Retrofit of Concrete Moment Frames with Masonry Infill in High Seismic Zones

Pembo, Philippines

A Senior Project presented to
the Faculty of the Architectural Engineering Department
California Polytechnic State University, San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Bachelor of Science

by

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TABLE OF CONTENTS

PROJECT DESCRIPTION AND INTENT

Global Considerations

Seismic events happen all throughout the world and each country has a slightly different way of handling the design of structures subjected to seismic forces. The goal of this project is to provide citizens of the Philippines with an effective way to retrofit their potentially unsafe buildings in the event of an earthquake. However, this retrofit manual will be able to help globally in other third world countries that have similar building techniques. In order to achieve this type of solution, we had to come up with options that took into account the lack of access to tools, materials, and skilled construction.

Social Considerations

When beginning to address the impact of our solution, it was important to consider the means of a typical family in the Philippines in order to complete the project outlined herein. In many third world countries, including the Philippines, governing bodies have adopted some form of a building code intended to be used when designing and constructing a building. In practice, however, the governing bodies do not regulate or enforce this building code, resulting in poor design and construction practices. This in turn, results in poorly built structures.

The type of masonry infilled structures addressed in this report can fail in many ways, but the deadliest is when failure occurs within the CMU infill wall. Large seismic events can cause the walls to crack diagonally in shear, as well as cause out of plane failure. Out of plane failure is characterized by the CMU infill falling out from the concrete moment frame.

When out of plane failure occurs, there are many consequences that can occur. Firstly, out-of-plane failure can be detrimental due to its ability to cause fatalities. During a seismic event, the masonry can fall out from the wall, possibly landing on people inside the building or in the spaces around the building below. This can potentially result in a massive loss of life within the area. Secondly, when masonry falls out of plane there can be significant damages to any vehicles or personal property of the occupants when wall debris falls to the streets below. Most importantly, walls falling inhibits the ability of rescue vehicles to reach affected areas after an earthquake. When this failure occurs, a lot of time and money must be spent to clean up and bulldoze the fallen debris. Due major hazards of the results of out of plane failure, it should be avoided in any case.

Cultural Considerations

Poorly built structures in third world countries are constructed partly due to the lack of financial means to hire an engineer and construct a safe building. This lack of means is demonstrated by how residential construction is expanded. In the United States, when a family is growing, the existing culture is to buy a new home, or to buy new land to expand a home, or to build a new house. In the Philippines, due to extremely high prices for land, it is typical for families to build a new story on top of their currently existing home. In combination with the lack of engineering and specialty in seismic design, this method of expansion can have catastrophic results in the event of a large earthquake.

Environmental Considerations

When masonry infilled structures fail in shear or out of plane, they must be entirely replaced. Because these failure types are very common, when an earthquake hits this area, many buildings will need to have major replacements. The buildings would fail and produce significant amounts of debris which would overflow the landfills. Replacing an entire building (or many buildings) can have a large impact on the environment due to the need for new materials to be mass manufactured and transported to the site. The manufacturing process releases dangerous air emissions, releases wastewater contaminants, and drains the earth's resources. The retrofit idea proposed in this manual would significantly lessen the amount of materials required to make a building safe during an earthquake, thus reducing the need for buildings to be completely rebuilt or replaced.

Economic Considerations

Special considerations were taken in order to provide a low-cost solution that would be accessible to as many people as possible.

When approaching a solution to the problem at hand, we maintained a focus on engineering retrofit ideas that are feasible for the Philippine people and the economic climate they face. Typical construction in the United States employs the use of specialized products like Simpson Strong Tie connections and expensive/specialized building methods which are not available in the Philippines. (i.e. use of cranes, welding, etc.). These building methods require high levels of skilled labor to construct which is expensive, this results in average people building their own homes to save money. This is directly contrasted with the level of specialized labor and products available for sale within the local economy in the Philippines. Because of this lack of specialized products and labor, the buildings in the Philippines are very simple. This created the challenge of engineering a retrofit solution that Philippine people in the field would be able to accomplish. In creating a retrofit idea, we always came back to the idea of creating a solution that is simple enough for village contractors to implement themselves. By creating a simple solution that is easy to understand and implement, there can be many opportunities for buildings to get retrofitted without the use of skilled labor. In doing this, local contractors can complete the retrofit themselves using local materials and our manual provided to them.

Team Evaluations

By Tricia Pope:

Maddie:

Easy to work with and got tasks done on time. Maddie became an expert on the building systems and created construction documents quickly and easily. She was not able to attend all of our group meetings but always made sure to keep up with the decisions/work assigned at meetings.

Zorana:

Extremely passionate and enthusiastic about the project. She worked to come up with solutions throughout the entire length of the project and was constantly updating and enhancing the project as we went. Zorana worked on the small details and inner workings of the project tirelessly while also keeping in mind the broader concerns of social/cultural/economic/etc.

By Madeleine Rasmussen:

Tricia:

Laid back and easy to work with. Had valuable input throughout project and was instrumental to formatting and coding excel sheets used to calculate values. Attended group meetings and was productive in working throughout them. Maybe could speak up more so we can hear all the great things she has to bring to the table.

Zorana:

Was very enthusiastic about the project which made working with her fun. Took initiative which is appreciated but sometimes needs to delegate and trust others a bit better when completing various project tasks. Made models for presentation and attended group meetings. Had a large role in final retrofit solution idea/and calculations associated

By Zorana Tat:

Tricia:

Tricia contributed by formatting the excel spreadsheets for the calculations. Tricia was able to demonstrate a firm understanding of the initial calculations such as load combinations, unit load take off, and load flow.

Maddie:

Maddie completed the AutoCAD drawings of the details. Maddie demonstrated a firm understanding of construction.

What did you learn on your own while working on the project?

<u>Tricia Pope:</u>

What I found most valuable throughout this project was how to take the mindset of an engineer with the limitations of materials/labor/etc. in a different country. I learned a lot about how other parts of the world approach engineering and building safety by going through the building codes and design examples from the Philippines and Nepal.

<u>Madeleine Rasmussen:</u>

Throughout this project I learned just how fortunate we are in the United States to have a building code that is adapted nationwide and is strictly enforced. I have grown a new appreciation for these entities that make sure our structures are safe and enforce building codes. In completing this project I have come to respect and understand what building officials and inspectors do and why we need them as a society. This project taught me how to think outside the box and take a specific problem and come up with a solution that is applicable using various skills. In researching masonry retrofits I gained an expanded knowledge for the behavior of this material and the buildings that they make up. Lastly, I learned about the cultural needs for different building economies and how to consider them when engineering.

<u>Zorana Tat:</u>

I learned how to think with a retrofit mindset as well as work around existing cultural building techniques. An easy “retrofit” idea would be to remove the inadequate existing structure and build a new one, however this project showed me how to build around existing structures as well as how avoid being invasive to the existing tenants.

In addition, I learned how to adjust to different cultural building materials and techniques. A third world country such as the Philippines has a very different building culture from the United States. The United States has access to many different types of materials and specialized skill sets. The United States also has strict regulations on building permits as well as ensuring a licensed professional is working on the building. The Philippines has engineers and builders with the skillset to build, however those people are expensive and there is no government regulation on the building code. This results in average people building when and how they want.

What methodology did you use to learn on your own?

Tricia Pope:

The main approach I took to learning on my own was spending a lot of time reading various resources. To learn about the building system we worked with, I read the chapter of the masonry code pertaining to participating vs. non-participating masonry infill. Additionally, I spent time working to understand the foreign building codes by reading and comparing the design practices to those I know from the United States.

Madeleine Rasmussen:

Utilizing our resources and studying previous explorations where CMU walls occur were both crucial to learning tools throughout this project. Curiosity was a huge part of being able to learn on my own. By having a desire to delve deeper into the information I came across, I was able to understand the “WHY” in various engineering designs.

Zorana Tat:

To learn on my own I utilized the skillset of the faculty on campus and the existing retrofit ideas on the Build change website. For example, I received notes on how to design a concrete moment frame from the Civil Engineering 552 Advanced Concrete Design class taught by Professor Chadwell. I also gained knowledge by speaking to my advisor Professor James Mwangi who had firsthand experience in the Philippines.

GENERAL NOTES

NOTES:

(1) TYPICAL MEMBER SIZES DETERMINED BASED ON NEPAL NATIONAL BUILDING CODE (NBC 205: 1994)

(2) MEMBER SIZES WERE CONVERTED FROM SI UNITS TO ENGLISH UNITS TO CARRY OUT CALUCLATIONS

(3) DETERMINATION OF SEISMIC COEFFICIENTS BASED ON NATIONAL STRUCTURAL CODE OF THE PHILIPPINES: VOLUME 1, SIXTH EDITION, FOURTH PRINTING, 2013 (NSCP)

(4) ANALYSIS BASED ON 2 STORY BUILDING. ROOF LEVEL REFERRED TO AS STORY II

ABBREVIATIONS:

LFRS - LATERAL FORCE RESISTING SYSTEM

REINF - REINFORCEMENT

TYP. - TYPICAL

(N) - NEW

(E) - EXISTING

CONC. - CONCRETE

CMU - CONCRETE MASONRY UNIT

UNO - UNLESS NOTED OTHERWISE

O.C. - ON CENTER

EMBED. - EMBEDMENT

EA. - EACH

STRUCTURAL MATERIALS

MATERIAL SPECIFICATIONS: Typical unless noted otherwise in calculations.

MASONRY:

3-Cell Blocks, 15 cm X 20 cm X 40 cm

Typical Masonry Grouted with Density 22 (kN/m^3)

CONCRETE:

Slab on grade: f’c = 4000 psi

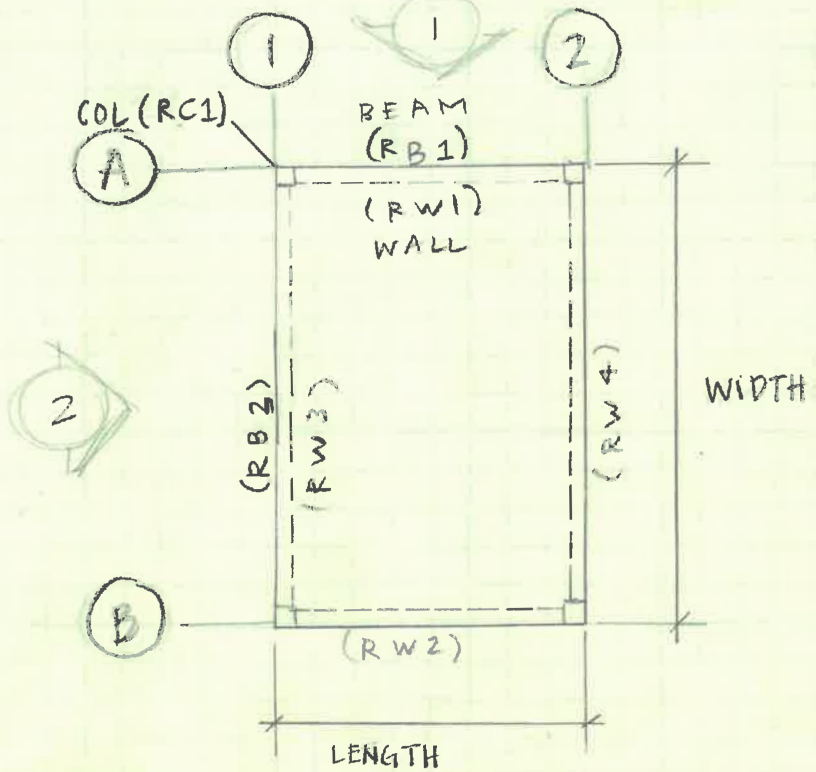
Concrete Overlay: f’c = 4000 psi

Concrete Framing: f’c = 4000 psi

REINFORCING STEEL:

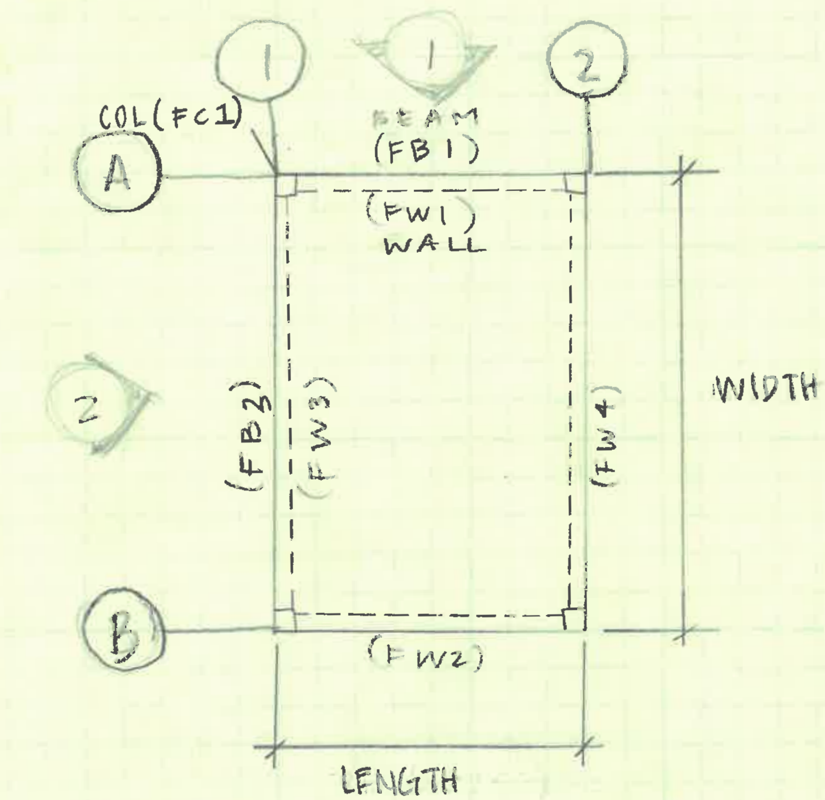
4T16, T08, & T06

Fe415 STEEL BARS.



