# THE SIGNAL HILL PROFESSIONAL CENTER

## IMPLEMENTING A CONCRETE STRUCTURAL SYSTEM

Joseph Henry
Senior Thesis, Structural Emphasis
Dr. Hanagan, Advisor
Department of Architectural Engineering
The Pennsylvania State University
Spring 2006

# Signal Hill Professional Center

MANASSAS, VIRGINIA

http://www.arche.psu.edu/thesis/eportfolio/current/portfolios/hjh139

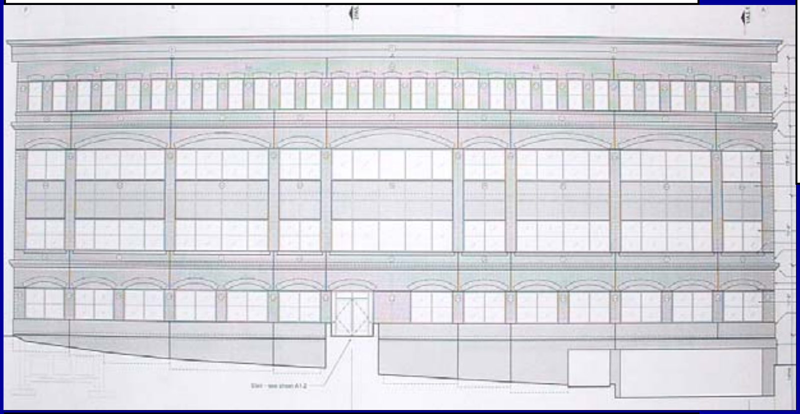
Joseph Henry, Structural Option

## A TRADITIONAL SUBURBAN OFFICE BUILDING.

45,000 square feet for office condos and a bank with four floors above grade and one floor of underground parking close to the Manassas Town Center to be completed in 2006

## PROJECT TEAM.

| | |
|---|---|
| **OWNER** | Mid-Atlantic Real Estate Investments |
| **GC** | R.W. Murray Co. |
| **ARCHITECT** | The M Group Architects |
| **STRUCTURAL** | Morabito Consultants |
| **MEP** | K.T.A. Group Inc. |
| **CIVIL** | Bowman Consulting |



## MECHANICAL FEATURES.

**HVAC**—Two rooftop units each with 75-ton chillers, and 43-ton heating coils, with ductwork and VAV unit locations flexible per tenant requests

**PARKING AREA**—277V 3-phase wires placed in ground surface used as ice-melting system

**PLUMBING**—Three stacks throughout building designed for future tenant expansion

## ARCHITECTURAL FEATURES.

**SITE**—Underground parking roof sloped to match site topography and to support fire engine loads

**ENVELOPE**—Traditional Virginian brick detail on exterior achieved through slender wall pre-cast concrete panel system, allowing 25% less themal transfer than traditional walls

## STRUCTURAL FEATURES.

**OFFICE BUILDING**—Composite steel frame with 3.5” lightweight concrete slab

**PARKING STRUCTURE**—Traditional steel framing with W10 infill beams angled to match the topography of the site; 4.5” normal weight concrete slab with 4” topping

**CONNECTIONS**—Unique system of coped beams, varied connection heights, and W6 hangers to allow the driveway surface to connect to the building at varying elevations


## ELECTRICAL/LIGHTING FEATURES

**POWER**—Three panelboards for floor for 480/277V and 208/120V loads, with much room for expansion

**LIGHTING**—System of 277V HID, fluorescent, and compact fluorescent lights throughout the parking area, surrounding grass area, common areas, and basic office lighting.

## TABLE OF CONTENTS

## TABLE OF CONTENTS, CONTINUED

## EXECUTIVE SUMMARY

The Signal Hill Professional Center is a suburban office building that houses over 68,000 square feet of open office space on four above ground levels in Manassas, Virginia. To increase the number of parking spaces, it takes advantage of its sloping site by excavating into the hillside to accommodate an underground parking area. To maximize this area to nearly 21,300 square feet, this underground space extends beyond the footprint of the building to nearly the limits of the site, and the supporting building structure slopes with the natural terrain.

As designed by Morabito Consultants of Baltimore, the current building structure employs a composite steel system in order to reduce floor section depth and building weight. This system generally uses W10 beams spanning 20'-0" to support a lightweight concrete slab on composite deck, while W21 and W24 girders spanning 30'-0" are sufficient in the office and parking structure, respectively. Due to smaller lateral loads in Northern Virginia, a system of moment frames which transfer shear forces to concrete shear walls in the basement are sufficient in preventing excessive drift.

Though an analysis of the original design revealed that composite steel was an efficient system for the given design conditions, the Signal Hill Professional Center is located outside Washington DC, where concrete design should be commonplace. In the District, strict height restrictions dictate that local structures normally use concrete flat plate systems to reduce floor-to-floor heights through smaller floor section depths. Though this particular building is not limited by height restrictions, and though a drop ceiling would negate any benefits from reduced floor section depth, perhaps the large presence of concrete contractors in the area may make a concrete design more economical.

Therefore, to investigate the possibility of using concrete instead of steel, a concrete system was designed for the Signal Hill Professional Center. This system was then evaluated for structural efficiency, architectural impact, constructability, and effectiveness at integrating green design considerations.

**Structural Efficiency.** While initially flexure and deflection controlled selection of a two-way concrete floor system, shear around columns from moment transfer came to control in most situations. Further, a new column layout was necessary to create square bays conducive to a two-way slab. The final design features:

- 8" concrete slab with 3.5" drops around all columns in Roof.
- 10" concrete slab with 3.5" and 4.5" drops around columns in Floors 2-4.
- 11" concrete slab with 3.5" and 7" drops around columns in the First Floor/Parking Deck.

Column sizes came to be controlled by shear rather than axial loads; larger column sizes led to larger shear perimeters and therefore larger shear resistance. Though a system of concrete moment frames was sufficient to resist drift, lateral loads increased these unbalanced moments around columns and intensified shear.

**Architectural Impact.** Since the new structural design relied upon a new column grid, this affected both the central corridor core layout and the positioning of precast panels on the east and west building façade. By re-evaluating the required areas in the

corridor core, three alternative floorplans were created which take advantage of the new column layout. These floorplans, as evaluated by the Building Owners and Managers Association industry standard, increased rentable areas, which could increase annual owner rental income by as much as $17,750.

Due to the flexible nature of precast panels in the building façade, the elevations can be rearranged to prevent concrete columns from interrupting windows. A further study of façade arrangement produced a variety of possible elevations, which would reinforce the traditional base-shaft-capital office building icon.

**Constructability.** Including larger footing sizes, an estimate using R.S. Means 2006 revealed that the concrete system would cost about $200,000 more than a composite steel system and would take almost three additional weeks to erect. Upon surveying both structural engineers and construction managers in the Washington DC area, it became readily apparent that steel may be the best solution because:

- Though regional adjustment factors for R.S. Means reveal that concrete is generally cheaper than steel, these factors do not offset the $200,000 cost discrepancy.
- The Portland Cement Association placed Washington DC on the cement “tight supply” list for 2005, which would inhibit the ability of concrete contractors to cut costs for lower bids.
- Wintry conditions during building construction meant that heaters, covers, and protective devices would be necessary for concrete construction, which would increase cost and erection time.

**Installation of a Green Roof.** Using standard roof garden assemblies from Roofscapes, a green roof company in Philadelphia, roof gardens ranging from lightweight systems featuring sedum plants to extensive systems featuring turf and trees were assessed for possible improvements to the building; results show that:

- Structurally, the lighter systems would not drastically increase supporting gravity systems in both steel and concrete. The heavier systems would increase the roof structure to sizes beyond those in the office floors; further, larger loads at the roof diaphragm would produce larger seismic loads. Therefore, lateral systems would need to increase, primarily in the steel system.
- Aesthetically, a roof garden would produce a livable outdoor space in a setting where busy roads and large box stores overshadow pedestrianism. This increased livability comes at the expense of a 10% increase in initial cost and roughly $1,000 per year to maintain.

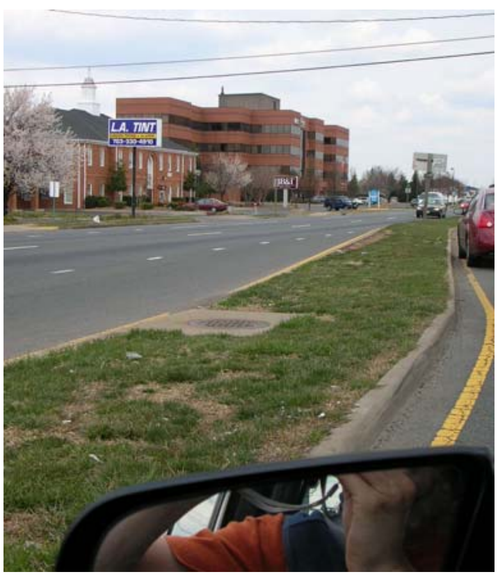
Per the recommendation of many professionals in the Washington area, the most efficient final design may be a hybrid structure, using concrete columns and slabs in the first floor, and composite steel in the office areas above. Benefits would include increased lateral resistance for the steel system, which would make a green roof possible, and a natural fire stop between the parking area and offices above. Given that steel was determined to be more economical for Manassas, these benefits would not come at the expense of dramatically increased cost or construction duration. To enjoy the benefits of the new column layout with a reduced number of columns, member sizes would increase accordingly within reason.

## INTRODUCTION AND BUILDING OVERVIEW

Located in the outskirts of Manassas, Virginia, the Signal Hill Professional Center houses over 68,000 square feet of open office space on four above ground levels. While the first floor houses a drive-through suitable for a bank, the upper floors feature flexible office areas.

Sited along Centreville Road in a commercial and light industrial district, the building compensates for its small sloping site by excavating into the hillside to accommodate an underground parking lot. To maximize parking area to nearly 21,300 square feet, this underground space extends beyond the footprint of the building to nearly the limits of the site, and the supporting building structure slopes with the natural terrain.

A brief tour of the greater Manassas area reveals a Northern Virginia icon: the suburban, low rise office building. While many nearby office buildings aim primarily for economy with limited design detail and anonymous parking areas, they have indeed become central to congested exurbs. Therefore, to improve the Signal Hill Professional Center structurally, aesthetically, economically, and environmentally, a new building design will borrow structural ideas in concrete from nearby Washington DC, explore the interplay of material supplies and local trades, play with spaces and compositions of both the floor plan and façade, and challenge the suburban office paradigm to include livable green spaces for the people working inside.




## CURRENT BUILDING DESIGN REVIEW

Structural System

**Gravity System.** The Signal Hill Professional Center employs a composite steel system, which was originally chosen to:

- Reduce floor section thickness and associated weight,
- Span longer distances to provide large open office areas,
- Increase constructability through reducing the number of laborers required and erection time

The column grid creates bays ranging in size from 17'-6"x25'-0" to 20'-0"x30'-0" with beams generally spanning in the short direction. See Figures 1A and 1B for sample layouts.

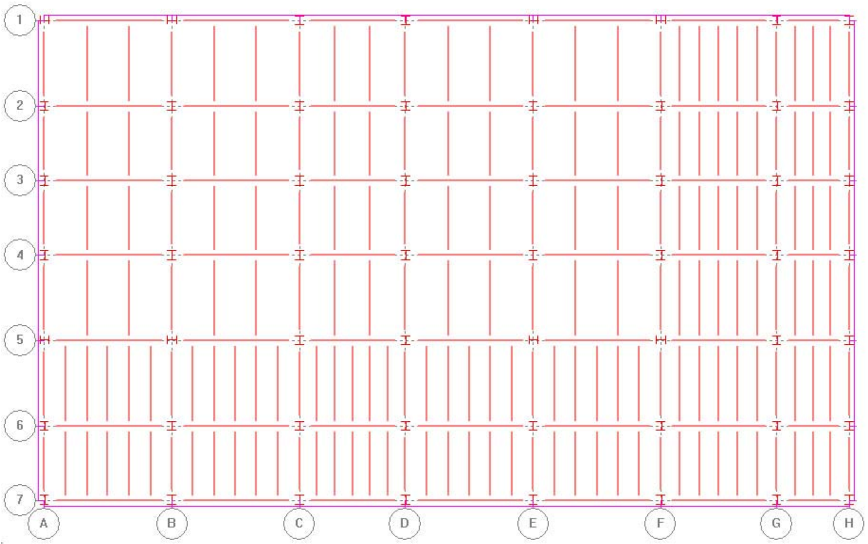



Figure 1A. Existing Composite Steel Layout, First Floor

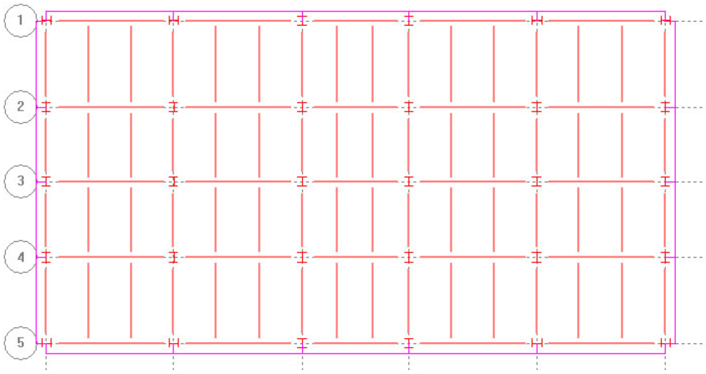



Figure 1B. Existing Composite Steel Layout, Floors 2-4

Though loads are standard for an open office building, they become more significant in the parking area:

- Roof Loads: 2.5 psf DL from 2" deck [USD catalog]
  7.5 psf DL from additional finishes and roof membrane [ASCE-07]
  30 psf Snow Load [IBC 2003, Northern Virginia]
- Office Areas: 100 psf LL [Open Office, ASCE-07]
  60 psf DL from 3" deck with additional 3.5" lightweight concrete slab [USD catalog]
  10 psf DL from additional finishes and MEP [ASCE-07]
- Parking Areas: 250 psf LL [Fire Engine loading]
  93 psf DL from 2" deck with additional 4.5" normal weight concrete slab and additional 4" asphalt topping [USD catalog, ASCE-07]
  30 psf Snow Load [IBC 2003, Northern Virginia]
- Precast Walls: 440 plf DL [2" precast concrete on light gage framing, ASCE-07]

As compared in a RAMSteel model, the structural sizes given in the existing design were more than adequate for the given loads:

- Roof Design: 2" non-composite deck and ballasted roof supported by W12x16 beams spaced 10'-0" OC, resting on W16x26 and W18x40 girders
- Office Areas: 3" composite deck and 3.5" lightweight concrete slab supported by W10x15 beams spaced 10'-0" OC, resting on W18x35 and W21x44 girders
- Parking Areas: 2" composite deck and 4" normal weight concrete slab supported by W10x15 and W10x19 beams spaced 5'-0" OC, supported by W24x55 and W 24x76 girders.

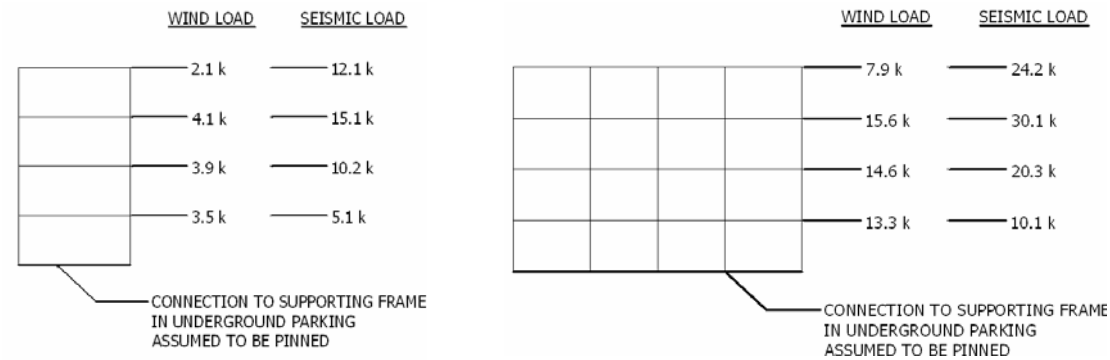
Columns under these loads range from W10x33 supporting the roof to W12x96 supporting all four office floors and parking structure.

Where the sloped parking area meets the office structure, beams and girders under the larger fire engine live loads frame into girders framing the office via a variety of connections, including:

- Beams in parking area coped at various levels to frame in at higher or lower elevations than the office areas. In certain locations, required W10 beams were upsized to W16 to establish suitable depth for large copes
- Where the elevation difference approached 33", a system of W6 hangers, welded into the first floor girder, would suspend beams in the parking area.

Additional infill beams throughout the office area frame superimposed loads from bank vaults, stairwell shaft walls, air handling units, and openings.

**Lateral System.** Since the structure only extends four floors above ground, and since Northern Virginia features less extreme wind and seismic loads, moment frames on the perimeter of the building were adequate. Lateral loads on each frame system are shown in Figure 2, and the moment frame layout is shown in Figure 3.




EW Moment Frame
NS Moment Frame

Figure 2. Lateral Loads to Each Moment Frame in Each Direction

Three key load combinations were considered for this analysis, per ASCE-07:

1. 1.2D + 1.6L
2. 1.2D + 0.5L + 1.6W
3. 1.2D + 0.5L + 1.0E

While the gravity analysis showed that the W21 beams and W12 columns in the frames were oversized, an analysis in STAAD revealed that these were larger to resist lateral moments. In order to reduce beam and column sizes in the basement area, the concrete retaining wall was used as a shear wall; lateral loads were transferred from the frame to the wall through concrete piers, poured integrally. By absorbing more shear at the lowest building level, this system reduced moments and therefore member sizes in the critical frames adjoining both the office and parking areas.

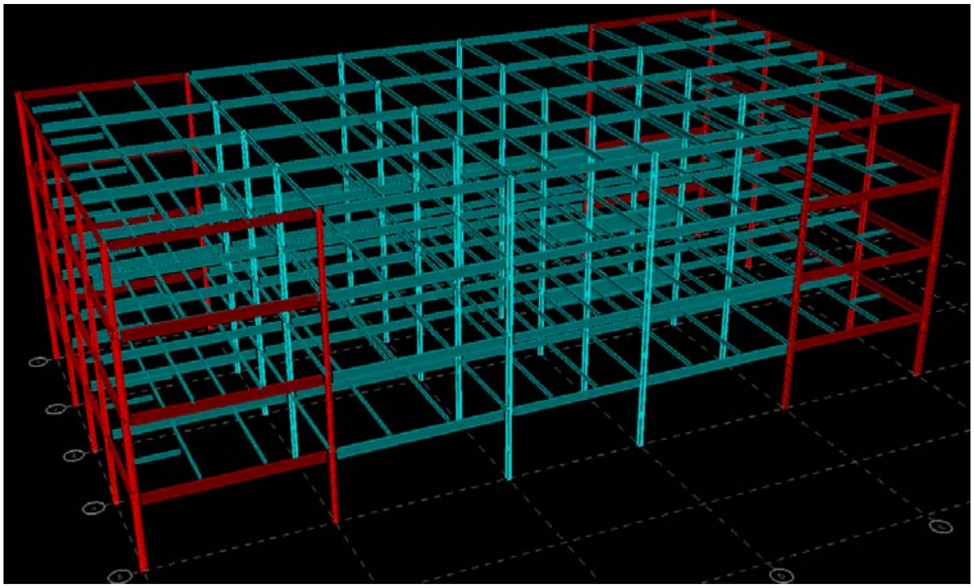


Figure 3. Moment Frame Layout: Gravity Structure in Blue, Moment Frames in Red

Building Architecture

**Floorplan.** Using the inner columns as a guide, the central core of the building features two elevators, two stairwells, restrooms, and telephone and electrical rooms. On the first floor, this layout changes to accommodate three entrances and an office area catering to a bank, with a separate vestibule entrance and a drive-through window.

**Façade.** Unlike many office buildings in the area, the Signal Hill Professional Center pays close attention to brick detail in archways around buildings and cornices between floors and at the roof. Though this brick detail is realistic, it is actually achieved through using the "Slender Wall" precast concrete exterior wall system produced by Smith-Midland of Midland, Virginia. This system employs galvanized steel studs attached to 2" thick precast concrete exterior panels, reinforced with welded wire fabric. With a ½" air space between concrete panel and steel stud, this system claims to reduce thermal transfer by up to 25% and help isolate the exterior concrete skin from lateral stresses and movement incurred in the building superstructure. These façade elements are then connected to the steel frame at the floor diaphragm.

Mechanical/HVAC

Two rooftop air handling units serve each side of the building. Each features a 44.1 horsepower fan capable of supplying 27000 cfm of recirculated air, 75 ton chillers, and 43 ton heating coils with four compressors. Ductwork servicing these rooftop units extend downward through the electrical rooms to floors 1 through 4. Though ductwork is pre-existing in the office spaces, tenants are merely advised as to where to place VAV distribution boxes.

Lighting and Electrical

Power enters the building from the west side via a 10-way concrete ductbank featuring 10 4" PVC pipes. The main feeder consists of seven sets of 4 500 KCMIL wires with two #2/0 ground wires capable of carrying 2500A at 480/277V. Upon entering the main distribution panelboard, the power is distributed to five 480/277V panelboards, one per floor. These panelboards service exterior HID lighting, floor heaters, VAV boxes, water heaters, corridor compact fluorescent lamps, and existing interior fluorescent lighting. Each floor also features a step down transfer to provide 208/120V power for two additional panelboards, intended for individual tenant use.

Plumbing

Water is brought into the building via 3" pipes which then serve four separate risers which become progressively smaller as they ascend the building. One riser is used for the bathrooms, while an additional two are capped for future tenant use.

<u>Fire Protection</u>

Office, bathroom, and parking areas are protected by an automatic sprinkler system to be installed by the contractor. Additionally, bays responsible for dividing the parking and office areas and bays primarily around corridors, the stairway, and elevator feature 2-hour fire rated slabs, 2-hour rated beam fireproofing, and 2-hour rated column fireproofing.

<u>Foundation System</u>

To support the given loads, columns and foundation walls rest on spread footings, formed from 3000 psi concrete, while the site features a 5000 psf bearing capacity.

## PROPOSAL AND SCOPE OF DESIGN

### Problem Statement

Though an analysis of the original design revealed that composite steel was an efficient system for the given design conditions, the Signal Hill Professional Center is located outside Washington DC, where concrete design should be commonplace. In the District, strict height restrictions dictate that local structures normally employ concrete flat plate systems to reduce floor-to-floor heights through smaller floor section depths.

Unlike office and residential structures downtown, this building uses a drop ceiling and ceiling mounted air handling equipment, which negates any benefits from using the underside of a concrete slab as a finished surface. However, it is possible that the availability of more concrete contractors in Northern Virginia with associated lower prices may make a steel system less economical. Combined with the benefits of a smaller section depth and a natural fire stop under the parking area, concrete indeed may be the better design.

### Design Approach

To redesign the Signal Hill Professional Center as a concrete building, initial hand calculations using ACI 318-05 will be used to direct design while ADOSS and ETABS will be used to confirm hand calculations and further evaluate the efficiency of the concrete frame as a lateral resisting system. The concrete design will include:

- Two-Way Slab, with additional considerations for superimposed loads and the connection between the parking deck and office first floor slab
- Concrete Moment Frames
- Columns
- Foundations

### Assumptions

Since this is a for-lease suburban office building, economy rather than architectural expression should direct design. Therefore, for the concrete structure, key assumptions include:

- **Floorplan Flexibility.** The only restrictions on floor layout are the parking spaces in the basement and the location of the bank vault on the first floor. If it would lead to greater structural efficiency, both the column layout and the central corridor core layout can be altered accordingly.
- **Façade Flexibility.** Since this building uses precast architectural panels, they can be easily adjusted and moved around to better align the structural system with the exterior windows and columns.
- **Constant Building Height.** The building was originally intended to house four floors of office space, and since height changes would be generally small and therefore less influential on lateral loads, it will be assumed that the floor-to-floor height will remain a constant 13’-4”.

Methods of Evaluation

When determining the feasibility of the concrete system for the Signal Hill Professional Center, the new concrete design will be evaluated according to:

- **Structural Efficiency.** For the gravity system, this includes floor section depth, building weight, deflections, overall complexity, and material usage. For the lateral system, this includes drift and overall complexity.
- **Architectural Usability (Breadth 1).** New column sizes and layouts will affect the location of service facilities in the corridor core area, as well as the layout of the exterior façade. New layouts will be evaluated considering profitability of the given space and overall appeal and flexibility.
- **Constructability (Breadth 2).** Through takeoffs and estimates, approximate costs for both the concrete and steel systems will be compared, taking into account local building practices, material availability, and opinions from construction managers in the Washington area. Duration of construction will also be a consideration.
- **Application to Green Architecture (Breadth 3).** Since recyclable or locally produced materials in structural design only play a small role in environmentally friendly construction, the structural, economical, and architectural implications of a much more significant green roof will be considered.

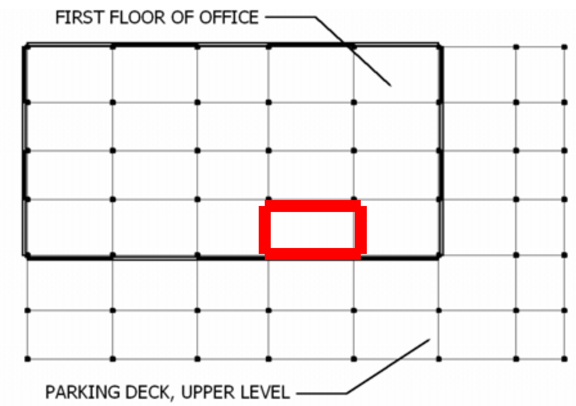
## DEPTH ANALYSIS: CONCRETE DESIGN

<u>Two-Way Floor Slab</u>

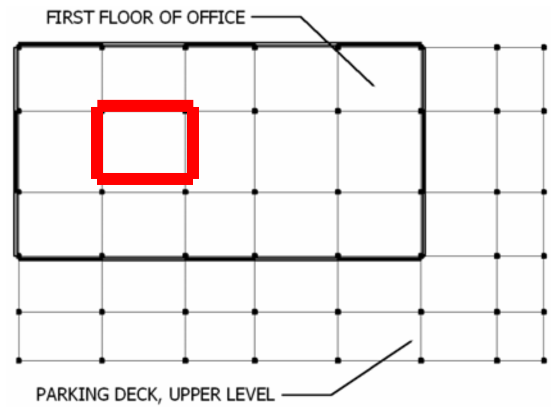
**Alternatives.** An initial estimate of differing floor systems using the CRSI Manual found that a two-way slab, though heavy, would effectively reduce floor section thickness, and provide for easiest construction. However, this estimate assumed a new column layout with square bays rather than the current 30'-0"x17'-6" size. In addition, to more effectively control the large live loads in both the office and parking areas, differing two-way slab systems were considered, including:

- Flat Plate
- Flat Plate with Edge Beams
- Flat Slab with Drops
- Flat Slab with Drops and Edge Beams
- Flat Slab with Beams between all Columns

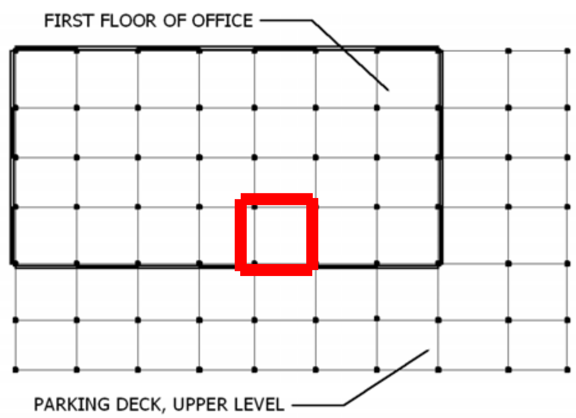
Four differing column layouts were considered, making sure to provide a column-free entry centered on the north and south building façade, as shown in Figure 4.



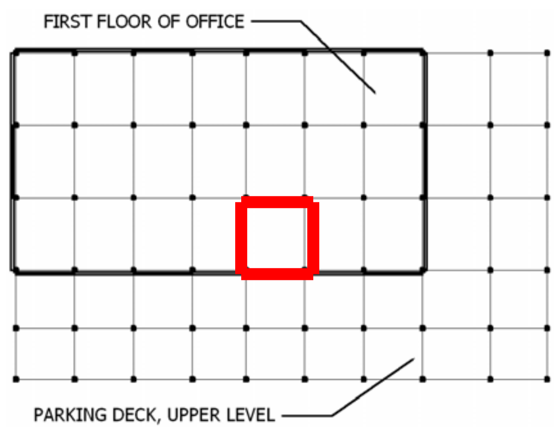

LAYOUT 1: Existing Column Layout
Maximum Bay Size: 20'-0"x30'-0"




LAYOUT 2: Adjusted in N-S Direction
Maximum Bay Size: 30'-0"x30'-0"




LAYOUT 3: Adjusted in E-W Direction
Maximum Bay Size: 20'-0"x21'-0"




LAYOUT 4: Adjusted in Both Directions
Maximum Bay Size: 25'-0"x21'-0"

Figure 4. Column Layout Overview

**Procedure.** Before using a more exact analysis, the **Direct Design Method** was used to find approximate values of positive and negative moments in the column and middle strips of the two way slabs. The Direct Design Method can be used throughout the entire structure because [ACI 318-05 13.6.1]:

- In each condition, there are at least three spans in all directions.
- The most drastic rectangular bay is 17'-6" x 30'-0", which has a $l_2/l_1$ = 1.72<2.0.
- The most drastic shift in span length between two adjacent spans is 5'-0", or 16%, less than one-third of the larger span.
- Columns are minimally offset from the basic building grid.
- Only in a few situations are separate concentrated or line loads presented (ie. Bank Vault, HVAC equipment). These panels will be assessed individually. Even in the parking structure, due to the large dead weight of concrete, live loads should not be greater than two times the dead load.

The minimum slab depths given by Table 13.5 of *Design of Concrete Structures* (436) are used to ensure satisfactory deflections.

Using results from the Direct Design Method, acceptable designs and layouts were then assessed in **ADOSS** at six different sections, as shown in Figure 5:

- On an interior column line in the East-West direction in the office.
- On an interior column line in the North-South direction in the office.
- On an interior column line in the East-West direction passing between the first floor of the office and the parking deck.
- On an interior column line in the East-West direction passing entirely through the parking deck.
- On an interior column line in the North-South direction passing between the first floor of the office and the parking deck.
- On an interior column line in the North-South direction passing entirely through the parking deck.

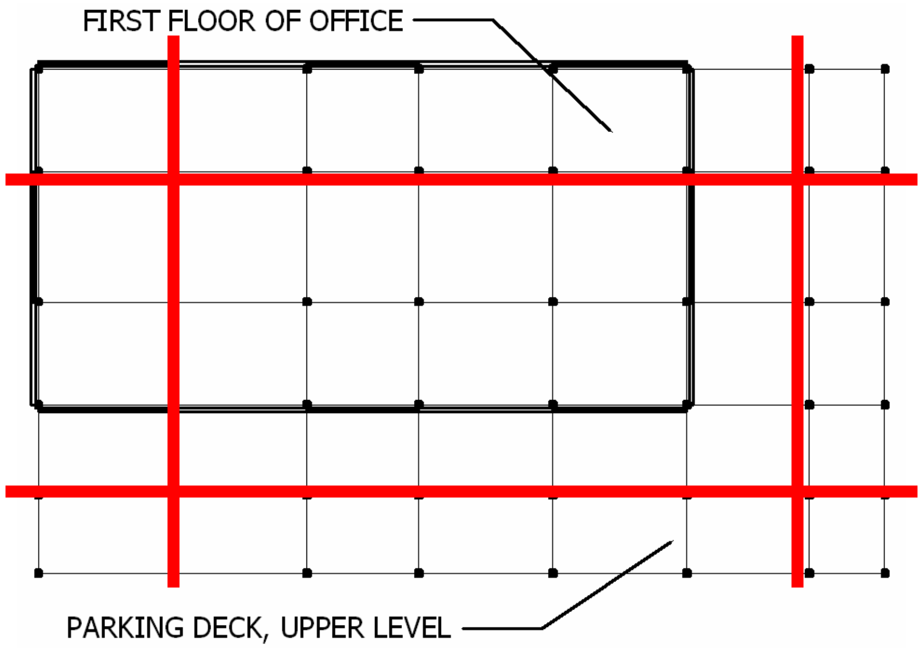



Figure 5. Frame Sections Analyzed by ADOSS in Red

**Findings, Direct Design Method.** Results are summarized in the Table 1. For comparison purposes, worst case reinforcement requirements at the interior support of the exterior span are presented.

| Slab Type, Bay Size | Design Estimate | Notes |
|---|---|---|
| Office Flat Plate, 30'-0" | 12" thick<br>#7@6", As=1.20 $in^2$<br>(worst case) | Largest slab moment (417 ft-k) at interior support, column strip, end span |
| Office Flat Slab with Drops, 30'-0" | 11" thick<br>3.5" thk 6'-8"x10'-0" drops<br>#6@6", As=0.88 $in^2$<br>(worst case) | Moment distribution largely unaffected, weight reduction |
| Office Flat Plate with 12'x20" edge beam, 30'-0" | 11" thick<br>#7@6", As=1.20 $in^2$<br>(worst case) | Interior moment in end span effectively reduced by 40 ft-k, interior spans generally unaffected |
| Office Flat Slab with 12"x20" beams between all columns, 30'-0" | 8" thick<br>#5@4", As=0.91 $in^2$<br>(worst case) | Moments in slabs drastically reduced (by over 350 ft-k at interior support, column strip, end span), steel larger from smaller slab |
| Parking Flat Plate, 30'-0" | 14" thick<br>#6@4", As=1.32 $in^2$<br>(worst case) | Largest slab moment (632 ft-k) at interior support, column strip, end span |
| Parking Flat Slab with Drops, 30'-0" | 14" thick<br>3.5" thick drops<br>#5@3", As=1.24 $in^2$<br>(worst case) | Similar moment distribution to flat plate, larger drops required |
| Parking Flat Slab Slab with 14"x24" beams between all columns, 30'-0" | 10" thick<br>(slab) #5@3", As=1.24 $in^2$<br>(beam) 4-#9, As=4.0 $in^2$<br>(worst case) | Slab moment effectively reduced to 345 ft-k at interior support, column strip, end span |
| Office Flat Plate, 25'-0" | 10" thick<br>#6@6", As=0.88 $in^2$<br>(worst case) | Largest slab moment (298 ft-k) significantly reduced from 30'-0" span condition |
| Office Flat Plate with 12"x20" edge beam, 25'-0" | 9.5" thick<br>#6@6", As=0.88 $in^2$<br>(worst case) | Moment distribution not largely affected |
| Office Flat Slab with 12"x20" beams between all columns, 25'-0" | 7" thick<br>(slab) #5@12", As=0.31 $in^2$<br>(beam) 4-#9, As=4.0 $in^2$<br>(worst case) | Drastically reduced moments throughout al slab sections |

Table 1. Summary of Estimates for Concrete Size and Required Steel Area

Initial estimates found that:

- When estimating sizes for the larger 30'-0" span, deflections came to control slab thickness; as the span reduced in length, thickness reduced significantly. However, this is using conservative deflection guidelines.
- The constructability of a flat plate system outweighs its larger thickness than with other systems; the 12" thick plate needed for the existing office area layout could be reduced to 10" if the maximum bay length were reduced to 25'-0". However, in the parking structure, a 14" slab combined with a 4" asphalt topping seems less effective.
- 12"x20" edge beams serve mostly the purpose of reducing positive midspan moment in the exterior bays, which does not significantly affect slab thickness at the more critical negative moment areas, but may affect deflection.
- 3.5" thick drop panels do not significantly affect moment distribution, but rather increase effective slab depths to reduce steel sizes.
- 12"x20" beams between all columns serve to reduce enhance flexural resistance and to reduce deflection, requiring slab thicknesses as small as 7". Though these beams will affect plenum space, they will be hidden by a drop ceiling in the office area, and are significantly smaller than existing girders in the parking structure.

**Findings, ADOSS Analysis.** Through changing values in ADOSS at each of the six sections, it was easy to adjust design parameters, concrete sizes, and ascertain whether each size is feasible. Three problems not completely considered in the Direct Design Method became immediately apparent:

- **Excessive Deflection.** While economizing slab depth, deflection came to control especially with larger 30'-0" spans, with two apparent solutions. A first solution would be edge beams, which are able to absorb negative moment at the exterior edge to reduce positive moment at midspan and therefore deflection. Another solution would be placing beams between all columns, which effectively absorb most midspan moment.
- **Flexure and Unbalanced Moments.** Since the smaller spans throughout the first floor of the office area in layouts 3 and 4 are more capable of absorbing unbalanced moments from the adjacent parking area, they experience deflection and flexure problems that can only be solved by a thicker slab.
- **Shear and Moment Transfer.** At the exterior edge of the floor slab, smaller column sizes provided for large shear from moment transfer through alternating load patterns. To combat this problem, larger columns in conjunction with drops were used despite relatively small compressive loads; larger column dimensions produced greater shear areas and torsional moments of inertia, reducing shear transfer. Therefore, column sizes increased to a minimum of 20" square, and since the transverse column direction affected shear transfer more than the parallel direction, rectangular columns up to 20"x30" were used.

Therefore, only two-way slab systems with edge beams and drop panels or beams between all columns were analyzed, with results summarized in the following table. As it became apparent that Layout 2 was most likely the best choice, further analysis produced varying column sizes. Results are summarized in the Table 2.

