Lancaster County Bible Church

Manheim, Pennsylvania

Daniel Bellay – Structural Option

Thesis Consultant: Professor Behr

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Executive summary

The purpose of this technical report is to investigate the lateral system at Lancaster County Bible Church. Five braced frames, two frames on the 100-level and three frames on the 300-level, resist the lateral forces present at Lancaster County Bible Church. All of the braced frames are located on the exterior of the structure.

Calculations were performed two different methods; hand calculations and computer model calculations. Hand calculations relied upon relative stiffness factors that were generated through a Staad computer model. With these stiffness factors individual frames strength and serviceability issues were evaluated to determine the controlling factor. The second method of calculations was done using a Staad computer model. This computer model was loaded under various load combinations to determine the story drift, base shear, overturning moment, and uplift forces.

As a final check a visual inspection of the Staad computer model was made to determine the braced frames under the heaviest loading. The 2 ½" x 2 ½" x ¼" tubular steel bracing that is used in the braced frames at Lancaster County Bible Church was then evaluated for strength through hand calculations.

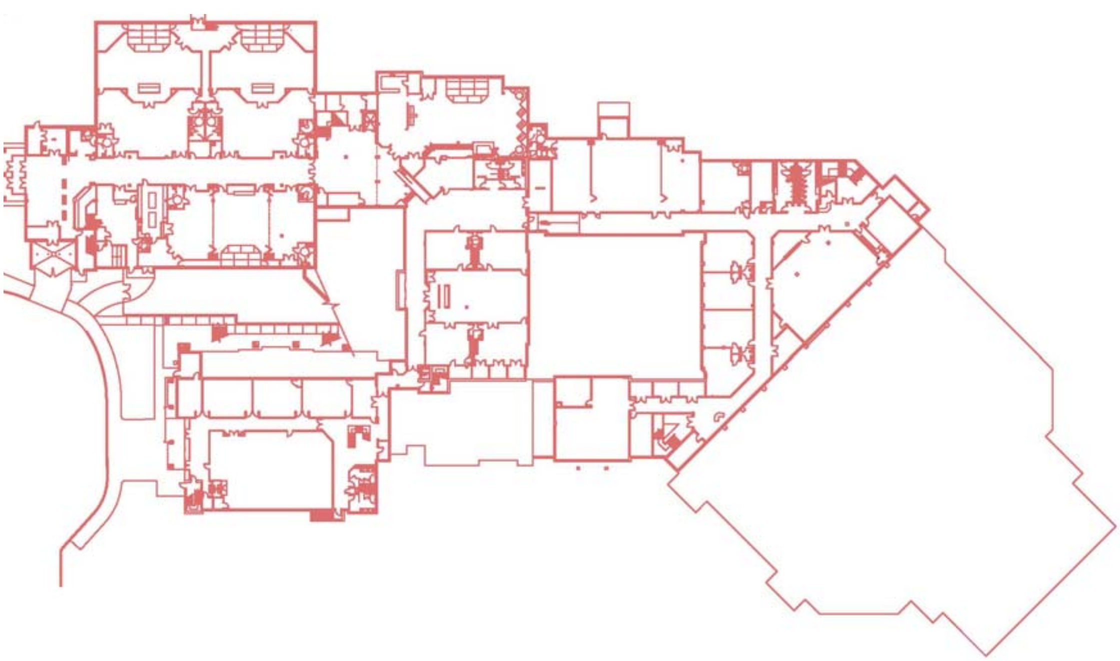
In conclusion, the calculations that I performed found the lateral system to be sufficient to resist the lateral forces present at Lancaster County Bible Church. The largest story shear and story drift are produced from winds loads. Additionally, the largest overturning moment was due to wind loading as well.

Introduction

LCBC (Lancaster County Bible Church) needed to expand its existing facility to accommodate the increased number of guests at it Sunday mass. The new expansion to LCBC would be focused towards the youth population and would include classrooms and youth performance areas. A three story, 78,000 square foot addition was designed by Mann Hughes Architecture. Construction began May 2008.

The new addition comprises three levels of multi-functional space. On the 100-level of the addition there is a large classroom and arcade areas for the younger children. Office spaces for the church's staff are the focus of the 200-level with executive offices for the pastor. In order to accommodate the needs of the adolescent population of LCBC a large performance and lounge area are provided on the 300 level. The 100-level, 200-level, and 300-level enjoy a 14'-0", 14'-0", and 15'-4" story height respectively. Total above grade height is 48'-0" to the top of the addition's parapet.

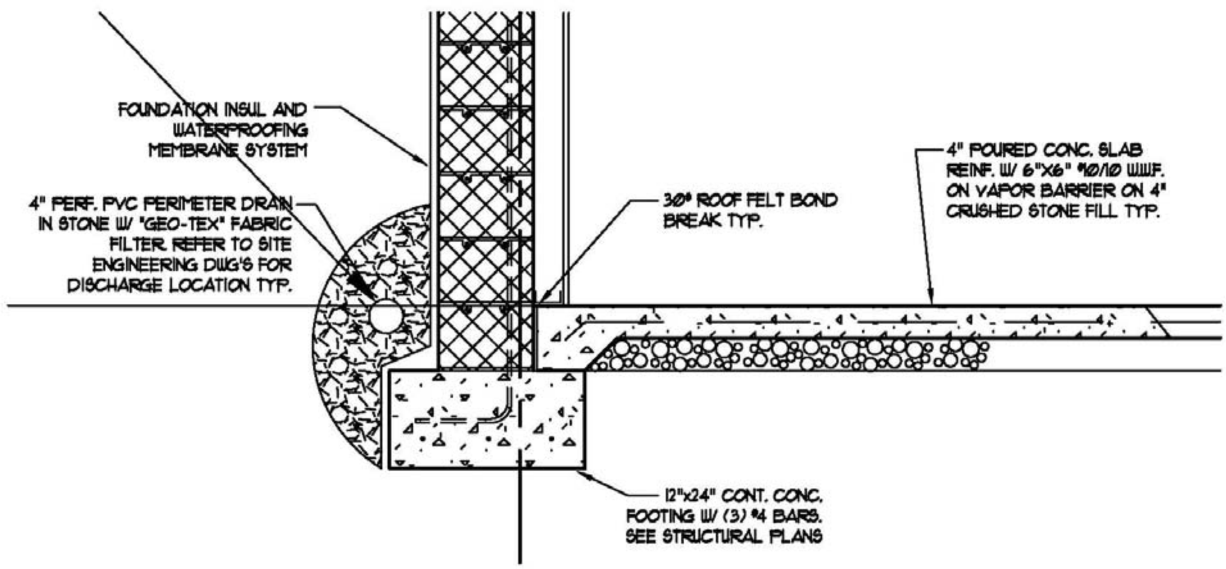
Land was not a restrictive component when the design of LCBC was made. Therefore the design of LCBC is a low profile sprawling structure with 100-level exhibiting a building footprint of 28,000 square feet. Successive levels step back from the 100-level's initial footprint giving the building its unique shape. Stucco panels were chosen as the exterior finish for the addition to complement the existing facilities façade.



100-Level Layout

Foundations

Various sized spread footings were designed to support column loads at LCBC. An F20, 2'x2'x12", is the smallest spread footing found at LCBC. Reinforcing for an F20 footing is provided by (3) #4 bars in each direction. Interior columns require the largest spread footing and exhibit F110's, 11'x11'x2'. Reinforcing for F110 is provided by (18) #7 bars in each direction. Typically spread footings are square however there are two rectangular footings, F 70x90 and F50x60. Load bearing masonry walls are supported by continuous spread footings that measure 24"x12". Horizontal reinforcing for the continuous footings is provided by (3) #4 bars. Vertical reinforcing is provided by #6 dowels with 4" hooks @ 8" O.C.