N

STORY II (ROOF) FRAMING PLAN



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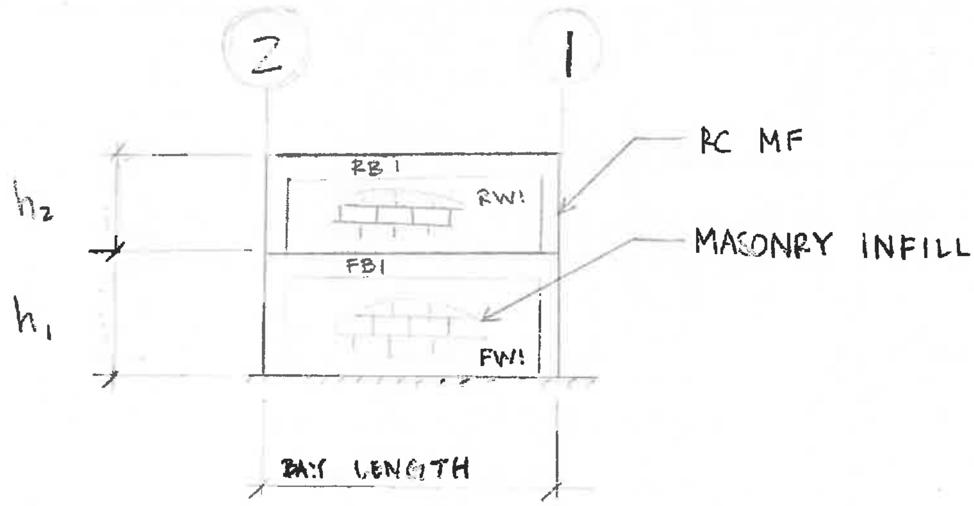
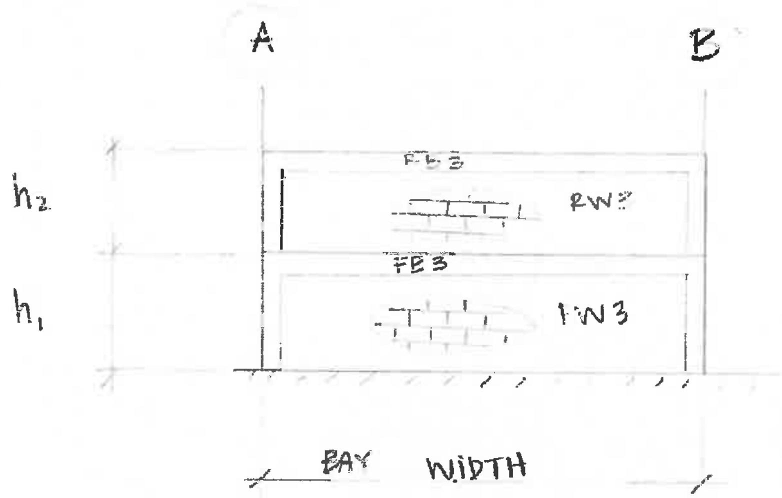
STORY I (FLOOR) FRAMING PLAN



1 SOUTH ELEVATION



2 WEST ELEVATION

SI UNITS

COLUMN VERTICAL REINFORCEMENT									
	CORNER COLUMN			FACE COLUMN			INTERIOR COLUMN		
STORY	LENGTH (mm)	WIDTH (mm)	REINF.	LENGTH (mm)	WIDTH (mm)	REINF.	LENGTH (mm)	WIDTH (mm)	REINF.
II	450	450	4T16	230	230	4T16	230	230	8T12
I	450	450	4T16	270	270	4T16	270	270	8T12

NOTES:
(1) 4T16 STANDS FOR (4) - 16mm DIA. Fe415 STEEL BARS.

COLUMN TRANSVERSE STIRRUPS			
LOCATION	LENGTH (mm)	REINF.	SPACING o.c. (mm)
ENDS OF COL	600	T08	100
REMAINING HEIGHT OF COL (center)	-	T06	125

SLAB THICKNESS	
100	mm

TYPICAL BAY		
LENGTH (m)	WIDTH (m)	Area (m^2)
6	9	54

BEAM SIZES	
LENGTH (mm)	WIDTH (mm)
175	400
200	400
250	400
300	400

TYPICAL STORY HEIGHT			
STORY 1	3.2	m	floor to floor height
UPPER STOREYS	2.8	m	floor to floor height

CMU SIZE		
WIDTH (cm)	HEIGHT (cm)	LENGTH (cm)
15	20	40

PLINTH (GRADE) BEAM SIZES	
LENGTH (mm)	WIDTH (mm)
230	200
240	200

ENGLISH UNITS

COLUMN VERTICAL REINFORCEMENT									
	CORNER COLUMN			FACE COLUMN			INTERIOR COLUMN		
STORY	LENGTH (in)	WIDTH (in)	REINF.	LENGTH (in)	WIDTH (in)	REINF.	LENGTH (in)	WIDTH (in)	REINF.
II	17.72	17.72	4T16	9.06	9.06	4T16	9.06	9.06	8T12
I	17.72	17.72	4T16	10.63	10.63	4T16	10.63	10.63	8T12

NOTES:
(1) 4T16 STANDS FOR (4) - 16mm DIA. Fe415 STEEL BARS.

COLUMN TRANSVERSE STIRRUPS			
LOCATION	LENGTH (in)	REINF.	SPACING o.c. (in)
ENDS OF COL	23.62	T08	3.94
REMAINING HEIGHT OF COL (center)	-	T06	4.92

SLAB THICKNESS	
3.94	in

TYPICAL BAY		
LENGTH (ft)	WIDTH (ft)	AREA (ft^2)
19.69	29.53	581

Concrete Compressive Strength (psi)	
f'c=	4000

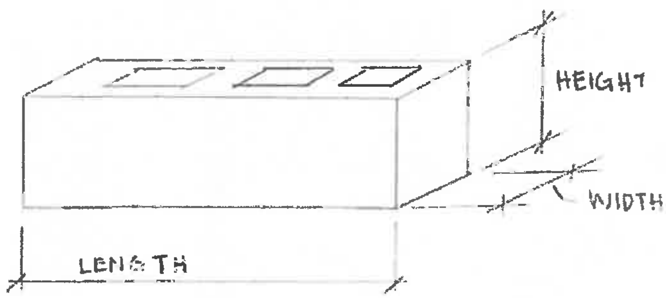
BEAM SIZES	
LENGTH (in)	WIDTH (in)
6.89	15.75
7.87	15.75
9.84	15.75
11.81	15.75

TYPICAL STORY HEIGHT			
STORY 1	10.50	ft	floor to floor height
UPPER STOREYS	9.19	ft	floor to floor height

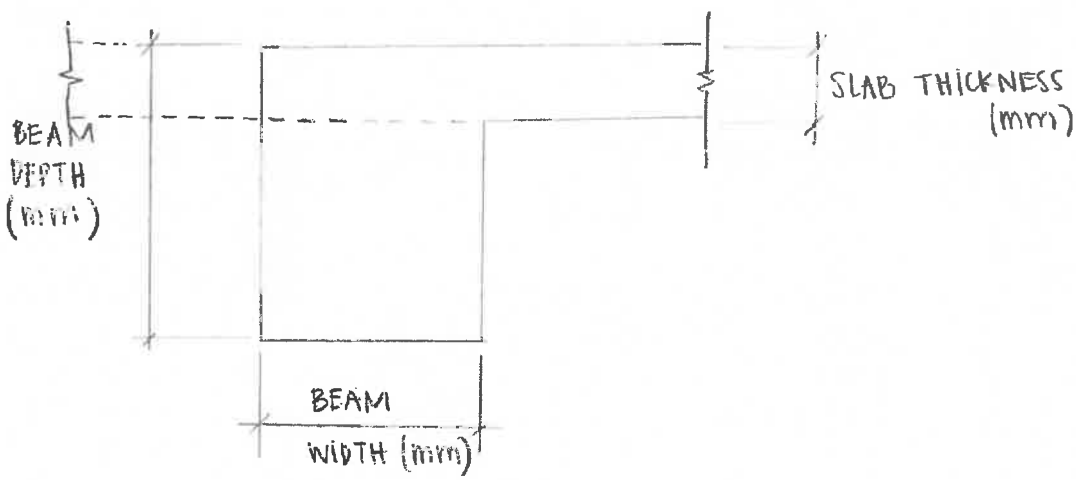
CMU SIZE		
WIDTH (in)	HEIGHT (in)	LENGTH (in)
5.91	7.87	15.75

PLINTH (GRADE) BEAM SIZES	
LENGTH (in)	WIDTH (in)
9.06	7.87
9.45	7.87

CMU DIMENTIONS



BEAM / SLAB DIMENTIONS



SI UNITS

DEAD LOAD UNIT WEIGHTS		
Component	Density (kN/m^3)	Weight (kPa)
Reinforced Concrete, Stone	23.6	-
CMU, Normal Weight	21.2	-
Masonry Grout	22	-
Plaster (1" both sides)	-	0.48
Cement Tile	-	0.77

UNIFORM LIVE LOAD		
Residential Basic Floor Area	1.9	kPa

ENGLISH UNITS

DEAD LOAD UNIT WEIGHTS			
Component	Density (pcf)	Weight (psf)	
Reinforced Concrete, Stone	151.59	-	
CMU, Normal Weight	136.17	-	
Masonry Grout	141.31	-	
Average Block/Grout Weight	138.74	-	*Assuming CMU are fully grouted
Plaster (1" both sides)	-	10.03	
Cement Tile	-	16.08	

UNIT DEAD LOAD TAKEOFF					
STORY II					
ITEM	THICKNESS (ft)	AREA (ft^2)	APPLIED LOAD (lbs)		
SLAB	0.33	581	28907		
CEMENT TILE	-	581	9348		
RC COLUMN (x4)	4.593178333	2.180	6071		
MASONRY WALL (North/South)	4.593178333	8.938	5695		
MASONRY WALL (East/West)	4.593178333	13.781	8782		
PLASTER (1"EA. SIDE, North/South)	-	90.417	906		
PLASTER (1"EA. SIDE, East/West)	-	135.625	1360	NORTH-SOUTH	EAST-WEST
		Level Load:	61069	54467	50927

STORY I					
ITEM	THICKNESS (ft)	AREA (ft^2)	APPLIED LOAD (lbs)		
SLAB	0.33	581	28907		
CEMENT TILE	-	581	9348		
RC COLUMN (x4)	9.842525	2.180	13008		
MASONRY WALL (North/South)	9.842525	8.938	12205		
MASONRY WALL (East/West)	9.842525	13.781	18819		
PLASTER (1"EA. SIDE, North/South)	-	193.751	1942		
PLASTER (1"EA. SIDE, East/West)	-	290.626	2914	NORTH-SOUTH	EAST-WEST
		Level Load:	87143	72996	65410

