8ª JORNADA
COMISIÓN PERMANENTE
del Código Modelo Sísmico para América Latina y El Caribe

Bioma

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Ing. OM Ramirez y Asociados, S.A.

San Salvador, El Salvador
10 de octubre de 2025

www.codigomodelosismico.org

Código Modelo Sísmico América Latina y El Caribe
INSTITUTO DE LA CONSTRUCCIÓN
MOPT

Bioma Diseño Sísmico basado en desempeño

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- Metodologías de Diseño de Diseño REP-2021/ASCE SEI 7

Métodos Prescriptivos
Reduccion de Fuerza Elástica

- Fuerza Lateral Equivalente
- Analisis Modal Espectral
- LTHA, NLTHA

- ❑ Sistema Estructural Prescrito
- ❑ Premisa de Ductilidad
- ❑ No apto para Edificios Flexibles

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Código Modelo Sísmico
América Latina y El Caribe

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Metodologías de Diseño de Diseño REP-2021/LATBSDC(2020)

PBD
Performance Based Design
Diseño Basado en Desempeño

- Analisis Modal Espectral
  Servicio – SLE (43 años)
- NLTHA
  Strength – MCE (2475 años)

PANEL DE REVISION EXTERNA *(Geotecnia, Ing. Sísmica, Ing. Estructural)*

- Sistema Estructural Propuesto por el Diseñador
- Estudio de Amenaza Sísmica
- Estudio Especifico de Sitio. Espectros SLE (43 años) y MCE (2475 años)
- 11 pares de Señales/calibradas/escaladas
- Evaluación de D/C para SLE (43 años) y MCE (2475 años)
- Confinamiento basado en evaluación de deformación

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REP2021-DSPB: DOCUMENTOS/NORMAS/CODIGOS

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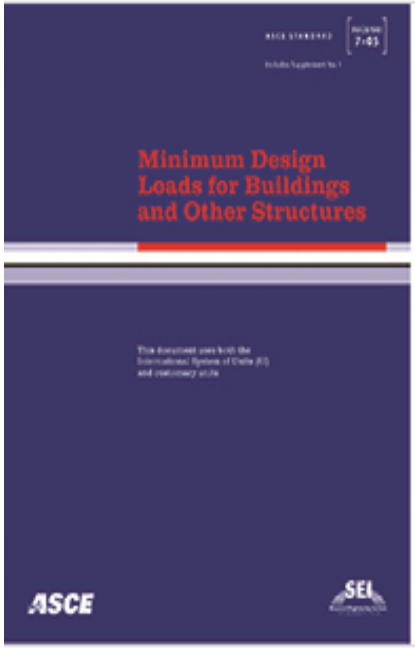

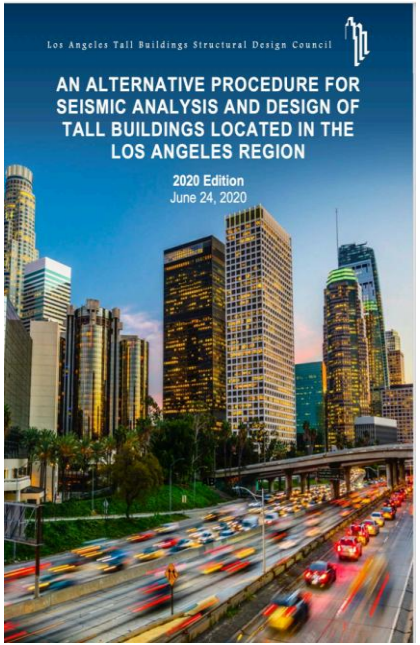

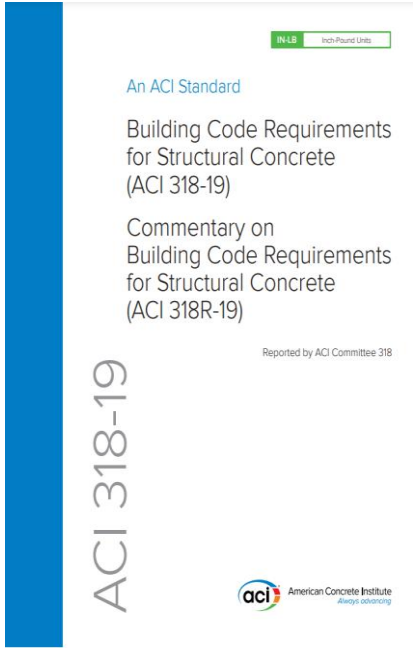

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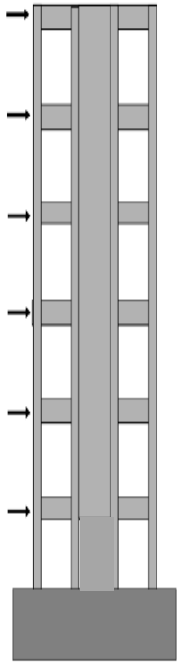
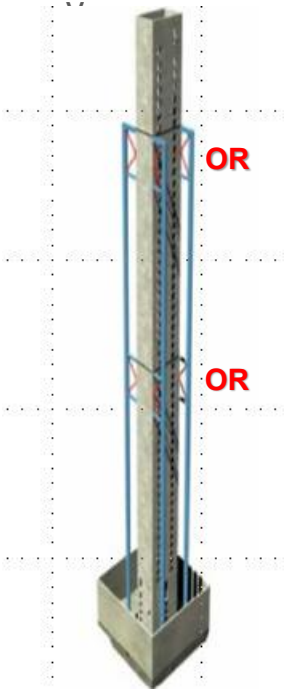
Muro-pórtico



Muro de Corte + “outriggers”



Sistema Estructural para Edificios Flexibles

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BIOMA

OWNER:	THE VELOPER GROUP
UBICACION:	Costa del Este, Panamá.
ARCHITECT:	MALLOL
STRUCTURAL ENGINEER:	Ing. OM RAMIREZ & Asociados, S.A
GEOTECHNICAL ENGINEER:	TECNILAB, S.A.
GEOTECHINICAL CONSULTANT:	Juan D. Jaramillo - RDC Cesar Sierra - RDC
PEER REVIEW PANEL	
Geotechnical and Seismic:	Luis Alfaro, Francisco Grajales
Structural:	Andrew Whittaker
WIND TUNNEL TESTING:	RWDI, Guelph, Canada.
Altura del Edificio:	265m + 17m (5 Sotanos)
Relación de Esbeltéz:	H/B = 16
Area de Construcción:	120,000 m2.

Bioma Diseño Sísmico basado en desempeño

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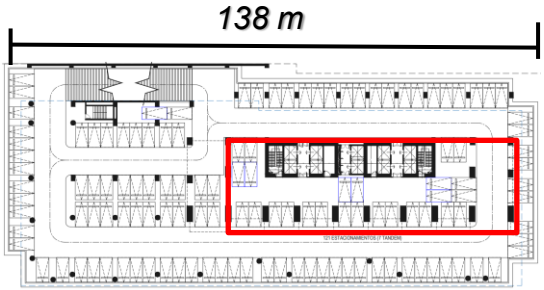
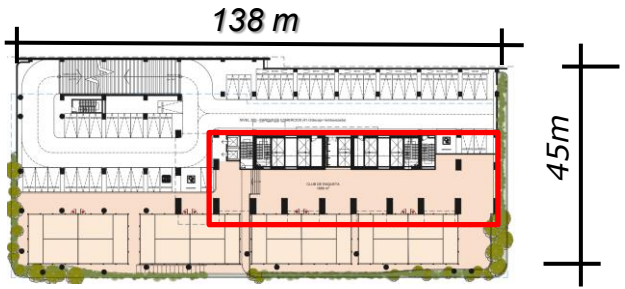
General plan dimensions

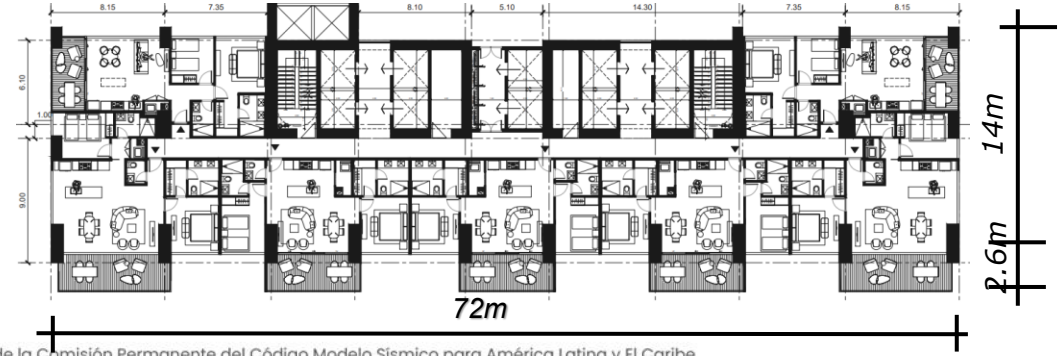
Typical Basement Level -100 to -500



Podium Level 000-700



Typical Residential Level 700-6600



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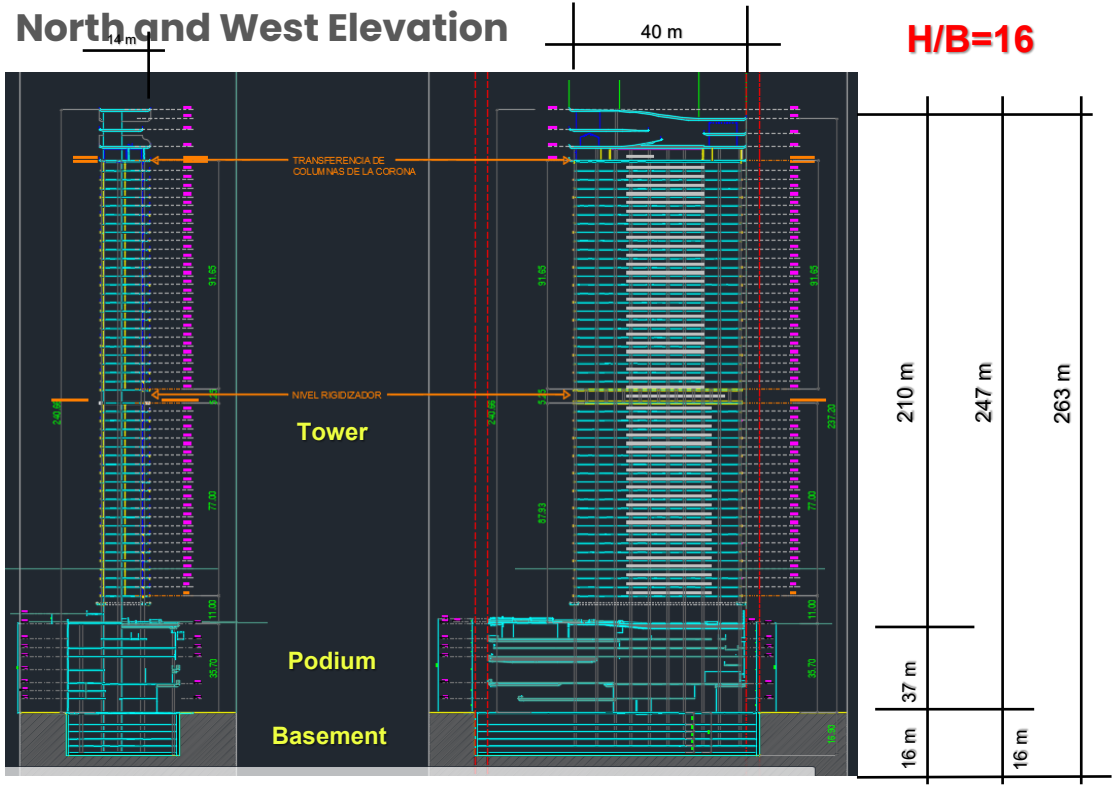
North and West Elevation



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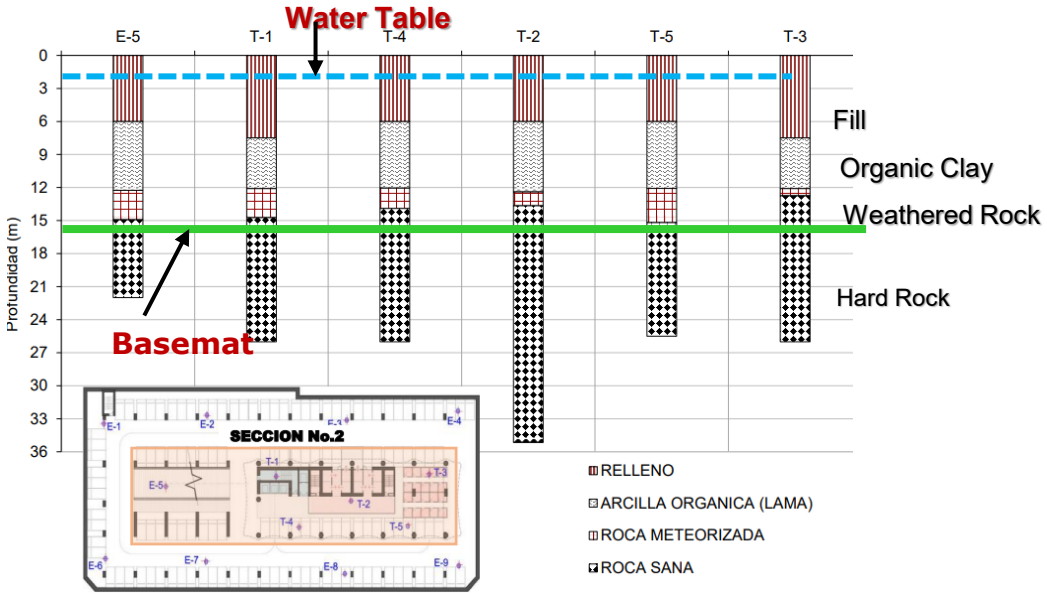
Site Profile



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Gravity loads (ASCE/SEI-7)

Live Load

Live Loads	Uniform Loads (kN/m²)	Concentrated Loads (kN)	Table
Boiler Room	14.36	-	C4-1
Elevator Machine Room	7.18	-	
Fan Room	7.18	-	
Transformer Room	9.58	-	
Apartments (Residential)	1.92	-	4-1
Office Use	2.40	8.90	
Lobbies	4.79	-	
Balconies	4.79	-	
Pool Rooms	3.59	-	
Corridors	4.79	-	
Passenger Vehicules Parking Zones	1.92	13.35	
Gymnasiums	4.79	-	
Public Rooms	4.79	-	
Roof	0.96	-	
Stairs	4.79	1.33 (Stair Treads)	
Storage Areas (deposits and small warehouses)	6.00	-	
Yard and terraces, pedestrian	4.79	-	

Live load maps will be added as part of the structural drawings of the project.

