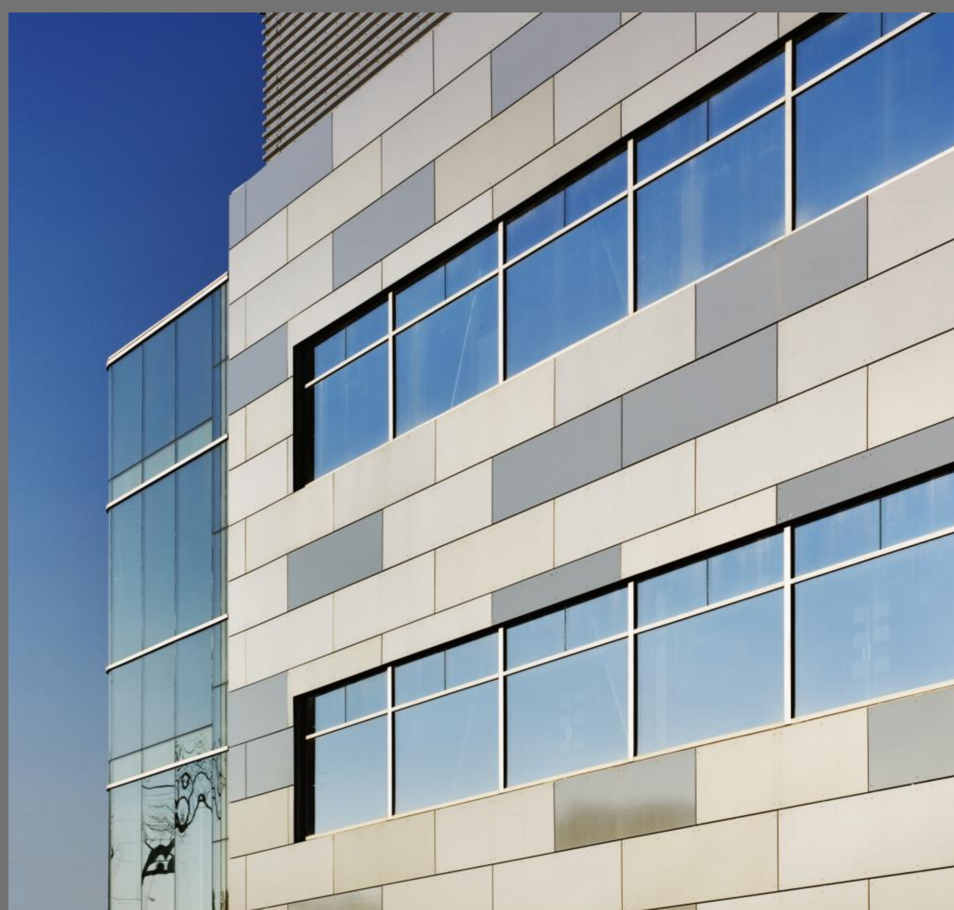
**TECHNICAL REPORT II**

# Gen*NY*Sis Center for Excellence in Cancer Genomics

Rensselaer, NY

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Structural Option

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The following is an exploration into alternative floor systems for the Gen*NY*Sis Center for Excellence. Four options of alternate flooring systems, in addition to the existing system, are evaluated based on the factors of constructability, fire protection, cost, serviceability, and architecture, to determine their practicality. The current system in place consists of composite steel decking with composite steel beams, which permits large live loads (for the corridor) and larger steel spans (open plan for labs and offices). Other systems investigated are:

~Post tensioned two-way slab

~Precast one-way slab

~Two-way concrete flat slab

~Open web steel bar joists

It appears through this report that the most suitable alternate to the original composite steel floor system is a precast hollow core plank system. Not only can precast planks withstand the heavy live load of the corridor and it's vibrations, but It would allow a thinner system with an open grid plan and no additional fireproofing, and at a cheaper price. The use of an alternative lateral system will be investigated in a later report.

Gen*NY*Sis Center for Excellence in Cancer Genomics is University at Albany owned, state-funded medical research lab. Standing four stories tall with the first floor partially below grade, the Center for Genomics sits atop a hill with a beautiful outlook over Rensselaer, NY and the Hudson River. The Research Center houses research laboratories, offices, an animal facility, a seminar room, mechanical rooms and a loading dock.

As the signature building of University at Albany's East Campus Technology Park, the Research Center is a model for the co-location of academia, industry, and government. To signify its technological presence, a glass curtain wall and exposed frames promote a fresh, new look for the campus.

A main design goal was to maximize vertical space for utilities in the corridor and in the laboratories. Another concern was the minimization of vibration from foot-traffic in the corridor through the center of the building so a 100 psf live load was predominantly used for designing. The use of composite steel with concrete slab on deck forms the 117,400 square feet plan with a typical bay size of 21 feet by 27 feet. The lateral system is a series of braces frames spaced throughout the plan of the building.

This report examines four alternate floor systems for Gen*NY*Sis Center for Excellence in Cancer Genomics. Each floor system is compared and evaluated in five categories: cost, constructability, fire protection, serviceability, and architecture. The goal of this report is to provide a simpler comparison of options in structural framing for consideration in my thesis proposal. This paper is not an exhaustive analysis of each floor framing system. All calculations and designs are considered preliminary and schematic design.

## List of Codes and References

Gen*NY*Sis Tech Report II

2003 International Building Code

Minimum Design Loads for Buildings and Other Structures (ASCE 7-05)

Building Code Requirements for Reinforced Concrete (ACI 318-05)

Specifications for Structural Steel Buildings (AISC 13th Edition)

Wind and Seismic Provisions for Structural Steel Buildings (AISC 13th Edition)

Steel Joist and Joist Girders Catalog (Vulcraft 2001)

Pre-Stressed Concrete Institute Handbook (6th Edition)

RS Means Building Construction Cost Data (meancostworks.com)

Dead Loads

Construction Dead Load

| | |
|---|---|
| Concrete | 150 pcf |
| Steel | 490 pcf |

Construction Dead Load

| | |
|---|---|
| Partitions | 20 psf |
| M.E.P. | 10 psf |
| Finishes | 5 psf |
| Windows and Framing | 20 psf |
| Roof | 20 psf |

Live Loads

| | |
|---|---|
| Laboratories | 60 psf |
| | 70 psf for office/lab flexibility |
| Offices | 70 psf |
| Lobbies | 100 psf |
| First Floor Corridor | 100 psf |
| Corridors above First Floor | 80 psf |
| Stairs and Exits | 100 psf |
| Seminar Room | 100 psf |
| Catwalks | 40 psf |
| Balcony/Terrace | 100 psf |
| Mechanical Rooms | Weight of equipment |

## Lateral Loads

Gen*NY*Sis Tech Report II

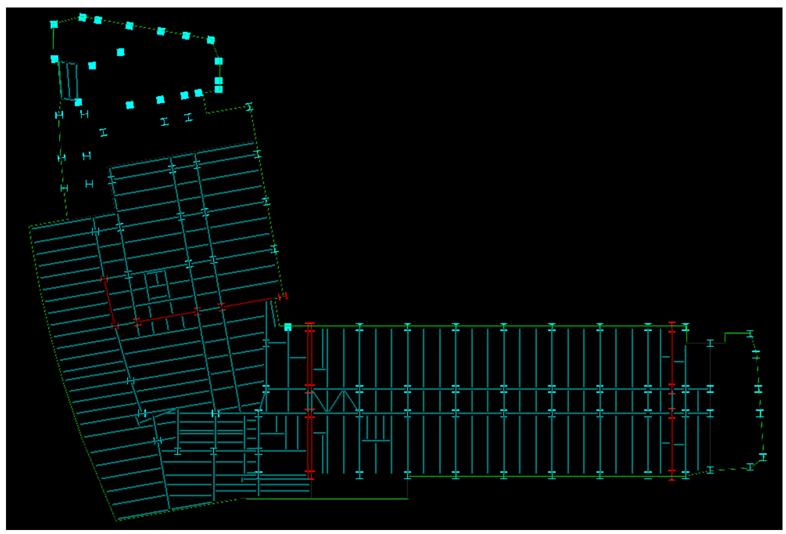
| | WIND | | | SEISMIC | | |
|---|---|---|---|---|---|---|
| | Load (kips) | Shear (kips) | Overturning Moment (ft-kips) | Force (kips) | Shear (kips) | Overturning Moment (ft-kips) |
| Penthouse | 71.4 | 0 | 6212 | 45.8 | 0 | 3984 |
| Roof | 51.4 | 71.4 | 3392 | 103.6 | 45.8 | 6840 |
| 3rd | 49.4 | 122.8 | 2470 | 69.6 | 149.4 | 3482 |
| 2nd | 45.2 | 172.2 | 1537 | 38.7 | 219.0 | 1315 |
| 1st | 46.3 | 217.4 | 833 | 20.9 | 257.7 | 375 |
| BASE | 263.7 | 263.1 | 14444 | 278.6 | 278.6 | 15997 |

Foundation

Typical footings are 9-feet square 25-inches deep calling for 11#9 reinforcing bars each way on bottom. Typical continuous wall footings are 1-foot deep by 2-feet wide calling for 3#5 continuous bars and 1#5 bar at 12-inches on center, transverse.

Floor Framing

The floor system of the Center for Genomics is composed of a composite steel system with a typical bay of 21 feet by 27 feet. It includes 2.0 inch, 20-gage composite decking with a 4.5" normal weight concrete slab, and ¾" diameter, 4" long studs. A 2 hour-rated construction is provided for all columns and beams supporting all floors. Typical floor beams are W16x31 spaced 7-feet apart and 20 shear connectors. Filler beams across the 10-foot corridor are W10x12 spaced 7-feet apart. Girders along the interior column lines and along the exterior walls are W18x35 with 32 shear connectors. Camber is not be accounted for due to relatively short spans.



Columns

Typical columns are W12x72 members at the lower tier and W12x53 member at the top tier. Using W12 columns as a minimum size simplifies fabrication of connections of beams framing into the columns. Perimeter columns bear on footings 1-foot below the Ground Floor elevation of 175.0'.

Lateral Force Resisting System

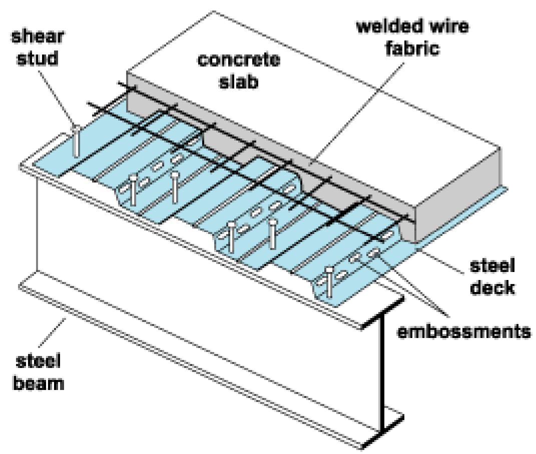
Steel braced frames will resist wind and seismic lateral loads. An expansion joint at the intersection of the two building wings will isolate the two sections from each other. The expansion joint will require a row of columns along each side of the joint, with the building structures separated by a distance sufficient to provide seismic isolation—approximately 6 to 8-inches. Each building section has braced frames across the ends, and two bays of bracing along the length of each exterior wall. Bracing diagonals are typically HSS8x8x5/16 in non-moment-resisting eccentrically braced frames. The building is designed for wind loading drift criteria of H/400, including second order effects.

System Advantages

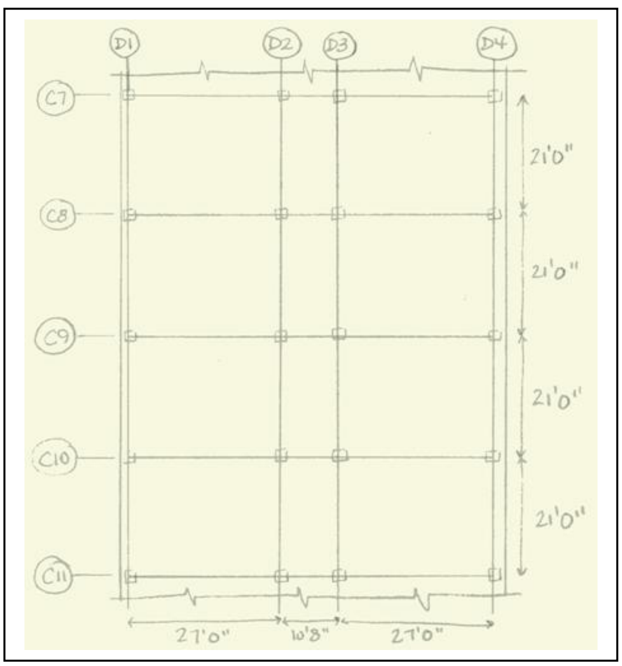
Composite steel can operate under significant live loads and still maintain long spans to keep an open floor plan. With a 6.5" thick decking and concrete slab, it also complies with the required 2-hour fire rating for the desired storage of chemicals and research labs. The necessary deep and heavy steel sections for the long spans also help to conquer the vibration control for the labs. Bearing on fill and indigenous soils, footings are used as the foundation for the weighty structure. Cost is minimal since forms and shoring are not required for construction. Most of the cost goes into renting a crane for steel erection. Although it has an involved shape, pouring the slab is relatively simple especially since there are relatively minimal slab openings, allowing fast pouring.

System Disadvantages

The amount of material used in this system amounts to about 24 inches think which takes away from the amount of floor-to-floor space. The majority of this system is in the deep sections of steel which is increasing in price every year.




