thesis proposal:

steel and precast systems to minimize construction time

faculty advisor:

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27 january 2007

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executive summary

Granby Tower is a proposed mixed-use, luxury, high-rise located in the downtown historic district of Norfolk, Virginia. The tower stands 450 feet to the top of its spire, and consists of 34 floors, 6 of which are reserved for parking. Post-tensioned slabs allow for maximum span to depth ratio, while dual shear wall cores are centrally located to allow for unobstructed views of downtown Norfolk.

The construction of Granby Tower has been paused since September 18, 2007 when a major financial supporter of the luxury condominium tower pulled their funding due to the shaky housing market. This major delay will drastically affect presales unless construction resumes, but more importantly, if construction does not catch up to schedule, Granby Tower may lose many potential condominium-owners.

depth study

Research will be conducted to investigate effectiveness of alternate framing materials that correlate with a quicker construction time. The gravity system will change from cast-in-place concrete to steel. This material change will occur above the 7th level because the lower six levels consist of an open air parking garage, and the salty air of Norfolk Virginia would cause increased weathering on the steel columns. The floor framing system will remain two-way post-tensioned flat plate slabs on the lower six levels while the upper levels will become precast hollow-core planks. The precast planks will be part of the girder-slab system for the purpose of minimizing floor to floor height; as investigated in technical report II. The results of the Girder-Slab analysis revealed a necessary change in column bays and thus requiring transfer girders to minimize the number of columns in the parking garage on the lower levels.

breadth studies

Construction Schedule and Cost Analysis

The driving factor of this proposed material change is the associated decreased construction time, so an analysis comparing the estimated construction schedules will be conducted. This analysis will address the lead time associated with procuring steel shapes, transfer girders, D-Beams for the Girder-Slab system, and precast hollow-core planks. The schedule is a very important aspect of this redesign but it also must be a cost effective solution. Analyzing the economic advantages associated with an earlier turnover, coupled with the cost of steel columns, transfer girders, and precast planks, will determine if an expedited construction process is appropriate.

Sustainability

The next breadth study will focus on receiving certification through the United States Green Building Council's Leadership in Energy and Environmental Design (LEED) program. LEED is a rating system that incorporates proper planning, material selection, and commissioning to minimize the impact of a building on its environment. Steel is the most recycled product in the country, so at least four points are available within the Materials and Resources category.

introduction

The Granby Tower (*fig 1*) is a proposed mixed-use, luxury, high rise located in the downtown historic district of Norfolk, Virginia. Historically Granby Street was the premier shopping, dining, gathering and theatre corridor, and these luxuries were supplemented by the direct connection to the Elizabeth River waterfront. The conveniences of Granby Street fell out of favor in the 1960's as suburban development between Norfolk and Virginia Beach promised bargain shopping malls. Due to the decline in popularity of a very important landmark and cultural center, city officials began reviving the city center in the 1970's and are still working to regain the prestige that Granby Street held in the early 1900's.

Granby Tower will be the tallest building in Norfolk upon completion and will provide roughly 300 luxury apartments with views of downtown Norfolk and the Elizabeth River, 6 stories of parking, a roof top fitness center and pool, leasable office space. It is becoming increasingly popular in the Norfolk and Virginia Beach areas to build above parking structures for a number of reasons. One of the most obvious reasons is that you must provide parking space, and since the site has little open space for a free standing garage, the best way to maximize your profit is to utilize the lower floors for parking. The second main reason for an above ground parking structure housed within the buildings structure is due to the sandy soil conditions and high ground water table that don't allow for deep foundations. Most designs, especially heavy concrete structures, require slab on grade with deep piles to penetrate the deep Yorktown Strata layer that is buried beneath layers of unstable sand and clay.

The lateral force resisting system at Granby Tower is designed as a concrete shear wall core which helps to maximize leasable space while keeping most views unobstructed. The floor framing system is a two-way flat-plate post-tensioned slab with minimal drop panels to capitalize on floor to ceiling height. The longest span seen by the slab is 30 feet with typical bays at 26' x 30'. These design features will allow spaces to feel spacious and elegant and with a design focused on luxury, it is easy to see that Granby Tower will stand as a landmark for the city to celebrate a vibrant history and a promising future.

fig 1 – rendering of Granby Tower

structural overview

foundation

To determine the soil bearing capacity, sixteen (16) 100 to 110-foot deep Standard Penetration Test borings were drilled within the proposed Granby Tower site. Borings were conducted in accordance with ASTM D 1586 standards and performed with rotary wash drilling procedures to analyze the soil types at 5 foot integrals. Soil tests determined that the first 20 feet of most samples consisted of silty fine sand (SM) or poorly graded fine sand (SP-SM). The next 25 feet of bore was composed of clay (CL) followed by 55 feet of poorly graded fine to coarse sand (SP-SM) and/or silty fine sand (SM). Due to the composition of the soil and location of the groundwater table (6 to 7 feet below grade), the geotechnical engineer recommended a deep pile foundation system with driven, precast, pre-stressed, concrete piles since shallow foundations would result in excessive settlements due to the extreme building weight.

To determine the feasibility and required depths of the piles, fifteen test piles were driven with and evaluated with a Pile Driving Analyzer. The analysis dictated the use of 12” square, precast, pre-stressed concrete piles (SPPC) at 80 feet deep with 100 ton capacity and 14” SPPC at 90 feet with 140 ton capacity. Roughly 1000 piles were driven throughout the site with 255-14” SPPC piles supporting the ordinary shear wall core (*fig 2*). Due to the lateral forces seen by the shear walls, the outer 156 piles are designed for tension. The pile cap supporting the shear wall is 10 feet thick with a 28-day compressive strength (f’c) of 5000 psi and #10 and #11 reinforcing on top and bottom, while all other pile caps will be designed with an f’c of 4000 psi and # 7 and #8 reinforcing.

The slab on grade is 5” thick, reinforced with 6x6-W2.9xW2.9 welded wire fabric over a 10 mil polyethylene vapor barrier. The geotechnical engineer specified the slab to be placed over 4” porous fill with less than 5% passing the No. 200 sieve to act as a capillary barrier. The slab should also be “floating” in the sense that it is not rigidly connected to columns or foundations to reduce cracking.