Dead Load

Description	Uniform Loads (kN/m²)
Ceiling	0.25
Internal Partitions (6" CMU)	2.94
Internal Light Wall	1.00
Flooring	1.76
Services	0.49
Others	0.20
Gardens	Variable Weight
Water Tanks	16.20
Pools	14.70

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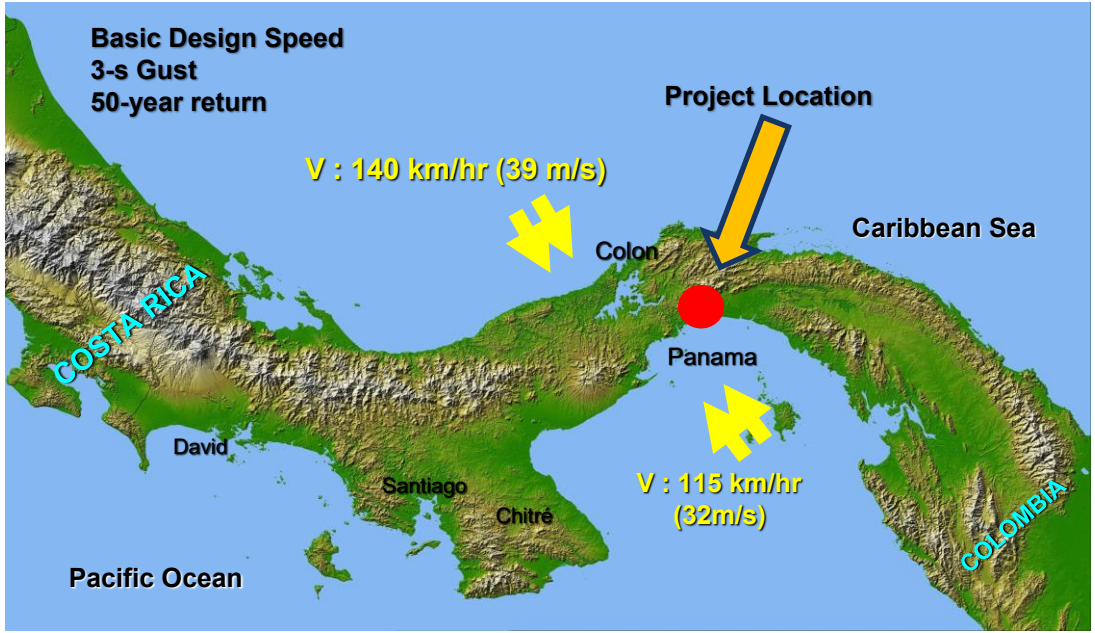
Basic Wind Velocity



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Preliminary Sizing

- Adequate cross section of vertical elements to:
  - *Control Axial Stress in vertical elements: Pu/Ag ≤ 0.30 f´c*
  - *Control of relative axial deformation of vertical elements*
- Adequate lateral stiffness/strength to control Wind-induced vibrations and to sustain wind induced forces.
  - *ASCE/SEI 7 - Method 2*
- Adequate lateral stiffness, Strength, and ductility to outperform during seismic events
  - *RSA at Service Level Earthquake (SLE-43 years)*
  - *Capacity*

Bioma Diseño Sísmico basado en desempeño

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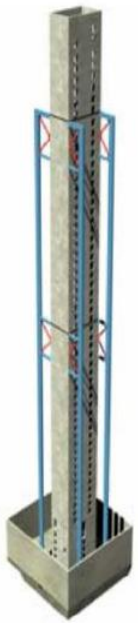
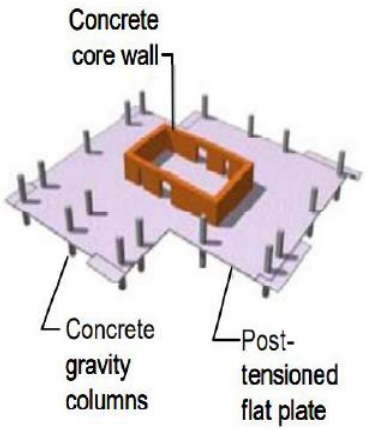
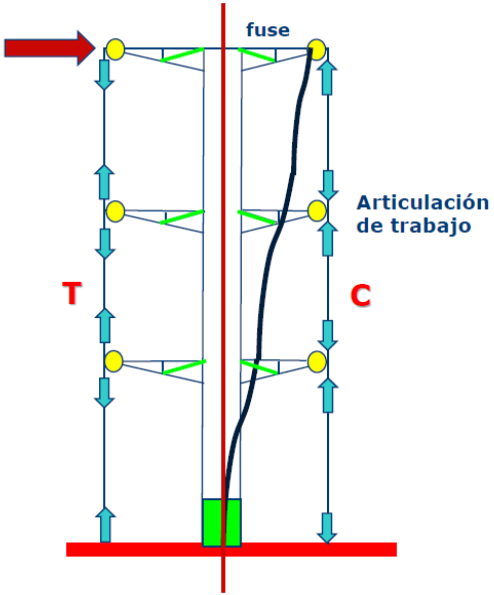
Lateral Stiffness Solutions







Outrigger System

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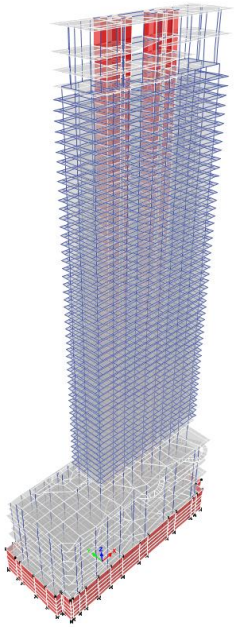
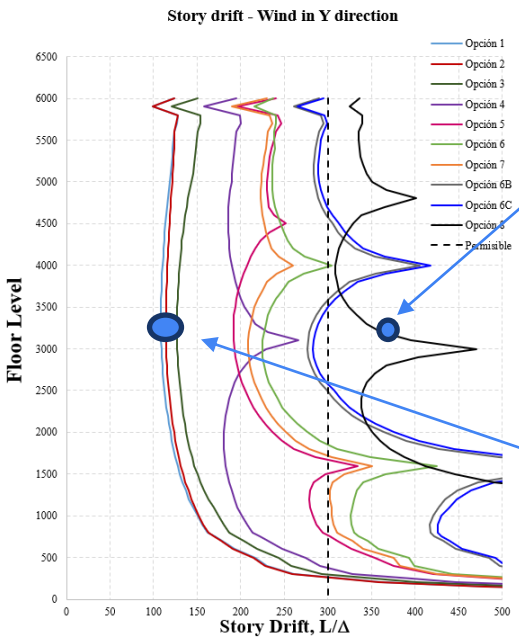
Lateral Stiffness Solutions





Lateral Wind drift adding “outriggers at different locations

Lateral Wind drift per architectural layout

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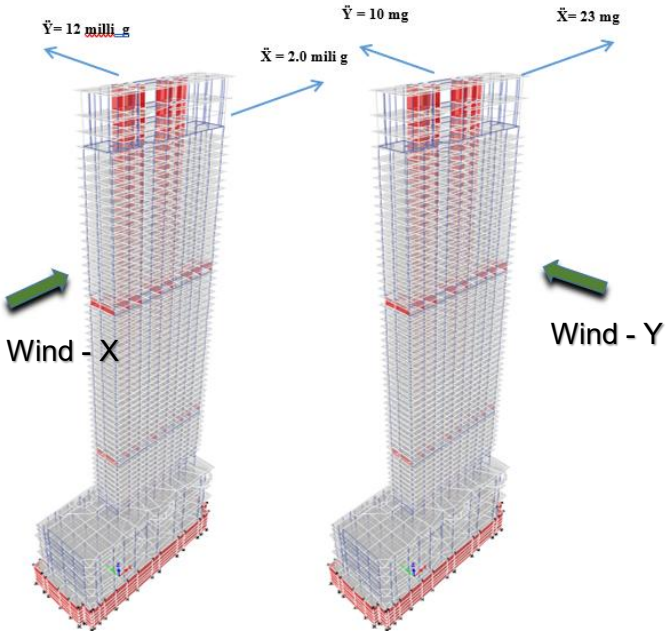
Preliminary wind-induced vibration analysis



Estimated vibrational response

G. SOLARI ASCE 108

Ẍ, Ÿ ≤ 15-20 milli-g

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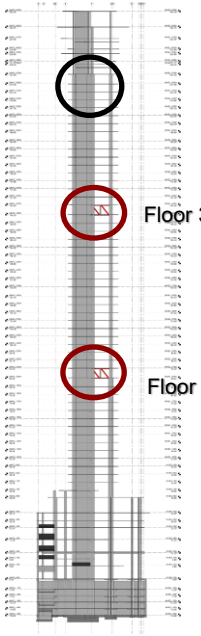
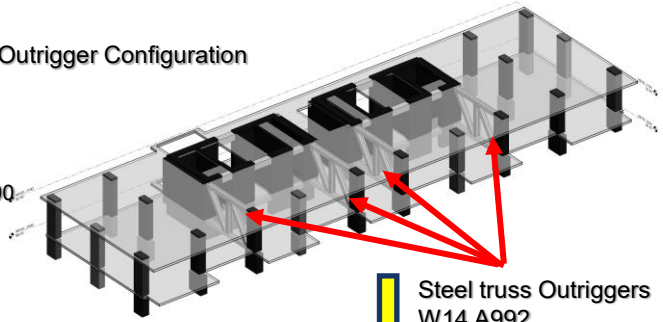
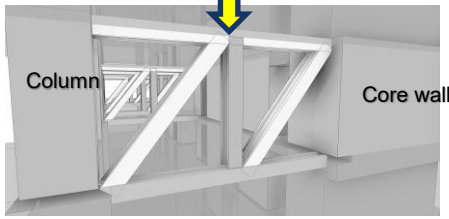
Preliminary Seismic/Wind Framing







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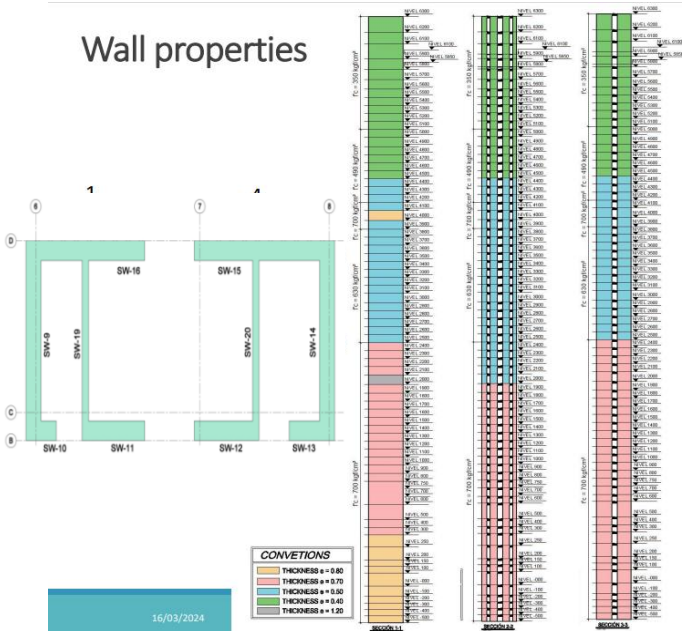
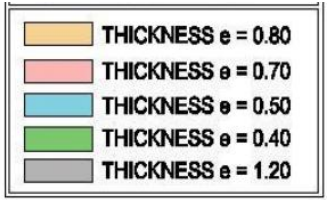
Preliminary sizing of the core Shear walls





Specified concrete strength

- ***Shear Walls***

  35 Mpa ≤ f´c ≤ 70 Mpa

- ***Columns***

  28 Mpa ≤ f´c ≤ 84 Mpa

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LATBSDC (2020) Expected Material Strength

Table 2. Expected Material Strengths

Material	Expected strength	
Reinforcing Steel	Expected Yield Strength, f_{ye}, ksi	Expected Ultimate Strength, f_{ue}, ksi
A615 Grade 60	70	106
A615 Grade 75	82	114
A706 Grade 60	69	95
A706 Grade 80	85	112
A706 Grade 100	105	To be determined based on tests and documented substantiations
Structural Steel* **		
Hot-rolled structural shapes and bars		
ASTM A36/A36M	$1.5\,f_y$*	$1.2\,f_u$**
ASTM A572/A572M Grade 50	$1.1\,f_y$	$1.1\,f_u$
ASTM A913/A913M Grade 50, 60, 65 or 70	$1.1\,f_y$	$1.1\,f_u$
ASTM A992/A992M	$1.1\,f_y$	$1.1\,f_u$
Plates		
ASTM A36/A36M	$1.3\,f_y$	$1.2\,f_u$
ASTM A572/A572M Grade 50, 55	$1.1\,f_y$	$1.2\,f_u$
Concrete	$f'_{ce} = 1.3 f'_c$	

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Element Specified/expected Concrete Strength properties

$f'_{ce}=1.3f'_c$ (LATBSDC, 2020)

Element	Floor	Specified compressive strength f'c (kgf/cm^2)	Expect compressive strength f'ce (kgf/cm^2)
Walls	N -500 @ N -300	630	819
	N -300 @ N 600	840	1092
	N 600 @ N 1800	700	910
	N 1800 @ N 2300	840	1092
	N 2300 @ N 2500	700	910
	N 2500 @ N 3800	630	819
	N 3800 @ N 4300	840	1092
	N 4300 @ N 5100	490	637
	N 5100 @ N 6200	350	455
Podium columns Type 1	N -500 @ N 700	350	455
Podium columns Type 2	N -500 @ N 700	560	728
Podium columns Type 3	N -500 @ N 200	840	1092
	N 200 @ N 600	350	455
Podium columns Type 4	N -500 @ N 200	700	910
	N 200 @ N 600	350	455

