CIVL 310 Final Project

Prepared for
Dr. Robabah Jazaei

Slippery Rock University
Department of Physics and Engineering

By
M.I

December 3, 2021

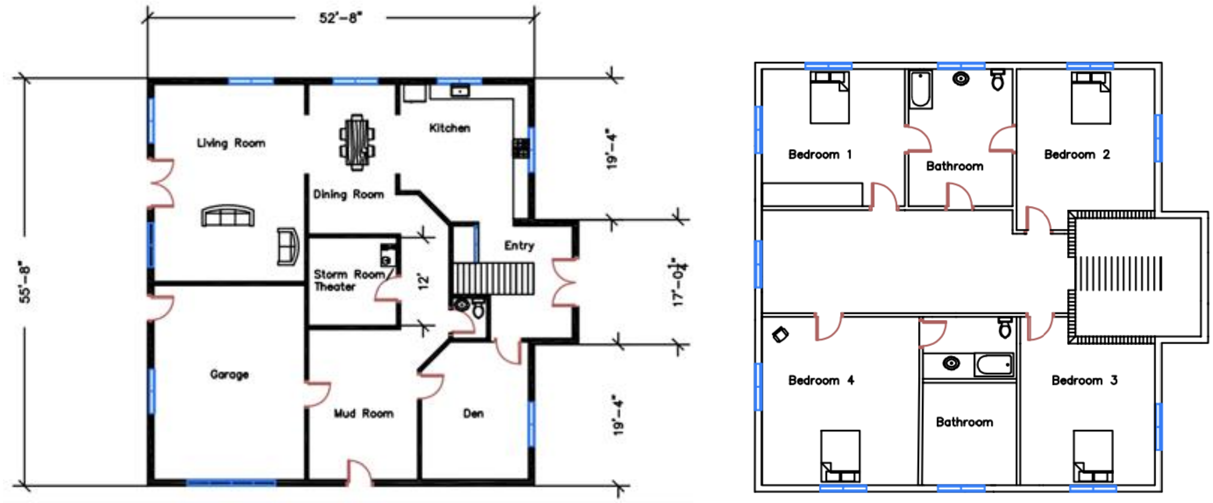
Table of Contents

Table of Figure

Table of Tables

Executive Summary

In many southern states, where tornadoes are common, homes are often lacking basements to protect residents from these storms. This occurs due to the water table or bedrock existing close to the surface. This often causes the construction of basements to be either complicated or cost prohibited. For this reason, homes are often designed with rooms that will withstand tornados that could cause catastrophic home damage while protecting the occupants. The structure is a two-story single family residence that will be built in Oklahoma with a spacious concrete storm shelter in the center of the ground level that will serve daily as an additional room. The floor plan in figure 1 shows the floor plan of this home using AutoCAD software.



Ground Level

2nd Floor

Figure 1 Floor Plan of Residential Structure.

Concrete columns are designed of 4000 normal weight concrete that span from the ground level to the roof and measure 20 feet in height along the perimeter of the structure. The four central columns are designed of hot rolled wide flange beams of W8x10 with a height of 10 feet. Figure 2 shows the placement of columns using AutoCAD software.

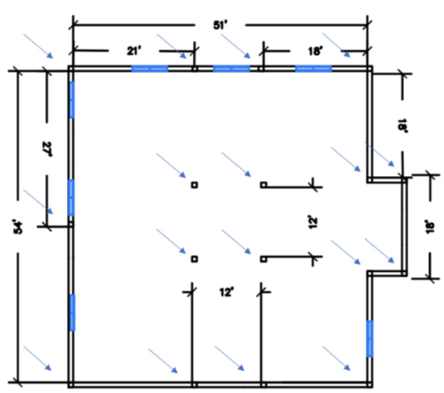


Figure 2 Column Plan.

The columns are connected by girders of steel wide flange beams W10x33. The walls of the storm shelter are also concrete. The Pratt roof truss and floor beams are designed with southern pine of 2x6, 2x8, or 2x10. Figure 3 shows a model of the structure using RISA software.

