



ACIES

Asociación Colombiana de Ingeniería Estructural

Presentación Técnica

“Sistemas de protección sísmica y resiliencia estructural”



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Decano de la Facultad de Ingeniería de la
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Ingeniería Estructural y Geotécnica

An aerial photograph of a coastal city, likely Valparaíso, Chile, showing a dense urban area built on hills overlooking the ocean. The city is characterized by its colorful buildings and winding streets. In the foreground, there are modern high-rise buildings. The ocean is visible on the left, with waves breaking against the shore. Mountains are visible in the background under a clear sky.

Asociación Colombiana de Ingeniería Estructural

Sistemas de Protección Sísmica y Resiliencia Estructural

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PRESENTACIÓN

1

Terremotos
recientes en
Chile

2

Normativa y
Amenaza

3

Aislamiento
Sísmico

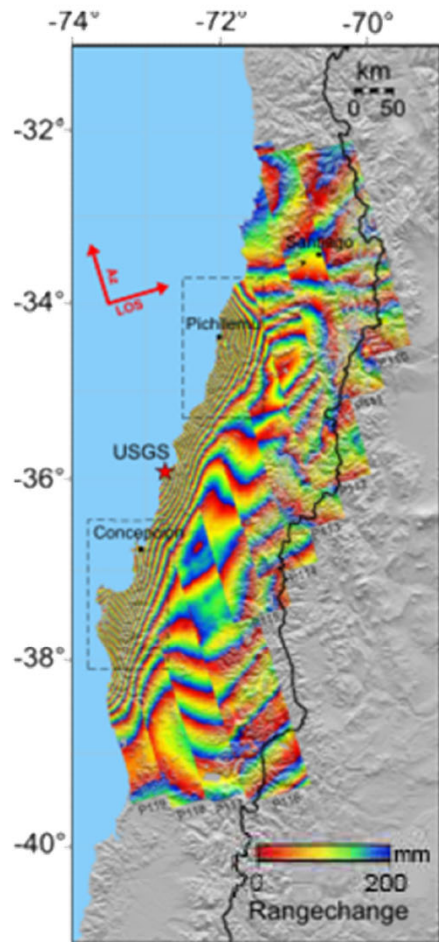
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Disipación de
Energía

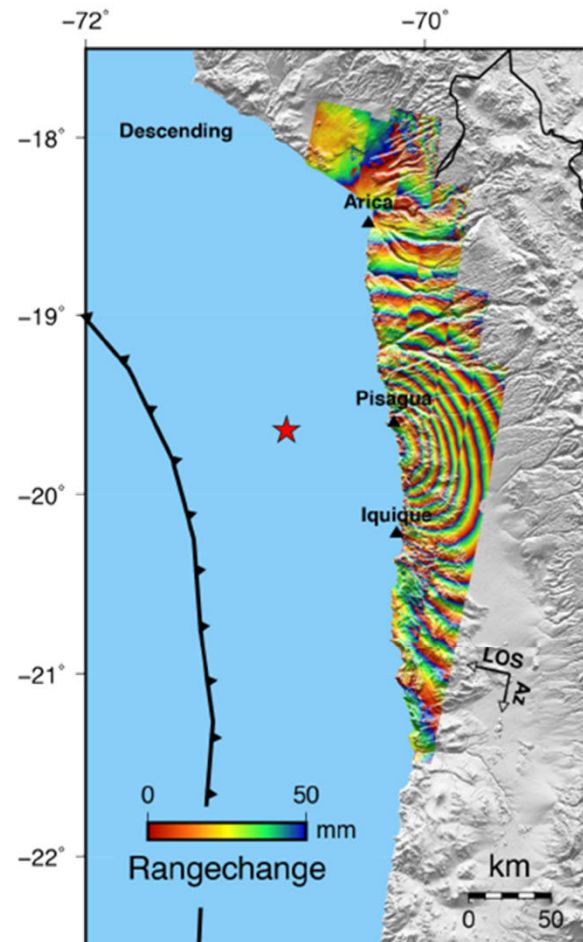
5

Discusión

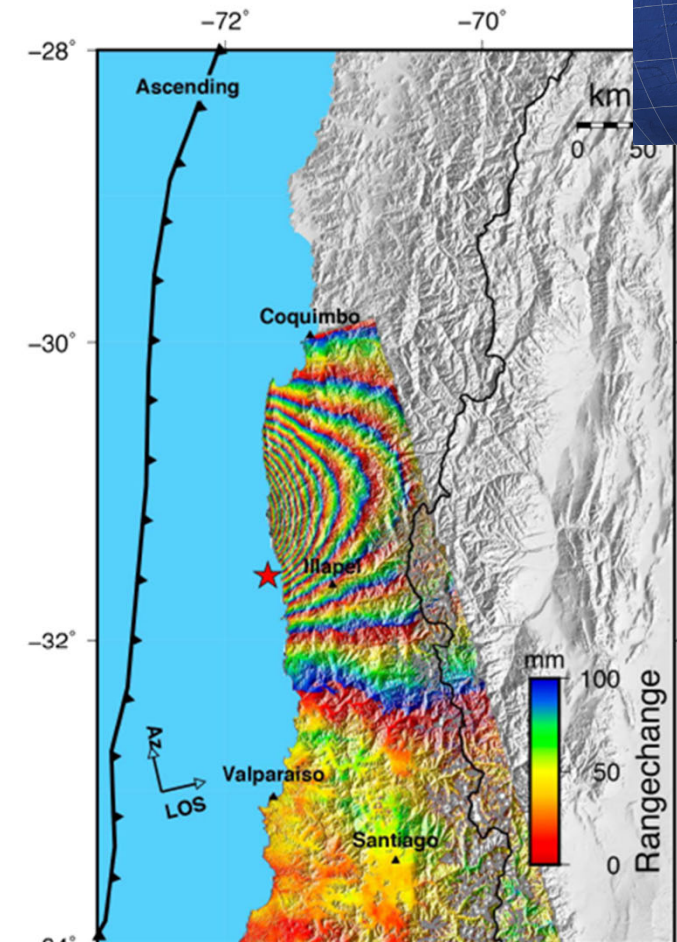
MAULE (2010), PISAGUA (2014), ILLAPEL (2015)



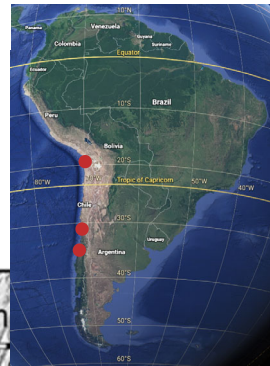
Maule, 2010, $M_w = 8.8$
Satélite: ALOS



Pisagua, 2014, $M_w = 8.2$
Satélite: TerraSAR-X

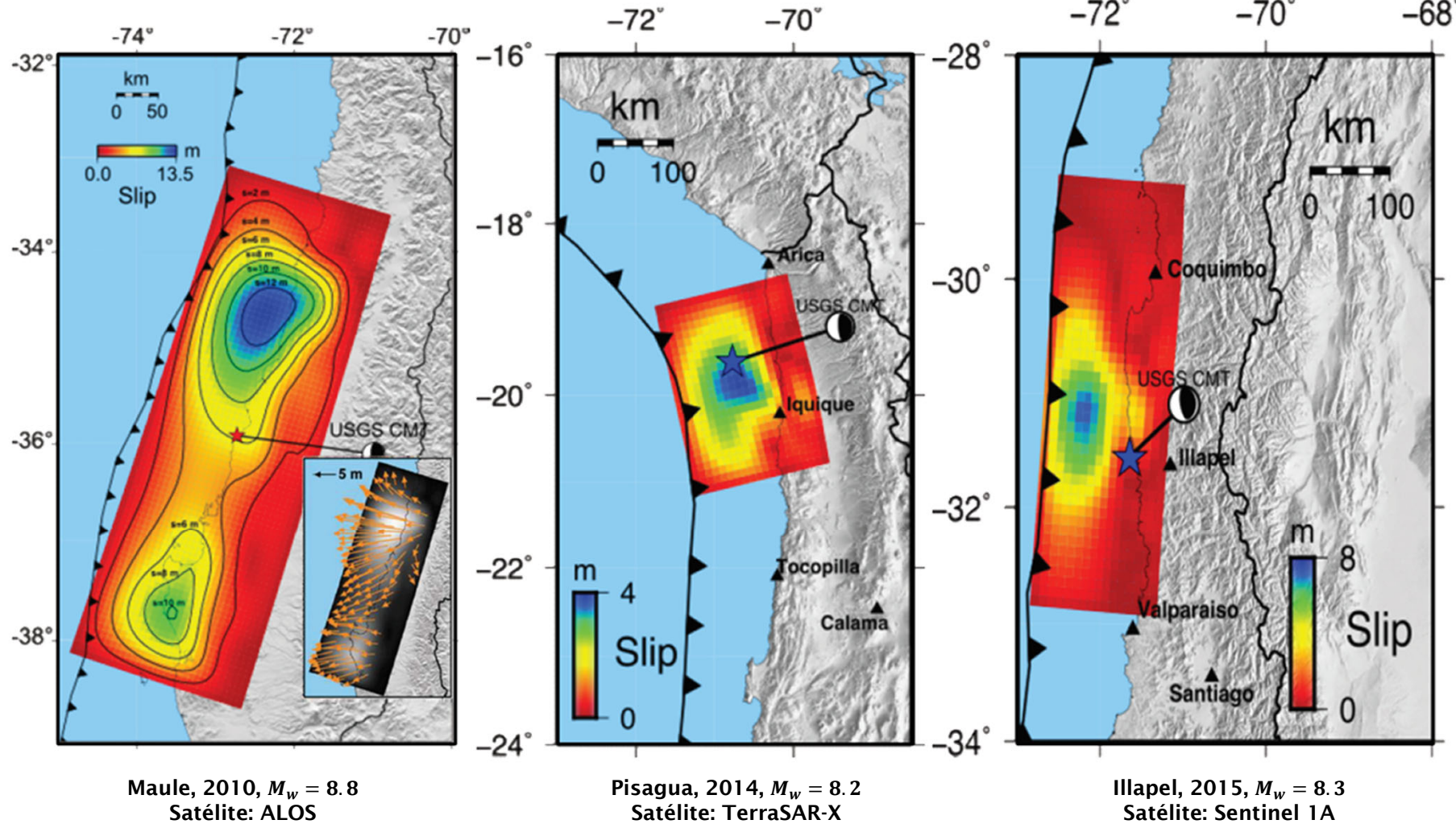
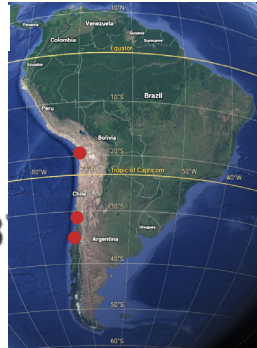


Illapel, 2015, $M_w = 8.3$
Satélite: Sentinel 1A



MODELOS DE FALLA

MAULE (2010), PISAGUA (2014), ILLAPEL (2015)



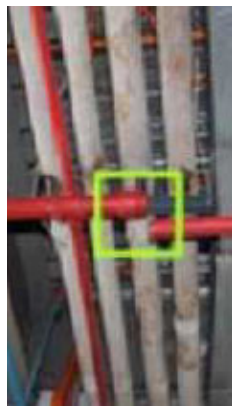
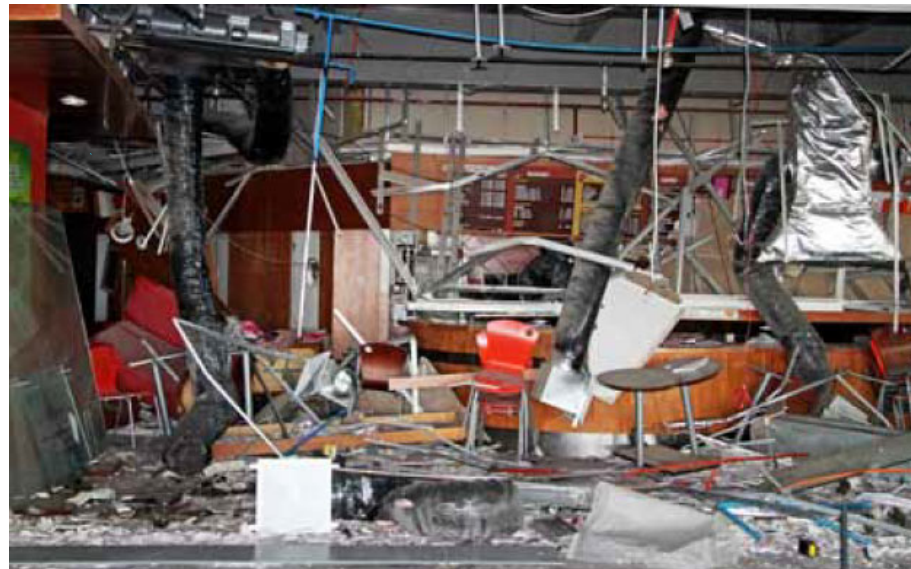
DAÑOS MAULE, 2010

EERI Special Earthquake Report (2010)
De la Llera et al (2017)



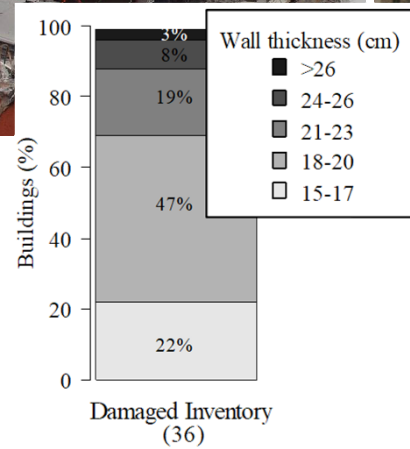
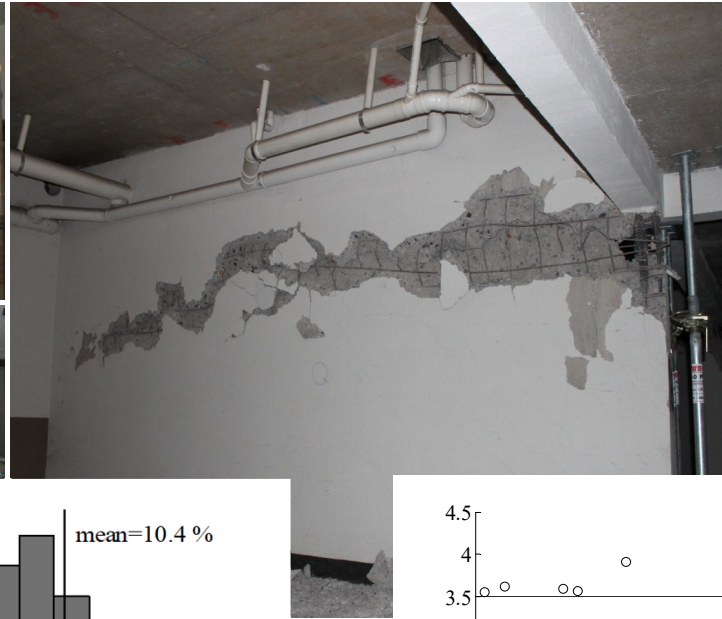
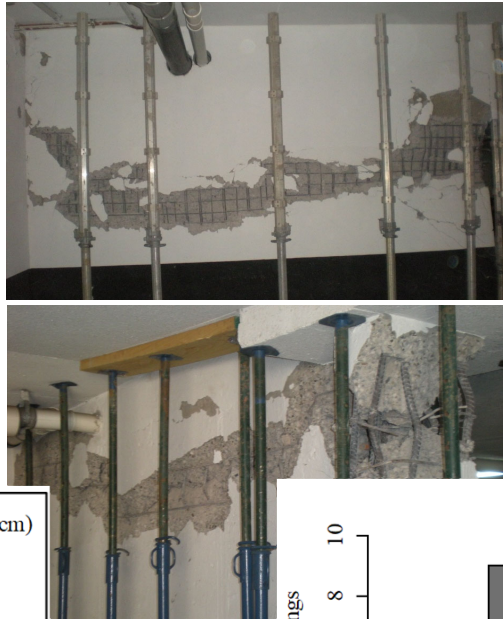
DAÑOS MAULE, 2010

Fuentes: EERI Special Earthquake
Report (2010); Miranda et al (2012)

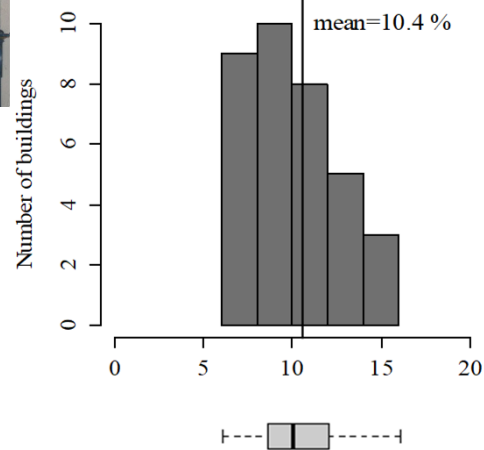


MAULE, 2010

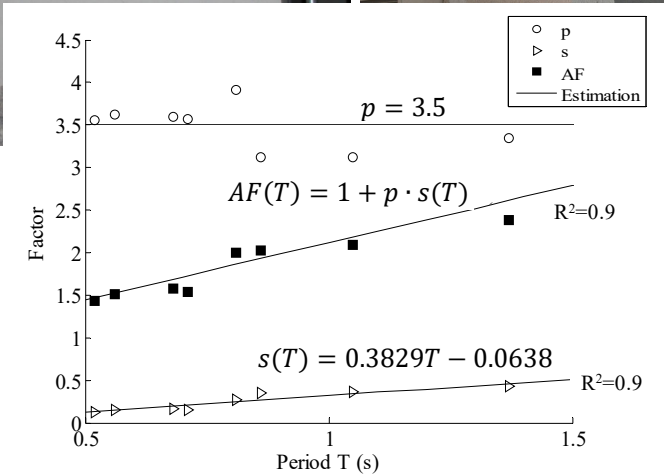
EDIFICIOS DE MUROS DE H.A.



Distribución de espesores



ALR 1er piso



Factor de amplificación dinámica (4 edificios)

EDIFICIOS DE H.A. CAUSA DE LA FALLA

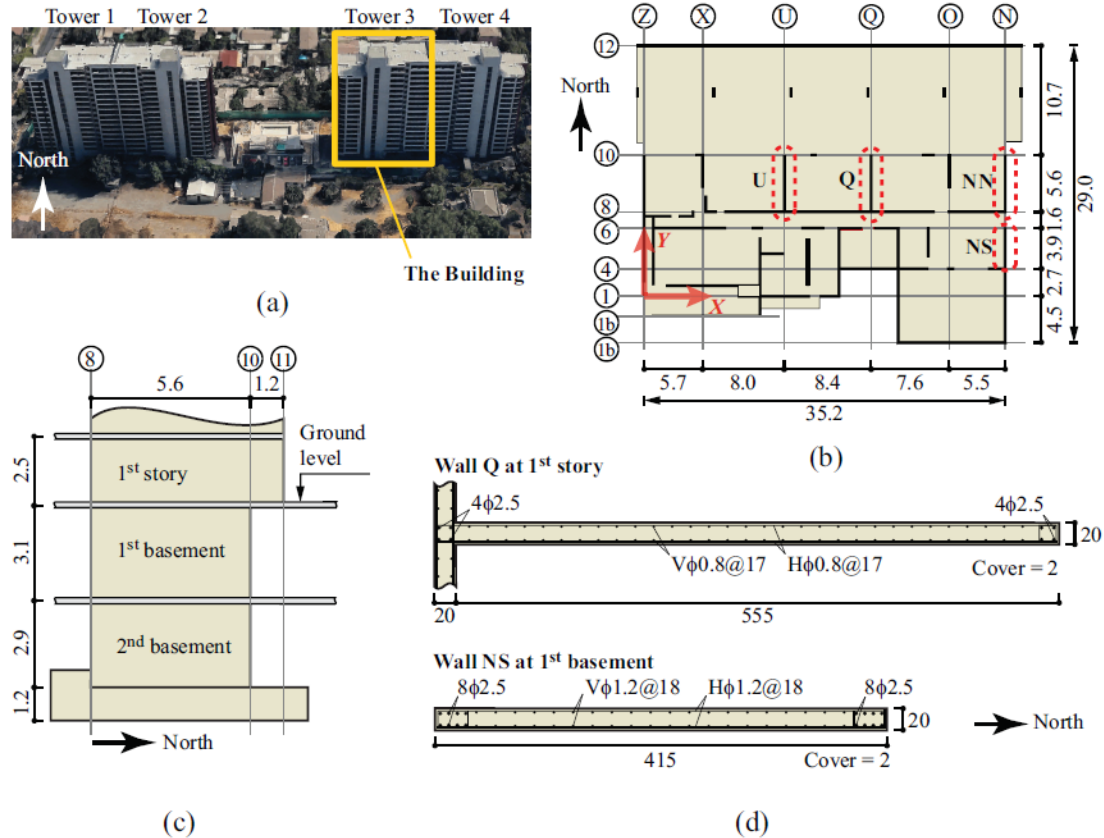


Figure 1. (a) Building complex from Google Earth®, 2017 Google; (b) first basement floor plan with damaged walls circled; (c) elevation of walls U, Q, and NN; and (d) cross sections of walls Q and NS at the critical sections. Dimensions in (b) to (c) are in meters, and dimensions in (d) are in centimeters.

