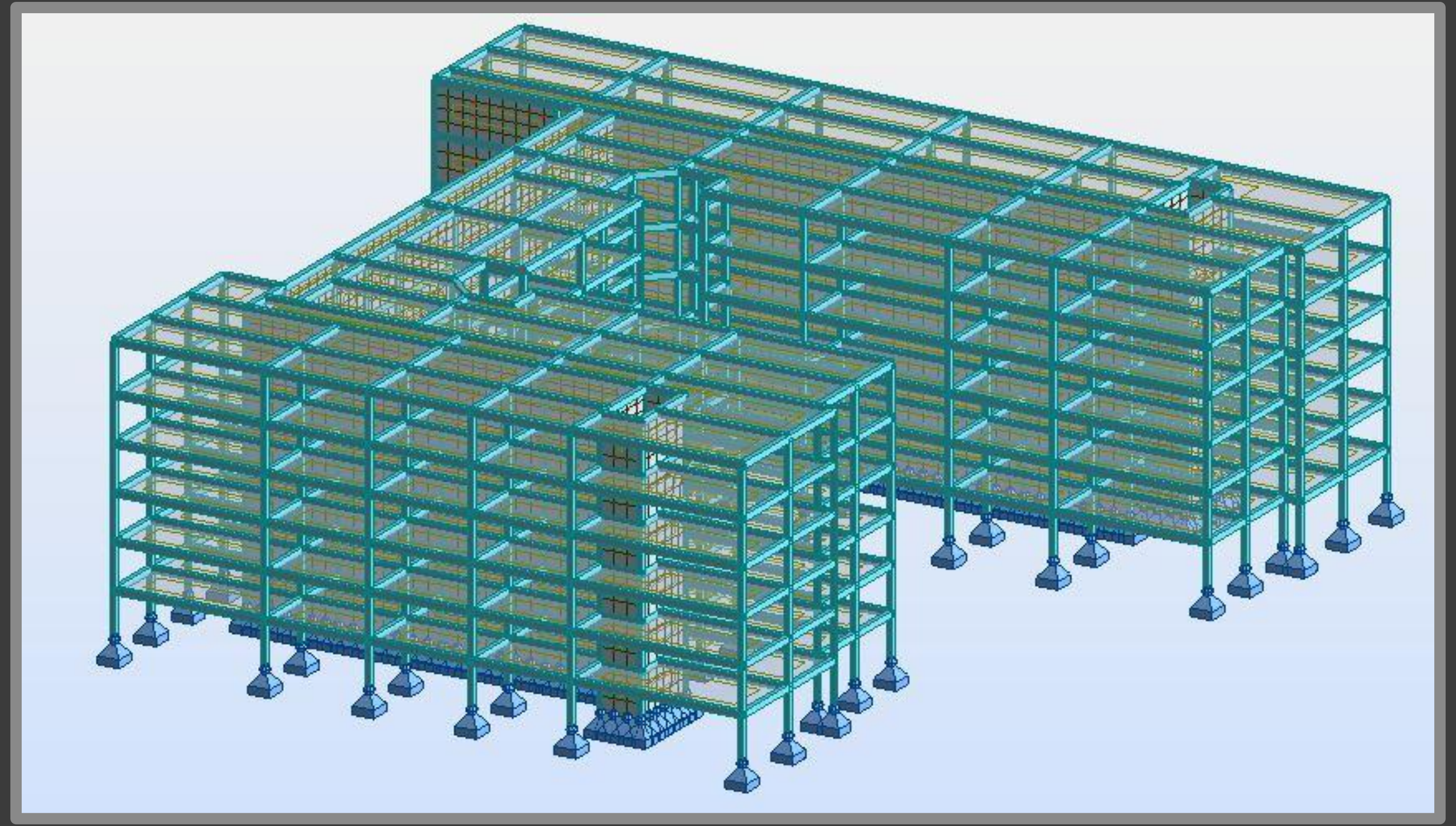


The Residences

Anne Arundel County , Maryland

Ryan English
Structural Option
AE 482 – Senior Thesis

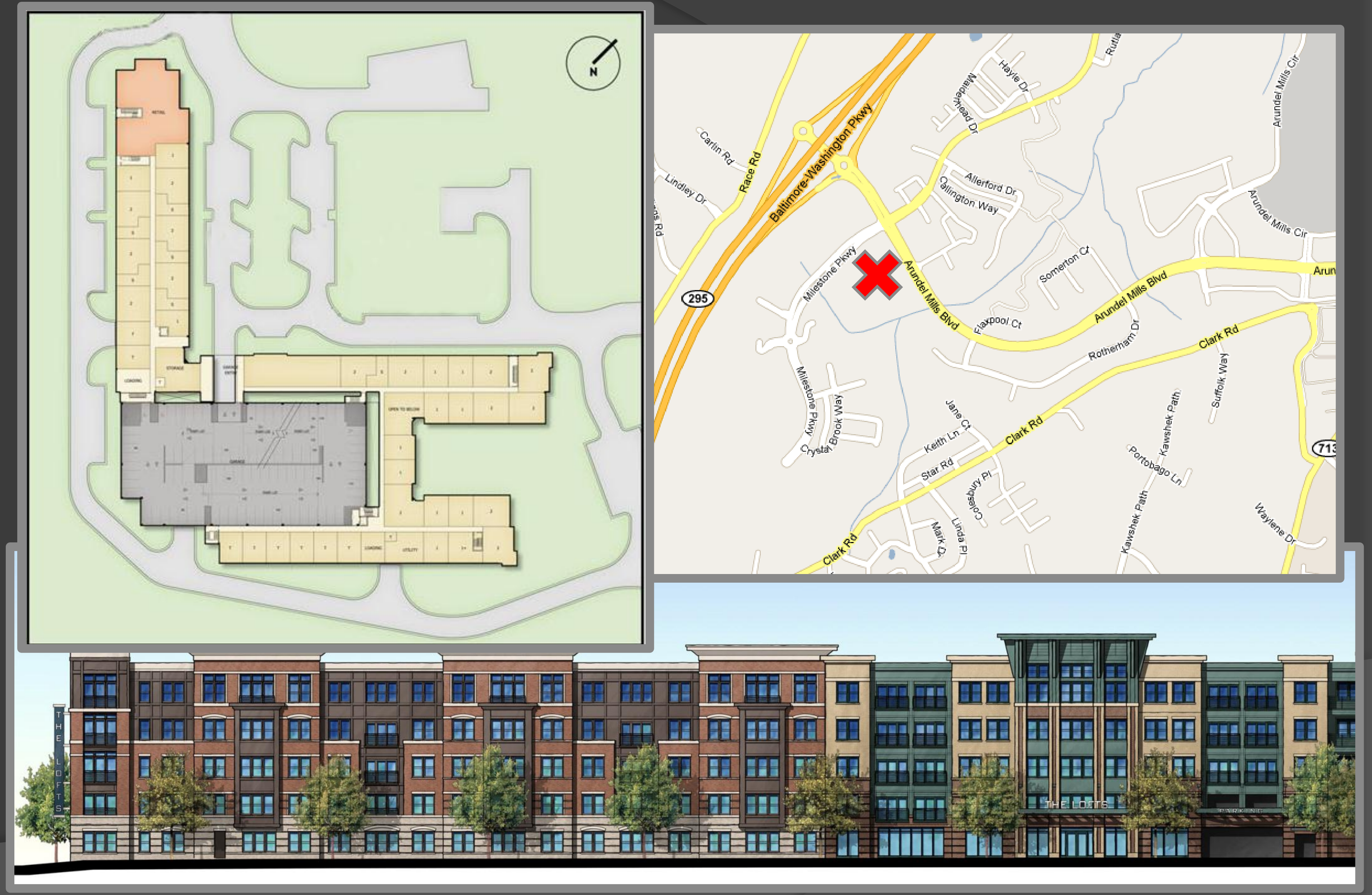
Dr. Richard Behr – Faculty Advisor

Introduction
- Building Statics
- Project Team
- Architectural
- Existing Structural

Proposal
Structural Redesign
Cost And Schedule Impact
Sustainability
Conclusion

Building Statics

- **Building name:** The Residences
- **Location:** Anne Arundel County, Maryland
- **Occupancy:** Mix use, Residential /Retail
- **Size:** 300,000 gross s.f.
- **Height:** 5-6 stories, 60 ft
- **Dates of construction:** September 2009- February 2011
- **Cost:** $39 Million
- **Project delivery method:** Design-bid-build