Element	Floor	Specified compressive strength f'c (kgf/cm^2)	Expect compressive strength f'ce (kgf/cm^2)
Tower columns Type 1	N -500 @ N 2000	840	1092
	N 2000 @ N 3000	700	910
	N 3000 @ N 4000	630	819
	N 4000 @ N 4400	560	728
	N 4400 @ N 6200	350	455
Tower columns Type 2	N -500 @ N 2100	840	1092
	N 2100 @ N 3000	700	910
	N 3000 @ N 4000	630	819
	N 4000 @ N 4100	840	1092
	N 4100 @ N 4400	560	728
	N 4400 @ N 6300	350	455
Tower columns Type 3	N -500 @ N 1200	840	1092
	N 1200 @ N 2000	630	819
	N 2000 @ N 3000	560	728
	N 3000 @ N 4000	490	637
	N 4000 @ N 4400	420	546
	N 4400 @ N 6300	350	455
Tower columns Type 4	N -500 @ N 000	700	910
	N 000 @ N 700	630	819
	N 700 @ N 1200	560	728
	N 1200 @ N 3000	490	637
	N 3000 @ N 4400	420	546
	N 4400 @ N 6200	350	455

Element	Floor	Specified compressive strength f'c (kgf/cm^2)	Expect compressive strength f'ce (kgf/cm^2)
Tower columns Type 5	N -500 @ N 000	700	910
	N 000 @ N 2000	630	819
	N 2000 @ N 2100	840	1092
	N 2100 @ N 4000	630	819
	N 4000 @ N 4100	840	1092
	N 4100 @ N 4400	490	637
	N 4400 @ N 6300	350	455
Tower columns Type 6	N -500 @ N 700	700	910
	N 700 @ N 2100	630	819
	N 2100 @ N 3000	560	728
	N 3000 @ N 4400	490	637
	N 4400 @ N 6200	350	455
Tower columns Type 7	N -500 @ N 700	700	910
	N 700 @ N 2000	630	819
	N 2000 @ N 2100	840	1092
	N 2100 @ N 3000	560	728
	N 3000 @ N 4000	490	637
	N 4000 @ N 4100	840	1092
	N 4100 @ N 4400	490	637
	N 4400 @ N 6300	350	455

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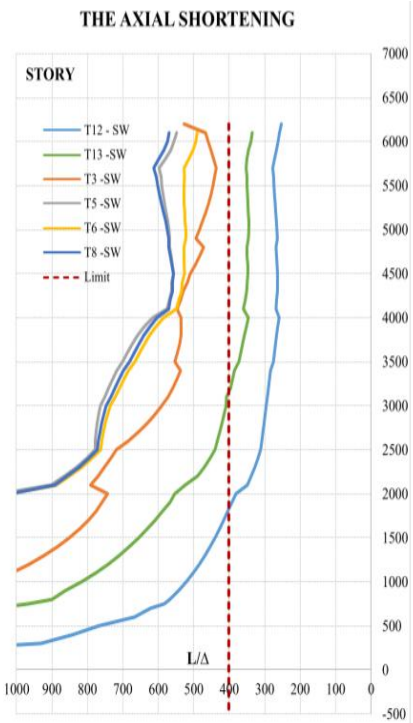
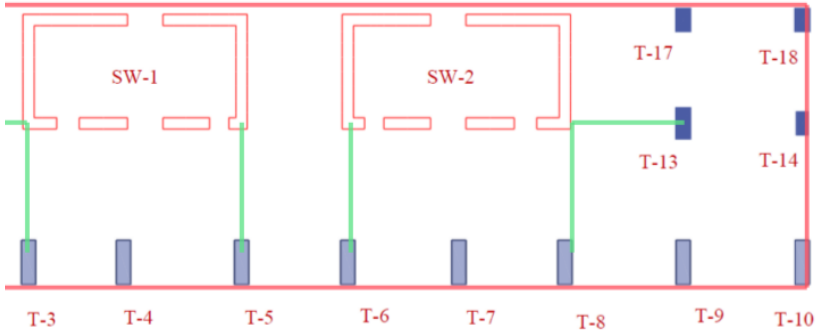
Checking Axial Shorthening





- Increase column cross section
- Increase f'_c
- Increase amount of longitudinal Reinforcement, ρ
- Increase both f'_c and ρ
- Add structural steel core to column section

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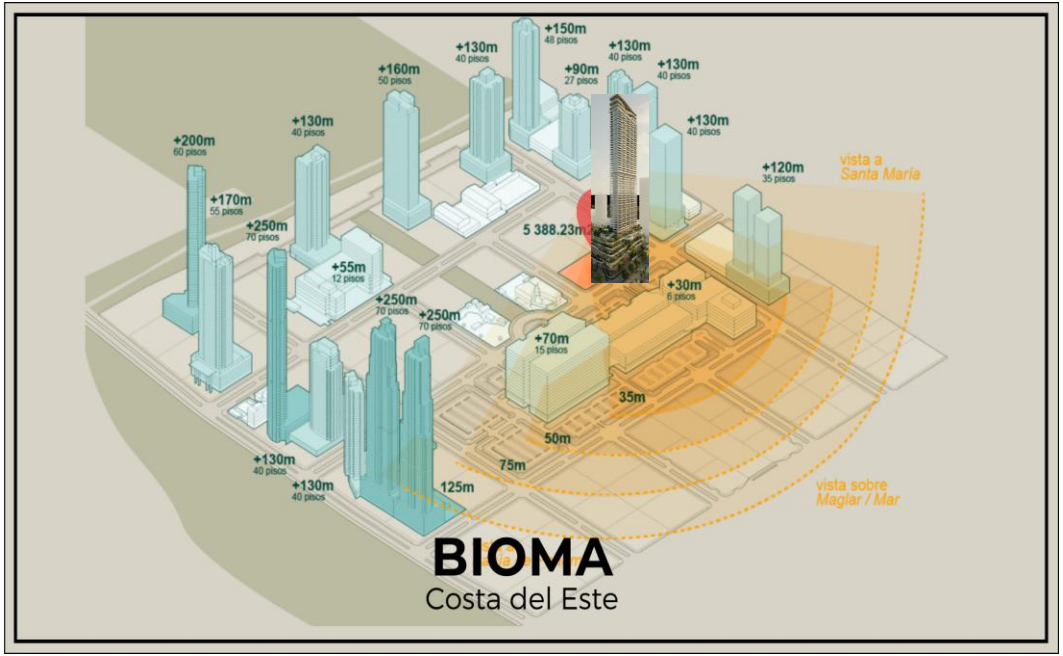
Climate study and WTT



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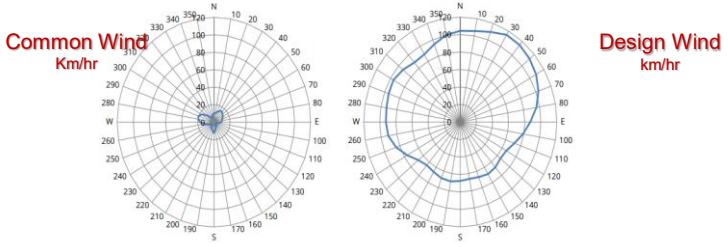
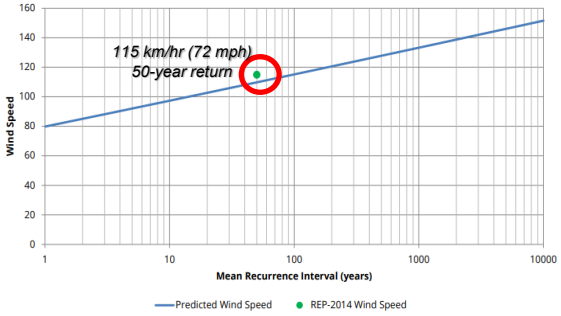
Basic Wind Velocity and directionality





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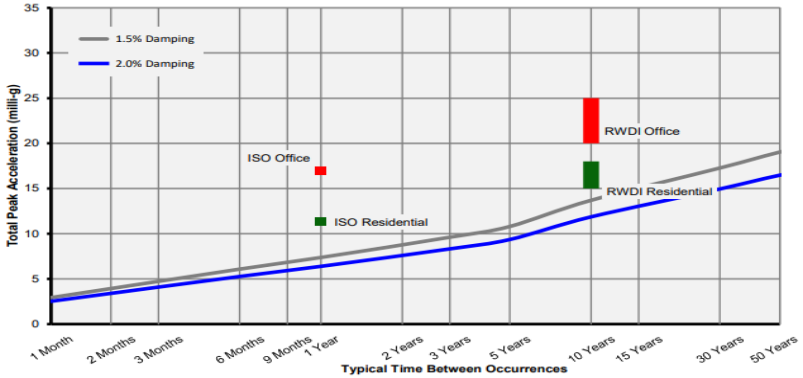
Experimental Wind Vibration Response (WTT)



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Dtructural Wind Loads and Force Combination Rules

Table 1: Summary of Predicted Peak Overall Structural Wind Loads

Moments			Shears	
My (N-m)	Mx (N-m)	Mz (N-m)	Fx (N)	Fy (N)
7.52E+08	2.79E+09	7.61E+07	5.25E+06	1.82E+07

Table 2: Effective Static Floor-by-Floor Wind Loads

Floor Level	Height (m) Above Level 0	Fx (N)	Fy (N)	Mz (N-m)
6200	247.7	73400	312000	641000
6100	240.55	180400	732700	2006000
6000	235.8	162500	550600	2012000
5900	231.15	178000	625200	2336000
5800	225.75	121500	472000	1320000
5700	222.05	179300	754500	2704000
5600	217.85	123000	462500	1839000
5500	214.35	114500	433000	1729000
5400	210.85	112500	423600	1707000
5300	207.35	110500	414100	1682000
5200	203.85	108500	404800	1658000
5100	200.35	106600	395400	1632000
5000	196.85	104500	386300	1608000

Table 3: Recommended Wind Load Combination Factors

Load Combination	Recommended Wind Load Combination Factors for Simultaneous Application of Loads in Table 2		
	X Forces (Fx)	Y Forces (Fy)	Torsion (Mz)
1	+90%	+30%	+50%
2	+90%	+30%	-30%
3	+90%	-40%	+50%
4	+90%	-40%	-30%
5	-100%	+40%	+60%
6	-100%	+40%	-30%
7	-100%	-30%	+60%
8	-100%	-30%	-30%
9	+30%	+90%	+50%
10	+30%	+90%	-30%
11	+45%	-100%	+45%
12	+45%	-100%	-30%
13	-45%	+90%	+50%
14	-45%	+90%	-30%
15	-30%	-100%	+45%
16	-30%	-100%	-30%
17	+30%	+50%	+100%
18	+35%	+35%	-90%
19	+30%	-30%	+100%
20	+35%	-35%	-90%
21	-70%	+50%	+100%
22	-50%	+35%	-90%
23	-70%	-30%	+100%
24	-50%	-35%	-90%

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Seismic Analysis and Design Procedure (LATBSDC, 2020)

- ❑ Capacity Design - Classification of Structural Actions
- ❑ Groundmotion Characterization
- ❑ Modelling Req´s and Evaluation at SLE (43 years)
- ❑ Modelling Req´s and Evaluation at MCE (2475 years)

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Classification of Structural Actions (LATBSDC, 2020)

Component	Seismic action	Deformation Controlled	Forced controlled	
			Critical	Ordinary
Structural Walls	Flexure (in P-M-M)	X		
	Shear		X	
Columns	Flexure (in P-M-M)	X		
	Shear		X	
Outrriggers Columns	Flexure (in P-M-M)	X		
	Shear		X	
Beams	Flexure	X		
	Shear		X	
Outrriggers Beams	Flexure	X		
	Shear		X	
Below Grade Perimeter Retaining Wall	Axial		X	
	Shear		X	
	Flexure		X	
Typical (non transfer slab) Diaphragms	Axial			X
	Shear			X
	Flexure			X
Diaphragms with Major Shear Transfer	Axial		X	
	Shear		X	
	Flexure		X	
Vertical Element-to Diaphragm-Connection	Bearing		X	
	Shear Transfer (Shear Friction)		X	
All drag (collector) members	Compression		X	
	Tension		X	
Cantilevers	Flexure		X	
	Shear		X	

- **Deformation-controlled actions**

"Action expected to undergo nonlinear behavior, and which is evaluated for its ability to sustain such behavior"

- **Force-controlled actions**

"Action not expected to undergo nonlinear behavior, and which is evaluated on the basis of its available strength"

  - Critical (failure likely to lead to partial or total structural collapse)
  - Ordinary (failure unlikely to lead to structural collapse)

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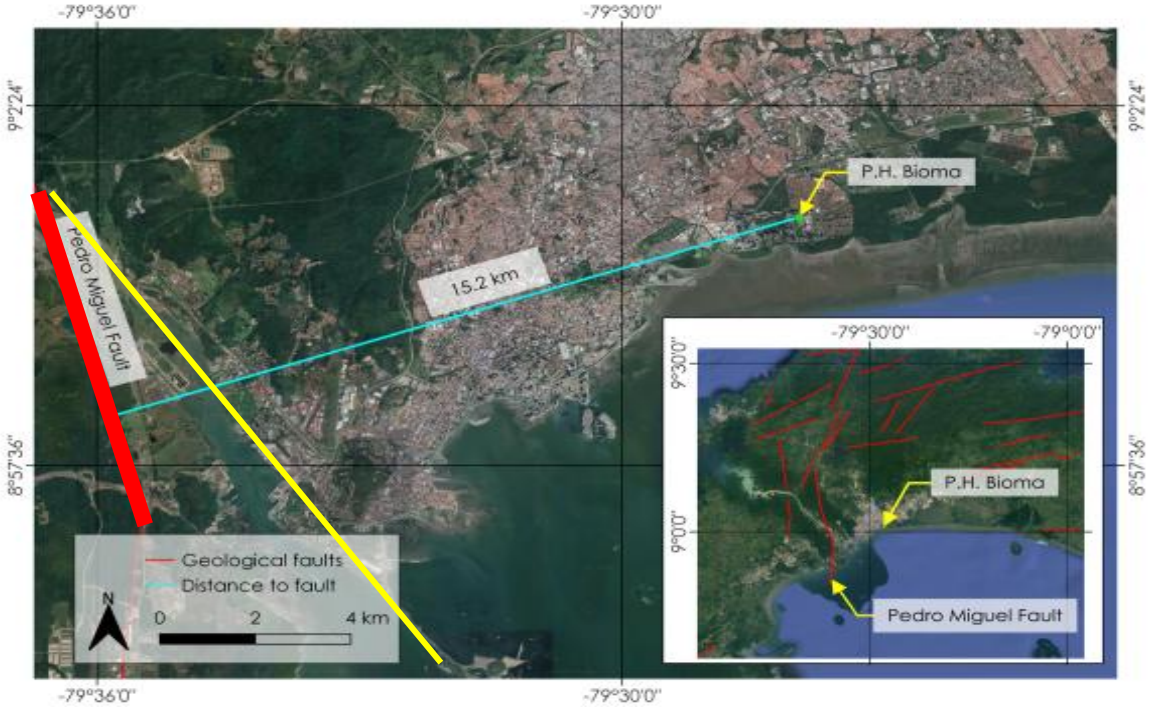
Groundmotion characterization



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Seismic Hazard – REP 2021

2475 yr

Figure 20. Spectral values for MCE level (2475-year) earthquake shaking. S_1 map.

