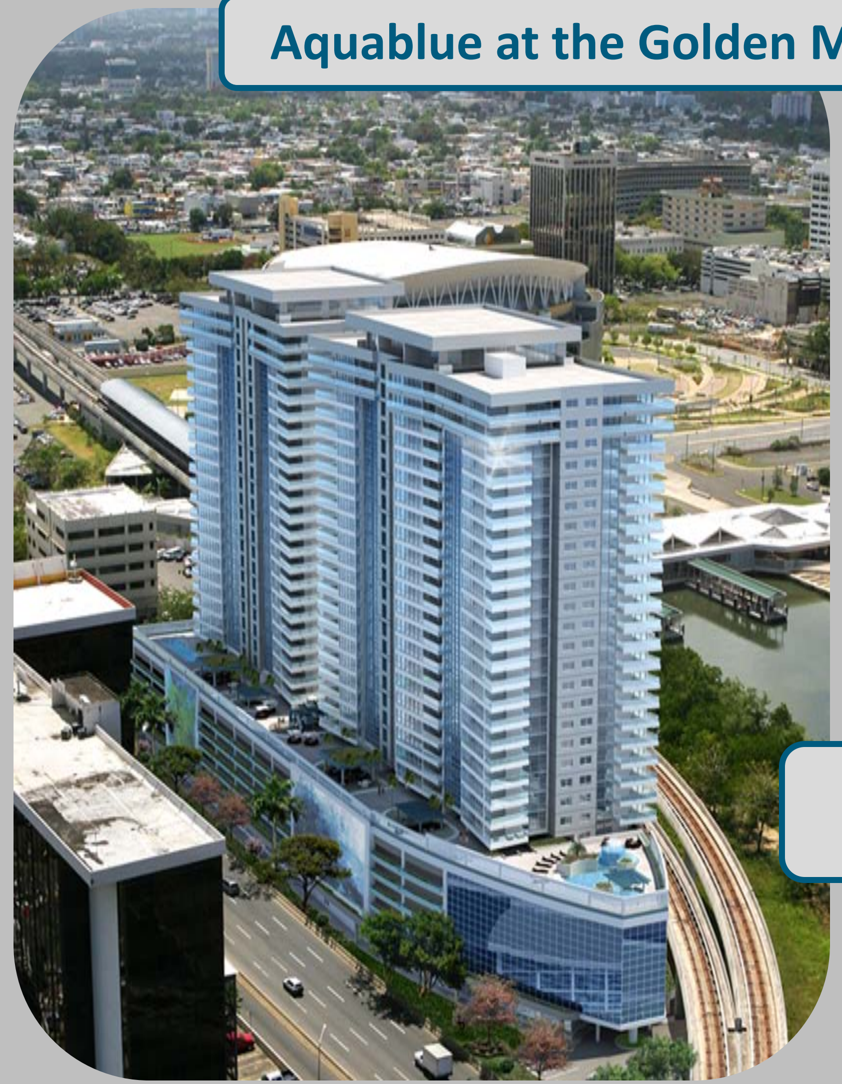
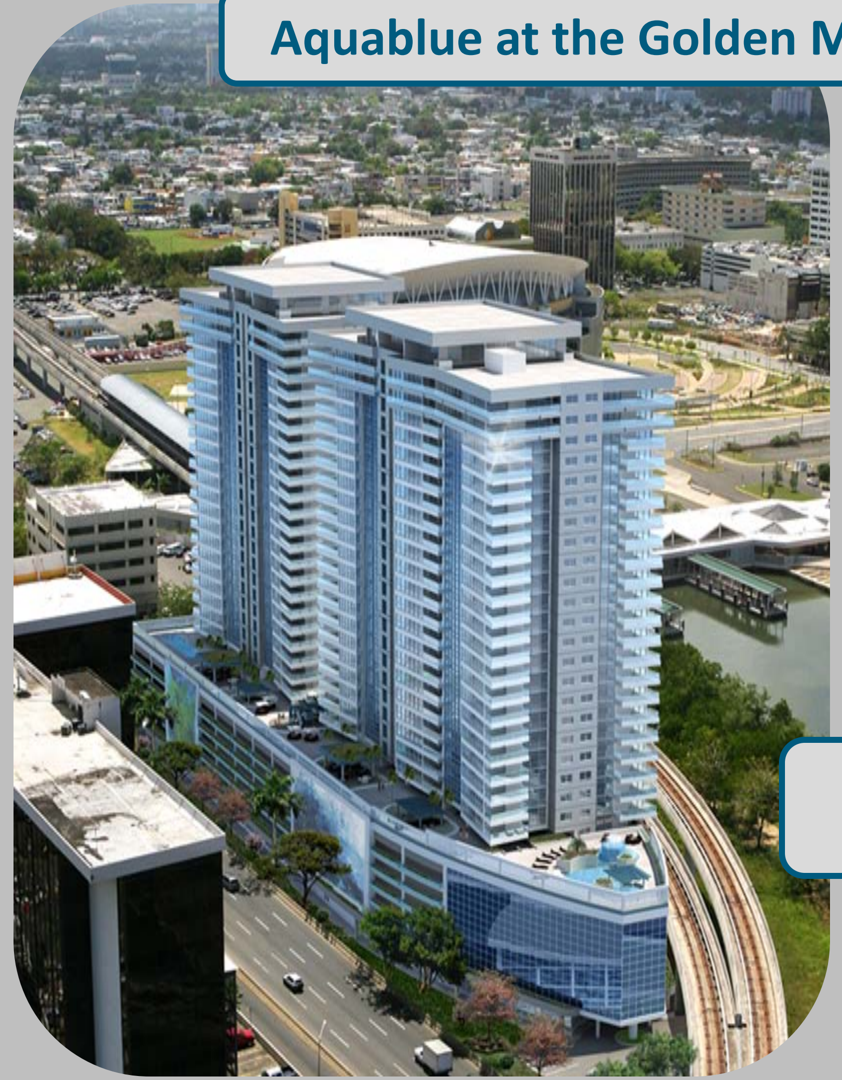
Aquablue at the Golden Mile



Hato Rey,
Puerto Rico

Aquablue at the Golden Mile



Hato Rey, Puerto Rico

Building Facts:

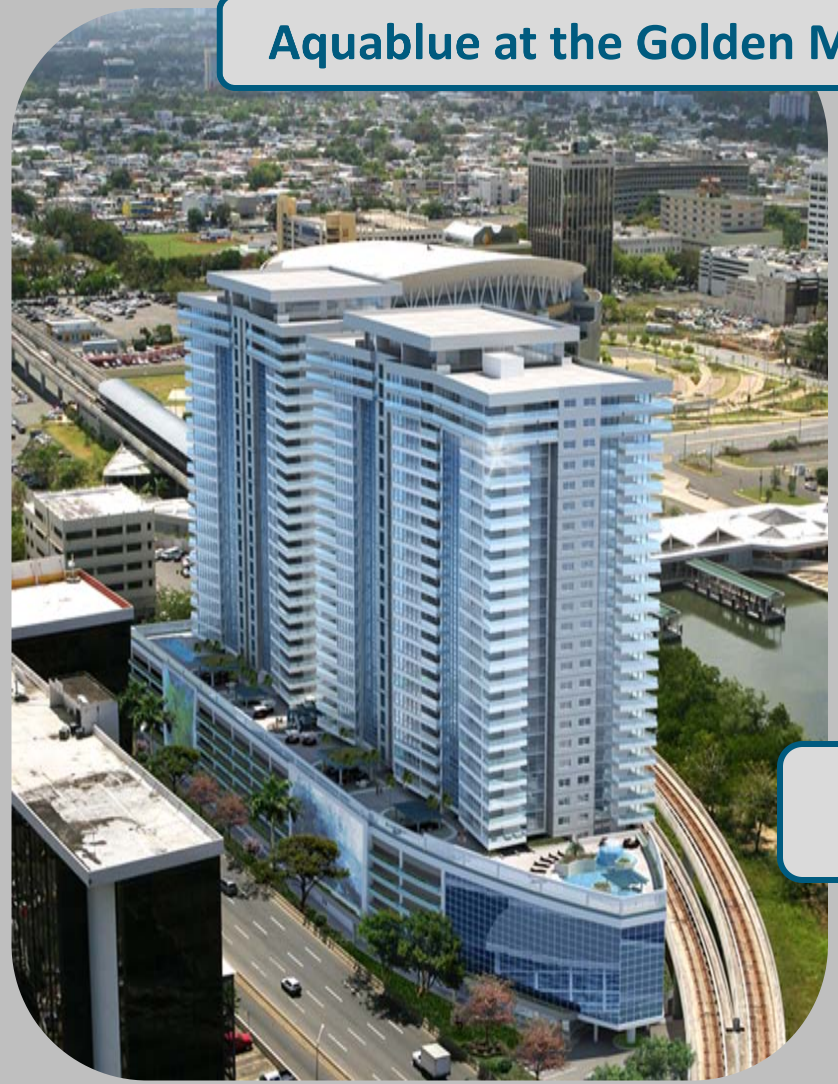
- 7-story parking structure + luxury apartments
- 900,000 ft^2
- 31 stories above grade
- total height = 276’
- approximate plan dimensions = 120’ x 490’
- Construction dates: February 2007 – August 2009
- Structural Engineer: DeSimone Consulting Engineers

Existing Structural System:

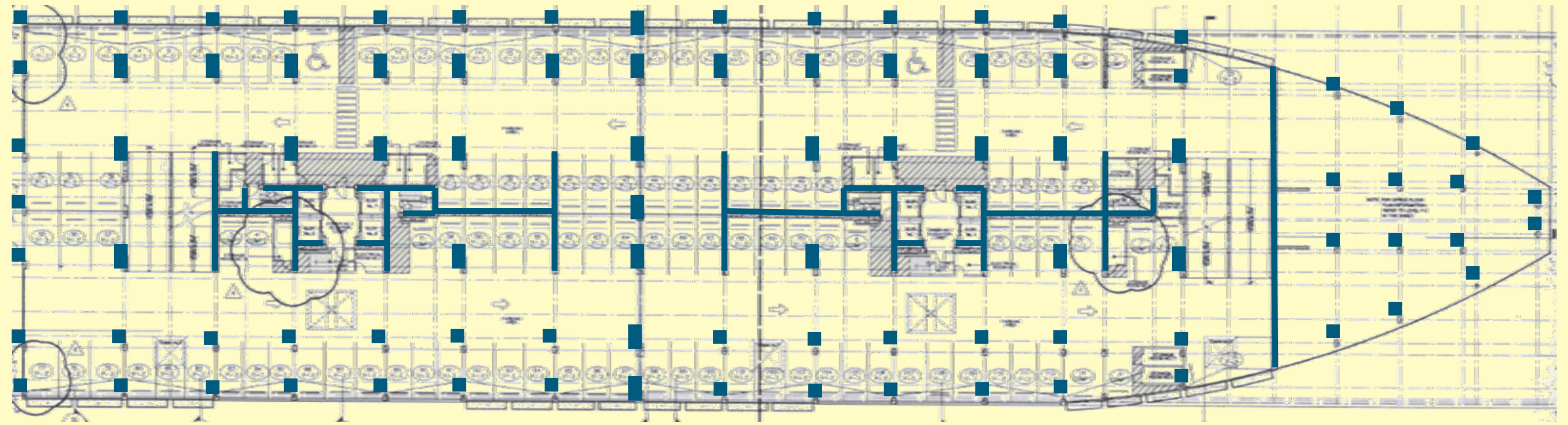
- foundation – drilled piles beneath 10” concrete slab
- gravity system – two-way, post-tensioned slabs
- lateral system – 18” concrete shear walls
- 5” seismic joint

Typical Floor Plans

Aquablue at the Golden Mile

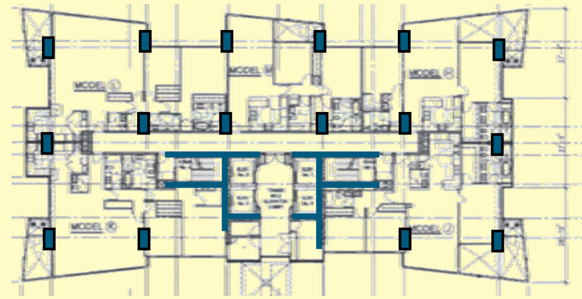


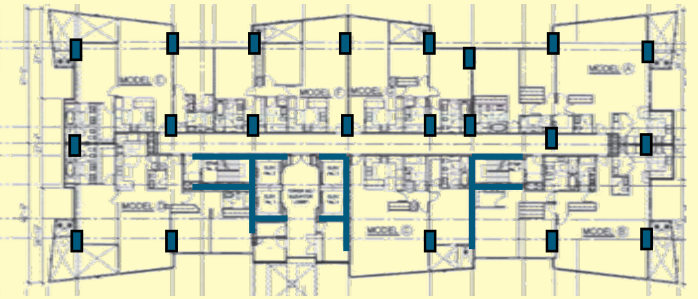
Hato Rey, Puerto Rico



Parking Garage Level

- 51,900 ft^2
- plan dimensions = 120’ x 490’

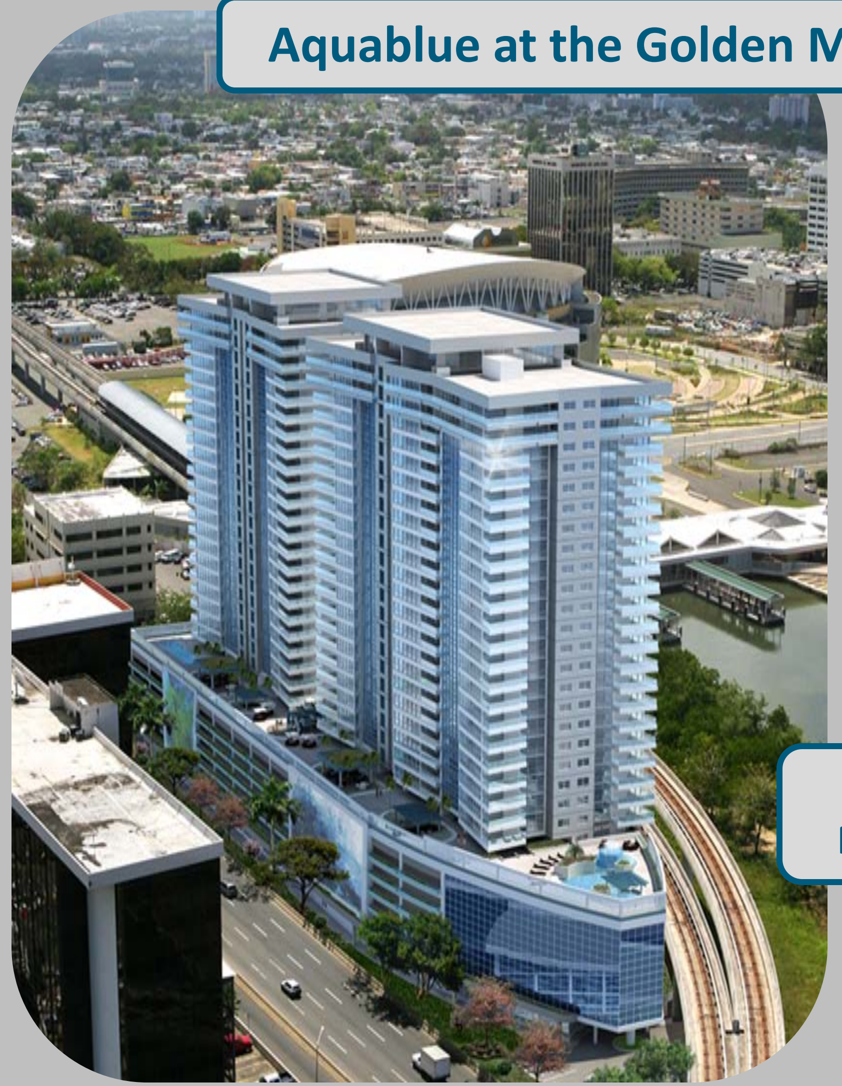




Apartment Towers

- 11,600 ft^2 and 14,500 ft^2
- plan dimensions = 90’ x 160’ and 90’ x 200’

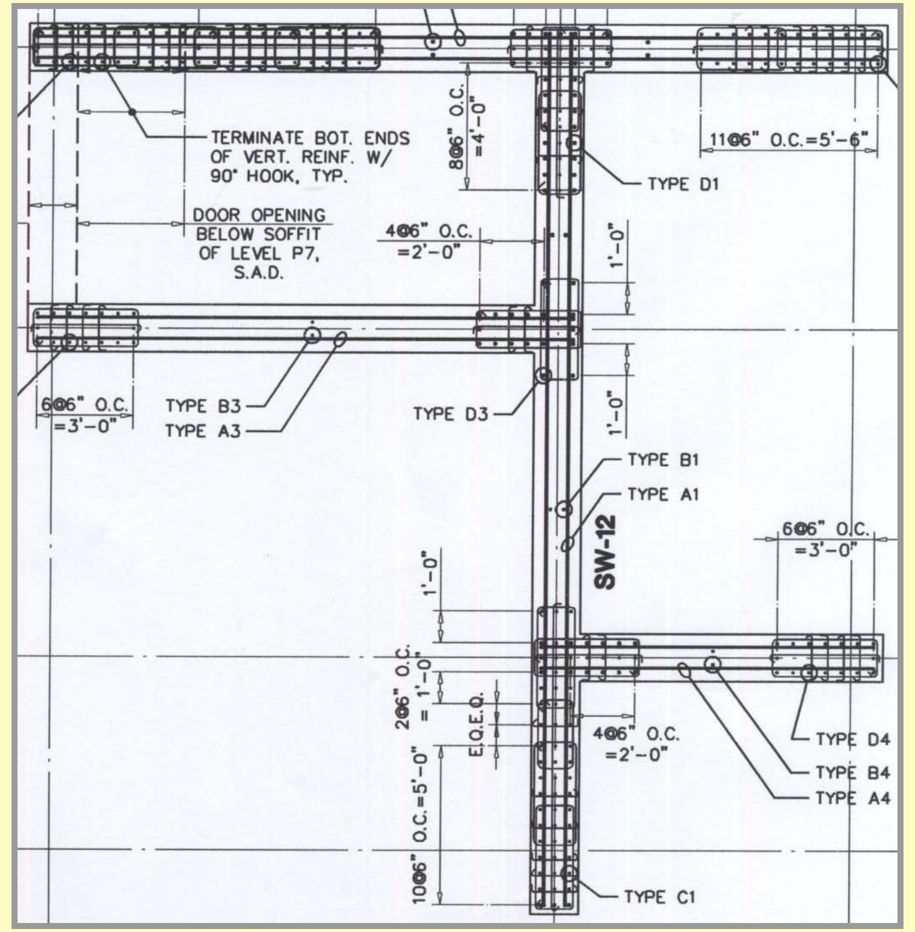
Aquablue at the Golden Mile



Hato Rey, Puerto Rico

Features of Shear Walls:

- f'_c = 8000 psi up to level 13
- f'_c = 6000 psi above level 13
- Detailed integration of shear wall segments
- Intricate construction process



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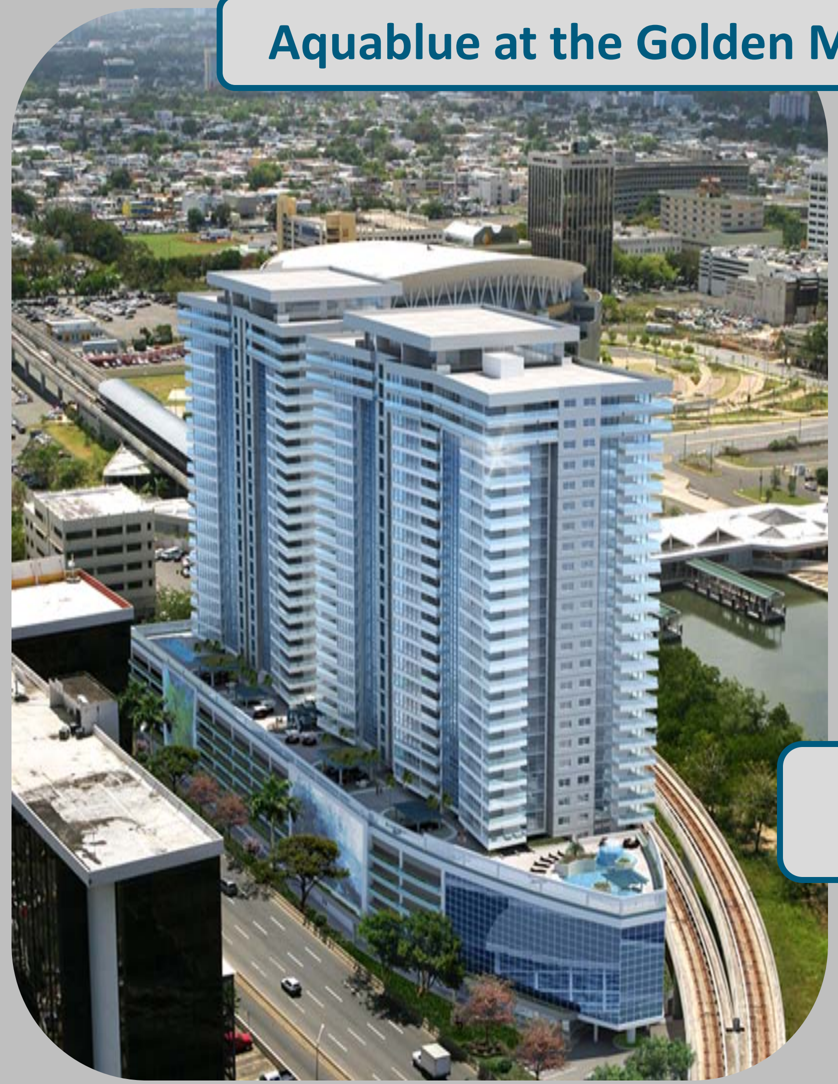


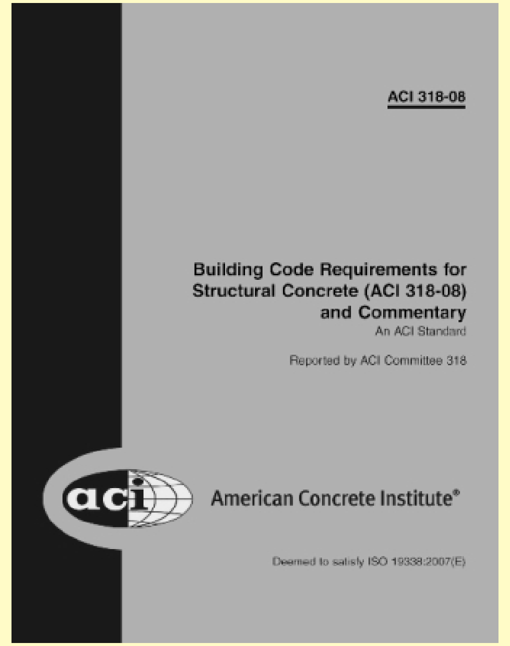
Hato Rey,
Puerto Rico

National Model Codes used by DeSimone Consulting Engineers:

- Puerto Rico Building Code 1999
- UBC 1997 (Uniform Building Code)
- ACI 318-99 (“Building Code Requirements for Structural Concrete”)
- ACI 530-99 (“Building Code Requirements for Masonry Structures”)
- SJI 1994 (Steel Joist Institute)

Codes and References used for this design project:

- ACI 318-08 (American Concrete Institute)
- ASCE 7-05 (American Society of Civil Engineering)
- IBC 2006 (International Building Code)
- ETABS Nonlinear v9.2.0 (Computers and Structures, Inc.)
- pcaColumn v3.64 (Portland Cement Association)



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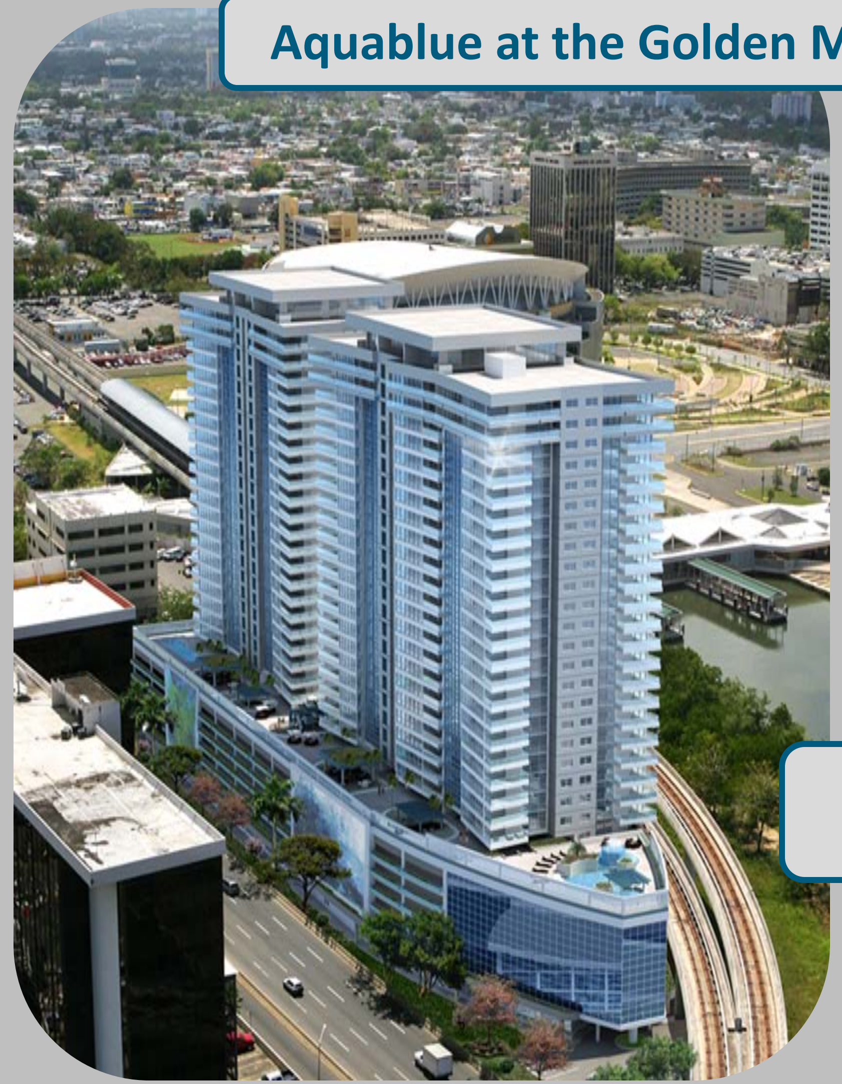


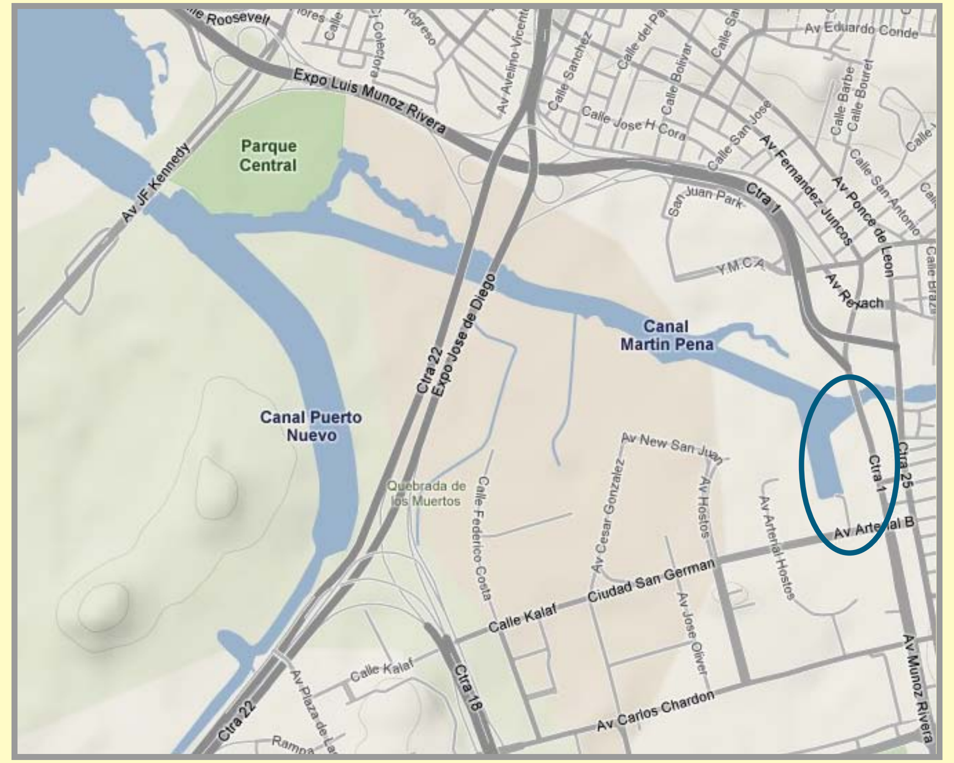
Hato Rey, Puerto Rico

Overview of Project Proposal:

- Lateral force analysis
- Shear wall and coupling beam re-design
- Reinforcement design
- ETABS and pcaColumn analysis
- Architectural breadth study
- Construction Management breadth study

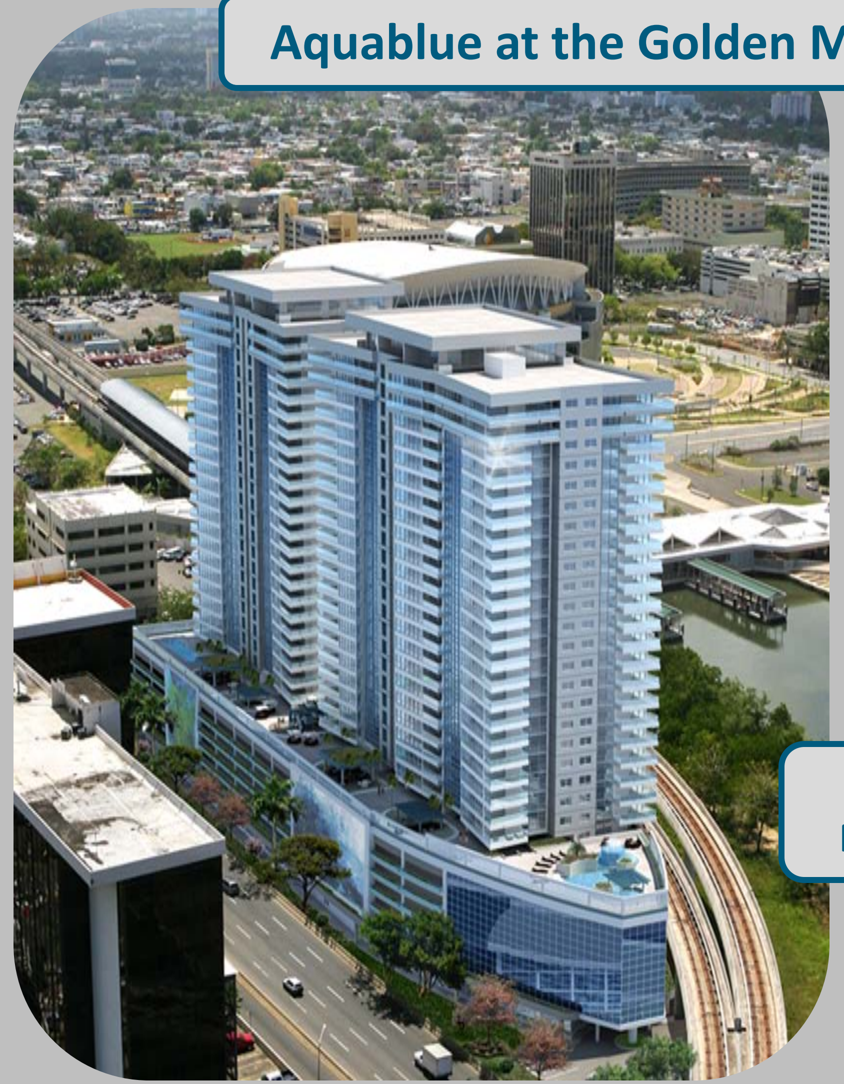
Project Goals:

- Detailed analysis of lateral loads
- Concrete shear wall design (ACI 318-08 building code)
- Computer modeling as a means of structural analysis
- Architectural impact of structural design



Hato Rey Central, PR

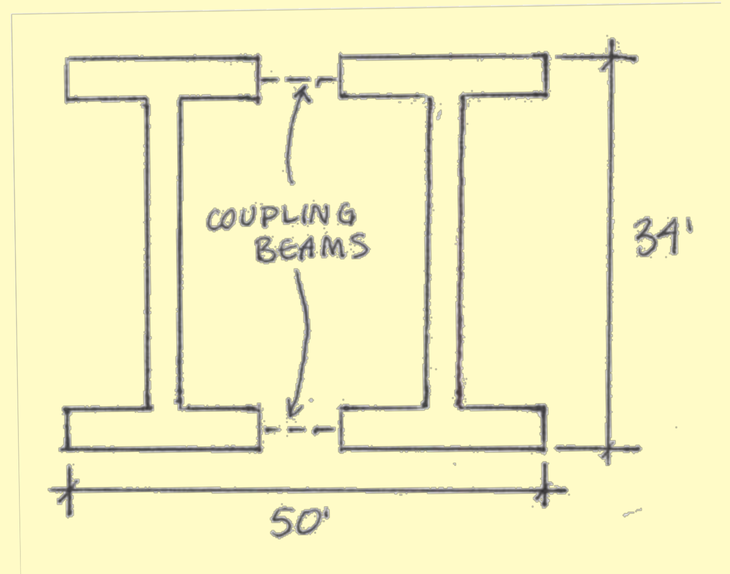
Aquablue at the Golden Mile



Hato Rey, Puerto Rico

Ideas for Shear Wall Re-design:

- Two I-shaped shear walls with connecting coupling beams
- More regular and efficient shape
- Minor architectural impact
- Hand calculations + computer modeling for analysis
- Reinforcement design
- Focus on the core of one tower



Preliminary Sketch (N.T.S.)