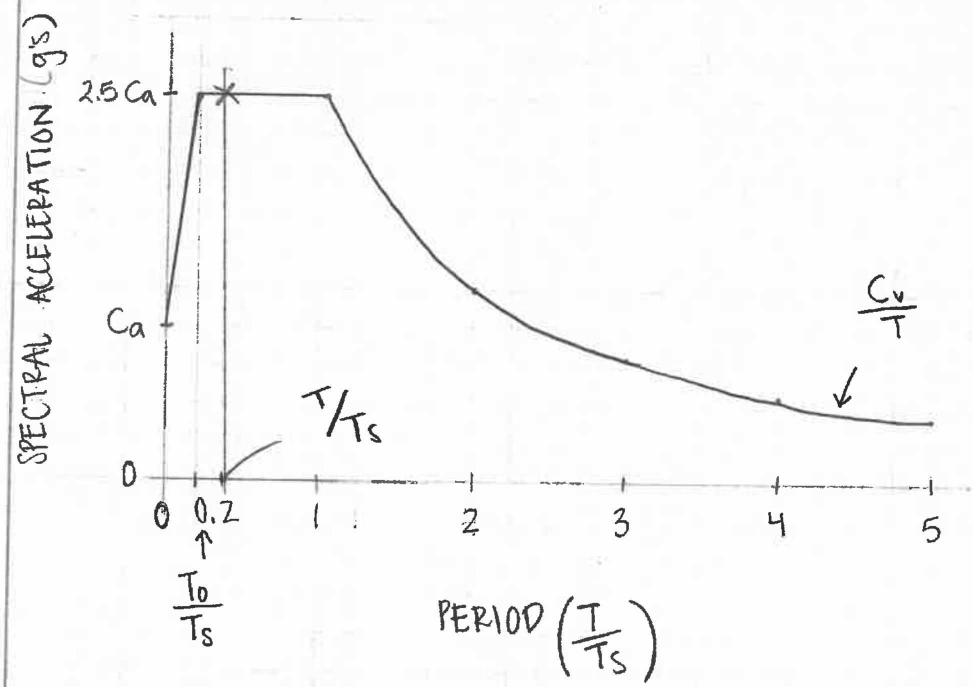
W_{TOTAL} (lbs)	148212

BASE SHEAR	
$V_{N/S}$ (lbs)	57686
$V_{E/W}$ (lbs)	52651

UNIFORM LIVE LOAD		
Residential Basic Floor Area	39.7	psf

CALCULATE SEISMIC COEFFICIENT, S_{DS}

NSCP FIG. 208-3 DESIGN RESPONSE SPECTRA



$$T_S = \frac{C_v}{2.5 C_a} = \frac{1.024}{2.5(0.528)} = 0.7757$$

$$T_0 = 0.2 T_S = 0.2(0.7757) = 0.1551$$

$$T = C_t h_n^{(3/4)} = 0.0731(6m)^{(3/4)} = 0.2802$$

C_t = 0.0731 (FOR RC MF)

$$\frac{T}{T_S} = \frac{0.2802}{0.7757} = 0.361$$

$$S_{DS} = 2.5 C_a = 2.5(0.528) \Rightarrow \boxed{S_{DS} = 1.32}$$

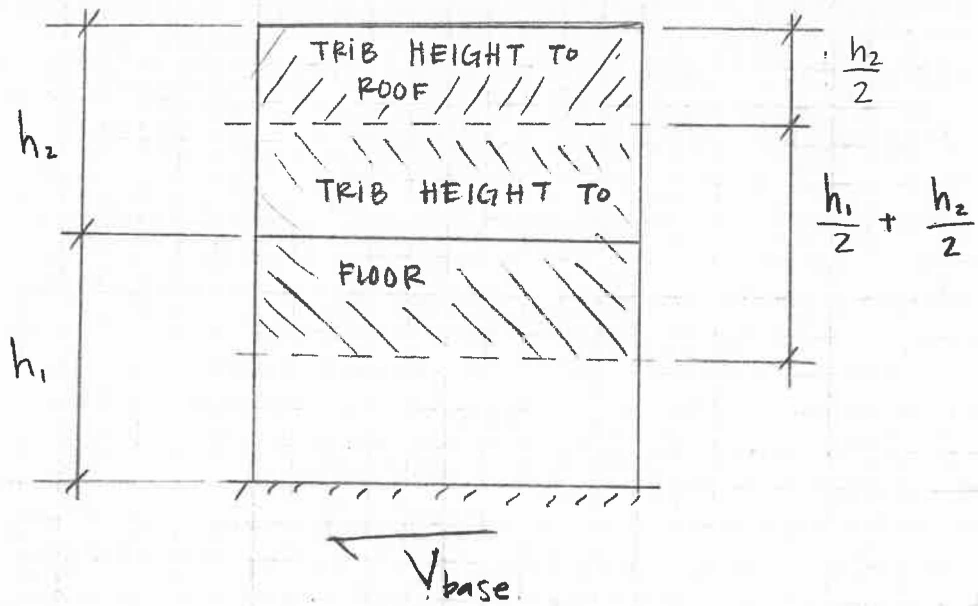
SEISMIC COEFFICIENTS

NOTES:
(1) COEFFICIENTS DETERMINED USING NSCP C101-10

DETERMINATION OF SEISMIC BASE SHEAR COEFFICIENTS			
NOTES	COEF.	VALUE	NSCP C101-10
SHORT PERIOD RESPONSE VALUE AT (T=0.2s)	S_{DS} =	1.32	Figure 208-3
SEISMIC IMPORTANCE FACTOR IV, "STANDARD OCCUPANCY"	I =	1	Table 208-1
SEISMIC SOURCE TYPE: "A"	M =	M>0.7	Table 208-4
DISTANCE TO SEISMIC FORCE < 5 km	N_a =	1.2	Table 208-5
DISTANCE TO SEISMIC FORCE < 5 km	N_v =	1.6	Table 208-6
SEISMIC ZONE	Z =	0.4	Figure 208-1
SEISMIC COEFFICIENT 0.44Na	C_a =	0.528	Table 208-7
SEISMIC COEFFICIENT 0.64Nv	C_v =	1.024	Table 208-8
EARTHQUAKE RESISTING SYSTEM (ORDINARY REINF. CONC. MOMENT FRAME)	R =	3.5	Table 208-11A
DESIGN BASE SHEAR COEFFICIENT, V = (3Ca/R)*W	(3Ca/R)=	0.452571429	208-5

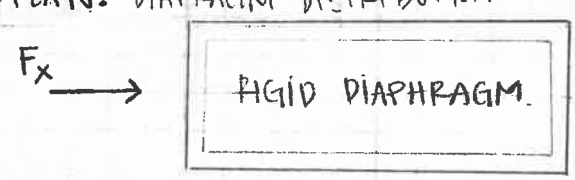
DETERMINATION OF STRUCTURAL PERIOD			
NOTES	COEF.	VALUE	NSCP C101-10
REINF. CONC. MOMENT FRAME	C_t =	0.0731	208-12
h_n (m)	h_n(I)	3.2	
	h_n(II)	6	
CALCULATE STRUCTRUAL PERIOD, $T = C_t h_n^{(3/4)}$	T(I) =	0.174895993	
	T(II) =	0.280240446	

TRIB HEIGHT FOR SEISMIC WEIGHT CALCULATIONS.

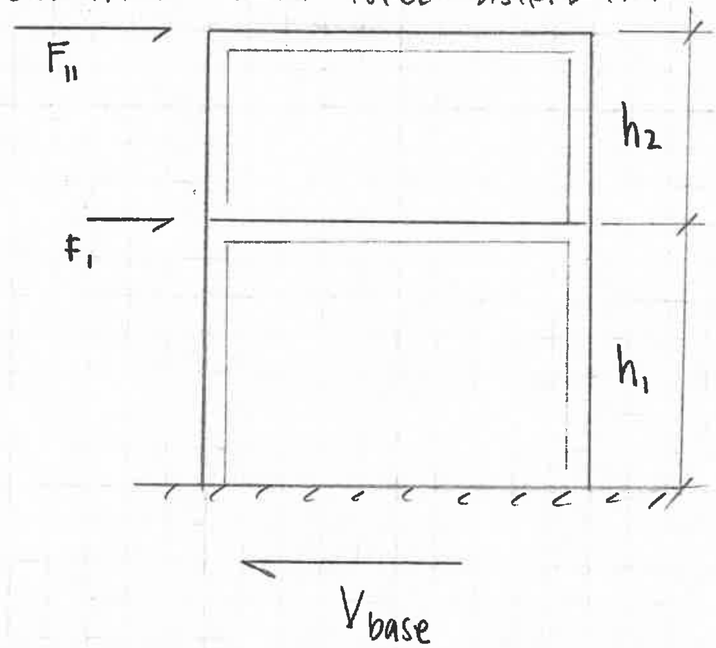


SEISMIC DISTRIBUTION OF STORY FORCES.

PLAN: DIAPRAGM DISTRIBUTION



ELEVATION: STORY FORCE DISTRIBUTIONS.



NOTES:

(1) PORTAL METHOD

(2) ASSUMING INFLECTION POINT AT MIDSPAN OF COLUMNS

DETERMINATION OF LOADING

Distribute story forces to LFRS

NORTH-SOUTH

STORY (x)	F_x (lbs) Line 1	F_x (lbs) Line 2
II	16820	16820
I	12023	12023

EAST-WEST

STORY (x)	F_x (lbs) Line A	F_x (lbs) Line B
II	15623	15623
I	10702	10702

NOTE:
(1) SINCE LFRS IS SYMMETRIC IN EACH ORTHOGANAL DIRECTION, ONE REPRESENTATIVE CALCULATION WILL BE CARRIED OUT
(2) ρ=1.3 DUE TO LACK OF REDUNDANCY IN SYSTEM

LRFD LOAD COMBINATIONS (ASCE 7-10: 2.3.2)

BASIC LOAD COMBINATIONS

1) 1.4D	D=	SEE BELOW	lbs	ρ=	1.3	
2) 1.2D + 1.6L + 0.5(L_r or S or R)	L_r=	23065	lbs	S_{DS}=	1.32	
3) 1.2D + 1.6(L_r or S or R) + (L or 0.5W)	L=	23065	lbs	A_{floor}=	581.252	ft^2
4) 1.2D + 1.0W + L + 0.5(L_r or S or R)	S=	0	lbs			
5) 0.9D + 1.0W	R=	0	lbs			
6) 1.2D + E_v + E_h + L + 0.2S	W=	0	lbs			
7) 0.9D - E_v + E_h	E=	SEE BELOW	lbs			

SEISMIC LOAD COMBINATIONS (ASCE 7-10: 12.4.2.3)

$E_h = \rho Q_E$

NOTE: $Q_E = F_X$ AT STORY LEVEL, AT SPECIFIC LINE

$E_v = 0.2S_{DS}D$

NORTH-SOUTH STORY II (ROOF)

STORY II, LINE 1		
E_h=	21866.6	lbs
E_v=	16122.2	lbs
D=	61069	lbs

Load Combination	D	L	L_r	S	R	W	E_v	E_h	Total GRAVITY	LATERAL
1) 1.4D	85497	-	-	-	-	-	-	-	85497	0
2) 1.2D + 1.6L + 0.5(L_r or S or R)	73283	0	11533	0	0	-	-	-	84816	0
3) 1.2D + 1.6(L_r or S or R) + (L or 0.5W)	73283	0	36905	0	0	0	-	-	110188	0
4) 1.2D + 1.0W + L + 0.5(L_r or S or R)	73283	0	11533	0	0	0	-	-	84816	0
5) 0.9D + 1.0W	54962	-	-	-	-	0	-	-	54962	0
6) 1.2D + E_v + E_h + L + 0.2S	73283	0	-	0	-	-	16122.2	21866.6	73283	37989
7) 0.9D - E_v + E_h	54962	-	-	-	-	-	16122.2	21866.6	54962	5744

GOVERNING LOAD COMBINATION - GRAVITY		
STORY II, LINE 1	3) 1.2D + 1.6(Lr or S or R) + (L or 0.5W)	110188

GOVERNING LOAD COMBINATION - SEISMIC		GRAVITY	LATERAL
STORY II, LINE 1	6) 1.2D + Ev + Eh + L + 0.2S	73283	37989

NORTH-SOUTH STORY I (FLOOR)