Courtesy of www.answers.com

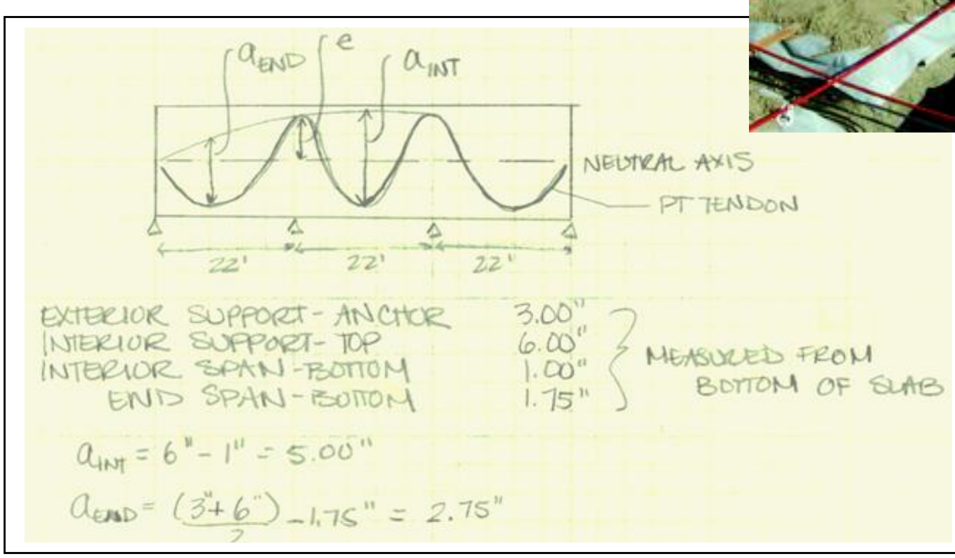


System Advantages

Post-tensioning is a way to strengthen a concrete member by stressing the reinforcing tendons after the concrete has set. This means that slabs of this kind can manage heavy live loads as well as large spans for open floor plans. This slab can also be supported using concrete instead of steel columns which allows the lateral loads to be taken by the concrete frame instead of the steel braces. With 6-inch thick concrete, 2-hour fire-proof rating is achieved so additional is needed. Since the floor thickness is small, there is more space allotted for the floor-to-floor measurement. Because of the use of concrete, the vibration is controlled for the labs. Less materials and formwork are needed to place a post-tensioned slab so the material construction cost is minimal and thus a rather fast formation.

System Disadvantages

To make a sufficient spacing for the tendons, the bay size needs to be changed and in my calculations I created a new 21' x 22' typical bay, which doesn't particularly fit the existing plan. With the weight of the concrete frame, the foundations need to be slightly increased to hold the extra weight. However, post-tensioning is requires a lot of experience to construct so it costs more for the specialized labor. In addition, safety is of utmost importance when jacking the tendons into place, so extra attention is needed when putting the slab into place. Also, once the slab is set and the tendons are jacked, putting in any new slab penetrations risks breaking into a tendon, so all slab openings must be planned and accounted in the plan.

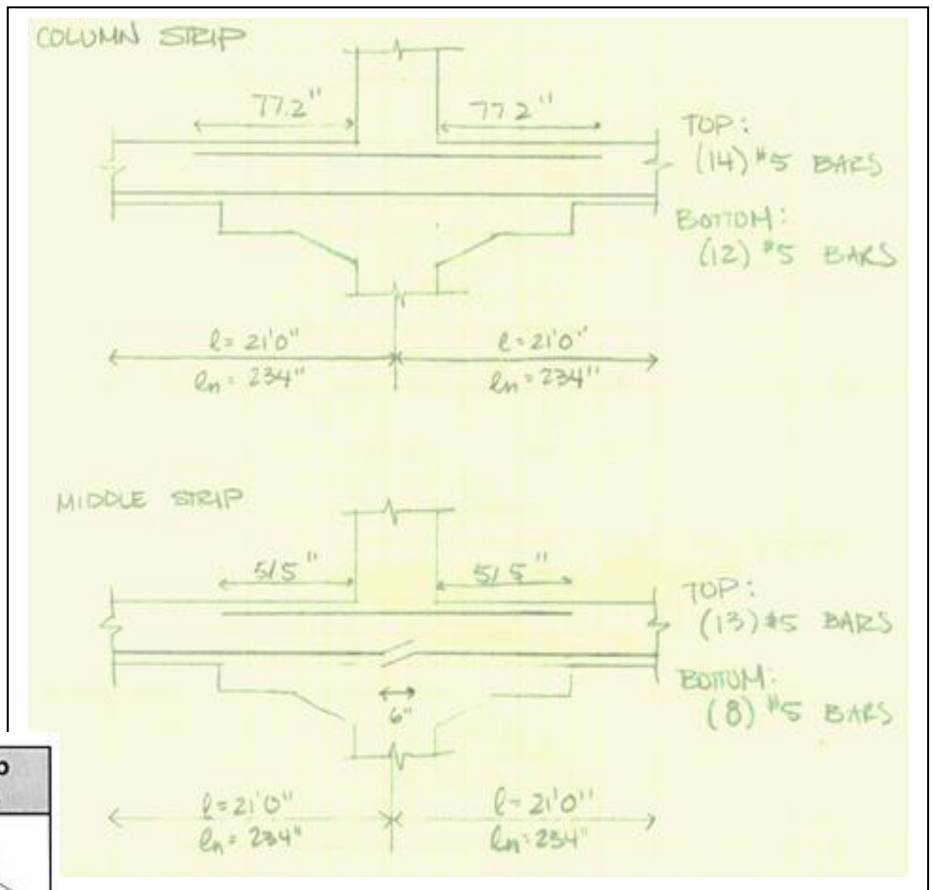


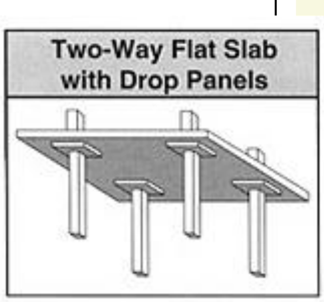
System Advantages

This two way flat slab that consists of a reinforced concrete slab can manage large live loads with a relatively small thickness of concrete. The slim section of flooring allows for a higher floor-to-floor dimension. A flat slab also fits into the current grid of columns and bays. Due to the denseness of concrete, no additional fireproofing is needed and the vibration in the floor is controlled. Concrete needs minimal formwork and only basic field labor. Columns can also be made of reinforced concrete which would lead to the use of shear walls to handle the lateral forces.

System Disadvantages

The use of concrete flat slabs needs a rather exact ratio of column spans, which doesn't always guarantee an open plan. In fact, this ratio requires a smaller sized bay which could mean more columns, but not for a typical bay taken into account for this building. The increased amount of concrete requires an increased amount of reinforcement. Since the columns are also reinforced concrete there is a complicated construction of intermingled reinforcement where columns and floors meet which can extend construction time.



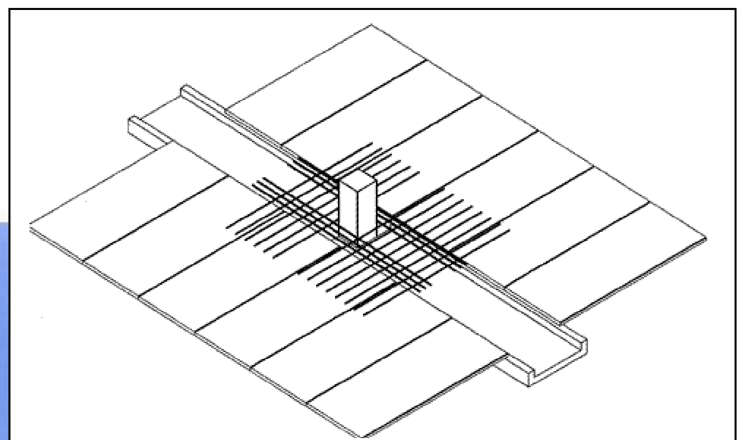



System Advantages

Precast concrete is made up of pre-stressed concrete rectangular bays that are quality-controlled off-site at the fabricator's shop. The precast concrete planks are able to carry heavy live loads as well as keep large column spacing, which can allow an open plan to be utilized. Hollow core planks provide a slim section of 10 inches of plank with a 2-inch concrete topping, and can be provided at the spans required to fit the current grid. To support this flooring, reinforced concrete columns or precast columns may be used. In either case, the lateral force resisting system is changed to the concrete frame or shear walls. The construction of this system has a quick assembly time and a minimal amount of manual labor. Part of the labor is the application of spray-on fire-proofing to reach the 2-hour fire-rating.

System Disadvantages

The long spans in this system are likely to induce vibrations instead of stop them. Lead time for precast concrete is a considerable amount ahead of on-site construction, which means that plans must be set pretty far ahead of construction. Also, any field cuts into the slab must be checked with the structural engineer. A crane is also required for the placement of the slabs which can become a costly expense as time lapses. Another costly expense is the addition of spray-proofing because it takes minimal and inexperienced effort but it still adds more cost and labor to the construction of the system.

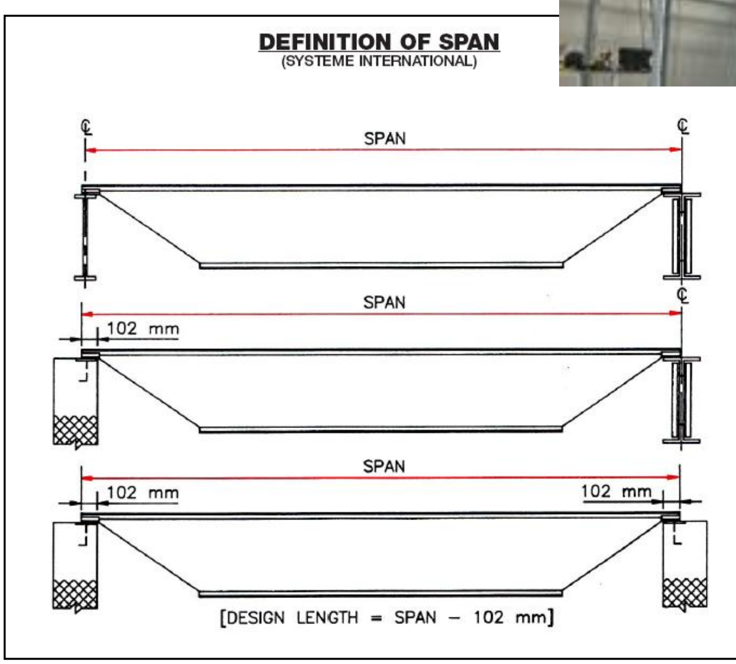


System Advantages

A series of parallel trusses, open web steel joists are an option that can manage heavy loads and large column spacing of an open plan. A 2-hour fire-rating can be reached with the addition of spray-on fire-proofing. This is another simple form of construction which uses small amounts of formwork for the 2.5-inch slab on top of the steel decking, much like the composite steel system. The lateral frame can continue to use the eccentric braced frames that are currently designed. Because of the light weight, the current foundation sizes are sufficient for this system.

System Disadvantages

The section of the open web steel joists required for the typical bay is about 20-inches in depth which limits the amount of floor-to-floor height. This depth doesn't include the ducts that will need to wind through the slab, which takes up more of the floor height. In addition, the spray-on fire-proofing requires some expertise to apply it the correct way. Because of its light weight, the steel joists are not a good suppressant of vibrations.



The following chart is a comparison of the five different floor layout systems.

| | Composite Steel (NWC) | Two-Way Post Tensioned | Two-Way Flat Slab | Precast Hollow Core | Steel Joists |
|---|---|---|---|---|---|
| Depth | 24" | 6" | 7" | 12" | 22.5" |
| Weight | 71 psf | 104 psf | 125 psf | 93 psf | 30 psf |
| Foundation | 9' x 9' x 25" | increase | increase | increase | decrease |
| Vibration | minimal | minimal | minimal | minimal | no control |
| Additional Fire Proofing | needed | none | none | none | needed |
| Floor-to-Floor Height | 16' | increased | increased | increased | increase |
| Open Floor Plan | yes | minimal | minimal | no | yes |
| Lead Time | average | shorter | average | longer | average |
| Total Cost | $48.92 | $86.65 | $33.87 | $12.04 | $57.20 |
| Feasibility | original | no | yes | yes | no |