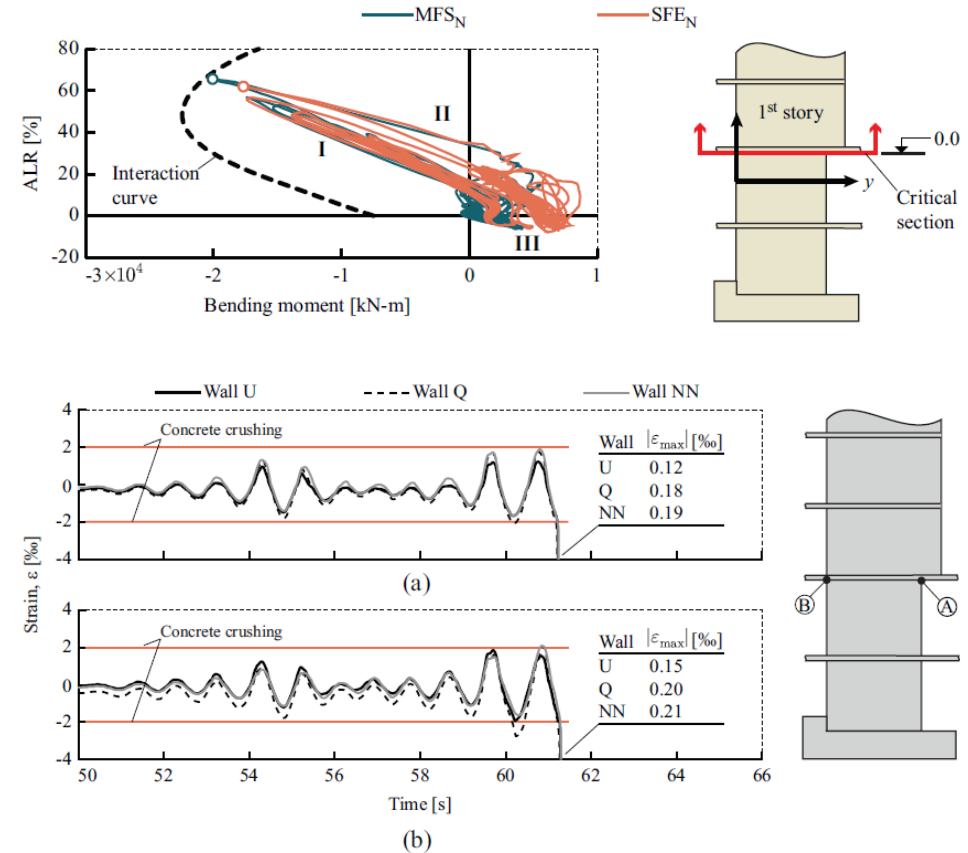


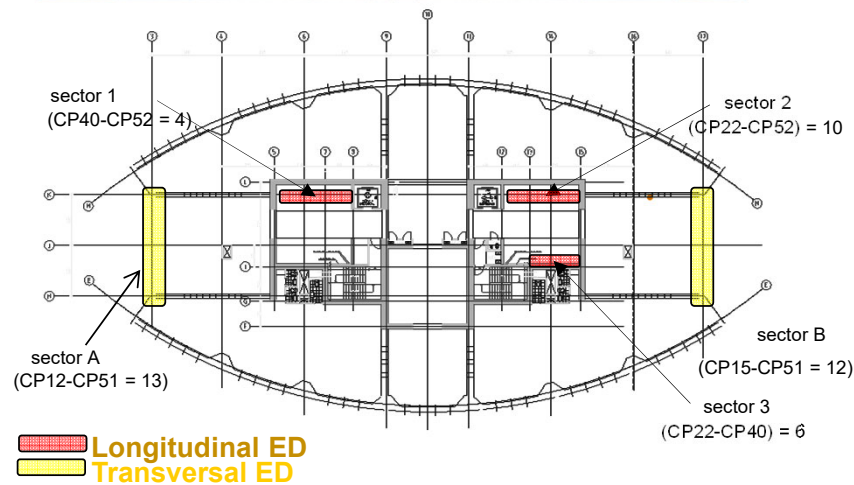
Figure 14. Strain history at boundary point A in the Y-direction at the critical section of walls U, Q, and NN using the two nonlinear models with the Y input of Puente Alto record: (a) MFS_N model; and (b) SFE_N model. Maximum strains before reaching failure are shown in each case.

(Fuente: Vasquez et al., 2019)

LA OTRA CARA DE LA MEDALLA



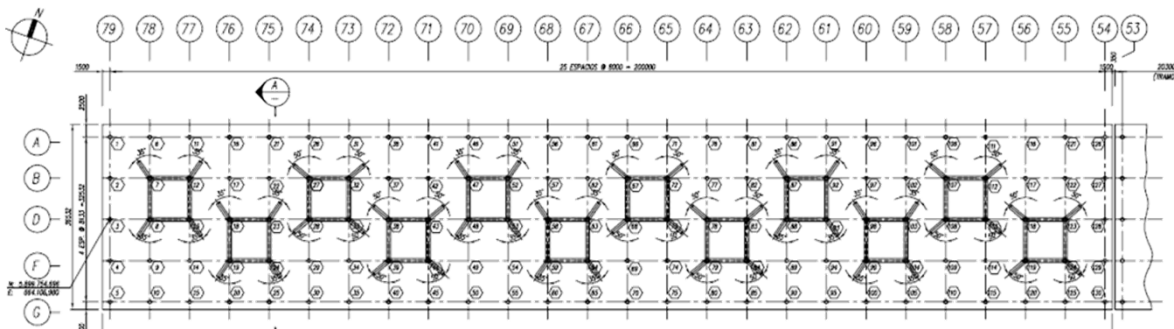
TORRE TITANIUM



MUELLE CORONEL



Ubicación y descripción: El muelle Coronel, aislado sísmicamente; 420m de largo y 37m de ancho; pilares de acero y tablero de concreto; grúas de 1200 ton, y 2.5 ton/m² de carga viva; 48 pilares inclinados (102 diseño original)





Centro de Investigación
para la Gestión Integrada
del Riesgo de Desastres



- 4 Chilean Universities
- 8 Principal Researchers
- 17 Associate Researchers
- 34 Professionals
- 13 Postdoctoral Fellows
- 20 Sponsored MSc Students
- 26 Sponsored PhD Students



Researchers from other six Chilean universities:



ESTRUCTURA DE CIGIDEN

Our mission :

Generate knowledge of excellence **to prevent** extreme natural events to become **disasters**.



SOCIAL PRACTICES

RL4 DISASTER CULTURES AND RISK GOVERNANCE



Manuel Tironi
*Sociology &
Anthropology*



Paula Repetto
*Disaster
Behavioral
Health*

RL6 CITIZEN GOVERNANCE



Carolina Martínez
*Geography &
Territorial Planning*

NATURAL SYSTEMS AND PROCESSES

RL1 SOLID EARTH PROCESSES AND ASSOCIATED HAZARDS



Gabriel González – Deputy Director
Earth Sciences & Natural Hazards

RL2 SURFACE WATER PROCESSES AND ASSOCIATED HAZARDS



Rodrigo Cienfuegos – Director
*Earth Sciences & Civil
Engineering*

RISK AND RESILIENCE ANALYSIS

RL3 RISK AND RESILIENCE OF COMPLEX SYSTEMS AND NETWORKS



Juan Carlos De la Llera
*Civil Engineering/Risk
Resilience of Physical Systems*

RL5 SOCIO-ECONOMIC OF DISASTERS AND MITIGATION STRATEGIES FOR RESILIENT CRITICAL INFRASTRUCTURE SYSTEMS



Nicolás Bronfman
*Risk Perception and
Socio-Economic
Assessment*



Alondra Chamorro
*Civil Engineering &
Infrastructure
Management*

LA ESTRATEGIA CREDEN E ITReND

► 5 Condiciones Habilitantes:

1. Institucionalidad para el **I+D+i+e** en resiliencia
2. Integración de **datos e información**
3. Desarrollo de **capital humano** avanzado en resiliencia
4. Desarrollo de infraestructura para el **descubrimiento científico** y la **innovación** en resiliencia
5. Outreach y **diseminación científica**

► Las 14 TAREAS de la Estrategia Creden:



NORMATIVA Y AMENAZA

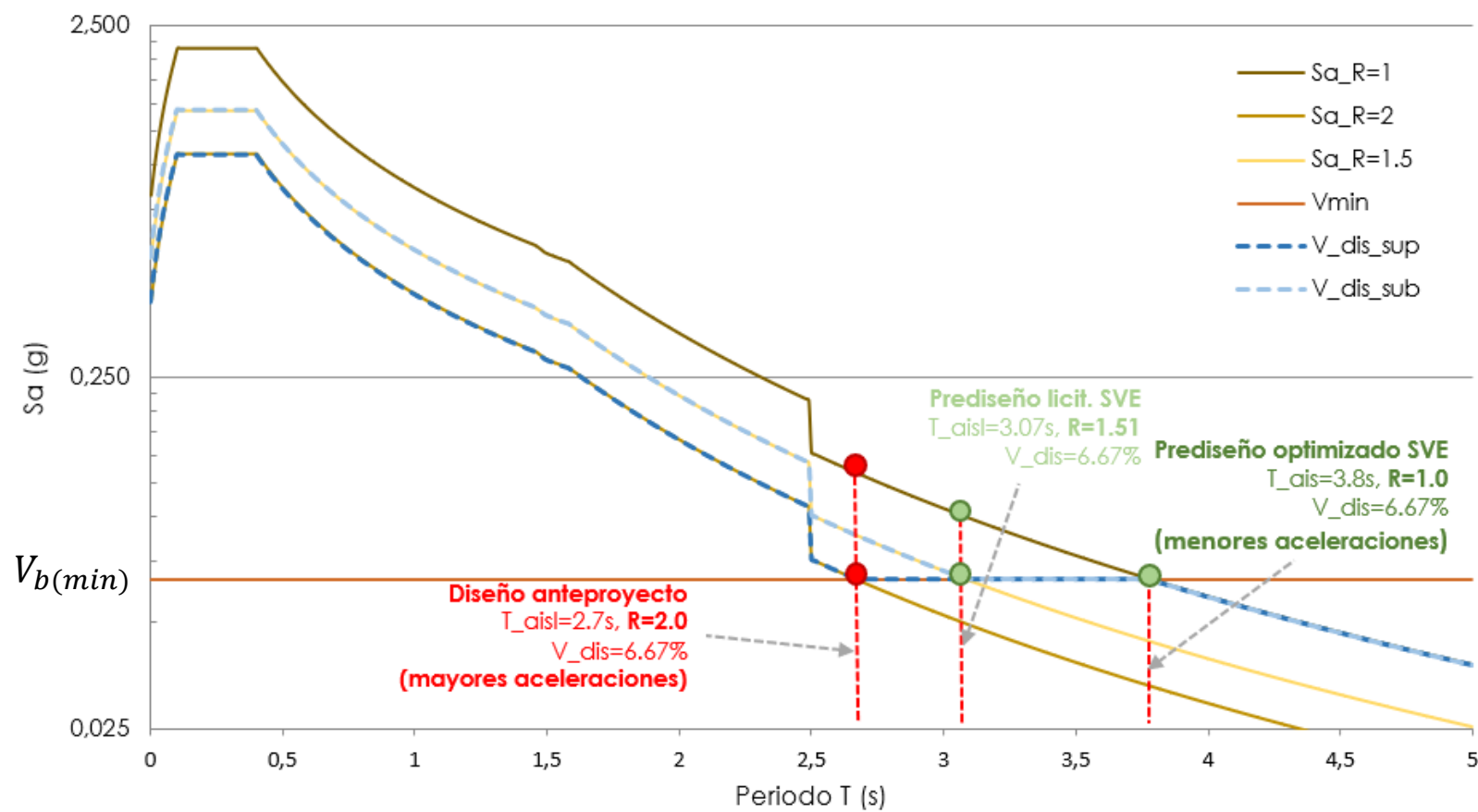


CAMBIOS NORMATIVOS LUEGO DEL 2010 PARA SPS

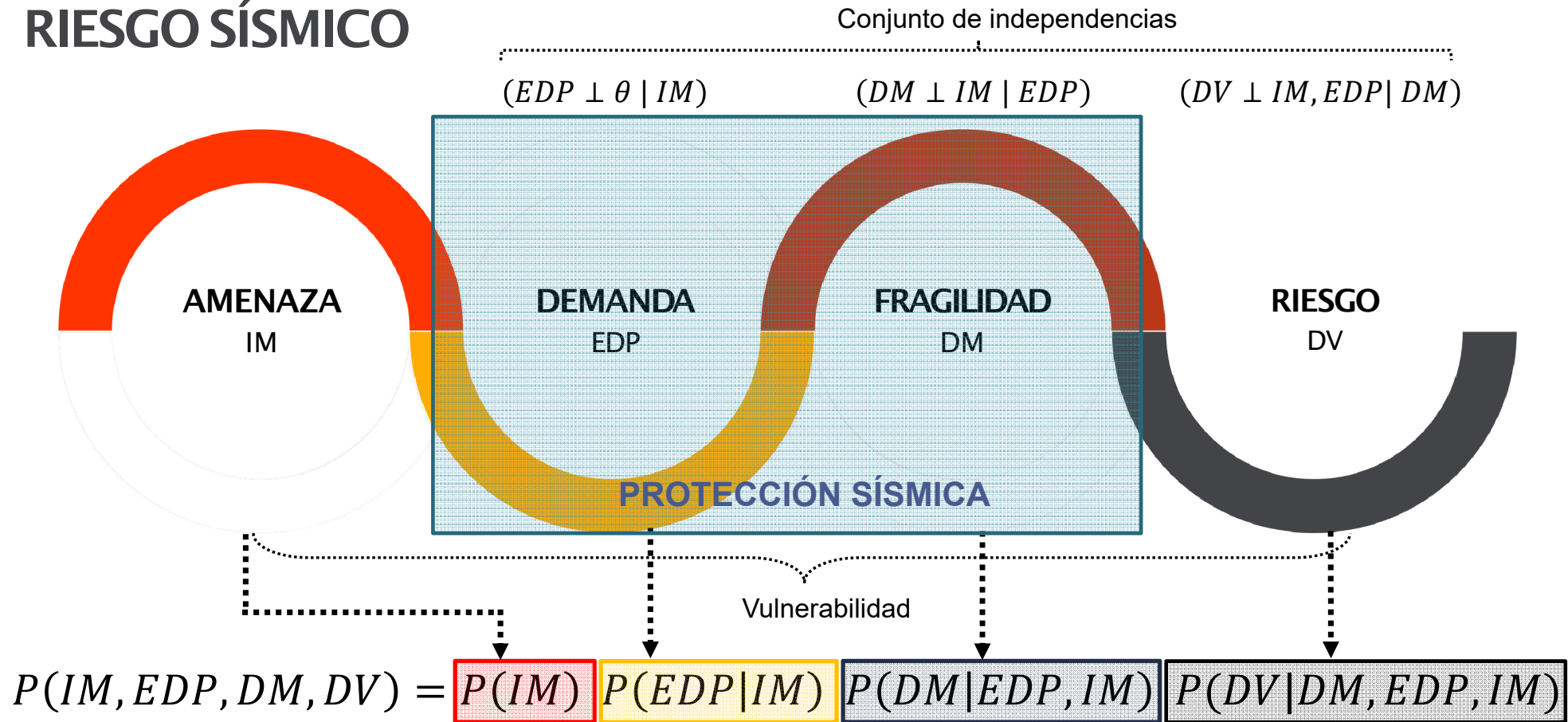
Cambio normativo	Efecto en diseño
Se incrementa R de la sub-estructura de 1.0 a 1.5	Bajan cuantías y secciones de estructura bajo aisladores
Se relaja el criterio de detallamiento de la superestructura desde marco especial a marco intermedio	Bajan cuantías de estructura sobre aisladores
Se incrementa el período máximo de validez del espectro de diseño desde 3.0 a 3.5 seg	Se consiguen menores cortes de diseño
Se limita el corte de diseño de la superestructura a un valor máximo igual al corte elástico	Se consiguen menores cortes de diseño
Se limita el corte de diseño de la subestructura a un valor mínimo igual al corte de la superestructura	Asegura que al utilizar $R = 1.5$ para la subestructura, esta nunca quede diseñada para menos esfuerzo que la superestructura.
Se exige utilizar en el cálculo del corte mínimo, $S = 1$ para todo tipo de suelo	Disminuye el corte mínimo de diseño para suelo tipo C y D y lo aumenta para suelo tipo A

DEMANDA SÍSMICA Y DISEÑO (Nch 2745 y DS61)