Reinforcement sizes are presented at the interior support of the exterior span, and serve as a comparison to direct design method findings. Under the first floor and parking deck, using drops instead of beams increased steel requirements within reason. Reinforcement layouts for a typical 30'-0"x30'-0" bay are shown in Figures 6 and 7.

| Slab Type, Layout | ADOSS Design Summary | Notes |
|---|---|---|
| Office Flat Slab<br>with 3.5" drops<br>with 15"x15" edge beam<br>Layout 1, 20'-0"x30'-0" bay | 9.5" slab, 15" columns<br>#7@7", As=1.02 $in^2$<br>(worst case) | Drops at edges should be thicker to combat shear moment transfer |
| Office Flat Slab<br>with 3.5" drops<br>with 20"x20" edge beam<br>Layout 2, 30'-0"x29" bay | 10" slab, varying columns<br>4.5" drops at ext columns<br>#7@8", As=0.92 $in^2$<br>(worst case) | Column and edge beam sizes increased to combat moment shear transfer; ext column sizes limited by exterior wall panel size and windows |
| Office Flat Slab<br>with 3.5" drops<br>with 15"x15" edge beam<br>Layout 3, 21'-0"x20'-0" bay | 7" slab, 15" columns<br>#5@7", As=0.53 $in^2$<br>(worst case) | |
| Office Flat Slab<br>With 3.5" drops<br>With 15"x15" edge beam<br>Layout 4, 21'-0"x25'-0" bay | 8" slab, 15" columns<br>#6@9", As=0.52 $in^2$<br>(worst case) | Drops at edges should be thicker to combat shear moment transfer |
| Parking Flat Slab<br>with beams between all columns<br>Layout 1, 20'-0"x30'-0" bay | (office) 8" slab, 15" columns, 15"x15" beams<br>#5@8", As=0.46 $in^2$<br>(parking) 10" slab, 18" columns, 18"x18" beams<br>#6@7", As=0.79 $in^2$<br>(worst case) | Edge beam used between office and parking areas, shear transfer a concern in north-south direction |
| Parking Flat Slab<br>with 3.5"/7" drops<br>with 20"x20" edge beam<br>Layout 2, 30'-0"x31'-0" bay | (office) 11" slab, varying columns, 20"x20" edge beam<br>#7@8", As=0.68 $in^2$<br>(parking) 11" slab, varying columns, 20"x20" edge beam<br>#9@12", As=0.96 $in^2$<br>(worst case) | Edge beam used between office and parking areas; increased drop depth at interior columns in parking area combats flexure without thicker slab |
| Parking Flat Slab<br>with beams between all columns<br>Layout 3, 21'-0"x20'-0" bay | (office) 7" slab, 15" columns, 15"x15" beams<br>#4@9", As=0.28 $in^2$<br>(parking) 9" slab, 18" columns, 18"x18" beams<br>#6@7", As=0.78 $in^2$<br>(worst case) | Shear moment transfer at columns a concern in east-west direction |
| Parking Flat Slab with beams between all columns Layout 4, 21'-0"x25'-0" bay | (office) 8"/9" slab, 15" columns, 15"x15" beams<br>#5@8", As=0.47 $in^2$<br>(parking) 10" slab, 18" columns, 18"x18" beams<br>#6@8", As=0.63 $in^2$<br>(worst case) | Thicker slab at office bay adjoining parking structure to combat flexure from unbalanced moment transfer, shear transfer a concern in north-south direction |

Table 2. Summary of Results for Concrete Size and Required Steel Area

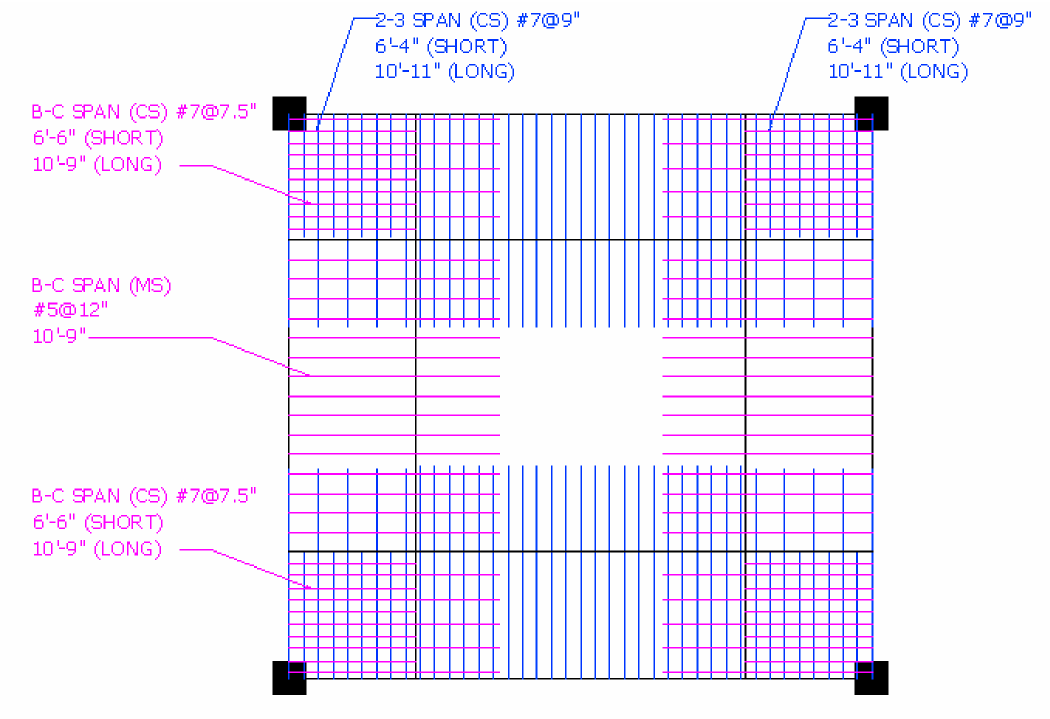



Figure 6A. Negative Reinforcement Layouts in Bay bounded by Column Lines B and C, 2 and 3

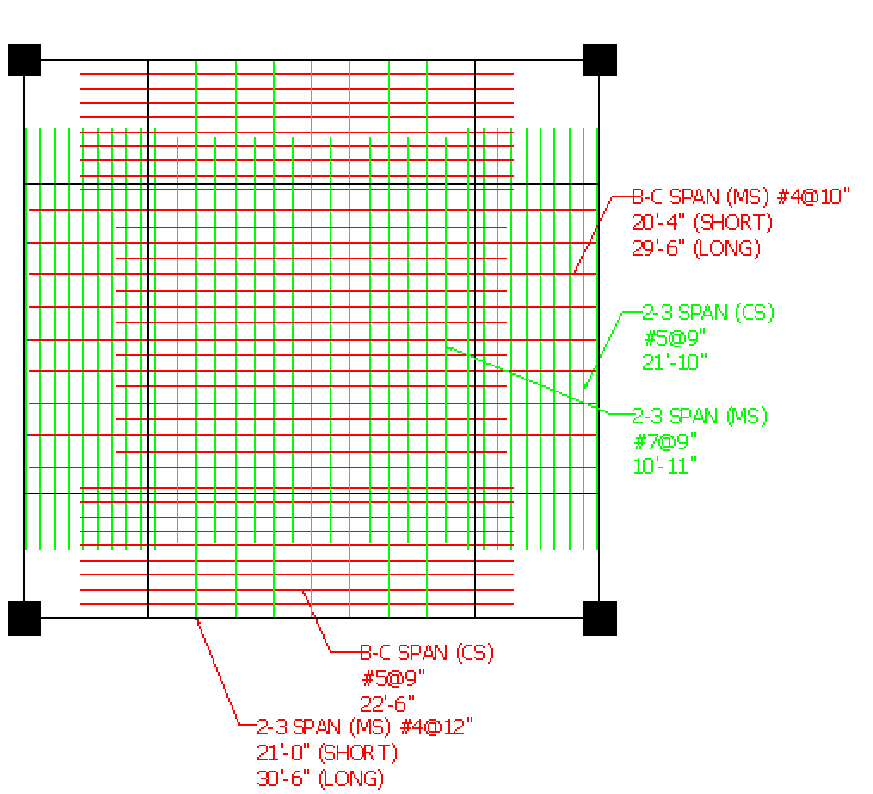



Figure 6B. Positive Reinforcement Layouts in Bay bounded by Column Lines B and C, 2 and 3

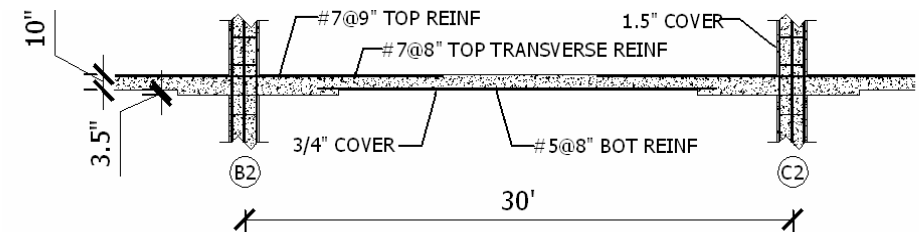



Figure 7. Sample Slab/Drop/Column Section along Column Line 2

**Superimposed Dead Loads.** When the 55,000-lb bank vault and two 10,230-lb air handling units on the roof were added to the ADOSS input for this design, the concrete slab design proved to be more forgiving to load irregularities than the steel system, as reinforcement areas changed to accommodate irregularities rather than the entire floor thickness. For example, when the bank vault load was applied, required steel areas in the column strip increased from 4.6 $in^2$ to 7.5 $in^2$ at midspan and from 9.24 $in^2$ to 12 $in^2$ and from 12 $in^2$ to 13.43 $in^2$ at each support, respectively. This added load served to only slightly increase moments and therefore required steel areas at supports in adjacent spans, while midspan steel areas reduced from 5.58 $in^2$ to 4.96 $in^2$ and from 7.92 $in^2$ to 7.48 $in^2$ in adjacent office and parking spans, respectively. From the perspective of moment transfer, larger 7" drops at columns adjacent to the vault would be sufficient to resist shear.

**Undulating Parking Structure.** This entire design assumed that the parking structure was flat when it actually fluctuates in elevation by 35" from one side to another. Though this will not significantly affect the actual slab design, the connection from the slab under the parking area to slab under the first floor of the office must be reviewed. The edge beam dividing the two areas will therefore be enlarged to provide a connection between two different elevations, and will need to be designed to torsion in addition to flexure and shear.

Shear, torsion, and moment output from the initial ADOSS analysis revealed that alternating load patterns between the parking and office span caused large unbalanced moments and therefore large torsion. Per ACI code 11.6.3.1, the size of each beam was expanded to a minimum of 20x26 along column line 4 and 24x32 along column line F to prevent cracking, while larger beam sizes accommodate variations in elevation between the office slab and parking deck. See Table 3 for a design summary, and Figure 8 for a sample detail.

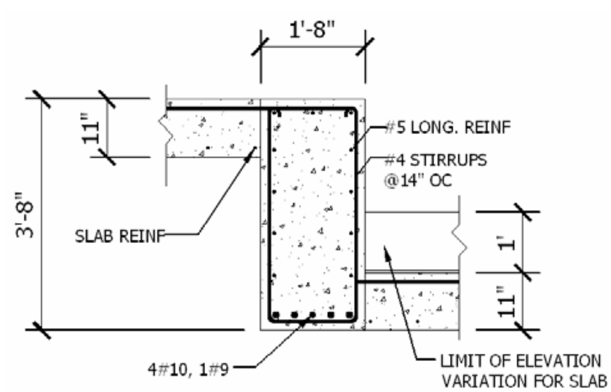



Figure 8. Sample Slab and Reinforcement Layout for Beam Spanning Column A4 to B4

| Beam | Size | Max Shear | Max Torsion | Max Moment | Steel Design Summary |
|---|---|---|---|---|---|
| A4-B4 | 20x44 | 80.7 | 107.9 | 888.6 | (shear) #4 stirrups @ 14"<br>11#5 long. Distributed on three sides<br>(flexure) 4#10, 1#9 |
| B4-C4 | 20x36 | 80.7 | 107.9 | 863.0 | (shear) #4 stirrups @ 12"<br>9 # 5 long. Distributed on three sides<br>(flexure) 4#11, 1#10 |
| C4-D4 | 20X30 | 80.7 | 107.9 | 516.9 | (shear) #4 stirrups @ 10"<br>7 #5 long. Distributed on three sides<br>(flexure) 4#10, 1#9 |
| D4-E4 | 20x26 | 80.7 | 107.9 | 7367 | (shear) #4 stirrups @ 9.5"<br>5 #5 long. Distributed on three sides<br>(flexure) bottom row: 4#10, 1#1<br>top row: 5#9 |
| E4-F4 | 20x28<br>+2"<br>elev. | 80.7 | 107.9 | 7367 | (shear) #4 stirrups @ 9.5"<br>5 #5 long. Distributed on three sides<br>(flexure) bottom row: 4#10, 1#1<br>top row: 5#9 |
| F1-F2 | 24x34<br>+2"<br>elev. | 96.0 | 151.0 | 606.4 | (shear) #4 stirrups @ 10"<br>7 # 5 long. Distributed on three sides<br>(flexure) 4#11, 4#10 |
| F2-F3<br>F3-F4 | 24x32 | 96.0 | 151.0 | 606.4 | (shear) #4 stirrups @ 10"<br>7 # 5 long. Distributed on three sides<br>(flexure) 4#11, 4#10 |

Table 3. Summary of Design Considerations for Transverse Beams

**Floor System Design Summary.** Layout 2 was determined to be the most effective because:

- Slab section depth did not increase dramatically as the north-south spans expanded; it increased by 0.5" in the office area, and by 1" in the parking area from the existing layout.
- It reduced the number of interior columns from 12 in the existing layout to 8. Meanwhile, Layout 3 used 18 columns while Layout 4 used 12. This provides for more unobstructed open office areas.
- The reduced east-west span length in Layouts 3 and 4 conflicted with the parking layout in the floor below; a 30'-0" wide entrance ramp in the existing layout would need to be moved so it could be evenly divided by a column, which would reduce the number of parking spaces.
- 22'-6" and 30'-0" spans in the north-south direction easily accommodate precast panels for the façade in increments of 3'-9" and 5'-0", as discussed further in the architectural breadth section.

See Figure 11 for a final design drawing.

Lateral System Design

**Alternatives.** Since this building design is only five stories tall, and since Northern Virginia experiences mild wind and seismic loads, it was proposed that the given structure could be modeled as a system of concrete moment frames. Therefore, there is no need for shear walls or additional lateral load resistance as long as drift and lateral stresses in slabs, columns, and beams are acceptable.

The given concrete frames, as optimized for the floor system, will therefore be evaluated based on:

- Shear and flexural capacity in the slab when loaded with lateral loads, and
- Total drift of the structure.

**Procedure.** Using new seismic loads derived from a greater building weight, a building model was created on ETABS and new loads were placed on the floor diaphragms. Assumptions for this model include:

- All floor areas are rigid diaphragms with columns rigidly attached. These are meshed at all column lines and drops, and lateral loads are directly applied to the centroid of each diaphragm.
- All columns are considered part of a concrete frame system.
- There are five total stories, and since the first floor is a basement, lateral loads are only applied to the top four. No restraint is provided at the first level to represent ground pressures, however, because some sides of the basement area will be excavated for access to underground parking and there will be no resisting compressive ground force.

The model, shown in Figure 9, was then checked for drift in each direction.

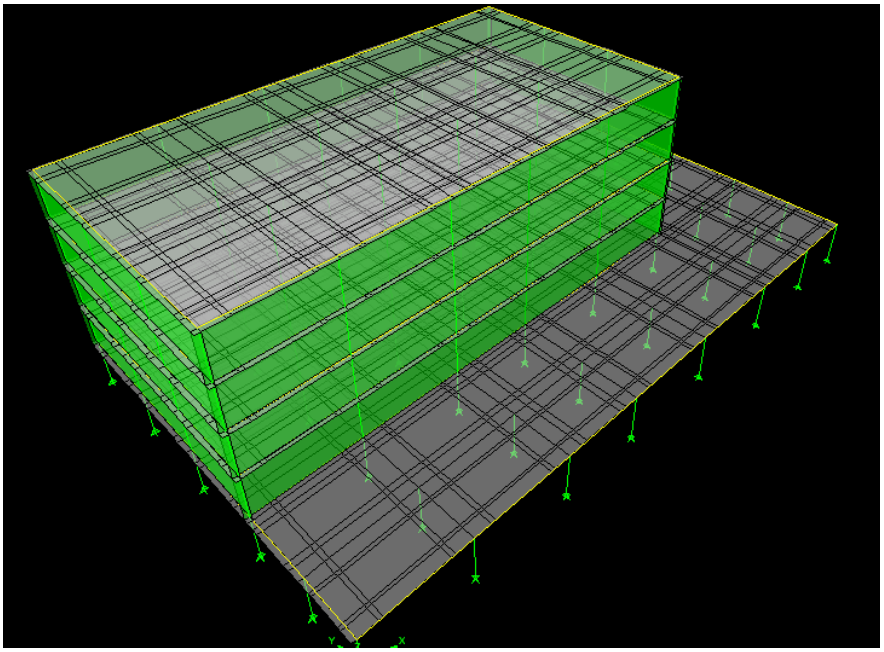


Figure 9. ETABS Model, Viewed from Southwest Corner

To assess flexural and shear capacity of the slab, first moments determined from the ETABS model were compared to a portal analysis of the concrete frames, assuming that exterior frames were half as stiff as interior frames and therefore resisted half the lateral forces. Then more conservative lateral loads were applied to the ADOSS model; since ADOSS calculates lateral loads using a simplified procedure similar to a portal analysis, this comparison ensures that larger and more conservative loads are used for the frame analysis.

**Analysis Findings.** Seismic loads dramatically increased due to much larger building weights than in the original steel design as shown in Table 4. With a base shear of 354 kips, these are almost double the seismic loads associated with steel construction, and these values in turn will control. For the serviceability requirement of drift, these values were then adjusted by a factor of 0.7 to bring them from ultimate to service values.

| Diaphragm | Wind Load (NS) *critical wind load | Wind Load (EW) | Seismic Load |
|---|---|---|---|
| Roof | 15.8k | 8.3k | 131k |
| Floor 4 | 31.1k | 16.4k | 111k |
| Floor 3 | 29.1k | 15.3k | 75k |
| Floor 2 | 26.4k | 13.9k | 37k |

Table 4. Summary of New Seismic Loads

Final drift values are summarized in Table 5, and deflection in both directions is shown in Figure 10. Allowable drift is H/400, or 1.57”. Therefore, these drift values are acceptable and there is no need for further lateral resisting elements than the slab and rigidly attached columns.

| Load Case | Diaphragm | Drift (in) |
|---|---|---|
| 0.7Ex | Roof | 0.876 |
| | 4 | 0.773 |
| | 3 | 0.607 |
| | 2 | 0.394 |
| | 1 | 0.186 |
| 0.7Ey | Roof | 0.818 |
| | 4 | 0.734 |
| | 3 | 0.605 |
| | 2 | 0.439 |
| | 1 | 0.253 |
| Wind | Roof | 0.292 |
| | 4 | 0.274 |
| | 3 | 0.237 |
| | 2 | 0.179 |
| | 1 | 0.105 |

Table 5. Drift Values in Both Directions Under Seismic and Wind Loads

Moments in the slab calculated using the portal frame analysis were generally greater than moments found in the ETABS model, revealing that the exterior frames may actually absorb more than half the lateral load. This more greatly affected resistance in the east-west direction, where there were only four frames.

Therefore, the same lateral loads used for the portal analysis were applied to the ADOSS model, which would analyze eight different loading patterns including both gravity and lateral loads. Results show that flexure in the slab was satisfactory; however, critical shear stresses from moment transfer in the interior columns were exceeded. Therefore, interior columns under the third floor, where lateral loads are greater, were upsized to 20x24 to increase the shear perimeter and reduce shear stresses.

See Figure 11 for a final design drawing.

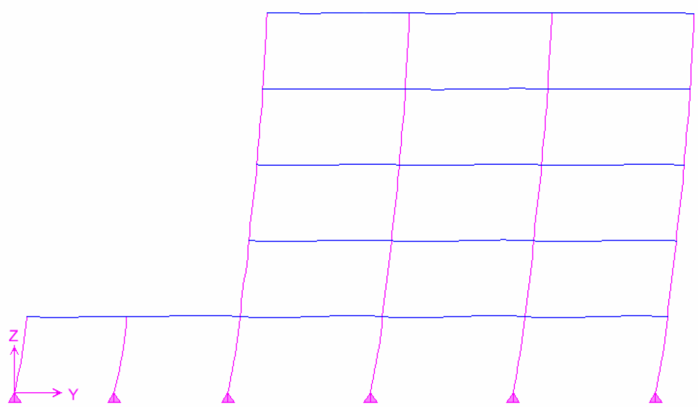



Figure 10A. Displacement from 0.7Ex

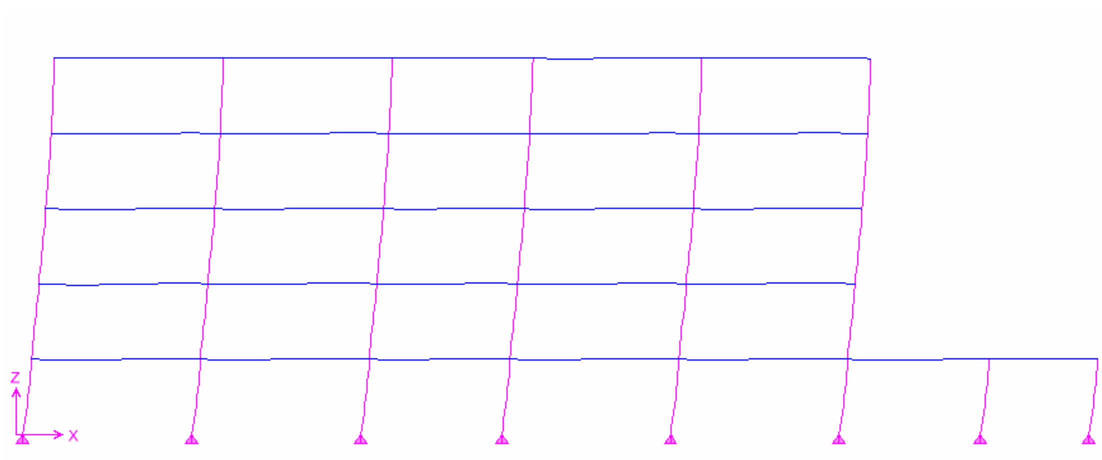



Figure 10B. Displacement from 0.7Ey

Column Design

**Procedure.** Initial column sizes were governed by shear transfer in the slabs and axial loads were determined directly from the ETABS model and then hand checked using tributary area. Moments in the columns were determined from the same ADOSS model used for the lateral load analysis; this way, unbalanced moments transferred to columns from both lateral loads and unbalanced gravity loading could be considered.

Upon determining moments and axial loads applied to representative columns along grid lines 3 and 5, rough steel design estimates were determined using the CRSI Handbook. For simplicity, the 1988 CRSI Handbook, with comparable load factors to ADOSS was used.

**Analysis Findings.** Column design considerations are summarized in Table 6. Results generally showed that:

- Moments determined on ETABS were generally less than as determined through a portal analysis. This can be attributed to an inaccurate assumption that the exterior frames only resist half as much lateral load as the interior frames; this assumption affects moments in the east-west direction more severely, as there are less frames. Larger and therefore more conservative loads from the portal analysis were used for the ADOSS analysis.
- Due to the relatively short 13'-4" unbraced length of each column and double curvature, slenderness effects could be neglected.
- While moments from lateral loads controlled in most columns, load patterns featuring only gravity loads controlled in select cases for exterior columns and columns supporting the parking deck. At these locations, unbalanced moment from large live load fluctuations between spans would be a key consideration.

See Figure 11 for a final design drawing.

| Grid | Floor | Moments Top/Bottom | Axial Load | Final Design |
|---|---|---|---|---|
| A2 | Floors 3-4 | 262.0/-235.1 | 171.1 | 20”x24”, 4#10 |
| | Floors 1-2 | 265.4/-238.1 | 602.8 | 20”x24”, 4#10 |
| | Parking | 278.5/0 | 777.9 | 20”x30”, 6#11 |
| B2 | Floors 3-4 | 139.8/-103.6 | 407.1 | 20”x20”, 4#9 |
| | Floors 1-2 | 153.4/-135.8 | 940.3 | 20”x24”, 4#10 |
| | Parking | 86.6/0 | 1234.1 | 24x24”, 8#10 |
| C2 | Floors 3-4 | 170.2/-126.8 | 363.3 | 20”x20”, 4#9 |
| | Floors 1-2 | 181.3/-177.5 | 838.4 | 20”x24”, 4#10 |
| | Parking | 129.8/0 | 1092.9 | 24x24”, 8#10 |
| E2 | Floors 3-4 | see B2 | | |
| | Floors 1-2 | see B2 | | |
| | Parking | see B2 | | |
| F2 | Floors 3-4 | see A2 | | |
| | Floors 1-2 | see A2 | | |
| | Parking | 279.2/0 | 962.6 | 24”x24”, 4#11 |
| G2 | Parking | 324.7/0 | 431.0 | 24”x24”, 8#8 |
| H2 | Parking | 123.5/0 | 156.0 | 20”x20”, 4#9 |
| A1 | Floors 3-4 | 262.0/-235.1 | 154.9 | 20”x20”, 4#9 |
| | Floors 1-2 | 265.4/-238.1 | 358.5 | 20”x20”, 4#9 |
| | Parking | 281.3/0 | 455.8 | 20”x20”, 4#9 |
| A5 | Parking | 581.5/0 | 199.8 | 20”x20”, 8#18 |
| B5 | Parking | 328.1/0 | 441.2 | 20”x20”, 8#10 |
| C5 | Parking | 315.3/0 | 369.8 | 20”x20”, 8#8 |
| D5 | Parking | 328.0/0 | 375.9 | 20”x20”, 8#8 |
| E5 | Parking | 288.0/0 | 419.6 | 20”x20”, 8#7 |
| F5 | Parking | 255.1/0 | 378.4 | 20”x20”, 8#7 |
| G5 | Parking | 209.2/0 | 304.2 | 20”x20”, 8#7 |
| H5 | Parking | 138.4/0 | 117.6 | 20”x20”, 8#7 |
| B6 | Parking | 155.7/0 | 172.4 | 20”x20”, 4#9 |

Table 6. Summary of Representative Column Design Details

Effects on Foundation System

**Procedure.** By using basement level column loads from the original steel analysis and the given 5000 psf soil bearing capacity, the original factor of safety can be determined. Using this factor of safety, new column takedown loads were used to size new footings. Since the original building was modeled to have pinned connections at the footings, any possible moment is determined to be minimal and only axial loads were considered.

**Analysis Findings.** Using a general factor of safety of 2, it was determined that though the spread footings under each column will drastically enlarge to offset heavier axial loads, the new sizes are still reasonable for the given design. See Table 7 for a summary of design conditions and Figure 12 for a design detail.

| Column | New/Old Axial Loads | Old Size | New Size | New Size Reinforcement |
|---|---|---|---|---|
| A3 | (new) 579k<br>(old) 198k | 9'x9'x28" | 13.5'x20'x28" | (long) 41#6<br>(short) 40#6 |
| B5 | (new) 305k<br>(old) 110k | 6.5'x6.5'x20" | 11.5'x11.5'x28" | 23#6 each direction |
| D2 | (new) 810k<br>(old) 251k | 8'x8'x24" | 16.5'x20'x34.5" | (long) 50#6<br>(short) 40#6 |
| D4 | (new) 639k<br>(old) 273k | 8'x8'x24" | 15'x18'x30" | (long) 45#6<br>(short) 36#6 |
| F4 | (new) 538k<br>(old) 254k | 9'x9'x28" | 15'x15'x28" | 30#6 each direction |
| G2 | (new) 303k<br>(old) 94k | 6'x6'x18" | 11.5'x11.5'x28" | 12#6 each direction |
| D1 | (new) 532k<br>(old) 226k | 8'x8'x24" | 12'x18'x26" | 36#6 each direction |
| D6 | (new) 104k<br>(old) 57k | 6.5'x6.5'x20" | 9'x9'x12" | 9#6 each direction |
| H3 | (new) 103k<br>(old) 54k | 6'x6'x18" | 9'x9'x12" | 9#6 each direction |

Table 7. Summary of Representative Footing Design Details

See Figure 11 for a final design drawing.

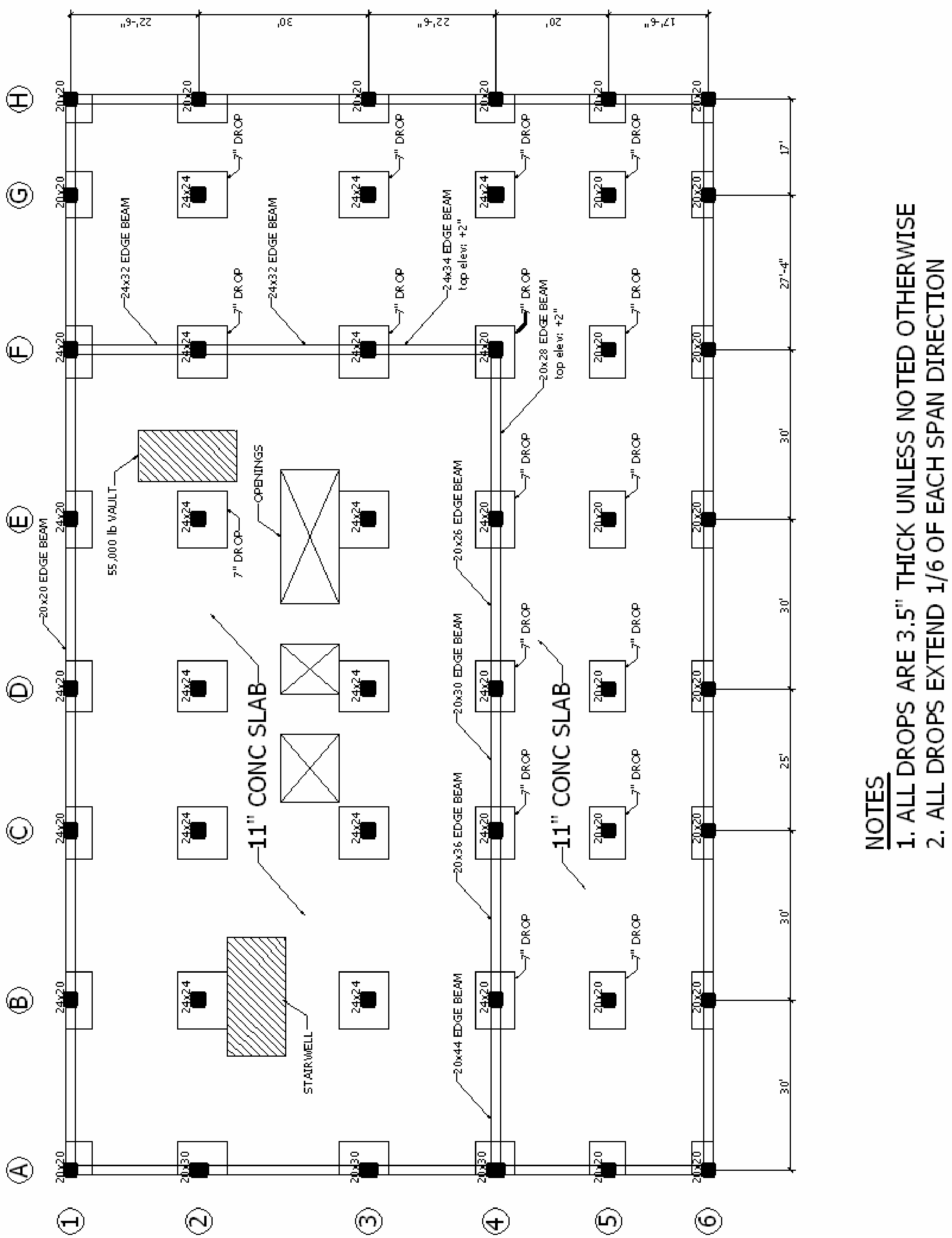



Figure 11A. First Floor/Parking Deck Final Design

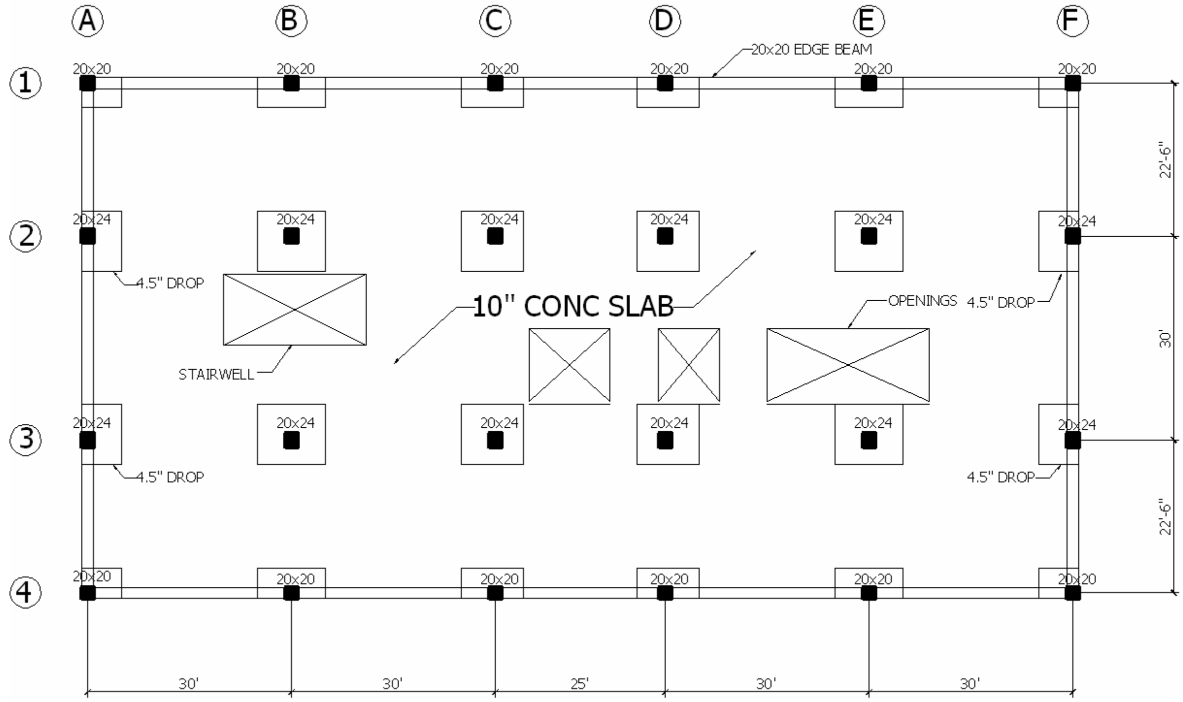



Figure 11B. Second, Third, and Fourth Floor Final Design

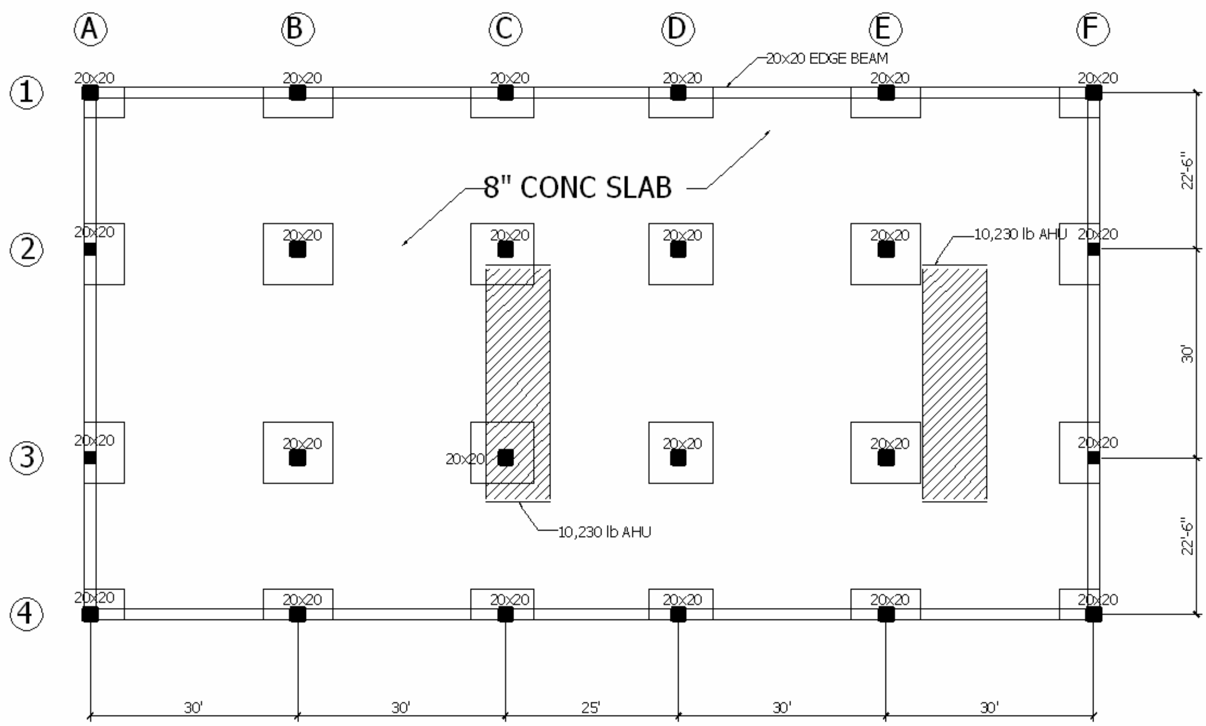



Figure 11C. Roof Floor Final Design

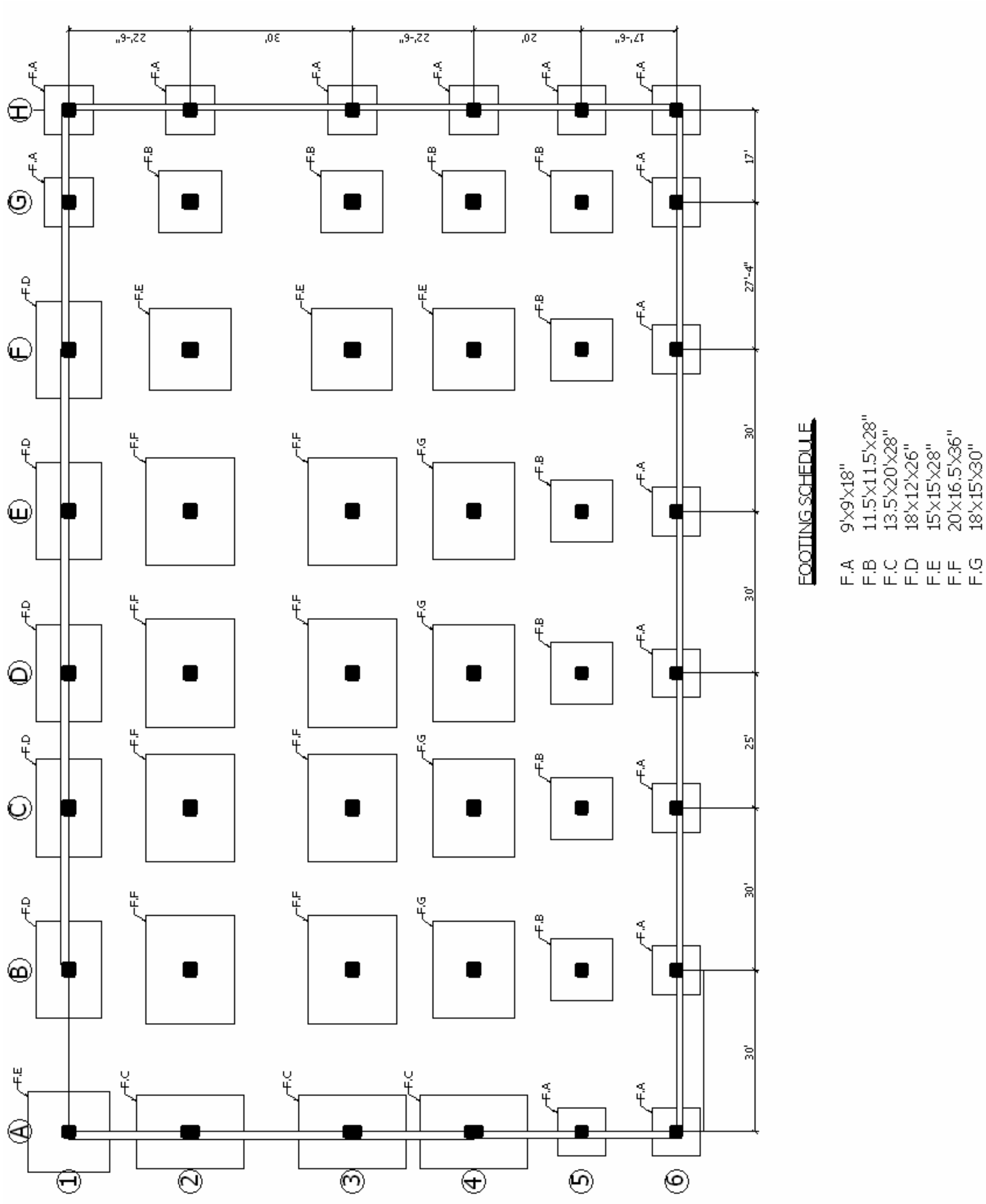



Figure 11D. Revised Footing Layout and Schedule

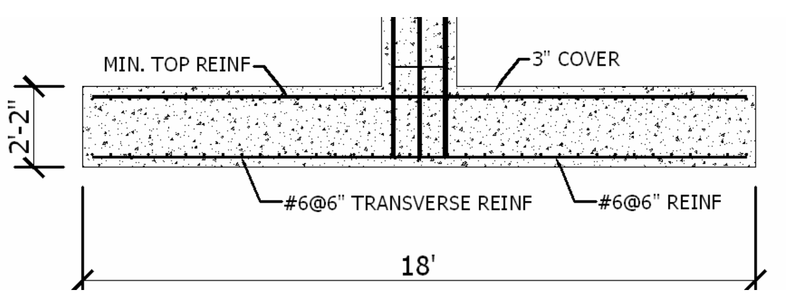



Figure 12. Sample Footing Detail

## BREADTH ANALYSIS 1:
## ARCHITECTURAL ALTERATIONS FROM CONCRETE SYSTEM

<u>Floorplan</u>

**Existing Architecture.** The focus of the existing layout is both parking orientation and office area efficiency. In the parking area, columns, elevators, and stairwells are situated around driveway areas that are a minimum of 17'-6" wide. Upstairs, the central core housing the elevators, stairwells, and service rooms is centered so it is wide enough between the exterior wall and central core to accommodate offices and internal corridors. Office areas were calculated and assessed using the Building Owners and Managers Association (BOMA) industry standard, where Rentable Area is most affected by Common Areas and Unusable Areas.

