North Shore Equitable Building

Stephan Northrop – Structural Option

Advisor: Dr. Hanagan

April 13, 2011

North Shore Equitable Building

Presentation Outline

Building Introduction
Existing Building Information
Problem Statement
Proposed Solution
Structural Depth

- Codes & Loads
- Proposed Gravity System
- Proposed Lateral System
- Foundation Assessment

Acoustic Analysis Breadth
Conclusion
Acknowledgements & Questions

North Shore Equitable Building

Building Introduction
Existing Building Information
Problem Statement
Proposed Solution
Structural Depth
- Codes & Loads
- Proposed Gravity System
- Proposed Lateral System
- Foundation Assessment

Acoustic Analysis Breadth
Conclusion
Acknowledgements & Questions

General Building Information

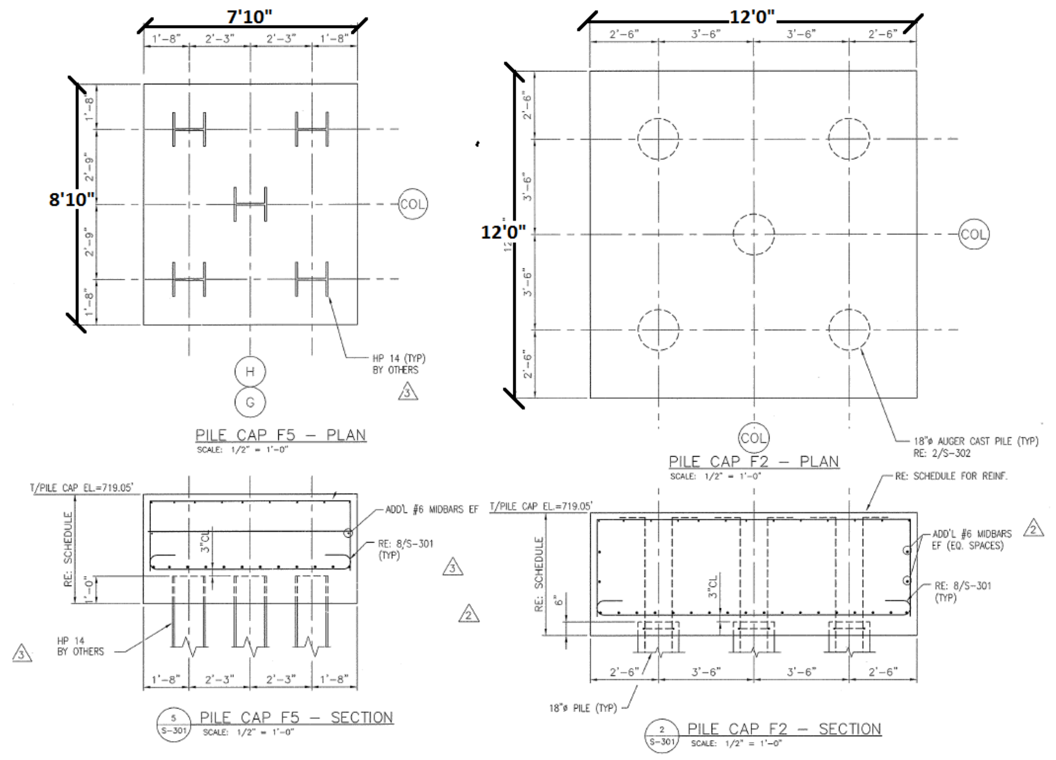
- Location: Pittsburgh's North Shore
- Owner: Continental Real-Estate
- Occupancy Type: Low rise commercial
- Delivery method: Design build
- Dates of construction: Oct '03 - Dec '04
- Cost: $70 million
- Size: 6 stories, 180,000 sq. Ft.
  87'1" building height

North Shore Equitable Building

Existing Structural System

Foundation

- 5 ½” Slab on grade
- 18” Auger Cast Piles
- Steel H piles
- Light rail transit line accommodation

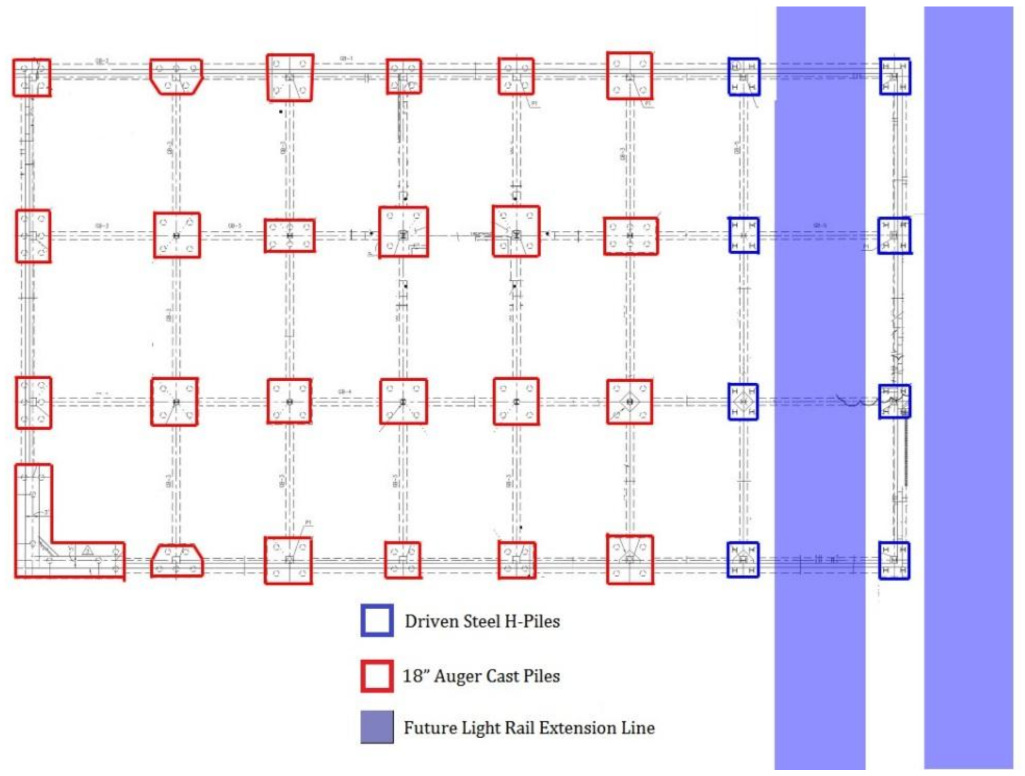


North Shore Equitable Building

Existing Structural System

Foundation

- 5 ½" Slab on grade
- 18" Auger Cast Piles
- Steel H piles
- Light rail transit line accommodation



North Shore Equitable Building

Existing Structural System

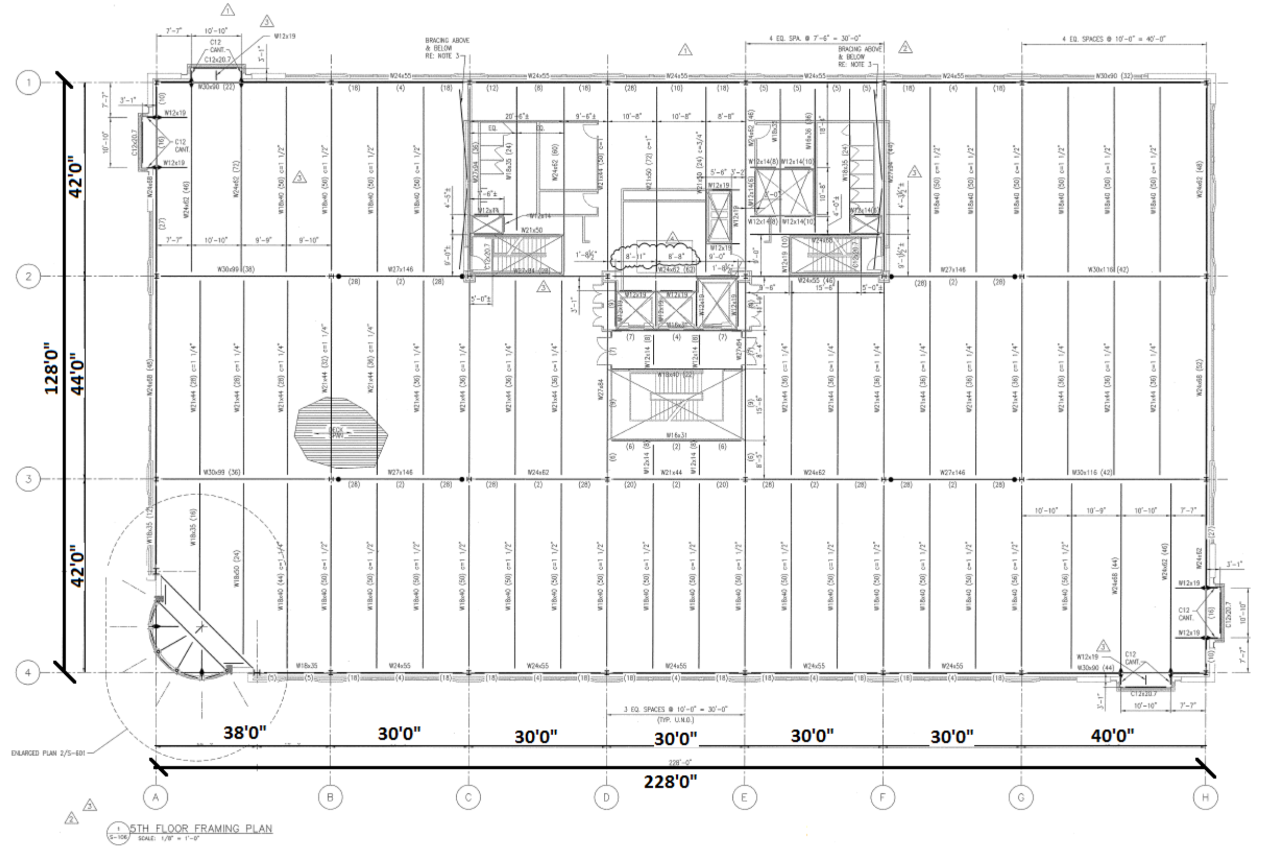
General Floor Framing

Gravity System

- 5 ½" Lightweight composite floor slab
- Steel wide flange beams and girders
- W14 steel columns

