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Design of Load Bearing Wall for Low Rise Building with Partially Grouted Reinforced Masonry

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DESIGN OF LOAD BEARING WALL FOR LOW RISE BUILDING WITH PARTIALLY GROUTED REINFORCED MASONRY

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by

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ABSTRACT

The seismic and wind load acting on the 2-storeyed building of dimension 120 ft x 98 ft located in Oxford, MS, were calculated and the seismic load was considered for the design of the 120 ft long and 24 ft high load-bearing wall because it being critical. The maximum loading was computed using different load combinations. The masonry behavior and masonry specifications were considered to select the masonry unit, grout, and mortar for the load-bearing wall. The seismic design requirement for the shear and slender wall was fulfilled for the special reinforced masonry wall. The in-plane and out-of-plane loading scenarios were considered for finding the required reinforcement in the wall to resist the bending moment and the shear. The special reinforced masonry wall was designed using the Strength Design method. The cost of construction of a 24 ft high wall with reinforced concrete and the reinforced masonry was computed. It was found that the construction with reinforced masonry came out much cheaper as compared to the construction with reinforced concrete.

DEDICATION

This thesis is dedicated to all my teachers and advisors who have blessed me with engineering knowledge and wisdom.

I also dedicate this work to my grandparents and parents who first taught me the value of education and hard work.

LIST OF SYMBOLS

A	Area (ft^2)
A_g	Gross area (ft^2)
A_n	Net area of the wall subtracting any reinforcement (ft^2)
A_{nv}	Net shear area of masonry wall (ft^2)
A_o	Openings area (ft^2)
A_s	Area of steel reinforcement in masonry wall (ft^2)
A_T	Tributary Area (ft^2)
ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
b	Width of masonry, cross-sectional (ft)
c	Coefficient for determining stress block height (ft)
C	Compression force (lb)
C_d	Deflection amplification factor
C_m	Compression force in the masonry (lb)
C_s	Seismic response coefficient
CMU	Concrete Masonry Unit
d	Effective length from the end of masonry to the centroid of the tensile steel (ft)
d_v	Total depth of masonry wall (ft)
D	Site Class
e	Eccentric distance of the force from the centroid of the cross-section (ft)
E_m	Modulus of Elasticity of masonry (psi)
E_s	Modulus of Elasticity of steel (psi)
f_m	Calculated compressive stress in masonry (psi)
f'_c	Compressive stress of concrete or mortar (psi)

f'_m	Masonry design compressive stress (psi)
f_r	Modulus of rupture (psi)
f_y	Yield stress in the steel reinforcement for masonry design (psi)
F_a	Short Period Site Coefficient
F_v	Long Period Site Coefficient
F_x	Horizontal force in the x-axis (lb)
g	Acceleration due to gravity (ft/sec^2)
G	Gust effect factor
GE	Ground Elevation (GE)
h	Height of wall (ft)
I	Importance factor
I_e	Seismic Importance factor
I_g	Moment of inertia of CMU (ft^4)
I_x	Moment of inertia with respect to the x-axis (ft^4)
k	Exponent related to the structural period
K_d	Wind directionality factor
K_{zt}	Topography factor
L	Span length of masonry wall (ft)
M	Type of masonry mortar
	Internal bending moment (lb-ft)
$ØM_n$	Design bending moment (lb-ft)
M_{cr}	Cracking moment capacity of a reinforced masonry (lb-ft)
M_s	Moment capacity for service loading on a reinforced masonry (lb-ft)
M_u	Ultimate moment demand of a reinforced masonry (lb-ft)
MWFRS	Main Wind Force Resisting System

n	Modular ratio for two materials
N	Number of stories in building
NCMA	National Concrete Masonry Association
P	Axial force (lb)
	Pressure (psf)
P_{fD}	Dead load from floors (lb)
P_{Lr}	Live load from occupancy (lb)
P_a	Allowable load in masonry wall (lb)
P_n	Nominal capacity (lb)
p_s	Design wind pressure (psf)
p_{s30}	Simplified design wind pressure at 30ft height (psf)
P_u	Ultimate axial load(lb)
P_{uf}	Dead load from floors (lb)
P_{uL}	Live load from floors (lb)
P_{uw}	Dead load from wall (lb)
$\emptyset P_n$	Design axial strength (lb)
r	Radius of gyration (ft)
R	Response modification factor
s	Spacing (ft)
S	Section modulus (ft^3)
S	Type of masonry mortar
S	Snow load (lb)
S_1	Peak ground acceleration for period 1.0 sec
S_s	Peak ground acceleration for period 0.2 sec
S_{D1}	Design spectral acceleration for period 1.0 sec

S_{DS}	Design spectral acceleration for period 0.2 sec
S_{M1}	Site-modified spectral acceleration value for period 1.0 sec
S_{MS}	Site-modified spectral acceleration value for period 0.2 sec
t	Thickness of masonry wall (ft)
T	Tension (lb)
T	Time-period (sec)
TMS	The Masonry Society
V	Wind Velocity (mph)
V_E	Shear force due to earthquake (lb)
V_n	Nominal shear force (lb)
V_{nm}	Shear force due to masonry (lb)
V_{ns}	Shear force due to steel (lb)
V_u	Ultimate shear force (lb)
W	Total weight (lb)
γ_m	Unit weight of masonry (psi)
ε_m	Strain in masonry
ε_s	Strain in reinforcing steel
ρ	Reinforcement ratio in masonry design
δ_u	Maximum wall deflection (ft)
Δ	Deflection (ft)
λ	Adjustment factor for building height and exposure
Ω	Overstrength (or global safety) factor for ASD
$\emptyset$	Resistance factor for LRFD

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CHAPTER 1

INTRODUCTION

The advancements in the civil engineering and construction industry have created many structural designs for the various structural walls with various types of loading in them. The safe and reliable operation of those structural walls is very important for holding the building structure for a long period without failing, upholding public safety. While constructing any load-bearing wall the cost and function come into play. Even though the reinforced concrete wall is capable of holding the maximum loadings, the cost of a reinforced concrete wall is very high. In that scenario where cost is an important factor to consider, a reinforced masonry wall in a building structure seems to be a good alternative. The reinforced masonry wall is very resistant to the tensile and shear stress-producing forces due to its combination of masonry units, reinforcements, grout, and mortar. The reinforcement in the masonry wall provides the required ductility and additional tensile strength to the masonry wall. Thus, reinforced masonry walls in the low-rise building can aid or replace reinforced concrete walls.

1.1 Project Overview

A two-storeyed commercial building of 120 ft x 98 ft footage and 24 ft total height located in Oxford, Mississippi needed to be designed as part of the senior capstone project. In that project, the building was designed with a rigid-frame structural system where cast-in-place (CIP) reinforce concrete (RC) beams and columns are present to resist the moment caused by the dead and live gravity loads in the building. In that system, non-load-bearing 8 inches RC walls are present around the perimeter of the building between the columns, around the elevator shafts, and stairwells. Taking the same project and building as a reference, the system of RC perimeter walls and exterior RC frames of the building is replaced with the load-bearing reinforced masonry walls. This leads to a dual masonry wall-RC frame system. Replacing the RC perimeter walls and frames with reinforced masonry (RM) walls decreases the construction cost and reduces the number of columns and beams used in the building, leading to more open space within the structure, and thus would increase profitability. The RM shear wall system in the building is shown to provide adequate resistance to the lateral forces such as wind and seismic.