Typical Foundation Detail

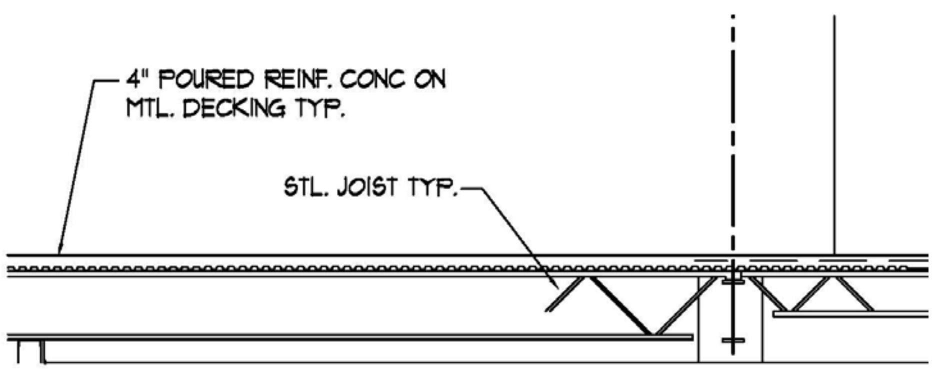
Flooring System

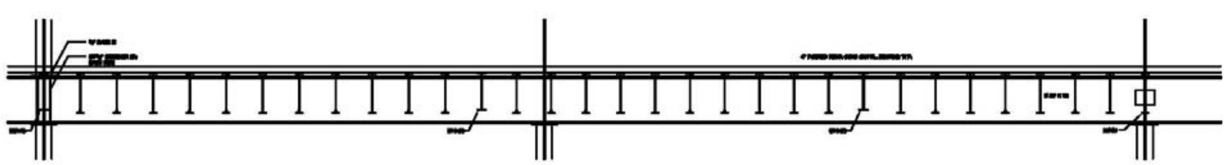
Reinforced concrete on metal decking was selected as the primary flooring system for LCBC. A 4" concrete slab is reinforced with 6x6 10/10 welded wire mesh. 1 ½", 26 gauge metal deck provides additional strength for the concrete deck. This one-way floor system transfers gravity loads to supporting girders and columns. Concrete used be 3,000 psi strength.

The typical bay size at LCBC is 38'-4" x 25'-0", however bay sizes vary to reflect the multi-functional nature of the building. On the 200-level floor framing the smallest bay size is 10'-9" x 16'-10" while the largest bay is 65'-0" x 38'-8". The 300-hundred level roof framing is dominated by a massive 67'-0"x 63'-4" frame which provides a large open space required for the performance area below.

Framing for the flooring is provided by various open web steel joists. Longer spans at LCBC, typically 38'-4", demand 26K9 or 26K10 open web steel joists. Shorter spans, typically 18'-25', are typically supported by 18K4 open web steel joists. The lightest open web steel joist is an 8K1. In contrast the long spans located in the roof framing implement a 36LH12.

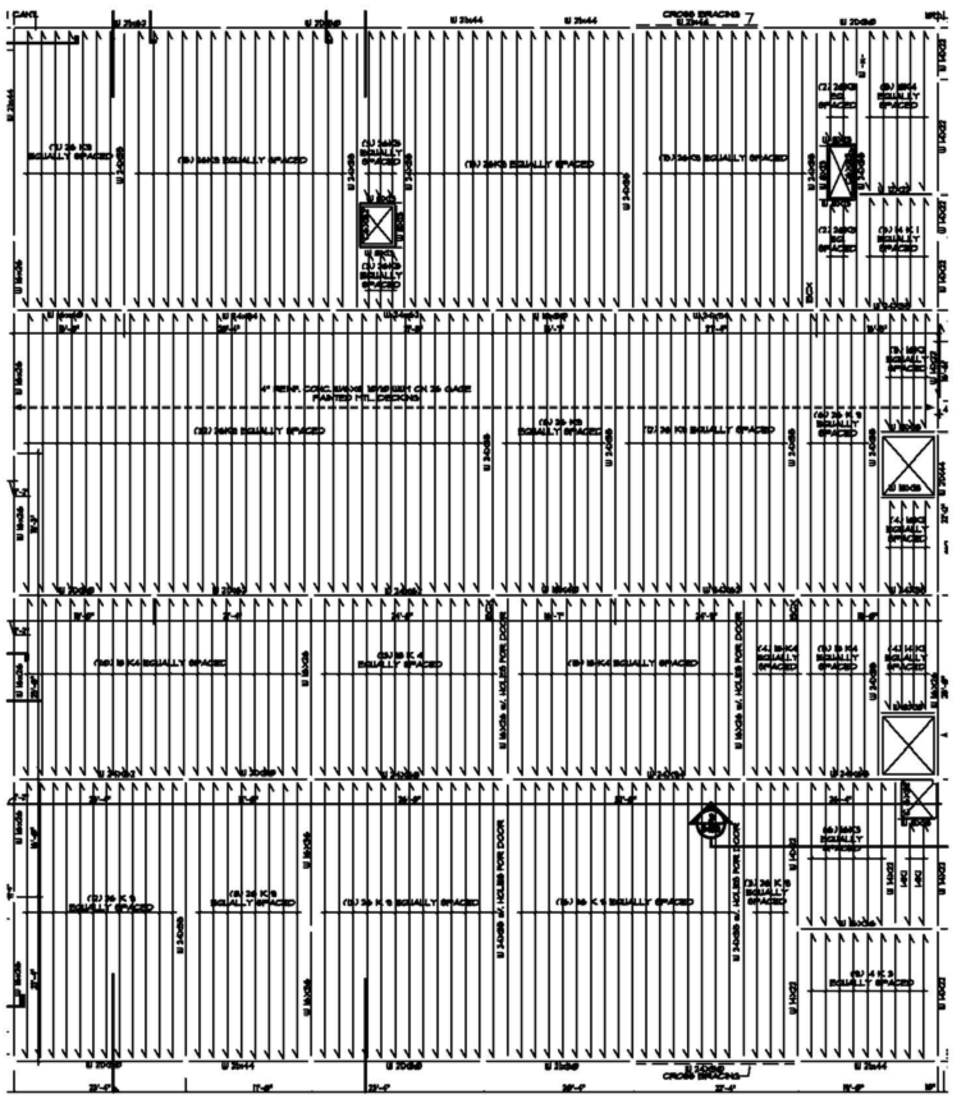
The 100-level flooring system is a slab on grade system. A 4" thick concrete slab is poured over a 6mm polyurethane vapor barrier. Underneath the vapor barrier on 4" of crushed stone on compacted earth.





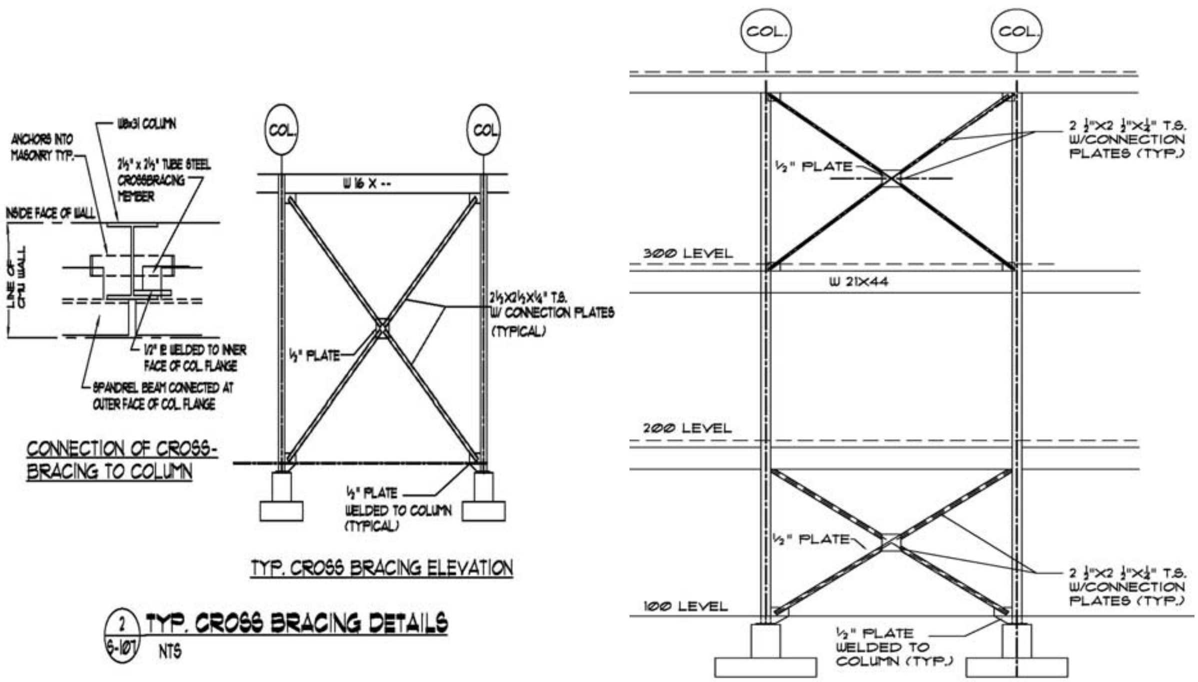
Gravity System

Gravity loads at LCBC are resisted by a simple steel framing system. The majority of the columns are W-shaped with the exception of a few HSS 4x4x3/8 columns. Typically columns will start 7" below grade and continue to the roof level. There are a few columns that start on the 200-level but they are the minority. Column sizes vary depending on how many floors the column supports and if they are interior or perimeter columns. A W10x60 is the heaviest column at LCBC and a W8x31 is the lightest. Beams and girders are W-shaped and range from a W12x16 to a W30x99.

