SUPPORTING DOCUMENTS

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SUPPORTING DOCUMENTS

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LESSONS LEARNED

During the design of the Growing Power headquarters, the structural partners learned a variety of lessons that helped guide and mold the ensuing design process. These valuable lessons are anticipated to be useful as the structural partners conclude their academic careers and enter the professional industry.

1. Organization and management of files is imperative:
   a. To streamline the design process, swift access to previously completed work is critical. This is facilitated by creating a clear formatting and naming convention for models, documents, spreadsheets, images, and presentations to enable user-friendly navigation and retrieval process. Various folders were created to sort files based on the project phase, discipline, and design package. However, it is important not to create too many folders, as files can easily be lost in the overwhelming mix.
2. Analysis and Design Software is a powerful resource:

   a. Throughout the development of the Growing Power headquarters, a number of analysis and design programs were used to assist in the design process. Structural design software can be extremely helpful tool during the design process. However, it can also be detrimental if used improperly. The “black box” of design software means that inputting poor information into a model will lead to poor output from said model. Therefore, the structural partners were vigilant to input precise data to ensure that accurate output was received. Spot checks via hand calculations were utilized to verify the validity of the results.

3. BIM software can be a useful tool for integrated project delivery and design:
   a. Inter-disciplinary collaboration can be greatly improved through the use of BIM software, as it provides a visual aid during discussions and a method of 3-D coordination and clash-detection among other things.
   b. Throughout the design process, the structural partners sought to maximize the utilization of BIM software interaction to create a more efficient process of design and information transfer.
      i. A number of processes linking Revit to RAM were explored, including RAM’s Integrated Structural Modelling (ISM), which included a midpoint software package that allowed the team to track changes coming from Revit and RAM, authorize updates, and continuously synchronize the models. After running some preliminary models, it was found that the ISM failed to properly transfer sloped framing data. Given the large amount of slope framing included on the greenhouse roof structures, the ISM was deemed inappropriate for software integration on this project. Instead, the structural partners utilized the Revit .dxf export to create the initial RAM model. Once the RAM model was created, the Revit and RAM models were managed and updated independently, because no adequate software transfer between the two model types was available.
      ii. Bentley’s RAM software includes in-house links between RAM Structural Systems, RAM Concept, RAM Elements, and RAM Connection, which were utilized to maintain structural loading information while a variety of components were analyzed and designed.
      iii. SP Slab and SP Column were used independently to determine preliminary concrete designs, because no software integration method currently exists to incorporate them with the software utilized in the project.
      iv. STAAD Pro was used independently, given the simplistic nature of the elements being analyzed and designed, mainly the lower greenhouse framing structures.
      v. DXF files were utilized to transfer geometric data from Revit to SAP2000 to minimize errors produced in modelling of the top greenhouse tree columns. However, no design data was transferred back to Revit through software integration methods. Revit, RAM SS, and SAP2000 seamlessly integrated with Microsoft Excel for data analysis. Bulk data was exported from each software and processed to create understandable tables and graphs that confirmed and helped refine engineering design decisions, such as critical members to update in the lateral system. It aided in expediting the processing of deflection data to determine the location of maximum deflection and the corresponding members. Large volumes of member forces were exported for initial selection of lateral members.

4. Effective Communication is vital for smooth design:

   a. Interdisciplinary communication throughout the design process is important for developing an integrated project. Through a continual flow of data among team members, ideas and developments can be quickly shared and discussed to ensure that any decisions are well-informed. In addition, any communication needs to be crystal-clear and any decisions confirmed to ensure that there is no confusion and the entire team is on the same page.

5. BIM technology can be misleading:
   a. Although BIM technology is extremely helpful for interdisciplinary collaboration, it can also provide a false sense of completion during the design. During preliminary system modeling, preliminary sizes are used to provide a layout and baseline to work with. However, this can lead to the belief that the design is further along and more complete than it really is, as the level of detail appears higher than in reality.
6. Prototype criteria needs to be determined early:
   a. The concept of developing a design that can easily be transferred to future locations means that numerous aspects and criteria must be taken into account. In order to facilitate effective, efficient design of a prototype, the various factors need to be determined early in the process in order to be properly incorporated into the design.

CODE ANALYSIS AND SOFTWARE

Codes / Standards

- American Concrete Institute (ACI). “Building Code Requirements for Structural Concrete and Commentary.” *ACI Standard 318-08*. (2008).
- American Institute of Steel Construction (AISC). *Steel Construction Manual.* 14th Edition. (2011).
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Software: Design / Analysis and Building Information Modelling

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To facilitate team collaboration and system integration, the structural partners worked to maintain a current structural design in Revit 2015. This enabled the team to easily coordinate various systems and reference the latest plans, sections, schedules, and details throughout the design process. In addition, this added in coordinating the various structural models by ensuring all information was up to date.

ORGANIZATION STRATEGIES

The structural partners strived to keep organized and on target and schedule by keeping written accounts of meetings and discussions with team members, faculty advisors, or industry professionals. In addition, a log of action items was used to map out upcoming phases of the design process and track completion of the different items. This method provided the team with easy access to information and reasoning discuss prior when reviewing or revisiting certain aspects of the design.

Meeting Minutes (11-12-14)

Lateral System:

- -eccentricity an issue with the two cores
- -focus on earthquake requirements
  - -will control overall concept due to varying requirements
- -symmetry
  - -"Symmetry is our friend."
  - -need something that is balanced due to multicity requirements
- - uniform distribution of lateral strength throughout plan is advantageous
  - -moment frames
  - -can drop off frames as mass drops off
- -try not using cores for lateral
  - -walls limit you and throw in eccentricity
- -use only frames to address the multicity requirements

Gathering Space:

- -need to allow the lateral system to transfer
  - -need to transfer moment out: need moment connections
  - -could also bump up the next lower level girder to larger size for stiffness
  - -make sure lower level sees stiffness by stiffening columns
    - -can reinforce section with addition W or WT
- -Increase column size if possible
  - -cheaper and easier than reinforcing the section, etc.

Miscellaneous:

- -concrete has had issues regarding transfer girder & moment frames
  - -valid reasoning for inherent frames or shear walls
- -symmetry and balance are critical with multiple locations
  - -variations in lateral requirements are a problem due the various code requirements
- -Need to focus on tracking the load path
- -Steel better for future flexibility
  - -can more easily remove and a bay and reinforce the opening for potential alterations in the future than concrete

1-20-15 Structural To-Do List

- ☒ Revise Milwaukee Lateral System
  - ☒ Verify Lateral Forces
  - ☒ Downsize beams, upsize columns
    - *Virtual Work*
- ☒ Foundation Revisions
  - ☒ Foundation wall design
    - *Include effects of water table*
  - ☒ Preliminary Mat Foundation Sizing for Comparison
- ☐ Evaluate and design openings in select beams
  - *Design Guide 2*
- ☒ Roof-Top Greenhouse Detail Sizing
  - ☒ Create Model for Daylighting study
  - ☒ Roofing Framing
  - ☒ C&C Wind Loading Values
  - ☒ Tree Columns
- ☐ Lower Greenhouse Details
  - ☒ Determine Validity of assumed detail in Revit Model
  - ☒ Size HSS Supporting Column
    - ☒ Upper HSS
    - ☐ Lower HSS
  - ☒ Lateral bracing perpendicular to frames
  - ☐ Steel Frame Alternate Design
  - ☒ Moisture Control of Wood
- ☐ Steel Connections
  - ☐ RAM Connection modeling
  - ☐ Spot Check (Hand Calcs.)

BUILDING DESIGN LOADS

The building structural design loads were determined utilizing the applicable codes & standards and various manufacturers for different building material products. The following load tables were developed for the various portions or the building and the structure, such that the structural partners could easily refer to and justify the design values throughout the design process.

Typical Roof Dead Load		
Type	**Load**	**Notes**
Decking	2 psf	Vulcraft 1.5B20
Rigid Insulation	10 psf	Superimposed
Roofing Membrane	5 psf	
MEP	10 psf	
Ceilings	2 psf	
Lighting	5 psf	
Total	34 psf	

Typical Base Building Floor Dead Load		
Type	**Load**	**Notes**
Decking	46 psf	Vulcraft 3.0VLI18 with 3 ¼" Topping Composite Deck with Light Weight Concrete
MEP	10 psf	Superimposed
Floor Finishes	3 psf	
Ceilings	2 psf	
Lighting	5 psf	
Total	66 psf	

Typical Transition Floor Dead Load		
Type	**Load**	**Notes**
Decking	46 psf	Vulcraft 3.0VLI18 with 3 ¼" Topping Composite Deck with Light Weight Concrete
MEP	10 psf	Superimposed
Floor Finishes	3 psf	
Ceilings	2 psf	
Lighting	5 psf	
Rigid Insulation	15 psf	
3 ¼" L.W. Topping Slab	30 psf	
Total	111 psf	

Typical Greenhouse Floor Dead Load		
Type	**Load**	**Notes**
Decking	46 psf	Vulcraft 3.0VLI18 with 3 ¼" Topping. Composite Deck with Light Weight Concrete
MEP	10 psf	Superimposed
Floor Finishes	3 psf	
Ceilings	2 psf	
Lighting	5 psf	
Grate System	10 psf	
2" L.W. Topping Slab	18 psf	
Membrane	2 psf	
Total	96 psf	

Typical Building Live Loads		
Type	**Load**	**Notes**
Market	125 psf	
Processing/Loading	125 psf	
Mechanical Rooms	125 psf	
Storage	125 psf	
Gathering Space	100 psf	
Classrooms	100 psf	Viewed as assembly occupancy given the nature of the building
Demo Kitchen	100 psf	Viewed as assembly occupancy given the nature of the building
Office	100 psf	Enable flexibility to alter program layout in the future. (80 psf corridor + 20psf partition)
Greenhouse	250 psf	Enable 4' deep aquaculture tanks anywhere in greenhouses

Façade Load		
Type	**Load**	**Notes**
Gypsum Wall Board	2.5 psf	*Reference: AISC Steel Manual*
Misc. MEP	1 psf	
Metal Studs	1.5 psf	*Reference: Clark Dietrich*
Dens Glass	2 psf	*Reference: Georgia-Pacific*
Vapor Barrier	1 psf	*Reference: AISC Steel Manual*
Insulation	2 psf	*Reference: AISC Steel Manual*
Metal Channels	5 psf	*Reference: AISC Steel Manual*
Terracotta Panels	10 psf	*Reference: Hunter Douglas*
Total	25 psf	

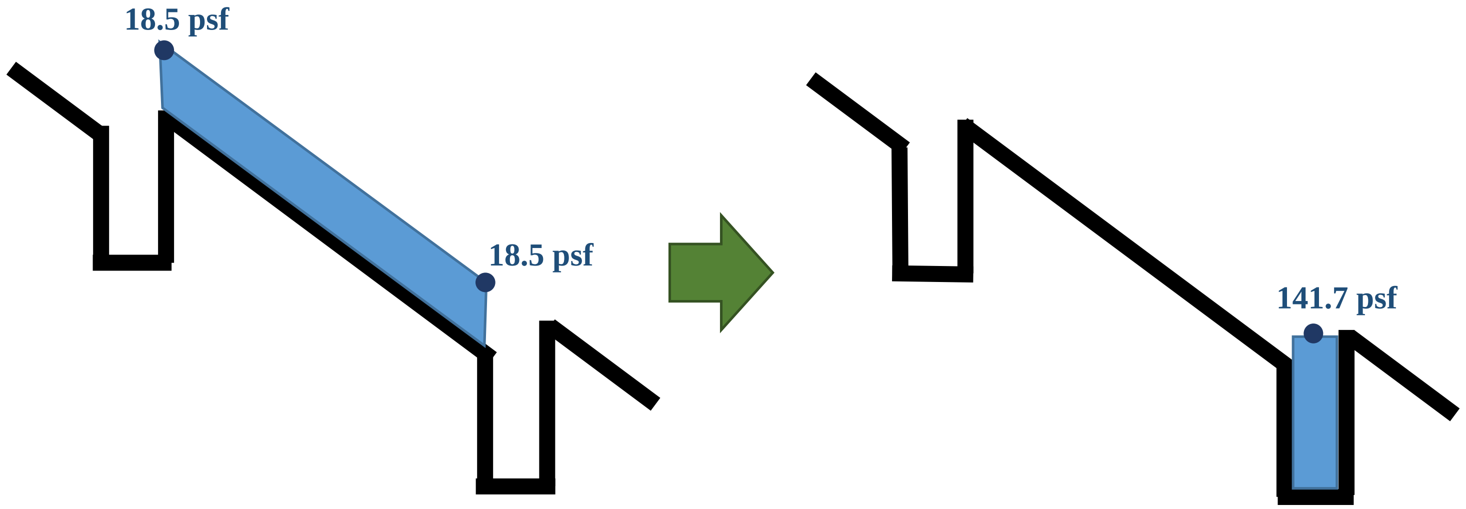
Snow Loading

Given the climate in Milwaukee, snow loading was an important factor in the structural design. The structural partners investigated various loading conditions (balanced and unbalanced) that would potentially occur due to snow drift on the greenhouse roofs.

The structural partners also considered the potential for snow to slide into the rainwater collection troughs between the cascading greenhouses, which could cause both an impact load and lateral pressure on the trough walls. Ideally, the greenhouses would always be heated, preventing excessive snow accumulation. However, there is the potential during construction or maintenance that the greenhouses may not be in operation.

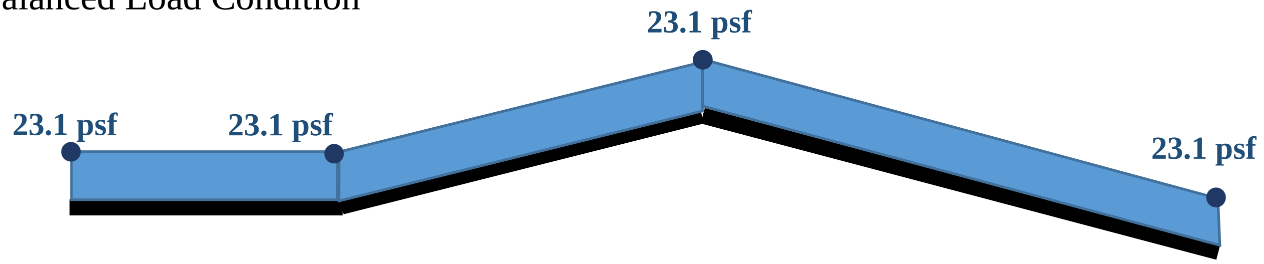
Milwaukee Snow Loading		
Reference Standard	ASCE 7-05	
Risk Category	III	
Ground Snow Load	30 psf	p_g
Importance Factor	1.1	
Exposure Factor	1.0	C_e
Thermal Factor	1.0	C_t
Flat Roof Snow Load	23.1 psf	p_f
Slope Factor (15° & 10°)	1.0	C_s
Slope Roof Snow Load	23.1 psf	p_s
Slope Factor (15° & 10°)	0.8	C_s
Slope Roof Snow Load	18.5 psf	p_s
Snow Density	17.9 pcf	γ

Cascading Greenhouse Load Conditions

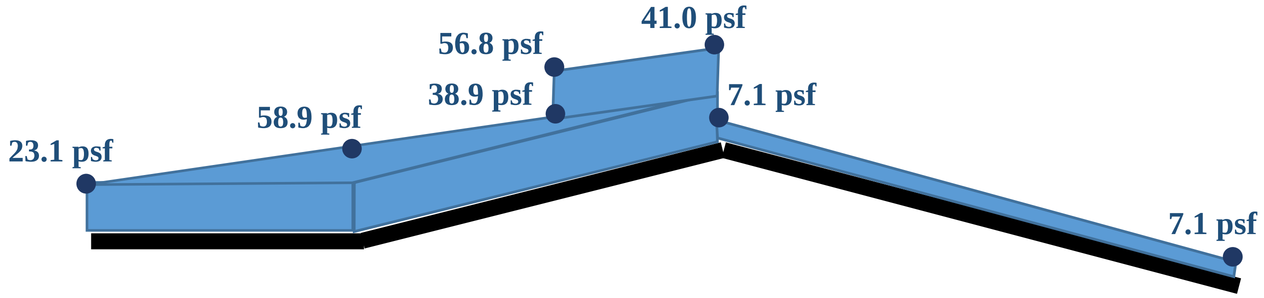


Roof Profile Load Conditions

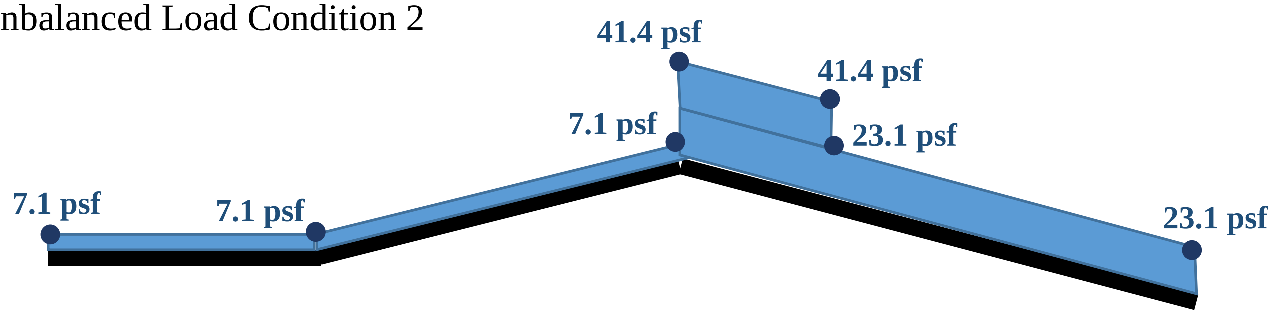
Balanced Load Condition



Unbalanced Load Condition 1



Unbalanced Load Condition 2



Wind Loading

The structural partners developed Excel spreadsheets for various loading calculations, easing the design process for various locations, as the different factors could be adjusted as necessary.