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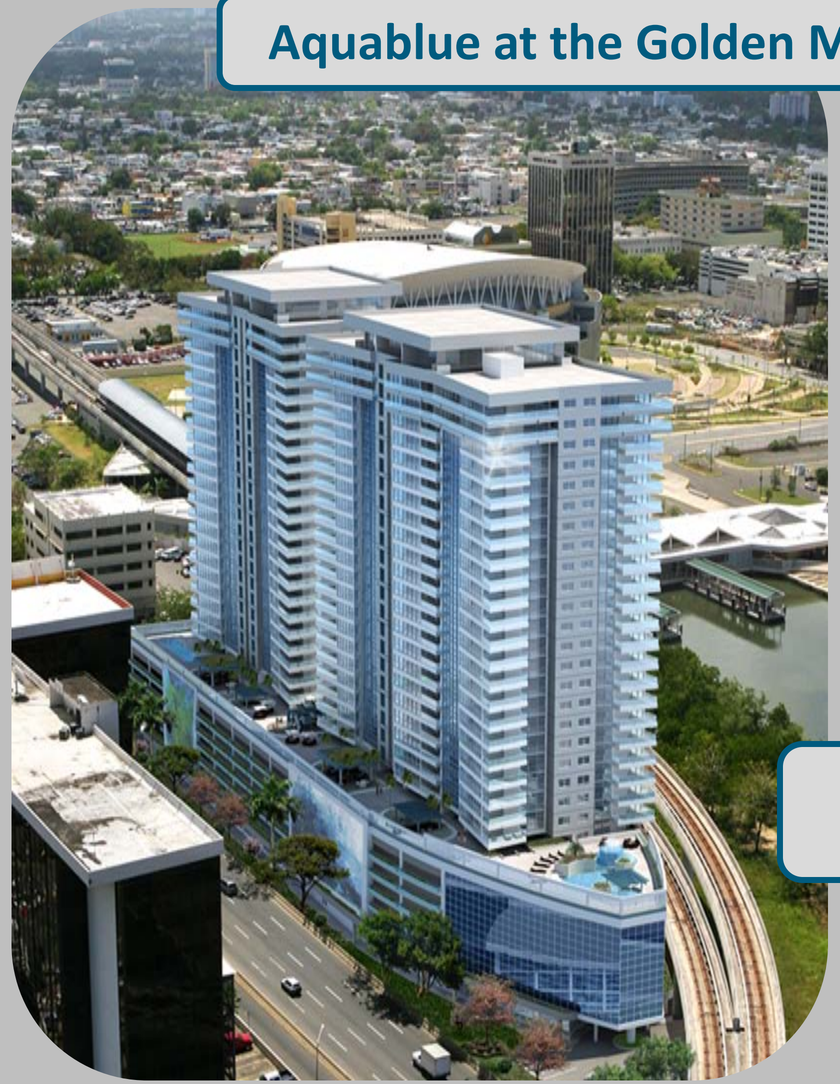
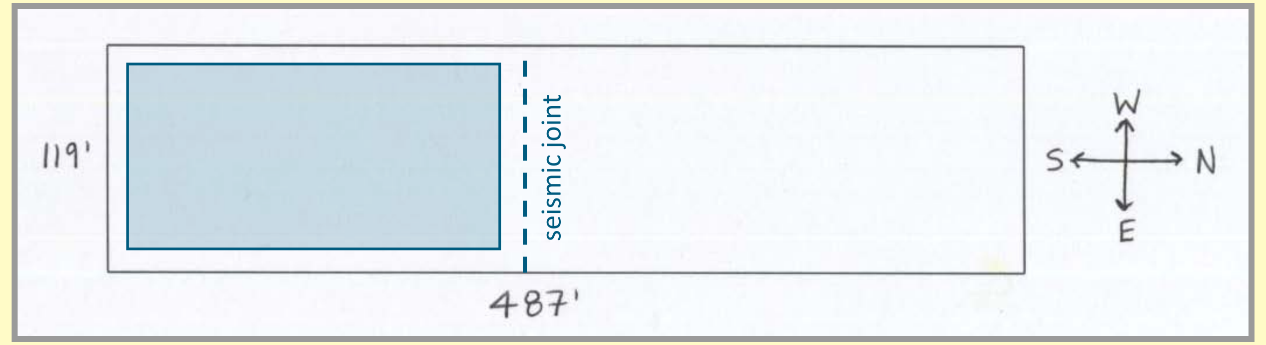


Hato Rey, Puerto Rico



Wind Analysis:

- ASCE 7-05 (Chapter 6)
- Analytical Procedure (Method 2)
- Basic Wind Speed, V = 145 mph
- Importance Factor, I = 1.0
- Exposure Category = B
- Special Wind Cases

Seismic Analysis:

- ASCE 7-05 (Chapters 11 and 12)
- Equivalent Lateral Force Procedure
- Importance Factor, I = 1.0
- Seismic Design Category = D
- Response Modification Coefficient, R = 6
- Fundamental Period, T = 2.031
- Seismic Response Coefficient, C_s = 0.0165

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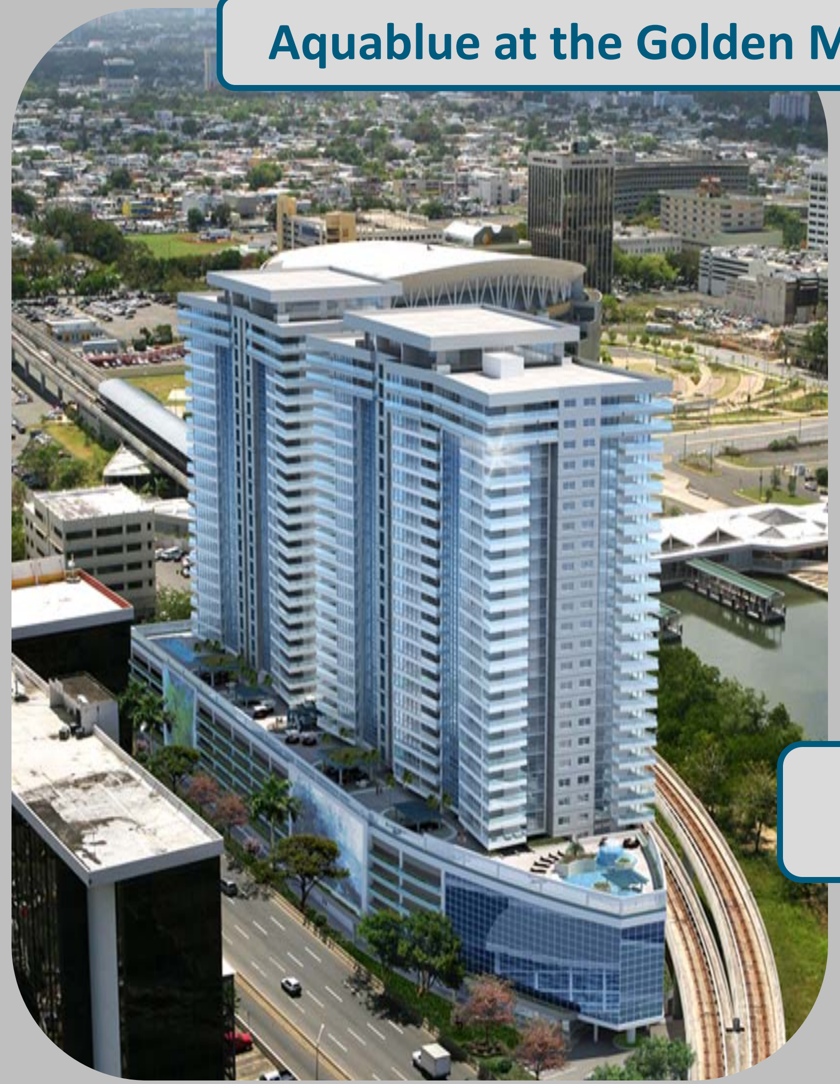

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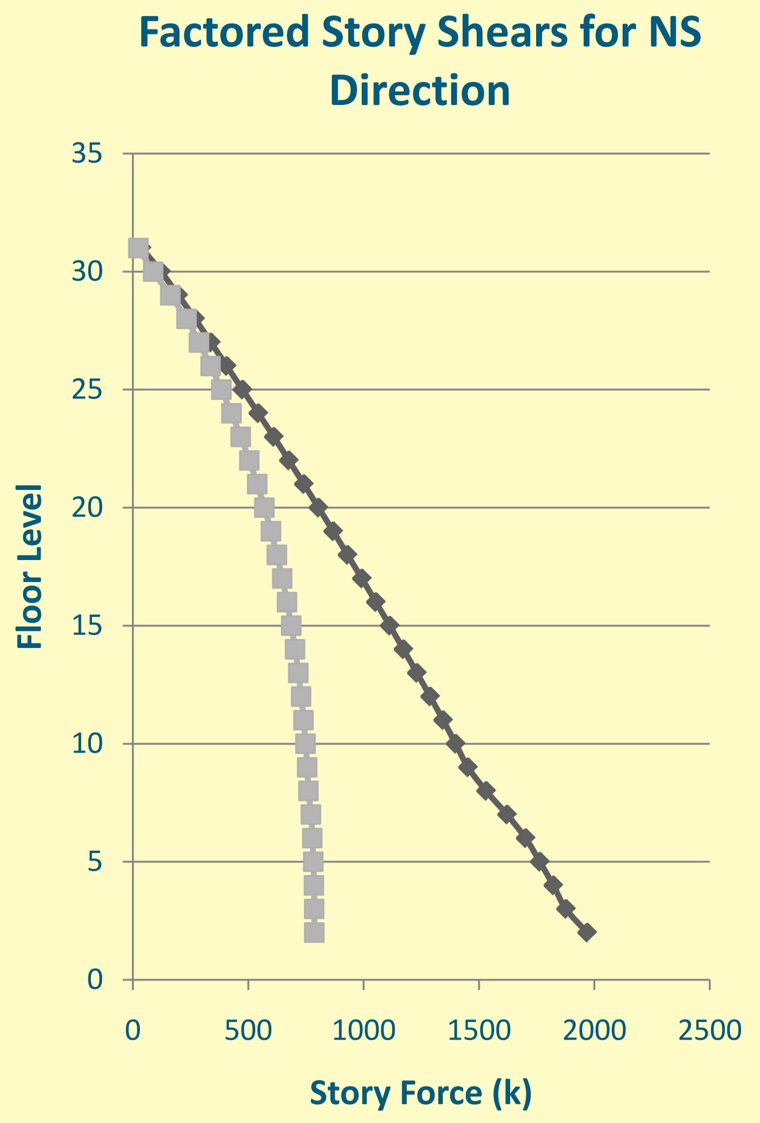
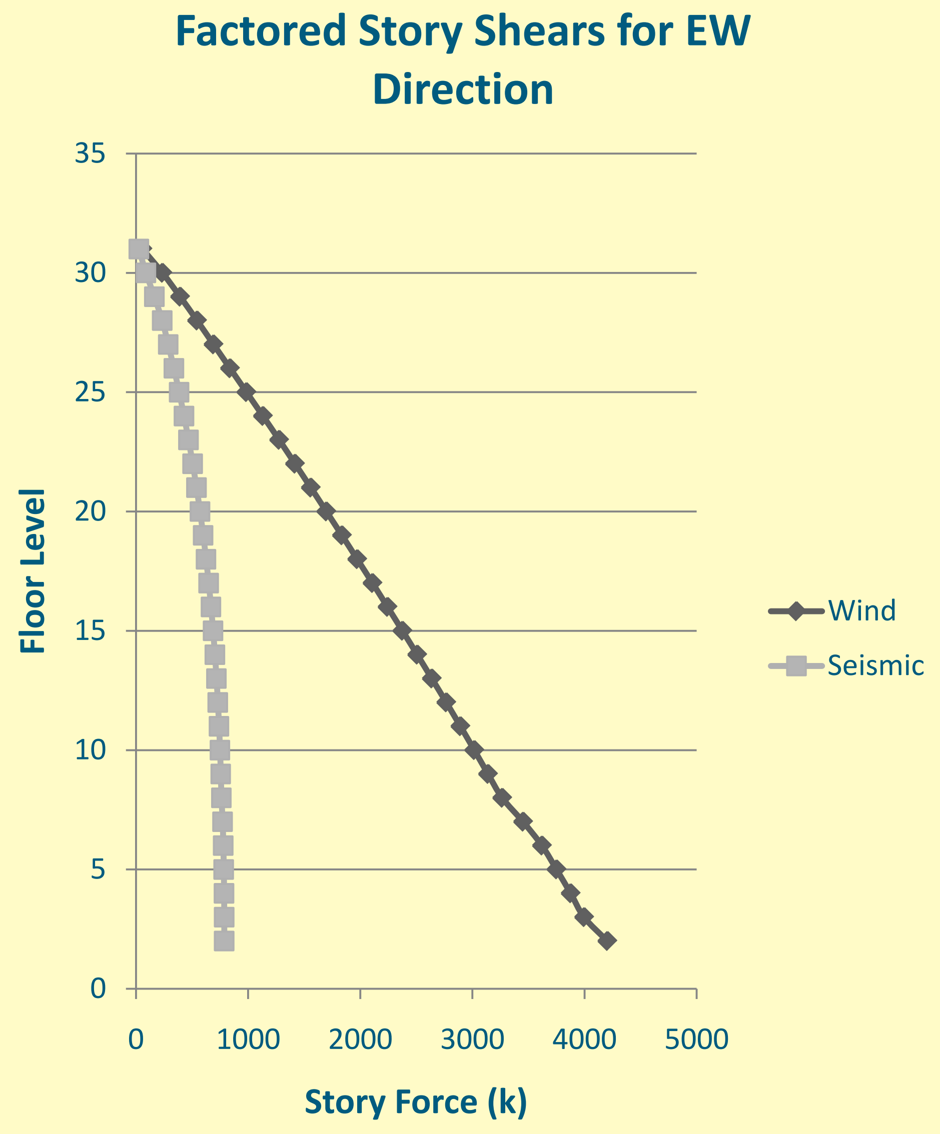
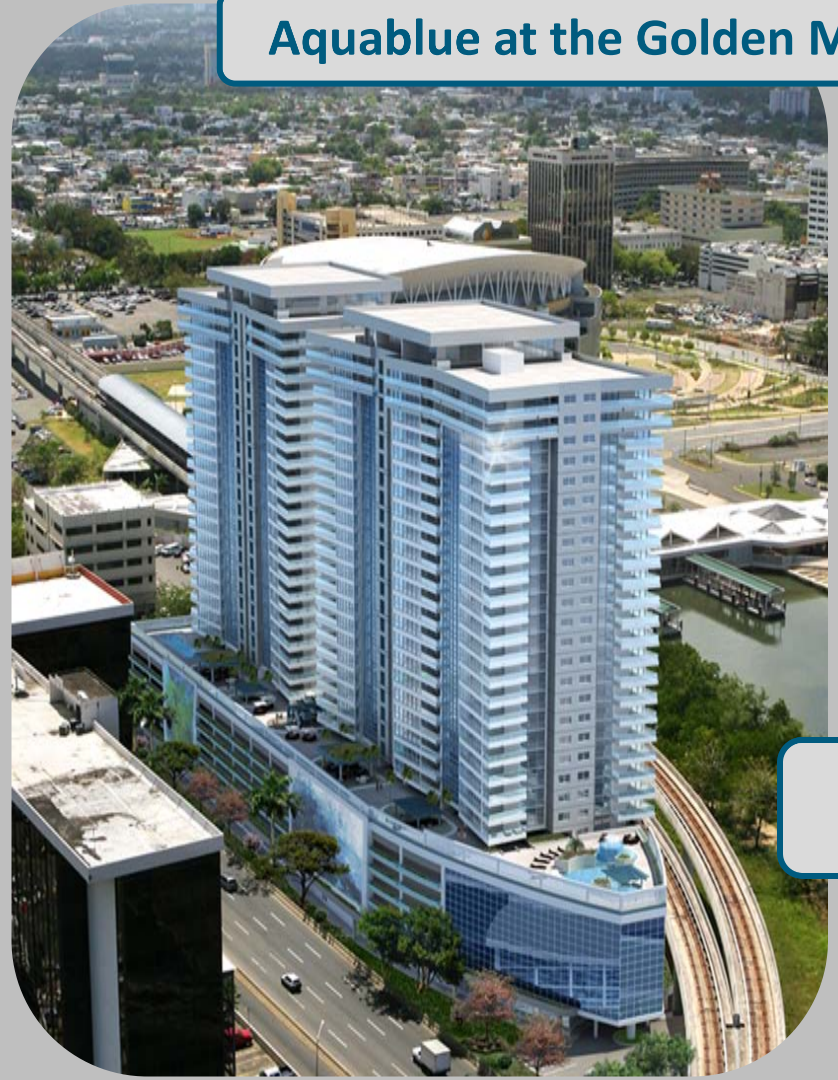




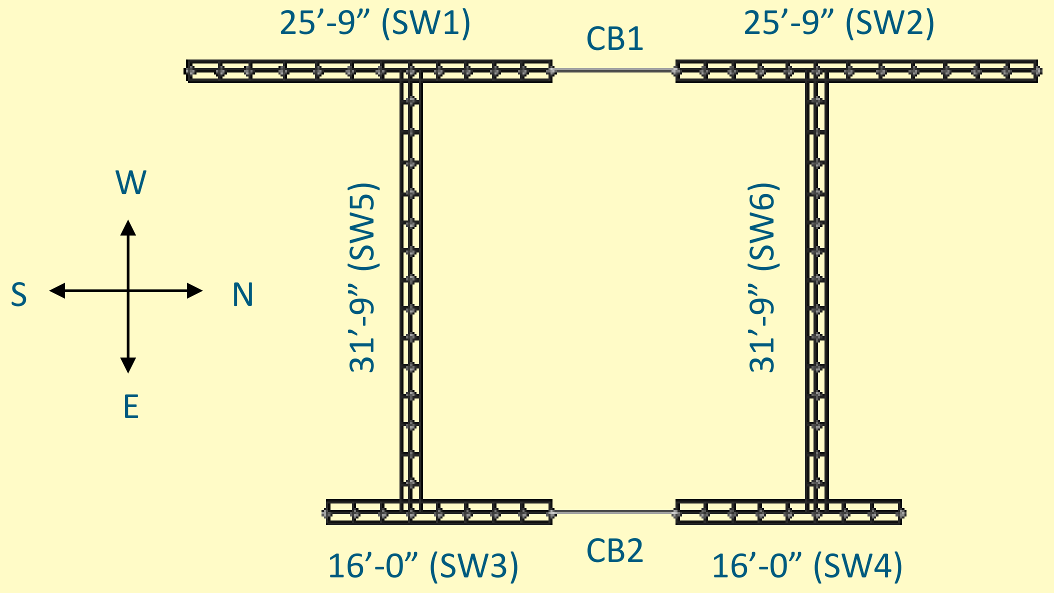
Preliminary Shear Wall Thicknesses

Aquablue at the Golden Mile



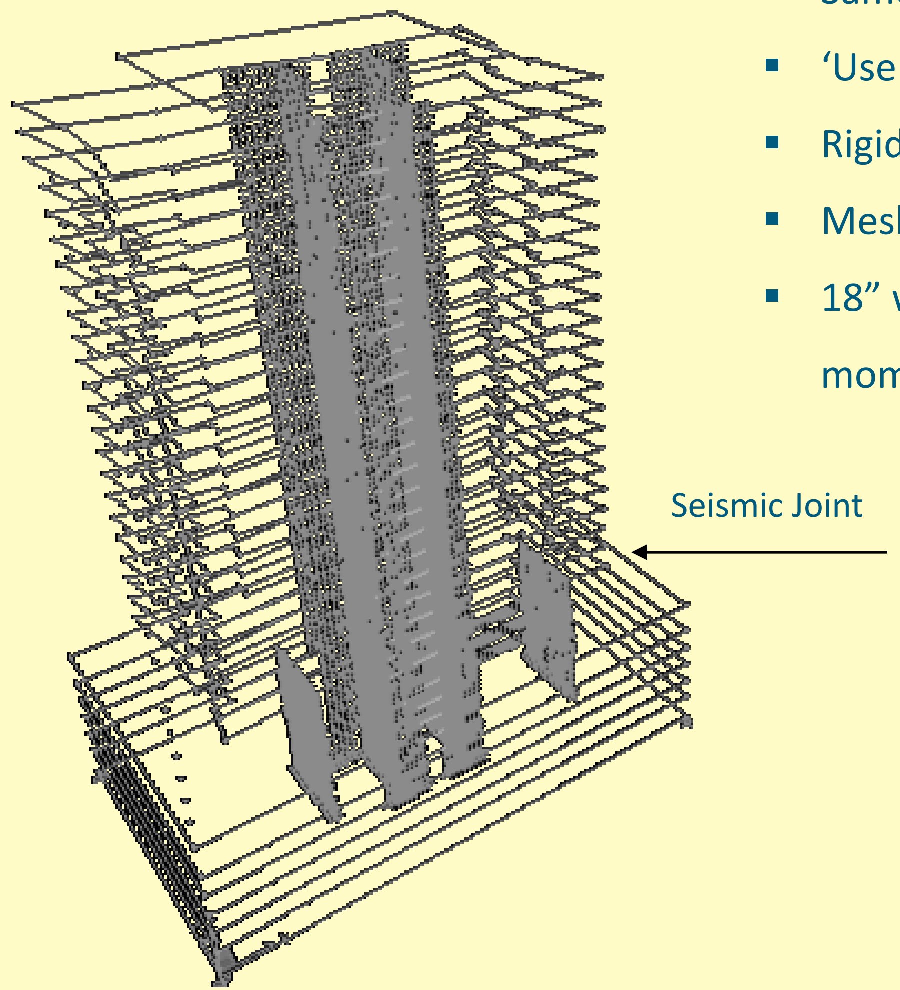
Hato Rey, Puerto Rico

$$t = \rho \frac{V_x}{\phi 3\sqrt{f'_c}(l_w)}$$



Equation variables:

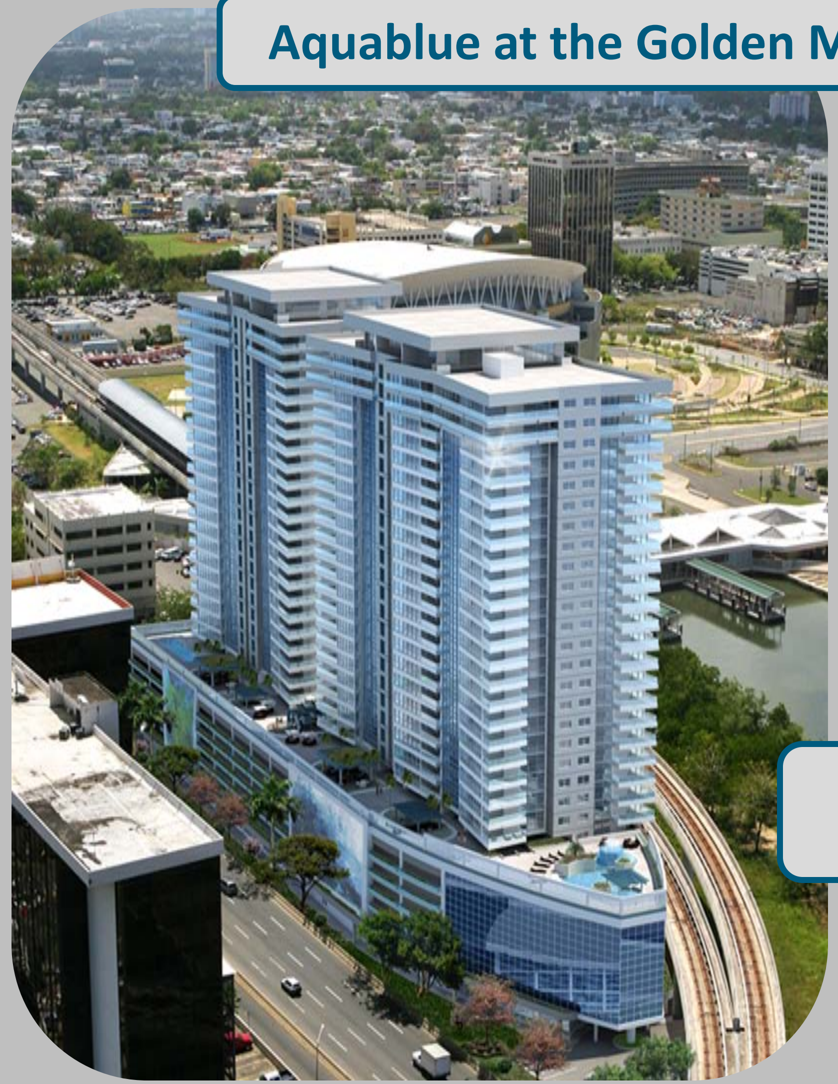
- t = wall thickness (in)
- ρ = fraction of story shear force
- V_x = total factored shear force
- ϕ = 0.75 for wind, ϕ = 0.60 for seismic
- $3\sqrt{f'_c}$ = approximate shear stress of the wall
- l_w = length of the wall (in)



Design Assumptions:

- Same concrete strength as original building
- 'User-defined' loads
- Rigid floor diaphragms with assigned masses
- Meshed walls with 0.7 multiplier for moment of inertia
- 18" wide x 19.5" deep coupling beams with reduced moment of inertia

Aquablue at the Golden Mile



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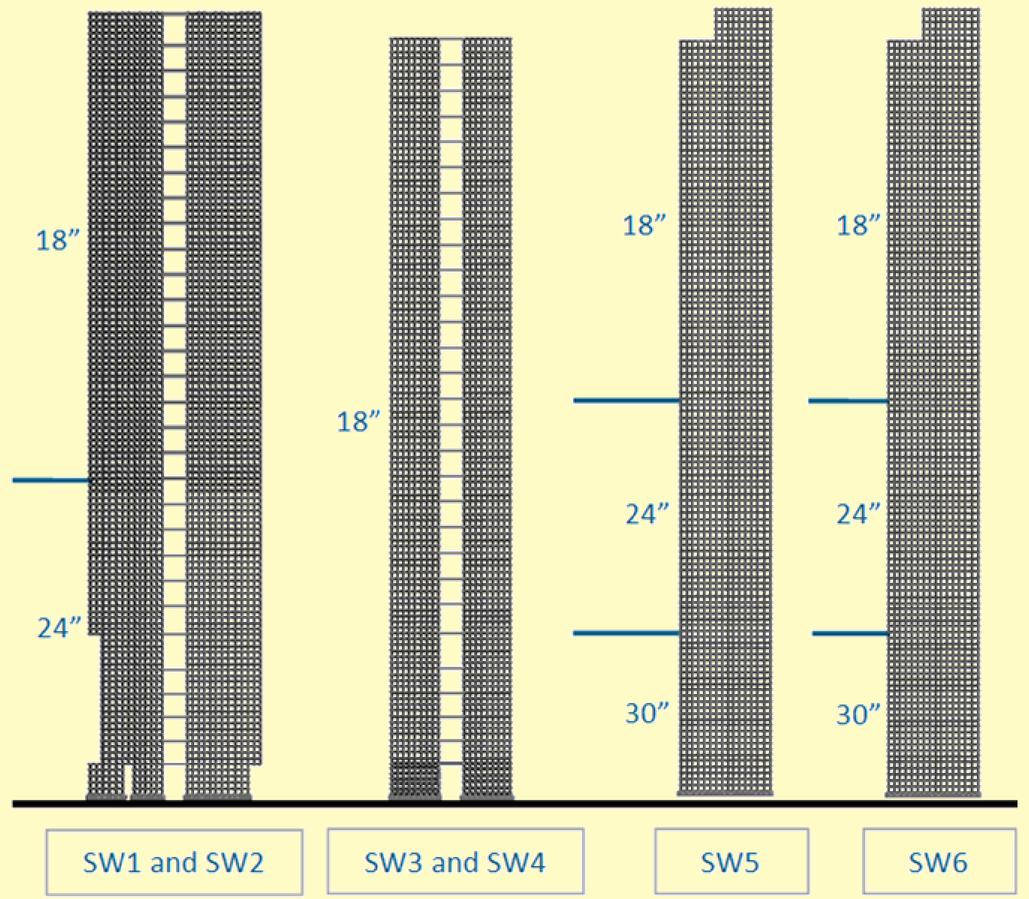
Final Shear Wall Thicknesses:

- 18” – 30” thickness
- (2) 18” thick walls added through parking levels



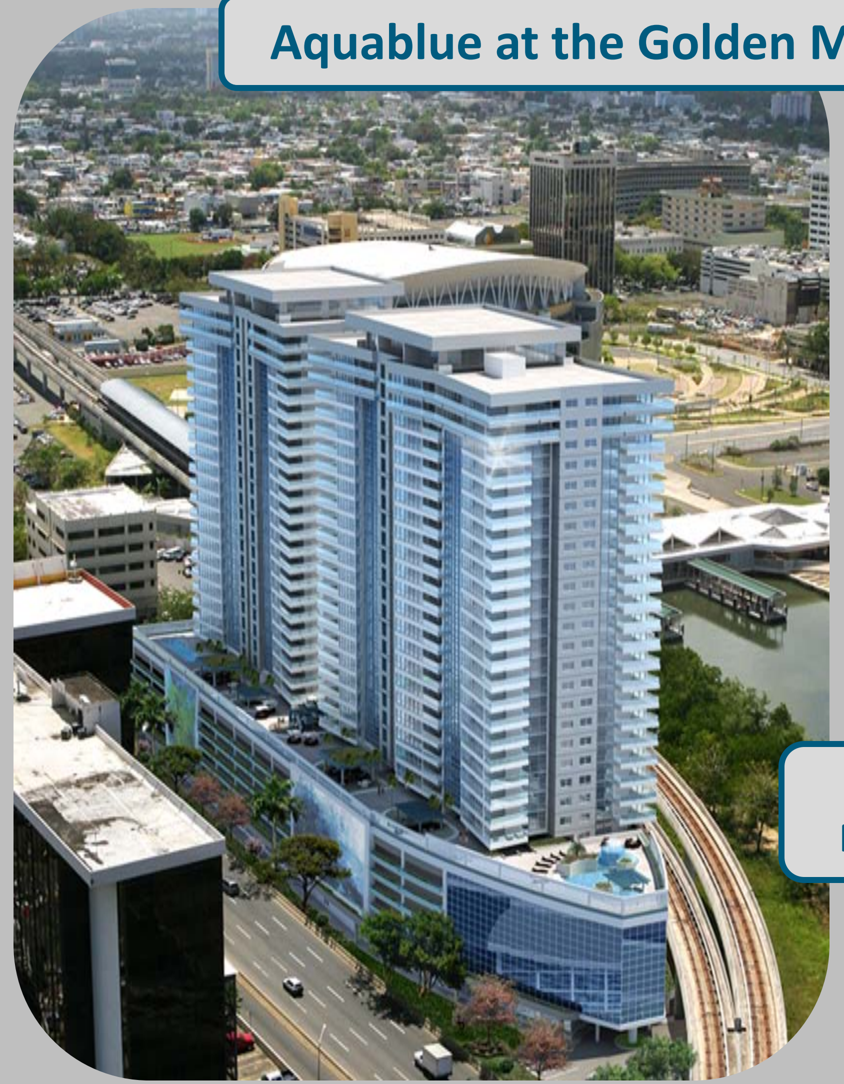
Check for horizontal structural irregularity:

- Extreme torsional irregularity
- Torsional amplification factor, A_x = 1.46
- Accidental eccentricity ratio = 0.073

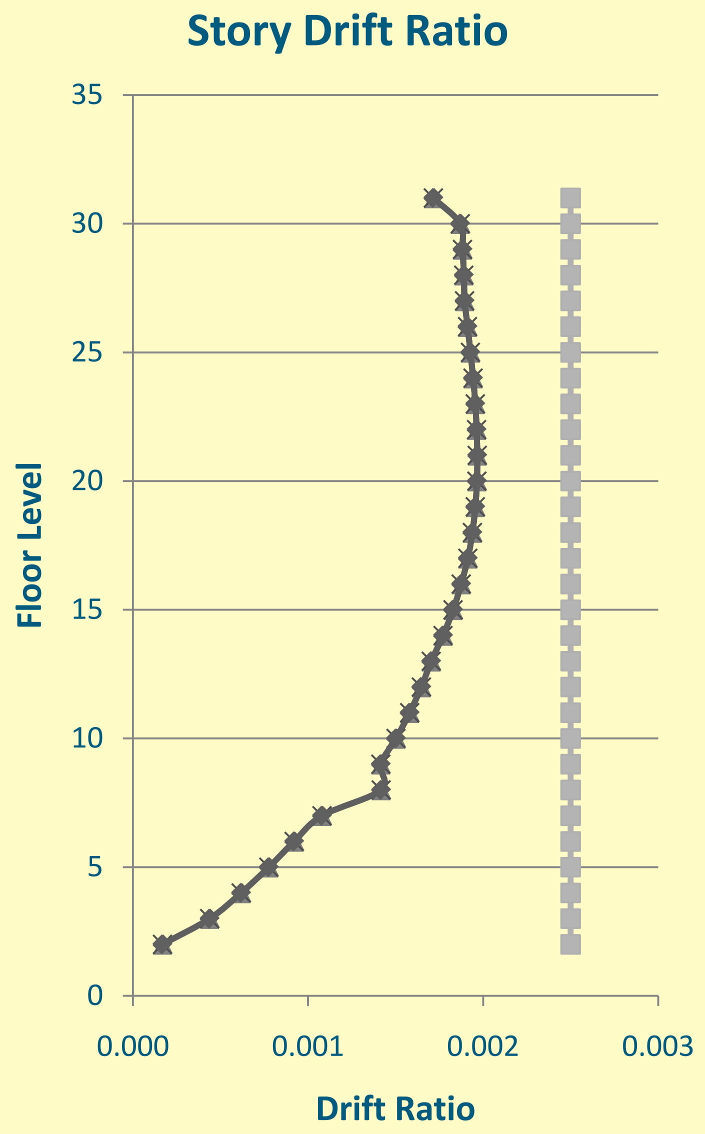
Drift limitations:

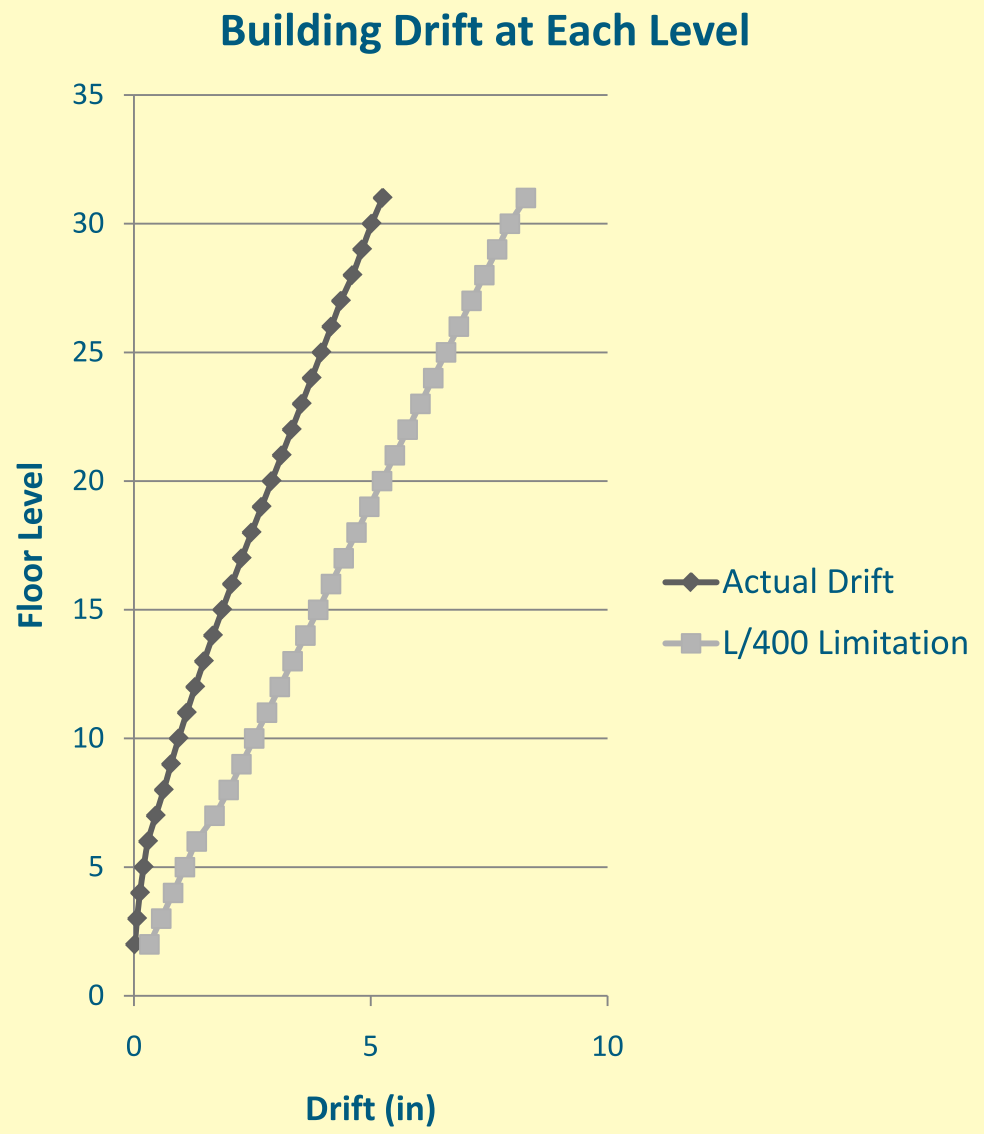
- L/400 for wind loads (0.70W permitted by section CC.1.2 of ASCE 7-05)
- 0.020h for seismic loads
- Deflection amplification factor, C_d = 5 (seismic drifts)
- Drifts within the required limits
- Maximum drift at level 7 = 1.06” (assumed that seismic joint is adequate)