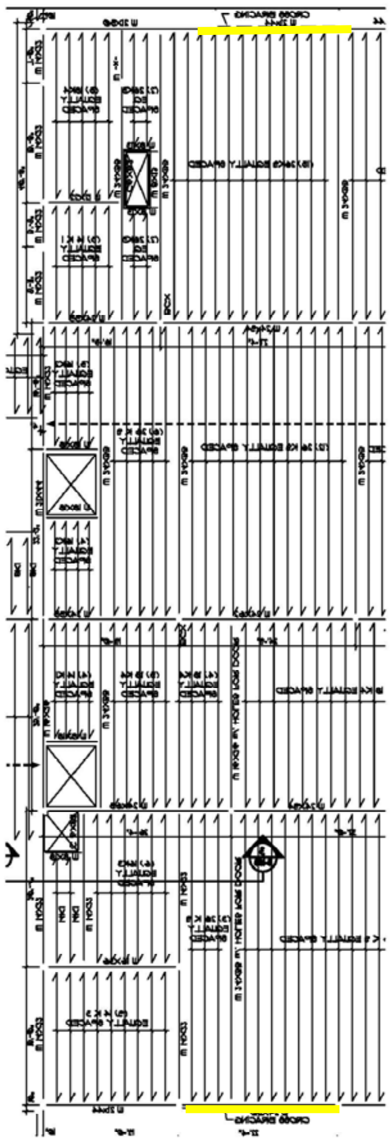


Lateral System

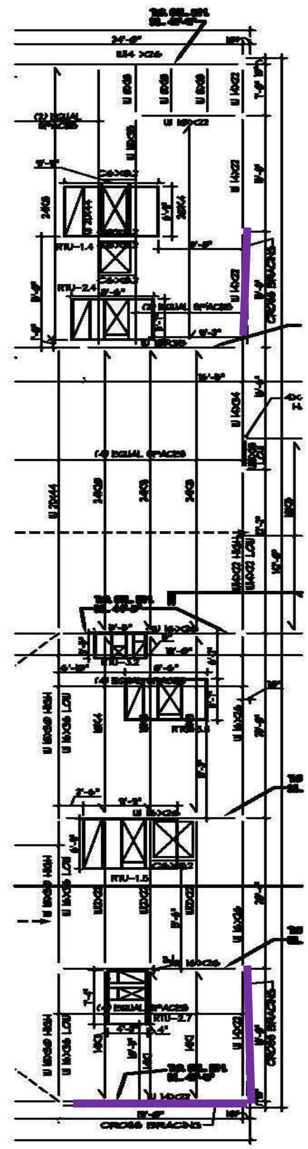
Lateral loads at LCBC are resisted by 5 braced frames. These 5 frames are all located on the perimeter column lines. The placement of the braced frames varies but is concentrated in the Southeast corner. Bracing is accomplished by welding (2) ½" steel plate to base of the column and (2) ½" steel plates the top of the same column. Then 2 ½" x 2 ½" tubular steel is welded to the steel plates in a cross arrangement. Lastly, a piece of ½" steel plate connects the cross bracing in the middle by means of welding.



Typical Cross-Bracing Detail



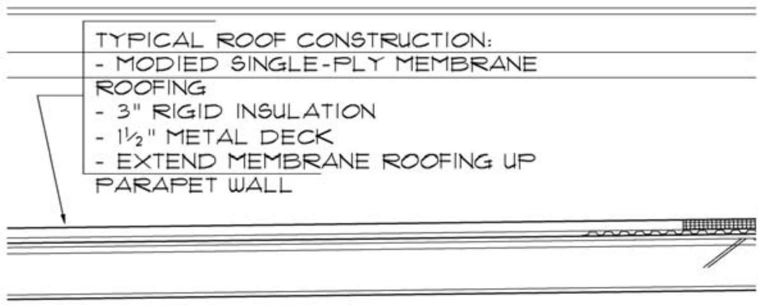
Cross-Bracing Layout 100-Level



Cross-Bracing Layout 300-Level

Roofing

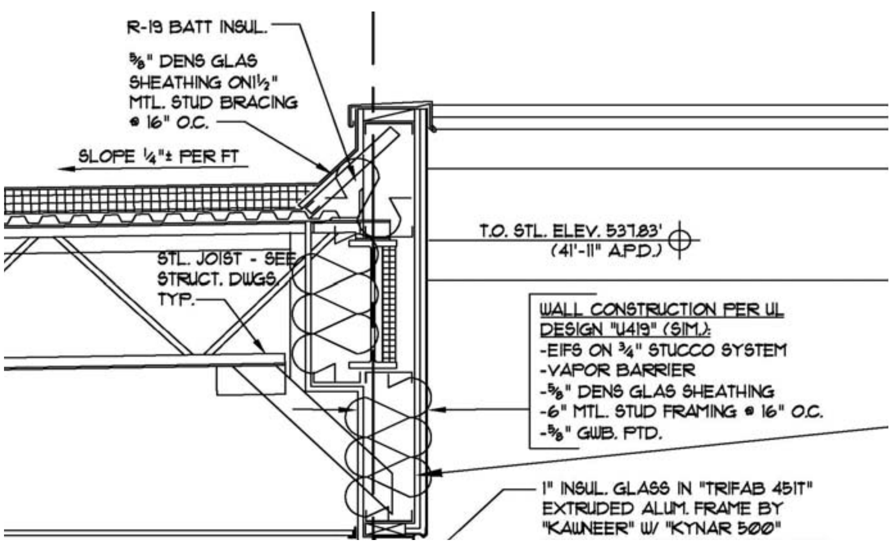
Two different flat roofing systems are implemented at Lancaster County Bible Church. The first flat roof system uses three-inch rigid insulation supported by 1 ½" metal decking. A single ply roofing membrane provides moisture protection. Tectum "E" structural roofing panels are used above the youth performance area. The panels are 6-inces thick and are constructed of: OSB sheathing, EPS insulation, and substrate.



Typical Roof Construction Detail

Building Envelope

The predominate façade of Lancaster County Bible Church is stucco. A ¾"prefabricated stucco panel called EIFS is installed on top of 5/8" dense glass. A vapor barrier provides moisture protection. 6" metal studs placed 16" on center provide support for the building's façade. R-19 batt insulation provides thermal resistance for the wall construction. Gypsum board is used for the interior finish.



Typical Wall Section

Codes:

Building Code
IBC 2003

Structural Steel
AISC Specification for Structural Steel Buildings
AISC Manual of Steel Construction – Allowable Stress Design, 9th Addition
Vulcraft Steel Joist and Steel Girders 2003

Concrete
ACI Details and Detailing of Concrete Reinforcement, ACI 315
ACI Manual of Engineering and Placing Drawings for Reinforced Concrete Structures, ACI 315R

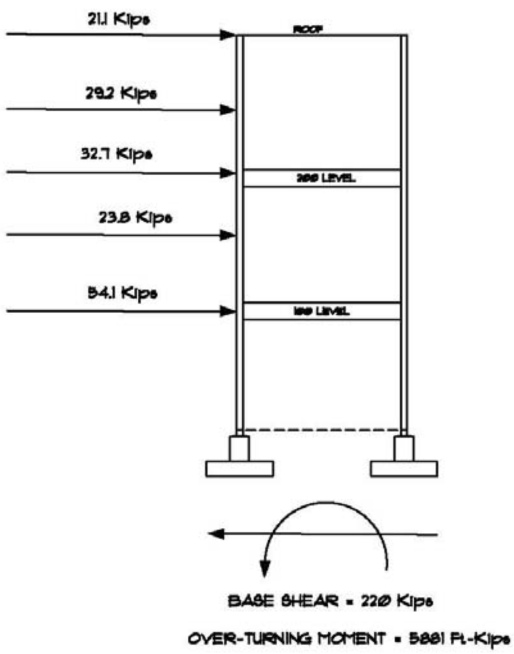
Design Loads
International Building Code 2000
American Society of Civil Engineers (ASCE), ASC- 7

