One City Center
Washington D.C.

Jeremy Swartz
Structural Option

Advisor: Dr. Aly Said

One City Center

Introduction

Existing System
Gravity System | Lateral System

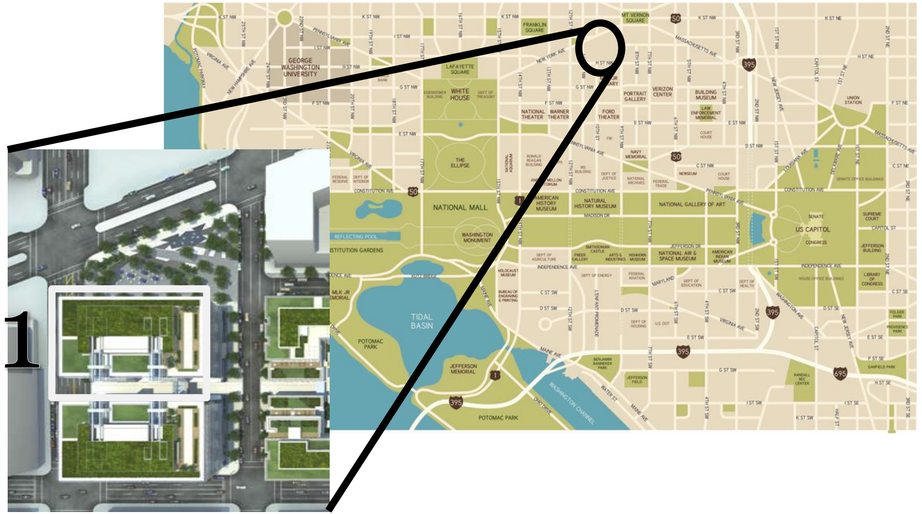
Structural Depth
Proposed System | Blast Design | Progressive Collapse

Construction Breadth
Cost Comparison | Schedule Comparison

Conclusion

Introduction:

- Occupancy: Mixed use, Office and Commercial
- Size: 12 floors, 59,000 sqft per floor
  -157.5’ total height
- Dates: April 2011 – 2014



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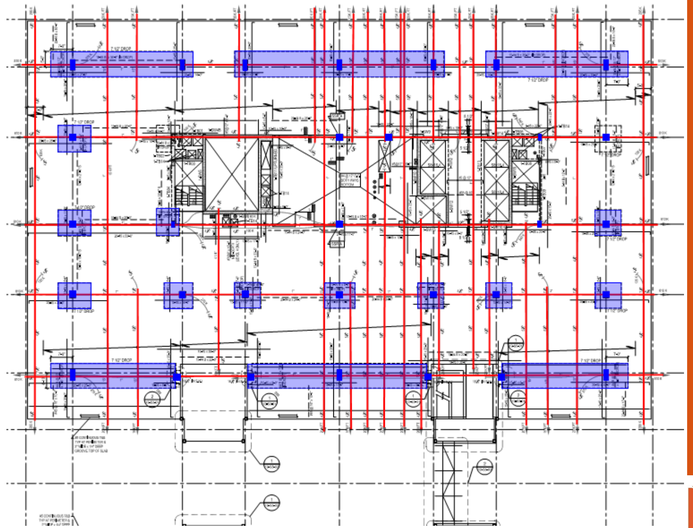
Gravity System:

- 8 ½” Two way post tensioned slab with mild steel
  - 1/2” 7-wire strand grade 270 ksi
  -#4 and #5 mild steel at columns
  - F’c of 5000 psi
- Banded tendons run E-W (810 kips) draped profile
- Distributed tendons run N-S (20 kips/ft spaced @ 6’) draped profile
- 24”x24” typical columns with 8 #8 bars and #3 ties @ 16”, F’c changes with height (8ksi-6ksi)
- 7 ½” Drop panels and Shear capitals

Tendons

Columns



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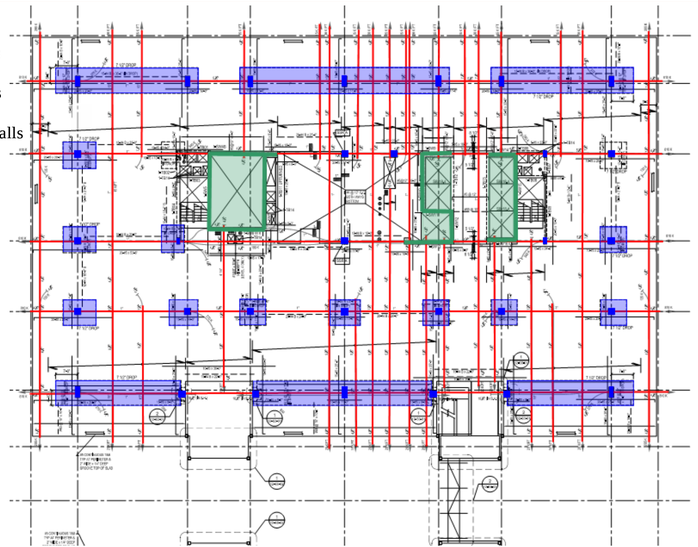
Lateral System:

- Reinforced Concrete Shear Walls with boundary elements.

- Shear Walls that run N-S are 10” thick
  Shear Walls that run E-W are 12” thick
  Both have either #4 or #5 bars at 12” for both longitudinal and transverse reinforcement.
  Typical boundary elements are 12#7 or 8#8 bars
  F’c changes with height (same as columns)

Tendons
Columns
Shear Walls



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Structural Depth:

- Redesign of the gravity system into a two way flat plate
- Redesign of shear walls for new load
- Blast design for interior and exterior explosion
- Progressive Collapse for interior explosion

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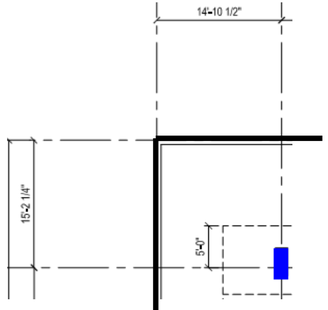
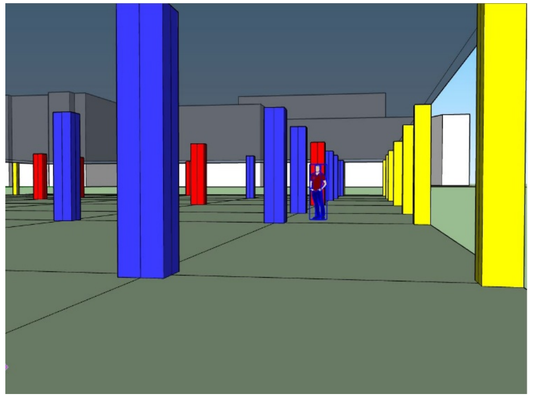
Proposed Gravity System:

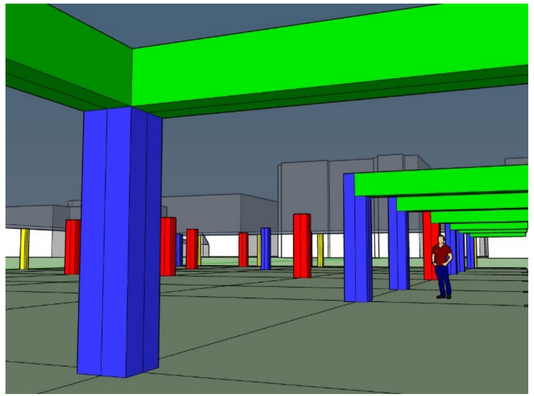
- Gravity redesign into a two way flat plate
  - -15’ overhangs are too large
  - -Add perimeter beams
  - -Add perimeter columns



Perimeter Columns



Perimeter Beams



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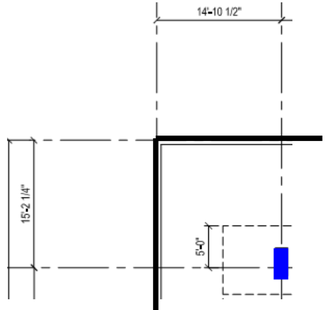
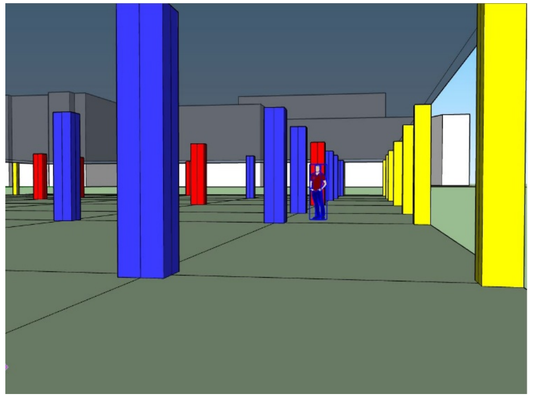
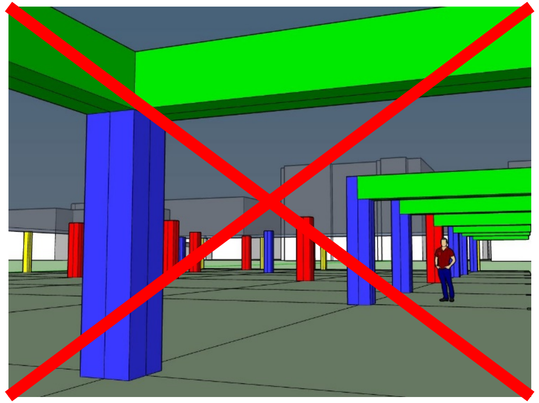


Perimeter Columns



Perimeter Beams



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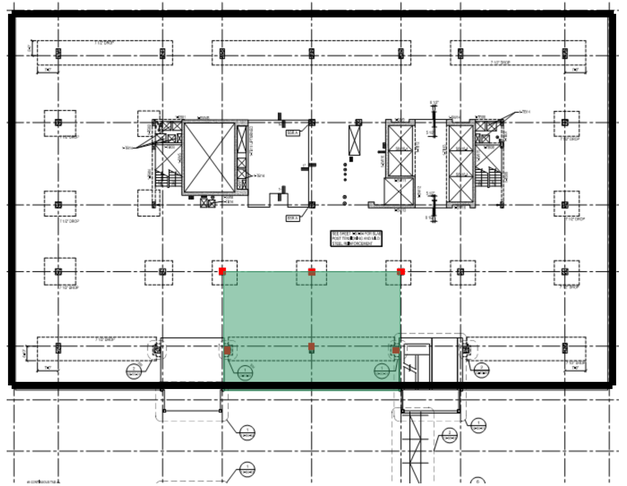
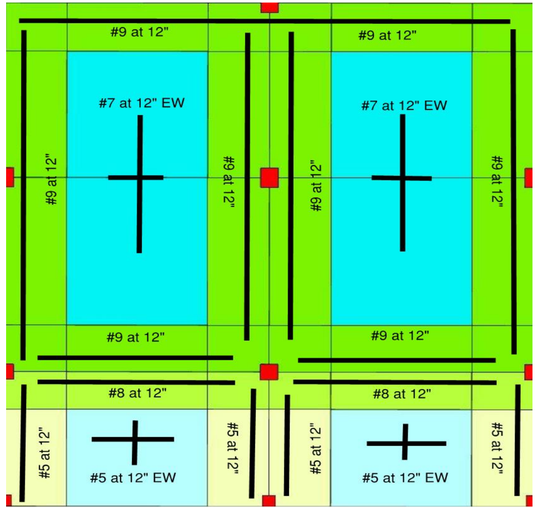
Proposed Slab System:

- Two way flat plate
  -Direct Design method
  -Designed for controlling interior and exterior bay



Proposed Slab System:

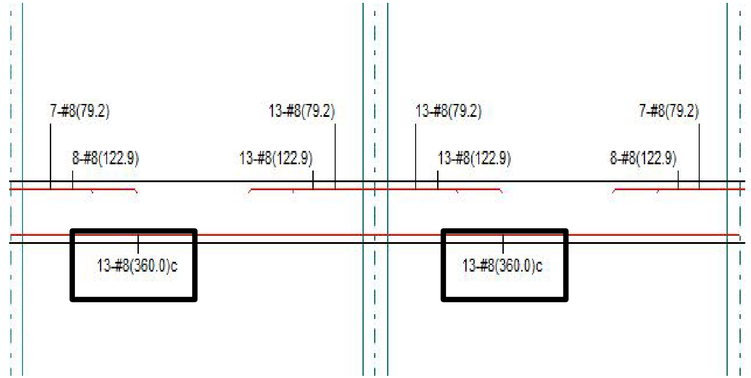
- Two way flat slab
  - -Direct Design method
  - -Interior Bays #9 @ 12” within 7’ of column
    #7 @ 12” everywhere else
  - -Exterior Bays #8 @ 12” within 5’ of column
    #5 @ 12” everywhere else
  - -Top reinforcement @ 6”
  - -F’c of 4000 psi
  - -11” thick slab



Top and Bottom Reinforcement

Slab System Verification:

- Verification
  -Reinforcement designed by hand matched that designed by spSlab



13 #8 spaced at 12” within a 13’ wide strip = #8 at 12”

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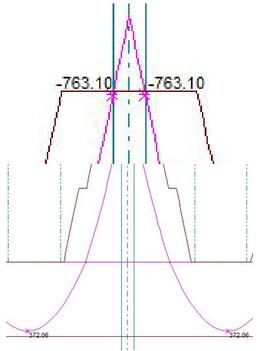
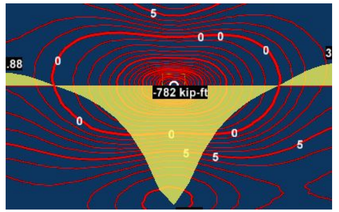
Slab System Verification:

- Verification
  - -Reinforcement designed by hand matched that designed by spSlab
  - -Moments at the same location were within 10% of each other

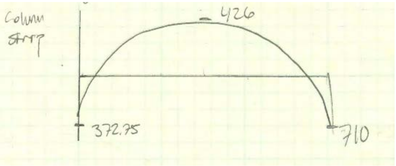
spSlab



RAM Concept



Hand Calcs



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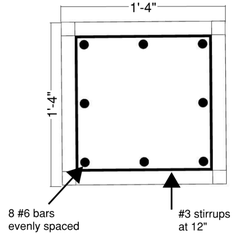
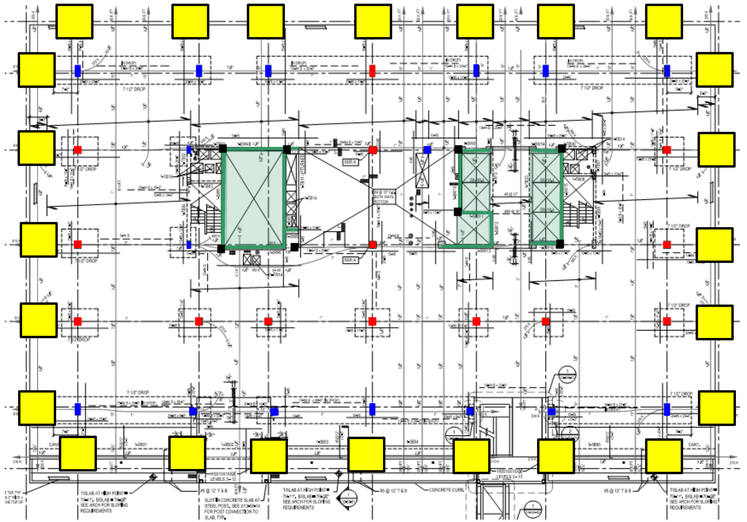
Proposed Gravity System:

- Three different columns were designed to meet the new loads
  -16”x16” with 8#6 bars #3 stirrups at 12”



16”x16”



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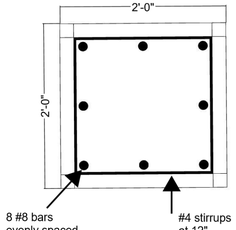
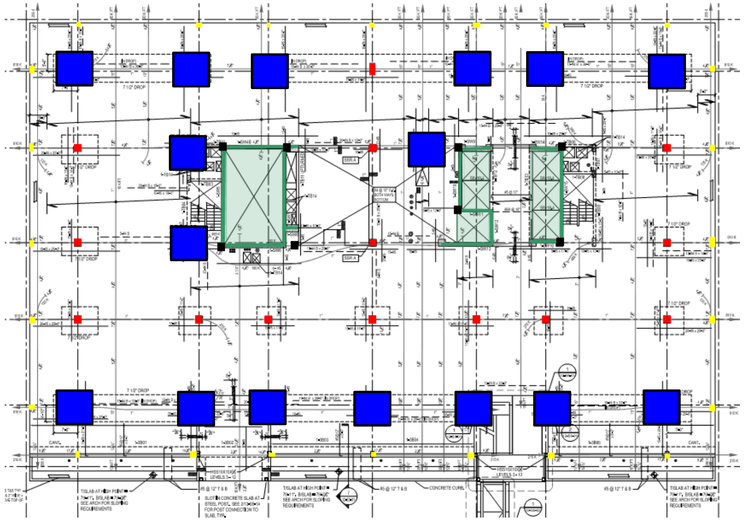
Proposed Gravity System:

- Three different columns were designed to meet the new loads
  - -18”x18” with 8#6 bars #3 stirrups at 12”
  - -24”x24” with 8#8 bars #4 stirrups at 12”



24”x24”



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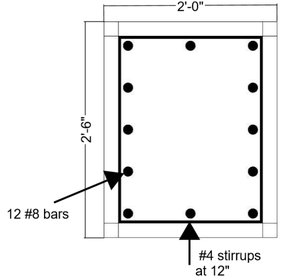
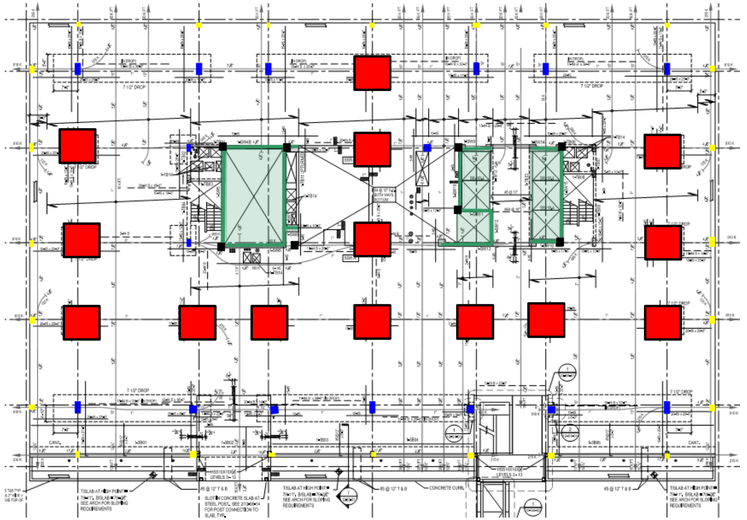
- Three different columns were designed to meet the new loads
  - -18”x18” with 8#6 bars #3 stirrups at 12”
  - -24”x24” with 8#8 bars #4 stirrups at 12”
  - -24”x30” with 12#8 bars #4 stirrups at 12”



24”x30”



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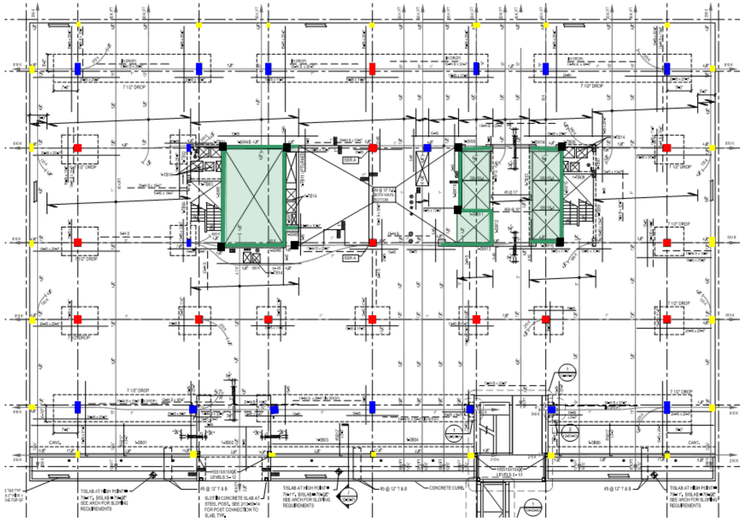
Proposed Gravity System:

- Three different columns were designed to meet the new loads
  - -18”x18” with 8#6 bars #3 stirrups at 12”
  - -24”x24” with 8#8 bars #4 stirrups at 12”
  - -24”x30” with 12#8 bars #4 stirrups at 12”
- Columns verified through hand calcs and spColumn
- F’c decreases with height similar to existing system