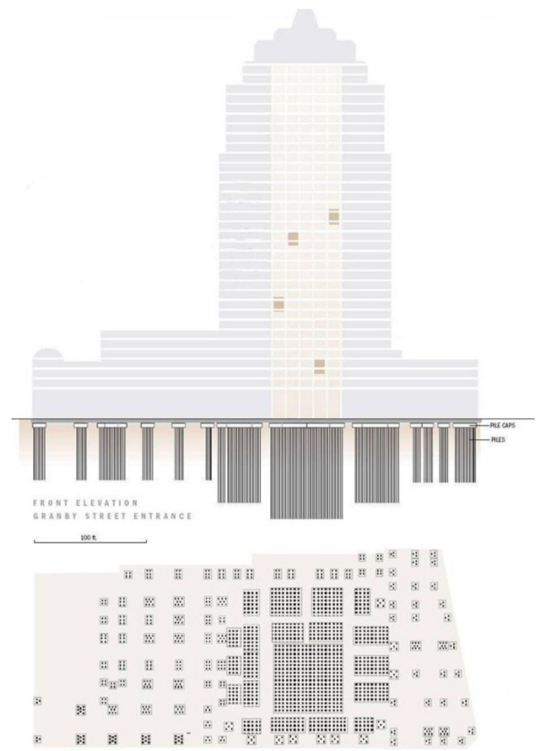

fig 2 – front elevation and plan of piles for Granby Tower. source: Abiouness, Cross and Bradshaw, Inc.

floor system

The floor system for the Granby Tower consists of a two-way flat plate post tensioned slab (*fig 3*) designed in accordance with the Post-Tensioning Manual 6th Edition by the Post-Tensioning Institute and ACI 318-02. All slabs are designed with a 28-day compressive strength (f’c) of 5000 psi, and the first 7 levels of the tower require a 9” slab while the remaining levels are designed as an 8” slab. Tendons for post-tensioning will be ½” diameter (ø), 7-wire, low relaxation strand, fully encased in grease with a minimum sheathing thickness of 50mm. Maximum sag for tendons will be 5 ½” and supported by chairs or bolsters. Post-tensioning will occur when the concrete has reached 75% of its designed f’c, and all of the uniform tendons shall be stressed before banded tendons. Uniform tendons are even distributed through the north-south (long) direction with a maximum span of 26' while banded tendons run east-west (short direction) along column lines with a maximum span of 30'.

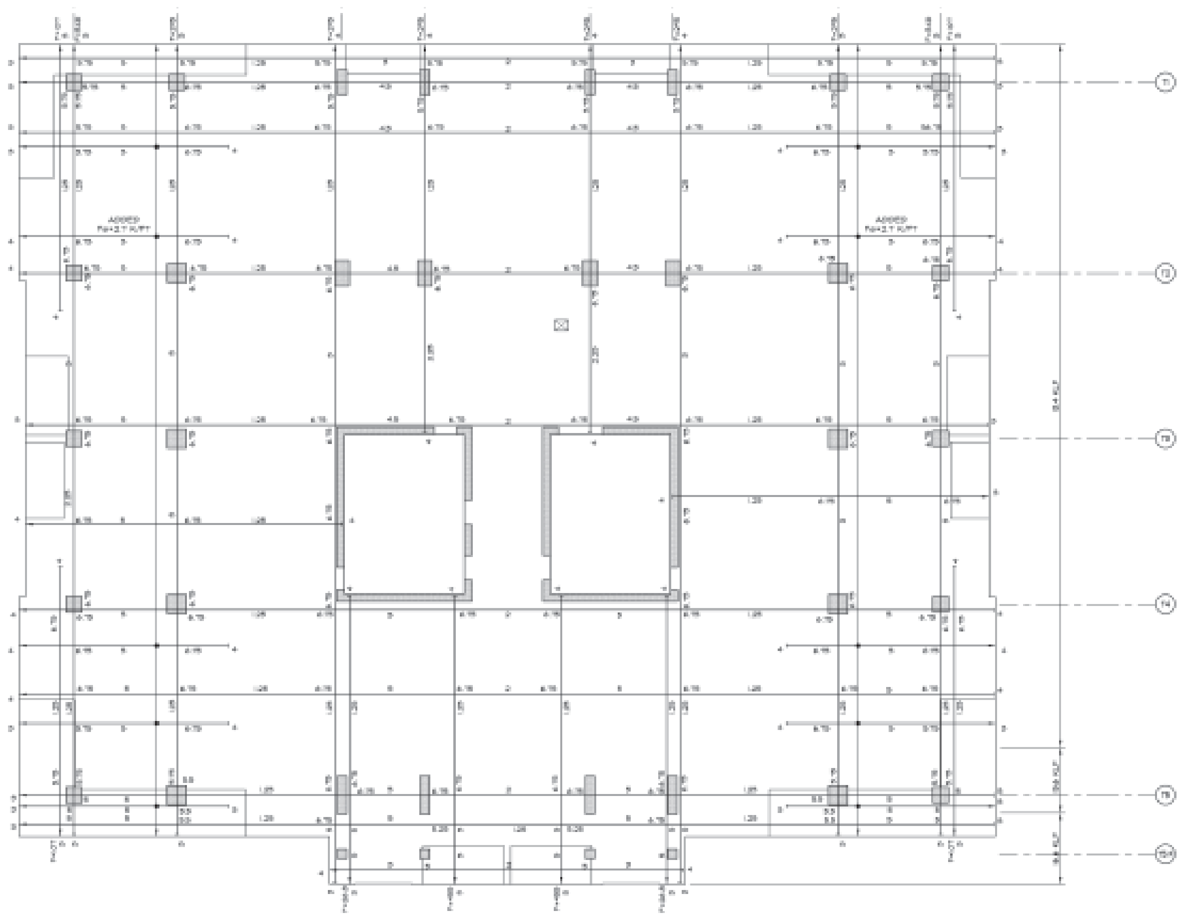

fig 3 – typical post-tensioning plan for levels 8 through 12. Plan and True North **→N (x-direction)**

columns

Gravity columns are laid out on a fairly regular grid with the largest bay at 26'x30' (refer again to *fig 3* for column layout). Roughly 32 columns run the full building height with some of the exterior columns terminating at the buildings first significant set-back on the 29th floor. Most columns are square reinforced columns with rebar ranging from #7 to #10, but rectangular columns with the strong axis in the short building direction (east-west) are architecturally situated in central east and west apartments. Columns above the parking garage (Level 7) are designed with f'c = 5000 psi, and columns between Level 6 and the foundation are designed with f'c = 6500 psi. Banded tendons running through columns should be within 1.5 x T (thickness slab) of the column face and placed above other uniform tendons or rebar. Some drop panels are required on upper floors as column sizes decrease and slab edges become flush with exterior columns.