Lateral System

- N/S Direction: Braced frames
- E/W Direction: Steel moment frames



Existing Structural System

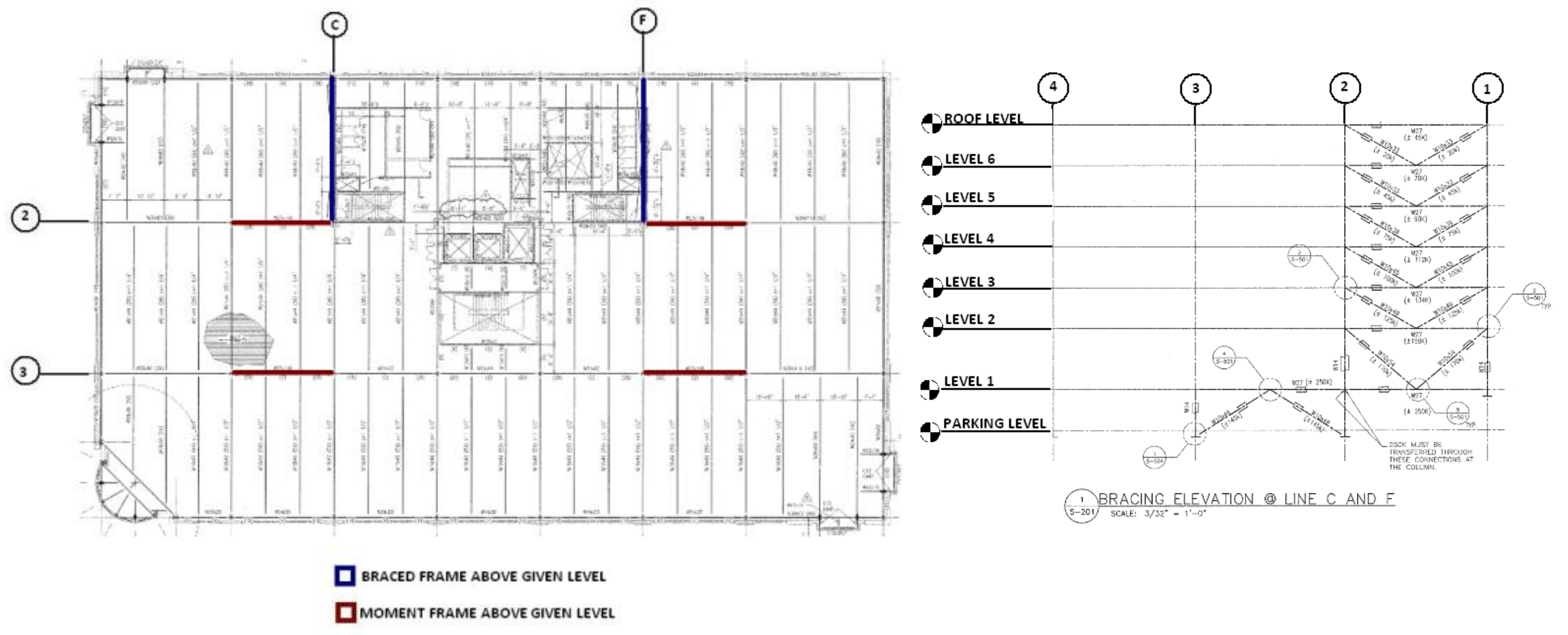
General Floor Framing

Gravity System

- 5 ½" Lightweight composite floor slab
- Steel wide flange beams and girders
- W14 steel columns

Lateral System

- N/S Direction: Braced frames
- E/W Direction: Steel moment frames



Problem Statement

- Subgrade light rail transit line poses vibration and noise control issues
- Large bay sizes are required

<u>Project Goals</u>

- Improve noise control
- Maintain existing grid layout

Proposed Solution

Structural Depth Study

- Redesign the structure as a one way concrete pan joist and beam system
- Investigate the impact on the building foundation

Acoustic Analysis

- Investigate the noise reduction benefits of a concrete structure

Cost & Schedule Analysis (not presented)

- Investigate the cost and scheduling implications of a concrete structure

Proposed Solution

One Way Concrete Pan Joist and Beam System

- **Inherent noise & vibration reduction**
- **Ability to accommodate long spans**
- **Decreased floor depth**
- **Possibility of decreased construction costs**

Codes & Loads

Existing Design

- 100 PSF live loads at all levels
- AISC 9th edition, ACI 318-95, and ASCE 7-95 used for design

Redesigned Structure

- 80 PSF live load at all upper levels
- 100 PSF live load at ground level
- ACI 318-08 and ASCE 7-05 used for redesign

Live Loads

Load Type	As Designed (psf)	Per ASCE 7-05 (psf)	Redesign (psf)
Floor Live Loads			
Office	100	50	80
Corridors	100	100 (first level) 80 (upper levels)	100 (first level) 80 (upper levels)
Mechanical	150	(not provided)	150
Stairs	100	100	100
Retail	100	100	100
Garage Live Load	50	40	40
Roof Live Load	20 (min)	20	20

North Shore Equitable Building

Proposed Gravity System

Slab/Pan Joist Design

- Normal weight, 4000 psi concrete
- Designed using Excel spreadsheets and hand calculations
- 24.5" deep floor system

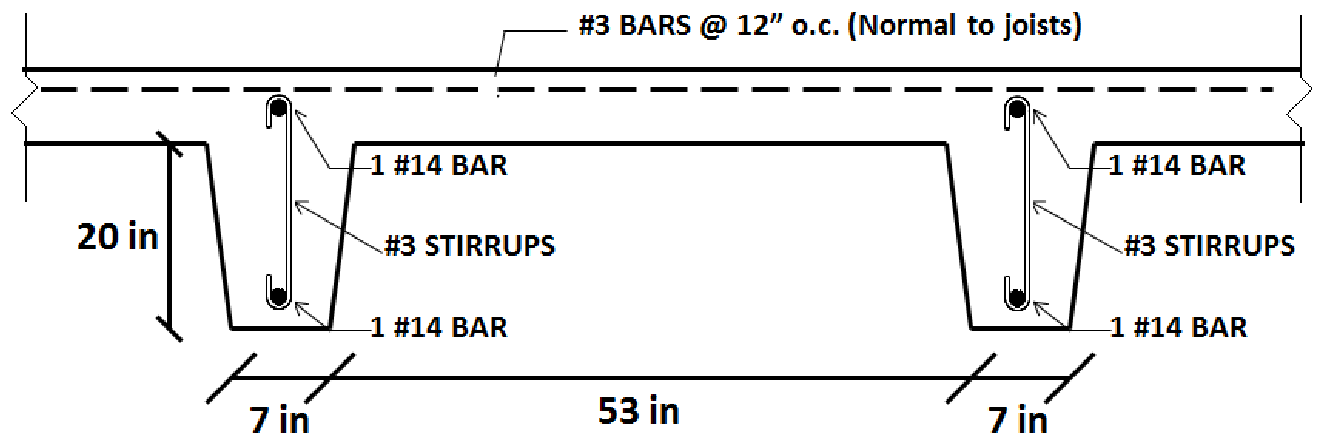
Slab

- 4.5" thick slab with #3 bars @ 12" o.c.