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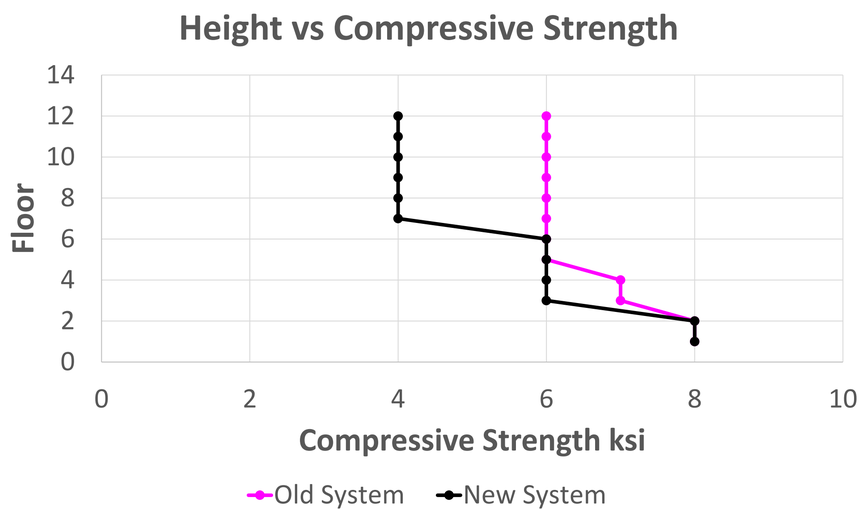

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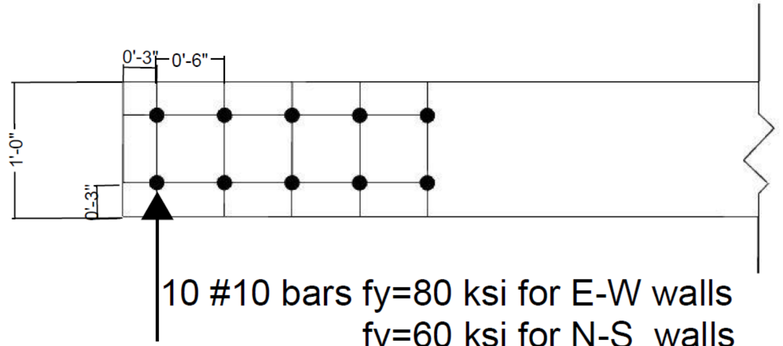
Proposed Lateral System:

- Shear walls for new system
  - -Controlling case was seismic in E-W
  - -Thickness increased to 12”
  - -80 ksi steel used
  - -Length of wall was not changed



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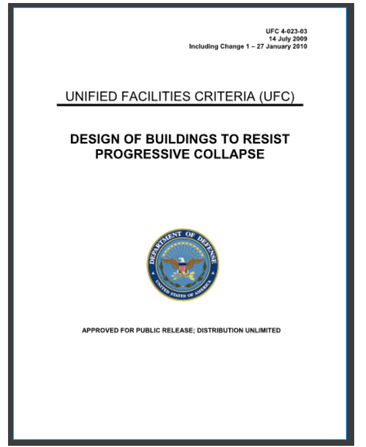
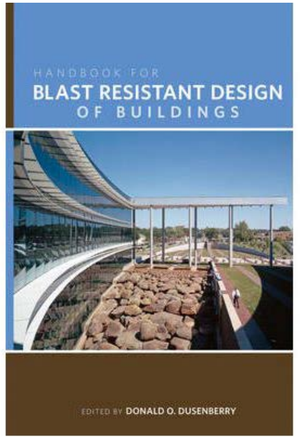
Blast Design *Research*:

- Blast design followed *UFC 3-340-02*, structures to resist the effects of accidental explosions, and procedures in the *Handbook for Blast Resistant Design of Buildings*
- Handbook heavily references UFC 3-340-02
- Handbook had empirical procedure for determining the effects of blast





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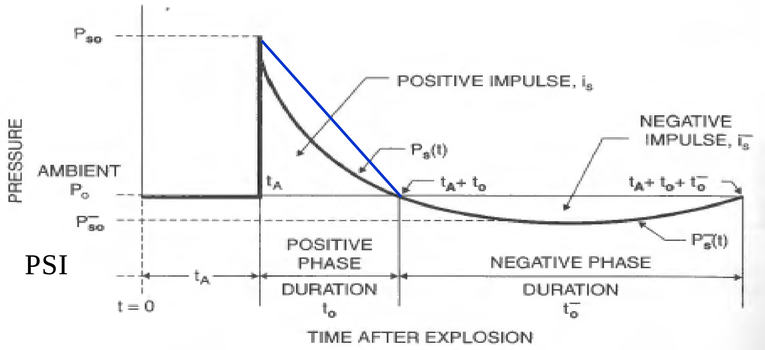
Blast Design *Effect*:

- Effect of blast has both a positive impulse and negative impulse over time.
- Empirical procedure utilized for simplicity
- Blast acts similar to wind load



PSI

Milliseconds

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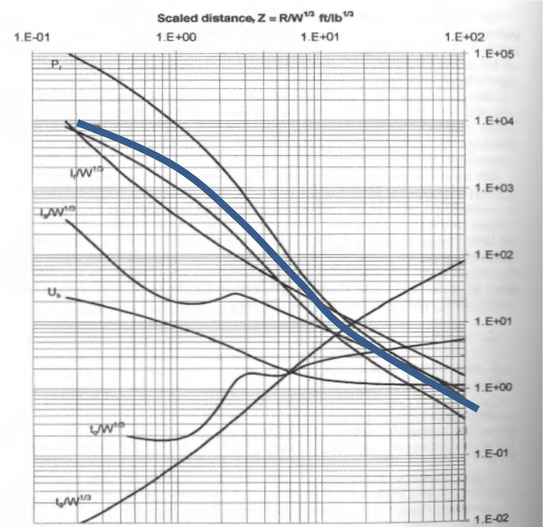
Blast Design *Effect*:

- Effect of blast has both a positive impulse and negative impulse over time.
- Empirical procedure utilized for simplicity
- Blast acts similar to wind load
- Pressures are then determined by
  - -Mass of the bomb - **W**
  - -Distance - **R**
- Scaled distance factor

$$Z = R/W^{1/3}$$

P_{so} = Side-on overpressure



Blast Design *Intensity*:

- What kind of bomb would go off
- Search was based on relatively small explosions
- 5 kg bomb was chosen

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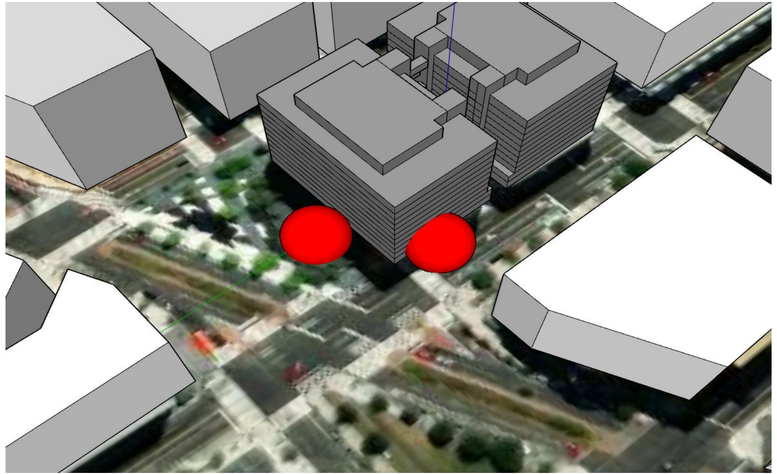
Blast Design *Location (Exterior)*:

- Initial Exterior Location
  - -2 locations were conceived testing each side of the building
  - -pressures were too large ≈ 65 psi = 9360 lbs/sqft



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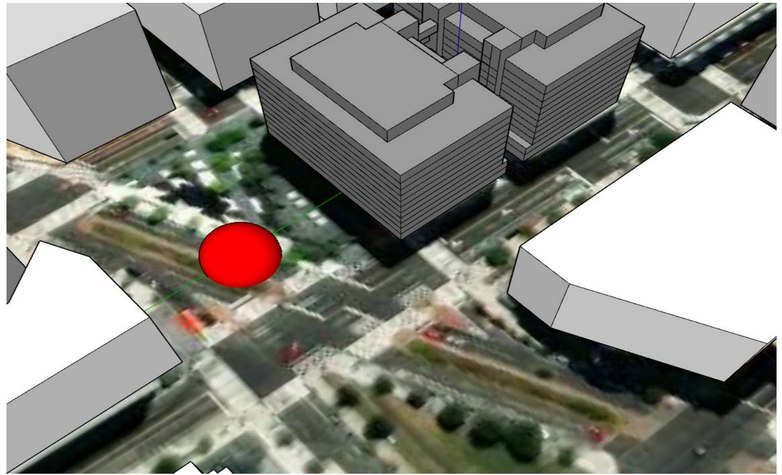
Blast Design *Location (Exterior)*:

- Initial Exterior Location
  - -2 locations were conceived testing each side of the building
  - -pressures were too large ≈ 65 psi = 9360 lbs/sqft
- Feasible Exterior Location
  - -More probable location was conceived
  - -Bomb 6ft away from the building would be equivalent to an interior explosion.



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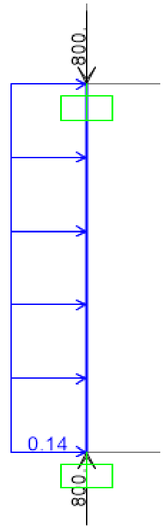
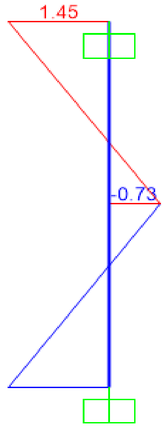
Blast Design *(Exterior)*:

- Modeled as a lateral pressure
- Moment from blast was added to existing moment on exterior column

Load



Moment



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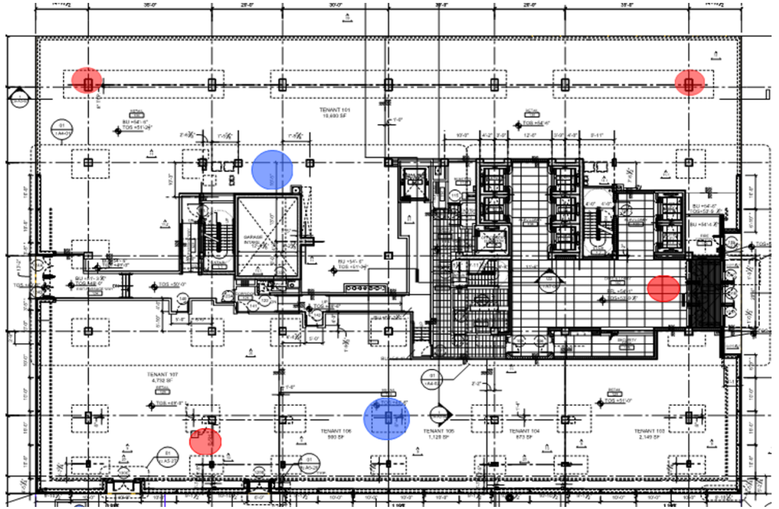
Blast Design *Location (Interior)*:

- Initial Interior Location
  - -Based on probability
  - -Based on structure
  - -Intention was so members could survive 5 kg blast
  - -Interior columns could only survive 9ft away
  - -Redesign was thought to be unreasonable

Structure

Probability



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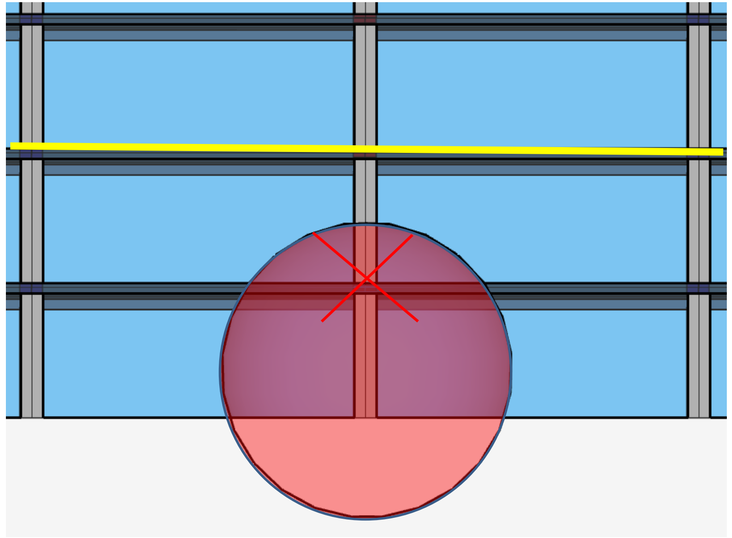
Progressive Collapse:

- Design conditions
  - Handbook does not specify progressive collapse
  - UFC 3-340-02 states that at minimum there needs to be an “alternate path for specified column and wall removal”
  - 2nd floor was designed to transfer load



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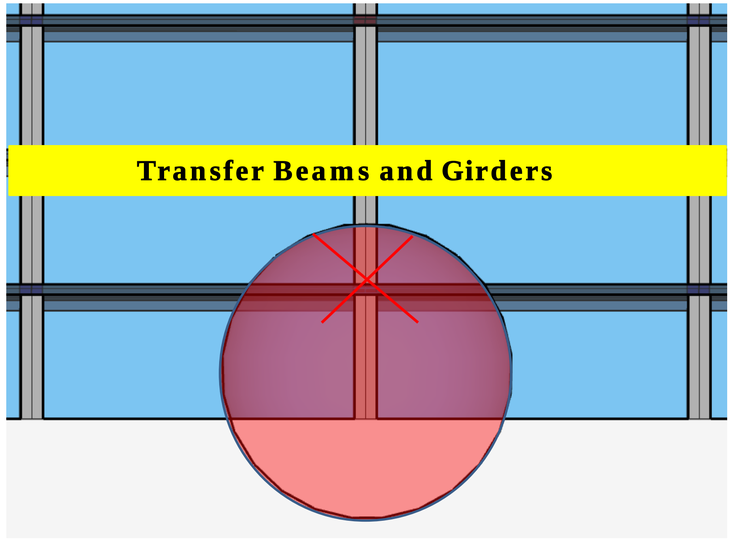
Progressive Collapse *Design*:

- Two systems created
  - -First would have added interior columns less span = shallower members
  - -Second would not have added columns larger members tightly spaced



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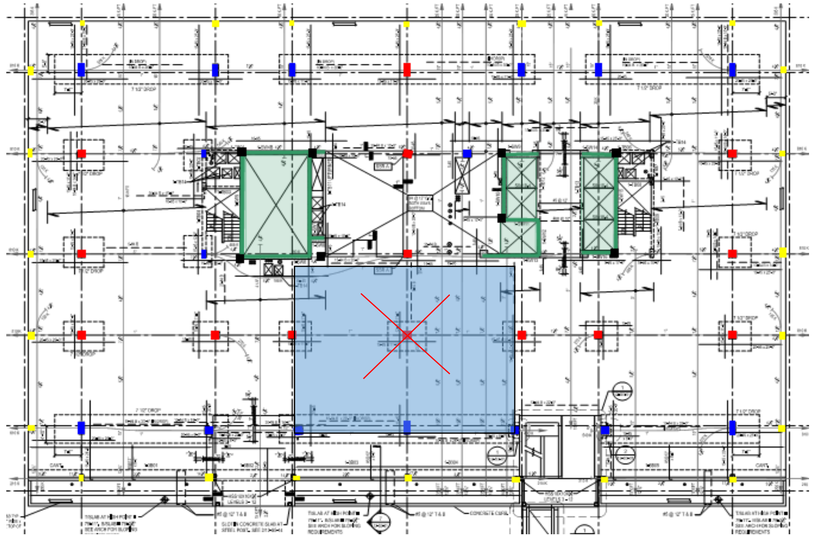
Progressive Collapse *Design*:

- Two systems created
  - -First would have added interior columns
    less span = shallower members
  - -Second would not have added columns
    larger members tightly spaced
  - -Controlling bay analyzed



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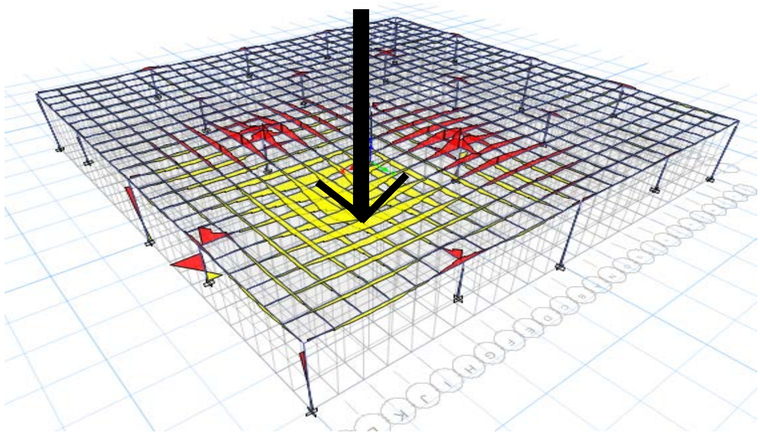
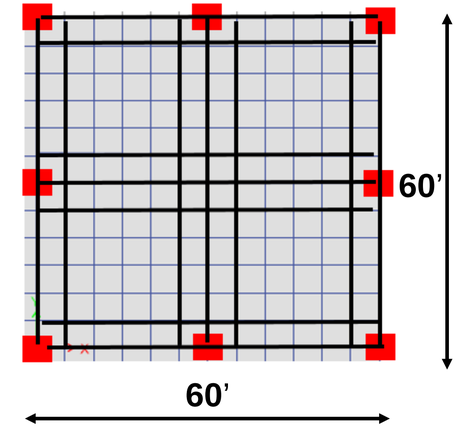
Progressive Collapse System 2





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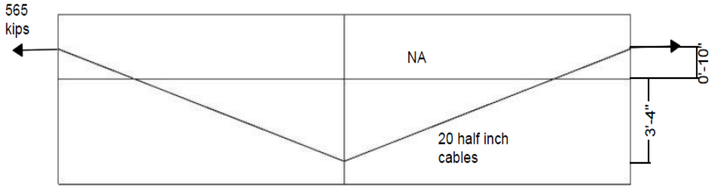
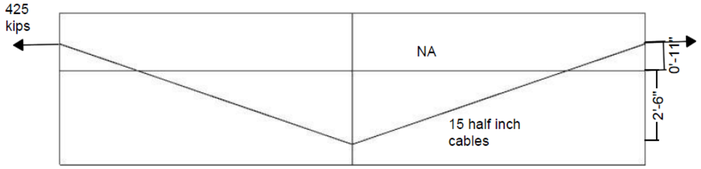
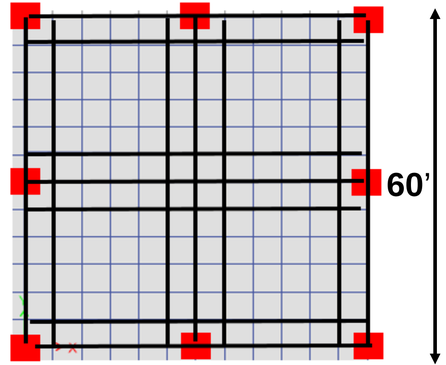
Progressive Collapse System 2

Main Beams
24x54 with 20 half inch cables



Intermediate Beams
24x48 with 15 half inch cables





Main Beams

Intermediate Beams

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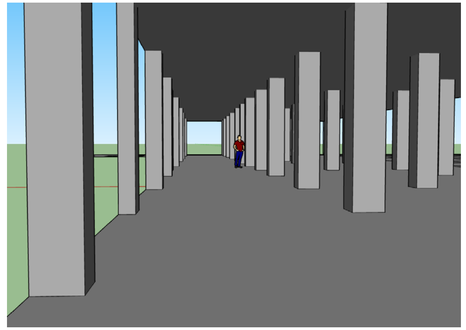
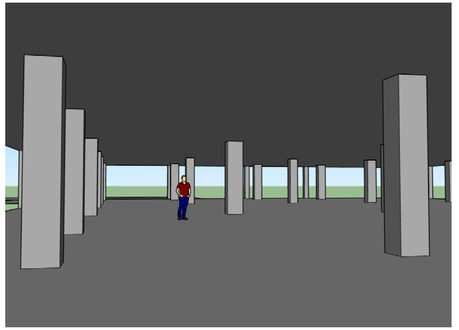
Progressive Collapse *System Comparison*:

- System 1
  - -Ground floor height 13 ft
  - -Additional columns
- System 2
  - -Ground floor height 11.5ft
  - -Additional beams
- Choice
  - -Up to owner or architect?