The building was designed under Risk Category III to ensure the safety of the large number of occupants anticipated in the gathering space. The Miami design was conducted as a partially enclosed structure due to the potential for flying debris to damage the glazing of the greenhouses during hurricanes. In addition, the Miami design was conducted for Exposure Category C because a specific site was not selected.

Milwaukee Wind Loading		
Reference Standard	ASCE 7-05	
Risk Category	III	
V, Basic Wind Speed	90 mph	V
K_d, Wind Directionality Factor	0.85	K_d
I, Importance Factor	1.15	I
Exposure Category	B	
Kz, Velocity pressure coefficient	0.90	K_z
Kzt, Topographic Factor	1	K_{zt}
G, Gust Effect Factor	0.85	G
Enclosure Classification	Enclosed	
Gcpi, Internal Pressure Coefficient	0.18	GC_{pi}
Cp, External Pressure Coefficient		
Windward	0.8	C_p
Leeward	-0.5	
Side Wall	-0.7	
Velocity pressure	18.3 psf	q
Windward MAX Design Pressure	15.7 psf	p_{ww}
Leeward Design Pressure	-11.1 psf	p_{lw}
Side Wall Design Pressure	-14.2 psf	p_{sw}

Miami Wind Loading		
Reference Standard	ASCE 7-05	
Risk Category	III	
V, Basic Wind Speed	150 mph	V
K_d, Wind Directionality Factor	0.85	K_d
I, Importance Factor	1.15	I
Exposure Category	C	
Kz, Velocity pressure coefficient	1.18	K_z
Kzt, Topographic Factor	1	K_{zt}
G, Gust Effect Factor	0.85	G
Enclosure Classification	Partially Enclosed	
Gcpi, Internal Pressure Coefficient	0.55	GC_{pi}
Cp, External Pressure Coefficient		
Windward	0.8	C_p
Leeward	-0.5	
Side Wall	-0.7	
Velocity pressure	66.7 psf	q
Windward MAX Design Pressure	82.0 psf	p_{ww}
Leeward Design Pressure	-65.0 psf	p_{lw}
Side Wall Design Pressure	-76.4 psf	p_{sw}

Components and Cladding Summary Table - Milwaukee

	ZONE 1	ZONE 2	ZONE 3	ZONE 4		ZONE 5	
	Roof	Roof	Roof	WW	LW / SW	WW	LW / SW
(SQFT)	(psf)						
10	-28.6	-44.9	-61.1	19.5	-19.5	19.5	-35.8
20	-28.4	-44.6	-60.8	19.5	-19.5	19.5	-35.8
50	-27.8	-43.8	-59.8	19.2	-19.3	19.2	-34.9
100	-26.9	-42.5	-58.2	18.6	-18.9	18.6	-33.4
200	-25.1	-40.0	-54.8	17.5	-18.2	17.5	-30.4
500	-19.5	-32.2	-44.9	14.1	-15.9	14.1	-21.3

Risk Category	III	
Basic Wind Speed	90	mph
Exposure Category	B	
Enclosure Classification	Enclosed	
Importance Factor	1.15	

Components and Cladding Summary Table - Miami

	ZONE 1	ZONE 2	ZONE 3	ZONE 4		ZONE 5	
	Roof	Roof	Roof	WW	LW / SW	WW	LW / SW
(SQFT)	(psf)						
10	-128.9	-188.4	-247.9	95.9	-95.9	95.9	-155.3
20	-128.2	-187.5	-246.7	95.9	-95.9	95.9	-155.3
50	-126.2	-184.6	-243.0	94.6	-95.0	94.6	-152.0
100	-122.8	-179.9	-237.0	92.5	-93.6	92.5	-146.5
200	-116.1	-170.5	-224.8	88.4	-90.9	88.4	-135.5
500	-95.9	-142.1	-188.4	76.0	-82.6	76.0	-102.5

Risk Category	III	
Basic Wind Speed	150	mph
Exposure Category	C	
Enclosure Classification	Partially Enclosed	
Importance Factor	1.15	

DIAPHRAGM FORCES

Forces on Diaphragms - Milwaukee

E-W

Level	WW (psf)	LW (psf)	Level Height (ft)	Influence Width (ft)	AREA WW (ft^2)	AREA LW (ft)	WW F (kip)	LW F (kip)	TOTAL F (kip)
1	11.22	-11.08	14	159.5	2233.0	2233.0	25.05	-24.73	49.8
2GH	11.22	-11.08	14	42.0	588.0	588.0	6.60	-6.51	13.1
2	11.22	-11.08	14	117.5	1645.0	1645.0	18.45	-18.22	36.7
3GH	12.76	-11.08	14	42.0	588.0	588.0	7.50	-6.51	14.0
3	12.76	-11.08	14	96.5	1351.0	1351.0	17.24	-14.96	32.2
4GH	13.93	-11.08	14	33.2	464.3	464.3	6.47	-5.14	11.6
4	13.93	-11.08	14	84.3	1180.7	1180.7	16.44	-13.08	29.5
5GH	14.84	-11.08	14	73.5	1029.0	1029.0	15.27	-11.40	26.7
5UP	14.84	-11.08	14	23.0	322.0	322.0	4.78	-3.57	8.3
Roof	15.75	-11.08	14	96.5	1351.0	1351.0	21.27	-14.96	36.2
								Total Base Shear (kip)	208.4

N-S

Level	WW (psf)	LW (psf)	Level Height (ft)	Influence Width (ft)	AREA WW (ft^2)	AREA LW (ft)	WW F (kip)	LW F (kip)	TOTAL F* (kip)
1	11.22	-7.79	14	71.7	1003.3	1003.3	11.25	-7.81	19.1
2GH	11.22	-7.79	14	71.7	1003.3	1003.3	11.25	-7.81	19.1
2	11.22	-7.79	14	71.7	1003.3	1003.3	11.25	-7.81	19.1
3GH	12.76	-7.79	14	71.7	1003.3	1003.3	12.81	-7.81	20.6
3	12.76	-7.79	14	71.7	1003.3	1003.3	12.81	-7.81	20.6
4GH	13.93	-7.79	14	71.7	1003.3	1003.3	13.97	-7.81	21.8
4	13.93	-7.79	14	71.7	1003.3	1003.3	13.97	-7.81	21.8
5GH	14.84	-7.79	14	71.7	1003.3	1003.3	14.89	-7.81	22.7
5UP	14.84	-7.79	14	71.7	1003.3	1003.3	14.89	-7.81	22.7
Roof	15.75	-7.79	14	71.7	1003.3	1003.3	15.80	-7.81	23.6
								Total Base Shear (kip)	107.8

**Note: Windward Force and Leeward Force will not be applied to same diaphragm*

Forces on Diaphragms - Miami

E-W

Level	WW (psf)	LW (psf)	Level Height (ft)	Influence Width (ft)	AREA WW (ft^2)	AREA LW (ft)	WW F (kip)	LW F (kip)	TOTAL F (kip)
1	69.18	-65.02	14	159.5	2233.0	2233.0	154.48	-145.20	299.7
2GH	69.18	-65.02	14	42.0	588.0	588.0	40.68	-38.23	78.9
2	69.18	-65.02	14	117.5	1645.0	1645.0	113.80	-106.96	220.8
3GH	73.75	-65.02	14	42.0	588.0	588.0	43.36	-38.23	81.6
3	73.75	-65.02	14	96.5	1351.0	1351.0	99.63	-87.85	187.5
4GH	77.05	-65.02	14	33.2	464.3	464.3	35.78	-30.19	66.0
4	77.05	-65.02	14	84.3	1180.7	1180.7	90.97	-76.77	167.7
5GH	79.57	-65.02	14	73.5	1029.0	1029.0	81.88	-66.91	148.8
5UP	79.57	-65.02	14	23.0	322.0	322.0	25.62	-20.94	46.6
Roof	82.03	-65.02	14	96.5	1351.0	1351.0	110.82	-87.85	198.7
								Total Base Shear (kip)	1196.5

N-S

Level	WW (psf)	LW (psf)	Level Height (ft)	Influence Width (ft)	AREA WW (ft^2)	AREA LW (ft)	WW F (kip)	LW F (kip)	TOTAL F* (kip)
1	69.18	-53.05	14	71.7	1003.3	1003.3	69.41	-53.22	122.6
2GH	69.18	-53.05	14	71.7	1003.3	1003.3	69.41	-53.22	122.6
2	69.18	-53.05	14	71.7	1003.3	1003.3	69.41	-53.22	122.6
3GH	73.75	-53.05	14	71.7	1003.3	1003.3	73.99	-53.22	127.2
3	73.75	-53.05	14	71.7	1003.3	1003.3	73.99	-53.22	127.2
4GH	77.05	-53.05	14	71.7	1003.3	1003.3	77.30	-53.22	130.5
4	77.05	-53.05	14	71.7	1003.3	1003.3	77.30	-53.22	130.5
5GH	79.57	-53.05	14	71.7	1003.3	1003.3	79.83	-53.22	133.1
5UP	79.57	-53.05	14	71.7	1003.3	1003.3	79.83	-53.22	133.1
Roof	82.03	-53.05	14	71.7	1003.3	1003.3	82.30	-53.22	135.5
								Total Base Shear (kip)	649.0

**Note: Windward Force and Leeward Force will not be applied to same diaphragm*

SEISMIC LOADING

Milwaukee Seismic Loading		
Reference Standard	ASCE 7-05	
Risk Category	III	
Seismic Site Class	D	
Spectral Response Acceleration, Short-Period	0.105	S_s
Spectral Response Acceleration, One-Second	0.044	S_1
Site Coefficient, Short Period	1.6	F_a
Site Coefficient, Long Period	2.4	F_v
MCE Spectral Response Acceleration, Short Period	0.168	S_{MS}
MCE Spectral Response Acceleration, One-Second	0.105	S_{M1}
Design Spectral Response Acceleration, Short-Period	0.112	S_{DS}
Design Spectral Response Acceleration, One-Second	0.07	S_{D1}
Long Period	12	T_L
Seismic Design Category	B	

Miami Seismic Loading		
Reference Standard	ASCE 7-05	
Risk Category	III	
Seismic Site Class	D	
Spectral Response Acceleration, Short-Period	0.053	S_s
Spectral Response Acceleration, One-Second	0.02	S_1
Site Coefficient, Short Period	1.6	F_a
Site Coefficient, Long Period	2.4	F_v
MCE Spectral Response Acceleration, Short Period	0.085	S_{MS}
MCE Spectral Response Acceleration, One-Second	0.048	S_{M1}
Design Spectral Response Acceleration, Short-Period	0.056	S_{DS}
Design Spectral Response Acceleration, One-Second	0.032	S_{D1}
Long Period	8	T_L
Seismic Design Category	A	

Building Effective Seismic Weight							
Level	Area (ft^2)	Façade Perimeter (ft)	Dead Load (psf)	Façade Dead Load (plf)	Partitions (psf)	20% Flat Roof Snow Load (psf)	Total Weight (kip)
Roof	5663	345	42	350	0	0	359
5UP	560	84	66	350	0	0	66
5GH	5103	261	96	350	10	0	632
4	4689	249	66	350	10	0	444
4GH	2350	138	96	350	10	0	297
3	5446	275	66	350	10	0	510
3GH	3146	154	96	350	10	0	387
2	7327	317	66	350	10	0	668
2GH	2880	154	96	350	10	0	359
						Total Seismic Weight	3723

Seismic Diaphragm Forces - Milwaukee						
Direction	Resisting System	Response Modification Factor (R)	Seismic Importance Factor (Ie)	Seismic Response Coefficient (Cs)	Seismic Weight (kip)	Design Force (kip)
N-S	Ordinary Steel Moment Frame	3.5	1.25	0.0243	3723	90.5
E-W	Ordinary Steel Moment Frame	3.5	1.25	0.0285	3723	106.1

Seismic Diaphragm Forces - Miami				
Direction	Resisting System	Seismic Coefficient	Seismic Weight (kip)	Design Force (kip)
N-S	Ordinary Steel Moment Frame	0.01	3723	37.2
E-W	Ordinary Steel Moment Frame	0.01	3723	37.2

The structural partners used Excel spreadsheet to help verify and tabulate seismic design values. These spreadsheets vary from calculating seismic design properties to determining the building's effective seismic weight to tracking the load path through the various floor diaphragms for both Milwaukee and Miami.

Earthquake Forces on Diaphragms - Milwaukee					
E-W					
V =	106.1	T =	0.882	k =	1.191
Level	h_x (ft)	w_x (k)	$w_x h_x^k$	C_{vx}	Fx (k)
Roof	73	359	59472	0.213	22.6
5UP	56	66	7973	0.029	3.0
5GH	56	632	76350	0.274	29.1
4	42	444	38078	0.137	14.5
4GH	42	297	25471	0.091	9.7
3	28	510	26986	0.097	10.3
3GH	28	387	20477	0.073	7.8
2	14	668	15482	0.056	5.9
2GH	14	360	8343	0.030	3.2
		Σ	278632	1	
N-S					
V =	90.5	T =	1.034	k =	1.267
Level	h_x (ft)	w_x (k)	$w_x h_x^k$	C_{vx}	Fx (k)
Roof	73	359	82399	0.222	20.1
5UP	56	66	10827	0.029	2.6
5GH	56	632	103674	0.279	25.3
4	42	444	50587	0.136	12.3
4GH	42	297	33839	0.091	8.2
3	28	510	34763	0.094	8.5
3GH	28	387	26379	0.071	6.4
2	14	668	18920	0.051	4.6
2GH	14	360	10196	0.027	2.5
		Σ	371585	1	

Earthquake Forces on Diaphragms - Miami			
E-W			
V = 37.2			
Level	w_x (k)	Seismic Coefficient	Fx (k)
Roof	359	0.01	3.6
5UP	66	0.01	0.7
5GH	632	0.01	6.3
4	444	0.01	4.4
4GH	297	0.01	3.0
3	510	0.01	5.1
3GH	387	0.01	3.9
2	668	0.01	6.7
2GH	360	0.01	3.6
N-S			
V = 37.2			
Level	w_x (k)	Seismic Coefficient	Fx (k)
Roof	359	0.01	3.6
5UP	66	0.01	0.7
5GH	632	0.01	6.3
4	444	0.01	4.4
4GH	297	0.01	3.0
3	510	0.01	5.1
3GH	387	0.01	3.9
2	668	0.01	6.7
2GH	360	0.01	3.6

PRELIMINARY SYSTEM EVALUATION

AEI Team 4 utilized a decision matrix to help guide the design by relating various system options back to the project goals. Each option was rated on a scale of 1-5 based on how well it matched the respective goals. The colors correspond to the four project initiatives: **Flexibility, Sustainability, Community, and Economy**. This helped to narrow down the options to a select few that best matched the project goals, at which point the structural partners further explored and evaluated the final options before selecting the system to use in each facet of the structural design.

Decision Matrix Colors		
🟦	Flexibility	
🟩	Sustainability	
🟥	Community	
🟪	Economy	

Decision Matrix Goals	
1	Flexibility/ Adaptability to account for multiple space types/ locations
2	Economic use of materials
3	Maintainability of system for life span
4	Prototypability of building/ ability to replicate in other locations
5	Consideration of other systems (depth, size, etc.)
6	Specialized Market
7	Recyclability of materials
8	Innovation
9	Energy Saving Potential (Still to come)
10	Education value

Prelimnary System Rating

			Two-Way Flat Plate				*Precast Concrete*	
Rating	1 to 5	Steel Frame - Rigid Connections	Two-Way Flat Plate	Posttenssioned Two-Way Flat Plate	Two-Way Flat Slab	Posttenssioned Two-Way Flat Slab	Solid Slab	Hollow Core Slab
2	Highly Irregular Building Form	0	1	1	1	1	0	0
4	Exposed Structure (Fire)	0	1	1	1	1	1	1
3	Irregular Column Placement	0	1	1	1	1	0	0
2	Thin Floor System	0	1	1	1	1	1	1
4	Long Span	1	0	0	0	0	0	0
3	Easy to Change	1	0	0	0	0	1	1
4	Any Construction Conditions	1	0	0	0	0	1	1
3	Minimize off-site fabrication time	0	1	1	1	1	0	0
4	Minimize on-site erection time	1	0	0	0	0	1	1
4	Minimize Construction Time	1	1	1	1	1	1	1
4	Minimize lateral obstruction	1	1	1	1	1	0	0
1	Minimize Dead load	1	0	0	0	0	0	0

The structural partners developed a rating system matrix, which utilized structural goals and design challenges, to supplement the Project Decision Matrix. This served as additional rationale for selecting various systems when project goals and initiatives did not lead to a clear-cut decision.