Aquablue at the Golden Mile



Hato Rey, Puerto Rico





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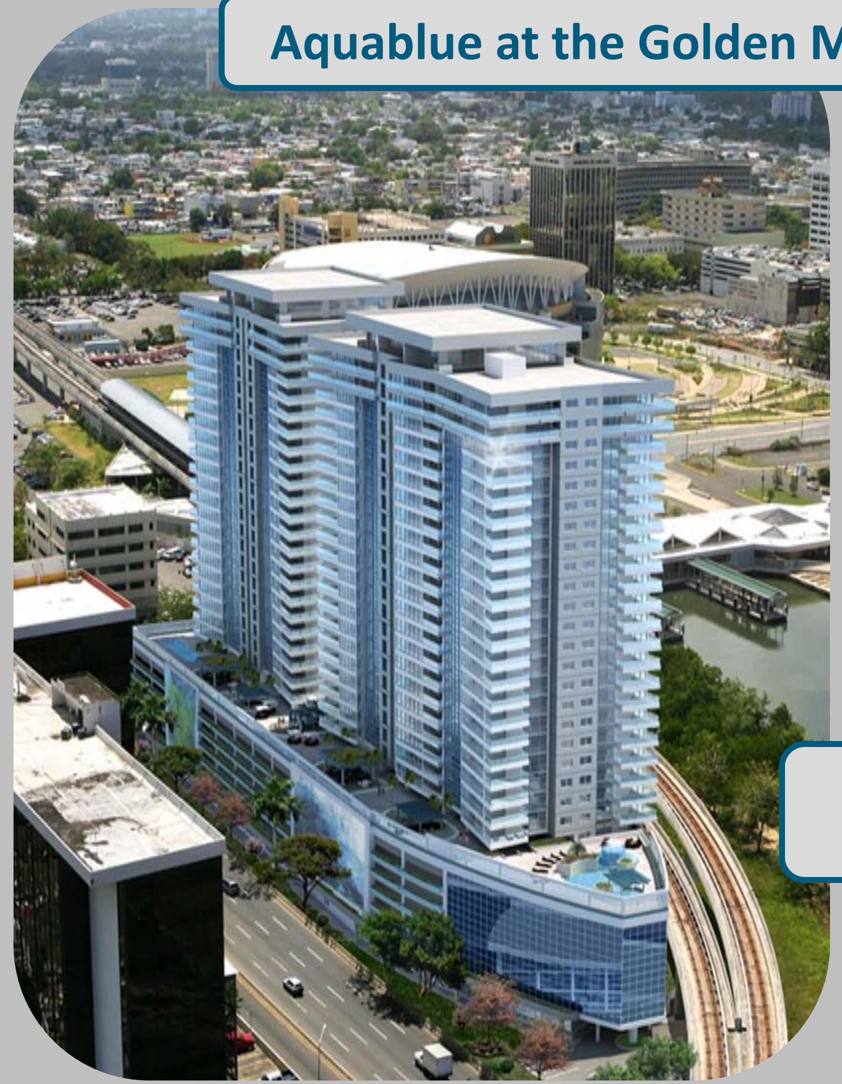
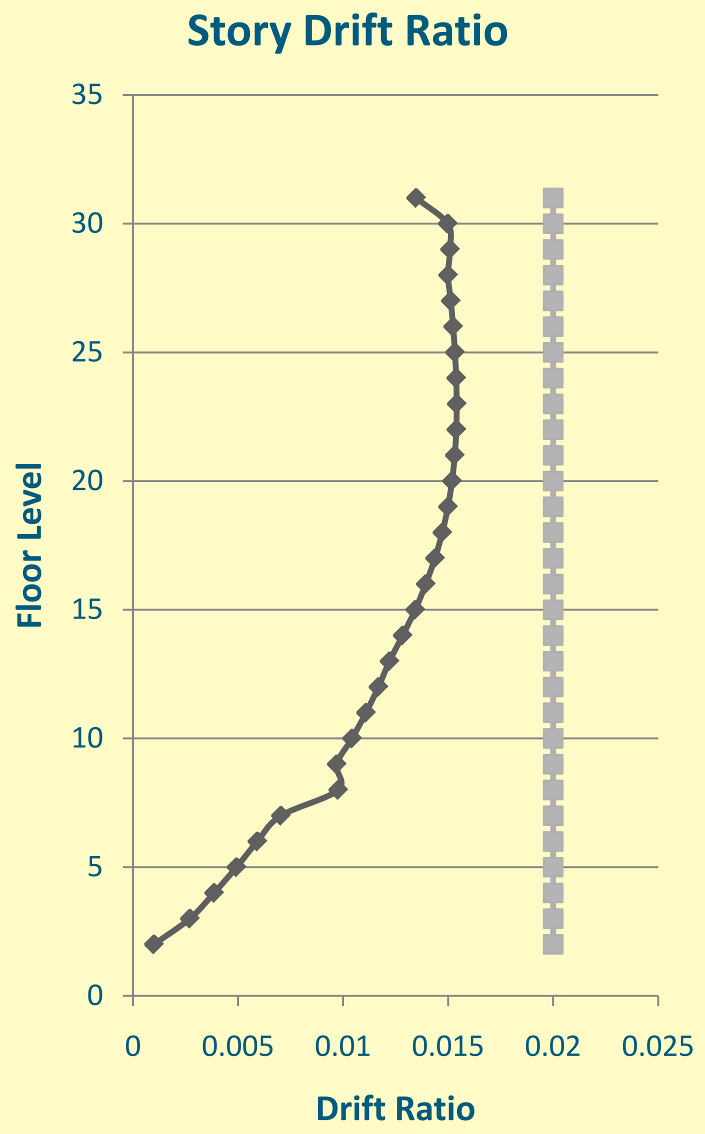
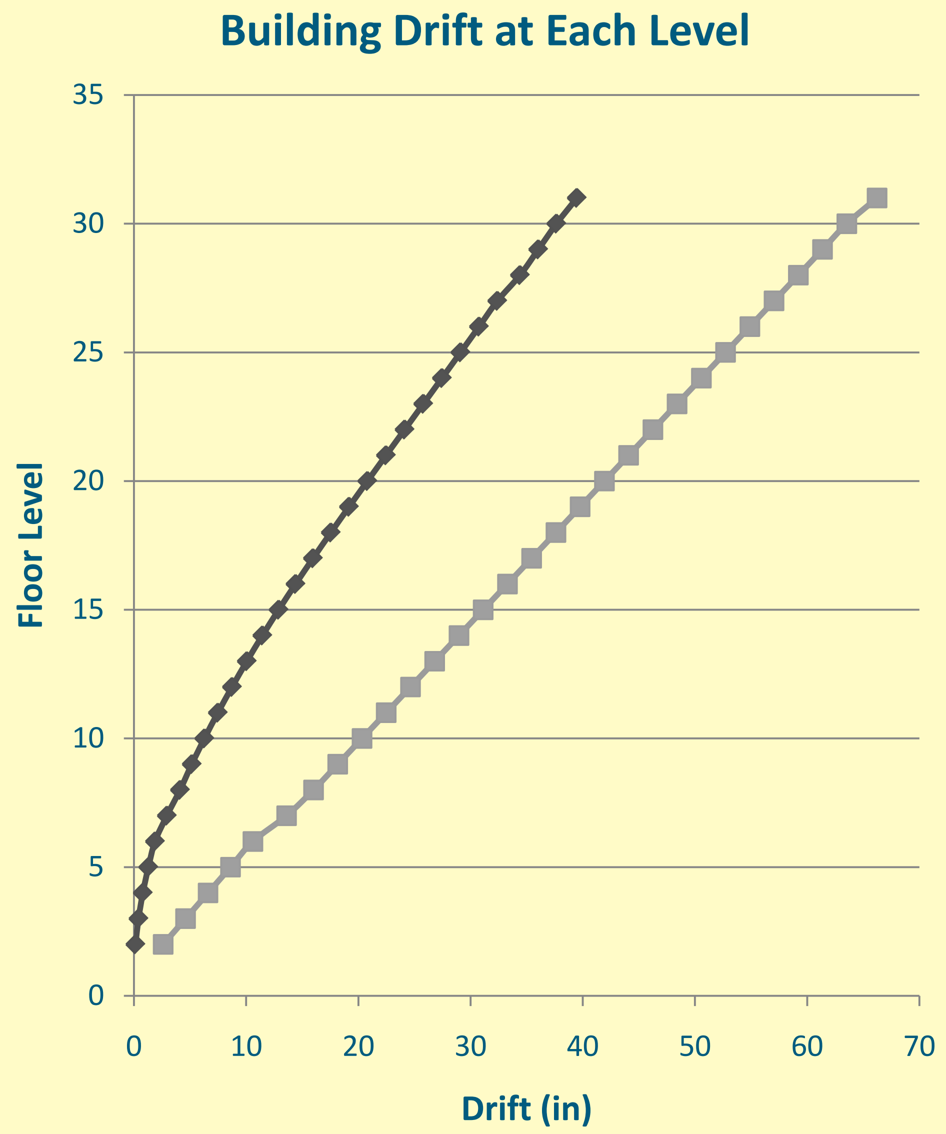


Hato Rey, Puerto Rico





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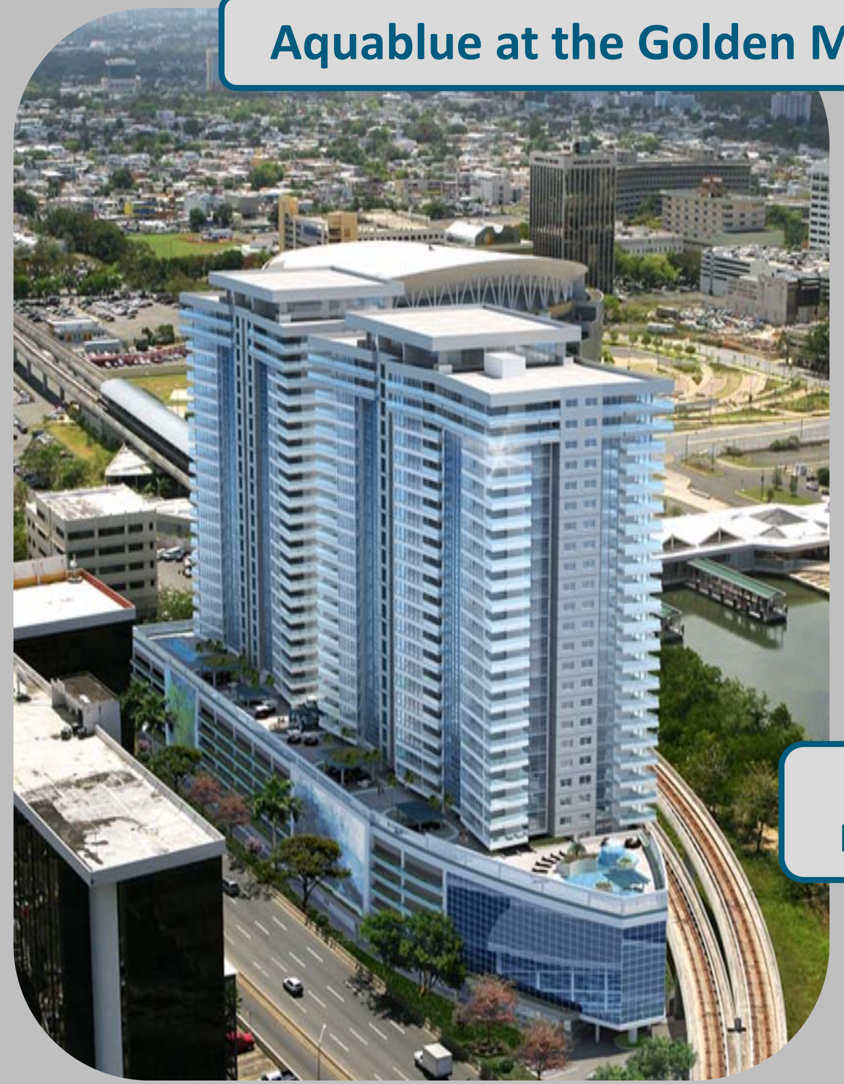

Hato Rey, Puerto Rico

$$\frac{V_u/\phi}{\lambda\sqrt{f'_c}A_{cw}} \le \begin{cases} 12(wind) \\ 4(seismic \end{cases}$$

Equation variables:

- V_u = factored shear force in the beam
  - 1.2D + 0.5L + 1.6W
  - 0.9D + 1.6W
  - 1.32D + 0.5L + 1.0E
  - 0.78D + 1.0E
- λ = 1 (normal weight concrete)
- A_{cw} = cross-sectional area of the beam

Results:

- Diagonal reinforcement is not required
- Beam depths are feasible

Coupling Beam Feasibility Test

- General Building Information
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- Drift Analysis
- **Coupling Beam Feasibility Test**
- Final Shear Wall Design
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- Architectural Breadth Study
- Conclusions

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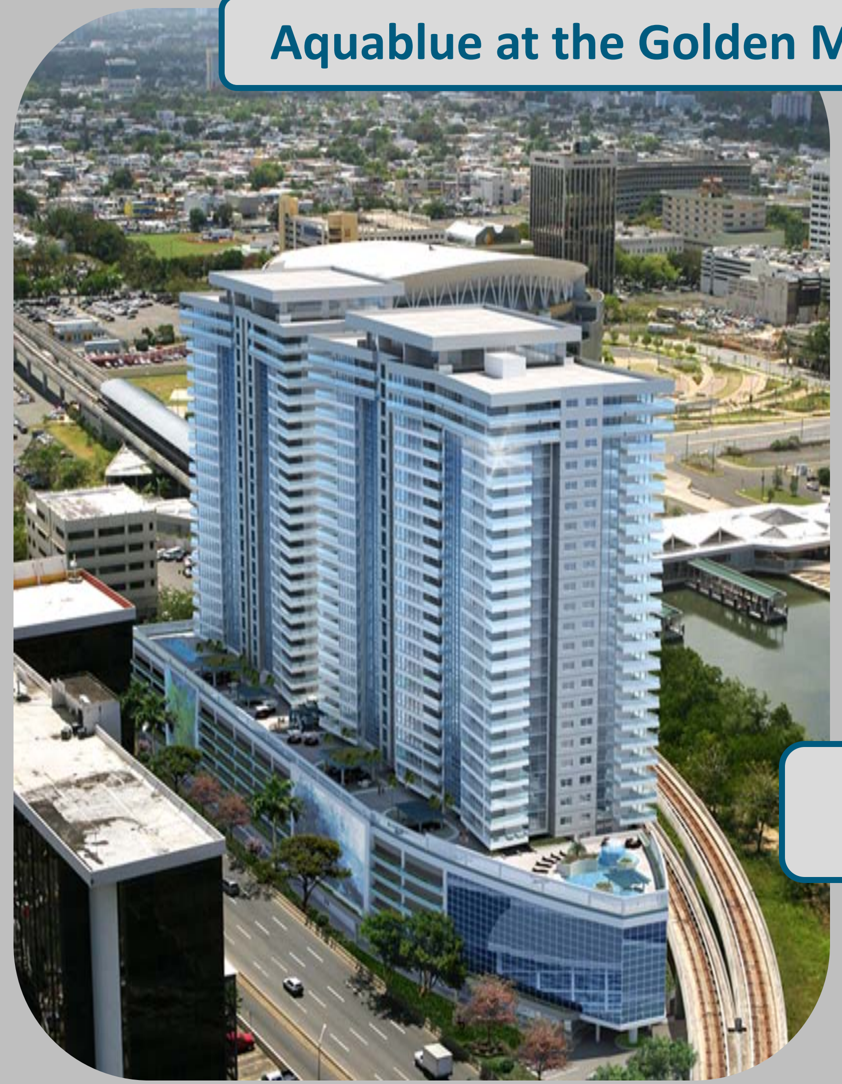