Espectros de aceleraciones y Cortes basales de diseño



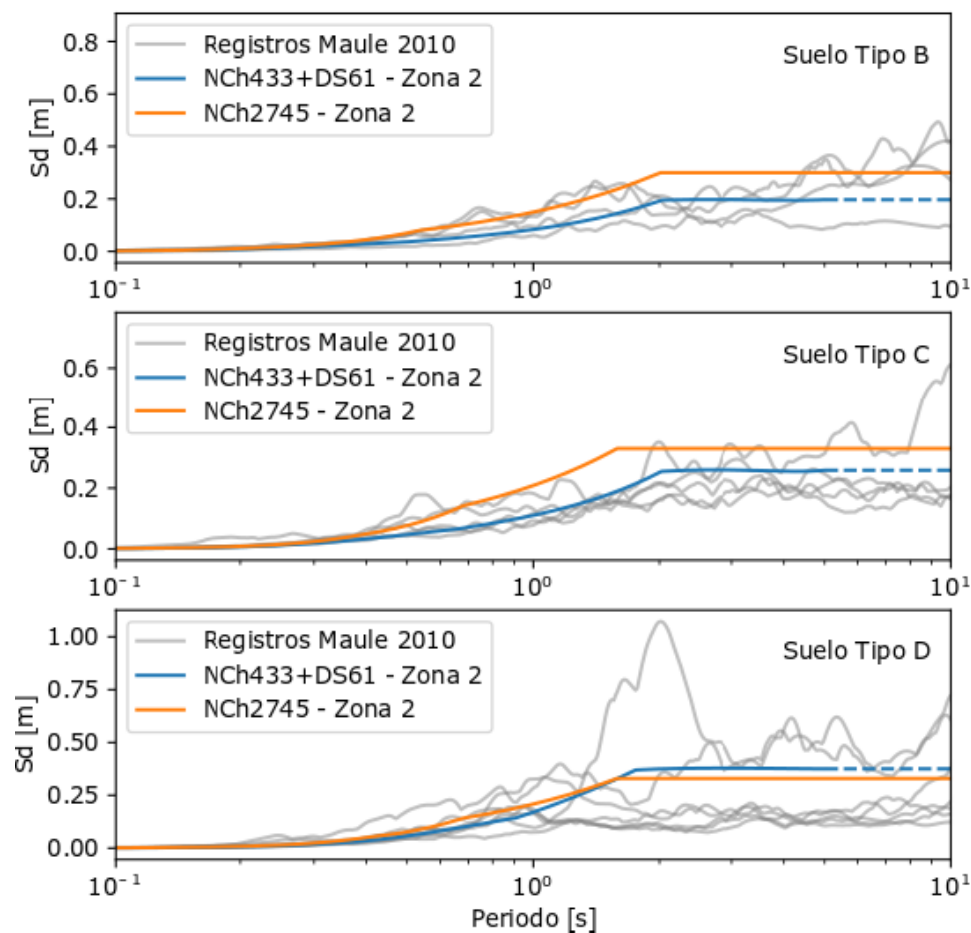
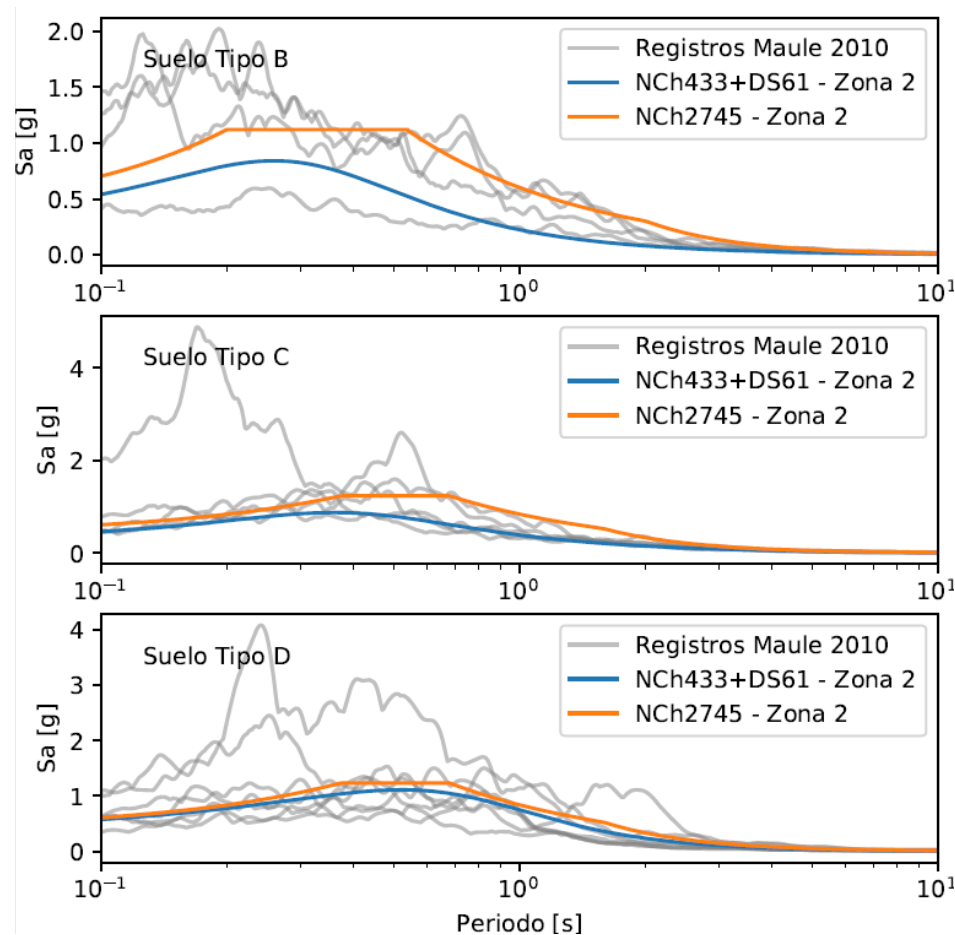
EVALUACIÓN DEL RIESGO SÍSMICO



ESPECTROS DE RESPUESTA (2010)

Aceleración Espectral, RotD100

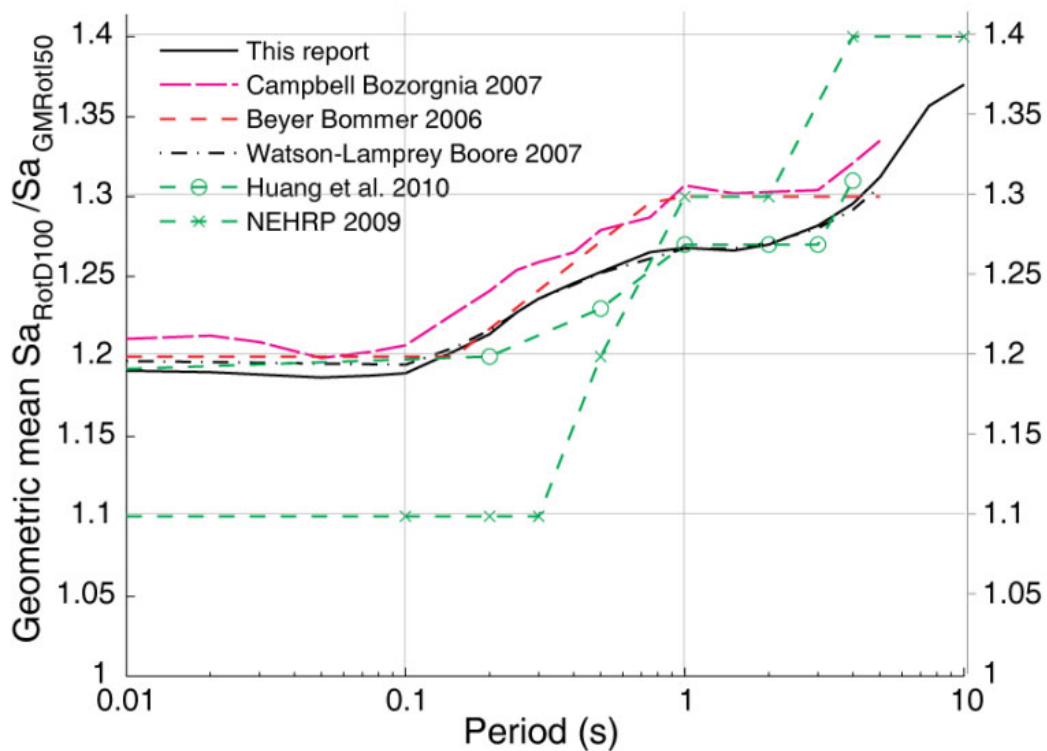
Desplazamiento Espectral, RotD100



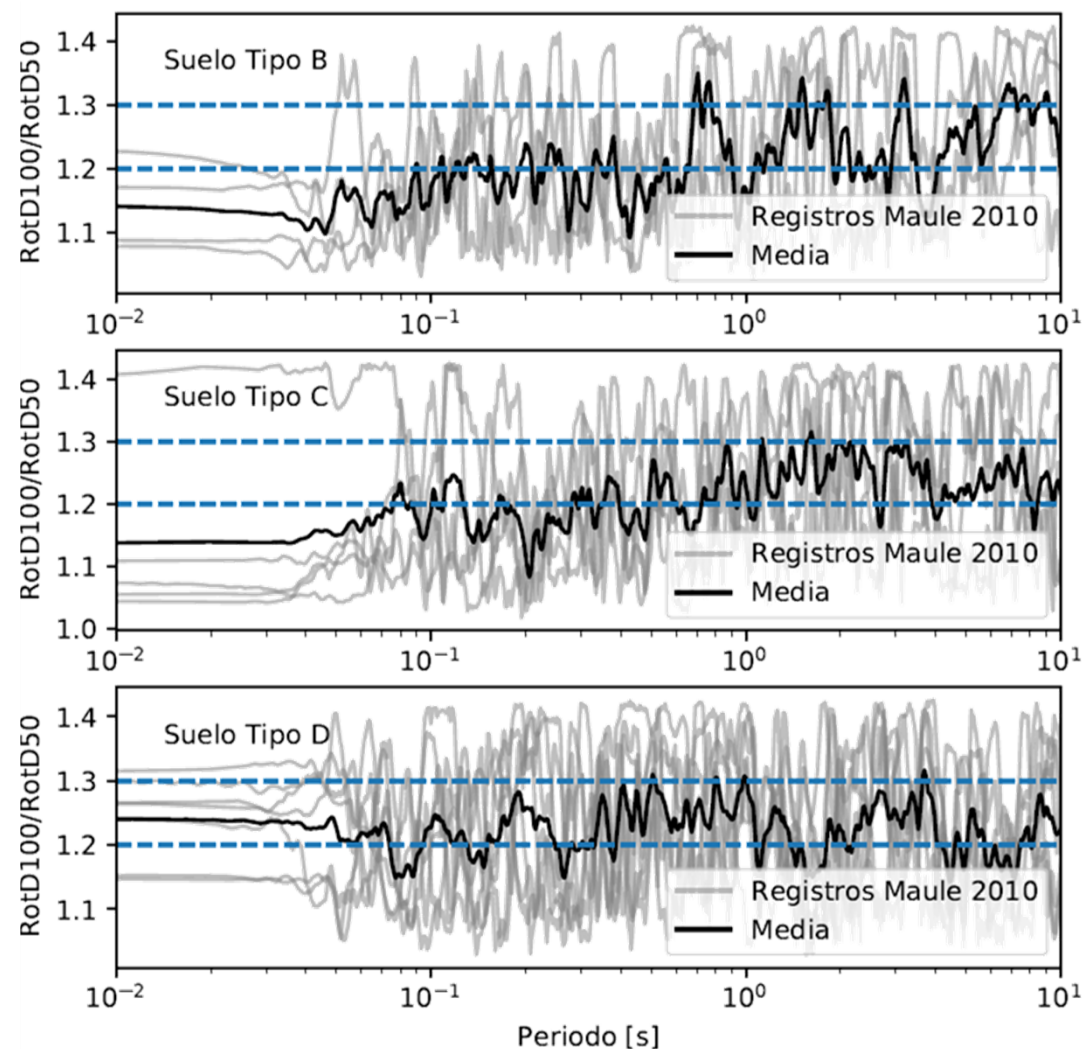
ROTD100/ROTD50

(Source: www.siberrisk.cl/StrongMotionDatabase)

Razón Espectral, RotD100/RotD50



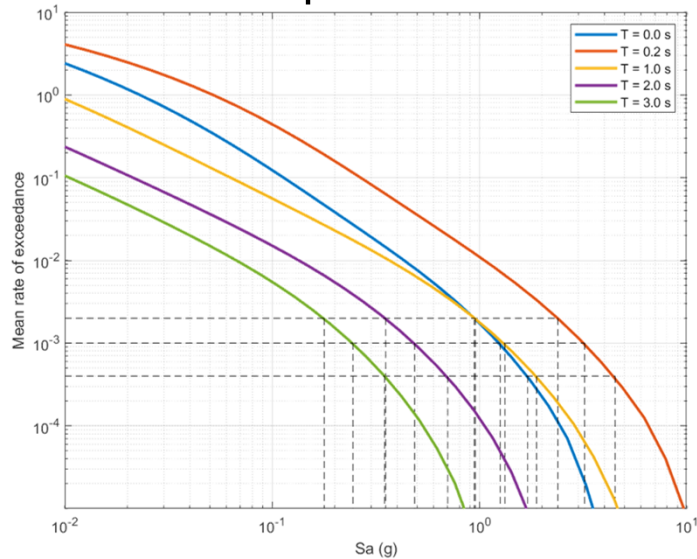
(Source: Shahi & Baker, 2013)



AMENAZA

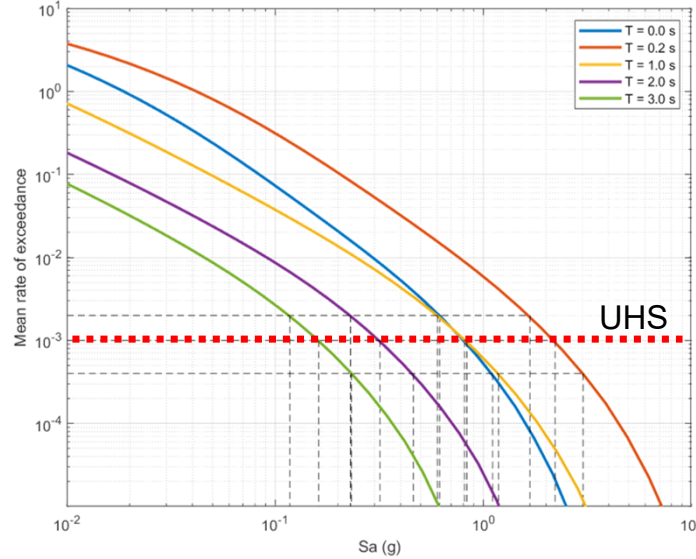
$S_A(T = 0s, 0.2s, 1s, 2s, 3s), T_r = 500, 100, 2500 a.$

Valparaíso



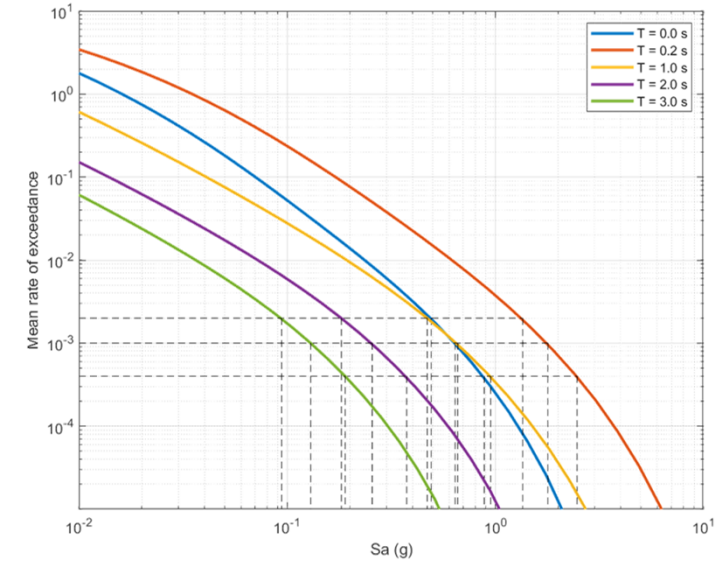
$Tr_{1,2} (a)$		Periodo, $T(s)$				
		PGA	0.2	1.0	2.0	3.0
$S_a (g)$	500	0.94	2.38	0.95	0.35	0.18
	1000	1.26	3.21	1.32	0.49	0.25
	2500	1.71	4.50	1.88	0.70	0.35
$S_a(Tr_1) \div S_a(Tr_2)$	1000/500	1.33	1.35	1.39	1.38	1.38
	2500/500	1.81	1.89	1.97	1.99	1.96
	2500/1000	1.36	1.40	1.42	1.44	1.42

Santiago



$Tr_{1,2} (a)$		Periodo, $T(s)$				
		PGA	0.2	1.0	2.0	3.0
$S_a (g)$	500	0.62	1.67	0.60	0.23	0.12
	1000	0.81	2.21	0.83	0.32	0.16
	2500	1.11	3.01	1.18	0.46	0.23
$S_a(Tr_1) \div S_a(Tr_2)$	1000/500	1.32	1.32	1.38	1.38	1.38
	2500/500	1.80	1.80	1.96	2.00	1.98
	2500/1000	1.36	1.36	1.42	1.45	1.44

Los Libertadores



$Tr_{1,2} (a)$		Periodo, $T(s)$				
		PGA	0.2	1.0	2.0	3.0
$S_a (g)$	500	0.49	1.35	0.47	0.18	0.09
	1000	0.64	1.79	0.66	0.26	0.13
	2500	0.88	2.47	0.95	0.37	0.19
$S_a(Tr_1) \div S_a(Tr_2)$	1000/500	1.30	1.32	1.40	1.41	1.38
	2500/500	1.80	1.82	2.02	2.06	2.02
	2500/1000	1.38	1.38	1.44	1.46	1.46

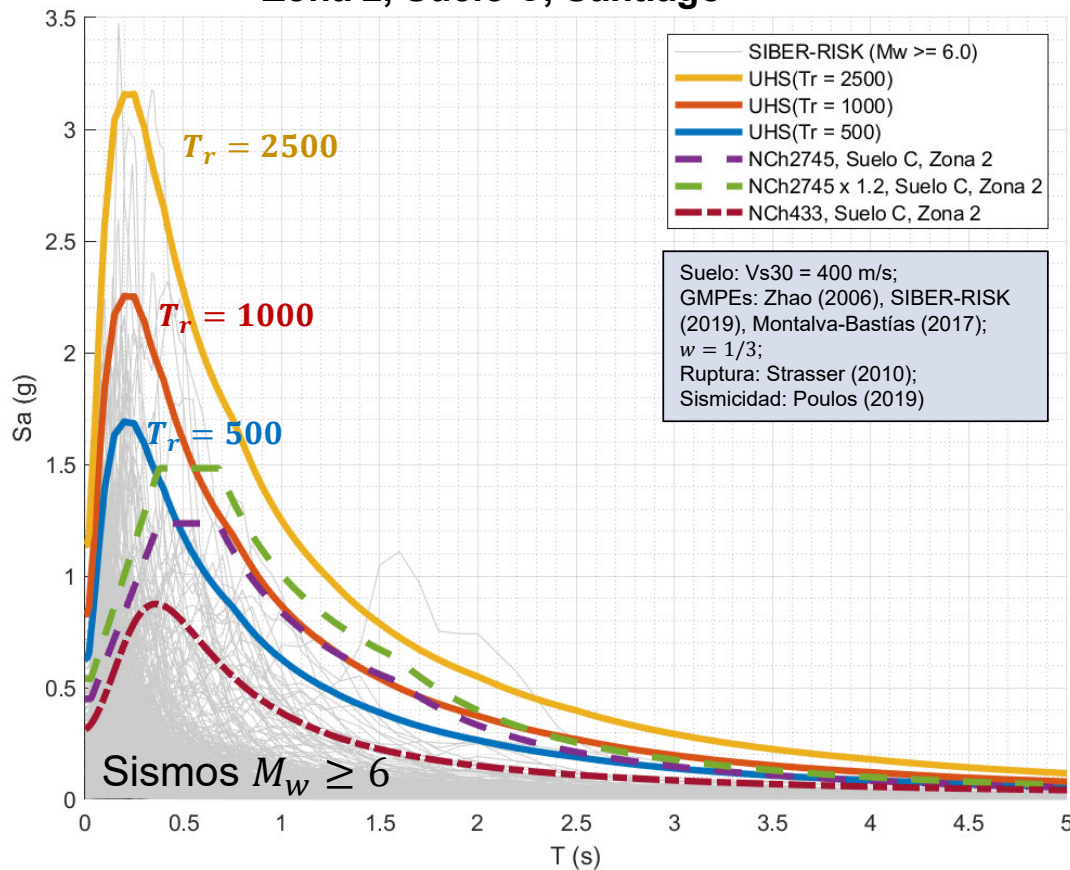
Suelo: Vs30 = 400 m/s;
GMPEs: Zhao (2006), SIBER-RISK (2019), Montalva-Bastías (2017);
 $w = 1/3$;
Ruptura: Strasser (2010);
Sismicidad: Poulos (2019)

Punto clave: El factor correcto que debemos usar en la NCh2745 es $M_m \approx 1.4$ y no 1.2