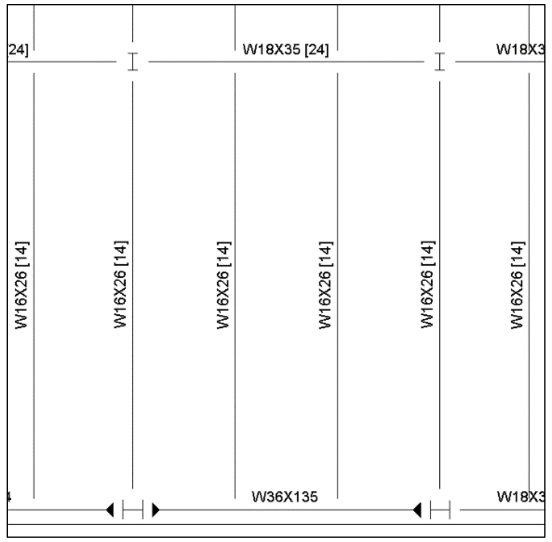
Project Decision Matrix

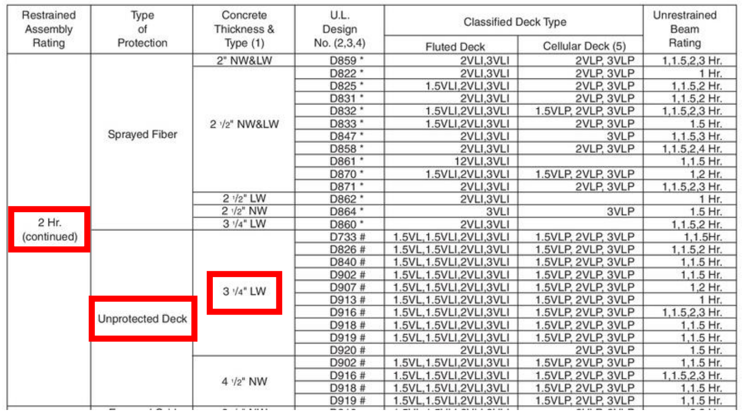
Option	Goals										Risks	Select
	1	4	7	9	10	2	3	5	6	8		X
Gravity System												
Steel Noncomposite	4	2	3	3	3	3	3	2	5	2		
Steel Composite	4	2	2	3	3	4	3	3	5	2		X
Steel Castellated Beams	4	3	3	3	4	5	3	5	4	4	Manufacturing different	
Timber Framing	2	2	5	3	4	2	1	2	2	4	Slightly specialized market	
Concrete Two-way Slab	2	4	4	3	3	3	3	3	5	2		X
Concrete Pre-cast Double Tee	4	2	4	3	3	4	4	2	2	4	Slightly specialized market	
Concrete Post Tension	3	3	3	3	3	5	4	4	3	2		
Concrete Bubble Deck	2	4	5	3	4	4	3	2	1	5	Extremely specialized market	
Acetylated Wood	2	2	5	3	4	3	5	3	4	5		
Foundation System												
Mat Foundation	4	3	3	3	3	2	4	3	5	3		
Spread/Strip Footing	4	4	3	3	3	5	4	4	5	3		
Beam (Grillage)	2	3	3	3	3	2	2	3	4	3		
Deep Foundations	2	2	3	3	3	2	3	2	2	4	Expensive, invasive, slow	
Slurry Wall	2	2	3	3	3	3	3	2	2	4	Expensive, invasive, slow	
Geopiers	4	4	4	3	4	5	4	4	2	5		X
Lateral Systems												
Steel Moment Frame	5	5	3	3	3	2	3	5	4	3		X
Steel Braced Frame	2	4	3	3	3	3	3	3	4	3		
Masonry Shear Walls	2	2	4	3	3	3	4	1	4	3		
Concrete Moment Frame	5	5	4	3	3	4	4	4	4	3		
Concrete Shear Wall	2	3	4	3	3	4	4	2	4	3		
Green House Structural System												
Wood	2	2	4	3	4	5	1	2	5	4		X
Steel	5	4	4	3	3	5	4	4	5	3		X
Non-toxic Treated Wood	4	2	5	3	4	4	5	3	4	5		
Façade Systems												
Precast Panel	3	1	2	3	4	4	4	3	3	2		
Brick Cavity Wall	2	2	2	3	3	3	4	3	3	2	Efflorescence, moisture, weight, slow	
Rainscreen	5	5	3	5	5	3	4	5	2	4	Terracotta shipping location	X

The options were rated on a scale of 1-5 based on how they met each of the ten goals. Coloring corresponds to the four project initiatives: Flexibility, Sustainability, Economy, and Community.

STRUCTURAL STEEL GRAVITY SYSTEM DESIGN AND ANALYSIS

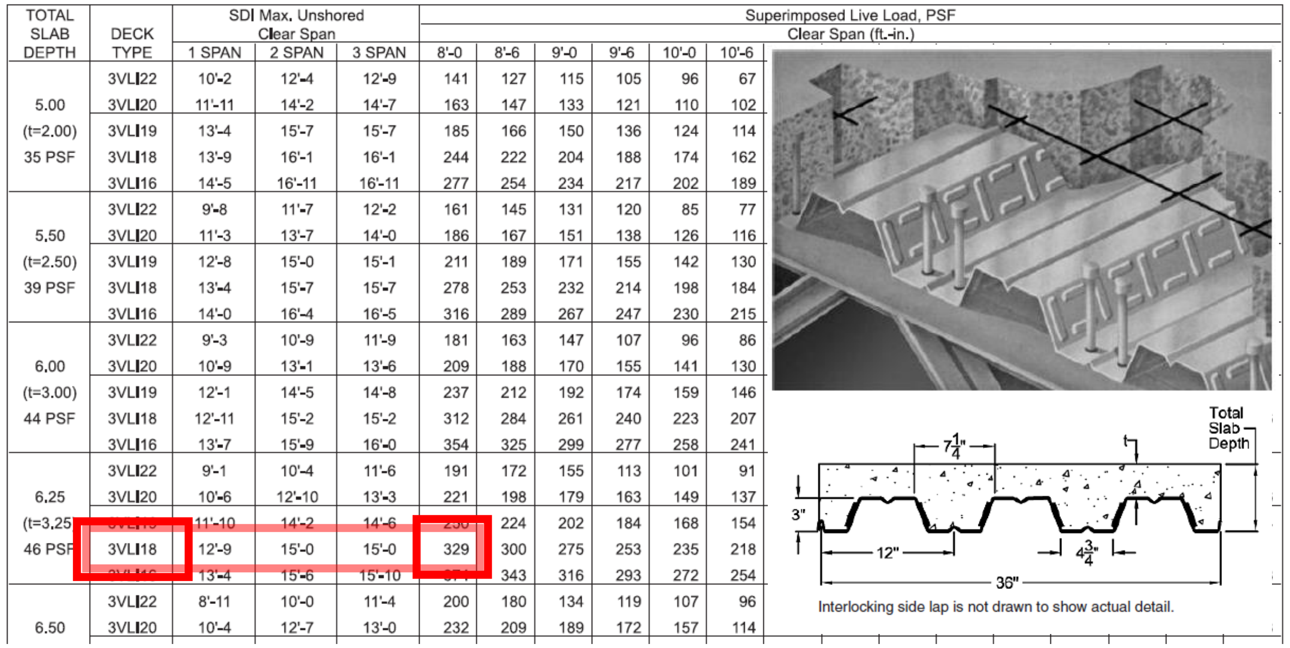
The final gravity system was designed with composite steel beams to minimize structural depth, as well as overall building mass. Vulcraft 3VLI18 deck with 3 ¼" lightweight concrete, as shown below, was selected, which also achieved the necessary fire rating. The design and analysis was conducted utilizing RAM Structural System, but spot checks were conducted to verify the results. An example of these hand calculations is presented, detailing the composite design for a typical bay for the base building.





Restrained Assembly Rating	Type of Protection	Concrete Thickness & Type (1)	U.L. Design No. (2,3,4)	Classified Deck Type		Unrestrained Beam Rating
				Fluted Deck	Cellular Deck (5)	
2 Hr. (continued)	Sprayed Fiber	2" NW&LW	D859 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 ½" NW&LW	D822 *	2VLI,3VLI	2VLP, 3VLP	1 Hr.
			D825 *	1.5VLI,2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D831 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2 Hr.
			D832 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D833 *	1.5VLI,2VLI,3VLI	2VLP, 3VLP	1.5 Hr.
			D847 *	2VLI,3VLI	3VLP	1,1.5,3 Hr.
			D858 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,4 Hr.
			D861 *	12VLI,3VLI		1,1.5 Hr.
			D870 *	1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,2 Hr.
			D871 *	2VLI,3VLI	2VLP, 3VLP	1,1.5,2,3 Hr.
		2 ½" LW	D862 *	2VLI,3VLI		1 Hr.
		2 ½" NW	D864 *	3VLI	3VLP	1.5 Hr.
		3 ¼" LW	D860 *	2VLI,3VLI		1,1.5,2 Hr.
	Unprotected Deck	3 ¼" LW	D733 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5Hr.
			D826 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2 Hr.
			D840 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D907 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,2 Hr.
			D913 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D920 #	2VLI,3VLI	2VLP, 3VLP	1.5 Hr.
		4 ½" NW	D902 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D916 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5,2,3 Hr.
			D918 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.
			D919 #	1.5VL,1.5VLI,2VLI,3VLI	1.5VLP, 2VLP, 3VLP	1,1.5 Hr.

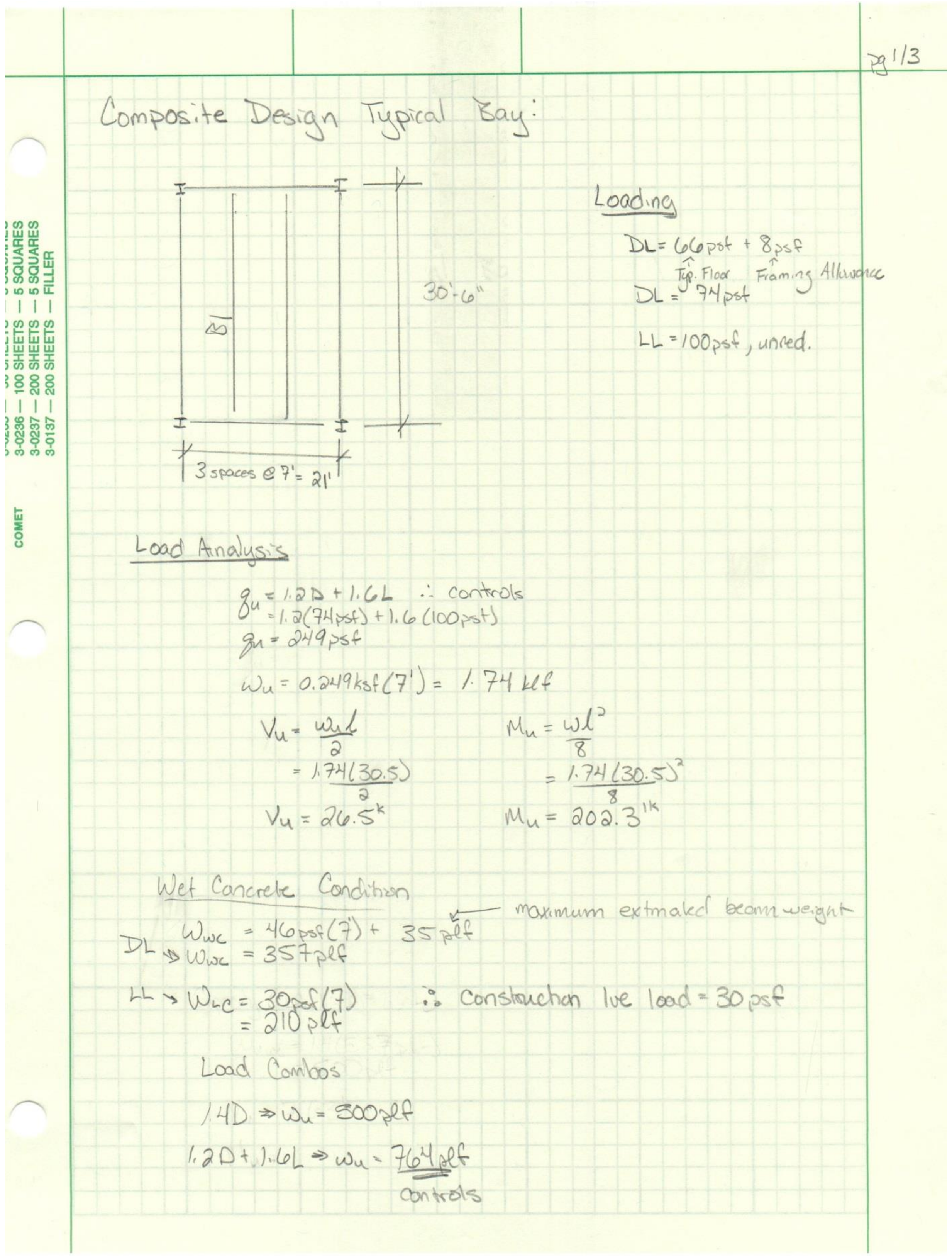
(N=14.15) LIGHTWEIGHT CONCRETE (110 PCF)



TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)					
		1 SPAN	2 SPAN	3 SPAN	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6
5.00 (t=2.00) 35 PSF	3VLI22	10'-2	12'-4	12'-9	141	127	115	105	96	67
	3VLI20	11'-11	14'-2	14'-7	163	147	133	121	110	102
	3VLI19	13'-4	15'-7	15'-7	185	166	150	136	124	114
	3VLI18	13'-9	16'-1	16'-1	244	222	204	188	174	162
	3VLI16	14'-5	16'-11	16'-11	277	254	234	217	202	189
5.50 (t=2.50) 39 PSF	3VLI22	9'-8	11'-7	12'-2	161	145	131	120	85	77
	3VLI20	11'-3	13'-7	14'-0	186	167	151	138	126	116
	3VLI19	12'-8	15'-0	15'-1	211	189	171	155	142	130
	3VLI18	13'-4	15'-7	15'-7	278	253	232	214	198	184
	3VLI16	14'-0	16'-4	16'-5	316	289	267	247	230	215
6.00 (t=3.00) 44 PSF	3VLI22	9'-3	10'-9	11'-9	181	163	147	107	96	86
	3VLI20	10'-9	13'-1	13'-6	209	188	170	155	141	130
	3VLI19	12'-1	14'-5	14'-8	237	212	192	174	159	146
	3VLI18	12'-11	15'-2	15'-2	312	284	261	240	223	207
	3VLI16	13'-7	15'-9	16'-0	354	325	299	277	258	241
6.25 (t=3.25) 46 PSF	3VLI22	9'-1	10'-4	11'-6	191	172	155	113	101	91
	3VLI20	10'-6	12'-10	13'-3	221	198	179	163	149	137
	3VLI19	11'-10	14'-2	14'-6	250	224	202	184	168	154
	3VLI18	12'-9	15'-0	15'-0	329	300	275	253	235	218
	3VLI16	13'-4	15'-6	15'-10	374	343	316	293	272	254
6.50	3VLI22	8'-11	10'-0	11'-4	200	180	134	119	107	96
	3VLI20	10'-4	12'-7	13'-0	232	209	189	172	157	114

Interlocking side lap is not drawn to show actual detail.

COMPOSITE



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Composite Design Typical Bay:

30'-6"

3 spaces @ 7' = 21'

Loading

DL = 66psf + 8psf

Typ. Floor — Framing Allowance

DL = 74psf

LL = 100psf, unred.