| | | |
|---|---|---|
| good | better | best |

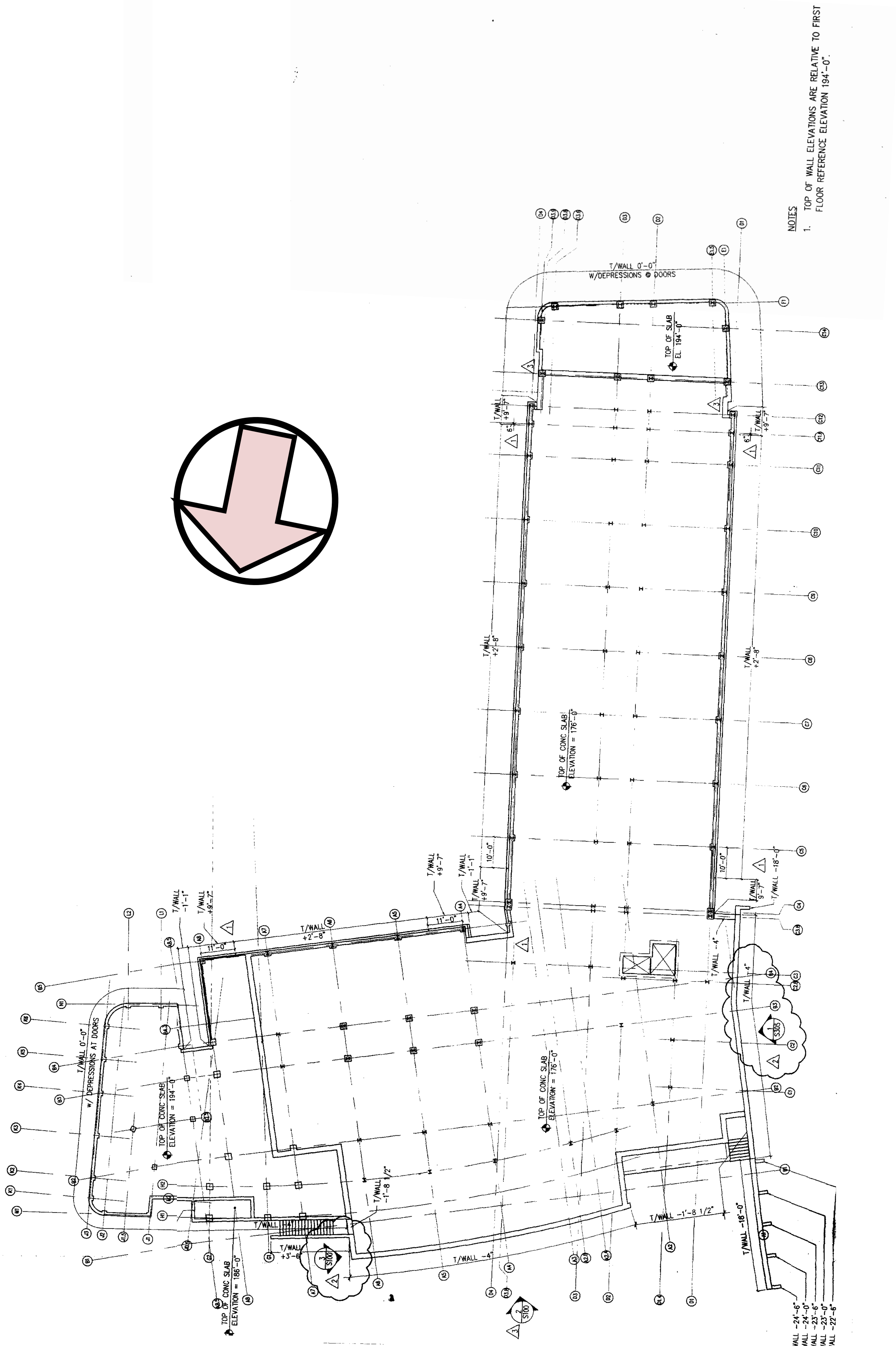
Figure 11. Comparison Chart

The Gen*NY*Sis Center for Genomics is made up mostly of laboratories, offices, and chemical storage rooms, which makes vibration and an open floor plan critical for comparison. Based solely on vibration, which can be intrusive to experiments and chemical, open web steel joists cannot be used. Due to a reorganization of the grid system, two-way post tensioned, two-way flat slab, and precast hollow core planks don't allot for an open floor plan. Schematic design to grand opening lasted about 17 months, so lead time was especially critical in the fast-tracking of this project. Personally, I think the use of steel enhances the technological look meant for this building. Based strictly on cost, which is more realistic, then precast hollow core planks are the option to choose.

This report is an investigation into alternative structural floor designs for the Gen*NY*Sis Center for Genomics. The original schematic design narrative has been used as a basis for comparison and guidelines for evaluating and choosing these alternatives. The research included structural systems using composite steel, two-way post-tensioned concrete slab, two-way flat concrete slab, precast hollow core planks, and open web steel joists.

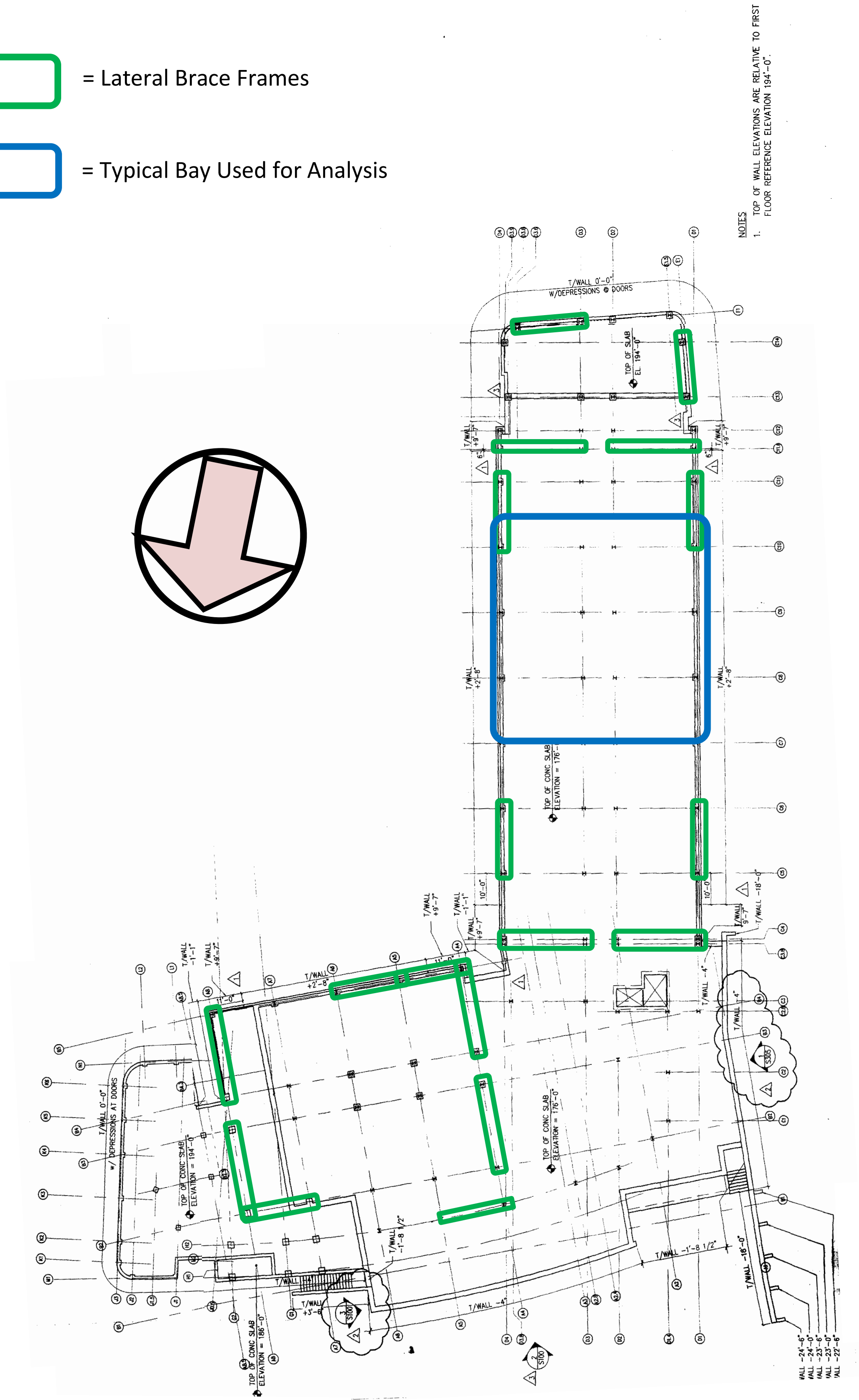
Given that this building contains sensitive equipment and some sizing accommodations, a few demands need to be addressed. First off, many of the rooms are designed at a certain size and the typical bay is created around a 10-foot 8-inch hallway in between, so in this aspect there needs to be an open plan applicable to form the hallway and make sure that the rooms remain column-free. Also, most of the rooms contain chemicals and laboratories which need to stay as motionless as possible so vibration control is of the utmost importance. Based on the original schematic design, a fast track was used for construction, but is not considered an important factor in this comparison (although it is observed).

It can be determined that precast hollow core planks are a viable alternative. This system provides an open plan and minimum vibration at an affordable price. Furthermore, no additional fireproofing is needed with the precast concrete which also adds to the dimension from floor-to-floor. However, the planks system weighs considerably more than the existing composite steel system so the columns will be thicker which amounts to larger foundation footings. Another possible holdback is that precast planks require a longer lead time than most systems. Based on these factors, precast hollow core planks are the most feasible alternate for the structural system of the Gen*NY*Sis Center for Genomics.


NOTES
1. TOP OF WALL ELEVATIONS ARE RELATIVE TO FIRST FLOOR REFERENCE ELEVATION 194'-0".
TOP OF CONC SLAB ELEVATION = 176'-0"
TOP OF CONC SLAB ELEVATION = 194'-0"
TOP OF CONC SLAB ELEVATION = 186'-0"
T/WALL 0'-0" W/DEPRESSIONS @ DOORS

= Lateral Brace Frames

= Typical Bay Used for Analysis



Picture 1: Typical Structural Column on Pier

Picture 2: View of Structural Frame

Picture 3: Interior View of 1st Floor

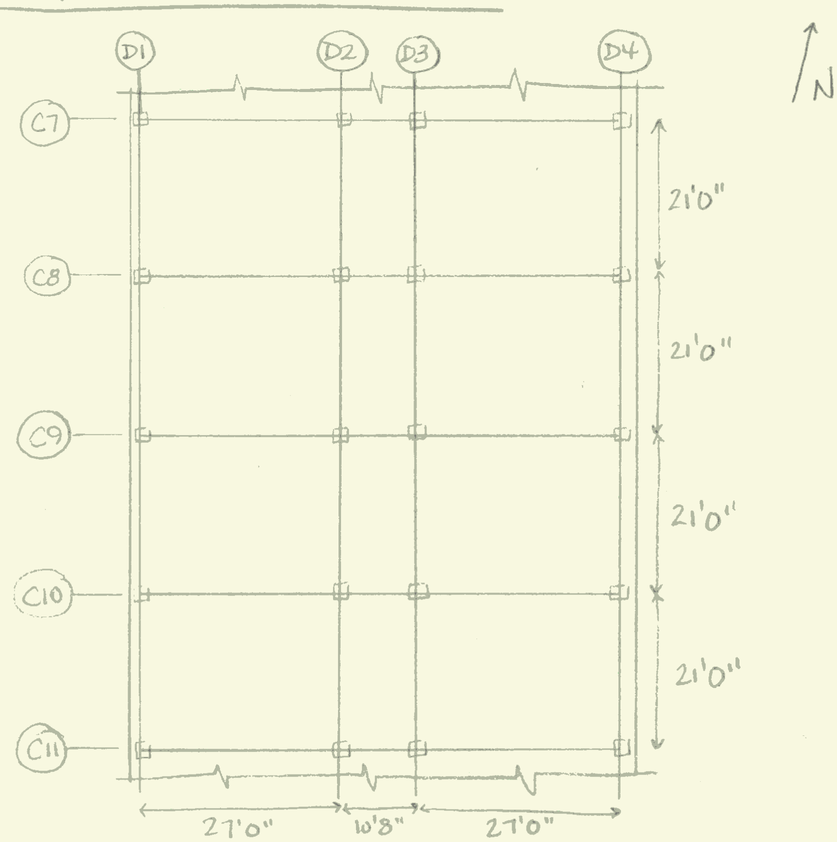
Picture 4: Typical Lateral Brace Connection

Picture 5: Typical Column-Girder Connection

Picture 6: Penthouse Mechanical Screen

GEN*NY*SIS CENTER FOR GENOMICS - TWO WAY POST TENSIONED

TWO-WAY POST-TENSIONED SLAB




$f'_c = 5000$ psi
$f_y = 60{,}000$ psi
$w_c = 150$ pcf (NWC)

SUPERIMPOSED DEAD LOAD = 10 psf
PARTITION LOAD = 20 psf
LIVE LOAD = 100 psf (1st FLOOR CORRIDOR)

ASSUME FLOOR-TO-FLOOR HEIGHT = 16'0"
SQUARE COLUMNS = 18" x 18"

UNBONDED TENDONS
1/2" $\phi$, 7-WIRE STRANDS, $A = 0.153$ in$^2$
$f_{pu} = 270{,}000$ psi
PRESTRESS LOSSES ≈ 15000 psi (ACI 318-05 SEC. 18.6)
$f_{se} = 0.70 f_{pu}$ (ACI 318-05 SEC. 18.5.1)
(0.70)(270,000 psi) − 15,000 psi
$f_{se} = 174$ ksi
$P_{eff} = (0.153\ in^2)(174\ ksi) = 26.6^k$ / TENDON

GEN*NY*SIS CENTER FOR GENOMICS – 2WAY PT 2/12

SLAB THICKNESS [h]:

LONGEST SPAN/45

$27' \times 12 / 45$

$h = 7.2 \rightarrow$ TRY $h = 7.5"$

SLAB WEIGHT

$(150\ pcf)(7.5"/12) = 94\ psf$

AREAS OF INFLUENCE [AI]:

INT: $(42')(10'8" + 27') = 1582\ ft^2$

EXT: $(42')(27') = 1134\ ft^2$

LIVE LOAD REDUCTION [LL]