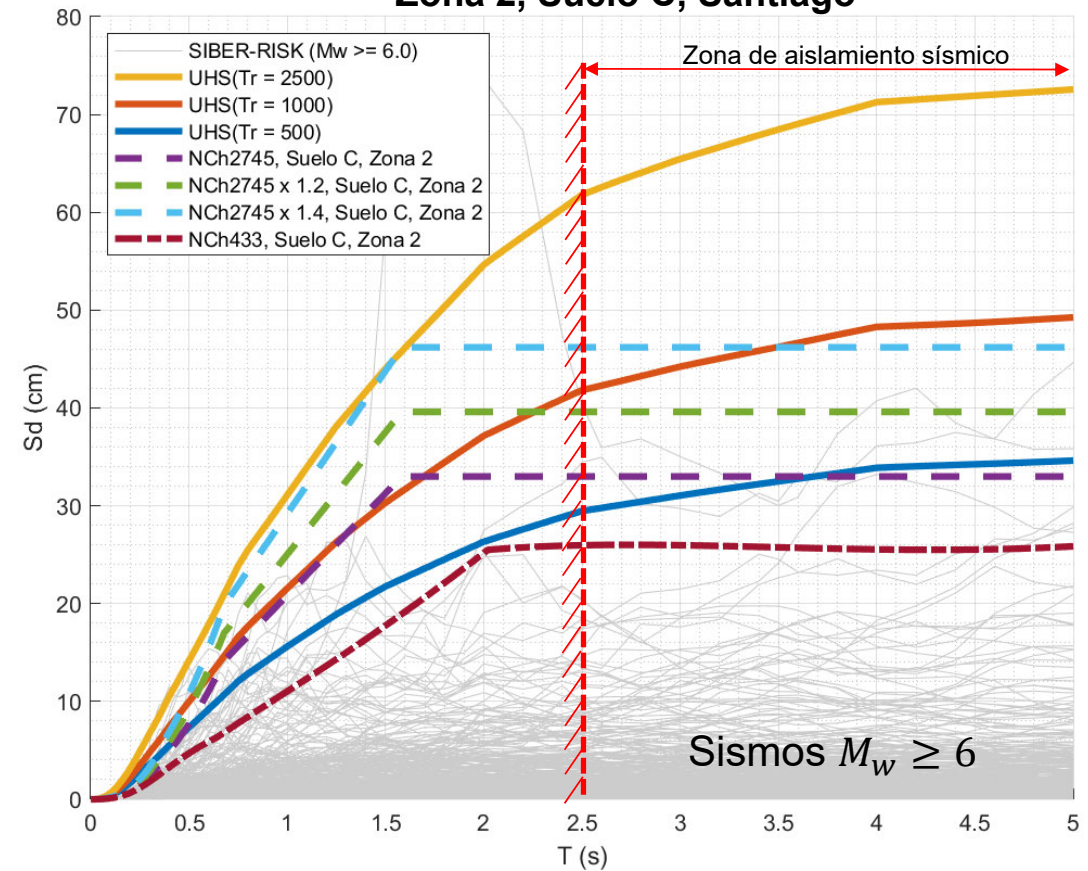
AMENAZA

RESPUESTA ESPECTRAL Y AMENAZA UNIFORME

Zona 2, Suelo C, Santiago

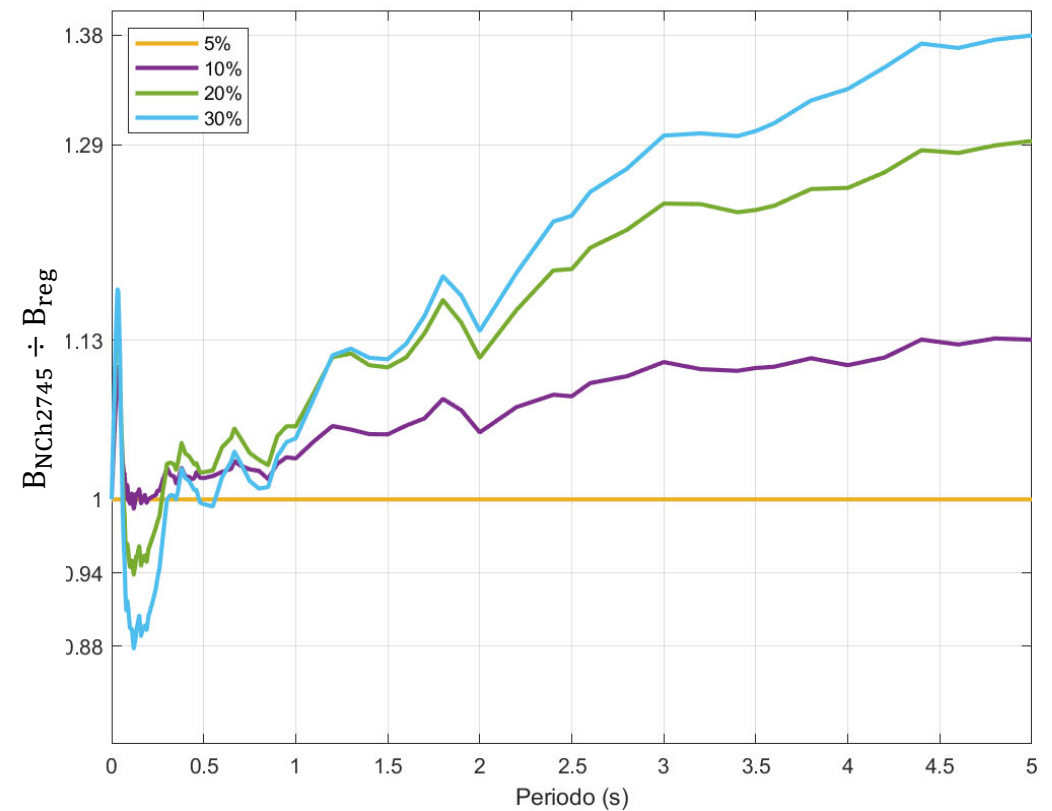
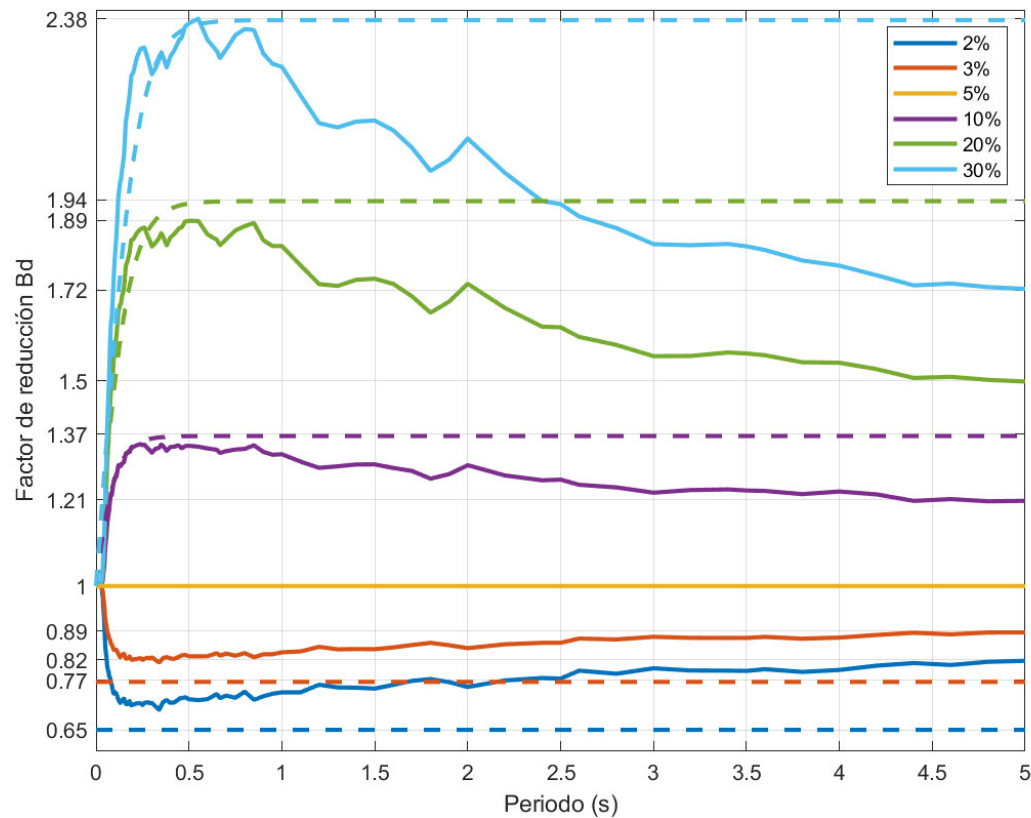


Zona 2, Suelo C, Santiago



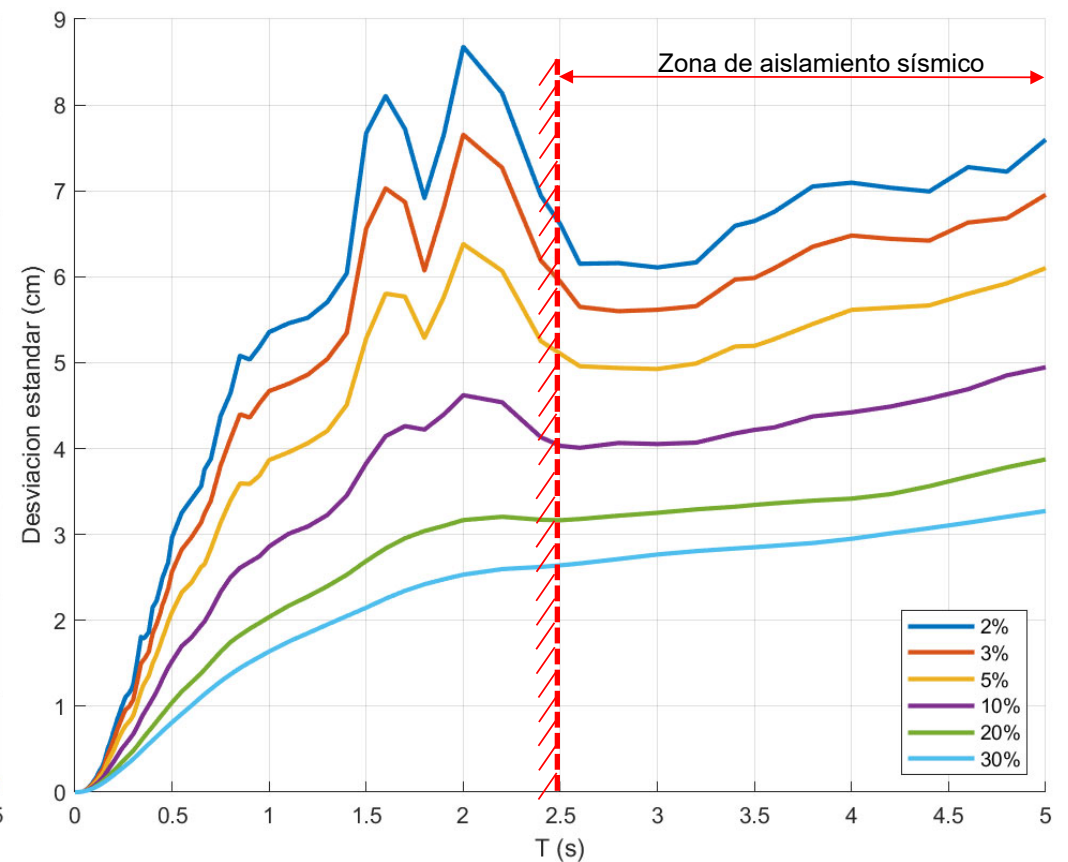
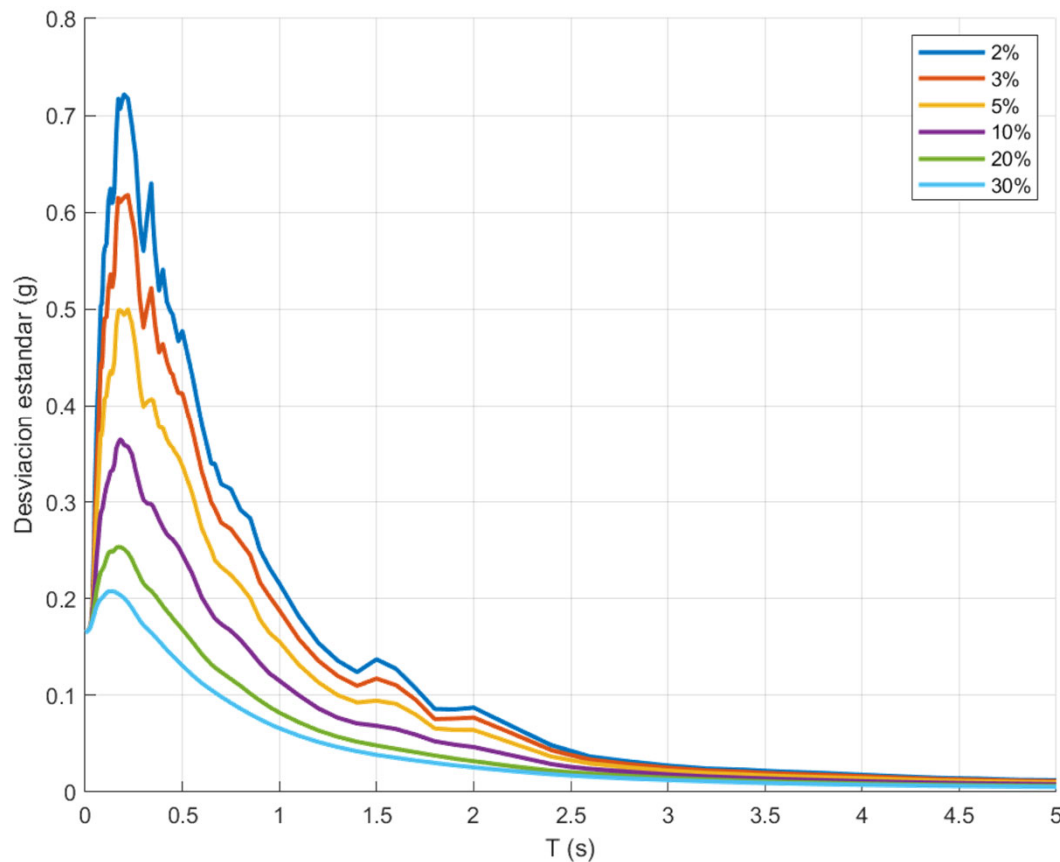
Punto clave: El espectro de amenaza uniforme $T_r = 500$ a es aprox. consistente con el de la NCh 2745

AMENAZA REDUCCIÓN POR AMORTIGUAMIENTO



Punto clave: Necesitamos corregir el factor B en la NCh 2745 para considerar los datos de registros reales

AMENAZA VARIANZA EN DEMANDA ESPECTRAL

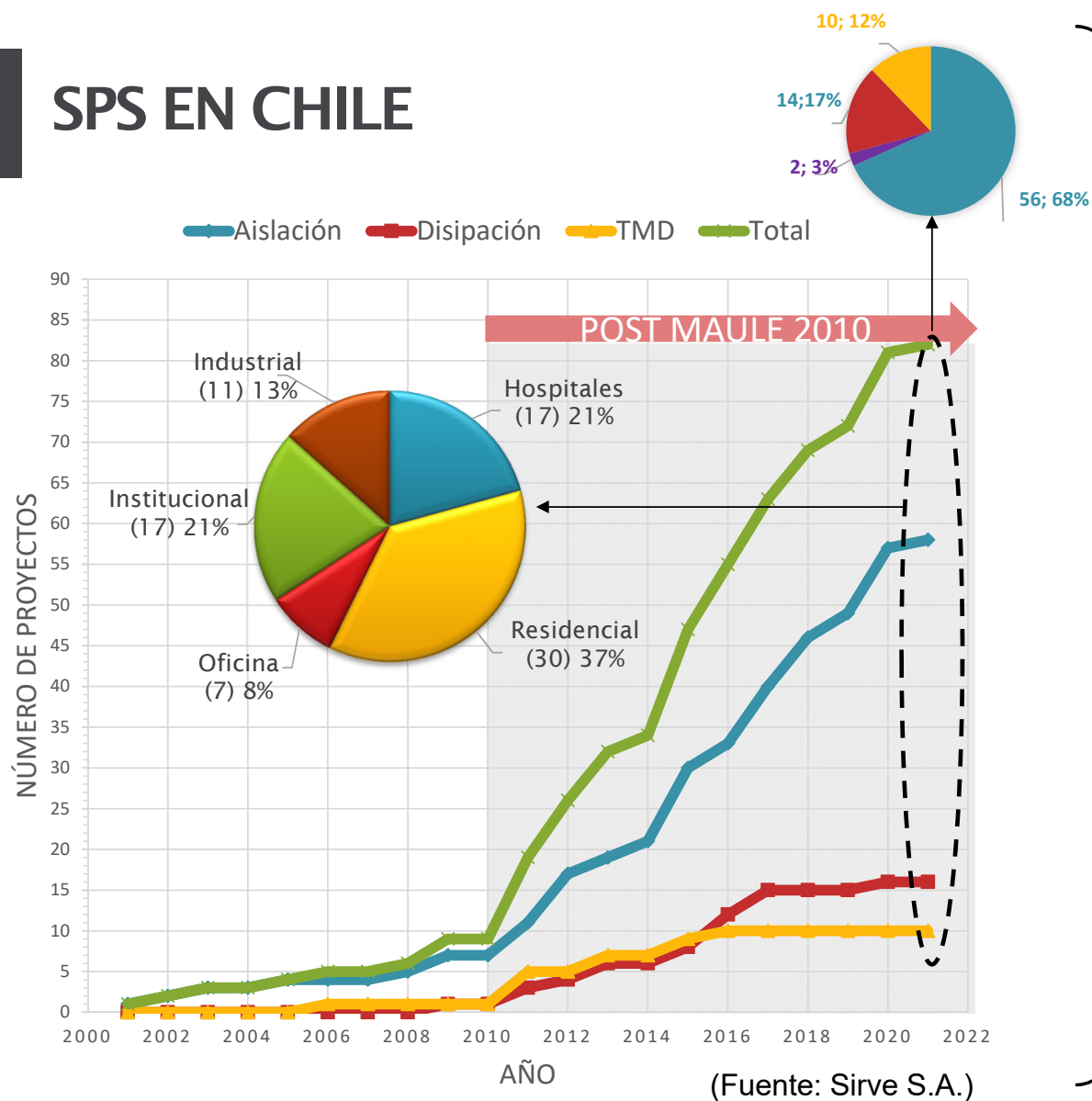


Punto clave: La variación en aceleración espectral σ_{reg} se reduce por alargamiento del período y amortiguamiento