Load Analysis

$q_u = 1.2D + 1.6L$ ∴ controls

$= 1.2(74\text{psf}) + 1.6(100\text{psf})$

$q_u = 249\text{psf}$

$w_u = 0.249\text{ksf}(7') = 1.74\text{klf}$

$V_u = \frac{w_u l}{2}$

$= \frac{1.74(30.5)}{2}$

$V_u = 26.5^k$

$M_u = \frac{wl^2}{8}$

$= \frac{1.74(30.5)^2}{8}$

$M_u = 202.3^{1k}$

Wet Concrete Condition

DL ⇒ $W_{wc} = 46\text{psf}(7') + 35\text{plf}$ ← maximum estimated beam weight

$W_{wc} = 357\text{plf}$

LL ⇒ $W_{LC} = 30\text{psf}(7)$

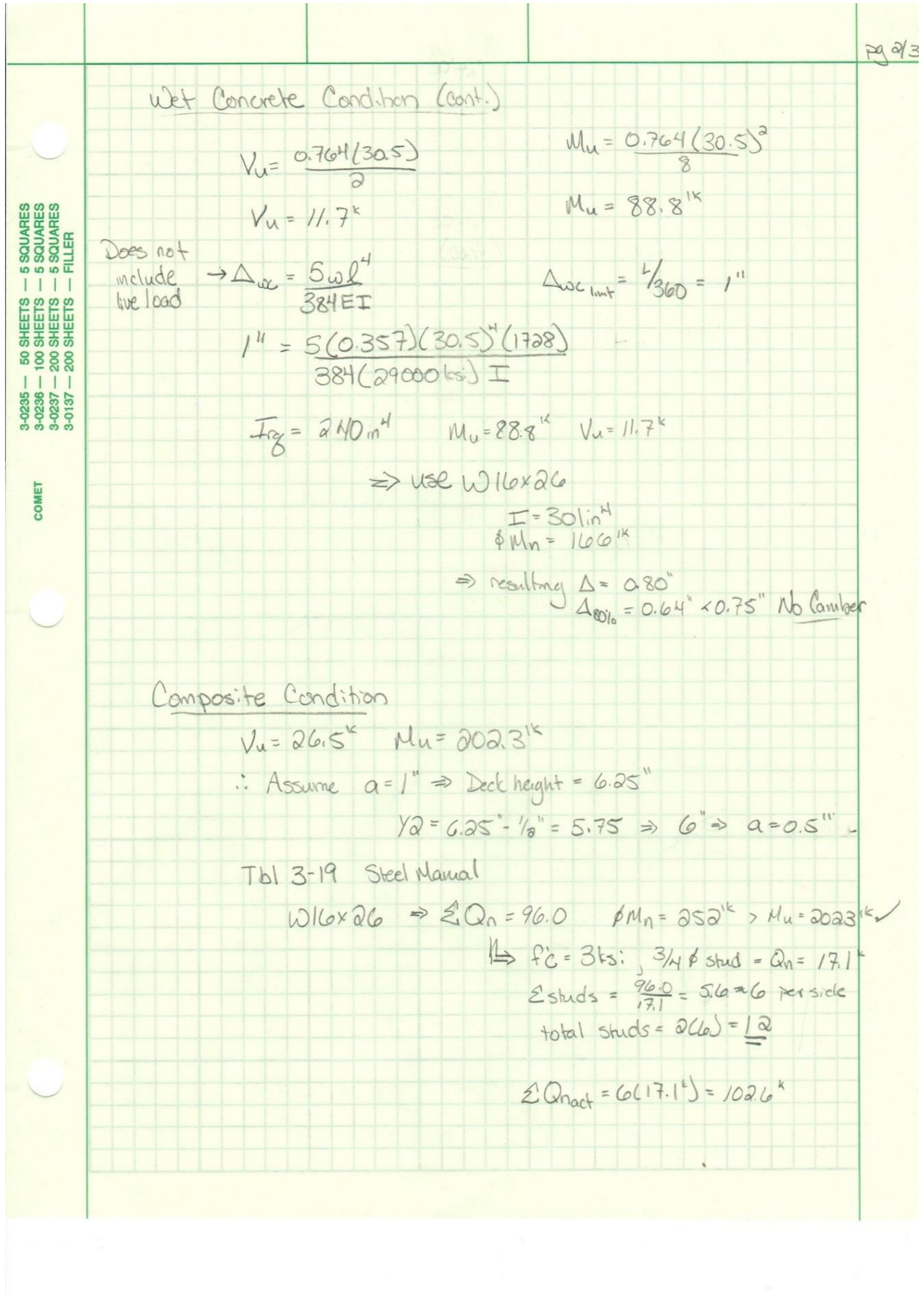
$= 210\text{plf}$ ∴ construction live load = 30 psf

Load Combos

$1.4D \Rightarrow w_u = 500\text{plf}$

$1.2D + 1.6L \Rightarrow w_u = \underline{764\text{plf}}$

controls



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3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

Wet Concrete Condition (cont.)

$$V_u = \frac{0.764(30.5)}{2} \qquad M_u = \frac{0.764(30.5)^2}{8}$$

$$V_u = 11.7^k \qquad M_u = 88.8^{1k}$$

Does not include live load $\rightarrow \Delta_{wc} = \frac{5wl^4}{384EI}$ $\qquad \Delta_{wc_{limit}} = {}^{L}/_{360} = 1''$

$$1'' = \frac{5(0.357)(30.5)^4(1728)}{384(29000\text{ksi})I}$$

$I_{reg} = 240\text{in}^4 \qquad M_u = 88.8^{1k} \qquad V_u = 11.7^k$

$\Rightarrow$ use W16x26

$I = 301\text{in}^4$
$\phi M_n = 166^{1k}$

$\Rightarrow$ resulting $\Delta = 0.80''$
$\Delta_{80\%} = 0.64'' < 0.75''$ No Camber

Composite Condition

$V_u = 26.5^k \qquad M_u = 202.3^{1k}$

$\therefore$ Assume $a = 1'' \Rightarrow$ Deck height $= 6.25''$

$Y2 = 6.25'' - {}^{1}/_{2}'' = 5.75 \Rightarrow 6'' \Rightarrow a = 0.5''$

Tbl 3-19 Steel Manual

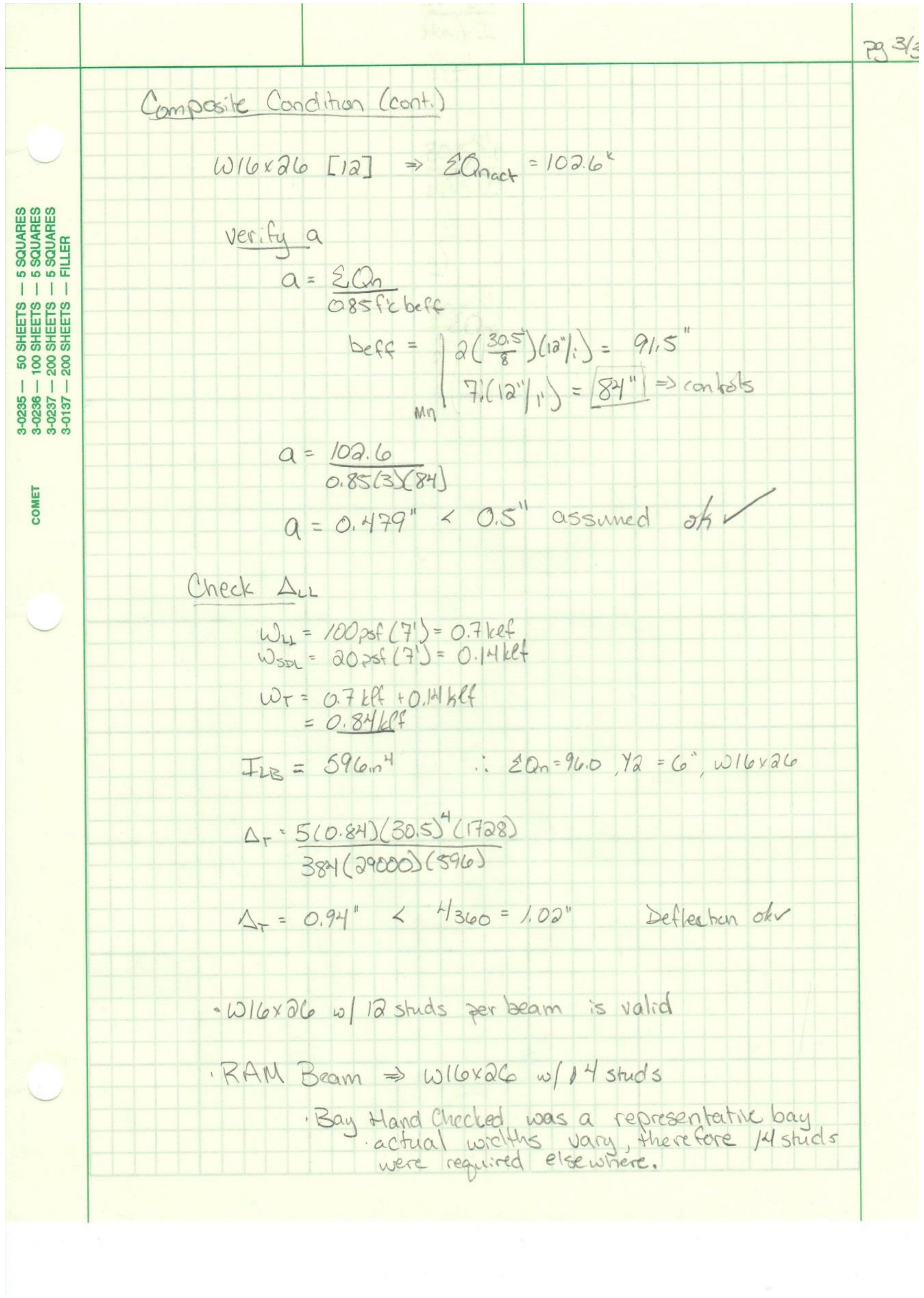
W16x26 $\Rightarrow \Sigma Q_n = 96.0 \qquad \phi M_n = 252^{1k} > M_u = 202.3^{1k}$ ✓

$\Rightarrow f'_c = 3\text{ksi}; \; {}^{3}/_{4}\phi$ stud $= Q_n = 17.1^k$

$\Sigma\text{studs} = \frac{96.0}{17.1} = 5.6 \approx 6$ per side

total studs $= 2(6) = \underline{\underline{12}}$

$\Sigma Q_{n_{act}} = 6(17.1^k) = 102.6^k$



pg 3/3

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

Composite Condition (cont.)

W16x26 [12] $\Rightarrow \Sigma Q_{n_{act}} = 102.6^k$

verify a

$$a = \frac{\Sigma Q_n}{0.85 f'_c b_{eff}}$$

$$b_{eff} = \min \begin{cases} 2\left(\frac{30.5'}{8}\right)\left(12''/1'\right) = 91.5'' \\ 7'\left(12''/1'\right) = \boxed{84''} \Rightarrow \text{controls} \end{cases}$$

$$a = \frac{102.6}{0.85(3)(84)}$$

$a = 0.479'' < 0.5''$ assumed ok ✓

Check Δ_{LL}

$w_{LL} = 100\text{psf}(7') = 0.7\text{klf}$
$w_{SDL} = 20\text{psf}(7') = 0.14\text{klf}$

$w_T = 0.7\text{klf} + 0.14\text{klf}$
$= \underline{0.84\text{klf}}$

$I_{LB} = 596\text{in}^4 \qquad \therefore \Sigma Q_n = 96.0,\ Y2 = 6'',\ \text{W16x26}$

$$\Delta_T = \frac{5(0.84)(30.5)^4(1728)}{384(29000)(596)}$$

$\Delta_T = 0.94'' < {}^{L}/_{360} = 1.02''$ Deflection ok ✓

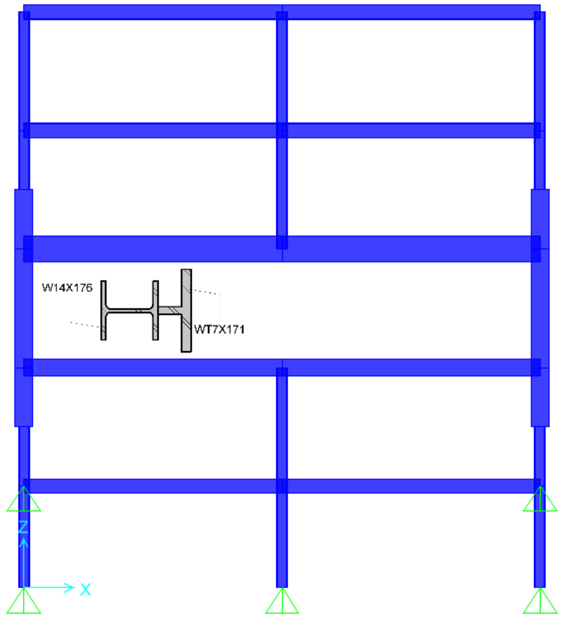
- W16x26 w/ 12 studs per beam is valid

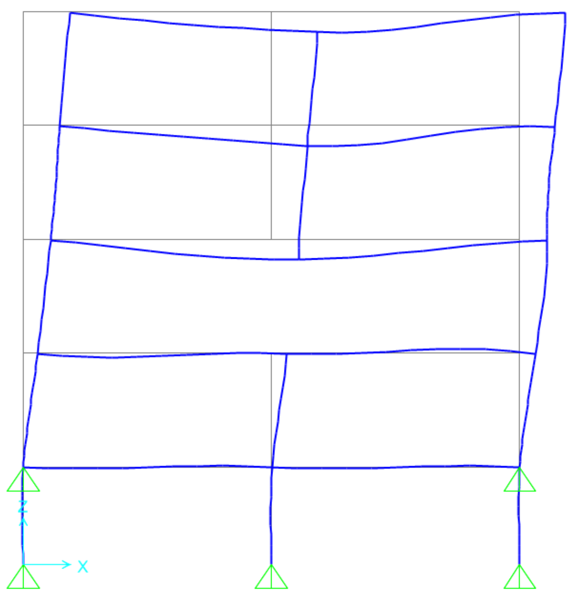
- RAM Beam $\Rightarrow$ W16x26 w/ 14 studs
  - Bay Hand Checked was a representative bay
  - actual widths vary, therefore 14 studs were required elsewhere.

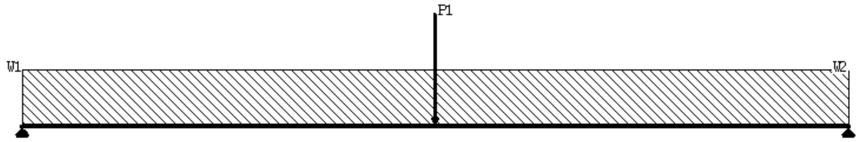
TRANSFER GIRDER DESIGN

The structural transfer elements were necessary in order to clear span the third floor to create an open, column-free gathering space, as shown below. The design of the transfer elements was a design challenge for the structural partners, which led to subsequent challenges for the other design disciplines, but in the end provided Growing Power with a column-free gathering space. The presence of columns in the space was anticipated to obscure the view of the audience and intrude upon the open, welcoming nature of the space, as shown in the view below.

In order to facilitate the implementation of the transfer elements, the structural partners had to consider a number of different factors. This included system coordination within the plenum, constructability, and economy. In addition, the structural partners had to consider and address the impact of the transfer elements on the structural system as a whole, including the lateral system and the effects of a "soft story.

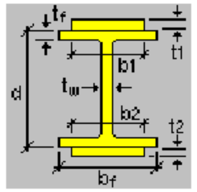




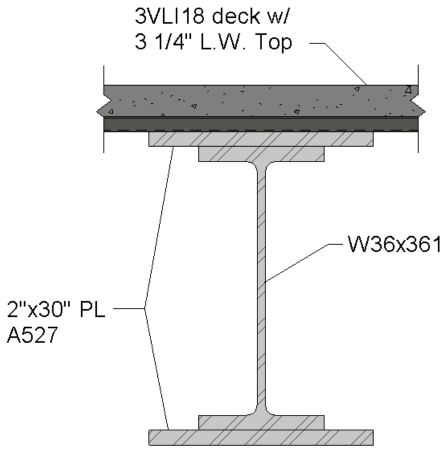


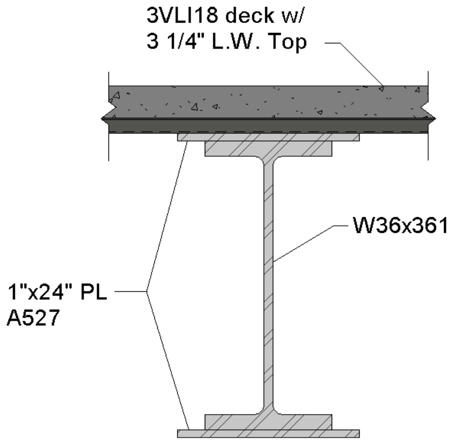
Load	Dist	DL	LL+	LL-	PL+	PL-	Max Tot
	ft	kips	kips	kips	kips	kips	kips
P1	30.500	172.704	261.528	0.000	0.000	0.000	434.232
	ft	k/ft	k/ft	k/ft	k/ft	k/ft	k/ft
W1	0.000	1.062	0.685	0.000	0.000	0.000	1.747
W2	61.000	1.062	0.685	0.000	0.000	0.000	1.747

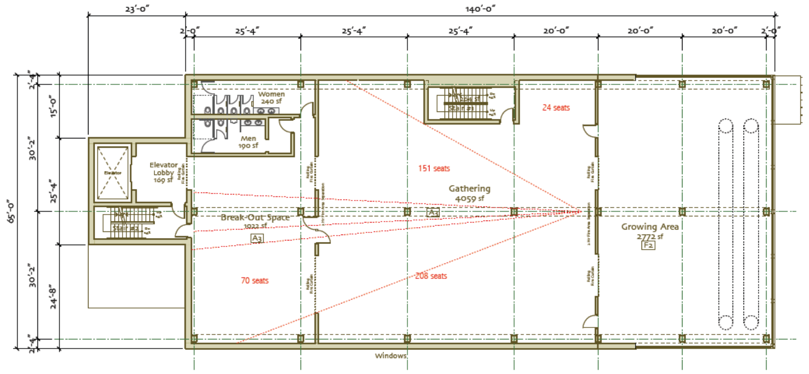
Dimensions

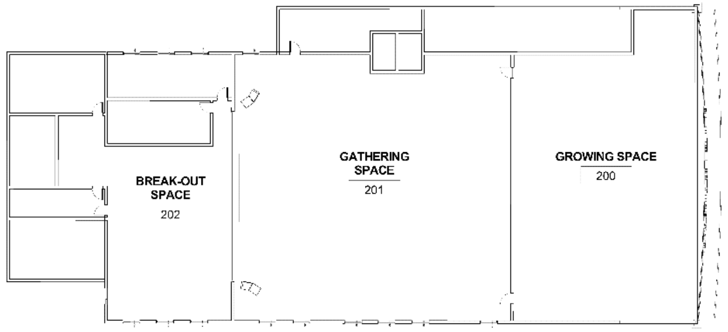


b1 = 30.000 [in] Plate Width (top)
b2 = 30.000 [in] Plate Width (bot)
bf = 16.700 [in] Flange width
d = 38.000 [in] Depth
t1 = 2.000 [in] Plate Thickness (top)
t2 = 2.000 [in] Plate Thickness (bot)
tf = 2.010 [in] Flange thickness
tw = 1.120 [in] Web thickness