lateral system

The lateral load resisting system of Granby Tower consists of ordinary reinforced concrete shear walls (*fig 4*) that were designed in accordance to ACI 318-02. These two shear wall cores house the elevators, stairs, electrical and gas lines, and fire dampers. The first 6 levels consist of 24" thick reinforced shear walls with f'c = 8000 psi, while the remaining levels consist of 14" shear walls with 28-day compressive strengths of 6000 (Levels 7 through 23) and 5000 psi (Levels 24 through 34). Typical vertical reinforcement ranges in size and spacing from #10 @ 6" o.c. to #8 @ 12" o.c. while horizontal reinforcement ranges from #6 @ 6" o.c. to #5 @ 12" o.c. Typical end reinforcement consists of ten vertical rebar within a square section determined by the wall width and #4 ties @ 8" o.c vertical spacing from the foundation to Level 7 and #3 ties @ 8" o.c. vertical spacing from Level 7 to 34.

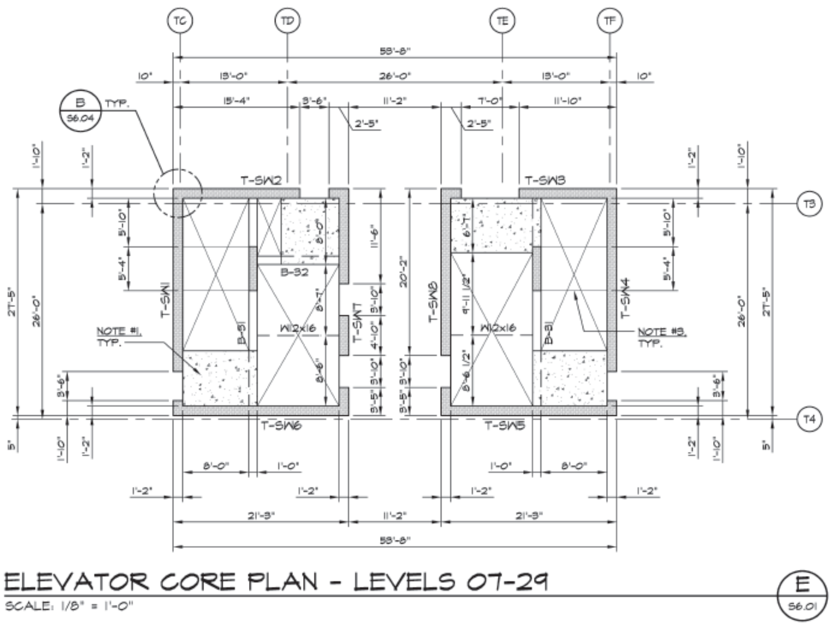

fig 4 – typical plan of shear wall core.

proposal

problem statement

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proposed solution

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breadth studies

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methods

depth

The steel redesign of Granby Tower will involve some coordination with the architecture of the condominiums as the column grid will change slightly. The analysis results of the Girder-Slab system in technical report II proved that the typical bay (26'x 30') was too large to for the D-Beam (proprietary product of Girder-Slab) to span the 26 foot direction while carrying 8" hollow core planks with 2" topping spanning 30 feet. For these reasons, a brief architectural study will be conducted to determine the least intrusive column location. Upon completion of this task, a gravity analysis will be conducted using RAM. This analysis will provide helpful insight as to the required loadings the transfer girders will be required to carry. A thorough analysis and design of the transfer girders will allow for a whole building gravity analysis in RAM and then a lateral analysis in ETABS.

breadths

Construction Schedule and Cost

To accommodate for the lead time associated with procuring steel shapes, transfer girders, and precast planks, these structural members will be mill ordered after funding is in place and construction commences. The construction of the lower 6 levels, including the incomplete foundation work, will last approximately 10 months, so the structural members will be ready for erection. At this point, the construction schedule will pick up since very little cast-in-place concrete will remain; mainly the concrete shear walls. The construction of these activities will cut a significant amount of time (estimated 6 months) off of the schedule, thus lowering construction overhead and allowing for an earlier return on investment, but there may be an increase in material costs, cladding costs, and erection costs that should be considered.

Sustainability

Since no considerations were taken to make Granby Tower "green," earning 26 points (enough to qualify for a LEED Certified rating) may be a challenge. The USGBC New Construction & Major Renovation, Version 2.2 Reference Guide will provide the best insight as to which points are possible. With at least 4 points available for changing structural materials to steel, this leaves roughly 20 points required to fulfill the rating criteria. Some basic points worth pursuing in this sustainability breadth include:

WE Credit 1.1 • Water Efficient Landscaping: Reduce by 50%

WE Credit 3.2 • Water Use Reduction: 20% Reduction

SS Credit 4.1 • Alternative Transportation: Public Transportation Access

MR Credit 2.1 • Construction Waste Management: Divert 75% from Disposal

MR Credit 4.2 • Recycled Content: 20% (post-consumer + ½ pre-consumer) - STEEL

MR Credit 5.2 • 20% Extracted, Processed & Manufactured Regionally - STEEL

tasks and tools

depth

Task 1: Recheck Girder-Slab calculations.

Task 2: Check floor system at non-typical floors (mechanical floor)

Task 3: Determine placement of columns

- Adjust floor plans.

Task 4: Model building with gravity analysis program (RAM).

Task 5: Design transfer girders/base plates where applicable.

Task 6: Check concrete column capacity.

Task 7: Analyze new gravity system and transfer girders in ETABS.

Task 8: Redesign according to lateral analysis.

Task 9: Meet with Consultant.

Task 10: Report.

breadths

Schedule and Cost Analysis

Task 1: Investigate time savings of steel and Girder-Slab system.

- Ask Technical Discussion Board.

Task 2: Create Schedule.

Task 3: Compare Schedule with Turner Construction schedule.

- Contact Turner representative to discuss.

Task 4: Begin cost analysis.

- Ask Technical Discussion Board for advice.

Task 5: Determine cost effectiveness

- Incorporate scheduled closeout times.