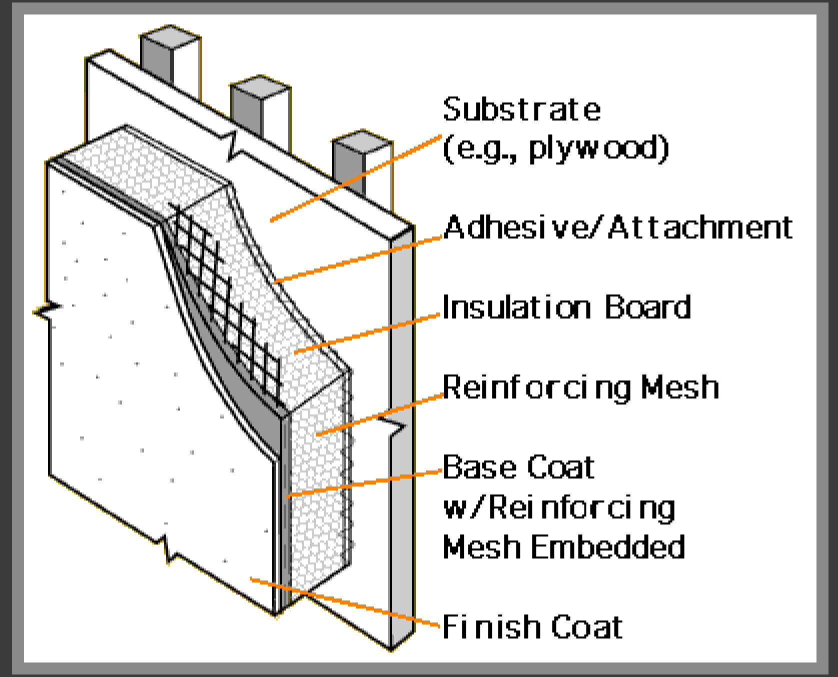


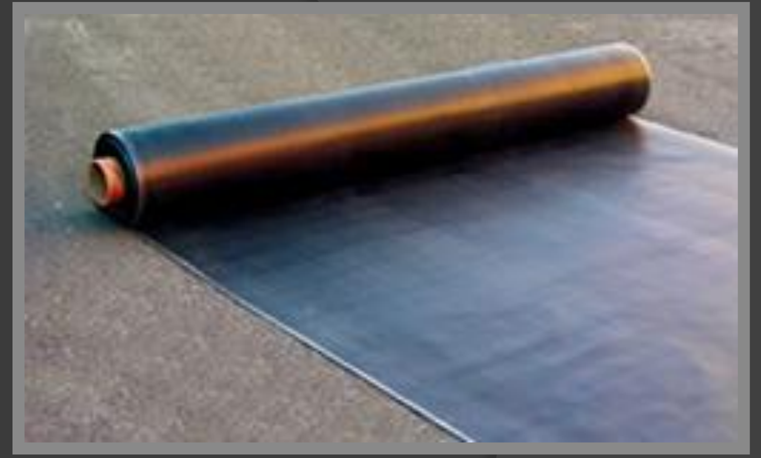
Project Team

- **Owner:** Summerset Construction
- **General Contractor/Developer:** Encore Developer
- **Architect:** CE*X, Inc
- **Structural Engineer:** Cates Engraining, Ltd.
- **Civil Engineer:** Morris & Ritchie Associates, Inc.
- **MEP Engineer:** Siegel, Rutherford, Bradstock & Ridgway, Inc.
- **Geotechnical:** Geo-Technology Associates, Inc
- **Landscape Architect:** The Faux Group, Inc

Architectural

- The building is part of the Arundel Preserve Town Center Phase I project
- 242 upscale residential units
- clubhouse, health center, and an outside pool
- Facade: brick veneer and Exterior Insulation Finishing System (EIFS)
- Roofing: single-ply EPDM (ethylene propylene diene Monomer) membrane covering 2" rigid insulation
- No predominate sustainability feature

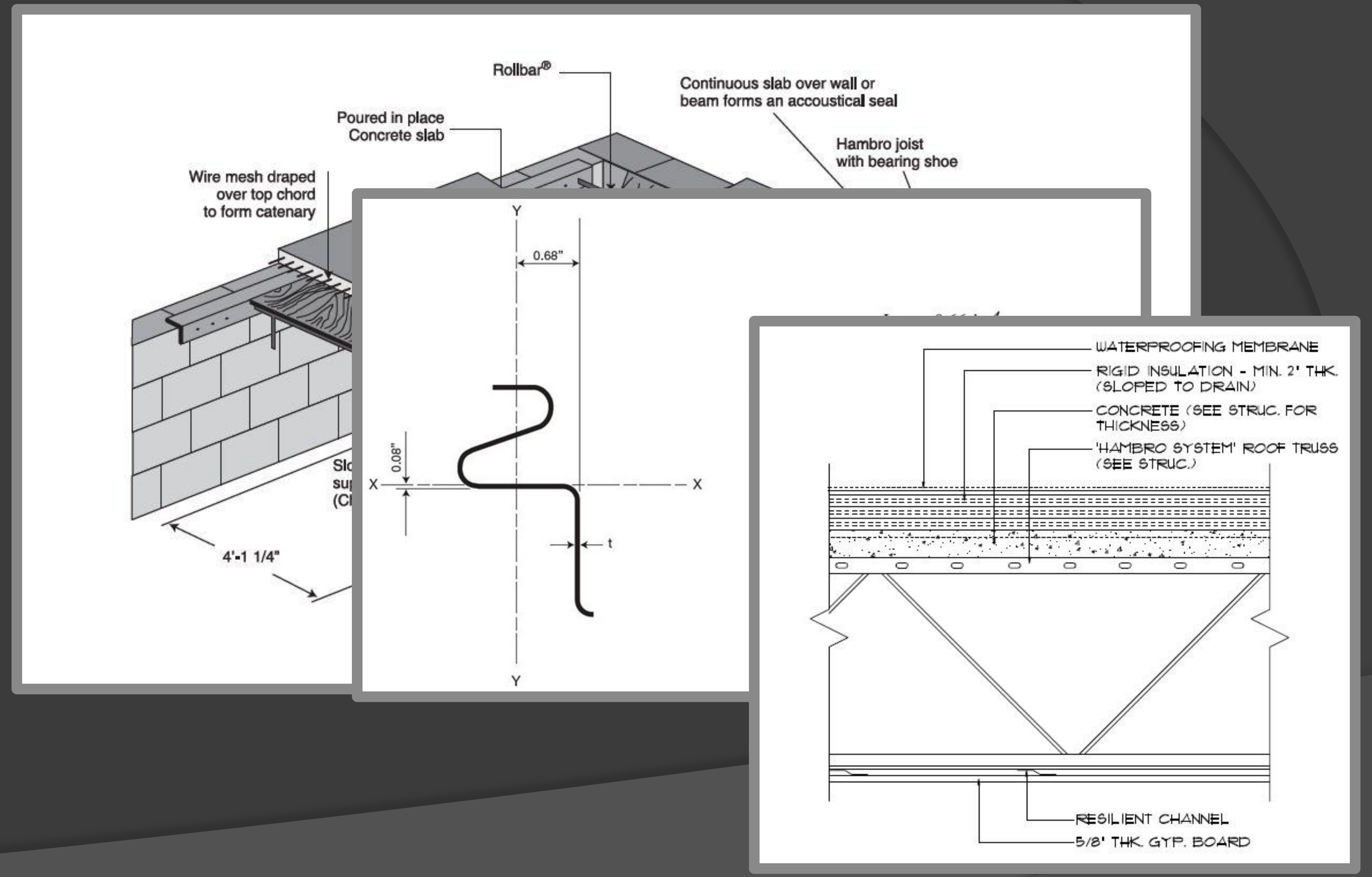




Floor System

- the Hambro floor joist flooring system.
- “s” shape top compression cord
  - compression member
  - chair for the welded wire fabric
  - continuous shear connection
- 3” thick 3,000psi slab
- 20” deep Hambro bar joist

Existing Structural



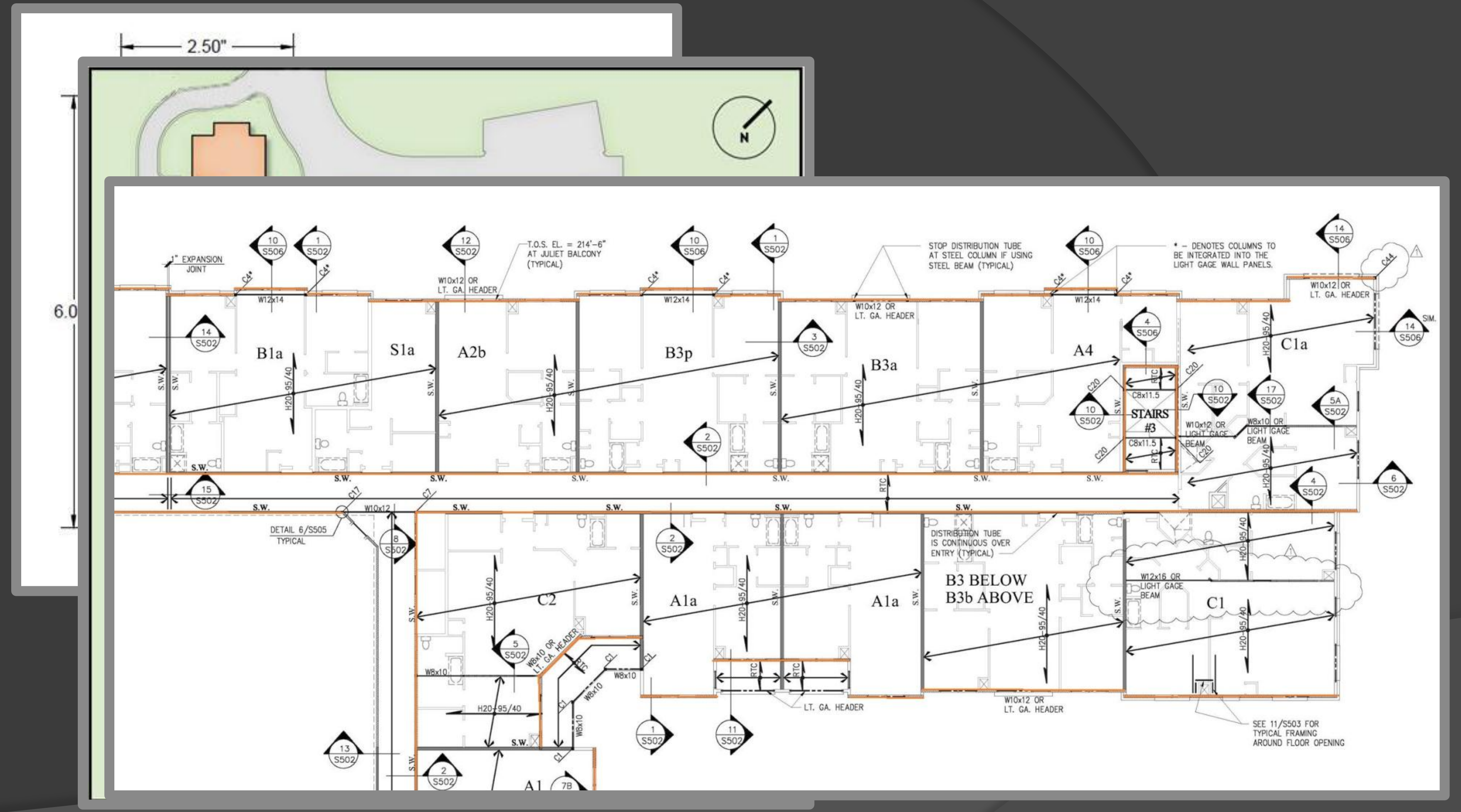
Introduction
- Building Statics
- Project Team
- Architectural
- Existing Structural