Figure 21. Spectral values for MCE level (2475-year) earthquake shaking. S_1 map.

43 yr

Localización	Ss(43)	S1(43)		Localización	Ss(43)	S1(43)
Represa Gatún	0.22	0.11		Coronado	0.18	0.09
Represa Madden	0.59	0.23		David	0.7	0.16
Represa Cocolí Norte	0.55	0.16		El Real	0.45	0.15
Represa Cocolí Sur	0.51	0.18		El Valle	0.19	0.08
Aguadulce	0.18	0.08		Jaqué	0.54	0.25
Ailigandí	0.33	0.12		La Palma	0.35	0.15
Almirante	0.47	0.14		Las Tablas	0.24	0.1
Bocas del Toro	0.4	0.12		Panamá Paitilla	0.36	0.13
Boquete	0.65	0.15		Penonomé	0.17	0.08
Changuinola	0.46	0.13		Portobelo	0.36	0.12
Chepo	0.31	0.14		Puerto Armuelles	0.75	0.19
Chiriquí Grande	0.37	0.12		Puerto Obaldía	0.35	0.14
Chitré	0.19	0.09		Santiago	0.2	0.08
Chorrera	0.27	0.1		Soná	0.23	0.11
Colón	0.38	0.13		Tonosí	0.31	0.13

Valores S_s y S_1 de para un período de retorno de 43 años y 5% de amortiguamiento crítico.

Figure 22. Values of S_s and S_1 for a 43-year return period (Ref. REP-2021).

Site mapped acceleration Parameters for MCE (2475-year)

S_S= 0.96 **S_1 = 0.38**

Site mapped acceleration parameters for SLE (43-year)

S_S= 0.36 **S_1 = 0.13**

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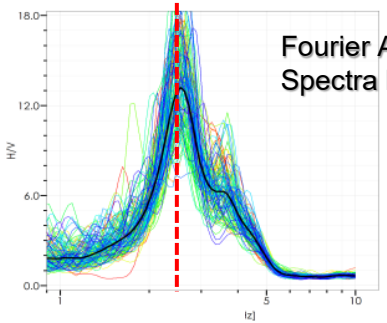
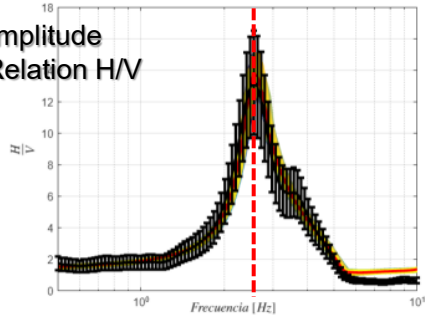
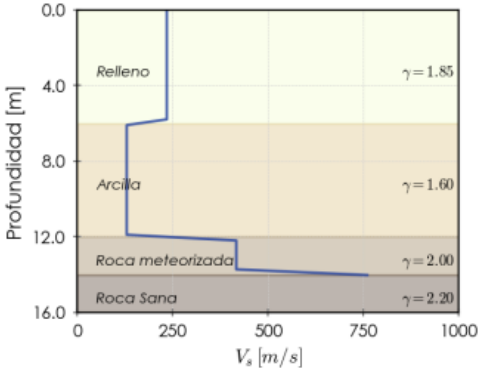
Site Dynamic properties

Fotografía Nº 2.2.1: Sismógrafo digital empleado



Fourier Amplitude
Spectra Relation H/V





Average shear
velocity distribution

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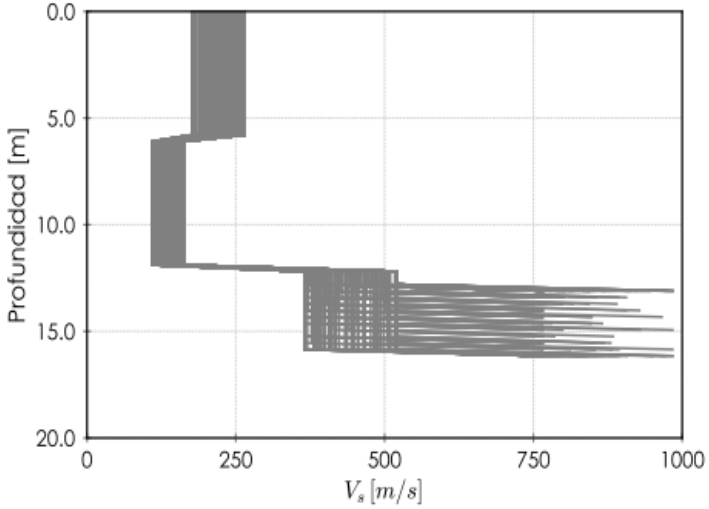
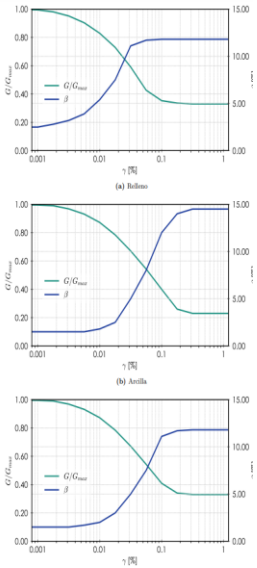
Groundmotion characterization



Resulting shear velocity profiles

Soil stiffness degradation (*G/Gmax*) and damping (*β*) variation curves



Fill layer

Organic clay layer

Wheathered rock layer

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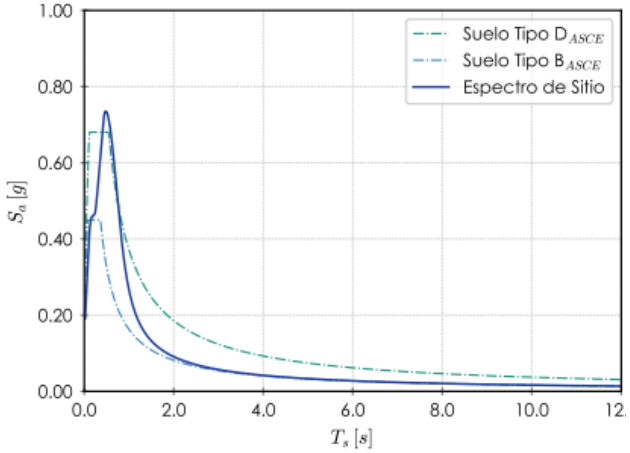
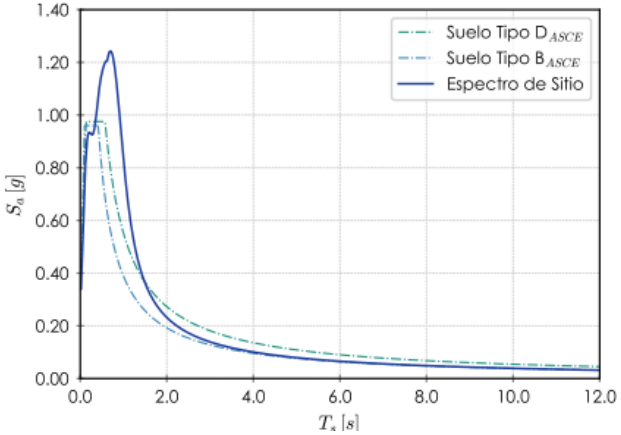
Groundmotion characterization



Site Spectrum, β=1.25%
Tr=43 years



Site Spectrum, β=5%
Tr=2475 years

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Groundmotion Characterization

Sismo	Fecha [D/M/A]	Estación	Mw	Distancia [km]
El Centro	May 19-1940	Array 09	6.90	13.0
Hector Mine	Oct 16-1999	Amboy	7.13	59.8
Hector Mine	Oct 16-1999	Hector	7.13	30.6
Chi-Chi	Sep 20-1999	TCU047	7.62	76.2
Loma Prieta	Oct 17-1989	SLAC	6.90	58.6
Ridgecrest	Jul 05-2019	CCC Lake	7.10	38.5
Amberley	Nov 13-2016	Kaikoura	7.80	80.5
Kobe	Ene 16-1995	Abeno	6.90	20.2
Landers	Jun 28-1992	Yermo Fire	7.4	88.1
North Ridge	Ene-17-1997	Old Ridge Route	6.90	25.8
South Napa	Agu 24-2014	Lovall Valley	6.0	17.5

Scaling factors

No Señal	Factores de amplificación	
	Señal X	Señal Y
1	1.19	0.94
2	1.01	1.11
3	1.14	0.99
4	0.78	1.44
5	1.4	0.81
6	0.76	1.49
7	1.64	0.68
8	0.86	1.3
9	1.07	1.05
10	0.74	1.52
11	1.49	0.76

Selected set of 11 pairs of groundmotions

Bioma Diseño Sísmico basado en desempeño

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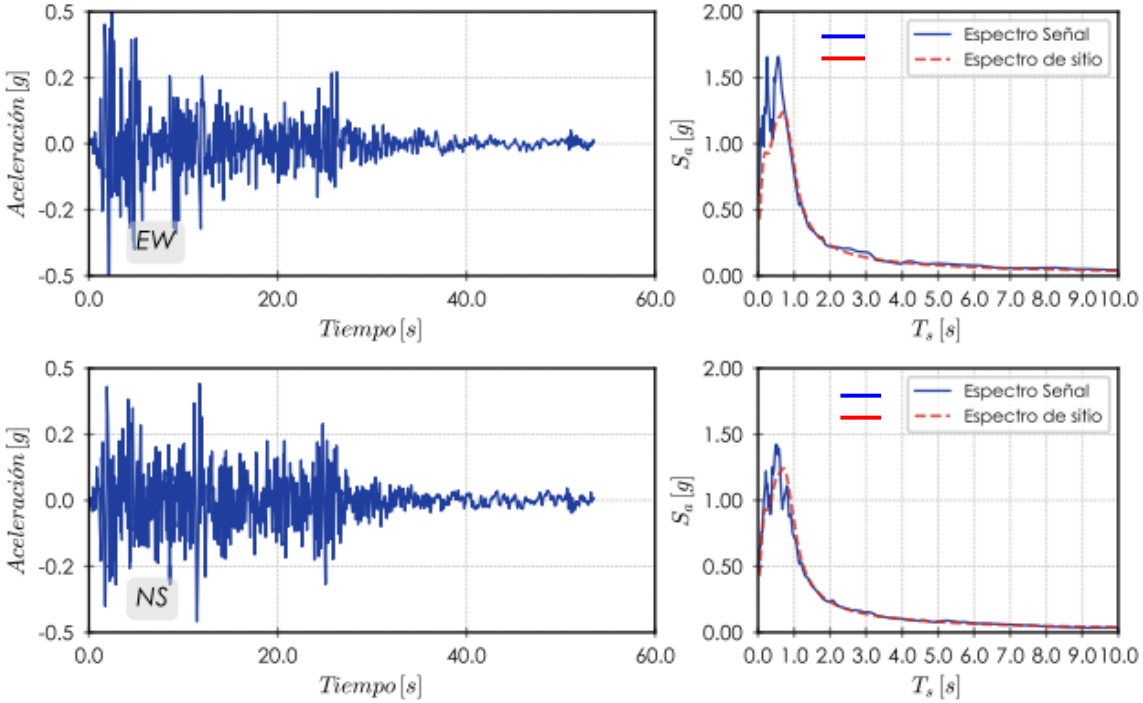
Groundmotion Characterization



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Modelling Requirements

Table 3. Reinforced Concrete Stiffness Properties*

Component	*Service-Level Linear Models*			*MCER-Level Nonlinear Models*		
	Axial	**Flexural**	**Shear**	**Axial**	**Flexural**	**Shear**
Structural walls[1] (in-plane)	$1.0E_c^{*}A_g$ *or* $0.75\ E_cA_g^{**}$	$0.75E_cI_g$	$0.4E_cA_g$	$1.0E_cA_g$	$0.35E_cI_g$	$0.2E_cA_g$
Structural walls (out-of-plane)	--	$0.25E_cI_g$	--	--	$0.25E_cI_g$	--
Basement walls (in-plane)	$1.0E_cA_g$	$1.0E_cI_g$	$0.4E_cA_g$	$1.0E_cA_g$	$0.8E_cI_g$	$0.2E_cA_g$
Basement walls (out-of-plane)	--	$0.25E_cI_g$	--	--	$0.25E_cI_g$	--
Coupling beams with or without diagonal reinforcement	$1.0E_cA_g$	$0.07\left(\frac{\ell}{h}\right)E_cI_g \leq 0.3E_cI_g$	$0.4E_cA_g$	$1.0E_cA_g$	$0.07\left(\frac{\ell}{h}\right)E_cI_g \leq 0.3E_cI_g$	$0.4E_cA_g$
Coupling beams with steel-fiber reinforcement	$1.0E_cA_g$	$0.07\left(\frac{\ell}{h}\right)E_cI_g \leq 0.3E_cI_g$	$0.4E_cA_g$	$1.0E_cA_g$	$0.07\left(\frac{\ell}{h}\right)E_cI_g \leq 0.3E_cI_g$	$0.4E_cA_g$
Steel Coupling Beams[2]	$1.0E_sA_s$	$0.07\left(\frac{\ell}{h}\right)(EI)_{tr}$	$0.4E_sA_{web}$	$1.0E_sA_s$	$0.07\left(\frac{\ell}{h}\right)(EI)_{tr}$	$0.4E_sA_{web}$
Non-PT diaphragms[3]	$0.5E_cA_g$	$0.5E_cI_g$	$0.4E_cA_g$	$0.25E_cA_g$	$0.25E_cI_g$	$0.1E_cA_g$
PT diaphragms[3]	$0.8E_cA_g$	$0.8E_cI_g$	$0.4E_cA_g$	$0.5E_cA_g$	$0.5E_cI_g$	$0.2E_cA_g$
Beams	$1.0E_cA_g$	$0.5E_cI_g$	$0.4E_cA_g$	$1.0E_cA_g$	$0.3E_cI_g$	$0.4E_cA_g$
Columns	$1.0E_cA_g$	$0.7E_cI_g$	$0.4E_cA_g$	$1.0E_cA_g$	$0.7E_cI_g$	$0.4E_cA_g$
Mat (in-plane)	$0.8E_cA_g$	$0.8E_cI_g$	$0.4E_cA_g$	$0.5E_cA_g$	$0.5E_cI_g$	$0.4E_cA_g$
Mat[4] (out-of-plane)	--	$0.8E_cI_g$	--	--	$0.5E_cI_g$	--