Pan Joists

- 20" depth, 7" width
- Spaced at 60" o.c.
- 2 #9 top bars & 2 #10 bottom bars

SLAB/PAN JOIST DETAIL

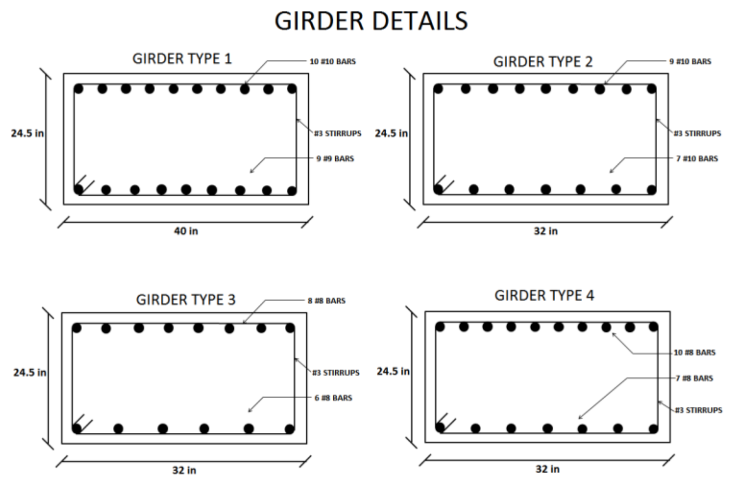


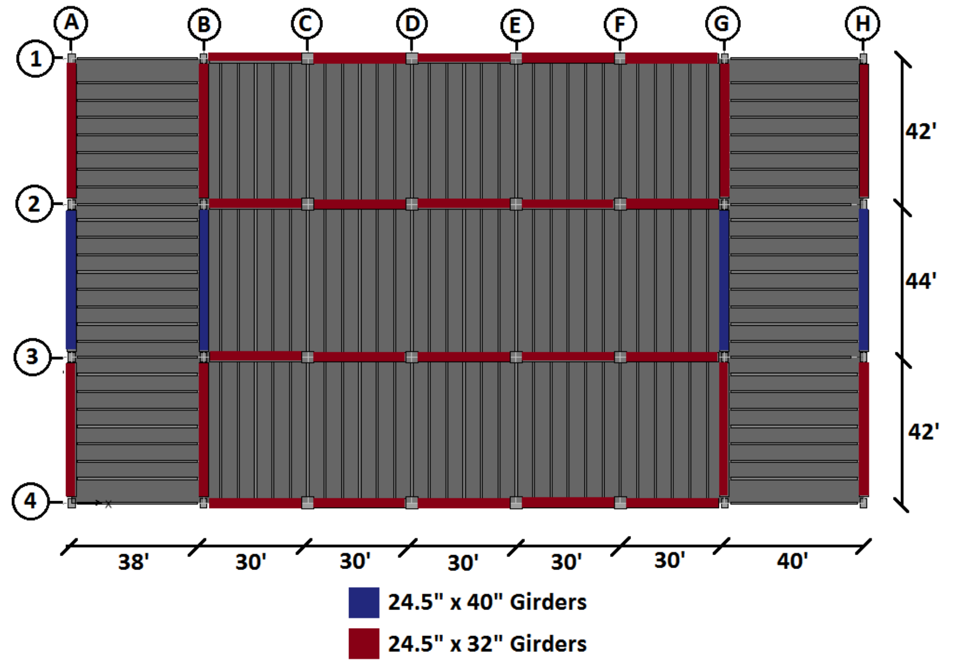
North Shore Equitable Building

Proposed Gravity System

Girder Design

- Designed using Excel spreadsheets and hand calculations
- 24.5” x 40” Girders used for 44’ spans
- 24.5” x 32” girders used for spans less than 44’
- Spans > 40’ reinforced with #9 and #10 bars
- Spans < 40’ reinforced with #8 bars

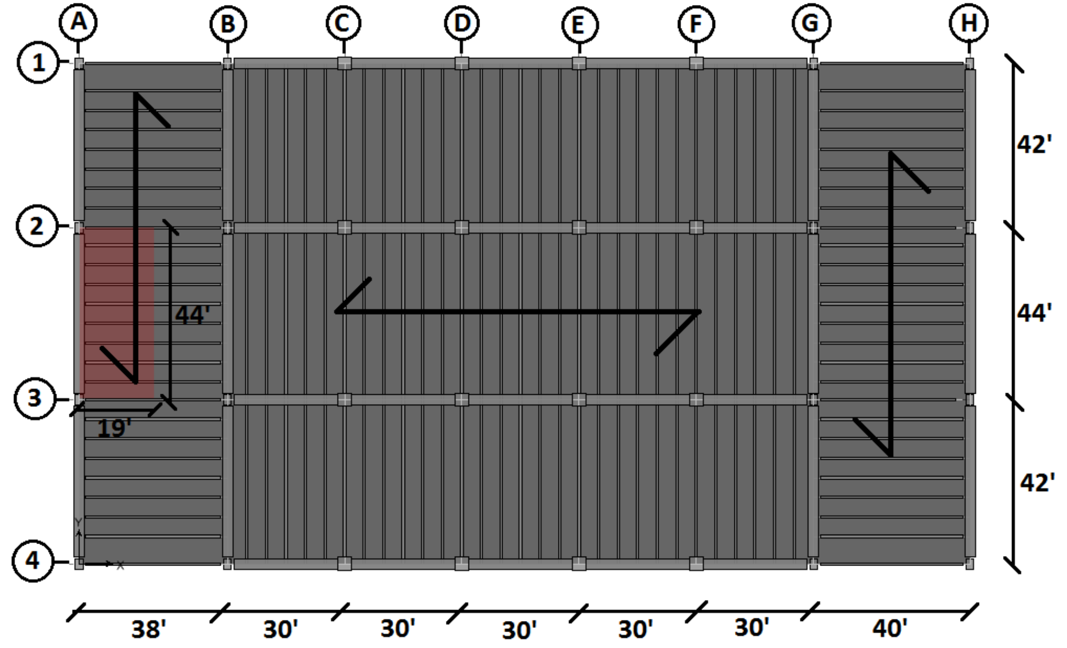




North Shore Equitable Building

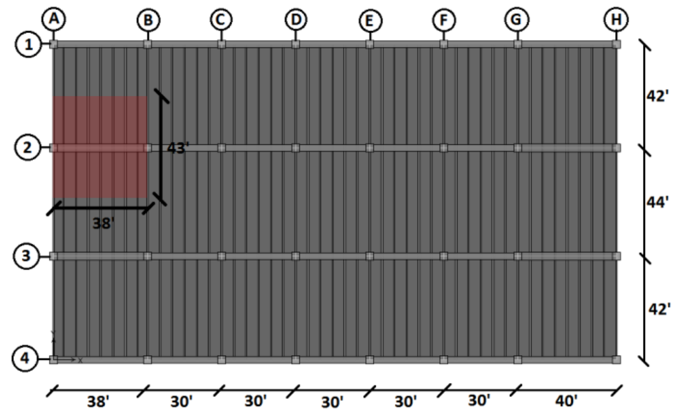
Proposed Gravity System

Floor System Framing Plan

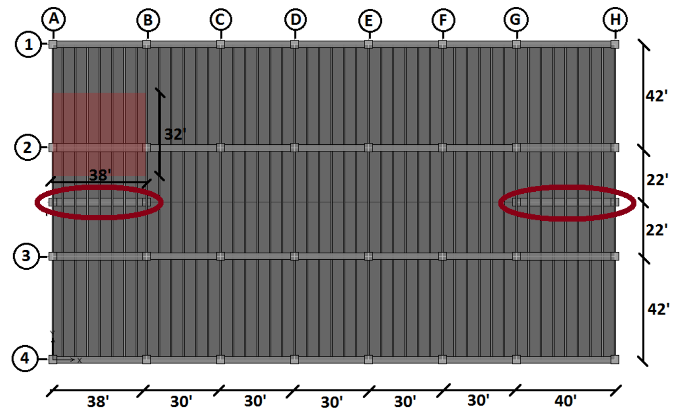


Floor System Framing Plan

- Decreased tributary area
- No additional columns necessary



Excessive tributary area

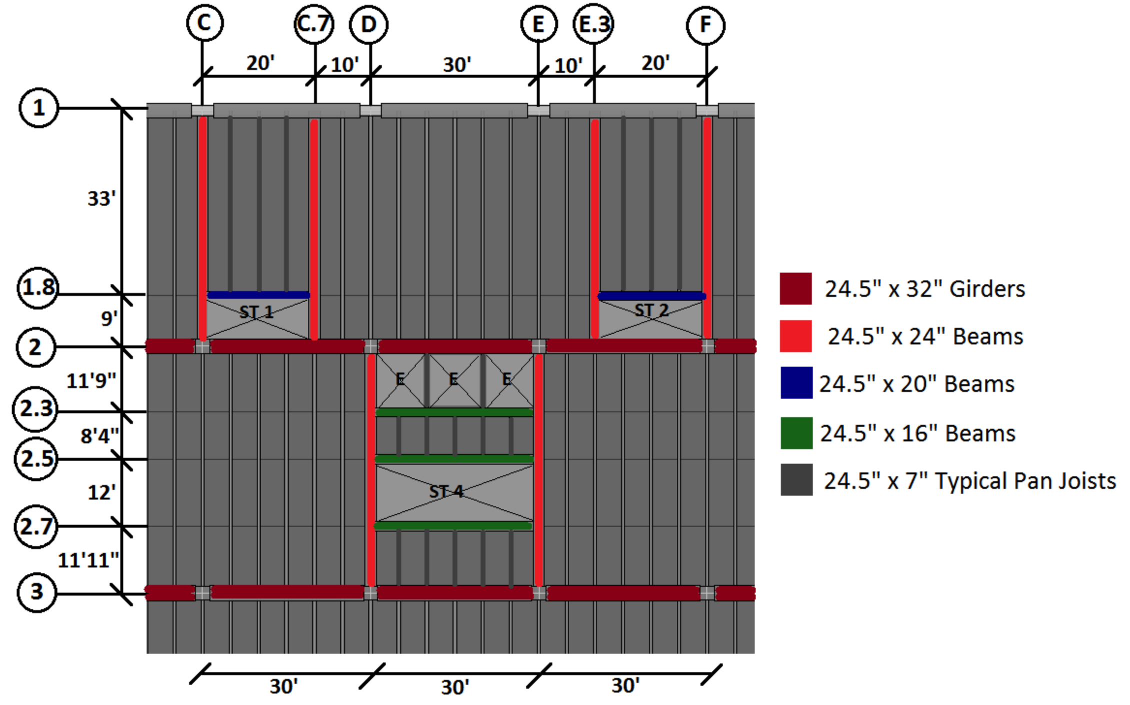


Disrupted open floor space

North Shore Equitable Building

Proposed Gravity System

Stairwell & Elevator Shaft Framing



Stairwell & Elevator Shaft Framing

- Beam widths of 24", 20" and 16" used
- Spans range from 20' to 44'
- #6 and #8 bars used for reinforcing

Stairwell and Elevator Framing Members

Member Size	Span	Top Reinf.	Bottom Reinf.
24.5" x 24" Beam	42' – 44'	8 #8 Bars	5 #8 Bars
24.5" x 20" Beam	20'	6 #6 Bars	4 #6 Bars
24.5" x 16" Beam	30'	4 #8 Bars	4 #8 Bars

