Mitigation of Progressive Collapse

Based on the performance of the Silver Spring Gateway, Silver Spring, Maryland

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Consultant:
Dr. Linda Hanagan

Topic Outline

- Proposal and Background Information
- Goals for Success
- Structural Resistance to Progressive Collapse Mechanisms
- Site Security Design to Limit Attack Threats
- Façade Design for Blast and Moisture Protection
- Conclusions and Recommendations

Background Information

- Owner: JBG Companies
- Structural: Tadjer-Cohen-Edelson (TCE)
- Architect: Weihe Design Group (WDG)
- Location: Silver Spring, Maryland
- Height: 15 stories at 143 feet
- Building Area : 766,459 sq. ft.
- Cost: $89 Million

Personal Photo taken 20 July 2007

Mixed use high rise development containing:

- 14,080 sq. ft. of retail
- 100,215 sq. ft. of parking
- 395,439 sq. ft. of residential space (condominiums and apartments)

Existing Structural System

- Foundation: Drilled Caissons with transfer girders and grade beams
- Primary Structure: 7 – 9" two-way flat plate post-tensioned concrete slab supported by 176 columns with a concrete compressive strength ranging from 4000 to 8000 psi
- Lateral System: (3) 12" thick concrete shears walls in one direction and a concrete moment frame in the other
- Pedestrian Bridge: Composite transfer trusses comprised of W14 chords and W12 web members

Personal Photos taken 20 July 2007

Proposal and Goals

Proposal:
Theoretically, JBG Companies has had substantial success with the Silver Spring Gateway and has acquired a site in downtown Washington, D.C. The clientele for this development will be foreign dignitaries and domestic diplomats and will need a strict security protocol.

Goals:
- Redesign Structural System to withstand a terrorist attack without affecting the architecture
- Redesign the Site Layout to prevent a terrorist attack without affecting the public space atmosphere
- Redesign the Façade to withstand blast effects, match surrounding facades, and prevent thermal and moisture related problems
- Minimize the effect of the redesign on the lease premium

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Structural Resistance to Progressive Collapse

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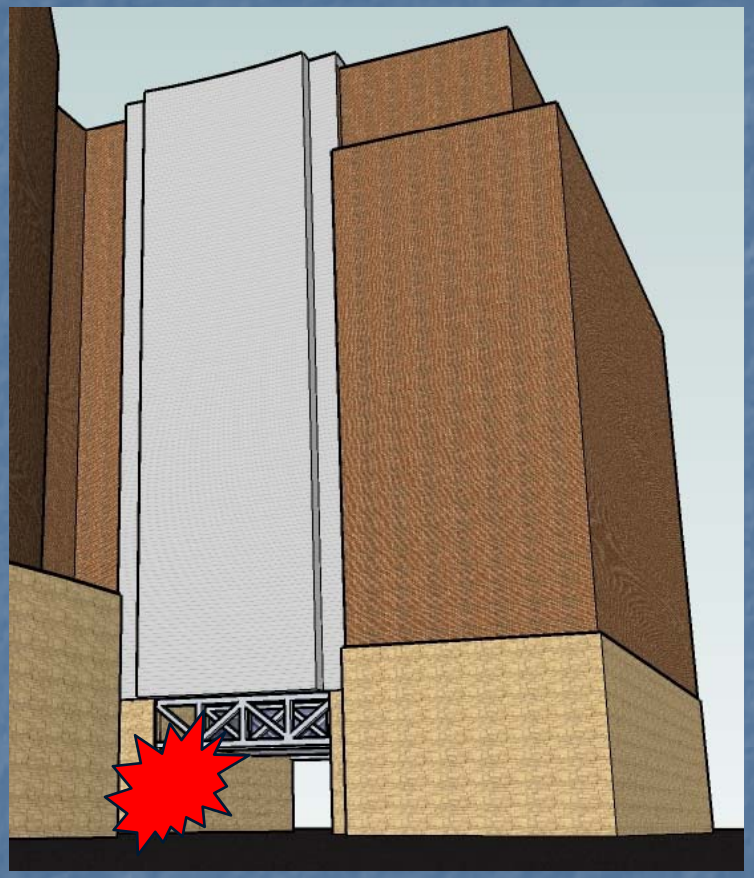
Blast Threat Scenarios

Site Plan created by WDG Architecture



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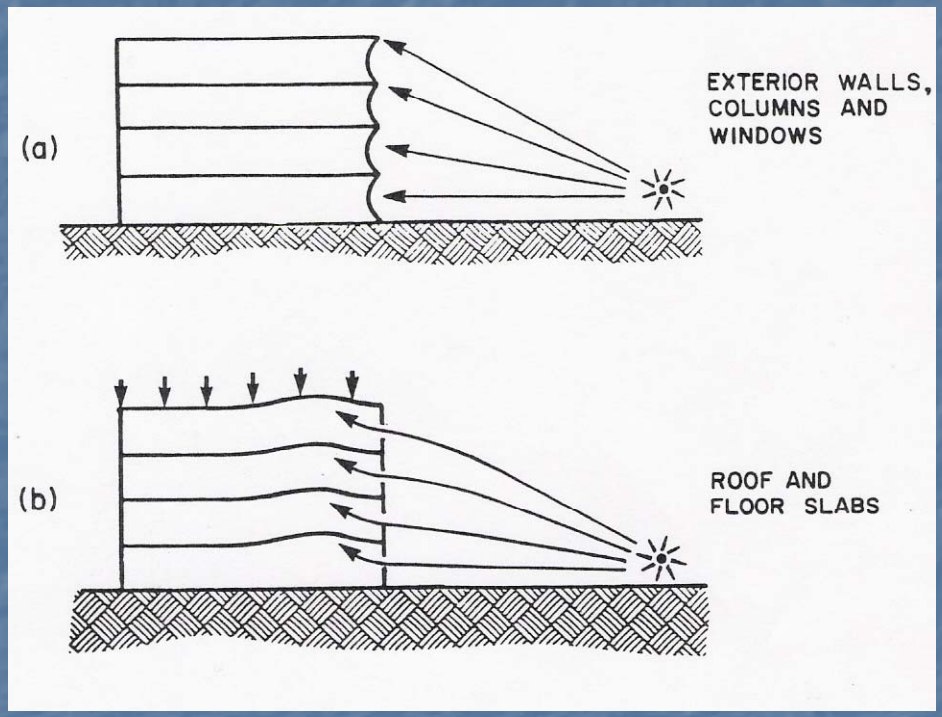
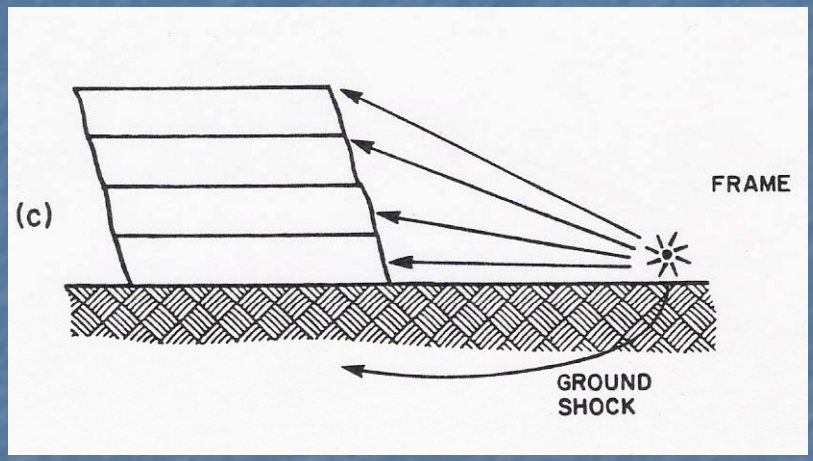
Structural Resistance to Progressive Collapse

Blast Load Theory





These phases pertain to a blast separated some distance from its target.

Blast locations are close and confined!

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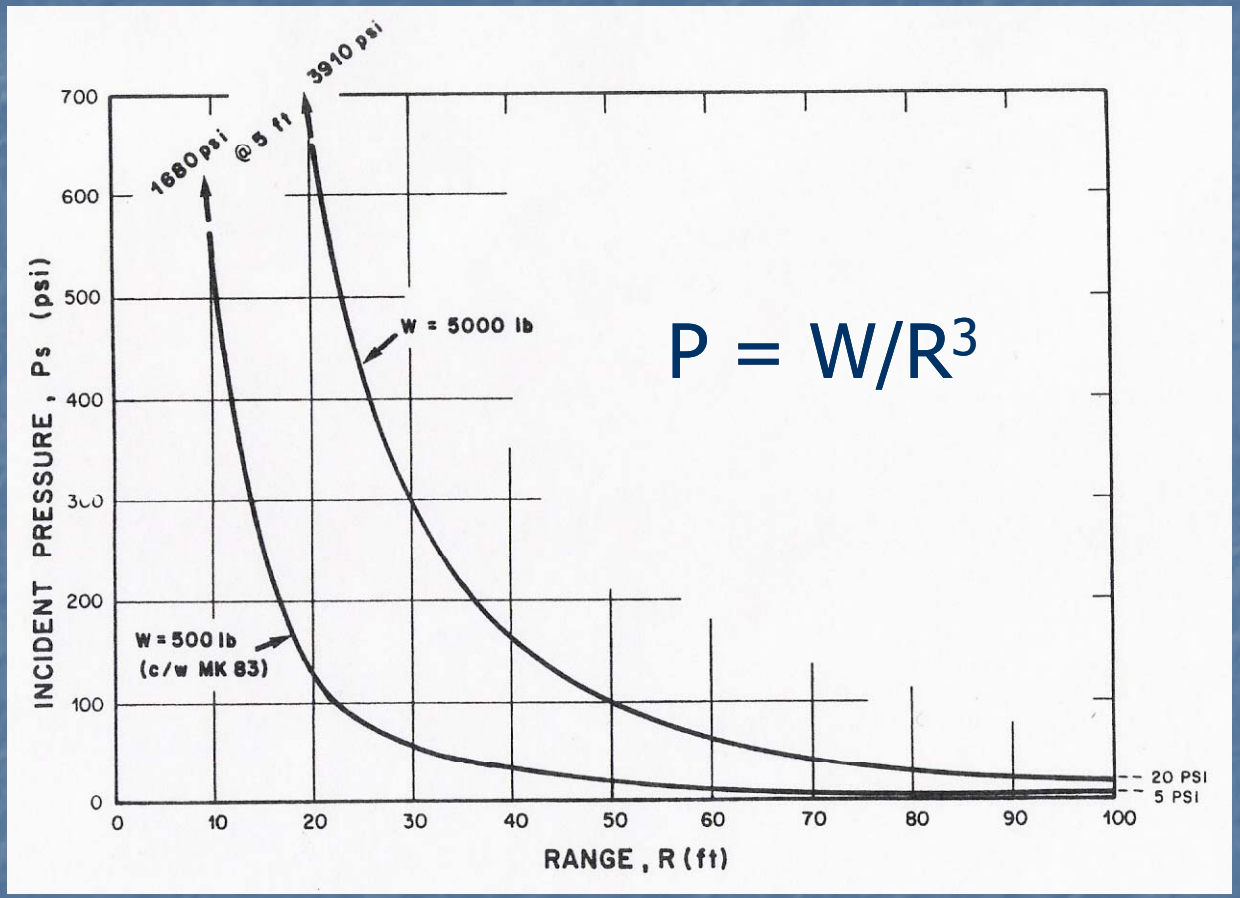
Blast Load Theory



$$P = W/R^3$$

This phenomenon is related to distance and bomb size.

Designing for an arbitrary blast load adds vulnerability!