Gravity Loads (Dead & Live Loads):

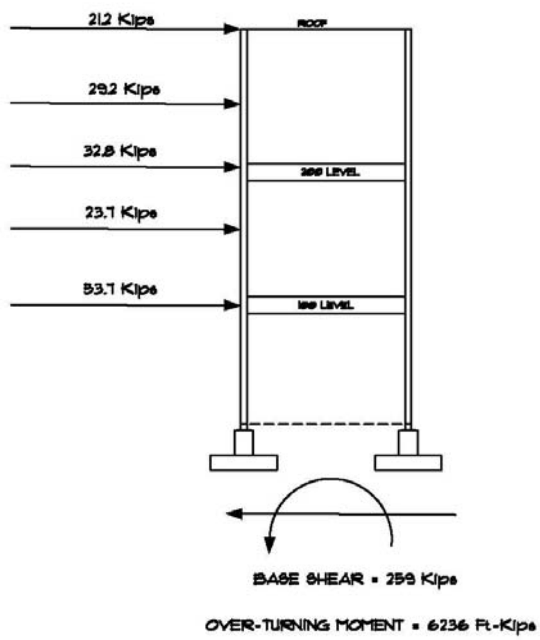
Live Loads	
Area	Design Load (psf)
Corridor	100
Office	100
Stairs	60
Storage Rooms	80
Roof	30
Dead Loads	
Description	Design Load (psf)
Floor Dead Load	50
Partitions	20
Framing	8
Ceilings	3
Mechanical Ductwork	3

Wind Load Calculations

Wind loads were calculated in accordance to ASCE 7-05 Chapter 6. North-South direction and East-West direction were determined using analytical method two. The East-West face of the building is broader than that of the North-South direction resulting in larger wind forces present there. Appendix A summarizes the calculations that were used to determine wind forces.



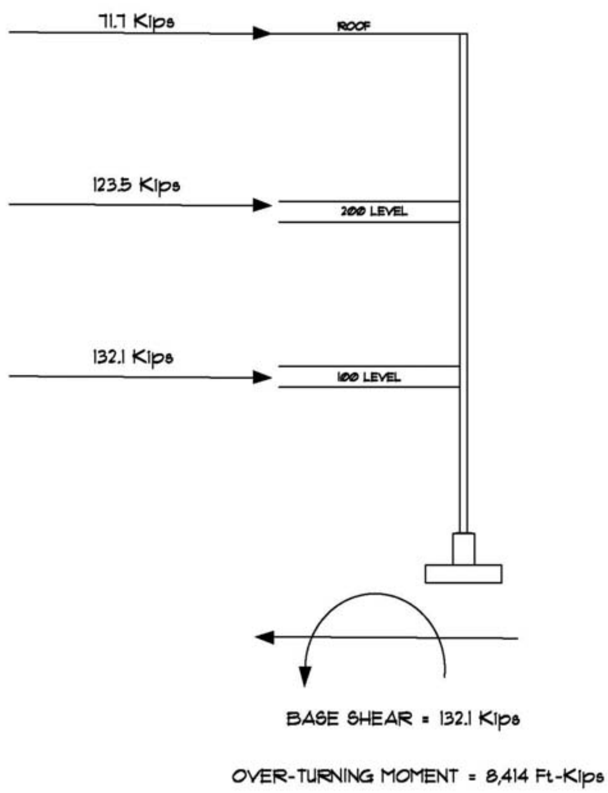
North-South Wind Forces



East-West Wind Forces

Seismic Calculations

Seismic loads on Lancaster County Bible Church are calculated according to IBC Chapter 6. The seismic flowcharts located in this portion of the code detail the calculations used to determine lateral forces that are produce during a seismic event. Lancaster County Bible Church is a steel framed structure thusly it is light, 333.3 Kips, compared to a similar sized concrete building. In addition, Manheim Pennsylvania is not a seismic area further reducing seismic forces. Appendix B summarizes calculations used to perform the seismic analysis.

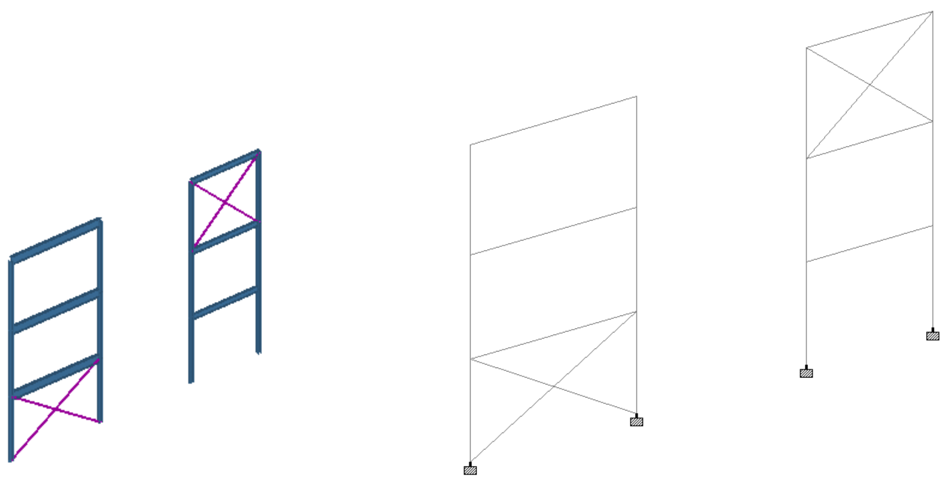


Seismic Forces

To better understand the lateral system present at Lancaster County Bible Church two methods of calculations were employed. The first method of analysis is a hand calculation for the two different braced frames. Hand calculations were compared to a Staad generated computer model. Results from the two different methods are then compared for differences.

METHOD 1: Hand calculations

A Staad computer model was generated for the each braced frame. Each braced frame was loaded using a 1000 pound force. Deflections of the frame were then calculated by the computer. Using the inverse of the frame deflection produces a frames relative stiffness. Assuming the center of mass to be at the geometric center of the structure the center of rigidity is calculated using a frame's relative stiffness.



Using the following equations Table (FILL IN THE BLANK) was compiled.

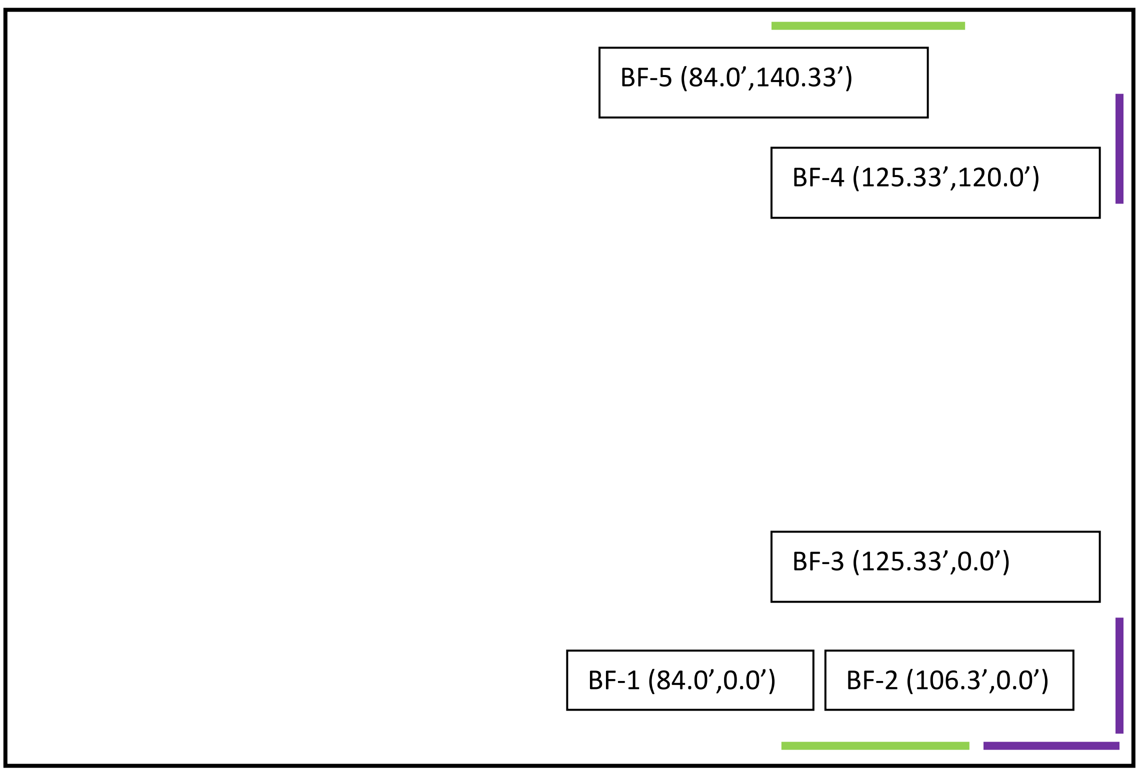
- Direct Shear Force Equation: $F_{ix\ direct} = (k_{ix} * P) / (\Sigma K_{ix})$ and $F_{iy\ direct} = (k_{iy} * P) / (\Sigma K_{iy})$
- Torsion Forces: $F_{i\ torsion} = (k_i * d_i * P_x * e_y) / (\Sigma k_i d_{i2})$
- Total Forces: $F_i = F_{idirect} \pm F_{itorsion}$