System 1



System 2

One City Center

Introduction

Existing System
Gravity System | Lateral System

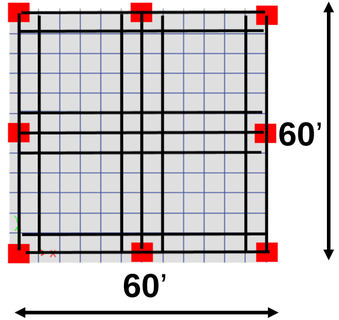
Structural Depth
Proposed System | Blast Design | **Progressive Collapse**

Construction Breadth
Cost Comparison | Schedule Comparison

Conclusion

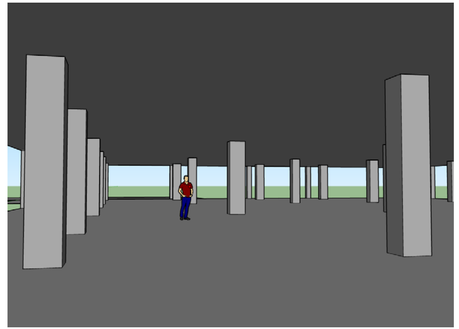
Progressive Collapse *System Comparison*:

- System 1
  - -Ground floor height 13 ft
  - -Additional columns
- System 2
  - -Ground floor height 11.5ft
  - -Additional beams
- Choice
  - -Up to owner or architect?
  - -Up to engineer, system 2



Main Beams

Intermediate Beams



System 2

One City Center

Introduction

Existing System
Gravity System | Lateral System

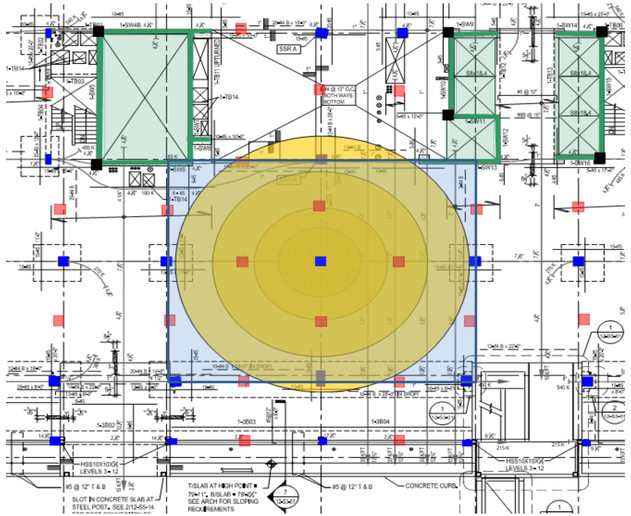
Structural Depth
Proposed System | Blast Design | **Progressive Collapse**

Construction Breadth
Cost Comparison | Schedule Comparison

Conclusion

Progressive Collapse *System Comparison*:

- System 1
  - -Ground floor height 13 ft
  - -Additional columns
- System 2
  - -Ground floor height 11.5ft
  - -Additional beams
- Choice
  - -Up to owner or architect?
  - -Up to engineer, system 2
- Why
  - -Height is sacrificed either way
  - -Second system has more capacity to withstand larger bombs



One City Center

Introduction

Existing System
Gravity System | Lateral System

Structural Depth
Proposed System | Blast Design | Progressive Collapse

Construction Breadth
Cost Comparison | Schedule Comparison

Conclusion

Construction Breadth:

- Detailed Cost estimate and comparison of all systems
- Duration estimate and comparison of the existing and proposed systems

One City Center

Cost comparison:

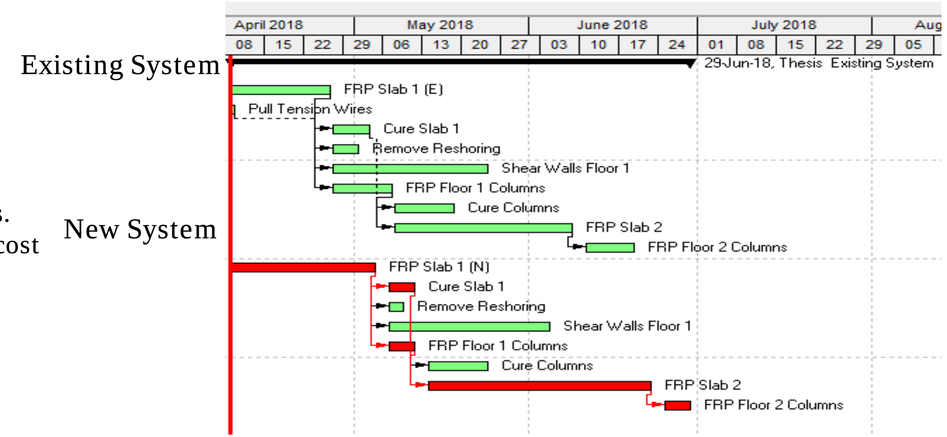
- Existing systems slab proved to be why it was more expensive.
- Second Progressive collapse system was more expensive due to the larger amount and size of interior beams.

System	Cost
Existing	9.4 million
New	9 million
Progressive Collapse 1	0.48 million
Progressive Collapse 2	1.1 million

One City Center

Schedule comparison:

- Existing system takes 20 days per floor
  - -Overall time 10 month 3 and a half weeks
- New system takes 22 days per floor
  - -Overall time 12 months
- Crew sizes were not altered between the two systems.
  - -Possible to accelerate time by increasing the cost



Conclusion:

- Existing system
  - -costs $400,000 more
- New system
  - -takes a month longer
  - -increased effective depth by 2 ½ “
  - -perimeter columns added
  - -increased lateral capacity
  - -decrease in needed compressive strength
- Progressive Collapse system
  - -support removal of column due to 5kg bomb
  - -potential to withstand larger bombs

Thank you

Questions

Appendix

Building Features/Analysis

Rebar
Deflections
Fire Rating
Load differences
Progressive Collapse
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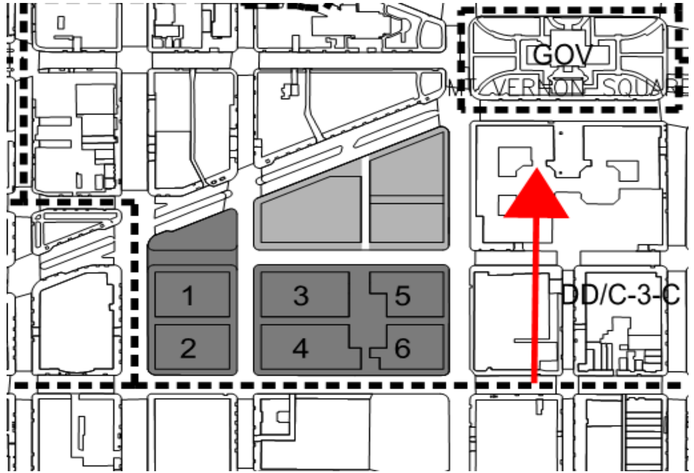
Proposed system

Building Features:

- Multi-lot development
- Staggered bridges that span between buildings
- 4 story underground parking



Appendix

Building Features/Analysis

Rebar
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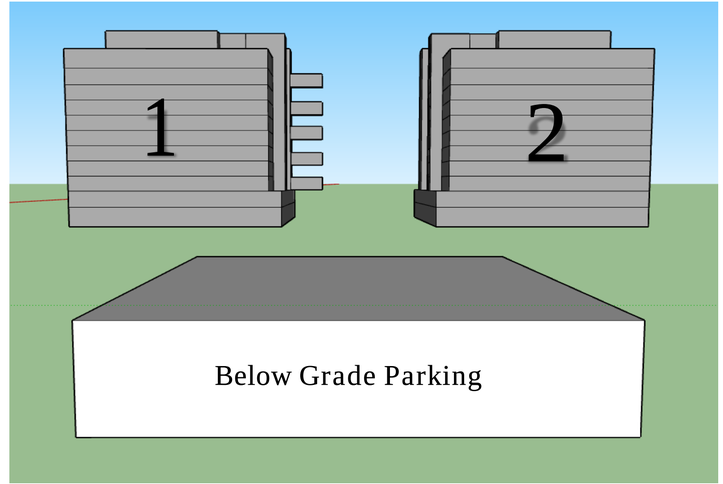
Building Features:

- Multi-lot development
- Staggered bridges that span between buildings
- 4 story underground parking



Appendix

Building Features/Analysis

Rebar

Deflections

Fire Rating

Load differences

Progressive Collapse

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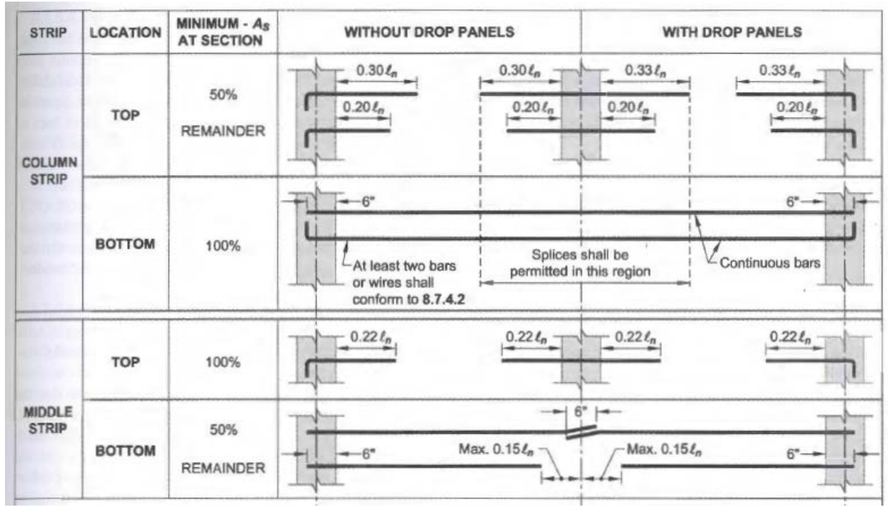
Proposed system

Development length of Rebar:

- In accordance with ACI 3-18



Appendix

80 ksi rebar:

- ASTM A706 Grade 80
- Available is sizes 3-11
- Not meant for members with significant inelastic deformations
- Not meant to resist torsion
- Meant for seismic design

Specified Minimum Yield Strength, ksi	Compression Control, e_{cl}	Tension Control, e_{tl}
60	0.002	0.005
75	0.0026	0.0054
80	0.0028	0.0056

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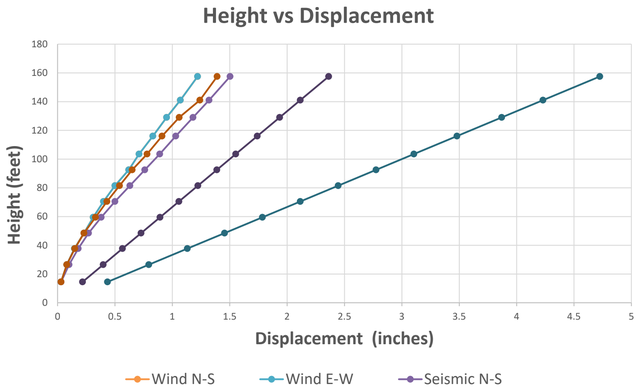
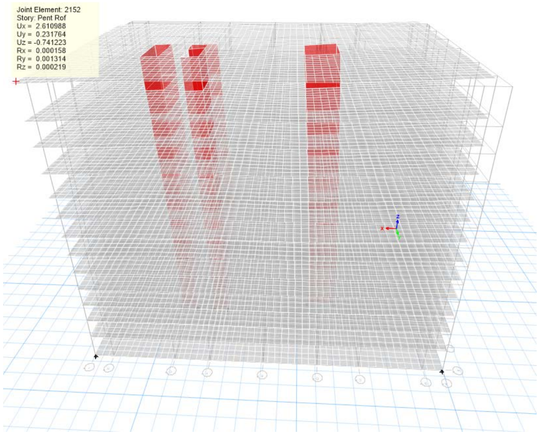
Deflections:

- Lateral deflections from ETABS, verified through comparison of shear forces in shear walls.