$L_0 \left[0.25 + 15/\sqrt{A_I}\right]$

$100\left[0.25 + 15/\sqrt{1582}\right]$ $100\left[0.25 + 15/\sqrt{1134}\right]$

INT LL = 79.2 psf EXT LL = 83.4 psf

NORTH-SOUTH FRAME

ACI 318-05 SEC. 18.3.3

AREA = $bh = (21' \times 12"/') (7.5") = 1890\ in^2$

SECTION MODULUS = $(1/6)(b)(h^2) = (1/6)(21 \times 12")(7.5")^2 = 2363\ in^3$

AT TIME OF JACKING: $f'_{ci} = 3000\ psi$

ACI 18.4.1

$C = (0.6)(3000\ psi) = 1800\ psi$

$T = 3\sqrt{3000}\ psi = 164\ psi$

AT SERVICE LOADS: $f'_{ci} = 5000\ psi$

ACI 18.4.2

$C = (0.45)(5000\ psi) = 2250\ psi$

$T = 6\sqrt{5000}\ psi = 424\ psi$

PRECOMPRESSION LIMITS

$P/A$ = 125 MIN ACI 318.12.4

300 MAX

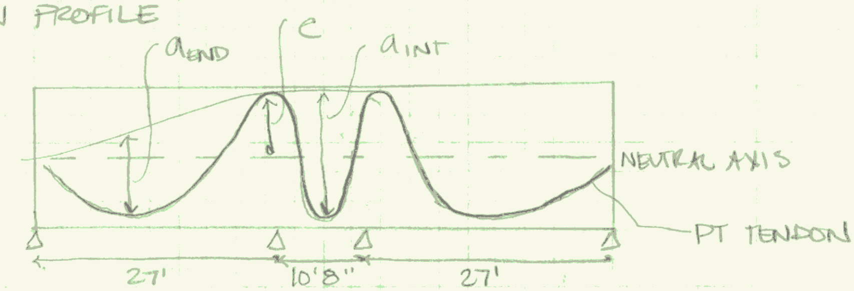
TARGET LOAD BALANCES: 75%

$W_{DL} = 0.75(94\ psf) = 71\ psf$

GEN*NY*SIS CENTER FOR GENOMICS – 2WAY PT 3/12

COVER REQUIREMENTS
2-HOUR FIRE RATING
RESTRAINED SLABS ⟶ 0.75" BOTTOM

TENDON PROFILE




| | | |
|---|---|---|
| EXTERIOR SUPPORT – ANCHOR | 3.75" | MEASURED FROM BOTTOM OF SLAB |
| INTERIOR SUPPORT – TOP | 7.50" | |
| INTERIOR SPAN – BOTTOM | 1.00" | |
| END SPAN – BOTTOM | 1.75" | |

$a_{INT} = 7.5" - 1.0" = 6.5"$

$a_{END} = \frac{(3.75" + 7.5")}{2} - 1.75" = 3.88"$

PRESTRESS FORCE

$w_b = (71\ psf)(21\ ft) = 1491\ plf$

$P = \frac{w_b L^2}{8 a_{END}} = \frac{(1491\ plf)(27')^2}{8(3.88/12')} = 421^k$ FOR EXTERIOR BAY

$\#\ TENDONS = (421^k)/26.6\ ^k/_{TENDON} = 16\ TENDONS$

$P_{ACTUAL} = 426^k,\quad w_{b\,ACTUAL} = 1.51\ ^k/_{ft}$

PRECOMPRESSION STRESS $= 426^k / 1890\ in^2 = 225\ psi$ $> 125$ ✓ $< 300$ ✓

$P = \frac{w_b L^2}{8 a_{INT}} = \frac{(1491\ plf)(10.667')^2}{8(6.5"/12)} = 39^k << 421^k$

LESS FORCE REQUIRED IN CENTER BAY

$w_b = (421^k)(8)(6.5/12')/(10.667')^2 = 16.0\ ^k/_{ft}$

$\frac{16.0\ ^k/_{ft}}{1.51\ ^k/_{ft}} > 100\%$ ∴ NOT ACCEPTABLE

THEREFORE MUST CHANGE SPANS AND COLUMN LOCATIONS

\

GEN*NY*SIS CENTER FOR GENOMICS – 2WAY PT 4/12

TOTAL WIDTH = 64'8"
NEED AT LEAST 10'8" FOR CORRIDOR

TRY EQUAL SIZED BAYS : 22'

SLAB THICKNESS [h] :
$21' \times 12 / 45$

$h = 5.6" \rightarrow$ TRY 6"

SLAB WEIGHT [DL]
$(150 \text{ pcf})(6/12') = 75 \text{ psf}$

AREA OF INFLUENCE [AI]
$(22'+22')(21'+21')$ — INT = 1848 ft²
$(22')(21'+21')$ — EXT = 924 ft²

LIVE LOAD REDUCTION [LL]
$100\left[0.25 + 15/\sqrt{1848}\right]$ — INT LL = 77 psf
$100\left[0.25 + 15/\sqrt{924}\right]$ — EXT LL = 86 psf

$A = (21' \times 12"/1)(6") = 1512 \text{ in}^2$
$S = (1/6)(21 \times 12")(6")^2 = 1512 \text{ in}^3$

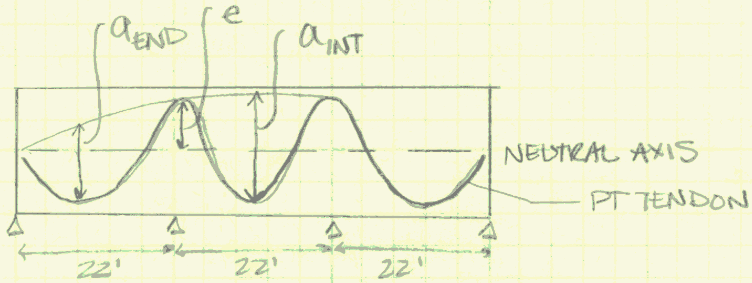
AT TIME OF JACKING : $f'_{ci} = 3000$ psi
C = 1800 psi
T = 164 psi

AT SERVICE LOADING : $f'_{ci} = 5000$ psi
C = 2250 psi
T = 424 psi

TARGET LOAD BALANCE
$0.75 \text{ DL} = 0.75(75 \text{ psf}) = 56.25 \text{ psf}$

0.75" COVER

GEN*NY*SIS CENTER FOR GENOMICS - 2WAY PT 5/12




EXTERIOR SUPPORT - ANCHOR 3.00"
INTERIOR SUPPORT - TOP 6.00"
INTERIOR SPAN - BOTTOM 1.00"
END SPAN - BOTTOM 1.75"
} MEASURED FROM BOTTOM OF SLAB

$a_{INT} = 6" - 1" = 5.00"$

$a_{END} = \frac{(3" + 6")}{2} - 1.75" = 2.75"$

PRESTRESS FORCE

$w_b = (57 psf)(21 ft) = 1197 plf$

$P = \frac{(1197 plf)(22')^2}{8(2.75/12')} = 316^k$ FOR EXTERIOR BAY

$\#$ TENDONS $= 316^k / 26.6^{k/TENDON} = 12$ TENDONS

$P_{ACTUAL} = 319.2^k, w_{b\,ACTUAL} = 1.21$ klf

$P_{ACTUAL}/A = 211$ psi $> 125$ ✓ $< 300$ ✓

$P = \frac{(1.21 klf)(22')^2}{8(2.75/12')} = 319^k = 319^k$

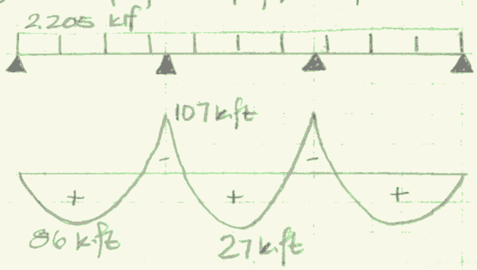
SAME FORCE REQUIRED IN EITHER BAY

EFFECTIVE PRESTRESS FORCE $= 319^k$

GEN*NY*SIS CENTER FOR GENOMICS – 2WAY PT SLAB 6/12

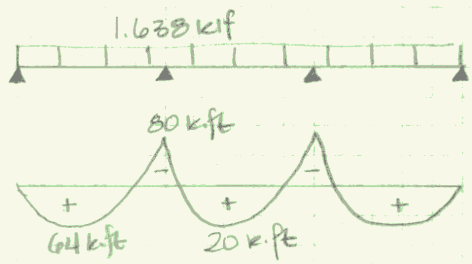
DEAD LOAD MOMENTS

$w_{DL} = (75\ psf + 30\ psf)(21\ ft) = 2.205\ klf$



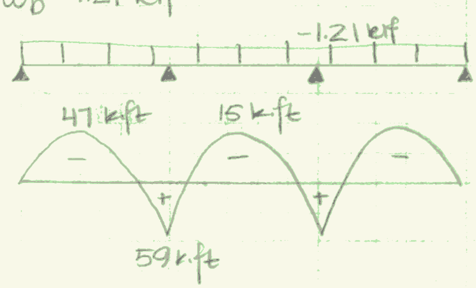

LIVE LOAD MOMENTS

$w_{LL} = (78\ psf)(21\ ft) = 1638\ plf$




TOTAL BALANCING MOMENTS

$w_b = 1.21\ klf$




STAGE 1: IMMEDIATELY AFTER JACKING (DL + PT) ACI 18.4.1

MIDSPAN

$$f_{top} = \frac{(-M_{DL} + M_{bal})}{S} - P/A$$

$$f_{bottom} = \frac{(M_{DL} - M_{bal})}{S} - P/A$$

INTERIOR SPAN: $\frac{(-27\ k.ft + 15\ k.ft)}{1512\ in^3} - 211\ psi = -306\ psi < 1800\ psi$ ✓

GEN*NY*SIS CENTER FOR GENOMICS – 2WAY PT 7/12

STAGE 1: AFTER JACKING (DL + PT) ACI 18.4.1

MIDSPAN

INTERIOR SPAN

$$f_{top} = \frac{(-27\ k\cdot ft + 15\ k\cdot ft)}{1512\ in^3} - 211\ psi = -306\ psi < 1800\ psi\ \checkmark$$

$$f_{bottom} = \frac{(27\ k\cdot ft - 15\ k\cdot ft)}{1512\ in^3} - 211\ psi = -116\ psi < 1800\ psi\ \checkmark$$

END SPAN

$$f_{top} = \frac{(-86\ k\cdot ft + 47\ k\cdot ft)}{1512\ in^3} - 211\ psi = -520\ psi < 1800\ psi\ \checkmark$$

$$f_{bottom} = \frac{(86\ k\cdot ft - 47\ k\cdot ft)}{1512\ in^3} - 211\ psi = 99\ psi < 164\ psi\ \checkmark$$

SUPPORT

$$f_{top} = \frac{(107\ k\cdot ft - 59\ k\cdot ft)}{1512\ in^3} - 211\ psi = 170\ psi > 164\ psi$$

NEED REINF.

$$f_{bottom} = \frac{(-107\ k\cdot ft + 59\ k\cdot ft)}{1512\ in^3} - 211\ psi = -592\ psi < 1800\ psi\ \checkmark$$

STAGE 2: SERVICE LOAD (DL + LL + PT) ACI 18.3.3, 18.4.2

MIDSPAN

INTERIOR SPAN

$$f_{top} = \frac{(-27\ k\cdot ft - 20\ k\cdot ft + 15\ k\cdot ft)}{1512\ in^3} - 211\ psi = -465\ psi < 2250\ psi\ \checkmark$$

$$f_{bottom} = \frac{(27\ k\cdot ft + 20\ k\cdot ft - 15\ k\cdot ft)}{1512\ in^3} - 211\ psi = 43\ psi < 424\ psi\ \checkmark$$

END SPAN

$$f_{top} = \frac{(-86\ k\cdot ft - 64\ k\cdot ft + 47\ k\cdot ft)}{1512\ in^3} - 211\ psi = -1028\ psi < 2250\ psi\ \checkmark$$

$$f_{bottom} = \frac{(86\ k\cdot ft + 64\ k\cdot ft - 47\ k\cdot ft)}{1512\ in^3} - 211\ psi = 606\ psi > 424\ psi$$

NEED REINF.

SUPPORT

$$f_{top} = \frac{(107\ k\cdot ft + 80\ k\cdot ft - 59\ k\cdot ft)}{1512\ in^3} - 211\ psi = 805\ psi > 424\ psi$$

NEED REINF.

$$f_{bottom} = \frac{(-107\ k\cdot ft - 80\ k\cdot ft + 59\ k\cdot ft)}{1512\ in^3} - 211\ psi = -1226\ psi < 2250\ psi\ \checkmark$$

GEN*NY*SIS CENTER FOR GENOMICS - 2WAY PT 8/12

ULTIMATE STRENGTH

PRIMARY MOMENT

$M_1 = 319^k (2/12') = 53\ k\cdot ft$

SECONDARY MOMENT

$M_2 = M_{bal} - M_1 = 59 - 53 = 6\ k\cdot ft$

$M_U = 1.2 M_{DL} + 1.6 M_{LL} + M_2$

@ MIDSPAN: $M_U = 1.2(86\ k\cdot ft) + 1.6(64\ k\cdot ft) + (3k\cdot ft) = 209\ k\cdot ft$

@ SUPPORT: $M_U = 1.2(-107\ k\cdot ft) + 1.6(-80\ k\cdot ft) + (6k\cdot ft) = -250\ k\cdot ft$

BONDED REINFORCEMENT

POSITIVE MOMENT REGION

INTERIOR SPAN: $f_t = 15\ psi < 2\sqrt{f'_c} = 2\sqrt{5000}\ psi = 141\ psi$ ✓

NO POSITIVE REINF. NEEDED

EXTERIOR SPAN: $f_t = 180\ psi > 141\ psi$

POSITIVE REINF. NEEDED

$y = \frac{f_t}{(f_t + f_c)} h = \frac{180\ psi}{(180\ psi + 622\ psi)}(6\ in) = 1.35\ in$

$N_c = \frac{M_{DL+LL}}{2S} y\, \ell_2 = \frac{(86+64\ k\cdot ft)}{2\ (1512\ in^3)}(1.35\ in)(22 \times 12\ in) = 212^k$

$A_{s\,min} = \frac{N_c}{0.5 f_y} = \frac{212^k}{0.5(60\ ksi)} = \frac{7.07\ in^2}{22\ ft} = 0.32\ in^2/ft$

USE #6 @ 12" o.c.