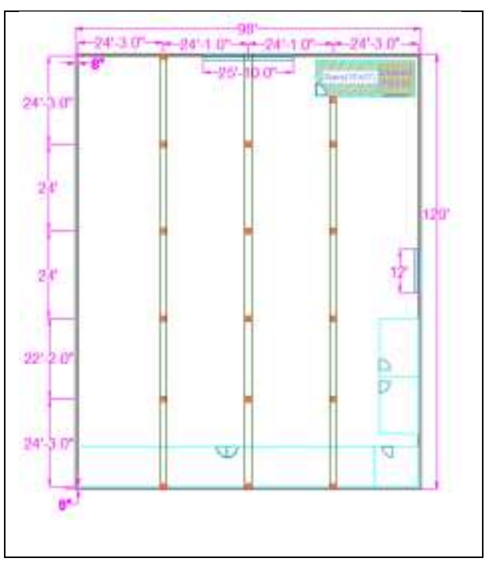

Figure 1: Top View of the Building

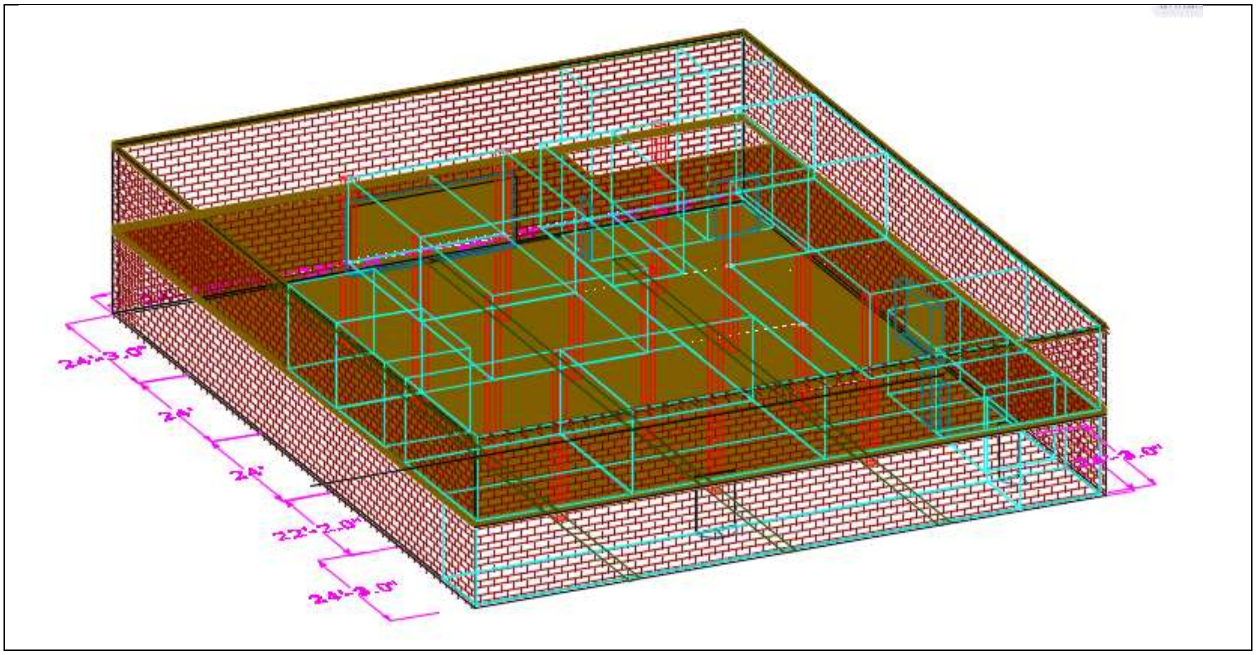

Figure 2: Isometric View of the Building

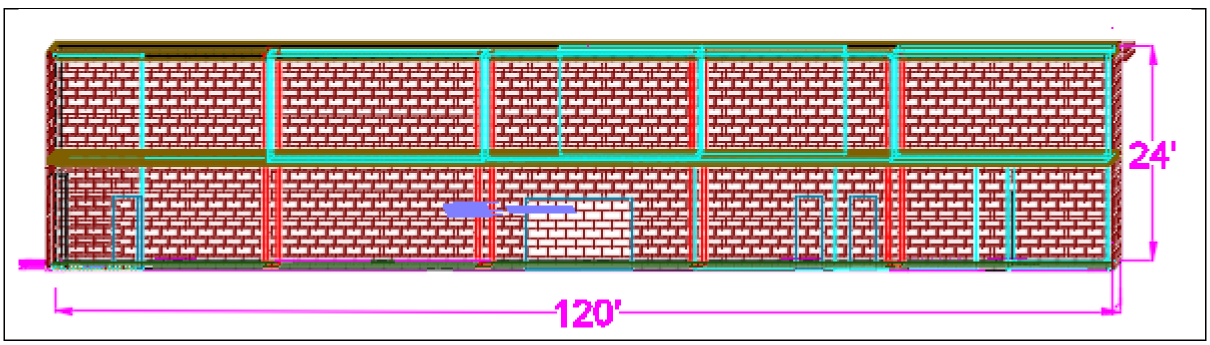

Figure 3: Front View of the Building

1.2 Masonry Wall

The building structures are categorized into three main types: low-rise, mid-rise, and high-rise based on the height from the grade level. The building of 60 feet or less height where the height is no longer than the least horizontal dimension are called low-rise buildings (SEI 7-05).

These are the buildings which are usually 4 or fewer stories in height. These buildings can be constructed with various types of masonry materials.

Masonry walls are the walls built with the masonry units like bricks, blocks, stones, marbles, tiles, granites, and so forth bounded together by a mortar, which can be cement, soil, lime, or any other material. These walls provide strength, durability, and insulation to the building structure. Based on the types of the individual masonry units selected and the functions of the wall, they are mainly classified into 5 types. They are Load Bearing Masonry Wall, Reinforced Masonry Wall, Hollow Masonry Wall, Composite Masonry Wall, and Post-Tensioned Masonry Wall. The reinforced masonry wall is the one that is particularly selected for this project. The reinforced masonry can be both load-bearing and non-load bearing. The load-bearing walls take all the load from the roof and floor level to the ground while the non-load-bearing wall doesn't take any loads from a roof or floor level. Load-bearing walls are used in this project which takes a few of the loads from the roof and the floor level to the ground. Along with the load-bearing walls, the columns in the center also takes the load from the roof and the floor to the ground in this project.

The reinforcement in the wall withstands the tension, compressive, and lateral loads like wind and seismic, and reinforcement help to avoid the cracks during heavy loading and seismic events. The horizontal and vertical reinforcement and spacing are selected based on the loading and structural condition on the wall. The mortar and grout in the masonry wall help to stabilize the reinforcement and provide the stability and strength to the wall. Based on the amount of grout used in the reinforced masonry walls, they can be partially grouted or fully grouted. Partially grouted means only adding the grouts to certain masonry units leaving the voids in the middle while fully grouted means filling the void space between the masonry units with grout, which is a cementitious binding material. The partially grouted reinforced masonry wall is the one that is designed in this project, being a partially grouted wall more economical than a fully grouted wall.

1.3 Material Selection

The reinforced masonry wall gets its strength and ductility from the four different components and their composite action. The four main components of the reinforced masonry wall are:

1. Concrete Masonry Units (CMUs)

   These are usually hollow rectangular blocks made up of Portland cement, aggregates, and water. They are brittle and have very high compressive strength. They come in various sizes and weights. Standard Specification for Load-Bearing Masonry Units (ASTM C90) provides requirements for materials, dimensions, finish, and appearance of CMUs. The two types of CMUs are selected based on their functions and shapes for this project. They are 8x8x16 Standard CMU and 8x8x16 Bond Beam. Normally standard size concrete block is used in the wall for vertical reinforcement and vertical grouting. However, the bond beam is used in the wall where horizontal and vertical reinforcement is necessary for the wall. The actual dimensions of CMUs are 3/8 inches smaller than the nominal dimensions to allow for mortar joints. The CMUs of compressive strength (f'_m) 2000 psi, unit weight of (γ_m) 125 psi, and modulus of elasticity (E_m) 1,800,000 psi are used in the project. The actual sizes of the CMUs are shown in the figure below:

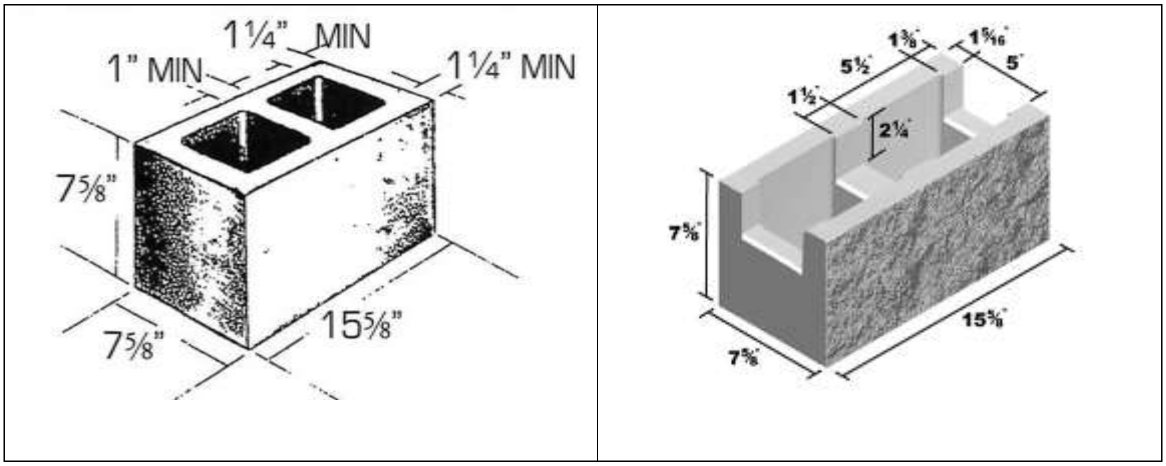

Figure 4: Concrete Masonry Units (CMUs) (4.a.Standard CMU;4.b.Bond Beam CMU)

2. Reinforcement

The reinforcement is provided in the wall in both vertical and horizontal directions, and in joints of the CMUs to provide the necessary ductility to withstand the moment, axial, and lateral loadings. The deformed and plain carbon steel bars of Grade 60 with a yield strength (F_y) of 60,000 psi in the vertical and horizontal direction and ladder-type joint reinforcement in the horizontal direction between the CMUs layers are used in the wall. The deformed bars of sizes ranging from #3 (0.375 in diameter) to #9 (1.128 in diameter) are recommended to use for the strength design of the wall. The typical way of reinforcement in a partially grouted reinforced masonry wall is shown in the figure below:

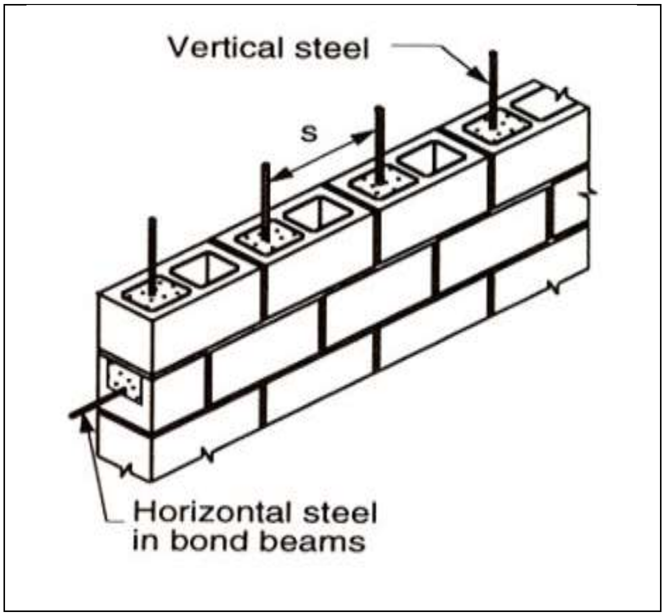

Figure 5: Reinforcement in Partially Grouted Reinforced Masonry Wall

3. Mortar

This is the mix of cementitious materials like Portland cement, fine aggregates (sand), and water. It acts as a bonding material between the individual concrete masonry units and converts individual units into a solid unit. Type M mortar made up of Portland cement with an average compressive strength (f'_c) of 2500 psi and maximum air content as 12% is selected for the wall.

