IV. Curtain Wall Design Analysis

Introduction

The building's façade is primarily a glazed aluminum curtain wall with the exception of some areas around the parking garage. The curtain wall ties into the cast-in-place concrete structure through steel anchor plates. On the west elevation, the curtain wall is sloped outward at 5.63^o all the way from lobby floor up to the roof of the building. The slope of the curtain wall can be seen in **Figure 4.1** outlined by the arrow in the box.
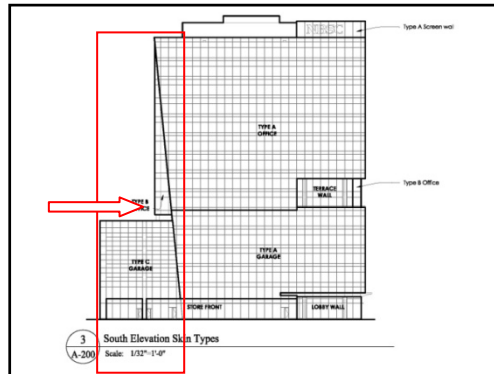

Figure 4.1: South Elevation

Problem Statement

This design adds to the complexity of constructing the curtain wall. The complexity comes from having to install different shaped pieces of glass at different angles. **Figure 4.2** shows the sloped wall joining the vertical wall where unique curtain wall panels will be necessary. The different shaped pieces of glass necessary will add to the cost since this eliminates the opportunity to order in a mass quantity. This curtain wall design also eliminates some floor area of the building on the lower levels. If the slope is eliminated and more square footage is provided, the owner could increase the cost to its tenants because he is providing more leasable area.
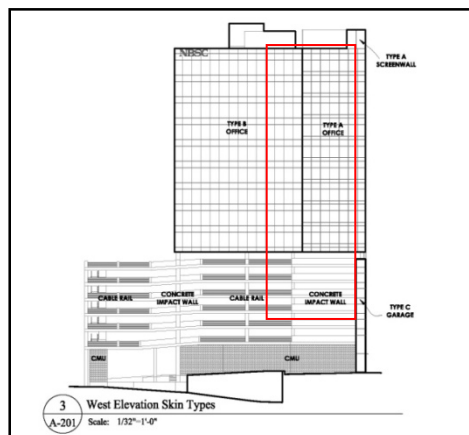

Figure 4.2: West Elevation

Analysis Goal

The goal of this analysis is to understand what the implications are of eliminating the slope in the curtain wall. Eliminating the slope will be done by extending the shorter horizontal distance to line up in the same plane as the longer horizontal distance at the top of the building. This can be seen in **Figure 4.3.** This would provide more square footage to the building's leasing area. Adding more square footage requires adding more concrete slab area to the floor plan. This will change the demands of the structure, specifically the columns located near the curtain wall. Changing the slope of the curtain wall will affect how the sun shines through the glazing. If the new sun angles on the façade changes in a way that increases solar gain through the window significantly, it could heighten the energy demands of the cooling system during the summer months.
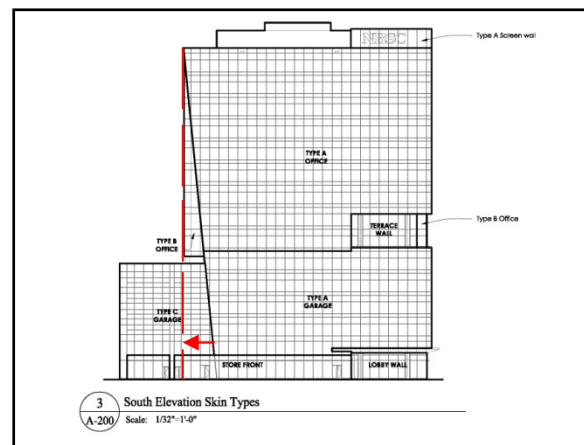
Figure 4.3: Curtain Wall Extension

Analysis Methods

The first section of this analysis will consider the area gained with an expanded floor plan. Floor plans are provided to obtain a clearer picture of the advantages with extending the floor plan. A table is included that provides the amount of extra square footage added to the floor plans. Finally, with the additional floor area, the extra money the owner can obtain from this new leasable area is suggested.

The second section analyzes the new demands of the structure to support the curtain wall vertical to the ground. It will be necessary to add any columns, beams or joists to support the additional concrete slab. After the necessary structural elements are implemented, the construction costs of these items are calculated.

The third section involves analyzing the solar gain through the curtain wall. The location of the proposed curtain wall revision is on the west elevation. The sun angles during the later portion of the day will have the most impact on the curtain wall. If the solar gain is considerable, it might change the energy demands of the cooling system during the summer months.