North Shore Equitable Building

Proposed Gravity System

Column Design

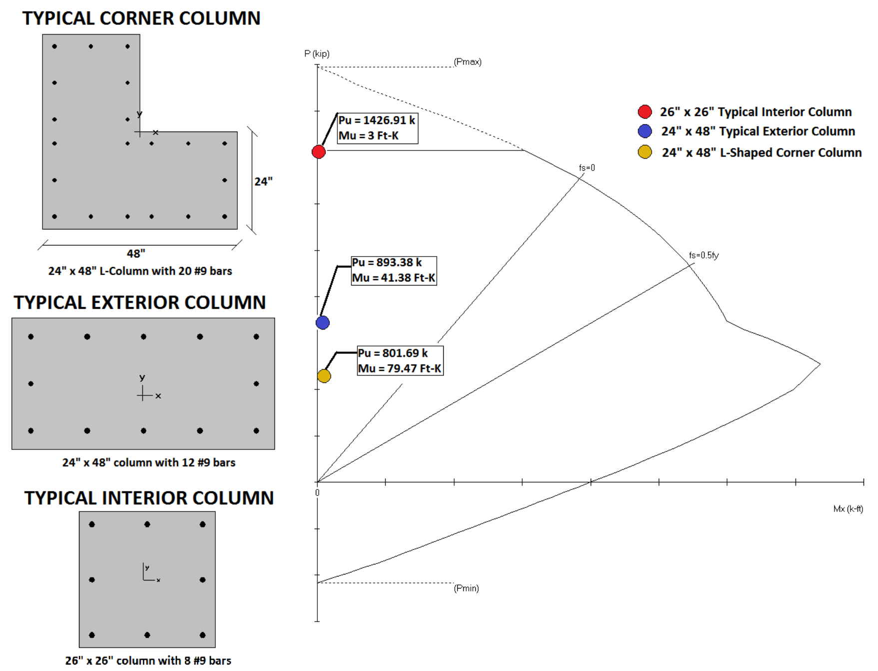
- Designed using an Excel spreadsheet and hand calculations
- Checked using spColumn

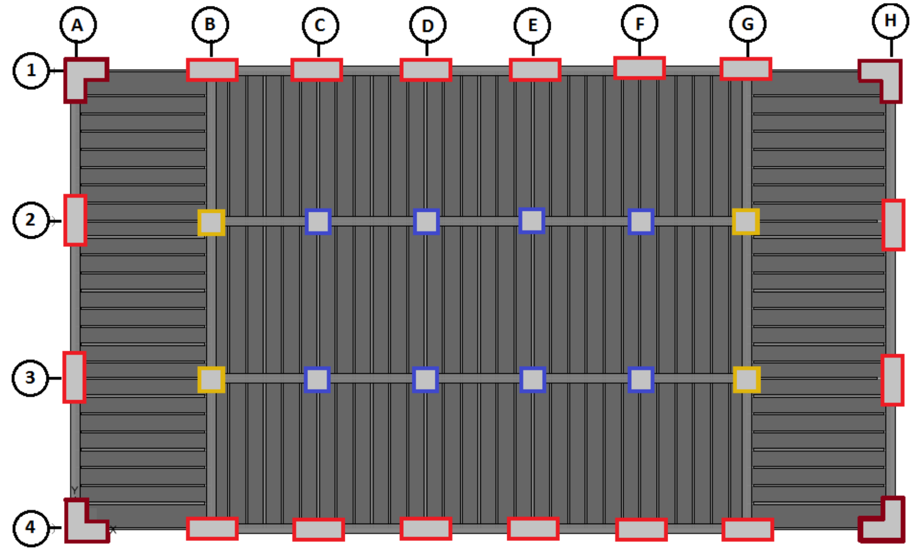
Exterior Columns

- 24”x48” L-shaped columns at all corners
- 24”x48” Rectangular columns along exterior

Interior Columns

- 30”x30” and 26”x26” square columns at 1st level
- Sizes decrease with ascending floor level





24" x 48" Exterior Columns (all levels)
24" x 48" Corner Columns (all levels)
26" x 26" Typical 1st Floor Interior Columns
30" x 30" 1st Floor Interior Columns

Stephan Northrop

Structural Option

North Shore Equitable Building

Proposed Gravity System

Column Design

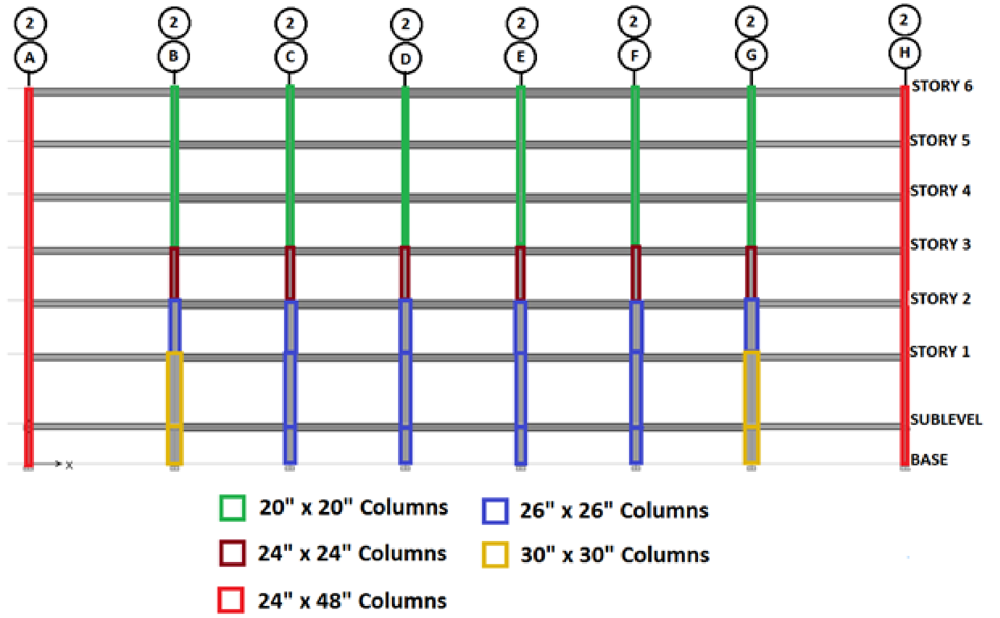
- Designed using an Excel spreadsheet and hand calculations
- Checked using spColumn

Exterior Columns

- 24"x48" L-shaped columns at all corners
- 24"x48" Rectangular columns along exterior

Interior Columns

- 30"x30" and 26"x26" square columns at 1st level
- Sizes decrease with ascending floor level



North Shore Equitable Building

Proposed Lateral System

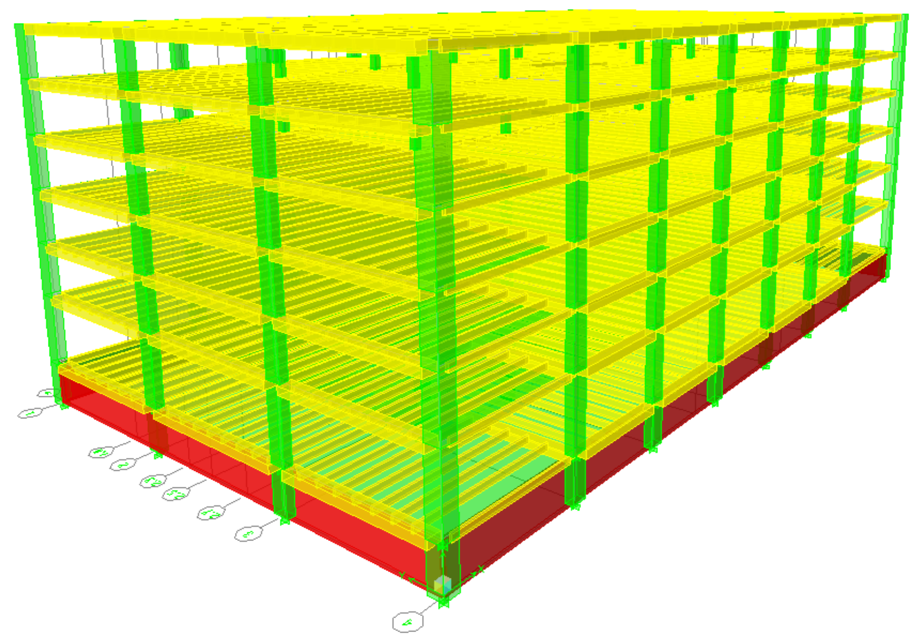
- Ordinary concrete moment frames
- L-shaped and rectangular columns along exterior to add stiffness
- Concrete shear walls at core avoided to minimize torsion

Proposed Lateral System

ETABS Computer Model

Modeling Assumptions

- Rigid Diaphragms used at all levels
- Building mass represented as diaphragm additional area mass
- Cracked moment of inertias considered
- Rigid end offsets applied to all members using a factor of 0.5



Proposed Lateral System

Wind & Seismic Loading Application

Wind Forces

- Calculated using ASCE 7-05 MWFRS
- North/South direction controls due to a larger exposure area

Wind & Seismic Story Forces

Level	E/W Wind (K)	N/S Wind (K)	Seismic
Roof	12.94	22.67	153.11
6	22.84	40.02	179.18
5	22.59	39.59	138.89
4	21.37	37.45	99.45
3	19.82	34.73	63.11
2	20.42	35.78	30.86
1	11.73	20.56	0
Base Shear	134.56	233.59	672.92

North Shore Equitable Building

Proposed Lateral System

Wind & Seismic Loading Application

Seismic Forces

- Calculated using ASCE 7-05
- Controls over wind due to building weight
- R = 3.0 for ordinary concrete moment frames
- C_uT_a = 1.76 s (controlling period)

