICR/IGR	.130	.163	.188	.209	.243		.150	.202	.235	.259	.289	
POSITIVE MOMENT												
STEEL AREA (SQ. IN.)	.60	.88	1.04	1.10	1.39		.60	.88	1.04	1.19	1.39	
ACTUAL STEEL %	.370	.546	.646	.737	.867		.370	.546	.646	.737	.867	
EFF. DEPTH, IN.	16.75	16.63	16.59	16.64	16.53		16.75	16.63	16.59	16.64	16.53	
+ICR/IGR	.124	.174	.202	.230	.260		.124	.174	.202	.230	.260	
SINGLE LEG STIRRUP AT 8 IN. CONSTANT SPACING-DISTANCE (IN.)												

(1) For gross section properties, see Table 8-3.
(2) Computation of deflection is not required above horizontal line (thickness ≥ ℓ_n/18.5 for end spans, ℓ_n/21 for interior spans).
(3) Single leg stirrup size space at X in. c.-c. Distance over which stirrups must extend from face of support at each end (in.).

FLAT PLATE SYSTEM (WITHOUT SHEARHEADS)

f'_c = 4,000 psi
Grade 60 Bars

SQUARE EDGE PANEL

9 in. = TOTAL THICKNESS OF SLAB — 0.750 c.f./s.f.