STORY I, LINE 1		
E_h=	15629.4	lbs
E_v=	39127.9	lbs
D=	148212	lbs

Load Combination	D	L	L_r	S	R	W	E_v	E_h	Total GRAVITY	LATERAL
1) 1.4D	207496	-	-	-	-	-	-	-	207496	0
2) 1.2D + 1.6L + 0.5(L_r or S or R)	177854	36905	0	0	0	-	-	-	84816	0
3) 1.2D + 1.6(L_r or S or R) + (L or 0.5W)	177854	23065	0	0	0	0	-	-	200919	0
4) 1.2D + 1.0W + L + 0.5(L_r or S or R)	177854	23065	0	0	0	0	-	-	200919	0
5) 0.9D + 1.0W	133391	-	-	-	-	0	-	-	133391	0
6) 1.2D + E_v + E_h + L + 0.2S	177854	23065	-	0	-	-	39127.9	15629.4	200919	54757
7) 0.9D - E_v + E_h	133391	-	-	-	-	-	39127.9	15629.4	133391	-23499

GOVERNING LOAD COMBINATION - GRAVITY		
STORY II, LINE 1	1) 1.4D	207496

GOVERNING LOAD COMBINATION - SEISMIC		GRAVITY	LATERAL
STORY II, LINE 1	6) 1.2D + Ev + Eh + L + 0.2S	200919	54757

EAST-WEST STORY II (ROOF)

STORY II, LINE 1		
E_h=	20310.4	lbs
E_v=	16122.2	lbs
D=	61069	lbs

Load Combination	D	L	L_r	S	R	W	E_v	E_h	Total GRAVITY	LATERAL
1) 1.4D	85497	-	-	-	-	-	-	-	85497	0
2) 1.2D + 1.6L + 0.5(L_r or S or R)	73283	0	11533	0	0	-	-	-	84816	0
3) 1.2D + 1.6(L_r or S or R) + (L or 0.5W)	73283	0	36905	0	0	0	-	-	110188	0
4) 1.2D + 1.0W + L + 0.5(L_r or S or R)	73283	0	11533	0	0	0	-	-	84816	0
5) 0.9D + 1.0W	54962	-	-	-	-	0	-	-	54962	0
6) 1.2D + E_v + E_h + L + 0.2S	73283	0	-	0	-	-	16122.2	20310.4	73283	36433
7) 0.9D - E_v + E_h	54962	-	-	-	-	-	16122.2	20310.4	54962	4188

GOVERNING LOAD COMBINATION - GRAVITY		
STORY II, LINE 1	3) 1.2D + 1.6(Lr or S or R) + (L or 0.5W)	110188

GOVERNING LOAD COMBINATION - SEISMIC		GRAVITY	LATERAL
STORY II, LINE 1	6) 1.2D + Ev + Eh + L + 0.2S	73283	36433

EAST-WEST STORY I (FLOOR)

STORY I, LINE 1		
E_h=	13912.7	lbs
E_v=	39127.9	lbs
D=	148212	lbs

Load Combination	D	L	L_r	S	R	W	E_v	E_h	Total GRAVITY	LATERAL
1) 1.4D	207496	-	-	-	-	-	-	-	207496	0
2) 1.2D + 1.6L + 0.5(L_r or S or R)	177854	36905	0	0	0	-	-	-	84816	0
3) 1.2D + 1.6(L_r or S or R) + (L or 0.5W)	177854	23065	0	0	0	0	-	-	200919	0
4) 1.2D + 1.0W + L + 0.5(L_r or S or R)	177854	23065	0	0	0	0	-	-	200919	0
5) 0.9D + 1.0W	133391	-	-	-	-	0	-	-	133391	0
6) 1.2D + E_v + E_h + L + 0.2S	177854	23065	-	0	-	-	39127.9	13912.7	200919	53041
7) 0.9D - E_v + E_h	133391	-	-	-	-	-	39127.9	13912.7	133391	-25215

GOVERNING LOAD COMBINATION - GRAVITY		
STORY II, LINE 1	1) 1.4D	207496

GOVERNING LOAD COMBINATION - SEISMIC		GRAVITY	LATERAL
STORY II, LINE 1	6) 1.2D + Ev + Eh + L + 0.2S	200919	53041

DETERMINATION OF DEMAND DUE TO LATERAL LOADS ON COLUMNS

NORTH-SOUTH	LATERAL	GRAVITY		
STORY (x)	F_x (lbs)	P_x (lbs)	Length (ft)	w (plf)
II	37989	73283	20	3722.77
I	54757	200919	20	10206.7

EAST-WEST	LATERAL	GRAVITY		
STORY (x)	F_x (lbs)	P_x (lbs)	Length (ft)	w (plf)
II	36433	73283	30	2481.85
I	53041	200919	30	6804.47

STORY FORCES / DIAPHRAGM FORCES

DETERMINE BUILDING WEIGHT IN EACH DIRECTION

NORTH-SOUTH	
Story	W_{NS}
II	54467
I	72996
Σw_x	127463

EAST-WEST	
Story	W_{EW}
II	50927
I	65410
Σw_x	116337

DETERMINATION OF STORY FORCES

NORTH-SOUTH	$V_{N/S}$ (lbs)	57686						
STORY (x)	h_x (ft)	k	h_x^k	W_x (lbs)	$W_x(h_x^k)$	C_{vx}	F_x (lbs)	F_x/W_x
II	19.69	1	19.69	54467	1072190	0.583171882	33641	0.6176
I	10.50	1	10.50	72996	766359	0.416828118	24045	0.3294
				$\Sigma w_x h_x^k$	1838548	ΣF_x	57686	

FORMULAS:

$Fx = C_{vx}V$

$Cvx = w_x(h_x^k)/\Sigma w_x(h_x^k)$

EAST-WEST	$V_{E/W}$ (lbs)	52651						
STORY (x)	h_x (ft)	k	h_x^k	W_x (lbs)	$W_x(h_x^k)$	C_{vx}	F_x (lbs)	F_x/W_x
II	19.69	1	19.69	50927	1002506	0.593470555	31247	0.6136
I	10.50	1	10.50	65410	686720	0.406529445	21404	0.3272
				$\Sigma w_x h_x^k$	1689226	ΣF_x	52651	

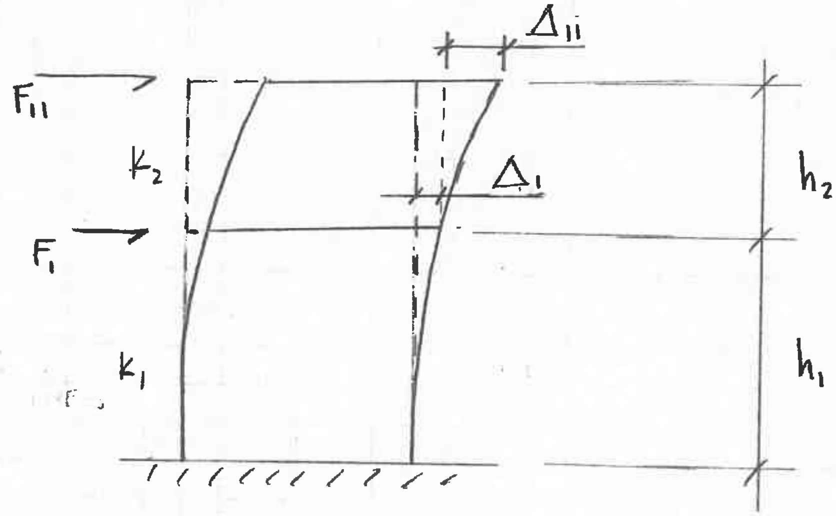
DETERMINATION OF DIAPHRAGM FORCES

NORTH-SOUTH						
STORY (x)	F_i (lbs)	W_x (lbs)	F_{px} (lbs)	$F_{px\ max}$ (lbs)	$F_{px\ min}$ (lbs)	Design F_{px} (lbs)
II	33641	54467	24650.30	28759	14379	24650
I	24045	72996	33035.73	38542	19271	33036
Σ=	57686	127463				

COEFFICIENTS	
S_{DS}	1.32
I	1

EAST-WEST						
STORY (x)	F_i (lbs)	W_x (lbs)	F_{px} (lbs)	$F_{px\ max}$ (lbs)	$F_{px\ min}$ (lbs)	Design F_{px} (lbs)
II	31247	50927	23048	26890	13445	23048
I	21404	65410	29603	34537	17268	29603
Σ=	52651	116337				

STORY DRIFT



K_x = STORY STIFFNESS

STORY DRIFT

DETERMINATION OF STORY DRIFTS

NORTH-SOUTH

STORY (x)	h_x (in)	I (in^4)	k (k-in) x 4 columns	F (Story Force)	Δ (in)	Demand/Capacity
II	110.24	8210	1060.492	33.641	0.032	0.084591878
I	125.98	8210	710.447	24.045	0.034	0.090253684

EAST-WEST

STORY (x)	h_x (in)	I (in^4)	k (k-in) x 4 columns	F (Story Force)	Δ (in)	Demand/Capacity
II	110.24	8210	1060.492	31.247	0.029	0.078571833
I	125.98	8210	710.447	21.404	0.030	0.08034069

E_c=	3605	ksi
Max Deflection	0.375	in

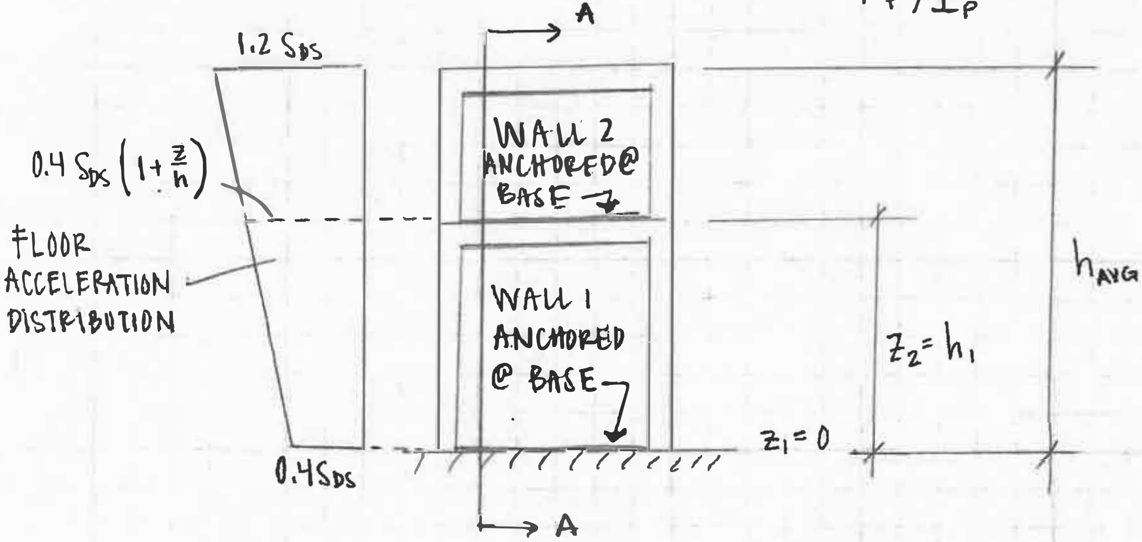
FORMULAS:
k (stiffness)=R (rigidity)
F=k*Δ

Fixed-Fixed End Conditions:
$k=(12*E*I)/h^3$
$I=b*h^3/12$

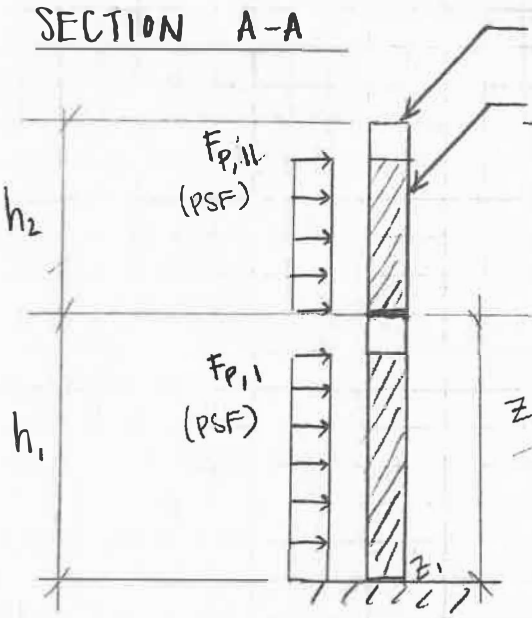
NOTES:
(1) GOAL DRIFT SHALL BE LESS THAN OR EQUAL TO 3/8" (MAX DEFORMATION FOR NON-PARTICIPATING MASONRY INFILL)