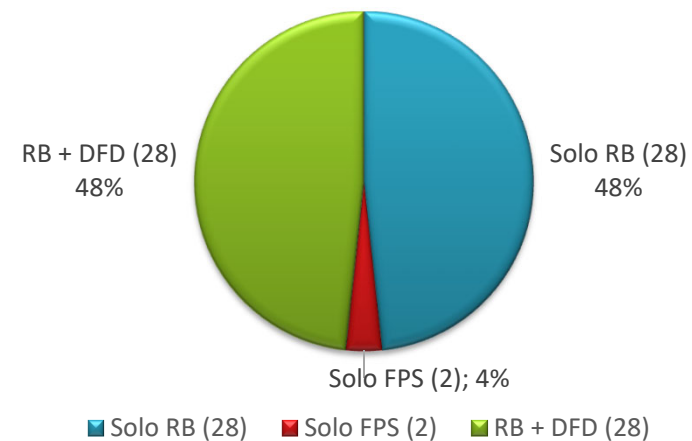
AISLAMIENTO SISMICO



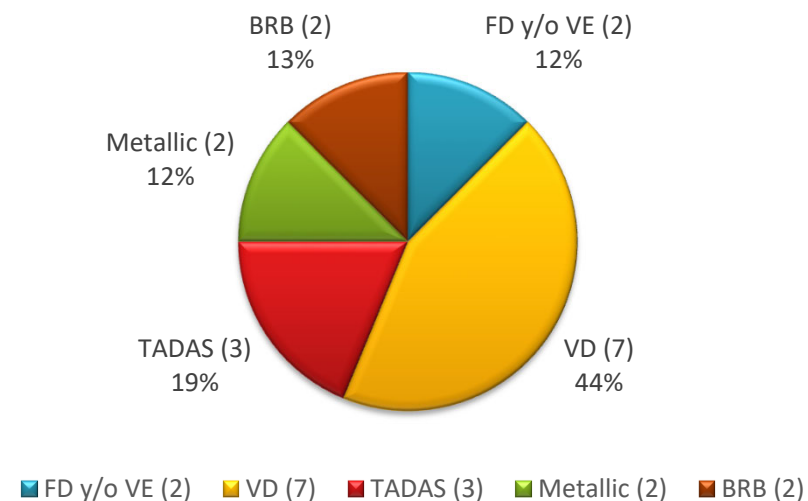
SPS EN CHILE



58 edificios aislados

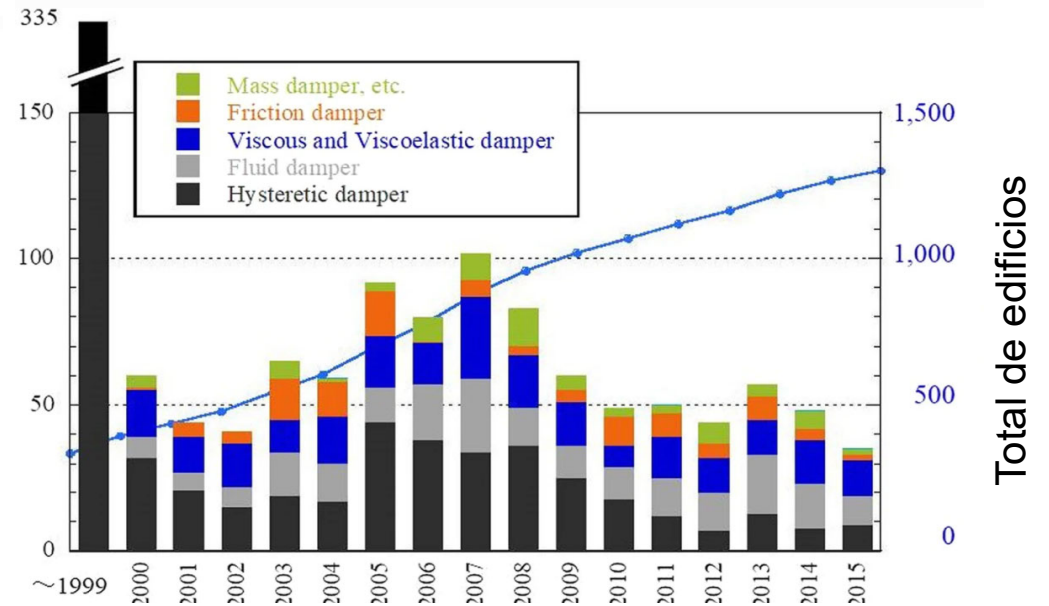
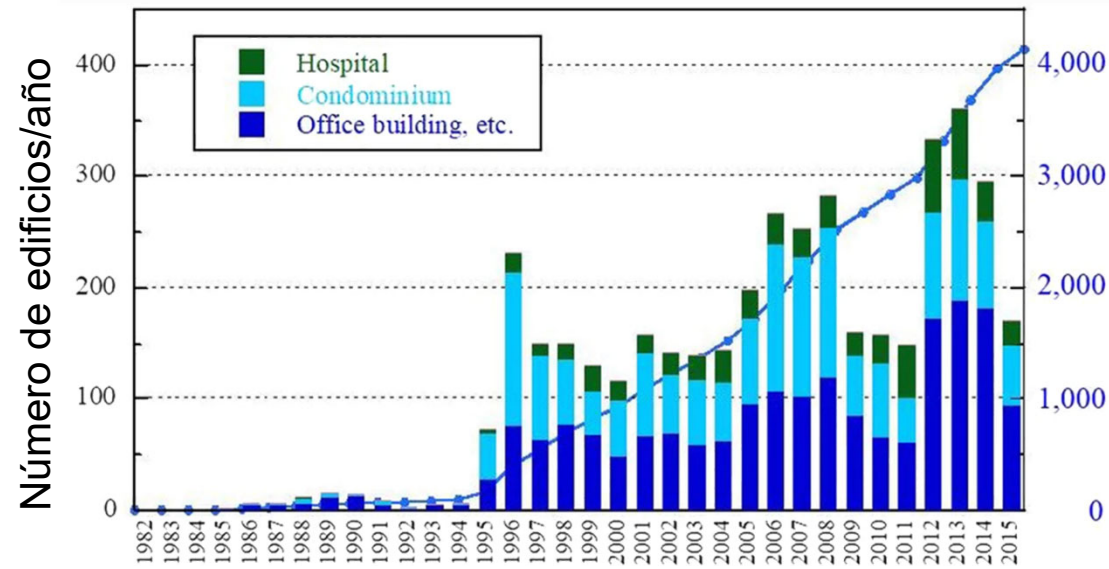


16 edificios con disipación



TOHOKU, 2011

INVENTARIO DE SPS

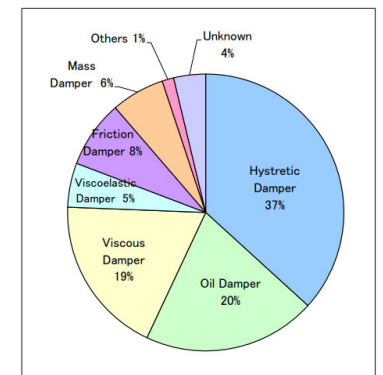
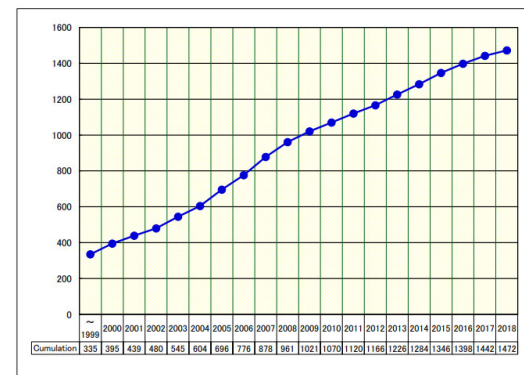
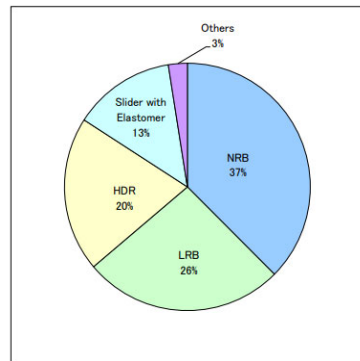
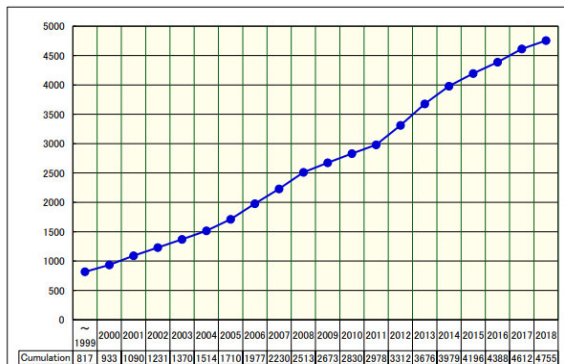


Number of ST Buildings in Japan, by Year

Usage Ratio of Isolators (2004~2018)

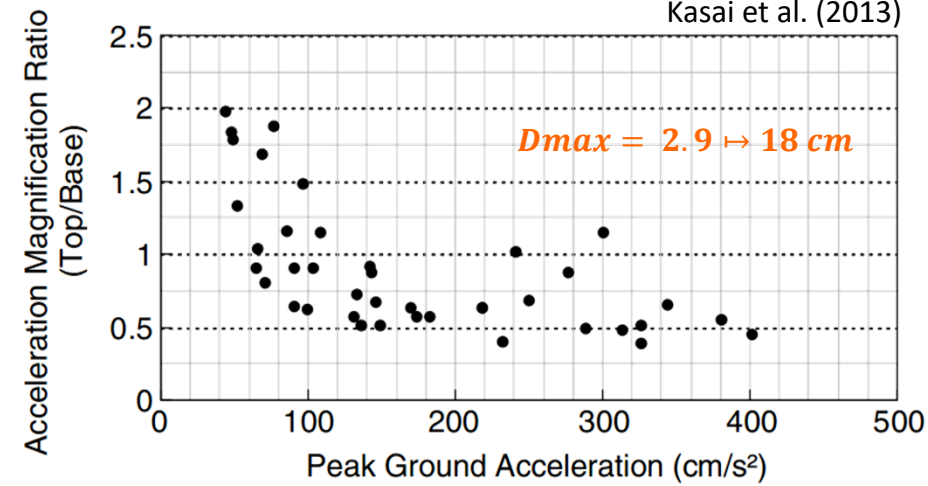
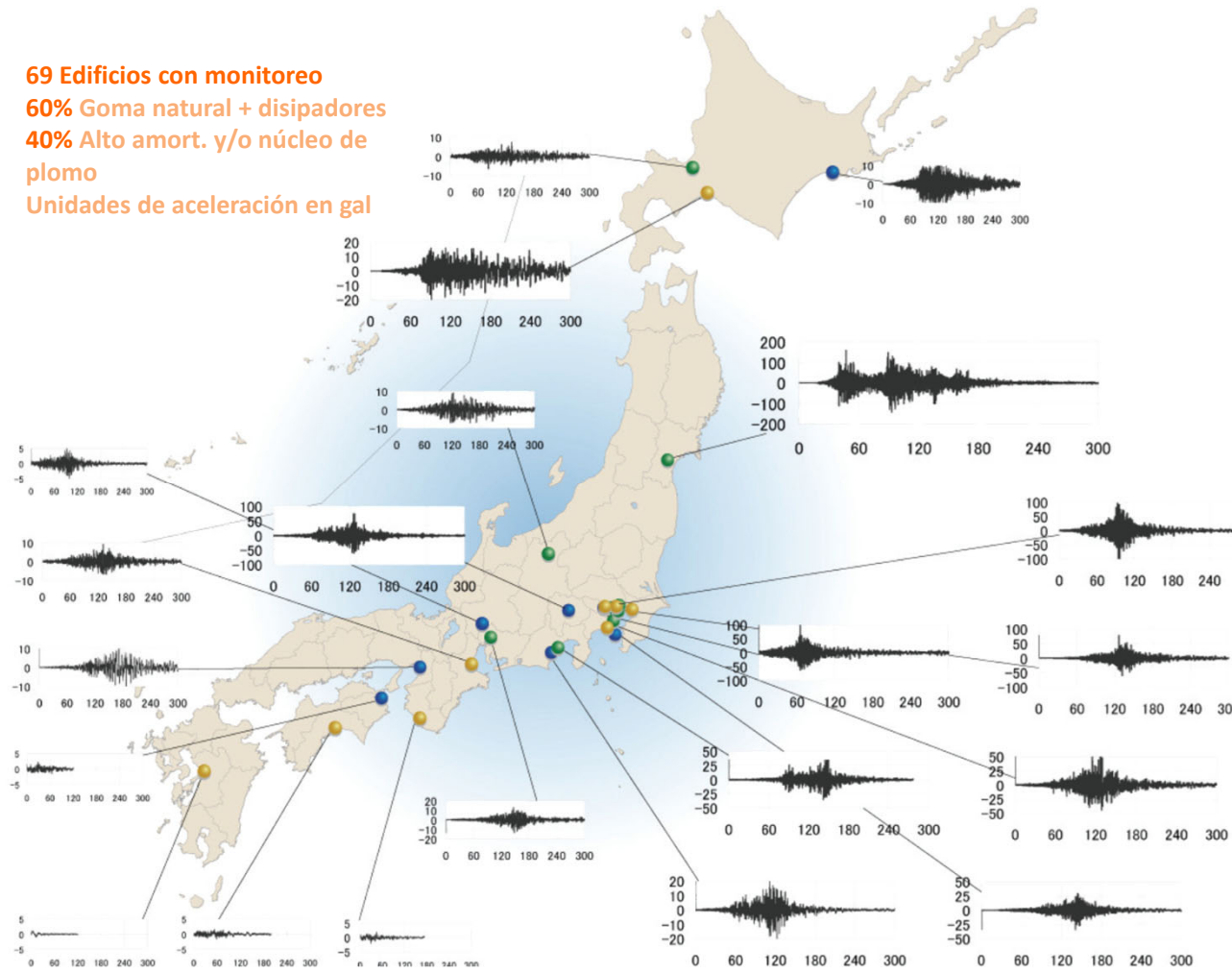
Number of VC Buildings in Japan, by Year

Usage Ratio of VC devices (2004~2018)



TOHOKU, 2011 RESPUESTA SPS

- 69 Edificios con monitoreo
- 60% Goma natural + disipadores
- 40% Alto amort. y/o núcleo de plomo
- Unidades de aceleración en gal

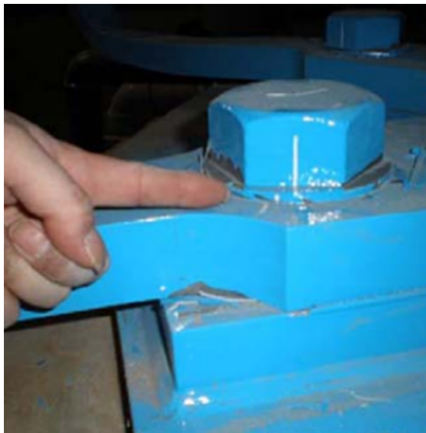


Prefecture	City	Isolater	Damper	Stories	PGA _x (cm/s²)	PGA _y (cm/s²)	PRA _x (cm/s²)	PRA _y (cm/s²)	U _ω (cm)
Tokyo	Chofu City	Natural rubber	Oil damper Steel damper	2	109	143	124	125	4.0
Miyagi	Sendai City	High damping rubber	—	3	301	241	344	244	11.5
Chiba	Funabashi City	Natural rubber	Viscous damper	3	150	134	75	96	7.8
Kanagawa	Yokohama City	Synthetic rubber Sliders	—	4	97	77	143	145	4.2
Miyagi	Sendai City	High damping rubber	—	5	327	345	167	224	11.2
Chiba	Funabashi City	High damping rubber Lead rubber	—	5	143	170	130	107	2.9
Miyagi	Sendai City	High damping rubber	—	6	381	277	209	240	18.0
Tokyo	Koto Ward	Lead rubber	—	6	137	132	70	75	7.6
Ibaraki	Tsukuba City	Natural rubber Lead rubber	—	7	327	233	126	91	5.9
Kanagawa	Yokohama City	High damping rubber	Oil damper	7	147	87	99	100	6.8
Kanagawa	Yokohama City	Natural rubber	Semi-active oil damper Passive oil damper	7	66	71	68	57	12.0
Chiba	N/A	High damping rubber	—	8	174	219	99	137	4.7
Miyagi	Sendai City	Natural rubber	Lead damper Steel damper	9	251	289	170	142	16.8

Goto et al. (2012)

TOHOKU, 2011

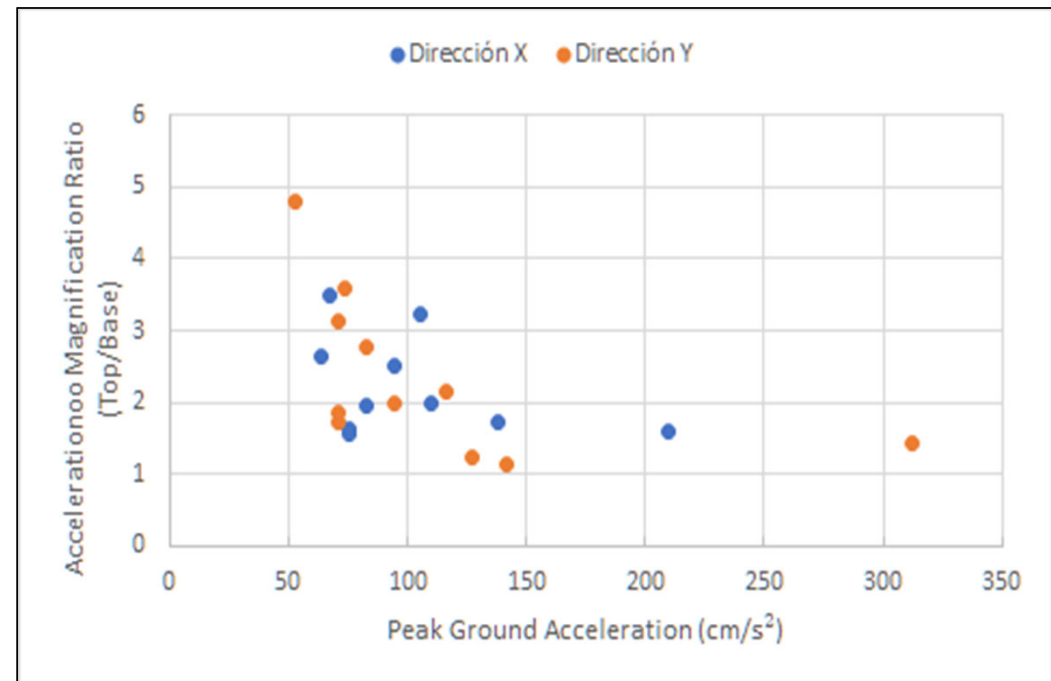
RESPUESTA SPS



TOHOKU, 2011

RESPUESTA SPS

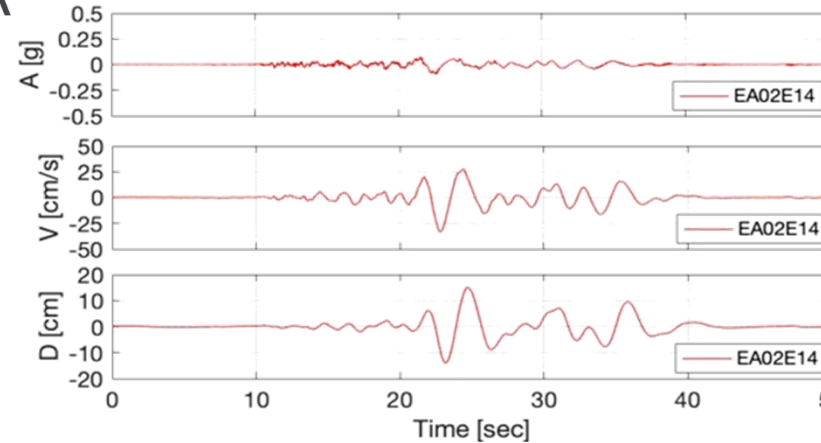
Prefecture	City	Damper	Stories	Period X (sec)	Period Y (sec)	PGA _X (cm/s ²)	PGA _Y (cm/s ²)	PRA _X (cm/s ²)	PRA _Y (cm/s ²)	Ave. Drift X (rad)	Ave. Drift Y (rad)
Tokyo	Meguro Ward	Buckling restrained brace	5	0.25	0.34	138	116	238	250	0.00026	0.00043
Kanagawa	Yokohama City	Shear steel panel	11	0.65	0.69	67	53	234	255	0.00058	0.00078
Tokyo	Chiyoda Ward	Buckling restrained brace Viscous Wall	14	1.21	1.66	110	127	218	155	0.00116	0.00105
Tokyo	Hino City	Mild steel honeycomb damper	17	2.04	2.23	105	83	338	231	0.00372	0.00296
Miyagi	Sendai City	Rotary damping tube Lead extrusion damper	21	2.73	3.08	210	312	338	444	0.00415	0.00347
Tokyo	Chiyoda Ward	Extra mild steel damper Viscous wall	21	1.87	2.03	75	71	121	131	0.00099	0.00121
Saitama	Saitama City	Extra mild steel damper	26	2.72	2.78	63	74	686	265	0.00193	0.00177
Tokyo	N/A	Extra mild steel panel	37	5.08	5.16	83	94	162	186	0.00298	0.00292
Tokyo	N/A	Buckling restrained brace Viscous wall	38	4.05	3.97	64	71	170	223	0.00222	0.00279
Tokyo	Minato Ward	Oil damper	41	3.97	4.10	75	71	118	123	0.00268	0.00207
Tokyo	Shinjuku Ward	Oil damper	54	5.37	6.25	94	142	236	161	0.00227	0.00241