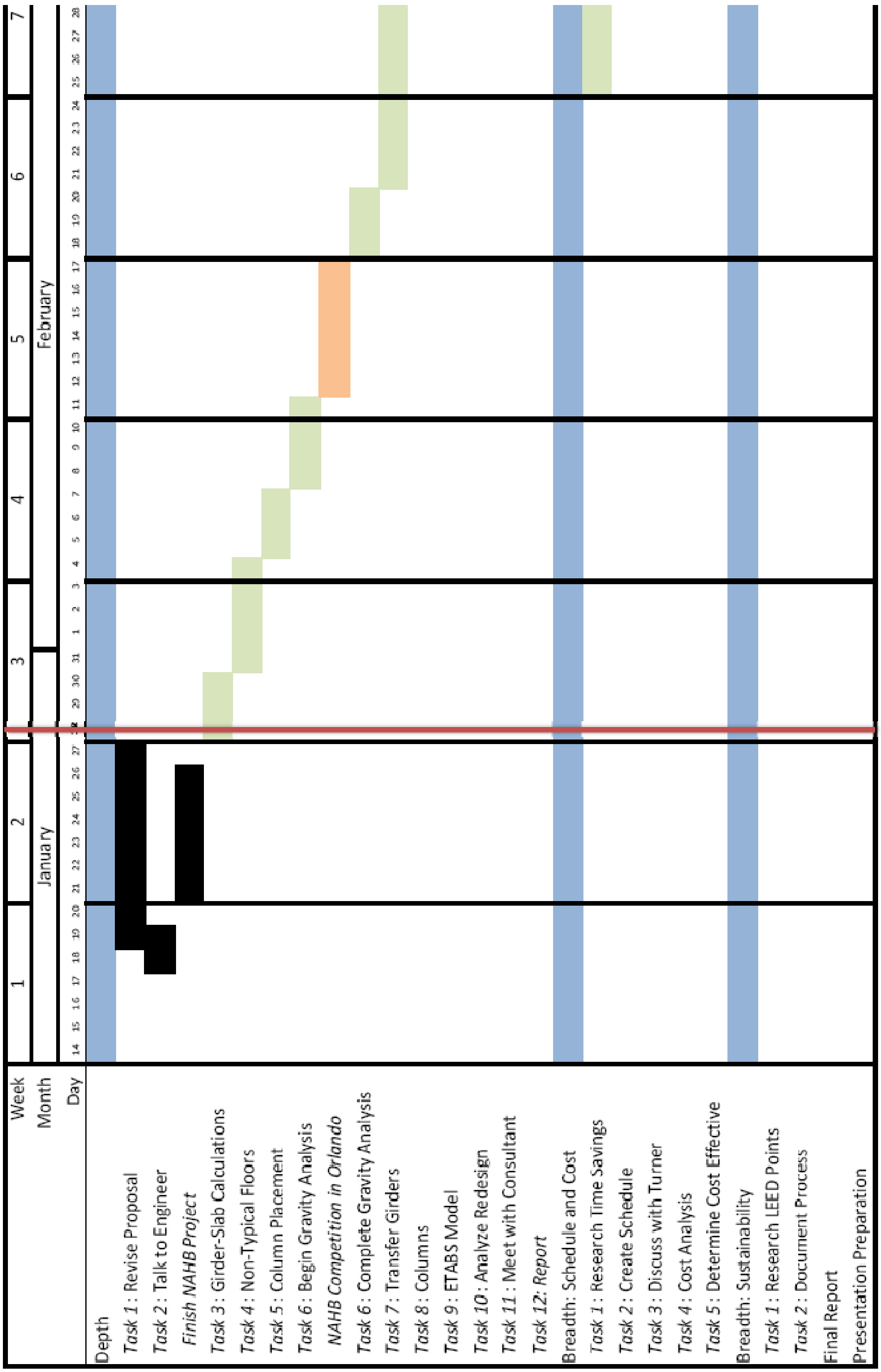
Sustainability

Task 1: Research possible LEED points.

- Determine requirements necessary to earn credit.
- Investigate means of fulfilling requirements.
- Evaluate feasibility.

Task 2: Document process.

schedule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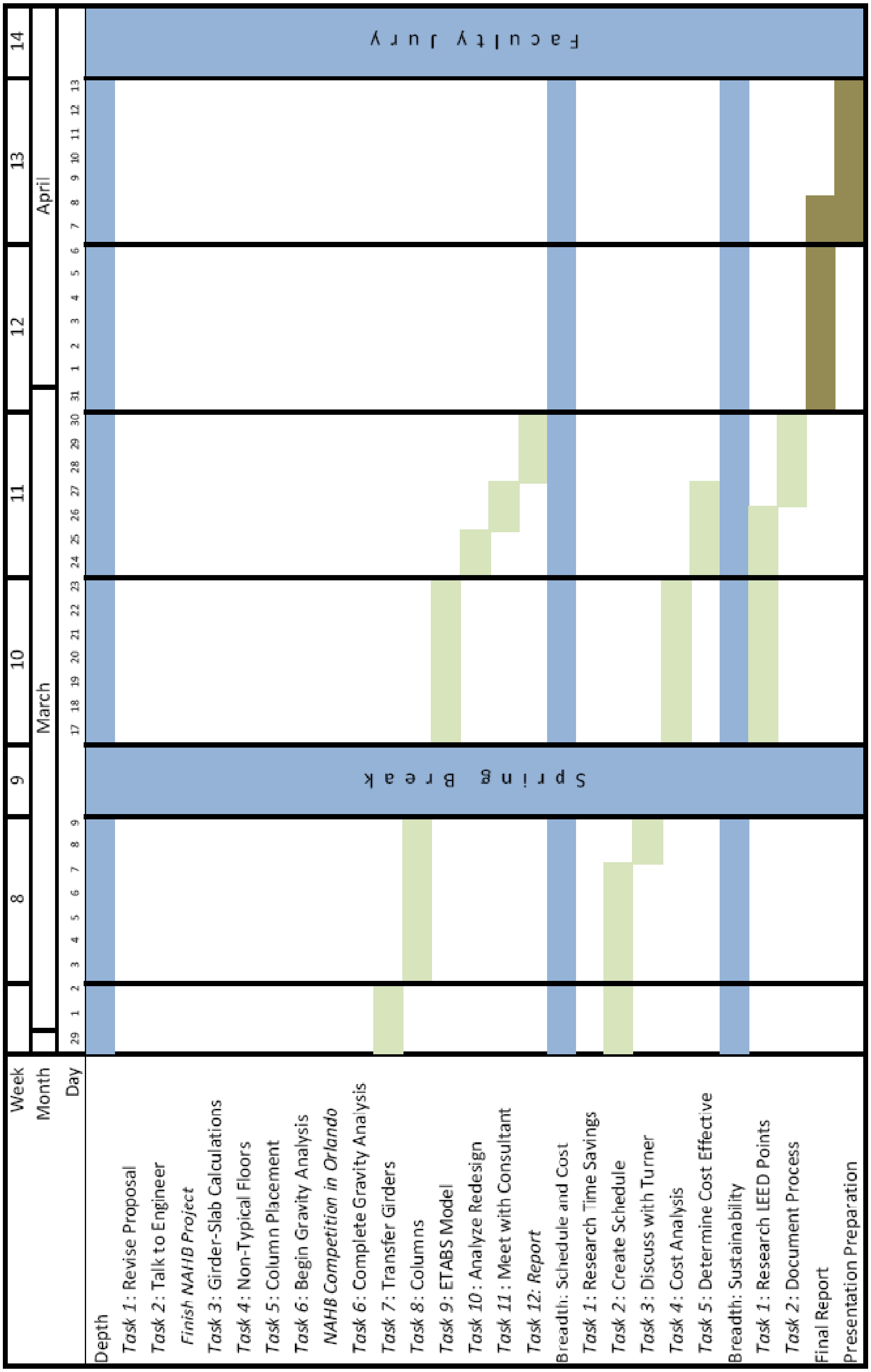
Depth
Task 1: Revise Proposal
Task 2: Talk to Engineer
Finish NAHB Project
Task 3: Girder-Slab Calculations
Task 4: Non-Typical Floors
Task 5: Column Placement
Task 6: Begin Gravity Analysis
NAHB Competition in Orlando
Task 6: Complete Gravity Analysis
Task 7: Transfer Girders
Task 8: Columns
Task 9: ETABS Model
Task 10: Analyze Redesign
Task 11: Meet with Consultant
Task 12: Report
Breadth: Schedule and Cost
Task 1: Research Time Savings
Task 2: Create Schedule
Task 3: Discuss with Turner
Task 4: Cost Analysis
Task 5: Determine Cost Effective
Breadth: Sustainability
Task 1: Research LEED Points
Task 2: Document Process
Final Report
Presentation Preparation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Task 2: Document Process
Final Report
Presentation Preparation
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Spring Break
Faculty Jury