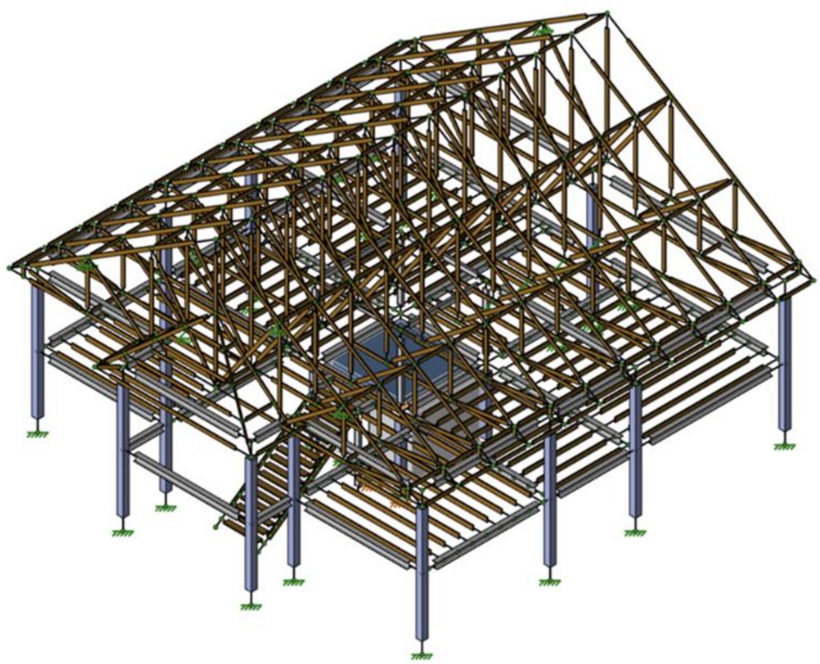


Figure 3 3-D Residential Frame Design

Load Design and Standards

For the interior floors of the residential home, a live load of 40 lb/ft^2 was applied in accordance with minimum requirements set by ASCE/SEI 7-16 (American Society of Civil Engineers). The dead load was automatically applied using the material weight established by the RISA software.

The ground snow load was found to be 20 lb/ft^2 which was calculated as a snow load of 11.2 lb/ft^2 by formula $p_f = 0.7C_eC_tI_sp_g$ (sample calculation on calculation page). The wind load was calculated based on 120 mph winds that would withstand a weak tornado. Weak tornados designated as an EF0 or EF1 account for 78% of all tornados according to FEMA research over a 56-year period. This wind load was found using formulas, $p = qG_p - q_h(GC_{pi})$ and $q_z=0.00256K_z K_{zt} K_d K_e V^2$, *to* be 31.7 lb/ft^2 on the roof and a tapered load of 31.3-37.6 lb/ft^2 along the walls from 0-25 feet respectfully (sample calculation on the calculations page).

The storm shelter within the structure received additional loading set by FEMA P-361 (Federal Emergency Management Agency). Therefore, the storm shelter received additional live load of 100 lb/ft^2 across the concrete ceiling slab. The wind load was calculated with wind speeds of 250 mph of 97.7 lb/ft^2(sample calculation on the calculations page).

With the loads placed on the model frame, three members, one of each material were chosen to evaluate the deflection, shear, and moment of the member. The following are the reports of those members.

Steel

In this design, steel girders support floor loads as well as wind loads along exterior walls. Exterior girder, M34, shown in figure 4 was selected for analysis. Analysis of member M34 is shown below in figure 5.

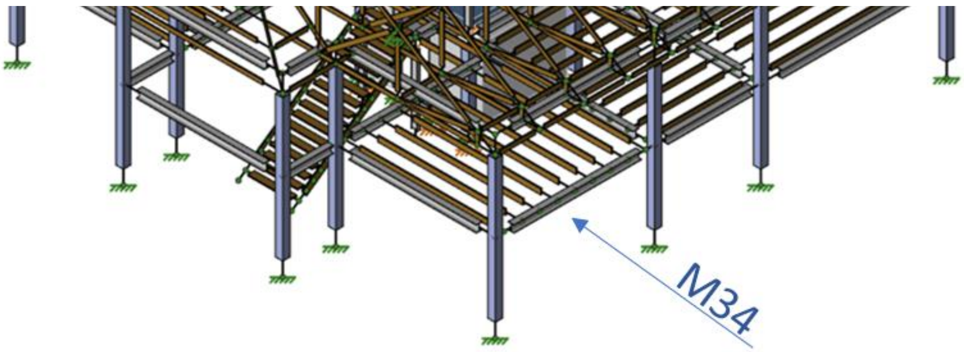
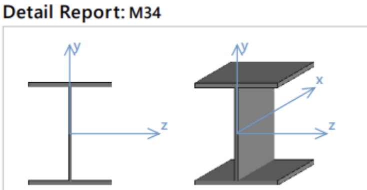


Figure 4 Location of analyzed beam member M34.