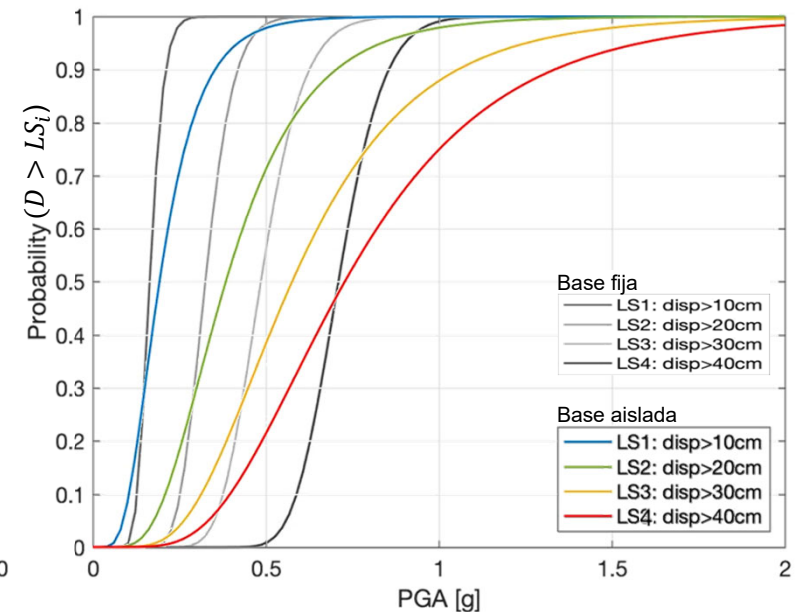
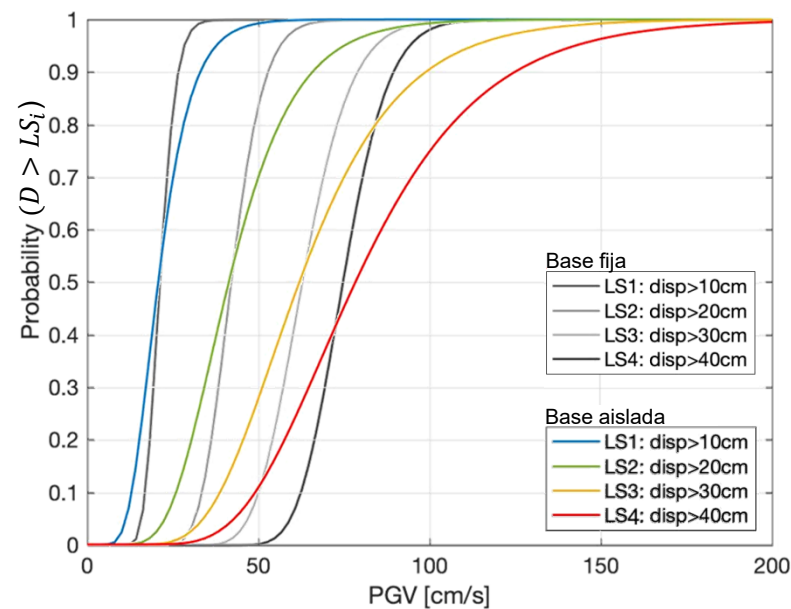
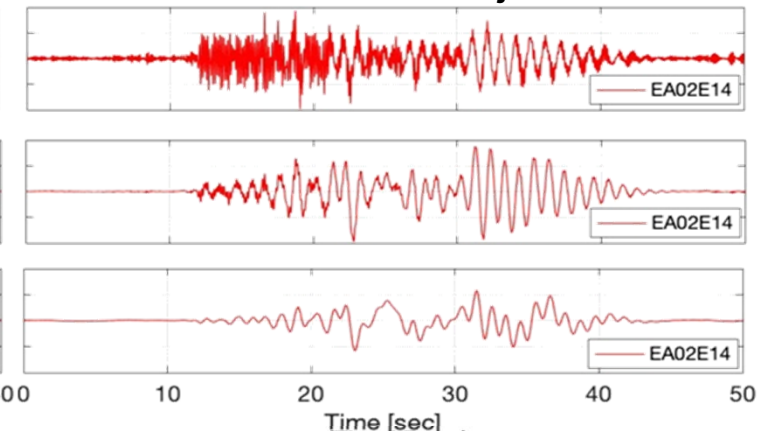
SAN DIEGO MESA VIBRADORA

Nota: Equipos de ultrasonido L4 y L5 (Fijo al suelo)

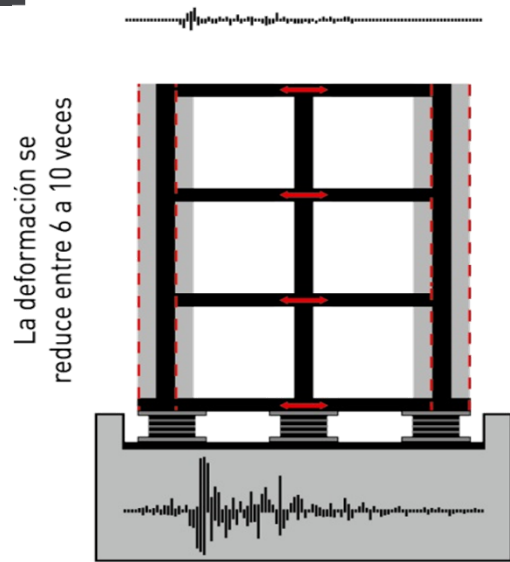
Edificio base aislada



Edificio base fija



AISLAMIENTO SISMICO



Elastomérico:

- Goma natural (LRB)
- Alto amortiguamiento (HDRB)

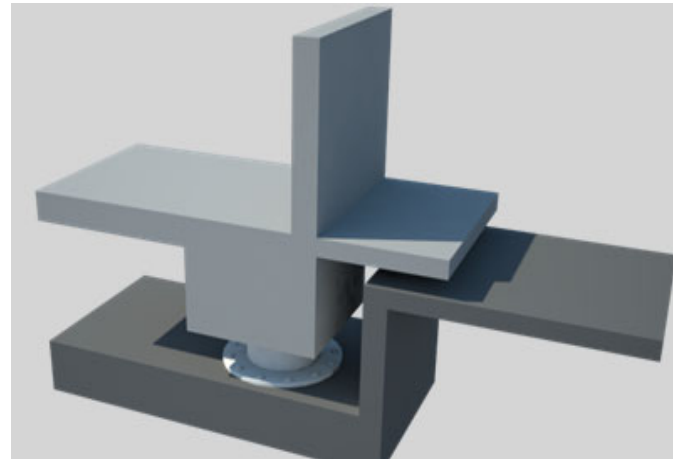
Friccional:

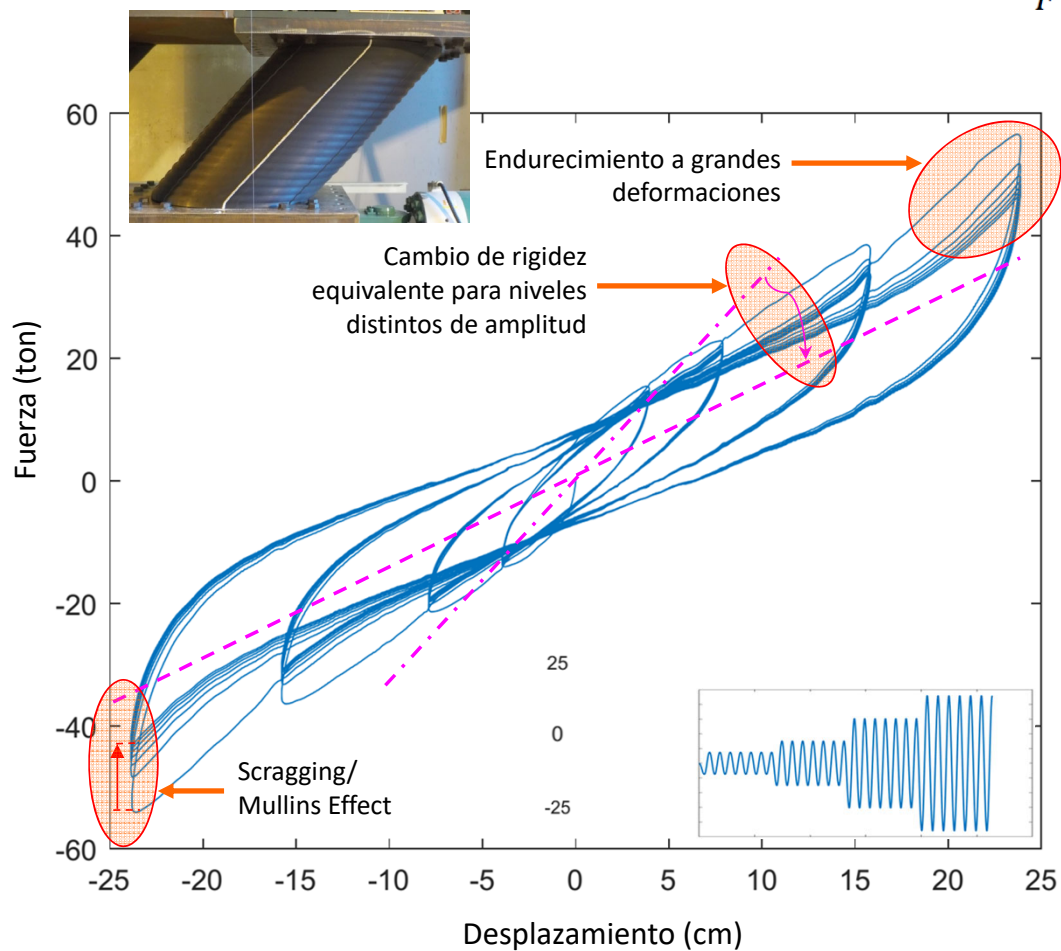
- Péndulo friccional (FPS)
- Deslizador friccional y POT

Cinemático:

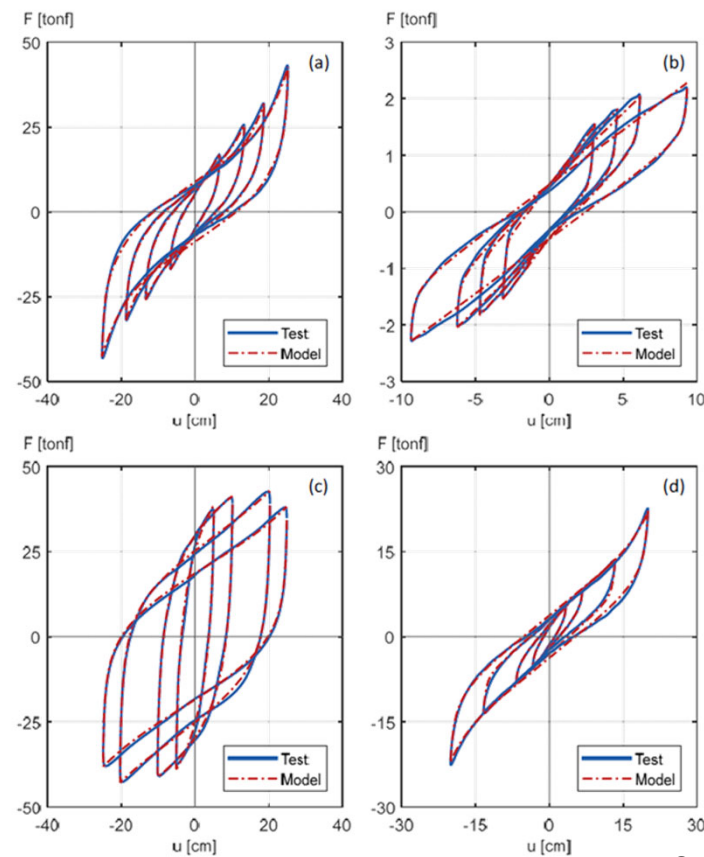
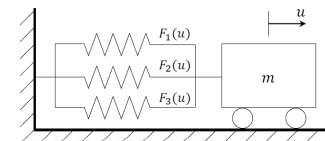
- Biela

Dispositivos para tracción



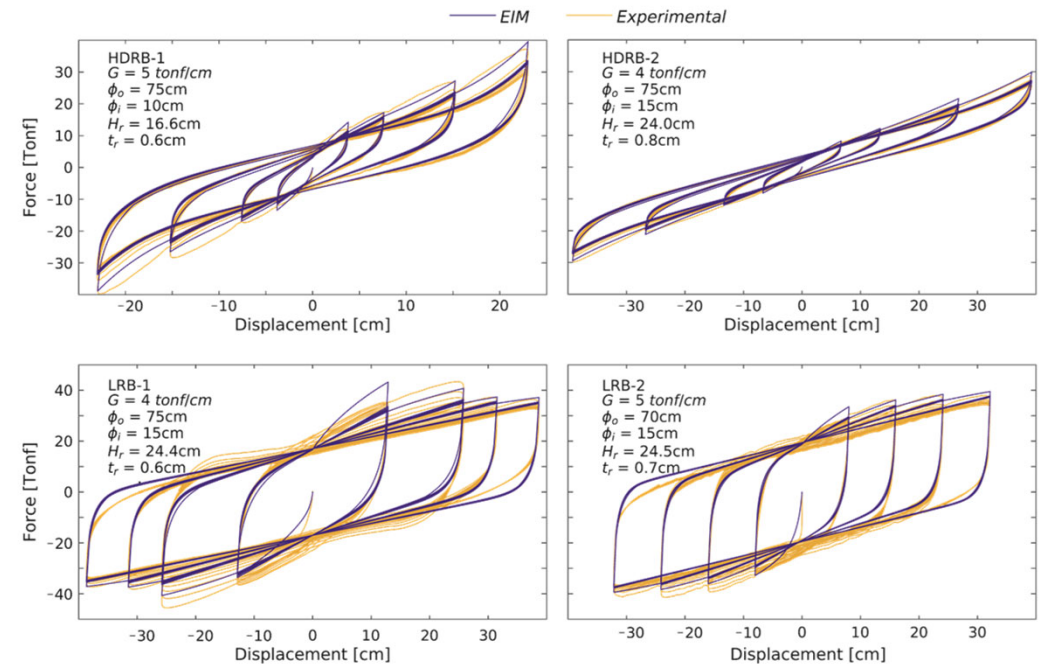
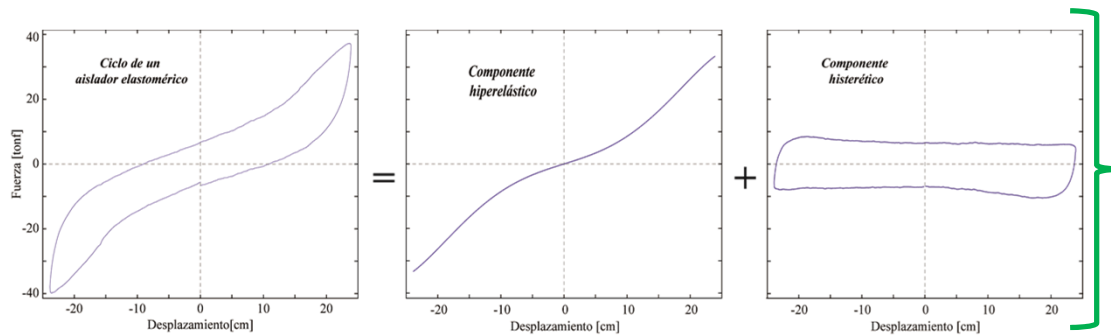


$$F(u) = \frac{\frac{F_y}{u_y}(1-b)u}{(1+(\frac{u}{u_y})^R)^{\frac{1}{R}}} + \frac{F_y}{u_y}bu + \text{sign}(u) \left(\frac{|u|}{u_h}\right)^n$$



S. Miranda et al., 2020

MODELAMIENTO DE AISLADORES ELASTOMERICOS



- Componente hiperelástica (a partir del modelo de Ogden):

$$F_{hyp} = a_1 \gamma + a_2 \gamma^3 + a_3 \gamma^5$$

- Componente histerética (Bouc-Wen modificado):

$$F_{hys} = F_y z$$

$$\dot{z} = \frac{k}{F_y} \dot{u} [1 - |z|^n (\beta \text{sgn}(\dot{u}z) + \alpha - \Phi \text{sign}(\dot{u})(\text{sign}(z) + \text{sign}(\dot{u})))]$$

$$\Phi = \Phi_{max} \left[1 - \exp \left(-P_{\Phi} \left| \frac{u_{pl}}{u_y} \right| \right) \right]$$

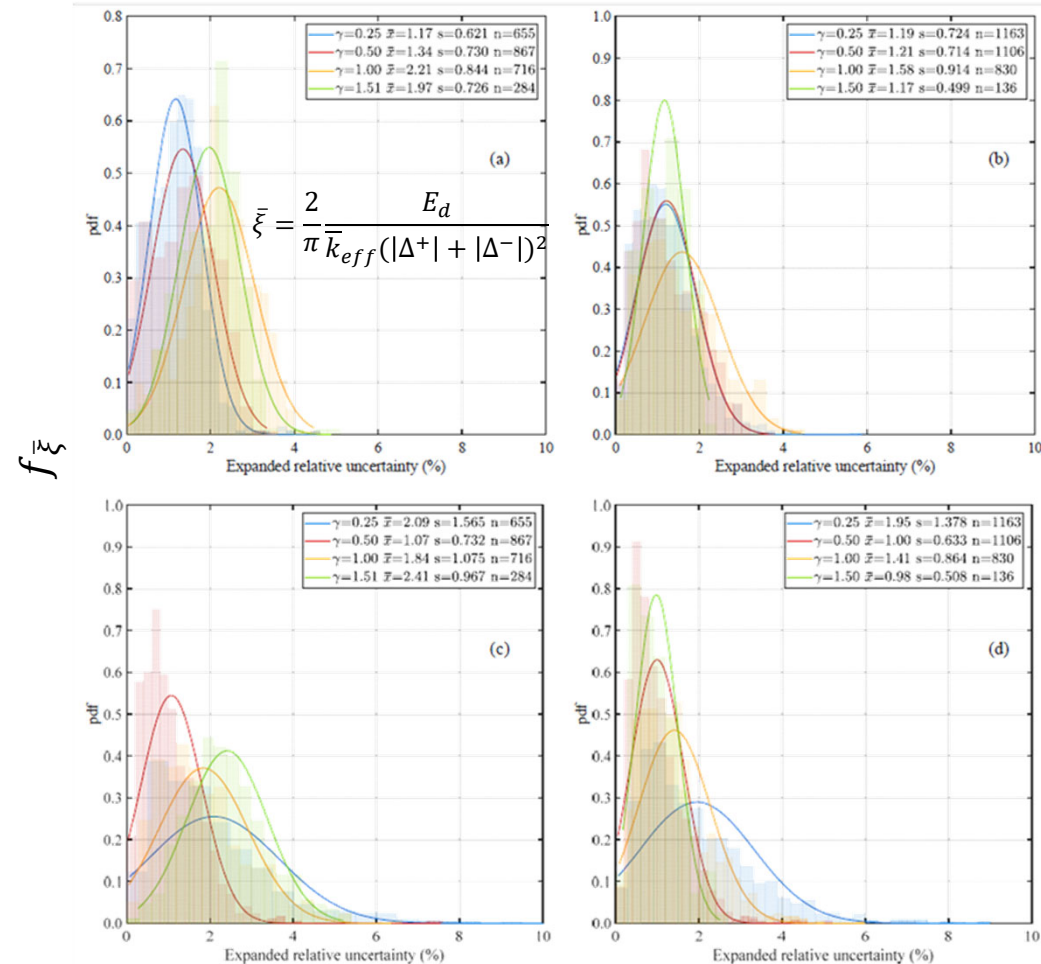
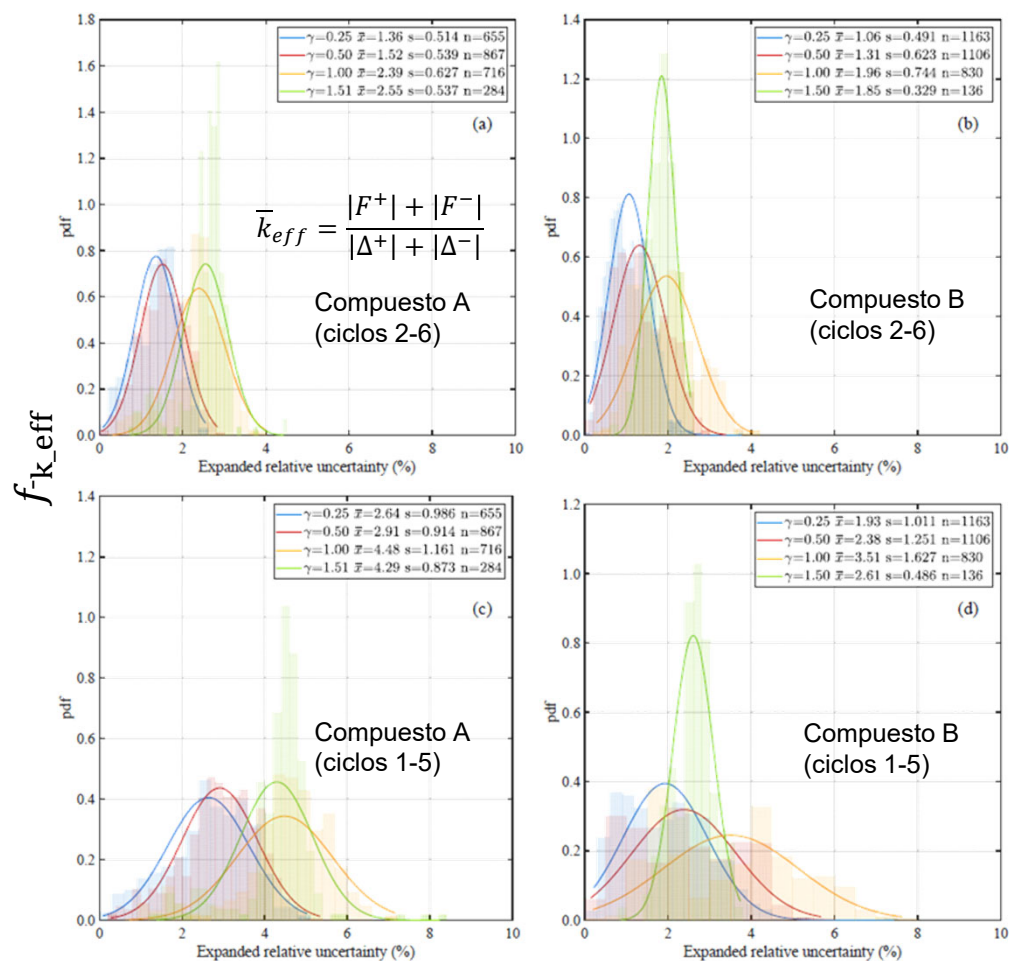
$$a_i = f s_i f m_i a_{i0} \text{ ----- Constante de material}$$

$$f s_i = \exp(-C_{si} \gamma_s^{p_{si}})$$

$$f m_i = \exp(-C_{mi} \gamma_m^{p_{mi}})$$

----- Degradación, Mullins (m),
Scragging (s)