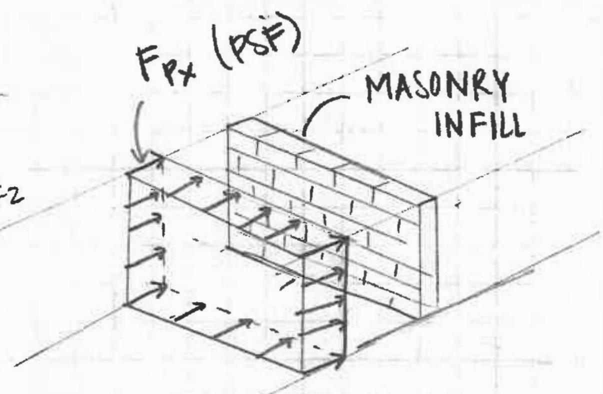
OUT OF PLANE BENDING FOR ARCHITECTURAL MASONRY INFILL.

$$F_{px} = \frac{0.4\, a_p\, S_{DS}\, W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right)$$



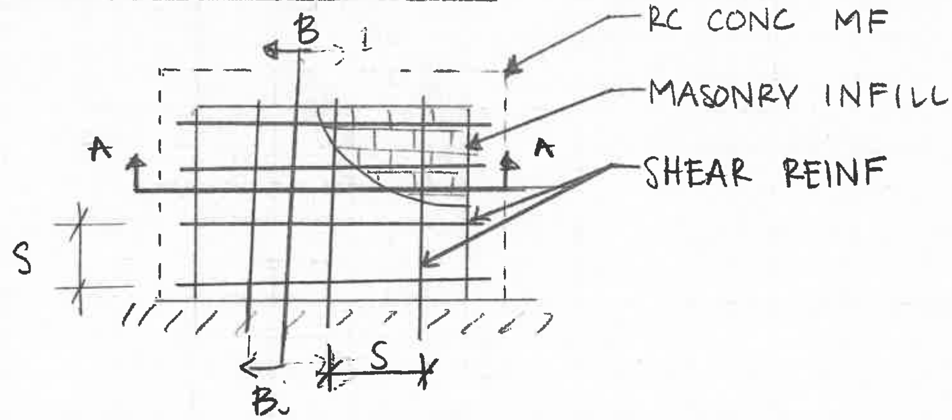
SECTION A-A

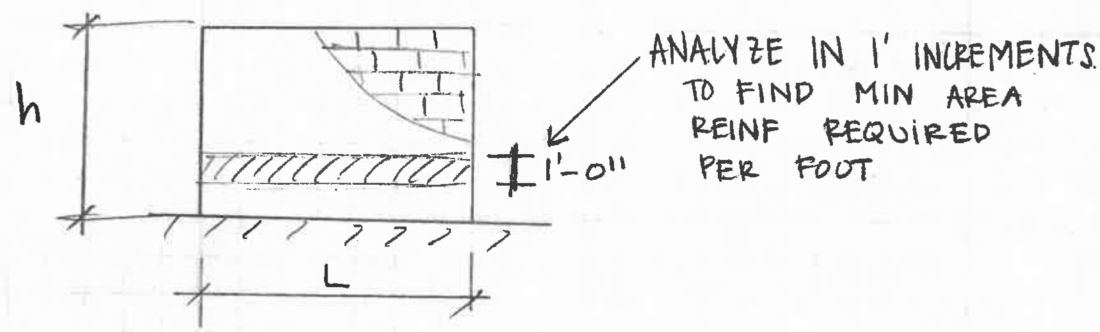




DESIGN OF MASONRY OUT OF PLANE

SHEAR REINFORCEMENT

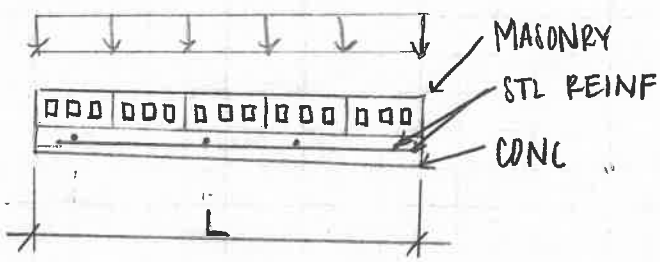


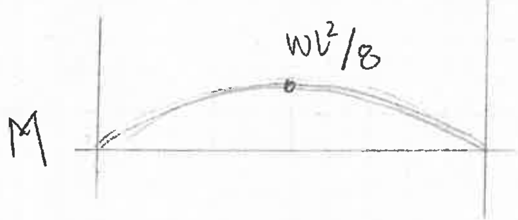


SECTIONS

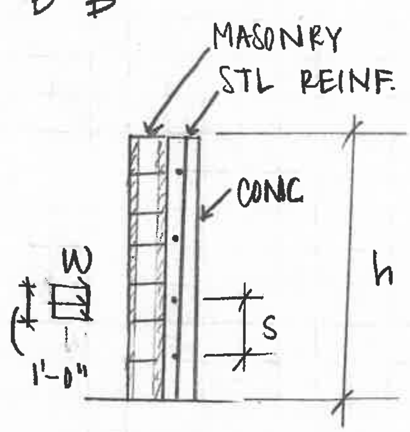
A – A

$w = F_{px}$ per 1' increment (PLF)





B – B



OUT OF PLANE BENDING

DETERMINE OUT OF PLANE BENDING FORCE

COEFFICIENTS / INPUTS			
Input	Value	Reference	Description
S_{DS}	1.32		
a_p	1.25	Table 13.5-1	For architectural exterior walls, faseners.
R_p	1	Table 13.5-1	
I_p	1.5	Table 13.1-3	Importance factor, Life Safety
R_p/I_p	0.666666667		
z			Height of structure at point of attachment of architectural component with respect to the base
W_p			Story I Wall Weight
h			Average roof height to base

FORMULAS (ASCE 7-16 13.3.1):
$F_p= 0.4*(a_p)*(S_{DS})*(W_p) * (1 +2*(z/h))/(R_p/I_p)$
$F_{p,max}=1.6*S_{DS}*I_p*W_p$
$F_{p,min=}0.3*S_{DS}*I_p*W_p$

W_p (psf)	78.30224237
h (ft)	19.68

Level	z (ft)	z/h	F_p (psf)	Fp_max (psf)	Fp_min (psf)	Design Fp
Story II	10.50	0.53347019	160.228	248.062	46.512	160.228
Story I	0	0	77.519	248.062	46.512	77.519

NOTES:
(1) CODE REFERENCE: ASCE7-16: 13.3-1

DESIGN MASONRY OUT OF PLANE SHEAR REINFORCEMENT

COEFFICIENTS / INPUTS			
Input	Value	Units	Description
j	0.95		Wide Compression Zone Factor
ϕ	0.9		Factor of Safety for Tension
d	1	in	Depth of Concrete to Flexural Steel
f_y	60	ksi	Yield Strength of Steel Reinf.
A_{bar}	0.11	in^2	Area of #3 Rebar
$A_{s,req}$		in^2/ft	Area of steel required per 1 unit wall length
s_{req}		in	Required spacing of steel
$A_{provided}$		in^2/ft	Area of steel provided per 1 unit wall length

FORMULAS
$M_u=w*L^2/8$
$A_{s,req}=M_u/(φ*f_y*j*d)$
$s=(A_{bar}*12)/A_{s,req}$

Level	Wall Label	Length (ft)	M_u (k-ft)	M_u (k-in)	$A_{s,req}$	s_{req} (in)	Design s (in)	$A_{provided}$
Story II	1	19.69	7.761	0.647	0.012607291	104	48	0.0275
	3	29.53	17.462	1.455	**0.028366406**	**46**	**24**	**0.055**
Story I	1	19.69	3.755	0.313	0.006099494	216	120	0.011
	3	29.53	8.448	0.704	0.013723863	96	48	0.0275

Use worst case Senario:
#3 rebar spaced @ 24" oc both directions
#3 rebar spaced @ ~60cm oc both directions

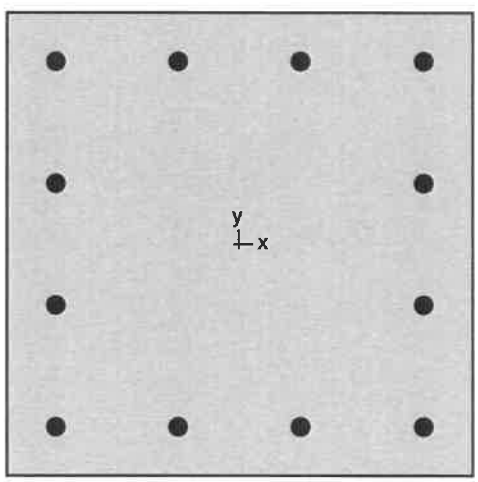
RISA Outputs

NORTH - SOUTH

	Member	Axial (K)	Shear (K)	Moment (K-FT)
C1	**M1**	**16.35**	**40.831**	**122.09**
	M1	**16.35**	**40.831**	**-8.568**
CR	**M2**	**-0.408**	**9.162**	**2.009**
	M2	**-0.408**	**9.162**	**-23.643**
C1	**M3**	**65.85**	**52.169**	**133.411**
	M3	**65.85**	**52.169**	**-33.531**
CR	**M4**	**22.608**	**28.838**	**35.343**
	M4	**22.608**	**28.838**	**-45.405**
BM F	M5	23.331	16.758	-10.577
	M5	23.331	-43.242	68.874
BM R	M6	28.838	-0.408	-23.643
	M6	28.838	-22.608	45.405
	Max Col forces	65.85	52.169	133.411
	Max BM Forces			

spColumn (TM)

spColumn v6.00
Computer program for the Strength Design of Reinforced Concrete Sections



StructurePoint

Contents

List of Figures

1. General Information

File Name	u:\1 senior...\col 450mm x 450mm ground floor.col
Project	---
Column	---
Engineer	---
Code	ACI 318-14
Bar Set	ASTM A615
Units	English
Run Option	Investigation
Run Axis	X - axis
Slenderness	Not Considered
Column Type	Structural

2. Material Properties

2.1. Concrete

Type	Standard
f'_c	4 ksi
E_c	3605 ksi
f_c	3.4 ksi
ε_u	0.003 in/in
β_1	0.85

2.2. Steel

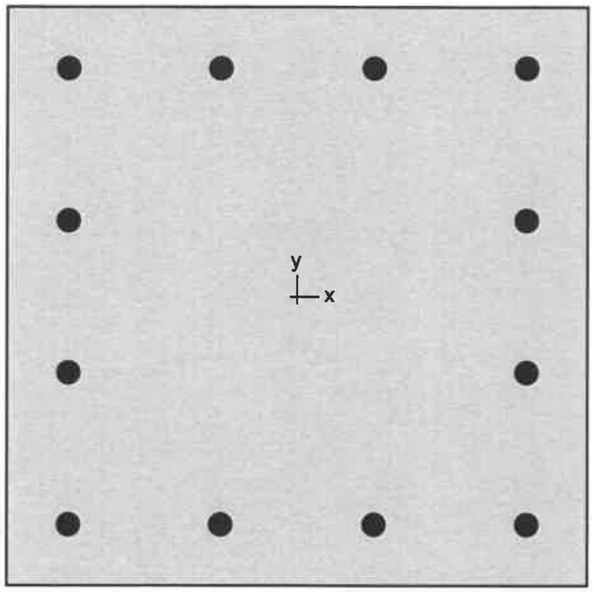
Type	Standard
f_y	60 ksi
E_s	29000 ksi
ε_{yt}	0.00206897 in/in

3. Section

3.1. Shape and Properties

Type	Rectangular
Width	17.72 in
Depth	17.72 in
A_g	313.998 in^2
I_x	8216.25 in^4
I_y	8216.25 in^4
r_x	5.11532 in
r_y	5.11532 in
X_o	0 in
Y_o	0 in

3.2. Section Figure



Rectangular 17.72 x 17.72 in 1.68% reinf.