conclusion

Throughout the upcoming semester, research will be conducted to determine the benefits of a structural system change from cast-in-place concrete with post-tensioned slabs to steel and precast hollow-core planks integrated with the Girder-Slab system. This study will provide the opportunity to design transfer girders necessary to minimize the number of columns throughout the parking garage. Computer modeling will supplement research by aiding in a gravity and lateral analysis. The feasibility of this system will be evaluated by cost, construction schedule, and architectural impact.

A breadth study will focus on the construction time savings associated with the erection of steel super structure and precast hollow-core planks. This valuable research will provide insight to the effective cost savings associated with shorter construction duration while considering the premium costs for steel, planks, cladding, and erection.

A second breadth study will focus on receiving certification by the United States Green Building Council's Leadership in Energy and Environmental Design Rating System. Research will provide insight as to the best means of fulfilling LEED requirements and the feasibility of implementing design solutions to earn proposed credits. The material change to steel presents the potential to earn at least 4 LEED points, so a minimum of 22 more points are necessary for certification. While Granby Tower is a proposed luxury apartment high-rise, this breadth study will seek to prove that luxury can be sustainable.

appendix a

girder-slab

The Girder-Slab System (*fig 1*) is a proprietary product developed by Girder-Slab Technologies LLC to develop composite action between hollow-core concrete planks and integrated steel girders. Interior girders called D-Beams (an open-web dissymetric beam) are connected to precast planks with cementitous grout. The advantage to a system such as this is a very shallow floor depth as would be possible with flat plate construction, but an expedited construction process due to precast products.

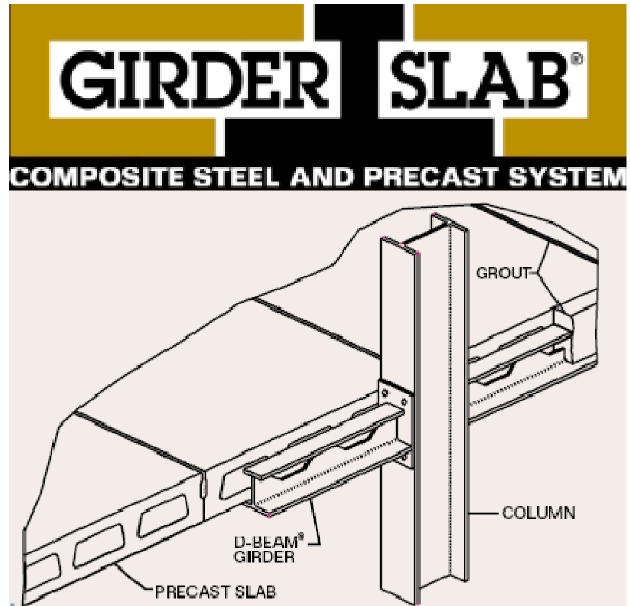


fig 1 – typical cut-away section of Girder-Slab construction including D-Beams and hollow core precast planks. Image provided by girder-slab.com

Precast panels were selected from the Nitterhouse Concrete Products design tables and chosen to span the 30' direction. The planks chosen were 8" x 4' hollow core plank, reinforced with (7) ½"Ø prestressing strands. This specific plank is topped with 2" of cast in place concrete to create a smooth finish. Refer to *fig 2*.

Selecting an appropriate D-Beam was aided with the Girder-Slab System D-Beam Calculator Reference Tool provided on the company's website. The spread sheet allowed me to analyze several scenarios to find the most advantageous layout. The resulting selection was DB 9 x 46; which is a transformed W14x61. The maximum achievable span with the Girder-Slab system was 16' so this involved adding several columns. Only 8 extra columns were needed since some bays are already 16' x 30' but nonetheless some of the additional columns would interfere with the floor plans. Preliminary column checks were also carried out for the Girder-Slab system and determined that W14x176 were required.