SPAN c.-c. Cols. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	(1) Min. Square Column (in.)	(1) Min. Square Column	Total Panel Moments −M Ext. (ft-kip)	+M Int. (ft-kip)	−M 1st. Int. (ft-kip)	Reinforcing Bars, Each Column Strip: Top Ext.	+	Bottom	Top Int.	Each Middle Strip: Bottom	Top Int.	End Panel Steel (psf), Location of Panel: E	EC	C
23	50	15	0.767	74	148	200	12-#4	6	9-#5	11-#6	8-#5	8-#5	2.31	2.34	2.23
23	100	20	0.748	89	179	240	14-#4	7	16-#4	13-#6	8-#5	8-#5	2.52	2.54	2.50
23	150	24	0.677	103	207	278	16-#4	5	9-#6	15-#6	8-#5	8-#5	2.78	2.81	2.84
23	200	27	0.709	117	234	315	12-#5	5	10-#6	13-#7	14-#4	8-#5	3.12	3.16	3.25
23	250	31	0.641	129	257	346	13-#5	4	11-#6	11-#8	10-#5	13-#4	3.47	3.49	3.58
23	300	34	0.628	140	279	376	14-#5	3	9-#7	12-#8	8-#6	14-#4	3.79	3.82	3.89
23	350	40	0.610	147	293	396	22-#4	4	8-#8	13-#8	12-#5	10-#5	4.04	4.13	4.26
24	50	18	0.736	84	168	226	13-#4	5	10-#5	12-#6	8-#5	8-#5	2.33	2.35	2.27
24	100	22	0.724	101	201	271	15-#4	7	12-#5	11-#7	8-#5	8-#5	2.62	2.64	2.64
24	150	26	0.713	116	232	313	12-#5	5	10-#6	13-#7	9-#5	8-#5	2.97	3.01	3.12
24	200	30	0.662	131	262	352	13-#5	4	16-#5	12-#8	16-#4	13-#4	3.37	3.41	3.49
24	250	34	0.611	144	288	389	22-#4	4	17-#5	13-#8	8-#6	10-#5	3.69	3.74	3.88
24	300	39	0.610	154	307	414	23-#4	4	8-#6	17-#7	12-#5	10-#5	4.02	4.06	4.19
24	350	45	0.609	161	322	433	16-#5	2	8-#8	14-#8	9-#6	16-#4	4.29	4.31	4.45
25	50	20	0.733	94	188	252	14-#4	7	11-#5	14-#6	13-#4	13-#4	2.45	2.47	2.44
25	100	24	0.724	113	225	303	17-#4	8	10-#6	13-#7	9-#5	13-#4	2.86	2.88	2.88
25	150	29	0.661	130	260	349	13-#5	4	11-#6	19-#6	16-#4	13-#4	3.19	3.21	3.32
25	200	33	0.633	146	292	393	22-#4	7	10-#7	13-#8	12-#5	10-#5	3.66	3.71	3.84
25	250	39	0.610	158	316	425	16-#5	2	10-#7	14-#8	19-#4	16-#4	3.81	3.96	4.08
25	300	45	0.609	167	334	450	25-#4	3	20-#5	15-#8	13-#5	11-#5	4.17	4.19	4.35
25	350	51	0.608	175	351	472	13-#8	1	9-#8	16-#8	10-#6	12-#5	4.53	4.82	4.85
26	50	22	0.715	105	209	281	16-#4	6	9-#6	15-#6	13-#4	13-#4	2.53	2.56	2.53
26	100	27	0.618	125	251	337	19-#4	6	11-#6	14-#7	10-#5	13-#4	2.88	3.00	3.02
26	150	31	0.655	145	290	380	22-#4	7	10-#7	13-#8	12-#5	10-#5	3.51	3.54	3.57
26	200	37	0.636	161	322	433	16-#5	5	14-#6	14-#8	9-#6	16-#4	3.82	3.87	3.98
26	250	44	0.619	172	345	464	17-#5	4	11-#7	15-#8	10-#6	12-#5	4.17	4.23	4.39
26	300	51	0.618	182	364	490	13-#8	1	9-#8	16-#8	22-#4	12-#5	4.46	4.49	4.67
26	350	58	0.617	189	378	509	19-#5	1	10-#8	17-#8	11-#6	9-#6	4.75	4.82	5.05
27	50	24	0.717	116	232	313	12-#5	5	10-#5	13-#7	9-#5	9-#5	2.72	2.76	2.71
27	100	29	0.693	139	279	375	14-#5	6	9-#7	12-#8	11-#5	14-#4	3.18	3.21	3.26
27	150	34	0.654	160	321	432	16-#5	5	14-#6	14-#8	19-#4	16-#4	3.60	3.66	3.79
27	200	41	0.630	176	351	473	13-#6	3	9-#8	16-#8	10-#6	12-#5	4.12	4.19	4.35
27	250	49	0.668	188	376	506	19-#5	3	12-#7	17-#8	11-#6	9-#6	4.43	4.48	4.64
27	300	56	0.607	198	396	533	14-#6	1	10-#8	18-#8	16-#5	13-#5	4.71	4.78	4.95
27	350	64	0.606	205	410	552	15-#6	0	11-#8	18-#8	9-#7	10-#6	5.02	5.08	5.27
28	50	26	0.709	129	258	347	19-#4	10	23-#4	14-#7	10-#5	14-#4	2.78	2.79	2.77
28	100	31	0.679	154	308	414	15-#5	6	10-#7	13-#8	12-#5	10-#5	3.33	3.36	3.47
28	150	36	0.662	176	351	472	13-#6	4	15-#6	15-#8	10-#6	12-#5	3.92	3.92	4.06
28	200	46	0.609	191	381	513	19-#5	3	10-#8	17-#8	11-#6	13-#5	4.35	4.38	4.56
28	250	54	0.608	203	407	547	20-#5	3	13-#7	18-#8	16-#5	10-#6	4.62	4.68	4.93
28	300	62	0.607	213	426	574	16-#6	2	11-#8	19-#8	12-#6	10-#6	5.00	5.07	5.33
28	350	70	0.606	221	442	595	16-#6	0	11-#8	20-#8	10-#7	11-#6	5.22	5.30	5.60

SQUARE INTERIOR PANEL

9 in. = TOTAL THICKNESS OF SLAB — 0.750 c.f./s.f.