Figure 1: Column section

4. Reinforcement

4.1. Bar Set: ASTM A615

Bar	Diameter	Area	Bar	Diameter	Area	Bar	Diameter	Area
	in	in^2		in	in^2		in	in^2
#3	0.38	0.11	#4	0.50	0.20	#5	0.63	0.31
#6	0.75	0.44	#7	0.88	0.60	#8	1.00	0.79
#9	1.13	1.00	#10	1.27	1.27	#11	1.41	1.56
#14	1.69	2.25	#18	2.26	4.00			

4.2. Confinement and Factors

Confinement type	Tied
For #10 bars or less	#3 ties
For larger bars	#4 ties
Capacity Reduction Factors	
Axial compression, (a)	0.8
Tension controlled ϕ, (b)	0.9
Compression controlled ϕ, (c)	0.65

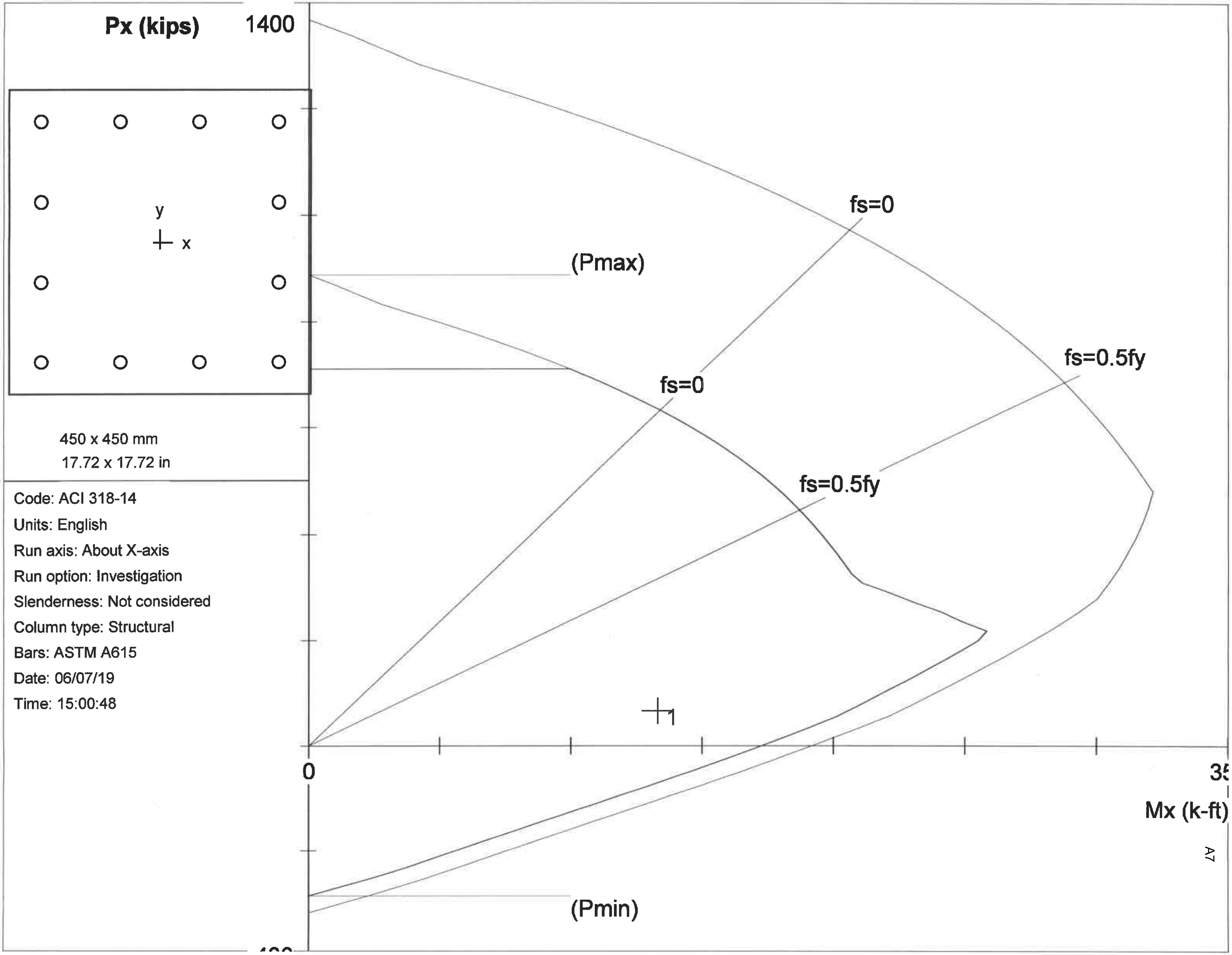
4.3. Arrangement

Pattern	All sides equal
Bar layout	Rectangular
Cover to	Longitudal bars
Clear cover	1.5 in
Bars	12 #6

Total steel area, A_s	5.28 in²
Rho	1.68 %
Minimum clear spacing	3.91 in

5. Factored Loads and Moments with Corresponding Capacities

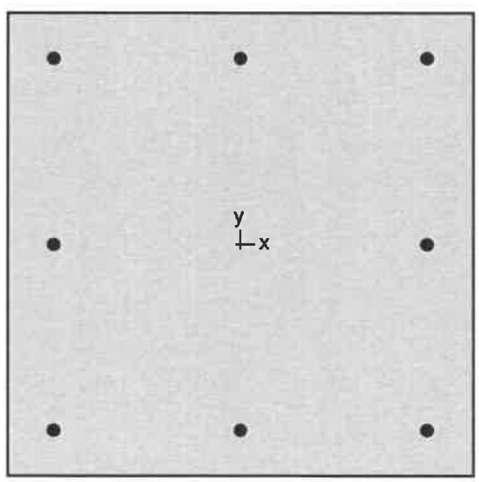
No	P_u	M_{ux}	ϕM_{nx}	$\phi M_n/M_u$	NA Depth	d_t Depth	ε_t	ϕ
	kip	k-ft	k-ft		in	in		
1	66.00	133.00	205.56	1.546	4.00	15.84	0.00888	0.900


Px (kips)
1400
y
x
450 x 450 mm
17.72 x 17.72 in
Code: ACI 318-14
Units: English
Run axis: About X-axis
Run option: Investigation
Slenderness: Not considered
Column type: Structural
Bars: ASTM A615
Date: 06/07/19
Time: 15:00:48
(Pmax)
fs=0
fs=0
fs=0.5fy
fs=0.5fy
1
0
Mx (k-ft)
(Pmin)

spcolumn (TM)

spColumn v6.00

Computer program for the Strength Design of Reinforced Concrete Sections



Contents

List of Figures

1. General Information

File Name	u:\1 senior project...\col 450mm x 450mm roof.col
Project	---
Column	---
Engineer	---
Code	ACI 318-14
Bar Set	ASTM A615
Units	English
Run Option	Investigation
Run Axis	X - axis
Slenderness	Not Considered
Column Type	Architectural

2. Material Properties

2.1. Concrete

Type	Standard	
f'_c	4	ksi
E_c	3605	ksi
f_c	3.4	ksi
ε_u	0.003	in/in
β_1	0.85	

2.2. Steel

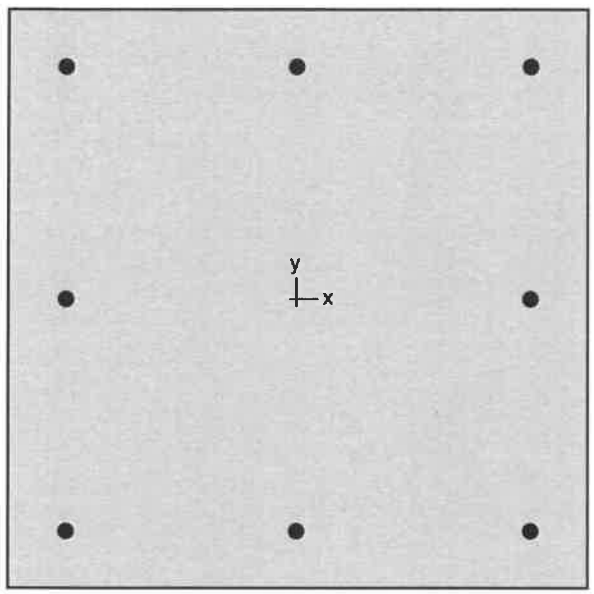
Type	Standard	
f_y	60	ksi
E_s	29000	ksi
ε_{yt}	0.00206897	in/in

3. Section

3.1. Shape and Properties

Type	Rectangular	
Width	17.72	in
Depth	17.72	in
A_g	313.998	in^2
I_x	8216.25	in^4
I_y	8216.25	in^4
r_x	5.11532	in
r_y	5.11532	in
X_o	0	in
Y_o	0	in

3.2. Section Figure



Rectangular 17.72 x 17.72 in 0.51% reinf.

Figure 1: Column section

4. Reinforcement

4.1. Bar Set: ASTM A615

Bar	Diameter	Area	Bar	Diameter	Area	Bar	Diameter	Area
	in	in²		in	in²		in	in²
#3	0.38	0.11	#4	0.50	0.20	#5	0.63	0.31
#6	0.75	0.44	#7	0.88	0.60	#8	1.00	0.79
#9	1.13	1.00	#10	1.27	1.27	#11	1.41	1.56
#14	1.69	2.25	#18	2.26	4.00			

4.2. Confinement and Factors

Confinement type	Tied
For #10 bars or less	#3 ties
For larger bars	#4 ties
Capacity Reduction Factors	
Axial compression, (a)	0.8
Tension controlled ϕ, (b)	0.9
Compression controlled ϕ, (c)	0.65

4.3. Arrangement

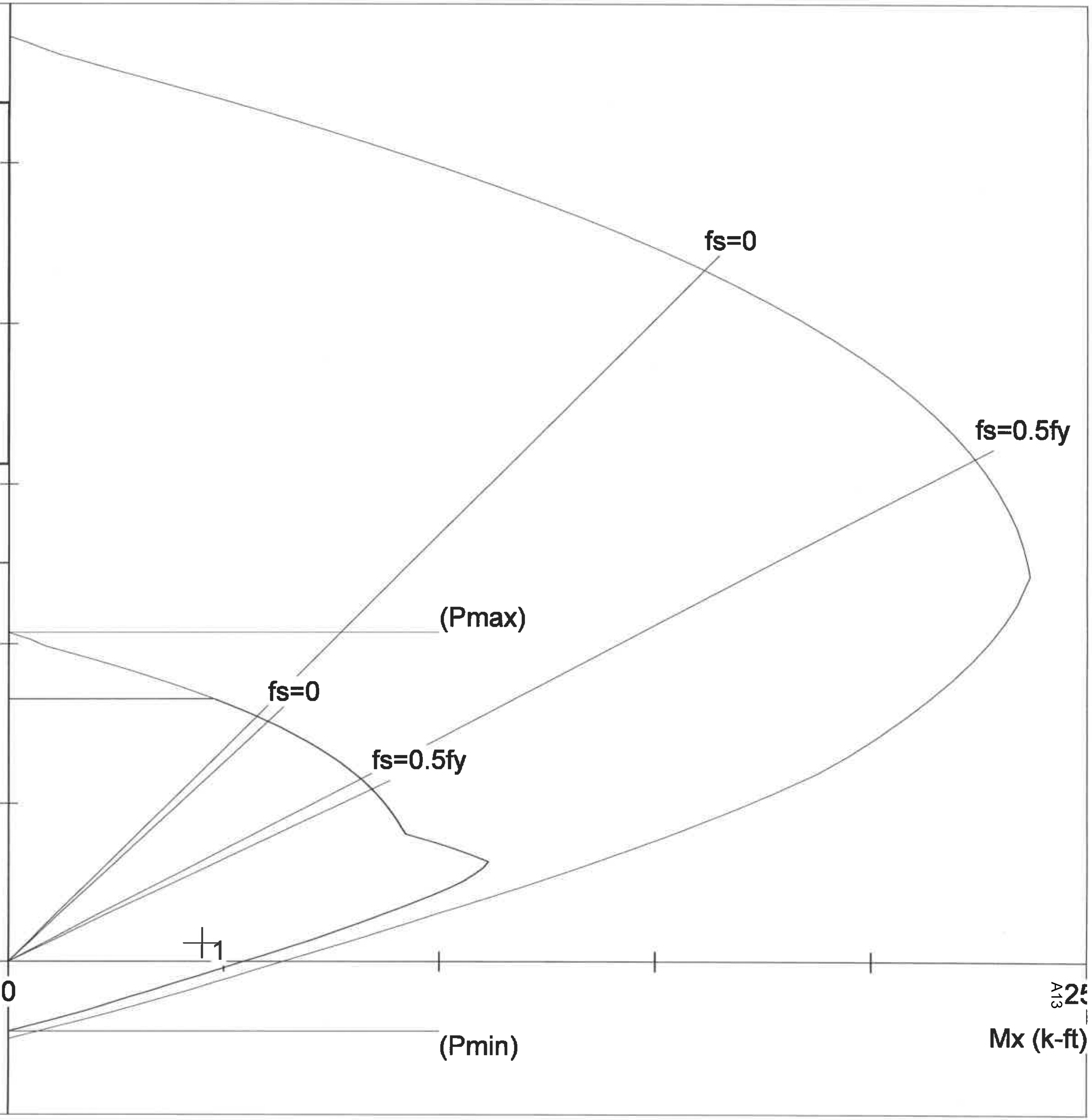
Pattern	All sides equal
Bar layout	Rectangular
Cover to	Longitudal bars
Clear cover	1.5 in
Bars	8 #4