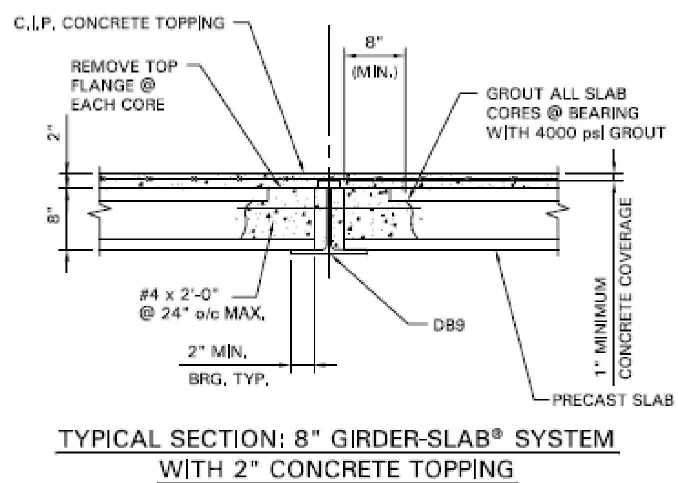


fig 2 – typical section provided by girder-slab.com

Pro

The Girder-Slab system was developed to address the floor depth issues associated with precast concrete planks and precast concrete girders. By integrating girder and plank systems to develop compositely, the floor depth remains minimal (10" plus finish). As with most precast products, the construction process is much faster since little time is spent preparing the framing members to receive a slab. The ease of construction is a huge benefit of this system because a speedier construction process will reduce the overall project costs.

Con

The main drawback to this system is the need to rearrange the column grid slightly to adapt to the span limitations of D-Beams. While minimal change is required, the architectural impact of stray columns will detract from the feeling of elegance. If desired, architectural study could be done to consider how to properly integrate this system with the existing floor plan, but the benefits of the other systems may deter one from considering further investigation.

Other negative aspects of this a precast girder-slab system include fire protection, vibration, and lead time. As with the non-composite framing system, fire protection is needed at all columns and results in additional cost. This system may be more susceptible to vibrations since the weight is relatively low, but more study could address this issue. Lastly, the lead time associated with this system would be much higher since two proprietary products are specified.

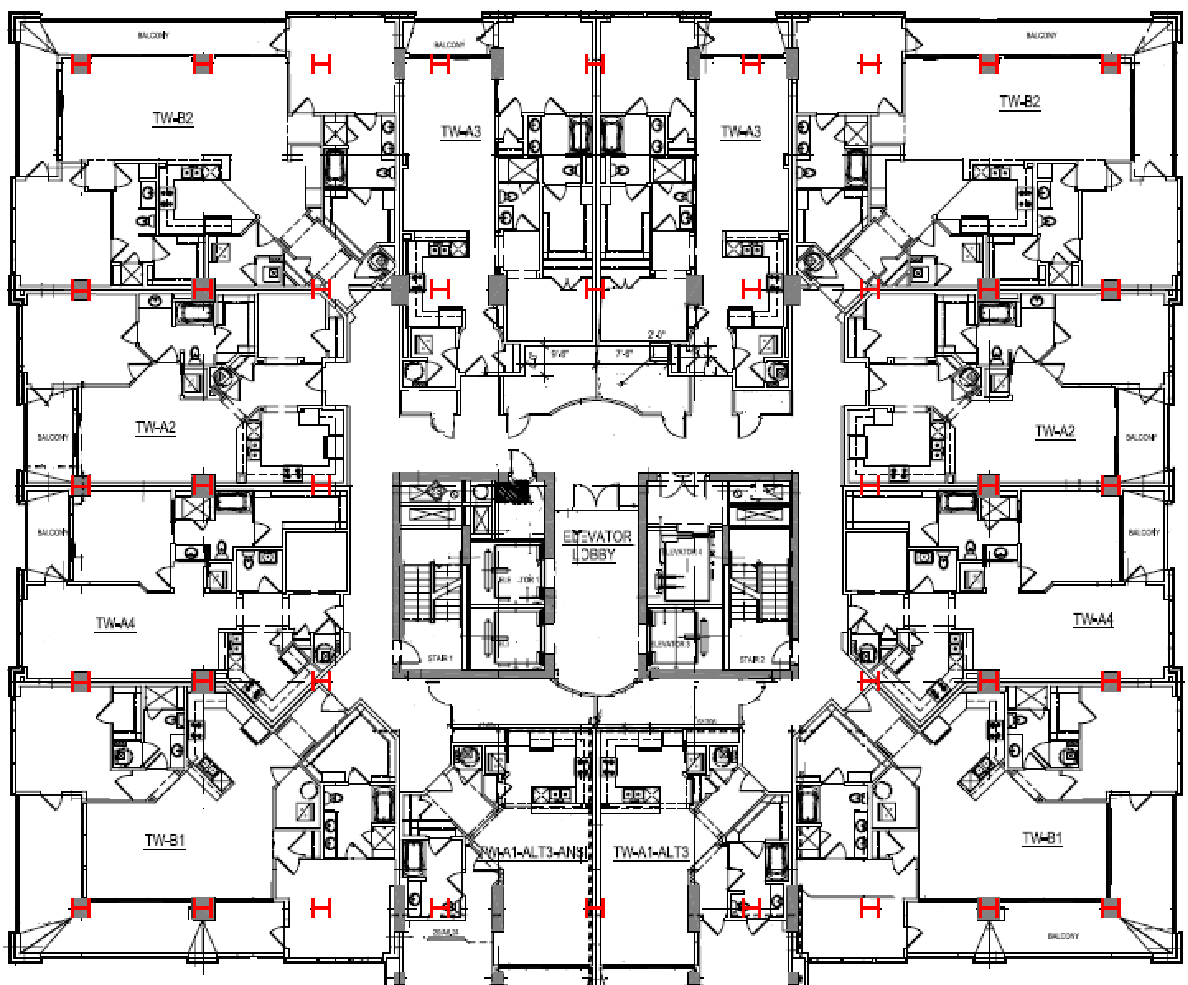
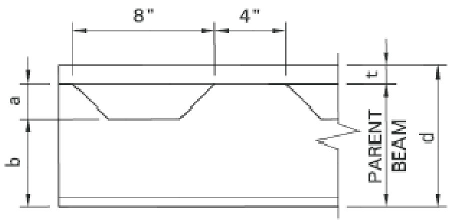


fig 3 – typical floor plan with possible alternate column arrangement. Interface between slab and shear wall assumed integrated without columns.

appendix b

girder-slab calculations

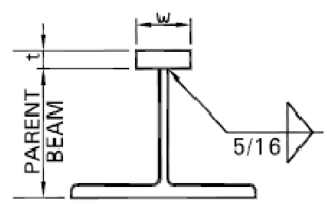
D-BEAM® DIMENSIONS TABLE



Designation	Web Included		Depth	Web	Parent Beam			Top Bar
	Weight	AVG AREA	d	Thickness t_w	Size	a	b	w x t
	lb./ft.	In.²	In.	In.		In.	In.	In. x In.
DB 8 x 35	34.7	10.2	8	.340	W10 x 49	4	3	3 x 1
DB 8 x 37	36.7	10.8	8	.345	W12 x 53	2	5	3 x 1
DB 8 x 40	39.8	11.7	8	.340	W10 x 49	3	3.5	3 x 1.5
DB 8 x 42	41.8	12.3	8	.345	W12 x 53	1	5.5	3 x 1.5
DB 9 x 41	40.7	11.9	9.645	.375	W14 x 61	3.375	5.25	3 x 1
DB 9 x 46	45.8	13.4	9.645	.375	W14 x 61	2.375	5.75	3 x 1.5