Proposal
Structural Redesign
Cost And Schedule Impact
Sustainability
Conclusion

Gravity System

- Light gage steel load bearing walls
- SigmaStud® - Steel Network Company
- Engineered Stud to have a significant increase in load capacity.
- 6” wide 18 gage stud

Existing Structural

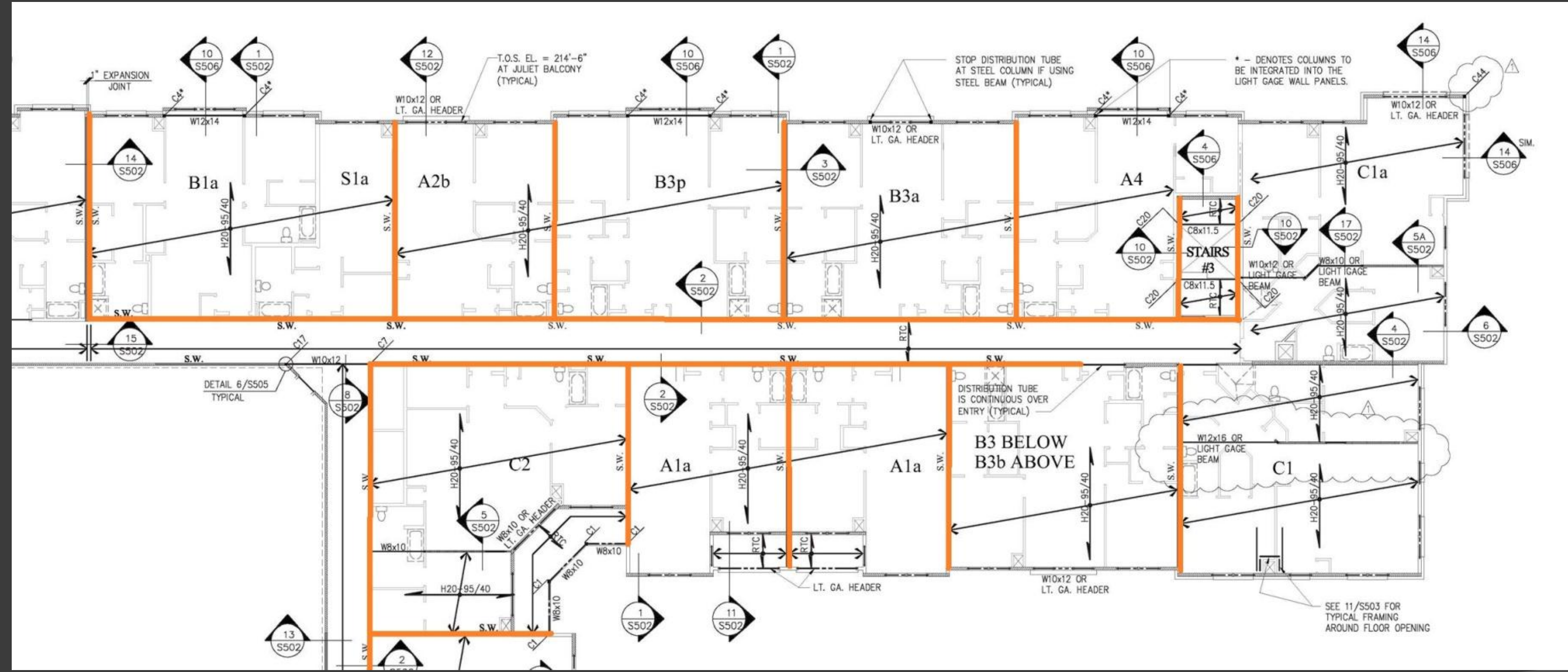


Introduction
- Building Statics
- Project Team
- Architectural
- Existing Structural

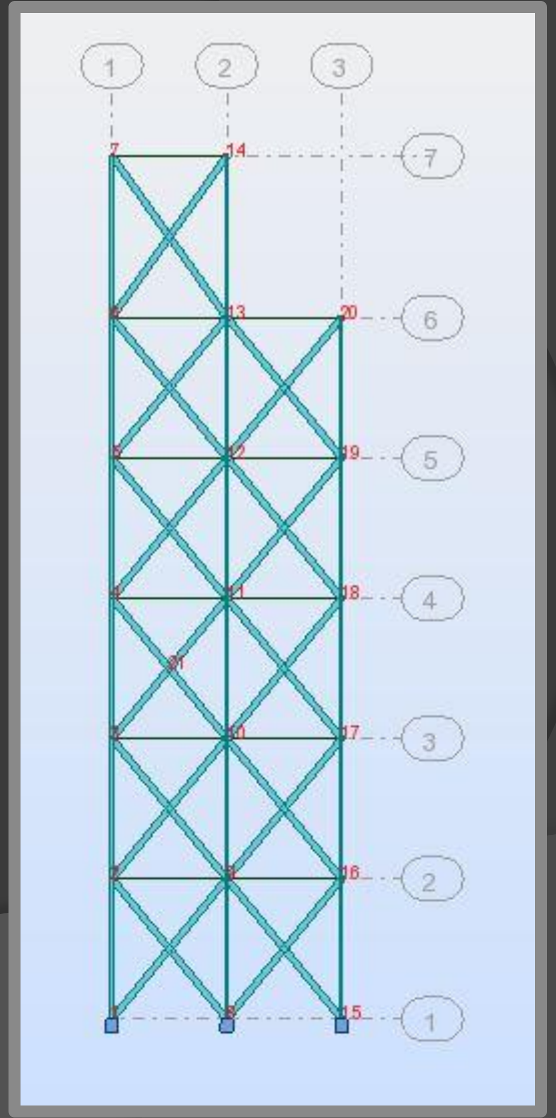
Proposal
Structural Redesign
Cost And Schedule Impact
Sustainability
Conclusion

Lateral System

- light gage shear wall system
- Steel Network Company.
- 50 ksi 6” steel straps on both sides of the wall