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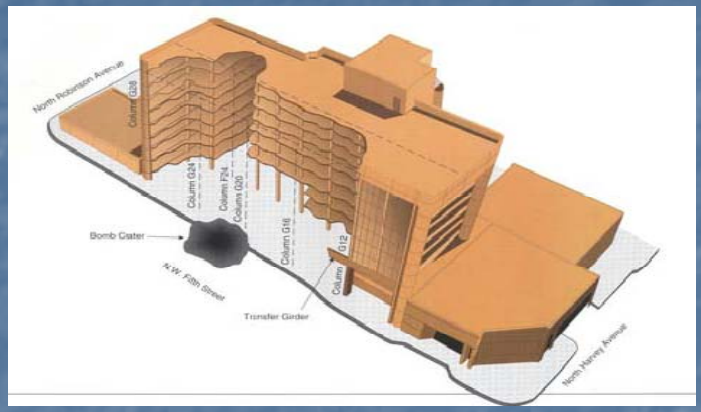
Progressive Collapse Mitigation Theory

Per the National Institute of Standards and Technology (NIST), the load combination for progressive collapse and abnormal loading conditions is:

(0.9 to 1.2)D + 0.5L + 0.2W or 0.2S

ASCE 7-05 defines two design methodologies:

- Direct Design
  - Alternative Load Path
  - Specific Local Resistance
- Indirect Design



Images of the Oklahoma City bombing collapse from NIST

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Transfer Girder Truss: Indirect Method

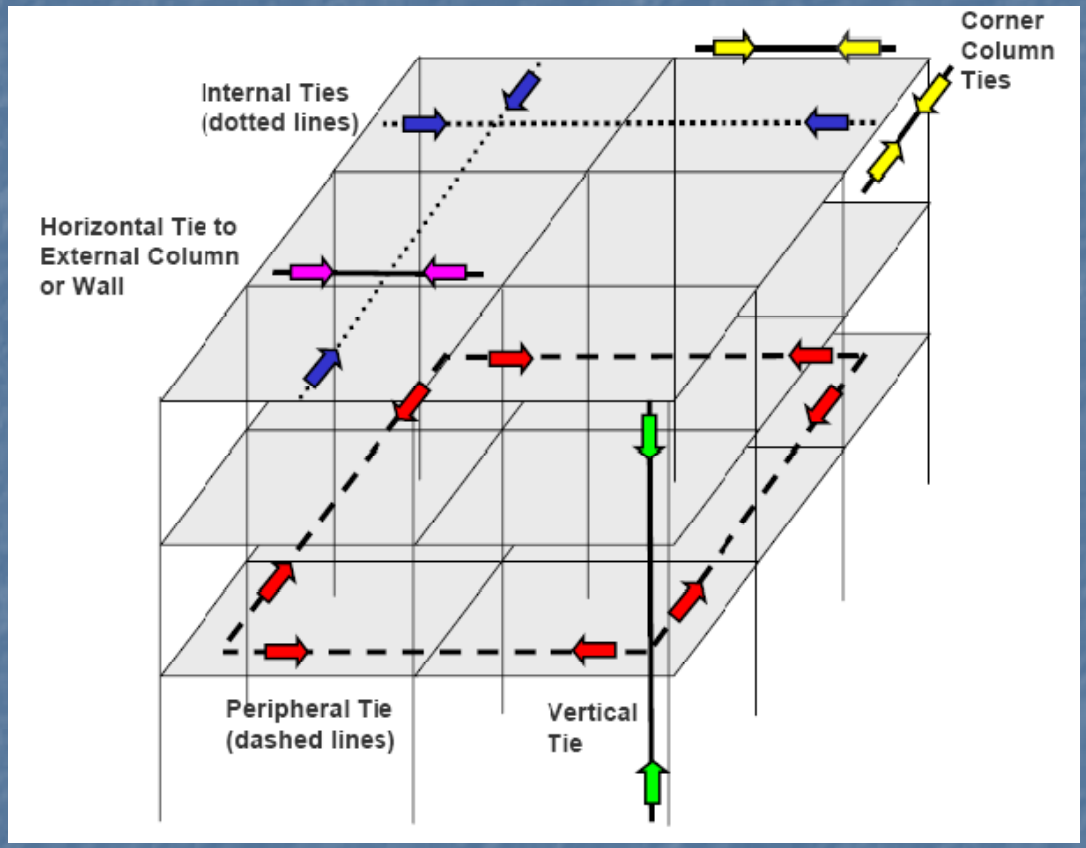

Diagram of tie forces taken from Design of Buildings to Resist Progressive Collapse, UFC 4-023-03

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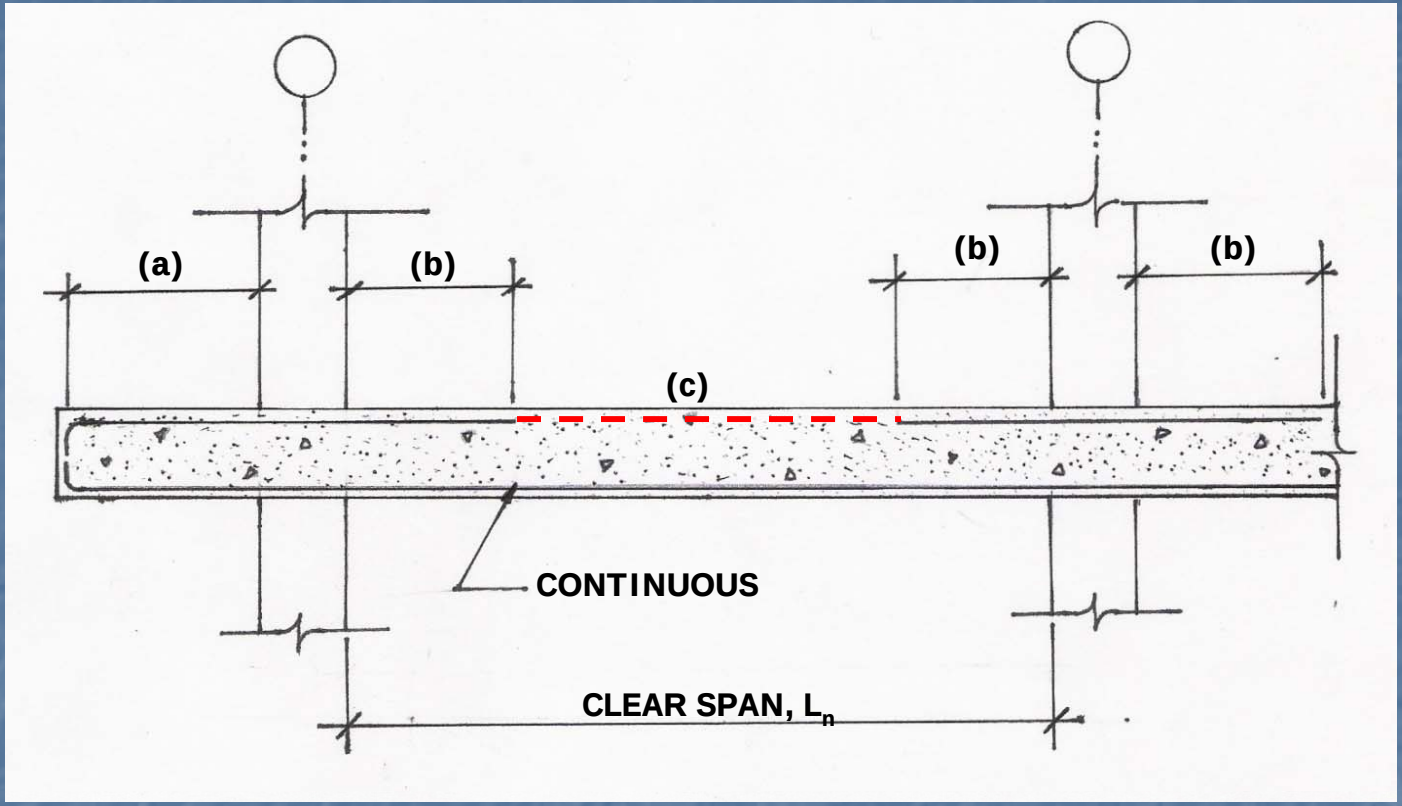
Transfer Girder Truss: Indirect Method

Tie Type	Tie Force	Required A_s	Provided A_s
Peripheral	13.5 kips	0.24 in^2	3.95 in^2
Internal (N-S)	7049 lb/ft-width	0.125 in^2/ft	0.61 in^2/ft
Internal (E-W)	6579 lb/ft-width	0.117 in^2/ft	0.402 in^2/ft
Horizontal	14.95 kips	0.266 in^2	1.24 in^2
Vertical	149.3 kips	2.654 in^2	5.08 in^2

The provided reinforcement is more than adequate to develop the tie force; however, typical ACI 318 development length details are not sufficient to obtain the ductility necessary for the indirect method

Transfer Girder Truss: Indirect Method



New detail follows typical detail within ACI 318-05 with (a) equaling the greater of $0.22L_n$ (Middle Strip), $0.30L_n$ (Column Strip), or the cantilever length, (b) equaling $0.22L_n$ (Middle Strip), $0.30L_n$ (Column Strip) and (c) continuous portion of top reinforcement to satisfy the tie force strength.

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Transfer Girder Truss: Direct Method

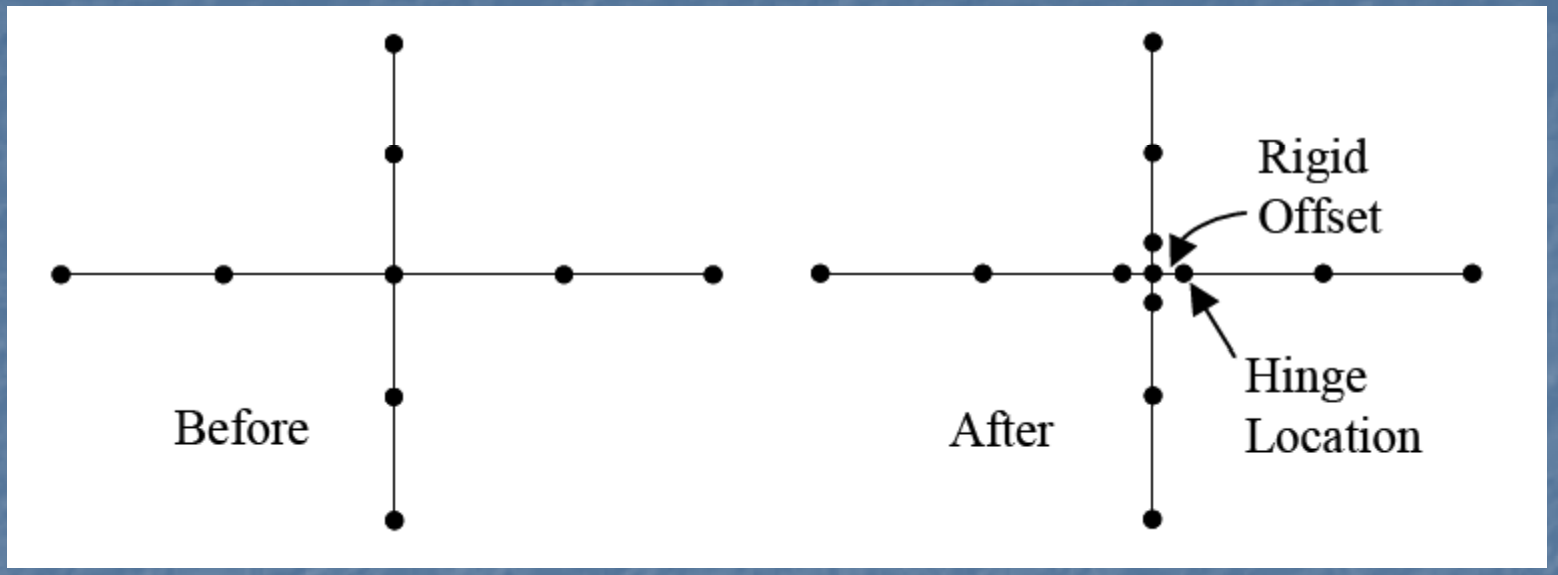

Diagram of plastic hinge development locations taken from Progressive Collapse Analysis and Design Guidelines published by GSA