Additional Area Analysis

By eliminating the slope of the curtain wall and extending the wall, the floor plan increases the square footage available. Starting with the ninth floor, which is the first office level, the most area is gained and the increments of area obtained slowly declines as the wall extends to the roof level. The areas gained in the floor plans can be seen in **Figure 4.4**. A red box outlines the new areas obtained. Also indicated in **Figure 4.4** is a red circle, which shows where the floor plan cannot be utilized effectively. The tenant might find it difficult to locate an office around the column near the red circle. If the floor plan is extended, the area can be utilized more efficiently.
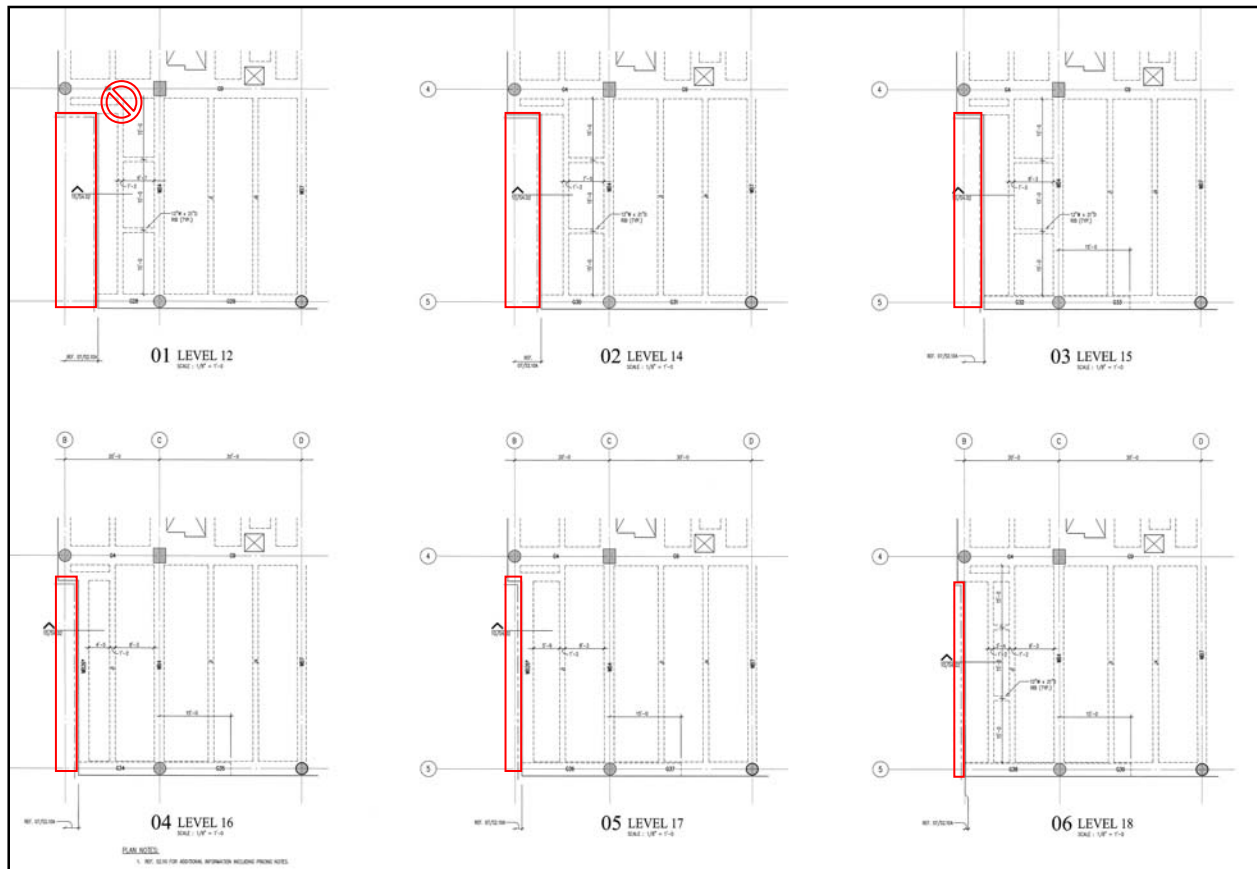

Figure 4.4 Office Floor Plans

Office Floor	Length	Width	Additional Area
9	12'-10 5/8"	41'-6"	535 ft^2
10	11'-5 ½"	41'-6"	475 ft^2
11	10'-6"	41'-6"	435 ft^2
12	8'-8 ½"	41'-6"	362 ft^2
14	7'-3 7/8"	41'-6"	304 ft^2
15	5'-11 3/8"	41'-6"	247 ft^2
16	4'-6 ¾"	41'-6"	190 ft^2
17	3'-2 ¼"	41'-6"	133 ft^2
18	1'-9 ¾"	41'-6"	75 ft^2
Total	-	-	**2756 ft^2**

Table 4.1: Additional Area Provided per Floor

Eliminating the slope in the curtain wall and extending the floor plan provides an additional 2756 ft^2 to the building. **Table 4.1** shows the additional area provided by each floor. This allows the owner to charge more to the tenants for them to lease the space. By observing rent costs that other owners are charging, it can be estimated that the rent/ft^2/year for Main & Gervais is around $21.00/ft^2/year. At $21.00/ft^2/year the owner could charge an additional $57,876.00 each year to its tenants. After ten years, that amount would reach over half a million dollars. This is a considerable amount of money to convince the owner to consider the option of eliminating the slope.

(ft^2)	(rent/ft^2/year)	(rent/year)	(ten years)
2756	$ 21.00	$ 57,876.00	$ 578,760.00

Table 4.2: Proposed Rent Costs

Structural Load Analysis (Structural Breadth)

The proposed method of adding area to the building's footprint requires a structural analysis to determine whether the addition is acceptable. Most likely, additional support is necessary to maintain structural integrity. This is done by adding an additional column and joist to each floor of the office tower. Also, the beam that is located on the perimeter between the proposed column and existing column needs to be resized. The following analysis provides the structural adjustment necessary to allow the curtain wall extension.

The first section of this analysis displays the location of the new columns in the building and the calculations to verify the application. The second section indicates which beam needs replacement to support the additional loads. The third section provides the additional costs that accompany the extra joists, columns, and slabs.

The program *pcaColumn* was utilized for the column analysis. RAM Conce*pt* was used to analyze the beam to replace the existing beam because eliminate the beam is post-tensioned. Hand calculations were performed where necessary.