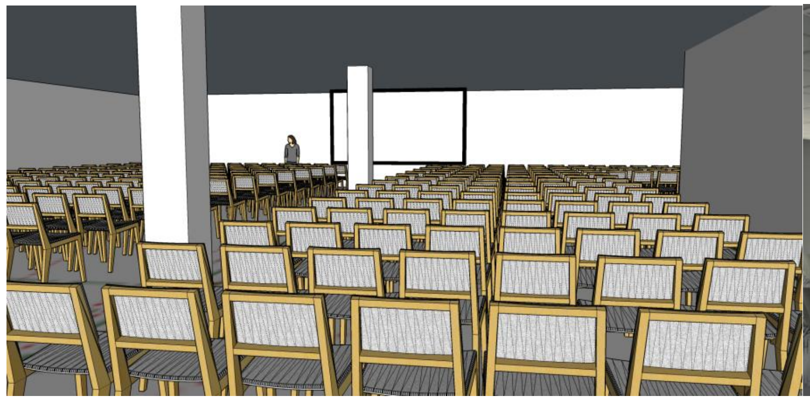




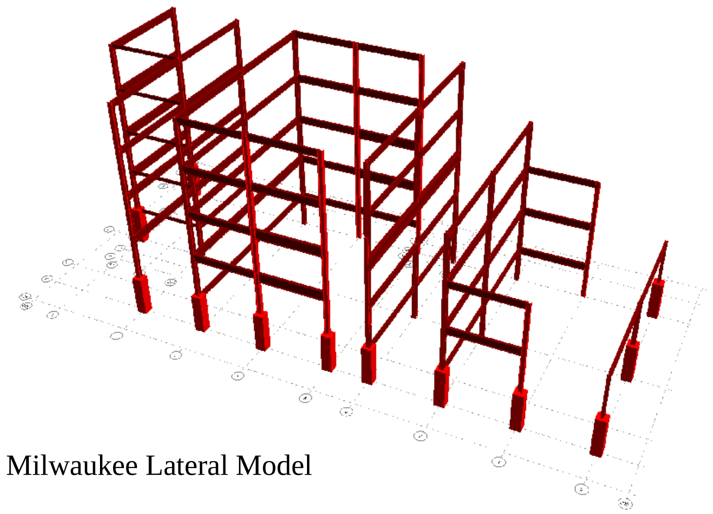


Properties

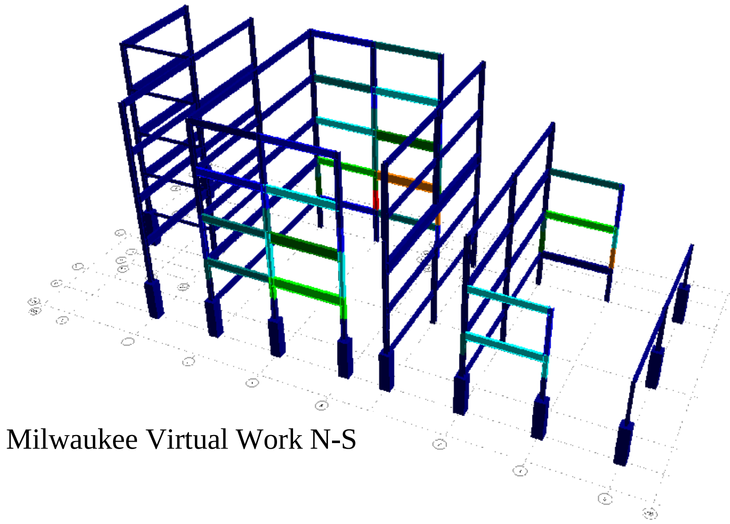
Section properties	Unit	Major axis	Minor axis
Gross area of the section. (Ag)	[in2]	227.443	
Moment of Inertia (local axes) (I)	[in4]	74152.868	10564.464
Moment of Inertia (principal axes) (I')	[in4]	74152.868	10564.464
Bending constant for moments (principal axis) (J')	[in]	0.000	0.000
Radius of gyration (local axes) (r)	[in]	18.056	6.815
Radius of gyration (principal axes) (r')	[in]	18.056	6.815
Saint-Venant torsion constant. (J)	[in4]	267.264	
Section warping constant. (Cw)	[in6]	3.74E+06	
Distance from centroid to shear center (principal axis) (xo,yo)	[in]	0.000	0.000
Top elastic section modulus of the section (local axis) (Ssup)	[in3]	3531.089	704.298
Bottom elastic section modulus of the section (local axis) (Sinf)	[in3]	3531.089	704.298
Top elastic section modulus of the section (principal axis) (S'sup)	[in3]	3531.089	704.298
Bottom elastic section modulus of the section (principal axis) (S'inf)	[in3]	3531.089	704.298
Plastic section modulus (local axis) (Z)	[in3]	3970.755	1180.284
Plastic section modulus (principal axis) (Z')	[in3]	3970.755	1180.284
Polar radius of gyration. (ro)	[in]	19.300	
Area for shear (Aw)	[in2]	187.134	40.309
Torsional constant. (C)	[in3]	132.967	



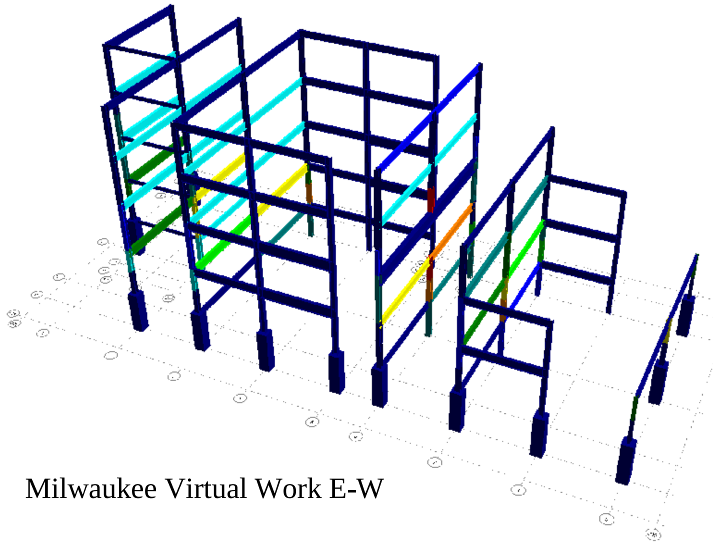
LATERAL SYSTEM DESIGN AND ANALYSIS



Milwaukee Lateral Model



Milwaukee Virtual Work N-S



Milwaukee Virtual Work E-W

The versatility of moment frames aligned directly with the project initiative of flexibility. In order to design the members, a preliminary lateral analysis was performed and the resulting forces were combined using the following effective axial load equation.

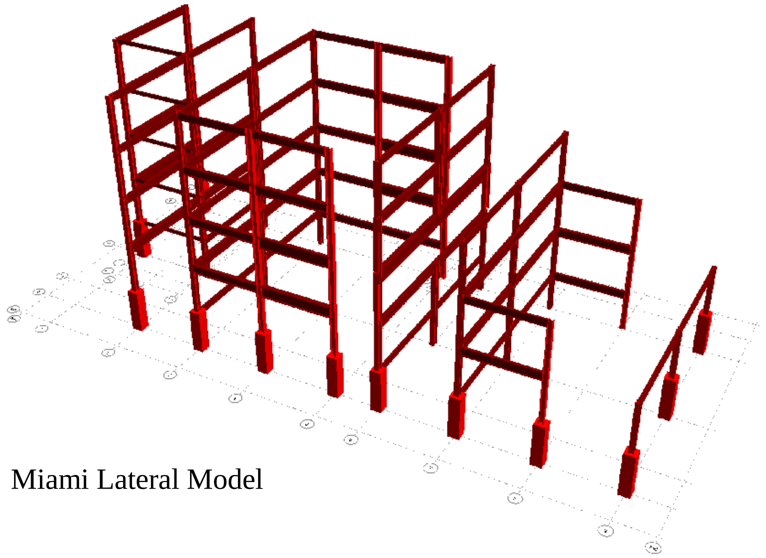
$$P_{eff} = P_r + mM_{rx} + mUM_{ry}$$

Where: P_r, M_{rx}, and M_{ry} are the required axial, strong axis moment, and weak axis moment respectively, accounting for P-Δ effects. U and m are constants that depend on the nominal column size. U = 2.86 and m = 1.71 for a W14 column, which was chosen because drifts typically control in moment frames. After the initial columns were selected, the virtual work method was utilized to maximize the economy of the system. The virtual work method calculates displacement participation factors based on volume, and member specific contributions based on axial, shear, flexural, and joint contribution. The most common factor utilized was the Total Displacement/Volume, which identified the members that were contributing the most to the story deflection. Multiple iterations of upsizing specific members were completed until the story drift met the goal of H/400.

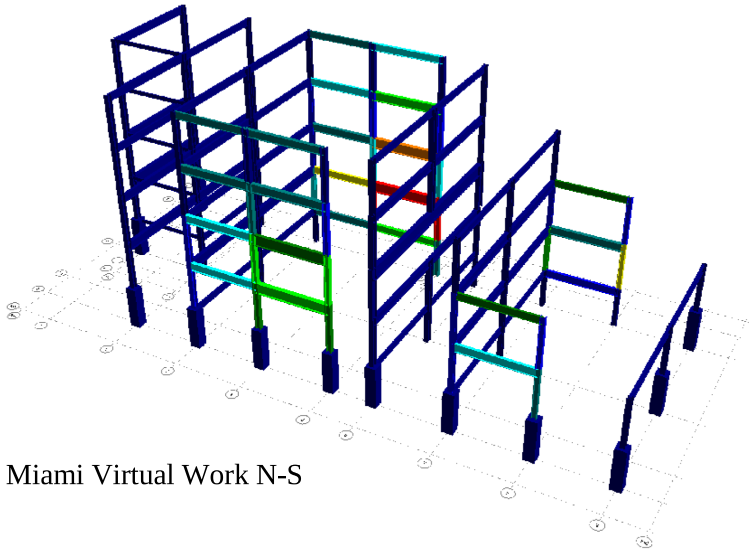
Virtual Work Model Colors	
⬛	0.00-0.19
🟦	0.20-0.29
🟦	0.30-0.39
🟦	0.40-0.49
🟩	0.50-0.59
🟩	0.60-0.69
🟨	0.70-0.79
🟧	0.80-0.89
🟥	0.90-1.00

Preliminary Column Design for Moment Frames

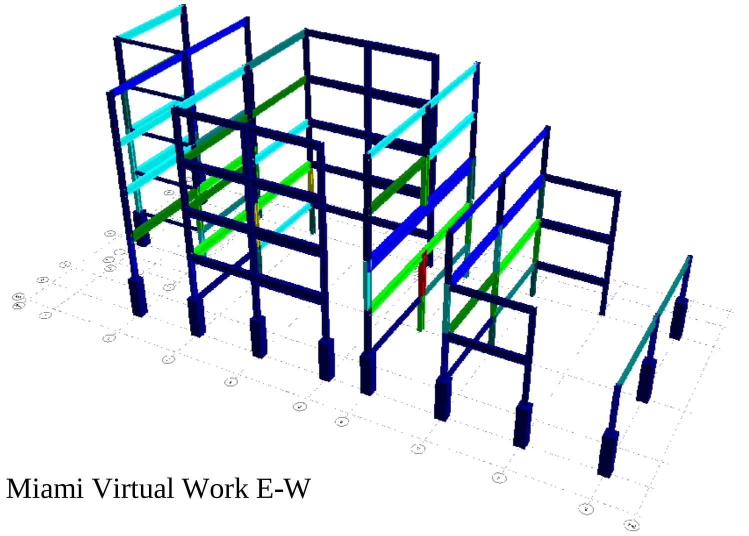
	Max of P	Max of Mmajor	Max of Mminor	Max of Peffective	Sizes				Capacity	USR
⊟ C	**1021**	**939**	**497**	**2721**						
2	641	347	67	1128	W	14	x	99	1130	100%
4	922	350	190	1617	W	14	x	145	1690	96%
5	594	269	67	938	W	14	x	90	1030	91%
8	1021	842	140	2471	W	14	x	233	2730	91%
12	415	273	26	719	W	14	x	82	772	93%
14	976	229	188	1484	W	14	x	132	1510	98%
15	551	178	309	1834	W	14	x	159	1850	99%
18	470	337	21	818	W	14	x	90	1030	79%
41	801	347	190	1660	W	14	x	145	1690	98%
42	683	497	91	1419	W	14	x	132	1510	94%
43	777	333	199	1530	W	14	x	145	1690	91%
44	840	939	203	2697	W	14	x	233	2730	99%
45	625	772	149	2137	W	14	x	193	2250	95%
46	738	731	297	2015	W	14	x	176	2050	98%
47	432	228	290	1702	W	14	x	159	1850	92%
52	330	568	35	1269	W	14	x	120	1370	93%
55	353	691	21	1328	W	14	x	120	1370	97%
57	111	227	41	557	W	14	x	61	571	98%
59	210	284	100	877	W	14	x	90	1030	85%
60	132	245	50	643	W	14	x	74	701	92%
62	183	649	12	1242	W	14	x	120	1370	91%
63	669	452	190	1819	W	14	x	159	1850	98%
64	524	478	20	1233	W	14	x	109	1240	99%
65	614	728	91	1701	W	14	x	159	1850	92%
66	690	236	199	1519	W	14	x	145	1690	90%
78	182	50	245	1362	*Concrete Piers (Steel Sizing Not Applicable)*					
79	281	100	284	1641						
80	119	41	227	1228						
81	369	555	35	1293						
82	472	181	230	1573						
83	775	297	325	2204						
84	663	772	149	2161						
85	879	939	203	2721						
86	482	93	325	1867						
87	321	51	376	2115						
90	258	27	497	2700						
91	306	44	339	1956						