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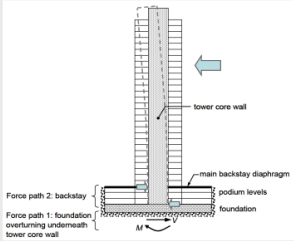
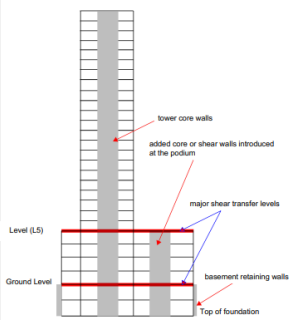
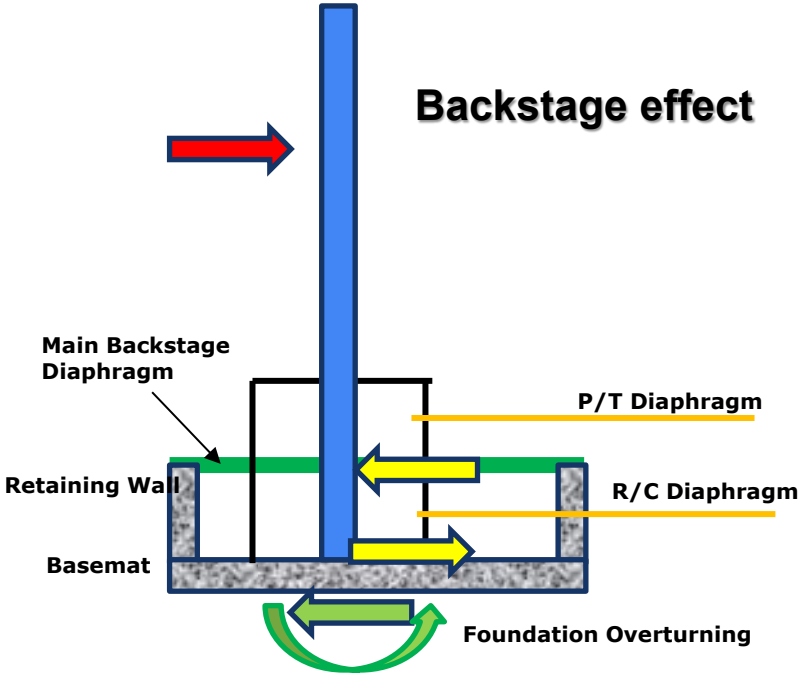
Modelling Requirements for SLE (43 years)



(Illustration from ATC-72)



Example Configuration



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Modelling Requirements for SLE (43 years)

Table 5. Stiffness parameters for Upper Bound and Lower Bound Models

Stiffness Parameters	UB	LB
R/C Diaphragms at the podium and below		
$E_c I_g$	0.35	0.10
$E_c A$	0.14	0.04
PT Diaphragms at the podium and below		
$E_c I_g$	0.60	0.14
$E_c A$	0.24	0.06

Figure: Stiffness parameters to be used in the backstay analysis (figure taken from 2020 LATBSDC).

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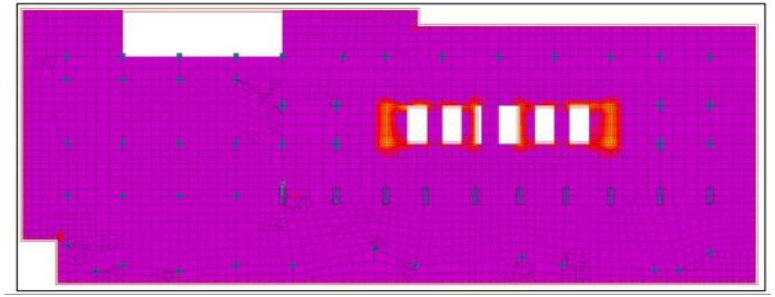
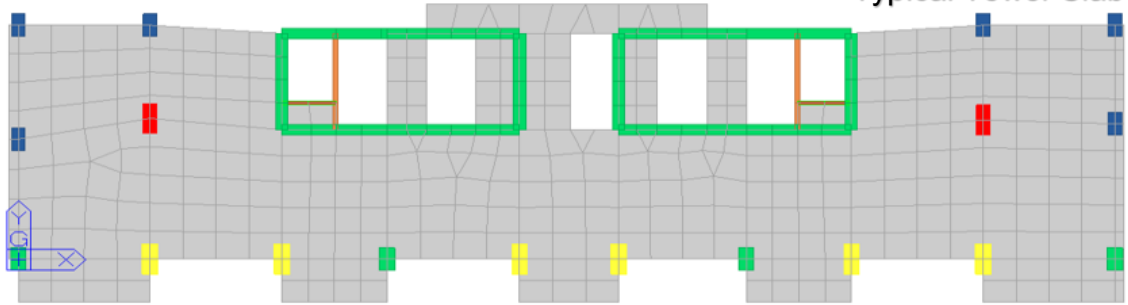
Modelling Requirements for SLE (43 years)



Platform Slab

Typical Tower Slab



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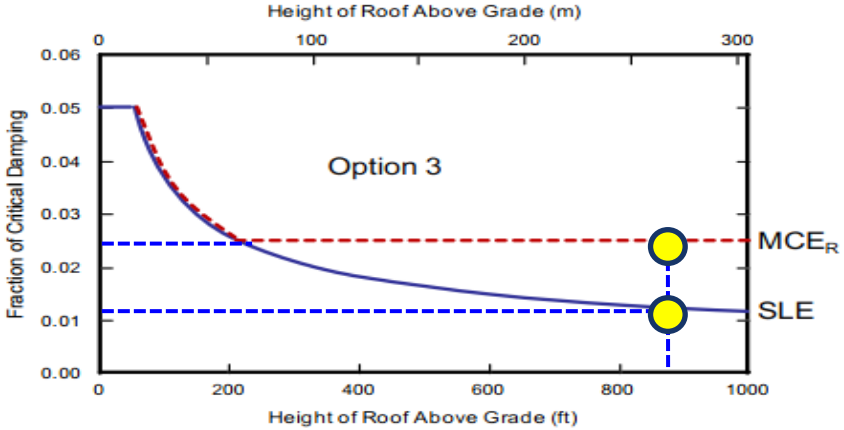
Modelling Requirements for SLE (43 years)

$$\textbf{For SLE}: \ \varepsilon_{critical} = \frac{0.20}{\sqrt{H}} \leq 0.05 \quad (H \ in \ meters) = \mathbf{1.25\%}$$

$$\textbf{For MCER}: \ \varepsilon_{critical} = 0.025 \leq \frac{0.20}{\sqrt{H}} \leq 0.05 \quad (H \ in \ meters) = \mathbf{2.50\%}$$



Equivalent viscous damping versus building height (*Ref.LATBSDC-2020).*

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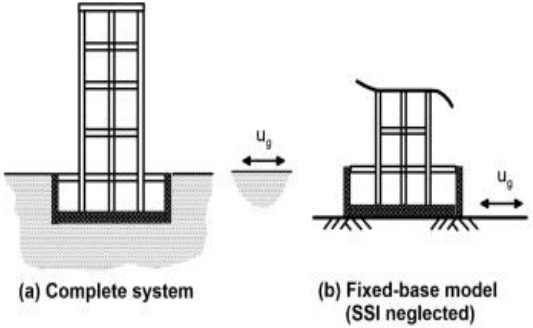
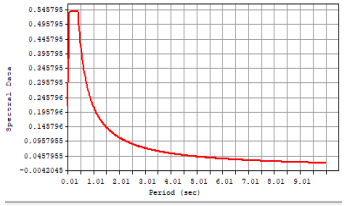
Modelling Requirements for SLE (43 years)

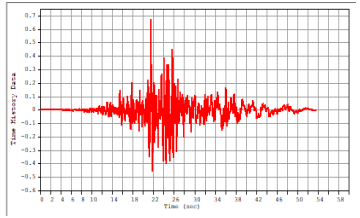
Foundation Modelling



SLE evaluation (43 years)
Response Spectrum Analysis



MCE evaluation (2475 years)
Nonlinear Time-history analysis



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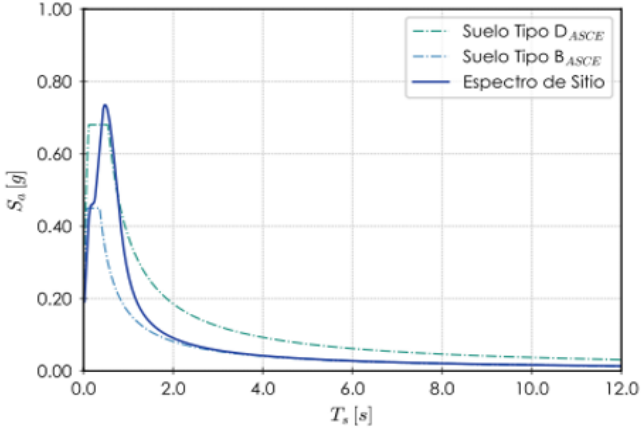
Performance Evaluation for SLE (43 years)



(a) Response Spectrum Analysis

$$1.0D + L_{exp} \pm 1.0E_x \pm 0.3E_y$$

$$1.0D + L_{exp} \pm 1.0E_y \pm 0.3E_x$$

Section 3.5.3 LATBSDC (2020)

- **Story Drift Control**
  - Maximum story drift at any location within the floor should not exceed 0.5% of story height.
- **Evaluation of Accidental Torsion, Ax=?**
  - If Ax > 1.5, and drift at MCE is larger than 0.01 then, accidental torsion at MCE evaluation must be addressed.
- **Acceptability Criteria**

STRENGTH:

Demand to capacity ratio should not exceed:

a) Deformation-controlled elements:

1.50 for Risk Category I and II
1.20 for Risk Category III
< 1.20 for Risk category IV (SSRP)

b) Force-controlled actions: 0.7

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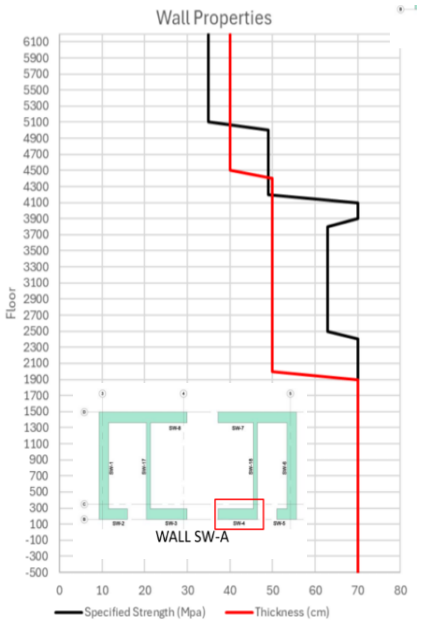
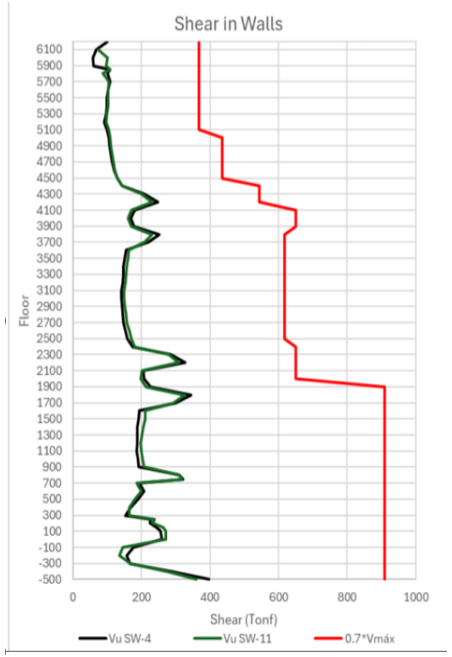
Performance Evaluation at SLE (43 years)





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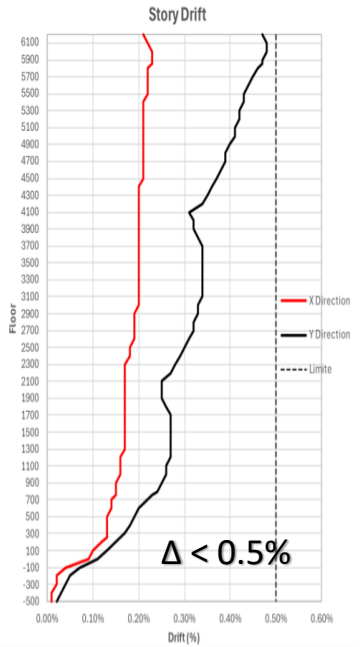
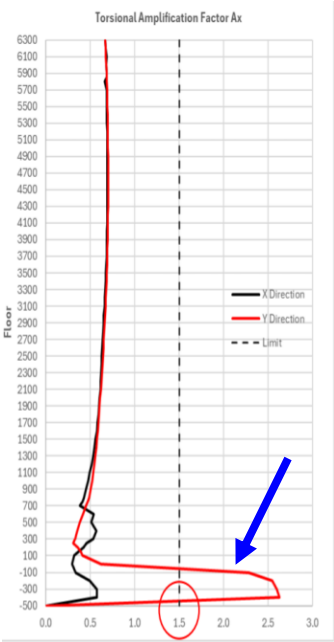
Performance Evaluation for SLE (43 years)



Story drift



TAF, Ax

Ax > 1.5 in Y-direction at floors N-100 to N-400

"check story drift at MCE"

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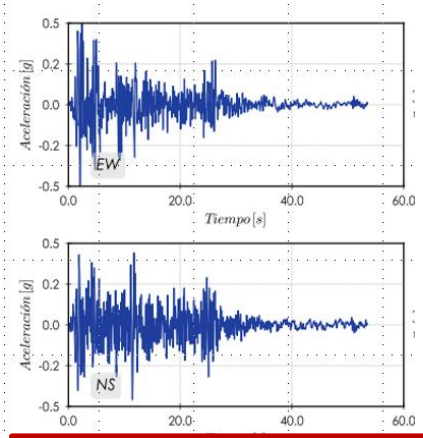
Performance Evaluation for MCE (2475 years)



- Perform NLTHA (11 pairs of groundmotions)
- Report peak response values for each groundmotion at each story
- Report average of peak values
- Perform evaluation for:
  - Force-controlled actions
  - Deformation-controlled actions

$$1.0D + L_{exp} + 1.0E_x + 1.0E_y$$

1. Analytical solution fails to converge,
2. Predicted demands on deformation-controlled or force-controlled elements exceed the valid range of modeling, or
3. Predicted deformation demands on elements not explicitly modeled exceed the deformation limits at which the members are no longer able to carry their gravity loads.