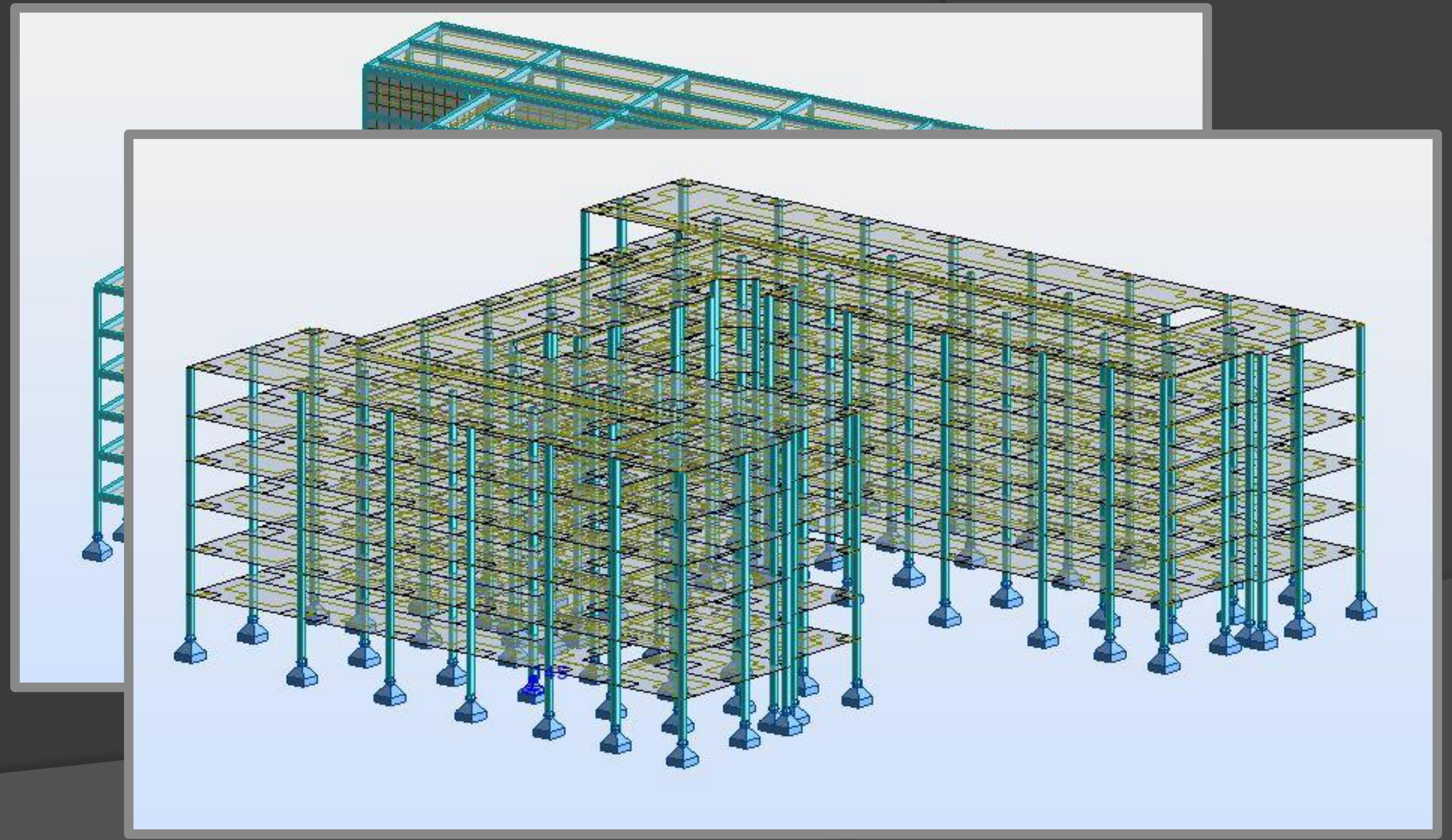
Existing Structural



Proposal

- Redesign supper structural
  - One Way Concrete Slab system
  - Two Way Concrete Slab System
- Redesign Lateral system
  - Current Location
  - High seismic location
  - Concrete Shear Walls
  - Added mass on roof
- 3D Modeling
  - Autodesk Robot Structural Analysis

Structural Depth



Introduction
Proposal
Structural Redesign
Cost And Schedule Impact
Sustainability
Conclusion

Cost and Schedule Breadth

- Cost comparison between the One Way Concrete Slab and Two Way Concrete Slab, and Original Design
- Schedule Comparison between the One Way Concrete Slab, Two Way Concrete Slab, and Original Design

Sustainability Breadth

- Green Roof layer study and design
- Rain water retention
- Load impact on gravity and lateral system.

Introduction
Proposal
Structural Redesign
- Design Goals
- One Way Concrete Slab
- Two Way Concrete Slab
- Seismic Design

Cost And Schedule Impact
Sustainability
Conclusion

Design Goals

- Compare the design of a One Way Concrete Slab and Two Way Concrete Slab
- Investigate the effects of having an increase of mass on the roof lever in high seismic region
- Not reduce the floor to ceiling height
- Minimizes architectural impact
- Use computer programs to aid in the design and analysis of the structural
- Evaluate the validity and ease of use of *Autodesk Robot Structural Analysis* program

Structural Redesign

One Way Concrete Slab

- Design Process
  - Preliminary design- f'c= 4000 psi
  - Determine slab thickness - L_n =15' , t = 5"
  - Determine beam height - L_n =30', t=19"
  - Preliminary Column size – 14" x 14"
  - 3D Model analysis
  - Determine slab reinforcing
  - Determine beam reinforcing
  - Determine Column size and reinforcing