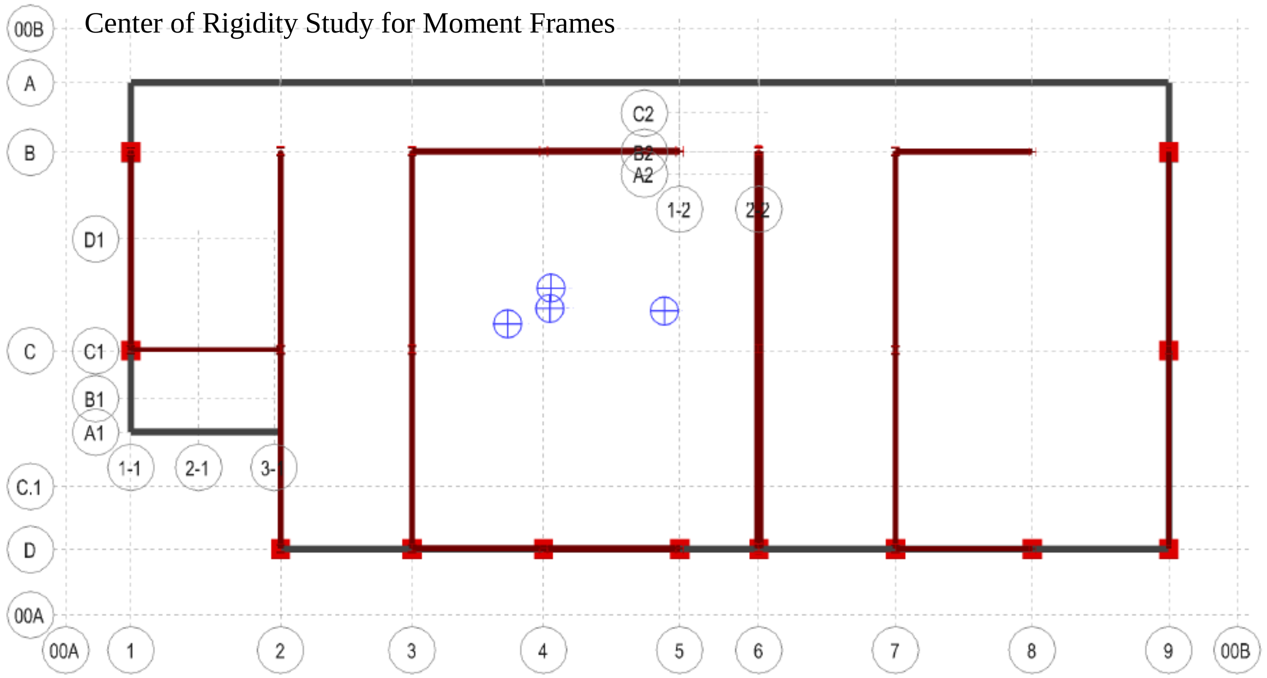
Miami Lateral Model



Miami Virtual Work N-S

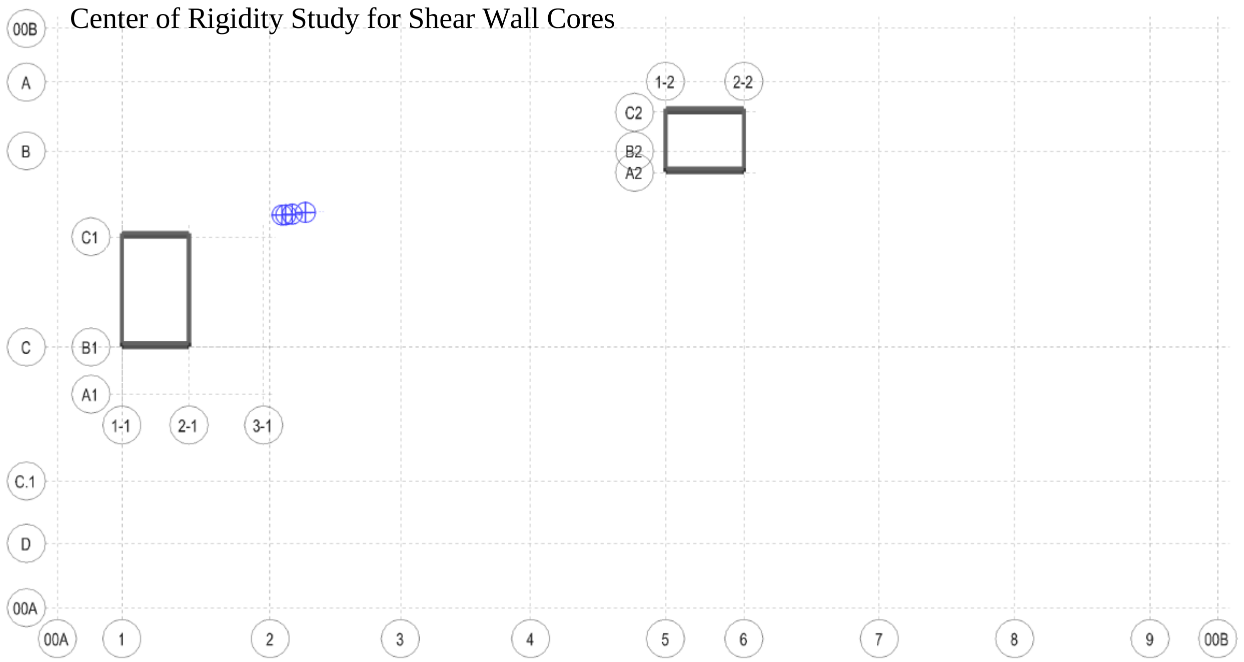


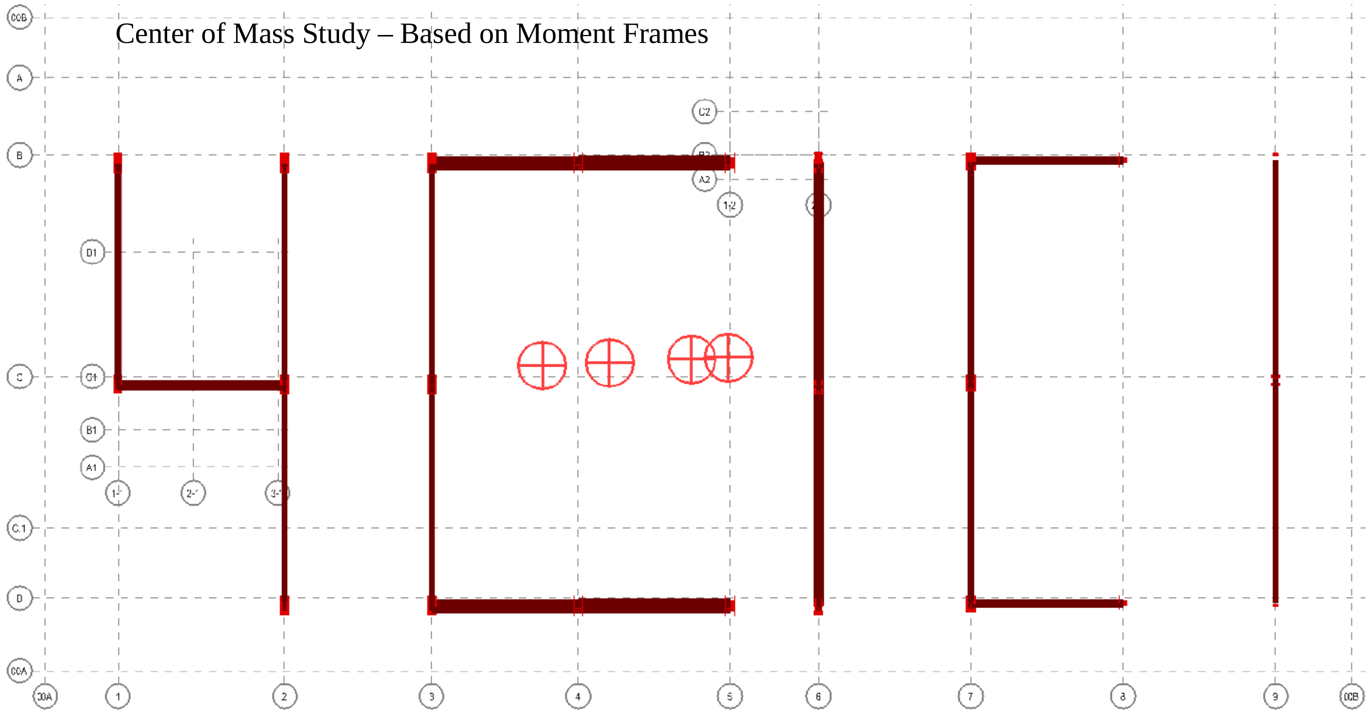
Miami Virtual Work E-W


Center of Rigidity Study for Moment Frames

The final lateral system utilized moment frames in each direction to limit the building drift. The selection of moment frames enhanced the ability of the structural design to be utilized in future locations, as members can be upsized, while maintaining the configuration of the system as a whole, and minimizing any impact on other building systems or components. The alternate lateral system used shear walls at the two elevator cores, but the eccentricity of the center of rigidity in this system was larger than that of the moment frames, as shown in images on the left. The eccentricity is very noticeable when compared to the center of mass diagram, shown below. Because the building steps back, the center of pressure caused by the wind force is comparable in location to the center of mass at each floor.

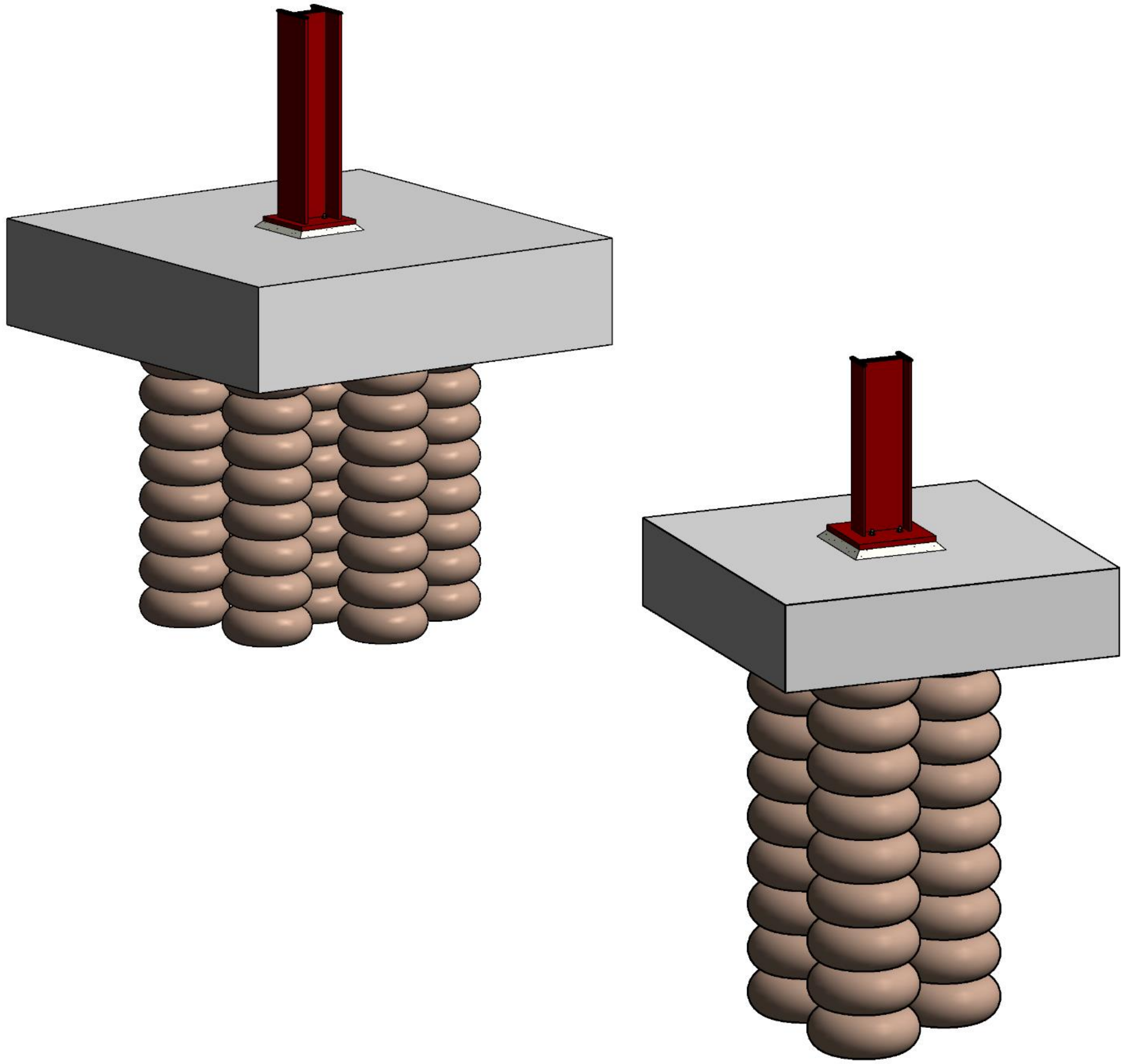
Legend	
⊕	Center of Rigidity (*Multiple Levels Shown on Figures*)
⊕	Center of Mass (*Multiple Levels Shown on Figure*)

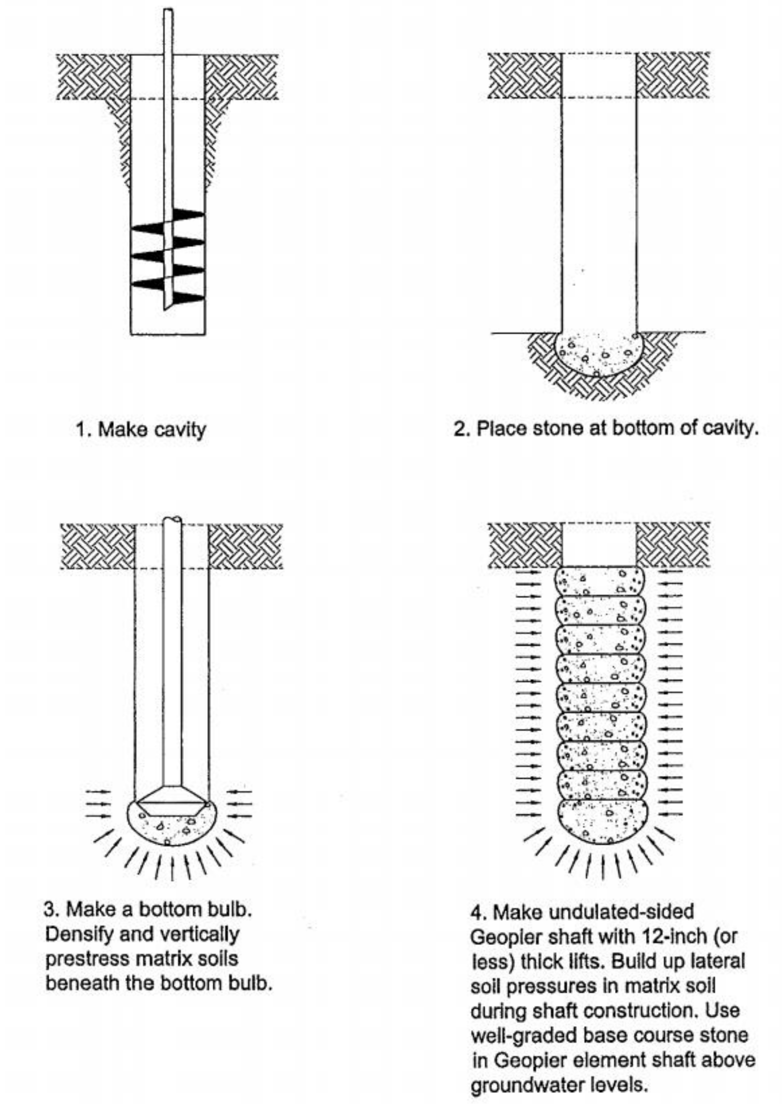

Center of Rigidity Study for Shear Wall Cores


Center of Mass Study – Based on Moment Frames

FOUNDATION SYSTEM DESIGN AND ANALYSIS

The structural partners explored several different methods for the foundation system, including MAT foundation and typical spread footings. However, the team decided to utilize Geopier® soil reinforcement to improve the allowable bearing capacity for the footings. The process, displayed below, involved constructing Rammed Aggregate Piers® in order to create lateral soil pressure, which increases the allowable bearing capacity. Footings were then designed utilizing RAM SS. The structural partners also designed 12" thick foundation walls in the basement, as shown in the section to the right.



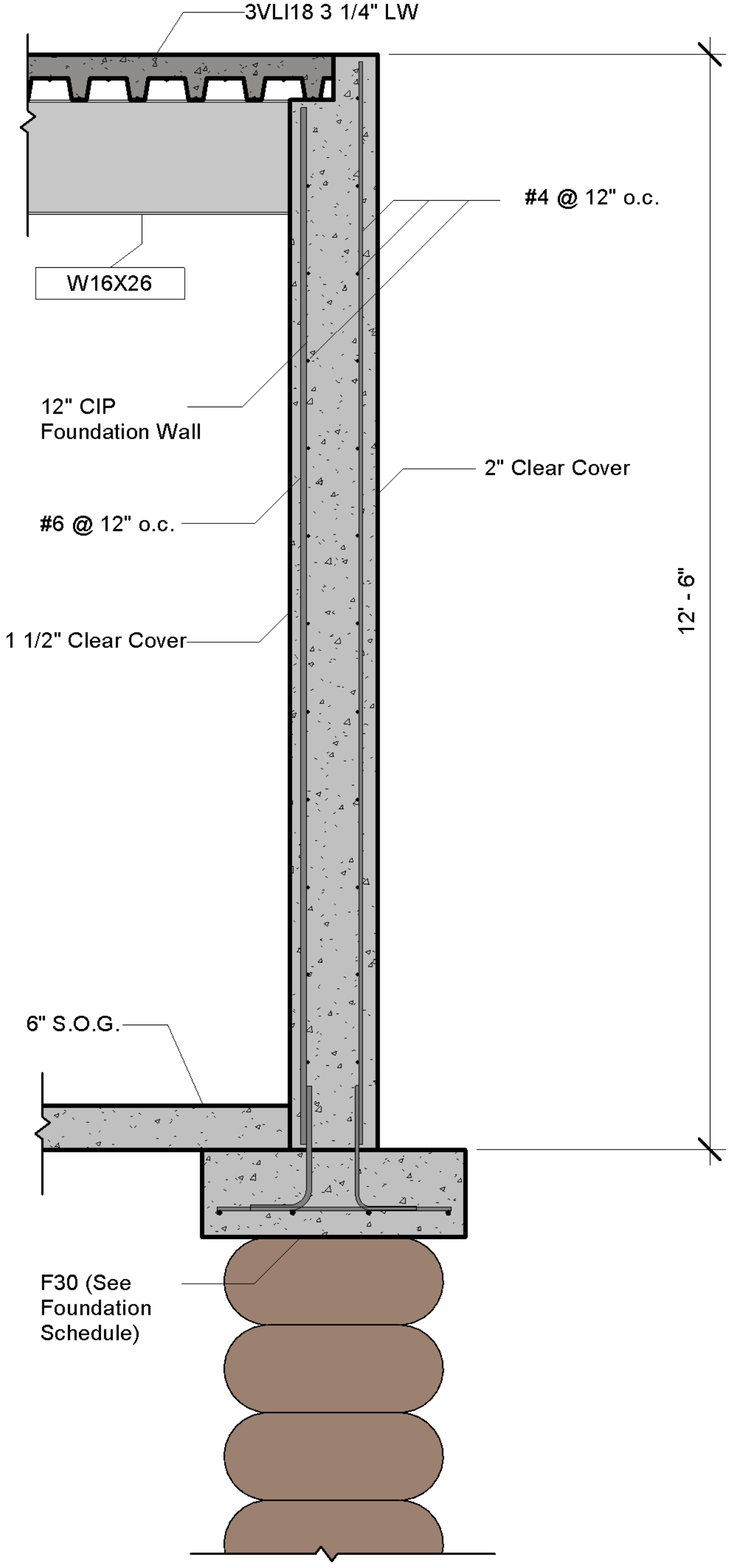


1. Make cavity

2. Place stone at bottom of cavity.

3. Make a bottom bulb. Densify and vertically prestress matrix soils beneath the bottom bulb.

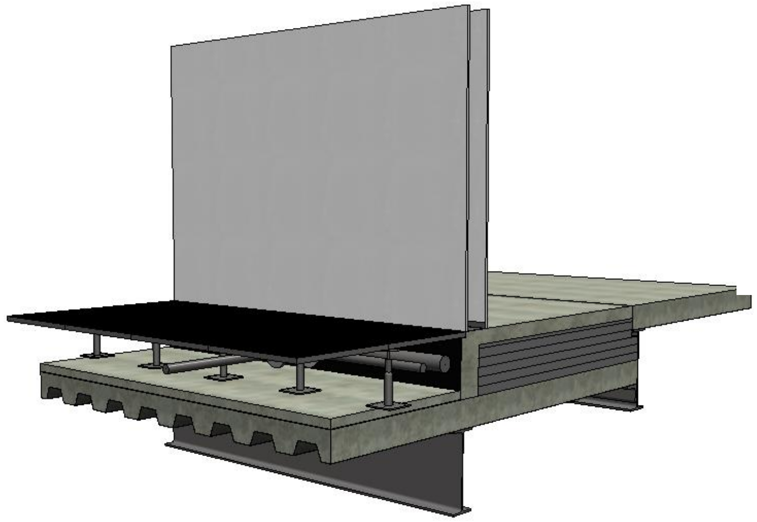
4. Make undulated-sided Geopier shaft with 12-inch (or less) thick lifts. Build up lateral soil pressures in matrix soil during shaft construction. Use well-graded base course stone in Geopier element shaft above groundwater levels.