(ACI 18.9.4.1) MIN. LENGTH 1/3 CLEAR SPAN & CENTERED

NEGATIVE MOMENT REGION

INTERIOR SUPPORT

$A_{cf} = (6")(21')(12) = 1512\ in^2$

$A_{s\,min} = 0.00075(1512\ in^2) = 1.13\ in^2$ → USE 6 #4 TOP ($1.20\ in^2$)

EXTERIOR SUPPORT

$A_{cf} = (6")(22' \times 12) = 1584\ in^2$

$A_{s\,min} = 0.00075(1584\ in^2) = 1.19\ in^2$ → USE 6 #4 BOTTOM ($1.20\ in^2$)

(ACI 18.9.4.2) MUST SPAN MIN 1/6 CLEAR SPAN ON EACH SIDE OF SUPPORT

(ACI 18.9.3.3) AT LEAST 4 BARS IN EACH DIRECTION

(ACI 18.9.3.3) PLACE TOP BARS WITHIN 1.5h = 9" AWAY FROM FACE OF SUPPORT

GEN*NY*SIS CENTER FOR GENOMICS – 2WAY PT 9/12

CHECK MIN. REINFORCEMENT

$M_n = (A_s f_y + A_{ps} f_{ps})(d - a/2)$

AT SUPPORTS

$d = 6'' - 3/4'' - 1/4'' = 5''$

$A_{ps} = 0.153 \text{ in}^2 (\text{\# OF TENDONS}) = 0.153(12) = 1.84 \text{ in}^2$

$f_{ps} = f_{pe} + 10000 \text{ psi} + \frac{f'_c b d}{300 A_{ps}} = 174000 + 10000 + \frac{(5000 \text{psi})(21 \times 12'')(5'')}{300\ (1.84 \text{in}^2)}$

$= 195413 \text{ psi}$

$a = \frac{(A_s f_y + A_{ps} f_{ps})}{0.85 f'_c b} = \frac{(1.20 \text{in}^2)(60 \text{ksi}) + (1.84 \text{in}^2)(185 \text{ksi})}{0.85\ (5 \text{ksi})(21 \times 12'')} = 0.39 \text{ in}$

$\phi M_n = 0.9[(1.20 \text{in}^2)(60 \text{ksi}) + (1.84 \text{in}^2)(195 \text{ksi})](5'' - \frac{0.39}{2}'')$

$= 1863 \text{ k·in} = 155 \text{ k·ft} < 250 \text{ k·ft}$

REINF. FOR ULTIMATE STRENGTH GOVERNS

$A_{s,req'd} = 1.35 \text{ in}^2$

7 #4 TOP @ INTERIOR SUPPORTS
6 #4 TOP @ EXTERIOR SUPPORTS

AT MIDSPAN

$d = 6'' - 1.5'' - 1/4'' = 4.25''$

$f_{ps} = 174000 \text{ psi} + 10000 \text{ psi} + \frac{(5000)(21 \times 12'')(4.25'')}{300\ (1.84 \text{in}^2)} = 193701 \text{ psi}$

$a = \frac{(6.77 \text{in}^2)(60 \text{ksi}) + (1.84 \text{in}^2)(195 \text{ksi})}{0.85\ (5 \text{ksi})\ (21 \times 12'')} = 0.70 \text{ in}$

$\phi M_n = 0.9 \frac{(6.77 \text{in}^2)(60 \text{ksi}) + (1.84 \text{in}^2)(185 \text{ksi})}{(4.25'' - 0.70/2'')} = 176 \text{ in·kips} = 14 \text{ ft·kips}$

14 ft·kips < 209 ft·kips

REINF. FOR ULTIMATE STRENGTH GOVERNS

$A_{s,req'd} = 0.48 \text{ in}^2/\text{ft}$

#7 @ 12" O.C. BOTTOM END SPANS

EAST-WEST FRAME

$A = (22' \times 12'')(6'') = 1584 \text{ in}^2$

$S = 1/6\,(22 \times 12'')(6'')^2 = 1584 \text{ in}^3$

$w_b = (57 \text{ psf})(22 \text{ft}) = 1254 \text{ plf}$

$P = \frac{w_b l^2}{8 a_{INT}} = \frac{(1.254 \text{ klf})(21')^2}{8\ (5/12')} = 166^k$

# TENDONS = 7 TENDONS

$P_{ACTUAL} = 187^k,\ w_{b\,ACTUAL} = 1.41 \text{ klf}$

GEN*NY*SIS CENTER FOR GENOMICS – 2WAY PT 10/12

$P/A = 126$ psi $> 125$ psi
$< 300$ psi

EFFECTIVE STRESS FOR EAST-WEST FRAME = $187^k$

DEAD LOAD MOMENTS
$w = (22 ft)(105 psf) = 2310$ plf

$M^- = -102$ k·ft (SUPPORT)
$M^+ = 25$ k·ft (MIDSPAN)

LIVE LOAD MOMENTS
$w = (22 ft)(78 psf) = 1716$ plf

$M^- = -76$ k·ft (SUPPORT)
$M^+ = 19$ k·ft (MIDSPAN)

BALANCING MOMENTS
$w = 1.41$ klf

$M^+ = 62$ k·ft (SUPPORT)
$M^- = -16$ k·ft (MIDSPAN)

STAGE 1

MIDSPAN
$f_{top} = \frac{(-25 k \cdot ft + 16 k \cdot ft)}{1584 in^3} - 126$ psi $= -133$ psi $< 1800$ psi ✓
$f_{bottom} = \frac{(25 k \cdot ft - 16 k \cdot ft)}{1584 in^3} - 126$ psi $= -58$ psi $< 1800$ psi ✓

SUPPORT
$f_{top} = \frac{(102 k \cdot ft - 62 k \cdot ft)}{1584 in^3} - 126$ psi $= 177$ psi $> 164$ psi
NEED REINF.
$f_{bottom} = \frac{(-102 k \cdot ft + 62 k \cdot ft)}{1584 in^3} - 126$ psi $= -429$ psi $< 1800$ psi ✓

STAGE 2
MIDSPAN
$f_{top} = \frac{(-25 k \cdot ft - 19 k \cdot ft + 16 k \cdot ft)}{1584 in^3} - 126$ psi $= -338$ psi $< 2250$ psi ✓
$f_{bottom} = \frac{(25 k \cdot ft + 19 k \cdot ft - 16 k \cdot ft)}{1584 in^3} - 126$ psi $= 86$ psi $< 424$ psi ✓

SUPPORT
$f_{top} = [(102 k \cdot ft + 76 k \cdot ft - 62 k \cdot ft)/1584] - 126$ psi $= 753$ psi $> 424$ psi
NEED REINF.
$f_{bottom} = [(-102 k \cdot ft - 76 k \cdot ft + 62 k \cdot ft)/1584] - 126$ psi $= -1005$ psi $< 2250$ ✓

GEN*NY*SIS CENTER FOR GENOMICS - 2WAY PT 11/12

ULTIMATE STRENGTH

$M_1 = Pe = 187^k(2/12') = 32$ k.ft

$M_2' = 62 - 32 = 30$ k.ft

@ MIDSPAN: $M_U = 1.2(25) + 1.6(19) + (15) = 75$ k.ft

@ SUPPORT: $M_U = 1.2(-102) + 1.6(-76) + 30 = -214$ k.ft

REINFORCEMENT

NO POSITIVE NEEDED

$A_{cf} = (6")(22' \times 12") = 1584$ in²

$A_{s,min} = 0.00075(1584 \text{ in}^2) = 1.19 \text{ in}^2$ USE 6 #4 TOP (1.20 in²)

CHECK MIN. REINFORCEMENTS

@ SUPPORTS

$d = 5"$

$A_{ps} = 0.153 \text{ in}^2 (7) = 1.07 \text{ in}^2$

$f_{ps} = 184000 \text{ psi} + \dfrac{(5000 \text{ psi})(22' \times 12")(5")}{300(1.07 \text{ in}^2)} = 205$ ksi

$a = \dfrac{(1.20 \text{ in}^2)(60 \text{ ksi}) + (1.07 \text{ in}^2)(205 \text{ ksi})}{0.85(5 \text{ ksi})(22' \times 12")}$ 0.26

$\phi M_n = 0.9[(1.20 \text{ in}^2)(60 \text{ ksi}) + (1.07 \text{ in}^2)(205 \text{ ksi})](5" - \frac{0.26}{2}")$

$= 1277$ k.in $= 106$ k.ft $< 214$ k.ft

$A_{s,req'd} = 1.38 \text{ in}^2 \longrightarrow$ 7 #4 @ INTERIOR SUPPORTS

6 #4 @ EXTERIOR SUPPORTS

@ MIDSPAN

$d = 4.25"$

$f_{ps} = 184000 \text{ psi} + \dfrac{(5000 \text{ psi})(22 \times 12")(4.25")}{300(1.07 \text{ in}^2)} = 201477$ psi

$a = \dfrac{(1.20 \text{ in}^2)(60 \text{ ksi}) + (1.07 \text{ in}^2)(201 \text{ ksi})}{0.85(5 \text{ ksi})(22 \times 12")} = 0.26$ in

$\phi M_n = 0.9[(1.20 \text{ in}^2)(60 \text{ ksi}) + (1.07 \text{ in}^2)(201 \text{ ksi})](5" - \frac{0.26}{2}")$

105 k.ft > 75 k.ft

#4 @ 12" o.c.

GEN*NY*SIS CENTER FOR GENOMICS - 2WAY PT 12/12

PUNCHING SHEAR

INTERIOR COLUMN

$d = 6" - 1 = 5"$

$V_c = 4\sqrt{f'c}\,bd \quad = 4\sqrt{5000}\,(84")(6") = 143^k$

$\left(\frac{\alpha_s d}{b} + 2\right)\sqrt{f'c}\,bd \quad = \left(\frac{(40)(6)}{80} + 2\right)\sqrt{5000}\,(84)(6) = 178^k$

$\left(2 + d/80\right)\sqrt{f'c}\,bd \quad \text{MIN} \quad = 6\sqrt{5000}\,(84)(6) = 214^k$

$\phi V_c = 0.75(143^k) = 107^k$

$DL = 1.2(105\ psf) = 126\ psf$

$LL = 1.6(78\ psf) = 125\ psf$ } 251 psf

$A_T = (22')(21') = 462\ ft^2$

$V_u = \left(462\ ft^2 - \frac{12 \times 12}{144}\ ft^2\right)(251\ psf) = 116^k > \phi V_c$ ∴ NEED DROP PANELS

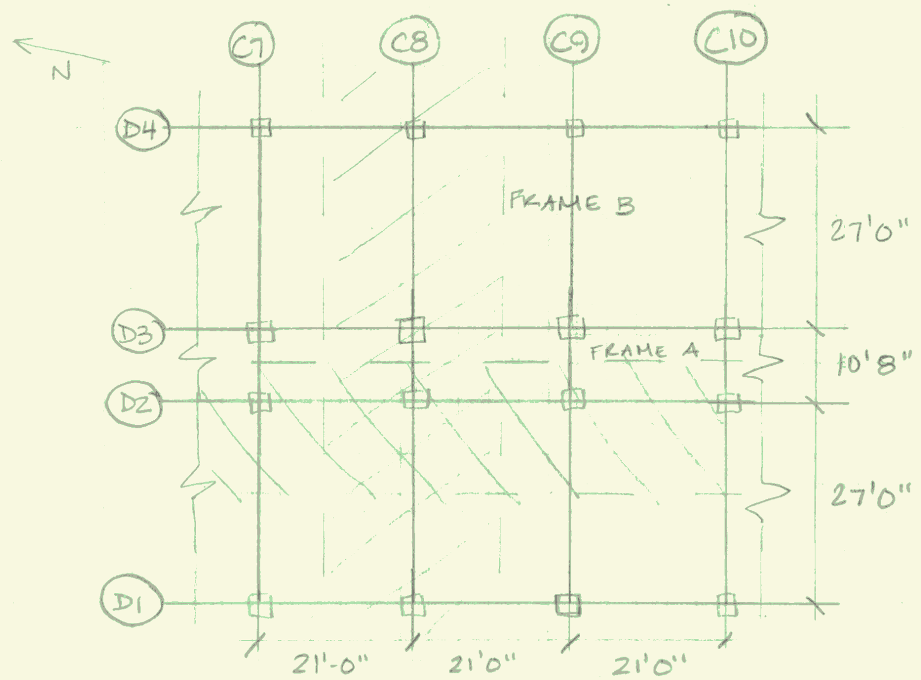
$116^k / 0.75 = 4\sqrt{5000}\ psi\ (b)(6") \rightarrow b = 91\ in$

$(91/4) - 12 = d = 10.75 \Rightarrow 12"$

SLAB = 6" → DROP PANEL = 6"

GEN*NY*SIS CENTER FOR GENOMICS - TWO WAY SLAB 1/7

## TWO-WAY SLABS




ASSUMPTIONS:

- $f'_c = 3500$ psi
- $f_y = 50000$ psi
- SUPERIMPOSED DEAD LOAD = 30 psf
- LIVE LOAD = 100 psf
- COLUMNS ARE SQUARE (18"×18")

FLOOR-TO-FLOOR = 16'0" ($1^{ST}$–$3^{RD}$)
18'0" (GROUND)