Calculation Summary									
Approximate Frame Stiffness									
Story	Load Direction	Frame	Load (Kips)	Displacement (Inches)	Stiffness	Stiffness Factor	Xi (Inches)	KiyXi (kips)	Center of Rigidity
		BF-1	1	0.156	6.41	0.422	0	0	
1	X	BF-2	1	0.228	4.39	0.289	0	0	
		BF-3	1	0.228	4.39	0.289	1684	7392.8	486.7”
				Sum = 15.19				7392.8	
	Y	BF-4	1	0.228	4.39	0.406	1504	6602.6	
1		BF-5	1	0.156	6.41	0.594	1504	9640.6	1504”
				Sum = 10.80				16,243.2	

Center of Mass (X,Y): (62’-8”, 70’-2)

Center of Rigidity (X,Y): (40’-7”, 125’-4”)

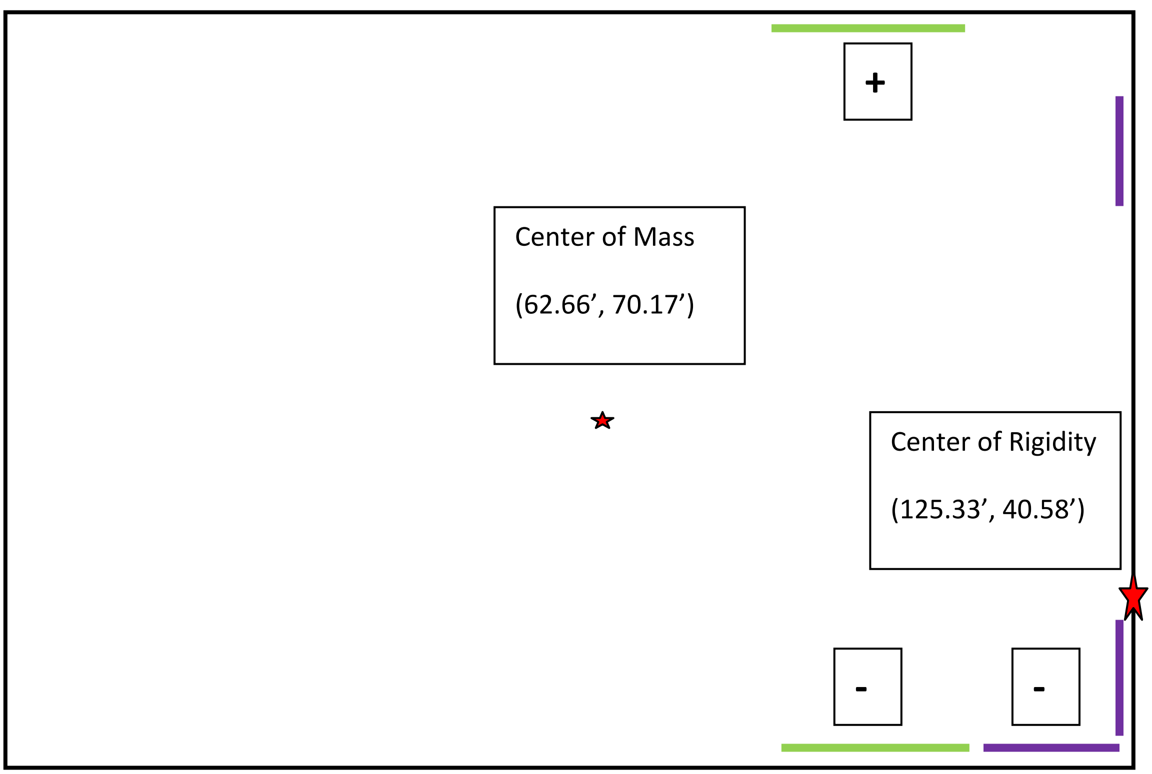
Eccentricity (X,Y): (22’-1”, 55’-2”)



Simplified Braced-Frame Layout

Calculation Summary								
Torsional Forces								
Story	Load Direction	Frame	Kix	di (ft)	Load	ey (ft)	J = Σkidi2 (kips/in) ft2	fit = kidiPxey / J (kips)
		BF-1	6.41	0.156	Px			0.125Px
1	X	BF-2	4.39	0.228	Px	29.58	61,466	0.0856Px
		BF-3	4.39	0.228	Px			0.211Px
			Kiy	di (ft)	Load	ex (ft)	J = Σkidi2 (kips/in) ft2	fit = kidiPxey / J (kips)
	Y	BF-4	4.39	0.228	Py			0.000Py
1		BF-5	6.41	0.156	Py	62.67	61,466	0.000Py

To properly determine the force distributed to each frame torsional forces must be incorporated. When the structure is loaded about the center of mass the structure rotates about the center of rigidity. Either + or – forces are added to the braced frame depending on the frames orientation. Figure below depicts the force each braced frame receives.

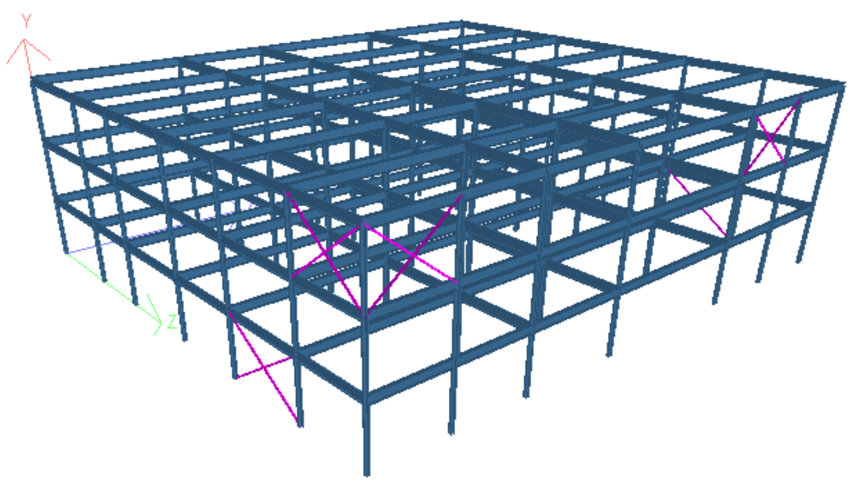


The resulting forces from hand calculation method are summarized in the table below

Hand Calculations – Total force Calculations						
Direction	Frame	Direct Force		Torsional Force		Total Force
	BF-1	0.422 Px	-	0.125	=	0.297 Px
X	BF-2	0.289 Px	-	0.0856Px	=	0.203 Px
	BF-5	0.289 Px	+	0.211Px	=	0.500 Px
Y	BF-3	0.406 Py	0	0	=	0.406 Py
	BF-4	0.594 Py	0	0	=	0.594 Py

Method Two: Staad Analysis

The second method used to analyze the lateral system at Lancaster County Bible Church was a computer analysis of the building. The first step in the computer analysis was the modeling of the entire building in Staad.Pro_2007. Following the modeling of the structure wind loads, seismic loads, and lateral forces were applied to determine forces present in the braced frames.