Column Addition Calculation

The corner of the building where there is originally nothing will now require a column to support the additional load placed on the larger concrete slab it supports. The new column placement can be seen in **Figure 4.5**. The necessity of this column is based on the assumption of symmetry. At the top left of the floor plan, there is a column located in the corner. The span is the same as in the lower left hand corner; therefore a column is necessary to maintain the structural integrity of the building.
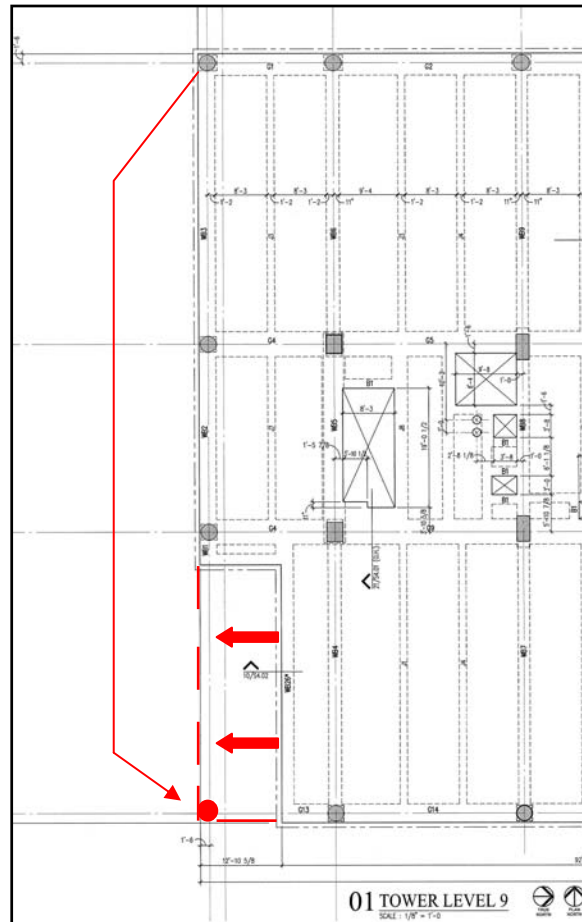

Figure 4.5: Column Placement

This placement of the column is continuous on all the office floors. There are nine office floors; therefore it is necessary to add nine columns (one for each floor). Since the column loads decrease as the levels get higher, implementing a smaller second column is possible. A second column with different properties is placed on floors fifteen through eighteen in the northwest corner. This same design is applied to the southwest corner. The first column (column **A**) proposed is a circular column. Its diameter is 30" and stands 13' tall. There are (16) #9 vertical bars with #4 bars @ 13" for ties. The column is made up of concrete with a compression strength of 7000 psi. The second column (column **B**) proposed is a circular column with the same dimensions but the concrete properties are changed. The compression strength of the concrete can sustain a reduction to 5000 psi.

Several calculations are necessary to verify that the column can support its loads. It is necessary to consider the dead load and live load. The wind load is not considered in these calculations as the dead load and live load are factored to compensate. The axial load is calculated after the factored loads are determined. Entering the properties of the columns into *pcaColumn* provide the max loads the columns can withstand. If the calculated axial loads are under this max, then the column is strong enough.

Structural Loads		
Live Load (psf)	Dead Load (psf)	Column (lb/ft^3)
120	63	150

Table 4.3: Structural Loads

	Load	Factor	Factored Load	Units
Live	120	1.6	192	psf
Dead	63	1.2	75.6	psf
Column	9572	1.2	11486	pounds

Table 4.4: Factored Loads

Table 4.3 provides the structural loads and **Table 4.4** shows these loads factored to calculate the axial loading on the column. The factored loads are calculated as follows.

- Live Load Calculation:
  - $Office\ Load\ \left(^{lbs}/_{ft^2}\right) + Partition\ Load\ \left(^{lbs}/_{ft^2}\right) = Live\ Load\ \left(^{lbs}/_{ft^2}\right)$
    - $100\ psf + 20\ psf = 120\ psf$

- Dead Load Calculation (floor slab):
  - $Concrete\ Weight\ \left(^{lbs}/_{ft^3}\right) x\ Slab\ Thickness\ (ft) = Dead\ Load\ (^{lbs}/_{ft^2})$
    - $\left(150\ ^{lbs}/_{ft^3}\right) x\ \left(\frac{5in}{\frac{12in}{ft}}\right) = 9572\ lbs$

- Column Load Calculation:
  - $Concrete\ Weight\ (^{lbs}/_{ft^3}) x\ Area\ (ft^2) x\ Length(ft) = Column\ Weight\ (lbs)$

    - $\left(150\ ^{lbs}/_{ft^3}\right) x\ \left(\frac{\pi(15in)^2}{\frac{144\ in^2}{ft^2}}\right) x\ (13ft) = 9572\ lbs$

Column	Floor	n	A$_t$ (ft^2)	Total Load (ksf)	Column Load (kips)	Axial Load (kips)
A	9	9	225	0.268	11.5	634
B	15	4	225	0.268	11.5	275

Table 4.5: Axial Loads

Table 4.5 displays the axial loads on column **A** and column **B**. Column **A** is the stronger column because it is supporting more loads above it. Any floors above it will take fewer loads than the column below it; therefore it is redundant to calculate floors ten through fourteen. Column **B** supports less therefore it uses concrete with less compressive strength. The axial loads are calculated as follows.

- $P_n = n \; x \; A_t \; x \; Total \; Load + (n-1)(Column \; Load)$

- Column **A** (floor 9):
  - $P_9 = (9) \; x \; (225 ft^2) \; x \; (0.268 \; ksf) + \; (9-1) \; x \; (11.5 \; kips)$
    - $P_9 = 634 \; kips$

- Column **B** (floor 15):
  - $P_4 = (4) \; x \; (225 ft^2) \; x \; (0.268 \; ksf) + \; (4-1) \; x \; (11.5 \; kips)$
    - $P_4 = 275 \; kips$
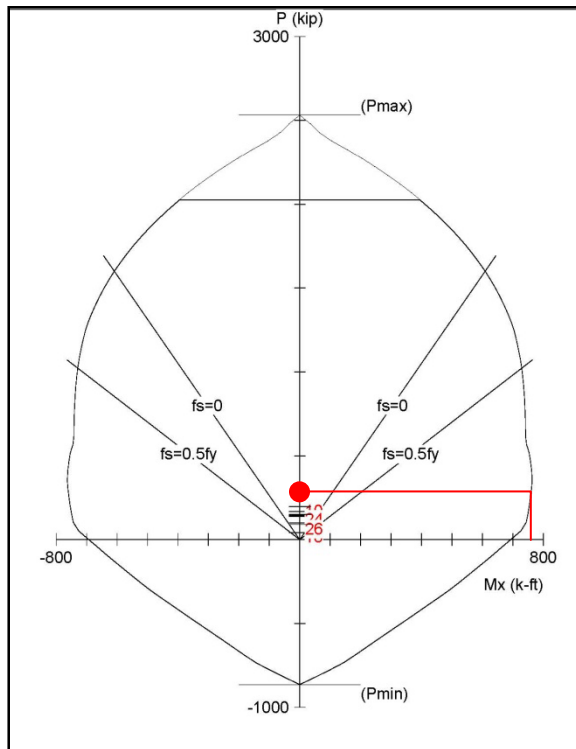