4. Grout

It is the mixture of cementitious material, aggregate, and enough water (to enhance steady flow) placed in the cells or cavities in the wall (at least when steel reinforcement is present). The bonding of grout with steel and the CMUs blocks acts together for resisting the loadings in the wall. Grout for Masonry (ASCE C476) provides requirements for grout in masonry construction. The water content in the grout is adjusted in such a way that the slump is between 8 to 11 inches to increase the workability of the mix. The grout with average compressive strength (f'_c) of 2500 psi is selected for the wall.

CHAPTER 2

RESULTS AND DISCUSSION

2.1 Loading on Masonry Wall

The partially grouted reinforced masonry wall is loaded with the dead and live load from the roof and floor level whereas the lateral loading is because of the wind and the seismic force. As the 120 ft span of the wall is more critical because of the beams and columns running in the same direction, it is considered for designing purpose so that overall designing of the wall located in the outside perimeter of the building will be safe with a higher factor of safety. The dead and live load from the roof and the first floor acting in the wall is calculated by taking the tributary area equals to the area covering half of the length from the center of the wall to the nearest beam running and it is shown in the table below:

Table 1: Dead and Live Loads on Reinforced Masonry Wall on 120 ft span

Dead Load From Roof ***(psf)***	Dead Load From 1st Floor ***(psf)***	Live Load From Roof ***(psf)***	Live Load From 1st Floor ***(psf)***
157	208.5	20	60
(plf)	***(plf)***	***(plf)***	***(plf)***
1904	2528	243	728

2.1.1 Wind Load

The wind load acting in the 120 ft long span of the partially grouted reinforced masonry wall is determined considering the wind speed of 110 mph [5]. The risk category and surface roughness category are considered to be R2 and C respectively [5] for determining the wind loading. The Main Wind Force Resisting System (MWFRS) is an assemblage of structural elements to provide support and stability for the overall structure and wind loading from more than one surface and this approach along with Method 6: 2015 IBC Section 1609.6 is used to determine the wind pressure acting in the wall.

Table 2: Wind Load Acting on Zone A, and Zone B of Building Wall

Zone	Wind Load ***(psf)***
A(i.e.Upto 10 ft from the end of the wall)	26
C(i.e. Anywhere in between 10 ft from the end of the wall)	17

The figure below shows the action of the wind pressure at zone A which is up to 10 ft from the end of the wall.

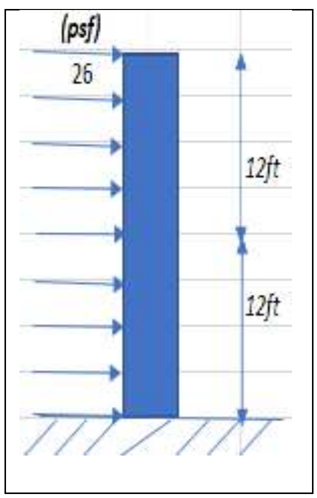

Figure 6: Wind pressure acting on Masonry Wall at zone A

2.1.2 Seismic Load

The seismic load acting in the wall is calculated considering the Risk Category for building as II and site class as D. Using the ASCE/SEI 7-05 for the structural wall, the following formula is used to calculate the out of plane seismic load for the wall.

$$F_p = 0.4 S_{DS} I_E W_p$$

Where, S_{DS} = Numeric seismic design value at 0.2s period

I_E = Seismic Importance Factor = 1

W_p =Weight of the structural wall in (psf)

The out-of-plane seismic load is found to be 38.9 psf.

The total base shear (V) for the building under seismic load is 107 kips. The force is calculated at various levels of the reinforced masonry wall like as shown in the table below:

Table 3: The Force calculation at the various Heights of the Masonry Wall

Level	Floor Height	h_x	Wx	$Wx.h_x^k$	C_{vx}	F_x	V_x / Story	OTM
	(ft)	*(ft)*	*(kips)*	*(kips-ft)*		*(kips)*	*(kips)*	*(kips-ft)*
Roof	24	24	389.7	9354.0	0.543	**58**	0	1397
First Floor	12	12	655.1	7861.1	0.457	**49**	58	587
Ground Floor	0	0	581.1	0	0	**0**	107	0
			Σ	17215.1	1	**107**		

The maximum overturning moment due to loading is 1397 kips-ft which is at the top of the masonry wall i.e. 24 ft.

The figure below shows the action of the forces in the reinforced masonry wall.

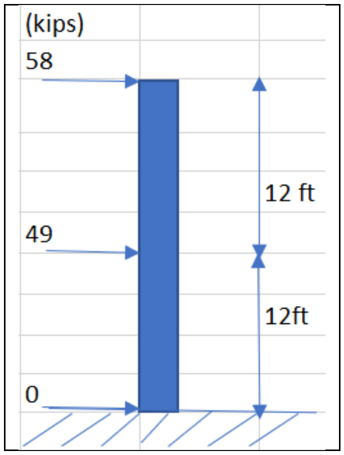

Figure 7: Force acting in masonry wall at various heights due to seismic

2.1.3 Final Loading on Masonry Wall

While comparing the wind and seismic loads acting on the reinforced masonry wall located in Oxford, MS, seismic load comes out to be more critical. So, seismic loading is considered while designing the masonry wall under both in-plane and out of plane loading. It means the wall needs to be designed for 38.9 psf out of plane loading, 107 kips base shear, and 1397 kips-ft overturning moment. The following table shows the loading applied to the reinforced masonry wall for designing with a Strength Design approach:

Table 4: Design Axial and Lateral Loading on the Masonry Wall

<table>
<tr><th>Loading Types</th><th></th><th>psf</th><th>plf</th><th>Direction</th></tr>
<tr><td rowspan="3">Axial</td><td>Dead Load
(Roof + First Floor)</td><td>365.5</td><td>4432</td><td>Along the Length</td></tr>
<tr><td>Live Load
(Roof + First floor)</td><td>80</td><td>971</td><td>Along the Length</td></tr>
<tr><td>Weight of Wall</td><td>48</td><td>576</td><td>Along the Length</td></tr>
<tr><td rowspan="2">Lateral Pressure</td><td>Wind Load</td><td>26</td><td>3120</td><td>Along the Height</td></tr>
<tr><td>Seismic Load</td><td>38.9</td><td>4668</td><td>Along the Height</td></tr>
</table>

2.2 Design of Masonry Wall for out-of-plane loading

The masonry wall is designed to withstand the out-of-plane loading caused by lateral forces like wind and seismic. The strength design procedure is followed with the fulfillment of TMS 402-16, Building Code Requirements for Masonry Structures, and TMS 602-16, Specification for Masonry Structures. One foot length of the wall is considered for the out-of-plane loading in the wall. The shear and moment acting on the wall due to axial and lateral loading is calculated and based on the shear and moment values the primary reinforcement is determined which comes out to be #9 bars @ 32 inches center to center spacing running vertically throughout the length of 120 ft. Before finalizing the reinforcement for the out-of-plane loading case, the maximum moment strength and the deflection requirement are checked for the preliminary amount of reinforcement. The wall deflection and out-of-plane moment are calculated using the following formulas.

$$M_u = \frac{w_u h^2}{8} + \frac{P_f e}{2} + P_u \delta \qquad 2.2.1$$

$$\delta_u = \frac{\left(\frac{w_u H^2}{8} + \frac{P_{uf} e}{2}\right) - M_{cr}\left(1 - \frac{I_{cr}}{I_g}\right)}{\frac{48 E_m I_{cr}}{5h^2} - (P_{uw} + P_{uf})} \qquad 2.2.2$$

Where: M_u = Maximum out of the plane moment

δ_u = Maximum wall deflection

h = Height on the wall

P_{uf} = Loading from floor

P_{uw} = Loading from wall

M_{cr} = Cracking moment

I_{cr} = Cracked moment of inertia

I_g = Uncracked moment of inertia

E_m = Masonry modulus of elasticity

The two goals of the design are:

1. The out-of-plane moment strength of the masonry wall must be greater than the factored out-of-plane moment demand.

   i.e. $\emptyset M_n \geq M_u$

2. The horizontal deflection at the mid-height under service loads must be less than 0.007H.

   i.e. $\delta_{mid\ height} \leq 0.00H$

Table 5: Reinforcement for the Out-of-Plane Loading (Slender Wall)

Reinforcement Type	**Reinforcing Bars and Spacing**
Vertical	#9 bars @ 32 inches c.c spacing

2.3 Design of Shear Masonry Wall

In masonry buildings, shear walls are the main elements of the lateral load resisting system buildings. The code (TMS 402) requires 80% load resistance to be provided by lateral walls if a response modification factor (R) is greater than 1.5. There are four primary causes of shear wall deflection: Shear, Flexure, Sliding, and Rocking. Among those, shear and flexure are the two main reasons for wall deflection in this project. The shear or flexural deformation depends on the aspect ratio: wall height (H) to its length (L). If 0.25< h/L < 4 then there is the possibility of both shear and flexural deformation. If h/L < 0.25 then the wall will more likely to deform due to shear while if h/L > 4 then it will primarily undergo flexural deformation. In the project h/L ratio is 0.24 which is less than 0.25 so it will deform due to shear. However, the wall is designed against flexural response to resist the seismic loads and provide adequate ductility in such seismic events. The Strength Design approach is used to design the shear wall in this project.