Wind & Seismic Story Forces

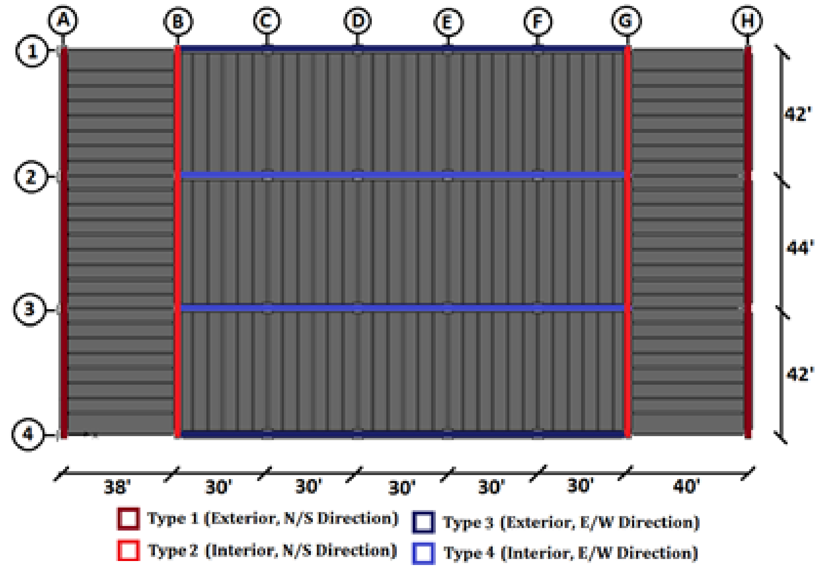
Level	E/W Wind (K)	N/S Wind (K)	Seismic
Roof	12.94	22.67	153.11
6	22.84	40.02	179.18
5	22.59	39.59	138.89
4	21.37	37.45	99.45
3	19.82	34.73	63.11
2	20.42	35.78	30.86
1	11.73	20.56	0
Base Shear	134.56	233.59	672.92

North Shore Equitable Building

Proposed Lateral System

Relative Stiffness & Center of Rigidity

- Stiffness of moment frames range from 65.80 (K/in) to 170.18 (K/in)
- Center of mass at center point of building
- Very little eccentricity due to symmetrical design



Frame Stiffness Values at Level 6

Frame Type	Applied force (K)	Deflection (in)	Stiffness ($K = p_i/\Delta$)
Type 1	100	1.5198	65.80 (K/in)
Type 2	100	1.3887	72.01 (K/in)
Type 3	100	0.5876	170.18 (K/in)
Type 4	100	0.7363	135.81 (K/in)

Center of Mass and Rigidity

	C.O.M.		ETABS C.O.R.		Hand	
Level	X(Ft.)	Y(Ft.)	X(Ft.)	Y(Ft.)	X(Ft.)	Y(Ft.)
Sublevel	114	64				
1	114	64	113.14	64.27	114	64
2	114	64	112.85	64.46	114	64
3	114	64	112.61	64.61	114	64
4	114	64	112.44	64.72	114	64
5	114	64	112.31	64.79	114	64
6	114	64	112.26	64.79	114	64

North Shore Equitable Building

Proposed Lateral System

Story Deflections

Controlling Wind Deflections

Load case (N/S):		1.2D + 1.6Wy + L + Lr	
Level	Deflection	Allowable Drift	Acceptable?
	Δ_y (in)	(h_x/400)	
1	0.1899	0.5100	yes
2	0.4590	0.9050	yes
3	0.7462	1.3000	yes
4	1.0058	1.6850	yes
5	1.2120	2.0750	yes
6	1.3626	2.4520	yes

Controlling Seismic Deflections

Load case (N/S):		1.2D + 1.0 Ey + L + Lr	
Level	Deflection	Allowable Drift	Acceptable?
	Δ_y (in)	($0.02h_{sx}$)	
1	0.4239	4.12	yes
2	1.0611	7.24	yes
3	1.7868	10.36	yes
4	2.4872	13.48	yes
5	3.0796	16.00	yes
6	3.5312	19.62	yes

Foundation Assessment

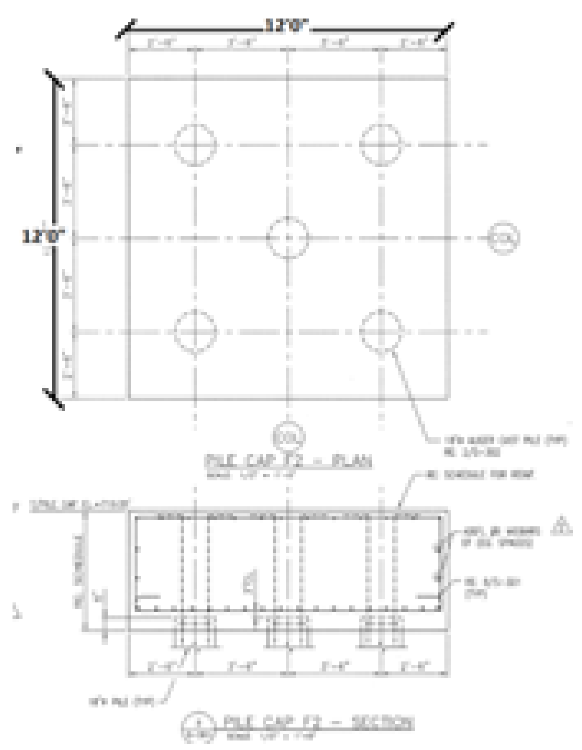
Existing System

- 18" Auger cast piles (290 K capacity)
- 5 piles per typical pile cap
- Bearing capacity = 1450 K per pile cap

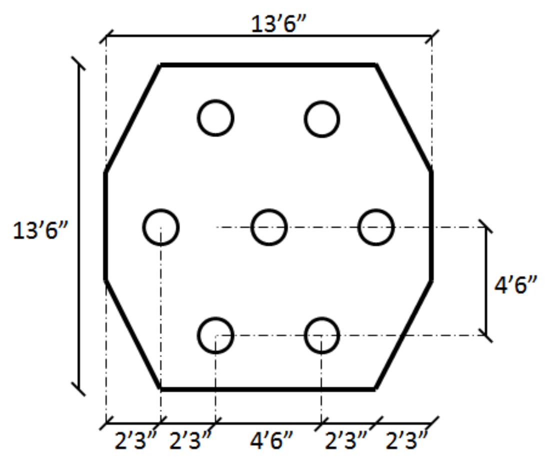
Redesigned System

- 2000.84 K axial load per column
- 7 - 18" piles per pile cap

Existing Pile Cap Design



Redesigned Pile Cap



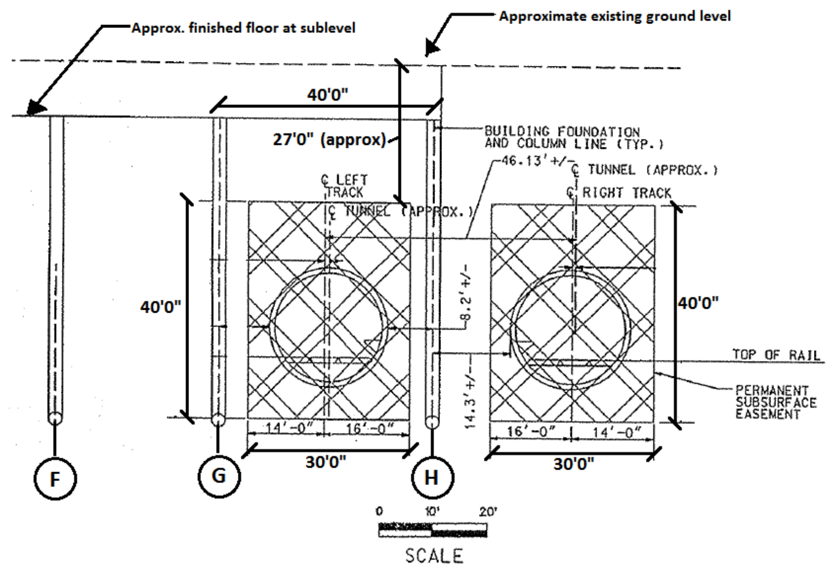
North Shore Equitable Building

Acoustic Analysis

Noise Sources under consideration

- 95 dB subway below grade
- 71 dB passenger car at parking sublevel
- Mechanical system at roof level

Target dB value at level 1 = 38 dB or less



Calculations Performed

- Transmission Loss through S.O.G. and parking level
- STL comparison of new and existing roof structures

Redesigned System STL at Parking Sublevel (Light Rail Transit)

	Octave Band Frequency (Hz)						
	125	250	500	1000	2000	4000	dBA
Light Rail Transit Train (dB)	102	94	90	86	87	83	95
dB reduction due to tunnel + soil	12.3	14.3	13.	14.7	15.1	15.1	13.
dB reduction due to S.O.G.	38	43	52	59	67	72	47
Perceived Noise at Parking	51.7	36.7	24.	12.3	4.9	0.0	34.
Redesigned System STL at Level 1							
dB reduction due parking level	32	30	32	38	45	49	38
Perceived Noise at Level 1	19.7	6.7	-7.4	-	-	-	-3.9

Redesigned System STL at Parking Sublevel (Passenger Car)

	Octave Band Frequency (Hz)						
	125	250	500	1000	2000	4000	dBA
Passenger car (at 55mph cruising speed)	70	67	66	67	66	59	71
dB reduction due parking level CMU walls	48	42	45	56	57	66	44
Perceived Noise at Level 1	22.0	25.0	21.0	11.0	9.0	-7.0	27.0

Acoustic Analysis

Noise Sources under consideration

- 95 dB subway noise at level 1
- 71 dB passenger car noise at level 1
- Mechanical noise at roof level

Calculations Performed

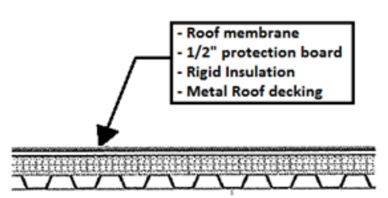
- STL at parking sublevel
- STL at Level 1
- STL comparison of new and existing roof structures

Target dB value at level 1 = 38 dB or less

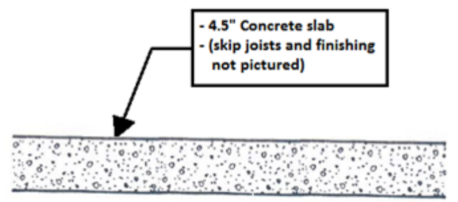
Sound Transmission Loss at Roof Level

Roof material	Octave band frequency (Hz)						
	125	250	500	1000	2000	4000	R_w (dB)
20 gage galvanized roof deck	8	14	20	26	32	38	24
4.5" concrete slab	38	38	41	48	57	65	47
Improvement in noise reduction	30	24	21	22	25	27	23