(2) Span c.-c. (ft)	(3) Load (psf)	(1) Min. Sq. Col. (in.)	Reinforcing Bars, Column Strip: Top	Bottom	Middle Strip: Top	Bottom	Steel (psf), Location of Panel: I	IE	IC
23	50	11	14-#5	8-#5	8-#5	8-#5	2.37	2.39	2.42
23	100	15	17-#5	8-#5	8-#5	8-#5	2.55	2.57	2.60
23	150	19	20-#5	13-#4	8-#5	8-#5	2.77	2.79	2.81
23	200	23	12-#7	10-#5	8-#5	8-#5	3.11	3.14	3.17
23	250	28	11-#8	16-#4	8-#5	8-#5	3.42	3.43	3.43
23	300	33	11-#8	8-#6	13-#4	8-#5	3.56	3.61	3.65
23	350	40	12-#8	12-#5	9-#5	8-#5	3.82	3.87	3.92
24	50	12	16-#6	8-#5	8-#5	8-#5	2.38	2.39	2.41
24	100	17	11-#7	8-#5	8-#5	8-#5	2.70	2.70	2.69
24	150	22	12-#7	14-#4	8-#5	8-#5	2.90	2.92	2.95
24	200	28	11-#8	16-#4	8-#5	8-#5	3.27	3.30	3.34
24	250	31	12-#8	12-#5	9-#5	8-#5	3.61	3.65	3.70
24	300	39	13-#8	19-#4	10-#5	8-#5	3.86	3.86	3.86
24	350	47	13-#8	9-#6	10-#5	13-#4	4.01	4.05	4.09
25	50	14	13-#6	13-#4	13-#4	13-#4	2.50	2.52	2.54
25	100	19	12-#7	9-#5	13-#4	13-#4	2.82	2.85	2.87
25	150	24	16-#7	16-#4	13-#4	13-#4	3.13	3.13	3.12
25	200	29	12-#8	12-#5	9-#5	13-#4	3.48	3.52	3.57
25	250	37	13-#8	9-#6	10-#5	13-#4	3.78	3.82	3.86
25	300	45	14-#8	20-#4	16-#4	9-#5	4.01	4.06	4.10
25	350	54	14-#8	10-#6	15-#4	9-#5	4.17	4.26	4.36
26	50	16	20-#5	13-#4	13-#4	13-#4	2.46	2.49	2.51
26	100	21	13-#7	10-#5	13-#4	13-#4	2.88	2.90	2.92
26	150	26	12-#8	12-#6	9-#5	13-#4	3.33	3.37	3.41
26	200	33	13-#8	13-#5	10-#5	13-#4	3.61	3.64	3.68
26	250	43	14-#8	10-#6	16-#4	9-#5	3.94	3.99	4.05
26	300	52	15-#8	22-#4	11-#5	10-#5	4.19	4.24	4.28
26	350	62	15-#8	11-#6	12-#5	10-#5	4.43	4.51	4.59
27	50	18	12-#7	10-#5	9-#5	9-#5	2.74	2.76	2.78
27	100	23	12-#8	17-#4	9-#5	9-#5	3.17	3.17	3.16
27	150	29	13-#8	13-#5	10-#5	13-#4	3.45	3.48	3.52
27	200	39	14-#8	10-#6	11-#5	14-#4	3.78	3.86	3.93
27	250	49	15-#8	11-#6	12-#5	10-#5	4.06	4.26	4.33
27	300	60	16-#8	16-#5	12-#5	16-#4	4.38	4.46	4.54
27	350	69	17-#8	16-#5	9-#6	16-#4	4.61	4.67	4.72
28	50	19	14-#7	16-#4	14-#4	14-#4	2.82	2.82	2.82
28	100	26	13-#8	19-#4	10-#5	14-#4	3.29	3.29	3.29
28	150	33	15-#8	14-#5	11-#5	10-#5	3.78	3.78	3.79
28	200	45	16-#8	23-#4	12-#5	10-#5	4.05	4.09	4.13
28	250	56	17-#8	16-#5	13-#5	16-#4	4.37	4.41	4.46
28	300	67	17-#8	12-#6	13-#5	11-#5	4.57	4.65	4.73
28	350	77	18-#8	17-#5	20-#4	12-#5	4.79	4.89	4.99

(1) Columns same above and below plate. (2) Center-to-center of columns; $\ell_1 = \ell_2$. (3) Superimposed factored load (factored dead load has been deducted).

ALT 2: CONCRETE FLAT PLATE

LIVE LOADS:

UNITS/CORRIDORS: 40 PSF

PARTITIONS: 15 PSF

SUPERIMPOSED DL:

MEP: 10 PSF

FLOORING: 3 PSF

FACTORED LOADS:

1.4(13) + 1.7(55) = 111.7 PSF

THICKNESS	9"	10"
CAPACITY (PSF)	150	150
WEIGHT (PSF)	112.5	125
TOP BARS EXT. CS	22 #4 BARS + 7	14 #5 BARS + 4
TOP BARS EXT. MS	10 #5 BARS	10 #5 BARS
TOP BARS INT. CS	12 #8 BARS	14 #7 BARS
TOP BARS INT MS	9 #5 BARS	10 #5 BARS
BOT BARS EXT CS	16 #7 BARS	9 #7 BARS
BOT BARS EXT MS	12 #5 BARS	10 #5 BARS
BOT BARS INT CS	12 #5 BARS	11 #5 BARS
BOT BARS INT MS	13 #4 BARS	10 #5 BARS
COLUMN SIZE	31" x 31"	28" x 28"
CHOICE	XX	

LIGHTER & LESS CONCRETE

f'_c = 4,000 psi Grade 60 Bars	FLAT SLAB SYSTEM SQUARE EDGE PANEL With Drop Panels No Beams	SQUARE INTERIOR PANEL With Drop Panels(2) No Beams

h = 9 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS

Square Edge Panel

SPAN c-c, $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel Depth (in.)	Square Drop Panel Width (ft)	(3) Square Column Size (in.)	Square Column γ_f	Column Strip (1) Top Ext. +	Column Strip Bottom	Column Strip Top Int.	Middle Strip Bottom	Middle Strip Top Int.	Total Steel (psf)	Moments Edge (−) (ft-k)	Moments Bot. (+) (ft-k)	Moments Int. (−) (ft-k)
23	100	4.00	7.67	12	0.771	12-#4 4	17-#4	19-#4	8-#5	8-#5	2.16	93.9	187.9	252.9
23	200	5.50	7.67	15	0.631	12-#4 1	11-#6	22-#4	10-#5	13-#4	2.81	125.9	251.8	339.0
23	300	7.00	7.67	17	0.631	13-#4 1	8-#8	25-#4	9-#6	16-#4	3.19	158.6	317.2	427.0
23	400	7.00	7.67	19	0.664	15-#4 3	17-#6	14-#6	11-#6	13-#5	3.89	190.0	380.0	511.5
23	500	8.50	9.20	21	0.629	16-#4 2	16-#7	11-#7	19-#5	8-#7	4.59	222.6	467.3	598.3
24	100	5.50	8.00	12	0.689	13-#4 2	13-#5	19-#4	13-#4	8-#5	2.20	107.5	215.0	280.4
24	200	5.50	8.00	15	0.746	13-#4 5	18-#5	12-#6	12-#5	10-#5	2.86	143.8	287.7	387.3
24	300	7.00	8.00	17	0.684	14-#4 4	12-#7	14-#6	8-#7	12-#5	3.58	181.3	362.6	488.2
24	400	8.50	8.00	19	0.631	16-#4 2	15-#7	11-#7	8-#8	8-#7	4.39	217.6	435.2	585.9
24	500	8.50	9.60	21	0.684	18-#4 3	14-#8	13-#7	11-#7	8-#8	5.08	253.8	507.6	683.4
25	100	5.50	8.33	12	0.735	13-#4 3	15-#5	14-#5	10-#5	13-#4	2.36	121.9	243.8	328.2
25	200	7.00	8.33	15	0.666	13-#4 4	20-#5	12-#6	13-#5	11-#5	2.95	163.7	327.5	440.8
25	300	8.50	8.33	17	0.633	15-#4 3	11-#8	14-#6	9-#7	10-#6	3.92	205.7	411.3	553.7
25	400	8.50	10.00	20	0.702	18-#4 5	13-#8	13-#7	20-#5	9-#7	4.55	247.2	494.5	665.6
25	500	8.50	10.00	24	0.669	13-#5 2	20-#7	19-#6	10-#8	14-#6	5.49	285.7	571.4	769.2
26	100	7.00	8.67	12	0.646	13-#4 2	9-#7	14-#5	11-#5	9-#5	2.47	138.0	276.0	371.6
26	200	7.00	8.67	15	0.720	15-#4 4	23-#5	14-#6	15-#5	19-#4	3.27	185.0	370.0	498.1
26	300	8.50	8.67	17	0.715	17-#4 5	12-#8	12-#7	10-#7	18-#5	4.13	232.6	465.2	626.2
26	400	8.50	10.40	22	0.687	13-#5 2	15-#8	26-#5	23-#5	10-#7	5.02	277.8	555.7	748.0
27	100	7.00	9.00	12	0.716	14-#4 3	19-#5	16-#5	19-#4	16-#4	2.81	155.0	310.1	417.4
27	200	8.50	9.00	15	0.658	15-#4 3	11-#8	14-#6	9-#7	10-#6	3.62	208.5	417.0	561.4
27	300	8.50	9.00	19	0.701	12-#5 3	14-#8	13-#7	15-#6	10-#7	4.52	260.0	520.0	700.0
27	400	8.50	10.80	24	0.717	22-#4 6	17-#8	12-#8	11-#8	9-#8	5.82	310.9	621.7	836.9