As the Seismic Design Category (SDC) for this project is D, the only type of masonry shear wall is the special reinforced shear wall according to ASCE 7-10. The table below shows the reinforcement requirement for various types of shear walls.

Table 6: Reinforced Masonry Shear Walls in various SDCs

Seismic Design Category	Ordinary Reinforced Masonry Shear Walls	Intermediate Reinforced Masonry Shear Walls	Special Reinforced Masonry Shear Walls
A	Permitted	Permitted	Permitted
B	Permitted	Permitted	Permitted
C	Permitted	Permitted	Permitted
D	Not permitted	Not permitted	Permitted
E	Not permitted	Not permitted	Permitted
F	Not permitted	Not permitted	Permitted

The vertical reinforcement in the shear wall can resist the moment demand only. The shear corresponding to the nominal flexural strength is calculated. The total shear strength is the sum of shear strength from masonry and the steel reinforcement. The vertical, horizontal, and joint reinforcements are determined based on the following inplane loading acting in the shear wall.

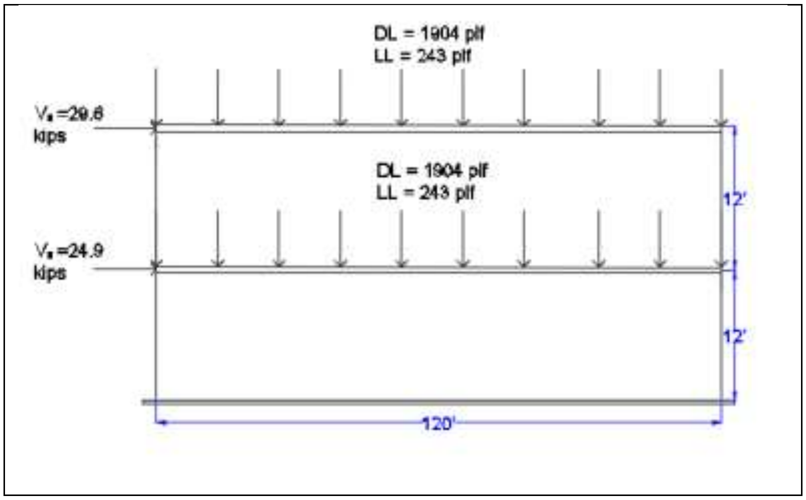

Figure 8: In-Plane Loading in the reinforced masonry wall

The reinforcement obtained in the shear wall from the calculation was verified following TMS 402-08/ACI 530-08/ASCE 5-08 codes for minimum and maximum requirement for the partially grouted special reinforced masonry wall. The following table shows the reinforcement requirement in the shear wall:

Table 7: Reinforcement for the In-Plane Loading (Shear Wall)

Reinforcement Type	Reinforcing Bars and Spacing
Vertical	#6 bars @ 32 inches c.c spacing
Horizontal	#5 bars @ 48 inches c.c spacing

2.4 Reinforcement for Masonry Wall

The ultimate reinforcement requirement from both slender (out-of-plane loading) and shear (in-plane loading) wall conditions are considered for the final design so that there will be a higher factor of safety and the lateral and axial loading will not lead to the failure in the structure. The table below shows the final special reinforcement for the partially grouted reinforced masonry wall to uphold all the axial and lateral loading conditions.

Table 8: Final Reinforcement for the Partially Grouted Reinforced Masonry Wall

Reinforcement Type	**Reinforcing Bars and Spacing**
Vertical Reinforcement	#9 bars @ 32 inches c.c spacing
Horizontal Reinforcement	#5 bars @ 48 inches c.c spacing
Horizontal Reinforcement around the openings	#5 bars with a development length of 28 inches past the opening
Joint Reinforcement	Ladder-type joint reinforcement

The figures below show the designed special reinforcement in the partially grouted reinforced masonry wall:

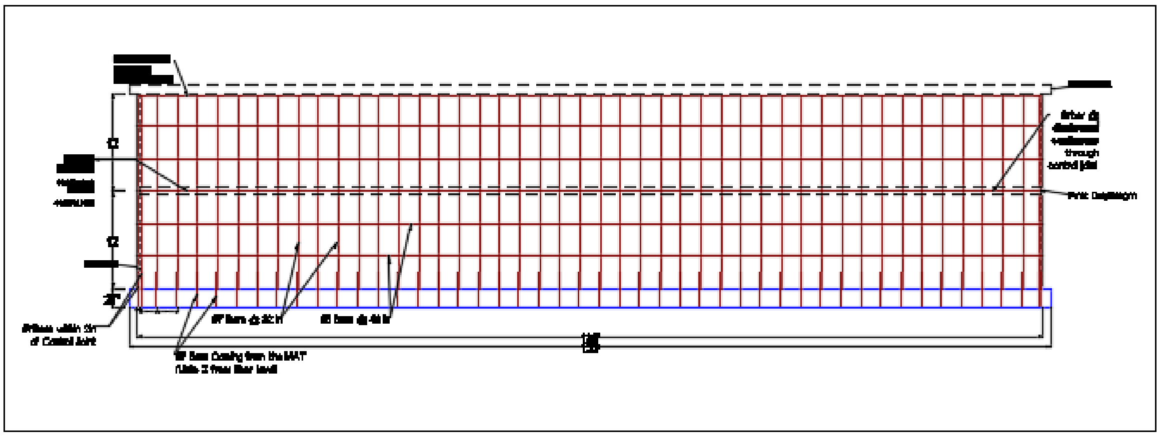

Figure 9: Reinforcement Detailing for Partially Grouted Reinforced Masonry Wall (Front view)

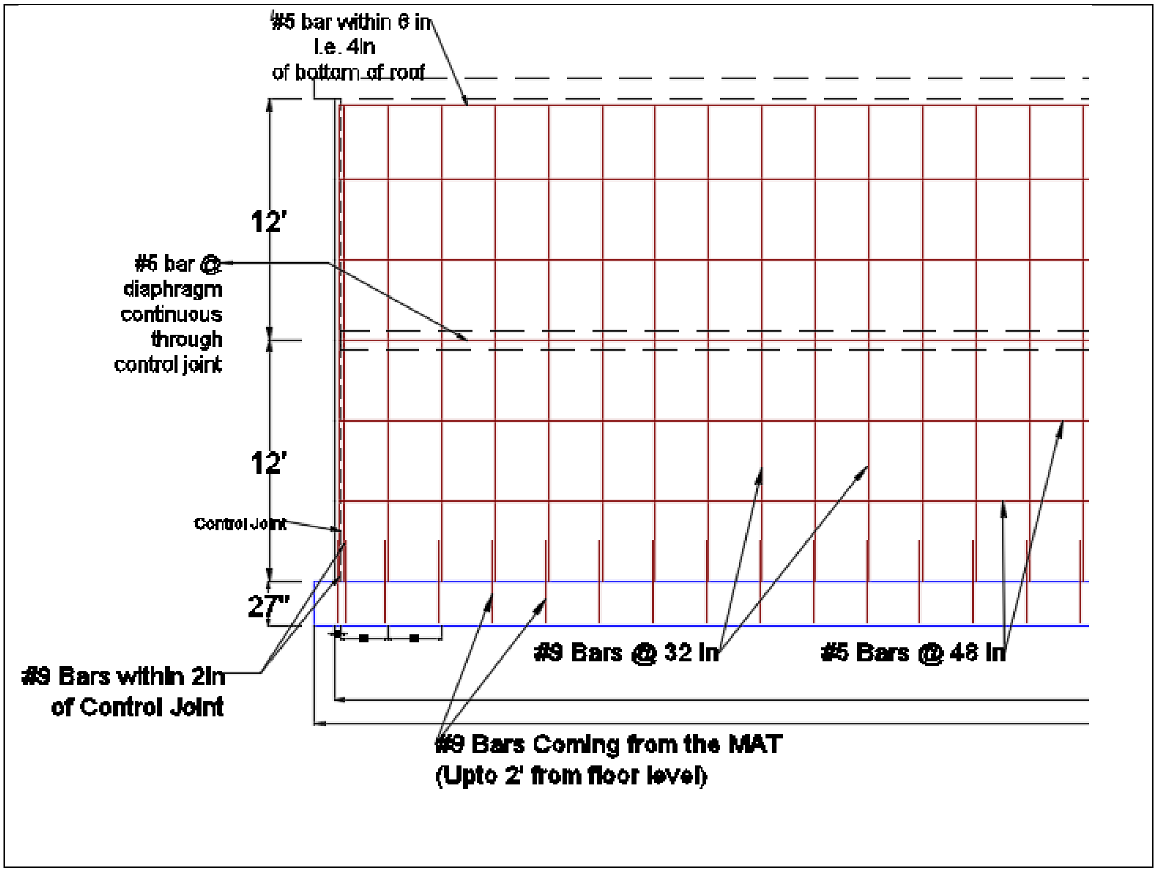

Figure 10: Reinforcement Detailing for Partially Grouted Reinforced Masonry Wall (Portion of the front view)

2.5 Cost Analysis

The construction of the perimeter wall of the building with the reinforced concrete and the partially grouted reinforced masonry is calculated and compared. The reinforced concrete wall is a non-load-bearing wall of thickness 8 inches while a partially grouted reinforced concrete masonry wall is a load-bearing wall which means the masonry wall takes a certain portion of the roof and floor load to the ground. Also, using load-bearing masonry wall replaces the 8 columns of 12 in x 12 inches dimensions and 4 beams of 22 in x 30 in cross-section in the 120 ft span of the building from the construction of the non-load-bearing wall. Considering, the cost of concrete for 27 cubic feet or 1 cubic yard as $120, the cost of one concrete masonry block of dimension 8in x 8in x 16 in, as $2, and the grout is placed at every 32 inches horizontal distance between the center of the bars, the construction cost is calculated. The cost for construction with both types of materials is shown and compared in the table below:

Table 9: Cost Comparision of the Reinforced Concrete Wall and Partially Grouted Reinforced Masonry Wall

	Reinforced Concrete Wall	Partially Grouted Reinforced Masonry Wall
	From 8 in Wall: $29,955	From Blocks: $23,058
	From 4 Beams: $9,778	From Grout: $7,751
	From 8 Columns: $853	
Total (round figure)	$41,000	$ 31,000
Total Saving	$10,000	

The table shows the selection of reinforced masonry load-bearing wall as construction design will reduce the cost by almost $10,000 as compared to the construction of a non-load bearing reinforced concrete wall of 8 inches.