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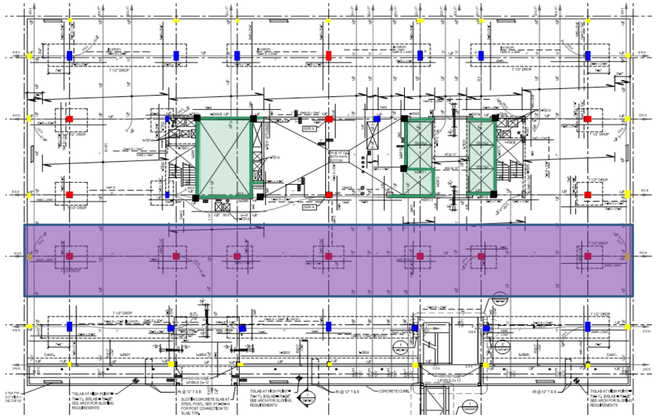
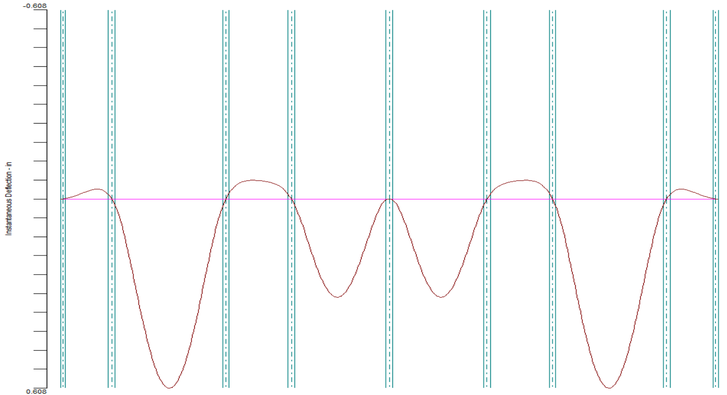
Deflections:

- Gravity deflections from spSlab, verified through hand calculations and RAM concept.





0.606” < allowable of 1”

Appendix

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TABLE 722.2.1.1
MINIMUM EQUIVALENT THICKNESS OF CAST-IN-PLACE OR PRECAST CONCRETE WALLS, LOAD-BEARING OR NONLOAD-BEARING

CONCRETE TYPE	MINIMUM SLAB THICKNESS (inches) FOR FIRE-RESISTANCE RATING OF				
	1 hour	$1^1/_2$ hours	2 hours	3 hours	4 hours
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

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Existing System Loads	New System Loads
Façade Load = 20psf	Façade Load = 20psf
Live Load = 64.5 psf (reduced from 80psf)	Live Load = 64.5 psf (reduced from 80psf)
Dead Load = 137 psf	Dead Load = 167.5 psf
Snow Load = 17.5 psf	Snow Load = 17.5 psf

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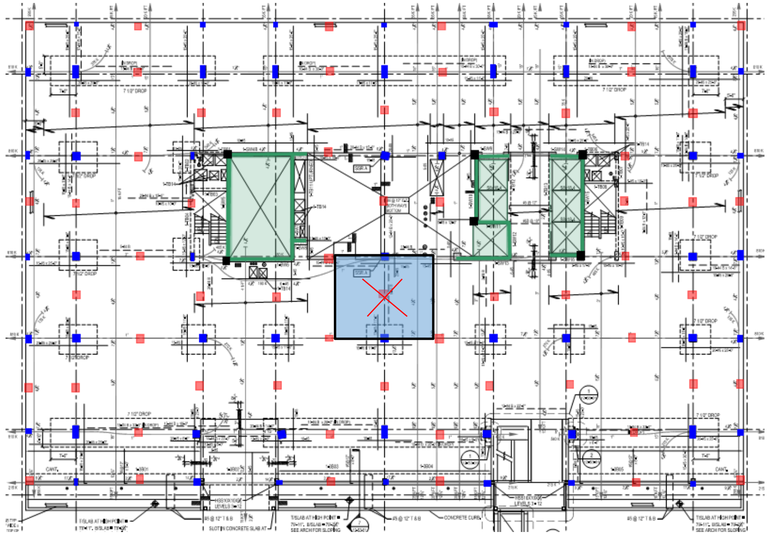
Progressive Collapse *Design*:

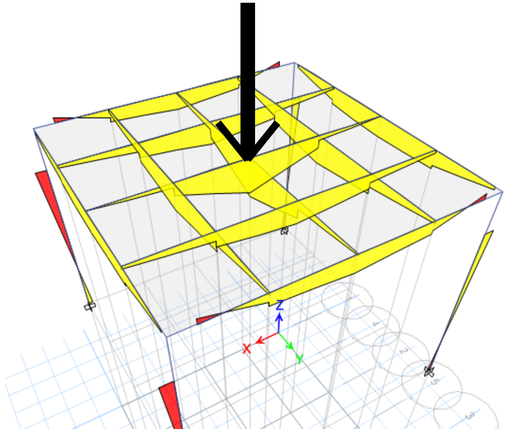
- First System for Progressive Collapse
  - -Attempt to keep large floor to floor height on ground floor
  - -Original floor height of 14.5ft
  - -Best way to keep members shallow is to decrease span
  - -Additional interior columns added (62 of them)

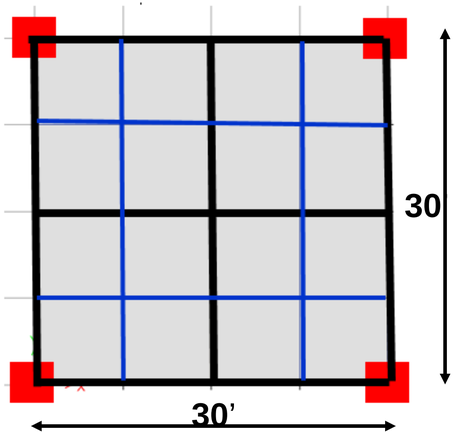


Appendix

Progressive Collapse *Design*:

- First System for Progressive Collapse
  - -Attempt to keep large floor to floor height on ground floor
  - -Original floor height of 14.5ft
  - -Best way to keep members shallow is to decrease span
  - -Additional interior columns added (62 of them)
  - -Post tensioned system created.

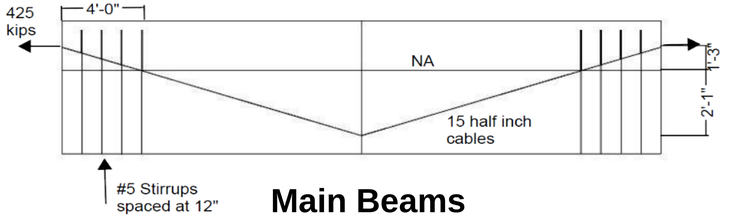




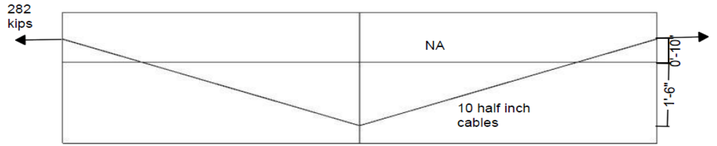
Appendix

Progressive Collapse *Design*:

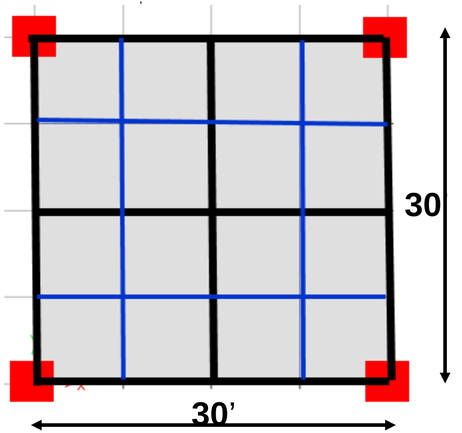
- First System for Progressive Collapse
  - -Main beams are 18x36 with 15 half inch cables
  - -Intermediate beams are 18x24 with 10 half inch cables
  - -Ground floor height with this system is 13ft



Main Beams



Intermediate Beams



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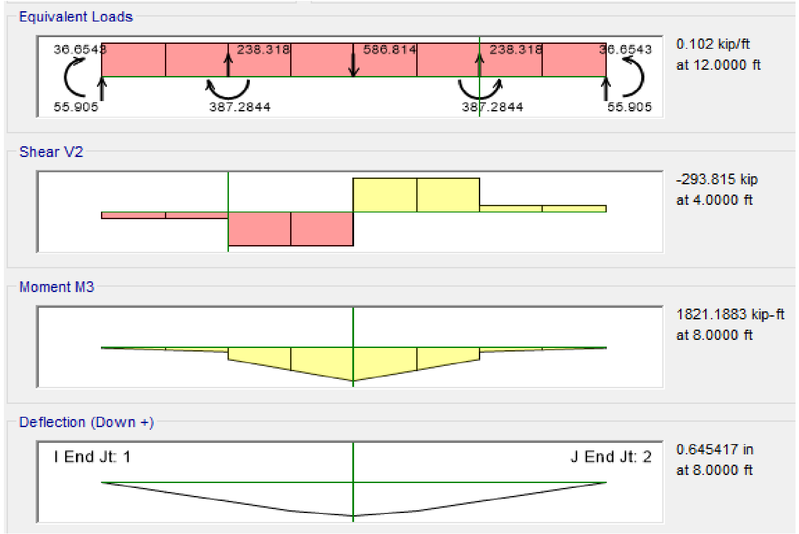