$$DCR = Q_{UD}/Q_{CE}$$

DCR ≤ 1.5 for atypical configurations
DCR ≤ 2.0 for typical configurations

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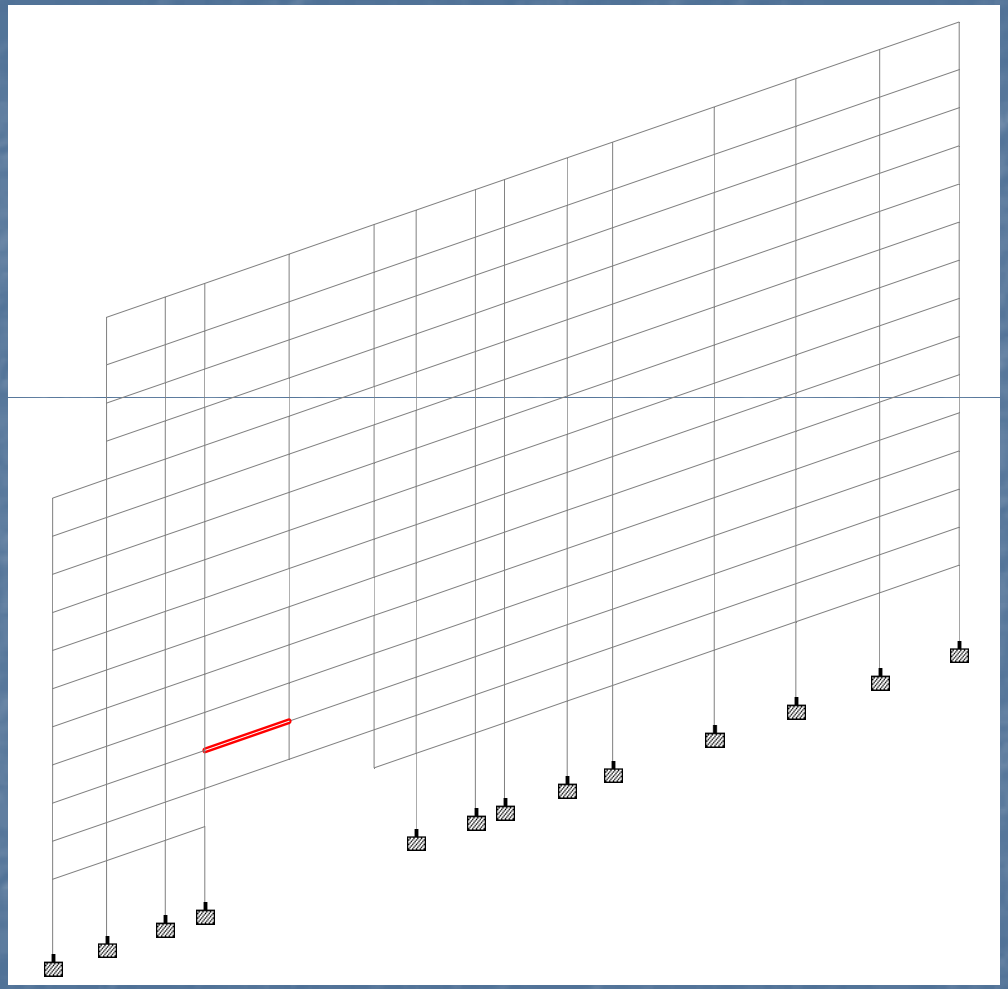
Transfer Girder Truss: Direct Method



Lost transfer girder and inboard concrete column due to blast

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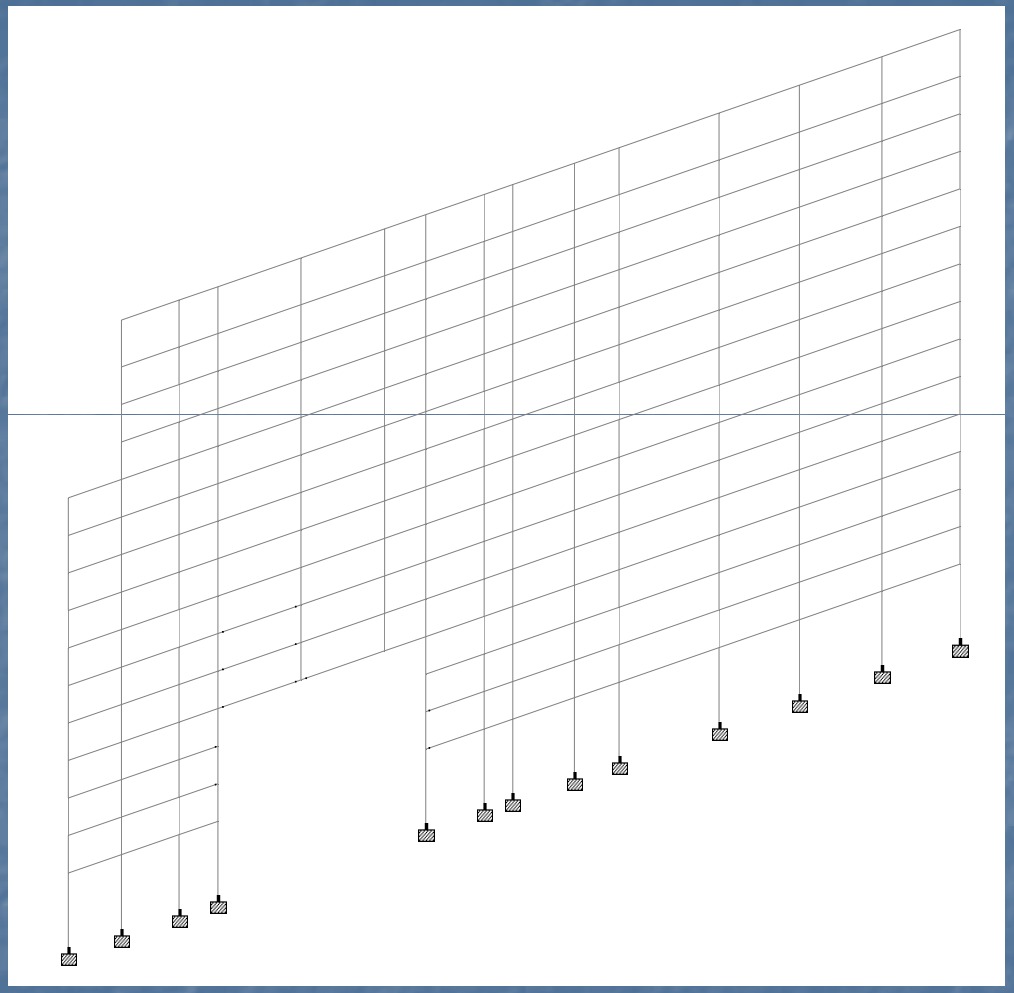
Transfer Girder Truss: Direct Method



Lost 3 spans on
Third Floor

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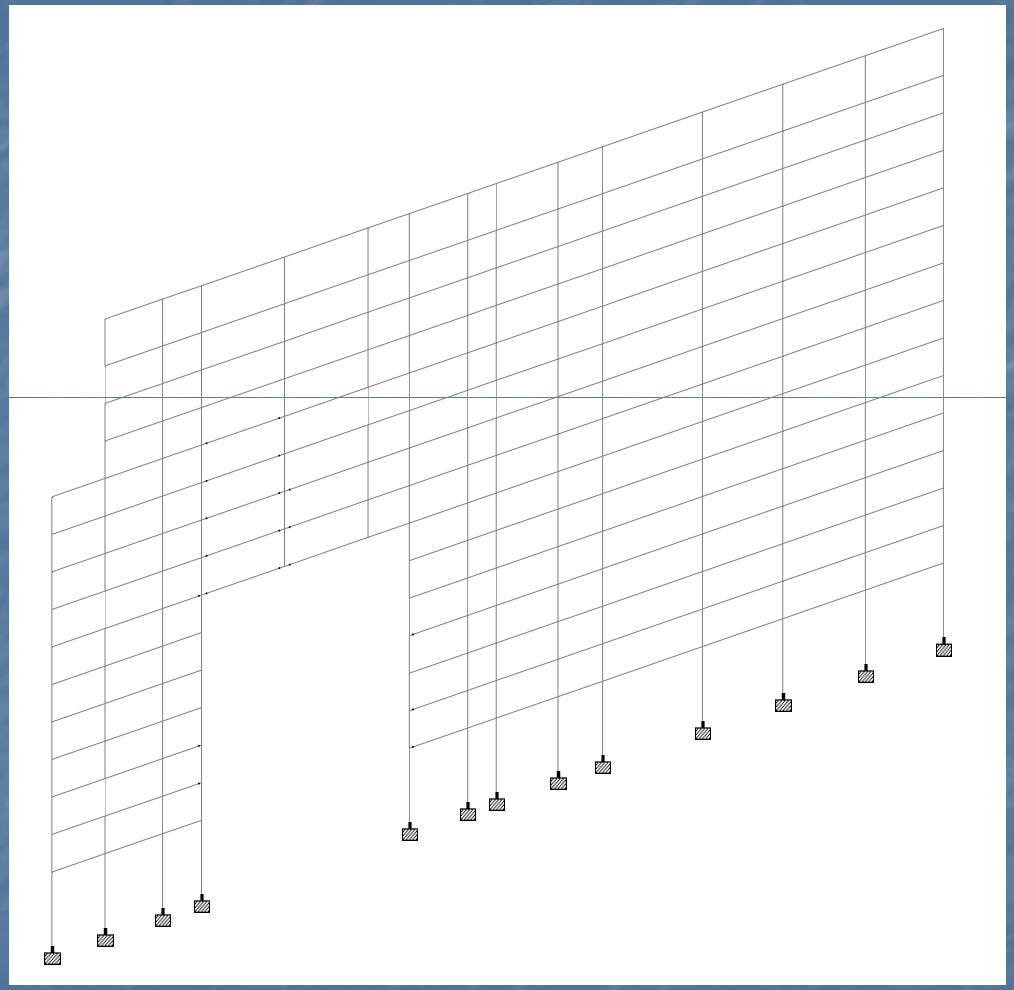
Transfer Girder Truss: Direct Method