CHAPTER 3

CONCLUSION AND RECOMMENDATION

The partially grouted special RM load-bearing wall in the outer parameter of the 2 storeyed commercial building located in Oxford, MS is designed for the axial loading due to dead and live gravity loads from the roof and the first floor, and lateral loading from wind and earthquakes. The vertical, horizontal, and joint reinforcement along with the partial grouting is determined based on the minimum requirements and the 2009 International Building Code (2009 IBC), and Building Code Requirements for Masonry Structures (TMS 402-08/ACI 530-08, ASCE 5-08). The cost of construction with 8 inches wide partially grouted reinforced masonry is almost $10,000 cheaper than that of the RC wall of 8 inches wide.

More detailed analysis and calculations are needed to get the most economical and safest partially grouted reinforced masonry wall. The masonry wall will gain strength if it is grouted fully, filling all the void spaces in the masonry blocks rather than partially grouting it. However, that will be expensive from the costing point of view.

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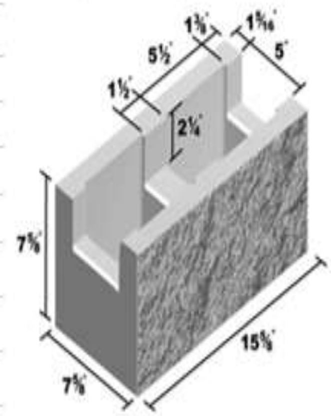
APPENDIX

A. Excel Worksheet for Material Selection

"Designing of low-rise building with partially grouted reinforced masonry"

Reinforced Masonry Unit:			
	8 x 8 x 16 Bond Beam		
	Thickness of CMU (b)	8	*in*
	Actual Thickness of CMU (t)	7.625	*in*
	Compressive Strength (f'_m or σ_W)	2000	*psi*
	Unit Weight of Masonary (γ_m)	125	*psi*
	Modulus of Elasticity (E_m)	1800000	*psi*
Mortar:			
	Type M		
	28 Days Compressive Strength (f'_c)	2500	*psi*
	Maximum Air Percentage	12	%
Steel:			
	Grade 60		
	Yield Strength of Reinforcing Steel (f_y)	60	*ksi*
	Modulus of Elasticity (E_s)	29000000	*psi*
Grout:			
	Slump	8 to 11	*in* *(For Workability)*



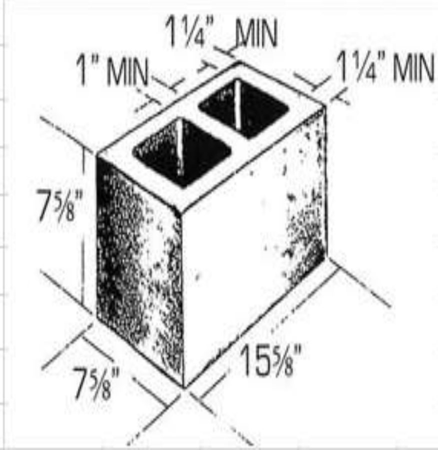


Image A: Materials Selection for Masonry Wall

B. Excel Worksheet for Wind Load Calculation

Wind Loading:

Risk Category	R2		
Basic Wind Speed (3 Second Gust)	110	mph	*(At 33 ft above ground in Exposure Category C and Speed (V) of ASCE 7-10)*
Mean Roof Height (h)	24	ft	*(For roof angle < 10 degrees , h = a) So for Flat roof h=a)*
For Exposure Category:			
Surface Roughness Category	C		*(Open terrain with scattered obstructions having heights generally less than 30 feet)*
Importance Factor (I)	1		*(For normal building withot any hazardlous materials in it)*
Adjustment Factor for Building Height and Exposure(λ)	1.35		

Enclosed Classification:

Area (A_g)	2352	ft^2	2880 ft^2
Openings Area (A_o)	354	ft^2	*(For Main Doors)*
0.01Ag	23.52	ft^2	
	4	ft^2	

Since, A_o > 4 ft^2, ***So, Partiall Enclosed Building***

Wind Directionality Factor (K_d)	0.85	*(0.85 g for Buildings, From ASCE 7-10 Table 26.6-1)*
Topography Factor (K_{zt})	1	*(No abrupt changes in the Topography and structure in on Level Ground)*
		(From ASCE 7-10 Section 26.8)
Gust Effect Factor (G)	0.85	*(For Rigid Structures)*

According to ASCE 7-10 Section 26.9.2, Low Rise Buildings (Mean roof height (h) < 6o ft) are considered Rigid

The building have Fundamental frequency >= 1HZ and Fundamental Period =< 1 second)

Main Wind Force Resisting System (MWFRS)

(An Assemblage of structural elements to provide support and stability for overall structure and wind loading from more than one surface)

Use Method 6: 2015 IBC Section 1609.6 (Alternate All Height Method)

(Applicable to simple diaphgram building with a. h=< 70 ft b. h/L or h/L =<4 c. Fundamental Period =<1 sec.

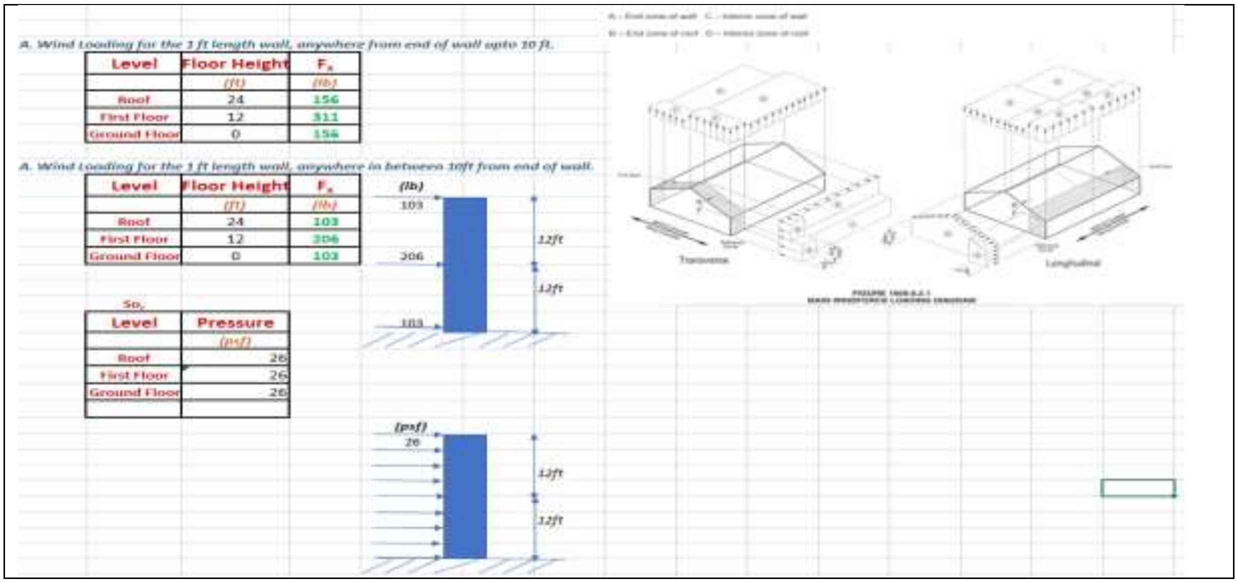
For Design Wind Pressure (p_s) for MWFRS:

Zone	P_{s30} (psf)	P_s (psf)		
A	19.2	26	> 16 psf	OK
B	-10	-14		
C	12.7	17	> 16 psf	OK
D	5.9	8		

For a:

	10 percent of least horizontal dimension	9.8	ft
OR	0.4h	9.6	ft

(It means 26 psf will act at the distance of 9.6 ft from the end of the wall from both end and in the middle 17 psf will act)



A. Wind Loading for the 1 ft length wall, anywhere from end of wall upto 10 ft.

Level	Floor Height	F_x
	(ft)	(lb)
Roof	24	156
First Floor	12	311
Ground Floor	0	156

A. Wind Loading for the 1 ft length wall, anywhere in between 10ft from end of wall.

Level	Floor Height	F_x
	(ft)	(lb)
Roof	24	103
First Floor	12	206
Ground Floor	0	103