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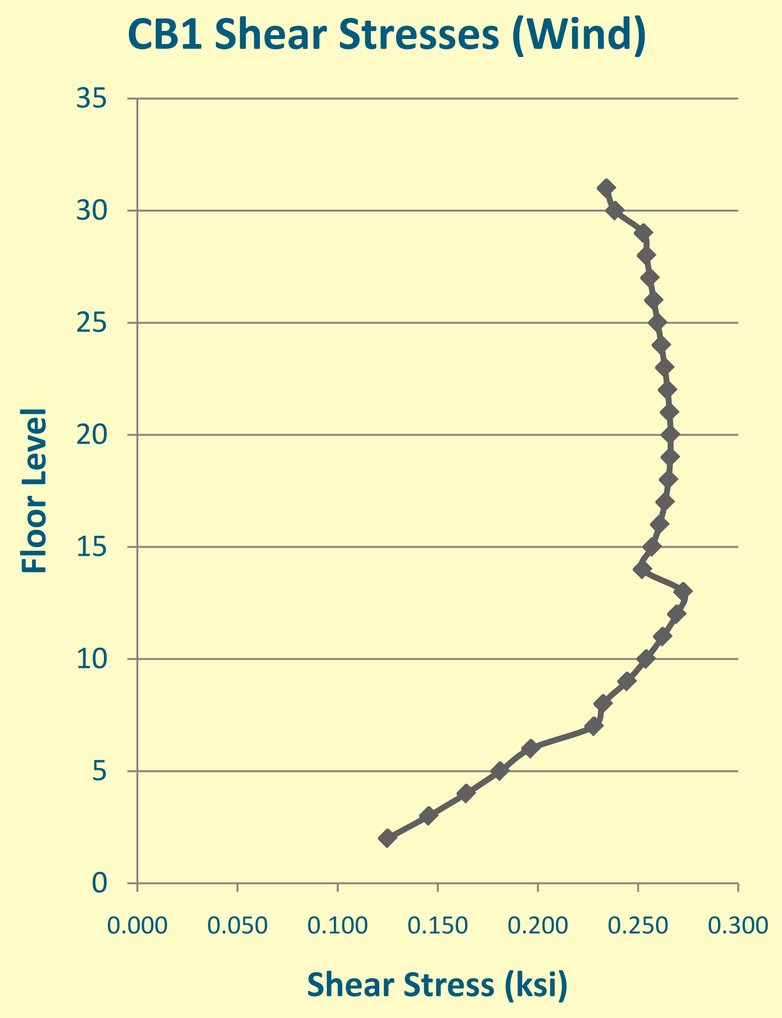
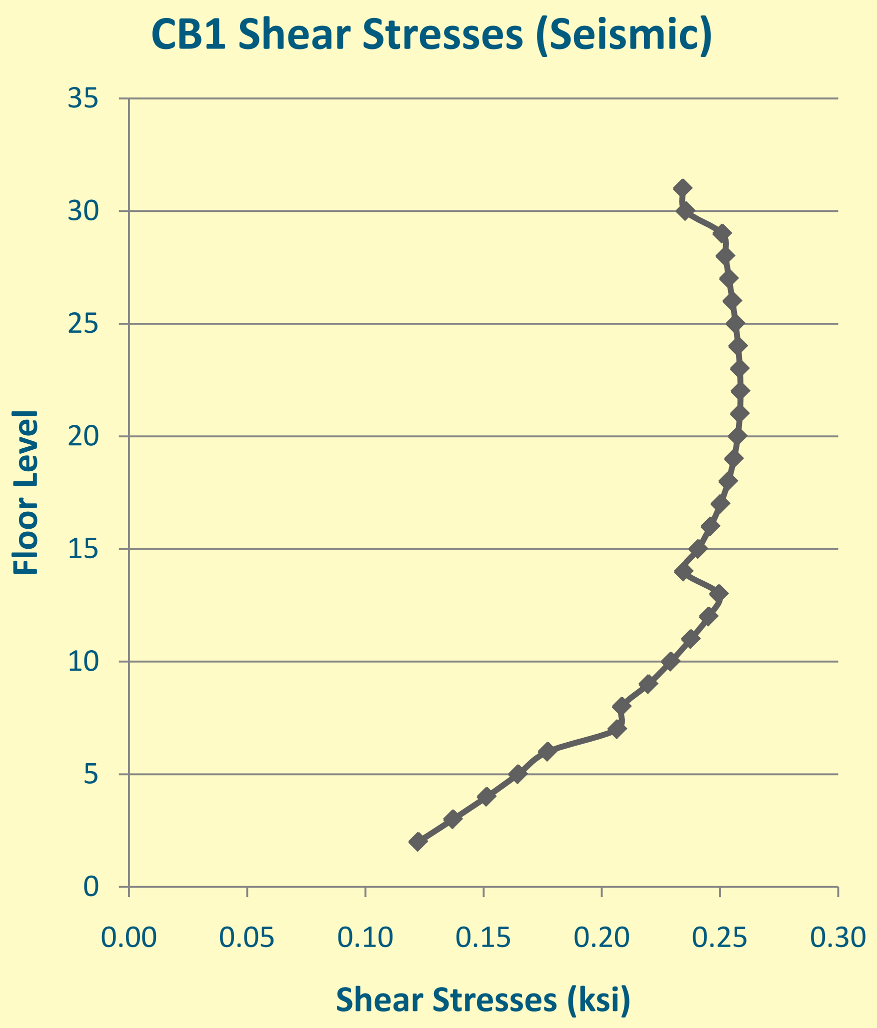
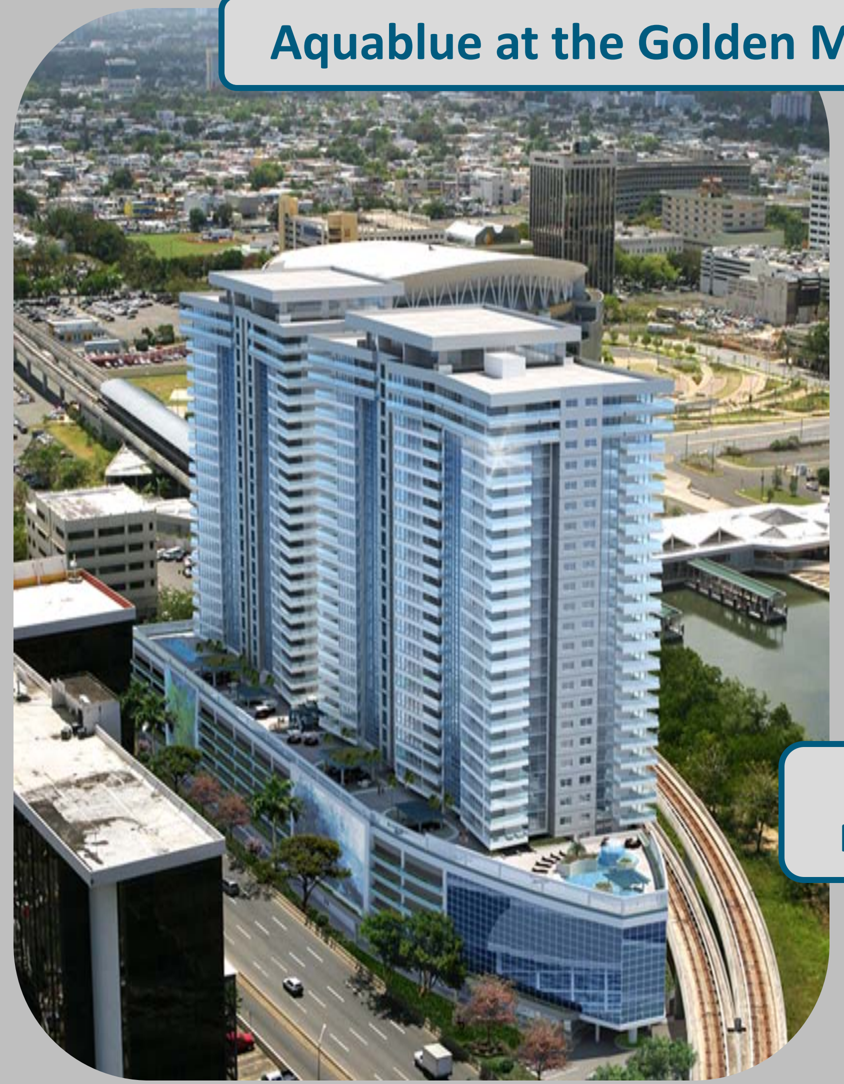




Coupling Beam Feasibility Test

Aquablue at the Golden Mile



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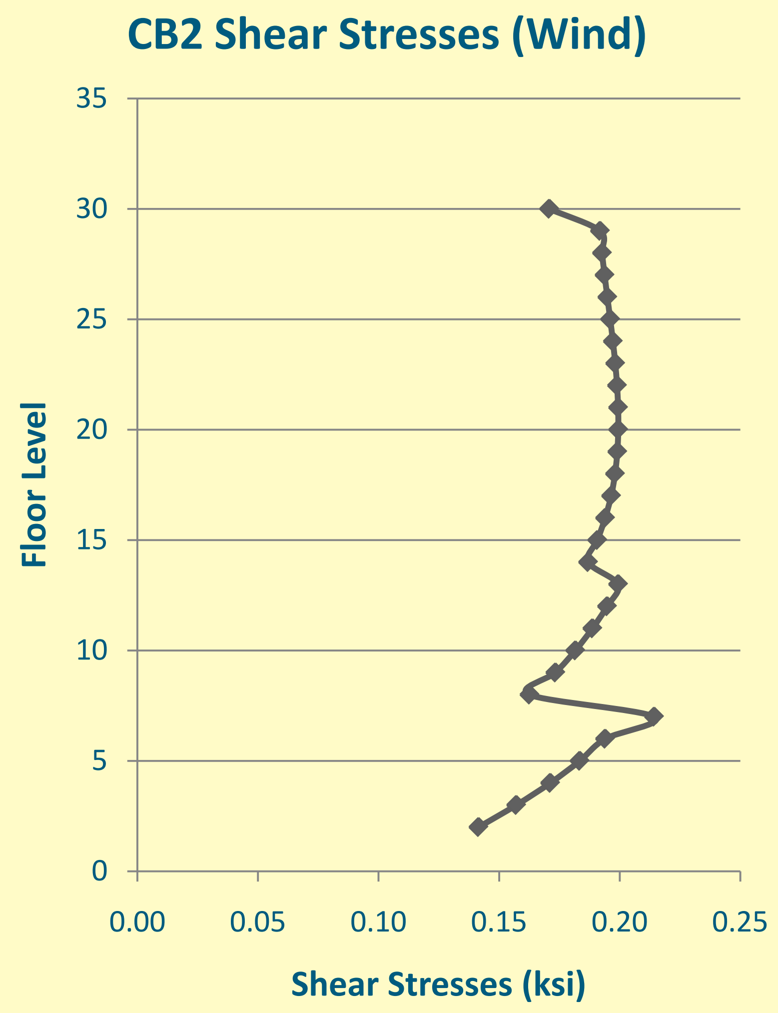

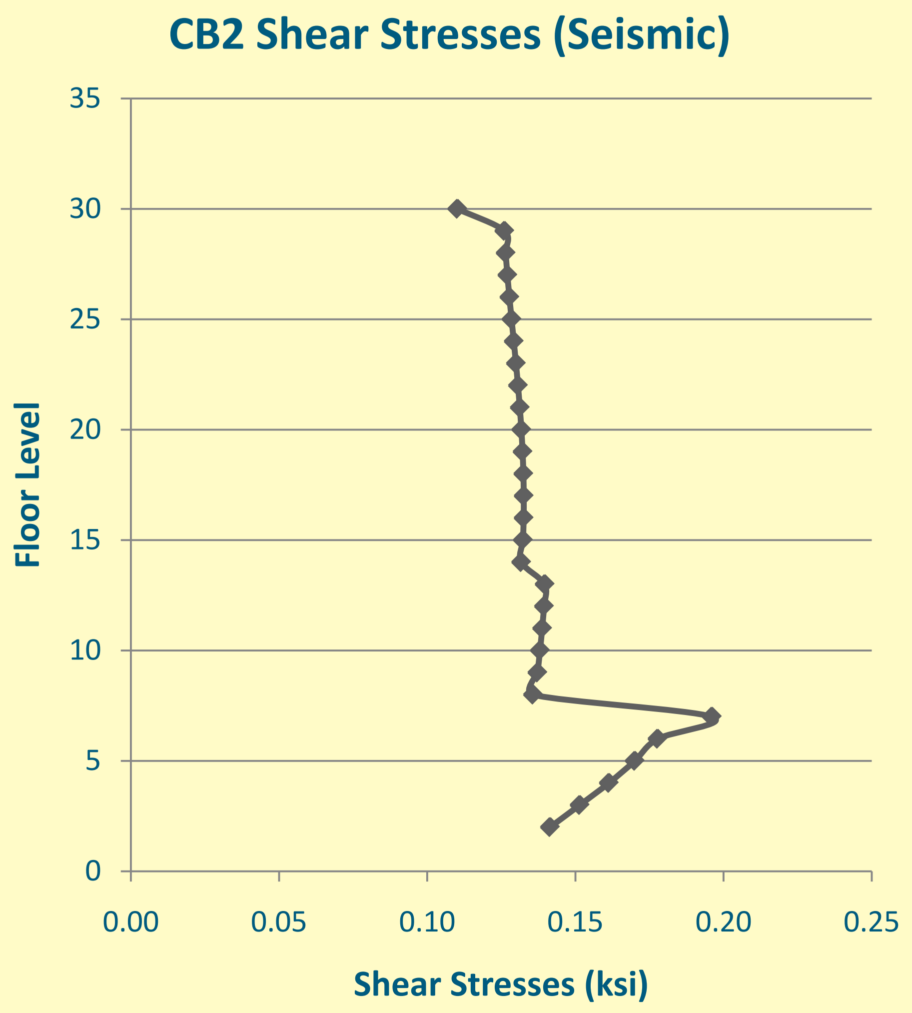

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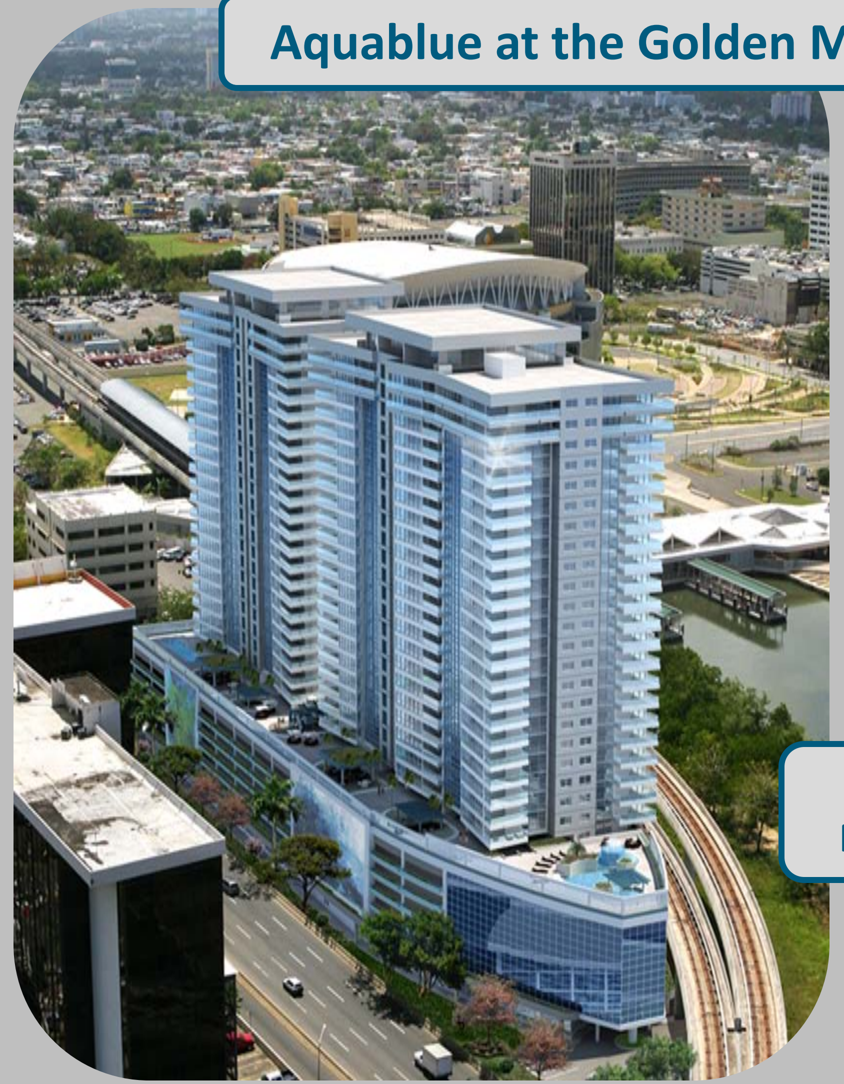

Hato Rey, Puerto Rico

Design process:

- Preliminary design according to seismic provisions of ACI 318-08, chapter 21
- Reinforcement checked for wind loads using ACI 318-08, chapter 11
- (2) curtains for both transverse and longitudinal reinforcement

$$\phi V_n = \phi A_{cv}(\alpha_c \lambda \sqrt{f'_c} + \rho_t f_y)$$

$$\phi V_n = \phi(2\lambda \sqrt{f'_c} t_w d + A_{s,t} f_y d / s)$$

	Transverse (horizontal)	Longitudinal (vertical)
Level	SW1 and SW2 reinforcement	
14 to sky lobby	(2) #5 @ 12"	(2) #5 @ 10"
4 to 13	(2) #5 @ 9"	(2) #5 @ 8"
2 to 3	(2) #7 @ 9"	(2) #7 @ 8"
	SW3 and SW4 reinforcement	
2 to sky lobby	(2) #5 @ 12"	(2) #5 @ 12"
	SW5 and SW6 reinforcement	
20 to sky lobby	(2) #5 @ 12"	(2) #5 @ 10"
16 to 19	(2) #5 @ 8"	(2) #5 @ 6"
2 to 15	(2) #7 @ 8"	(2) #7 @ 6"