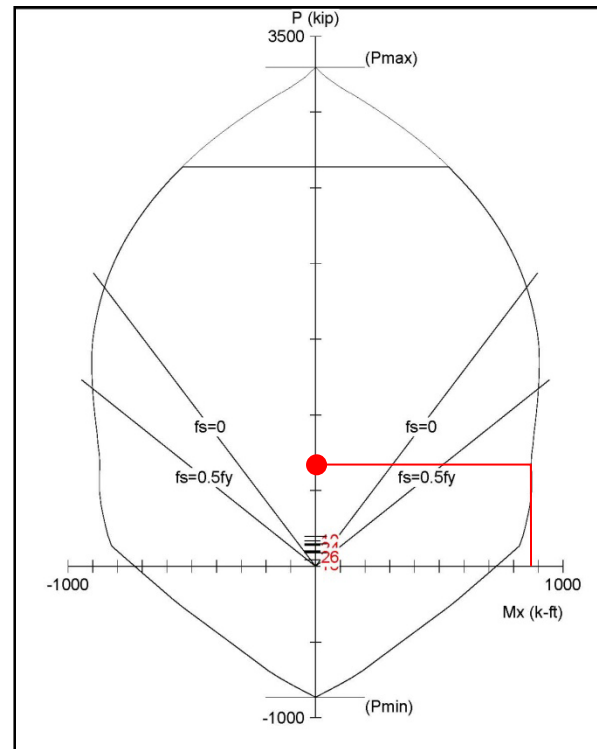**Figure 4.6:** *pcaColumn* **Diagram (Column B)**

Figure 4.7: *pcaColumn* **Diagram (Column A)**

Figure 4.6 and **4.7** are diagrams that display the graphs obtained from *pcaColumn*. These are just the graphs; the whole sheets are located in **Appendix E**. As seen in the figures indicated by the red circle, the calculated axial loads fall well within the allowable load. The line is extended to the right to determine the max moment the columns can withstand. This shows that the column is strong enough to resist the lateral loads (wind loads). These columns are sufficient enough to support the structural loads.

Beam Replacement Calculation

Extending the floor plan will increase the span distance between the columns. This result requires resizing the beam to support the new load applied to the slab. This assumption is based on symmetry. The other side of the building, or the other side of the red dashed line in **Figure 4.8**, shows that a larger beam is necessary to support the load given the larger area. **Figure 4.8** also displays where the existing beam is and the new beam's location for level nine.

Figure 4.8: Beam Replacement
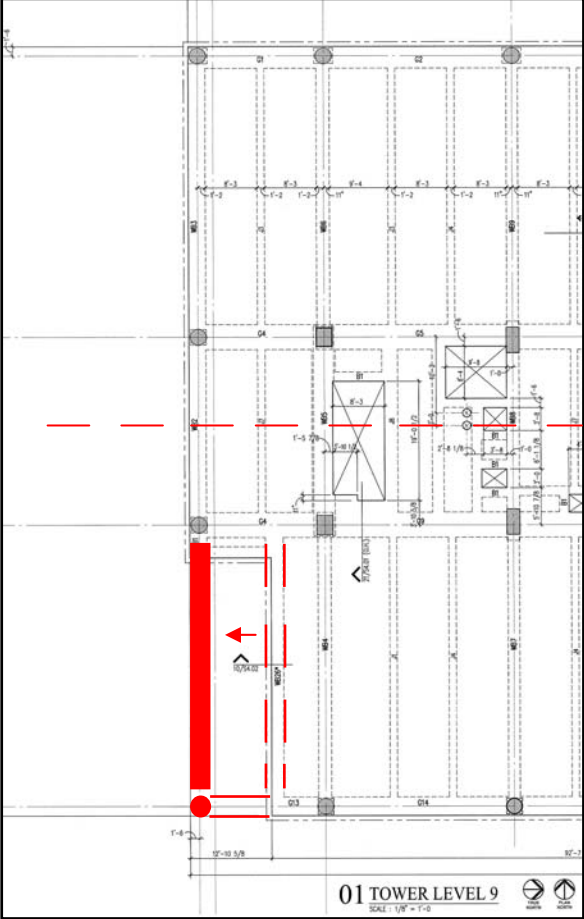
The existing beam is 23 ¾ inches in width and 21 inches deep and is outlined above in red dash marks. The replacement beam is 36 inches wide and 21 inches in depth. The reinforcement for each of the beams changes as well. These changes are displayed in **Table 4.6**. The existing beam is identified by WB26, the second row. And the proposed beam is identified by WB3, located in the first row.

WIND BEAM SCHEDULE MARK "WB"																
WIND BEAM				WIND BEAM REINFORCING						POST-TENSIONING						
MARK	FLOOR	WIDTH (IN.)	DEPTH (IN.)	BOTTOM N-S-T	TOP N-S-T	MIDBAR N-S-T (EA. FACE)	STIRRUPS S-T	STIRRUPS SPA. EA. END	NOTES	TYPE	PDT (KIPS)	A (IN.)	B (IN.)	C (IN.)	X (FT-IN)	NOTES
WB3	9-18	36*	21	6-6-W	5-7-P	4-6-P	#4-02	1@2, 16@6, R@12		1	188	18 1/2	2 1/2	12	22'-6	
WB26*	9,16,17	23 3/4	21	4-8-A	4-8-A	4-6-A	#4-02	1@2, 16@6, R@12		1	322	12 3/4	2 1/2	12 3/4	22'-6	