GREENHOUSE DESIGN AND ANALYSIS

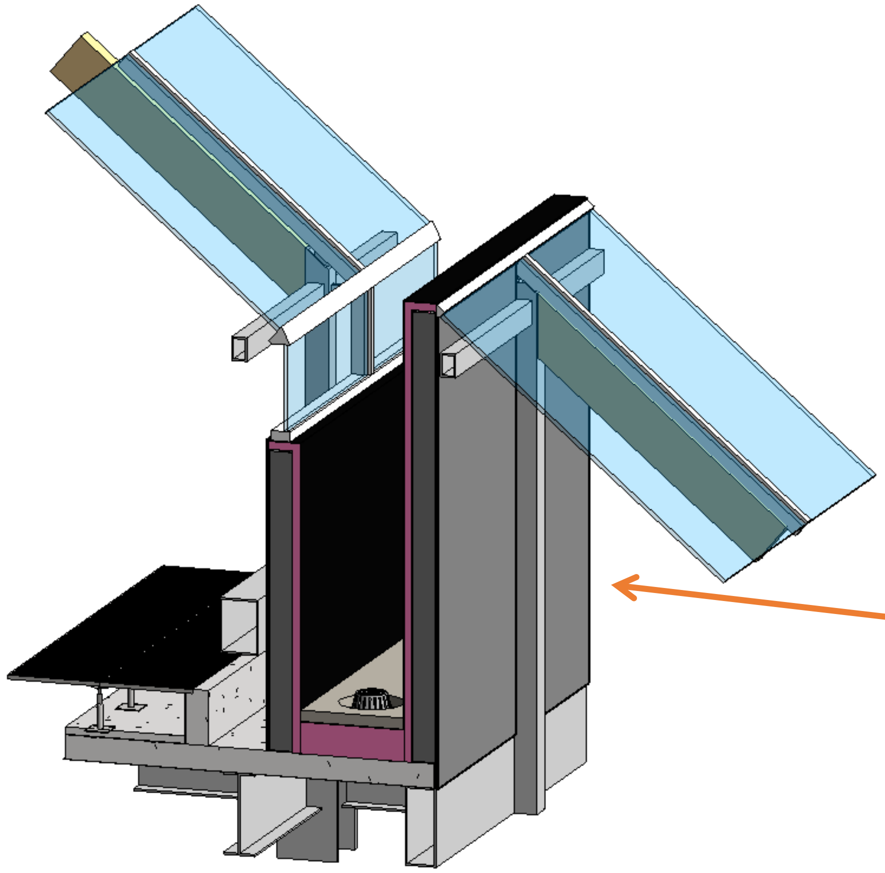
CASCADING GREENHOUSES

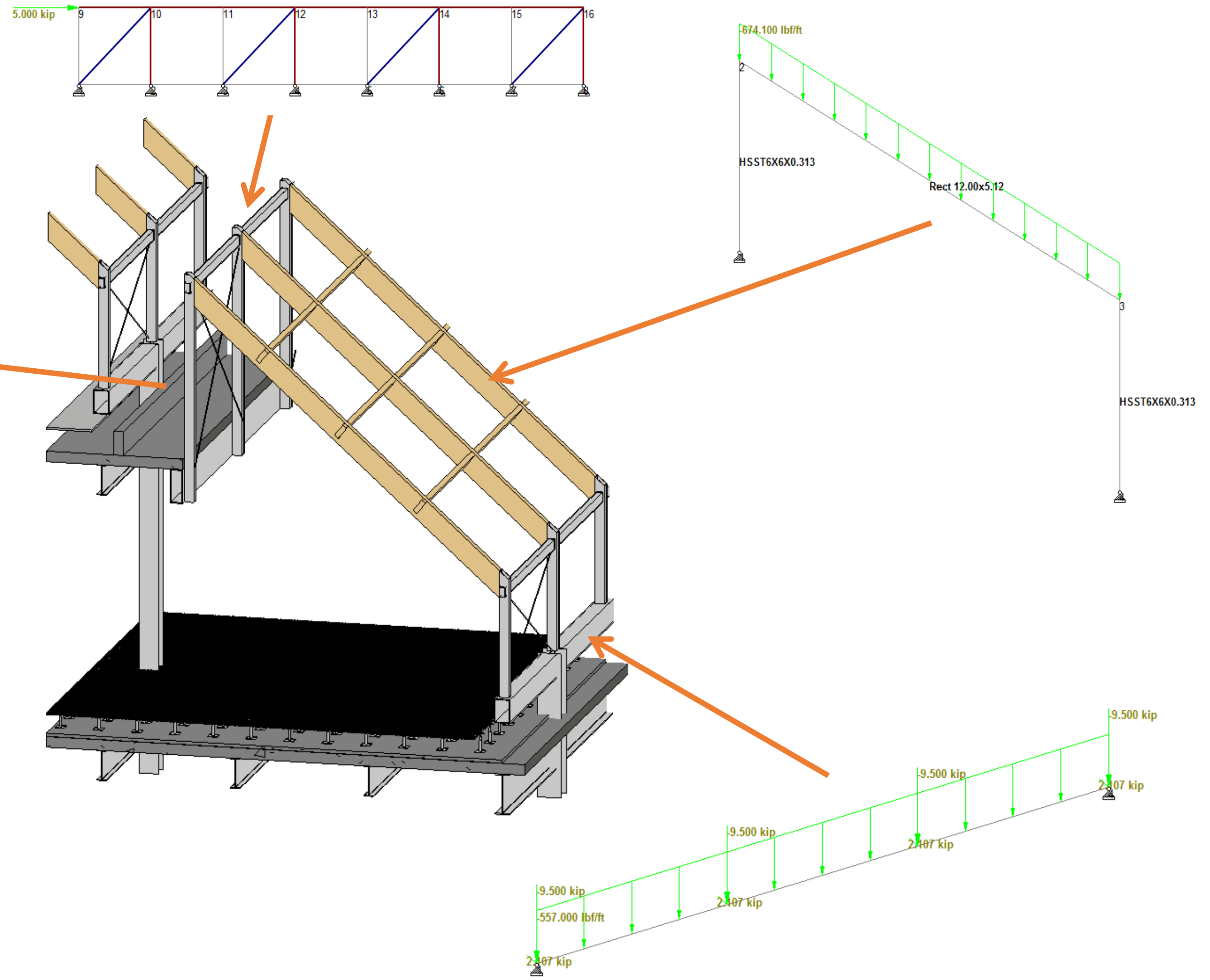
The design of the greenhouses provided an opportunity to develop and utilize various non-traditional structural schemes, matching the atypical nature of the spaces, while coordinating and integrating with the other building systems. The structural design in the greenhouses can be broken down into four main areas: the cascading greenhouse roofs, the top greenhouse roof, the rainwater collection troughs, and the grate system.



The raised floor grate system was developed to provide an unobstructed greenhouse floor, enabling Growing Power to more easily guide community tours through the space. The grate system allows piping and pumps to be place in the plenum space. In addition, the grate system helps facilitate proper drainage as the sloped topping slab is unblocked, other than the grate system feet, so water can proper flow to the bi-level drains.

The cascading greenhouse roof structure was designed utilizing 24F-V4 glulam members, indicating a bending stress of 2,400 psi and unbalanced layup of laminations. Glulam by Boise Cascade Engineered Wood Products is typically manufactured from Douglas Fir-Larch. (13) Architectural Appearance glulam members shall be used to provide the desired aesthetic characteristics. Preservative treatment shall be applied, in addition to the non-toxic pigmented acrylic latex paint or pigmented alkyd paint, to ensure the glulam is protected against moisture effects.





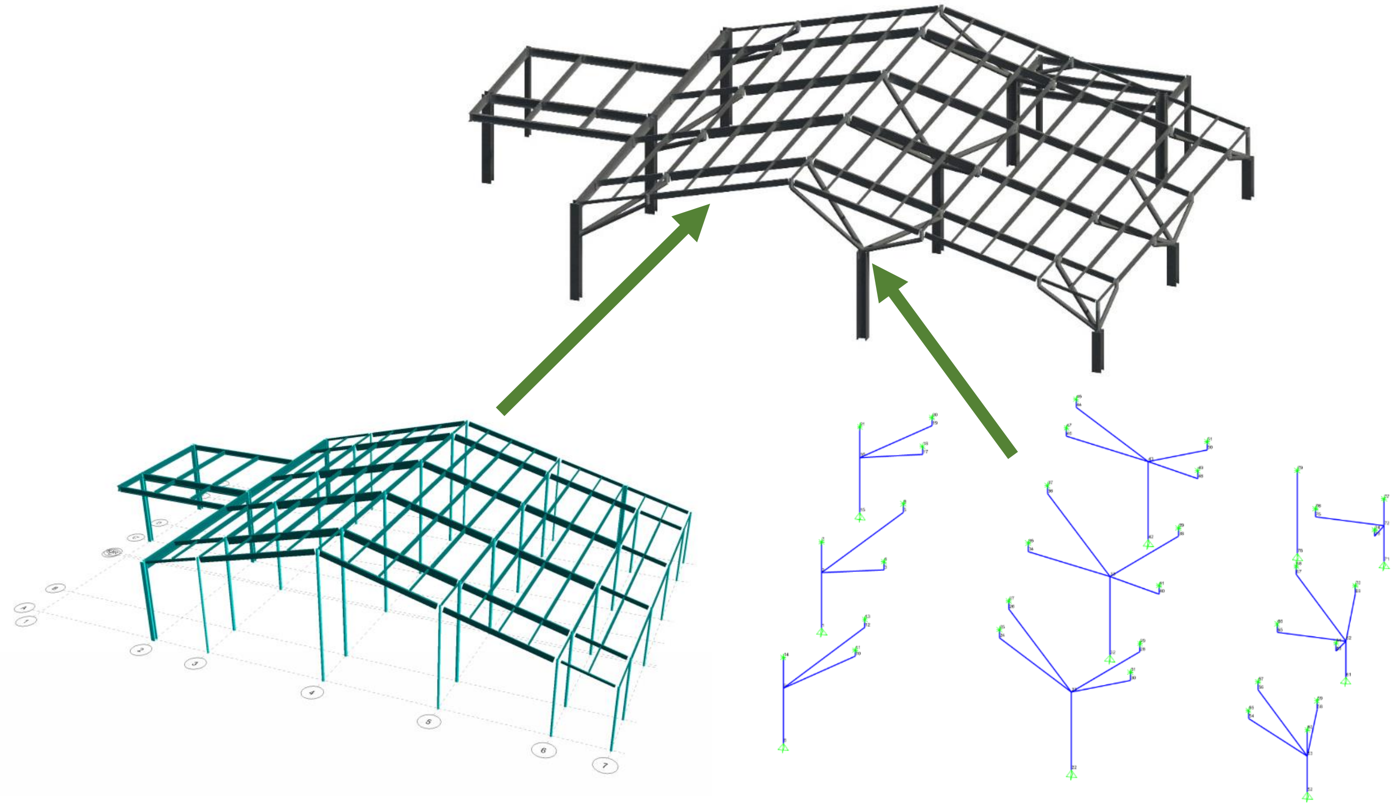
The cascading greenhouse roofs were designed utilizing renewable glulam members framing into HSS components. As the design is comprised of a number of different parts, several STAAD models were created to analyze the components independently while applying loads from one model to another as appropriate. The glulam members and HSS stub columns were modeled as a rigid frame to develop a design that limited deflections. The reactions from this model were then applied to the horizontal HSS members to examine the bi-axial bending that results from the rigid frame. The lateral system was studied with a truss model, relying on X-bracing tension rods to provide the lateral support.

The rainwater collection trough was designed in conjunction with the mechanical system. The trough was lined with waterproofing membrane and features bi-level drains to ensure proper water drainage. The trough sides and surrounding structure were designed to hold a full load of snow in the event that the drains clog and snow slides off of the greenhouse roofs rather than melting.

TOP GREENHOUSE

The top greenhouse design was conducted utilizing tree-columns after exploring a number of different options. Tree-columns were found to best balance the efficiency of structural members with the PAR levels within the greenhouses. The tree-columns enabled the structural partners to minimize structural member sizes while limiting columns impeding the greenhouse floor area by increasing the number of support points for the purlins. The structural concept was modeled in RAM SS and SAP 2000 to verify design. The base reactions were then applied to the model of the base building.

The table to the right is a comparison study done to maximize daylighting efficiency as well as structural economy. The ideal lighting angle for Milwaukee is 40 degrees, used in the cascading greenhouses. However this angle was not practical since it would result in a roof story height of ~70, which more than doubles the existing height. Based on the original profile and resulting heights, the 15 degree angle chosen allowed for the best compromise between structural and lighting disciplines.



Top Greenhouse Roof Slope Comparison

Start Height	10				
Length	73.5				
Roof Slope (Degrees)	*Start Height*	*Length*	*Change in Height*	*Total Final Height*	*Total Building Height*
0	10	73.5	0	10	66
1	10	73.5	1.3	11.3	67.3
2	10	73.5	2.6	12.6	68.6
3	10	73.5	3.9	13.9	69.9
4	10	73.5	5.1	15.1	71.1
5	10	73.5	6.4	16.4	72.4
6	10	73.5	7.7	17.7	73.7
7	10	73.5	9.0	19.0	75.0
8	10	73.5	10.3	20.3	76.3
9	10	73.5	11.6	21.6	77.6
10	10	73.5	13.0	23.0	79.0
11	10	73.5	14.3	24.3	80.3
12	10	73.5	15.6	25.6	81.6
13	10	73.5	17.0	27.0	83.0
14	10	73.5	18.3	28.3	84.3
15	10	73.5	19.7	29.7	85.7
16	10	73.5	21.1	31.1	87.1
17	10	73.5	22.5	32.5	88.5
18	10	73.5	23.9	33.9	89.9
19	10	73.5	25.3	35.3	91.3
20	10	73.5	26.8	36.8	92.8
22	10	73.5	29.7	39.7	95.7
24	10	73.5	32.7	42.7	98.7
26	10	73.5	35.8	45.8	101.8
28	10	73.5	39.1	49.1	105.1
30	10	73.5	42.4	52.4	108.4
32	10	73.5	45.9	55.9	111.9
34	10	73.5	49.6	59.6	115.6
36	10	73.5	53.4	63.4	119.4
38	10	73.5	57.4	67.4	123.4
40	10	73.5	61.7	71.7	127.7
42	10	73.5	66.2	76.2	132.2
44	10	73.5	71.0	81.0	137.0
45	10	73.5	73.5	83.5	139.5

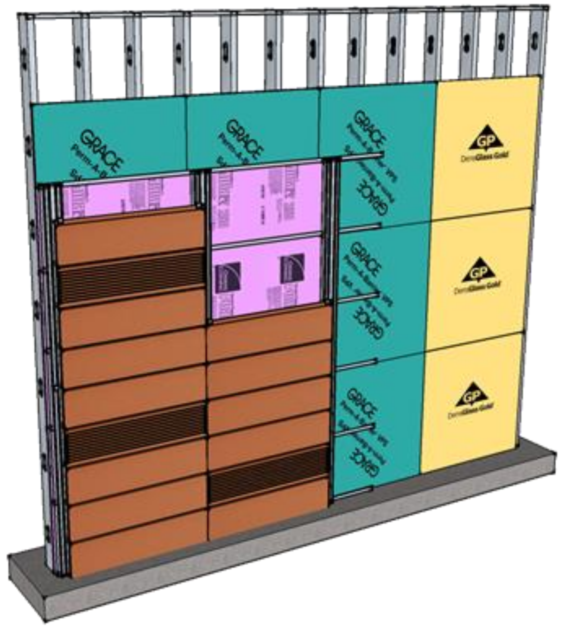
Façade Study

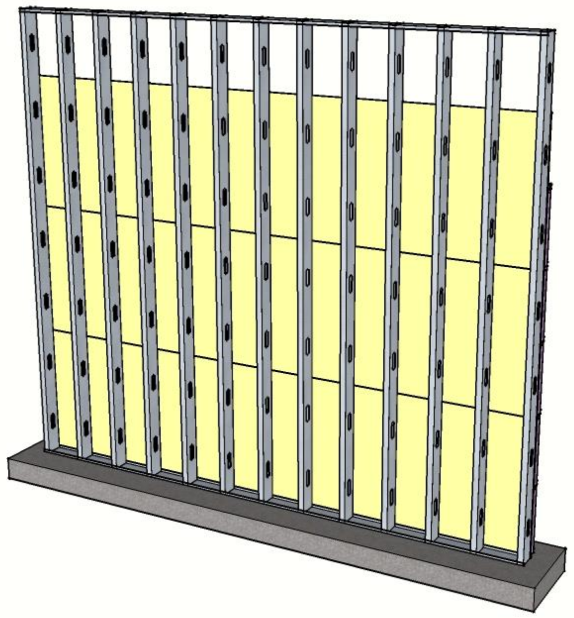
The rain screen façade attaches to clips which tie back to the cold-formed steel stud backup wall. The selection of the studs enabled the design to be more easily transferred to future locations, such as Miami, as the stud size and gage could be adjusted to meet the wind loading for each location. A spreadsheet was created to select studs based on the loading conditions and Clark Dietrich stud specifications. The tables to either side indicate the available stud specifications that would satisfy the façade loading conditions using AISIWIN.