**Problem.** The most significant impact of the new concrete system and column layout would be the location of columns directly over a driveway in the underground parking area; expanding the span from column line 1 to 2 by 2'-6" shifted columns 2'-6" into an already constricted area. Therefore, the central core area will need to be altered and shifted to allow for a minimal 17'-6" wide driveway in the basement.

**Proposed Solutions.** Though the central core could simply be moved 2'-6" to accommodate a suitable underground parking area layout, three alternate layouts were produced to represent floorplans that maximize rentable office area while minimizing common areas. See Figures 13, 14, 15 and 16.

Based on the given layout, the following requirements were established for each floor:

- Two Stairwells (232 square feet)
- Two Elevators (130 square feet)
- Men's Room (130 square feet) and Women's Room (160 square feet)
- Janitor's Closet (60 square feet) and Tech Room (70 square feet)
- Pump Room (125 square feet) / Electrical Room (275 square feet) in basement
- Three exterior entrances, first floor
- At least two entrances to office areas on Floors 2-4

Floorplans created primarily for the concrete structural system tried to place floor penetrations in the middle strip of each concrete bay, where the slab does not resist as much moment. While all must place elevator shafts and stairwells in some column strips, Alternative #3 most effectively centers these penetrations in bays. Where these openings most strongly affect slab moment resistance, concrete beams will serve as supplements.

From a purely architectural standpoint, the symmetry of Alternatives 1 and 2 are most appealing, and both of these alternatives create a central lobby room. This stands in contrast to the corridor-like spaces most prominent in the original layout. A summary of rentable area is provided in Table 8. Each floorplan presents a reduction in common area and increase in usable area for each office. Given an average annual rental value of $25 for a suburban office in Prince William County, these new floorplans may boost potential owner income by $7425 to $17750.

| BOMA Measurement | Existing Layout ($ft^2$) | Alt #1 | Alt #2 | Alt #3 |
|---|---|---|---|---|
| Floor 1 | | | | |
| Common Area | 1615 | 1314 | 1520 | 1482 |
| Unusable Area | 480 | 480 | 480 | 480 |
| (North Office) Rentable Area | 1932 | 2360 | 2317 | 2490 |
| (South Office) Rentable Area | 2560 | 1918 | 1914 | 2030 |
| (East Office) Rentable Area | 4095 | 4602 | 4491 | 4252 |
| Floors 2-4 | | | | |
| Common Area | 872 | 765 | 840 | 827 |
| Unusable Area | 480 | 480 | 480 | 480 |
| Rentable Area | 9381 | 9520 | 9435 | 9448 |
| Total | | | | |
| Common Area | 4231 | 3609 | 4040 | 3983 |
| Unusable Area | 1920 | 1920 | 1920 | 1920 |
| Rentable Area | 36730 | 37440 | 37027 | 37116 |
| R / U Ratio | 16.74% | 14.77% | 16.09% | 15.90% |
| Underground Parking Spaces | 44 | 48 | 46 | 47 |

Table 8. Summary of Rentable Areas for Three Alternative Floorplans

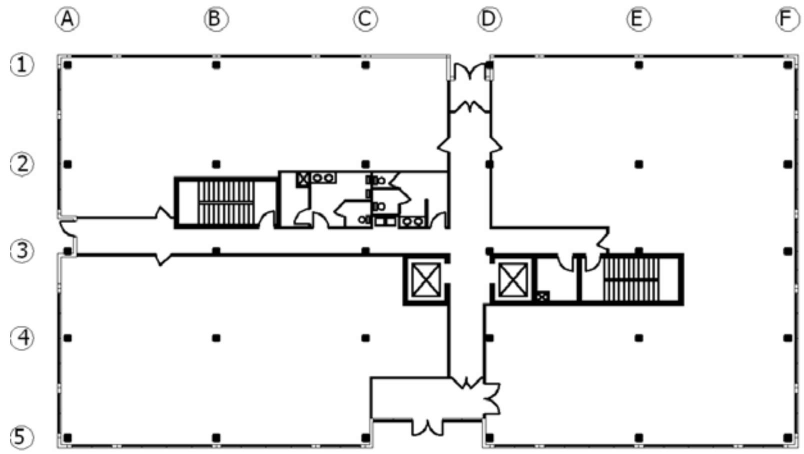



Figure 13A. Existing Layout, First Floor

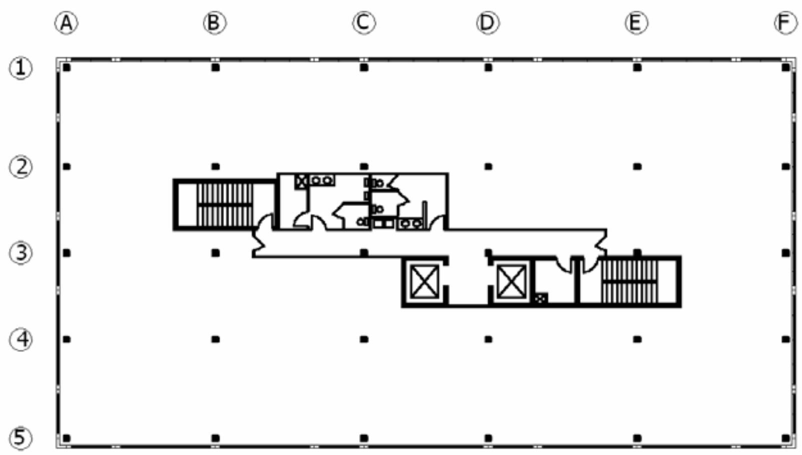



Figure 13B. Existing Layout, Floors 2-4

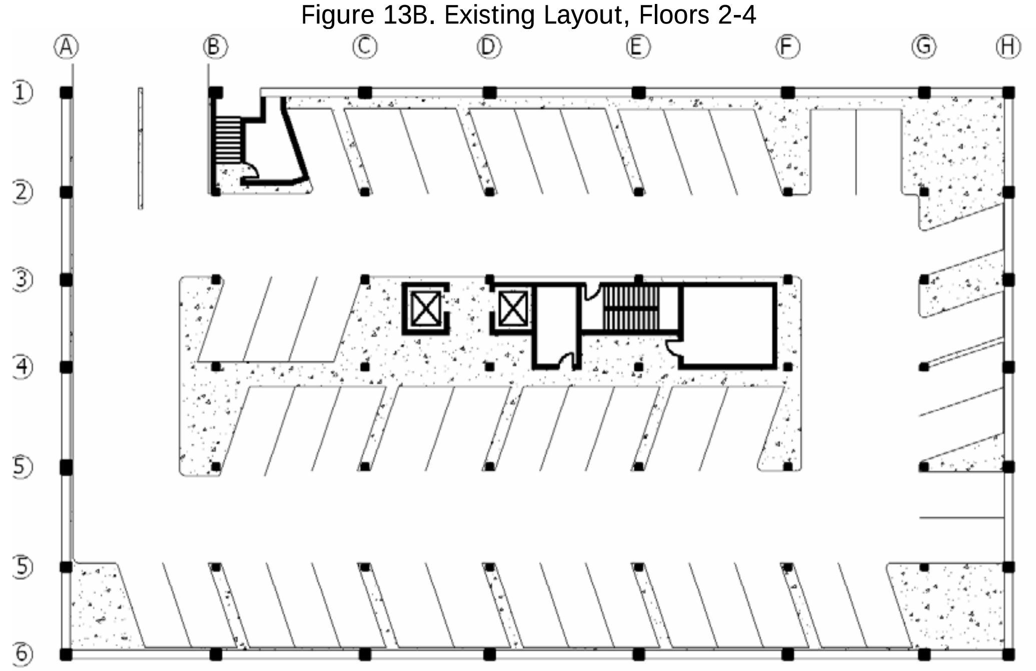



Figure 13C. Existing Layout, Underground Parking Area

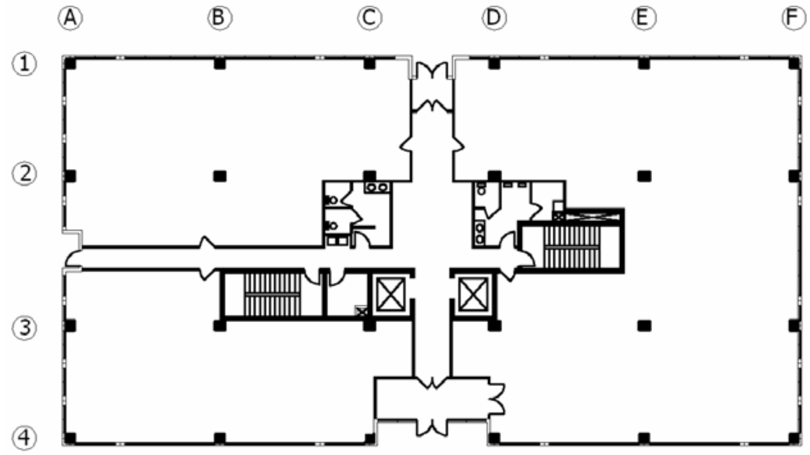



Figure 14A. Alternative #1, First Floor

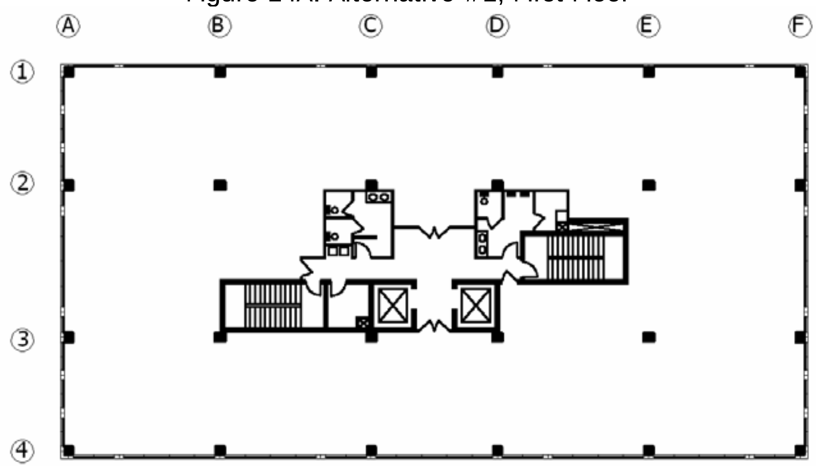



Figure 14B. Alternative #1, Floors 2-4

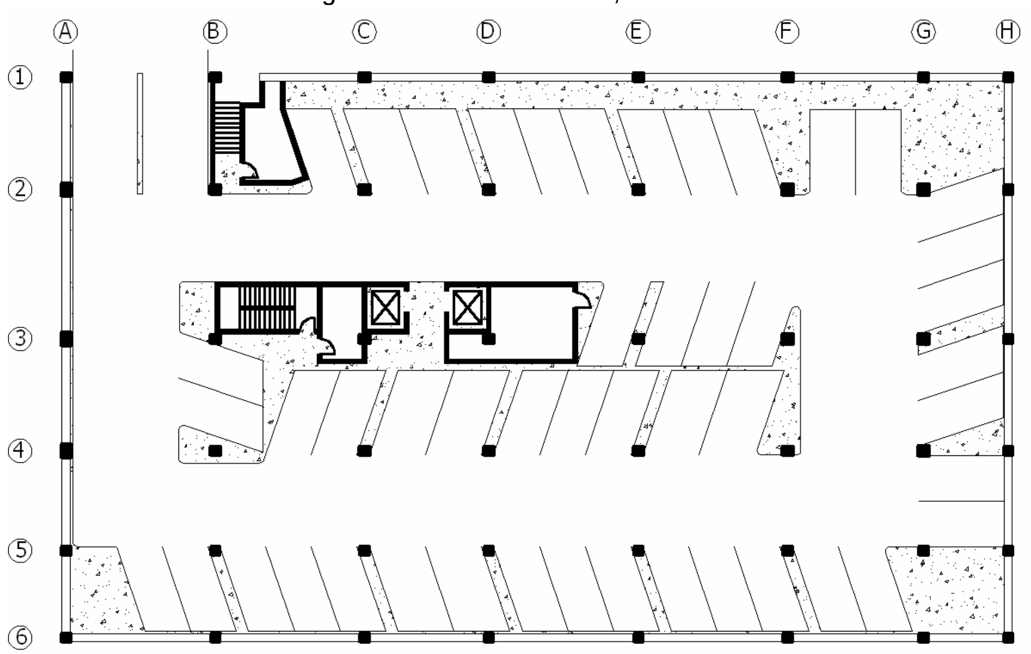



Figure 14C. Alternative #1, Underground Parking Area

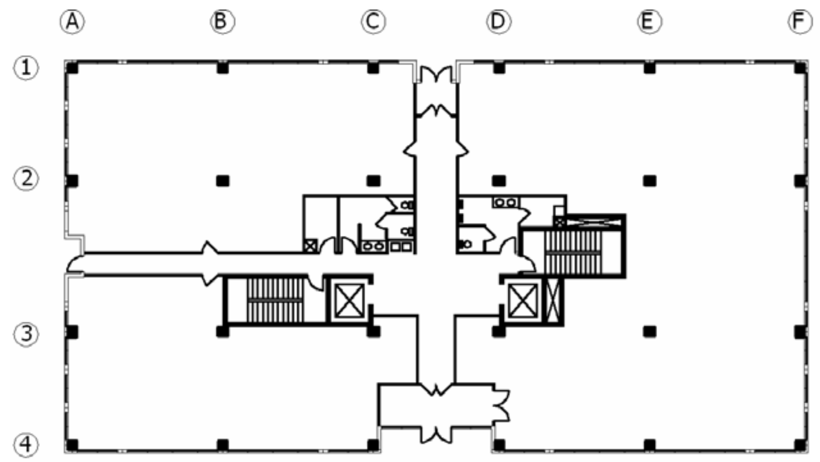



Figure 15A. Alternative #2, First Floor

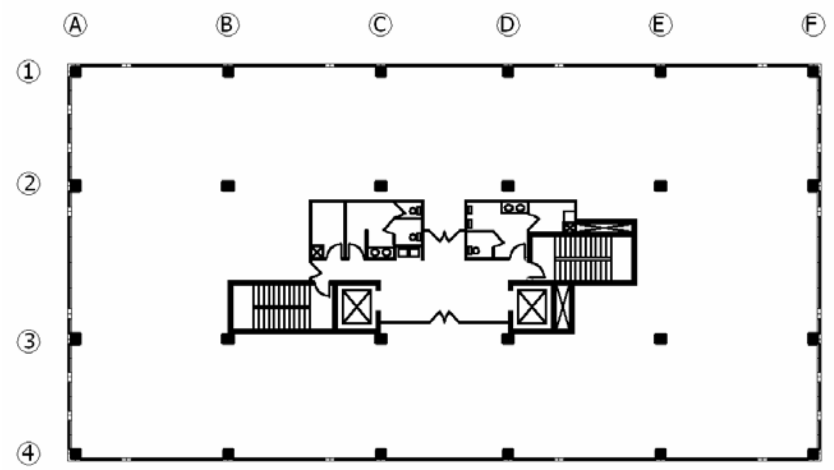



Figure 15B. Alternative #2, Floors 2-4

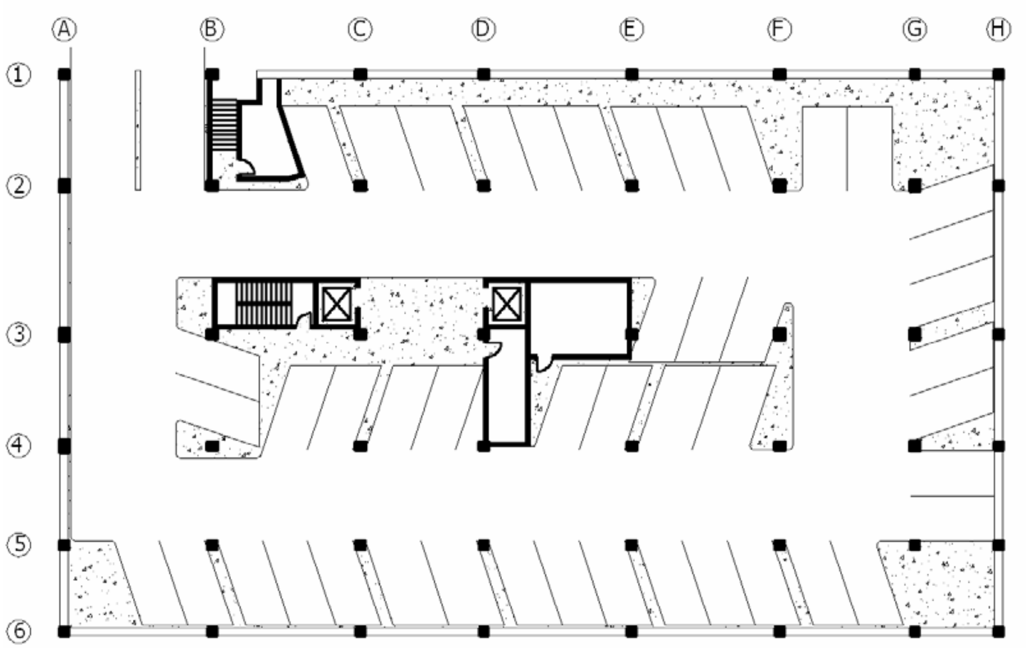



Figure 15C. Alternative #2, Underground Parking Area

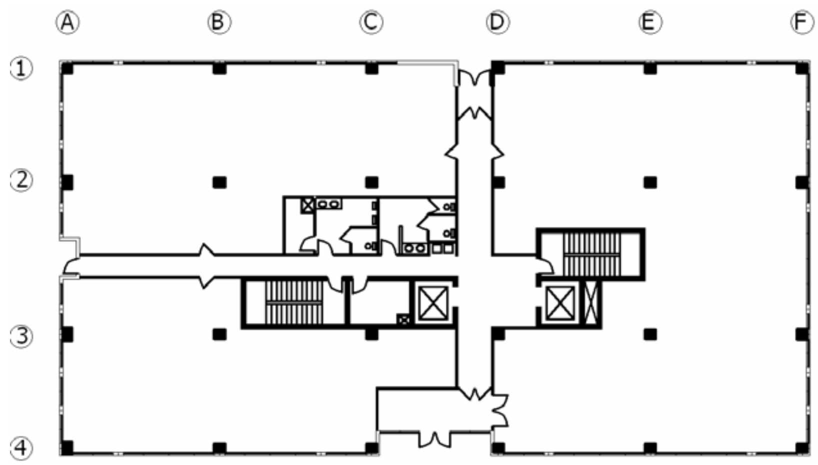



Figure 16A. Alternative #3, First Floor

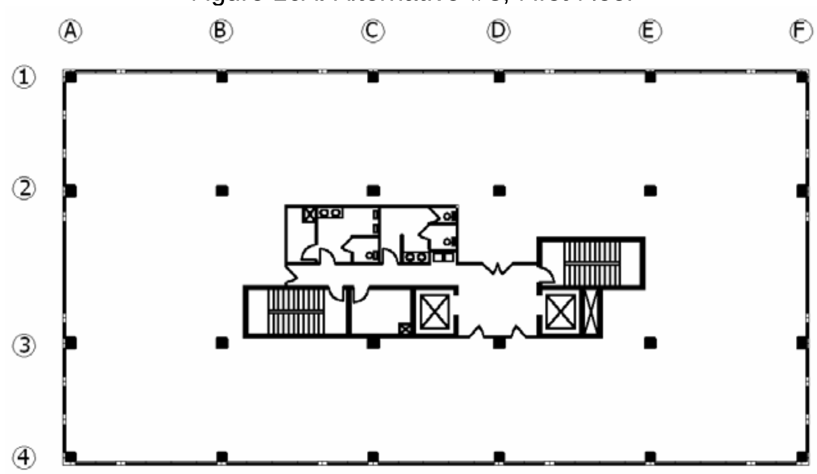



Figure 16B. Alternative #3, Floors 2-4

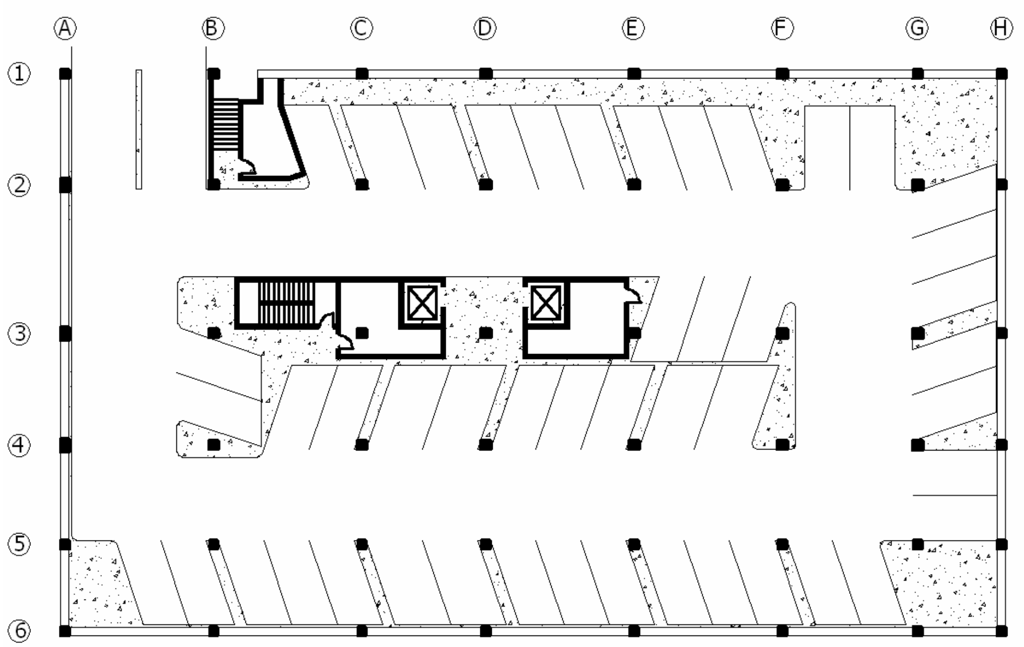



Figure 16C. Alternative #3, Underground Parking Area

Exterior Façade

**Existing Architecture.** Created from the Slender-Wall system by Smith-Midland, the exterior walls create a traditional Virginian brick look using concrete precast wall panels attached at the floor diaphragm. In order to simplify shipment, these are limited in length to a maximum 30' and certain panels are reused throughout.

Horizontally, the exterior façade adheres to modules that dictate window and brick placement. Used to simplify detailing the exterior façade, the north and south façade use a 5'-0" wide module while the east and west façade combine both 5'-0" and 3'-9" wide modules. Vertically, the façade adheres to the classic tall-office building icon; though modified for suburban purposes, the façade features a base, central shaft, and ornate capital, separated by cornices and differing window styles.

**Problem.** Though the steel structural system placed W10 columns in front of windows, the new concrete design features columns up to 24" wide. If the existing façade layout were to be used with the new column layout, 24" wide columns would be placed directly in front of windows, blocking views and sunlight. Therefore, the east and west facades must be rearranged in order to coordinate 2'-0" wide brick elements with columns.

**Proposed Solutions.** The new north-south column layout reflects the existing horizontal façade module; 3'-9" modules could cover the two 22'-6" spans, while 5'-0" modules could cover the 30'-0" span. The two 24x20 columns that would otherwise block the windows therefore are placed behind vertical brick elements and have less impact. See Figure 17 for an alternate facade. Similar panels between the two elevations are highlighted in red, blue and green.

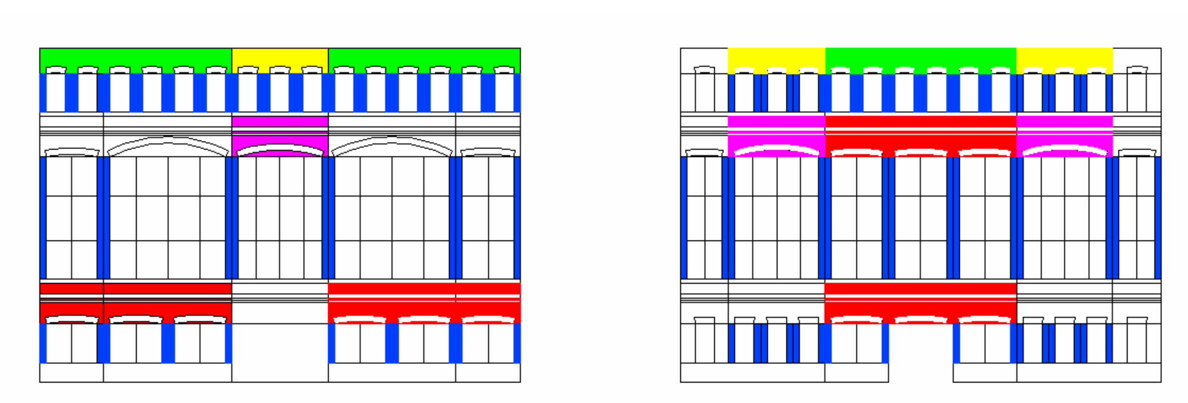


Figure 17. Original Elevation on Left, Rearranged Alternate Elevation on Right

This alternate façade represents the most logical new layout because it uses many similar precast sections with the north and south elevation, it creates a rhythm of windows suited towards dividing the interior into individual offices, and it maintains the vertical distribution of window surfaces.

Though this alternate is the most convenient, the use of precast wall sections for an exterior façade presents an interesting situation: by creating a collage of exterior wall elements, drastically different elevations can be produced. Figure 18 shows a variety of elevations using both 5'-0" and 3'-9" module widths.

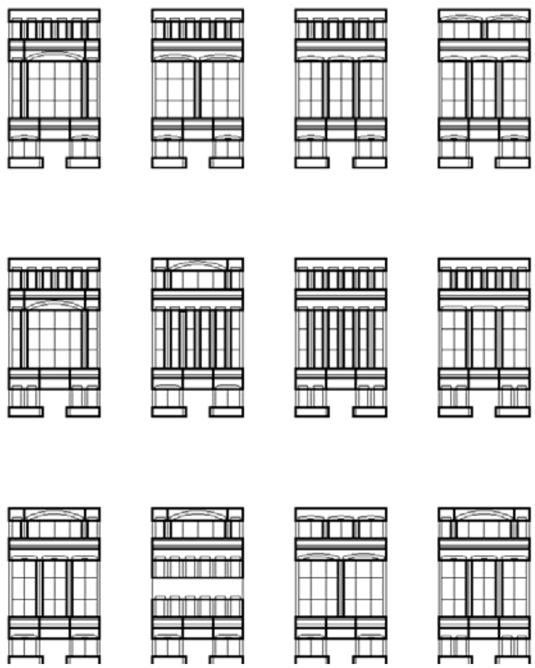


Figure 18A. Collaged 5'-0" Precast Panels

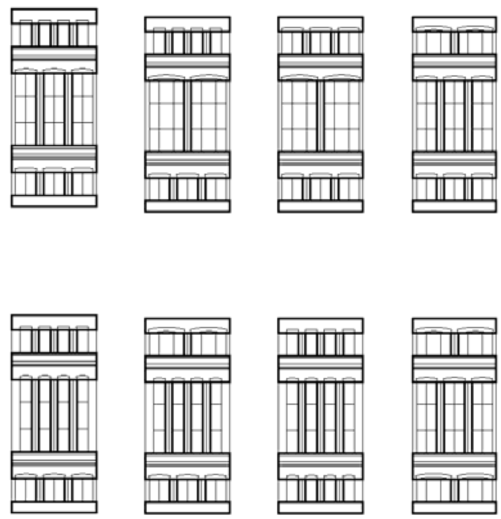


Figure 18B. Collaged 3'-9" Precast Panels

When these façades are combined, drastically different elevations are produced. See Figure 19 for possible combinations. While the first reinforces the dramatic base-shaft-capital building icon through an anonymous grid in the shaft section giving way to wide, arched windows in the capital section, the second reinforces the symmetry found in the original façade while maintaining even spacing for individual office divisions.

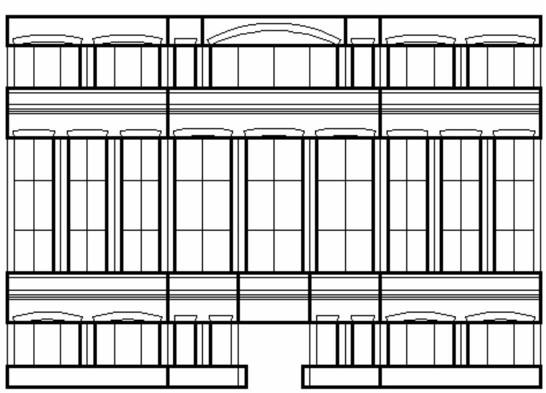


Figure 19A. Base-Shaft-Capital Façade Alternate

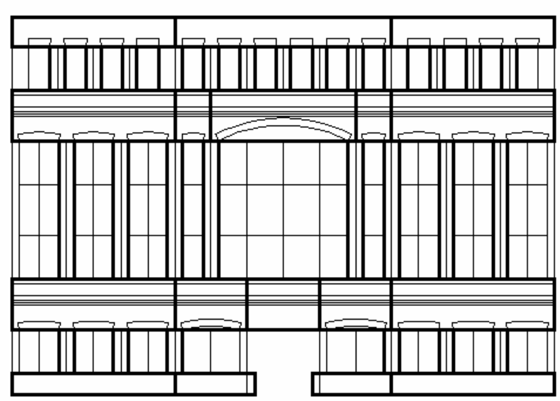


Figure 19B. Symmetrical Façade Alternate

## BREADTH ANALYSIS 2:
## CONSTRUCTION MANAGEMENT COMPARISON

Basis of Comparison

To most effectively compare the cost and constructability of both the steel and concrete systems, only the structures will be considered. For the concrete system, this includes concrete slabs, columns, and beams, while for the composite steel system, this includes steel columns and beams, composite decks, shear studs, concrete on the decks, and fireproofing. Since footings increased dramatically while floor section depths reduced under the concrete system, their impact will be analyzed, though separately.

Cost and Schedule Comparison

Using R.S. Means 2006, takeoffs and schedules are summarized in Table 9 and Figure 20. Cost estimates from the construction manager, R.W. Murray Company, suggest that the scope of structural steel encompassed 8 weeks erection time and $550,000, so it can be assumed that the steel estimate is conservative if not accurate.

| Material | Cost | Construction Duration |
|---|---|---|
| Concrete System | | |
| Columns, Slabs, Beams | $1,120,566 | 14 weeks |
| Footings | $230,887 | 2 weeks |
| Steel System | | |
| Columns and Beams | $668,928 | 8 weeks |
| Deck and Shear Studs | $170,345 | |
| Poured Conc. On Deck | $162,010 | |
| Fireproofing | $73,044 | |
| Total | $1,074,327 | 12 weeks, 4 days |
| Footings | $73,044 | 3 days |

Table 9. Summary of Cost and Duration for Both Structural Systems

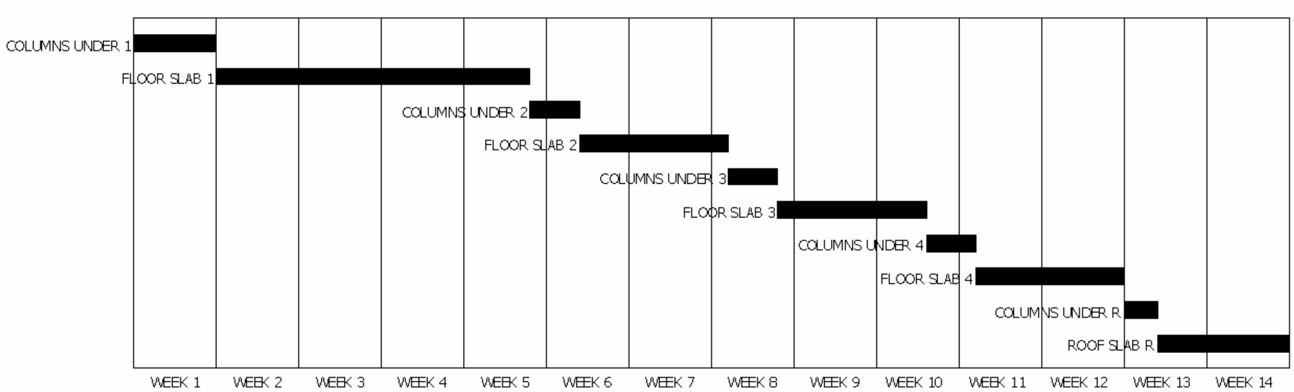



Figure 20A. Schedule for Concrete System, using Critical Path Method

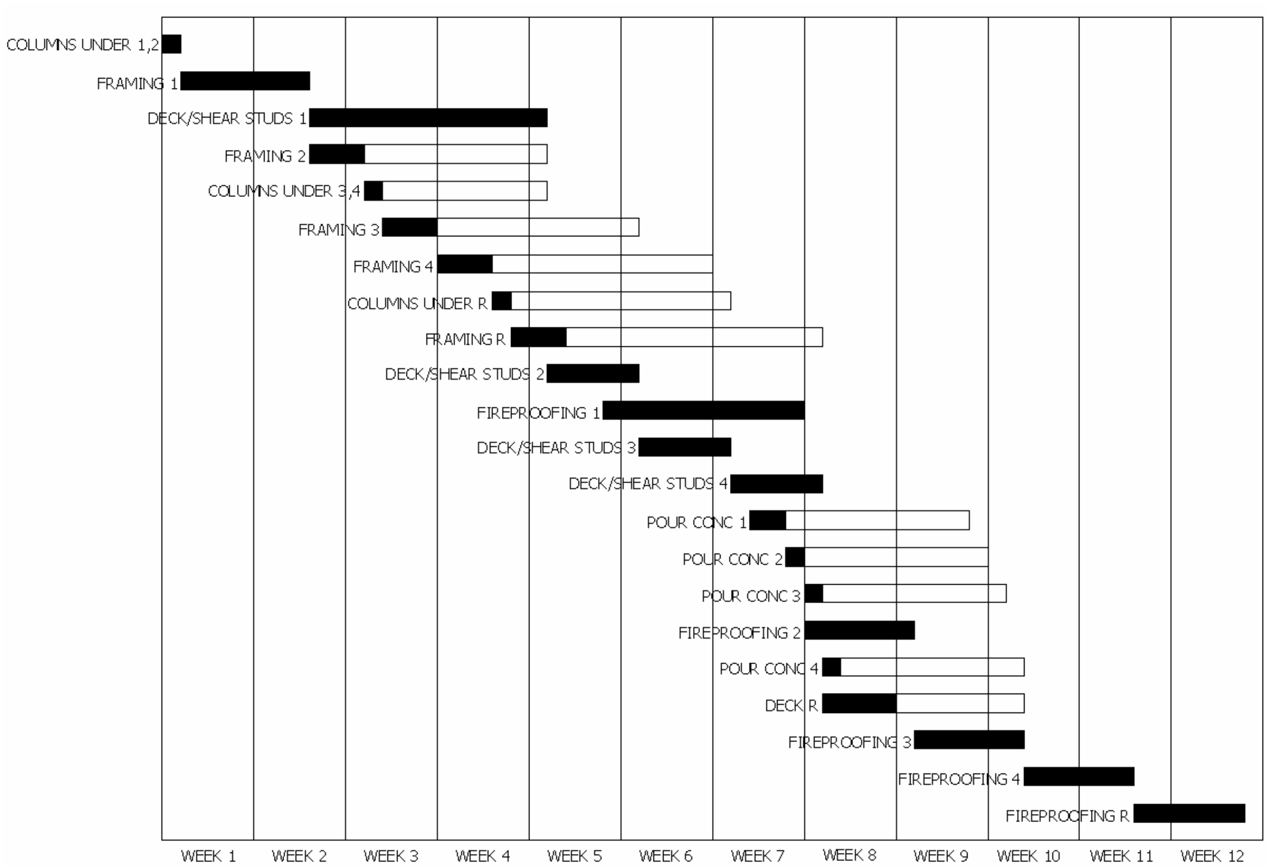



Figure 20B. Schedule for Steel System using Critical Path Method (Clear areas are float times)

It appears that the steel system is cheaper and requires a shorter erection time. When the increased footing size under the concrete system is additionally considered, the steel system becomes slightly more than $200,000 cheaper, requiring almost 3 less weeks of construction. Even when considering that the overall depth of the underground parking area will reduce by almost 13” in the concrete system due to a significantly narrower floor section depth, this equates to only about 400 less bank cubic yards of excavation, which would reduce construction costs by only $3,575 to $8,495.