Table 4.6: Reinforcement Properties

All this information presented in the figures and tables is necessary to utilize RAM Conce*pt*. The strip wizard in RAM Conce*pt* is simple enough for this application. The model drawn in RAM is shown in **Figure 4.9**. The beam in the left portion of the figure is the beam of interest. Main & Gervais is a post-tensioned cast-in-concrete structure, meaning that the structural integrity of one beam is dependent on the surrounding structural elements. Because of this, the beams along the same column line were considered too.
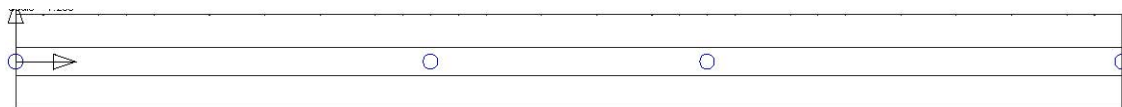
Figure 4.9: Model Plan from RAM Conce*pt*

To establish this model, the following properties were inputted into the program. The loads applied to the structure are the same as presented in **Table 4.3**. Concrete properties are 5000 psi for the slabs and beams and 6000 psi for the columns. Rebar and post-tensioning properties are taken from **Table 4.6**. All other inputs are located in **Appendix F**.
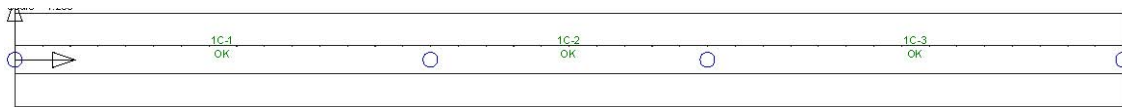
Figure 4.10: Status Plan from RAM Concept

As shown in **Figure 4.10**, the beam is structurally strong enough to support the loads applied to it. This is just for tower floor level nine. There are eight more floors of office above this floor that require resizing of the same beams. It is assumed that the proposed beam will suffice in the rest of the floors. This is because the scenario is similar for each of the floors.

Joist Addition Assumption

It is assumed that additional joists are necessary for the proposed floor plan. By observing **Figure 4.11,** it is shown by symmetry that the joist in the top left portion of the floor plan is necessary in the lower left hand corner if the floor plan is extended. Additional calculations are not necessary as it will be redundant considering the previous section, *Beam Replacement Calculation*. This section considered the load implications for the floor area above the replacement beam, which are similar to that which the loads the joists are supporting. Based on the symmetry of the design and the verification from the calculations in the previous section, the 14" wide and 21" deep joist in the upper left area is sufficient to

support the additional floor area. This assumption is applied to all the office levels. This requires an additional nine joists to bridge the gap between the beams, one for each floor.
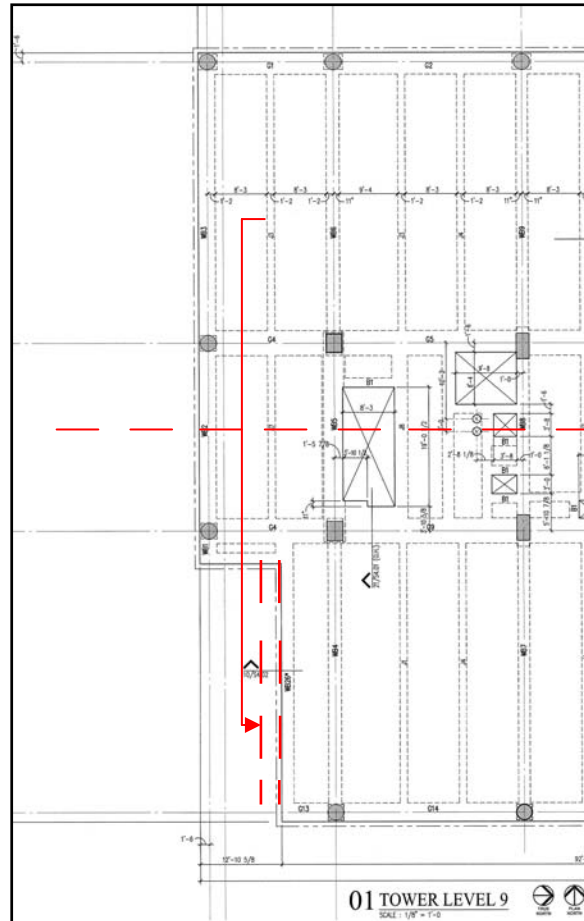

Figure 4.11: Joist Placement

Construction Costs

The additional columns, joists, and slabs will require additional material. The main materials required are concrete and reinforcement bars since each of the additional items are cast-in-place concrete. The cast-in-place concrete is designed for post-tensioning except for the columns. It is assumed that there is no additional formwork costs because each of the items exists on the drawings. In this case, the formwork is already purchased. The difference for construction costs in the replacement beams and the existing is minimal and not considered in **Table 4.7**.

Item	Description	Count	Unit	Material	Labor	Equip.	Cost/Unit	Total
Concrete	5000 psi (elevated slabs)	40	CY	$ 109.00			$ 109.00	$ 4,360.00
	6000 psi (joists)	40	CY	$ 124.00			$ 124.00	$ 4,960.00
	8000 psi (columns)	36	CY	$ 203.00			$ 203.00	$ 7,308.00
Rebar	Joists, #8 to #18	1.89	tons	$ 980.00	$ 520.00		$ 1,500.00	$ 2,835.00

	Columns, #8 to #18	0.76	tons	$	980.00	$	600.00			$ 1,580.00	$	1,200.80
	Elevated Slabs, #4 to #7	0.86	tons	$ 1,020.00		$	480.00			$ 1,500.00	$	1,290.00
Placement	Joists, crane & bucket	40	CY			$	52.50	$	26.50	$	79.00	$	3,160.00
	Columns, "	36	CY			$	23.50	$	11.90	$	35.40	$	1,274.40
	Elevated Slabs, "	40	CY			$	21.50	$	10.80	$	32.30	$	1,292.00
Prestressing	PT, 50' span, 300 kip	0.84	tons		1820	$	1,860.00	$	80.00	$ 3,760.00	$	3,147.87
Total											$ 30,828.07	

<div align="center">**Table 4.7: Construction Costs**</div>

As shown in **Table 4.7**, the total additional cost of extending the curtain wall amounts to $30,828.07.