LONGEST CLEAR SPAN [$\ell_n$]:

$$\left(\frac{21'}{2} + \frac{21'}{2}\right) - \frac{18}{12}'$$

$$\ell_n = 19.5 \text{ ft}$$

MINIMUM SLAB THICKNESS [$t_{min}$]

ACI 318-05 TABLE 9.5(c) → $f_y = 50$ ksi
WITHOUT DROP PANELS
$\ell_n / 34.5$

$$19.5' (12 \text{ in/ft}) / 34.5$$

$$t_{min} = 7 \text{ in}$$

GEN*NY*SIS CENTER FOR GENOMICS - TWO WAY SLABS 2/4

DESIGN LOAD [$w_u$]

1.2DL + 1.6LL

$$1.2\left[150\text{ pcf}\left(\frac{7}{12}'\right) + 30\text{ psf}\right] + 1.6(100\text{ psf})$$

$$w_u = 301\text{ psf}$$

DESIGN SHEAR [$V_u$]

$w_u A$

$$(301\text{ psf})\left[(21')\left(\frac{10'8''}{2} + \frac{27'}{2}\right) - \left(\frac{18\times18}{144}\text{ ft}^2\right)\right]$$

$$V_u = 118^k$$

BEAM LENGTH [b]

1/4 $SPAN_L$ + 1/4 $SPAN_R$ - $diA_{col}$

$$(1/8)(21') + (1/8)(21') - 18''$$

$$b = 45''$$

BEAM DEPTH [d]

t - 1

$d \approx 6$ in (ASSUMPTION)

PUNCHING SHEAR [$V_c$]:

$$4\sqrt{f'c}\,bd$$

$$\left(\frac{\alpha_c}{b/d} + 2\right)\sqrt{f'c}\,bd \quad \text{MIN}$$

$$4\sqrt{3500\text{ psi}}(45'')(6'') = 64^k \quad \leftarrow \text{CONTROLS}$$

$$\alpha_c = \frac{(EI)\text{ beam}}{(EI)\text{ slab}} \approx 40$$

$$\left(\frac{40}{45/6} + 2\right)\sqrt{3500}(45'')(6'') = 117^k$$

MIN

$$\phi V_c = (.75)(64^k) = 48^k$$

$V_u > \phi V_c$ ∴ MUST RECALCULATE d

$$V_u = \phi V_c = (0.75)(4)\sqrt{3500}\text{ psi}(45'')d = 118^k$$

$d = 15''$ ← TOO BIG FOR, UNECONOMICAL ∴ RECALCULATE WITH DROP PANELS

GEN*NY*SIS CENTER FOR GENOMICS - TWO WAY SLAB 3/7

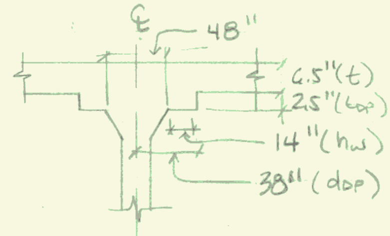
MINIMUM SLAB THICKNESS [$t_{min}$]:
ACI 318-05 TABLE 9.5(C) → $f_y$ = 50 ksi
WITH DROP PANELS
INTERIOR PANEL

$$\ell_n / 38$$

$$t_{min} = 6.5 \text{ in}$$

COLUMN CAPITAL DIAMETER [$d_{cc}$]
20% - 25% OF AVG SPAN

$$\frac{0.2\,(1/2)(18.83' + 21'0'')}{} = 48 \text{ in}$$




DROP PANEL WIDTH [$d_{DP}$]

$$\ell / 6$$

$$\frac{18.83' \times 12 \text{ in/ft}}{6}$$

$$d_{DP} = 38'' \text{ (DIST TO ℄)}$$

$$h_w = d_{DP} - 1/2\, d_{cc} = 38'' - (1/2)(48'') = 14''$$

$$b_t = (9)(76) + (6.5)(18) = 801 \text{ in}^2$$

$$t/4 \le t_{DP} < 1/4\, h_w$$

$$1.6'' \le t_{DP} < 3.5''$$

$$\longrightarrow t_{DP} = 2.5 \text{ in}$$

DESIGN LOAD [$W_u$]:
1.2DL + 1.6LL

$$1.2\left[\left[(9/12)(0.21) + (6.5/12)(0.79)\right](150 \text{ pcf}) + 30 \text{ psf}\right] + 1.6(100 \text{ psf})$$

$$W_u = 303 \text{ psf}$$

DESIGN MOMENT [$M_o$]

$$\frac{w_u \ell_2 \ell_n^2}{8}$$

FRAME A: $(303 \text{ psf})(18.83 \text{ ft})(14.5 \text{ ft})^2 / 8 = 272 \text{ ft·kips}$

FRAME B: $(303 \text{ psf})(21 \text{ ft})(18.83 - \frac{18}{12})^2 / 8 = 239 \text{ ft·kips}$

FRAME A: INT MOMENTS

$M^- = 0.65 M_o = 176.8 \text{ ft·kips}$

$M^+ = 0.35 M_o = 95.2 \text{ ft·kips}$

GEN*NY*SIS CENTER FOR GENOMICS – TWO WAY SLAB 4/7

FRAME B:

*ASSUMPTION: SLAB WITH BEAMS BETWEEN SUPPORTS

EXT. MOMENTS

$M^-_{ext} = 0.15\,M_0 = 35.9$ ft·kips

$M^+ = 0.57\,M_0 = 136.2$ ft·kips

$M^-_{int} = 0.70\,M_0 = 167.3$ ft·kips

INT. MOMENTS

$M^- = 0.65\,M_0 = 155.3$ ft·kips

$M^+ = 0.35\,M_0 = 83.7$ ft·kips

MOMENT DISTRIBUTION

FRAME A: $M^-$ = 75% TO COL. STRIP = 132.6 ft·kips

$M^+$ = 60% TO COL. STRIP = 57.1 ft·kips

FRAME B: $M_{int}^-$ = 75% TO COL. STRIP = 125.5 ft·kips

EXT $M_{ext}^-$ = 100% TO COL. STRIP = 35.9 ft·kips

$M^+$ = 60% TO COL. STRIP = 81.7 ft·kips

INT $M^-$ = 60% TO COL. STRIP = 93.2 ft·kips

$M^+$ = 60% TO COL. STRIP = 50.2 ft·kips

COLUMN STRIP [b]

$0.25\,\ell_1$

$0.25\,\ell_2$ | MIN

56.5"

MIDDLE STRIP

$MS_A = 169.5''$

$MS_B = 195.5''$

ASSUME $d_A > d_B$  $d_A \approx 6.5'' - 1.25'' = 5.25''$

$d_B \approx 4.5''$

FRAME A

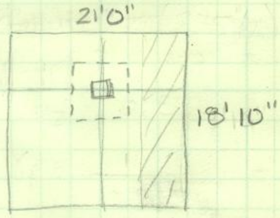
| | COL. STRIP | | MIDDLE STRIP | | |
|---|---|---|---|---|---|
| | $M^-$ | $M^+$ | $M^-$ | $M^+$ | |
| $M_u$ | -132.6 | 57.1 | -44.2 | 38.1 | |
| b | 56" | 56.5" | 169.5" | 169.5" | WIDTH OF DROP PANEL |
| d | 7.75" | 5.25" | 5.25" | 5.25" | EFFECTIVE DEPTH |
| $M_n$ | -147.3 | 63.4 | -49.1 | 42.3 | $M_u/\phi$ |
| R | 589 | 489 | 126 | 109 | $M_n/bd^2$ |
| $\rho$ | 0.0138 | 0.0113 | 0.0028 | 0.0025 | TABLE A.5a "DESIGN OF CONCRETE STRUCTURES" |
| $A_s$ | 5.23 in² | 3.35 in² | 2.49 in² | 2.22 in² | $\rho bd$ |
| $A_{s,min}$ | 1.60 in² | 1.60 in² | 1.60 in² | 1.60 in² | 0.002bt |
| N | 18 | 11 | 9 | 8 | $A_{s\,min}/A_{s\,bar}$ (#5) |
| $N_{min}$ | 6 | 6 | 6 | 6 | WIDTH OF STRIP / 2t |

GEN*NY*SIS CENTER FOR GENOMICS – TWO WAY SLAB 5/7

FRAME B

| | COLUMN STRIP | | MIDDLE STRIP | | |
|---|---|---|---|---|---|
| | $M^-$ | $M^+$ | $M^-$ | $M^+$ | |
| $M_u$ | −93.2 | 50.2 | −62.1 | 33.5 | |
| b | 50" | 56.5" | 195.5" | 195.5" | |
| d | 7.75" | 4.6" | 4.5" | 4.5" | |
| $M_n$ | −103.6 | 55.8 | −69.0 | 37.2 | |
| R | 414 | 585 | 209 | 113 | |
| $\rho$ | 0.0096 | 0.0138 | 0.0043 | 0.0025 | |
| $A_s$ | 3.72 in² | 3.51 in² | 3.78 in² | 2.2 in² | |
| $A_{s,min}$ | 1.60 | 1.60 | 1.60 | 1.60 | |
| N | 14 | 12 | 13 | 8 | (#5) |
| $N_{min}$ | 6 | 6 | 6 | 6 | |

SHEAR CHECK




$d_{AVG} = \frac{5.25" + 4.5"}{2} = 4.875"$

$(18.833')(6.3') = 119\ ft^2$

$V_u = (301\ psf)(119\ ft^2) = 36^k$

$\phi V_c = \phi 2\sqrt{f'c}\ bd = (0.75)(2)\sqrt{3500}\ psi\ (18.833 \times 12")(2.5")$
$= 50.1^k$

$\phi V_c > V_u$ ✓

PUNCHING SHEAR

$V_u = (301\ psf)[(18.833' \times 21') - (76" \times 76"/144)] = 107^k$

$\phi V_c = \phi 4\sqrt{f'c}\ bd \rightarrow (0.75)(4)\sqrt{3500}\ psi\ (152")(4.875") = 132^k$

$\left(\frac{\alpha_c}{b/d} + 2\right)\sqrt{f'c}\ bd$ MIN $\rightarrow \left(\frac{40}{152/4.875} + 2\right)\sqrt{3500}\ psi\ (152")(4.875") = 144^k$

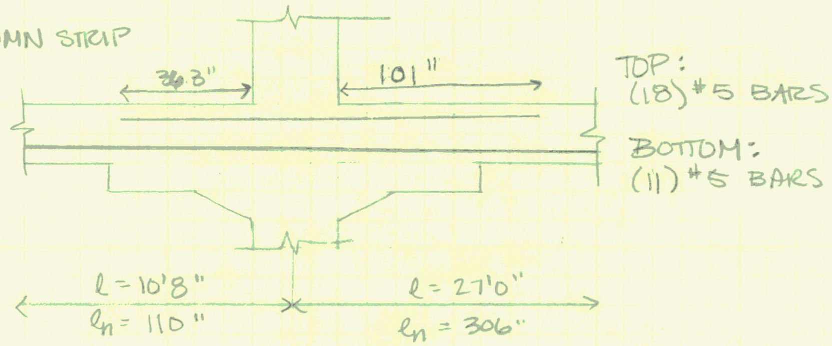
$\phi V_c > V_u$ ✓

GEN*NY*SIS CENTER FOR GENOMICS – TWO WAY SLAB 6/7

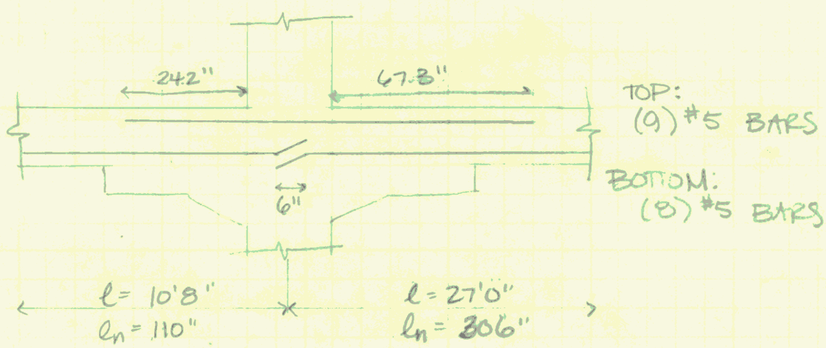
REINFORCEMENT EXTENSIONS
ACI 318-05 FIGURE 13.3.8

FRAME A

COLUMN STRIP



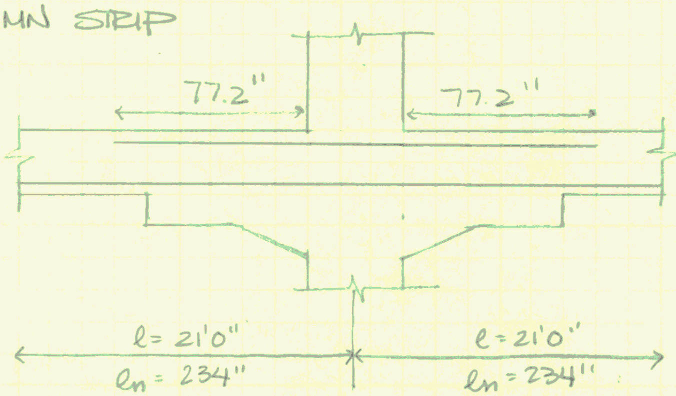

MIDDLE STRIP



GEN*NY*SIS CENTER FOR GENOMICS - TWO WAY SLAB 7/7

FRAME B

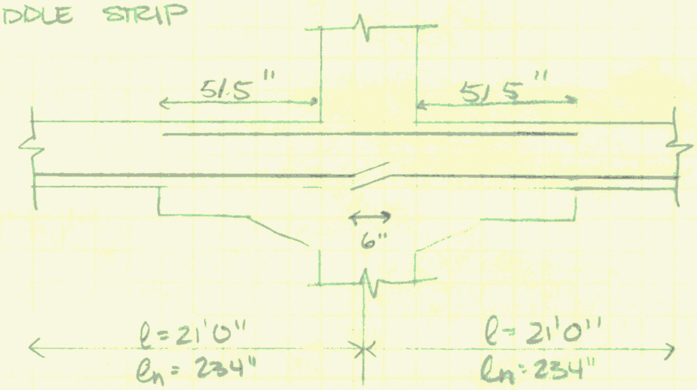
COLUMN STRIP




TOP:
(14) #5 BARS

BOTTOM:
(12) #5 BARS

MIDDLE STRIP




TOP:
(13) #5 BARS

BOTTOM:
(8) #5 BARS

GEN*NY*SIS CENTER FOR GENOMICS - PRECAST 1/

LOADS
SUPERIMPOSED DEAD LOAD = 30 psf
LIVE LOAD - CORRIDOR = 100 psf
- OFFICE/LAB = 70 psf

ASSUME: $f'c = 5000$ psi
$f_{pu} = 270000$ psi

FOR 27' SPAN, LOAD = 100 psf
10'8" SPAN, LOAD = 130 psf

1.2DL + 1.6LL = 1.2(30) + 1.6(100) = 196 psf

PCI 6TH EDITION LOAD TABLES
4HC8(+2) -78-S Δ = 1.1, 0.8
4HC10 -88-S Δ = 1.1, 1.4
4HC10(+2) -58-S Δ = 0.5, 0.3 ← GOVERNS
4HC12(+2) -68-S Δ = 0.7, 0.6