Additional Construction Considerations for the Washington DC Area

Though the reduced floor section depth in the concrete system does not play a large role in this particular building, reduced floor section depths are equated with more floors and therefore more profit in many buildings subject to strict height restrictions throughout the Washington area. However, it seems that the steel system for this given building is significantly and consistently cheaper than the concrete system. Perhaps the local construction trades and economy come to influence building construction, making R.S. Means less indicative of an accurate cost analysis.

**Cost Adjustments in Northern Virginia.** Data supplied by representatives at the American Institute of Steel Construction regarding steel and concrete costs relative to the national average are summarized in Table 10. In the Washington area, concrete construction is indeed less expensive on average than steel.

| Location | Concrete Costs | Steel Costs |
|---|---|---|
| Washington, DC | 0.992 | 1.062 |
| Fairfax, VA | 0.921 | 0.921 |
| Arlington, VA | 0.902 | 0.898 |
| Alexandria, VA | 0.915 | 0.952 |
| Winchester, VA | 0.795 | 0.891 |

Table 10. Summary of Material Costs relative to the National Average

Assuming that the Manassas area would be grouped with nearby Fairfax, the values given by R.S. Means are directly proportional to the national average. If the construction costs were compared neglecting footing placement, concrete would be cheaper in Washington, Alexandria, and Winchester, though steel is still cheaper at all locations when footings are considered.

**Lead Times.** Though the actual erection time for the steel system is shorter, the overall length of construction time increases with longer procurement lag times. On average, after design completion, procurement, submittals, and approvals, it takes 12 weeks to produce structural steel while it only takes 3 weeks to produce rebar for concrete construction. Therefore, even with the longer erection time, concrete may take 6 less weeks from design completion to complete structural construction.

**Supply and Demand.** In any area, it is possible that any given contractor can undercut a bid to promote either concrete or steel construction. However, short term influences can affect this ability; two years ago, steel costs increased dramatically due to relative shortages of scrap materials, while in 2005, the Portland Cement Association placed Washington DC on the “tight cement supply” list, with similar market conditions predicted for 2006.

**Weather Conditions and Schedule.** As suggested by R.W. Murray Company, wintry conditions onsite during construction would increase the time and cost to pour and place a concrete system. According to ACI 318-05, all concrete forms must be free from frost and all concrete materials must be protected from freezing conditions. Therefore, it is locally accepted that concrete will only be placed if conditions can be maintained above 40 degrees Fahrenheit. Given that winter temperatures in Northern Virginia are often below freezing, protective tarps, covers, and heaters may be required throughout structural construction, raising cost and extending construction duration.

## BREADTH ANALYSIS 3:
## INTEGRATION OF A GREEN ROOF

Overview of Green Roof Types

These systems range from less invasive systems featuring only 2" deep soil and 15 psf saturated weight supporting sedum plant species to most invasive systems featuring 9"+ deep soil and 54+ psf saturated weight supporting turf grasses and small trees. As systems become more intensive, weight when fully saturated with rainwater becomes more of a structural consideration, but improved energy efficiency and the possibility of creating inhabitable garden spaces may increase building livability in the long run.

Green roof systems were analyzed and compared to the existing system using model assemblies from Roofscapes, Inc., a green roof system provider located in Philadelphia. Consisting primarily of a thin plant layer, a growing media layer, and a drainage layer over a waterproofing membrane, these systems have been shown to

- Reduce runoff and erosion, improving water quality.
- Serve as a thermal and acoustic barrier to reduce energy usage.
- Increase the service life of the roof system.
- Improve the aesthetic environment for the building inhabitants.

While discussing Green Roof feasibility, structural, mechanical, acoustic, architectural, and cost considerations were analyzed in more detail.

Feasibility of a Green Roof

**Selection of a Green Roof.** Roofscapes, Inc. supplies data for four green roof systems ranging from non-invasive to large-scale. Weights and depths are summarized in Table 11.

| System | Thickness/<br>Sat.Weight |
|---|---|
| Flower Carpet | 2-3"/<br>12-18 psf |
| Aromatic Garden | 3-4"/<br>18-24 psf |
| Savannah | 4-6"/<br>24-36 psf |
| Meadows | 6-9"/<br>36-54 psf |

Table 11. Summary of Roofscapes Green Roof Types

For this analysis, all systems were considered both as a non-public space with merely the additional garden load, and as an accessible space, with the additional garden load and a 50 psf live load from limited walkways and patio areas. Composite steel designs assumed the same 3" composite deck with 3.5" slab used in the inhabitable office areas.

**Structural Considerations.** While the Flower Carpet System adds a relatively insignificant load to the building structure, a saturated Meadows system with public access places a 134 psf additional load on the roof structure, increasing steel and slab sizes beyond those of occupied office floors. Sizes are summarized in Table 12.

| Garden Type | Concrete Structural System | Steel Structural System |
|---|---|---|
| No Garden | 8” slab w/3.5” drops | W18x40 max girders |
| Flower Carpet | 8” slab w/3.5” drops | W16x40 max girders |
| Flower Carpet with pedestrian access | 9” slab w/3.5” drops | W21x48 max girders |
| Aromatic Garden | 8” slab w/3.5” drops | W16x40 max girders |
| Aromatic Garden with pedestrian access | 10” slab w/4.5” drops around column lines A and F, larger 20x24 interior columns | W21x50 max girders |
| Savannah | 8.5” slab w/3.5” | W21x44 max girders |
| Savannah with pedestrian access | 11” slab w/4.5” drops around column lines A and F, larger 20x24 interior columns | W14x22 composite girders, 3” deck with 3.5” conc slab |
| Meadows | 9” slab w/4.5” drops around column lines A and F, larger 20x24 interior columns | W21x48 max girders |
| Meadows with pedestrian access | 11” slab w/4.5” drops around column lines A and F, larger 20x24 interior columns | W14x22 max composite girders, 3” deck with 3.5” conc slab |

Table 12. Approximate Structural Systems Under Roof Gardens

In addition to larger concrete slabs and supporting steel girders, a larger roof weight increases controlling seismic base shear:

- **Concrete Design**. From 354k to 386k for the Flower Carpet System and to 420k for the Meadows System.
- **Steel Design**. From 170k to 180k for the Flower Carpet System and to 200k for the Meadows System.

While the concrete moment frame design effectively reduces drift and will most likely be able to resist these larger lateral loads, the steel moment frame lateral system may need to be enhanced by shear walls or braced frames around the core area.

**Mechanical Considerations.** A key benefit to a roof garden would be enhanced R-values in the roof system, reducing heating and cooling loads. However, R-values for roof garden systems are still under evaluation, as soil type between systems affects thermal resistance as well as saturation level in differing climates and seasons. As can be seen in the roof sections in Figure 21, added layers of water distribution fabric, porous gravel fill, soil, and vegetation would contribute to greater thermal resistance.

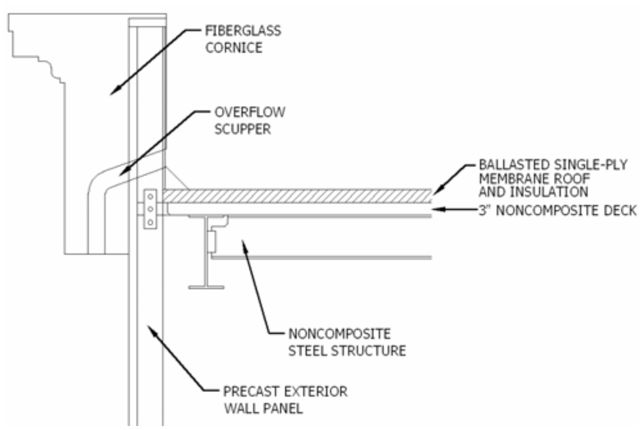



Figure 21A. Roof Section, Existing Steel System

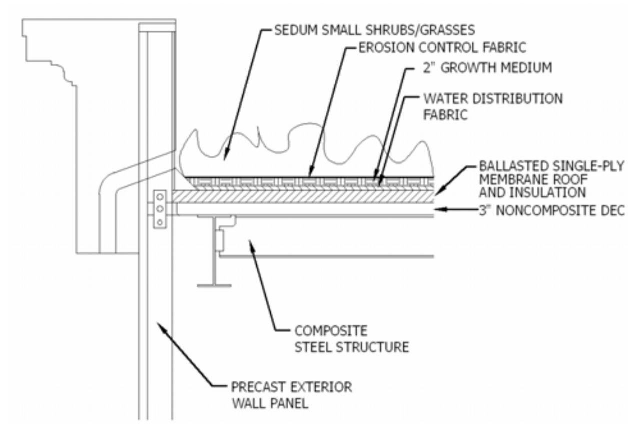



Figure 21B. Roof Section, Flower Carpet on Steel System.

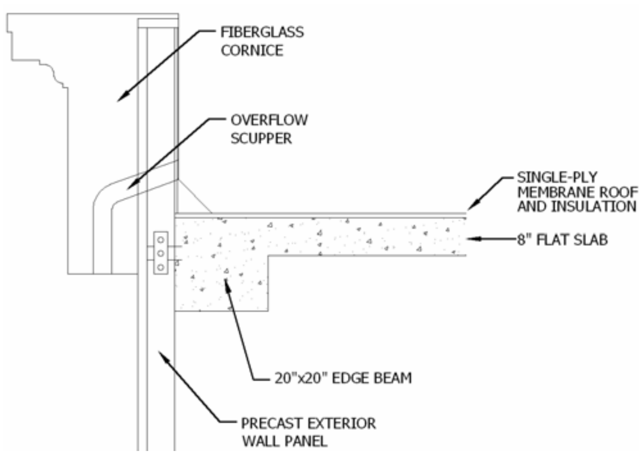



Figure 21C. Roof Section, Concrete System

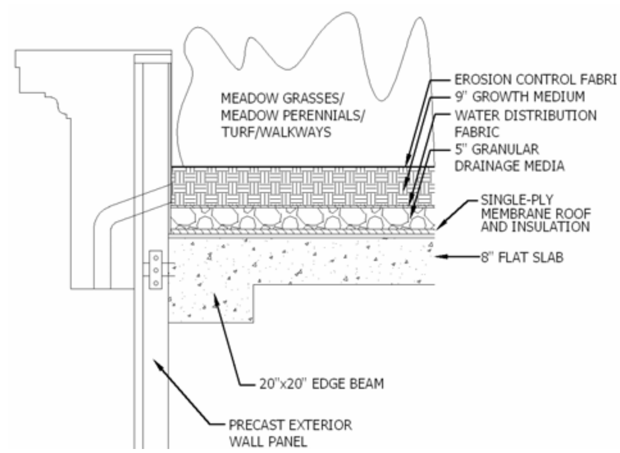



Figure 21D. Roof Section, Meadows on Concrete System.

**Acoustic Considerations.** Another benefit cited by green roof manufacturers are reduced sound transmission through the roof structure. Soil, as a solid and flexible material, would provide increased sound isolation over a regular system. As soil mass increases from the Flower Carpet System to the Meadows system, the STC rating will increase, though in less dramatic increments. Additional membranes and drainage layers would increase mass and therefore transmission loss through the roof system as well.

**Architectural Considerations.** Besides the structural, mechanical, and construction-related considerations of installing a green roof, the architectural implications of creating a green space on the roof of an office building present a unique opportunity to suburban architecture. Where the Centreville Road corridor through Manassas hosts a myriad of fast food restaurants, big-box stores, strip malls, car dealerships, and light industrial complexes, there are few green areas designed completely for pedestrian use, as shown in Figure 22. Therefore, the people who inevitably work in the Signal Hill Professional Center will not have any immediate areas to enjoy the outdoors.


Figure 22. Adjacent Green Space Along Liberia Avenue

The Roofscapes garden systems also include pavers for patios and walkways to pedestrianize their roof gardens, and by extending stairway access to the roof, those working inside the building only need to walk upstairs to enjoy the outdoors above the busy surrounding suburban area. Zoning regulations provided by the city of Manassas do not mention roof gardens; however, they do impose a 55'-0" height restriction to all B-1 rated office buildings. Since this building is currently 53'-4" tall, floor-to-floor heights would need to be reduced on each floor to allow an 8'-0" tall enclosure at the top of each stairwell.

To further improve the aesthetic of the roof garden and to disguise the functionality of the stairwells and rooftop air handling units, the same architectural precast panels used throughout the exterior façade could be implemented in a coordinated manner.

**Cost Considerations.** Cost information supplied by Roofscapes, Inc. indicates that it would cost $10-13 per square foot to install a 5" deep system. Further, maintenance to weed, fertilize, and replant roof gardens as necessary should require 4-6 man hours per 1000 square feet per year. Therefore, a 9000 square foot Savannah roof garden system would cost $90,000 to $117,000 to install and roughly $720 to $1,080 per year to maintain. In addition to roof garden installation, larger structural sizes under this system will increase structural construction costs by roughly $17,500 for the steel system and $30,000 for the concrete system.

However, reduced thermal loads through greater R-values in the roof system and increased productivity from a more livable work environment may offset these costs for the owner. Further, since more than 50% of the roof area would be vegetated despite air handling units, stairwells, walkways, and patios, this building would be eligible for one point under the LEED Green Building rating system (Heat Island Effect: Roof, Credit 7.2). However, given that 26 points are required for LEED Certification, further revision of all major building systems would be necessary.

## CONCLUSIONS AND RECOMMENDATIONS

Design Summary

Both the composite steel and concrete systems strive to support open office loads and large parking loads in an efficient manner. The composite steel system supports office loads through a 3” composite deck with 3.5” lightweight slab, supported by W10 beams spaced 10’-0” OC spanning the short direction of 30’-0”x20’-0” bays. In the parking structure, a 4” slab on 2” composite deck is supported by W10 beams spaced 5’-0” OC. Girders approach W21 in the office area and W24 in the parking structure. Due to lighter loads, the roof structure is non-composite with slightly larger beams.

The new reinforced concrete design maximizes the efficiency of a two-way slab by changing the column layout to produce a central 30’-0”x30’-0” bay. Though this is a relatively large bay, it produces a column layout conducive to the given parking layout utilizing four less columns than the given system. An 8”, 10” and 11” slab is found in the roof, office area and parking deck, respectively. While 3.5” drop panels are primarily used, they are upsized to 4.5” in edge columns in the office structure and to 7” in interior columns in the parking structure to combat shear by moment transfer. Larger columns ranging from 20” square to 20”x30” also combat shear by moment transfer, and they rest on enlarged spread footings.

Evaluation of the Concrete System

**Structural Efficiency**

Pros

- Smaller 15.5” (office) / 18” (parking) floor section depths
- Resilience to Superimposed Loads
- Simple Connections to Parking Structure
- Limited Lateral Drift
- No complicated fireproofing
- Possibly less excavation from smaller parking deck depth

Cons

- Heavy Structure: Larger Spread Footings
- Large (20x20) Obstructing Columns
- Drop Ceiling Negates Finished Surface
- Floor penetrations may present a problem

**Architectural Layout**

Pros

- Wider areas around building perimeter for office areas
- Larger Rentable Areas
- Columns disguised by central corridor core
- More parking spaces
- Compatible with precast exterior wall panels

Cons

- Differing rentable areas for first floor offices than originally planned

**Constructability**

Pros

- Shorter 3 week lead time for rebar
- Concrete may be cheaper in select Northern Virginia areas

Cons

- Longer erection time
- Construction in winter a concern
- Northern Virginia on PCA’s “tight cement supply” list
- More expensive according to RS Means 2006

**Green Roof**

Pros

- Concrete system able to resist larger lateral loads
- Concrete more resistant to water damage from saturated roof

Cons

- Slab sizes in roof under heaviest roof garden similar to slab under parking deck

Evaluation of the Composite Steel System

**Structural Efficiency**

Pros
- Lightweight system provides for smaller footings
- Smaller W10 columns take up less floor space

Cons
- Larger 27.5" (office) / 30" (parking) floor section depths
- Costly and time consuming moment connections needed for lateral system
- Complicated connections between parking structure and first floor
- Larger drift values
- Floor penetrations and superimposed loads require infill framing

**Architectural Layout**

Pros
- Columns less obstructive
- Columns can be placed in front of windows

Cons
- Less rentable area and more common area
- Fewer parking spaces

**Constructability**

Pros
- Less expensive by almost $200,000
- Faster erection time by over 2 weeks

Cons
- Complicated fireproofing required in parking structure and around common areas

**Green Roof**

Pros
- Under largest green roof system, composite roof structure comparable in size to office floor structure

Cons
- Lateral resistance of the given moment frame system a concern

Final Recommendations

Though concrete appears to be a more logical solution from the viewpoint of structural efficiency, its benefits soon become less convincing once a construction schedule and cost estimate reveal that it costs nearly $200,000 more and takes almost 3 additional weeks to construct. Even in Northern Virginia, where differing cost indexes show that there is a slight bias towards concrete construction, steel would still be the most economical choice. Where floor-to-floor height is not a concern, and where a drop ceiling system are used, concrete is less appropriate from an architectural standpoint.

Most of the complications involved in steel construction are found in the first floor/parking deck structure. Large supporting girders increase excavation depth and are less attractive while complicated fireproofing takes up to an additional three weeks to apply.

Therefore, as suggested by many professionals in the Washington area, the most logical solution would be a hybrid structure, with concrete columns and slab at the first floor and composite steel at the second, third, and fourth floors. By employing a concrete structure on the first floor, the building will benefit from smaller floor section depth and therefore reduced excavation, simplified connections at varying elevations, and a natural fireproofing mechanism. By employing a composite steel system in the office structure, the building will benefit from smaller column sizes, a lighter structure with smaller footings, and less expensive and lengthy construction.

Though the composite steel system would reap structural benefits, the improved architectural layouts depended on a new column layout, with eight interior columns rather than twelve. For a composite steel system resting on the altered layout used throughout the concrete design, brief hand calculations showed that:

- Girders on the critical interior Column Lines 2 and 3, with an expanded 26'-3" tributary width over a 30'-0" length would need to be either a W18x55 or W21x48. This is an increase in size from W18x35 and W21x44 girders with the existing column layout. Infill beams along the 30'-0" length would only need to be upsized to W10x19 spaced 10'-0" OC.
- Critical interior columns with an expanded 788 square foot tributary area would need to be either a W12x96 or W14x90. This is an increase in size from W10x49 in the existing layout; however, given that the concrete columns were over 20x20, larger W14 columns could be a possibility.

Though column sizes do increase dramatically to reflect significantly larger tributary areas, the actual girder and beam layout would not change drastically, and would not translate to significantly greater costs.

Though the green roof does deliver reduced sound and heat transmission through the roof deck, it would require a 10% greater upfront costs and consistent maintenance throughout the life of the building. Considering that this building was built with economy in mind, it would be hard to justify the green roof to the owner. However, when looking beyond initial costs, the addition of a green roof does present greater possibilities in terms of quality of the workspace and therefore overall marketability of the office areas to potential leasers.

## TABLES AND FIGURES

Tables



Figures

Figures, Continued

**ACKNOWLEDGEMENTS**

Thank you to my **family** for giving me the academic, personal and financial resources to get to Penn State.

Thank you to the **AE Faculty** for giving me the knowledge and confidence to get through Architectural Engineering at Penn State.

Thank you to the following for giving me the support to write my thesis and graduate from Penn State:

**Branden Ellenberger** of Morabito Consultants in Baltimore, for the project drawings and incredibly useful structural information

**Mark Bowles** of the M Group Architects in Vienna, for constant architectural references and assistance

**John Barbour** of the R.W. Murray Company in Fairfax, for guidance in the realm of construction management

**Pat Hopple**, as an excellent resource for ETABS questions

**Kathleen**, for the incredibly accurate column takeoffs

**The Structural and Construction Management Mentors**, of various companies, who directed my breadth analyses

Thank you to my **friends**, both on and off the water, for giving me the memories and friendships to miss Penn State.

## REFERENCES

American Concrete Institute. ACI 318-05. Farmington Hills, MI: ACI, 2005.

American Institute of Steel Construction. *Manual of Steel Construction, LRFD.* AISC, 2001.

ASCE 7-02

Concrete Reinforcing Steel Institute Design Manual. 1988 ed.

Das, Braja M. *Principles of Foundation Engineering.* Pacific Grove, CA: Brooks/Cole-Thomson Learning, 2004.

Egan, M. David. *Architectural Acoustics.* New York: McGraw Hill, Inc., 1988. pp 171-181.

*Facilities Construction Cost Data.* Livingston, MA: R.S. Means, Construction Publishers and Consultants, 2006.

IBC 2003.

McQuiston, F., Parker, J., and J. Spitler. *Heating, Ventilating, and Air Conditioning: Analysis and Design.* New York: John Wiley & Sons, Inc., 2000. pp 124-149.

Nilson, A., Darwin, D., and C. Dolan. *Design of Concrete Structures.* New York: McGraw Hill, Inc., 2004.

Office Finder. “A Summary of the Builders Owners and Managers Association (BOMA) Guidelines.” <http://www.officefinder.com/boma.html> 2006.

Slender Wall product information. <<www.smith-midland.com>> 2006.

Roofscapes, Inc. product information. <<http://www.roofmeadow.com>> 2006. Additional Information from Melissa in customer service.

U.S. Green Building Council. “Leed Green Building Rating System, Version 2.1.” <<http://www.usgbc.org/LEED/publications.asp>>. Revised 14 March 2003.

Various advisory e-mails from the Structural and Construction Management message board.

Zoning Ordinances. Article VIII, Division 11, 12, 13 and 14. *City of Manassas Webpage.* <<www.manassascity.org>>. 2006.

## APPENDIX A: LOAD CALCULATIONS

Snow Loading

$P_g$ = 30 PSF (MANASSAS, VA)
TERRAIN CATEGORY "C" (SUBURBAN)
↳ PARTIALLY EXPOSED ROOF — $C_e$ = 1.0 [1608.3.1]
THERMAL - NORMAL STRUCTURE — $C_t$ = 1.0 [1608.3.2]
IMPORTANCE: NORMAL STRUCTURE — I = 1.0

SNOW LOAD = 30(1.0)(1.0)(1.0) = **30 PSF**

Wind Loading

BASIC WIND SPEED — 90 MPH = V (MANASSAS, VA) FIG 6-1

WIND DIR. FACTOR — $K_D$ = 0.85 FOR MWFRS

IMPORTANCE — I = 1.0 (SPECS)

EXPOSURE CATEGORY — B (SPECS)
$Z_g$ = 1200 $\alpha$ = 7.0 TBL 6-2 Z = 53.33' MAX
$K_Z = 2.01(Z/Z_g)^{2/\alpha}$ = 0.8257 = $q_H$
$K_H$ = 0.83 (TBL 6-3)

TOPOGRAPHIC FACTOR — $K_{ZT}$ ~1.0 (SLOPING SITE, NO IRREGULARITIES)

GUST EFFECTS — G = 0.85 (RIGID STRUCTURE)

WALL PRESSURE COEFF — (COMPLETELY ENCLOSED
$C_p$ = 0.8 ($q_z$) WINDWARD
= −0.5 ($q_h$) LEEWARD (N-S DIR)
= −0.3 ($q_h$) LEEWARD (E-W DIR)

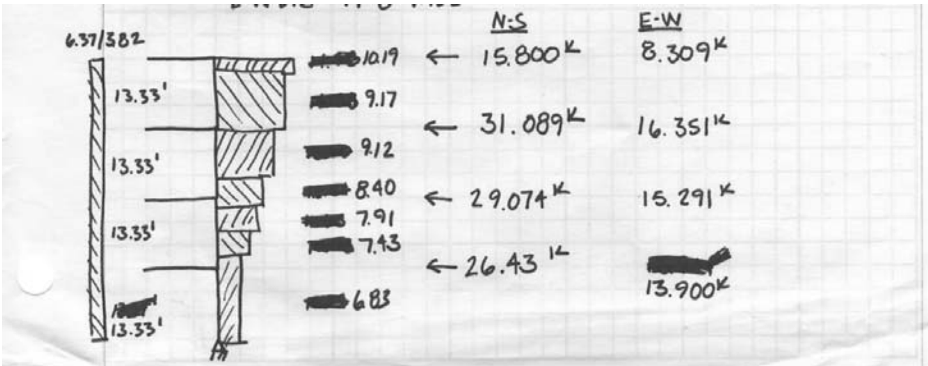
VELOCITY PRESSURE — $q_z = 0.00256 K_z K_{zT} K_D V^2 I$

| HEIGHT (FT) | $K_Z$ | $q_Z$ (PSF) | $GC_pq$ (WINDWARD) | $GC_pq$ (LEEWARD) |
|---|---|---|---|---|
| 0-15 | 0.57 | 10.05 | 6.83 | −6.37 (N-S) / −3.82 (E-W) |
| 15-20 | 0.62 | 10.93 | 7.43 | ↓ |
| 20-25 | 0.66 | 11.63 | 7.91 | ↓ |
| 25-30 | 0.70 | 12.34 | 8.40 | ↓ |
| 30-40 | 0.76 | 13.40 | 9.12 | ↓ |
| 40-50 | 0.81 | 14.28 | 9.71 | ↓ |
| 50-53.33 | 0.85 | 14.98 | 10.19 | N-S / E-W |

N-S DIR: 147'-8" WIDE
E-W DIR: 77'-8" WIDE

N-S E-W

Wind Loading, Continued




Seismic Loading, Composite Steel Structure

SEISMIC USE GROUP I
$I = 1.0$
$S_{DS} = 0.186$
$S_{D1} = 0.065$
SITE CLASS "D"
$R = 3.0$

$V = C_s W$

STRUCTURE WT: DL + 10PSF FOR PARTITIONS
10875 SQ. FT. ROUGH FLOOR AREA, 440FT PERIMETER

ROOF: 40 PSF (10875) + 440 PLF (440) = 629 K
FLOORS 2-4 80 PSF (10875) + 440 PLF (440) = 1064 K
$\Sigma$ 4883 K

$$C_s = \frac{S_{DS}}{R/I} = \frac{0.186}{3} = 0.062 \leftarrow$$

$$\frac{S_{D1}}{T(R/I)} = \frac{0.065}{0.67(3)} = 0.032$$

$$0.044 S_{DS} I = 0.044(0.186) = 0.008$$

$T = C_t h_n^x$ $C_t = 0.028$, $x = 0.80$ [MOMENT RESISTING STEEL]
$h_N = 53'\text{-}0$
$T = 0.67s.$

$V = C_s W = 0.062(4883) = 302^K$ BASE SHEAR

$F_x = C_{vx} V$, USING 170K BASE SHEAR IN SPECS.

$$C_{vx} = \frac{w_x h_x}{\Sigma w_x h_x}$$

| FLOOR | $w_x h_x$ |
|---|---|
| R | 33337 |
| 4 | 42206 |
| 3 | 28019 |
| 2 | 13832 |
| $\Sigma$ | 117394 |

$F_R = 48.3^K$
$F_4 = 61.1^K$
$F_3 = 40.6^K$
$F_2 = 20.1^K$

Seismic Loading, Concrete Structure

SEISMIC LOADING. EQUIVALENT LATERAL FORCE PROCEDURE IBC 2003

SEISMIC USE GROUP I

$I = 1.0$

$S_{DS} = 0.186$

$S_{D1} = 0.065$

SITE CLASS D

$R =$ [redacted] 3.0 (REINFORCED CONCRETE MOMENT FRAMES)

$V = C_s W$

STRUCTURE WT: DL + 20% SNOW LOAD

OFFICE [redacted]: $(10'' \text{ SLAB}/12)(150 \text{ PCF})(10875 \text{ ft}^2) + (3.5''/12'' \text{ DROP})(\overbrace{(10)(8.3')}^{\text{AVG DROP}})(15)$

$= 1360^K + 10 \text{ PSF DL}(10875)$

$= 1468^K$

$+(440 \text{ PLF WALL})(2(145) + 2(75)) = 1663^K$

ROOF: $(8/12)(150)(10875) + (\frac{3.5}{12})(10)(8.3)(15) + 10(10875)$

$+ (220)(2(145) + 2(75)) = 1294^K$

TOTAL WT $= 3(1468) + 1(1294) = 5698^K$

$C_s = \dfrac{S_{DS}}{R/I} = \dfrac{0.186}{3} = 0.062 \leftarrow$

$\dfrac{S_{D1}}{T(R/I)} = \dfrac{0.065}{0.57(3/1)} =$ [redacted] $0.038$

$T = C_t h_N^{\,x}$ $C_t = 0.016$ $x = 0.9$ [CONC FRAME CARRYING LATERAL LOAD]

$h_N = 4(13.3 \text{ FT}) = 53'$

$= (0.016)(53)^{\wedge}0.9$ $T = 0.57s$

$0.044(0.186) = 0.044 S_{DS} I = 0.008$

$V = C_s W = 0.062(5698) = \underline{354^K \text{ BASE SHEAR}}$.

$C_{vx} = \dfrac{w_x h_x}{\Sigma w_x h_x}$

| FLOOR | $w_x h_x$ | |
|---|---|---|
| R | 69010 | $F_R = 131^K$ |
| 4 | 58574 | $F_4 = 111^K$ |
| 3 | 39050 | $F_3 = 75^K$ |
| 2 | 19525 | $F_2 = 37^K$ |
| $\Sigma$ | 186159 | |

## APPENDIX B: CONCRETE FLOOR SYSTEM CALCULATIONS

Direct Design Method, Office Slab with Drops, 30'-0" Maximum Span Condition

OFFICE FLAT PLATE W/ DROPS

11" THICK 4000 psi NW CONC., 3" DROPS, 6'-8" x 10'-0"

$TL = 1.6(100) + 1.2(10 + \frac{11}{12}(150) + 5) = 343$ PSF

$M_{O\,MAX} = \frac{1}{8}(0.343)(20)(30^2) = 772$ FT-K

CS = 9.375' MS = 10.625'

end span

772 FT-K
- 70% INT(−) = 541 FT-K
  - 75% CS : 406 FT-K
  - 25% MS : 136 FT-K
- 57% (+) = 441 FT-K
  - 60% CS : 265 FT-K
  - 40% MS : 177 FT-K
- 26% EXT(−) : 201 FT-K
  - 100% CS : 201 FT-K
  - 0% MS : 0 FT-K

interior span

772 FT-K
- 65% (−) = 502 FT-K
  - 75% CS : 377 FT-K
  - 25% MS : 126 FT-K
- 35% (+) = 271 FT-K
  - 60% CS : 163 FT-K
  - 40% MS : 109 FT-K

(FLAT SLAB W/ DROPS)

406 FT-K(12) / 9.375 = 520 IN-K/FT    d ≈ 13"

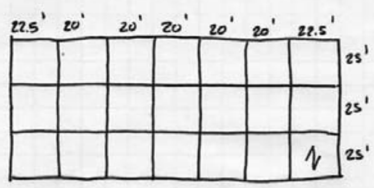
$A_S = \frac{520}{0.9(60)(0.9(13))} = 0.823$ IN² → $\boxed{\#6 @ 6"}$ $A_S = 0.88$ IN²

d = 12.875    a = 0.88(60) / 0.85(4)(12) = 1.294

$\phi M_N = 0.9(60)(0.88)(12.875 - 0.5(1.294)) = 581$ IN-K

Direct Design Method, Office Flat Plate, 25'-0" Maximum Span Condition

NEW BAY CONDITION




WORST CASE:
22'-6" x 25'-0" BAY

12 INTERIOR COLUMNS
(12 IN LAST DESIGN)

FLAT PLATE → SIMILAR DISTRIBUTION TO FLAT SLAB W/ DROPS, 9.5" THICK SLAB

$l_N/30$   (25·12)/30 = 10" THICK

$TL = 1.6(100) + 1.2(10 + \frac{10}{12}(150)) = 322$ PSF

$M_{O\,MAX} = \frac{1}{8}(0.322)(22.5)(25^2) = 566$ FT-K

$CS = \frac{1}{4}(22.5 + 20) = 10.625'$   MS = 11.875'

Direct Design Method, Office Flat Plate, 25'-0" Maximum Span Condition, Cont'd

end span

566 FT-K
- 70% ⊖ INT = 397 FT-K
  - 75% CS = 298 FT-K
  - 25% MS = 100 FT-K
- 57% ⊕ = 323 FT-K
  - 60% CS = 194 FT-K
  - 40% MS = 130 FT-K
- 26% ⊖ EXT : 148 FT-K
  - 100% CS = 148 FT-K
  - 0% MS = 0 FT-K

interior span

566 FT-K
- 65% ⊖ = 368 FT-K
  - 75% CS = 276 FT-K
  - 25% MS : 92 FT-K
- 35% ⊖ : 199 FT-K
  - 60% CS = 120 FT-K
  - 40% MS : 80 FT-K

(MAX MOMENT COND – FLAT PLATE)

$M = 298(12)/10.625 = 337$ IN-K/FT $\quad d \sim 9"$

$A_s = \frac{337}{0.9(60)(0.9)(9)} = 0.77$ IN² $\quad$ USE $\boxed{\#4 @ 3"}$

#6 @ 6"

#8 @ 12"

$d = 10 - 0.75 - 0.5(0.5) = 9"$

$a = \frac{0.80(60)}{0.85(4)(12)} = 1.17$ IN

$\phi M_N = 0.9(60)(0.80)(9 - 0.5(1.17)) = 364$ IN-K/FT ✓

Direct Design Method, Parking Slab with Beams Between All Columns

$\boxed{\text{FLAT SLAB W/BEAMS BTW ALL SUPPORTS}}$ $\quad$ \2

USE 10" THICK SLAB, 14"X24" BEAMS

$TL = 1.6(250) + 0.5(30) + 1.2(\frac{10}{12}(150) + 50 + \overset{\text{BEAMS}}{20}) = 649$ PSF

$M_o = \frac{1}{8}(20)(0.649)(27.5^2) = 1228$ FT-K

$C = \Sigma(1 - 0.63\frac{x}{y})\frac{x^3 y}{3} = \underset{13885}{(1 - 0.63(\frac{14}{24}))\frac{(14^3)(24)}{3}} + \overset{2567}{(1 - 0.63(\frac{10}{14}))\frac{(10^3)(14)}{3}} = 16452$

$I_s = \frac{1}{12}(20)(12)(10^3) = 20000 \qquad \alpha = \frac{16128}{20000} = 0.8064 \qquad \frac{\ell_2}{\ell_1} = 0.67$

$I_b = \frac{1}{12}(14)(24^3) = 16128 \qquad \beta = \frac{16452}{2(20000)} = 0.412 \qquad \alpha\frac{\ell_2}{\ell_1} = 0.541$

interior span

1228 FT-K
- 65% ⊖
  - 80% CS
    - 46% BM = 294 FT-K
    - 54% SLAB = 345 FT-K
  - 20% MS = 160 FT-K
- 35% ⊕
  - 73% CS
    - 46% BM = 145 FT-K
    - 54% SLAB = 170 FT-K
  - 20% MS = 86 FT-K

(BEAMS)

$M = 345(12)/8.375 = 495$ IN-K/FT $\quad d \sim 10 - 0.75 - 0.5 = 8.75"$

$A_s = \frac{495}{0.9(60)(0.9)(8.75)} = 1.164$ IN² $\rightarrow \boxed{\#5 @ 3"}$ $A_s = 1.24"$

$d = 10 - 0.75 - 0.5(0.625) = 8.9375 \qquad a = 1.24(60)/0.85(4)(12) = 1.83$

$\phi M_N = 0.9(1.24)(60)(8.9375 - 0.5(1.83)) = 537$ IN-K/FT

→ BEAM $\quad M = 294(12) = 3528$ IN-K $\quad d \sim 24 - 1.5 - 0.5 = 22$ IN

$A_s = 3528/0.9(60)(0.9)(22) = 3.3$ IN² $\rightarrow \boxed{\text{USE } 4\#9}$ $A_s = 4.0$