Once modeling of Lancaster County Bible Church was completed the center of mass for the structure needed to be determined. Self weight of the members was applied and the resulting in the following forces:

Mx = 21,312,871 ft x lbs

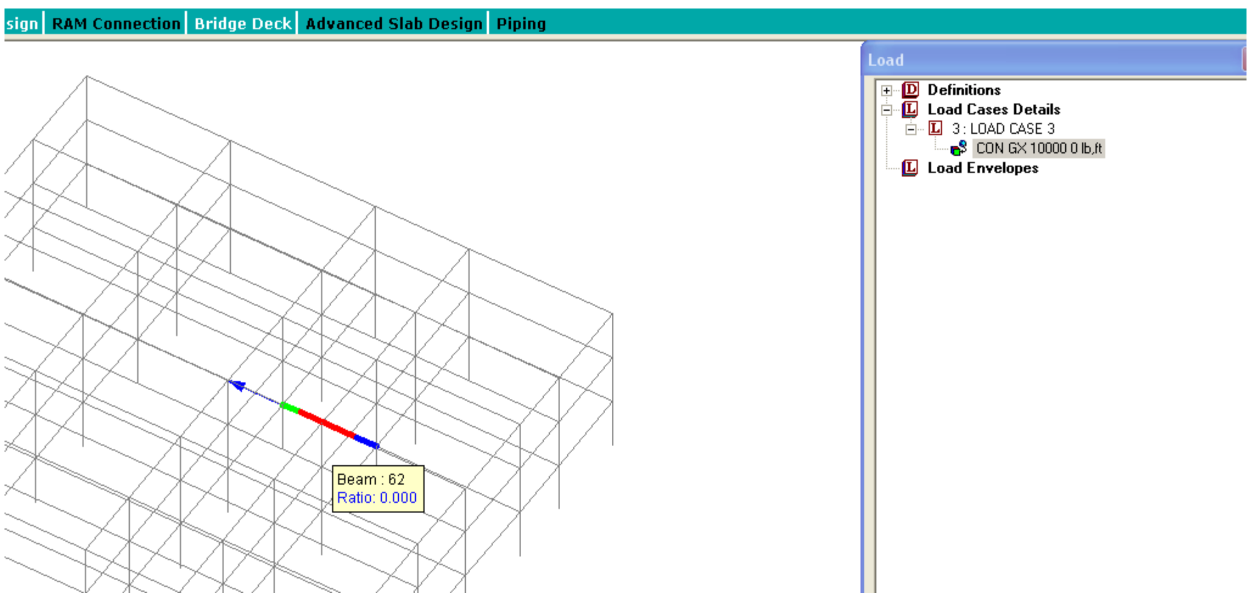
My = 0 ft x lbs

Mz = -23,110,927 ft x lbs

Fy = -333,296 lbs

Center of Mass = (X,Y) = (Mx/Fy , Mz/Fy) = (63.33' , 69.34')

Locating the center of mass is critical in determining the force different braced frames will receive. Adding a force at the center of mass of the structure will produce an accurate assessment of how much force is distributed to each braced frame. While seismic and wind forces do not produce a concentrated force at the center of mass the building will rotate about the center of mass. Therefore placing a large force (in my analysis I chose a 10,000 pound force) at the center of mass will show the effects of torsion on the braced frames.



Resulting brace frame forces from a 10,000 pound force placed about the center of mass in both the X and Y direction are summarized in the table below.

Method 2 Center of Rigidity Calculation						
Direction	Frame	Frame Load Applied (Pounds)	Total Horizontal Force Per Frame	Percent of Total Story Shear (%) K	Distance Di From Origin (Feet)	Center of Rigidity (Feet)
	BF-1		3,467	34.67	0	
X	BF-2	10,000	3,005.1	30.04	0	Y = 49.52
	BF-5		3,529.1	35.29	140.33	
Y	BF-3	10,000	5,019	50.19	125.33	X = 125.33
	BF-4		4,981	49.81	125.33	

Wind Drift From E-W Wind Force						
Story	Story Height iches	Story Drift (inches)	Allowable Story Drift Δwind = H / 400 (in.)	Total Drift (inches)	Allowable Total Drift Δwind = H/400	Serviceability Check Actual < Allowable
Roof	522	0.288	0.435	0.616	1.305	Okay
3	348	0.328	0.435	0.408	0.870	Okay
2	174	0.080	0.435	0.080	0.435	Okay

Wind Drift From N-S Wind Force						
Story	Story Height iches	Story Drift (inches)	Allowable Story Drift Δwind = H / 400 (in.)	Total Drift (inches)	Allowable Total Drift Δwind = H/400	Serviceability Check Actual < Allowable
Roof	522	0.172	0.435	0.280	1.305	Okay
3	348	0.108	0.435	0.154	0.870	Okay
2	174	0.046	0.435	0.046	0.435	Okay

Hand Verification of Output (Portal Method)

An estimate of braced frame deflection caused by wind loads was performed using the Portal Method. Wind loads were used from the computer analysis. Computer generated wind loads were what was used to determine the drift in the story drift. Therefore using the same wind loads will produce a result that is closer to the computer analysis. East-West direction wind loading was chosen for the hand calculations. The resulting deflection of the building was 0.230" at the roof level. This deflection is less than the 1.305" allowed by code. Appendix D summarizes the calculations employed for the hand verification.

Spot Checks

Member verifications were performed on critical braced frames. Two bracing typical bracing elements were analyzed for their strength. It was assumed the non-critical bracing elements would be able to resist lateral loading once the critical bracing elements were found to be sufficient. Calculations for these spot checks can be found in Appendix E.

Conclusions

In the third technical report of the Lancaster County Bible Church, an analysis of the lateral system was performed to verify that the lateral system meat all code requirements. Confirmation of the design was done using a 3-D model of the existing lateral system was created using Staad.Pro_2007. Two preliminary methods of analysis were employed to confirm the computer generated results. My results found that the lateral system at Lancaster County Bible Church is sufficient to resist lateral loads and deflection. Therefore my calculations agreed with the structural engineers calculations.

Appendix A: Wind Calculations

Wind Loading	Height (z) Feet	K_z	q_z	P_z (windward) psf	P_z (leeward) psf	Total Force (psf)	Lateral Force (Kips)	Overturning Moment (Ft.-kips)
	North-South Wind							
Parapet (top)	48'-0"	1.08	23.5	35.3	-23.5	58.8	26.1	1207
Parapet (bot.)	44'-6"	1.06	23.1	34.7	-23.1	57.8	33.0	1394
	40'-0"	1.04	22.7	19.67	-13.6	33.3	21.1	791
	35'-0"	1.01	22.0	19.2	-13.6	32.8	29.2	920
2nd Floor	28'-0"	0.97	21.1	18.6	-13.6	32.2	32.7	785
	20'-0"	0.90	19.6	17.6	-13.6	31.2	23.8	405
1st Floor	14'-0"	0.85	18.5	16.8	-13.6	30.4	54.1	379

Total Shear: 220 kips

Total Moment: 5881 ft-k

Wind Loading	Height (z) Feet	K_z	q_z	P_z (Windward) psf	P_z (Leeward) psf	Total Force (psf)	Lateral Force (Kips)	Overturning Moment
	East-West Wind							
Parapet (top)	48'-0"	1.08	23.5	35.3	-23.5	58.8	30.1	1392
Parapet (bot.)	44'-6"	1.06	23.1	34.7	-23.1	57.8	37.0	1563
	40'-0"	1.04	22.7	19.67	-10.2	29.9	21.2	795
	35'-0"	1.01	22.0	19.2	-10.2	29.4	29.2	920
2nd Floor	28'-0"	0.97	21.1	18.6	-10.2	28.8	32.8	787
	20'-0"	0.90	19.6	17.6	-10.2	27.8	23.7	403
1st Floor	14'-0"	0.85	18.5	16.8	-10.2	27.0	53.7	376