w = (196 psf)(27'/2) = 2646 lb/ft

L-BEAM (END SPANS)
LENGTH = 21'
20LB20 Δ = 0.6, 0.2

INVERTED T-BEAM (INTERIOR SPANS)
28IT20 Δ = 0.4, 0.1

GEN*NY*SIS CENTER FOR GENOMICS - PRECAST 1/

LOADS
SUPERIMPOSED DEAD LOAD = 30 psf
LIVE LOAD - CORRIDOR 100 psf
OFFICE/LAB 70 psf

ASSUMPTIONS
$f'c = 5000$ psi
$f_{pu} = 270000$ psi

FOR 27' SPAN, SERVICE LOAD = 100 psf
10'8" SPAN, SERVICE LOAD = 130 psf

PCI 6TH EDITION LOAD TABLES
4HC8 -68-S (NO TOPPING)
58-S (2" TOPPING)
4HC10 -~~58~~-S (NO TOPPING)
48-S (2" NW)
FS8 -78-S (2" NW)
} 27' SPAN (ALL COVER 10'8" SPAN)

1.2DL + 1.6LL = (1.2)(30 psf) + (1.6)(100 psf) = 196 psf
w = (196 psf)(27'/2) = 2646 k/ft = 2646 lb/ft

L-BEAM
20LB20 - 98S

**Strand Pattern Designation**
**48-S**

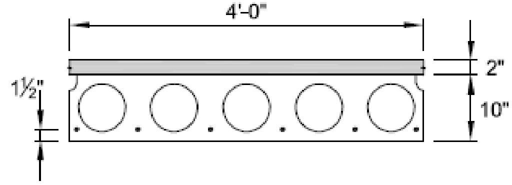
- S = straight
- Diameter of strand in 16ths
- No. of Strand (4)

*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.*

*Capacity of sections of other configurations are similar. For precise values, see local hollow-core manufacturer.*

Key
258 – Safe superimposed service load, psf
0.3 – Estimated camber at erection, in.
0.4 – Estimated long-time camber, in.

## HOLLOW-CORE
### 4'-0" x 10"
### Normal Weight Concrete




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

### Section Properties

| | Untopped | Topped |
|---|---|---|
| A = | 259 in.$^2$ | 355 in.$^2$ |
| I = | 3,223 in.$^4$ | 5,328 in.$^4$ |
| $y_b$ = | 5.00 in. | 6.34 in. |
| $y_t$ = | 5.00 in. | 5.66 in. |
| $S_b$ = | 645 in.$^3$ | 840 in.$^3$ |
| $S_t$ = | 645 in.$^3$ | 941 in.$^3$ |
| wt = | 270 plf | 370 plf |
| DL = | 68 psf | 93 psf |
| V/S = | 2.23 in. | |

**4HC10 + 2**

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

| Strand Designation Code | Span, ft | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 |
| 48-S | 308 | 287 | 256 | 228 | 204 | 183 | 165 | 148 | 133 | 119 | 107 | 96 | 86 | 74 | 63 | 52 | 43 | 34 | 26 | | | | | | | | |
| | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | –0.1 | –0.2 | –0.3 | –0.4 | | | | | | | | |
| | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | –0.1 | –0.2 | –0.3 | –0.4 | –0.6 | –0.8 | –1.0 | –1.2 | –1.4 | –1.7 | | | | | | | | |
| 58-S | 317 | 298 | 282 | 267 | 252 | 237 | 219 | 198 | 180 | 163 | 148 | 134 | 120 | 105 | 92 | 80 | 69 | 59 | 50 | 41 | 33 | 26 | | | | | |
| | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 | 0.0 | –0.1 | –0.3 | –0.4 | | | | | |
| | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 | 0.2 | 0.1 | 0.0 | –0.1 | –0.2 | –0.4 | –0.5 | –0.7 | –0.9 | –1.2 | –1.5 | –1.8 | –2.1 | | | | | |
| 68-S | 326 | 307 | 291 | 273 | 258 | 246 | 234 | 222 | 12 | 202 | 188 | 171 | 153 | 137 | 122 | 108 | 96 | 84 | 74 | 64 | 55 | 46 | 38 | 31 | | | |
| | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | .7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | –0.1 | –0.2 | | | |
| | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | .5 | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.0 | –0.1 | –0.3 | –0.5 | –0.7 | –0.9 | –1.2 | –1.5 | –1.8 | –2.2 | | | |
| 78-S | 335 | 313 | 297 | 279 | 267 | 252 | 240 | [illegible] | 218 | 208 | 196 | 189 | 181 | 165 | 150 | 135 | 122 | 109 | 97 | 86 | 76 | 67 | 58 | 50 | 42 | 35 | 28 |
| | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.1 | 0.0 | –0.2 |
| | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.5 | 0.4 | 0.3 | 0.2 | 0.0 | –0.2 | –0.4 | –0.6 | –0.9 | –1.2 | –1.6 | –1.9 | –2.3 | –2.8 |
| 88-S | 344 | 322 | 306 | 288 | 273 | 258 | 246 | 234 | 221 | 211 | 202 | 195 | 184 | 178 | 172 | 158 | 144 | 130 | 118 | 107 | 96 | 87 | 77 | 68 | 60 | 52 | 44 |
| | 0.7 | 0.8 | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 | 0.9 | 0.8 | 0.7 | 0.5 | 0.3 |
| | 0.8 | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.8 | 0.7 | 0.6 | 0.4 | 0.3 | 0.1 | –0.1 | –0.3 | –0.6 | –0.9 | –1.3 | –1.6 | –2.0 |

*Strength is based on strain compatibility; bottom tension is limited to $7.5\sqrt{f'_c}$ ; see pages 2–7 through 2–10 for explanation.*

GEN*NY*SIS CENTER FOR GENOMICS – STEEL JOIST 1/1

SUPERIMPOSED DEAD LOAD = 30 psf
LIVE LOAD = 100 psf (CORRIDOR)
= 70 psf (LAB/OFFICE)
SLAB WEIGHT (2.5") = 32 psf

VULCRAFT STEEL JOIST AND GIRDER CATALOG

TOTAL UNIFORM LOAD = 30 + 100 + 32 = 162 psf × $\frac{21\text{" o.c.}}{12}$
= 284 plf

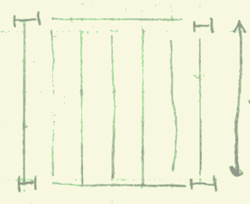
27' SPAN

14K6 w = 7.7 plf
16K5 w = 7.5 plf ← GOVERNS BASED ON WEIGHT AND DEPTH
18K4 w = 7.2 plf
20K4 w = 7.6 plf

10'8" SPAN

8K1 w = 5.1 lbs/ft

27' SPAN

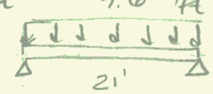



$DL = 30\text{ psf} + 32\text{ psf} + \frac{7.5\text{ plf}}{16/12} = 67.6\text{ psf}$

$LL = 100\text{ psf}\left(0.25 + \frac{15}{\sqrt{(2')(27')(4)}}\right) = 100\text{ psf}$

$1.2DL + 1.6LL = 242\text{ psf}$

$(242\text{ psf})(27\text{ ft})\left(\frac{21}{12}'\right) = \frac{11.4^k}{2} = 5.7^k/_{21/12} = 3.6^{k}/\text{ft}$




$M_u = \frac{(3.6\text{ k/ft})(21')^2}{8} = 198\text{ kip-ft}$

TABLE 3-6 LRFD
USE
W12×96 $\phi M_n = 210$
W14×82 $\phi M_n = 199$
W16×77 $\phi M_n = 214$
W18×71 $\phi M_n = 209$
W21×62 $\phi M_n = 206$ ← MOST ECONOMICAL, $I = 1330\text{ in}^4$
W24×62 $\phi M_n = 219$

$\Delta_{TOTAL\ LOAD} = \frac{5(0.242\text{ ksf})(21\text{ ft})^4(1728)}{384(29000)(1330)} = 0.027" < \frac{\ell}{240} = 1.05"$ ✓

$\Delta_{LIVE\ LOAD} = \frac{5(0.160\text{ ksf})(21\text{ ft})^4(1728)}{384(29000)(1330)} = 0.018" < \frac{\ell}{360} = 0.7"$ ✓

| JOIST DESIGNATION | 8K1 | 10K1 | 12K1 | 12K3 | 12K5 | 14K1 | 14K3 | 14K4 | 14K6 | 16K2 | 16K3 | 16K4 | 16K5 | 16K6 | 16K7 | 16K9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (IN.) | 8 | 10 | 12 | 12 | 12 | 14 | 14 | 14 | 14 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| APPROX. WT. (lbs./ft.) | 5.1 | 5.0 | 5.0 | 5.7 | 7.1 | 5.2 | 6.0 | 6.7 | 7.7 | 5.5 | 6.3 | 7.0 | 7.5 | 8.1 | 8.6 | 10.0 |
| SPAN (ft.) ↓ | | | | | | | | | | | | | | | | |
| 8 | 550 | | | | | | | | | | | | | | | |
| | 550 | | | | | | | | | | | | | | | |
| 9 | 550 | | | | | | | | | | | | | | | |
| | 550 | | | | | | | | | | | | | | | |
| 10 | 550 | 550 | | | | | | | | | | | | | | |
| | 480 | 550 | | | | | | | | | | | | | | |
| 11 | 532 | 550 | | | | | | | | | | | | | | |
| | 377 | 542 | | | | | | | | | | | | | | |
| 12 | 444 | 550 | 550 | 550 | 550 | | | | | | | | | | | |
| | 288 | 455 | 550 | 550 | 550 | | | | | | | | | | | |
| 13 | 377 | 479 | 550 | 550 | 550 | | | | | | | | | | | |
| | 225 | 363 | 510 | 510 | 510 | | | | | | | | | | | |
| 14 | 324 | 412 | 500 | 550 | 550 | 550 | 550 | 550 | 550 | | | | | | | |
| | 179 | 289 | 425 | 463 | 463 | 550 | 550 | 550 | 550 | | | | | | | |
| 15 | 281 | 358 | 434 | 543 | 550 | 511 | 550 | 550 | 550 | | | | | | | |
| | 145 | 234 | 344 | 428 | 434 | 475 | 507 | 507 | 507 | | | | | | | |
| 16 | 246 | 313 | 380 | 476 | 550 | 448 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 |
| | 119 | 192 | 282 | 351 | 396 | 390 | 467 | 467 | 467 | 550 | 550 | 550 | 550 | 550 | 550 | 550 |
| 17 | | 277 | 336 | 420 | 550 | 395 | 495 | 550 | 550 | 512 | 550 | 550 | 550 | 550 | 550 | 550 |
| | | 159 | 234 | 291 | 366 | 324 | 404 | 443 | 443 | 488 | 526 | 526 | 526 | 526 | 526 | 526 |
| 18 | | 246 | 299 | 374 | 507 | 352 | 441 | 530 | 550 | 456 | 508 | 550 | 550 | 550 | 550 | 550 |
| | | 134 | 197 | 245 | 317 | 272 | 339 | 397 | 408 | 409 | 456 | 490 | 490 | 490 | 490 | 490 |
| 19 | | 221 | 268 | 335 | 454 | 315 | 395 | 475 | 550 | 408 | 455 | 547 | 550 | 550 | 550 | 550 |
| | | 113 | 167 | 207 | 269 | 230 | 287 | 336 | 383 | 347 | 386 | 452 | 455 | 455 | 455 | 455 |
| 20 | | 199 | 241 | 302 | 409 | 284 | 356 | 428 | 525 | 368 | 410 | 493 | 550 | 550 | 550 | 550 |
| | | 97 | 142 | 177 | 230 | 197 | 246 | 287 | 347 | 297 | 330 | 386 | 426 | 426 | 426 | 426 |
| 21 | | | 218 | 273 | 370 | 257 | 322 | 388 | 475 | 333 | 371 | 447 | 503 | 548 | 550 | 550 |
| | | | 123 | 153 | 198 | 170 | 212 | 248 | 299 | 255 | 285 | 333 | 373 | 405 | 406 | 406 |
| 22 | | | 199 | 249 | 337 | 234 | 293 | 353 | 432 | 303 | 337 | 406 | 458 | 498 | 550 | 550 |
| | | | 106 | 132 | 172 | 147 | 184 | 215 | 259 | 222 | 247 | 289 | 323 | 351 | 385 | 385 |
| 23 | | | 181 | 227 | 308 | 214 | 268 | 322 | 395 | 277 | 308 | 371 | 418 | 455 | 507 | 550 |
| | | | 93 | 116 | 150 | 128 | 160 | 188 | 226 | 194 | 216 | 252 | 282 | 307 | 339 | 363 |
| 24 | | | 166 | 208 | 282 | 196 | 245 | 295 | 362 | 254 | 283 | 340 | 384 | 418 | 465 | 550 |
| | | | 81 | 101 | 132 | 113 | 141 | 165 | 199 | 170 | 189 | 221 | 248 | 269 | 298 | 346 |
| 25 | | | | | | 180 | 226 | 272 | 334 | 234 | 260 | 313 | 353 | 384 | 428 | 514 |
| | | | | | | 100 | 124 | 145 | 175 | 150 | 167 | 195 | 219 | 238 | 263 | 311 |
| 26 | | | | | | 166 | 209 | 251 | 308 | 216 | 240 | 289 | 326 | 355 | 395 | 474 |
| | | | | | | 88 | 110 | 129 | [illegible] | 133 | 148 | 173 | [illegible] | 211 | 233 | 276 |
| 27 | | | | | | 154 | 193 | 233 | 285 | 200 | 223 | 268 | 302 | 329 | 366 | 439 |
| | | | | | | 79 | 98 | 115 | 139 | 119 | 132 | 155 | 173 | 188 | 208 | 246 |
| 28 | | | | | | 143 | 180 | 216 | [illegible] | 186 | 207 | 249 | [illegible] | 306 | 340 | 408 |
| | | | | | | 70 | 88 | 103 | 124 | 106 | 118 | 138 | 155 | 168 | 186 | 220 |
| 29 | | | | | | | | | | 173 | 193 | 232 | 261 | 285 | 317 | 380 |
| | | | | | | | | | | 95 | 106 | 124 | 139 | 151 | 167 | 198 |
| 30 | | | | | | | | | | 161 | 180 | 216 | 244 | 266 | 296 | 355 |
| | | | | | | | | | | 86 | 96 | 112 | 126 | 137 | 151 | 178 |
| 31 | | | | | | | | | | 151 | 168 | 203 | 228 | 249 | 277 | 332 |
| | | | | | | | | | | 78 | 87 | 101 | 114 | 124 | 137 | 161 |
| 32 | | | | | | | | | | 142 | 158 | 190 | 214 | 233 | 259 | 311 |
| | | | | | | | | | | 71 | 79 | 92 | 103 | 112 | 124 | 147 |