$d = 21.936 \qquad a = (4)(60)/0.85(14)(4) = 5.04$

$\phi M_N = 0.9(4)(60)(21.936 - \frac{1}{2}(5.04)) = 4194$ IN-K

## Selected ADOSS Results, Alternative #2 Office Flat Slab with Drops

```
FILE NAME            P:\ODROPSFA.ADS

PROJECT ID.          Office Final Drops
                     -----------------------------------
SPAN ID.             BC
                     -------------------

ENGINEER             Henry

DATE                 02/09/06
TIME                 09:11:02

UNITS                U.S. in-lb
CODE                 ACI 318-89

SLAB SYSTEM          FLAT SLAB SYSTEM
FRAME LOCATION       INTERIOR

DESIGN METHOD        STRENGTH DESIGN
MOMENTS AND SHEARS   NOT PROPORTIONED

NUMBER OF SPANS  7

  SOLID HEAD DIMENSIONS :       COMPUTED BY PROGRAM


CONCRETE FACTORS      SLABS         BEAMS        COLUMNS
  DENSITY(pcf  )      150.0         150.0         150.0
  TYPE             NORMAL WGT    NORMAL WGT    NORMAL WGT
  f'c    (ksi)         4.0           4.0           4.0
  fct    (psi)        423.7         423.7         423.7
  fr     (psi)        474.3         474.3         474.3


REINFORCEMENT DETAILS: NON-PRESTRESSED
  YIELD STRENGTH Fy  =  60.00 ksi
  DISTANCE TO RF CENTER FROM TENSION FACE:
       AT SLAB TOP    =   1.50 in  OUTER LAYER
       AT SLAB BOTTOM =   1.50 in  OUTER LAYER
  MINIMUM FLEXURAL BAR SIZE:
       AT SLAB TOP    =  # 4
       AT SLAB BOTTOM =  # 4
  MINIMUM SPACING:
       IN SLAB =   6.00 in

03-30-** ADOSS(tm) 6.01  Proprietary Software of PORTLAND CEMENT ASSN. Page   3
12:15:29 PM Licensed to: ae, university park, PA

                                SPAN/LOADING DATA
                                *****************
```

| SPAN NUMBER | LENGTH L1 (ft) | Tslab (in) | WIDTH L2*** LEFT (ft) | WIDTH L2*** RIGHT (ft) | SLAB SYSTEM | DESIGN STRIP (ft) | COLUMN STRIP** (ft) | UNIFORM LOADS S. DL (psf ) | UNIFORM LOADS LIVE (psf ) |
|---|---|---|---|---|---|---|---|---|---|
| 1* | 1.3 | 10.0 | 11.3 | 15.0 | 2 | 26.3 | .0 | 10.0 | 100.0 |
| 2 | 30.0 | 10.0 | 11.3 | 15.0 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 3 | 30.0 | 10.0 | 11.3 | 15.0 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 4 | 25.0 | 10.0 | 11.3 | 15.0 | 2 | 26.3 | 11.9 | 10.0 | 100.0 |
| 5 | 30.0 | 10.0 | 11.3 | 15.0 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 6 | 30.0 | 10.0 | 11.3 | 15.0 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 7* | 1.3 | 10.0 | 11.3 | 15.0 | 2 | 26.3 | .0 | 10.0 | 100.0 |

```
*  -Indicates cantilever span information.
** -Strip width used for positive flexure.
***-L2 widths are 1/2 dist. to transverse column.
"E"-Indicates exterior strip.
```

LATERAL LOAD/OUTPUT DATA
************************

LATERAL LOADS ARE SPECIFIED AS BEING CAUSED BY WIND

| JOINT NO. | SLAB MOMENTS LEFT (ft-k) | SLAB MOMENTS RIGHT (ft-k) | COLUMN MOMENTS ABOVE (ft-k) | COLUMN MOMENTS BELOW (ft-k) |
|---|---|---|---|---|
| 1 | .00 | -71.00 | .00 | .00 |
| 2 | -71.00 | -65.00 | .00 | .00 |
| 3 | -63.00 | -71.00 | .00 | .00 |
| 4 | -71.00 | -63.00 | .00 | .00 |
| 5 | -64.00 | -70.00 | .00 | .00 |
| 6 | -61.00 | .00 | .00 | .00 |

DISTRIBUTION OF DESIGN MOMENTS AT SUPPORTS
******************************************

| COL NUM | CROSS SECTN | | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) | ( % ) | COLUMN STRIP MOMENT (ft-k) | ( % ) | BEAM MOMENT (ft-k) | ( % ) | MIDDLE STRIP MOMENT (ft-k) | ( % ) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | LEFT | TOP | -6.7 | .0 | 0 | -6.5 | 95 | .0 | 0 | -.3 | 4 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| | RGHT | TOP | 399.1 | .0 | 0 | 382.8 | 95 | .0 | 0 | 16.3 | 4 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| 2 | LEFT | TOP | -775.0 | .0 | 0 | -581.2 | 75 | .0 | 0 | -193.7 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| | RGHT | TOP | 742.1 | .0 | 0 | 556.6 | 75 | .0 | 0 | 185.5 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| 3 | LEFT | TOP | -555.5 | .0 | 0 | -416.6 | 75 | .0 | 0 | -138.9 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| | RGHT | TOP | 487.3 | .0 | 0 | 365.5 | 75 | .0 | 0 | 121.8 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| 4 | LEFT | TOP | -487.3 | .0 | 0 | -365.5 | 75 | .0 | 0 | -121.8 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| | RGHT | TOP | 555.5 | .0 | 0 | 416.6 | 75 | .0 | 0 | 138.9 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| 5 | LEFT | TOP | -742.1 | .0 | 0 | -556.6 | 75 | .0 | 0 | -185.5 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| | RGHT | TOP | 775.0 | .0 | 0 | 581.2 | 75 | .0 | 0 | 193.7 | 25 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| 6 | LEFT | TOP | -399.1 | .0 | 0 | -382.8 | 95 | .0 | 0 | -16.3 | 4 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |
| | RGHT | TOP | 6.7 | .0 | 0 | 6.5 | 95 | .0 | 0 | .3 | 4 |
| | | BOT | .0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 |

DISTRIBUTION OF DESIGN MOMENTS IN SPANS
***************************************

| SPAN NUM | CROSS SECTN | | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) ( % ) | COLUMN STRIP MOMENT (ft-k) ( % ) | BEAM MOMENT (ft-k) ( % ) | MIDDLE STRIP MOMENT (ft-k) ( % ) |
|---|---|---|---|---|---|---|---|
| 2 | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 374.3 | .0 ( 0) | 224.6 ( 60) | .0 ( 0) | 149.7 ( 40) |
| | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 374.3 | .0 ( 0) | 224.6 ( 60) | .0 ( 0) | 149.7 ( 40) |
| 3 | 15.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 322.6 | .0 ( 0) | 193.5 ( 60) | .0 ( 0) | 129.0 ( 40) |
| | 15.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 322.6 | .0 ( 0) | 193.5 ( 60) | .0 ( 0) | 129.0 ( 40) |
| 4 | 11.88 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 210.7 | .0 ( 0) | 126.4 ( 60) | .0 ( 0) | 84.3 ( 39) |
| | 11.88 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 210.7 | .0 ( 0) | 126.4 ( 60) | .0 ( 0) | 84.3 ( 40) |
| 5 | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 322.6 | .0 ( 0) | 193.5 ( 60) | .0 ( 0) | 129.0 ( 40) |
| | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 322.6 | .0 ( 0) | 193.5 ( 60) | .0 ( 0) | 129.0 ( 39) |
| 6 | 15.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 374.3 | .0 ( 0) | 224.6 ( 60) | .0 ( 0) | 149.7 ( 40) |
| | 15.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 374.3 | .0 ( 0) | 224.6 ( 60) | .0 ( 0) | 149.7 ( 40) |

S H E A R   A N A L Y S I S
***************************

NOTE--Allowable shear stress in slabs = 252.96 psi when ratio of col. dim. (long/short) is less than 2.0.

--Wide beam shear (see "CODE") is not computed, check manually.

--After the column numbers, C = Corner, E = Exterior, I = Interior.

D I R E C T   S H E A R   W I T H   T R A N S F E R   O F   M O M E N T
- - - - - - - - - - A R O U N D   C O L U M N - - - - - - - - - -

| COL. NO. | ALLOW. STRESS (psi) | PATT NO. | REACTION (kips) | SHEAR STRESS (psi) | PATT NO. | REACTION (kips) | UNBAL. MOMENT (ft-k) | SHEAR TRANSFR (ft-k) | SHEAR STRESS (psi) |
|---|---|---|---|---|---|---|---|---|---|
| 1E | 252.96 | 4 | 148.2 | 116.20 | 4 | 148.2 | 422.6 | 159.8 | 250.55 |
| 2I | 252.96 | 4 | 305.0 | 233.61 | 4 | 305.0 | -38.5 | -15.4 | 246.43 |
| 3I | 252.96 | 4 | 254.5 | 194.92 | 4 | 254.5 | -82.7 | -33.1 | 222.46 |
| 4I | 252.96 | 4 | 254.5 | 194.92 | 4 | 254.5 | 82.7 | 33.1 | 222.46 |
| 5I | 252.96 | 4 | 305.0 | 233.61 | 4 | 305.0 | 38.5 | 15.4 | 246.43 |
| 6E | 252.96 | 4 | 148.2 | 116.20 | 4 | 148.2 | -422.6 | -159.8 | 250.55 |

- - AROUND DROP/SOLID HEAD - -

| COLUMN NUMBER | ALLOW. STRESS (psi) | PATT NO. | REACTION (kips) | SHEAR STRESS (psi) |
|---|---|---|---|---|
| 1E | 185.35 | 4 | 124.5 | 62.93 |
| 2I | 170.90 | 4 | 266.1 | 76.10 |
| 3I | 172.82 | 4 | 218.9 | 65.29 |
| 4I | 172.82 | 4 | 218.9 | 65.29 |
| 5I | 170.90 | 4 | 266.1 | 76.10 |
| 6E | 185.35 | 4 | 124.5 | 62.93 |

## D E S I G N   R E S U L T S

NOTE--The schedule given below is a guide for proper reinforcement placement and is based on reasonable engineering judgement. Unusual boundary and/or loading conditions may require modification of this schedule.

### N E G A T I V E   R E I N F O R C E M E N T

| COLUMN NUMBER | COLUMN STRIP LONG BARS NO | SIZE | LEFT (ft) | RIGHT (ft) | COLUMN STRIP SHORT BARS NO | SIZE | LEFT (ft) | RIGHT (ft) | MIDDLE STRIP LONG BARS NO | SIZE | LEFT (ft) | RIGHT (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 11 | # 5 | 1.33 | 10.18 | 11 | # 5 | 1.33 | 6.50 | 14 | # 4 | 1.33 | 7.77 |
| 2 | 10 | # 7 | 10.77 | 10.77 | 10 | # 7 | 6.50 | 6.50 | 17 | # 5 | 10.77 | 10.77 |
| 3 | 10 | # 6 | 10.18 | 11.77 | 9 | # 6 | 6.50 | 6.77 | 19 | # 4 | 9.27 | 11.77 |
| 4 | 10 | # 6 | 11.77 | 10.18 | 9 | # 6 | 6.77 | 6.50 | 19 | # 4 | 11.77 | 9.27 |
| 5 | 10 | # 7 | 10.77 | 10.77 | 10 | # 7 | 6.50 | 6.50 | 17 | # 5 | 10.77 | 10.77 |
| 6 | 11 | # 5 | 10.18 | 1.33 | 11 | # 5 | 6.50 | 1.33 | 14 | # 4 | 7.77 | 1.33 |

### P O S I T I V E   R E I N F O R C E M E N T

| SPAN NUMBER | COLUMN STRIP LONG BARS NO | SIZE | LENGTH (ft) | COLUMN STRIP SHORT BARS NO | SIZE | LENGTH (ft) | MIDDLE STRIP LONG BARS NO | SIZE | LENGTH (ft) | MIDDLE STRIP SHORT BARS NO | SIZE | LENGTH (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 10 | # 5 | 25.92 | 10 | # 5 | 25.92 | 10 | # 4 | 29.92 | 10 | # 4 | 25.17 |
| 3 | 9 | # 5 | 22.50 | 8 | # 5 | 22.50 | 9 | # 4 | 30.50 | 9 | # 4 | 21.00 |
| 4 | 9 | # 4 | 18.75 | 8 | # 4 | 18.75 | 8 | # 4 | 25.50 | 8 | # 4 | 17.50 |
| 5 | 9 | # 5 | 22.50 | 8 | # 5 | 22.50 | 9 | # 4 | 30.50 | 9 | # 4 | 21.00 |
| 6 | 10 | # 5 | 25.92 | 10 | # 5 | 25.92 | 10 | # 4 | 29.92 | 10 | # 4 | 25.17 |

### D E F L E C T I O N   A N A L Y S I S

NOTES--The deflections below must be combined with those of the analysis in the perpendicular direction. Consult users manual for method of combination and limitations.

--Spans 1 and 7 are cantilevers.

--Time-dependent deflections are in addition to those shown and must be computed as a multiplier of the dead load(DL) deflection. See "CODE" for range of multipliers.

--Deflections due to concentrated or partialloads may be larger at the point of application than those shown at the centerline. Deflections are computed as from an average uniform loading derived from the sum of all loads applied to the span.

--Modulus of elasticity of concrete, Ec = 3834. ksi

| SPAN NUMBER | DEAD LOAD Ieff. (in^4) | COLUMN STRIP DEAD (in) | COLUMN STRIP LIVE (in) | COLUMN STRIP TOTAL (in) | MIDDLE STRIP DEAD (in) | MIDDLE STRIP LIVE (in) | MIDDLE STRIP TOTAL (in) |
|---|---|---|---|---|---|---|---|
| 1 | 48644. | -.015 | -.011 | -.026 | -.015 | -.011 | -.026 |
| 2 | 32569. | .208 | .262 | .470 | .108 | .120 | .229 |
| 3 | 31470. | .155 | .236 | .392 | .078 | .116 | .194 |
| 4 | 33935. | .050 | .083 | .133 | .011 | .028 | .039 |
| 5 | 31470. | .155 | .236 | .392 | .078 | .116 | .194 |
| 6 | 32569. | .208 | .262 | .470 | .108 | .120 | .229 |
| 7 | 48644. | -.015 | -.011 | -.026 | -.015 | -.011 | -.026 |

## Selected ADOSS Results, Alternative #2 Parking Flat Slab with Drops

```
FILE NAME            P:\PDROPSFA.ADS

PROJECT ID.          Parking Final Drops
                     -----------------------------------
SPAN ID.             BC
                     -------------------

ENGINEER             Henry

DATE                 02/09/06
TIME                 10:51:12

UNITS                U.S. in-lb
CODE                 ACI 318-89

SLAB SYSTEM          FLAT SLAB SYSTEM
FRAME LOCATION       INTERIOR

DESIGN METHOD        STRENGTH DESIGN
MOMENTS AND SHEARS   NOT PROPORTIONED

NUMBER OF SPANS  9

  SOLID HEAD DIMENSIONS :       COMPUTED BY PROGRAM


CONCRETE FACTORS      SLABS         BEAMS        COLUMNS
  DENSITY(pcf  )      150.0         150.0         150.0
  TYPE             NORMAL WGT    NORMAL WGT    NORMAL WGT
  f'c    (ksi)          4.0           4.0           4.0
  fct    (psi)        423.7         423.7         423.7
  fr     (psi)        474.3         474.3         474.3


REINFORCEMENT DETAILS: NON-PRESTRESSED
  YIELD STRENGTH Fy  =  60.00 ksi
  DISTANCE TO RF CENTER FROM TENSION FACE:
       AT SLAB TOP    =   1.50 in  OUTER LAYER
       AT SLAB BOTTOM =   1.50 in  OUTER LAYER
  MINIMUM FLEXURAL BAR SIZE:
       AT SLAB TOP    =  # 4
       AT SLAB BOTTOM =  # 4
  MINIMUM SPACING:
       IN SLAB =   6.00 in

                                SPAN/LOADING DATA
                                *****************
```

| SPAN NUMBER | LENGTH L1 (ft) | Tslab (in) | WIDTH L2*** LEFT (ft) | WIDTH L2*** RIGHT (ft) | SLAB SYSTEM | DESIGN STRIP (ft) | COLUMN STRIP** (ft) | UNIFORM LOADS S. DL (psf ) | UNIFORM LOADS LIVE (psf ) |
|---|---|---|---|---|---|---|---|---|---|
| 1* | 1.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | .0 | 10.0 | 100.0 |
| 2 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 3 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 4 | 25.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 11.9 | 10.0 | 100.0 |
| 5 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 6 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 7 | 27.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 12.5 | 50.0 | 280.0 |
| 8 | 17.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 8.5 | 50.0 | 280.0 |
| 9* | 1.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | .0 | 50.0 | 280.0 |

COLUMN/TORSIONAL DATA
*********************

| COLUMN NUMBER | COLUMN ABOVE SLAB C1 (in) | C2 (in) | HGT (ft) | COLUMN BELOW SLAB C1 (in) | C2 (in) | HGT (ft) | CAPITAL** EXTEN. (in) | DEPTH (in) | COLUMN STRIP* (ft) | MIDDLE STRIP* (ft) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 20.0 | 24.0 | 13.3 | 20.0 | 30.0 | 13.3 | .0 | .0 | 13.1 | 13.1 |
| 2 | 20.0 | 20.0 | 13.3 | 24.0 | 20.0 | 13.3 | .0 | .0 | 13.1 | 13.1 |
| 3 | 20.0 | 20.0 | 13.3 | 24.0 | 20.0 | 13.3 | .0 | .0 | 11.9 | 14.4 |
| 4 | 20.0 | 20.0 | 13.3 | 24.0 | 20.0 | 13.3 | .0 | .0 | 11.9 | 14.4 |
| 5 | 20.0 | 20.0 | 13.3 | 24.0 | 20.0 | 13.3 | .0 | .0 | 13.1 | 13.1 |
| 6 | 20.0 | 24.0 | 13.3 | 24.0 | 24.0 | 13.3 | .0 | .0 | 12.5 | 13.8 |
| 7 | .0 | .0 | 13.3 | 24.0 | 24.0 | 13.3 | .0 | .0 | 8.5 | 17.8 |
| 8 | .0 | .0 | 13.3 | 20.0 | 20.0 | 13.3 | .0 | .0 | 8.5 | 17.8 |

Columns with zero "C2" are round columns.
* -Strip width used for negative flexure.
**-Capital extension distance measured from face of column.

| COLUMN NUMBER | TRANSVERSE BEAM WIDTH (in) | DEPTH (in) | ECCEN (in) | DROP PANEL/SOLID HEAD LEFT (ft) | RIGHT (ft) | WIDTH (ft) | THICK (in) | SUPPORT FIXITY* % |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.0 | 20.0 | .0 | 1.3 | 5.0 | 8.8 | 3.5 | 100% |
| 2 | .0 | .0 | .0 | 5.0 | 5.0 | 8.8 | 3.5 | 100% |
| 3 | .0 | .0 | .0 | 5.0 | 4.2 | 8.8 | 3.5 | 100% |
| 4 | .0 | .0 | .0 | 4.2 | 5.0 | 8.8 | 3.5 | 100% |
| 5 | .0 | .0 | .0 | 5.0 | 5.0 | 8.8 | 3.5 | 100% |
| 6 | 24.0 | 32.0 | .0 | 5.0 | 4.6 | 8.8 | 7.0 | 100% |
| 7 | .0 | .0 | .0 | 4.6 | 2.8 | 8.8 | 7.0 | 100% |
| 8 | 20.0 | 20.0 | .0 | 2.8 | 1.3 | 8.8 | 3.5 | 100% |

* -Support fixity of 0% denotes pinned condition.
Support fixity of 999% denotes fixed end condition.

LATERAL LOAD/OUTPUT DATA
************************

LATERAL LOADS ARE SPECIFIED AS BEING CAUSED BY WIND

| JOINT NO. | SLAB MOMENTS LEFT (ft-k) | RIGHT (ft-k) | COLUMN MOMENTS ABOVE (ft-k) | BELOW (ft-k) |
|---|---|---|---|---|
| 1 | .00 | -71.00 | .00 | .00 |
| 2 | -71.00 | -65.00 | .00 | .00 |
| 3 | -63.00 | -70.00 | .00 | .00 |
| 4 | -70.00 | -63.00 | .00 | .00 |
| 5 | -65.00 | -67.00 | .00 | .00 |
| 6 | -66.00 | -40.00 | .00 | .00 |
| 7 | -26.00 | -26.00 | .00 | .00 |
| 8 | -32.00 | .00 | .00 | .00 |

LATERAL LOADS DISTRIBUTED TO THE COLUMN AND MIDDLE STRIPS ACCORDING TO CODE DISTRIBUTION FACTORS.

DISTRIBUTION OF DESIGN MOMENTS AT SUPPORTS
******************************************

| COL NUM | CROSS SECTN | | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) ( % ) | COLUMN STRIP MOMENT (ft-k) ( % ) | BEAM MOMENT (ft-k) ( % ) | MIDDLE STRIP MOMENT (ft-k) ( % ) |
|---|---|---|---|---|---|---|---|
| 1 | LEFT | TOP | -6.8 | .0 ( 0) | -6.6 ( 96) | .0 ( 0) | -.2 ( 3) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT | TOP | 377.3 | .0 ( 0) | 365.6 ( 96) | .0 ( 0) | 11.6 ( 3) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 2 | LEFT | TOP | -794.5 | .0 ( 0) | -595.9 ( 74) | .0 ( 0) | -198.6 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | RGHT | TOP | 750.8 | .0 ( 0) | 563.1 ( 75) | .0 ( 0) | 187.7 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 3 | LEFT | TOP | -555.8 | .0 ( 0) | -416.9 ( 75) | .0 ( 0) | -139.0 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT | TOP | 478.8 | .0 ( 0) | 359.1 ( 75) | .0 ( 0) | 119.7 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 4 | LEFT | TOP | -504.9 | .0 ( 0) | -378.7 ( 75) | .0 ( 0) | -126.2 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT | TOP | 597.4 | .0 ( 0) | 448.0 ( 75) | .0 ( 0) | 149.3 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 5 | LEFT | TOP | -653.6 | .0 ( 0) | -490.2 ( 75) | .0 ( 0) | -163.4 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT | TOP | 603.5 | .0 ( 0) | 452.6 ( 75) | .0 ( 0) | 150.9 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 6 | LEFT | TOP | -889.6 | .0 ( 0) | -667.2 ( 75) | .0 ( 0) | -222.4 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT | TOP | 1099.9 | .0 ( 0) | 824.9 ( 75) | .0 ( 0) | 275.0 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 7 | LEFT | TOP | -1023.3 | .0 ( 0) | -767.4 ( 75) | .0 ( 0) | -255.8 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT | TOP | 851.3 | .0 ( 0) | 638.5 ( 75) | .0 ( 0) | 212.8 ( 25) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |

DISTRIBUTION OF DESIGN MOMENTS AT SUPPORTS
******************************************

| COL NUM | CROSS SECTN | | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) ( % ) | COLUMN STRIP MOMENT (ft-k) ( % ) | BEAM MOMENT (ft-k) ( % ) | MIDDLE STRIP MOMENT (ft-k) ( % ) |
|---|---|---|---|---|---|---|---|
| 8 | LEFT | TOP | -41.7 | .0 ( 0) | -40.4 ( 96) | .0 ( 0) | -1.3 ( 3) |
| | | BOT | 36.0 | .0 ( 0) | 34.9 ( 96) | .0 ( 0) | 1.1 ( 3) |
| | RGHT | TOP | 12.6 | .0 ( 0) | 12.2 ( 96) | .0 ( 0) | .4 ( 3) |
| | | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |

DISTRIBUTION OF DESIGN MOMENTS IN SPANS
***************************************

| SPAN NUM | CROSS SECTN | | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) ( % ) | COLUMN STRIP MOMENT (ft-k) ( % ) | BEAM MOMENT (ft-k) ( % ) | MIDDLE STRIP MOMENT (ft-k) ( % ) |
|---|---|---|---|---|---|---|---|
| 2 | 12.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 410.8 | .0 ( 0) | 246.5 ( 60) | .0 ( 0) | 164.3 ( 40) |
| | 12.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 410.8 | .0 ( 0) | 246.5 ( 60) | .0 ( 0) | 164.3 ( 40) |
| 3 | 15.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 337.5 | .0 ( 0) | 202.5 ( 60) | .0 ( 0) | 135.0 ( 40) |
| | 15.75 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 337.5 | .0 ( 0) | 202.5 ( 60) | .0 ( 0) | 135.0 ( 40) |
| 4 | 11.88 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 215.9 | .0 ( 0) | 129.6 ( 60) | .0 ( 0) | 86.4 ( 40) |
| | 11.88 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 215.9 | .0 ( 0) | 129.6 ( 60) | .0 ( 0) | 86.4 ( 39) |
| 5 | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 355.1 | .0 ( 0) | 213.0 ( 60) | .0 ( 0) | 142.0 ( 40) |

DISTRIBUTION OF DESIGN MOMENTS IN SPANS

| SPAN NUM | CROSS SECTN | | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) ( % ) | COLUMN STRIP MOMENT (ft-k) ( % ) | BEAM MOMENT (ft-k) ( % ) | MIDDLE STRIP MOMENT (ft-k) ( % ) |
|---|---|---|---|---|---|---|---|
| | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 355.1 | .0 ( 0) | 213.0 ( 60) | .0 ( 0) | 142.0 ( 40) |
| 6 | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 296.4 | .0 ( 0) | 177.8 ( 60) | .0 ( 0) | 118.6 ( 39) |
| | 14.25 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 296.4 | .0 ( 0) | 177.8 ( 60) | .0 ( 0) | 118.6 ( 40) |
| 7 | 14.35 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 502.4 | .0 ( 0) | 301.5 ( 60) | .0 ( 0) | 201.0 ( 40) |
| | 14.35 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 502.4 | .0 ( 0) | 301.5 ( 60) | .0 ( 0) | 201.0 ( 40) |
| 8 | 9.77 | TOP | -29.9 | .0 ( 0) | -18.0 ( 60) | .0 ( 0) | -12.0 ( 39) |
| | | BOT | 257.9 | .0 ( 0) | 154.8 ( 60) | .0 ( 0) | 103.2 ( 40) |
| | 9.77 | TOP | -29.9 | .0 ( 0) | -18.0 ( 60) | .0 ( 0) | -12.0 ( 39) |
| | | BOT | 257.9 | .0 ( 0) | 154.8 ( 60) | .0 ( 0) | 103.2 ( 40) |

S H E A R   A N A L Y S I S

NOTE--Allowable shear stress in slabs = 252.96 psi when ratio of col. dim. (long/short) is less than 2.0.

--Wide beam shear (see "CODE") is not computed, check manually.

--After the column numbers, C = Corner, E = Exterior, I = Interior.

D I R E C T   S H E A R   W I T H   T R A N S F E R   O F   M O M E N T
A R O U N D   C O L U M N

| COL. NO. | ALLOW. STRESS (psi) | PATT NO. | REACTION (kips) | SHEAR STRESS (psi) | PATT NO. | REACTION (kips) | UNBAL. MOMENT (ft-k) | SHEAR TRANSFR (ft-k) | SHEAR STRESS (psi) |
|---|---|---|---|---|---|---|---|---|---|
| 1E | 252.96 | 4 | 151.1 | 111.67 | 4 | 151.1 | 397.4 | 144.0 | 220.02 |
| 2I | 252.96 | 4 | 320.8 | 207.35 | 4 | 320.8 | -52.3 | -21.7 | 220.91 |
| 3I | 252.96 | 4 | 264.9 | 171.20 | 4 | 264.9 | -97.1 | -40.2 | 196.38 |
| 4I | 252.96 | 4 | 272.1 | 175.92 | 4 | 272.1 | 114.5 | 47.4 | 205.59 |
| 5I | 252.96 | 4 | 289.8 | 187.33 | 4 | 289.8 | -71.4 | -29.5 | 205.83 |
| 6I | 252.96 | 4 | 446.6 | 157.08 | 4 | 446.6 | 314.0 | 125.6 | 195.73 |
| 7I | 252.96 | 4 | 482.4 | 212.30 | 4 | 482.4 | -213.3 | -85.3 | 244.35 |
| 8E | 252.96 | 4 | 135.6 | 109.14 | 1 | 135.5 | -52.1 | -20.5 | 127.29 |

- - AROUND DROP/SOLID HEAD - -

| COLUMN NUMBER | ALLOW. STRESS (psi) | PATT NO. | REACTION (kips) | SHEAR STRESS (psi) |
|---|---|---|---|---|
| 1E | 191.80 | 4 | 127.5 | 57.23 |
| 2I | 175.72 | 4 | 280.2 | 71.09 |
| 3I | 177.83 | 4 | 227.7 | 60.25 |
| 4I | 177.83 | 4 | 235.0 | 62.18 |
| 5I | 175.72 | 4 | 249.2 | 63.23 |
| 6I | 176.82 | 4 | 389.4 | 101.02 |
| 7I | 182.98 | 4 | 426.1 | 124.07 |
| 8E | 206.97 | 1 | 111.2 | 61.49 |

D E S I G N   R E S U L T S

NOTE--The schedule given below is a guide for proper reinforcement placement and is based on reasonable engineering judgement. Unusual boundary and/or loading conditions may require modification of this schedule.

N E G A T I V E   R E I N F O R C E M E N T

| COLUMN NUMBER | COLUMN STRIP LONG BARS NO | SIZE | LEFT (ft) | RIGHT (ft) | COLUMN STRIP SHORT BARS NO | SIZE | LEFT (ft) | RIGHT (ft) | MIDDLE STRIP LONG BARS NO | SIZE | LEFT (ft) | RIGHT (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 11 | # 5 | 1.33 | 10.13 | 10 | # 5 | 1.33 | 6.47 | 16 | # 4 | 1.33 | 7.76 |
| 2 | 10 | # 7 | 10.76 | 10.76 | 9 | # 7 | 6.63 | 6.63 | 24 | # 4 | 10.76 | 10.76 |
| 3 | 9 | # 6 | 10.24 | 11.75 | 8 | # 6 | 6.60 | 6.75 | 17 | # 4 | 9.25 | 11.75 |
| 4 | 10 | # 6 | 11.75 | 10.24 | 9 | # 6 | 6.75 | 6.60 | 18 | # 4 | 11.75 | 9.25 |
| 5 | 11 | # 6 | 10.75 | 10.75 | 10 | # 6 | 6.60 | 6.60 | 20 | # 4 | 10.75 | 10.75 |
| 6 | 10 | # 7 | 12.25 | 10.24 | 10 | # 7 | 7.00 | 6.60 | 22 | # 5 | 12.25 | 9.95 |
| 7 | 7 | # 8 | 9.78 | 9.36 | 7 | # 8 | 6.07 | 6.07 | 31 | # 4 | 9.78 | 8.38 |
| 8** | 7 | # 4 | 7.03 | 1.33 | 7 | # 4 | 4.06 | 1.33 | 21 | # 4 | 6.90 | 1.33 |

** - Positive reinforcement required, design manually.

P O S I T I V E   R E I N F O R C E M E N T

| SPAN NUMBER | COLUMN STRIP LONG BARS NO | SIZE | LENGTH (ft) | COLUMN STRIP SHORT BARS NO | SIZE | LENGTH (ft) | MIDDLE STRIP LONG BARS NO | SIZE | LENGTH (ft) | MIDDLE STRIP SHORT BARS NO | SIZE | LENGTH (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 10 | # 5 | 25.92 | 10 | # 5 | 25.92 | 10 | # 4 | 29.92 | 10 | # 4 | 25.17 |
| 3 | 8 | # 5 | 22.50 | 8 | # 5 | 22.50 | 8 | # 4 | 30.50 | 8 | # 4 | 21.00 |
| 4 | 8 | # 4 | 18.75 | 8 | # 4 | 18.75 | 9 | # 4 | 25.50 | 8 | # 4 | 17.50 |
| 5 | 9 | # 5 | 22.50 | 8 | # 5 | 22.50 | 9 | # 4 | 30.50 | 8 | # 4 | 21.00 |
| 6 | 11 | # 4 | 22.50 | 11 | # 4 | 22.50 | 8 | # 4 | 30.50 | 8 | # 4 | 21.00 |
| 7 | 9 | # 6 | 21.22 | 8 | # 6 | 21.22 | 12 | # 4 | 27.83 | 12 | # 4 | 19.13 |
| 8** | 6 | # 5 | 15.08 | 6 | # 5 | 15.08 | 11 | # 4 | 16.92 | 10 | # 4 | 14.12 |

D E F L E C T I O N   A N A L Y S I S

NOTES--The deflections below must be combined with those of the analysis in the perpendicular direction. Consult users manual for method of combination and limitations.

--Spans 1 and 9 are cantilevers.

--Time-dependent deflections are in addition to those shown and must be computed as a multiplier of the dead load(DL) deflection. See "CODE" for range of multipliers.

--Deflections due to concentrated or partialloads may be larger at the point of application than those shown at the centerline. Deflections are computed as from an average uniform loading derived from the sum of all loads applied to the span.

--Modulus of elasticity of concrete, Ec = 3834. ksi

| SPAN NUMBER | DEAD LOAD Ieff. (in^4) | COLUMN STRIP DEFLECTION DUE TO: DEAD (in) | LIVE (in) | TOTAL (in) | MIDDLE STRIP DEFLECTION DUE TO: DEAD (in) | LIVE (in) | TOTAL (in) |
|---|---|---|---|---|---|---|---|
| 1 | 52778. | -.014 | -.009 | -.023 | -.014 | -.009 | -.023 |
| 2 | 40937. | .181 | .186 | .367 | .095 | .087 | .182 |
| 3 | 42290. | .125 | .175 | .301 | .062 | .086 | .149 |
| 4 | 43859. | .042 | .052 | .094 | .009 | .016 | .025 |
| 5 | 43859. | .132 | .194 | .326 | .071 | .101 | .172 |
| 6 | 52428. | .098 | .121 | .218 | .044 | .044 | .088 |
| 7 | 60998. | .089 | .392 | .481 | .049 | .207 | .256 |
| 8 | 52428. | .020 | .039 | .059 | .002 | .003 | .005 |
| 9 | 52778. | -.003 | -.003 | -.006 | -.003 | -.004 | -.006 |

## Selected ADOSS Results, First Floor Slab with Superimposed Vault Load

```
PROJECT ID.          Parking Final Drops
                     ----------------------------------
SPAN ID.             BC
                     -------------------

ENGINEER             Henry

DATE                 02/09/06
TIME                 10:51:12

UNITS                U.S. in-lb
CODE                 ACI 318-89

SLAB SYSTEM          FLAT SLAB SYSTEM
FRAME LOCATION       INTERIOR

DESIGN METHOD        STRENGTH DESIGN
MOMENTS AND SHEARS   NOT PROPORTIONED

NUMBER OF SPANS  9

  SOLID HEAD DIMENSIONS :       COMPUTED BY PROGRAM


CONCRETE FACTORS      SLABS         BEAMS        COLUMNS
  DENSITY(pcf  )      150.0         150.0         150.0
  TYPE             NORMAL WGT    NORMAL WGT    NORMAL WGT
  f'c    (ksi)          4.0           4.0           4.0
  fct    (psi)        423.7         423.7         423.7
  fr     (psi)        474.3         474.3         474.3


REINFORCEMENT DETAILS: NON-PRESTRESSED
  YIELD STRENGTH Fy  =  60.00 ksi
  DISTANCE TO RF CENTER FROM TENSION FACE:
       AT SLAB TOP    =   1.50 in  OUTER LAYER
       AT SLAB BOTTOM =   1.50 in  OUTER LAYER
  MINIMUM FLEXURAL BAR SIZE:
       AT SLAB TOP    =  # 4
       AT SLAB BOTTOM =  # 4
  MINIMUM SPACING:
       IN SLAB =   6.00 in
```

SPAN/LOADING DATA
*****************

| SPAN NUMBER | LENGTH L1 (ft) | Tslab (in) | WIDTH LEFT (ft) | L2*** RIGHT (ft) | SLAB SYSTEM | DESIGN STRIP (ft) | COLUMN STRIP** (ft) | UNIFORM LOADS S. DL (psf ) | LIVE (psf ) |
|---|---|---|---|---|---|---|---|---|---|
| 1* | 1.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | .0 | 10.0 | 100.0 |
| 2 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 3 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 4 | 25.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 11.9 | 10.0 | 100.0 |
| 5 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 6 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 7 | 27.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 12.5 | 50.0 | 280.0 |
| 8 | 17.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 8.5 | 50.0 | 280.0 |
| 9* | 1.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | .0 | 50.0 | 280.0 |

```
*  -Indicates cantilever span information.
** -Strip width used for positive flexure.
***-L2 widths are 1/2 dist. to transverse column.
"E"-Indicates exterior strip.
```

PARTIAL LOADING DATA
********************

| SPAN No. | LOAD No. | TYPE | PARTIAL DEAD LOADS Wa | Wb | La | Lb | LOAD No. | TYPE | PARTIAL LIVE LOADS Wa | Wb | La | Lb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1* | | | | | | | | | | | | |
| 2 | 1 | UNIF | 702.5 | .0 | 20.0 | 30.0 | 1 | UNIF | 850.0 | .0 | 20.0 | 30.0 |
| 3 | 1 | UNIF | 702.5 | .0 | .0 | 10.0 | 1 | UNIF | 850.0 | .0 | .0 | 10.0 |
| 4 | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | |
| 6 | 1 | UNIF | 6111.0 | .0 | 6.7 | 15.7 | | | | | | |
| 7 | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | |
| 9* | | | | | | | | | | | | |

D E S I G N   R E S U L T S
***************************

NOTE--The schedule given below is a guide for proper reinforcement placement and is based on reasonable engineering judgement. Unusual boundary and/or loading conditions may require modification of this schedule.

N E G A T I V E   R E I N F O R C E M E N T
*********************************************

| COLUMN NUMBER | C O L U M N S T R I P: LONG BARS -B A R - L E N G T H- NO | SIZE | LEFT (ft) | RIGHT (ft) | SHORT BARS -B A R - L E N G T H- NO | SIZE | LEFT (ft) | RIGHT (ft) | M I D D L E S T R I P: LONG BARS -B A R - L E N G T H- NO | SIZE | LEFT (ft) | RIGHT (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1** | 10 | # 6 | 1.33 | 10.13 | 9 | # 6 | 1.33 | 6.47 | 16 | # 4 | 1.33 | 9.26 |
| 2 | 10 | # 7 | 12.26 | 12.26 | 10 | # 7 | 7.01 | 7.01 | 17 | # 5 | 12.26 | 12.26 |
| 3** | 10 | # 6 | 10.75 | 11.75 | 9 | # 6 | 6.60 | 6.75 | 19 | # 4 | 10.75 | 11.75 |
| 4** | 10 | # 6 | 11.75 | 10.75 | 9 | # 6 | 6.75 | 6.60 | 18 | # 4 | 11.75 | 10.75 |
| 5 | 10 | # 7 | 12.25 | 10.24 | 9 | # 7 | 7.00 | 6.60 | 16 | # 5 | 12.25 | 9.25 |
| 6 | 11 | # 7 | 12.25 | 11.32 | 10 | # 7 | 7.00 | 6.60 | 23 | # 5 | 12.25 | 11.32 |
| 7 | 7 | # 8 | 9.36 | 9.36 | 7 | # 8 | 6.07 | 6.07 | 30 | # 4 | 8.42 | 9.23 |
| 8** | 7 | # 4 | 7.03 | 1.33 | 7 | # 4 | 4.06 | 1.33 | 21 | # 4 | 6.90 | 1.33 |

** - Positive reinforcement required, design manually.

P O S I T I V E   R E I N F O R C E M E N T
*********************************************

| SPAN NUMBER | C O L U M N S T R I P: LONG BARS ---- B A R ---- NO | SIZE | LENGTH (ft) | SHORT BARS ---- B A R ---- NO | SIZE | LENGTH (ft) | M I D D L E S T R I P: LONG BARS ---- B A R ---- NO | SIZE | LENGTH (ft) | SHORT BARS ---- B A R ---- NO | SIZE | LENGTH (ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 10 | # 5 | 25.92 | 10 | # 5 | 25.92 | 10 | # 4 | 29.92 | 10 | # 4 | 25.17 |
| 3 | 9 | # 5 | 22.50 | 8 | # 5 | 22.50 | 9 | # 4 | 30.50 | 8 | # 4 | 21.00 |
| 4 | 8 | # 4 | 18.75 | 8 | # 4 | 18.75 | 9 | # 4 | 25.50 | 8 | # 4 | 17.50 |
| 5 | 12 | # 4 | 22.50 | 12 | # 4 | 22.50 | 8 | # 4 | 30.50 | 8 | # 4 | 21.00 |
| 6 | 9 | # 6 | 23.00 | 8 | # 6 | 23.00 | 12 | # 4 | 30.50 | 12 | # 4 | 21.00 |
| 7 | 9 | # 6 | 21.22 | 8 | # 6 | 21.22 | 12 | # 4 | 27.83 | 12 | # 4 | 19.13 |
| 8** | 7 | # 5 | 15.08 | 6 | # 5 | 15.08 | 11 | # 4 | 16.92 | 10 | # 4 | 14.12 |

** - Negative reinforcement required, design manually.

D E F L E C T I O N   A N A L Y S I S
***************************************

NOTES--The deflections below must be combined with those of the analysis in the perpendicular direction. Consult users manual for method of combination and limitations.