Structural Redesign

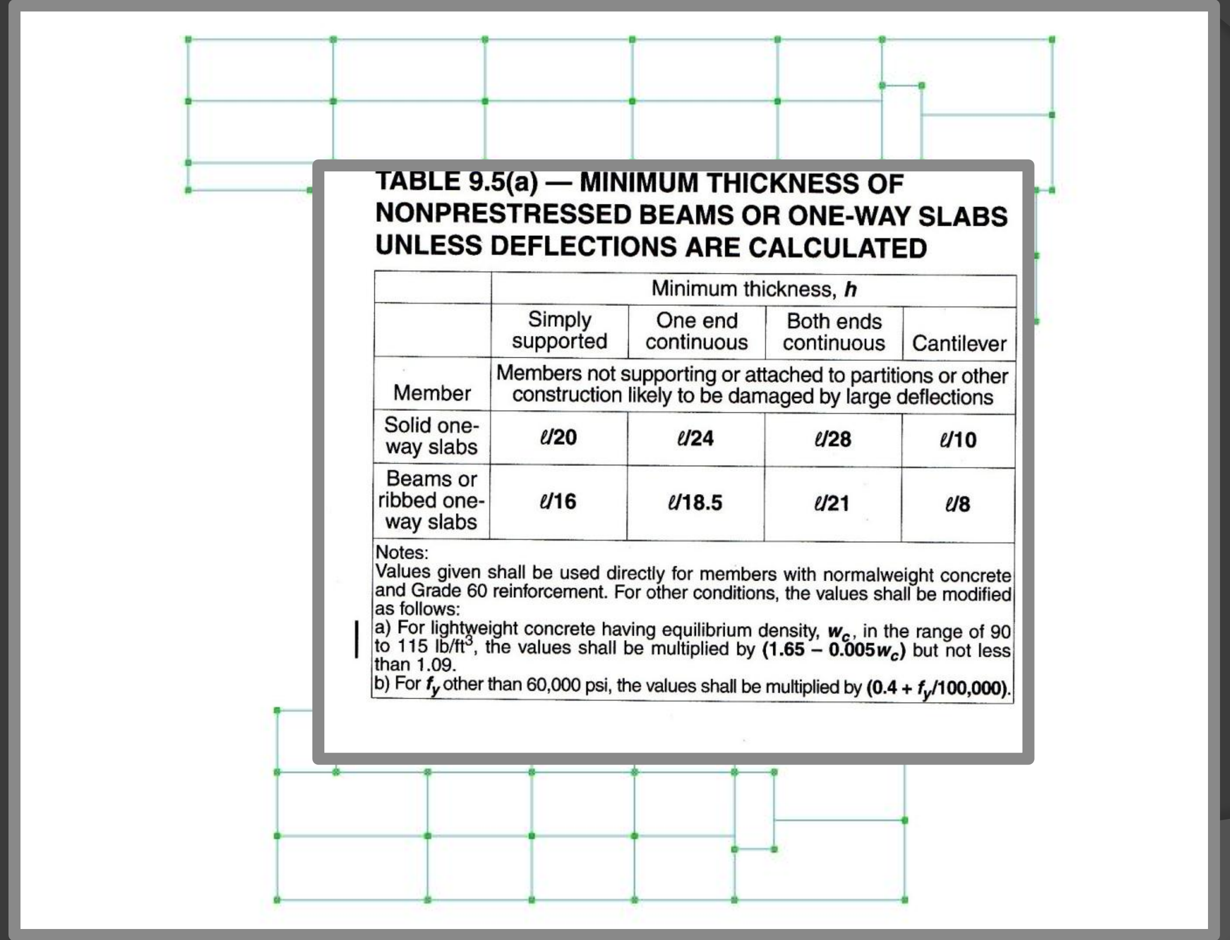


TABLE 9.5(a) — MINIMUM THICKNESS OF NONPRESTRESSED BEAMS OR ONE-WAY SLABS UNLESS DEFLECTIONS ARE CALCULATED

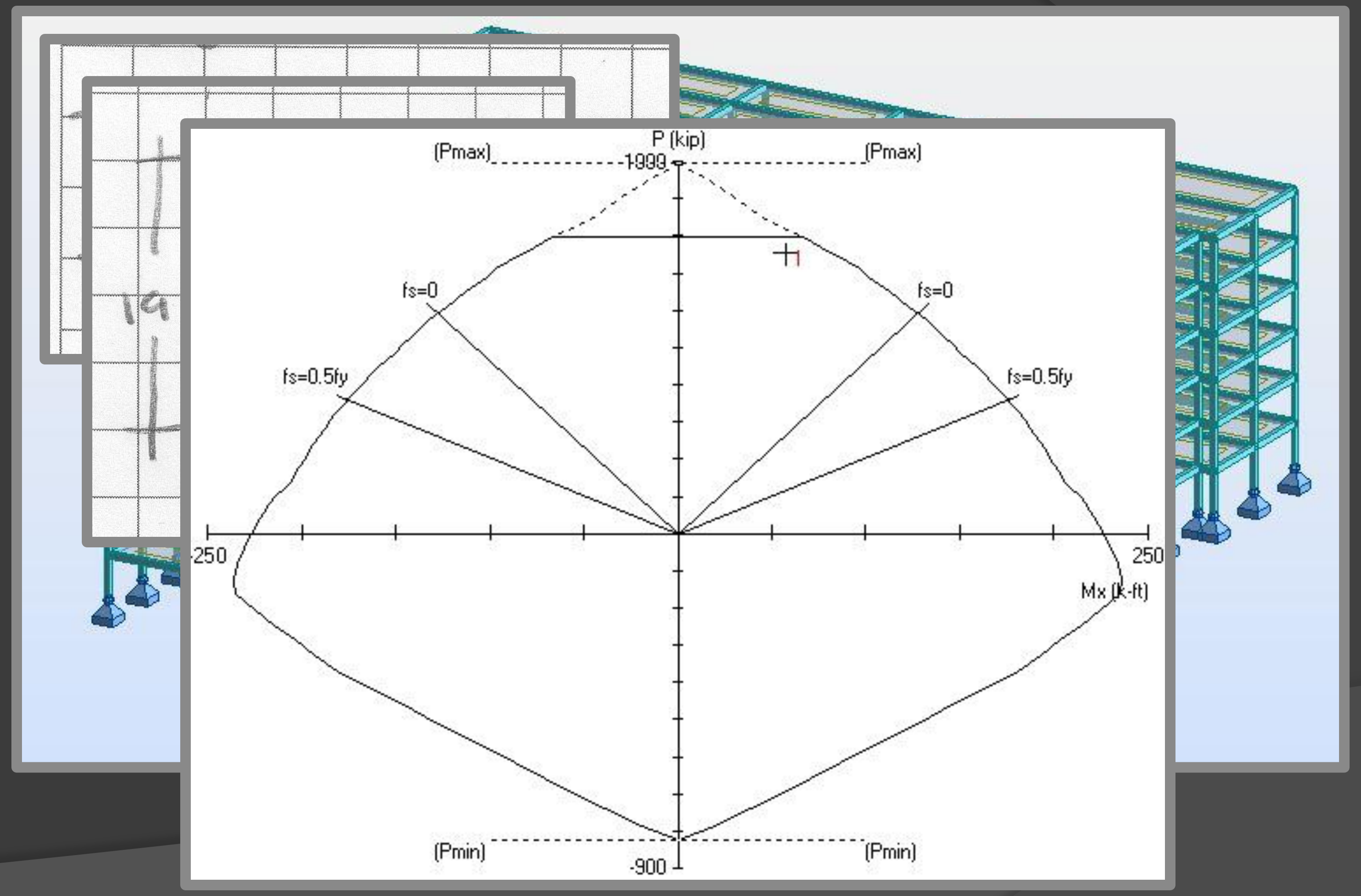
	Minimum thickness, *h*			
	Simply supported	One end continuous	Both ends continuous	Cantilever
Member	Members not supporting or attached to partitions or other construction likely to be damaged by large deflections			
Solid one-way slabs	$\ell/20$	$\ell/24$	$\ell/28$	$\ell/10$
Beams or ribbed one-way slabs	$\ell/16$	$\ell/18.5$	$\ell/21$	$\ell/8$

Notes:
Values given shall be used directly for members with normalweight concrete and Grade 60 reinforcement. For other conditions, the values shall be modified as follows:
a) For lightweight concrete having equilibrium density, w_c, in the range of 90 to 115 lb/ft^3, the values shall be multiplied by $(1.65 - 0.005w_c)$ but not less than 1.09.
b) For f_y other than 60,000 psi, the values shall be multiplied by $(0.4 + f_y/100,000)$.

One Way Concrete Slab

- Slab Reinforcing- $A_{s,req}$ =Mu/4d, 2 #5 per ft.
- Beam Reinforcing – Trial and error, As= 5#10, As’= 2#10
- Column Reinforcing- Interaction Diagrams
    - 3 different section - 14”x14”
    - 1st - 2nd stories: 12#10
    - 3rd – 4th stories: 8#10
    - 5th – 6th stories: 4#10

Structural Redesign



Introduction
Proposal
Structural Redesign
- Design Goals
- One Way Concrete Slab
- Two Way Concrete Slab
- Seismic Design

Cost And Schedule Impact
Sustainability
Conclusion

Two Way Concrete Slab

- Design Process
  - Preliminary design - f’c= 4000 psi
  - Determine slab thickness - L_n =29’ , t = 10”
  - Preliminary Column size 16”x16”
  - 3D Model analysis
  - Determine slab reinforcing
  - Determine Column size and reinforcing
  - Check shear in slab

Structural Redesign

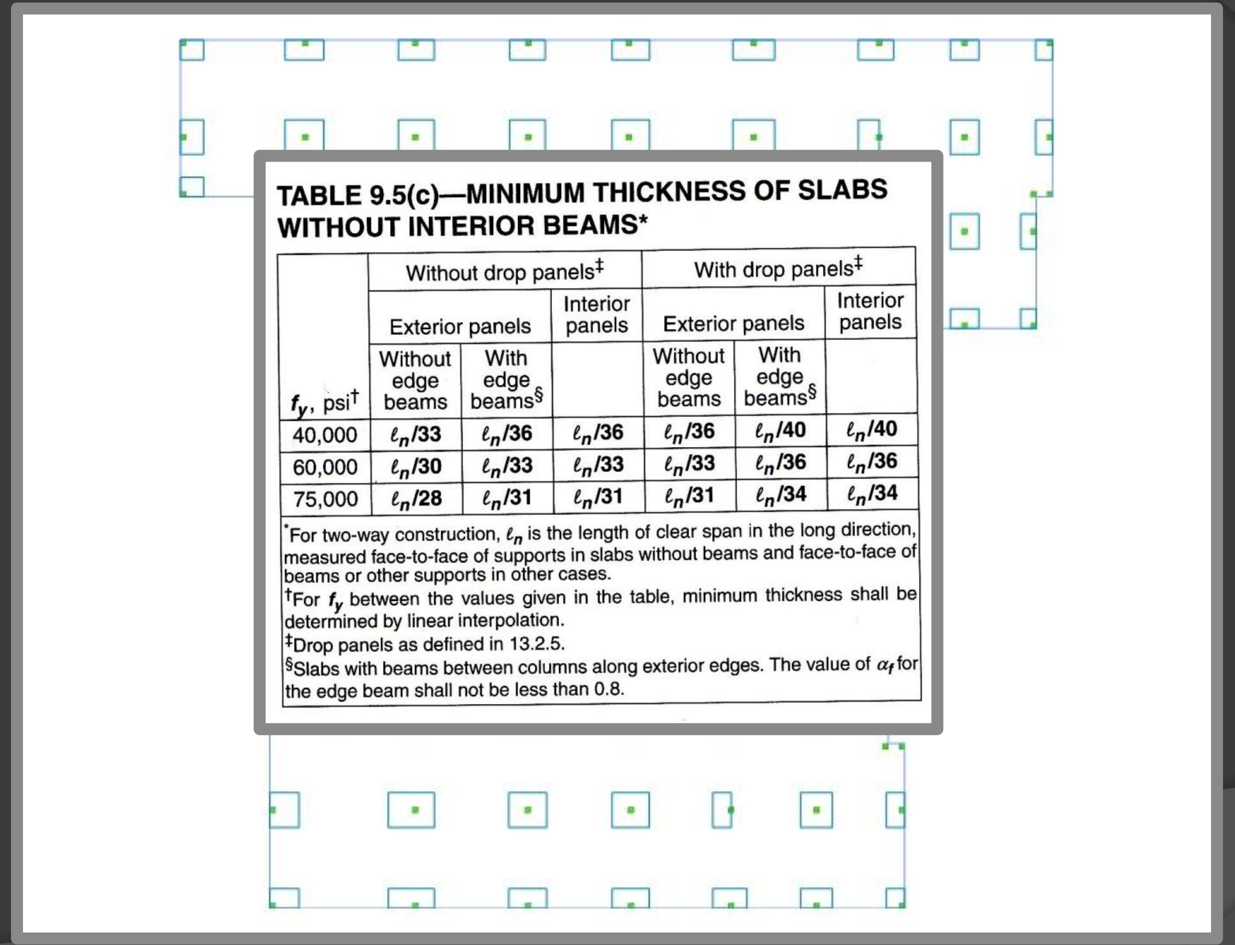


TABLE 9.5(c)—MINIMUM THICKNESS OF SLABS WITHOUT INTERIOR BEAMS*

f_y, psi†	Without drop panels‡			With drop panels‡		
	Exterior panels		Interior panels	Exterior panels		Interior panels
	Without edge beams	With edge beams§		Without edge beams	With edge beams§	
40,000	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$	$\ell_n/36$	$\ell_n/40$	$\ell_n/40$
60,000	$\ell_n/30$	$\ell_n/33$	$\ell_n/33$	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$
75,000	$\ell_n/28$	$\ell_n/31$	$\ell_n/31$	$\ell_n/31$	$\ell_n/34$	$\ell_n/34$

*For two-way construction, ℓ_n is the length of clear span in the long direction, measured face-to-face of supports in slabs without beams and face-to-face of beams or other supports in other cases.

†For f_y between the values given in the table, minimum thickness shall be determined by linear interpolation.