So,

Level	Pressure
	(psf)
Roof	26
First Floor	26
Ground Floor	26

Image B: Wind Load Calculation

C. Excel Worksheet for Seismic Load Calculation

Earthquake Design Parameters:				
Risk Category for Building	II			
Site Class	D			
MCE_R Peak ground motion (period=0.2s) (S_s)	0.414g	*(Based on ASCE 7-16) and ATC Hazard Calculation)*		
MCE_R Peak ground motion (period=1.0s) (S_1)	0.178g	*(Based on ASCE 7-16) and ATC Hazard Calculation)*		
Short Period Site Coeffecient (F_a)	1.457	*(ASCE 7-16, Table 11.4-1) and By straightline interpolation*		
		OK, as greater than 1.2 for site class D)		
Long Period Site Coeffecient (F_v)	1.884	*(ASCE 7-16, Table 11.4-2) and By straightline interpolation*		
Site-modified spectral acceleration value (S_{MS})	0.608g	*($S_{MS} = F_a x S_s$)*		
Site-modified spectral acceleration value (S_{M1})	0.4g	*($S_{M1} = F_v x S_1$)*		
Numeric seismic design value at 0.2s SA (S_{DS})	0.405g	*($S_{DS} = (2/3) x S_{MS}$)*		
Numeric seismic design value at 1.0s SA (S_{D1})	0.267g	*($S_{D1} = (2/3) x S_{M1}$)*		
Risk Category	C	*($0.33\ g \leq S_{DS} < 0.5\ g$)(From ASCE 7-16, Table ASCE 11.6-1)*		
Seismic Importance Factor (I_e)	1	*(From ASCE 7-16, Table 1.5-2, For Risk Category II)*		
Structural Roof Peak Height (h_n)	24	*ft*		
Number of Stories in Building (N)	2			
Response Modification Factor (R)	2	*(From ASCE 7-16, Table 12.2-1)*		
Overstrength Factor (Ω)	2.5	*(From ASCE 7-16, Table 12.2-1)* *(For Ordanlry reinforced AAC Masonry Shear Wall)*		
Deflection Amplification Factor (C_d)	2	*(From ASCE 7-16, Table 12.2-1)*		
The Seismic Response Coeffecient (C_s)	0.2025	*($Cs = S_{DS}/(R/I_e)$)*		
Time Period (T)	0.22	**sec**		*($T=C_t * h_n{}^x$)*
T_L	**12**	**sec**	>T	(So, $T<T_L$)
$(Cs)_{Max}$	0.93376	**>0.2025**	(OK)	*[$Cs = S_{DS}/(T(R/I_e))$]*
So, The Seismic Response Coeffecient (Cs)	0.2025			

For Weight of Building:

	Dead Load	Live Load
	psf	*psf*
Roof	157	20
First Floor	208.5	60
Ground Floor	208.5	100
Σ	365.5	80

Area of Building (A) 11760 ft^2

Total load 5239.08 ***Kips***

For Wall:

Tributary Area (A_T) 1455 ft^2

Slab(Live +Dead) 55.12 ***psf*** = 53 ***kips***

Number of Masonry Units Required 11529

Masonry Wall 472.7 ***Kips*** (41 lb for each unit of 8x8x16 in Bond Beam)

Bars 2.2 ***Kips*** (For #8 Bars of 1 inch Diameter Placed at 32 inches distance in wall, Wt of # 8 bar is 2.67 lb/ft)

Grout in Masonry 54 ***Kips*** (If Grout of Unit weight 150 pcf is placed at 32 inches of distance in the wall)

No. of Masonry with Grout 34 (If Grout is placed at 32 inches of distance in the wall)

Wt. of Masonry Wall 528.9 ***Kips*** (Bond Beam + Grout + Bars)

Total Weight of Building (W) 581.8 ***Kips***

Base Shear (V) 107 Kips $V = C_S\ W$

Vertical Distribution Of Lateral Forces:

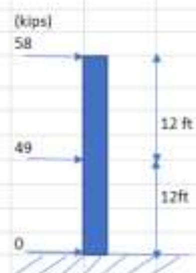
Exponent related to Structural Period (k) 1 (k =1 for Period 0.5 sec or less, k=2 for Period 2.5 Sec or more)

Number of Stories (N) 2

Ground Elevation (GE) 505 ***ft***

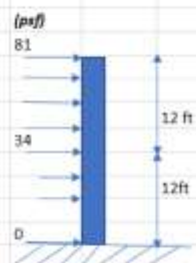
$$C_{vx} = \frac{W_x h_x^k}{\sum W_i h_i^k} \qquad F_x = C_{vx}\ V$$

Level	Floor Height	h_x	Wx	$Wx.h_x^k$	C_{vx}	F_x	V_x / Story	OTM
	(ft)	*(ft)*	*(kips)*	*(kips-ft)*		*(kips)*	*(kips)*	*(kips-ft)*
Roof	24	24	389.7	9354.0	0.543	58	0	1397
First Floor	12	12	655.1	7861.1	0.457	49	58	587
Ground Floor	0	0	581.1	0	0	0	107	0
			Σ	17215.1	1	107		



So,

Level	Pressure
	(psf)
Roof	81
First Floor	34
Ground Floor	0



The out of Plane Seismic Loading:

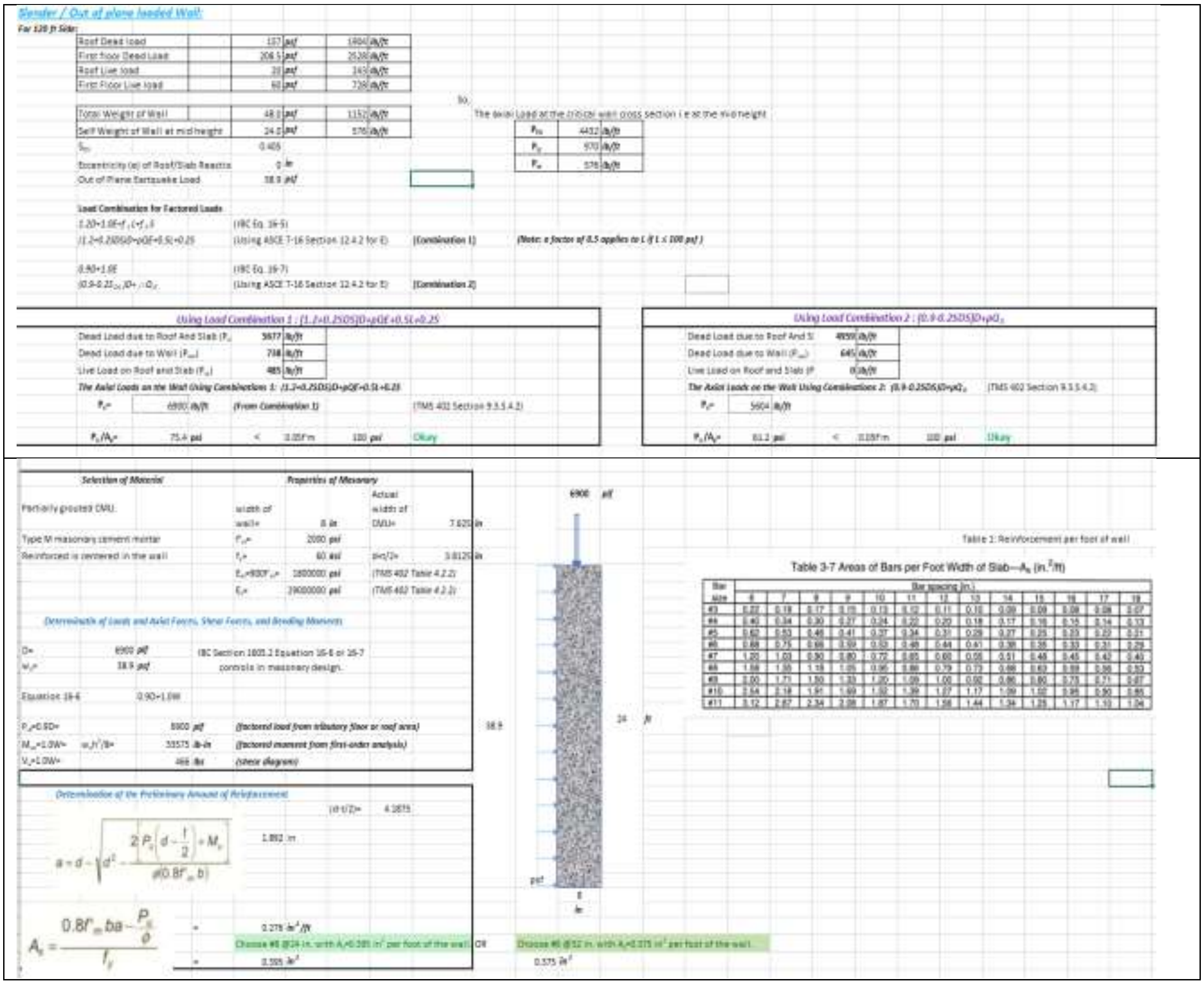
F_p = 111.92 ***Kips*** $F_p = 0.4 S_{DS} I_E W_p$

38.9 ***psf*** ***(ASCE/SEI 7-05)***

(Greater than the wind load)

Image C: Wind Load Calculation

D. Excel Worksheet for Designing the Reinforced Masonry Wall for Out-of-Plane Loading



Determination of Required Strength including Slenderness Effects (TMS 402 Section 9.3.5.4)

[illegible]

ASCE-7 Commentary Table C3-1							
Wall weight =	13	*psf*					
Wall properties based on NCMA TEK 14-1B							
A_g=	53.7	in^2/ft					
I_g=	360.5	in^4/ft					
r=	2.59	*in*					
Checking the factored Axial Stress			ϕ =	0.9			
P_u=	3945.9	*lb*					
P_u/A_g=	73.5	*psi*	<	$0.05f'_m$=	100 psi	Okay!	(TMS 402 Section 9.3.5.4.2)
$M_u = w_u h^2/8 + P_{uf} e_u/2 + P_u \delta_u$							(TMS 402 Eq. 9-23)
δ =	$(5M_u h^2)/(48E_m I_g)$		if	$M_u < M_{cr}$			(TMS 402 Eq. 9-25)
δ =	$(5M_{cr} h^2)/(48E_m I_g) + (5(M_u - M_{cr})h^2)/(48E_m I_{cr})$				if	M_u > or = M_{cr}	(TMS 402 Eq. 9-26)