D-BEAM® PROPERTIES TABLE

Designation	Steel Only Web Ignored						Transformed Section Web Ignored				
	Ix	C bot	C top	S bot	S top	Allowable Moment Fy=50 KSI f_b= 0.6Fy	Ix	C bot	C top	S bot	S top
	In.⁴	In.	In.	In.³	In.³	kft	In.⁴	In.	In.	In.³	In.³
DB 8 x 35	102	2.80	5.20	36.5	19.7	49	279	4.16	4.40	67.1	63.5
DB 8 x 37	103	2.76	5.24	37.3	19.7	49	282	4.16	4.42	67.7	63.8
DB 8 x 40	122	3.39	4.61	36.1	26.5	66	289	4.26	4.30	67.9	67.2
DB 8 x 42	123	3.35	4.65	36.9	26.5	66	291	4.26	4.32	68.4	67.5
DB 9 x 41	159	3.12	6.51	51.0	24.4	61	332	4.27	5.35	77.7	62.1
DB 9 x 46	195	3.84	5.79	50.8	33.7	84	356	4.43	5.20	80.6	68.6

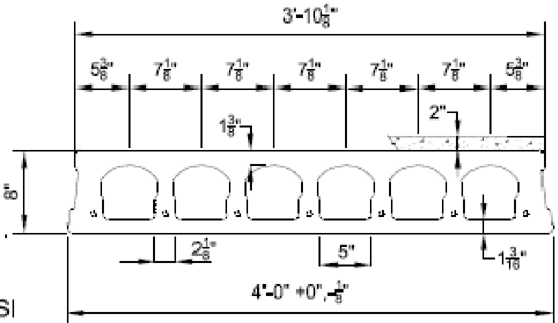


Prestressed Concrete
8"x4'-0" Hollow Core Plank

2 Hour Fire Resistance Rating With 2" Topping

PHYSICAL PROPERTIES
Composite Section

A_c = 278 in.^{2}	Precast S_{bc} = 583 in.^{3}
I_c = 2967 in.^{4}	Topping S_{tc} = 854 in.^{3}
Y_{bc} = 5.09 in.	Precast S_{tc} = 1019 in.^{3}
Y_{tc} = 2.91 in.	Wt_t = 221 PLF
	Wt_t = 55.25 PSF



DESIGN DATA

1. Precast Strength @ 28 days = 6000 PSI
2. Precast Strength @ release = 3500 PSI.
3. Precast Density = 150 PCF
4. Strand = 1/2"Ø 270K Lo-Relaxation.
5. Strand Height = 1.75 in.
6. Ultimate moment capacity (when fully developed)...
   4-1/2"Ø, 270K = 92.4 k-ft
   7-1/2"Ø, 270K = 148.4 k-ft
7. Maximum bottom tensile stress is $7.5\sqrt{f'c}$ = 580 PSI
8. All superimposed load is treated as live load in the strength analysis of flexure and shear.
9. Flexural strength capacity is based on stress/strain strand relationships.
10. Deflection limits were not considered when determining allowable loads in this table.
11. Topping Strength @ 28 days = 3000 PSI. Topping Weight = 25 PSF.
12. These tables are based upon the topping having a uniform 2" thickness over the entire span. A lesser thickness might occur if camber is not taken into account during design, thus reducing the load capacity.
13. Load values to the left of the solid line are controlled by ultimate shear strength.
14. Load values to the right are controlled by ultimate flexural strength or fire endurance limits.
15. Load values may be different for IBC 2000 & ACI 318-99. Load tables are available upon request.
16. Camber is inherent in all prestressed hollow core slabs and is a function of the amount of eccentric prestressing force needed to carry the superimposed design loads along with a number of other variables. Because prediction of camber is based on empirical formulas it is at best an estimate, with the actual camber usually higher than calculated values.

SAFE SUPERIMPOSED SERVICE LOADS — IBC 2003 & ACI 318-02 (1.2 D + 1.6 L)

Strand Pattern		SPAN (FEET)																		
		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
4 - 1/2"ø	LOAD (PSF)	281	242	209	181	156	135	117	101	87	74	63	53	44						
7 - 1/2"ø	LOAD (PSF)	479	447	403	356	315	280	249	222	199	177	159	142	127	113	101	90	80	70	62

NITTERHOUSE
CONCRETE PRODUCTS
2655 Molly Pitcher Hwy. South, Box N
Chambersburg, PA 17201-0813
717-267-4505 Fax 717-267-4518

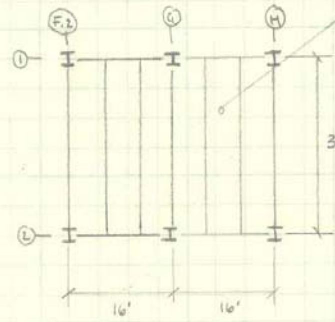
This table is for simple spans and uniform loads. Design data for any of these span-load conditions is available on request. Individual designs may be furnished to satisfy unusual conditions of heavy loads, concentrated loads, cantilevers, flange or stem openings and narrow widths. The allowable loads shown in this table reflect a 2 Hour & 0 Minute fire resistance rating.