Lost 3 spans on
floors 4 through 6

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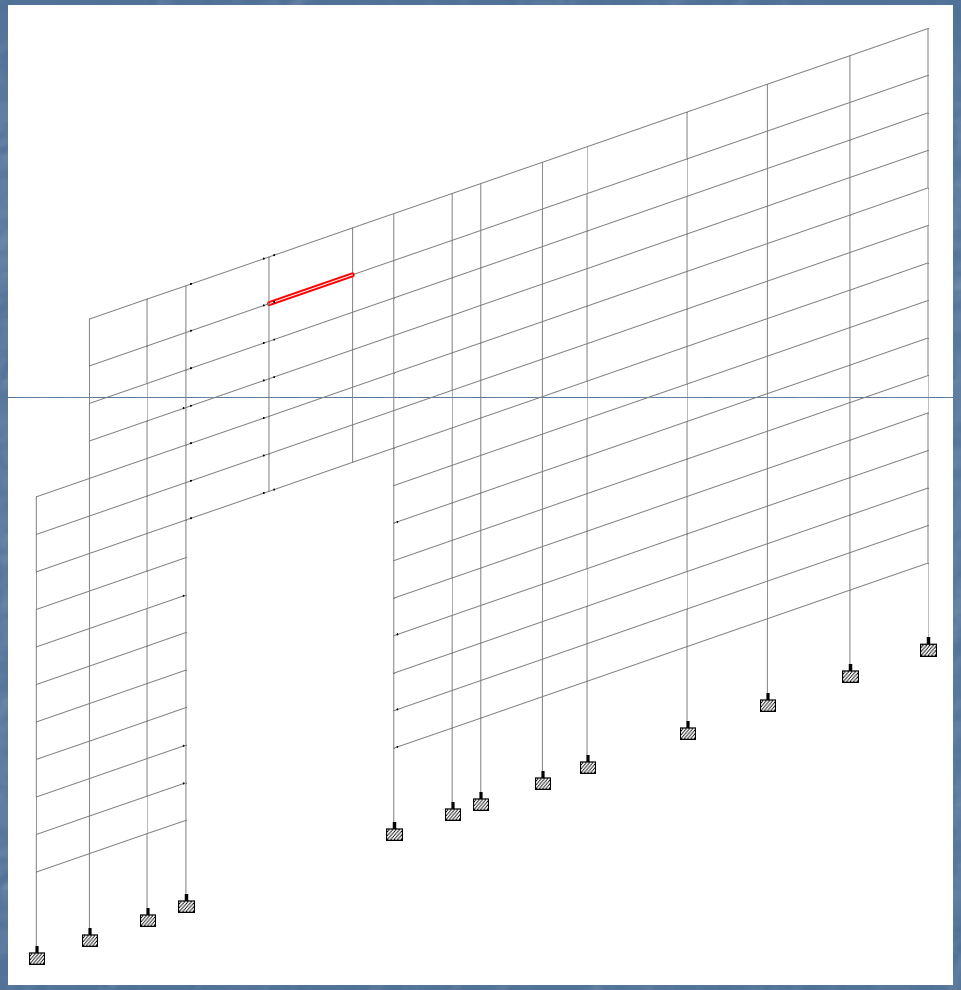
Transfer Girder Truss: Direct Method



Lost 3 spans on floors 7 and 8

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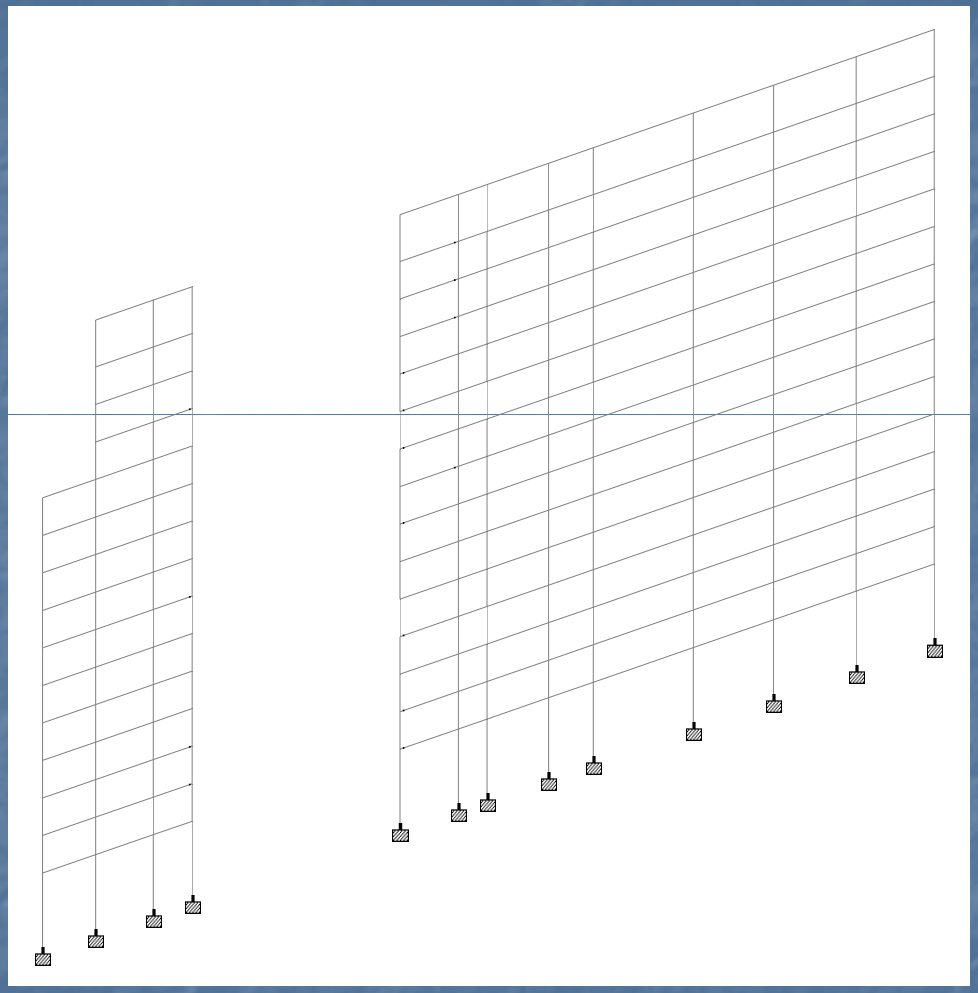
Transfer Girder Truss: Direct Method



Lost 3 spans on floors 9 through 15 causing a total collapse above transfer girder

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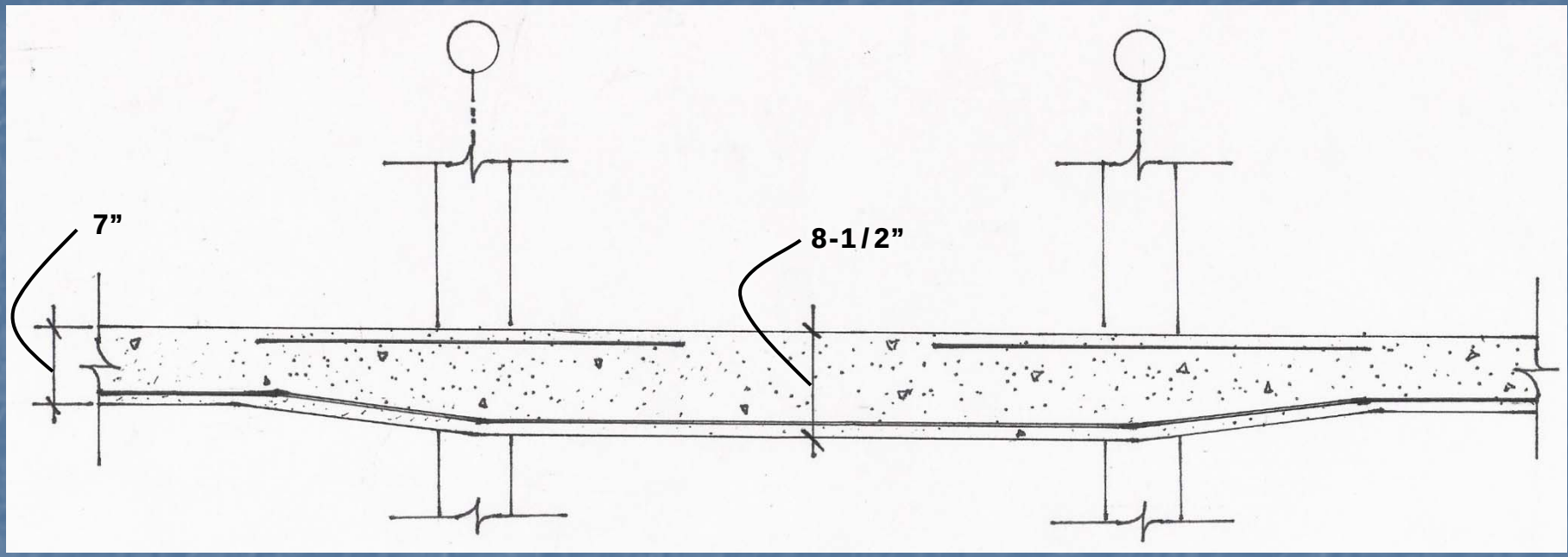
Transfer Girder Truss: Direct Method



In order to increase the ultimate moment capacity the slab thickness was increased over the necessary spans by 1-1/2 inches along with an increase in mild steel reinforcing area.

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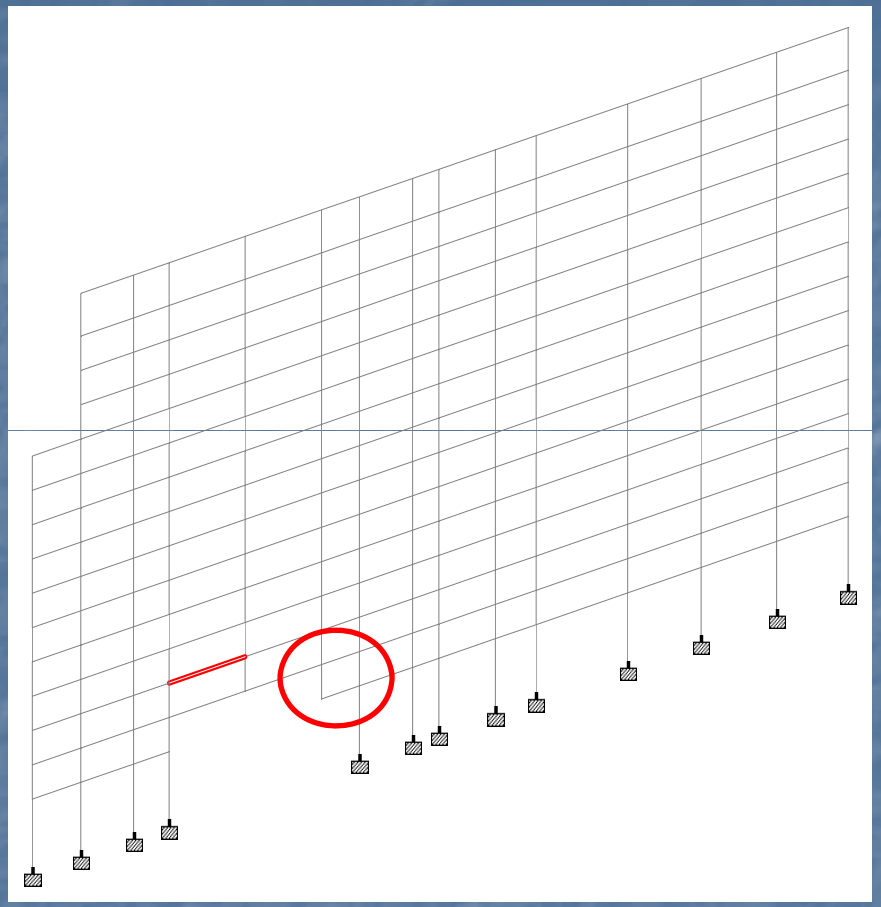
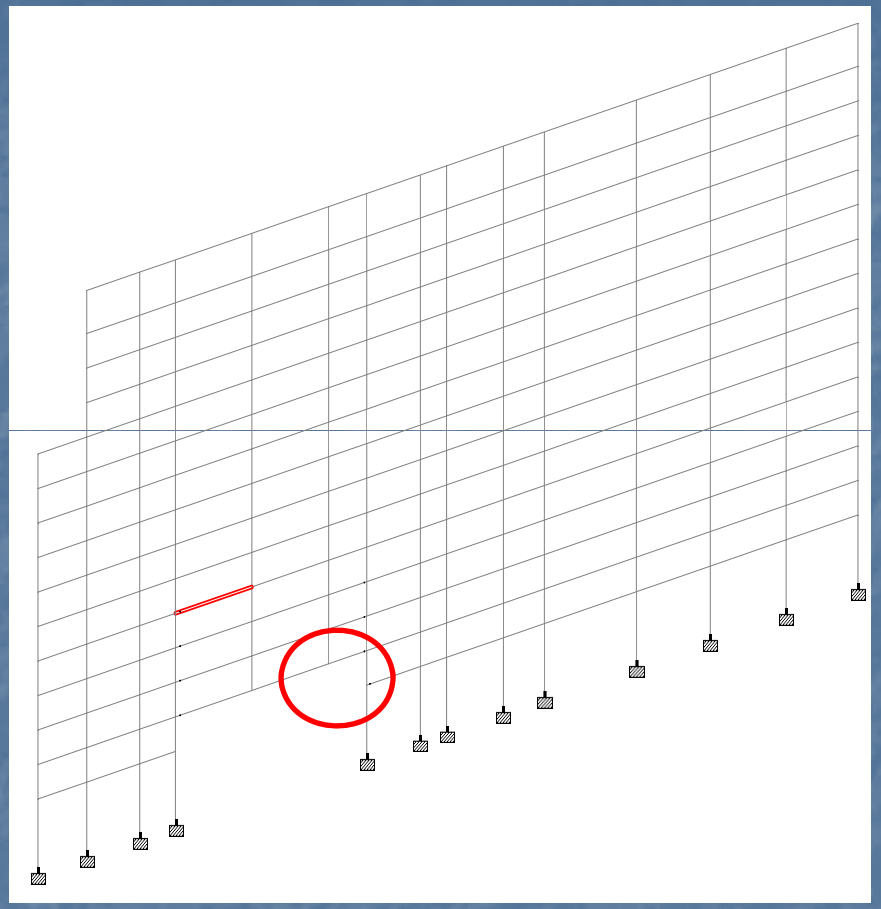
Transfer Girder Truss: Direct Method





The redesign contains the collapse to structural elements connected to the compromised members which satisfies the GSA Guidelines.