--Spans 1 and 9 are cantilevers.

--Time-dependent deflections are in addition to those shown and must be computed as a multiplier of the dead load(DL) deflection. See "CODE" for range of multipliers.

--Deflections due to concentrated or partialloads may be larger at the point of application than those shown at the centerline. Deflections are computed as from an average uniform loading derived from the sum of all loads applied to the span.

--Modulus of elasticity of concrete, Ec = 3834. ksi

| SPAN NUMBER | DEAD LOAD Ieff. (in^4) | COLUMN STRIP DEFLECTION DUE TO: | | | MIDDLE STRIP DEFLECTION DUE TO: | | |
|---|---|---|---|---|---|---|---|
| | | DEAD (in) | LIVE (in) | TOTAL (in) | DEAD (in) | LIVE (in) | TOTAL (in) |
| 1 | 52778. | -.014 | -.009 | -.023 | -.014 | -.009 | -.023 |
| 2 | 39764. | .194 | .230 | .424 | .100 | .104 | .204 |
| 3 | 40837. | .136 | .193 | .329 | .067 | .095 | .162 |
| 4 | 43859. | .046 | .050 | .096 | .013 | .015 | .027 |
| 5 | 39442. | .115 | .178 | .293 | .047 | .094 | .142 |
| 6 | 41495. | .219 | .144 | .363 | .124 | .053 | .177 |
| 7 | 60998. | .070 | .370 | .440 | .030 | .199 | .229 |
| 8 | 52428. | .023 | .038 | .061 | .005 | .002 | .007 |
| 9 | 52778. | -.003 | -.003 | -.007 | -.003 | -.003 | -.007 |

## Selected ADOSS Results, Torsion Beam between Office Floor and Parking Deck

FILE NAME P:\PDROPSFA.ADS

PROJECT ID. Parking Final Drops

SPAN ID. BC

ENGINEER Henry

UNITS U.S. in-lb
CODE ACI 318-89

SLAB SYSTEM FLAT SLAB SYSTEM
FRAME LOCATION INTERIOR

DESIGN METHOD STRENGTH DESIGN
MOMENTS AND SHEARS NOT PROPORTIONED

NUMBER OF SPANS 9

| CONCRETE FACTORS | SLABS | BEAMS | COLUMNS |
|---|---|---|---|
| DENSITY(pcf ) | 150.0 | 150.0 | 150.0 |
| TYPE | NORMAL WGT | NORMAL WGT | NORMAL WGT |
| f'c (ksi) | 4.0 | 4.0 | 4.0 |
| fct (psi) | 423.7 | 423.7 | 423.7 |
| fr (psi) | 474.3 | 474.3 | 474.3 |

REINFORCEMENT DETAILS: NON-PRESTRESSED
YIELD STRENGTH Fy = 60.00 ksi
DISTANCE TO RF CENTER FROM TENSION FACE:
AT SLAB TOP = 1.50 in OUTER LAYER
AT SLAB BOTTOM = 1.50 in OUTER LAYER
MINIMUM FLEXURAL BAR SIZE:
AT SLAB TOP = # 4
AT SLAB BOTTOM = # 4
MINIMUM SPACING:
IN SLAB = 6.00

SPAN/LOADING DATA
*****************

| SPAN NUMBER | LENGTH L1 (ft) | Tslab (in) | WIDTH LEFT (ft) | L2*** RIGHT (ft) | SLAB SYSTEM | DESIGN STRIP (ft) | COLUMN STRIP** (ft) | UNIFORM LOADS S. DL (psf ) | LIVE (psf ) |
|---|---|---|---|---|---|---|---|---|---|
| 1* | 1.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | .0 | 10.0 | 100.0 |
| 2 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 3 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 4 | 25.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 11.9 | 10.0 | 100.0 |
| 5 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 6 | 30.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 13.1 | 10.0 | 100.0 |
| 7 | 27.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 12.5 | 50.0 | 280.0 |
| 8 | 17.0 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | 8.5 | 50.0 | 280.0 |
| 9* | 1.3 | 11.0 | 15.0 | 11.3 | 2 | 26.3 | .0 | 50.0 | 280.0 |

T R A N S V E R S E B E A M S H E A R A N D T O R S I O N
R E Q U I R E M E N T S (kips, ft-k, SQ.in, /,in.)
**********************************************************************

LEFT SIDE

| BEAM No. | PATT. NO. | Vu@d SHEAR | Vc@d SHEAR | Tu@d TORSION | Tc@d TORSION | Av/s @d | At/s @d | Atot/s @d | Al @d |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 49.5 | 15.5 | 157.9 | 49.3 | .039 | .101 | .241 | 6.68 |
| 2 | * * | | | Transverse beam not specified | | | | | * * |
| 3 | * * | | | Transverse beam not specified | | | | | * * |
| 4 | * * | | | Transverse beam not specified | | | | | * * |
| 5 | * * | | | Transverse beam not specified | | | | | * * |
| 6 | 2 | 90.1 | 54.7 | 148.1 | 89.9 | .028 | .026 | .080 | 2.53 |
| 7 | * * | | | Transverse beam not specified | | | | | * * |
| 8 | 3 | 68.1 | 41.5 | 39.8 | 24.2 | .035 | .017 | .068 | 1.11 |

RIGHT SIDE

| BEAM No. | PATT. NO. | Vu@d SHEAR | Vc@d SHEAR | Tu@d TORSION | Tc@d TORSION | Av/s @d | At/s @d | Atot/s @d | Al @d |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 28.2 | 6.8 | 213.3 | 51.6 | .024 | .148 | .319 | 9.76 |
| 2 | * * | | Transverse beam not specified | | | | | | * * |
| 3 | * * | | Transverse beam not specified | | | | | | * * |
| 4 | * * | | Transverse beam not specified | | | | | | * * |
| 5 | * * | | Transverse beam not specified | | | | | | * * |
| 6 | 2 | 49.0 | 27.4 | 190.4 | 106.4 | .020* | .036 | .088 | 3.53 |
| 7 | * * | | Transverse beam not specified | | | | | | * * |
| 8 | 3 | 40.2 | 29.1 | 56.4 | 40.8 | .017* | .019 | .054 | 1.40 |

DISTRIBUTION OF DESIGN MOMENTS AT SUPPORTS
******************************************

| COL NUM | CROSS SECTN | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) ( % ) | COLUMN STRIP MOMENT (ft-k) ( % ) | BEAM MOMENT (ft-k) ( % ) | MIDDLE STRIP MOMENT (ft-k) ( % ) |
|---|---|---|---|---|---|---|
| 1 | LEFT TOP | -13.6 | .0 ( 0) | -2.0 ( 14) | -11.1 ( 81) | -.6 ( 4) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT TOP | 104.2 | .0 ( 0) | 15.0 ( 14) | 85.0 ( 81) | 4.3 ( 4) |
| | BOT | -45.2 | .0 ( 0) | -6.5 ( 14) | -36.9 ( 81) | -1.8 ( 4) |
| 2 | LEFT TOP | -1203.3 | .0 ( 0) | -112.2 ( 9) | -635.6 ( 52) | -455.5 ( 37) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT TOP | 1285.3 | .0 ( 0) | 146.5 ( 11) | 830.0 ( 64) | 308.9 ( 24) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 3 | LEFT TOP | -1262.2 | .0 ( 0) | -143.8 ( 11) | -815.1 ( 64) | -303.3 ( 24) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT TOP | 1179.3 | .0 ( 0) | 116.5 ( 9) | 660.3 ( 55) | 402.5 ( 34) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 4 | LEFT TOP | -534.9 | .0 ( 0) | -52.9 ( 9) | -299.5 ( 55) | -182.6 ( 34) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT TOP | 520.2 | .0 ( 0) | 390.2 ( 75) | .0 ( 0) | 130.1 ( 25) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 5 | LEFT TOP | -523.0 | .0 ( 0) | -392.2 ( 75) | .0 ( 0) | -130.7 ( 25) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | RGHT TOP | 523.5 | .0 ( 0) | 392.6 ( 75) | .0 ( 0) | 130.9 ( 25) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| 6 | LEFT TOP | -34.2 | .0 ( 0) | -33.8 ( 99) | .0 ( 0) | -.3 ( 0) |
| | BOT | 1.0 | .0 ( 0) | 1.0 ( 99) | .0 ( 0) | .0 ( 0) |
| | RGHT TOP | 12.5 | .0 ( 0) | 12.4 ( 99) | .0 ( 0) | .1 ( 0) |
| | BOT | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |

```
FILE NAME            P:\PDROPSF9.ADS
CODE                 ACI 318-89

SLAB SYSTEM          BEAM-SUPPORTED SLAB
FRAME LOCATION       INTERIOR

DESIGN METHOD        STRENGTH DESIGN
MOMENTS AND SHEARS   NOT PROPORTIONED

NUMBER OF SPANS  7
```

| CONCRETE FACTORS | SLABS | BEAMS | COLUMNS |
|---|---|---|---|
| DENSITY(pcf ) | 150.0 | 150.0 | 150.0 |
| TYPE | NORMAL WGT | NORMAL WGT | NORMAL WGT |
| f'c (ksi) | 4.0 | 4.0 | 4.0 |
| fct (psi) | 423.7 | 423.7 | 423.7 |
| fr (psi) | 474.3 | 474.3 | 474.3 |

```
REINFORCEMENT DETAILS: NON-PRESTRESSED
  YIELD STRENGTH (flexural) Fy  =  60.00 ksi
  YIELD STRENGTH (stirrups) Fyv =  60.00 ksi
```

```
  DISTANCE TO RF CENTER FROM TENSION FACE:
       AT SLAB TOP    =   1.50 in  OUTER LAYER
       AT SLAB BOTTOM =   1.50 in  OUTER LAYER
       AT BEAM TOP    =   1.50 in  OUTER LAYER
       AT BEAM BOTTOM =   1.50 in
  FLEXURAL BAR SIZES:    MINIMUM | MAXIMUM
       AT SLAB TOP    =   # 4
       AT SLAB BOTTOM =   # 4
       AT BEAM TOP    =   # 4       #14
       IN BEAM BOTTOM =   # 4       #14
  MINIMUM SPACING:
       IN SLAB =   6.00 in
       IN BEAM =   1.00 in

                             SPAN/LOADING DATA
                             *****************
```

| SPAN NUMBER | LENGTH L1 (ft) | Tslab (in) | WIDTH L2*** LEFT (ft) | WIDTH L2*** RIGHT (ft) | SLAB SYSTEM | DESIGN STRIP (ft) | COLUMN STRIP** (ft) | UNIFORM LOADS S. DL (psf ) | UNIFORM LOADS LIVE (psf ) |
|---|---|---|---|---|---|---|---|---|---|
| 1* | 1.3 | 11.0 | 15.0 | 15.0 | 4 | 30.0 | .0 | 60.0 | 250.0 |
| 2 | 21.0 | 11.0 | 15.0 | 15.0 | 4 | 30.0 | 8.5 | 60.0 | 250.0 |
| 3 | 31.0 | 11.0 | 15.0 | 15.0 | 4 | 30.0 | 13.0 | 60.0 | 250.0 |
| 4 | 23.0 | 11.0 | 15.0 | 15.0 | 4 | 30.0 | 9.5 | 60.0 | 250.0 |
| 5 | 20.0 | 11.0 | 15.0 | 15.0 | 4 | 30.0 | 10.0 | 60.0 | 250.0 |
| 6 | 17.5 | 11.0 | 15.0 | 15.0 | 4 | 30.0 | 8.8 | 60.0 | 250.0 |
| 7* | 1.3 | 11.0 | 15.0 | 15.0 | 4 | 30.0 | .0 | 60.0 | 250.0 |

BEAMS ALONG SPAN DATA
*********************

| SPAN NUMBER | BEAM WIDTH (in) | BEAM DEPTHS LEFT (in) | BEAM DEPTHS CENTER (in) | BEAM DEPTHS RIGHT (in) | HAUNCH LENGTHS LEFT (ft) | HAUNCH LENGTHS RIGHT (ft) |
|---|---|---|---|---|---|---|
| 1 | 24.0 | 32.0 | 32.0 | 32.0 | .0 | .0 |
| 2 | 24.0 | 32.0 | 32.0 | 32.0 | .0 | .0 |
| 3 | 24.0 | 32.0 | 32.0 | 32.0 | .0 | .0 |
| 4 | 24.0 | 32.0 | 32.0 | 32.0 | .0 | .0 |
| 5 | .0 | .0 | .0 | .0 | .0 | .0 |
| 6 | .0 | .0 | .0 | .0 | .0 | .0 |
| 7 | .0 | .0 | .0 | .0 | .0 | .0 |

DISTRIBUTION OF DESIGN MOMENTS IN SPANS
***************************************

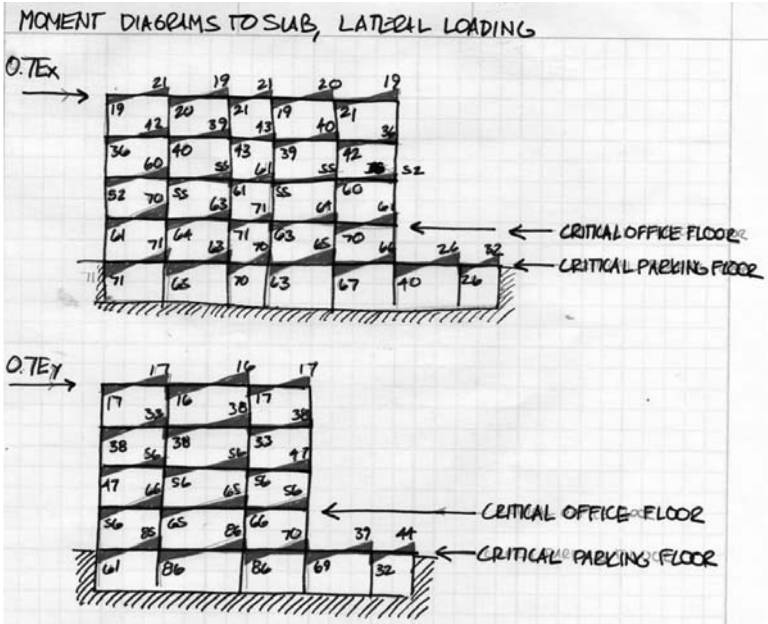
| SPAN NUM | CROSS SECTN | | TOTAL MOMENT (ft-k) | TOTAL-VERT DIFFERENCE (ft-k) ( % ) | COLUMN STRIP MOMENT (ft-k) ( % ) | BEAM MOMENT (ft-k) ( % ) | MIDDLE STRIP MOMENT (ft-k) ( % ) |
|---|---|---|---|---|---|---|---|
| 2 | 8.93 | TOP | -11.1 | .0 ( 0) | -1.0 ( 9) | -5.9 ( 52) | -4.2 ( 37) |
| | | BOT | 512.1 | .0 ( 0) | 47.7 ( 9) | 270.5 ( 52) | 193.9 ( 37) |
| 3 | 16.27 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 1016.3 | .0 ( 0) | 115.8 ( 11) | 656.3 ( 64) | 244.3 ( 24) |
| 4 | 12.07 | TOP | -96.1 | .0 ( 0) | -9.5 ( 9) | -53.8 ( 55) | -32.8 ( 34) |
| | | BOT | 575.5 | .0 ( 0) | 56.9 ( 9) | 322.2 ( 55) | 196.4 ( 34) |
| 5 | 10.50 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 357.6 | .0 ( 0) | 214.6 ( 60) | .0 ( 0) | 143.1 ( 40) |
| 6 | 10.06 | TOP | .0 | .0 ( 0) | .0 ( 0) | .0 ( 0) | .0 ( 0) |
| | | BOT | 384.4 | .0 ( 0) | 230.6 ( 60) | .0 ( 0) | 153.7 ( 39) |

Sample Spreadsheet Used to Size Torsion Beam

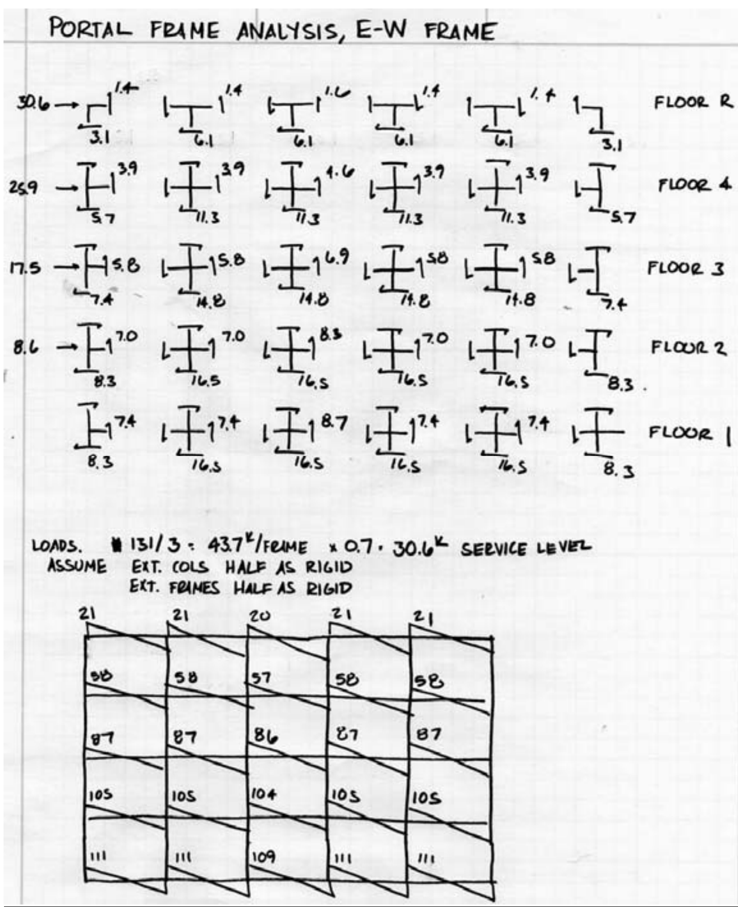
| | | | | |
|---|---|---|---|---|
| Tu= | 151 | | | |
| Vu= | 96 | | | |
| BEAM DIMENSIONS | | SIZE OK? | | |
| H= | 24 | 0.453012 | <? | 0.474 |
| B= | 26.5 | assumes f'c=4000 psi | | |
| Acp= | 636 | MAX SPACING | | |
| Pcp= | 101 | 10.875 | | |
| Aoh= | 471.5 | 10.25 | | |
| Ao= | 400.775 | 24 | | |
| ph= | 87 | final: | 10 | |
| TORSION | | SHEAR | | |
| At= | 0.050236 | Vc= | 51.53722 | |
| | | Av= | 0.048198 | |
| LONGITUDINAL REINFORCEMENT | | | | |
| Al= | 0.437053 | | | |
| Al= | 2.914961 | | | |
| FLEXURAL REINFORCEMENT | | | | |
| Mmax= | 769.1 | steel des | 8#10 | |
| As= | 8.929525 | AsFinal= | 10 | |
| phiMn= | 840.1665 | a= | 6.659267 | |

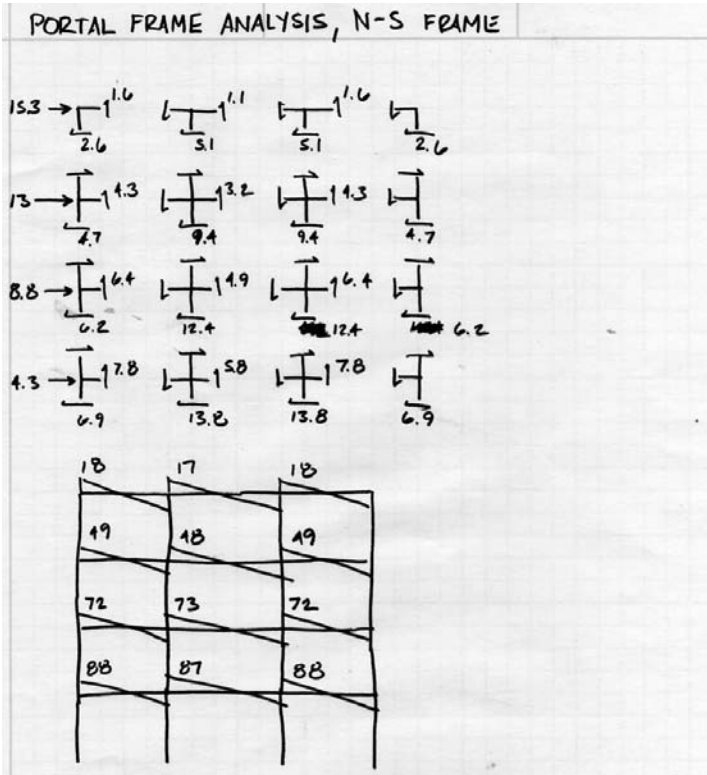
steel des At+Av — #4 stirrups @ 10"
steel des long — 10-#5 distributed upsize 1,4,5,8 bottom reinf to 11

Slab Moments from Lateral Loads Derrived from ETABS




Slab Moments Determined from Portal Frame Analysis






CRSI Tables Used to Size Columns and Reinforcing

**RECTANGULAR TIED COLUMNS 20" × 24"**

Short columns – no sidesway
Bending on major or minor axis

MI MA

$f'_c$ = 4,000 psi
$\phi M$ in inch-kips

$f_y$ = 60,000 psi
$\phi P$ in kips

| BARS | RHO | AXIS | Max Cap | | 0% fy | | 25% fy | | 50% fy | | 100% fy | | .1f'c Ag | | Zero Axial Load |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | φM | φP | φM | φP | φM | φP | φM | φP | φM | φP | φM | φP | φM |
| 4-#10 | 1.06 | MA | 2658 | 1075 | 3448 | 970 | 4330 | 816 | 4829 | 694 | 5361 | 509 | 3888 | 192 | 2792 |
| 2E | | MI | 2177 | 1075 | 2933 | 950 | 3604 | 798 | 3978 | 679 | 4368 | 497 | 3148 | 192 | 2277 |
| 4-#11 | 1.30 | MA | 2735 | 1112 | 3690 | 985 | 4599 | 826 | 5135 | 699 | 5755 | 502 | 4286 | 192 | 3354 |
| 2E | | MI | 2231 | 1112 | 3127 | 963 | 3813 | 807 | 4211 | 682 | 4665 | 490 | 3453 | 192 | 2720 |
| 4-#14 | 1.88 | MA | 2932 | 1199 | 4208 | 1034 | 5227 | 861 | 5880 | 720 | 6745 | 496 | 5282 | 192 | 4695 |
| 2E | | MI | 2375 | 1199 | 3532 | 1011 | 4300 | 841 | 4787 | 703 | 5430 | 482 | 4222 | 192 | 3773 |
| 4-#18 | 3.33 | MA | 3368 | 1421 | 5455 | 1161 | 6751 | 953 | 7696 | 777 | 9166 | 481 | 7717 | 192 | 7940 |
| 2E | | MI | 2688 | 1421 | 4496 | 1136 | 5469 | 932 | 6176 | 758 | 7268 | 464 | 6080 | 192 | 6282 |
| 6-# 9 | 1.25 | MA | 2744 | 1104 | 3611 | 991 | 4551 | 831 | 5103 | 705 | 5737 | 509 | 4266 | 192 | 3279 |
| 2L-3S | | MI | 2056 | 1104 | 2762 | 980 | 3401 | 821 | 3738 | 695 | 4051 | 504 | 3310 | 192 | 2667 |
| 6-#10 | 1.59 | MA | 2871 | 1155 | 3925 | 1020 | 4934 | 853 | 5559 | 717 | 6345 | 506 | 4878 | 192 | 4097 |
| 2L-3S | | MI | 2110 | 1155 | 2933 | 1010 | 3604 | 843 | 3978 | 708 | 4368 | 502 | 3680 | 192 | 3303 |
| 6-#11 | 1.95 | MA | 2981 | 1211 | 4265 | 1047 | 5326 | 871 | 6014 | 728 | 6938 | 499 | 5475 | 192 | 4919 |
| 2L-3S | | MI | 2154 | 1211 | 3127 | 1036 | 3813 | 861 | 4211 | 717 | 4665 | 494 | 4013 | 192 | 3930 |
| 6-#14 | 2.81 | MA | 3261 | 1342 | 5024 | 1123 | 6259 | 927 | 7128 | 762 | 8426 | 490 | 6973 | 192 | 6905 |
| 2L-3S | | MI | 2283 | 1342 | 3532 | 1115 | 4300 | 917 | 4787 | 752 | 5430 | 486 | 4843 | 192 | 5405 |
| 6-#18 | 5.00 | MA | 3882 | 1675 | 6861 | 1320 | 8529 | 1070 | 9847 | 851 | 12063 | 471 | 10635 | 192 | 11727 |
| 2L-3S | | MI | 2580 | 1675 | 4496 | 1315 | 5469 | 1061 | 6176 | 838 | 7268 | 464 | 6745 | 192 | 8116 |
| 6-# 9 | 1.25 | MA | 2504 | 1104 | 3232 | 1001 | 4072 | 840 | 4523 | 712 | 4956 | 519 | 4087 | 192 | 3273 |
| 3L-2S | | MI | 2244 | 1104 | 3061 | 971 | 3780 | 815 | 4197 | 690 | 4669 | 497 | 3447 | 192 | 2664 |
| 6-#10 | 1.59 | MA | 2579 | 1155 | 3448 | 1032 | 4330 | 863 | 4829 | 726 | 5361 | 517 | 4574 | 192 | 4073 |
| 3L-2S | | MI | 2338 | 1155 | 3310 | 1000 | 4081 | 835 | 4554 | 702 | 5144 | 494 | 3925 | 192 | 3312 |
| 6-#11 | 1.95 | MA | 2643 | 1211 | 3690 | 1061 | 4599 | 883 | 5135 | 737 | 5755 | 512 | 5020 | 192 | 4872 |
| 3L-2S | | MI | 2417 | 1211 | 3578 | 1025 | 4383 | 853 | 4901 | 712 | 5594 | 486 | 4381 | 192 | 3955 |
| 6-#14 | 2.81 | MA | 2817 | 1342 | 4208 | 1142 | 5227 | 942 | 5880 | 774 | 6745 | 507 | 6119 | 192 | 6762 |
| 3L-2S | | MI | 2619 | 1342 | 4170 | 1100 | 5107 | 907 | 5763 | 745 | 6743 | 477 | 5536 | 192 | 5504 |
| 6-#18 | 5.00 | MA | 3250 | 1675 | 5455 | 1349 | 6751 | 1093 | 7696 | 868 | 9166 | 495 | 8680 | 192 | 10502 |
| 3L-2S | | MI | 3073 | 1675 | 5585 | 1295 | 6847 | 1048 | 7842 | 833 | 9506 | 454 | 8325 | 192 | 9210 |
| 8-# 8 | 1.32 | MA | 2779 | 1114 | 3663 | 1000 | 4630 | 838 | 5205 | 709 | 5880 | 510 | 4410 | 192 | 3457 |
| 2L-4S | | MI | 2034 | 1114 | 2695 | 994 | 3322 | 833 | 3635 | 708 | 3912 | 507 | 3211 | 192 | 2795 |
| 8-# 9 | 1.67 | MA | 2911 | 1167 | 3990 | 1031 | 5030 | 861 | 5682 | 723 | 6517 | 507 | 5053 | 192 | 4311 |
| 2L-4S | | MI | 2084 | 1167 | 2850 | 1027 | 3504 | 857 | 3845 | 724 | 4188 | 504 | 3588 | 192 | 3435 |
| 8-#10 | 2.12 | MA | 3074 | 1236 | 4403 | 1071 | 5538 | 890 | 6290 | 741 | 7328 | 503 | 5871 | 192 | 5393 |
| 2L-4S | | MI | 2147 | 1236 | 3044 | 1070 | 3734 | 888 | 4111 | 744 | 4539 | 501 | 4057 | 192 | 4126 |
| 8-#11 | 2.60 | MA | 3217 | 1309 | 4839 | 1109 | 6053 | 917 | 6893 | 757 | 8122 | 495 | 6668 | 192 | 6475 |
| 2L-4S | | MI | 2197 | 1309 | 3257 | 1109 | 3965 | 915 | 4368 | 760 | 4867 | 491 | 4500 | 192 | 4753 |
| 8-#14 | 3.75 | MA | 3572 | 1484 | 5840 | 1212 | 7291 | 992 | 8376 | 804 | 10107 | 485 | 8669 | 192 | 9108 |
| 2L-4S | | MI | 2356 | 1484 | 3714 | 1218 | 4513 | 993 | 5006 | 811 | 5711 | 480 | 5443 | 192 | 6252 |
| 8-# 8 | 1.32 | MA | 2590 | 1114 | 3362 | 1008 | 4249 | 845 | 4744 | 715 | 5259 | 518 | 4277 | 192 | 3452 |
| 3E | | MI | 2124 | 1114 | 2863 | 987 | 3541 | 827 | 3914 | 699 | 4294 | 505 | 3469 | 192 | 2808 |
| 8-# 9 | 1.67 | MA | 2683 | 1167 | 3611 | 1040 | 4551 | 869 | 5103 | 730 | 5737 | 516 | 4872 | 192 | 4294 |
| 3E | | MI | 2192 | 1167 | 3061 | 1019 | 3780 | 850 | 4197 | 714 | 4669 | 502 | 3912 | 192 | 3477 |
| 8-#10 | 2.12 | MA | 2800 | 1236 | 3925 | 1083 | 4934 | 900 | 5559 | 750 | 6345 | 514 | 5556 | 192 | 5354 |
| 3E | | MI | 2278 | 1236 | 3310 | 1060 | 4081 | 880 | 4554 | 732 | 5144 | 499 | 4437 | 192 | 4314 |
| 8-#11 | 2.60 | MA | 2901 | 1309 | 4265 | 1123 | 5326 | 928 | 6014 | 766 | 6938 | 508 | 6196 | 192 | 6408 |
| 3E | | MI | 2353 | 1309 | 3578 | 1098 | 4383 | 906 | 4901 | 746 | 5594 | 490 | 4913 | 192 | 5133 |
| 8-#14 | 3.75 | MA | 3180 | 1484 | 5024 | 1231 | 6259 | 1008 | 7128 | 816 | 8426 | 502 | 7792 | 192 | 8936 |
| 3E | | MI | 2548 | 1484 | 4170 | 1204 | 5107 | 983 | 5763 | 793 | 6743 | 481 | 6117 | 192 | 7095 |
| 8-#18 | 6.67 | MA | 3829 | 1928 | 6861 | 1508 | 8529 | 1209 | 9847 | 943 | 12063 | 485 | 11562 | 192 | 14108 |
| 3E | | MI | 3015 | 1928 | 5585 | 1474 | 6847 | 1178 | 7842 | 912 | 9506 | 453 | 8921 | 192 | 10832 |
| 8-# 8 | 1.32 | MA | 2477 | 1114 | 3152 | 1016 | 3975 | 852 | 4394 | 725 | 4781 | 522 | 3939 | 192 | 3423 |
| 4L-2S | | MI | 2271 | 1114 | 3102 | 981 | 3843 | 822 | 4280 | 695 | 4786 | 499 | 3564 | 192 | 2807 |
| 8-# 9 | 1.67 | MA | 2548 | 1167 | 3347 | 1050 | 4206 | 877 | 4662 | 742 | 5135 | 521 | 4420 | 192 | 4225 |
| 4L-2S | | MI | 2371 | 1167 | 3361 | 1011 | 4159 | 844 | 4655 | 708 | 5286 | 495 | 4066 | 192 | 3484 |
| 8-#10 | 2.12 | MA | 2636 | 1236 | 3592 | 1095 | 4499 | 910 | 5003 | 765 | 5585 | 520 | 5021 | 192 | 5119 |
| 4L-2S | | MI | 2494 | 1236 | 3687 | 1050 | 4558 | 872 | 5131 | 726 | 5920 | 490 | 4704 | 192 | 4338 |
| 8-#11 | 2.60 | MA | 2712 | 1309 | 3862 | 1136 | 4800 | 940 | 5342 | 783 | 6021 | 513 | 5602 | 192 | 5930 |
| 4L-2S | | MI | 2592 | 1309 | 4028 | 1087 | 4953 | 898 | 5591 | 741 | 6523 | 482 | 5312 | 192 | 5179 |

## SQUARE TIED COLUMNS 16″ × 16″

Short columns; no sidesway
Bars symmetrical in 4 faces

$f'_c$ = 4,000 psi $\phi M$ in inch-kips    $f_y$ = 60,000 psi $\phi P$ in kips

| BARS | RHO | Max Cap φM | Max Cap φP | 0% fy φM | 0% fy φP | 25% fy φM | 25% fy φP | 50% fy φM | 50% fy φP | 100% fy φM | 100% fy φP | .1f'c Ag φM | .1f'c Ag φP | Zero Axial Load φM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-# 8 | 1.23 | 933 | 588 | 1326 | 504 | 1597 | 422 | 1750 | 357 | 1919 | 257 | 1407 | 102 | 1092 |
| 4-# 9 | 1.56 | 967 | 614 | 1422 | 518 | 1712 | 433 | 1887 | 364 | 2100 | 255 | 1589 | 102 | 1344 |
| 4-#10 | 1.98 | 1008 | 648 | 1542 | 537 | 1857 | 446 | 2059 | 372 | 2325 | 252 | 1820 | 102 | 1660 |
| 4-#11 | 2.44 | 1037 | 685 | 1666 | 554 | 1995 | 458 | 2217 | 378 | 2501 | 241 | 2031 | 102 | 1963 |
| 4-#14 | 3.52 | 1124 | 773 | 1945 | 604 | 2336 | 494 | 2623 | 400 | 2997 | 226 | 2574 | 102 | 2698 |
| 4-#18 | 6.25 | 1320 | 995 | 2598 | 734 | 3138 | 588 | 3541 | 451 | 4117 | 179 | 3856 | 102 | 4412 |
| 8-# 6 | 1.38 | 895 | 599 | 1260 | 518 | 1525 | 433 | 1670 | 365 | 1816 | 261 | 1468 | 102 | 1217 |
| 8-# 7 | 1.88 | 933 | 640 | 1373 | 542 | 1661 | 450 | 1831 | 376 | 2031 | 259 | 1706 | 102 | 1602 |
| 8-# 8 | 2.47 | 976 | 688 | 1503 | 571 | 1820 | 471 | 2020 | 389 | 2282 | 256 | 1976 | 102 | 2043 |
| 8-# 9 | 3.13 | 1022 | 741 | 1643 | 603 | 1991 | 495 | 2224 | 403 | 2554 | 253 | 2261 | 102 | 2513 |
| 8-#10 | 3.97 | 1078 | 809 | 1818 | 645 | 2207 | 524 | 2481 | 421 | 2893 | 248 | 2615 | 102 | 3056 |
| 8-#11 | 4.88 | 1121 | 883 | 1993 | 684 | 2409 | 552 | 2718 | 436 | 3158 | 231 | 2917 | 102 | 3461 |
| 8-#14 | 7.03 | 1254 | 1058 | 2404 | 790 | 2917 | 628 | 3325 | 481 | 3904 | 206 | 3718 | 102 | 4512 |
| 12-#10 | 5.95 | 1225 | 970 | 2172 | 752 | 2635 | 609 | 2996 | 476 | 3579 | 238 | 3407 | 102 | 4131 |
| 12-#11 | 7.31 | 1295 | 1081 | 2409 | 814 | 2915 | 653 | 3325 | 501 | 3953 | 213 | 3816 | 102 | 4720 |

## SQUARE TIED COLUMNS 18″ × 18″

| BARS | RHO | Max Cap φM | Max Cap φP | 0% fy φM | 0% fy φP | 25% fy φM | 25% fy φP | 50% fy φM | 50% fy φP | 100% fy φM | 100% fy φP | .1f'c Ag φM | .1f'c Ag φP | Zero Axial Load φM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-# 9 | 1.23 | 1344 | 744 | 1872 | 646 | 2281 | 542 | 2516 | 459 | 2777 | 331 | 2040 | 130 | 1576 |
| 4-#10 | 1.57 | 1397 | 778 | 2016 | 665 | 2455 | 555 | 2721 | 467 | 3049 | 328 | 2314 | 130 | 1952 |
| 4-#11 | 1.93 | 1437 | 815 | 2170 | 681 | 2626 | 566 | 2916 | 472 | 3302 | 322 | 2572 | 130 | 2322 |
| 4-#14 | 2.78 | 1549 | 902 | 2510 | 730 | 3038 | 602 | 3406 | 494 | 3943 | 314 | 3229 | 130 | 3211 |
| 4-#18 | 4.94 | 1797 | 1124 | 3312 | 858 | 4021 | 695 | 4579 | 552 | 5390 | 279 | 4799 | 130 | 5313 |
| 8-# 6 | 1.09 | 1254 | 728 | 1676 | 647 | 2056 | 543 | 2256 | 461 | 2437 | 338 | 1897 | 130 | 1421 |
| 8-# 7 | 1.48 | 1301 | 769 | 1810 | 671 | 2218 | 561 | 2447 | 472 | 2691 | 336 | 2211 | 130 | 1880 |
| 8-# 8 | 1.95 | 1354 | 817 | 1964 | 700 | 2406 | 582 | 2670 | 485 | 2989 | 334 | 2541 | 130 | 2407 |
| 8-# 9 | 2.47 | 1414 | 870 | 2132 | 732 | 2610 | 605 | 2913 | 500 | 3312 | 331 | 2891 | 130 | 2972 |
| 8-#10 | 3.14 | 1484 | 939 | 2343 | 774 | 2868 | 635 | 3221 | 518 | 3722 | 328 | 3325 | 130 | 3677 |
| 8-#11 | 3.85 | 1539 | 1012 | 2559 | 813 | 3118 | 663 | 3511 | 534 | 4103 | 320 | 3710 | 130 | 4331 |
| 8-#14 | 5.56 | 1703 | 1187 | 3058 | 920 | 3732 | 740 | 4246 | 580 | 5067 | 307 | 4702 | 130 | 5643 |
| 12-#10 | 4.70 | 1662 | 1100 | 2763 | 883 | 3390 | 716 | 3833 | 576 | 4540 | 321 | 4320 | 130 | 4997 |
| 12-#11 | 5.78 | 1750 | 1210 | 3058 | 946 | 3723 | 767 | 4238 | 602 | 5074 | 310 | 4843 | 130 | 5825 |
| 16-#10 | 6.27 | 1844 | 1261 | 3206 | 992 | 3921 | 802 | 4483 | 627 | 5403 | 321 | 5281 | 130 | 6324 |