Total Shear: 259 kips

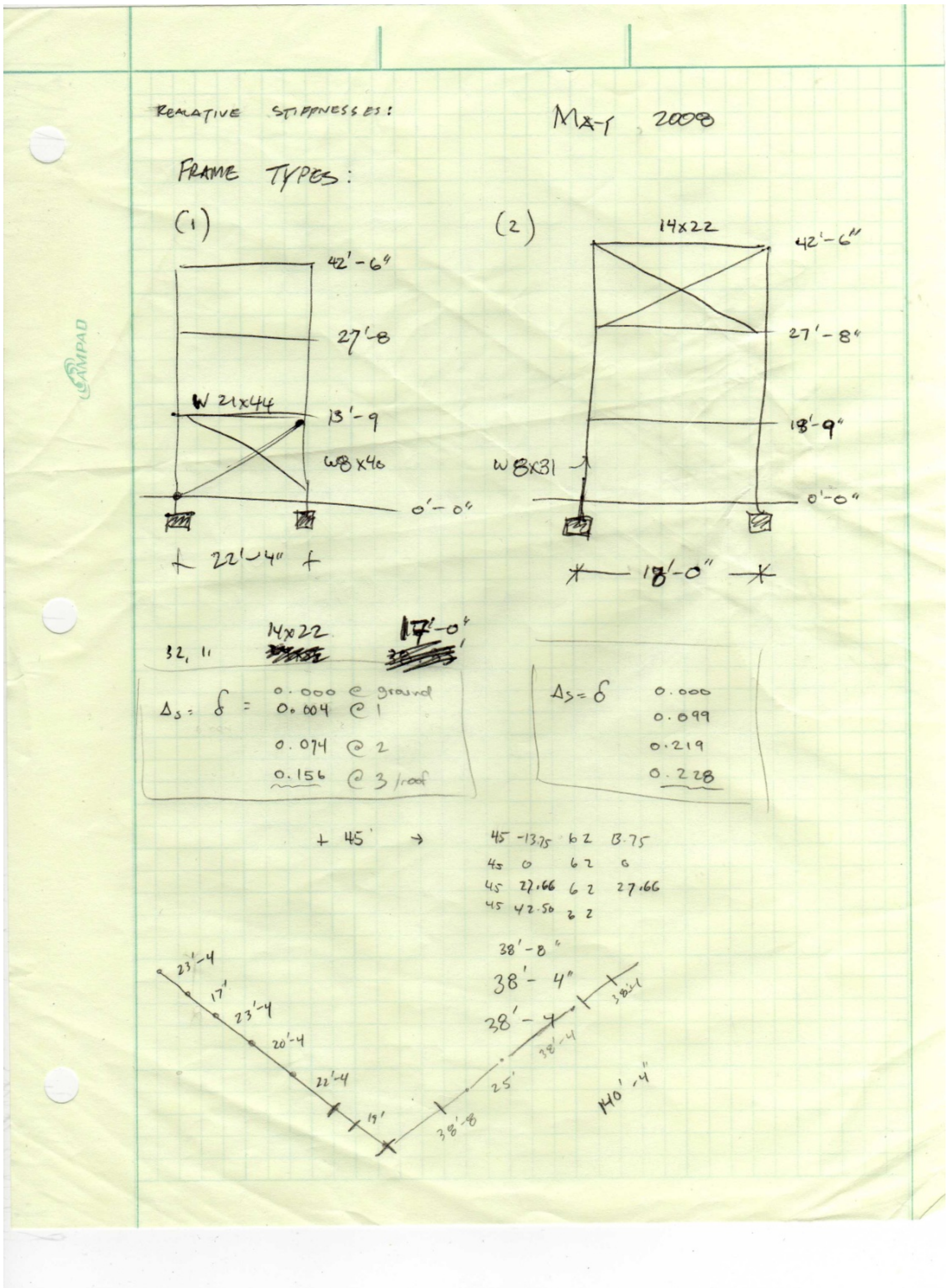
Total Moment: 6236 ft-k

Appendix B: Seismic Calculations

Seismic Loading Properties	Value	Source
Occupancy Category	I	Drawings
Seismic Importance Factor (I)	1.0	Drawings
Mapped Spectral Response Accelerations		
Short Period (S_S)	0.343	USGS Website
1-Second Period (S_s)	0.086	USGS Website
Site Class		
Spectral Response Coefficients		
Short Period (S_{DS})	0.229	USGS Website
1-Second Period (S_{D1})	0.057	USGS Website
Seismic Design Category (SDC)	C	Drawings
Response Modification Factor (R)	5	ASCE 7-05 Table12.2-1
Approx. Period of the Structure (T_a)		
h_n (ft.)	43'-4"	Drawings
C_t	0.020	ASCE 7-05 Table 12.8-2
X	0.75	ASCE 7-05 Table 12.8-2
T_a	0.346	ASCE 7-05 Eqn. 12.8-7
Long-Period Transition Period (T_L)	6	ASCE 7-05 Fig. 22-15
Seismic Response Coefficient (C_s)	0.033	ASCE 7-05 Eqn. 12.8-2
Exponent Related to the Structure(k)	0.923	ASCE 7-05 12.8.3

Floor	Area	Height Range (Feet)		Slab (psf)	Kips	Partitions (psf)	Kips	Roof Dead (psf)	Kips	Floor Weight (Kips)
3	19,270	28'-0"	43'-4"	50	964	20	385	15	289	1638
2	25,303	14'-0"	28'-0"	50	1265	20	506	0	0	1771
1	27,869	0'-0"	14'-0"	0	0	20	557	0	0	557.4
Total	72,442									5180

Appendix C: Center of Rigidity Calculations



Y - FRAMES : (2)

BF-3 (125'-4", 0)

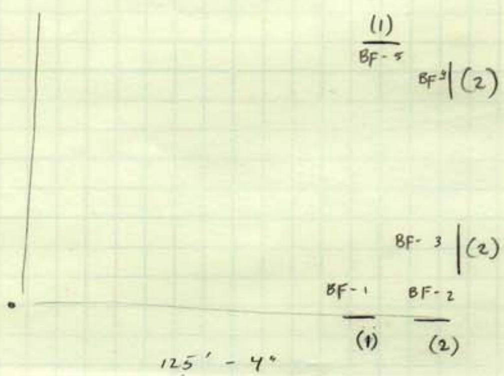
BF-4 (125'-4", 120)

X - FRAMES : (3)

BF-1 (84', 0)

BF-5 (84', 140. 33') } 2@ 0'

BF-2 (106. 33', 0') } 1 @ 140.33'



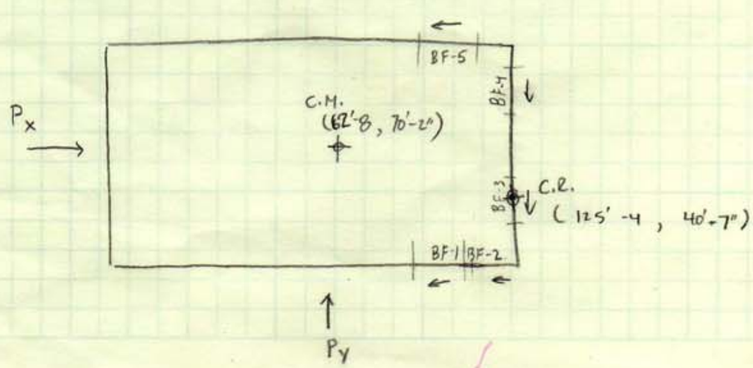
40.56', 125.3' ~ (125'-4", 40'-7")

(x, y)

center of Rigidity

center mass = (x,y)(62'-8, 70'-2")

eccentricity (x, y) = (62'-8", 29'-7")



DIRECT SHEAR FORCES:

X-DIR
BF-1 = 0.422 P_x
BF-2 = 0.289 P_x
BF-3 = 0.289 P_x

Y-DIR
BF-4 = 0.406 P_y
BF-5 = 0.594 P_y

Torsional effect (x-DIR) d_i ~ distance to C.R.