Detail Report: M34 | **Unity Check:** 0.691 (axial/bending) | **Load Combination:** LC 1: LL & DL



Input Data:

Shape:	W10X33	I Node:	N17
Member Type:	Beam	J Node:	N23
Length (ft):	18	I Release:	BenPIN
Material Type:	Hot Rolled Steel	J Release:	BenPIN
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	97	J Offset (in):	N/A

Material Properties:

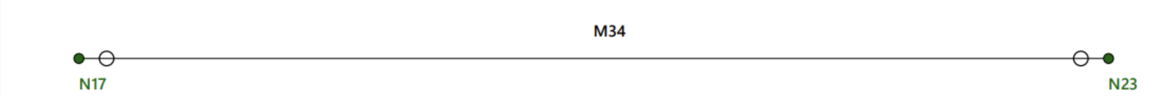
Material:	A992	Therm. Coeff. $(1e^{5\circ}F^{-1})$:	0.65	R_y:	1.1
E (ksi):	29000	Density (k/ft^3):	0.49	F_u (ksi):	65
G (ksi):	11154	F_y (ksi):	50	R_t:	1.1
Nu:	0.3				

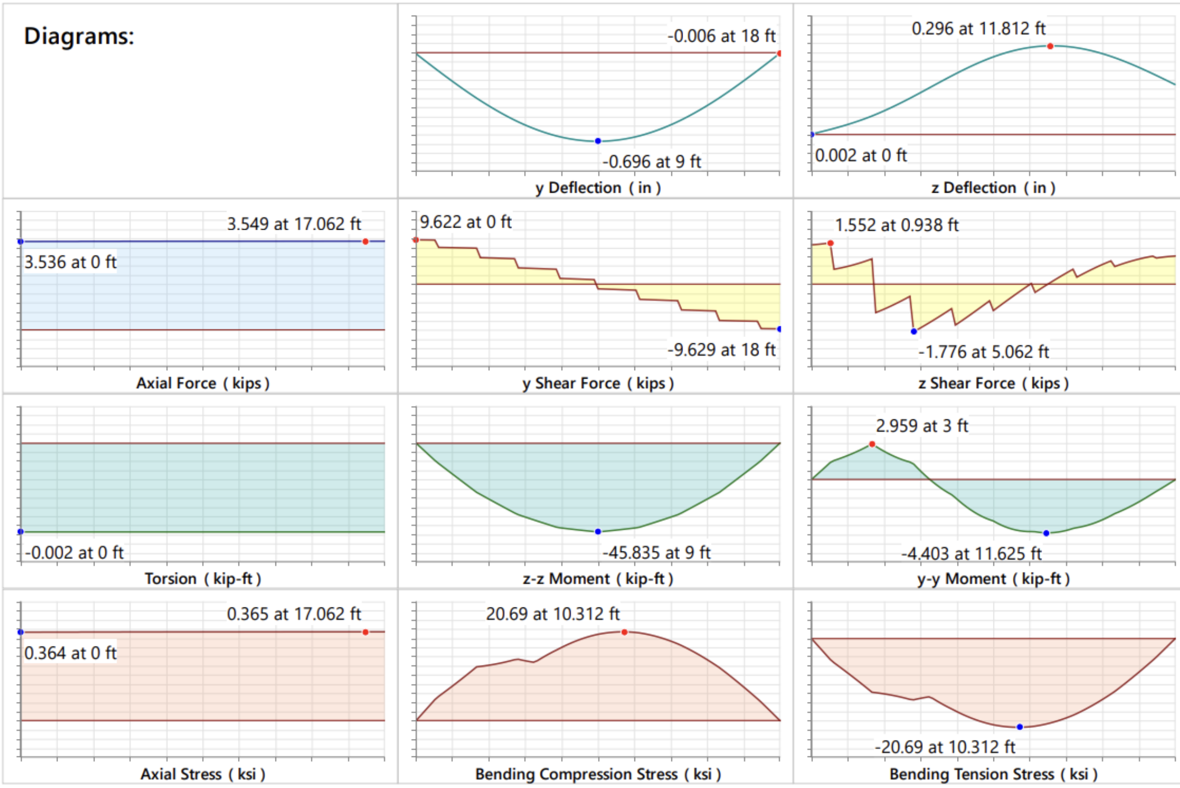
Shape Properties:

d (in):	9.73	Area (in^2):	9.71	S_w (in^4):	16
b_f (in):	7.96	Z_{yy} (in^3):	14	r_T (in):	2.16
t_f (in):	0.435	Z_{zz} (in^3):	38.8	J (in^4):	0.583
t_w (in):	0.29	C_w (in^6):	791	k_{det} (in):	1.125
I_{yy} (in^4):	36.6	W_{no} (in^2):	18.5	k_{des} (in):	0.935
I_{zz} (in^4):	171				

Design Properties:

$L_{b\ y\text{-}y}$ (ft):	N/A	$K_{y\text{-}y}$:	1	Max Defl Ratio:	L/314
$L_{b\ z\text{-}z}$ (ft):	N/A	$K_{z\text{-}z}$:	1	Max Defl Location:	9
$L_{comp\ top}$ (ft):	Lbyy	y sway:	No	Span:	1
$L_{comp\ bot}$ (ft):	N/A	z sway:	No		
L_{torque} (ft):	N/A	Function:	Lateral		
		Seismic DR:	None		





Limit State	Required	Available	Unity Check	Result
Applied Loading - Bending/Axial				
Applied Loading - Shear + Torsion	-	-	-	-
Axial Tension Analysis	0.000 k	290.719 k	-	-
Axial Compression Analysis	3.547 k	117.604 k	-	-
Flexural Analysis (Strong Axis)	44.848 k-ft	80.293 k-ft	-	-
Flexural Analysis (Weak Axis)	4.099 k-ft	34.93 k-ft	-	-
Shear Analysis (Major Axis y)	9.674 k	56.434 k	0.171	Pass
Shear Analysis (Minor Axis z)	1.171 k	124.405 k	0.009	Pass
Bending & Axial Interaction Check (UC Bending Max)	-	-	0.691	Pass

Figure 5 Analysis of Steel Member M34

Wood

Wood was selected for the roof and floor beams. Wood is easy to work with and a low-cost choice for building materials. A bottom cord of the roof truss, member M357, shown in figure 6 was chosen for further analysis as shown in figure 7.

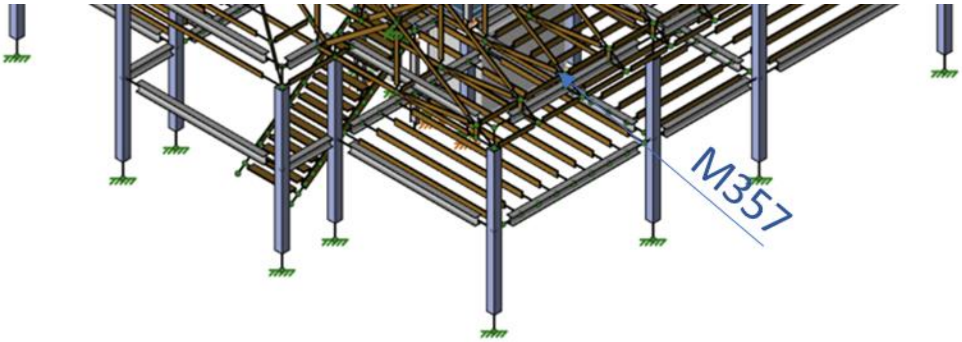
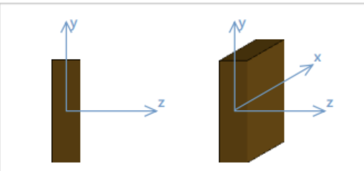


Figure 6 Location of analyzed beam member M357.