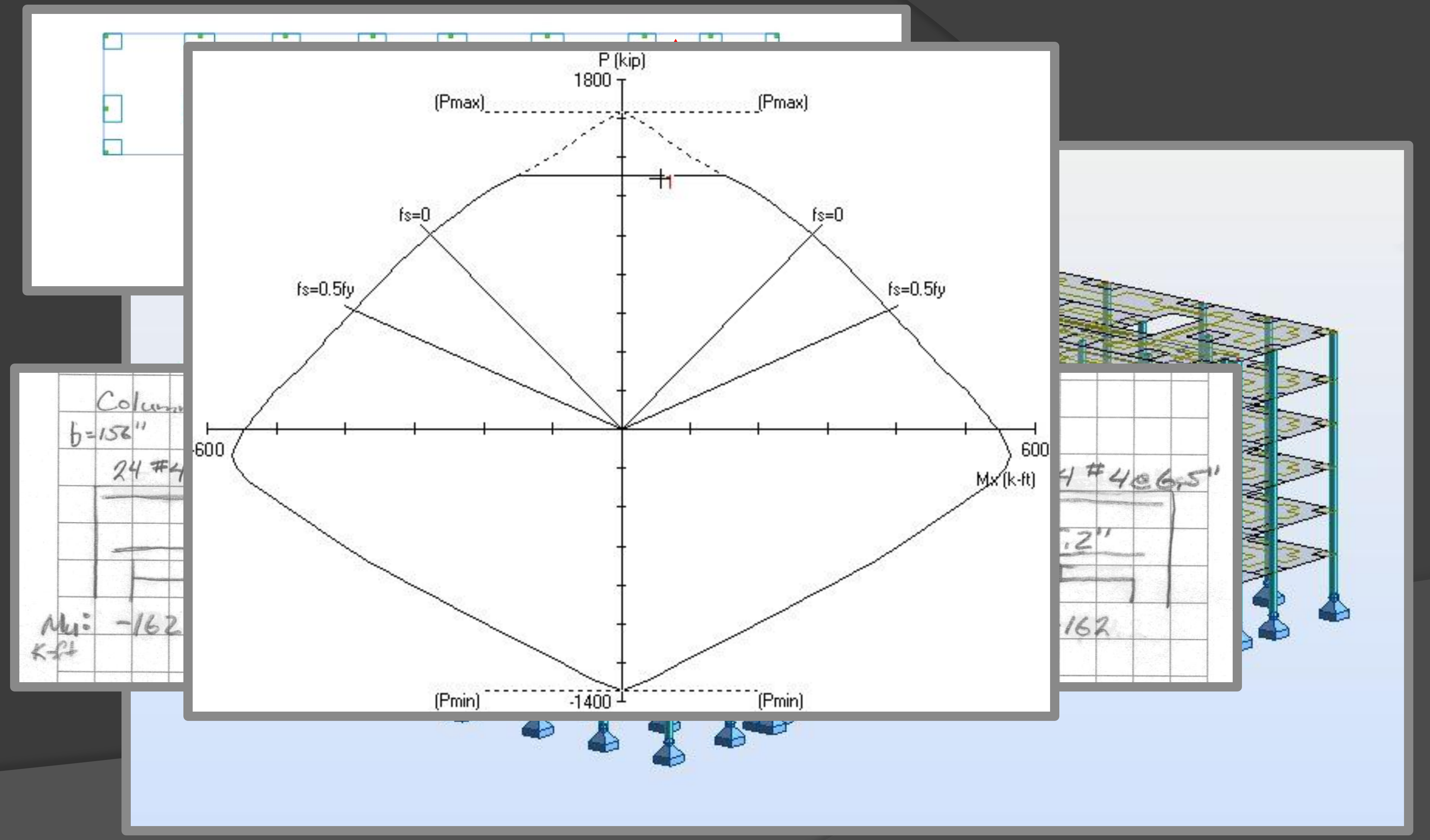
‡Drop panels as defined in 13.2.5.

§Slabs with beams between columns along exterior edges. The value of α_f for the edge beam shall not be less than 0.8.

Two Way Concrete Slab

- Slab Reinforcing- Direct Design Method, $A_{s,req}$ =Mu/4d
- Column Reinforcing- Interaction Diagrams
  - 3 different section
  - 1st - 2nd stories: 16#11 18"x18"
  - 3rd – 4th stories: 12#10 16"x16"
  - 5th – 6th stories: 8#8 16"x16"
- Slab Shear
  - One Way shear– ok
  - Punching shear with out drop panel- Does not work
  - Drop Panel- t = 15.25

Structural Redesign



Introduction
Proposal
Structural Redesign
- Design Goals
- One Way Concrete Slab
- Two Way Concrete Slab
- Seismic Design

Cost And Schedule Impact
Sustainability
Conclusion

Lateral Design

- Two seismic regions
  - Current location (Low Seismic Region)
  - Southern California (High Seismic Region)
- Seismic Design Category
  - Current location SDC: B
  - High Seismic Region SDC: D
- Lateral System
  - Low Seismic Region- Ordinary Reinforced Concrete shear wall: R – 5, C_d – 4.5
  - High Seismic Region – Special Reinforced Concrete shear wall: R – 6, C_d – 5

Lateral Forces

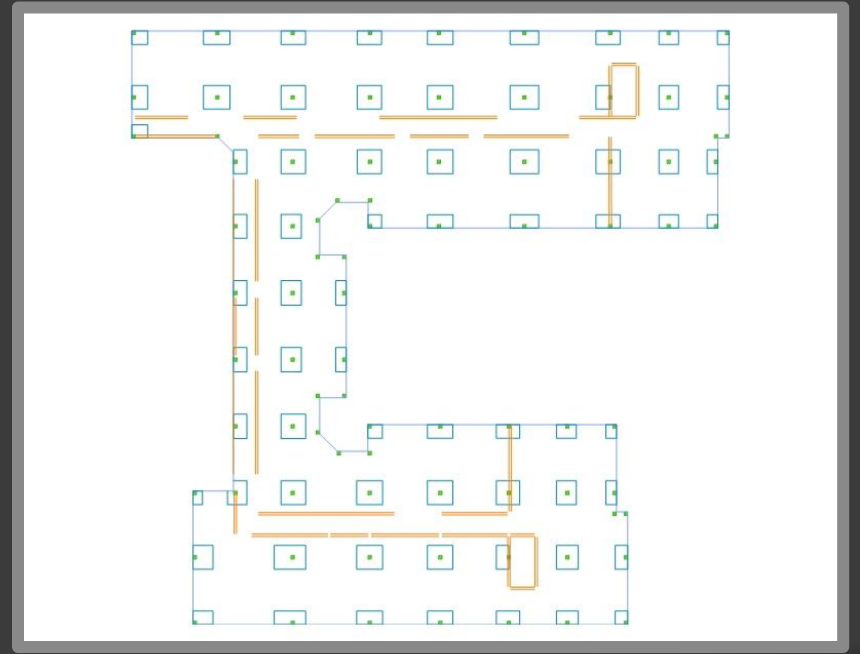
- Equivalent Lateral Force and Modal Response Spectrum Analysis
  - Low Seismic Region Base Shear
    - One Way Slab: 819 kip
    - Two Way Slab: 1,218 kip
  - High Seismic Region Base Shear
    - One Way Slab: 3,315 kip
    - Two Way Slab: 4,931 kip

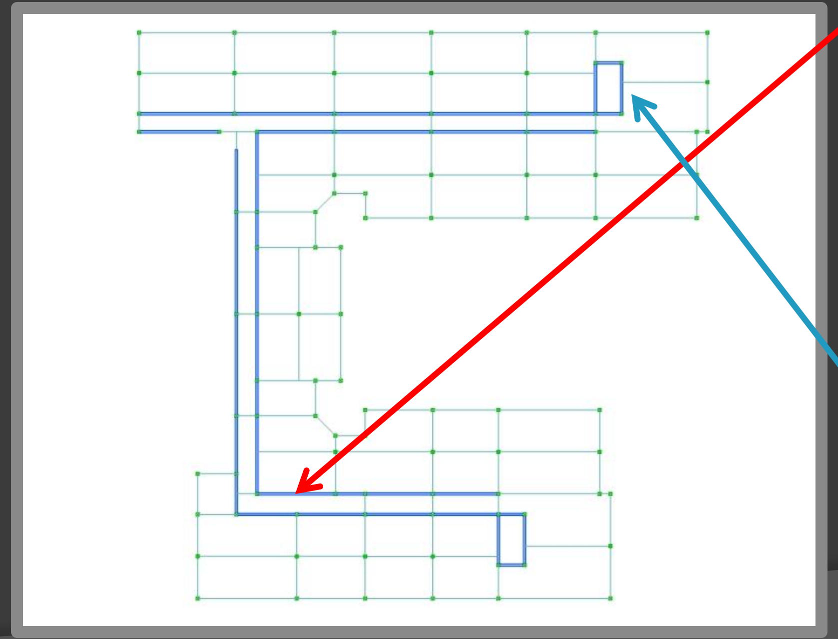
Introduction
Proposal
Structural Redesign
- Design Goals
- One Way Concrete Slab
- Two Way Concrete Slab
- Seismic Design

Cost And Schedule Impact
Sustainability
Conclusion

Lateral Design

- Preliminary shear wall location
- Base Shear Force distribution
- Shear Wall Design