Assume,	e_u=	0	in				
f_r=	153 psi (1 grouted cell/4 cells) + 51 psi (3 ungrouted cells/4 cells)			76.5	*psi*	(TMS 402 Table 9.1.9.2)	
	(Note: Linear interpolation for 1/6 cells grouted)						
$M_{cr} = (f_r + P/A_g)(I_g/(t/2))$=	14182	*in-lb*		(TMS 402 Section 9.3.5.4.4)			
$C = (A_s f_y + P_u)/(0.64f'_m b)$=	2.7	*in*		(TMS 402 Eq. 9-31)			
$I_{cr} = E_s/E_m(A_s + (P_u t_{sp}/f_y 2d))(d-c)^2 + bc^3/3$=	61.7	in^4		(TMS 402 Eq. 9-30, $t_{sp}/2d$=1 for centered reinforcement)			
Solving for M_u,							
M_u=	43248	*in-lb*	>	Mcr	14182	*in-lb*	Okay

$$M_u = \frac{\frac{w_u h^2}{8} + P_{uf}\frac{e_u}{2}}{1 - \frac{5P_u h^2}{48E_m I_n}} \quad \text{if } M_u < M_{cr}$$

$$M_u = \frac{\frac{w_u h^2}{8} + P_{uf}\frac{e_u}{2} + \frac{5M_{cr}P_u h^2}{48E_m}\left(\frac{1}{I_n} - \frac{1}{I_{cr}}\right)}{1 - \frac{5P_u h^2}{48E_m I_{cr}}} \quad \text{if } M_u \geq M_{cr}$$

Determination of Nominal and Design Strength

$a = (A_s f_y + P_u/\phi)/(0.80f'_m b)$ =	2.19	*in*					
$M_n = (P_u/\phi + A_s f_y)*(d - a/2)$ =	76261.7	*lb-in*					
Design flexural strength = ϕM_n =	68635.5	*lb-in*	>	Mu	43248	*lb-in*	Okay
Deflection:							
δ=	0.6	*in*	<	0.007H	1.008	*in*	(Okay)

$\delta_s \leq 0.007h$ (Deflection at Mid Height)

So, USE #9 Bars @ 32 in C.C Spacing OR **So, USE #8 Bars @ 24 in C.C Spacing**

Choose: #9 Bars @ 32 inches

Image D: Design of Reinforced Masonry Wall for out-of-plane loading

E. Excel Worksheet for Designing the Reinforced Masonry Wall for In-Plane Loading

"Design of partially grouted reinforced masonry wall in low rise building"

Shear Wall Design

Wall Properties:

b=	8 in	(thickness of CMU wall)	t= 7.625 in (actual width of CMU)
F_m=	2000 psi	(medium-weight)	
f_y=	60 ksi	(Grade 60 steel)	
S_{DS}=	0.405 g	(Calculated based on location)	
w=	184 psf	(weight of 8 in thick partial grouted masonry @ 32 inches with medium wt, From Calcu	γ_g= 0.75 (For Partially Grouted Shear Wall)
γ=	125 pcf	(unit weight of masonry)	

Dimension and Loads

L=	120 ft	(length of the wall)

First Floor:

V_E=	24.9 kips	(Earthquake load)
h=	12 ft	(Height of the wall)
w_D=	2528 plf	(Dead Load)
w_L=	728 plf	(Live Load)
W_w=	264425.9 lbs	(weight of the wall)

Roof:

V_E=	29.6 kips	(Earthquake load)
h=	12 ft	(Height of the wall)
w_D=	1904 plf	(Dead Load)
w_L=	243 plf	(Live Load)
W_w=	264425.9 lbs	(weight of the wall)

Earthquake Design Parameters

Seismic Design Catergory= D

For Wall 1: (No Opening)

Wall 1 Deflection/Flexibility (Δ_1)	0.608	$\Delta_1 = (\frac{H}{L})^3 + 3(\frac{H}{L})$; $R_1 = \frac{1}{\Delta_1}$
The relative Rigidity (R_1)	1.64	

For Wall2: (Opening of 10ft x 8ft at the center)

Deflection of solid wall ($\Delta_{solid\ wall}$)	0.608	$\Delta_{solid\ wall} = (\frac{H}{L})^3 + 3(\frac{H}{L})$
Deflection of solid strip ($\Delta_{solid\ strip}$)	0.200	$\Delta_{solid\ strip} = (\frac{8}{L})^3 + 3(\frac{8}{L})$
Deflection of pier (Δ_{pier})	0.448	$\Delta_{pier} = (\frac{8}{54})^3 + 3(\frac{8}{54})$; $\Delta_{piers} = \frac{1}{\frac{1}{\Delta_{pier1}} + \frac{1}{\Delta_{pier2}}}$
Deflection of piers (Δ_{piers})	0.224	
Wall 2 Deflection/Flexibility (Δ_2)	0.632	$\Delta_1 = \Delta_{solid\ wall} - \Delta_{Solid\ strip} + \Delta_{piers}$
The relative Rigidity (R_2)	1.58	$R_2 = \frac{1}{\Delta_2}$
Force in Wall 1 : @ 24 ft	29.6 kips	$F_1 = \left(\frac{\Delta_1}{\Delta_1+\Delta_2}\right) x\ V_{Total}$
Force in Wall 2 : @24ft	28.5 kips	$F_2 = \left(\frac{\Delta_2}{\Delta_1+\Delta_2}\right) x\ V_{Total}$
Force in Wall 1 : @12 ft	24.9 kips	
Force in Wall 2 : @12ft	24.0 kips	
Base Shear in Wall 1:	54.6 kips	$V_{Total} = F_{1@24ft} + F_{1@12ft}$

ρ= 1

S_{DS}= 0.405 g

Calculation of Deflection due to shear:

E_m =	1800000 psi	$E_m = 900 f'_m$
	259200 ksf	
E_v =	103680 ksf	$E_v = 0.4E_m$
A =	76.25 ft^2	$A = t.L$
I =	91500 ft^4	$I = \frac{tL^3}{12}$
$\Delta_{@<12\ ft}$=	0.00010 ft	$\Delta = \frac{VH^3}{12E_mI} + \frac{1.2VH}{AE_v} + \Delta_F\frac{2H}{L}$
	0.0012 in	
$\Delta_{@<24\ ft}$=	0.00011 ft	$\Delta = \left(\frac{H}{L}\right)^3 + 3\left(\frac{H}{L}\right)\frac{V}{tE_m}$
	0.0013 in	

Table A.4 Areas of Groups of Standard Bars (in.²)—U.S. Customary Units

Bar no.	Number of bars: 2	3	4	5	6	7	8	9	10
4	0.39	0.59	0.79	0.98	1.18	1.37	1.57	1.77	1.96
5	0.61	0.91	1.23	1.53	1.84	2.15	2.45	2.76	3.07
6	0.88	1.32	1.77	2.21	2.65	3.09	3.53	3.98	4.42
7	1.20	1.80	2.41	3.01	3.61	4.21	4.81	5.41	6.01
8	1.57	2.35	3.14	3.93	4.71	5.50	6.28	7.07	7.85
9	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
10	2.53	3.79	5.06	6.33	7.59	8.86	10.12	11.39	12.66
11	3.12	4.68	6.25	7.81	9.37	10.94	12.50	14.06	15.62
14	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50
18	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00

Bar no.	Number of bars: 11	12	13	14	15	16	17	18	19	20
4	2.16	2.36	2.55	2.75	2.95	3.14	3.34	3.53	3.73	3.93
5	3.37	3.68	3.99	4.30	4.60	4.91	5.22	5.52	5.83	6.14
6	4.86	5.30	5.74	6.19	6.63	7.07	7.51	7.95	8.39	8.84
7	6.61	7.22	7.82	8.42	9.02	9.62	10.22	10.82	11.43	12.03
8	8.64	9.43	10.21	11.00	11.78	12.57	13.35	14.14	14.92	15.71
9	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
10	13.92	15.19	16.45	17.72	18.98	20.25	21.52	22.78	24.05	25.31
11	17.19	18.75	20.31	21.87	23.44	25.00	26.56	28.12	29.69	31.25
14	24.75	27.00	29.25	31.50	33.75	36.00	38.25	40.50	42.75	45.00
18	44.00	48.00	52.00	56.00	60.00	64.00	68.00	72.00	76.00	80.00

Strength Design Solution:

Load Combination for Factored Loads

1.2D+1.0E+f_1L+f_2S	(IBC Eq. 16-5)	
(1.2+0.2SDS)D+ρQE+0.5L+0.2S	(Using ASCE 7-16 Section 12.4.2 for E)	**[Combination 1]**
0.9D+1.0E+1.6H	(IBC Eq. 16-7)	
(0.9-0.2S$_{DS}$)D+ρQ$_E$+1.6H	(Using ASCE 7-16 Section 12.4.2 for E)	**[Combination 2]**

First Floor Design

Loads at the base of the walls:

P_D=	1060.7	kips
P_L=	87.3	kips
P_{Lr}=	29.1	kips
Q_E=V_E=	54.6	kips

Using the load combinations and Loads:

M_u=	1011	*kip-ft*	1010535	lb-ft
P_u =	1229	*Kips*	**Combination:**	$Pu = D + 0.75L + 0.525Q_E$
P_u=	1402	*kips*	**[Combination 1]**	
P_u=	869	*kips*	**[Combination 2]**	

Preliminary Amount of Reinforcement (For Strength design, Distributed Reinforcement case)