Square Interior Panel

SPAN c-c, $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	(3) Square Column Size (in.)	Column Strip Top	Column Strip Bottom	Middle Strip Top	Middle Strip Bottom	Total Steel (psf)	Concrete (cu. ft / sq. ft)
23	100	12	12-#5	12-#4	8-#5	8-#5	2.09	0.787
23	200	18	14-#5	15-#4	8-#5	8-#5	2.34	0.801
23	300	20	15-#5	19-#4	10-#5	13-#4	2.71	0.815
23	400	22	18-#5	11-#6	12-#5	10-#5	3.38	0.815
23	500	23	14-#6	19-#5	10-#6	19-#4	3.93	0.863
24	100	12	12-#5	13-#4	8-#5	8-#5	2.04	0.801
24	200	18	11-#6	18-#4	9-#5	8-#5	2.51	0.801
24	300	20	17-#5	15-#5	8-#6	10-#5	3.07	0.815
24	400	22	14-#6	18-#5	10-#6	12-#5	3.70	0.829
24	500	24	12-#7	11-#7	16-#5	10-#6	4.32	0.863
25	100	12	13-#5	15-#4	13-#4	13-#4	2.13	0.801
25	200	18	16-#5	13-#5	10-#5	13-#4	2.58	0.815
25	300	21	18-#5	9-#7	19-#4	11-#5	3.32	0.829
25	400	23	15-#6	20-#5	11-#6	13-#5	3.87	0.863
25	500	24	13-#7	10-#8	10-#7	11-#6	4.80	0.863
26	100	12	13-#5	11-#5	13-#4	13-#4	2.15	0.815
26	200	18	18-#5	15-#5	12-#5	10-#5	2.87	0.815
26	300	21	14-#6	19-#5	22-#4	19-#4	3.46	0.829
26	400	23	13-#7	23-#5	10-#7	15-#5	4.36	0.863
27	100	12	15-#5	19-#4	10-#5	9-#5	2.31	0.815
27	200	18	18-#5	9-#7	13-#5	11-#5	3.07	0.829
27	300	21	12-#7	21-#5	16-#5	10-#6	3.79	0.829
27	400	23	12-#8	11-#8	14-#6	9-#7	4.91	0.863

ALT B: CONCRETE | FLAT SLAB w/ DROP PANELS

LIVE LOADS:

UNITS/CORRIDORS : 40 PSF

PARTITIONS : 15 PSF

SUPERIMPOSED DL:

MEP : 10 PSF

FLOORING : 3 PSF

FACTORED LOADS:

1.4(13) + 1.7(55) = 111.7 PSF

THICKNESS	9"	10"
CAPACITY (PSF)	200	200
WEIGHT (PSF)	123	135
TOP BARS EXT CS	15 #4 BARS + 4	12 #5 BARS + 1
TOP BARS EXT MS	19 # 4 BARS	12 #5 BARS
TOP BARS INT CS	18 # 5 BARS	17 #5 BARS
TOP BARS INT MS	12 # 5 BARS	11 #5 BARS
BOT BARS EXT CS	23 # 5 BARS	11 #7 BARS
BOT. BARS EXT MS	15 # 5 BARS	10 # 6 BARS
BOT BARS INT CS	15 # 5 BARS	14 # 5 BARS
BOT BARS INT MS	10 #5 BARS	10 #5 BARS
COLUMN SIZE	15" x 15"	15" x 15"
DROP PANEL DIM	8'-8" x 8'-8" x 7"	8'-8" x 8'-8" x 7"
CHOICE	XX	

NO HUGE GAINS FOR GOING TO NEXT SIZE

ALT 4: PRECAST CONCRETE SYSTEM

LIVE LOADS:

UNITS/CORRIDORS : 40 PSF

PARTITIONS : 15 PSF

SUPERIMPOSED DL:

MEP : 10 PSF

FLOORING : 3 PSF

TOTAL LOAD

13 + 55 = 68 PSF

	DOUBLE-TEE 8LDT12+2	HOLLOW CORE 4HC8+2
CAPACITY (PSF)	79	72
WEIGHT (PSF)	54	74
OVERALL DEPTH	14"	8"
STRAND DESIGNATION	68-S	96-S
WIDTH	8'	4'
CONCRETE	LIGHT WT f'_c = 5000 psi	NORMAL WT f'_c = 5000 psi
CHOICE	XX	

LIGHTER SYSTEM, FEWER PIECES

BEAMS

LIVE LOAD : (55)(26) = 1430 PLF

LIVE LOAD REDUCTION APPLICABLE BUT NOT NECESSARY

DEAD LOAD : 13(26) = 338 PLF

TOTAL LOAD = 1768 PLF

INVERTED T-BEAM (28IT20)

CAPACITY = 2409 PLF ; OVERALL DEPTH = 20"

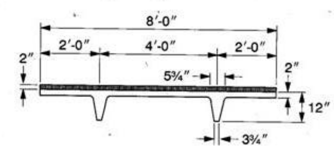
Strand Pattern Designation

68-D1
- No. of strand (6)
- S = straight D = depressed
- No. of depression points
- Diameter of strand in 16ths

Safe loads shown include dead load of 10 psf for untopped members and 15 psf for topped members. Remainder is live load. Long-time cambers include superimposed dead load but do not include live load.

Key
186 — Safe superimposed service load, psf
0.2 — Estimated camber at erection, in.
0.3 — Estimated long-time camber, in.

DOUBLE TEE
8'-0" x 12"
Lightweight Concrete



f'_c = 5,000 psi
f_{pu} = 270,000 psi

Section Properties

		Untopped	Topped
A	=	287 in²	—
I	=	2,872 in⁴	4,819 in⁴
y_b	=	9.13 in.	10.82 in.
y_t	=	2.87 in.	3.18 in.
S_b	=	315 in³	445 in³
S_t	=	1,001 in³	1,515 in³
wt	=	229 plf	429 plf
		29 psf	54 psf
V/S	=	1.22 in.	

8LDT12

Table of safe superimposed service load (psf) and cambers (in.) — **No Topping**

Strand Pattern	e_e, in. / e_c, in.	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
28-S	7.13 / 7.13	186	144	116	89	68	53	41	31								
		0.2	0.3	0.4	0.5	0.5	0.6	0.6	0.6								
		0.3	0.4	0.5	0.6	0.6	0.7	0.7	0.6								
48-S	5.13 / 5.13			195	153	120	95	77	62	50	41	33					
				0.6	0.7	0.8	1.0	1.1	1.2	1.3	1.3	1.3					
				0.8	0.9	1.1	1.2	1.3	1.3	1.4	1.3	1.2					
68-S	3.13 / 3.13				169	133	106	86	70	57	47	39	32				
					0.6	0.8	0.9	1.0	1.0	1.1	1.1	1.1	1.0				
					0.8	1.0	1.1	1.1	1.1	1.1	1.0	0.8	0.5				
68-D1	3.13 / 6.63											72	61	52	45	38	33
												2.6	2.8	3.0	3.1	3.2	3.2
												2.9	2.9	2.9	2.7	2.4	2.1

8LDT12+2

Table of safe superimposed service load (psf) and cambers (in.) — **2" Normal Weight Topping**

Strand Pattern	e_e, in. / e_c, in.	12	14	16	18	20	22	24	26	28	30	32	34	36	38
28-S	7.13 / 7.13	207	157	123	91	66	47	33							
		0.2	0.3	0.4	0.5	0.5	0.6	0.6							
		0.2	0.3	0.4	0.4	0.4	0.3	0.2							
48-S	5.13 / 5.13				175	134	103	80	62	48	36				
					0.7	0.8	1.0	1.1	1.2	1.3	1.3				
					0.7	0.8	0.8	0.7	0.6	0.5	0.2				
68-S	3.13 / 3.13					162	126	99	79	62	47				
						0.8	0.9	1.0	1.0	1.1	1.1				
						0.7	0.7	0.6	0.5	0.3	0.1				
68-D1	3.13 / 6.63											72	59	46	33
												2.6	2.8	3.0	3.1
												1.3	1.0	0.6	0.0

Strength based on strain compatibility; bottom tension limited to $12\sqrt{f'_c}$; see pages 2-2–2-6 for explanation.
Shaded values require release strengths higher than 3500 psi.