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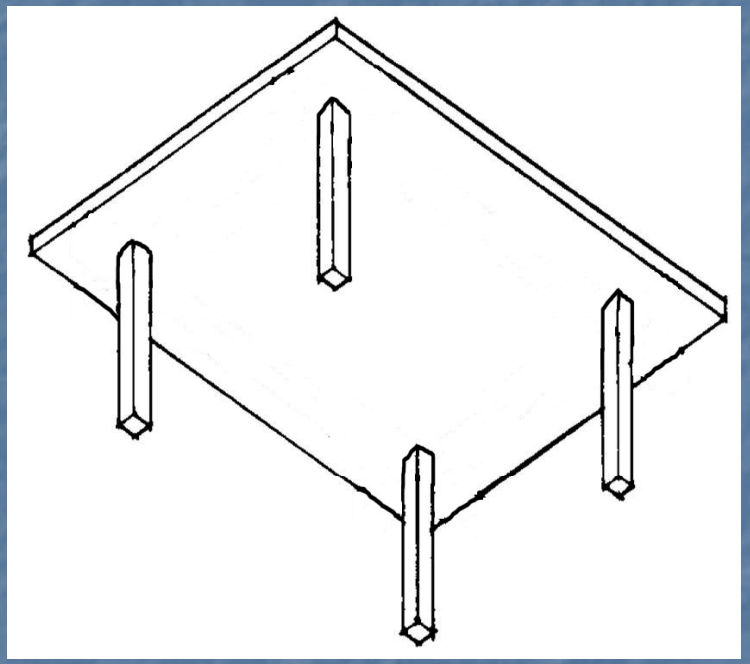
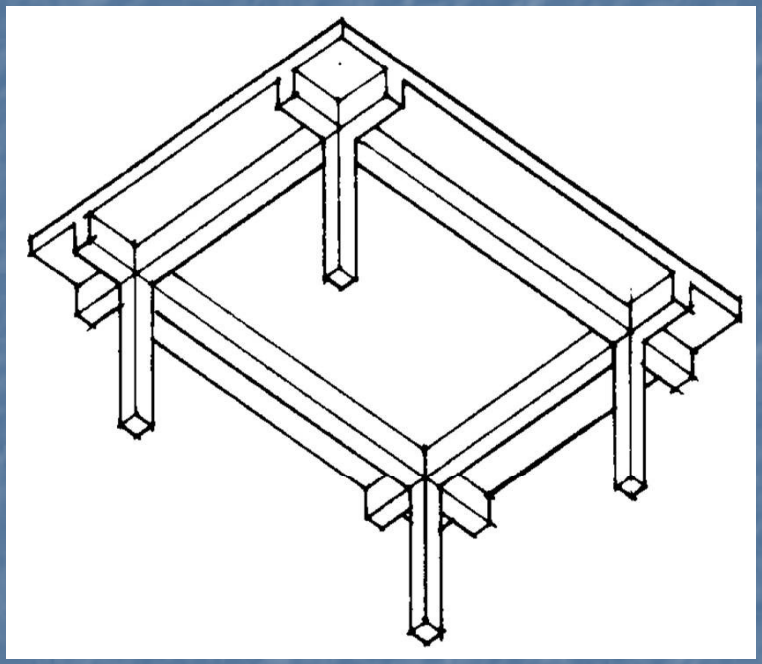
Parking Garage: Slab Redesign

Original Design: 9” thick two way flat plate post tensioned concrete slab



Redesign for Indirect Method: 10” thick two way flat plate reinforced concrete slab



Redesign for Direct Method: 10” thick two way reinforced concrete slab with beams

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Parking Garage: Indirect Method

Tie Type	Tie Force	Required A_s	Provided A_s
Peripheral	11.7 kips	0.22 in^2	1.24 in^2
Internal (N-S)	10531 lb/ft-width	0.1877 in^2/ft	0.62 in^2/ft
Internal (E-W)	9593 lb/ft-width	0.1705 in^2/ft	0.402 in^2/ft
Horizontal	14.95 kips	0.266 in^2	0.93 in^2
Vertical	149.3 kips	2.654 in^2	5.08 in^2

Typical anchorage and placement details provided by Design of Buildings to Resist Progressive Collapse, UFC 4-023-03

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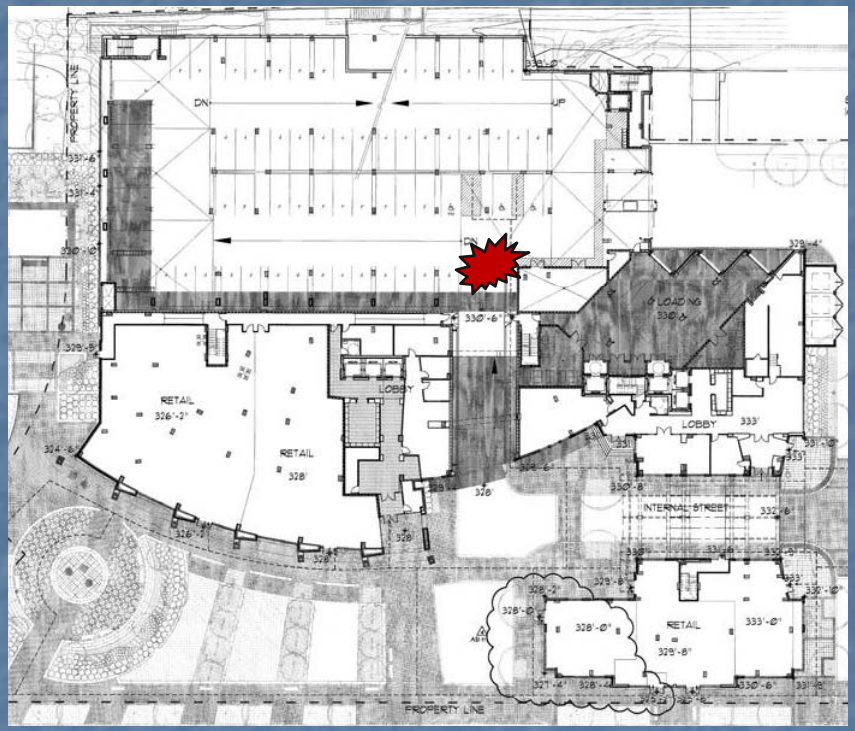
Parking Garage: Direct Method



Site Plan created by WDG Architecture

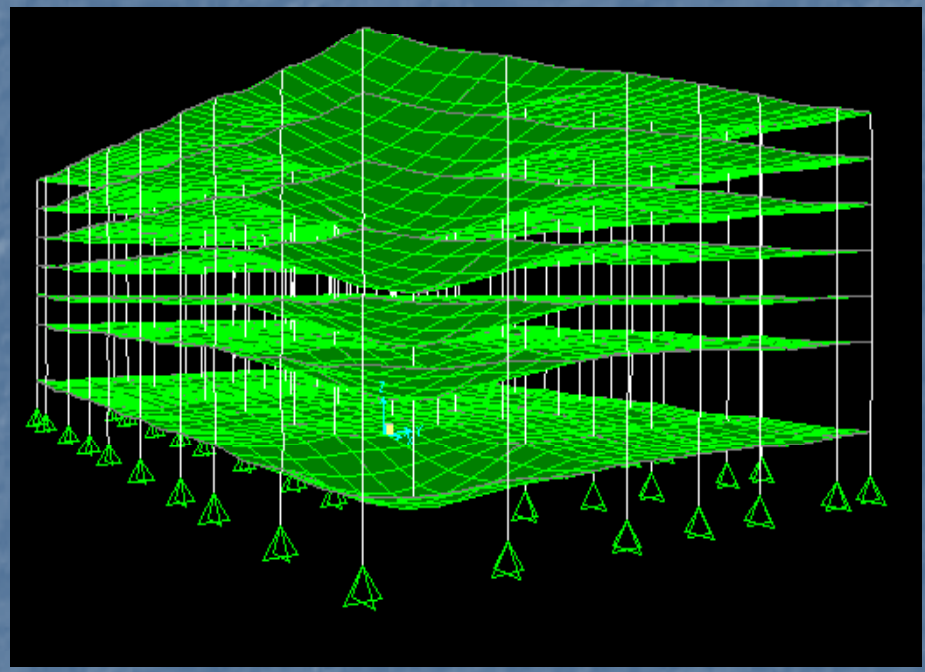


Image of deformed shaped from SAP2000

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Structural Resistance to Progressive Collapse

Parking Garage: Direct Method

Frame	Span	Location	$A_{sDESIGN}$ (in^2)	$A_{sCOLLASPE}$ (in^2)	$A_{sADD.}$ (in^2)	% Increase
10	H-I	Top	0.692	1.007	0.315	45.5
10	H-I	Bottom	0.658	0.658	0	0
10	I-J	Top	0.732	0.821	0.089	12.2
10	I-J	Bottom	0.658	0.658	0	0
I	8-9	Top	1.338	4.020	2.682	200
I	8-9	Bottom	1.125	1.836	0.711	63.2
I	9-10	Top	1.107	4.594	3.487	315
I	9-10	Bottom	0.936	2.120	1.184	126

Cost and Lease Premiums

Method	Transfer Girder Premium		Parking Garage Premium		Total Premium	
	Cost	Lease	Cost	Lease	Cost	Lease
Indirect	$15,686	0.007%	-$273,574	-0.117%	-$257,888	-0.11%
Direct	$230,052	0.099%	$763,489	0.33%	$993,541	0.43%

According to the National Research Council, for every 1.0 percent of cost premium, the lease rate increases by 0.385 percent.