Detail Report: M357 **Unity Check:** 0.462 (axial/bending) **Load Combination:** LC 1: LL & DL



Input Data:

Shape:	2X6 (nominal)	I Node:	N392
Member Type:	Beam	J Node:	N396
Length (ft):	29	I Release:	BenPIN
Material Type:	Wood	J Release:	BenPIN
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	97	J Offset (in):	N/A

Material Properties:

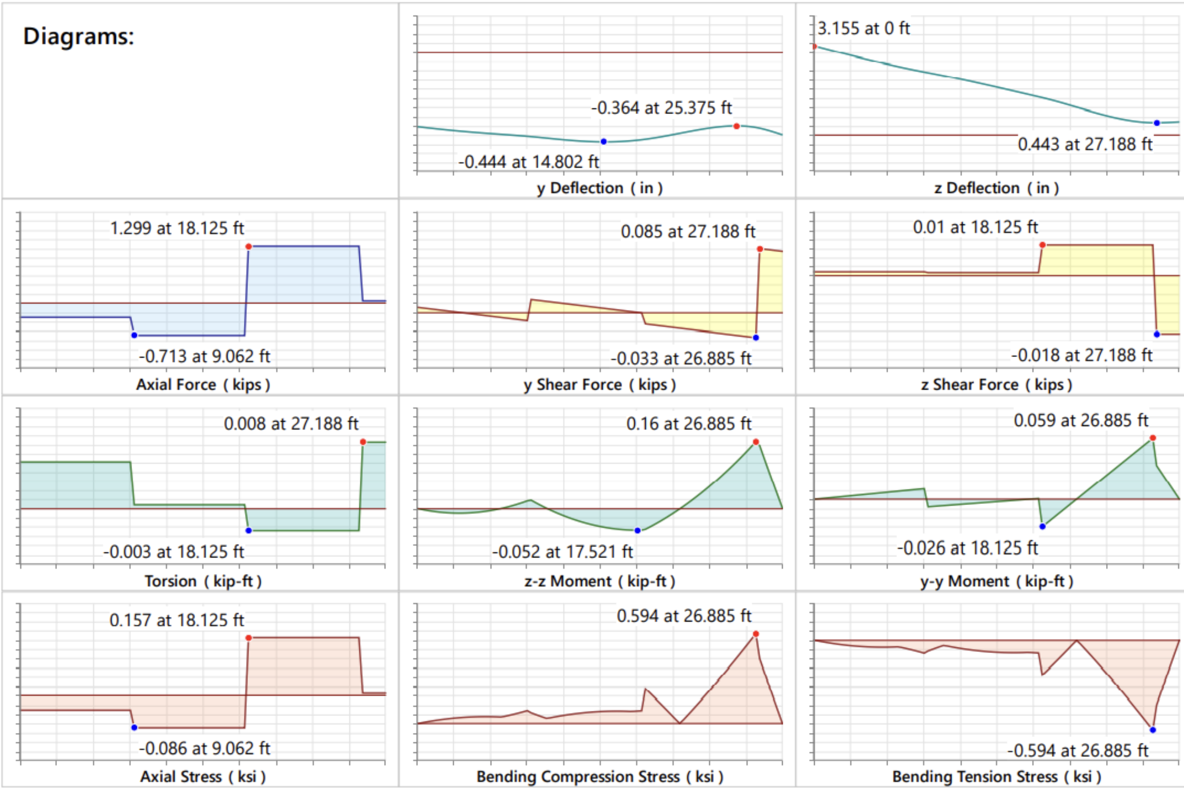
Material:	SP	Grade:	No.1	Nu:	0.3
Type:	Solid Sawn	Cm:	No	Therm. Coeff. ($1e^{5\circ}F^{-1}$):	0.3
Database:	Visually Graded	Emod:	1	Density (k/ft^3):	0.035
Species:	Southern Pine				

Shape Properties:

F_b (ksi):	1.35	E (ksi):	1600	E_{min} (ksi):	584.494
F_t (ksi):	0.875	E mod:	1	b (actual) (in):	1.5
F_v (ksi):	0.175	COV_E (Table F1):	0.25	d (actual) (in):	5.5
F_c (ksi):	1.55				