EXISTING ROOF STRUCTURE



REDESIGNED ROOF STRUCTURE



Acoustic Analysis

Conclusions

- **Noise transmission is not an issue in the redesigned system**
- **Noise reduction is improved at the roof level**
- **Noise reduction is improved in the redesign:**
  - **Increase in slab thickness and density**
  - **Increase in building weight leads to decreased vibrations**

Conclusion

All Project Goals were achieved

- Noise control is improved
- Existing grid layout is maintained

Additional Benefit:

- Construction cost is decreased

Drawbacks to redesigned Structure

- Excessively large column and girder sizes
- Increased building weight
- Increase construction time

Final Conclusion:

- Costs outweigh benefits
- Existing structure is the most economical

Acknowledgements

Primary Project Team:

- Mike Hudec — Continental Real-Estate
- Robert Modany — Continental Real-Estate
- Dina Snider — Strada Architects
- Ken Ash — Michael Baker
- Louis Mittleman — Michael Baker

The Pennsylvania State University:

- Dr. Linda Hanagan
- Prof. M Kevin Parfitt
- Prof. Robert Holland
- Ryan Solnosky, Shaun Kreidel and Dr. Andres Lepage
- The entire AE faculty and staff

A special thank you to my friends and family for their constant support

North Shore Equitable Building

Questions & Comments

North Shore Equitable Building

Final Thesis Presentation

North Shore Equitable Building

Additional Information

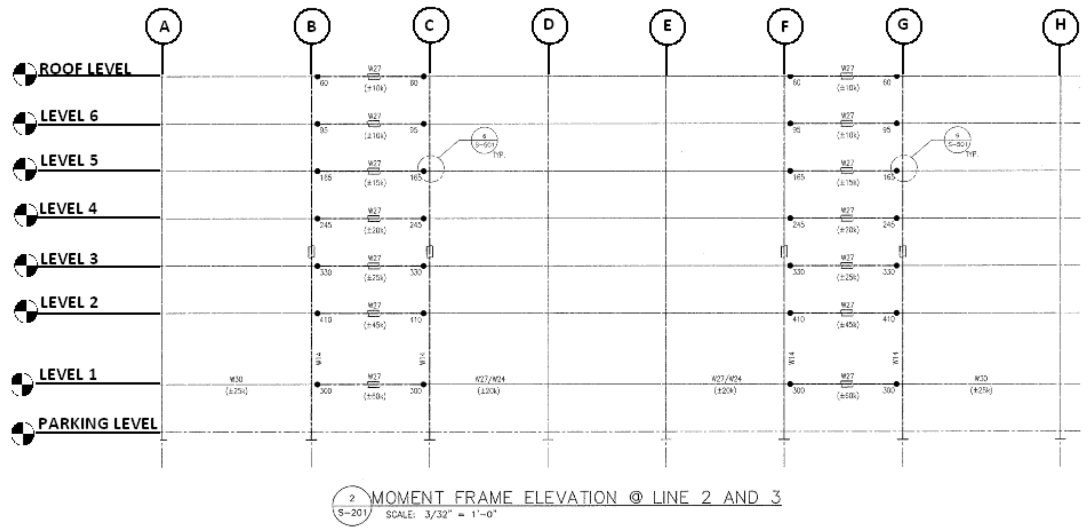


TABLE 5.5 - Dead Loads

Load Type	As Designed (psf)	Redesign (psf)
Superstructure Weight	5	79.58
Roofing, Ceiling, Misc.	8	8
Collateral Load (MEP)	7	7
Total Roof Dead Load	**20**	**94.58**
Concrete Floor Slab	45 (LW composite)	56.25 (NW)
Steel/Joist Framing	10	29.16
Ceiling, Misc.	5	5
MEP	5	5
Total Floor Dead Load	**65**	**95.41**
6" Metal Studs + Insul + GWB	10	10
4" Brick	40	40
Total Exterior Wall Load	**50**	**50**
Stairs	30	30
Stair Landings	40	40

One-Way Joist – 53" pan

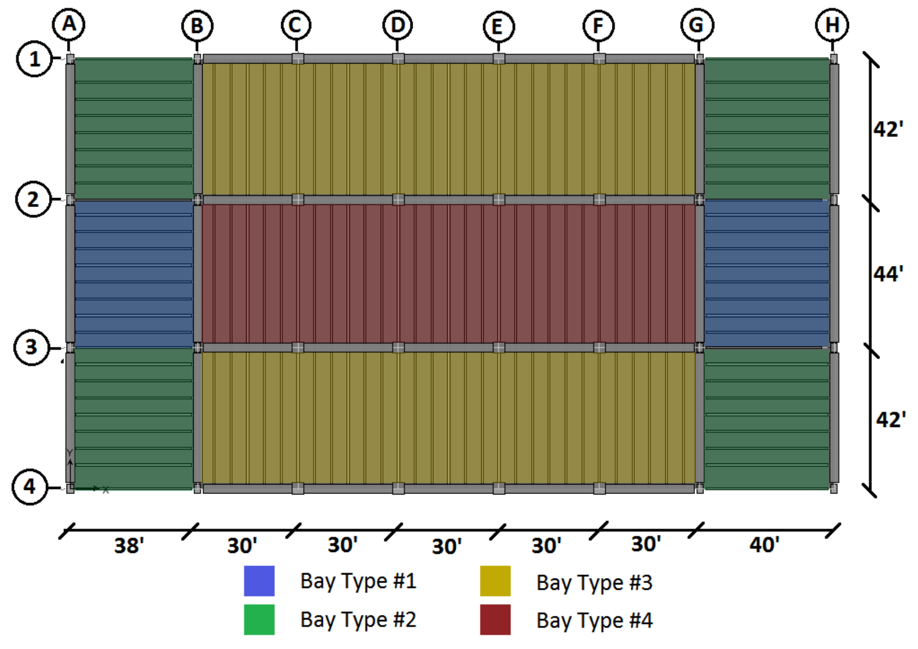
f'_c = 4,000 psi SIDL = 20 psf
Slab h = 4½" LL = 100 psf

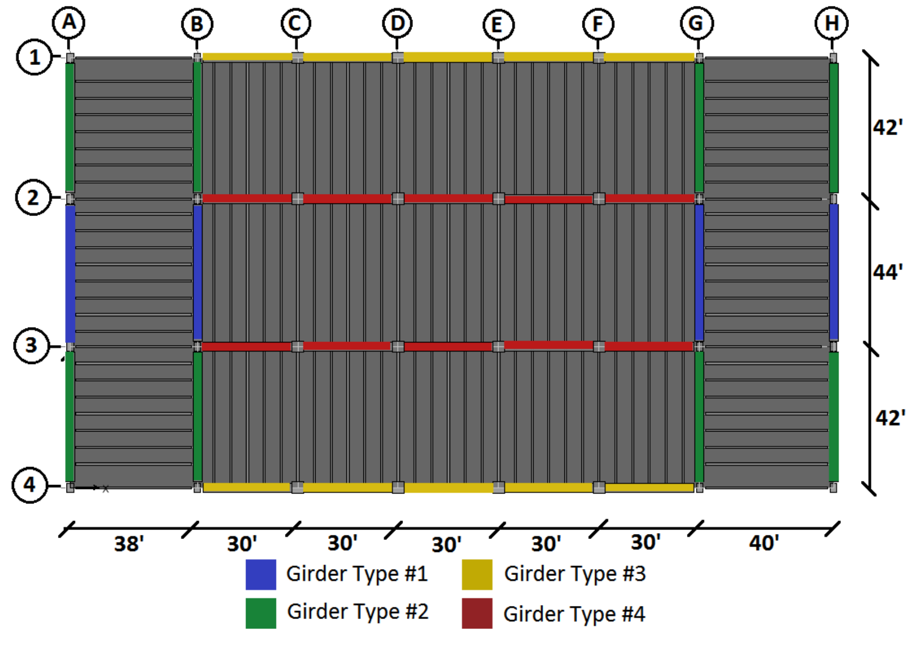
Bay Size (ft)	Pan Depth (in.)	Rib Width (in.)	Beam Width (in.)	Square Column Size (in.)	Concrete (ft^3/ft^2)	Reinforcement (psf)	Pan Area (%)
20 × 20	16	7	22	22	0.68	2.35	89
20 × 25	16	7	24	24	0.67	2.43	91
20 × 30	16	7	26	26	0.65	2.51	91
20 × 35	16	7	32	32	0.65	2.76	91
20 × 40	16	7	34	34	0.64	2.95	92
25 × 25	16	7	28	28	0.68	2.60	89
25 × 30	16	7	32	32	0.67	2.66	90
25 × 35	16	7	34	34	0.66	3.10	90
25 × 40	16	7	36	36	0.65	3.52	91
30 × 30	16	7	34	34	0.67	3.03	89
30 × 35	16	7	38	38	0.67	3.24	89
30 × 40	16	7	40	40	0.66	3.53	90
35 × 35	20	7	40	40	0.76	3.27	89
35 × 40	20	7	42	42	0.74	3.48	90
40 × 40	20	7	44	44	0.75	4.01	89
45 × 45	24	7	44	44	0.82	4.10	90
50 × 50	24	7	60	48	0.85	4.99	89