BF-1 d_i = (40'-7) - (0) = 40'-7" = 40.58'

BF-2 d_i = (40'-7") - (0') = 40'-7" = 40.58'

BF-3 d_i = 140.33 - 40'-7" = 99'-9" = 99.75'

BF-4 d_i = 0

BF-5 d_i = 0

$$J = \Sigma k_i d_i^2 = (6.41)(40.58)^2 + (4.39)(40.58')^2 + (4.39)(99.75)^2$$

$$= 10{,}555.6 + 7{,}229.2 + 43{,}680.8 = 61{,}466 \text{ k/in}$$

BF-1: $f_{it} = \dfrac{k_i d_i P_x e_y}{\Sigma k_i d_i^2} = \dfrac{(6.41)(40.58) P_x (29.58')}{61{,}466} = 0.125\ P_x$

BF-2: $f_{it} = \dfrac{(4.39)(40.58) P_x (29.58)}{61{,}466} = 0.0856\ P_x$

BF-3: $f_{it} = \dfrac{(4.39)(99.75)(29.58) P_x}{61{,}466} = 0.211\ P_x$

BF-4, BF-5 = 0 P_y

TOTAL SHEAR FORCES:

BF - 1 Fi = 0.422 Px − 0.125 Px = 0.297 Px

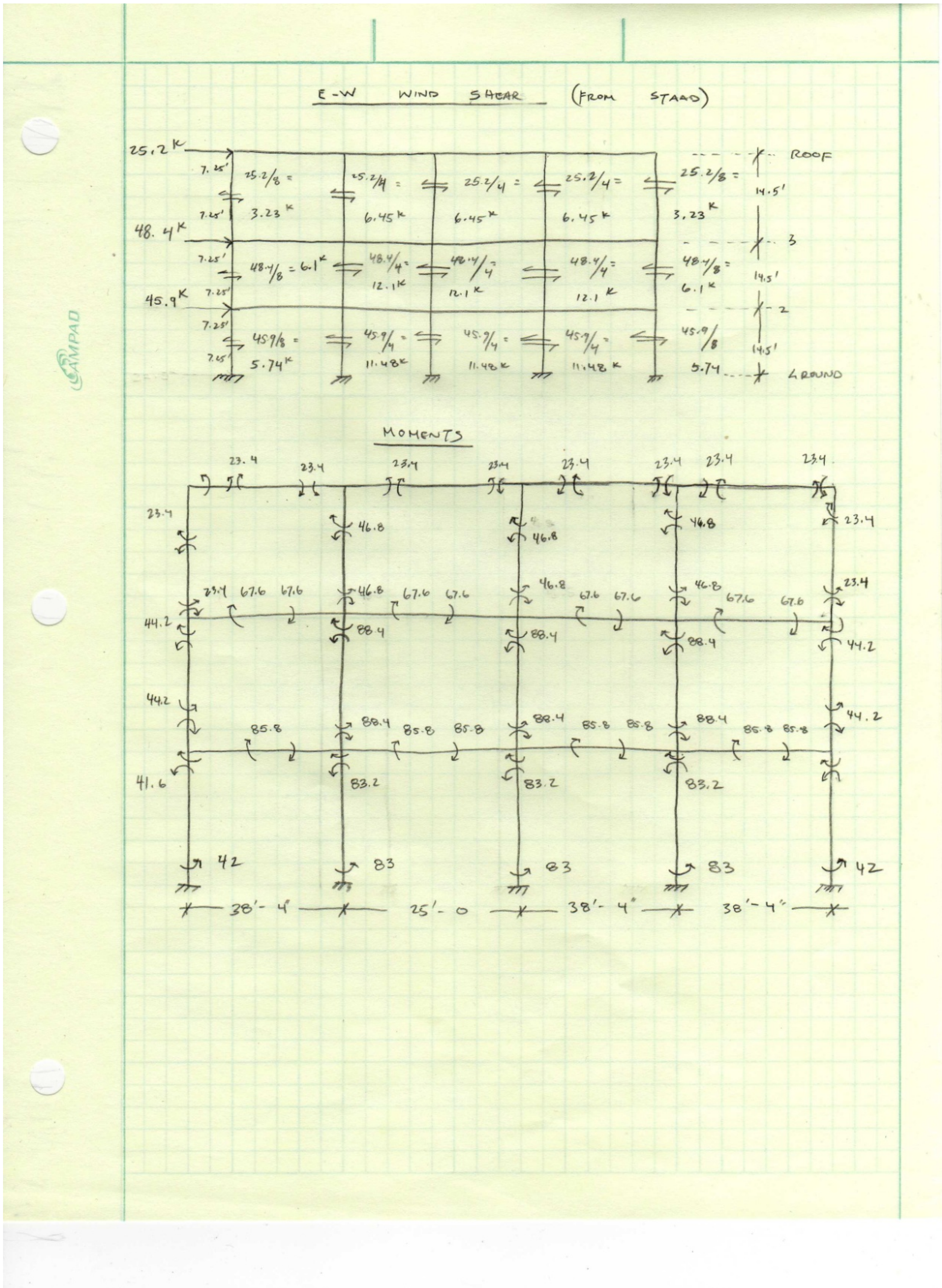
BF - 2 Fi = 0.289 Px − 0.0856 Px = 0.203 Px

BF - 5 Fi = 0.289 Px + 0.211 = 0.5 Px

BF - 3 Fi = 0.406 Py

BF - 4 Fi = 0.594 Py

Appendix D: Portal Method



LATERAL DISPLACEMENT ESTIMATES:

$$U_1 = \frac{(M_{COLUMN})(h_{COLUMN} \times 12)^2}{6 E I_{COLUMN}} + \frac{(h_{col} \times 12)(M_{BEAM})(l_{BEAM} \times 12)}{12 E I_{BEAM}}$$

$$\frac{(42)(14.5 \times 12)^2}{6(29{,}000)(110)} + \frac{(14.5 \times 12)(38.33 \times 12)(85.8)}{12(29000)(1350)} = \boxed{0.0810 \text{ inches}}$$

$$U_2 = U_1 + \left[\frac{(44.2)(14.5 \times 12)^2}{6(29{,}000)(110)} + \frac{(14.5 \times 12)(38.33 \times 12)(67.6 + 85.8)}{12(29000)(1350)}\right] = 0.0960 \quad \text{2nd story drift}$$

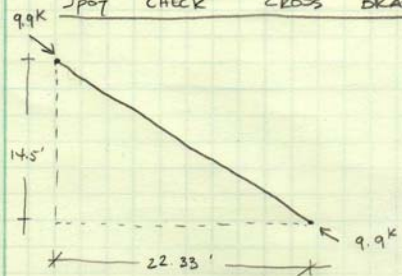
$$U_2 = 0.177 \text{ inches}$$

$$U_3 = U_2 + \left[\frac{(23.4)(14.5 \times 12)^2}{6(29{,}000)(110)} + \frac{(14.5 \times 12)(38.33 \times 12)(23.4 + 67.6)}{12(29{,}000)(1350)}\right] = 0.0525'' \quad \text{3rd story drift}$$

$$U_3 = 0.230''$$

Appendix E: Member Verification (Spot Checks)

Spot Check Cross Braces Frames (BF-1 & BF-5)



HSS T 2.5" x 2.5" x 0.25"

$A_g = 1.97 in^2$

1) Pin - Pinned ∴ K = 1.0

2) $L = \sqrt{(22.33)^2 + (14.5)^2} = 26.62'$

From Table 1-12 STL Manual : $r_x = 0.908$

3) $\frac{KL}{r} \times 12 = \frac{(1.0)(26.62 \times 12)}{0.908} = 102.3$

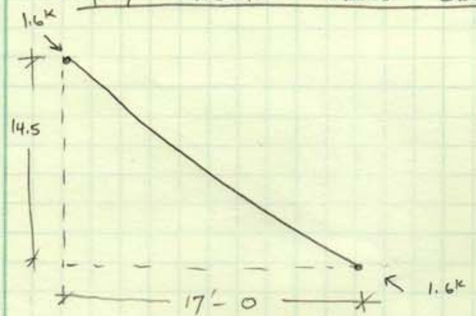
$4.71\sqrt{29{,}000/50} = 113 > 102.3$ ∴ Inelastic

Use Eqn : $F_e = \frac{\pi^2 E}{(KL/r \times 12)^2} = \frac{\pi^2 (29{,}000)}{(102.3)^2} = 27.3$

$F_{cr} = 50\left(0.658^{(50/27.3)}\right) = 23.2$

$\phi P_n = 0.9(23.2)(1.97) = 41.2^k > P_u = 9.9^k$ ∴ ok ✓

SPOT CHECK CROSS BRACING (BF - 2, 3, 4)



HSST 2.5" x 2.5" x 0.25"

$A_g = 1.97$ in

$k = 1.0$

$L = \sqrt{17^2 + 14.5^2} = 22.33'$ $\qquad r_x = 0.908$

$\frac{KL}{r} \times 12 = \frac{(1.0)(22.33)}{0.908} = 85.8 < 4.71\sqrt{29{,}000/50} = 113 \therefore$ inelastic

$F_e = \frac{\pi^2 E}{(KL/r \times 12)^2} = 38.9$

$F_{cr} = 50\left(0.658^{(50/38.9)}\right) = 29.2$

$\phi P_n = 0.9(29.2)(1.97) = 51.8^k > P_u = 1.6^k \therefore$ ok