Shear Wall Design

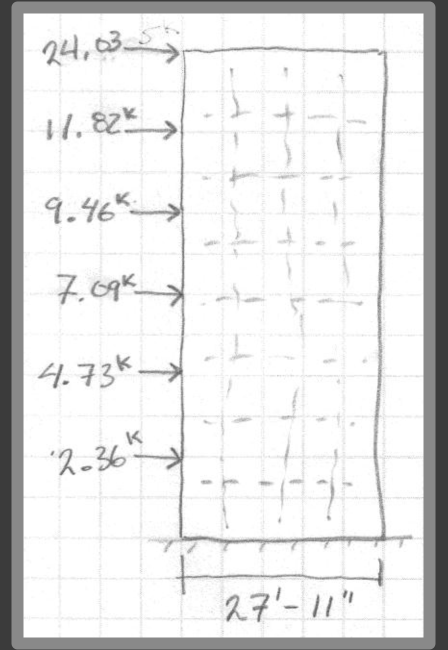
Story Force per frame per Diaphragm (kip)

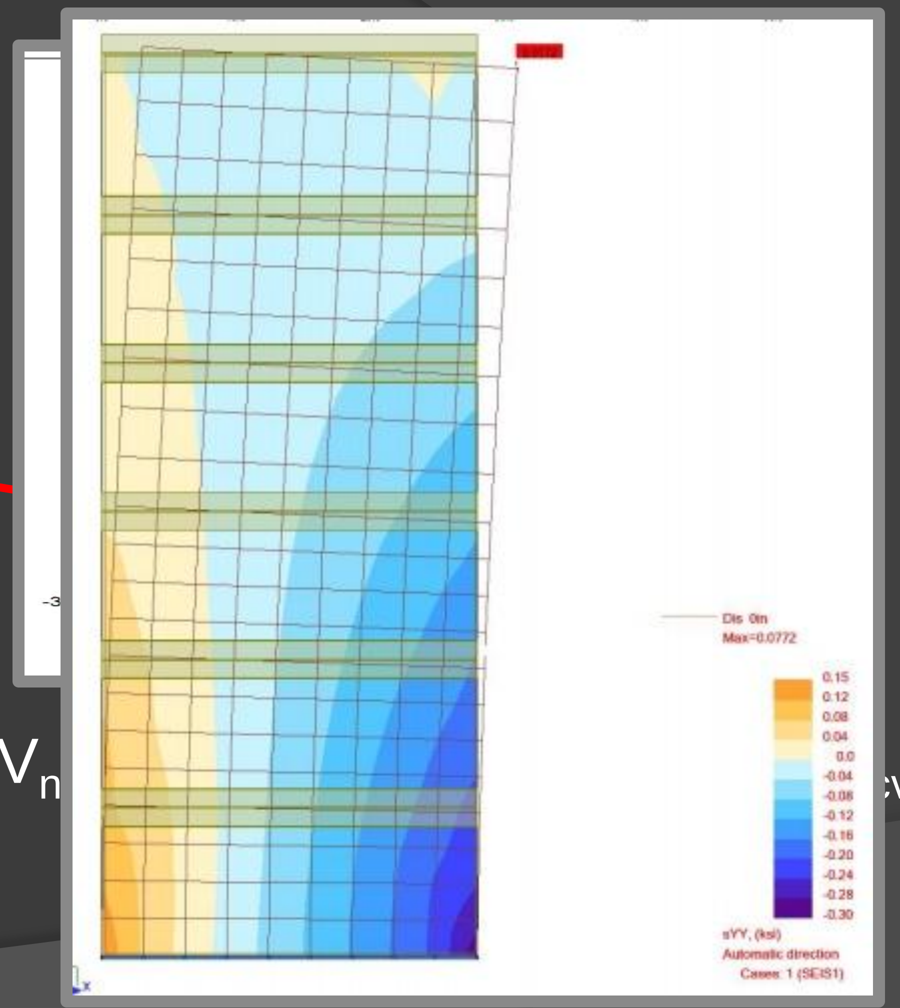
	Diaphragm 1	Diaphragm 2	Diaphragm 3	Diaphragm 4	Diaphragm 5	Diaphragm 6
Shear walls in X Direction						
SW_X_1	0.53	1.06	1.59	2.13	2.66	5.40
SW_X_2	2.13	4.27	6.40	8.53	10.66	21.67
SW_X_3	2.23	4.47	6.71	8.95	11.18	22.73
SW_X_4	2.18	4.37	6.55	8.74	10.92	22.20
SW_X_5	2.13	4.27	6.40	8.53	10.66	21.67
SW_X_6	1.52	3.04	4.56	6.08	7.59	15.44
SW_X_7	0.53	1.06	1.59	2.12	2.65	5.39
SW_X_8	1.78	3.57	5.35	7.13	8.91	18.12
SW_X_9	1.71	3.43	5.14	6.86	8.58	17.43
SW_X_10	2.18	4.37	6.55	8.74	10.92	22.19
SW_X_11	2.13	4.26	6.39	8.53	10.66	21.66
SW_X_12	1.52	3.04	4.55	6.07	7.59	15.43
SW_X_13	2.36	4.73	7.09	9.46	11.82	24.03
SW_X_14	0.85	1.69	2.54	3.39	4.23	8.61
SW_X_15	2.02	4.05	6.08	8.10	10.13	20.59
SW_X_16	1.96	3.93	5.88	7.85	9.81	19.94
SW_X_17	1.83	3.67	5.51	7.34	9.18	18.66
SW_X_18	2.09	4.19	6.29	8.39	10.48	21.30
SW_X_19	2.07	4.15	6.22	8.30	10.37	21.08
SW_X_20	2.01	4.02	6.03	8.04	10.05	20.42
SW_X_21	0.74	1.47	2.21	2.95	3.69	7.49
SW_X_22	0.78	1.56	2.34	3.12	3.90	7.92
Shear Walls in Y Direction						
SW_Y_1	1.78	3.56	5.34	7.12	8.89	18.08
SW_Y_2	2.90	5.80	8.69	11.60	14.49	29.46
SW_Y_3	2.90	5.80	8.69	11.60	14.49	29.46
SW_Y_4	1.61	3.22	4.82	6.43	8.04	16.34
SW_Y_5	1.10	2.20	3.30	4.40	5.50	11.18
SW_Y_6	2.46	4.92	7.38	9.85	12.30	25.01
SW_Y_7	1.01	2.03	3.04	4.05	5.06	10.29
SW_Y_8	1.99	3.98	5.97	7.96	9.95	20.22
SW_Y_9	1.99	3.98	5.97	7.96	9.95	20.22
SW_Y_10	1.00	2.00	2.99	3.99	4.99	10.15
SW_Y_11	2.34	4.68	7.02	9.37	11.71	23.79
SW_Y_12	3.26	6.53	9.79	13.07	16.33	33.19
SW_Y_13	3.48	6.97	10.44	13.93	17.41	35.38
SW_Y_14	4.06	8.13	12.19	16.26	20.32	41.30
SW_Y_15	4.27	8.56	12.84	17.13	21.40	43.50

Lateral Design

- Ordinary Reinforced Concrete shear wall f'c =4000psi t=10"
  - Determine Required Load (V_u, M_u, P_u)
    - 1.2D +1.0E
    - 0.9D +1.0E
  - Determine Shear Wall reinforcing
    - ACI 318-08 – Chapter 14 Walls
  - Shear Wall - Interaction Diagrams
  - Computer Model