## SQUARE TIED COLUMNS 20″ × 20″

| BARS | RHO | Max Cap φM | Max Cap φP | 0% fy φM | 0% fy φP | 25% fy φM | 25% fy φP | 50% fy φM | 50% fy φP | 100% fy φM | 100% fy φP | .1f'c Ag φM | .1f'c Ag φP | Zero Axial Load φM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-# 9 | 1.00 | 1804 | 888 | 2401 | 790 | 2960 | 664 | 3268 | 566 | 3582 | 416 | 2564 | 160 | 1807 |
| 4-#10 | 1.27 | 1869 | 923 | 2570 | 808 | 3163 | 678 | 3507 | 573 | 3898 | 413 | 2882 | 160 | 2244 |
| 4-#11 | 1.56 | 1922 | 959 | 2756 | 823 | 3367 | 688 | 3739 | 578 | 4198 | 407 | 3187 | 160 | 2680 |
| 4-#14 | 2.25 | 2062 | 1047 | 3156 | 872 | 3852 | 723 | 4315 | 600 | 4963 | 400 | 3956 | 160 | 3723 |
| 4-#18 | 4.00 | 2370 | 1269 | 4110 | 1000 | 5017 | 815 | 5702 | 657 | 6802 | 384 | 5814 | 160 | 6212 |
| 8-# 7 | 1.20 | 1753 | 914 | 2325 | 816 | 2884 | 685 | 3186 | 580 | 3481 | 423 | 2766 | 160 | 2156 |
| 8-# 8 | 1.58 | 1817 | 962 | 2505 | 845 | 3102 | 706 | 3445 | 593 | 3824 | 420 | 3187 | 160 | 2770 |
| 8-# 9 | 2.00 | 1886 | 1015 | 2701 | 877 | 3339 | 729 | 3726 | 608 | 4199 | 418 | 3605 | 160 | 3430 |
| 8-#10 | 2.54 | 1971 | 1084 | 2947 | 919 | 3639 | 759 | 4083 | 627 | 4675 | 415 | 4123 | 160 | 4257 |
| 8-#11 | 3.12 | 2045 | 1157 | 3207 | 958 | 3938 | 787 | 4429 | 642 | 5126 | 407 | 4592 | 160 | 5060 |
| 8-#14 | 4.50 | 2242 | 1332 | 3794 | 1065 | 4659 | 865 | 5290 | 690 | 6276 | 399 | 5784 | 160 | 6859 |
| 8-#18 | 8.00 | 2718 | 1776 | 5199 | 1337 | 6394 | 1061 | 7368 | 811 | 9041 | 373 | 8572 | 160 | 10508 |
| 12-#10 | 3.81 | 2187 | 1245 | 3434 | 1029 | 4245 | 841 | 4793 | 686 | 5622 | 411 | 5313 | 160 | 5898 |
| 12-#11 | 4.68 | 2295 | 1355 | 3788 | 1092 | 4660 | 886 | 5275 | 714 | 6257 | 401 | 5975 | 160 | 6892 |
| 12-#14 | 6.75 | 2604 | 1617 | 4613 | 1258 | 5679 | 1006 | 6485 | 791 | 7872 | 387 | 7636 | 160 | 9357 |
| 16-#10 | 5.08 | 2398 | 1406 | 3949 | 1140 | 4861 | 929 | 5548 | 740 | 6624 | 413 | 6417 | 160 | 7539 |
| 16-#11 | 6.24 | 2545 | 1553 | 4401 | 1227 | 5394 | 993 | 6175 | 777 | 7451 | 401 | 7313 | 160 | 8738 |

## RECTANGULAR TIED COLUMNS 20″ × 30″

Short columns — no sidesway    MI
Bending on major or minor axis    MA

$f'_c$ = 4,000 psi $\phi M$ in inch-kips    $f_y$ = 60,000 psi $\phi P$ in kips

| BARS | RHO | AXIS | Max Cap φM | Max Cap φP | 0% fy φM | 0% fy φP | 25% fy φM | 25% fy φP | 50% fy φM | 50% fy φP | 100% fy φM | 100% fy φP | .1f'c Ag φM | .1f'c Ag φP | Zero Axial Load φM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6-#11 | 1.56 | MA | 4540 | 1439 | 6034 | 1290 | 7693 | 1078 | 8722 | 908 | 10013 | 642 | 7731 | 240 | 6435 |
| 2L-3S | | MI | 2611 | 1439 | 3683 | 1246 | 4481 | 1040 | 4919 | 873 | 5367 | 618 | 4490 | 240 | 4016 |
| 6-#14 | 2.25 | MA | 4947 | 1570 | 7051 | 1366 | 8944 | 1134 | 10217 | 943 | 12008 | 634 | 9746 | 240 | 9092 |
| 2L-3S | | MI | 2734 | 1570 | 4096 | 1323 | 4972 | 1095 | 5496 | 906 | 6130 | 610 | 5340 | 240 | 5530 |
| 6-#18 | 4.00 | MA | 5859 | 1903 | 9536 | 1563 | 12017 | 1277 | 13897 | 1032 | 16930 | 615 | 14720 | 240 | 15615 |
| 2L-3S | | MI | 3029 | 1903 | 5075 | 1520 | 6147 | 1236 | 6887 | 990 | 7965 | 585 | 7273 | 240 | 8609 |
| 6-# 9 | 1.00 | MA | 3867 | 1333 | 4660 | 1245 | 6023 | 1049 | 6739 | 894 | 7375 | 665 | 5846 | 240 | 4245 |
| 3L-2S | | MI | 2706 | 1333 | 3602 | 1185 | 4440 | 996 | 4902 | 848 | 5373 | 624 | 3846 | 240 | 2711 |
| 6-#10 | 1.27 | MA | 3974 | 1384 | 4946 | 1277 | 6367 | 1072 | 7144 | 909 | 7912 | 664 | 6573 | 240 | 5307 |
| 3L-2S | | MI | 2803 | 1384 | 3855 | 1212 | 4744 | 1016 | 5260 | 860 | 5848 | 619 | 4323 | 240 | 3366 |
| 6-#11 | 1.56 | MA | 4071 | 1439 | 5274 | 1306 | 6732 | 1093 | 7560 | 921 | 8448 | 660 | 7239 | 240 | 6388 |
| 3L-2S | | MI | 2883 | 1439 | 4134 | 1235 | 5051 | 1032 | 5609 | 868 | 6296 | 610 | 4780 | 240 | 4020 |
| 6-#14 | 2.25 | MA | 4322 | 1570 | 5968 | 1389 | 7573 | 1154 | 8559 | 960 | 9776 | 658 | 8759 | 240 | 8948 |
| 3L-2S | | MI | 3093 | 1570 | 4734 | 1308 | 5778 | 1085 | 6472 | 900 | 7444 | 600 | 5934 | 240 | 5585 |
| 6-#18 | 4.00 | MA | 4953 | 1903 | 7655 | 1600 | 9637 | 1310 | 11019 | 1060 | 13054 | 652 | 12327 | 240 | 14911 |
| 3L-2S | | MI | 3554 | 1903 | 6164 | 1499 | 7525 | 1223 | 8553 | 985 | 10204 | 575 | 8721 | 240 | 9319 |
| 8-# 8 | 1.05 | MA | 4242 | 1343 | 5224 | 1243 | 6753 | 1045 | 7629 | 890 | 8582 | 654 | 6291 | 240 | 4481 |
| 2L-4S | | MI | 2490 | 1343 | 3232 | 1208 | 3981 | 1015 | 4339 | 867 | 4617 | 633 | 3639 | 240 | 2859 |
| 8-# 9 | 1.33 | MA | 4431 | 1396 | 5656 | 1274 | 7283 | 1068 | 8261 | 904 | 9425 | 650 | 7144 | 240 | 5607 |
| 2L-4S | | MI | 2539 | 1396 | 3391 | 1240 | 4165 | 1039 | 4550 | 882 | 4893 | 630 | 4023 | 240 | 3522 |
| 8-#10 | 1.69 | MA | 4663 | 1464 | 6203 | 1314 | 7957 | 1097 | 9067 | 922 | 10501 | 646 | 8234 | 240 | 7039 |
| 2L-4S | | MI | 2602 | 1464 | 3589 | 1282 | 4396 | 1069 | 4817 | 902 | 5242 | 627 | 4501 | 240 | 4337 |
| 8-#11 | 2.08 | MA | 4873 | 1538 | 6794 | 1352 | 8654 | 1124 | 9885 | 937 | 11579 | 639 | 9317 | 240 | 8497 |
| 2L-4S | | MI | 2649 | 1538 | 3813 | 1319 | 4633 | 1094 | 5075 | 916 | 5569 | 615 | 4953 | 240 | 5014 |
| 8-#14 | 3.00 | MA | 5396 | 1713 | 8135 | 1455 | 10315 | 1199 | 11874 | 985 | 14240 | 629 | 12010 | 240 | 12024 |
| 2L-4S | | MI | 2804 | 1713 | 4278 | 1426 | 5185 | 1171 | 5715 | 966 | 6412 | 603 | 6004 | 240 | 6556 |
| 8-# 8 | 1.05 | MA | 3984 | 1343 | 4829 | 1252 | 6253 | 1054 | 7025 | 897 | 7768 | 664 | 6100 | 240 | 4476 |
| 3E | | MI | 2583 | 1343 | 3400 | 1201 | 4200 | 1010 | 4619 | 859 | 4999 | 631 | 3875 | 240 | 2859 |
| 8-# 9 | 1.33 | MA | 4116 | 1396 | 5158 | 1285 | 6653 | 1078 | 7500 | 913 | 8400 | 663 | 6891 | 240 | 5590 |
| 3E | | MI | 2652 | 1396 | 3602 | 1232 | 4440 | 1032 | 4902 | 872 | 5373 | 628 | 4347 | 240 | 3539 |
| 8-#10 | 1.69 | MA | 4282 | 1464 | 5574 | 1327 | 7162 | 1109 | 8105 | 933 | 9206 | 661 | 7891 | 240 | 7000 |
| 3E | | MI | 2738 | 1464 | 3855 | 1273 | 4744 | 1061 | 5260 | 890 | 5848 | 624 | 4900 | 240 | 4389 |
| 8-#11 | 2.08 | MA | 4432 | 1538 | 6034 | 1368 | 7693 | 1138 | 8722 | 950 | 10013 | 656 | 8819 | 240 | 8429 |
| 3E | | MI | 2808 | 1538 | 4134 | 1308 | 5051 | 1085 | 5609 | 902 | 6296 | 614 | 5386 | 240 | 5228 |
| 8-#14 | 3.00 | MA | 4818 | 1713 | 7051 | 1478 | 8944 | 1219 | 10217 | 1002 | 12008 | 652 | 11008 | 240 | 11852 |
| 3E | | MI | 3008 | 1713 | 4734 | 1412 | 5778 | 1161 | 6472 | 948 | 7444 | 604 | 6607 | 240 | 7226 |
| 8-#18 | 5.33 | MA | 5763 | 2157 | 9536 | 1759 | 12017 | 1426 | 13897 | 1134 | 16930 | 643 | 16224 | 240 | 19850 |
| 3E | | MI | 3465 | 2157 | 6164 | 1679 | 7525 | 1352 | 8553 | 1065 | 10204 | 575 | 9436 | 240 | 11297 |
| 8-# 8 | 1.05 | MA | 3831 | 1343 | 4557 | 1261 | 5898 | 1062 | 6570 | 909 | 7147 | 670 | 5660 | 240 | 4447 |
| 4L-2S | | MI | 2735 | 1343 | 3639 | 1195 | 4502 | 1004 | 4984 | 854 | 5491 | 626 | 3962 | 240 | 2853 |
| 8-# 9 | 1.33 | MA | 3932 | 1396 | 4815 | 1296 | 6205 | 1088 | 6927 | 927 | 7617 | 670 | 6298 | 240 | 5521 |
| 4L-2S | | MI | 2837 | 1396 | 3902 | 1224 | 4819 | 1026 | 5360 | 867 | 5990 | 621 | 4464 | 240 | 3536 |
| 8-#10 | 1.69 | MA | 4059 | 1464 | 5141 | 1341 | 6595 | 1122 | 7381 | 951 | 8216 | 670 | 7096 | 240 | 6856 |
| 4L-2S | | MI | 2962 | 1464 | 4232 | 1263 | 5221 | 1053 | 5837 | 884 | 6624 | 616 | 5101 | 240 | 4398 |
| 8-#11 | 2.08 | MA | 4174 | 1538 | 5508 | 1384 | 7006 | 1153 | 7844 | 971 | 8812 | 666 | 7896 | 240 | 8083 |
| 4L-2S | | MI | 3065 | 1538 | 4585 | 1297 | 5621 | 1077 | 6299 | 897 | 7225 | 606 | 5709 | 240 | 5251 |
| 8-#14 | 3.00 | MA | 4481 | 1713 | 6299 | 1501 | 7962 | 1240 | 8961 | 1031 | 10292 | 665 | 9796 | 240 | 10739 |
| 4L-2S | | MI | 3334 | 1713 | 5372 | 1398 | 6585 | 1150 | 7448 | 942 | 8758 | 595 | 7249 | 240 | 7311 |
| 8-#18 | 5.33 | MA | 5289 | 2157 | 8222 | 1797 | 10303 | 1459 | 11707 | 1181 | 13938 | 661 | 13840 | 240 | 17010 |
| 4L-2S | | MI | 3937 | 2157 | 7253 | 1658 | 8903 | 1339 | 10219 | 1059 | 12442 | 565 | 10968 | 240 | 12243 |
| 10-#10 | 2.12 | MA | 4939 | 1545 | 6831 | 1364 | 8752 | 1134 | 10029 | 945 | 11796 | 643 | 9549 | 240 | 8743 |
| 2L-5S | | MI | 2663 | 1545 | 3726 | 1343 | 4535 | 1120 | 4995 | 932 | 5468 | 632 | 4895 | 240 | 5003 |
| 10-#11 | 2.60 | MA | 5195 | 1637 | 7554 | 1413 | 9616 | 1169 | 11048 | 966 | 13144 | 635 | 10906 | 240 | 10555 |
| 2L-5S | | MI | 2721 | 1637 | 3975 | 1391 | 4796 | 1155 | 5285 | 951 | 5834 | 619 | 5375 | 240 | 5827 |
| 10-#10 | 2.12 | MA | 4577 | 1545 | 6203 | 1378 | 7957 | 1146 | 9067 | 957 | 10501 | 658 | 9208 | 240 | 8693 |
| 3L-4S | | MI | 2775 | 1545 | 3965 | 1333 | 4873 | 1106 | 5393 | 926 | 6019 | 624 | 5271 | 240 | 5313 |

(1) "0% $f_y$" indicates zero tension in bars on the tension side, "50% $f_y$" indicates 50% $f_y$ stress in bars on the tension side, and "100% $f_y$" indicates 100% $f_y$ stress (i.e., balance point) in bars on the tension side.

(2) L = long face, S = short face, E = each face; 3E = 3 bars each face; 2L-3S = 2 bars each long face and 3 short face.

## SQUARE TIED COLUMNS 22" × 22"

Short columns; no sidesway
Bars symmetrical in 4 faces

$f'_c$ = 4,000 psi $\phi M$ in inch-kips
$f_y$ = 60,000 psi $\phi P$ in kips

| BARS | RHO | Max Cap $\phi M$ | Max Cap $\phi P$ | 0% fy $\phi M$ | 0% fy $\phi P$ | 25% fy $\phi M$ | 25% fy $\phi P$ | 50% fy $\phi M$ | 50% fy $\phi P$ | 100% fy $\phi M$ | 100% fy $\phi P$ | .1f'c Ag $\phi M$ | .1f'c Ag $\phi P$ | Zero Axial Load $\phi M$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-#10 | 1.05 | 2435 | 1083 | 3211 | 968 | 3992 | 814 | 4430 | 692 | 4890 | 507 | 3532 | 194 | 2535 |
| 4-#11 | 1.29 | 2500 | 1119 | 3430 | 982 | 4231 | 823 | 4699 | 697 | 5236 | 501 | 3882 | 194 | 3038 |
| 4-#14 | 1.86 | 2671 | 1207 | 3891 | 1031 | 4789 | 858 | 5360 | 718 | 6114 | 494 | 4765 | 194 | 4235 |
| 4-#18 | 3.31 | 3044 | 1429 | 4998 | 1157 | 6136 | 949 | 6963 | 773 | 8248 | 478 | 6910 | 194 | 7112 |
| 8-# 8 | 1.31 | 2374 | 1122 | 3133 | 1006 | 3919 | 843 | 4355 | 714 | 4803 | 516 | 3887 | 194 | 3131 |
| 8-# 9 | 1.65 | 2455 | 1175 | 3356 | 1038 | 4190 | 867 | 4676 | 728 | 5229 | 514 | 4407 | 194 | 3886 |
| 8-#10 | 2.10 | 2556 | 1244 | 3638 | 1080 | 4532 | 897 | 5083 | 747 | 5771 | 511 | 5012 | 194 | 4835 |
| 8-#11 | 2.58 | 2641 | 1317 | 3942 | 1118 | 4880 | 924 | 5484 | 763 | 6293 | 504 | 5569 | 194 | 5772 |
| 8-#14 | 3.72 | 2880 | 1492 | 4618 | 1226 | 5708 | 1002 | 6472 | 811 | 7611 | 497 | 6969 | 194 | 8017 |
| 8-#18 | 6.61 | 3437 | 1936 | 6245 | 1500 | 7714 | 1201 | 8871 | 934 | 10818 | 476 | 10253 | 194 | 12476 |
| 12-#10 | 3.15 | 2799 | 1405 | 4192 | 1191 | 5222 | 980 | 5891 | 808 | 6848 | 510 | 6326 | 194 | 6833 |
| 12-#11 | 3.87 | 2938 | 1515 | 4605 | 1254 | 5705 | 1025 | 6450 | 836 | 7583 | 500 | 7188 | 194 | 7998 |
| 12-#14 | 5.58 | 3298 | 1777 | 5557 | 1421 | 6875 | 1147 | 7839 | 916 | 9436 | 489 | 9173 | 194 | 10859 |
| 16-#10 | 4.20 | 3050 | 1566 | 4779 | 1303 | 5923 | 1070 | 6749 | 863 | 7988 | 514 | 7627 | 194 | 8755 |
| 16-#11 | 5.16 | 3223 | 1713 | 5306 | 1391 | 6543 | 1134 | 7477 | 902 | 8947 | 503 | 8693 | 194 | 10231 |
| 20-#10 | 5.25 | 3262 | 1727 | 5372 | 1414 | 6659 | 1153 | 7618 | 924 | 9143 | 512 | 8912 | 194 | 10541 |
| **SQUARE TIED COLUMNS 24" × 24"** | | | | | | | | | | | | | | |
| 4-#11 | 1.08 | 3180 | 1294 | 4199 | 1158 | 5228 | 973 | 5810 | 827 | 6432 | 604 | 4668 | 230 | 3394 |
| 4-#14 | 1.56 | 3381 | 1382 | 4723 | 1205 | 5859 | 1007 | 6556 | 847 | 7422 | 597 | 5663 | 230 | 4746 |
| 4-#18 | 2.78 | 3829 | 1604 | 5983 | 1330 | 7390 | 1097 | 8374 | 902 | 9841 | 581 | 8096 | 230 | 8010 |
| 8-# 8 | 1.10 | 3032 | 1297 | 3853 | 1183 | 4870 | 994 | 5416 | 846 | 5939 | 622 | 4664 | 230 | 3491 |
| 8-# 9 | 1.39 | 3126 | 1350 | 4106 | 1215 | 5174 | 1018 | 5776 | 860 | 6416 | 620 | 5266 | 230 | 4341 |
| 8-#10 | 1.76 | 3243 | 1419 | 4424 | 1257 | 5559 | 1048 | 6233 | 879 | 7023 | 617 | 6000 | 230 | 5412 |
| 8-#11 | 2.17 | 3344 | 1492 | 4773 | 1295 | 5955 | 1075 | 6689 | 895 | 7616 | 610 | 6649 | 230 | 6481 |
| 8-#14 | 3.13 | 3625 | 1667 | 5539 | 1402 | 6891 | 1154 | 7805 | 944 | 9103 | 603 | 8261 | 230 | 9039 |
| 8-#18 | 5.56 | 4267 | 2111 | 7389 | 1677 | 9168 | 1354 | 10526 | 1068 | 12737 | 585 | 12056 | 230 | 14554 |
| 12-#10 | 2.65 | 3522 | 1580 | 5045 | 1369 | 6332 | 1133 | 7138 | 941 | 8231 | 617 | 7433 | 230 | 7803 |
| 12-#11 | 3.25 | 3673 | 1690 | 5519 | 1432 | 6883 | 1178 | 7775 | 970 | 9066 | 608 | 8420 | 230 | 9143 |
| 12-#14 | 4.69 | 4100 | 1952 | 6596 | 1599 | 8207 | 1300 | 9345 | 1051 | 11159 | 598 | 10835 | 230 | 12407 |
| 16-#10 | 3.53 | 3796 | 1741 | 5703 | 1482 | 7118 | 1223 | 8101 | 998 | 9510 | 623 | 8927 | 230 | 9907 |
| 16-#11 | 4.33 | 4009 | 1888 | 6308 | 1569 | 7826 | 1288 | 8931 | 1037 | 10600 | 613 | 10160 | 230 | 11732 |
| 16-#14 | 6.25 | 4544 | 2238 | 7714 | 1796 | 9543 | 1458 | 10982 | 1147 | 13333 | 604 | 13189 | 230 | 15832 |
| 20-#10 | 4.41 | 4049 | 1902 | 6360 | 1592 | 7945 | 1307 | 9076 | 1060 | 10805 | 622 | 10387 | 230 | 12008 |
| 20-#11 | 5.42 | 4297 | 2086 | 7104 | 1705 | 8817 | 1390 | 10100 | 1112 | 12153 | 611 | 11873 | 230 | 14121 |

(1) "0% $f_y$" indicates zero tension in bars on the tension side, "50% $f_y$" indicates 50% $f_y$ stress in bars on the tension side, and "100% $f_y$" indicates 100% $f_y$ stress (i.e., balance point) in bars on the tension side.

Sample Footing Spreadsheet

| | | | | |
|---|---|---|---|---|
| LOADING | | | | |
| **DL=** | 54 | | q(given)= | 5000 |
| **LL=** | 49 | | | |
| Pcn= | 103 | | **Pce=** | 54 |
| TL= | 143.2 | | | |
| | | | | |
| COLUMN | | | | |
| **Cdx(big)=** | 20 | | Afootingexst= | 36 |
| **Cdy(sm)=** | 20 | | | |
| Ratio= | 1 | | | |
| | | | | |
| FSexst= | 3.333333 | <2? | *CHANGED FS TO 3.5 | |
| | | | | |
| FOOTING SIZE | | | | |
| B= | 8.577379 | | **Bfinal=** | 9 |
| L= | 8.577379 | | **Lfinal=** | 9 |
| | | | | |
| DIRECT SHEAR | | | | |
| q= | 12.27709 | <164? | phi*4*(3000psi)^0.5 | |
| | | | | |
| TWO WAY SHEAR | | | | |
| 328+q= | 340.2771 | | | |
| Cdx+Cdy= | 40 | | d= | 7.441323 |
| 656+q= | 668.2771 | | **dfinalL=** | 8.625 |
| BL= | 11664 | | **dfinalS=** | 7.875 |
| CdxCdy= | 400 | | **hfinal=** | 12 |
| | | | | |
| WIDE BEAM SHEAR | | | | |
| Q= | 1.767901 | | | |
| phiVnL= | 8.503388 | >? | VL= | 5.211626 |
| phiVnS= | 7.763963 | >? | VS= | 5.322119 |
| | | | | |
| REINFORCEMENT | | | | |
| AsL= | 0.436482 | <? | **AsLfinal=** | 0.44 |
| aL= | 0.862745 | | | |
| MuL= | 14.73865 | <? | phiMn= | 16.22338 |

# APPENDIX C: TAKEOFF INFO AND MEANS REFERENCES

## Takeoff Spreadsheet, Concrete Structural System

| CSI # | Description | Quantity | Units | Mat | Mat Cost | Labor | Labor Cost | Equip | Equip Cost | Daily Output | Crew | Duration | Total | OP | InclOP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2400900 | Concrete Cols 24x24 | 33 | CY | 225 | 7425 | 370 | 12210 | 37.5 | 1237.5 | 16.2 | C-14A | 2.03704 | 20872.5 | 905 | 29865 |
| | Average Size Minimum | 34.1 | | 225 | 7672.5 | 370 | 12617 | 37.5 | 1278.75 | 16.2 | | 2.10234 | 21568.25 | 905 | 30860.5 |
| | Reinforcement | 34.1 | | 225 | 7672.5 | 370 | 12617 | 37.5 | 1278.75 | 16.2 | | 2.10234 | 21568.25 | 905 | 30860.5 |
| | | 34.1 | | 225 | 7672.5 | 370 | 12617 | 37.5 | 1278.75 | 16.2 | | 2.10234 | 21568.25 | 905 | 30860.5 |
| | | 75.9 | | 225 | 17077.5 | 370 | 28083 | 37.5 | 2846.25 | 16.2 | | 4.67941 | 48006.75 | 905 | 68689.5 |
| | | 211.2 | | | 47520 | | 78144 | | 7920 | | | 13.0235 | 133584 | | 191136 |
| 2401900 | Flat Slab w/Drops, 20' Span | 72.1 | | 242 | 17448.2 | 192 | 13843.2 | 18.75 | 1351.875 | 38.5 | C-14B | 1.87516 | 32643.28 | 610 | 43981 |
| | Flat Slab w/Drops, 25' Span | 50 | | 246 | 12300 | 169 | 8450 | 16.45 | 822.5 | 44.8 | | 1.11732 | 21572.5 | 570 | 28500 |
| | | 61.8 | | 246 | 15202.8 | 169 | 10444.2 | 16.45 | 1016.61 | 44.8 | | 1.37946 | 26663.61 | 570 | 35226 |
| | | 61.8 | | 246 | 15202.8 | 169 | 10444.2 | 16.45 | 1016.61 | 44.8 | | 1.37946 | 26663.61 | 570 | 35226 |
| | | 61.8 | | 246 | 15202.8 | 169 | 10444.2 | 16.45 | 1016.61 | 44.8 | | 1.37946 | 26663.61 | 570 | 35226 |
| | | 102.3 | | 246 | 25165.8 | 169 | 17288.7 | 16.45 | 1682.835 | 44.8 | | 2.28348 | 44137.34 | 570 | 58311 |
| | Flat Slab w/Drops, 30' Span | 239 | | 250 | 59750 | 145 | 34655 | 14.15 | 3381.85 | 51 | | 4.68719 | 97786.85 | 530 | 126670 |
| | | 295.8 | | 250 | 73950 | 145 | 42891 | 14.15 | 4185.57 | 51 | | 5.8 | 121026.6 | 530 | 156774 |
| | | 295.8 | | 250 | 73950 | 145 | 42891 | 14.15 | 4185.57 | 51 | | 5.8 | 121026.6 | 530 | 156774 |
| | | 295.8 | | 250 | 73950 | 145 | 42891 | 14.15 | 4185.57 | 51 | | 5.8 | 121026.6 | 530 | 156774 |
| | | 607.5 | | 250 | 151875 | 145 | 88087.5 | 14.15 | 8596.125 | 51 | | 11.9118 | 248558.6 | 530 | 321975 |
| | | 2143.7 | | | 533997 | | 322330 | | 31441.725 | | | 43.4133 | 887769.1 | | 1155437 |
| 2402550 | One Way Beam, 25' Avg Span | 27.2 | CY | 287 | 7806.4 | 455 | 12376 | 46 | 1251.2 | 15.6 | C14A | 1.74136 | 21433.6 | 1125 | 30600 |
| | | 20.4 | | 287 | 5854.8 | 455 | 9282 | 46 | 938.4 | 15.6 | | 1.30769 | 16075.2 | 1125 | 22950 |
| | | 20.4 | | 287 | 5854.8 | 455 | 9282 | 46 | 938.4 | 15.6 | | 1.30769 | 16075.2 | 1125 | 22950 |
| | | 20.4 | | 287 | 5854.8 | 455 | 9282 | 46 | 938.4 | 15.6 | | 1.30769 | 16075.2 | 1125 | 22950 |
| | | 37.5 | | 287 | 10762.5 | 455 | 17062.5 | 46 | 1725 | 15.6 | | 2.40385 | 29550 | 1125 | 42187.5 |
| | | 125.9 | | | 36133.3 | | 57284.5 | | 5791.4 | | | 8.06828 | 99209.2 | | 141638 |
| 2402850 | Footings | 798.2 | | 242 | 193164 | 47 | 37515.4 | 0.26 | 207.532 | 81 | C-14C | 9.84946 | 230887.3 | 345 | 275379 |
| | | | | | | | | | | | | 9.84946 | 230887.3 | | 275379 |
| | | | | | | | | | | | **$TOT:** | **66.2862** | **1252240** | | **1621952** |

## Takeoff Spreadsheet, Composite Steel Structural System

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 260600 | Columns, Supporting Roof | | | | | | | | | | | | | | |
| | W10x33 | 252.7 | LF | 47 | 11876.9 | 2.11 | 533.197 | 1.38 | 348.726 | 1032 | | 0.24486 | 12758.82 | 57 | 14403.9 |
| | W10x39 | 53.2 | | 47 | 2500.4 | 2.11 | 112.252 | 1.38 | 73.416 | 1032 | | 0.05155 | 2686.068 | 57 | 3032.4 |
| | W10x49 | 26.7 | | 71 | 1895.7 | 2.21 | 59.007 | 1.45 | 38.715 | 984 | | 0.02713 | 1993.422 | 83.5 | 2229.45 |
| | W12x40 | 66.5 | | 52.5 | 3491.25 | 2.11 | 140.315 | 1.38 | 91.77 | 1032 | | 0.06444 | 3723.335 | 63 | 4189.5 |
| | W12x45 | 13.3 | | 52.5 | 698.25 | 2.11 | 28.063 | 1.38 | 18.354 | 1032 | | 0.01289 | 744.667 | 63 | 837.9 |
| | | 412.4 | | | 20462.5 | | 872.834 | | 570.981 | | | 0.40087 | 21906.32 | | 24693.2 |
| | Columns, Supporting 3-4 | | | | | | | | | | | | | | |
| | W10x33 | 239.4 | | 47 | 11251.8 | 2.11 | 505.134 | 1.38 | 330.372 | 1032 | | 0.23198 | 12087.31 | 57 | 13645.8 |
| | W10x39 | 106.4 | | 47 | 5000.8 | 2.11 | 224.504 | 1.38 | 146.832 | 1032 | | 0.1031 | 5372.136 | 57 | 6064.8 |
| | W10x45 | 106.4 | | 47 | 5000.8 | 2.11 | 224.504 | 1.38 | 146.832 | 1032 | | 0.1031 | 5372.136 | 57 | 6064.8 |
| | W10x49 | 53.2 | | 71 | 3777.2 | 2.21 | 117.572 | 1.45 | 77.14 | 984 | | 0.05407 | 3971.912 | 83.5 | 4442.2 |
| | W10x54 | 79.8 | | 71 | 5665.8 | 2.21 | 176.358 | 1.45 | 115.71 | 984 | | 0.0811 | 5957.868 | 83.5 | 6663.3 |
| | W10x60 | 26.7 | | 71 | 1895.7 | 2.21 | 59.007 | 1.45 | 38.715 | 984 | | 0.02713 | 1993.422 | 83.5 | 2229.45 |
| | W10x68 | 26.7 | | 71 | 1895.7 | 2.21 | 59.007 | 1.45 | 38.715 | 984 | | 0.02713 | 1993.422 | 83.5 | 2229.45 |
| | W12x40 | 26.7 | | 52.5 | 1401.75 | 2.11 | 56.337 | 1.38 | 36.846 | 1032 | | 0.02587 | 1494.933 | 63 | 1682.1 |
| | W12x45 | 26.7 | | 52.5 | 1401.75 | 2.11 | 56.337 | 1.38 | 36.846 | 1032 | | 0.02587 | 1494.933 | 63 | 1682.1 |
| | W12x58 | 53.2 | | 52.5 | 2793 | 2.11 | 112.252 | 1.38 | 73.416 | 1032 | | 0.05155 | 2978.668 | 63 | 3351.6 |
| | W12x65 | 53.2 | | 91 | 4841.2 | 2.21 | 117.572 | 1.45 | 77.14 | 984 | | 0.05407 | 5035.912 | 106 | 5639.2 |
| | | 798.4 | | | 44925.5 | | 1708.584 | | 1118.564 | | | 0.78497 | 47752.65 | | 53694.8 |
| | Columns, Supporting P-2 | | | | | | | | | | | | | | |
| | W10x33 | 26.7 | | 47 | 1254.9 | 2.11 | 56.337 | 1.38 | 36.846 | 1032 | | 0.02587 | 1348.083 | 57 | 1521.9 |
| | W10x45 | 26.7 | | 47 | 1254.9 | 2.11 | 56.337 | 1.38 | 36.846 | 1032 | | 0.02587 | 1348.083 | 57 | 1521.9 |
| | W10x49 | 438.9 | | 71 | 31161.9 | 2.21 | 969.969 | 1.45 | 636.405 | 984 | | 0.44604 | 32768.27 | 83.5 | 36648.2 |
| | W10x54 | 53.2 | | 71 | 3777.2 | 2.21 | 117.572 | 1.45 | 77.14 | 984 | | 0.05407 | 3971.912 | 83.5 | 4442.2 |
| | W10x68 | 93.1 | | 71 | 6610.1 | 2.21 | 205.751 | 1.45 | 134.995 | 984 | | 0.09461 | 6950.846 | 83.5 | 7773.85 |
| | W10x88 | 53.2 | | 71 | 3777.2 | 2.21 | 117.572 | 1.45 | 77.14 | 984 | | 0.05407 | 3971.912 | 83.5 | 4442.2 |
| | W12x65 | 53.2 | | 91 | 4841.2 | 2.21 | 117.572 | 1.45 | 77.14 | 984 | | 0.05407 | 5035.912 | 106 | 5639.2 |
| | W12x79 | 26.6 | | 91 | 2420.6 | 2.21 | 58.786 | 1.45 | 38.57 | 984 | | 0.02703 | 2517.956 | 106 | 2819.6 |
| | W12x96 | 39.9 | | 125 | 4987.5 | 227 | 9057.3 | 1.49 | 59.451 | 960 | | 0.04156 | 14104.25 | 144 | 5745.6 |
| | | 811.5 | | | 60085.5 | | 10757.2 | | 1174.533 | | | 0.82318 | 72017.23 | | 70554.6 |
| 6400010 | Structural Steel Members, Roof | | | | | | | | | | | | | | |
| | W8x10 | 32 | | 10.45 | 334.4 | 3.63 | 116.16 | 2.38 | 76.16 | 600 | E-2 | 0.05333 | 526.72 | 20.5 | 656 |
| | W12x14 | 332.5 | | 14.65 | 4871.13 | 2.48 | 824.6 | 1.62 | 538.65 | 880 | | 0.37784 | 6234.375 | 22.5 | 7481.25 |
| | W12x16 | 902.5 | | 16.74 | 15107.9 | 2.48 | 2238.2 | 1.62 | 1462.05 | 880 | | 1.02557 | 18808.1 | 25 | 22562.5 |
| | W14x22 | 150 | | 27 | 4050 | 2.2 | 330 | 1.44 | 216 | 990 | | 0.15152 | 4596 | 35.5 | 5325 |
| | W16x26 | 245 | | 27 | 6615 | 2.18 | 534.1 | 1.43 | 350.35 | 1000 | | 0.245 | 7499.45 | 35.5 | 8697.5 |
| | W18x35 | 120 | | 36.5 | 4380 | 3.28 | 393.6 | 1.58 | 189.6 | 960 | E-5 | 0.125 | 4963.2 | 47.5 | 5700 |
| | W18x40 | 360 | | 42 | 15120 | 3.28 | 1180.8 | 1.58 | 568.8 | 960 | | 0.375 | 16869.6 | 53.5 | 19260 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2142 | | | 50478.4 | | 5617.46 | | 3401.61 | | | 2.35326 | 59497.45 | | 69682.3 |
| | Structural Steel Members, 2-4 | | | | | | | | | | | | | | |
| | W8x10 | 25 | | 10.5 | 262.5 | 3.63 | 90.75 | 2.38 | 59.5 | 600 | E-2 | 0.04167 | 412.75 | 20.5 | 512.5 |
| | W10x15 | 1080.5 | | 23 | 24851.5 | 3.63 | 3922.215 | 2.38 | 2571.59 | 600 | | 1.80083 | 31345.31 | 34.5 | 37277.3 |
| | W10x22 | 35 | | 23 | 805 | 3.63 | 127.05 | 2.38 | 83.3 | 600 | | 0.05833 | 1015.35 | 34.5 | 1207.5 |
| | W14x22 | 30 | | 27 | 810 | 2.2 | 66 | 1.44 | 43.2 | 990 | | 0.0303 | 919.2 | 35.5 | 1065 |
| | W14x26 | 40 | | 27 | 1080 | 2.2 | 88 | 1.44 | 57.6 | 990 | | 0.0404 | 1225.6 | 35.5 | 1420 |
| | W16x26 | 75 | | 27 | 2025 | 2.18 | 163.5 | 1.43 | 107.25 | 1000 | | 0.075 | 2295.75 | 35.5 | 2662.5 |
| | W16x31 | 150 | | 32.5 | 4875 | 2.42 | 363 | 1.59 | 238.5 | 900 | | 0.16667 | 5476.5 | 41.5 | 6225 |
| | W18x35 | 210 | | 36.5 | 7665 | 3.28 | 688.8 | 1.58 | 331.8 | 960 | E-5 | 0.21875 | 8685.6 | 47.5 | 9975 |
| | W18x40 | 50 | | 42 | 2100 | 3.28 | 164 | 1.58 | 79 | 960 | | 0.05208 | 2343 | 53.5 | 2675 |
| | W21x44 | 390 | | 46 | 17940 | 2.96 | 1154.4 | 1.42 | 553.8 | 1064 | | 0.36654 | 19648.2 | 57.5 | 22425 |
| | | 2085.5 | | | 62414 | | 6827.715 | | 4125.54 | | | 2.85058 | 73367.26 | | 85444.8 |
| | Structural Steel Members, Park | | | | | | | | | | | | | | |
| | W8x10 | 22.5 | LF | 10.5 | 236.25 | 3.63 | 81.675 | 2.38 | 53.55 | 600 | E-2 | 0.0375 | 371.475 | 20.5 | 461.25 |
| | W10x15 | 1927.5 | | 23 | 44332.5 | 3.63 | 6996.825 | 2.38 | 4587.45 | 600 | | 3.2125 | 55916.78 | 34.5 | 66498.8 |
| | W10x19 | 1060 | | 23 | 24380 | 3.63 | 3847.8 | 2.38 | 2522.8 | 600 | | 1.76667 | 30750.6 | 34.5 | 36570 |
| | W12x19 | 39.5 | | 23 | 908.5 | 2.48 | 97.96 | 1.62 | 63.99 | 880 | | 0.04489 | 1070.45 | 31.5 | 1244.25 |
| | W12x22 | 40 | | 23 | 920 | 2.48 | 99.2 | 1.62 | 64.8 | 880 | | 0.04545 | 1084 | 31.5 | 1260 |
| | W14x22 | 47.5 | | 27 | 1282.5 | 2.2 | 104.5 | 1.44 | 68.4 | 990 | | 0.04798 | 1455.4 | 35.5 | 1686.25 |
| | W16x26 | 353 | | 27 | 9531 | 2.18 | 769.54 | 1.43 | 504.79 | 1000 | | 0.353 | 10805.33 | 35.5 | 12531.5 |
| | W18x35 | 185 | | 36.5 | 6752.5 | 3.28 | 606.8 | 1.58 | 292.3 | 960 | E-5 | 0.19271 | 7651.6 | 47.5 | 8787.5 |
| | W18x40 | 40 | | 42 | 1680 | 3.28 | 131.2 | 1.58 | 63.2 | 960 | | 0.04167 | 1874.4 | 53.5 | 2140 |
| | W16x31 | 17 | | 32.5 | 552.5 | 2.42 | 41.14 | 1.59 | 27.03 | 900 | | 0.01889 | 620.67 | 41.5 | 705.5 |
| | W21x50 | 25 | | 52.5 | 1312.5 | 2.96 | 74 | 1.42 | 35.5 | 1064 | | 0.0235 | 1422 | 64.5 | 1612.5 |
| | W24x55 | 52.33 | | 57.5 | 3008.98 | 2.84 | 148.6172 | 1.37 | 71.6921 | 1110 | | 0.04714 | 3229.284 | 69.5 | 3636.94 |
| | W24x62 | 150 | | 65 | 9750 | 2.84 | 426 | 1.37 | 205.5 | 1110 | | 0.13514 | 10381.5 | 78 | 11700 |
| | W24x76 | 230 | | 79.5 | 18285 | 2.84 | 653.2 | 1.37 | 315.1 | 1110 | | 0.20721 | 19253.3 | 94 | 21620 |
| | | 4189.33 | | | 122932 | | 14078.46 | | 8876.1021 | | | 6.17423 | 145886.8 | | 170454 |
| 2403200 | NonComposite Deck, Roof 22 Ga, 3" Deep | 13335.5 | SF | 2.02 | 26937.7 | 0.36 | 4800.78 | 0.02 | 266.71 | 3600 | E-4 | 3.70431 | 32005.2 | 2.92 | 38939.7 |
| 2405800 | Composite Deck, 2-4 20 Ga, 3" | 11469.5 | | 1.71 | 19612.8 | 0.43 | 4931.885 | 0.03 | 344.085 | 3000 | | 3.82317 | 24888.82 | 2.72 | 31197 |
| | Composite Deck, Park 20 Ga, 3" | 22214.2 | | 1.71 | 37986.3 | 0.43 | 9552.106 | 0.03 | 666.426 | 3000 | | 7.40473 | 48204.81 | 2.72 | 60422.6 |
| 7001500 | Poured Concrete on Deck, 2-4 | 123.9 | CY | 246 | 30479.4 | 13.55 | 1678.845 | 5.3 | 656.67 | 160 | C-20 | 0.77438 | 32814.92 | 28 | 3469.2 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Poured Concrete on Deck, Park | 240 | | 246 | 59040 | 13.55 | 3252 | 5.3 | 1272 | 160 | | 1.5 | 63564 | 28 | 6720 |
| 8401000 | Weld Shear Connectors, 2-4 3/4" Diameter, 5.5" Long, | 1629 | Ea | 0.62 | 1009.98 | 0.72 | 1172.88 | 0.29 | 472.41 | 905 | E-10 | 1.8 | 2655.27 | 2.35 | 3828.15 |
| | Park | 4603 | | 0.62 | 2853.86 | 0.72 | 3314.16 | 0.29 | 1334.87 | 905 | | 5.08619 | 7502.89 | 2.35 | 10817.1 |
| 7812 | Cementitious Fireproofing On Corrugated Deck, 1" | 11469.5 | SF | 0.64 | 7340.48 | 0.56 | 6422.92 | 0.09 | 1032.255 | 1250 | G-2 | 9.1756 | 14795.66 | 1.71 | 19612.8 |
| | | 22214.2 | | 0.64 | 14217.1 | 0.56 | 12439.95 | 0.09 | 1999.278 | 1250 | | 17.7714 | 28656.32 | 1.71 | 37986.3 |
| 2402850 | Footings | 235.7 | CY | 242 | 57039.4 | 47 | 11077.9 | 0.26 | 61.282 | 81 | C-14C | 2.90988 | 68178.58 | 345 | 81316.5 |