Solar Heat Gain Analysis (Mechanical Breadth)

The original design for the curtain wall is sloped on the west façade. The way the sun shines in on sloped glazing differs from the way it shines in on vertical glazing. The angle of incidence of the sun changes for the tilt in the glazing. Therefore, the reflectivity of the glass is going to change at a different angle. The following analysis observes the current design of the curtain wall and compares it to the proposed method.

The first two sections provide calculations and their respective results for the total solar radiation on the glazing. The third section provides a means of measuring window heat gain for Main & Gervais. The last section compares the current state of Main & Gervais and the proposed design for the curtain wall on the west elevation in terms of energy expenses.

Calculation methods and solar data were obtained from *Heating, Ventilating, and Air Conditioning, 6th Edition* by McQuiston, Parker, and Spitler. Sun angles were obtained by *Sustainable by Design* at www.susdesign.com/sunposition. Information was obtained from the *ASHRAE Handbook, 2005* as well.

Sloped Façade Solar Radiation Calculation

To obtain the solar radiation for the west façade, it is necessary to calculate the direct radiation, diffuse radiation, and reflected radiation. The summation of these values will provide the total radiation on a sloped surface, specifically the west façade of Main & Gervais. This section provides the means of obtaining these values. The first subsection includes the calculations necessary and then the following subsection applies these calculations to Main & Gervais.

Calculation Steps
The following steps include the calculations necessary to obtain the amount of total solar radiation on the sloped curtain wall façade.

Step 1

- Calculate normal direct irradiation, G_{ND} (btu/hr-ft^2)

- $G_{ND} = \dfrac{A}{e^{\frac{B}{\sin \beta}}} \times C_N$
    - A = apparent solar irradiation at air mass equal to zero (btu/hr-ft^2)
    - B = atmospheric extinction coefficient
    - β = solar altitude angle
    - C_N = clearness number

Step 2

- Calculate direct radiation, **G$_D$** (btu/hr-ft^2)
- $G_D = G_{ND} \cos \theta$
    - G$_{ND}$ = normal direction irradiation
    - θ = angle of incidence
        - $\cos \theta = \cos \beta \cos \gamma \sin \alpha + \sin \beta \cos \alpha$
            - β = solar altitude angle
            - γ = surface solar azimuth
            - α = angle of tilt for an arbitrary surface (Σ in **Figure 4.12**)
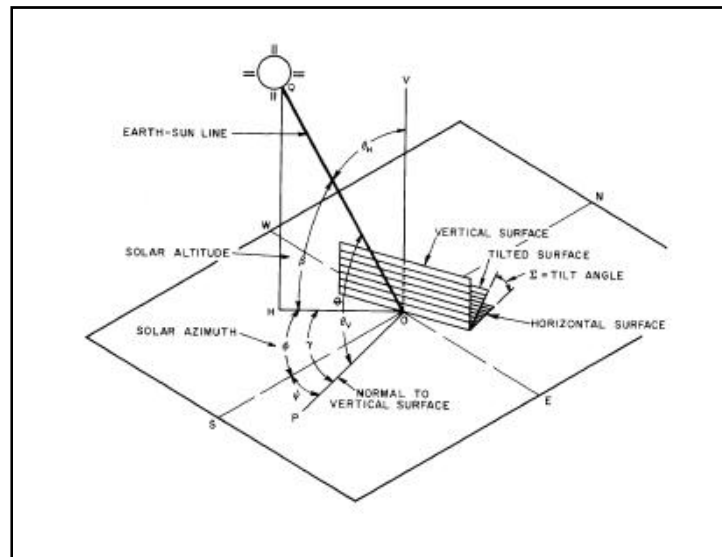   - **Figure 4.12** displays these angles

Figure 4.12: Solar Angles for Vertical and Horizontal Surfaces

Step 3

- Calculate diffuse irradiation, G$_{d\theta}$ (btu/hr-ft^2)
- $G_{d\theta} = C G_{ND} F_{ws}$
    - C = dimensionless factor
    - G$_{ND}$ = normal direction irradiation
    - F$_{ws}$ = fraction of the energy that leaves the surface and "strikes" the sky directly

$$\blacksquare \quad F_{ws} = \frac{1+\cos\alpha}{2}$$

Step 4

- Calculate reflected irradiation, G_R (btu/hr-ft^2)
- $G_R = G_{tH}\rho_g F_{wg}$
    - G_{tH} = rate at which the total radiation (direct plus diffuse) strikes the horizontal surface or ground in front of the wall (btu/hr-ft^2)
    - ρ_g = reflectance of ground or horizontal surface
    - F_{wg} = configuration or angle factor from wall to ground, defined as the fraction of the radiation leaving the wall of interest that strikes the horizontal surface or ground directly
        - $$F_{wg} = \frac{1-\cos\alpha}{2}$$
            - α = angle of tilt for an arbitrary surface

Step 5

- Calculate **G_t,** total solar radiation, by summing **G_D (Step 2)**, **$G_{d\theta}$ (Step 3)**, **G_R (Step 4)**
- $G_t = G_D + G_{d\theta} + G_R = \left[\cos\theta + CF_{ws} + \rho_g F_{wg}\sin\beta + C\right]G_{ND}$

Application to Main & Gervais

Now that the steps to calculate the total solar radiation on a sloped surface have been outlined, it is necessary to apply them to Main & Gervais in its current state. The application below is set for 3:00 pm on May 21, 2009, at 34° latitude, which is where Columbia, South Carolina, is located. **Table 4.8** provides the information necessary to complete the steps listed in the previous section. This section will provide a simple version of the calculation. The written calculations can be found in **Appendix G.**

Solar Data	Solar Angles	Surface Properties
A = 350.6 btu/hr-ft^2	β = 64.12°	ρ_g = 0.32 (concrete)
B = 0.177	Ψ = 255°	
C = 0.130	ϕ_z = -64.51°	
C_N = 0.94	γ = 40.5°	
	α = 95.63°	