| JOIST DESIGNATION | 18K3 | 18K4 | 18K5 | 18K6 | 18K7 | 18K9 | 18K10 | 20K3 | 20K4 | 20K5 | 20K6 | 20K7 | 20K9 | 20K10 | 22K4 | 22K5 | 22K6 | 22K7 | 22K9 | 22K10 | 22K11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (IN.) | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 22 | 22 | 22 | 22 | 22 | 22 | 22 |
| APPROX. WT. (lbs./ft.) | 6.6 | 7.2 | 7.7 | 8.5 | 9.0 | 10.2 | 11.7 | 6.7 | 7.6 | 8.2 | 8.9 | 9.3 | 10.8 | 12.2 | 8.0 | 8.8 | 9.2 | 9.7 | 11.3 | 12.6 | 13.8 |
| SPAN (ft.) | | | | | | | | | | | | | | | | | | | | | |
| 18 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | | | | | | | | | | | | | | |
| | 550 | 550 | 550 | 550 | 550 | 550 | 550 | | | | | | | | | | | | | | |
| 19 | 514 | 550 | 550 | 550 | 550 | 550 | 550 | | | | | | | | | | | | | | |
| | 494 | 523 | 523 | 523 | 523 | 523 | 523 | | | | | | | | | | | | | | |
| 20 | 463 | 550 | 550 | 550 | 550 | 550 | 550 | 517 | 550 | 550 | 550 | 550 | 550 | 550 | | | | | | | |
| | 423 | 490 | 490 | 490 | 490 | 490 | 490 | 517 | 550 | 550 | 550 | 550 | 550 | 550 | | | | | | | |
| 21 | 420 | 506 | 550 | 550 | 550 | 550 | 550 | 468 | 550 | 550 | 550 | 550 | 550 | 550 | | | | | | | |
| | 384 | 426 | 460 | 460 | 460 | 460 | 460 | 453 | 520 | 520 | 520 | 520 | 520 | 520 | | | | | | | |
| 22 | 382 | 460 | 518 | 550 | 550 | 550 | 550 | 426 | 514 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 | 550 |
| | 316 | 370 | 414 | 438 | 438 | 438 | 438 | 393 | 461 | 490 | 490 | 490 | 490 | 490 | 548 | 548 | 548 | 548 | 548 | 548 | 548 |
| 23 | 349 | 420 | 473 | 516 | 550 | 550 | 550 | 389 | 469 | 529 | 550 | 550 | 550 | 550 | 518 | 550 | 550 | 550 | 550 | 550 | 550 |
| | 276 | 323 | 362 | 393 | 418 | 418 | 418 | 344 | 402 | 451 | 468 | 468 | 468 | 468 | 491 | 518 | 518 | 518 | 518 | 518 | 518 |
| 24 | 320 | 385 | 434 | 473 | 528 | 550 | 550 | 357 | 430 | 485 | 528 | 550 | 550 | 550 | 475 | 536 | 550 | 550 | 550 | 550 | 550 |
| | 242 | 284 | 318 | 345 | 382 | 396 | 396 | 302 | 353 | 396 | 410 | 448 | 448 | 448 | 431 | 483 | 495 | 495 | 495 | 495 | 495 |
| 25 | 294 | 355 | 400 | 435 | 485 | 550 | 550 | 329 | 396 | 446 | 496 | 541 | 550 | 550 | 438 | 493 | 537 | 550 | 550 | 550 | 550 |
| | 214 | 250 | 281 | 305 | 337 | 337 | 337 | 268 | 312 | 350 | 380 | 421 | 426 | 426 | 381 | 427 | 464 | 474 | 474 | 474 | 474 |
| 26 | 272 | 328 | 369 | 402 | 448 | 538 | 550 | 304 | 366 | 412 | 449 | 500 | 550 | 550 | 404 | 455 | 496 | 550 | 550 | 550 | 550 |
| | 190 | [illegible] | 249 | 271 | 299 | 354 | 381 | 236 | [illegible] | 310 | 337 | 373 | 405 | 405 | 338 | 379 | 411 | 454 | 454 | 454 | 454 |
| 27 | 252 | 303 | 342 | 372 | 415 | 498 | 550 | 281 | 339 | 382 | 416 | 463 | 550 | 550 | 374 | 422 | 459 | 512 | 550 | 550 | 550 |
| | 169 | [illegible] | 222 | 241 | 267 | 315 | 347 | 211 | [illegible] | 277 | 301 | 333 | 389 | 389 | 301 | 337 | 367 | 406 | 432 | 432 | 432 |
| 28 | 234 | 282 | 318 | 346 | 385 | 463 | 548 | 261 | 315 | 355 | 386 | 430 | 517 | 550 | 348 | 392 | 427 | 475 | 550 | 550 | 550 |
| | 151 | 177 | 199 | 216 | 239 | 282 | 331 | 189 | 221 | 248 | 269 | 298 | 353 | 375 | 270 | 302 | 328 | 364 | 413 | 413 | 413 |
| 29 | 218 | 263 | 298 | 322 | 359 | 431 | 511 | 243 | 293 | 330 | 360 | 401 | 482 | 550 | 324 | 365 | 398 | 443 | 532 | 550 | 550 |
| | 136 | 159 | 179 | 194 | 215 | 254 | 298 | 170 | 199 | 223 | 242 | 268 | 317 | 359 | 242 | 272 | 295 | 327 | 387 | 399 | 399 |
| 30 | 203 | 245 | 276 | 301 | 335 | 402 | 477 | 227 | 274 | 308 | 336 | 374 | 450 | 533 | 302 | 341 | 371 | 413 | 497 | 550 | 550 |
| | 123 | 144 | 161 | 175 | 194 | 229 | 269 | 153 | 179 | 201 | 218 | 242 | 286 | 338 | 219 | 245 | 268 | 295 | 349 | 385 | 385 |
| 31 | 190 | 229 | 258 | 281 | 313 | 376 | 446 | 212 | 256 | 289 | 314 | 350 | 421 | 499 | 283 | 319 | 347 | 387 | 465 | 550 | 550 |
| | 111 | 130 | 146 | 158 | 175 | 207 | 243 | 138 | 162 | 182 | 198 | 219 | 259 | 304 | 198 | 222 | 241 | 267 | 316 | 369 | 369 |
| 32 | 178 | 215 | 242 | 264 | 294 | 353 | 418 | 199 | 240 | 271 | 295 | 328 | 395 | 468 | 265 | 299 | 326 | 363 | 436 | 517 | 549 |
| | 101 | 118 | 132 | 144 | 159 | 188 | 221 | 126 | 147 | 165 | 179 | 199 | 235 | 276 | 180 | 201 | 219 | 242 | 287 | 337 | 355 |
| 33 | 168 | 202 | 228 | 248 | 276 | 332 | 393 | 187 | 226 | 254 | 277 | 309 | 371 | 440 | 249 | 281 | 306 | 341 | 410 | 486 | 532 |
| | 92 | 108 | 121 | 131 | 145 | 171 | 201 | 114 | 134 | 150 | 163 | 181 | 214 | 251 | 164 | 183 | 199 | 221 | 261 | 307 | 334 |
| 34 | 158 | 190 | 214 | 233 | 260 | 312 | 370 | 176 | 212 | 239 | 261 | 290 | 349 | 414 | 235 | 265 | 288 | 321 | 386 | 458 | 516 |
| | 84 | 98 | 110 | 120 | 132 | 156 | 184 | 105 | 122 | 137 | 149 | 165 | 195 | 229 | 149 | 167 | 182 | 202 | 239 | 280 | 314 |
| 35 | 149 | 179 | 202 | 220 | 245 | 294 | 349 | 166 | 200 | 226 | 246 | 274 | 329 | 390 | 221 | 249 | 272 | 303 | 364 | 432 | 494 |
| | 77 | 90 | 101 | 110 | 121 | 143 | 168 | 96 | 112 | 126 | 137 | 151 | 179 | 210 | 137 | 153 | 167 | 185 | 219 | 257 | 292 |
| 36 | 141 | 169 | 191 | 208 | 232 | 278 | 330 | 157 | 189 | 213 | 232 | 259 | 311 | 369 | 209 | 236 | 257 | 286 | 344 | 408 | 467 |
| | 70 | 82 | 92 | 101 | 111 | 132 | 154 | 88 | 103 | 115 | 125 | 139 | 164 | 193 | 126 | 141 | 153 | 169 | 201 | 236 | 269 |
| 37 | | | | | | | | 148 | 179 | 202 | 220 | 245 | 294 | 349 | 198 | 223 | 243 | 271 | 325 | 386 | 442 |
| | | | | | | | | 81 | 95 | 106 | 115 | 128 | 151 | 178 | 116 | 130 | 141 | 156 | 185 | 217 | 247 |
| 38 | | | | | | | | 141 | 170 | 191 | 208 | 232 | 279 | 331 | 187 | 211 | 230 | 256 | 306 | 366 | 419 |
| | | | | | | | | 74 | 87 | 98 | 106 | 118 | 139 | 164 | 107 | 119 | 130 | 144 | 170 | 200 | 228 |
| 39 | | | | | | | | 133 | 161 | 181 | 198 | 220 | 265 | 314 | 178 | 200 | 218 | 243 | 292 | 347 | 397 |
| | | | | | | | | 69 | 81 | 90 | 98 | 109 | 129 | 151 | 98 | 110 | 120 | 133 | 157 | 185 | 211 |
| 40 | | | | | | | | 127 | 153 | 172 | 188 | 209 | 251 | 298 | 169 | 190 | 207 | 231 | 278 | 330 | 377 |
| | | | | | | | | 64 | 75 | 84 | 91 | 101 | 119 | 140 | 91 | 102 | 111 | 123 | 146 | 171 | 195 |
| 41 | | | | | | | | | | | | | | | 181 | 181 | 197 | 220 | 264 | 314 | 359 |
| | | | | | | | | | | | | | | | 85 | 95 | 103 | 114 | 135 | 159 | 181 |
| 42 | | | | | | | | | | | | | | | 153 | 173 | 188 | 209 | 252 | 299 | 342 |
| | | | | | | | | | | | | | | | 79 | 83 | 96 | 106 | 126 | 148 | 168 |
| 43 | | | | | | | | | | | | | | | 146 | 165 | 179 | 200 | 240 | 285 | 326 |
| | | | | | | | | | | | | | | | 73 | 82 | 89 | 99 | 117 | 138 | 157 |
| 44 | | | | | | | | | | | | | | | 139 | 157 | 171 | 191 | 229 | 272 | 311 |
| | | | | | | | | | | | | | | | 68 | 76 | 83 | 92 | 109 | 128 | 146 |