Site Security Design to Limit Attack Threats

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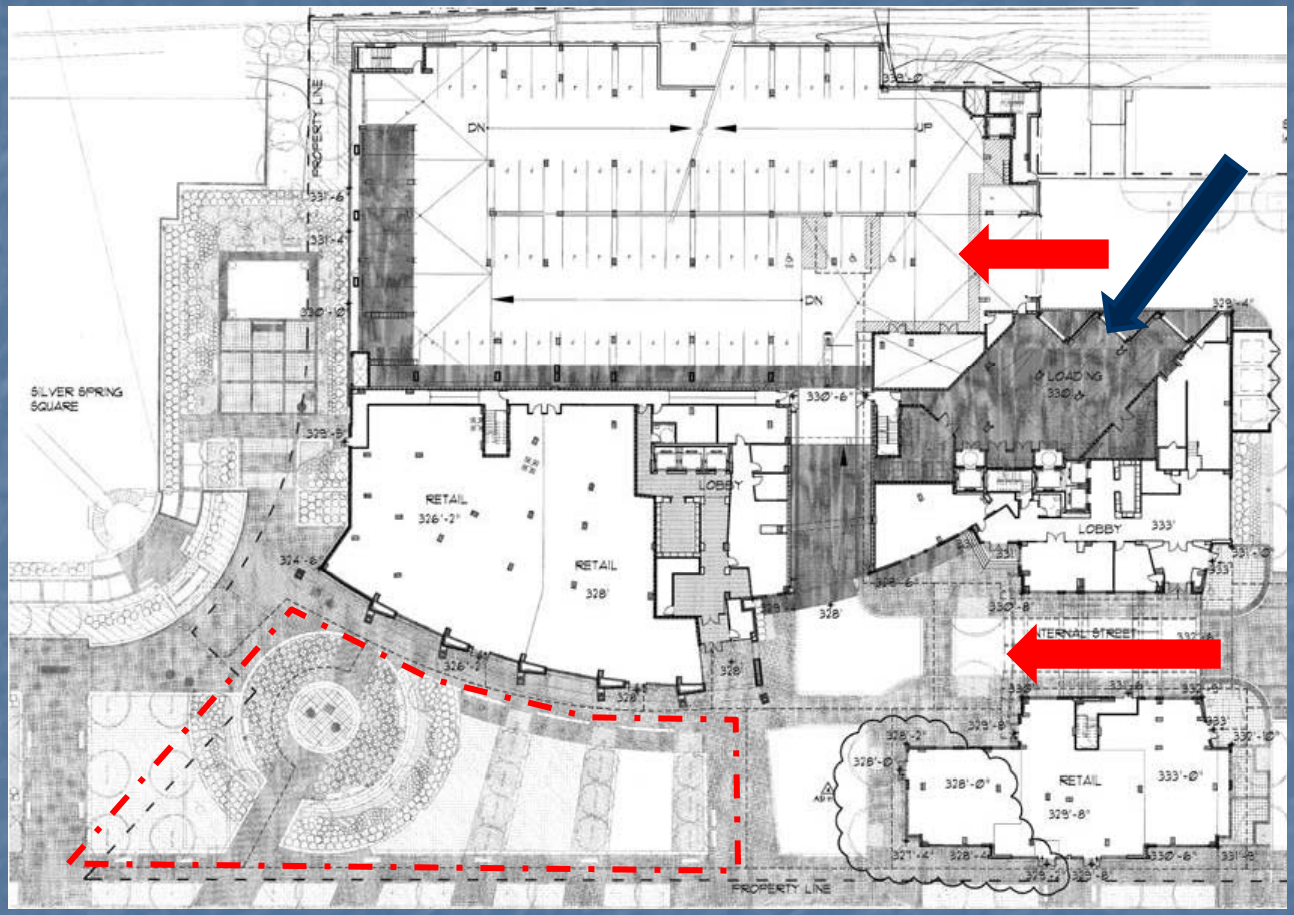
Original Site Layout



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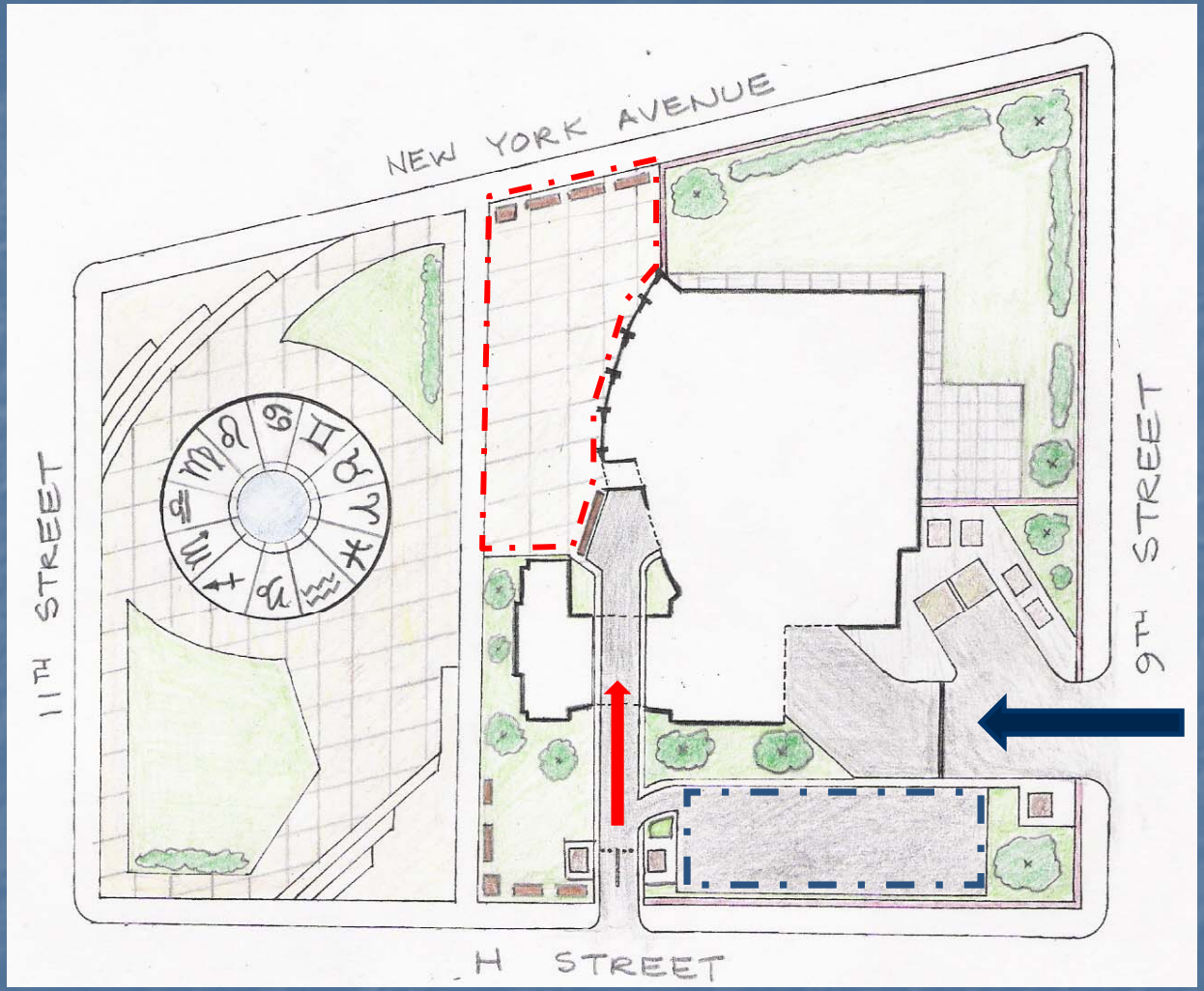
Site Security Design to Limit Attack Threats

Redesigned Site Layout



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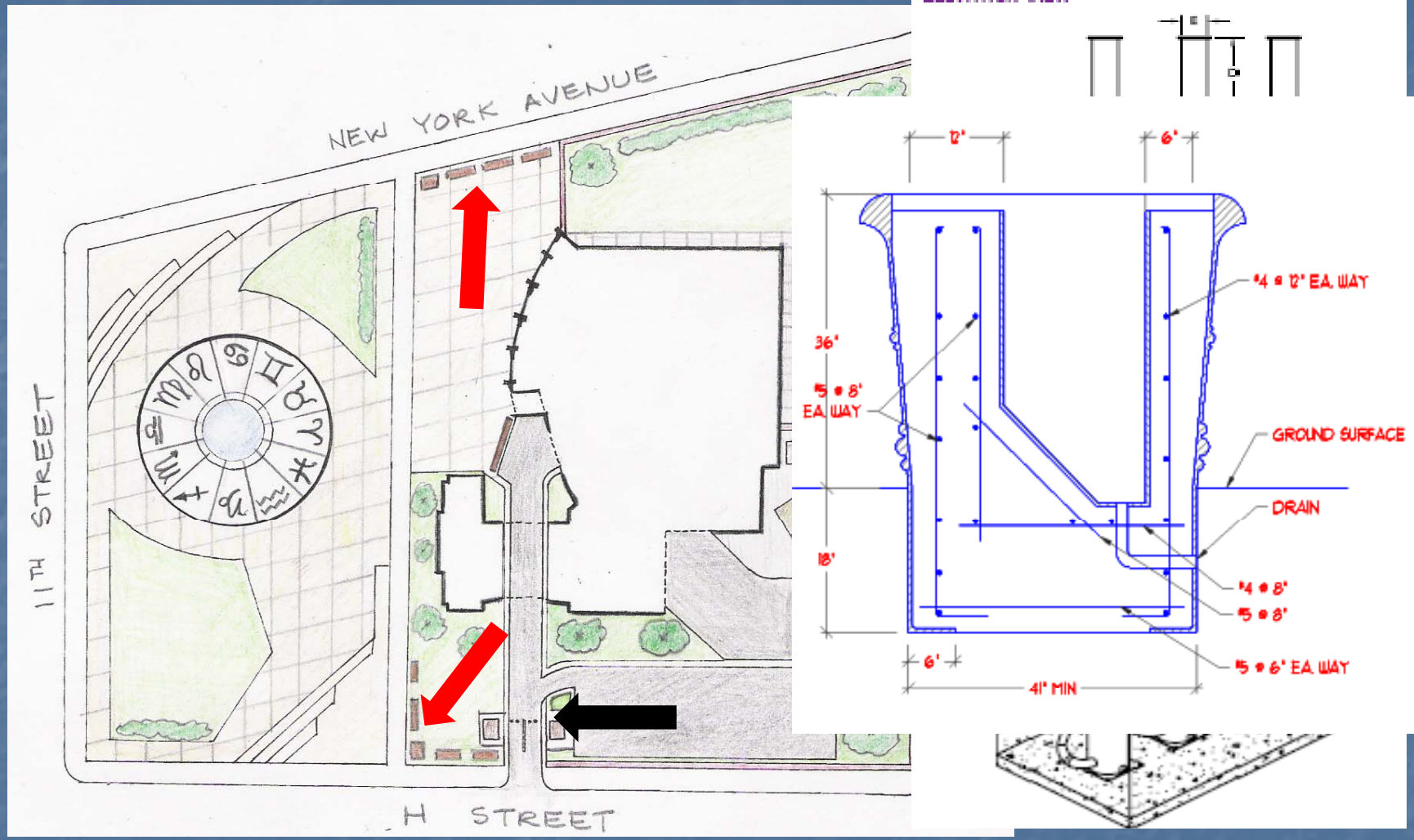
Site Security Design to Limit Attack Threats

Redesigned Site Layout



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Site Security Design to Limit Attack Threats