Select Initial reinforcement of #8 bars @48inches

#8	@	48	in	
So, Number of Bars (n)		29.8		
		31.0	*bars*	
Area of #8 Bars		0.76	*in²*	
Total Area of steel (A_s)		23.56	*in²*	
c_t=	4		*in*	*(Assume the centroid of tension steel)*
d=	1436		*in*	*(The depth of equivalent rectangular stress block)*
d_v=	1440		*in*	*(Total Length)*
ε_m	0.0025			*(For CMU)*
ε_y	0.00207			*(For Grade 60 steel)*

Minimum Reinforcement Calculation for Shear Wall								
c_t=	4	*in*	*(Assume the centroid of tension steel)*					
d=	1296	*in*	*(The depth of equivalent rectangular stress block, for distributed reinforcement)*					
d_v=	1440	*in*	Approximate $d = 0.9d_v$					
c_{bal} =	709.0	*in*					$c_{bal} = \frac{\varepsilon_{mu}}{\varepsilon_{mu} + \varepsilon_y} d$	
a=	51.63	*in*						$a = d - \sqrt{d^2 - \frac{2[P_u(d - d_v/2) + M_u]}{\phi(0.8 f'_m t_{sp})}}$
c =	64.53	*in*	<	c_{bal}	709.0	*in*	Okay	
			(So Tension Controlled)					
$A_{s,\,required}$=	12.26	in^2					$A^*_{s,reqd} = \frac{A_{s,reqd}}{0.65 d_v}$	$A_{s,reqd} = \frac{0.8 f'_m t_{sp} a - P_u/\phi}{f_y}$
$A^*_{s,\,required}$=	0.16	in^2/ft						
Choose	44	#6	*bars*	A_s=	19.36	in^2		
	Spacing (s)	32.5	*in*		*(>19.2in²*	*with 0.16 in²/ft)*		(Use at least 32in spacing for # 6 Bars)
Choose	32	#7	*bars*	A_s=	19.2	in^2		
	Spacing (s)	44.8	*in*		*(>19.2in²*	*with 0.16in²/ft)*		(Use at least 40 in spacing for # 7 Bars)
Choose	96	#4	*bars*	A_s=	19.2	in^2		
	Spacing (s)	14.9	*in*		*(>19.2in²*	*with 0.16in²/ft)*		(Use at least 8 in spacing for #4 Bars)
Choose	62	#5	*bars*	A_s=	19.22	in^2		
	Spacing (s)	23.1	*in*		*(>19.2in²*	*with 0.16in²/ft)*		(Use at least 16 in spacing for #5 Bars)
Choose	25	#8	*bars*	A_s=	19.75	in^2		
	Spacing (s)	57.3	*in*		*(>19.2n²*	*with 0.16 in²/ft)*		(Use at least 56 in spacing for #8Bars)

Design Strength Determination						
∅=	0.9					
C-T=P_n			(From Free Body Diagram)			
P_u=	869	*lbs*	(From Combination 2)			
$P_n=P_u/\emptyset$=	965.2	*lbs*	$A_s = \frac{0.8f'_m ta - \frac{P_u}{\emptyset}}{f_y}$			
a=	115.95	*in*				
c=	144.93	*in*				
C=	1414565.2	*lbs*				
T=	1413600	*lbs*				
M_n=	1.75E+09	*lb-in*				
	145892713	*lb-ft*				
Design Strength ØMn=	131303	*kips-ft*	>	Mu	1011	Okay
P_u=	1402	*lbs*	(From Combination 1)			
$P_n=P_u/\emptyset$=	1558	*lbs*				
a=	95	*in*				
c=	119	*in*				
C=	1163002	*lbs*				
T=	1161600	*lbs*				
M_n=	1451009911	*lb-in*				
	120917493	*lb-ft*				
Design Strength ØMn=	108826	*kips-ft*	>	Mu	1011	Okay

Nominal Axial Strength Calculation [TMS 402 Section 9.3.4.1.1]							
∅=	0.9						
r =	2.59	*in*	(Partially grouted wall @ 32 in, From Table 3a)				
H/r=	55.6	*in/in*	<	99	→	(Use TMS Equation 9-15 for P_n)	
Nominal Axial Capacity:							
P_n=	12764953	*lbs*	$P_n = 0.8\left[0.8f'_m(A_n - A_s) + f_y A_s\right]\left[1 - \left(\frac{H}{140r}\right)^2\right]$				
Design axial strength=							
∅ P_n=	11488.5	*kips*					
Maximum P_u value from above=			1402	<	11488	(Design axial	Okay
			kips		*kips*		

Nominal Shear Strength:							
ϕ =	0.8						
$M_u/V_u d_v$=	0.15	≤ 0.25		So,	α =	1.5	
Nominal Masonry Shear Strength:							
Numbers of bars	31						
Net Area (A_{nv}) =	4871	in^2	(Net area except hollow space of bond beam)				
V_{nm}=	839.8	kips	$V_{nm} = \left[4 - 1.75\left(\frac{M_u}{V_u d_v}\right)\right] A_{nv}\sqrt{f'_m} + 0.25P_u$			$V_{ns} = 0.5\left(\frac{A_v}{s}\right) f_y d_v$	
A_v =	0.19	in^2/ft					
V_{ns}=	128.25	kips				$V_n = (V_{nm} + V_{ns})\gamma_g$	
V_n=	968.1	kips		(V_u) =			
ϕV_n=	774.5	kips	>	54.6	kips	Okay	
Maximum Nominal Shear Limit:				V_n=		$V_n \leq \left(6A_{nv}\sqrt{f'_m}\right)\gamma_g$	For $\frac{M_u}{V_u d_v} \leq$
$\left(6A_{nv}\sqrt{f'_m}\right)$ =	980	kips	>=	968.1	kips	Okay	

Maximum Spacing requirement:			
Maximum Spacing (S_{max})	48	inches	• minimum{ one-third length, one-third height, 48 in.

Shear Strength Design:			
With No Reinforcement Just CMU units (Wall):			Except V_n need not be greater than $2.5V_u$. (doubles shear)
Vn =	109.1	kips	$V_n = 2.5V_u$, or $\phi V_n = \phi 2.5V_u = 2.0V_u$
Area of Bar	0.0	in^2	
Av =	0	in^2	
ϕ =	0.8		
$M_u/V_u d_v$=	0.08	≤ 0.25	So, α = 1.5
Numbers of bars	0		
Net Area (A_{nv}) =	3600	in^2	(Net area except hollow space of bond beam)
Masonry Shear:			$V_{nm} = \left[4 - 1.75\left(\frac{M_u}{V_u d_v}\right)\right] A_{nv}\sqrt{f'_m} + 0.25P_u$
V_{nm}=	929.5	kips	
Required Steel Strength:			$V_n = (V_{nm} + V_{ns})\gamma_g$
$V_{ns,required}$=	-747.6	kips	$V_{ns} = 0.5\left(\frac{A_v}{s}\right) f_y d_v \Rightarrow s = \frac{0.5A_v f_y d_v}{V_{ns,reqd}}$
	(So, No need Reinforcement)		

Vertical Reinforcement :		#6 bars @	32	*in*	Spacing
	0.00180	>	0.0007		Okay
Horizontal reinforcement:		Use Minimum		$\rho \geq 0.0007$ in each direction $\rho_v + \rho_h \geq 0.002$	
		0.00070			
		1.5372	***in²***		
	Select,	#5 bars			
	Layers Required	5	Layers		
	Spacing Require	57.6	inches		
	USE	48	inches	spacing	
	So, Use	#5 bars @	48	in	
	Total reinforcement check:				
	0.00250	>	0.002		Okay

Image E: Design of Reinforced Masonry Wall for in-plane loading

F. Excel Worksheet for Final Reinforcement for Partially Grouted Reinforced Masonry Wall

Vertical Reinforcement :		**#9 bars @**		**32 *in***	Spacing
		Starts from 4 in from the end of the wall			
Horizontal Reinforcement:		**#5 bars @**		**48 in**	Spacing
Horizontal Reinforcement around the Opening:					
			# 5 bars		
	Development length Past Opening			**28 in**	Dev. Length
Base Concrete in Foundation					
Earthquake Band at lintel Level, Roof level , Plinth level					

Image F: Final Reinforcement for Partially grouted Reinforced Masonry Wall

G. Excel Worksheet for Cost Analysis

Cost Calculation of Reinforced Concrete Wall			
Concrete Cost:	$113 and **$126** per cubic yard (27 cubic feet)		
Total Area of Wall (A)		10110	***ft*** ^{2}
Cost of Wall	$	29955	
Extra Column Cost	$	853	
Extra Beams Cost:	$	9778	
Total Cost:	$	40586	
Cost Calculation of Partially Grouted Reinforced Masonry Wall			
Take Average:	$	**2**	***per block*** (In Home Depo)
Number of Blocks		11529	
Cost of Blocks	$	23058	
Cost of Grout	$	7751	
Total Cost:	$	30809	
Saving	**$**	**9777**	***(Exact figure)***
	$	**10000**	***(Round Figure)***

Image G: Cost Analysis between construction with Reinforced Concrete and Reinforced Masonry

VITA

Anil Bhatt, born and raised in Nepal, came to the University of Mississippi to pursue a Bachelor of Science in Civil Engineering. He completed his high school at St. Xavier's College, Nepal. During his bachelor's study, he is involved in the Sally McDonnell Barksdale Honors College, Americal Society of Civil Engineers chapter at the University of Mississippi, and many other student organizations. He is involved in the summer and part-time internship with Precision Engineering Corporation (PEC) as a Construction Material Testing Technician since his junior year at the college. After graduating from the University of Mississippi, he is planning to work full time as a Structural Engineer.