Table 4.8: Information for May 21, 2009 in Columbia, South Carolina

- $$G_{ND} = \frac{350.6\ ^{btu}/_{hr-ft^2}}{e^{\frac{0.177}{\sin 64.12°}}} \times 0.94$$
    - $G_{ND} = 270.71\ ^{btu}/_{hr-ft^2}$

- $\cos\theta = \cos 64.12°\cos 40.5°\sin 95.63° + \sin 64.12°\cos 95.63°$

- o $\cos \theta = 0.242$

- $F_{ws} = \frac{1 + \cos 95.63°}{2}$
  - o $F_{ws} = 0.451$

- $F_{wg} = \frac{1 - \cos 95.63°}{2}$
  - o $F_{wg} = 0.549$

- $G_t = [0.242 + (0.13)(0.451) + (0.32)(0.549) \sin(64.12° + 0.13)\,](270\,^{btu}/_{hr - ft^2})$
  - o $G_t = 124.22\,^{btu}/_{hr - ft^2}$

The total solar radiation on Main & Gervais' sloped curtain wall on the west elevation at 3:00 pm May 21, 2009, is 124.22 btu/hr-ft². **Appendix H** provides a comprehensive list of values for the 21st of May, June, July, and August. The values listed in the table are only for the times in which the sun is shining down on the west façade. All other points of the day are irrelevant for this analysis.

Vertical Façade Solar Radiation Calculation

Calculation Steps
The following steps include the calculations necessary to obtain the amount total solar radiation on the proposed vertical curtain wall façade.

Step 1

- Calculate normal direct irradiation, **G_{ND}** (btu/hr-ft²)
- $G_{ND} = \frac{A}{e^{\frac{B}{\sin \beta}}} \times C_N$
  - o A = apparent solar irradiation at air mass equal to zero (btu/hr-ft²)
  - o B = atmospheric extinction coefficient
  - o β = solar altitude angle
  - o C_N = clearness number

Step 2

- Calculate direct radiation, **G_D** (btu/hr-ft²)
- $G_D = G_{ND} \cos \theta$
  - o G_{ND} = normal direction irradiation
  - o θ = angle of incidence
    - ▪ $\cos \theta = \cos \beta \cos \gamma$
      - β = solar altitude angle
      - γ = surface solar azimuth

Step 3

- Calculate diffuse irradiation, **G$_{d\theta}$** (btu/hr-ft^2)
- $G_{d\theta} = \frac{G_{dV}}{G_{dH}} C G_{ND}$
    - $G_{dV}/G_{dH} = 0.55 + 0.437 \cos\theta + 0.313 \cos^2\theta$
    - C = dimensionless factor
    - G$_{ND}$ = normal direction irradiation

Step 4

- Calculate reflected irradiation, G$_R$ (btu/hr-ft^2)
- $G_R = G_{tH}\rho_g F_{wg}$
    - G$_{tH}$ = rate at which the total radiation (direct plus diffuse) strikes the horizontal surface or ground in front of the wall (btu/hr-ft^2)
    - ρ_g = reflectance of ground or horizontal surface
    - F$_{wg}$ = configuration or angle factor from wall to ground, defined as the fraction of the radiation leaving the wall of interest that strikes the horizontal surface or ground directly
        - $F_{wg} = \frac{1 - \cos\alpha}{2}$
            - α = angle of tilt for an arbitrary surface

Step 5

- Calculate **G$_t$,** total solar radiation, by summing **G$_D$ (Step 2)**, **G$_{d\theta}$ (Step 3)**, **G$_R$ (Step 4)**
- $G_t = G_D + G_{d\theta} + G_R = \left[\cos\theta + \frac{G_{dV}}{G_{d\theta}}C + \rho_g F_{wg} \sin\beta + C\right]G_{ND}$

Application to Main & Gervais

Now that the steps to calculate the total solar radiation on a vertical surface have been outlined, it is necessary to apply them to the proposed curtain wall design for Main & Gervais. The application below is set for 3:00 pm on May 21, 2009, at 34° latitude. **Table 4.8** provides the information necessary to compute the calculations. This section will provide a simple version of the calculation. The written calculations can be found in **Appendix G.**

- $G_{ND} = \frac{350.6\ ^{btu}/_{hr-ft^2}}{e^{\frac{0.177}{\sin 64.12°}}} \times 0.94$
    - $G_{ND} = 270.71\ ^{btu}/_{hr-ft^2}$

- $\cos\theta = \cos 64.12° \cos 40.5°$
    - $\cos\theta = 0.242$

- $G_{dV}/G_{dH} = 0.55 + 0.437(0.242) + 0.313(0.242)^2$
  - $G_{dV}/G_{dH} = 0.73$

- $F_{wg} = \dfrac{1-\cos 90°}{2}$
  - $F_{wg} = 0.5$

- $G_t = [0.242 + (0.242)(0.73) + (0.32)(0.5)\sin(64.12° + 0.13)\,](270\ {}^{btu}/_{hr-ft^2})$
  - $G_t = 154.58\ {}^{btu}/_{hr-ft^2}$

The total solar radiation on Main & Gervais' vertical curtain wall on the west elevation at 3:00 pm May 21, 2009, is 154.58 btu/hr-ft². **Appendix I** provides a list of values for the 21st of May, June, July, and August. The values listed in the table are only for the times in which the sun is shining down on the west façade. All other points of the day are irrelevant for this analysis.