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ALT 5: COMPOSITE STEEL DECK/BEAMS

LIVE LOADS

UNITS/CORRIDORS = 40 PSF
PARTITIONS = 15 PSF

DEAD LOADS

MEP = 10 PSF
FLOORING = 3 PSF
SLAB = 36 PSF
DECK = 2 PSF
BEAM = 15 PLF
GIRDER =

FACTORED LOADS

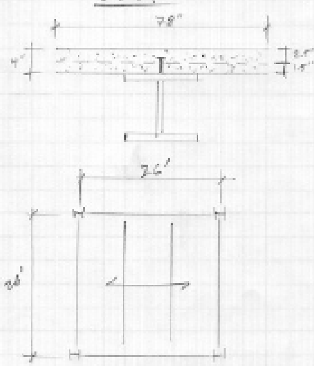
SLAB: $1.2(51) + 1.6(55) = 149.2$ PSF

BEAM: $149.2(8.667) = 1295$ PLF

GIRDER: $2\left(\frac{26(1295)}{2}\right) = 33.6^{k}$

SLAB & DECK
1.5 SB NORMAL WT WHEELING DECK
4" CONC
20 GAGE
9'-2" UNSHORED CLEARSPAN
201 PSF CAPACITY @ 9'

BEAM



$f'_c = 4000$ psi   A992 W-SHAPE
3/4" Ø 3" STUDS

TRIB WIDTH = 8'-8"

$b_{eff} = \begin{cases} 8'-8" \\ \frac{1}{4}(26') = 6'-6" \leftarrow \text{USE} \end{cases}$

$M_u = \frac{1.295(26)^2}{8} = 110$ ft·k $= 1320$ in·k

$M_n = \frac{M_u}{\phi} = \frac{1320}{0.85} = 1555$ in·k

ASSUME $a = 1 \therefore Y_2 = 3.5$

TRY W10×17
$A_g = 4.99$ in²
$d = 10.1$"

ALT 5: CONTINUED

$C_c = 0.85(4)(2.5)78 = 1663$ in·k

$T_s = 50(4.99) = 249.5$ in·k

$T_s = C_c = 249.5$

$249.5 = 0.85(4)(78)a \rightarrow a = 0.94$" ok

$M_n = 249.5\left(4 - \frac{0.94}{2}\right) + 249.5\left(\frac{10.1}{2}\right) = 2140.6$ in·k > 1555 in·k ok

STUDS: $\frac{0.85}{\sqrt{1}}\left(\frac{2.0}{1.5}\right)\left[\left(\frac{3}{1.5}\right) - 1\right] = 1.13 \leq 1.0 \rightarrow$ USE 1.0

$q_n = 1.0(26.1) = 26.1$ k/stud

TRY W10×15
$A_g = 4.41$ in²
$d = 9.99$"