INCERTIDUMBRE EN PROPIEDADES



S. Miranda et al., 2020

REEMPLAZO DE AISLADORES



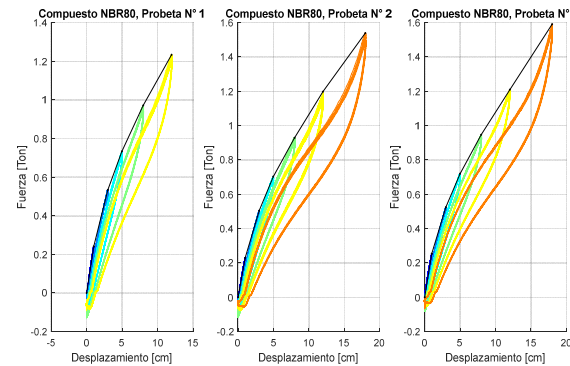
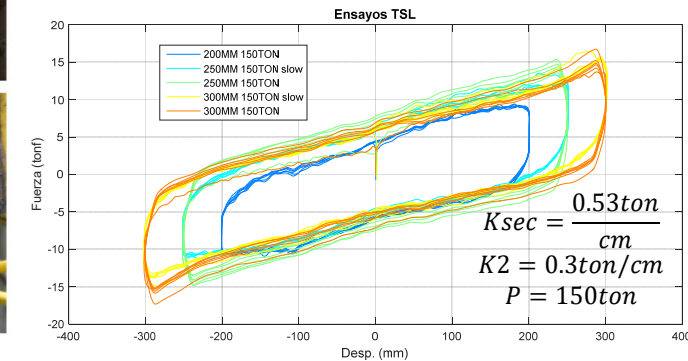
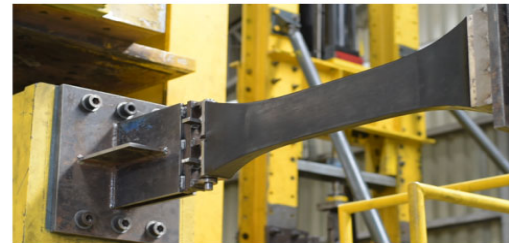
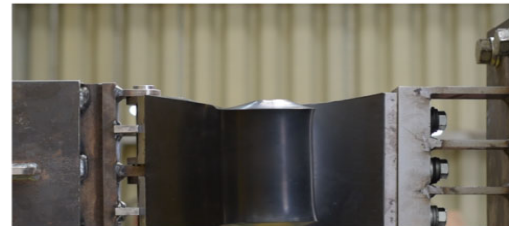
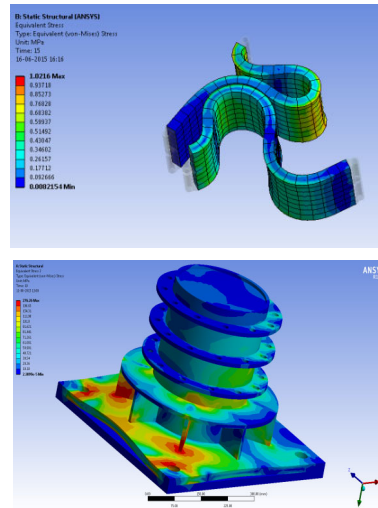
AISLADORES DE BAJO COSTO TSL

TSL

- Deslizador con tirantes de bajo costo para estructuras livianas.
- Pensado para cargas axiales de 120 a 160 ton
- Desplazamiento de hasta 30 cm
- Rigidez secante objetivo $\approx 0.5 \text{ ton/cm}$

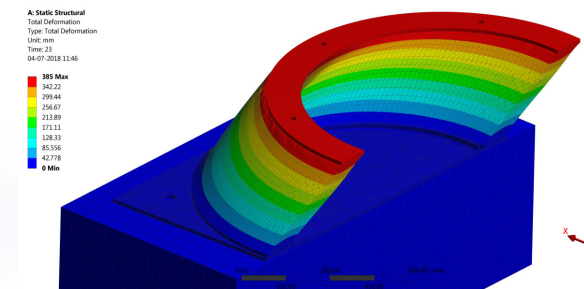
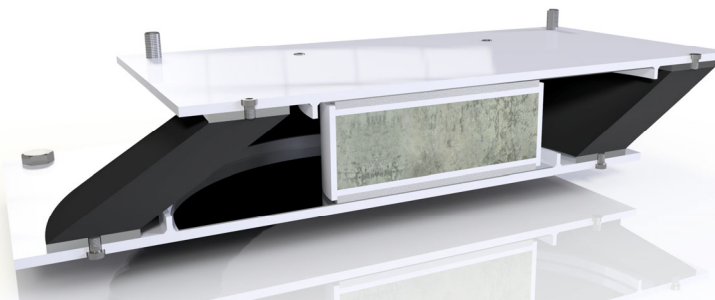
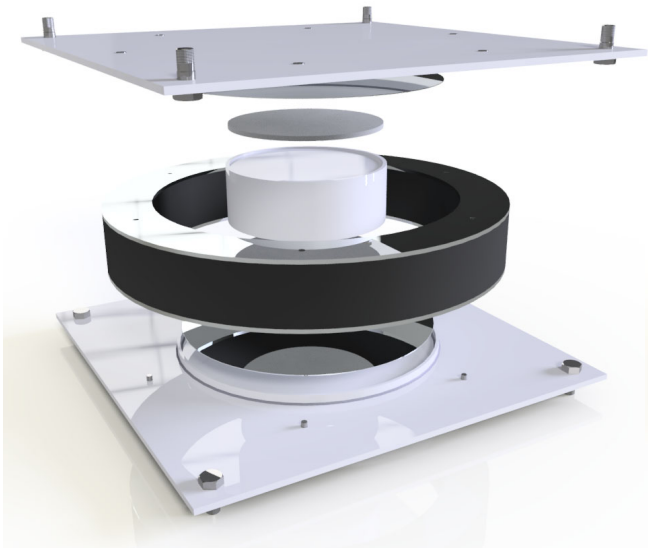
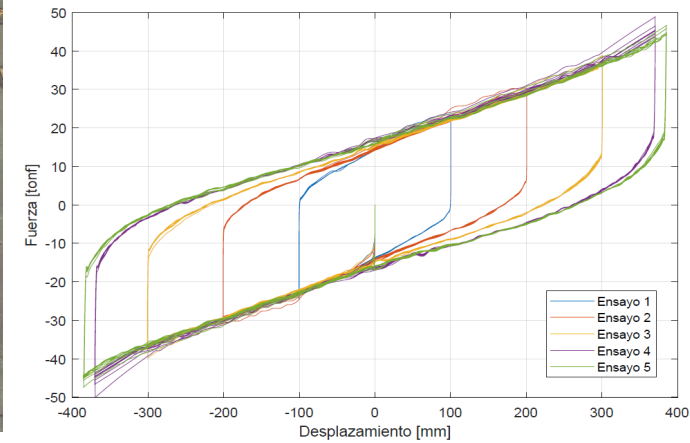
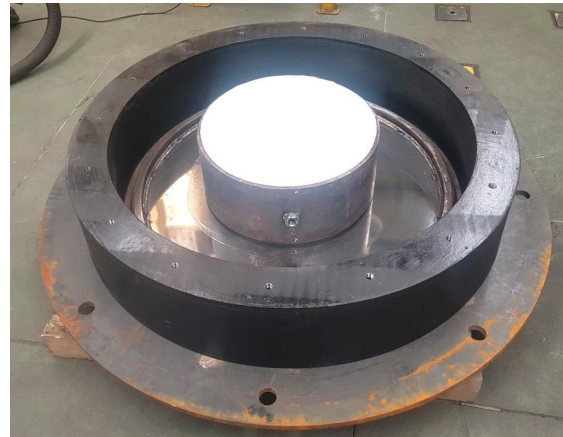
Prototipo

- Capacidad vertical de **150 ton** y desplazamiento **30 cm**
- Rigidez secante de **0.53 ton/cm**
- Coeficiente de Fricción de 3%



AISLADOR DE BAJO COSTO DSR

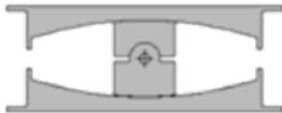
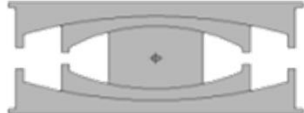
- Componentes trabajan de manera desacoplada para carga axial, restitución y amortiguamiento.
- Restitución a través de un anillo de goma que no necesita laminas de acero
- Núcleo de bajo costo formado por tubo de acero relleno con hormigón
- Se reduce entre un 20-40% el costo de un aislador tradicional equivalente
- Niveles de carga hasta 1500 ton y rigidez entre 0.5 a 2 ton/cm



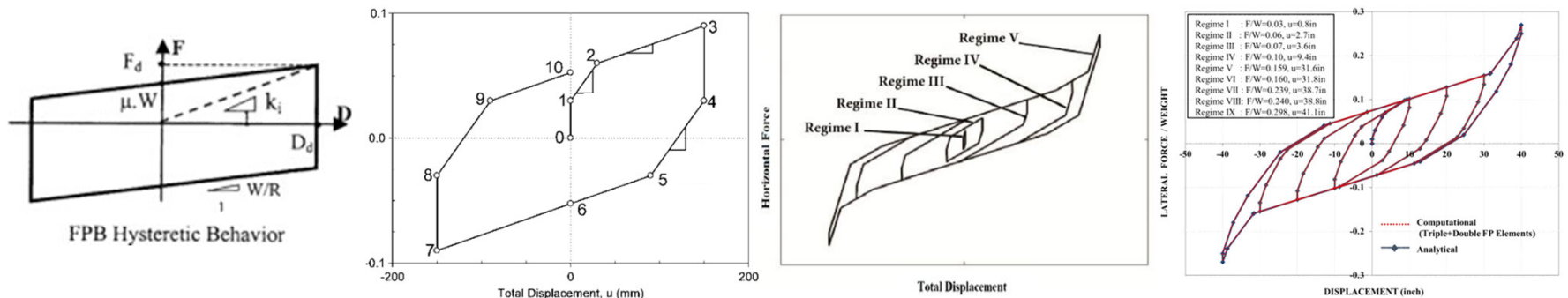
AISLADORES FPS

COMPORTAMIENTOS

After Lee & Constantinou (2016)

	Single FP	Double FP	Triple FP	Quintuple FP
Configuración				
Número de péndulos efectivos	1	2	3	5
Número de regímenes de deslizamiento	1	3	5	9

Forma
histerética



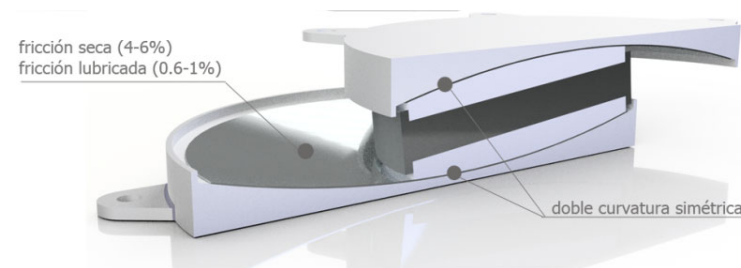
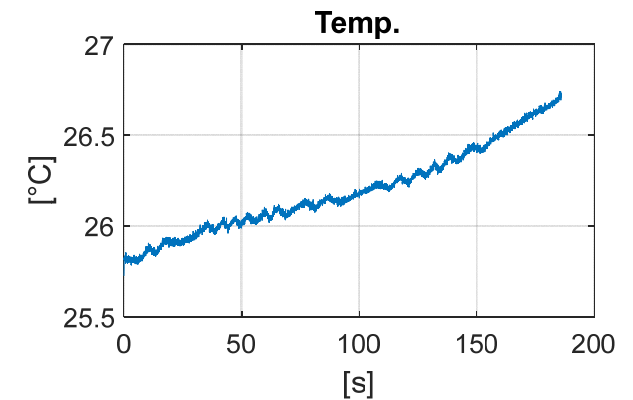
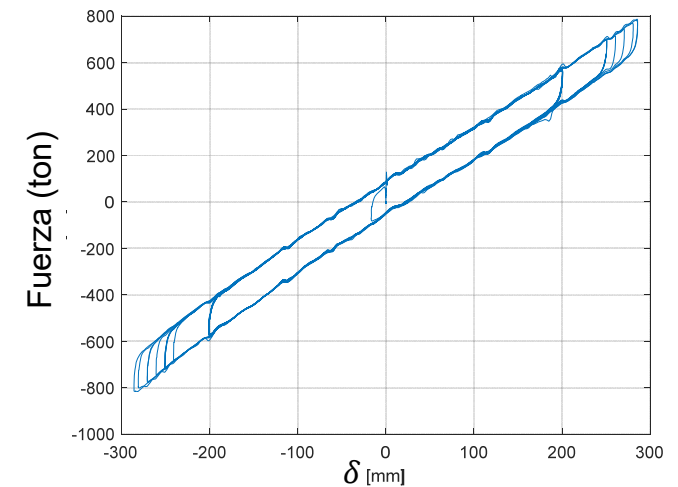
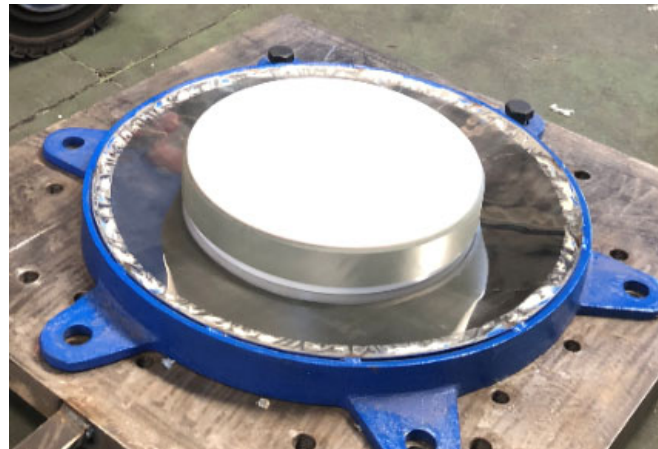
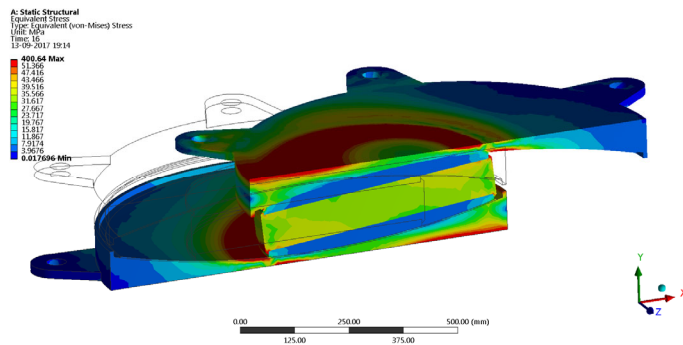
AISLADORES FPS PÉNDULO DOBLE

FPS doble

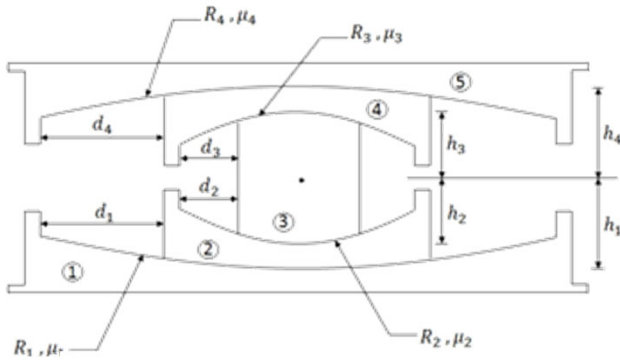
- Péndulo friccional con doble curvatura simétrica

Prototipo

- Capacidad de **1000 ton.**
- Desplazamiento de **35 cm**
- Materialidad de Acero y Hormigón