Design Properties:

le2 (ft):	0	C_D:	1	Max Defl Ratio:	L/1360
le1 (ft):	Segment	R_B:	0	Max Defl Location:	29
le-bend top (ft):	Segment	C_L:	1	Span:	4
le-bend bot (ft):	0	C_r:	1		
K_{y-y}:	1	C_{fu}:	1.15		
K_{z-z}:	1	C_P:	0.611		
y sway:	No				
z sway:	No				



Limit State	Required	Available	Unity Check	Result
Applied Loading - Bending/Axial	-	-	-	-
Applied Loading - Shear + Torsion	-	-	-	-
Axial Compression Analysis	0.157 ksi	0.948 ksi	-	-
Axial Tension Analysis	0.000 ksi	0.875 ksi	-	-
Flexural Analysis, Fb1'	0.253 ksi	1.35 ksi	-	-
Flexural Analysis, Fb2'	0.341 ksi	1.553 ksi	-	-
Bending & Axial Compression Analysis	-	-	0.462	Pass
Bending & Axial Tension Analysis	-	-	0.407	Pass
Shear Analysis	0.042 ksi	0.175 ksi	0.238	Pass

Figure 7 Analysis of Steel Member M357

Concrete

Exterior columns as well as the walls and ceiling of the storm shelter were designed of reinforced concrete. The square columns measuring 10 inches reached 20 feet high. These columns supported the girders which transferred the weight of the roof and floor loads to the ground below. Member M551 shown in figure 8 was chosen for analysis shown in figure 9.

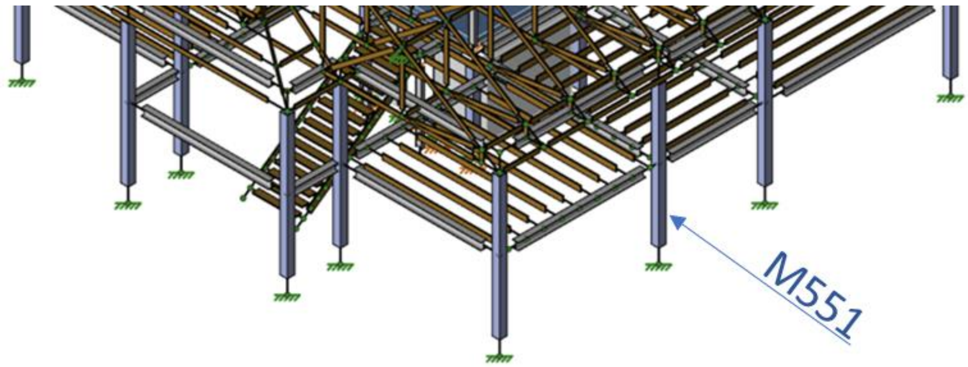
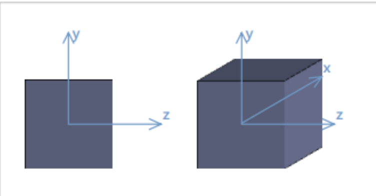


Figure 8 Location of analyzed beam member M357.

Detail Report: M551 **Unity Check:** 0.264 (axial/bending) **Load Combination:** Envelope



Input Data:

Shape:	CRECT10X10	I Node:	N16
Member Type:	Column	J Node:	N363
Length (ft):	20	I Release:	Fixed
Material Type:	Concrete	J Release:	BenPIN
Design Rule:	Typical	I Offset (in):	N/A
Number of Internal Sections:	97	J Offset (in):	N/A
Design Code:	ACI 318-19		

Material Properties:

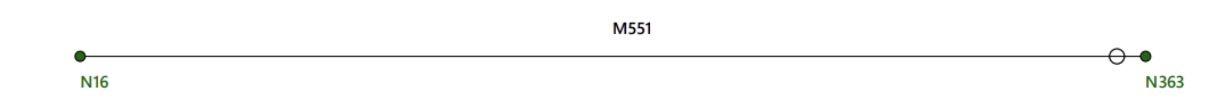
Material:	Conc3000NW	Therm. Coeff. ($1e^5 °F^{-1}$):	0.6	Lambda:	1
E (ksi):	3156	Density (k/ft^3):	0.145	Flex Steel (ksi):	60
G (ksi):	1372	f'c (ksi):	3	Shear Steel (ksi):	60
Nu:	0.15				