05/14/07

8F2.0T

ALTERNATE FLOOR SYSTEMS | GRANBY TOWER | GIRDER SLAB 1

HOLLOW CORE PLANKS ON TRANSFORMED W-SHAPE GIRDERS



8" PLANK w/ 2" NWC TOPPING (2HR RATING)

* CHANGE TYPICAL BAY TO 16' x 30'

LOADING

PARTITION = 20 PSF

LIVE = 40 PSF

HOLLOW CORE PLANK DESIGN

→ TRY 8" x 4' HOLLOW CORE PLANK w/ 2" NWC TOPPING + (7) ½" ϕ LO-RELAX STRAND

SPAN 30'

$w_T = 1.2(20\text{ PSF}) + 1.6(40\text{ PSF}) = 88\text{ PSF}$

→ SAFE SUPERIMPOSED SERVICE LOAD = 113 PSF > 88 PSF OK

CHECK PLANK CAPACITY

$f'_c = 6000\text{ psi}$ $\qquad$ $w_{D\,PLANK} = 55.25\text{ PSF}$

$\phi M_n = 148.4\text{ ft k}$ $\qquad$ $w_{D\,TOPPING} = 25\text{ PSF}$

$w_u = 1.2(55.25 + 25 + 20) + 1.6(40\text{ PSF}) = 184.3\text{ PSF}$

$w_{u,PLANK} = (4')(184.3\text{ PSF}) = 0.737\text{ kLF}$

$M_u = \left(\frac{1}{8}\right)(0.737\text{ kLF})(30')^2 = 83\text{ ft k} < \phi M_n = 148.4\text{ ft k}$ OK

CHECK DEFLECTION

$E = w_c^{1.5} \cdot 33 f'^{1/2}_c = (150)^{1.5}\, 33(6000)^{0.5} = 4696\text{ ksi}$

$\Delta = \frac{5(0.737\text{ kLF})(30)^4(1728)}{384(4696)(2967\text{ in}^4)} = 0.96\text{ in} < L/360 = 30(12)/360 = 1\text{ in}$ OK

USE 8" x 4' HOLLOW CORE PLANK w/ (7) ½" ϕ LO RELAX STRAND AND 2" NWC TOPPING

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GIRDER-SLAB D-BEAM DESIGN

DESIGN INFORMATION

LOADING
DEAD (PLANK) = 55.25 PSF
PARTITION = 20 PSF
CONC TOPPING = 25 PSF
LIVE = 40 PSF
SPAN LENGTHS
DB = 16 FT
PLANK = 30 FT
COMPRESSIVE STRENGTH
GRMT, $f'c$ = 4000 psi
CONC PLANK, $f'c$ = 6000 psi
$\Delta_{LL} = L/360 = 0.53$ in

DB PROPERTIES (DB 9 X 46)

STEEL SECTION
$I_S = 195 \text{ in}^4$
$S_t = 33.7 \text{ in}^3$
$S_b = 50.8 \text{ in}^3$
$M_{SCAP} = 84$ ft-k
$t_w = 0.375$ in
$b = 5.75$ in
TRANSFORMED SECTION
$I_t = 356 \text{ in}^4$
$S_t = 68.6 \text{ in}^3$
$S_b = 30.6 \text{ in}^3$

INITIAL LOAD - PRECOMPOSITE

$M_{DL} = \frac{1}{8}(55.25 \text{ psf})(16^2)(30) = 53$ ft-k $< M_{SCAP} = 84$ ft-k ok ✓

$$\Delta_{DL} = \frac{5(30\text{ft})(0.055 \text{ ksf})(16')^4(1728)}{384(195 \text{ in}^4)(29000)} = 0.43 \text{ in}$$

$\Delta = L/[(16)(12)/0.43] = L/446$

TOTAL LOAD - COMPOSITE

$M_{SUP} = \frac{1}{8}(20+25+40 \text{ psf})(16^2)(30) = 81.6$ ft-k

$M_{TOT} = M_{DL} + M_{SUP} = 134.6$ ft-k

$S_{REQ} \geq (134.6 \text{ k ft})(12 \text{ in/ft}) / (0.6)(50 \text{ k/in}^2) = 53.9 \text{ in}^3 < S_t = 68.6 \text{ in}^3$ ok ✓

$$\Delta_{SUP} = \frac{5(30\text{ft})(0.085 \text{ ksf})(16')^4(1728)}{384(356 \text{ in}^4)(29000)} = 0.36 \text{ in} < \Delta_{LL} = 0.53 \quad \text{ok ✓}$$

$\Delta_{TOT} = 0.8$ in $= L/[(16)(12)/0.8] = L/240$ ok

CHECK COMPRESSIVE STRESS ON CONCRETE

$N = E_{STL}/E_{CONC} = 29000 \text{ ksi}/[57000(4000)^{.5}] = 8.04$

$S_{tc} = 8.04(68.6) = 552 \text{ in}^3$

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$f_c = (81.6\ kft)(12)/552\ in^3 = 1.77\ ksi$

$F_c = 0.45(4ksi) = 1.8\ ksi > f_c = 1.77\ ksi$ ok ✓

CHECK BOTTOM FLANGE TENSILE STRESS

$f_b = (53\ ftk)(12)/(50.8) + (81.6\ ftk)(12)/(80.6\ in^3) = 24.7\ ksi$

$F_b = 0.9(50\ ksi) = 45\ ksi > f_b = 24.7\ ksi$ ok ✓

CHECK SHEAR

TOTAL LOAD = 140 PSF
$W = 0.14\ ksf\ (30') = 4.2\ KLF$

$R = (4.2\ KLF)(16/2') = 33.6\ k$

$f_v = (33.6\ k)/(0.375)(5.75\ in) = 15.6\ ksi$

$F_v = 0.4(50\ ksi) = 20\ ksi > f_v = 15.6\ ksi$ ok ✓

ANALYSIS
USE (16') DB 9×46 (OPEN WEB DISSYMETRIC BEAM) TO SUPPORT 8" × 4' HOLLOWCORE PLANKS REINFORCED w/ (7) 1/2" ϕ LO-RELAXATION STRAND AND TOPPED WITH 2" NORMAL WEIGHT CONCRETE.
COLUMN SPACING MUST BE 16' MAXIMUM BETWEEN COLUMN LINES 1,2, ETC. TO ALLOW FOR DBEAM GIRDERS TO MEET CAPACITY REQUIREMENTS

COLUMN CHECK

$L = L_o(0.25 + 15/\sqrt{4(16)(30)}) = 0.59$
$P_u = [1.2(20\ PSF + 80\ PSF) + 1.7(0.59)(40)](16)(30)(24\ FLOORS) = 1845\ k$

$L = L_o(0.25 + 15/\sqrt{2(16)30}) = 0.73$
$FEM_1 = \frac{1}{12}(1.2(100) + 1.6(40))(26)(30)^2(\frac{1}{1000}) = 358.9\ ft\,k$
$FEM_2 = \frac{1}{12}(1.2(100))(26)(30)^2(\frac{1}{1000}) = 234\ ft\,k$

$P_{EFF} = 1845\ k + (\frac{24}{14})(62.4\ ftk) = 1952\ k$

→ USE W 14×176 $\phi P_n = 2150 > P_{EFF} = 1952\ k$