## R.S. Means 2006 Cost Data

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 240 | 0010 | **CONCRETE IN PLACE** | R033053 -10 | | | | | | | | | |
| | 0020 | Including forms (4 uses), concrete, placement, reinforcing | | | | | | | | | | |
| | 0050 | steel and finishing unless otherwise indicated | R033053 -50 | | | | | | | | | |
| | 0300 | Beams, 5 kip per L.F., 10' span | | C-14A | 15.62 | 12.804 | C.Y. | 287 | 455 | 46 | 788 | 1,1 |
| | 0350 | 25' span | R033053 -60 | " | 18.55 | 10.782 | | 298 | 385 | 39 | 722 | 1,0 |
| | 0500 | Chimney foundations, industrial, minimum | | C-14C | 32.22 | 3.476 | | 129 | 118 | .66 | 247.66 | 3 |
| | 0510 | Maximum | R033105 -80 | " | 23.71 | 4.724 | | 152 | 160 | .90 | 312.90 | 4 |
| | 0700 | Columns, square, 12" x 12", minimum reinforcing | | C-14A | 11.96 | 16.722 | | 305 | 595 | 60.50 | 960.50 | 1,4 |
| | 0720 | Average reinforcing | R033105 -85 | | 10.13 | 19.743 | | 485 | 705 | 71.50 | 1,261.50 | 1,7 |
| | 0740 | Maximum reinforcing | | | 9.03 | 22.148 | | 725 | 790 | 80 | 1,595 | 2,2 |
| | 0800 | 16" x 16", minimum reinforcing | | | 16.22 | 12.330 | | 243 | 440 | 44.50 | 727.50 | 1,0 |
| | 0820 | Average reinforcing | | | 12.57 | 15.911 | | 410 | 565 | 57.50 | 1,032.50 | 1,4 |
| | 0840 | Maximum reinforcing | | | 10.25 | 19.512 | | 640 | 695 | 70.50 | 1,405.50 | 1,9 |
| | 0900 | 24" x 24", minimum reinforcing | | | 23.66 | 8.453 | | 207 | 300 | 30.50 | 537.50 | 7 |
| | 0920 | Average reinforcing | | | 17.71 | 11.293 | | 370 | 400 | 41 | 811 | 1,1 |
| | 0940 | Maximum reinforcing | | | 14.15 | 14.134 | | 585 | 505 | 51 | 1,141 | 1,5 |
| | 1000 | 36" x 36", minimum reinforcing | | | 33.69 | 5.936 | | 182 | 211 | 21.50 | 414.50 | 5 |
| | 1020 | Average reinforcing | | | 23.32 | 8.576 | | 325 | 305 | 31 | 661 | 8 |
| | 1040 | Maximum reinforcing | | | 17.82 | 11.223 | | 545 | 400 | 40.50 | 985.50 | 1,3 |
| | 1200 | 16" diameter, minimum reinforcing | | | 31.49 | 6.351 | | 236 | 226 | 23 | 485 | 6 |
| | 1220 | Average reinforcing | | | 19.12 | 10.460 | | 415 | 370 | 38 | 823 | 1,1 |
| | 1240 | Maximum reinforcing | | | 13.77 | 14.524 | | 630 | 515 | 52.50 | 1,197.50 | 1,6 |
| | 1300 | 20" diameter, minimum reinforcing | | | 41.04 | 4.873 | | 238 | 174 | 17.60 | 429.60 | 5 |
| | 1320 | Average reinforcing | | | 24.05 | 8.316 | | 400 | 296 | 30 | 726 | 9 |
| | 1340 | Maximum reinforcing | | | 17.01 | 11.758 | | 630 | 420 | 42.50 | 1,092.50 | 1,4 |
| | 1400 | 24" diameter, minimum reinforcing | | | 51.85 | 3.857 | | 223 | 137 | 13.90 | 373.90 | 4 |
| | 1420 | Average reinforcing | | | 27.06 | 7.391 | | 400 | 263 | 26.50 | 689.50 | 9 |
| | 1440 | Maximum reinforcing | | | 18.29 | 10.935 | | 620 | 390 | 39.50 | 1,049.50 | 1,3 |
| | 1500 | 36" diameter, minimum reinforcing | | | 75.04 | 2.665 | | 224 | 95 | 9.60 | 328.60 | 4 |
| | 1520 | Average reinforcing | | | 37.49 | 5.335 | | 380 | 190 | 19.25 | 589.25 | 7 |
| | 1540 | Maximum reinforcing | | | 22.84 | 8.757 | | 600 | 310 | 31.50 | 941.50 | 1,2 |
| | 1900 | Elevated slabs, flat slab with drops, 125 psf Sup. Load, 20' span | | C-14B | 38.45 | 5.410 | | 242 | 192 | 18.75 | 452.75 | 6 |
| | 1950 | 30' span | | | 50.99 | 4.079 | | 250 | 145 | 14.15 | 409.15 | 5 |
| | 2100 | Flat plate, 125 psf Sup. Load, 15' span | | | 30.24 | 6.878 | | 220 | 245 | 24 | 489 | 6 |

| 03310 | Structural Concrete | | CREW | DAILY OUTPUT | LABOR-HOURS | UNIT | 2006 BARE COSTS MAT. | LABOR | EQUIP. | TOTAL | TOTAL INCL O&P | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2150 | 25' span | R033053 -10 | C-14B | 49.60 | 4.194 | C.Y. | 226 | 149 | 14.55 | 389.55 | 510 | 240 |
| 2300 | Waffle const., 30" domes, 125 psf Sup. Load, 20' span | | | 37.07 | 5.611 | | 330 | 200 | 19.45 | 549.45 | 715 | |
| 2350 | 30' span | R033053 -50 | | 44.07 | 4.720 | | 294 | 168 | 16.40 | 478.40 | 620 | |
| 2500 | One way joists, 30" pans, 125 psf Sup. Load, 15' span | | | 27.38 | 7.597 | | 410 | 270 | 26.50 | 706.50 | 930 | |
| 2550 | 25' span | R033053 -60 | | 31.15 | 6.677 | | 375 | 237 | 23 | 635 | 830 | |
| 2700 | One way beam & slab, 125 psf Sup. Load, 15' span | | | 20.59 | 10.102 | | 245 | 360 | 35 | 640 | 905 | |
| 2750 | 25' span | R033105 -80 | | 28.36 | 7.334 | | 225 | 261 | 25.50 | 511.50 | 705 | |
| 2900 | Two way beam & slab, 125 psf Sup. Load, 15' span | | | 24.04 | 8.652 | | 232 | 310 | 30 | 572 | 800 | |
| 2950 | 25' span | R033105 -85 | | 35.87 | 5.799 | | 196 | 206 | 20 | 422 | 575 | |
| 3100 | Elevated slabs including finish, not | | | | | | | | | | | |
| 3110 | including forms or reinforcing | | | | | | | | | | | |
| 3150 | Regular concrete, 4" slab | | C-8 | 2613 | .021 | S.F. | 1.18 | .66 | .27 | 2.11 | 2.67 | |
| 3200 | 6" slab | | | 2585 | .022 | | 1.74 | .67 | .27 | 2.68 | 3.31 | |
| 3250 | 2-1/2" thick floor fill | | | 2685 | .021 | | .76 | .65 | .26 | 1.67 | 2.17 | |
| 3300 | Lightweight, 110# per C.F., 2-1/2" thick floor fill | | | 2585 | .022 | | 1.04 | .67 | .27 | 1.98 | 2.54 | |
| 3400 | Cellular concrete, 1-5/8" fill, under 5000 S.F. | | | 2000 | .028 | | .70 | .87 | .35 | 1.92 | 2.57 | |
| 3450 | Over 10,000 S.F. | | | 2200 | .025 | | .66 | .79 | .32 | 1.77 | 2.36 | |
| 3500 | Add per floor for 3 to 6 stories high | | | 31800 | .002 | | | .05 | .02 | .07 | .11 | |
| 3520 | For 7 to 20 stories high | | | 21200 | .003 | | | .08 | .03 | .11 | .17 | |
| 3800 | Footings, spread under 1 C.Y. | | C-14C | 38.07 | 2.942 | C.Y. | 175 | 99.50 | .56 | 275.06 | 360 | |
| 3850 | Over 5 C.Y. | | | 81.04 | 1.382 | | 242 | 47 | .26 | 289.26 | 345 | |
| 3900 | Footings, strip, 18" x 9", unreinforced | | | 40 | 2.800 | | 109 | 95 | .53 | 204.53 | 278 | |
| [illegible] | [illegible] | | | 35 | 3.200 | | 130 | 108 | .61 | 238.61 | 325 | |
| | COLUMNS, STRUCTURAL | R051223 -20 | | | | | | | | | | 260 |
| | Shop fab'd for 100-ton, 1-2 story project, bolted conn's. | | | | | | | | | | | |
| | Steel, concrete filled, extra strong pipe, 3-1/2" diameter | | E-2 | 660 | .085 | L.F. | 31.50 | 3.30 | 2.16 | 36.96 | 43 | |
| | 4" diameter | | | 780 | .072 | | 35 | 2.79 | 1.83 | 39.62 | 45.50 | |
| | 5" diameter | | | 1020 | .055 | | 41.50 | 2.14 | 1.40 | 45.04 | 51.50 | |
| | 6" diameter | | | 1200 | .047 | | 55 | 1.82 | 1.19 | 58.01 | 65 | |
| | 8" diameter | | | 1100 | .051 | | 55 | 1.98 | 1.30 | 58.28 | 65.50 | |
| | For galvanizing, add | | | | | Lb. | .22 | | | .22 | .25 | |
| | For web ties, angles, etc., add per added lb. | | 1 Sswk | 945 | .008 | | .95 | .34 | | 1.29 | 1.68 | |
| | Steel pipe, extra strong, no concrete, 3" to 5" diameter | | E-2 | 16000 | .004 | | .95 | .14 | .09 | 1.18 | 1.39 | |
| | 6" to 12" diameter | | | 14000 | .004 | | .95 | .16 | .10 | 1.21 | 1.44 | |
| | Steel pipe, extra strong, no concrete, 3" diameter x 12'-0" | | | 60 | .933 | Ea. | 117 | 36.50 | 24 | 177.50 | 220 | |
| | 4" diameter x 12'-0" | | | 58 | .966 | | 171 | 37.50 | 24.50 | 233 | 283 | |
| | 6" diameter x 12'-0" | | | 54 | 1.037 | | 325 | 40.50 | 26.50 | 392 | 460 | |
| | 8" diameter x 14'-0" | | | 50 | 1.120 | | 575 | 43.50 | 28.50 | 647 | 745 | |
| | 10" diameter x 16'-0" | | | 48 | 1.167 | | 830 | 45.50 | 29.50 | 905 | 1,025 | |
| | 12" diameter x 18'-0" | | | 45 | 1.244 | | 1,125 | 48.50 | 31.50 | 1,205 | 1,350 | |
| | Structural tubing, square, A500GrB, 4" to 6" square, light section | | | 11270 | .005 | Lb. | .95 | .19 | .13 | 1.27 | 1.54 | |
| | Heavy section | | | 32000 | .002 | " | .95 | .07 | .04 | 1.06 | 1.22 | |
| | Concrete filled, add | | | | | L.F. | 3.47 | | | 3.47 | 3.81 | |
| | Structural tubing, sq, 4" x 4" x 1/4" x 12'-0" | | E-2 | 58 | .966 | Ea. | 157 | 37.50 | 24.50 | 219 | 267 | |
| | 6" x 6" x 1/4" x 12'-0" | | | 54 | 1.037 | | 257 | 40.50 | 26.50 | 324 | 385 | |
| | 8" x 8" x 3/8" x 14'-0" | | | 50 | 1.120 | | 555 | 43.50 | 28.50 | 627 | 720 | |
| | 10" x 10" x 1/2" x 16'-0" | | | 48 | 1.167 | | 1,025 | 45.50 | 29.50 | 1,100 | 1,250 | |
| | Structural tubing, rect, 5" to 6" wide, light section | | | 8000 | .007 | Lb. | .95 | .27 | .18 | 1.40 | 1.74 | |
| | Heavy section | | | 12000 | .005 | | .95 | .18 | .12 | 1.25 | 1.51 | |
| | 7" to 10" wide, light section | | | 15000 | .004 | | .95 | .15 | .10 | 1.20 | 1.41 | |
| | Heavy section | | | 18000 | .003 | | .95 | .12 | .08 | 1.15 | 1.36 | |
| | Structural tubing, rect, 5" x 3" x 1/4" x 12'-0" | | | 58 | .966 | Ea. | 152 | 37.50 | 24.50 | 214 | 262 | |
| | 6" x 4" x 5/16" x 12'-0" | | | 54 | 1.037 | | 238 | 40.50 | 26.50 | 305 | 365 | |
| | 8" x 4" x 3/8" x 12'-0" | | | 54 | 1.037 | | 345 | 40.50 | 26.50 | 412 | 480 | |
| | 10" x 6" x 3/8" x 14'-0" | | | 50 | 1.120 | | 555 | 43.50 | 28.50 | 627 | 720 | |
| | 12" x 8" x 1/2" x 16'-0" | | | 48 | 1.167 | | 1,025 | 45.50 | 29.50 | 1,100 | 1,250 | |
| | W Shape, A992 steel, 2 tier, W8 x 24 | | | 1080 | .052 | L.F. | 25 | 2.02 | 1.32 | 28.34 | 32.50 | |
| | W8 x 31 | | | 1080 | .052 | | 32.50 | 2.02 | 1.32 | 35.84 | 40.50 | |
| | W8 x 48 | | | 1032 | .054 | | 50 | 2.11 | 1.38 | 53.49 | 60.50 | |
| | W8 x 67 | | | 984 | .057 | | 70 | 2.21 | 1.45 | 73.66 | 82.50 | |
| | W10 x 45 | | | 1032 | .054 | | 47 | 2.11 | 1.38 | 50.49 | 57 | |

CONCRETE 3

METALS

| | | | | Crew | Daily Output | Labor-Hours | Unit | Mat. | Labor | Equip. | Total | Total Incl O&P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 640 | 0010 | **STRUCTURAL STEEL MEMBERS** | R051223 -10 | | | | | | | | | |
| | 0020 | Shop fab'd for 100-ton, 1-2 story project, bolted conn's. | | | | | | | | | | |
| | 0102 | W 6 x 9 | R051223 -15 | E-2 | 600 | .093 | L.F. | 9.40 | 3.63 | 2.38 | 15.41 | 19.45 |
| | 0302 | W 8 x 10 | | | 600 | .093 | | 10.45 | 3.63 | 2.38 | 16.46 | 20.50 |
| | 0502 | x 31 | | | 550 | .102 | | 32.50 | 3.96 | 2.59 | 39.05 | 45.50 |
| | 0702 | W 10 x 22 | | | 600 | .093 | | 23 | 3.63 | 2.38 | 29.01 | 34.50 |
| | 0902 | x 49 | | | 550 | .102 | | 51 | 3.96 | 2.59 | 57.55 | 66.50 |
| | 1102 | W 12 x 14 | | | 880 | .064 | | 14.65 | 2.48 | 1.62 | 18.75 | 22.50 |
| | 1302 | x 22 | | | 880 | .064 | | 23 | 2.48 | 1.62 | 27.10 | 31.50 |
| | 1502 | x 26 | | | 880 | .064 | | 27 | 2.48 | 1.62 | 31.10 | 36 |
| | 1702 | x 72 | | | 640 | .088 | | 75 | 3.40 | 2.23 | 80.63 | 91.50 |
| | 1902 | W 14 x 26 | | | 990 | .057 | | 27 | 2.20 | 1.44 | 30.64 | 35.50 |
| | 2102 | x 30 | | | 900 | .062 | | 31.50 | 2.42 | 1.59 | 35.51 | 40.50 |
| | 2302 | x 34 | | | 810 | .069 | | 35.50 | 2.69 | 1.76 | 39.95 | 46 |
| | 2502 | x 120 | | | 720 | .078 | | 125 | 3.03 | 1.98 | 130.01 | 146 |
| | 2702 | W 16 x 26 | | | 1000 | .056 | | 27 | 2.18 | 1.43 | 30.61 | 35.50 |
| | 2902 | x 31 | | | 900 | .062 | | 32.50 | 2.42 | 1.59 | 36.51 | 41.50 |
| | 3102 | x 40 | | ▼ | 800 | .070 | | 42 | 2.72 | 1.78 | 46.50 | 53 |
| | 3302 | W 18 x 35 | | E-5 | 960 | .083 | | 36.50 | 3.28 | 1.58 | 41.36 | 47.50 |
| | 3502 | x 40 | | | 960 | .083 | | 42 | 3.28 | 1.58 | 46.86 | 53.50 |
| | 3702 | x 50 | | | 912 | .088 | | 52.50 | 3.46 | 1.66 | 57.62 | 65.50 |
| | 3902 | x 55 | | | 912 | .088 | | 57.50 | 3.46 | 1.66 | 62.62 | 71 |
| | 4102 | W 21 x 44 | | | 1064 | .075 | | 46 | 2.96 | 1.42 | 50.38 | 57.50 |
| | 4302 | x 50 | | | 1064 | .075 | | 52.50 | 2.96 | 1.42 | 56.88 | 64.50 |
| | 4502 | x 62 | | | 1036 | .077 | | 65 | 3.04 | 1.46 | 69.50 | 78.50 |
| | 4702 | x 68 | | | 1036 | .077 | | 71 | 3.04 | 1.46 | 75.50 | 85 |
| | 4902 | W 24 x 55 | | | 1110 | .072 | | 57.50 | 2.84 | 1.37 | 61.71 | 69.50 |
| | 5102 | x 62 | | | 1110 | .072 | | 65 | 2.84 | 1.37 | 69.21 | 78 |
| | 5302 | x 68 | | | 1110 | .072 | | 71 | 2.84 | 1.37 | 75.21 | 84.50 |
| | 5502 | x 76 | | | 1110 | .072 | | 79.50 | 2.84 | 1.37 | 83.71 | 94 |
| | 5702 | x 84 | | | 1080 | .074 | | 88 | 2.92 | 1.40 | 92.32 | 103 |
| | 5902 | W 27 x 94 | | | 1190 | .067 | | 98 | 2.65 | 1.27 | 101.92 | 114 |
| | | | | | [illegible] | [illegible] | | [illegible] | 2.63 | 1.26 | 106.89 | 120 |

## 05310 | Steel Deck

| | | 05310 Steel Deck | | Crew | Daily Output | Labor-Hours | Unit | Mat. | Labor | Equip. | Total | Total Incl O&P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 2006 Bare Costs | | | | |
| 300 | 0010 | **METAL DECKING** Steel decking | R053100 -10 | | | | | | | | | |
| | 0200 | Cellular units, galv, 2" deep, 20-20 gauge, over 15 squares | | E-4 | 1460 | .022 | S.F. | 5.85 | .89 | .06 | 6.80 | 8.20 |
| | 0250 | 18-20 gauge | | | 1420 | .023 | | 6.65 | .91 | .06 | 7.62 | 9.05 |
| | 0300 | 18-18 gauge | | | 1390 | .023 | | 6.85 | .93 | .06 | 7.84 | 9.30 |
| | 0320 | 16-18 gauge | | | 1360 | .024 | | 8.15 | .95 | .07 | 9.17 | 10.80 |
| | 0340 | 16-16 gauge | | | 1330 | .024 | | 9.05 | .97 | .07 | 10.09 | 11.85 |
| | 0400 | 3" deep, galvanized, 20-20 gauge | | | 1375 | .023 | | 6.45 | .94 | .06 | 7.45 | 8.95 |
| | 0500 | 18-20 gauge | | | 1350 | .024 | | 7.80 | .96 | .07 | 8.83 | 10.40 |
| | 0600 | 18-18 gauge | | | 1290 | .025 | | 7.75 | 1 | .07 | 8.82 | 10.50 |
| | 0700 | 16-18 gauge | | | 1230 | .026 | | 8.75 | 1.05 | .07 | 9.87 | 11.65 |
| | 0800 | 16-16 gauge | | | 1150 | .028 | | 9.55 | 1.13 | .08 | 10.76 | 12.70 |
| | 1000 | 4-1/2" deep, galvanized, 20-18 gauge | | | 1100 | .029 | | 9 | 1.18 | .08 | 10.26 | 12.20 |
| | 1100 | 18-18 gauge | | | 1040 | .031 | | 8.95 | 1.24 | .09 | 10.28 | 12.25 |
| | 1200 | 16-18 gauge | | | 980 | .033 | | 10.05 | 1.32 | .09 | 11.46 | 13.60 |
| | 1300 | 16-16 gauge | | ▼ | 935 | .034 | ▼ | 10.95 | 1.38 | .10 | 12.43 | 14.75 |
| | 1500 | For acoustical deck, add | | | | | | 15% | | | | |
| | 1700 | For cells used for ventilation, add | | | | | | 15% | | | | |
| | 1900 | For multi-story or congested site, add | | | | | | | 50% | | | |
| | 2100 | Open type, galv., 1-1/2" deep wide rib, 22 gauge, under 50 squares | | E-4 | 4500 | .007 | S.F. | 1.47 | .29 | .02 | 1.78 | 2.17 |
| | 2400 | Over 500 squares | | | 5100 | .006 | | 1.06 | .25 | .02 | 1.33 | 1.65 |
| | 2600 | 20 gauge, under 50 squares | | | 3865 | .008 | | 1.73 | .33 | .02 | 2.08 | 2.56 |
| | 2700 | Over 500 squares | | | 4300 | .007 | | 1.24 | .30 | .02 | 1.56 | 1.95 |
| | 2900 | 18 gauge, under 50 squares | | | 3800 | .008 | | 2.24 | .34 | .02 | 2.60 | 3.13 |
| | 3000 | Over 500 squares | | | 4300 | .007 | | 1.61 | .30 | .02 | 1.93 | 2.35 |
| | 3050 | 16 gauge, under 50 squares | | | 3700 | .009 | | 3.01 | .35 | .02 | 3.38 | 3.99 |
| | 3100 | Over 500 squares | | | 4200 | .008 | | 2.17 | .31 | .02 | 2.50 | 2.99 |
| | 3200 | 3" deep, 22 gauge, under 50 squares | | | 3600 | .009 | | 2.02 | .36 | .02 | 2.40 | 2.92 |
| | 3300 | 20 gauge, under 50 squares | | | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | Crew | Daily Output | Labor-Hours | Unit | Mat. | Labor | Equip. | Total | Total Incl O&P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 840 | 0010 | **WELD SHEAR CONNECTORS** | | | | | | | | | |
| | 0020 | 3/4" diameter, 3-3/16" long | E-10 | 960 | .017 | Ea. | .41 | .68 | .28 | 1.37 | 2.03 |
| | 0030 | 3-3/8" long | | 950 | .017 | | .43 | .69 | .28 | 1.40 | 2.07 |
| | 0200 | 3-7/8" long | | 945 | .017 | | .46 | .69 | .28 | 1.43 | 2.12 |
| | 0300 | 4-3/16" long | | 935 | .017 | | .48 | .70 | .28 | 1.46 | 2.15 |
| | 0500 | 4-7/8" long | | 930 | .017 | | .54 | .70 | .29 | 1.53 | 2.22 |
| | 0600 | 5-3/16" long | | 920 | .017 | | .56 | .71 | .29 | 1.56 | 2.27 |
| | 0800 | 5-3/8" long | ▼ | 910 | .018 | ▼ | .57 | .72 | .29 | 1.58 | 2.29 |

| | 07812 Cementitious Fireproofing | | Crew | Daily Output | Labor-Hours | Unit | 2006 Bare Costs Mat. | Labor | Equip. | Total | Total Incl O&P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 600 | 1300 | Difficult access, minimum | G-2 | 225 | .107 | S.F. | .48 | 3.12 | .52 | 4.12 | 6.20 |
| | 1400 | Maximum | ↓ | 130 | .185 | ↓ | .53 | 5.40 | .90 | 6.83 | 10.35 |
| | 1500 | Intumescent epoxy fireproofing on wire mesh, 3/16" thick | | | | | | | | | |
| | 1550 | 1 hour rating, exterior use | G-2 | 136 | .176 | S.F. | 5.55 | 5.15 | .86 | 11.56 | 15.50 |
| | 1600 | Magnesium oxychloride, 35# to 40# density, 1/4" thick | | 3000 | .008 | | 1.17 | .23 | .04 | 1.44 | 1.71 |
| | 1650 | 1/2" thick | | 2000 | .012 | | 2.35 | .35 | .06 | 2.76 | 3.22 |
| | 1700 | 60# to 70# density, 1/4" thick | | 3000 | .008 | | 1.55 | .23 | .04 | 1.82 | 2.13 |
| | 1750 | 1/2" thick | | 2000 | .012 | | 3.12 | .35 | .06 | 3.53 | 4.06 |
| | 2000 | Vermiculite cement, troweled or sprayed, 1/4" thick | | 3000 | .008 | | 1.06 | .23 | .04 | 1.33 | 1.59 |
| | 2050 | 1/2" thick | | 2000 | .012 | ↓ | 2.10 | .35 | .06 | 2.51 | 2.94 |
| | 9000 | Minimum labor/equipment charge | ↓ | 3 | 8 | Job | | 234 | 39 | 273 | 425 |

RUCTION

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | .044 | | | | | 5.12 | |
| | | | | | | ↓ | 1.49 | 5.25 | 6.74 | | |
| 462 | 0010 | **EXCAVATION, STRUCTURAL** | | | | | | | | | 0310 |
| | 0015 | Hand, pits to 6' deep, sandy soil (R312316-40) | 1 Clab | 8 | 1 | B.C.Y. | 27.50 | | 27.50 | 42 | 0320 |
| | 0020 | Normal soil | B-2 | 16 | 2.500 | | 69.50 | | 69.50 | 106 | 0330 |
| | 0030 | Medium clay | | 12 | 3.333 | | 92.50 | | 92.50 | 144 | 0400 |
| | 0040 | Heavy clay | | 8 | 5 | | 139 | | 139 | 216 | 0450 |
| | 0050 | Loose rock | ↓ | 6 | 6.667 | | 185 | | 185 | 289 | 0500 |
| | 0100 | Heavy soil or clay | 1 Clab | 4 | 2 | | 55 | | 55 | 85.50 | 0540 |
| | 0200 | Pits to 2' deep, normal soil | B-2 | 24 | 1.667 | | 46.50 | | 46.50 | 72 | 0550 |
| | 0210 | Sand and gravel | | 24 | 1.667 | | 46.50 | | 46.50 | 72 | 0560 |
| | 0220 | Medium clay | | 18 | 2.222 | | 62 | | 62 | 96 | 0600 |
| | 0230 | Heavy clay | ↓ | 12 | 3.333 | | 92.50 | | 92.50 | 144 | 0700 |
| | 0300 | Pits 6' to 12' deep, sandy soil | 1 Clab | 5 | 1.600 | | 44 | | 44 | 68 | 1000 |
| | 0500 | Heavy soil or clay | | 3 | 2.667 | | 73 | | 73 | 114 | 1100 |
| | 0700 | Pits 12' to 18' deep, sandy soil | | 4 | 2 | | 55 | | 55 | 85.50 | 1110 |
| | 0900 | Heavy soil or clay | ↓ | 2 | 4 | ↓ | 110 | | 110 | 171 | 1120 |
| | 1000 | Hand trimming, bottom of excavation | B-2 | 2400 | .017 | S.F. | .46 | | .46 | .72 | 1130 |
| | 1010 | Slopes and sides | | 2400 | .017 | " | .46 | | .46 | .72 | 1150 |
| | 1030 | Around obstructions | ↓ | 8 | 5 | B.C.Y. | 139 | | 139 | 216 | 1200 |
| | 1100 | Hand loading trucks from stock pile, sandy soil | 1 Clab | 12 | .667 | | 18.25 | | 18.25 | 28.50 | 1220 |
| | 1300 | Heavy soil or clay | " | 8 | 1 | ↓ | 27.50 | | 27.50 | 42.50 | 1240 |
| | 1500 | For wet or muck hand excavation, add to above | | | | % | | | 50% | 50% | 1245 |
| | 1550 | Excavation rock by hand/air tool | B-9 | 3.40 | 11.765 | B.C.Y. | 325 | 43.50 | 368.50 | 560 | 1250 |
| | 6000 | Machine excavation, for spread and mat footings, elevator pits, | | | | | | | | | 1255 |
| | 6001 | and small building foundations | | | | | | | | | 1300 |
| | 6030 | Common earth, hydraulic backhoe, 1/2 C.Y. bucket | B-12E | 55 | .291 | B.C.Y. | 9.55 | 6.10 | 15.65 | 21.50 | 1400 |
| | 6035 | 3/4 C.Y. bucket | B-12F | 90 | .178 | | 5.80 | 5.30 | 11.10 | 14.75 | 1600 |
| | 6040 | 1 C.Y. bucket | B-12A | 108 | .148 | | | | | | 1800 |
| | 6050 | 1-1/2 C.Y. bucket | | | | | | | | | 2000 |
| | 6060 | | | | | | | | | | 2010 |

## APPENDIX D: HAND STEEL CALCULATIONS UNDER ROOF GARDEN AND WITH NEW COLUMN LAYOUT

Under Roof Garden

STEEL CALCULATIONS UNDER ROOF GARDEN.

FLOWER CARPET.

DL = 10 PSF + 18 PSF
LL = neg.
SL = 30 PSF
TL = 1.2(28) + 1.6(30) = 82 PSF

(82)(18.75' TRIB) = 1.54 KLF
$M_{MAX} = \frac{1}{8}(1.54)(30^2) = 173.3$ FT-K

LRFD MANUAL W14x30 NONCOMPOS.
→ EXISTING W18x40, OK.

DL = 10 PSF + 18 PSF
LL = 50 PSF
SL = 30 PSF
TL = 1.2(28) + 0.5(30) + 1.6(50)
= 128.6 PSF

2.42 KLF
= 272.3 FT-K

W16x40

AROMATIC GARDEN

DL = 10 PSF + 24
LL = neg.
SL = 30
TL = 89 PSF

$M_{MAX}$ = 188 FT-K
W16x31
→ USE NONCOMPOSITE SYSTEM

DL = 34
LL = 50
SL = 30
TL = 136 PSF

$M_{MAX}$ = 287 FT-K
W18x40

SAVANNAH

DL: 46 PSF
LL: neg.
SL: 30
TL: 104 PSF

$M_{MAX}$ = 220 FT-K
COMPOSITE SYSTEM W/ 3" DECK + 3.5" CONC.
Y1 = 0, Y2 = 4.75
→ W10x15
(NONCOMPOSITE) W18x35 ✓

COMPOSITE
DL: 46 + 60
LL: 50
SL: 30
TL: ~~[illegible]~~ PSF
219.8

$M_{MAX}$ = 317 FT-K
↓
W21x44

$M_{MAX}$: ~~[illegible]~~ 464 FT-K
W14x22
→ (beff = 3.75')
281/0.85(4)(3.75) → a = 1.84"
Y2 = 6.5 - 0.5(1.84) = 5.58

MEADOWS

DL: 64 PSF
LL: neg
SL: 30
TL: 125
$M_{MAX}$: 264 FT-K
→ W16x40

DL: 64 + 60
LL: 50
SL: 30
TL: 172
$M_{MAX}$: ~~[illegible]~~ 515 FT-K
Y1 = 0 Y2 = 4.75
W14x22

With New Column Grid

NEW STEEL LAYOUT

GIRDERS

30' LONG, 26'-3" TRIB

100 PSF LL
60 PSF DL + 10

TL = 244 PSF
= 6.405 KLF
$M_{MAX}$ = 720.56 FT-K
W18x55
W21x48

a = 420/(0.85)(4)(12)(3.75)
Y1 ~ 0 Y2 = 5.13 ✓

a = 2.745

a = 401/(0.85)(4)(12)(3.75) = 2.6209
Y1 ~ 0 Y2 = 5.19 ✓

COLUMNS ROOF TL: 60 PSF OFFICE TL: 244 PSF

$(30^2)(60 + 4(244)) = 933^K$
13'-4" UNBRACED LENGTH → W12x96
W14x90