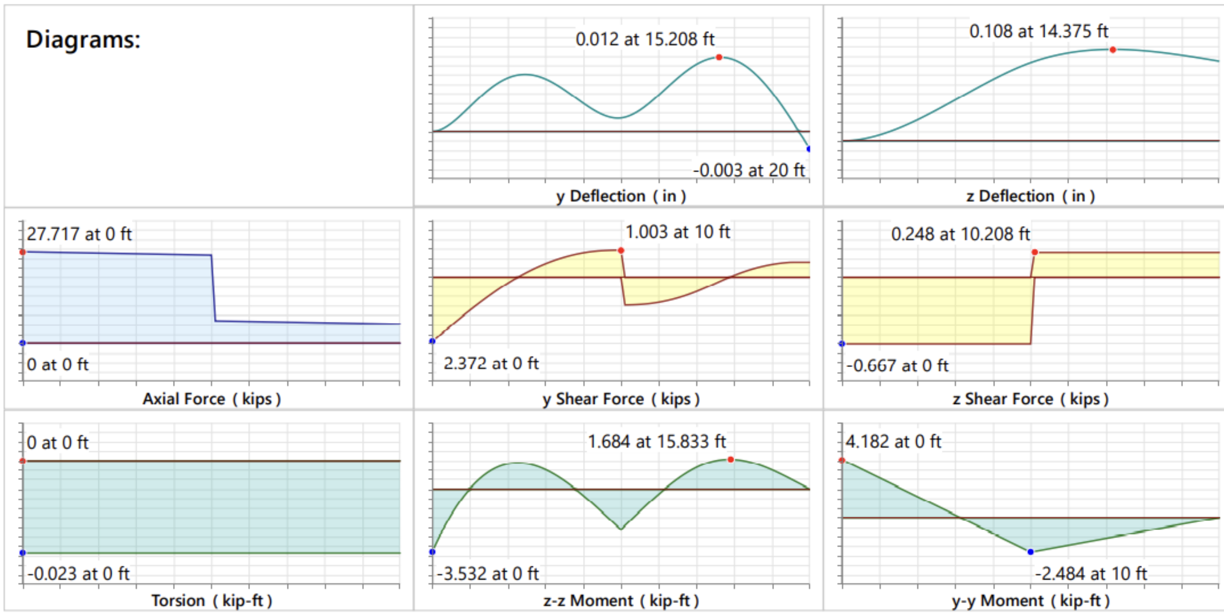
Shape Properties:

D (in):	10	W (in):	10

Design Properties:

$C_{m\ y\text{-}y}$:	N/A	Concrete Stress Block:	Rectangular	Flex Rebar Set:	ASTM A615
$C_{m\ z\text{-}z}$:	N/A	Cracked Sections Used:	Yes	Shear Rebar Set:	ASTM A615
$K_{y\text{-}y}$:	1	Cracked "I" Factor:	0.7	Top Cover (in) :	1.5
$K_{z\text{-}z}$:	1	Effective "I" (in^4) :	583.333	Bottom Cover (in) :	1.5
y sway:	No	Effective "I" (Service) (in^4) :	834.167	Side Cover (in) :	1.5
z sway:	No			Legs/Stirrup:	2





Limit State	Gov. LC	Required	Available	Unity Check	Result
Applied Loading - Bending/Axial					
Flexural Reinforcement	1	1 in^2	1.227 in^2	-	Pass
Axial Capacity	1	27.717 k	104.86 k	0.264	Pass
Bending Unity Check	1	-	-	0.264	Pass
Y Shear Design Strength	0	2.372 k	22.564 k	-	-
Z Shear Design Strength	0	0.667 k	22.564 k	-	-
Threshold Torsion		0.023 k-ft	0.964 k-ft	1	Pass
Span Information					
Rebar Detailing					

Figure 9 Analysis of Steel Member M357.