Stephan Northrop Structural Option

North Shore Equitable Building

Additional Information





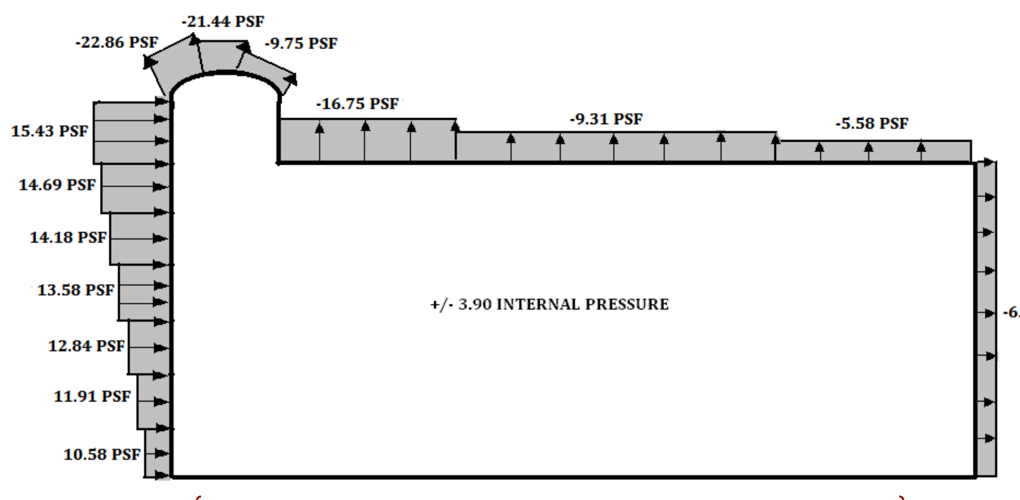
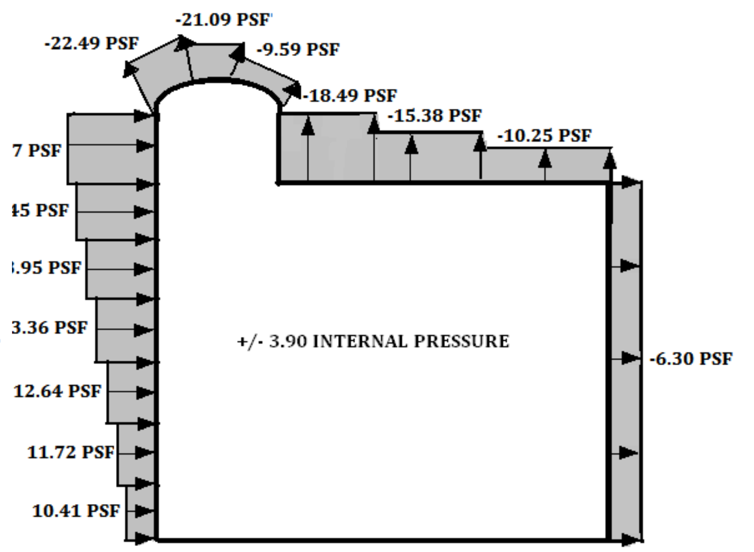


Figure 5-15: East/West Wind Pressure Elevation View



Bay Type:	1	
(// to joists) (x-axis)	40	ft
(perp to joists) (y-axis	44	ft
Bay type:	exterior	
Design Slab		
slab self weight =	56.25	psf
joist/slab area =	2.847	ft^2
joist/slab self weight =	85.4167	psf
girder self weight =	1020.83	lb/ft
Dead Load =	0.07625	k/ft^2
Live Load =	0.08	k/ft^2
w_u = 1.2DL + 1.6LL =	0.2195	k/ft^2
Min reinf = .0018A_g =	0.0972	in^2/ft width
Try #3 bars @ 12" spacing		
Bar Area =	0.11	in^2
Is $A_s > A_{min}$?	yes, ok	
l_n =	4.42	ft
Mu = $w_u l_n^2/10$ =	0.428	ft.k/ft width
a=$A_s f_y$/.85f'$_c$b =	0.162	in
øM$_n$ = ø$A_s F_y$(d-(a/2)) =	1.07371	ft/k
Is øM$_n$ > M$_u$?	YES, OK	
Required top reinf =	1.92	in^2
Try 2 #10 bottom bars	A_s (in^2) =	2.54
Is $A_s > A_{s\,req}$?	YES, OK	
bar diameter =	1.27	in
depth =	21.99	in
	67	
B_{eff} =	79	67
	117	
a=$A_s f_y$/.85f'$_c$b =	0.669	in
c = a/$β_1$ =	0.787	in
$ε_s$ =(d-c)/c =	0.0808	
Does Tension Control?	YES, OK	
øM$_n$ = ø$A_s F_y$(d-(a/2)) =	247.52	ft/k
Is øM$_n$ > M$_u$?	YES, OK	

Design Parameters		
slab thickness:	4.5	in
pan size:	53	in
pan depth:	20	in
rib width:	7	in
girder width:	40	in
Column size:	40	in
f'c =	4000	psi
Steel F_y =	60	ksi
conc weight =	150	pcf
SDL =	20	psf
LL =	80	psf
Design Pan Joists		
Dead Load =	0.527	k/ft
Live Load =	0.400	k/ft
w_u = 1.2DL + 1.6LL =	1.273	k/ft
l_n =	36.67	
M_{uA}^- (exterior) =	71.28	ft.k
M_{uB}^- (interior) =	171.08	ft.k
M_u^+ (midspan) =	122.20	ft.k
Design reinforcement		
depth =	22.25	in
Required top reinf =	1.37	in^2
Try 2 #9 top bars	A_s (in^2) =	2
Is $A_s > A_{s\,req}$?	YES, OK	
ρ = A_s/bd =	0.0128	
a=$A_s f_y$/.85f'$_c$b =	5.042	in
c = a/$β_1$ =	5.932	in
$ε_s$ =(d-c)/c =	0.0083	
Does Tension Control?	YES, OK	
øM$_n$ = ø$A_s F_y$(d-(a/2)) =	177.56	ft.k
Is øM$_n$ > M$_u$?	YES, OK	

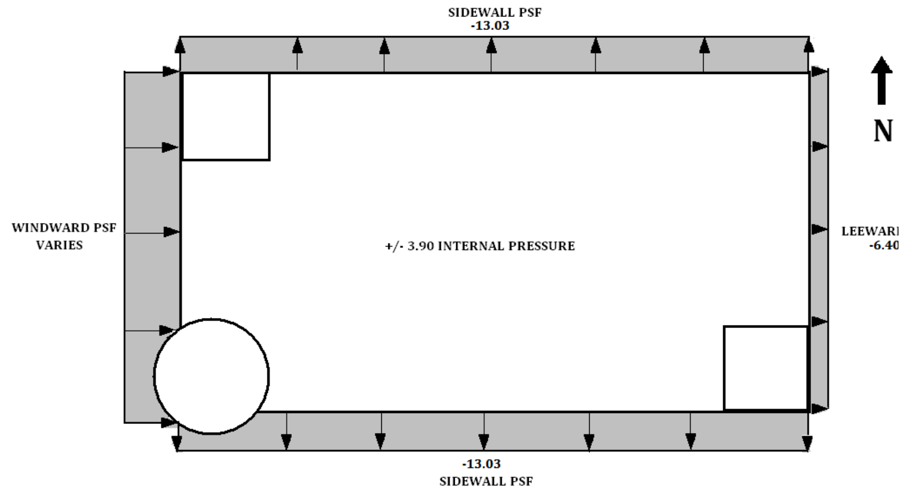
Bay Type 1		
Girder Type: 1		
Interior Span		
Wall Load =	0.9	k/ft
Dead Load =	3.74	k/ft
Live Load =	1.60	k/ft
w_u = 1.2DL + 1.6LL =	7.05	k/ft
M_{uA}^- (interior) =	1060.42	ft.k
M_{uB}^- (interior) =	1060.42	ft.k
M_u^+ (midspan) =	729.04	ft.k
depth =	22	in
Required top reinf =	12.05	in^2
Try 10 #10 top bars	A_s (in^2) =	12.7
Is $A_s > A_{s\,req}$?	YES, OK	
# of bars =	10	
d_b =	1.27	
a=$A_s f_y$/.85f'$_c$b =	5.60	
c = a/$β_1$ =	6.59	
Does Tension Control?	YES, OK	
$ε_t$ =	0.005	ø = 0.9
Recalculated depth =	21.865	in
øM$_n$ = ø$A_s F_y$(d-(a/2)) =	1089.48	ft.k
Is øM$_n$ > M$_u$?	YES, OK	
Check bar spacing	OKAY	
Required bot reinf =	8.28	in^2
Try 9 #9 bot bars	A_s (in^2) =	9
Is $A_s > A_{s\,req}$?	YES, OK	
# of bars =	9	
d_b =	1	
Check bar spacing	OKAY	
a=$A_s f_y$/.85f'$_c$b =	3.97	
c = a/$β_1$ =	4.67	
Does Tension Control?	YES, OK	
Recalculated depth =	22.125	in
øM$_n$ = ø$A_s F_y$(d-(a/2)) =	815.66	ft.k
Is øM$_n$ > M$_u$?	YES, OK	