Façade Design for Blast and Moisture Protection

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Surrounding Architecture

Silver Spring Gateway Rendering

Tech Main Building

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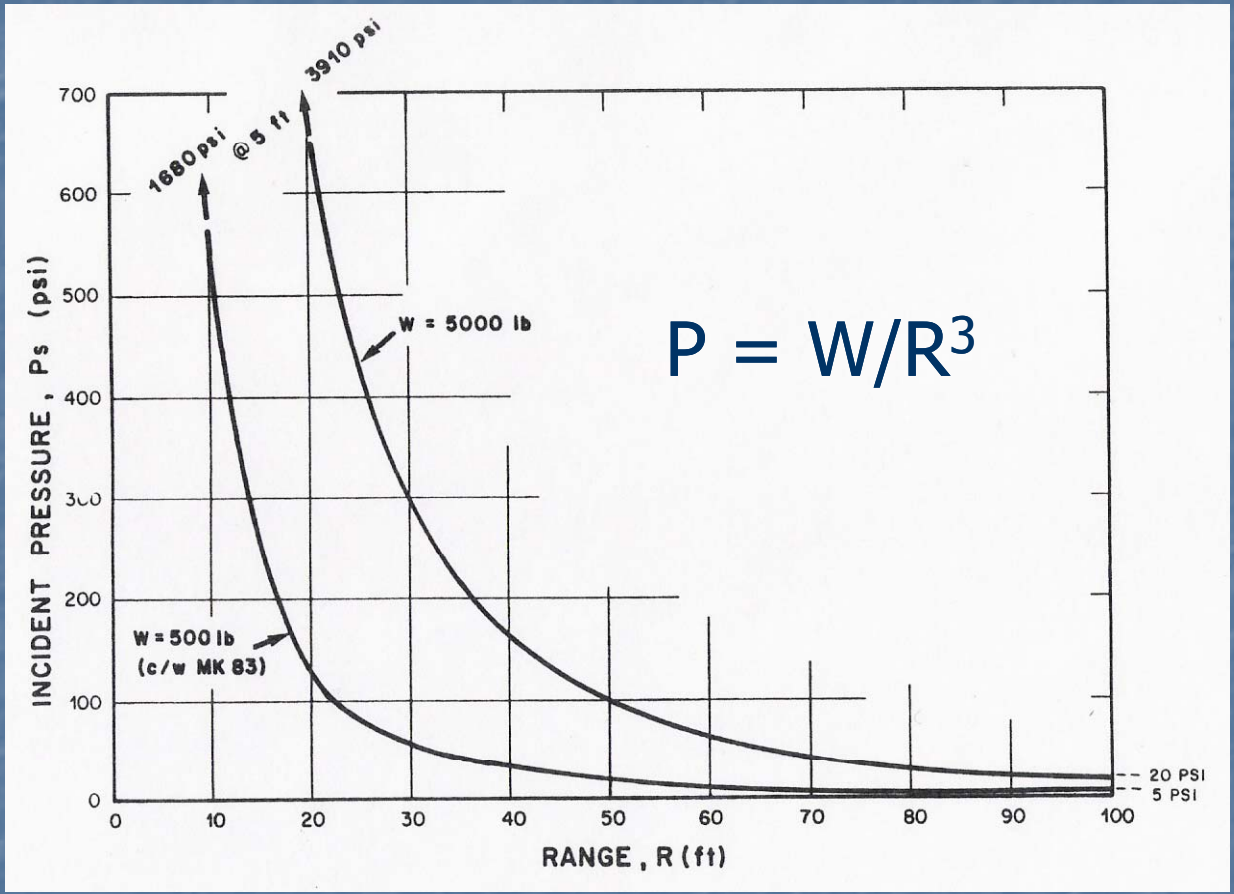
Façade Design for Blast and Moisture Protection

Blast Resistant Glazing



$$P = W/R^3$$

Tempered Glass Breakage Pressure: 24,000 psi (60 minute loading)

Blast Loading is several times faster!

However, stand-off range is +100'

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Blast Resistant Glazing

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glass cracks. Fragments enter space and land on floor no further than 1 meter (3.3 feet) from window.

Performance Conditions for Windows from FEMA 427: Primer for the Design of Commercial Buildings to Mitigate Terrorist Attacks

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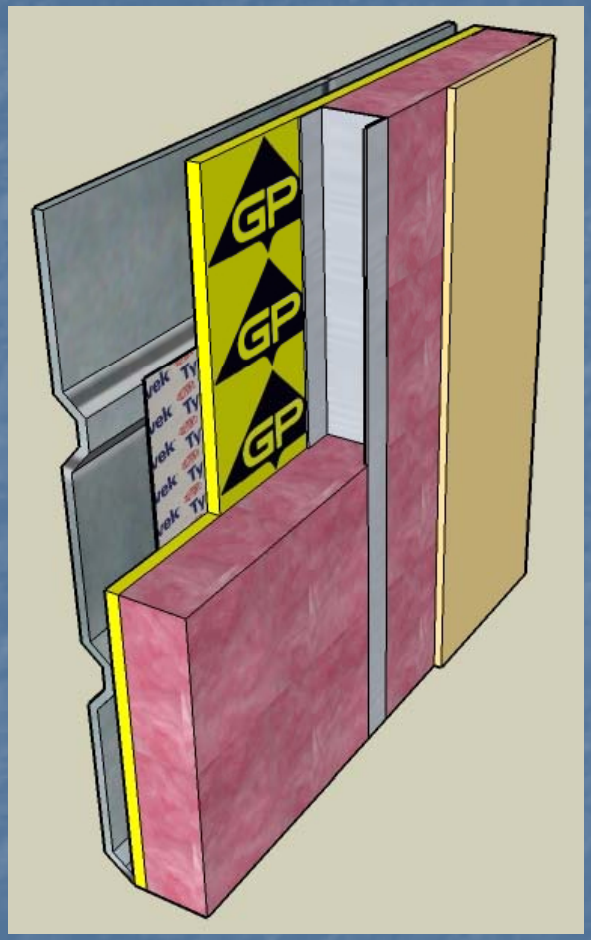
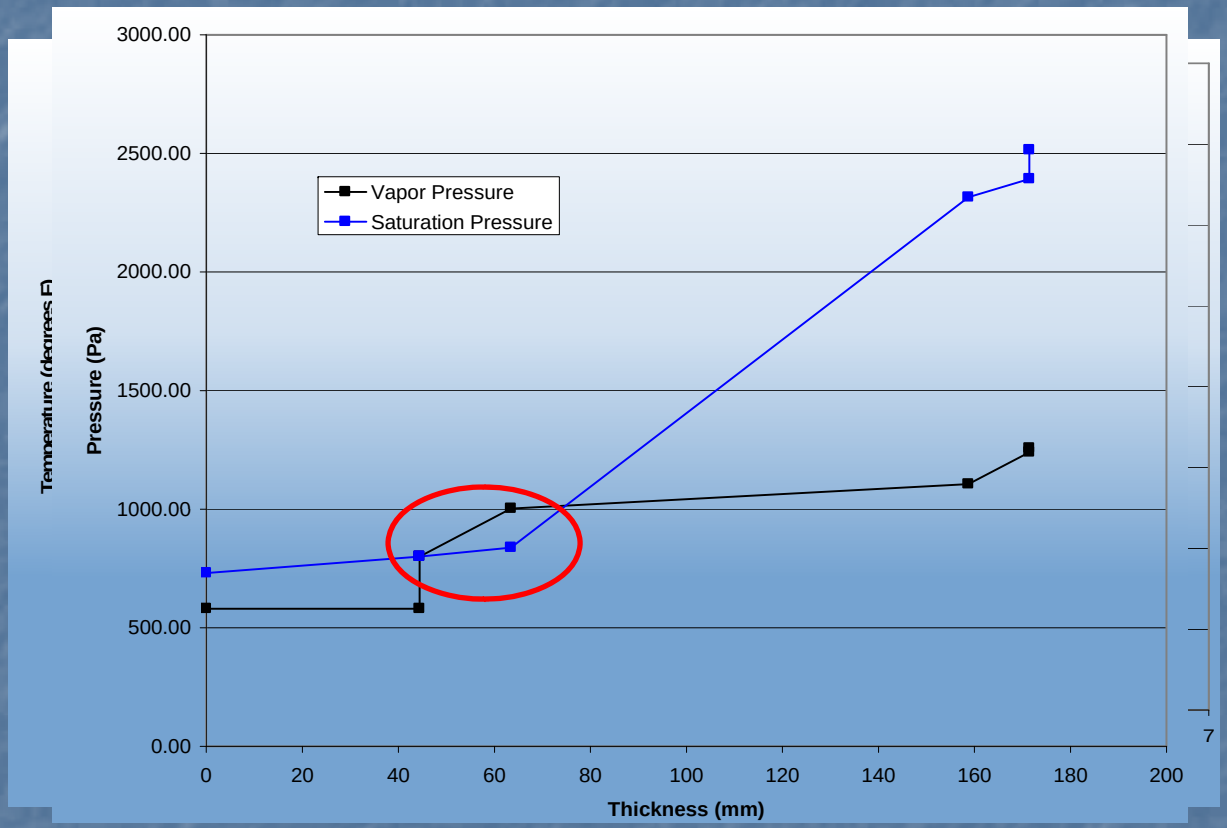
Thermal and Moisture Protection





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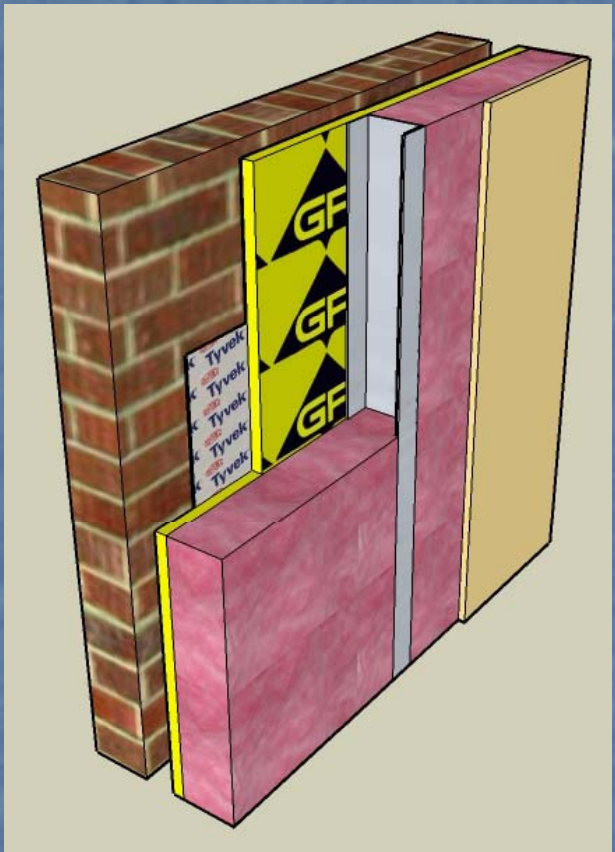
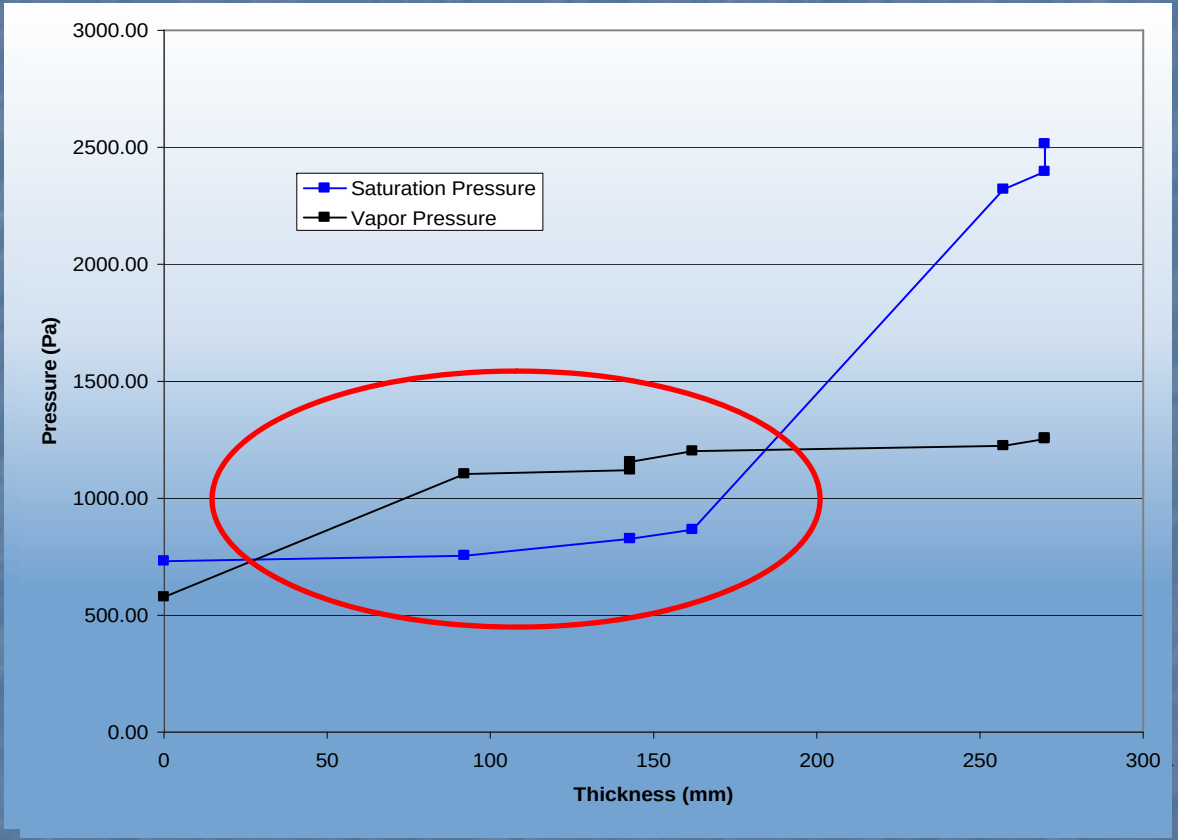
Façade Design for Blast and Moisture Protection