Shear Wall Design



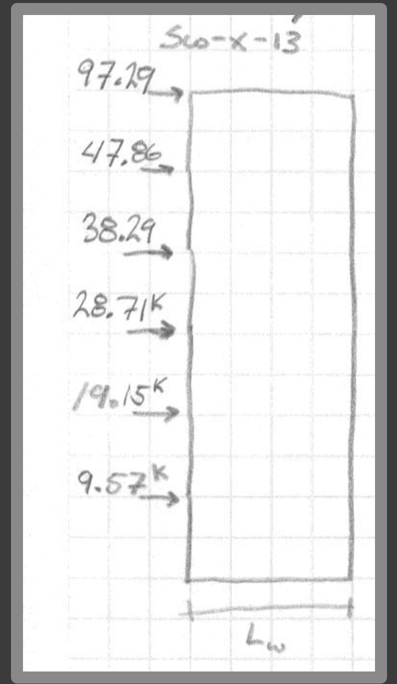


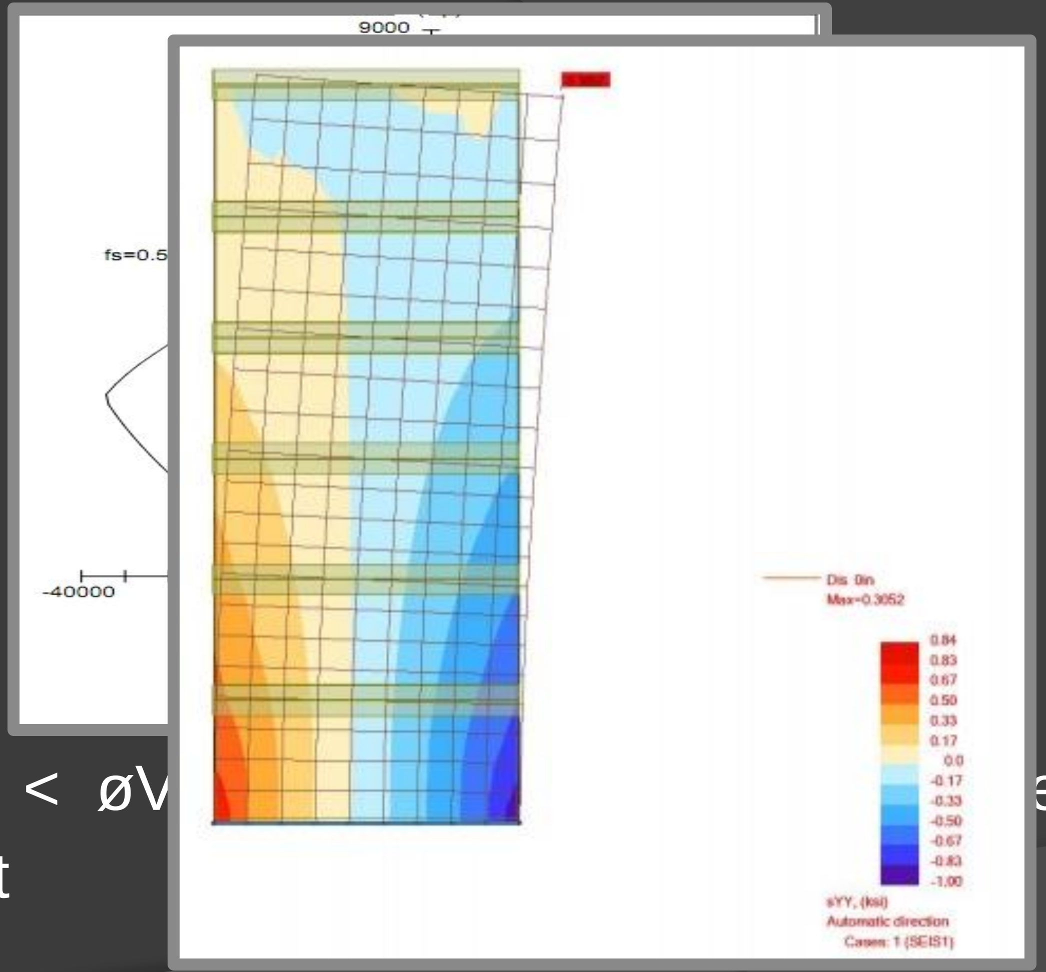
- V_u – 55.49 kip < $øV_n$ … cv * √f'c
- M_u – 6,310 k-ft
- P_u – 221 kip
- P_u – 292 kip

Lateral Design

- Special Reinforced Concrete shear wall f'c =4000psi t=10"
  - Determine Required Load (V_u, M_u, P_u)
    - 1.2D +1.0E
    - 0.9D +1.0E
  - Determine Shear Wall reinforcing
    - ACI 318-08 – Chapter 21.9 Special structural walls
    - #4 at 14" -> $øV_n$ 591.9 kip
  - Shear Wall - Interaction Diagrams
  - Check Boundary Element
    - $C \geq l_w/600(\delta_u/h_w)$, c= 38.65" < 79.8"
  - Computer Model

Shear Wall Design





- V_u – 240.84 kip < øV … eeded
- M_u – 12,310 k-ft
- P_u – 164.8 kip
- P_u – 328.6 kip

Introduction
Proposal
Structural Redesign
- Design Goals
- One Way Concrete Slab
- Two Way Concrete Slab
- Seismic Design

Cost And Schedule Impact
Sustainability
Conclusion

Lateral Design

One Way	Current location			
Story		Story Drift (in)	Drift Ratio	Total Drift (in)
1	0.033	0.150	0.11%	0.150
2	0.057	0.255	0.19%	0.405
3	0.076	0.340	0.26%	0.745
4	0.092	0.414	0.31%	1.160
5	0.105	0.471	0.36%	1.630
6	0.122	0.548	0.38%	2.178

One Way	High Seismic			
Story		Story Drift (in)	Drift Ratio	Total Drift (in)
1	0.141	0.705	0.53%	0.705
2	0.239	1.195	0.90%	1.900
3	0.319	1.596	1.21%	3.496
4	0.389	1.945	1.47%	5.441
5	0.442	2.210	1.67%	7.650
6	0.514	2.571	1.79%	10.221

Story Drifts

Two Way	Current location			
Story		Story Drift (in)	Drift Ratio	Total Drift (in)
1	0.135	0.607	0.46%	0.607
2	0.191	0.861	0.65%	1.468
3	0.233	1.048	0.79%	2.515
4	0.249	1.120	0.85%	3.635
5	0.271	1.219	0.92%	4.854
6	0.305	1.371	0.95%	6.224

Two Way	High Seismic			
Story		Story Drift (in)	Drift Ratio	Total Drift (in)
1	0.300	1.349	1.02%	1.349
2	0.425	1.913	1.45%	3.262
3	0.517	2.328	1.76%	5.590
4	0.553	2.489	1.89%	8.079
5	0.562	2.528	1.92%	10.607
6	0.635	2.856	1.98%	13.463

Design Goals

- Compare the results to the original design
- Reduce the cost of the structure
- Reduce the schedule of the structure

Cost And Schedule

Introduction
Proposal
Structural Redesign
Cost And Schedule Impact
Design Goals
Cost Analysis
Schedule Analysis
Sustainability
Conclusion

Cost

- RS Means 2010 and retail values
- Cost based on columns, slab, beam, and walls
- Original design is assumed to have foundation cost included

	One Way Slab	Two Way Slab	Original Design
Cost	$4.6 million	$4.4 million	$10.5 million**
Cost per SF	$170.08	$162.78	$183.96

Schedule

- RS Means
- Overlapping of tasks

Schedule Summary	
	# Days
One Way Concrete Slab	375
Two Way Concrete Slab	262
Original Design	267

Introduction
Proposal
Structural Redesign
Cost And Schedule Impact
Sustainability
    Design Goals
    Green Roof Design
Conclusion

Design Goals

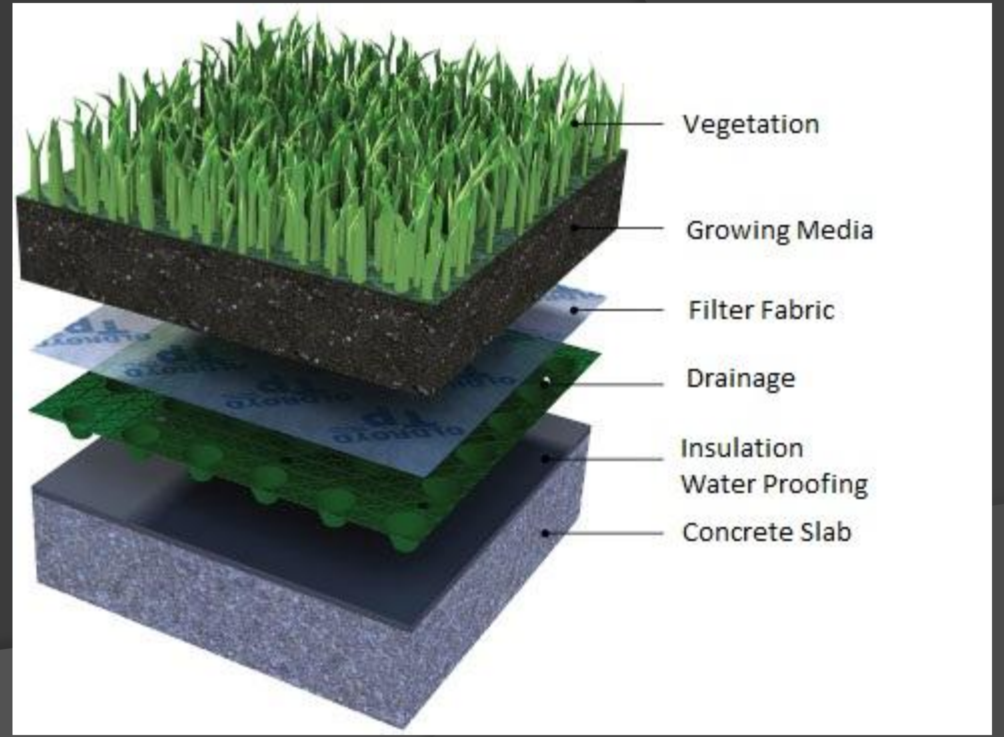
- Retain and collect rain water runoff.
- Gray water collection system.
- Accessibility to building occupants.

Green Roof Design

6” extensive green roof

Layers of Green Roofs:

- Vegetation
- Growing Media
- Filter Fabric
- Drainage
- Insulation
- Water Proofing



Green Roof Design

- Climate data (original location, 5 year study)
  - Max Temp. 100 °F
  - Min Temp. 8 °F
  - Max rain 3.0”
- Three important layers: Vegetation, Growing Media, and Drainage
- Vegetation: Resist the climate.
- Growing Media: Organic matter.
- Drainage: Take excess water.

Green Roof Design

Lightweight Aggregate	50%-70%
Organic Material	10%-20%
Sand	20%-30%

Introduction
Proposal
Structural Redesign
Cost And Schedule Impact
Sustainability
Conclusion

Conclusion

- Structural Redesign
  - Adding mass on the roof lever is important in high seismic region
  - The Two Way Concrete Slab did not minimizes architectural impact
- Cost and Schedule
  - A Two Way Concrete Slab was cheaper and shorter schedule than a One Way Concrete Slab
- Sustainability
  - Important to design the right Vegetation, Growing Media, and Drainage

Acknowledgements

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Mike Stansbury
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Questions