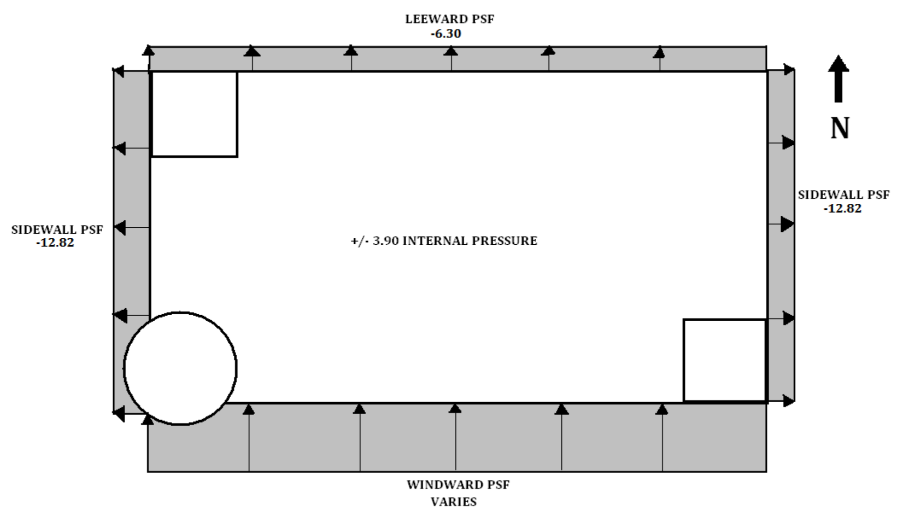
Stephan Northrop

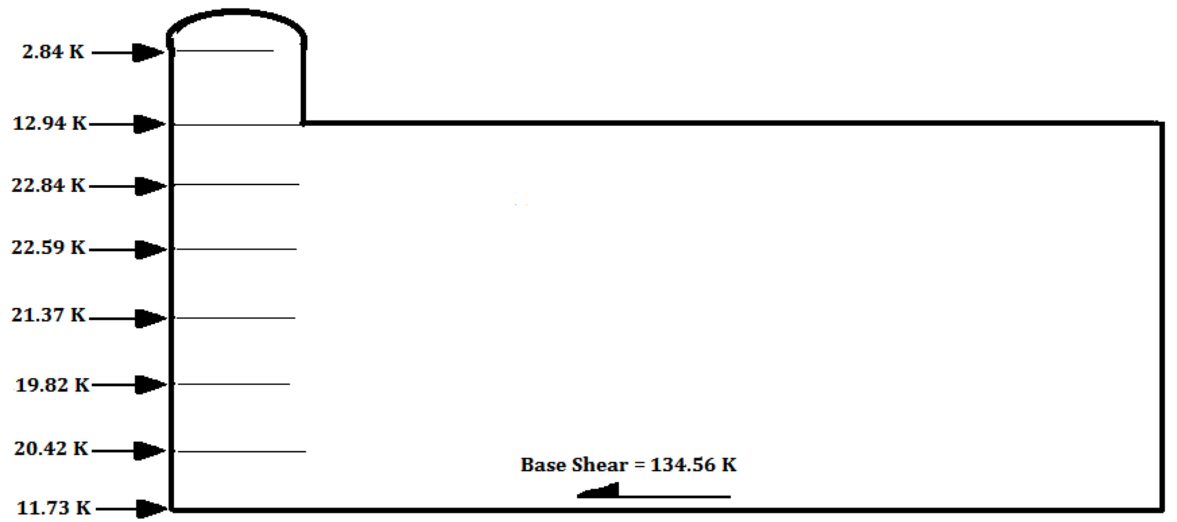
Structural Option

North Shore Equitable Building

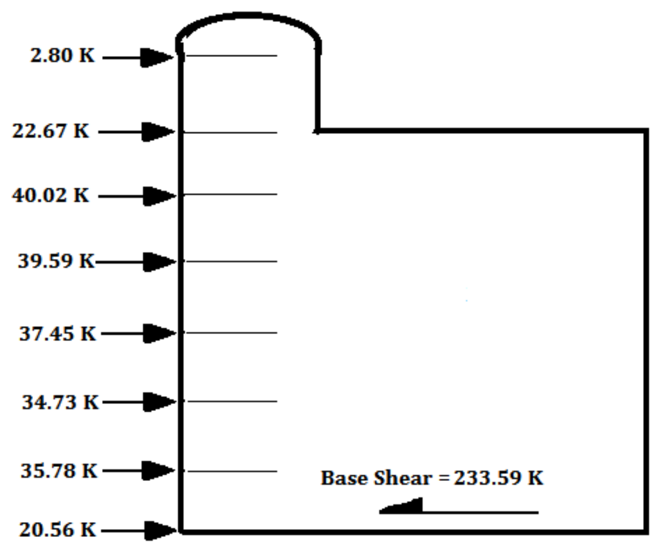
Additional Information







E/W wind story forces



N/S wind story forces

Story Wind Forces (North/South Direction)

Level	Height	Face	Elevatio	Pressure	Story	Story Shear
	(Ft.)	(Ft.)	(Ft.)	(psf)	(K)	(K)
Turret	8.13	22.67	103	15.17	2.80	2.80
Roof	6.88	228	81.75	14.45	22.67	25.47
Level 6	12.58	228	69.17	13.95	40.02	65.49
Level 5	13.00	228	56.17	13.36	39.59	105.08
Level 4	13.00	228	43.17	12.64	37.45	142.53
Level 3	13.00	228	30.17	11.72	34.73	177.26
Level 2	15.08	228	17.17	10.41	35.78	213.03
Level 1	8.58	228	0	10.51	20.56	233.59

Story Seismic Forces

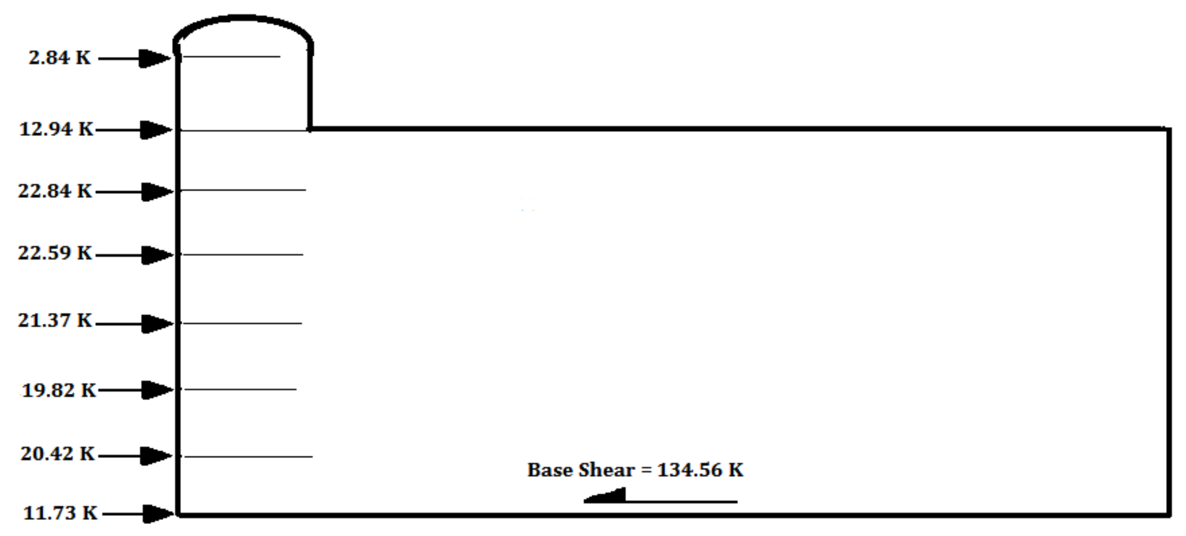
Level	Story Weight	Story Height			Story Force	Story Shear
	w_x (K)	h_x (Ft.)	$w_x h_x^k$	C_{vx}	F_x (K)	V_x (K)
Level 1	5162.89	0.00	0.00	0.00	0.00	672.92
Level 2	4821.02	17.17	177814.0	0.05	30.86	672.92
level 3	4821.02	30.17	363634.6	0.09	63.11	642.06
Level 4	4821.02	43.17	573040.0	0.15	99.45	578.95
Level 5	4821.02	56.17	800313.3	0.21	138.89	479.51
Level 6	4775.62	69.17	1032488.	0.27	179.18	340.61
Roof	3300.91	81.75	882228.0	0.23	153.11	161.43
Upper	142.54	98.01	47957.76	0.01	8.32	8.32

Stephan Northrop

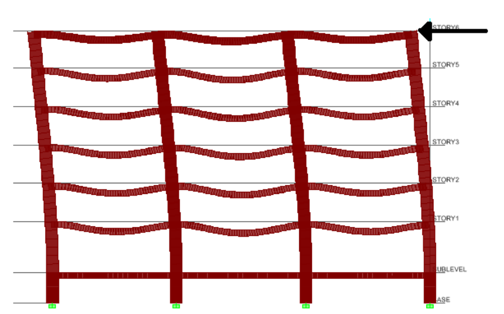
Structural Option

North Shore Equitable Building

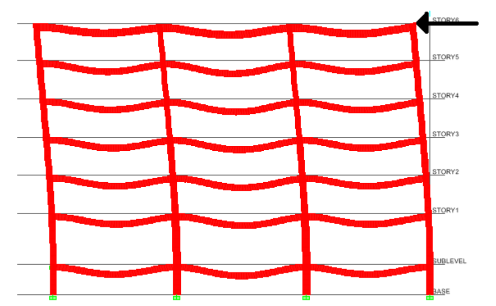
Additional Information



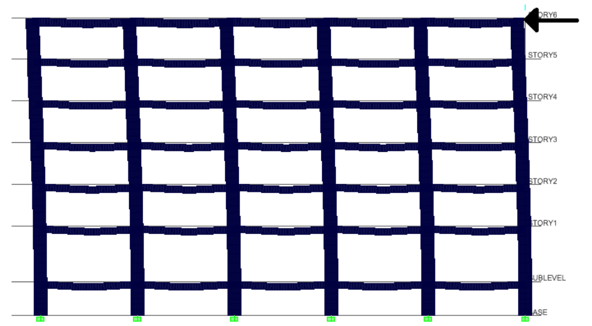
E/W Seismic story forces



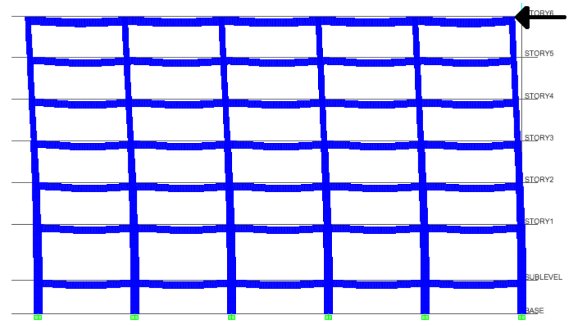
Frame Type 1 (N/S Exterior)



Frame Type 2 (N/S Interior)



Frame Type 3 (E/W Exterior)



Frame Type 4 (E/W Interior)