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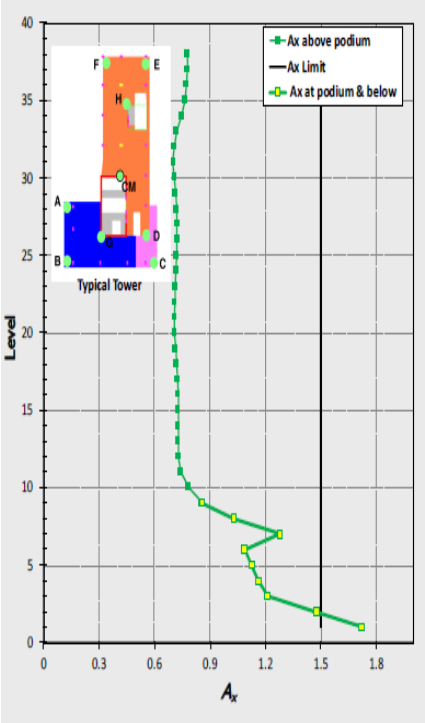
Performance Evaluation for MCE (2475 years):

- Acceptability Criteria LATBSDC (2020)

- Story Drift Control
  - Mean Peak Transient Drift: 0.03
  - Peak Transient Drift: 0.045
  - Mean Residual Drift: 0.01
  - Peak Residual Drift: 0.045

- Evaluation of Accidental Torsion, Ax=?
  - If Ax > 1.5, and drift at MCE is larger than 0.01 then, accidental torsion at MCE evaluation must be addressed.



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Performance Evaluation for MCE (2475 years):

3.6.3.2.1 ***Force-Controlled Actions*** LATBSDC (2020)

(a) Critical Actions Not Sensitive to Vertical Accelerations

Critical force-controlled actions not sensitive to vertical accelerations shall satisfy either Equation (5a) or Equation (5b):

$$1.0Q_{ns} + 1.3I_e\left(Q_T - Q_{ns}\right) \le \phi_s BR_n \qquad (5a)^1$$

$$1.0Q_{ns} + 1.5I_e\left(Q_T - Q_{ns}\right) \le \phi_s BR_{nem} \qquad (5b)^1$$

(b) Critical Actions Sensitive to Vertical Accelerations

Critical force-controlled actions sensitive to vertical accelerations shall satisfy either Equations (5c) **and** (5d), **or** Equations (5e) **and** 5(f):

$$\left\{\begin{array}{l} (1.2 + 0.12S_{MS})D + 1.0L_{\exp} + 1.3I_e\left(Q_T - Q_{ns}\right) \le \phi_s BR_n \\ (0.9 - 0.12S_{MS})D + 1.3I_e\left(Q_T - Q_{ns}\right) \le \phi_s BR_n \end{array}\right\} \begin{array}{l} (5c) \\ (5d) \end{array}$$

$$\left\{\begin{array}{l} (1.2 + 0.12S_{MS})D + 1.0L_{\exp} + 1.5I_e\left(Q_T - Q_{ns}\right) \le \phi_s BR_{nem} \\ (0.9 - 0.12S_{MS})D + 1.5I_e\left(Q_T - Q_{ns}\right) \le \phi_s BR_{nem} \end{array}\right\} \begin{array}{l} (5e) \\ (5f) \end{array}$$

(c) Ordinary Actions

Ordinary force-controlled actions shall satisfy either Equation (6a) or Equation (6b):

$$Q_{ns} + 0.9I_e(Q_T - Q_{ns}) \le \phi_s BR_n \qquad (6a)$$

$$Q_{ns} + I_e(Q_T - Q_{ns}) \le \phi_s BR_{nem} \qquad (6b)$$

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Performance Evaluation for MCE (2475 years) LATBSDC (2020)

APPENDIX B – Recommended *B* and ϕ_s Values to be used in conjunction with Equations 5a, 5b, 5c, 5d, 5e, 5f, 6a, and 6b.

Component	Seismic Action	Classification	ϕ_s	*B*
Below Grade Perimeter Walls	Flexure	Ordinary	0.9	1.0
	Shear	Ordinary	0.9	1.0
Other walls (below and above grade) $h_w/\ell_w < 2.0$	Shear	Critical	0.75	1.25
Other walls (below and above grade) $h_w/\ell_w \geq 2.0$	Shear	Critical	0.75	1.35
Core Walls	Shear	Critical	0.75	1.35
Diaphragm with Major Shear Transfer	Flexure	Critical***	0.9	1.0
	Shear	Critical	0.75	1.35
Typical (non-transfer slab) Diaphragm Forces (excludes collectors and shear transfer to vertical element)	Axial (includes chord forces)	Ordinary	0.9	1.0
	Flexure	Ordinary	0.9	1.0
	Shear	Ordinary	0.9	1.0
Drag (Collector) Members	Compression	Critical	0.65	1.0
	Tension	Critical	0.9	1.0
Vertical Element-to-Diaphragm Connection	Bearing	Critical	0.65	1.0
	Shear Transfer (Shear Friction)	Critical	0.75	1.0
Gravity Columns and Special Moment Frames (Beams, Columns, Beam-Column joints) excluding, Intentional Outrigger Columns, & Columns Supporting Discontinuous Vertical Elements)	Axial	Critical	0.65	1.0
	Shear	Critical	0.75	1.0
	Flexure (in Axial – Flexure Combinations)	Ordinary	0.9	1.0
Intentional Outrigger Columns & Columns Supporting Discontinuous Vertical Elements*	Axial	Critical	0.65	1.0
	Shear	Critical	0.75	1.0
	Flexure (in Axial – Flexure Combinations)	Ordinary	0.9	1.0
Transfer Girders*	Flexure	Critical	0.9	1.0
	Shear	Critical	0.75	1.0
Foundations	Flexure	Ordinary	0.9	1.0
	Shear (with A_v**)	Critical	0.75	1.35
	Shear (w/o A_v**)	Critical	0.75	1.00
Foundation Piles (Structural Capacity)	Compression	Critical	0.65	1.0
	Tension	Ordinary	0.9	1.0
	Flexure	Ordinary	0.9	1.0
	Shear	Critical	0.75	1.0

* Effects of vertical acceleration shall be considered.
** A_v = Shear reinforcement
*** See the footnote on page 58 regarding different factors for application of Equations 5a to 5f for this case.

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Table 6-1 Seismic resistance factors, ϕ_s

Action Type	ϕ_s
Critical force-controlled element	ϕ as specified in the applicable material standard (ACI 318, AISC 360, AISC 341, AISC 358)
Ordinary force-controlled element	0.9

Table 2. Expected Material Strengths

Material	Expected strength	
Reinforcing Steel	Expected Yield Strength, f_{ye}, ksi	Expected Ultimate Strength, f_{ue}, ksi
A615 Grade 60	70	106
A615 Grade 75	82	114
A706 Grade 60	69	95
A706 Grade 80	85	112
A706 Grade 100	105	To be determined based on tests and documented substantiations
Concrete		$f'_{ce} = 1.3f'_c$

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Código Modelo Sísmico
América Latina y El Caribe

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Performance Evaluation for MCE (2475 years):

3.6.3.2.2 Deformation-Controlled Actions LATBSDC (2020)

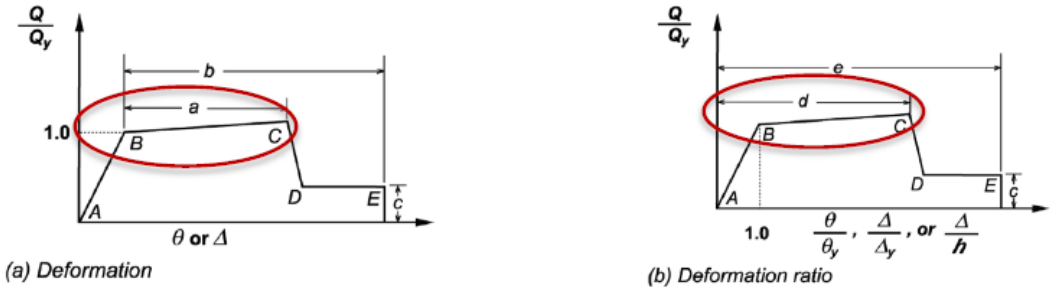

Figure 5. ASCE 41 Generalized Component Force-Deformation Relations for Depicting Modeling and Acceptance Criteria.

Acceptance criterion may be assumed to be equal to $1/I_e$ times the "a" values for plastic deformations or $1/I_e$ times the "d" values for deformation ratios published in ASCE 41 tables for nonlinear response procedures (see Figure 5).

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Performance Evaluation for MCE (2475 years):

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Table 6-2. Recommended deformation limits for deformation-controlled actions

Item		Engineering Demand Parameter	Acceptance Limit
Reinforced concrete walls (outside of primary hinge zone)	No confinement	Concrete compression strain over gage length [1]	0.001
		Steel tension strain over gage length [1]	$2\varepsilon_y$
	Intermediate confinement per ACI 318-19 18.10.6.5	Concrete compression strain over gage length [1]	0.003
		Steel tension strain over gage length [1]	0.01
	Full confinement per ACI 318-19 18.10.6.4 except provisions of Section 18.10.6.4(i) need not be satisfied [2]	Concrete compression strain over gage length [1]	0.005 (0.01 [3])
		Steel tension strain over gage length[1]	0.01 (0.05 [3])
Reinforced concrete walls (primary hinge zone)	Full confinement of the entire cross section per ACI 318-19 18.10.6.4 [2]	Concrete compression strain over gage length [1]	0.005 (0.01 [3])
		Steel tension strain over gage length [1]	0.01 (0.05 [3])
Coupling beams	Conventionally-reinforced [4]	Total chord rotation	0.04
	Diagonally-reinforced	Total chord rotation	0.06
	Fiber-reinforced [5]	Total chord rotation	0.04
	Steel-reinforced	Total chord rotation	0.06
Slab outrigger beams	At wall end	Total rotation	0.05 (0.08) [6]
	At column end [7], with shear reinforcement, $v_{uv}/(v_c+v_s) \leq 0.7$	Total rotation	0.05
	At column end [7], with shear reinforcement, $v_{uv}/(v_c+v_s) > 0.7$	Total rotation	0.03
	At column end, without shear reinforcement	Total rotation	refer to ACI 318-19 18.14.5

3.6.3.2.2 Deformation-Controlled Actions

LATBSDC (2020)

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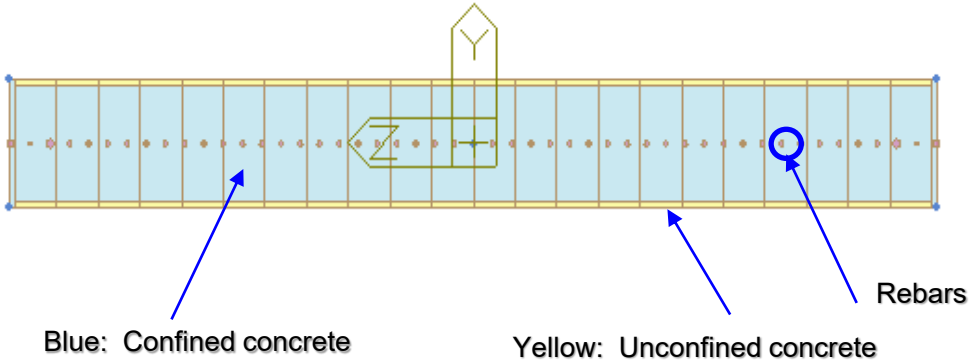
Modelling Requirements for MCE (2475 years)

Core walls model

- Fiber elements with spread plasticity
- Typical fiber length of rectangular elements: ≤ 0.30m.
- For short elements (peers): 0.20m
- Minimum of 6 fibers per pier
- Fiber length : 1.20m.
- A stress-strain relation assigned to each element

$$l_p \leq \text{minimum of} \begin{Bmatrix} 0.5l_w \\ h_i \\ 0.1h_n \end{Bmatrix}$$

Section 3.4.14 of LATBSDC (2020)