$T_s = C_c = 220.5$ in·k

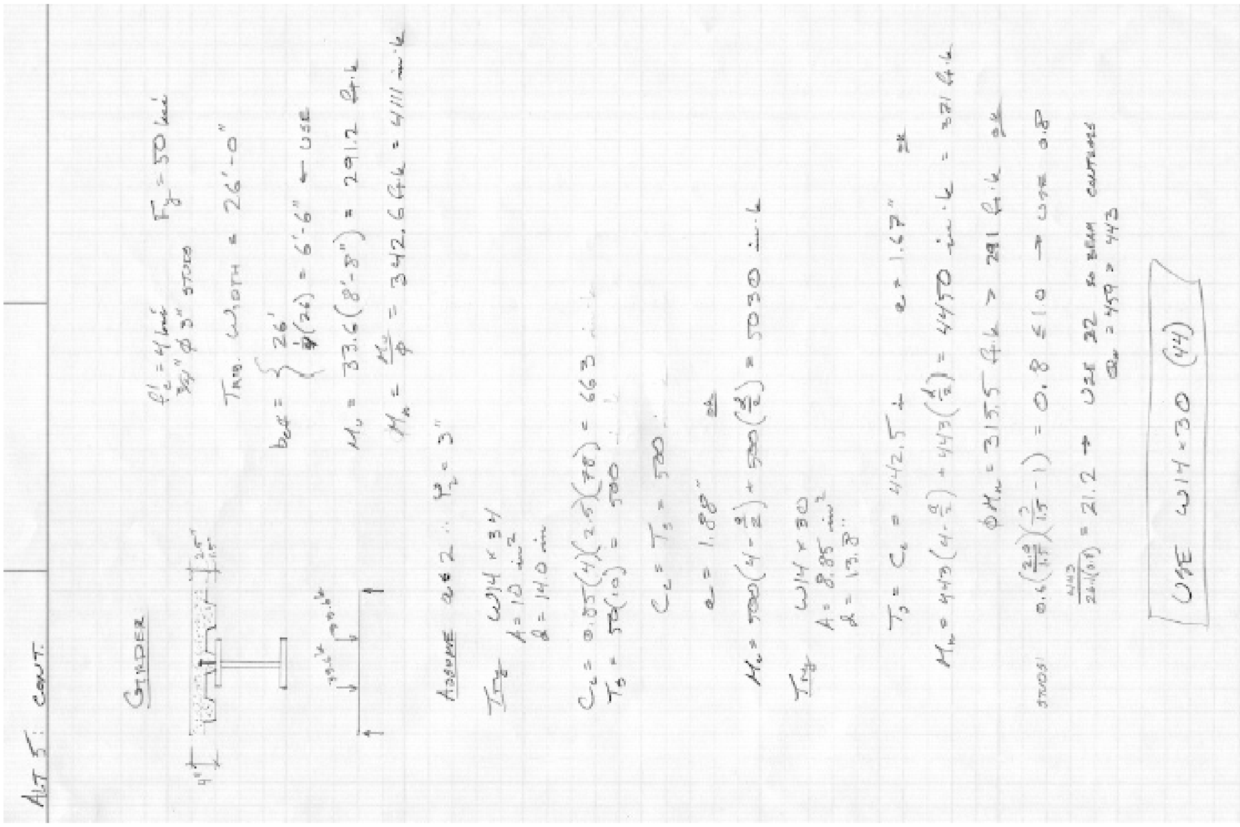
$a = 0.83$"

$M_n = 1890$ in·k $= 157$ ft·k

$\phi M_n = 134$ ft·k > 110 ft·k ok

$\frac{220.5}{26.1} = 8.45 \rightarrow$ USE 9 so STEEL CONTROLS
$Q_n = 234.9 > 220.5$

USE W10×15 (18)



ALT 5: CONT.

GIRDER

$f'_c = 4$ ksi, $F_y = 50$ ksi
3/4" φ 3" studs

TRIB. WIDTH = 26'-0"

$b_{eff} = \{ 26' ; \frac{1}{4}(26) = 6'\text{-}6" \leftarrow$ USE

$M_u = 33.6(8'\text{-}8") = 291.2$ ft·k

$M_n = \frac{M_u}{\phi} = 342.6$ ft·k $= 4111$ in·k

ASSUME $a \leq 2$ ∴ $Y_2 = 3"$

TRY W14×34
$A = 10$ in²
$d = 14.0$ in

$C_c = 0.85(4)(2.5)(78) = 663$ k
$T_s = 50(10) = 500$ k

$C_c = T_s = 500$ k

$a = 1.88"$ ok

$M_n = 500(4 - \frac{1.88}{2}) + 500(\frac{d}{2}) = 5030$ in·k

TRY W14×30
$A = 8.85$ in²
$d = 13.8"$

$T_s = C_c = 442.5$ k $a = 1.67"$ ok

$M_n = 443(4 - \frac{a}{2}) + 443(\frac{d}{2}) = 4450$ in·k $= 371$ ft·k

$\phi M_n = 315.5$ ft·k > 291 ft·k ok

STUDS: $0.6(\frac{2.0}{1.5})(\frac{3}{1.5} - 1) = 0.8 \leq 1.0 \rightarrow$ USE 0.8

$\frac{443}{26.1(0.8)} = 21.2 \rightarrow$ USE 22 ∴ BEAM CONTROLS
$Q_n = 459 > 443$

USE W14×30 (44)