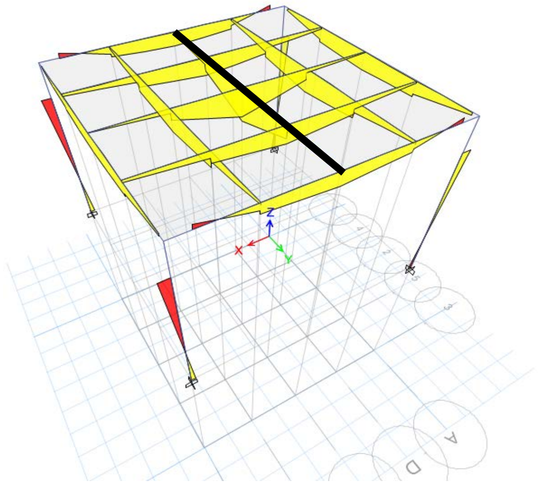

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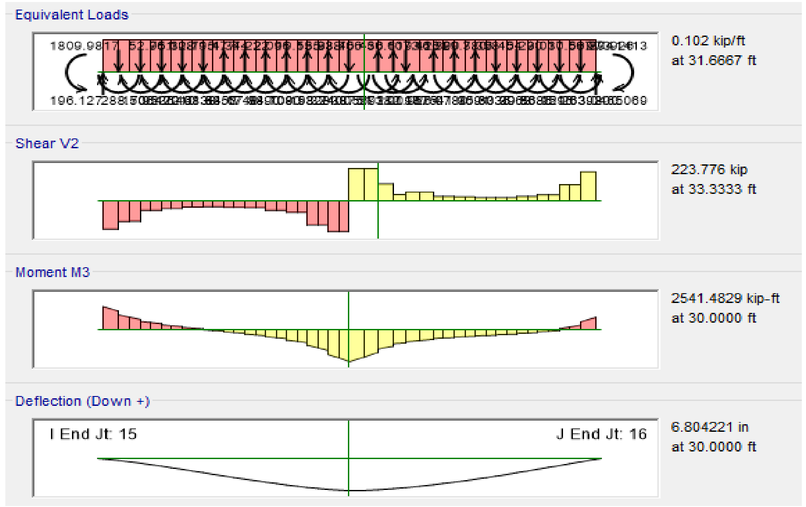
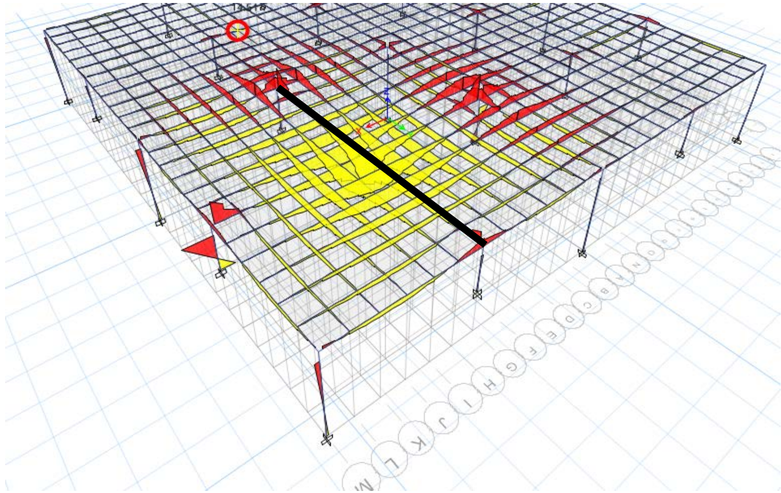
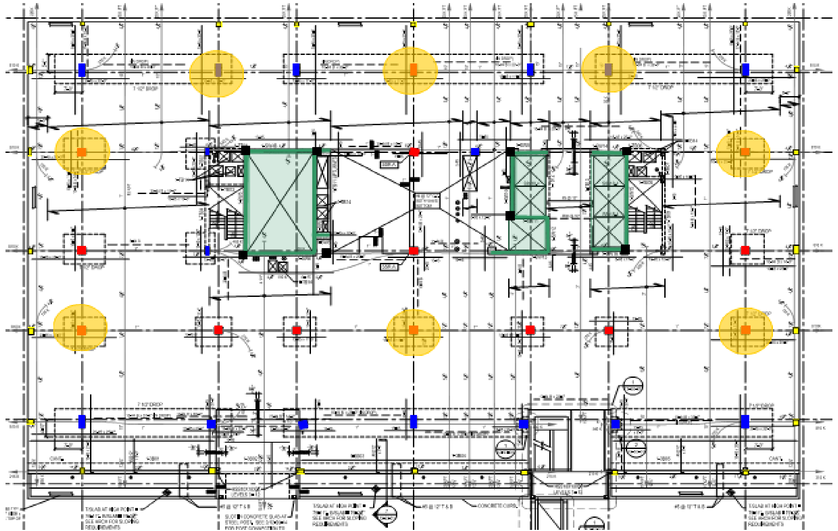




Appendix

Limitations:

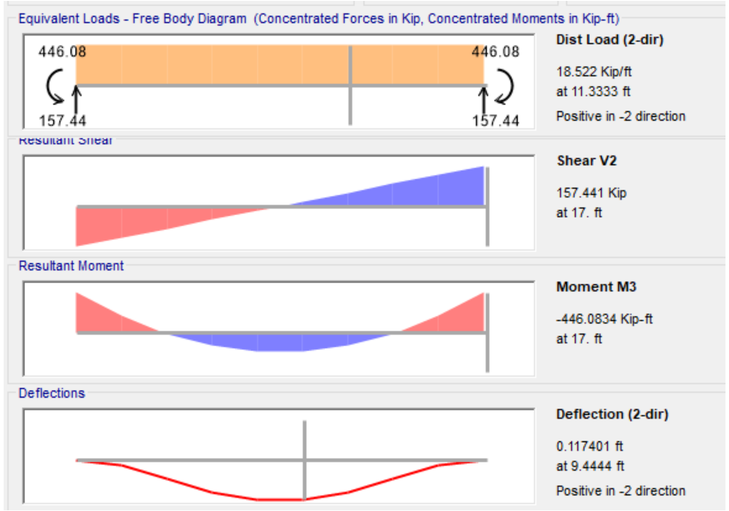
- Progressive collapse designs protect only the circled columns
- Determined to be most at risk
- If all columns were deemed in danger of progressive collapse a PT slab system would be implemented

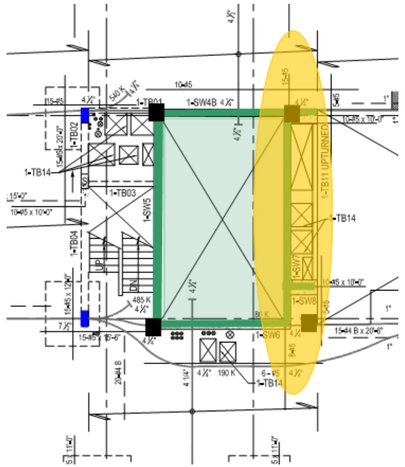


Appendix

Shear wall elimination:

- Controlling Shear wall analyzed for progressive collapse
- Forces were significantly smaller than capacity of PT beams





Appendix

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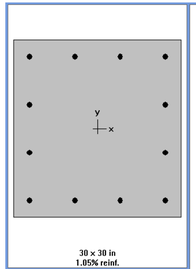
Increased column section:

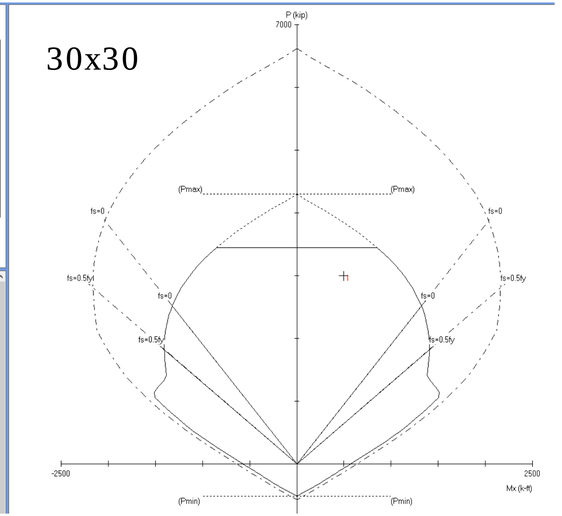
- System 1 column is 30”x30”
- System 2 column is 36”x36”

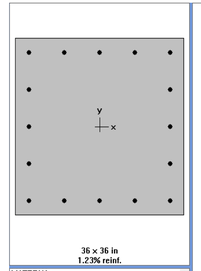


MATERIAL:
========
f'c = 8 ksi
Ec = 5098.24 ksi
fc = 6.8 ksi
Beta1 = 0.65
fy = 60 ksi
Es = 29000 ksi

SECTION:
========
Ag = 900 in^2
Ix = 67500 in^4
Iy = 67500 in^4
Xo = 0 in
Yo = 0 in

REINFORCEMENT:
==============
12 #8 bars @ 1.053%
As = 9.48 in^2
Confinement: Tied
Clear Cover = 2.38 in
Min Clear Spacing = 7.08 in

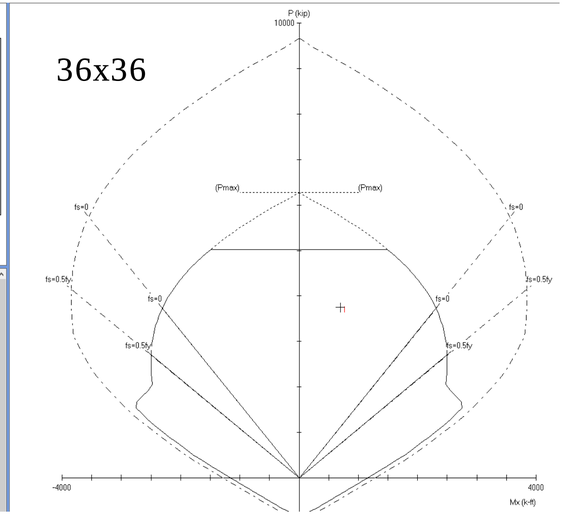




MATERIAL:
========
f'c = 8 ksi
Ec = 5098.24 ksi
fc = 6.8 ksi
Beta1 = 0.65
fy = 60 ksi
Es = 29000 ksi

SECTION:
========
Ag = 1296 in^2
Ix = 139968 in^4
Iy = 139968 in^4
Xo = 0 in
Yo = 0 in

REINFORCEMENT:
==============
16 #9 bars @ 1.235%
As = 16 in^2
Confinement: Tied
Clear Cover = 2.38 in
Min Clear Spacing = 6.40 in

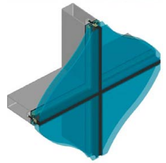


Appendix

Façade :

- 2.75” in overall thickness
- Large Span capability
- Needs HSS sections but those are already present on the façade
- Can resist 29 kpa or 4.2 psi > external blast pressure

wrightstyle ltd
Steel Glazing Systems



Before

After

Appendix

Building Features/Analysis
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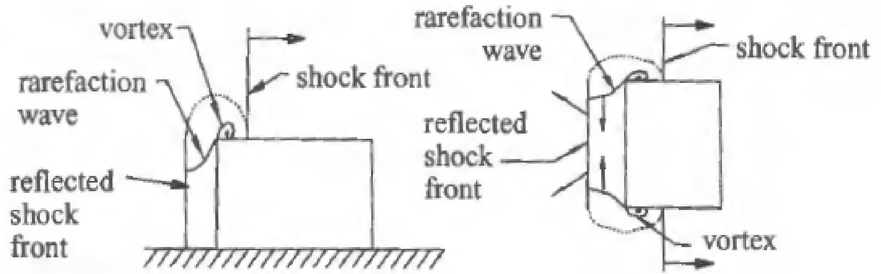
Blast Design *Effect*:

- Effect of blast has both a positive impulse and negative impulse over time.
- Empirical procedure only takes positive impulse into account.
- Blast then acts on the building similarly to a wind load. Pressures bend around the building.