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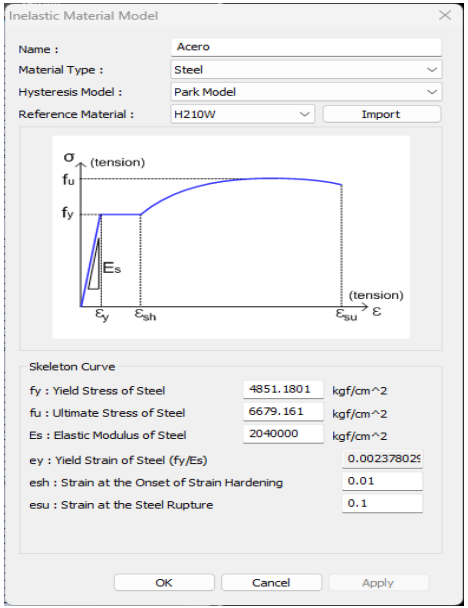
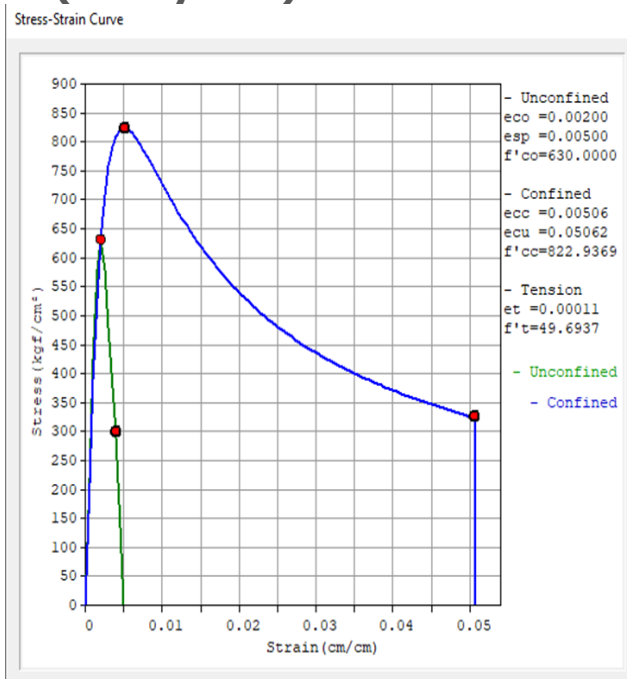
Modelling Requirements for MCE (2475 years)



Stress-strain model for reinforcement. Park (1971)



Stress-strain model for confined and unconfined concrete. *Mander et. al (1988)*

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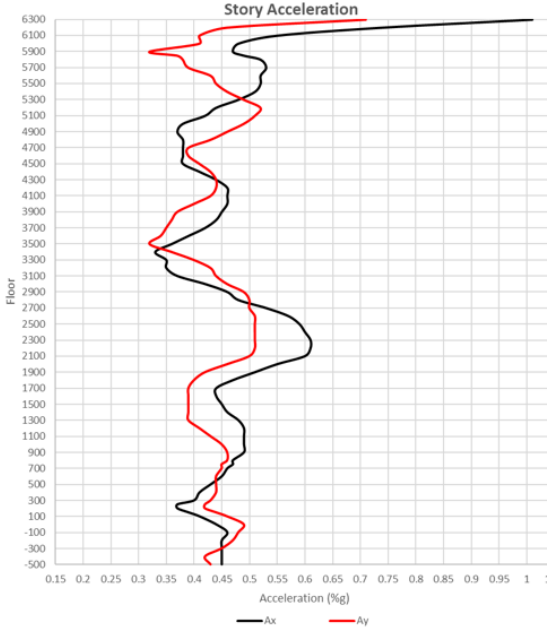
Performance Evaluation for MCE (2475 years)



- Average Peak Floor Acceleration

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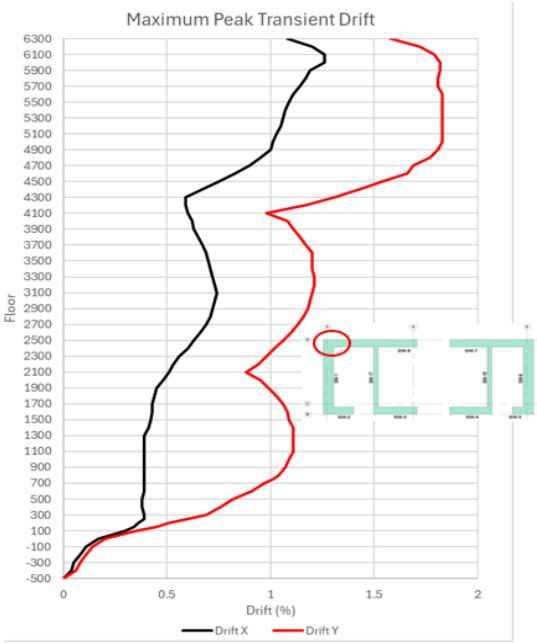
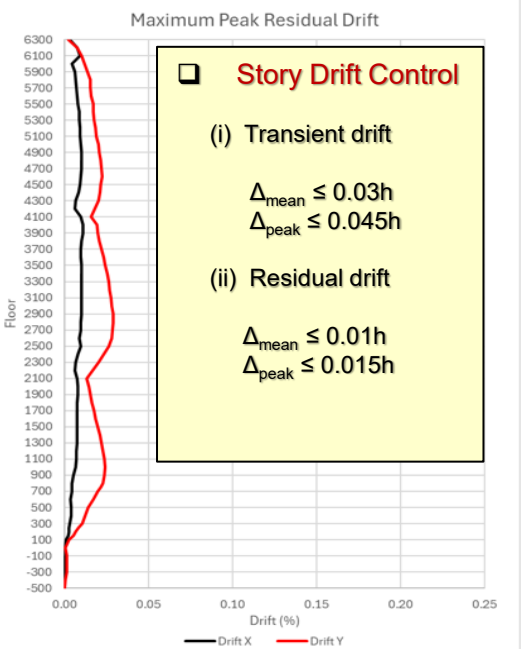
Performance Evaluation for MCE (2475 years)





- **Story Drift Control**

(i) Transient drift

$\Delta_{mean} \leq 0.03h$
$\Delta_{peak} \leq 0.045h$

(ii) Residual drift

$\Delta_{mean} \leq 0.01h$
$\Delta_{peak} \leq 0.015h$

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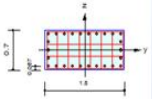
Performance Evaluation for MCE (2475 years)

Columns (P-M-M: deformation-controlled / Shear: force-controlled)

Design Condition

Design Code : ACI318-08 UNIT SYSTEM : tonf, m
Member Number : 2607 (PM), 2607, 2618 (Shear-y,z)
Material Data : fc = 4550, fy = 48500, fys = 48500 tonf/m^2
Column Height : 4.15 m
Section Property : C0.70x1.50 (No : 26)
Rebar Pattern : 26 - 5 - #8 Ast = 0.0132516 m^2 (Rhost = 0.013)

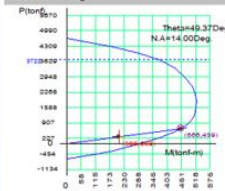


Axial and Moments Capacity

Load Combination : 2 (Pos : J)

Concentric Max. Axial Load	PhiPn-max	= 3721.86 tonf	
Axial Load Ratio	Pu / PhiPn	= 309.155 / 666.443	= 0.464 < 1.000 ..... O.K
Moment Ratio	Mo / PhiMn	= 208.956 / 459.149	= 0.455 < 1.000 ..... O.K
	Moy / PhiMny	= 134.943 / 298.986	= 0.451 < 1.000 ..... O.K
	Moz / PhiMnz	= 159.540 / 348.461	= 0.458 < 1.000 ..... O.K

P-M Interaction Diagram



PhiPn(tonf)	PhiMn(tonf-m)
4652.33	0.00
4310.76	171.93
3721.29	369.80
2932.03	477.39
2204.53	518.10
1609.07	520.43
1263.60	512.92
1053.91	502.54
692.03	463.37
294.38	379.60
-100.65	261.89
-476.97	106.53
-642.70	0.00

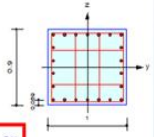
Shear Capacity

[END]	y (LCB : 2, POS : J)	z (LCB : 2, POS : J)
Applied Shear Force (Vu)	88.6562 tonf	39.0082 tonf
Design Shear Strength (PhiVc+PhiVs)	137.229 + 114.400 = 251.629 tonf	141.110 + 100.748 = 241.859 tonf
Shear Ratio	0.352 < 1.000 ..... O.K	0.161 < 1.000 ..... O.K
As-H_use	0.00189 m^2/m, 4-#3 @150	0.00378 m^2/m, 8-#3 @150

[MIDDLE]	y (LCB : 2, POS : 1/2)	z (LCB : 2, POS : 1/2)
Applied Shear Force (Vu)	88.6562 tonf	39.0082 tonf
Design Shear Strength (PhiVc+PhiVs)	137.631 + 114.400 = 252.031 tonf	141.490 + 100.748 = 242.238 tonf
Shear Ratio	0.352 < 1.000 ..... O.K	0.161 < 1.000 ..... O.K
As-H_use	0.00189 m^2/m, 4-#3 @150	0.00378 m^2/m, 8-#3 @150

Design Condition ACI [redacted]

Design Code UNIT SYSTEM : tonf, m
Member Number : 2946 (PM), 2860, 2946 (Shear-y,z)
Material Data : fc = 3640, fy = 48500, fys = 48500 tonf/m^2
Column Height : 4.55 m
Section Property : C0.90x1.00 (No : 21)
Rebar Pattern : 22 - 6 - #9 Ast = 0.0141935 m^2 (Rhost = 0.016)

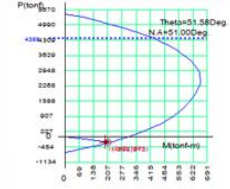


Axial and Moments Capacity

Load Combination : 2 (Pos : I)

Concentric Max. Axial Load	PhiPn-max	= 4387.67 tonf	
Axial Load Ratio	Pu / PhiPn	= -241.68 / 254.559	= 0.949 < 1.000 ..... O.K
Moment Ratio	Mo / PhiMn	= 197.374 / 211.526	= 0.933 < 1.000 ..... O.K
	Moy / PhiMny	= 124.218 / 131.435	= 0.945 < 1.000 ..... O.K
	Moz / PhiMnz	= 153.383 / 165.735	= 0.925 < 1.000 ..... O.K

P-M Interaction Diagram



PhiPn(tonf)	PhiMn(tonf-m)
5484.58	0.00
5138.14	182.24
4411.89	429.51
3400.76	614.67
2389.59	659.19
1579.57	606.21
1157.04	560.44
952.77	532.61
605.75	470.55
209.43	372.30
-184.25	239.52
-527.49	88.92
-688.39	0.00

Shear Capacity

[END]	y (LCB : 3, POS : J)	z (LCB : 2, POS : J)
Applied Shear Force (Vu)	13.6592 tonf	36.9014 tonf
Design Shear Strength (PhiVc+PhiVs)	66.3016 + 65.0334 = 131.335 tonf	15.9648 + 46.4384 = 62.4032 tonf
Shear Ratio	0.104 < 1.000 ..... O.K	0.591 < 1.000 ..... O.K
As-H_use	0.00237 m^2/m, 5-#3 @150	0.00189 m^2/m, 4-#3 @150

[MIDDLE]	y (LCB : 3, POS : 1/2)	z (LCB : 2, POS : 1/2)
Applied Shear Force (Vu)	13.6592 tonf	36.9014 tonf
Design Shear Strength (PhiVc+PhiVs)	66.5320 + 65.0334 = 131.565 tonf	17.1741 + 46.4384 = 63.6125 tonf
Shear Ratio	0.104 < 1.000 ..... O.K	0.580 < 1.000 ..... O.K
As-H_use	0.00237 m^2/m, 5-#3 @150	0.00189 m^2/m, 4-#3 @150

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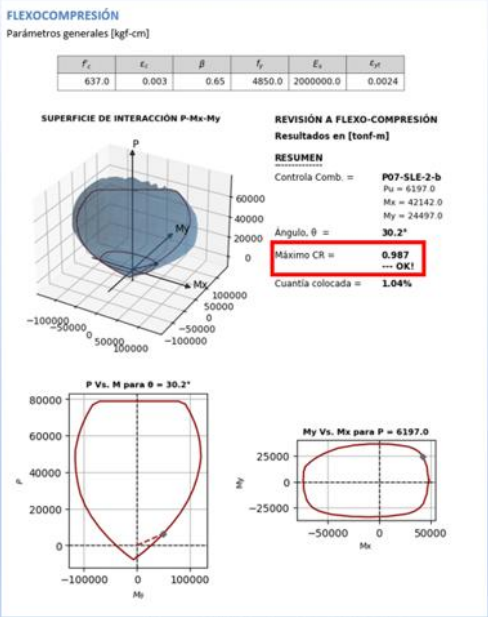
Performance Evaluation for MCE (2475 years)

P-M-M in walls (deformation-controlled action)



FLEXOCOMPRESIÓN

Parámetros generales [kgf-cm]

f'_c	ε_c	β	f_y	E_s	ε_{yt}
637.0	0.003	0.65	4850.0	2000000.0	0.0024

SUPERFICIE DE INTERACCIÓN P-Mx-My

REVISIÓN A FLEXO-COMPRESIÓN

Resultados en [tonf-m]

RESUMEN

Controla Comb. = P07-SLE-2-b
Pu = 6197.0
Mx = 42142.0
My = 24497.0

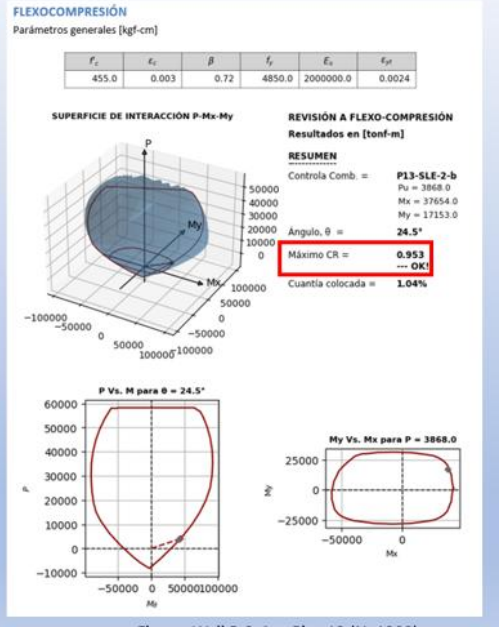
Ángulo, θ = 30.2°

Máximo CR = 0.987 --- OK!

Cuantía colocada = 1.04%

P Vs. M para θ = 30.2°

My Vs. Mx para P = 6197.0



FLEXOCOMPRESIÓN

Parámetros generales [kgf-cm]

f'_c	ε_c	β	f_y	E_s	ε_{yt}
455.0	0.003	0.72	4850.0	2000000.0	0.0024

SUPERFICIE DE INTERACCIÓN P-Mx-My

REVISIÓN A FLEXO-COMPRESIÓN

Resultados en [tonf-m]

RESUMEN

Controla Comb. = P13-SLE-2-b
Pu = 3868.0
Mx = 37654.0
My = 17153.0

Ángulo, θ = 24.5°

Máximo CR = 0.953 --- OK!