Thermal and Moisture Protection





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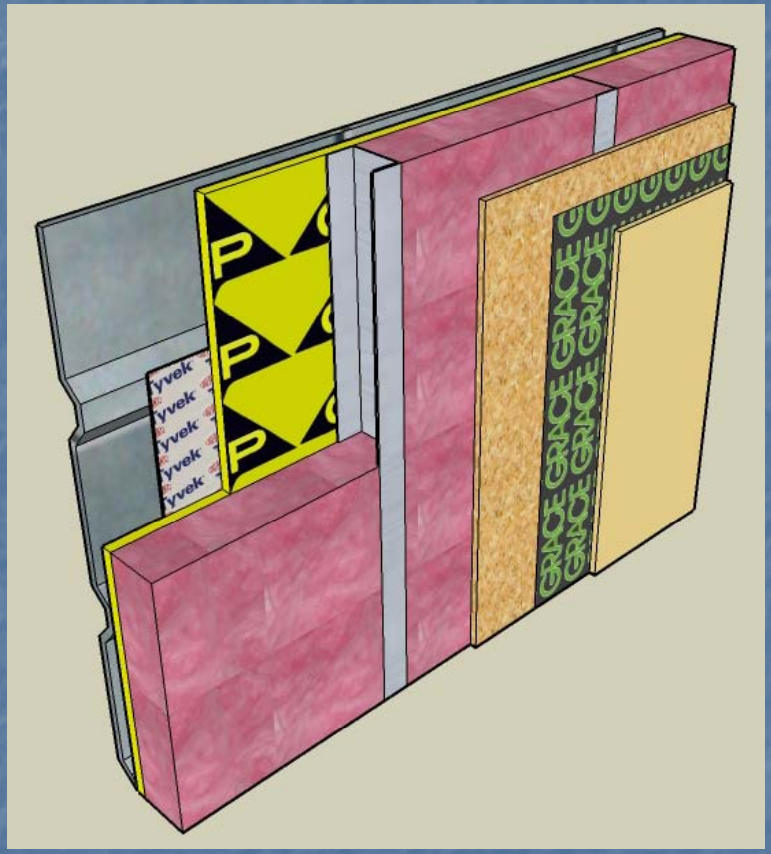
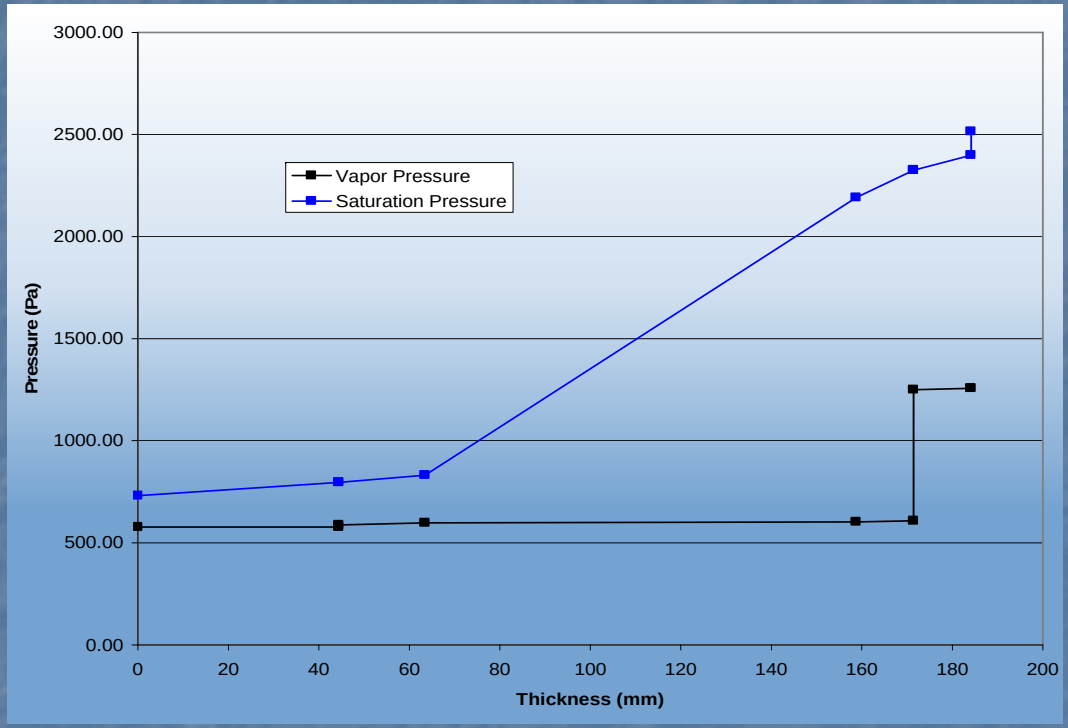
Façade Design for Blast and Moisture Protection

Thermal and Moisture Protection





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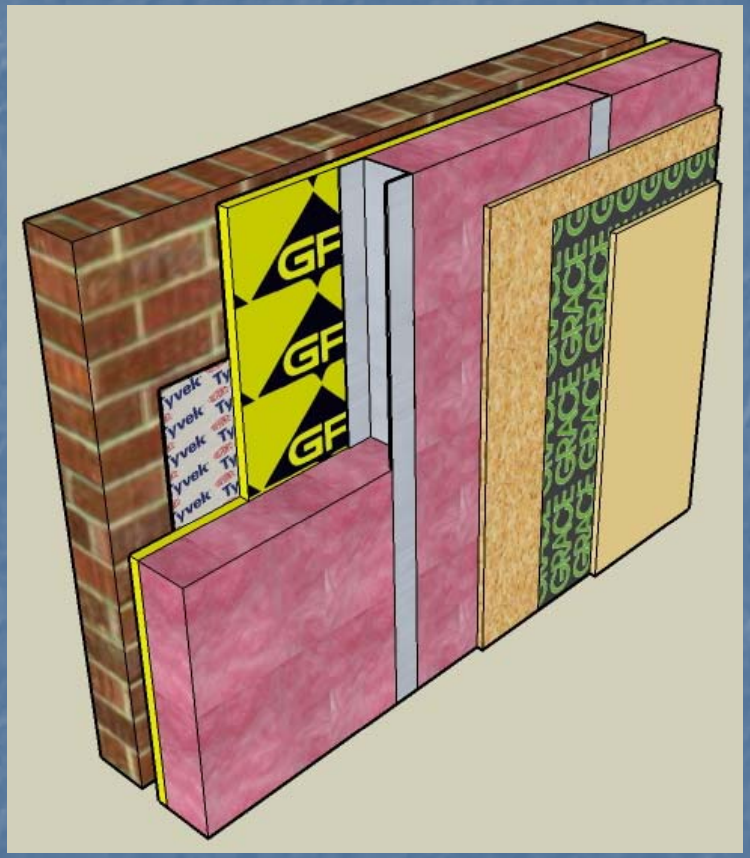
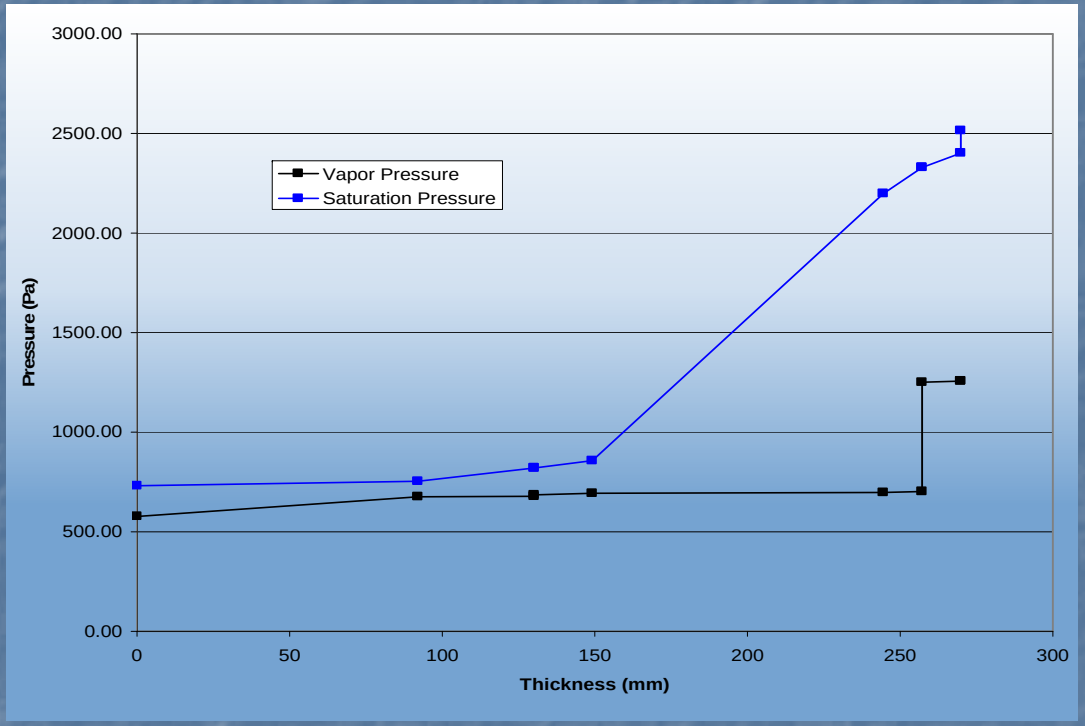
Thermal and Moisture Protection





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Façade Design for Blast and Moisture Protection

Recommendations

It is recommended that JBG pursue the development of this site for its desired clientele for the following reasons:

Goal #1: The structural system was redesigned to withstand a terrorist attack without defiling the architectural program.

Goal #2: The site layout was redesigned to prevent a terrorist attack; however, the most important aspect is distance. This site works well; if a smaller site is chosen, it may not perform adequately.

Goal #3: The façade currently matches its environment and has blast resistant glazing. Only a minor change was made to increase its thermal and moisture protection performance.

Goal #4: A minor amount was saved for the structural system and added for the façade redesign. The added site technology and acreage moderately add to the cost.

Acknowledgements

Thanks to:

Turner

WJE

Pennsylvania State University:

- Dr. Linda Hanagan
- Andreas Phelps

Special Thanks to: My family and my fellow AEs

Questions?

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