Elevation

Plan

Appendix

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Blast Design *Effect*:

- Dynamic increase factors for members based on loading type

Table 4.2 Dynamic Increase Factors for Reinforced Concrete (Adapted from DoD 2008)

	Low Pressure			High Pressure		
	Rebar			Rebar		
Action	Yield	Tensile	Concrete	Yield	Tensile	Concrete
Flexure	1.17	1.05	1.19	1.23	1.05	1.25
Compression	1.10	1.00	1.12	1.13	1.00	1.16
Shear—DT	1.00	1.00	1.00	1.10	1.00	1.00
Shear—Direct	1.10	1.00	1.10	1.10	1.00	1.10
Bond	1.17	1.05	1.00	1.23	1.05	1.00

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Blast Design:

- Ways to increase capacity
  - -Proprietary methods for increasing blast capacity
  - -Composite sections
  - -Encase columns in carbon fiber or steel

G21 Blast Panel®

Blast testing

InterDam Blast Tests November 2016

No.	Panel span [m]	Support rail: HEA bar	Peak Pressure	Duration
1	1.2	without BIR	138	133
2			308	80
3			475	70
4	1.2	with BIR	235	100
5			325	50
6			437	70
7			586	120
8			783	100
9	1.6	without BIR	360	74

In this webinar

InterDam

1 mbar = 0.0145 psi
475 mbar = 6.8 psi

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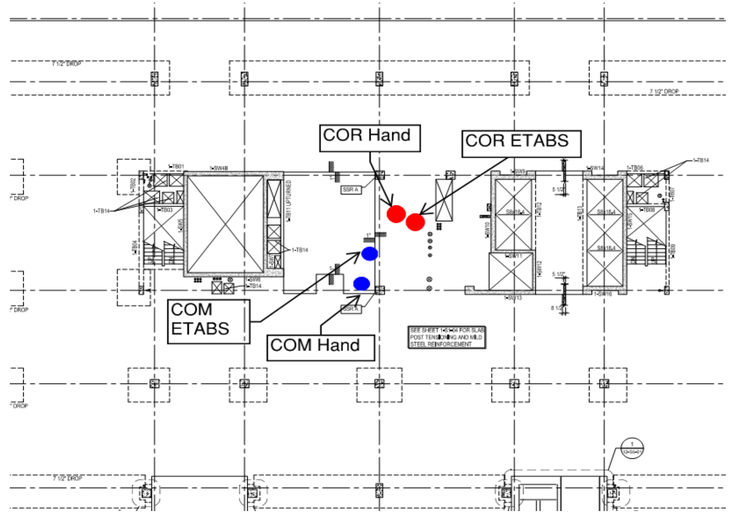
Center of Mass and Center of Rigidity:

- Compared between hand calculations and ETABS
- Largest difference was 1’
- Largest eccentricity was 9’



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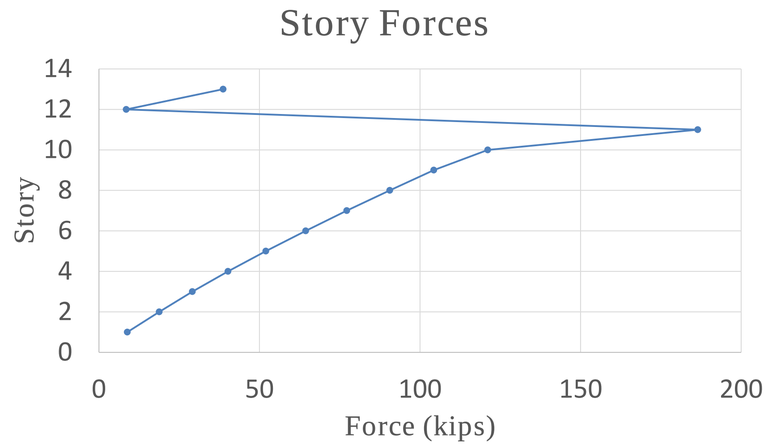
Seismic Parameters:

- Site Class C
- Responds Coefficient = 0.0357
- R=4
- Ω=2.5
- Cd=4
- Risk Category II
- Total Weight 42000 kips
- TL = 8 seconds
- Fundamental period = 0.9 seconds



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- Total Weight 42000 kips
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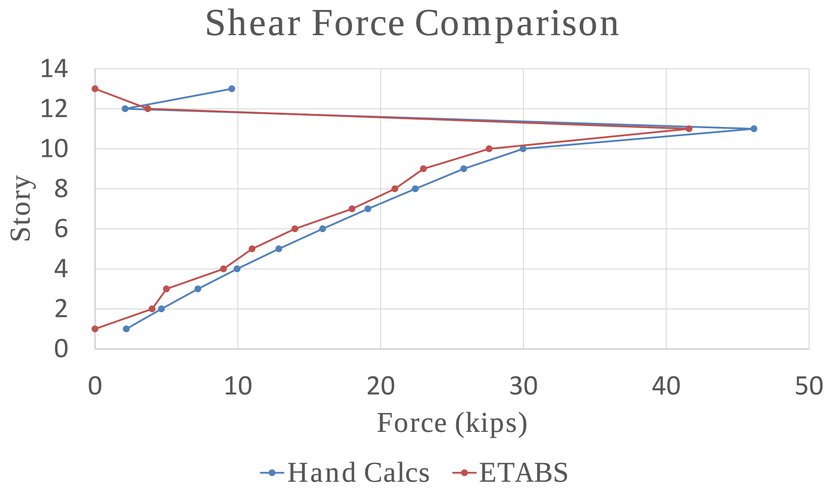

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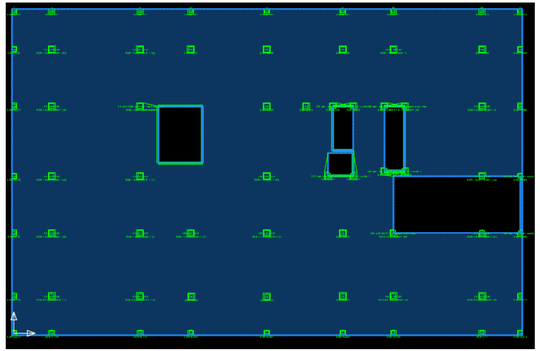
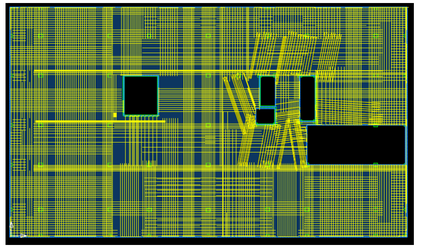
Blast
Proposed system

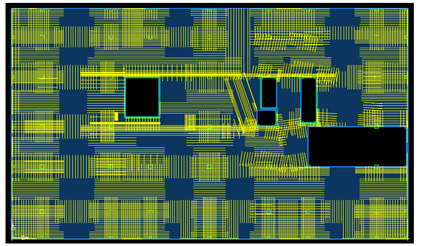


Punching Shear

Bottom Reinforcement



Top Reinforcement



Appendix

Building Features/Analysis

Rebar

Deflections

Fire Rating

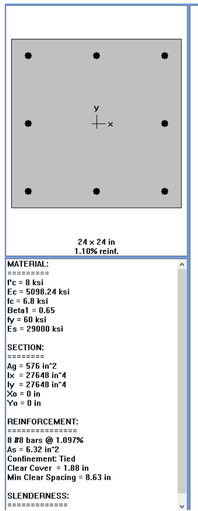
Load differences

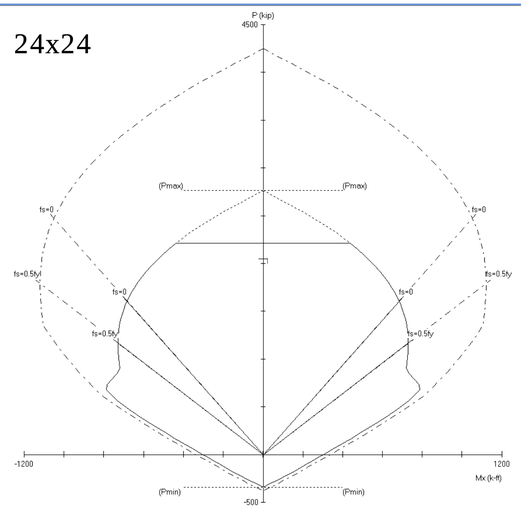
Progressive Collapse

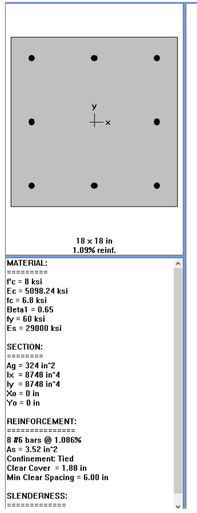
Façade

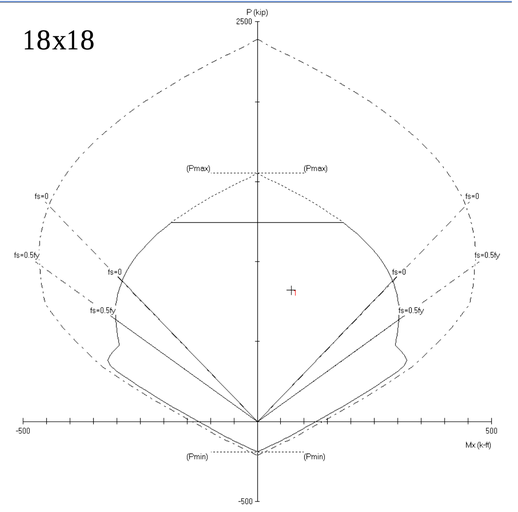
Blast

Proposed system









Appendix

Building Features/Analysis
Rebar
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Cost Evaluation:

- Cost per sqft of entire building from RS means $131.5 = $93,365,000 (93 million)
- The structural costs are 9.4 and 9 million resulting in a little over 10% of building cost
- According to RS means structural costs can be somewhere between 14 – 21% of total cost
- Fairly close to statistical percentages
- Differing factors between One city Center and building described in RS means