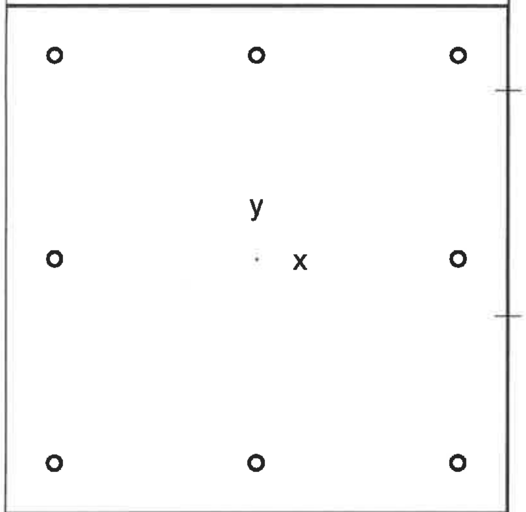
Total steel area, A_s	1.60	in^2
Rho	0.51	%
Minimum clear spacing	6.61	in

(Note: Rho < 1.0%)

5. Factored Loads and Moments with Corresponding Capacities

No	P_u kip	M_{ux} k-ft	ϕM_{nx} k-ft	$\phi M_n/M_u$	NA Depth in	d_t Depth in	ε_t	ϕ
1	23.00	45.00	68.06	1.513	2.64	15.97	0.01513	0.900





450 x 450 mm

17.72 x 17.72 in

Code: ACI 318-14

Units: English

Run axis: About X-axis

Run option: Investigation

Slenderness: Not considered

Column type: Architectural

Bars: ASTM A615

Date: 06/07/19

Time: 15:03:10

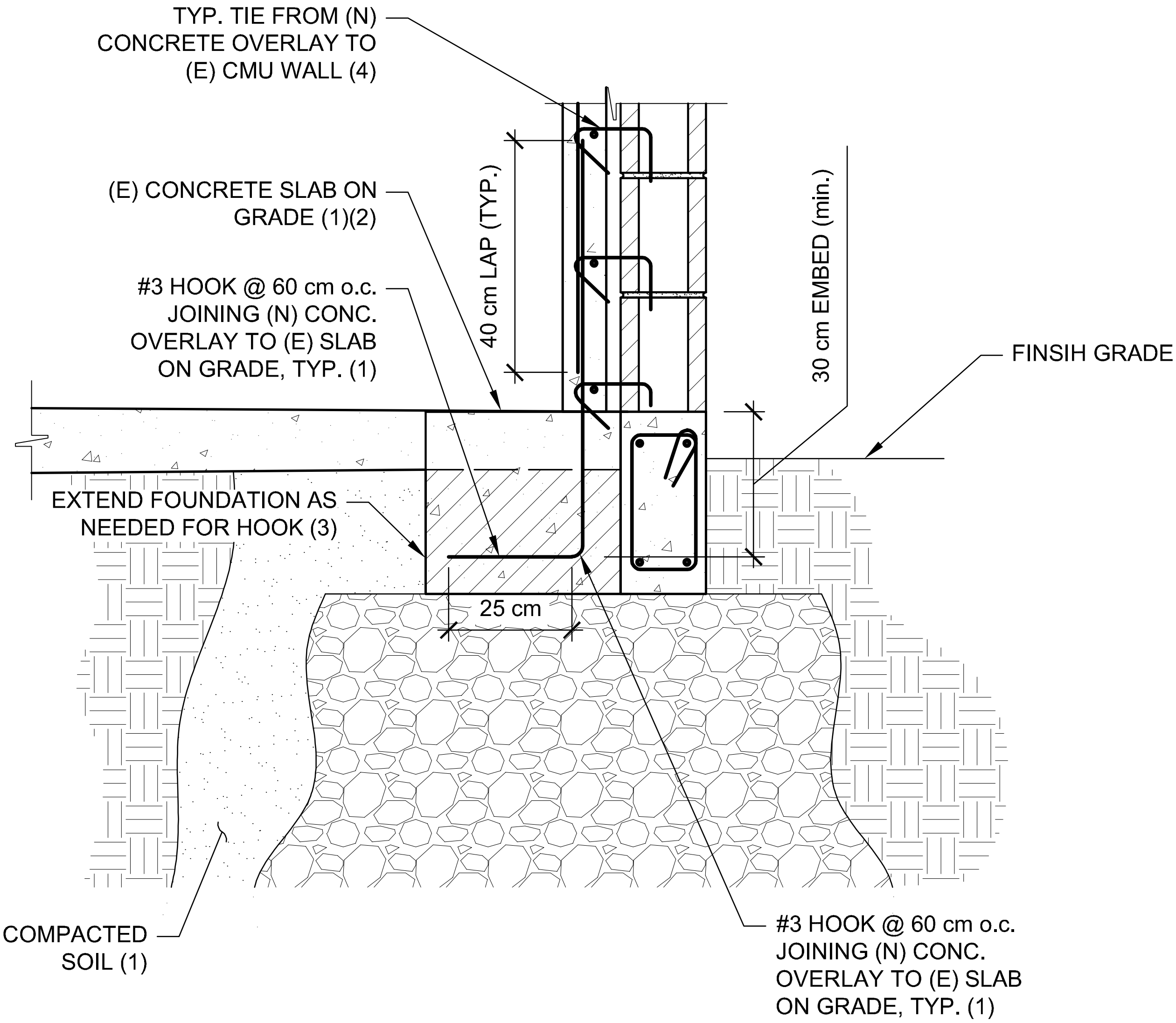
1.0				**BUILDING SYSTEM**	**NOTES:**
1.1	C	NC	N/A	MATERIALS: Materials used for the gravity and lateral load resisting system shall consist of reinforced concrete and concrete masonry.	
1.2	C	NC	N/A	LOAD PATH: A minimum of two seperate lines of wall is required in each direction; an additional line of walls is required for each 8.0 m of building dimentions over 8.0 m. Walls considered for lateral resistance shall be at least 1.0 m long. Parallel walls are located no reater than 4.5 m apart. Walls shall be connected to the diaphragm at the top and bottom by a continuous reinforced concrete floor that is centered on the wall and contiuous with the floor slab. A rigid diaphragm roof system IS required to resist seismic forces.	
1.3	C	NC	N/A	STORY HEIGHTS: The maximum story height of the first floor is 3.0 m from the ground floor slab and the floor to floor height of the upper levels is no more than 2.8 m.	
1.4	C	NC	N/A	WALLS: Walls shall consist of at least 15cm thick concrete masonry unites with sand cement mortar with no less than 40% net solid area.	
1.5	C	NC	N/A	DAMAGE: Structures have no earthquake or excessive weather related damage to the masonry walls or roof system. Damaged buildings are NON-COMPLIANT but may be repaired to become COMPLIANT.	

2.0				**MASONRY WALLS**	**NOTES:**
2.1	C	NC	N/A	INFILL MASONRY: Reinforced concrete frame (RC frame) built with masonry infill. Mortar between RC frame and infill must be greater than 3/8".	

If 1.1 - 2.1 are COMPLIANT, then see DET-01 & DET-02 for concrete overlay retrofit.

3.0				**CONCRETE MOMENT FRAME**	**NOTES:**
3.1	C	NC	N/A	COLUMNS: Concrete columns must have a cross sectional area of 400mm x 400mm. If greater than 400mm x 400mm, then COMPLIANT. If less than 400mm x 400mm, then NOT COMPLIANT.	

if 3.1 is NOT COMPLIANT, then see DET-03 & DET-04 for column jacket retrofit



<u>NOTES</u>: (#)

1. REMOVE SLAB AT BASE OF WALL WHILE PRESERVING REINFORCEMENT, AFTER FOUNDATION ADDITION IS POURED, BACKFILL WITH COMPACTED SOIL
2. REINFORCEMENT NOT SHOWN FOR CLARITY
3. MAINTAIN A MINIMUM CLEAR COVER OF 8 cm FOR REINFOCEMENT
4. REFER TO DET-02 FOR TIE SPECIFICATIONS

DRAWN BY:	MGR	REINFORCED CONCRETE OVERLAY	SHEET NUMBER:
CHECKED BY:	PFP,ZT		DET-01
DATE:	06/04/19	SEISMIC RETROFIT PEMBO, PHILIPPINES	
CAL POLY			

								f'c= 4,000 psi	
								fy= 60,000 psi	
			Tension						
			Straight		Hook	Class B Splice		Class A Splice	
Bar	D_b	A_b	l_d	top	l_{dk}	(l_d * 1.3)	top	(l_d * 1.0)	top
#3	0.375	0.11	14	18	7	18	24	14	18
#4	0.5	0.2	19	25	9	25	32	19	25
#5	0.625	0.31	19	25	12	25	32	19	25
#6	0.75	0.44	28	37	14	37	48	28	37
#7	0.875	0.6	42	54	17	54	70	42	54
#8	1	0.79	47	62	19	62	80	47	62
#9	1.128	1	54	70	21	70	90	54	70
#10	1.27	1.27	60	78	24	78	102	60	78
#11	1.41	1.56	67	87	27	87	113	67	87
#14	1.693	2.25	80	104	32	n/a	n/a	n/a	n/a
#18	2.257	4	107	139	43	n/a	n/a	n/a	n/a

DRAWN BY:	MGR
CHECKED BY:	PFP,ZT
DATE:	06/04/19

CAL POLY

DEVELOPMENT LENGTH TABLE

SEISMIC RETROFIT
PEMBO, PHILIPPINES

SHEET NUMBER:

TBL-01

Column Properites		Longitudinal Reinforcement	
Column Type	Column Size	Quantity	Bar Size
RC1	450 mm X 450 mm	8	#4
FC1	450 mm X 450 mm	12	#6