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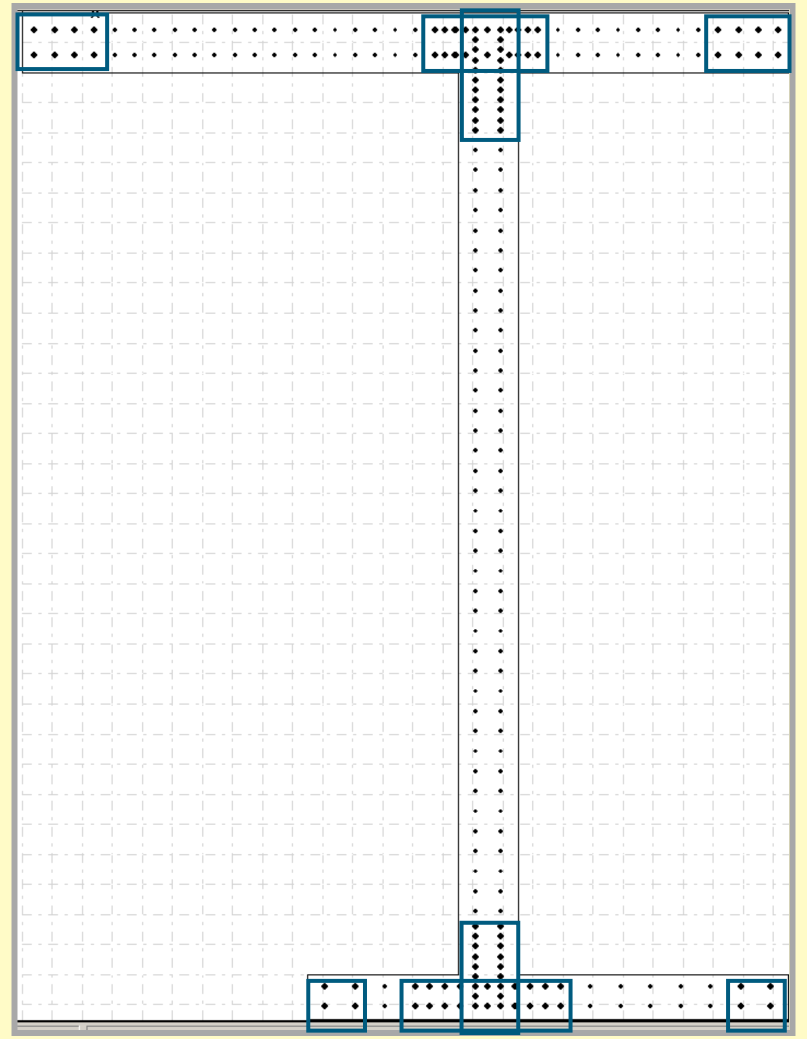
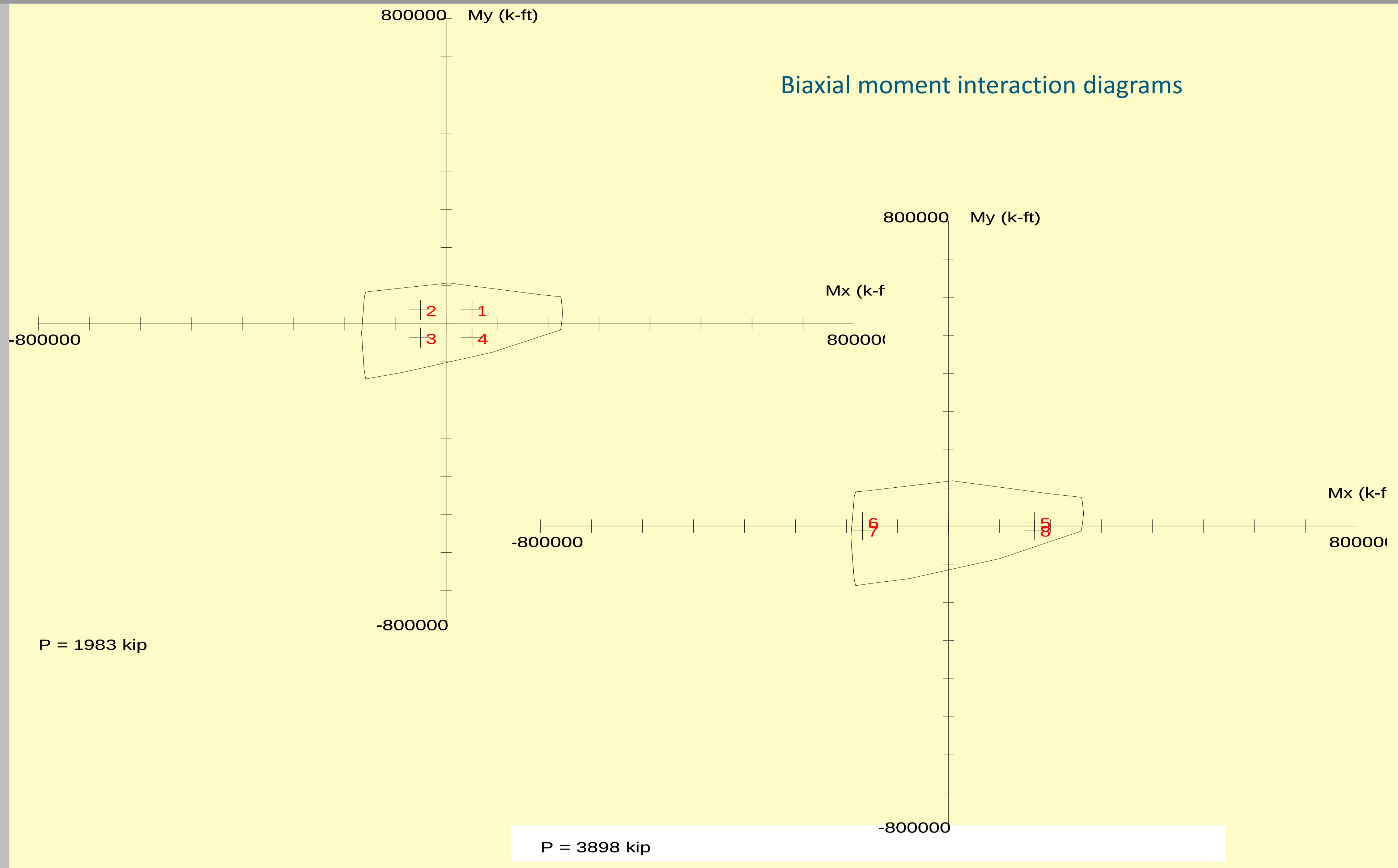
Check in pcaColumn:

- Shear wall design checked in pcaColumn for level 9
- #5 bars at either 8” or 12” spacing
- #9 bars for the boundary elements



Shear Wall Reinforcement



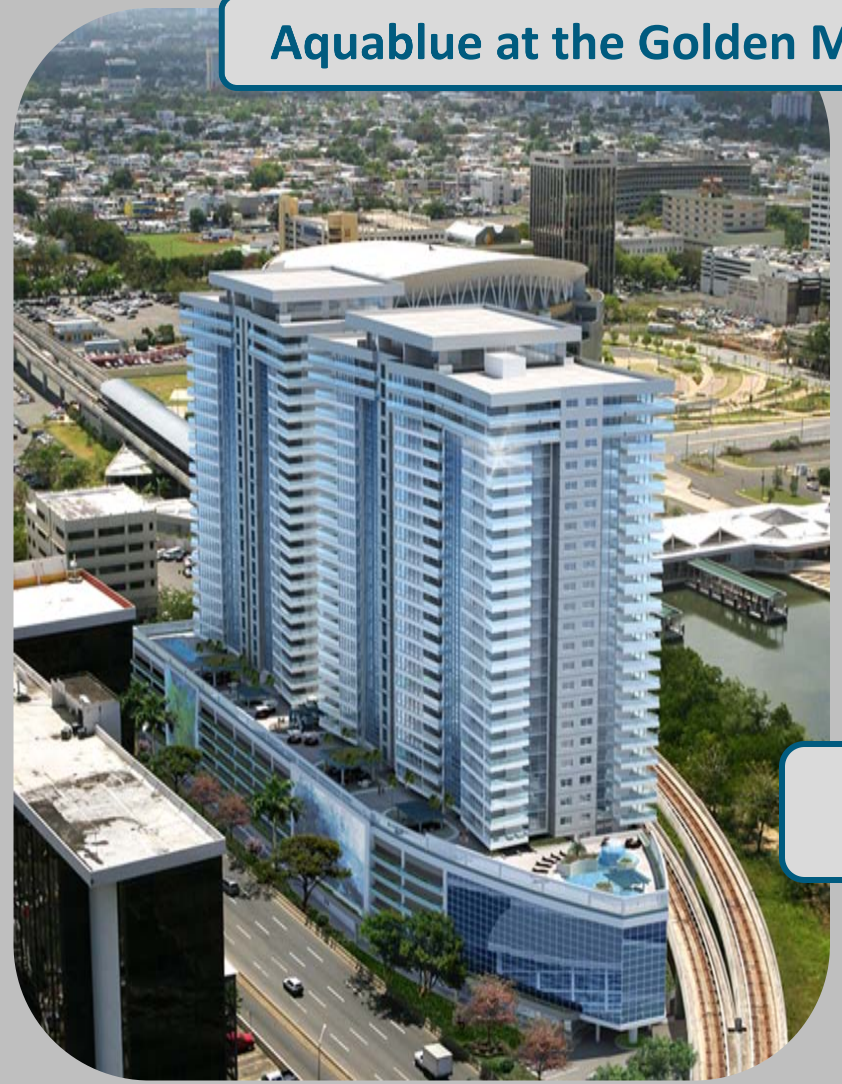
Longitudinal reinforcement design:

- Minimum steel area from chapters 10 and 21 of ACI 318-08
- Area of steel for 6 ksi strength concrete $$A_s = \frac{M_u}{4.17d}$$
- Area of steel for 8 ksi strength concrete $$A_s = \frac{M_u}{4.25d}$$
- Generally, (6) – (10) #7 bars at both the top and bottom of the beams sufficed
- Reinforcement ratio below 0.025 (acceptable)

	CB1
Level	Required Reinforcement (top and bottom)
9 to sky lobby	(10) #7
7 to 8	(8) #7
5 to 6	(6) #7
3 to 4	(4) #7
2	(2) #7

	CB2
Level	Required Reinforcement (top and bottom)
11 to roof level	(8) #7
6 to 10	(6) #7
3 to 5	(4) #7
2	(2) #7

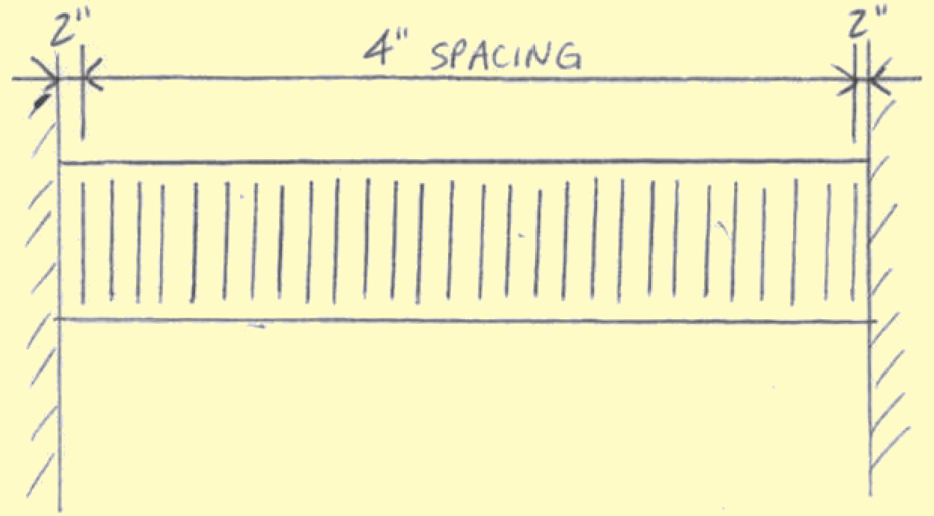
Aquablue at the Golden Mile

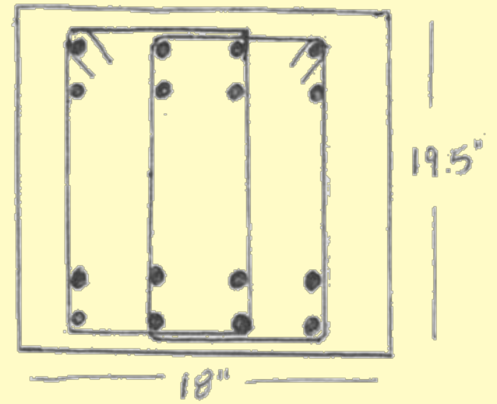


Hato Rey, Puerto Rico

Stirrup reinforcement design:

- Shear capacity of concrete neglected
- Required steel area determined by chapters 11 and 21 of ACI 318-08
- (3) – (4) legs of #3 stirrups in each beam
- 2" spacing at supports
- 4" spacing throughout beam





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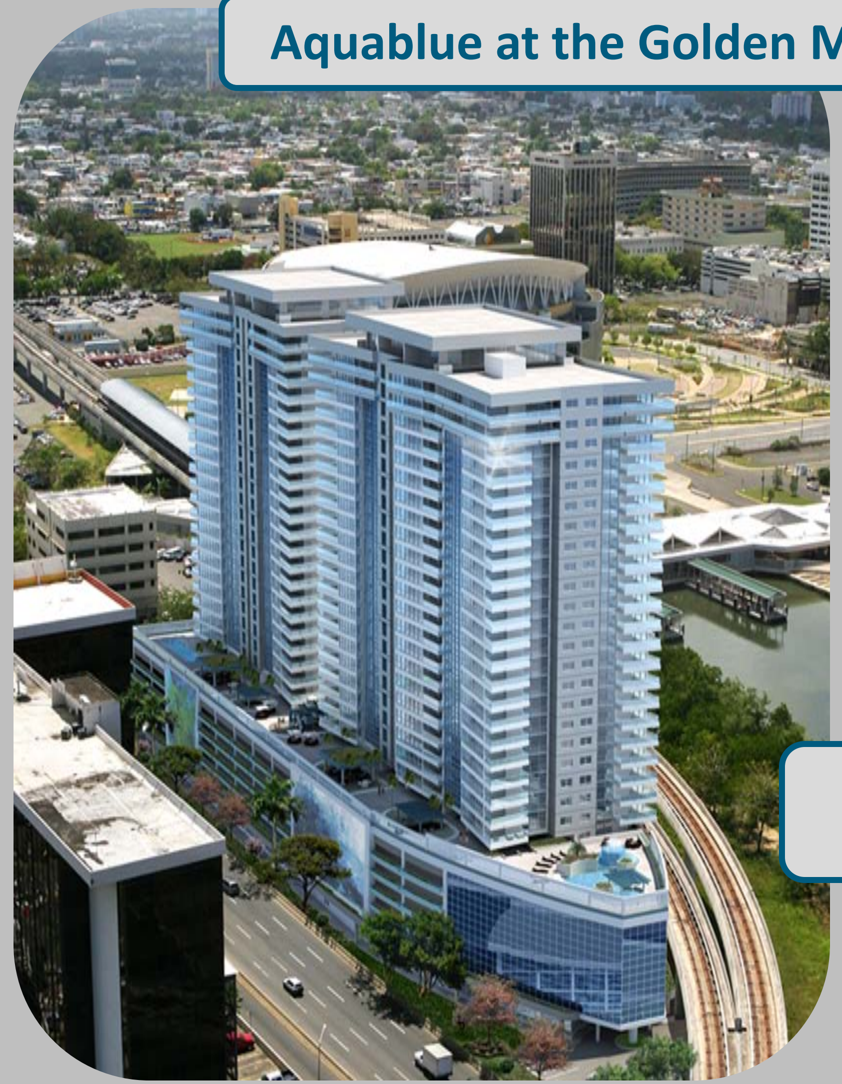


Hato Rey, Puerto Rico

Original foundation:

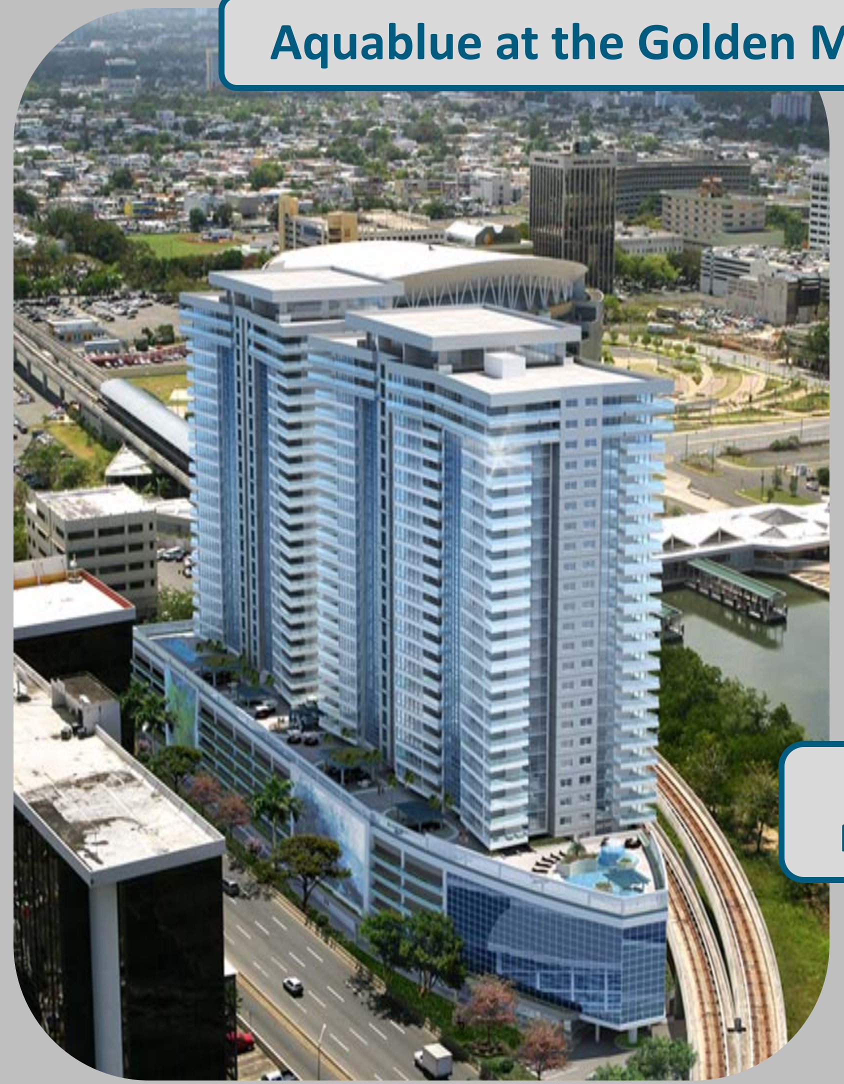
- Drilled compression piles (147) and drilled tension piles (23)
  - Compression capacity = 200 tons (170 total piles)
  - Lateral capacity = 20 tons (170 total piles)
  - Tension capacity = 40 tons (23 tension piles)
- Mat slab under group of columns and shear walls

Analysis of lateral capacity:

- Maximum factored base shear determined
- Force converted to number of required piles
- No change necessary for existing design

	East-West Direction	North-South Direction
	Total Shear (k)	Total Shear (k)
Wind Case 1a	0.8	1961.8
Wind Case 1b	2951.6	304.0
Wind Case 2a	151.9	1472.4
Wind Case 2b	2183.1	183.9
Wind Case 3	2214.2	1466.1
Wind Case 4	1630.9	1102.0
Seismic - NS	9.7	932.1
Seismic - EW	540.7	75.9
Total Shear (tons) =	1475.8	980.9
Required Piles =	**73.8**	**49.0**

Aquablue at the Golden Mile



Hato Rey, Puerto Rico

Analysis of tension capacity:

- Maximum factored overturning moment determined
- Moment divided by wall length for tension force at extreme fiber
- Force converted to number of required piles
- Approximately 33 required piles unnecessary due to gravity load effects
- 56 piles still required (convert 33 compression piles to tension piles)

	Base Moment (k-ft)	Tension Force (k)	Tension Force (tons)	Number of Required Piles
Wind Case 1a	182637.4	7092.7	3546.4	**88.7**
Wind Case 1b	33349.4	1295.1	647.6	16.2
Wind Case 2a	136919.1	5317.2	2658.6	66.5
Wind Case 2b	23847.2	926.1	463.1	11.6
Wind Case 3	138366.3	5373.4	2686.7	67.2
Wind Case 4	103416.1	4016.2	2008.1	50.2
Seismic - NS	96733.5	3756.6	1878.3	47.0
Seismic - EW	8881.0	344.9	172.4	4.3

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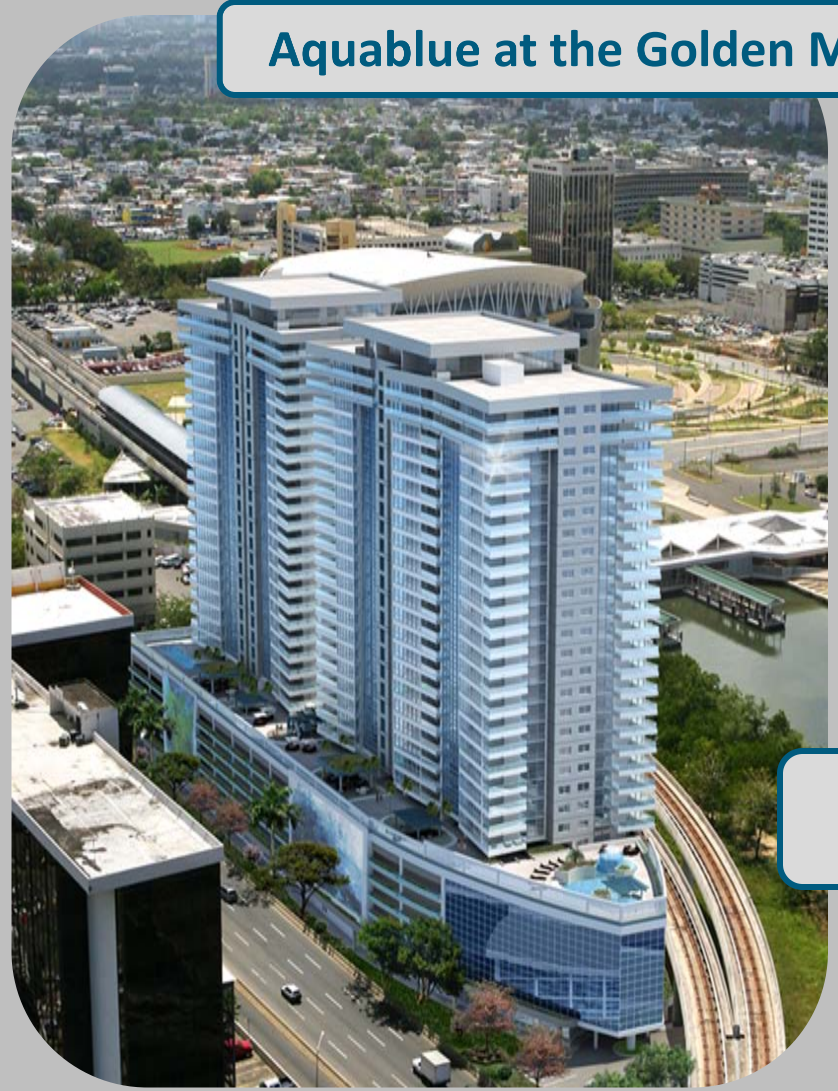
Aquablue at the Golden Mile



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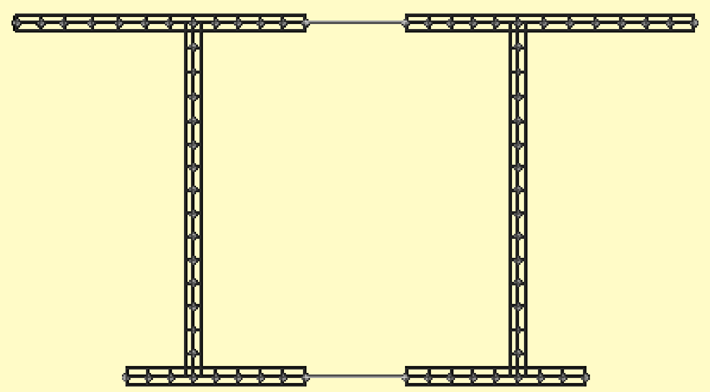
Impact of New Shear Wall Design on the Existing Architecture:

- Elimination of two columns of existing windows
- More narrow bedroom windows

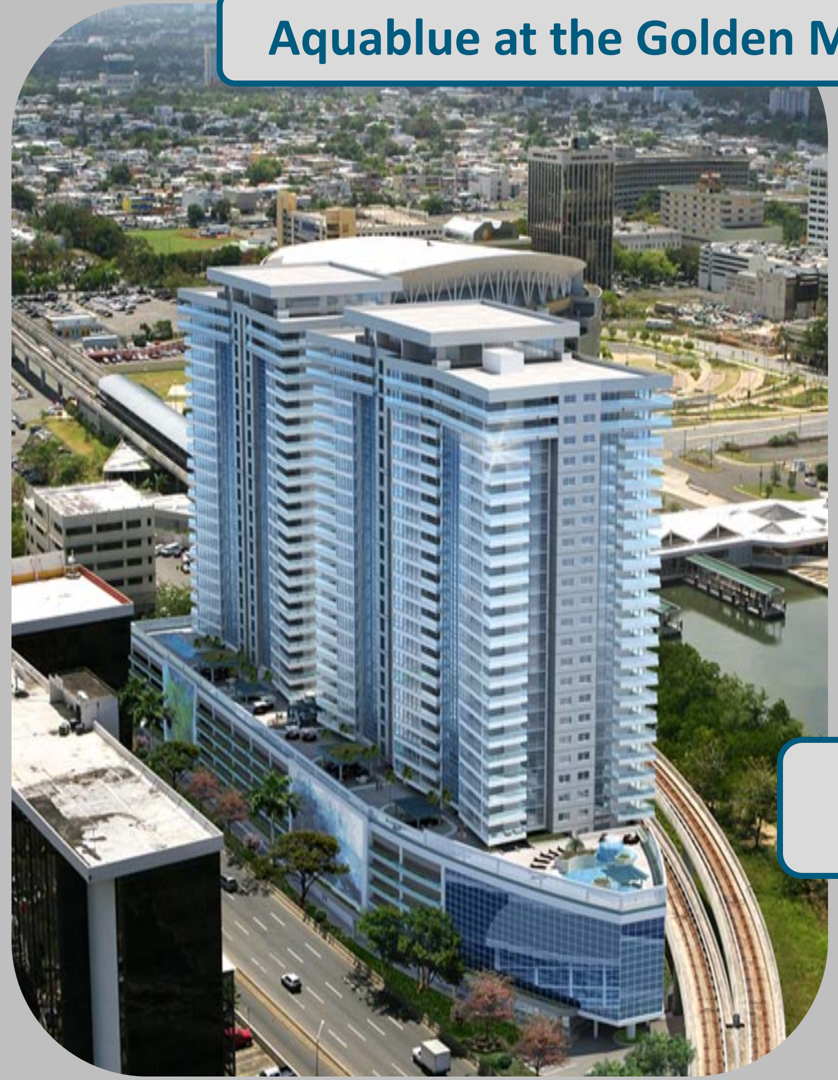


New Shear Wall Design

Existing Shear Wall Design

- General Building Information
- Proposal and Project Goals
- Proposed Shear Wall Design
- Lateral Design Loads
- ETABS Model
- Drift Analysis
- Coupling Beam Feasibility Test
- Final Shear Wall Design
- Impact on Existing Foundation
- **Architectural Breadth Study**
- Conclusions

Aquablue at the Golden Mile



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Impact of New Shear Wall Design on the Existing Architecture:

- Elimination of two columns of existing windows

General Building Information
Proposal and Project Goals
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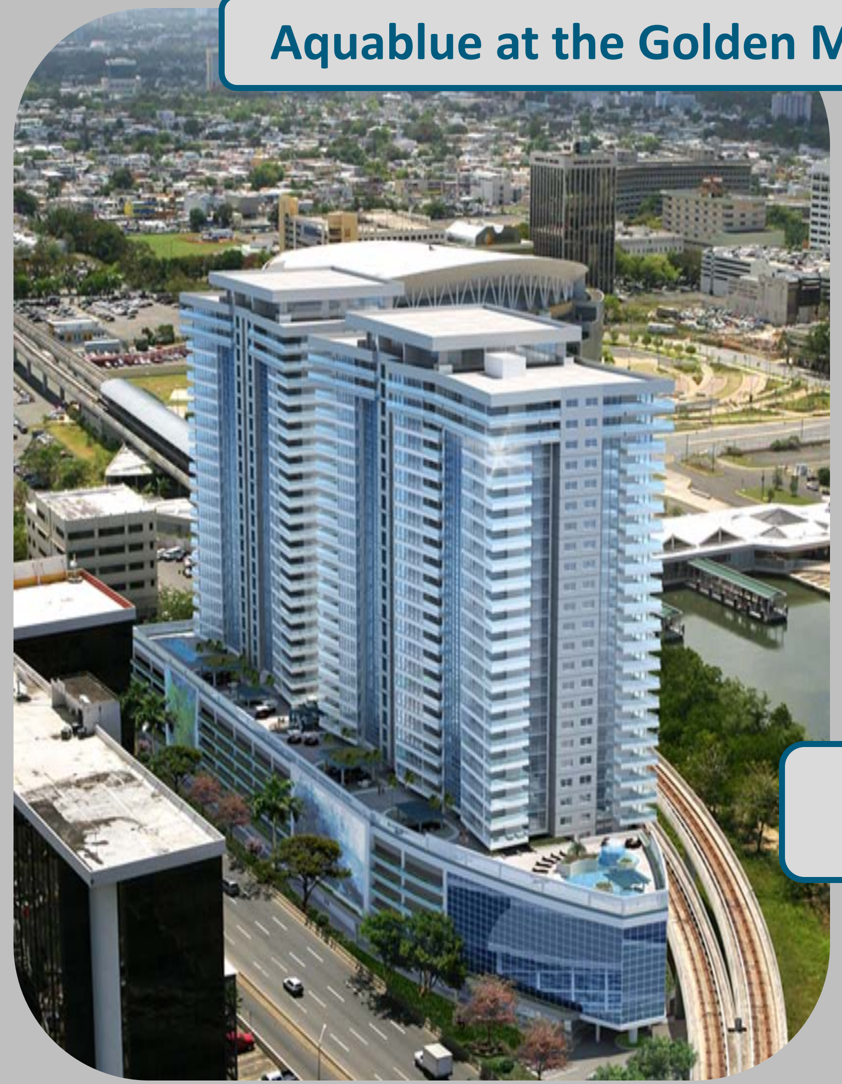
Aquablue at the Golden Mile



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Impact of New Shear Wall Design on the Existing Architecture:

- Additional Floor Space

Level	Original Shear Wall Design Percentage of Floor Area (%)	New Shear Wall Design Percentage of Floor Area (%)	Floor Area Gained in New Design (ft^2)
sky lobby roof level	4.47	4.56	-4.0
17 - roof level	1.75	1.60	20.3
14 – 16	2.14	2.23	-10.0
8 – 13	2.14	2.45	-34.8
3 – 7	1.88	1.72	38.6
2	2.08	1.72	83.9

Conclusions

The project was a success because the initial goals were met and valuable design experience was gained:

- Completion of lateral analysis
- Familiarity with the ACI 318-08 design code
- Use of ETABS for modeling purposes
- Study of architectural impact

Opportunity for further study – Dynamic analysis of the structure

Acknowledgements

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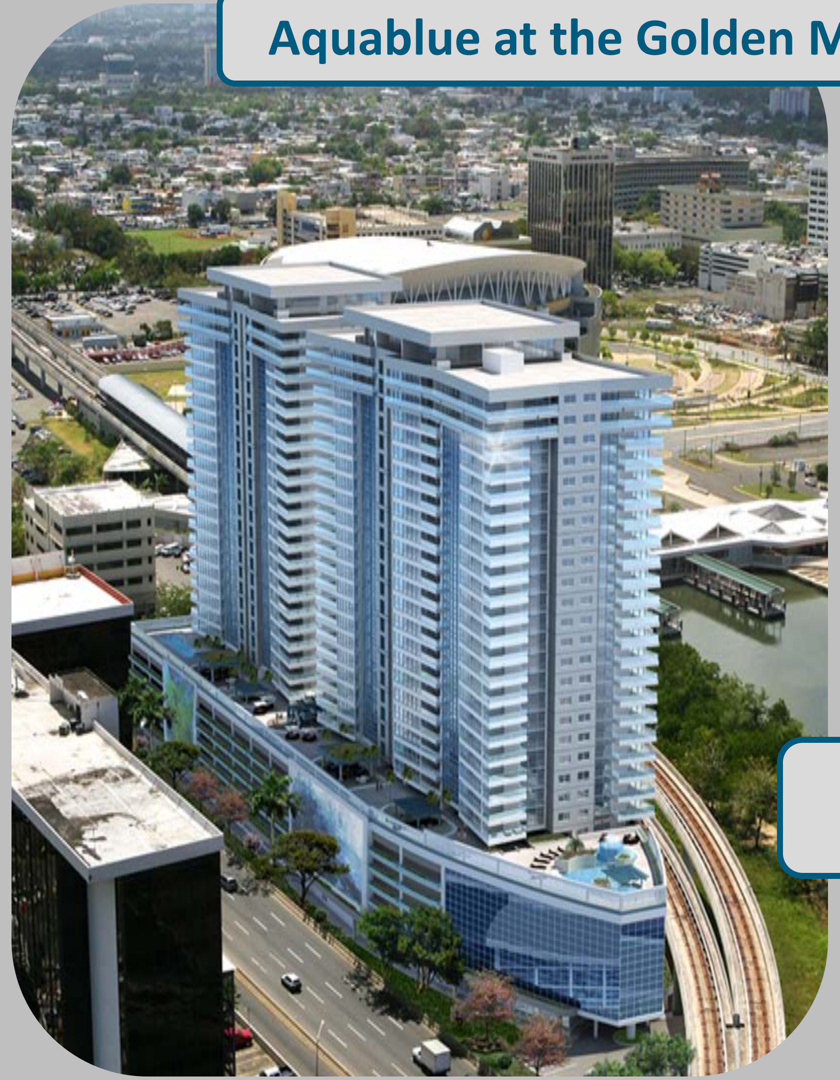

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- Professor Robert Holland (general thesis advisor)
- Anh Trong Nguyen (project structural engineer)
- Architectural Engineering Peers
- Family and Friends

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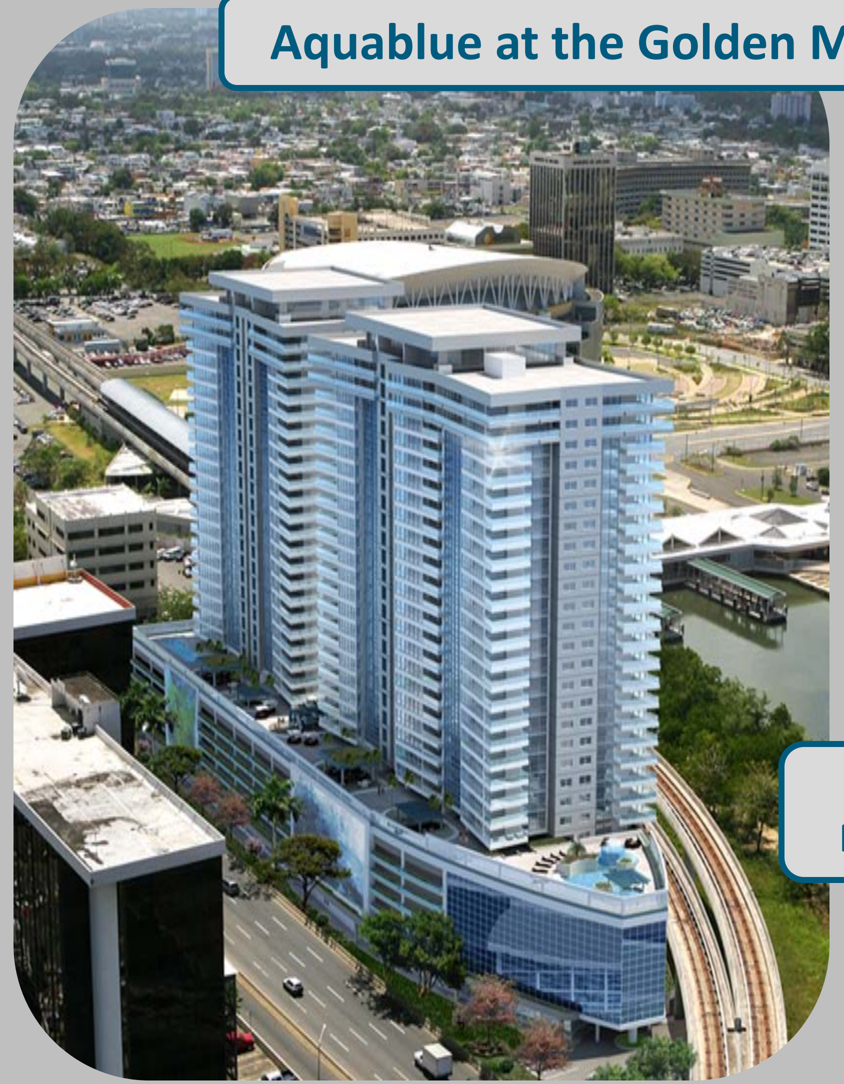
Aquablue at the Golden Mile



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Questions?