Window Heat Gain Calculation

The two previous sections provided the total solar radiation on the building at a specific time. Now it is important to note how that solar radiation will impact the curtain wall. This analysis focuses strictly on the office portion of the building. The typical glazing for the office tower is Solarscreen Radiant Low-E (VRE) Insulating Glass VRE 1-46 manufactured by Viracon.
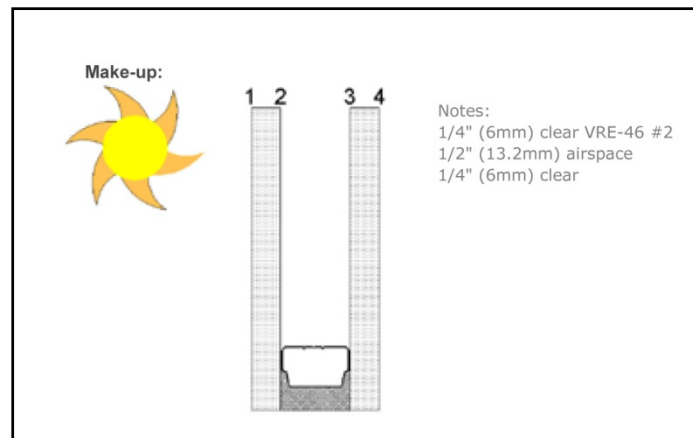

Figure 4.12: Curtain Wall Glazing Properties

The solar factor (SHGC) for this product is 0.278. This value multiplied by the total solar radiation, which is highlighted in each of the two previous sections, will obtain the window heat gain at 3:00 pm on May 21, 2009. **Appendix I** provides a list of values for window heat gain for the 21st of May, June, July, and August.

- $q_i = (G_i)(SHGC)$
- $q_i = (124.22)(0.278)$
- $q_i = 34.53\ ^{btu}/_{hr-ft^2}$

- $q_i = (G_i)(SHGC)$
- $q_i = (154.58)(0.278)$
- $q_i = 43.06\ ^{btu}/_{hr-ft^2}$

The left column displays the calculations for the sloped curtain wall and the right column displays the calculations for the vertical curtain wall. There is a 25% increase in heat gain for this particular hour.

Energy Load Comparison

The previous sections analyzed one particular hour for one day for the purpose of understanding the calculations. The following table, **Table 4.9**, provides the increase in window heat gain over the course of four months: May, June, July, and August. This provides a legitimate means of comparing the energy costs between the two different designs.

Month	Day (btu/ft²/day)				Month (btu/ft²/month)			
	Sloped	Vertical	q_i Inc.	% Inc.	Sloped	Vertical	q_i Inc.	% Inc.
May	279	333	54.29	19%	8364	9993	1628	19%
June	281	337	55.92	20%	8437	10115	1677	20%
July	273	327	54.53	20%	8189	9825	1636	20%
August	244	292	48.90	20%	7322	8789	1466	20%

Table 4.9: Energy Comparison

As shown in **Table 4.9**, the energy demand increases by 20%. This will increase the energy bill each month for the owner of the building. The average utility rate during November 2008 for commercial buildings in South Carolina is 8.76 cents/kwh. This value was obtained from the Energy Information Administration. **Table 4.10** provides the converted numbers to be capable of calculating the energy costs. **Table 4.11** provides the energy costs for the select months and the increase in cost for the change in design.

Month	(btu/ft²/hr)		(btu/hr)		(kwh)	
	Sloped	Vertical	Sloped	Vertical	Sloped	Vertical
May	39.83	47.58	52692	62953	15.44	18.45
June	40.18	48.17	53156	63725	15.57	18.67
July	39.00	46.79	51593	61899	15.12	18.14
August	34.87	41.85	46130	55371	13.52	16.22

Table 4.10: Energy Unit Conversion

Month	($/day)		($/month)		$ Inc.	% Inc.
	Sloped	Vertical	Sloped	Vertical	Sloped	Vertical
May	$ 324.58	$ 387.79	$ 9,737.39	$ 11,633.73	$ 1,896.34	19%
June	$ 327.44	$ 392.54	$ 9,823.14	$ 11,776.29	$ 1,953.15	20%
July	$ 317.81	$ 381.30	$ 9,534.31	$ 11,438.95	$ 1,904.64	20%
August	$ 284.16	$ 341.09	$ 8,524.81	$ 10,232.61	$ 1,707.80	20%

Table 4.11: Energy Costs

The energy consumption in btu/hr is calculated in **Table 4.10** given that the area of curtain wall under consideration is 4,536 ft^2. As seen in **Table 4.11**, the price for energy costs increases by 20%. The amount expressed under ($/day) is based on seven hours of the day that the energy is transmitting through the window. These months under consideration are assumed to be when the air conditioning system will be running. The total increase in price during this time period is $7,461.94. This amount is minimal considering this portion is a fraction of the total footprint of the building.

Conclusion

The implementation of the new curtain wall design requires several considerations. These considerations include examining the benefits of the new curtain wall design, inputting new structural elements and verifying the integrity, and calculating the increases in energy demand due to window heat gain. The following conclusions can be obtained from this analysis.

Additional Area

Extending the curtain wall provides additional area to the floor plan for each level of office space. This extra area amounts to 2756 ft^2. The owner can charge $21.00/ft^2/year for this space, which will amount to an additional $57,876.00.

Structural Load Analysis

Adding extra floor area will require additional columns, joists, and beams to support the extended slab. The construction costs for adding these elements will cost $30,828.07.

Solar Heat Gain Analysis

Changing the slope of the curtain wall will change the amount of solar energy that transmits through. The amount of window heat gain increases by 20% with the proposed design. This will result in an additional $7,461.94 for the energy bill each year.

Final Comments

Implementing the new design will put more money in the owner's pocket over time. There is an upfront cost of $30,828.07 for construction of the new structural elements. Also, each year the owner will expect an increase in the energy budget of $7,461.94 to run the air conditioning units to compensate for the window heat gain. The first year, the owner can expect an additional $19,585.99 in revenue. Years following, the owner can expect to bring an additional $50,414.06. This can be seen in **Table 4.12**.

	Construction Cost	Energy Cost	Rent Income	Difference
Year 1	$ 30,828.07	$ 7,461.94	$ 57,876.00	$ 19,585.99
Year 2	$ -	$ 7,461.94	$ 57,876.00	$ 50,414.06
Year 3	$ -	$ 7,461.94	$ 57,876.00	$ 50,414.06

Table 4.12: Profit