Cost of Materials

The exterior frame of the structure has been designed with cement columns measuring 10 inches square. Each girder was designed of hot rolled steel wide flanged beams of W10x33 connecting all columns. The roof using, 2x6, and floor beams using, 2x8, have been designed using southern pine. The interior storm shelter is designed of 8-inch, 4000 normal weight concrete walls and ceiling framed by hot rolled steel wide flange columns of W8x10. By mixing the design of sturdy concrete and steel supports paired with wood components this home will be further protected by having less sturdy wood components break away during a catastrophic storm while leaving the sturdy steel and cement frame intact. This will allow the structure to be repaired more efficiently and cost effectively in the event of a catastrophic storm.

	Material	Size	Pieces	Length[ft]	Weight[K]
1	Hot Rolled Steel				
2	A992	W10X33	42	702	23.195
3	A992	W8X10	14	170	1.712
4	Total HR Steel		56	872	24.907
5					
6	Wood				
7	SP	2X6	341	3835.1	7.69
8	SP	2X10	18	119.2	0.402
9	SP	2X8	73	1134	2.998
10	Total Wood		432	5088.3	11.09
11					
12	Concrete Members			Volume (yds...	
13	Conc3000NW	CRECT10X10	17	7.7	30.208
14	Concrete Walls				
15	Conc4000NW		5	10.9	42.533
16	Total Concrete		22	18.6	72.742
17					
18	Plate Elements	Thickness (in)		Volume (yds...	
19	gen_Conc4NW	8	1	3.6	13.92
20	Total Plates		1	3.6	13.92

Hot Rolled Steel	$36,932.58
Southern Pine Lumber	$6,957.87
Concrete	$2,775
Grand Total $46,665.45	

Table 1 Materials Cost Summary

Summary

This two-story residential structure was designed with a combination of wood, steel, and concrete materials. The design is intended to be built in Oklahoma state where windstorms and tornados frequently exceed wind speeds of 90 mph. This structure was designed to withstand windspeeds of 120 mph which exceeds windspeeds of an EF1 tornado. This structure is designed with an interior room that serves as a storm shelter that will withstand 250 mph windspeeds equivalent to an EF5 tornado.

Calculations

Velocity Pressure: $q_z = 0.00256 K_z K_{zt} K_d K_e V^2$ (lb/ft^2)

where:
q_z = velocity pressure (psf) calculated at height z above ground
K_z = velocity pressure exposure coefficient at height z above ground
K_{zt} = topographic factor = 1.0
K_d = wind directionality factor = 1.0
K_e = ground elevation factor = 1.0
V = design wind speed (mph)

Sample Calculation: Considering windspeed of 250mph.

$q_z = 0.00256(0.85)(1)(1)(1)(250^2) = 136$ lb/ft^2

K_z = 0.85 at 0-15ft
K_{zt} = 1.0
K_d = 1.0
K_e = 1.0
V = 250 mph

Pressure: $p = qGC_p - q_i(GC_{pi})$

where:
p = pressure (psf)
q = q_z for windward walls calculated at height z above ground
q = q_h for leeward walls, sidewalls, and roofs evaluated at height h
G = gust-effect factor
Cp = external pressure coefficients
q_i = q_h = velocity pressure calculated at mean roof height
GC_{pi} = internal pressure coefficients

Sample Calculation: Wind load applied to storm shelter.

$p = qGC_p - q_i(GC_{pi}) = 92.48 \pm 5.184$ lb/ft^2

q = q_z = 136 lb/ft^2
G = 0.85
Cp = 0.8
q_i = q_h = 28.8
GC_{pi} = ±0.18

Snow load: $p_f = 0.7 C_e C_t I_s p_g$

where:
C_e = exposure factor for unobstructed area = 0.8
C_t = thermal factor for heated structure = 1.0
I_s = importance factor for residential structures = 1.0
p_g = ground snow load for Oklahoma = 20 lb/ft^2

Sample Calculation: Snow for unobstructed area on a residential structure in Oklahoma.

$p_f = 0.7 C_e C_t I_s p_g = 11.2$ lb/ft^2

where:
C_e = for unobstructed area = 0.8
C_t = for heated structure = 1.0
I_s = for residential structures = 1.0
p_g = for Oklahoma = 20 lb/ft^2