Cuantía colocada = 1.04%

P Vs. M para θ = 24.5°

My Vs. Mx para P = 3868.0

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Performance Evaluation for MCE (2475 years)

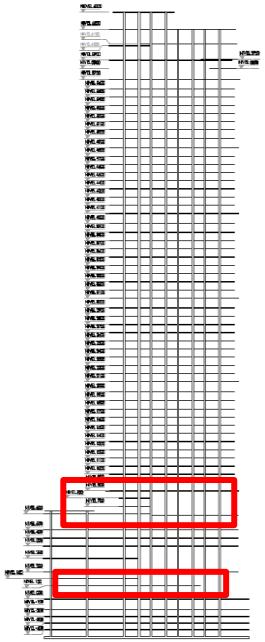

Table 6-2. Recommended deformation limits for deformation-controlled actions

Item		Engineering Demand Parameter	Acceptance Limit
Reinforced concrete walls (outside of primary hinge zone)	No confinement	Concrete compression strain over gage length [1]	0.001
		Steel tension strain over gage length [1]	$2\varepsilon_y$
	Intermediate confinement per ACI 318-19 18.10.6.5	Concrete compression strain over gage length [1]	0.003
		Steel tension strain over gage length [1]	0.01
	Full confinement per ACI 318-19 18.10.6.4 except provisions of Section 18.10.6.4(i) need not be satisfied [2]	Concrete compression strain over gage length [1]	0.005 (0.01 [3])
		Steel tension strain over gage length[1]	0.01 (0.05 [3])
Reinforced concrete walls (primary hinge zone)	Full confinement of the entire cross section per ACI 318-19 18.10.6.4 [2]	Concrete compression strain over gage length [1]	0.005 (0.01 [3])
		Steel tension strain over gage length [1]	0.01 (0.05 [3])

[1] Strain gage length should be taken per Equation (2) on page 48. The limits in this table are selected to reflect the gage length concerns discussed in commentary C.3.6.3.2.2 below.

[2] Full confinement is required for the entire cross section of the core at the wall critical section and shall be extended vertically above and below per ACI 318-19 18.10.6.2, but need not exceed two levels above and below the critical section.

[3] For compressive strains larger than 0.005 or tensions strains larger than 0.01 refer to Appendix A.1, which requires a reduction in wall shear strength.

Ref. LATBSDC 2020

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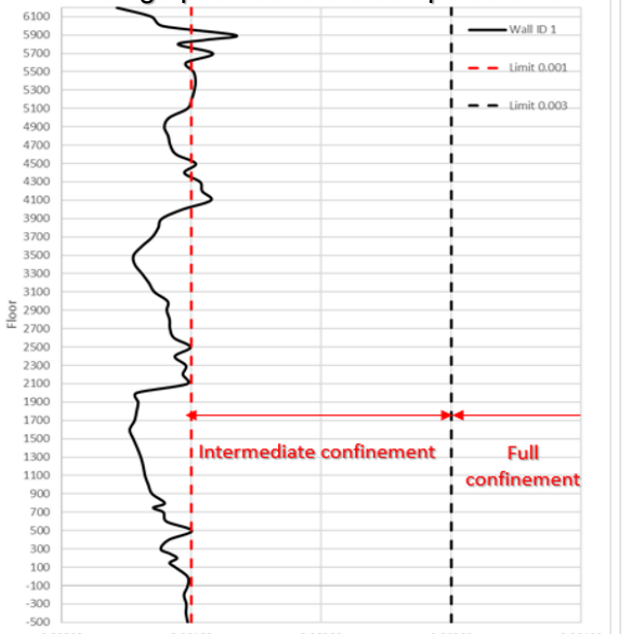
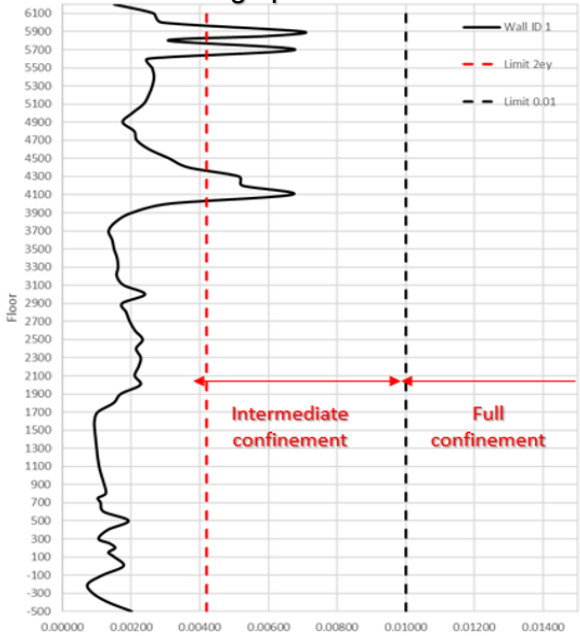
Performance Evaluation for MCE (2475 years)

Average peak concrete compression strain



Average peak steel strain



Evaluation of concrete and steel fiber deformation limits

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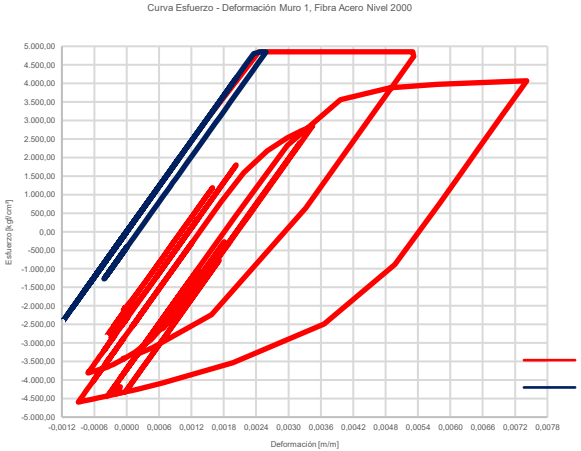
Performance Evaluation for MCE (2475 years)

δx vs δy
Movimiento de Azotea



σ vs ε
Fibra de Acero N2000

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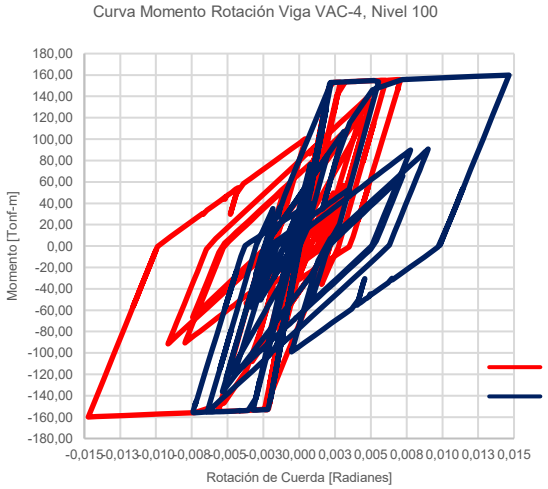
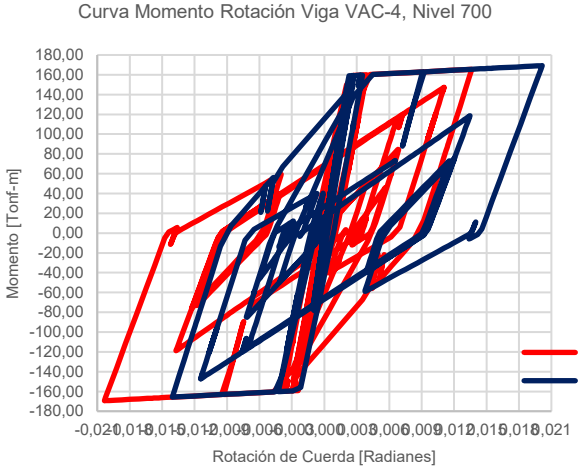
Performance Evaluation for MCE (2475 years)



M vs θ

VAC-4 N+100



M vs θ

VAC-4 N+700

Bioma Diseño Sísmico basado en desempeño

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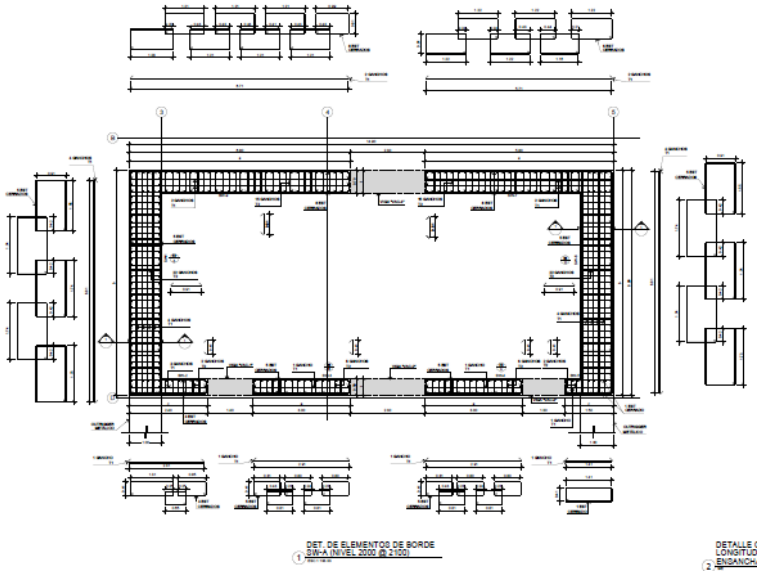
Detalles Estructurales



Shear Wall N2000-N2100

Bioma | Diseño Sísmico basado en desempeño

Código Modelo Sísmico
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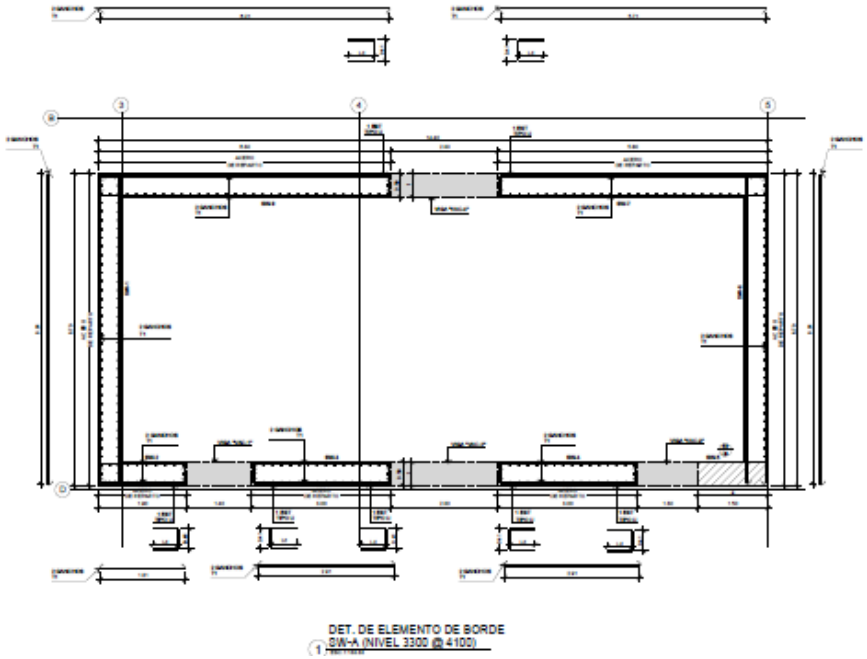
Detalles Estructurales

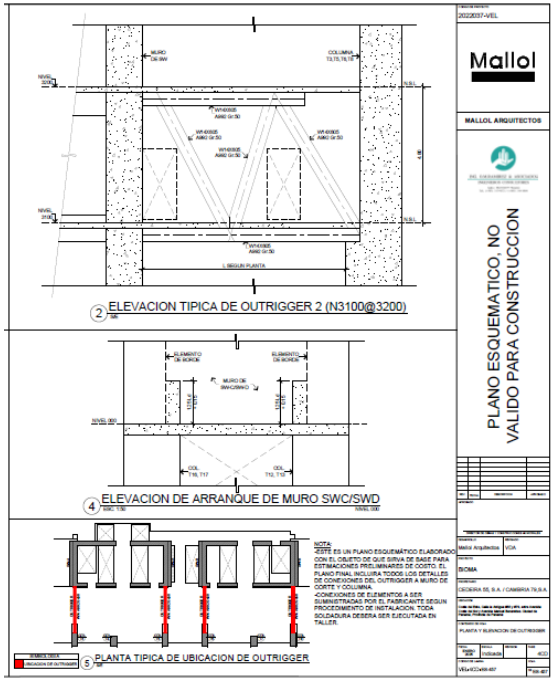


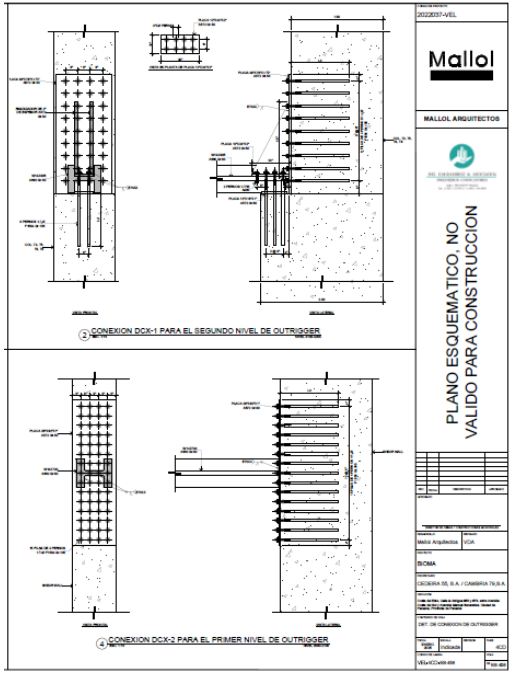
Shear Wall N3300-N4100

Bioma | Diseño Sísmico basado en desempeño

Bioma by The Velopers

Detalles Estructurales





IPANEMA
AT COSTA DEL ESTE
Waterfront Residences

Gracias por su atención

CMS Código Modelo Sísmico

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