DRAWN BY:	MGR
CHECKED BY:	PFP,ZT
DATE:	06/04/19

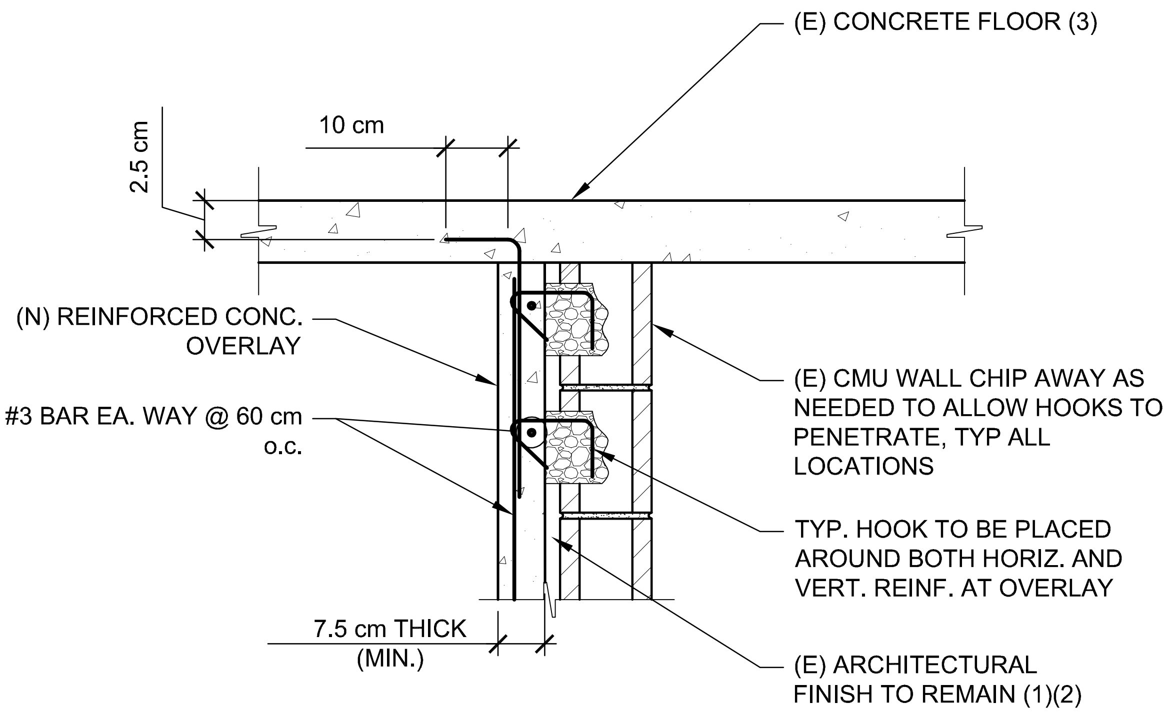
CAL POLY

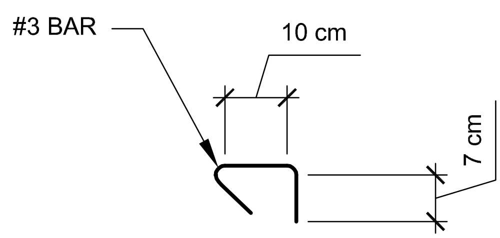
COLUMN REBAR SCHEDULE

SEISMIC RETROFIT
PEMBO, PHILIPPINES

SHEET NUMBER:

TBL-02



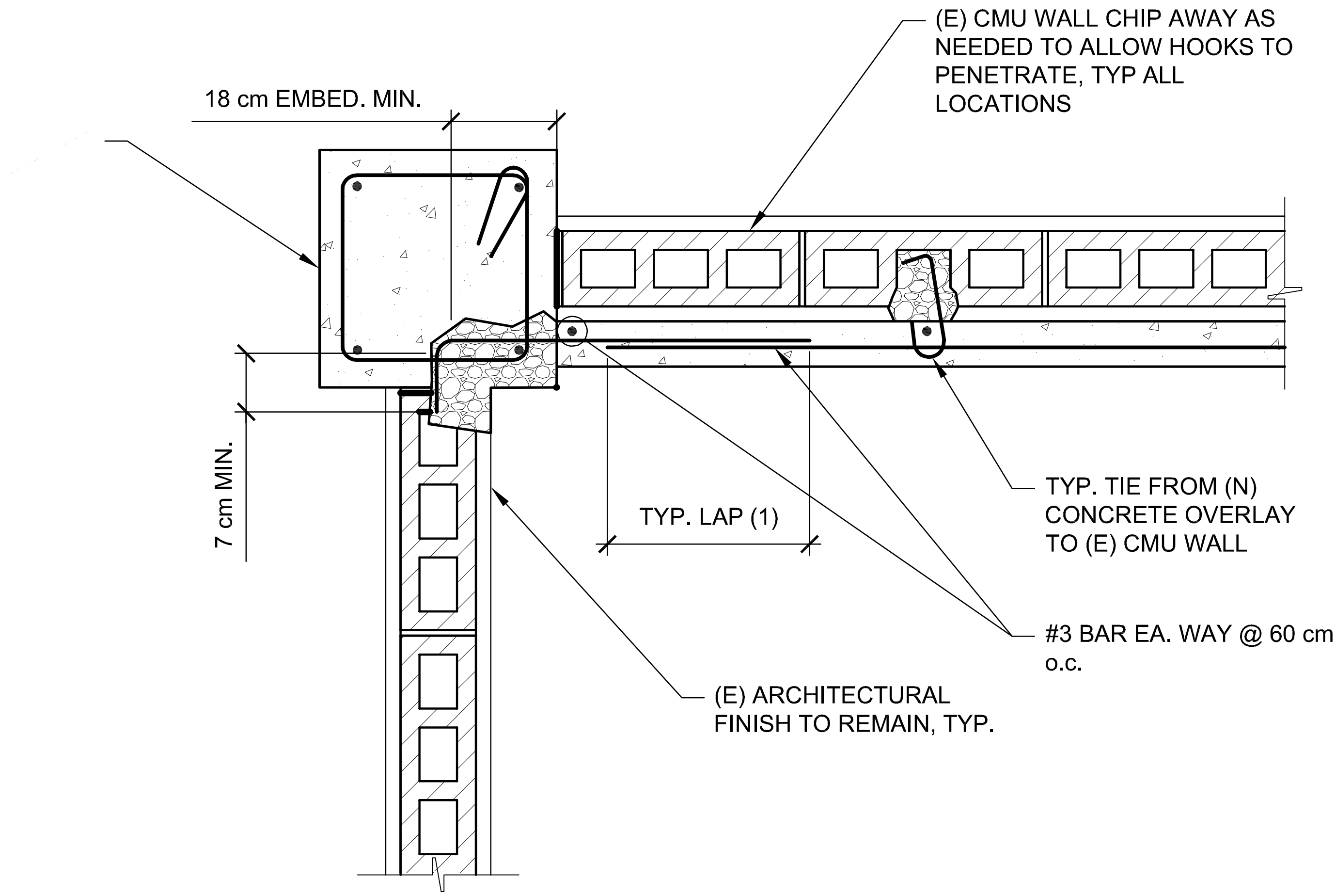


TYPICAL TIE

NOTES: (#)

1. REMOVE WHERE NECESSARY TO ALLOW TIES TO PENETRATE INTO CMU
2. IF WALL HAS A PLASTER FINISH, CHIP VARIOUS HOLES THROUGH PLASTER ALLOW CONCRETE TO BOND
3. REINFORCEMENT NOT SHOWN FOR CLARITY

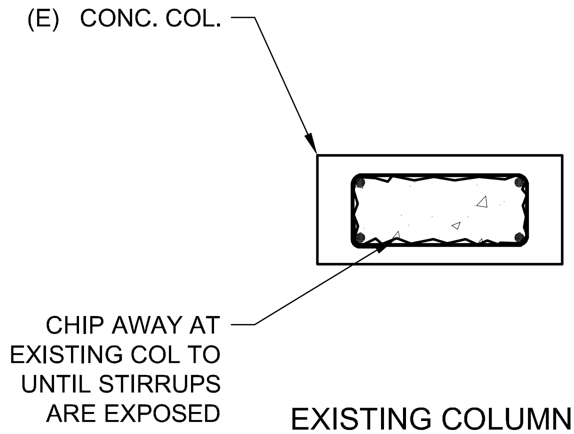
DRAWN BY:	MGR	REINFORCED CONCRETE OVERLAY	SHEET NUMBER:
CHECKED BY:	PFP,ZT		
DATE:	06/04/19	SEISMIC RETROFIT PEMBO, PHILIPPINES	DET-02
CAL POLY			



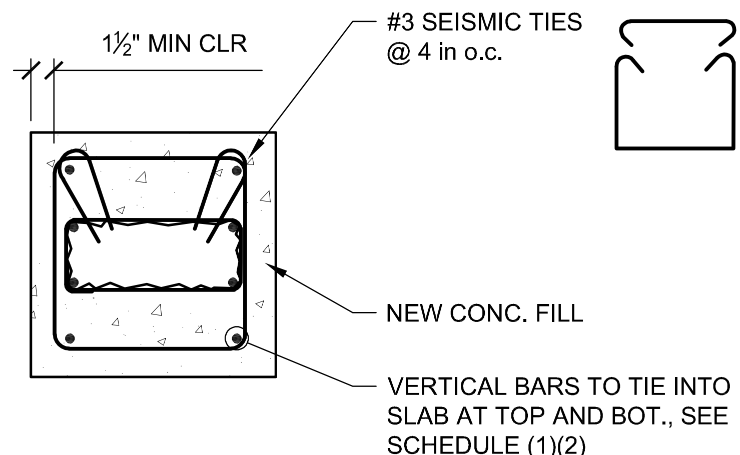
NOTES: (#)

1. SEE DET-06 FOR TYPICAL LAP SPECIFICATIONS

DRAWN BY:	MGR	REINFORCED CONCRETE OVERLAY	SHEET NUMBER:
CHECKED BY:	PFP,ZT		DET-03
DATE:	06/04/19	SEISMIC RETROFIT PEMBO, PHILIPPINES	
CAL POLY			



EXISTING COLUMN

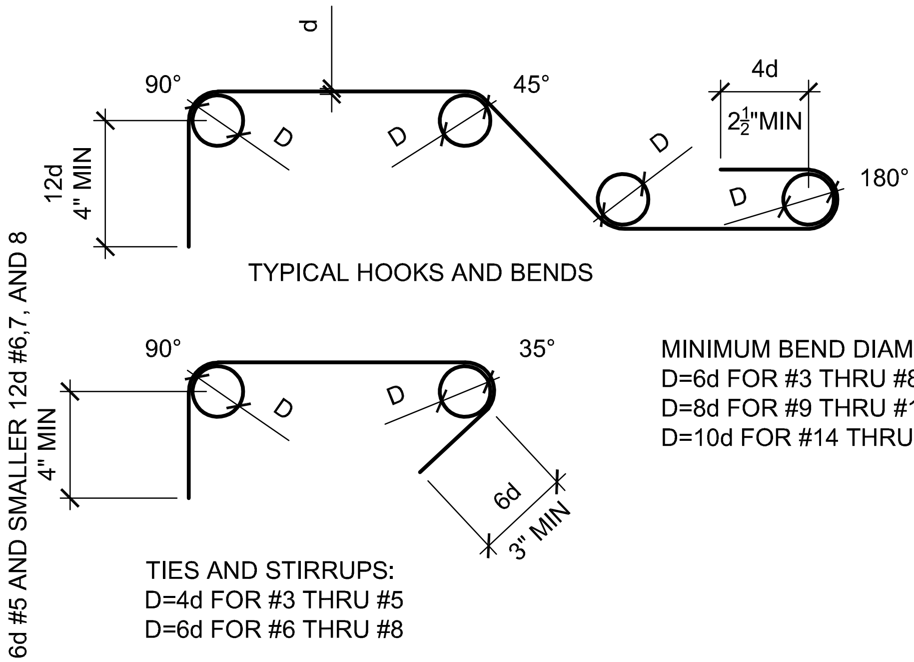


COLUMN WITH JACKET

NOTES: (#)

1. HOOK TO BE AS SPECIFIED IN DET-01 & DET-02 FOR EA. CONDITION
2. REFER TO COLUMN REBAR SCHEDULE FOR REINFORCEMENT SIZES AND QUANTITES

DRAWN BY:	MGR	COLUMN JACKET	SHEET NUMBER: DET-04
CHECKED BY:	PFP,ZT		
DATE:	06/04/19	SEISMIC RETROFIT PEMBO, PHILIPPINES	
CAL POLY			



TYPICAL HOOKS AND BENDS

MINIMUM BEND DIAMETER
D=6d FOR #3 THRU #8
D=8d FOR #9 THRU #11
D=10d FOR #14 THRU #18

TIES AND STIRRUPS:
D=4d FOR #3 THRU #5
D=6d FOR #6 THRU #8

NOTES: (#)

1. ALL HOOKS SHALL BE 90° STANDARD HOOKS UNLESS OTHERWISE SHOWN OR NOTED

DRAWN BY:	MGR	TYPICAL REBAR HOOKS & BENDS	SHEET NUMBER:
CHECKED BY:	PFP,ZT		
DATE:	06/04/19	SEISMIC RETROFIT PEMBO, PHILIPPINES	DET-05
CAL POLY			