Applicable Studs for Exterior Façade - Miami

Wall Height		14	ft	
Axial Load		350	plf	
Wall Weight		25	psf	
Axial Load per Stud	*8" o.c*	233	lbs	
	12" o.c	350	lbs	
	16" oc.	467	lbs	
Wind Pressure		155	psf	*Zone 5*

	Clark Dietrich Designation				**Actual Values**	
Spacing	**Depth**	**Flange Width**	**Minimum Gage**	**Fy**	**Depth**	**Gage**
8	600	137	97	50	6	12
		162	68	50	6	14
		200	68	50	6	14
		250	68	50	6	14
		300	68	50	6	14
	800	137	68	50	8	14
		162	68	50	8	14
		200	68	50	8	14
		250	68	50	8	14
		300	68	50	8	14
12	600	162	97	50	6	12
		200	97	50	6	12
		250	97	50	6	12
		300	97	50	6	12
	800	137	97	50	8	12
		162	97	50	8	12
		200	97	50	8	12
		250	97	50	8	12
		300	97	50	8	12
16	600	250	97	50	6	12
		300	97	50	6	12
	800	200	97	50	8	12
		250	97	50	8	12
		300	54	50	8	16





Applicable Studs for Exterior Façade - Milwaukee

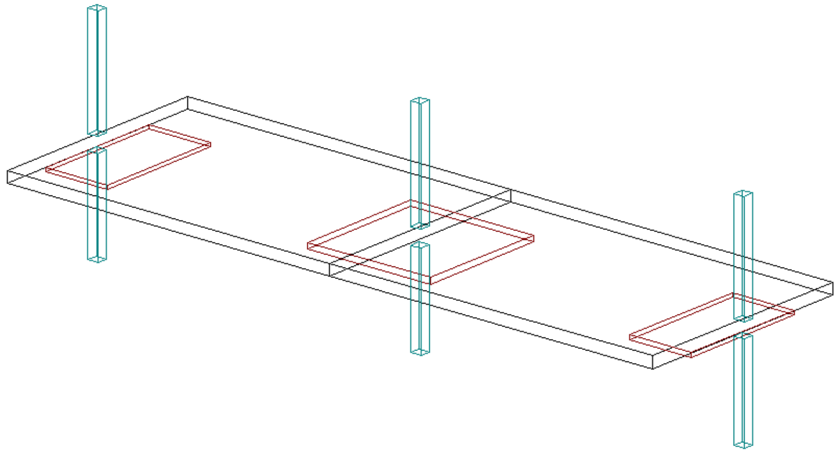
Wall Height		14	ft	
Axial Load		350	plf	
Wall Weight		25	psf	
Axial Load per Stud	*12" o.c.*	350	lbs	
	16" o.c.	467	lbs	
	24" o.c.	700	lbs	
Wind Pressure		36	psf	*Zone 5*

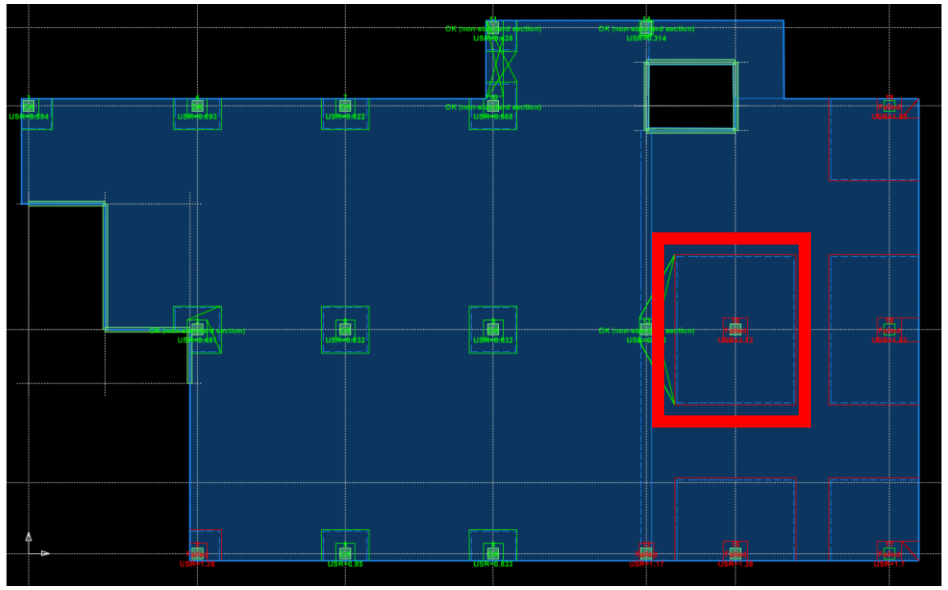
	Clark Dietrich Designation				**Actual Values**	
Spacing	*Depth*	*Flange Width*	*Minimum Gage*	*Fy*	*Depth*	*Gage*
12	600	137	54	50	6	16
		162	54	50	6	16
		200	43	50	6	18
		250	43	50	6	18
		300	54	50	6	16
	800	137	54	50	8	16
		162	54	50	8	16
		200	54	50	8	16
		250	54	50	8	16
		300	54	50	8	16
16	600	137	68	50	6	14
		162	54	50	6	16
		200	54	50	6	16
		250	54	50	6	16
		300	54	50	6	16
	800	137	54	50	8	16
		162	54	50	8	16
		200	54	50	8	16
		250	54	50	8	16
		300	54	50	8	16
24	600	137	97	50	6	12
		162	68	50	6	14
		200	68	50	6	14
		250	54	50	6	16
		300	54	50	6	16
	800	137	97	50	8	12
		162	68	50	8	14
		200	54	50	8	16
		250	54	50	8	16
		300	54	50	8	16

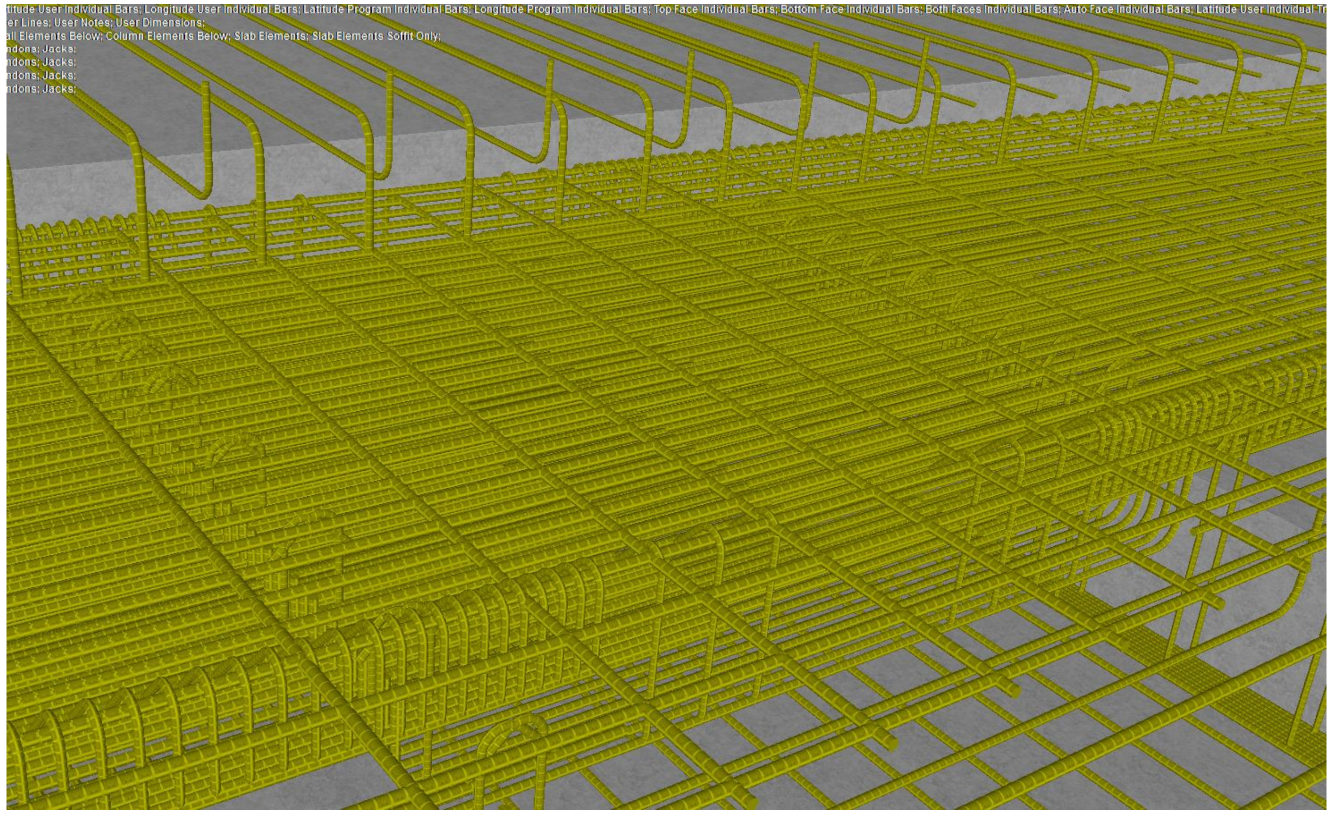
CONCRETE GRAVITY SYSTEM DESIGN AND ANALYSIS

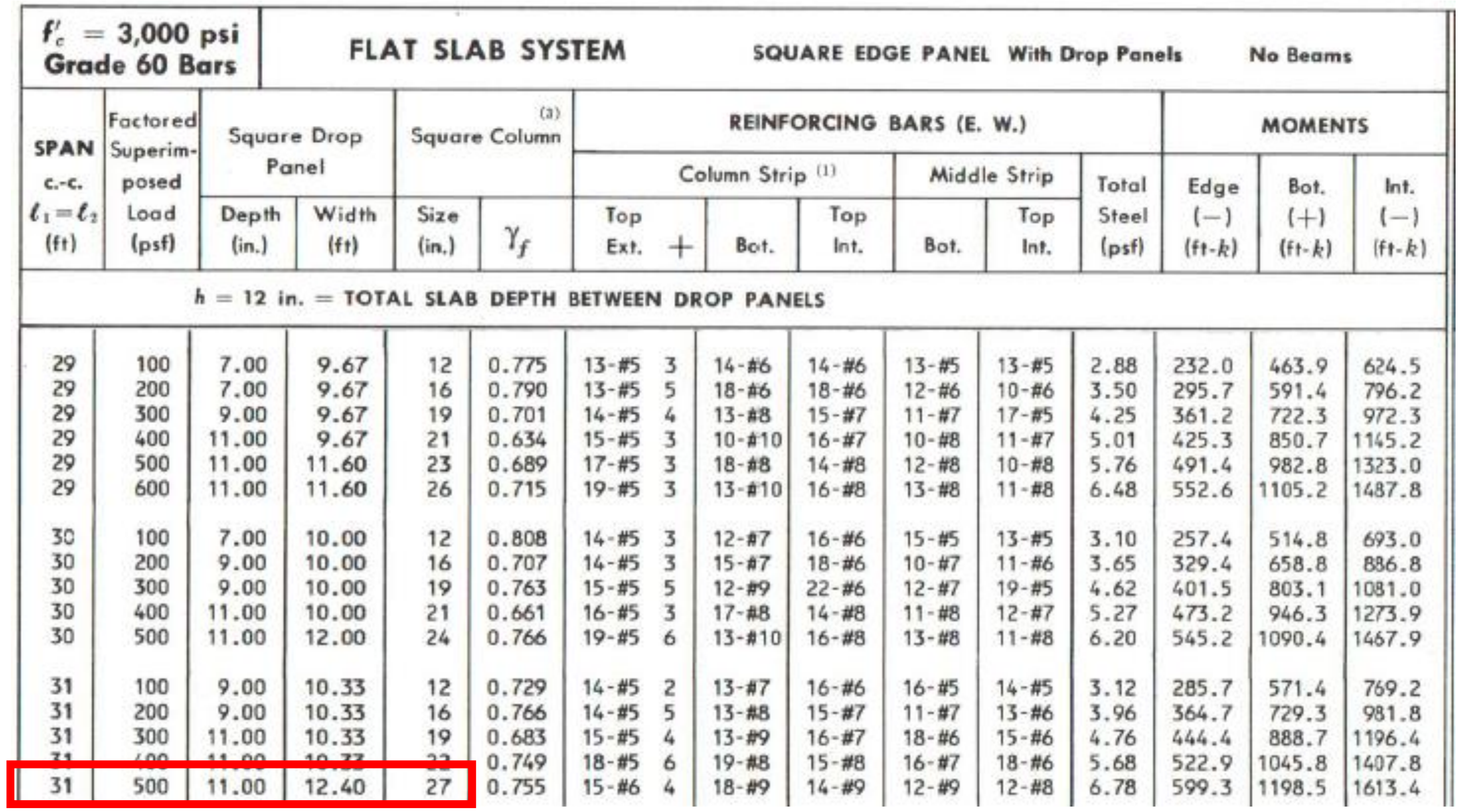
The structural partners conducted a preliminary design of a two-way concrete system with drop panels. The preliminary design was conducted with aid from spSlab and spColumn to develop baseline designs with which to proceed. Based on this information, the selection of concrete was expected to achieve a thinner depth than a structural system, which would have eased interdisciplinary coordination within the ceiling plenum. In addition, a concrete structure would have benefits in relation to vibration, durability, and fire protection. However, architectural refinement and in-depth design utilizing RAM Concept revealed an issue with shear, especially supporting the greenhouses and at the structural drop-down. The shear issues often required reinforcing at extremely close spacing, often not meeting code. In order to remedy the issues, more concrete and reinforcing were necessary which cause more shear, creating a loop. In addition, the high building mass was a major concern given the bearing capacity provided in the Geotechnical Exploration Report. The CRSI Design Handbook was also used to provide a rough baseline for the preliminary design.

The plan to the right shows the excessive measures taken to attempt to limit punching shear. The highlighted drop panel was 20’ x 18’ and 22” below the slab for a total depth of 30”. Even with this large amount of concrete, the high live loads of the greenhouses were causing the concrete to fail.









f'_c = 3,000 psi
Grade 60 Bars

FLAT SLAB SYSTEM **SQUARE EDGE PANEL With Drop Panels** **No Beams**

h = 12 in. = TOTAL SLAB DEPTH BETWEEN DROP PANELS

SPAN c.-c. $\ell_1 = \ell_2$ (ft)	Factored Superimposed Load (psf)	Square Drop Panel		Square Column [(a)]		REINFORCING BARS (E. W.)							MOMENTS		
						Column Strip [(1)]				Middle Strip		Total Steel (psf)	Edge (−) (ft-k)	Bot. (+) (ft-k)	Int. (−) (ft-k)
		Depth (in.)	Width (ft)	Size (in.)	γ_f	Top Ext.	+	Bot.	Top Int.	Bot.	Top Int.				
29	100	7.00	9.67	12	0.775	13-#5	3	14-#6	14-#6	13-#5	13-#5	2.88	232.0	463.9	624.5
29	200	7.00	9.67	16	0.790	13-#5	5	18-#6	18-#6	12-#6	10-#6	3.50	295.7	591.4	796.2
29	300	9.00	9.67	19	0.701	14-#5	4	13-#8	15-#7	11-#7	17-#5	4.25	361.2	722.3	972.3
29	400	11.00	9.67	21	0.634	15-#5	3	10-#10	16-#7	10-#8	11-#7	5.01	425.3	850.7	1145.2
29	500	11.00	11.60	23	0.689	17-#5	3	18-#8	14-#8	12-#8	10-#8	5.76	491.4	982.8	1323.0
29	600	11.00	11.60	26	0.715	19-#5	3	13-#10	16-#8	13-#8	11-#8	6.48	552.6	1105.2	1487.8
30	100	7.00	10.00	12	0.808	14-#5	3	12-#7	16-#6	15-#5	13-#5	3.10	257.4	514.8	693.0
30	200	9.00	10.00	16	0.707	14-#5	3	15-#7	18-#6	10-#7	11-#6	3.65	329.4	658.8	886.8
30	300	9.00	10.00	19	0.763	15-#5	5	12-#9	22-#6	12-#7	19-#5	4.62	401.5	803.1	1081.0
30	400	11.00	10.00	21	0.661	16-#5	3	17-#8	14-#8	11-#8	12-#7	5.27	473.2	946.3	1273.9
30	500	11.00	12.00	24	0.766	19-#5	6	13-#10	16-#8	13-#8	11-#8	6.20	545.2	1090.4	1467.9
31	100	9.00	10.33	12	0.729	14-#5	2	13-#7	16-#6	16-#5	14-#5	3.12	285.7	571.4	769.2
31	200	9.00	10.33	16	0.766	14-#5	5	13-#8	15-#7	11-#7	13-#6	3.96	364.7	729.3	981.8
31	300	11.00	10.33	19	0.683	15-#5	4	13-#9	16-#7	18-#6	15-#6	4.76	444.4	888.7	1196.4
31	400	11.00	10.33	22	0.749	18-#5	6	19-#8	15-#8	16-#7	18-#6	5.68	522.9	1045.8	1407.8
31	500	11.00	12.40	27	0.755	15-#6	4	18-#9	14-#9	12-#9	12-#8	6.78	599.3	1198.5	1613.4