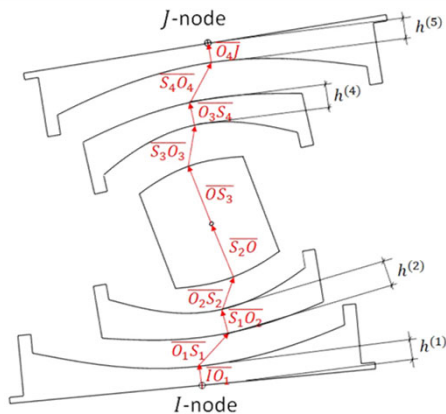


FUNCIONAMIENTO TFP



Regimes	Surfaces in motion	Force interval
I	2 and 3	$F_{f2} \leq F < F_{f1}$
II	1 and 3	$F_{f1} \leq F < F_{f4}$
III	1 and 4	$F_{f4} \leq F < F_{d1}$
IV	2 and 4	$F_{d1} \leq F < F_{d4}$
V	2 and 3	$F_{d4} \leq F < F_{d2}$

$$\vec{IO}_1 + \vec{O}_1\vec{S}_1 + \vec{S}_1\vec{O}_2 + \vec{O}_2\vec{S}_2 + \vec{S}_2\vec{O}_3 + \vec{O}_3\vec{S}_3 + \vec{S}_3\vec{O}_4 + \vec{O}_4\vec{S}_4 + \vec{S}_4\vec{O}_1 = \vec{I}\vec{J}$$



$$R_{effi} = R_i - h_i$$

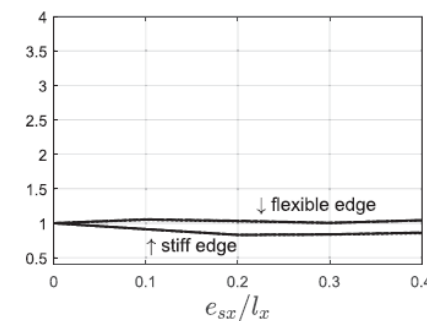
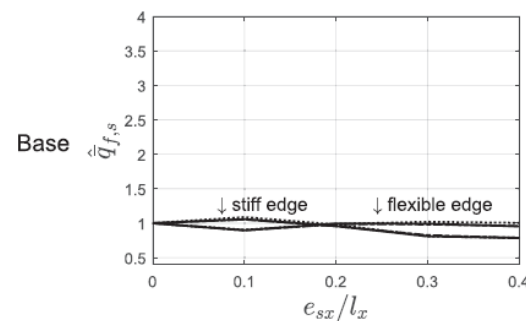
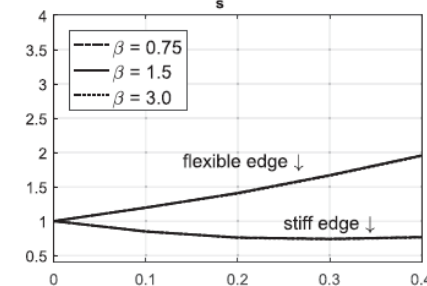
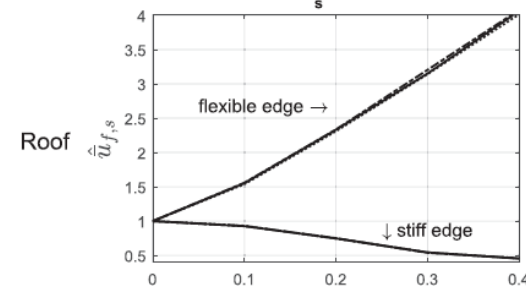
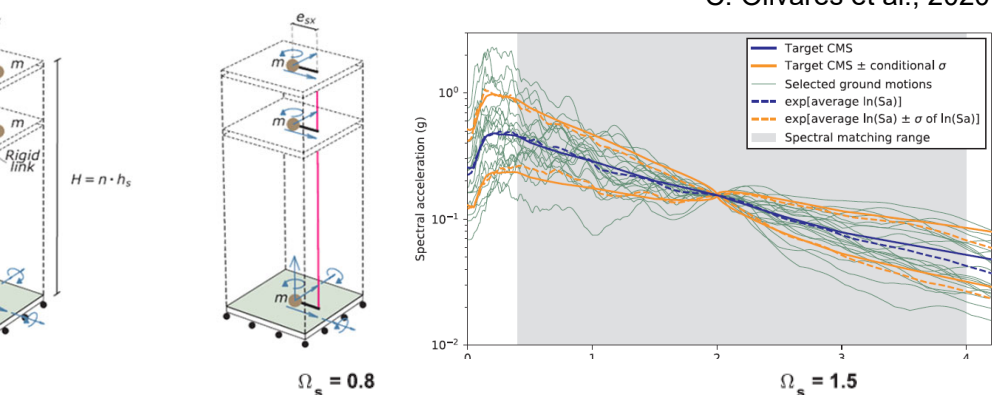
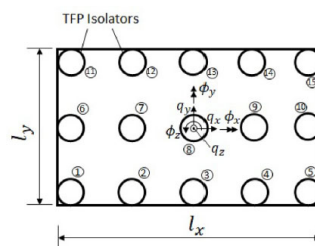
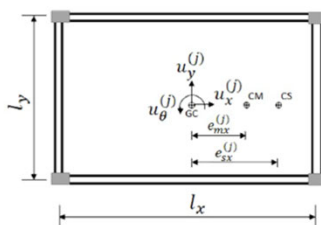
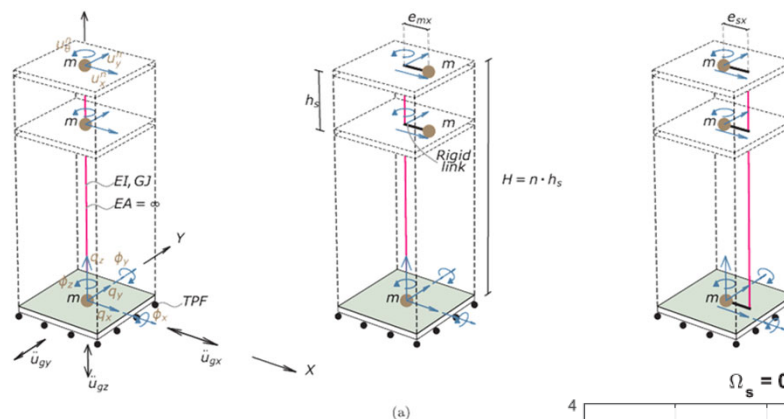
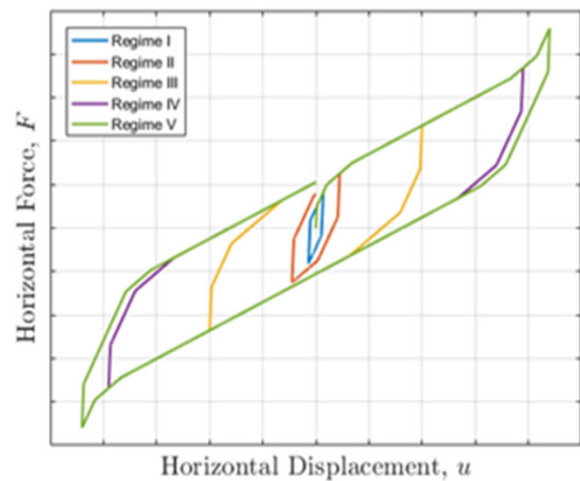
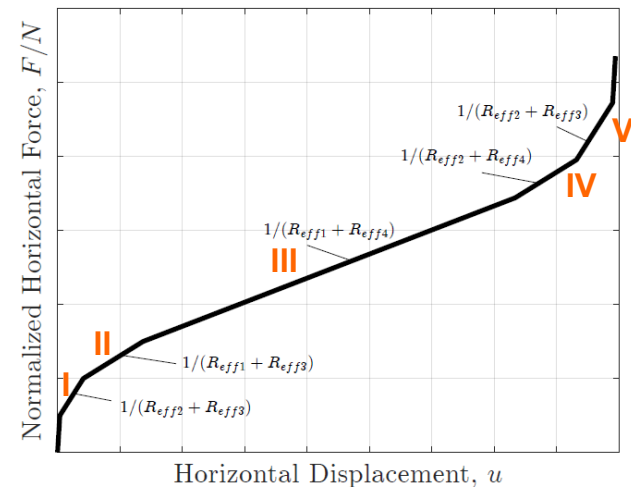
(1) $R_{eff1} = R_{eff4} \gg R_{eff2} = R_{eff3}$, (2) $\mu_2 = \mu_3 < \mu_1 < \mu_4$, (3) $d_1 > (\mu_4 - \mu_1)R_{eff1}$, (4), $d_2 > (\mu_1 - \mu_2)R_{eff2}$, (5) $d_3 > (\mu_4 - \mu_3)R_{eff3}$

Description	Force-Displacement Relationship
I Sliding on surfaces 2 and 3 only	$F = \frac{W}{R_{eff2} + R_{eff3}} u + \frac{F_{f2}R_{eff2} + F_{f3}R_{eff3}}{R_{eff2} + R_{eff3}}$ Valid until: $F = F_{f1} = \mu_1 W$, $u = u^* = (\mu_1 - \mu_2)R_{eff2} + (\mu_1 - \mu_3)R_{eff3}$
II Motion stops on surface 2; Sliding on surfaces 1 and 3	$F = \frac{W}{R_{eff1} + R_{eff3}} u + \frac{F_{f1}(R_{eff1} - R_{eff2}) + F_{f2}R_{eff2} + F_{f3}R_{eff3}}{R_{eff1} + R_{eff3}}$ Valid until: $F = F_{f4} = \mu_4 W$, $u = u^{**} = u^* + (\mu_4 - \mu_1)(R_{eff1} + R_{eff3})$
III Motion is stopped on surfaces 2 and 3; Sliding on surfaces 1 and 4	$F = \frac{W}{R_{eff1} + R_{eff4}} u + \frac{F_{f1}(R_{eff1} - R_{eff2}) + F_{f2}R_{eff2} + F_{f3}R_{eff3} + F_{f4}(R_{eff4} - R_{eff3})}{R_{eff1} + R_{eff4}}$ Valid until:
IV Slider contacts restrainer on surface 1; Motion remains stopped on surface 3; Sliding on surface 2 and 4	$F = \frac{W}{R_{eff2} + R_{eff4}} (u - u_{dr1}) + \frac{W}{R_{eff1}} d_1 + F_{f1}$ Valid until: $F = F_{dr4} = \frac{W}{R_{eff4}} d_4 + F_{f4}$, $u = u_{dr4} = u_{dr1} + \left[\left(\frac{d_4}{R_{eff4}} + \mu_4 \right) - \left(\frac{d_1}{R_{eff1}} + \mu_1 \right) \right] (R_{eff2} + R_{eff4})$
V Slider bears on restrainer of surface 1 and 4; Sliding on surfaces 2 and 3	$F = F_{dr1} = \frac{W}{R_{eff1}} d_1 + F_{f1}$, $u = u_{dr1} = u^{**} + d_1 \left(1 + \frac{R_{eff4}}{R_{eff1}} \right) - (\mu_4 - \mu_1)(R_{eff1} + R_{eff4})$

Fenz et al., 2008

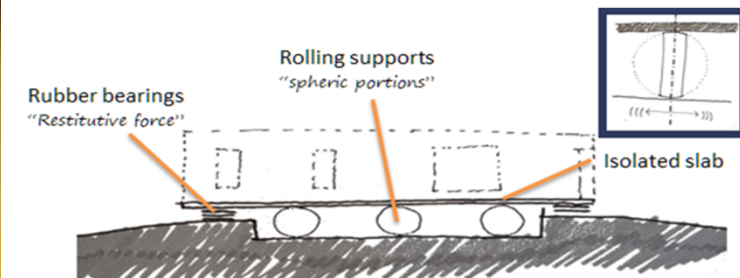
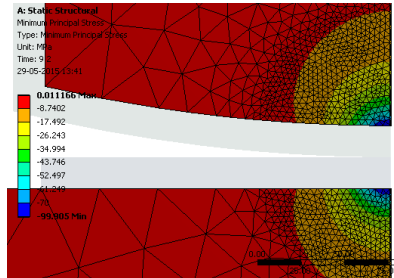
TORSIÓN EN LA SUPERESTRUCTURA

C. Olivares et al., 2020



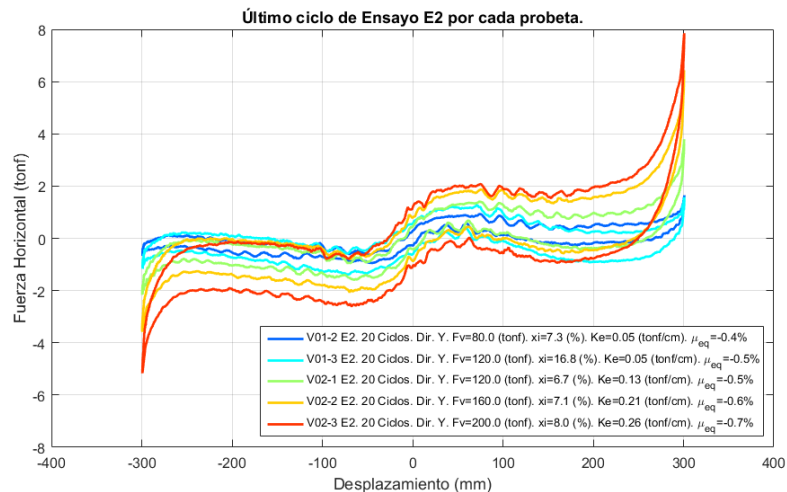
AISLADOR CINEMATICO PPP

- Biela esférica de hormigón armado para estructuras livianas
- El dispositivo actúa como un deslizador equivalente y está pensado para cargas de 120 a 160 Ton y desplazamiento de hasta 35 cm.



Prototipo

- Capacidad axial de 100 Ton
- Desplazamiento de 40 cm

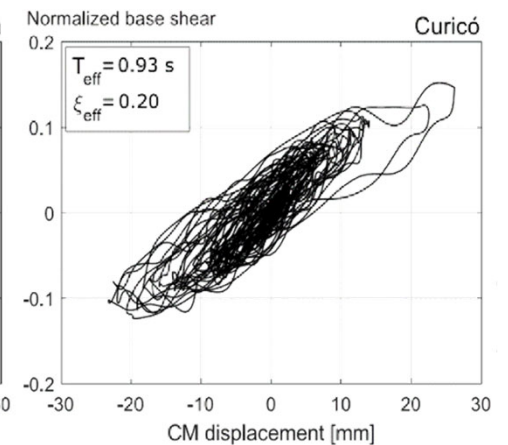
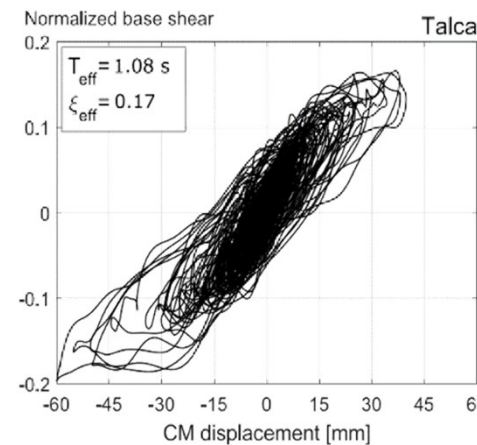
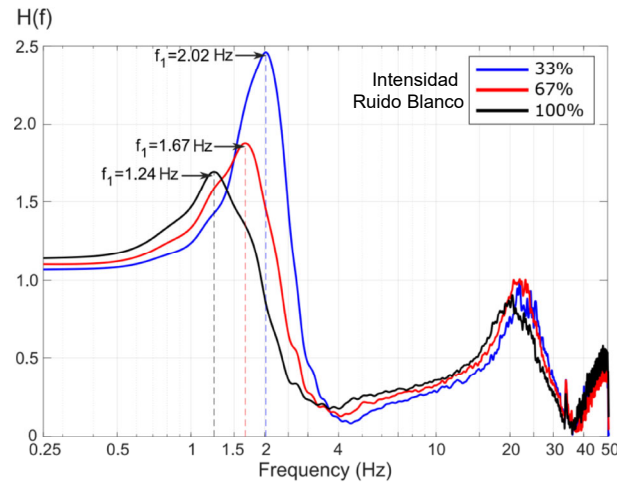


AISLAMIENTO DE ESTANQUES ISO3D-2G

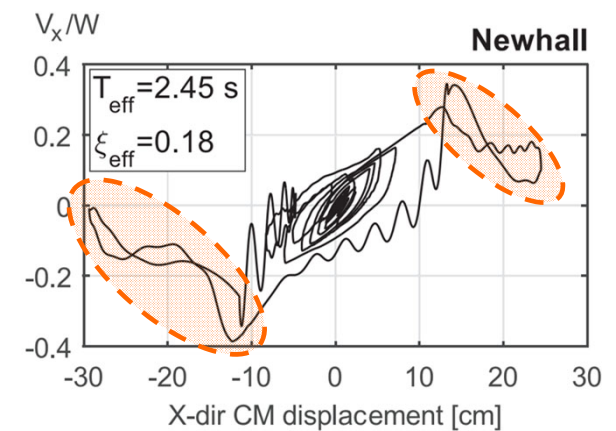
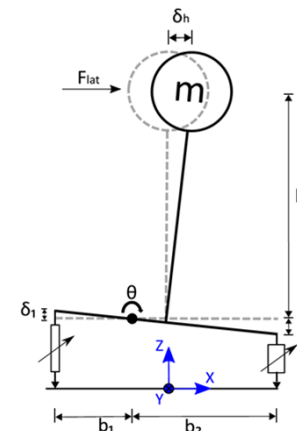
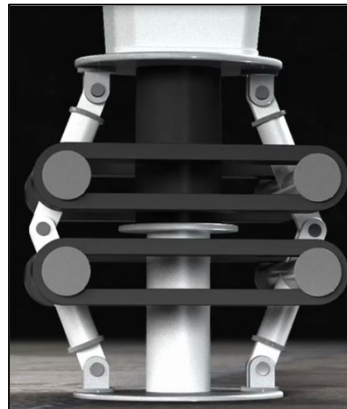
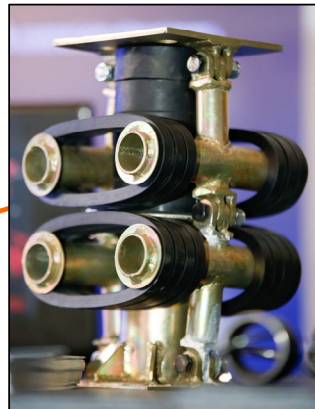
$T = 0,3 \mapsto 1,0 \text{ seg}$
 $\xi = 2 \mapsto 20 \%$
 Reducción = 85%



Montaje experimental en mesa vibradora 1D



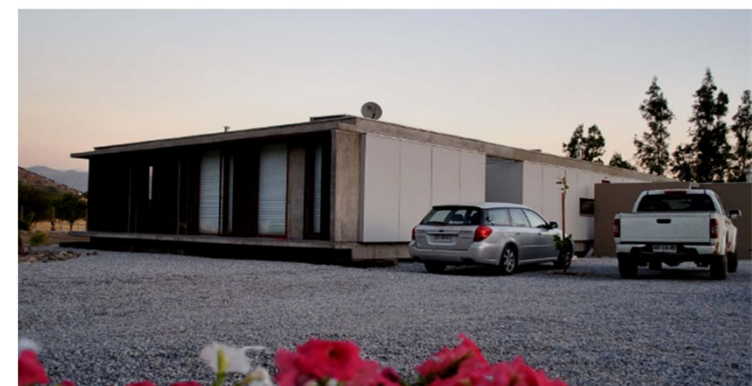
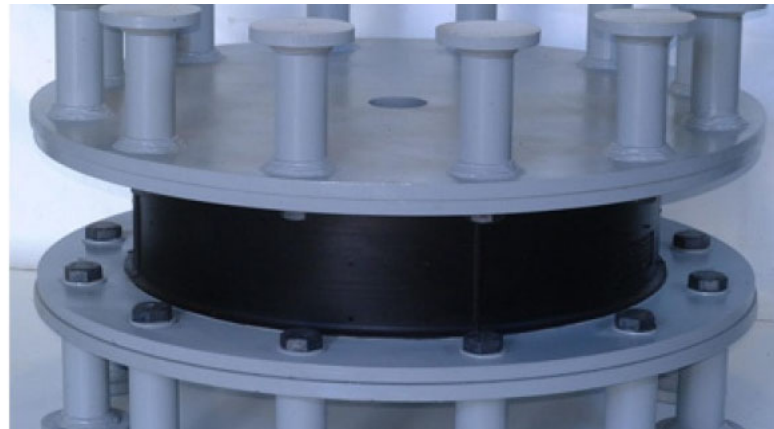
Resultados experimentales en mesa vibradora. Identificación del Sistema y registros sísmicos.



Modelación computacional. Efecto del levantamiento del estanque

S. Reyes et al., 2020

ALGUNAS APLICACIONES



CHILE

NUEVOS HOSPITALES AISLADOS



Maipú (2011)

70.000 m²; W= 89.545 ton;
 $T_{1,2} = 3.30s, 3.28s$



La Florida (2011)

85.000 m²; W= 68.322 ton;
 $T_{1,2} = 3.06s, 3.07s$



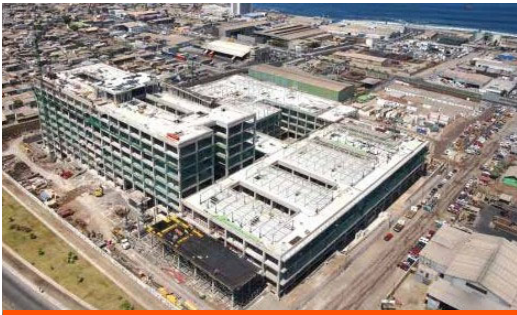
Exequiel González Cortés (2016)

57.000 m²; W= 50.794 ton;
 $T_{1,2} = 3.23s, T_y = 3.20s$



Servicio Médico Legal (2020)

31.000 m²; W= 45.746 ton;
 $T_x = 3.51s, T_y = 3.42s$



Antofagasta (2015)

90.000 m²; W= 124.378 ton;
 $T_{1,2} = 3.07s, 3.18s$



Félix Bulnes (2017)

130.000 m²; W= 179.942 ton;
 $T_{1,2} = 4.03s, 3.98s$



Cruz Blanca (2017)

130.000 m²; W= 179.942 ton;
 $T_x = 3.71s, T_y = 3.52s$



Del Salvador (2019)

180.000 m²; W= 215.000 ton;
 $T_x = 3.62s, T_y = 3.54s$

HOSPITAL DE ANTOFAGASTA (2015)

- **Ubicación:** Antofagasta
- **Superficie:** $\sim 114.000\text{m}^2$
- **Peso sísmico de la estructura aislada:** 124.378 ton
- **SPS:** aislamiento elastomérico, 422 HDRB + 139 Deslizadores; $D_{TM} = 24.8\text{ cm}$
- **Estructura:** marcos intermedios, Capítulo 21, ACI
- **Períodos:** $T_x = 3.07\text{s}$, $T_y = 3.18\text{s}$ ($\xi_{eq} = 14.3\%$; $\frac{V_{bsup,bsub}}{W} = 6\%, 7\%$)

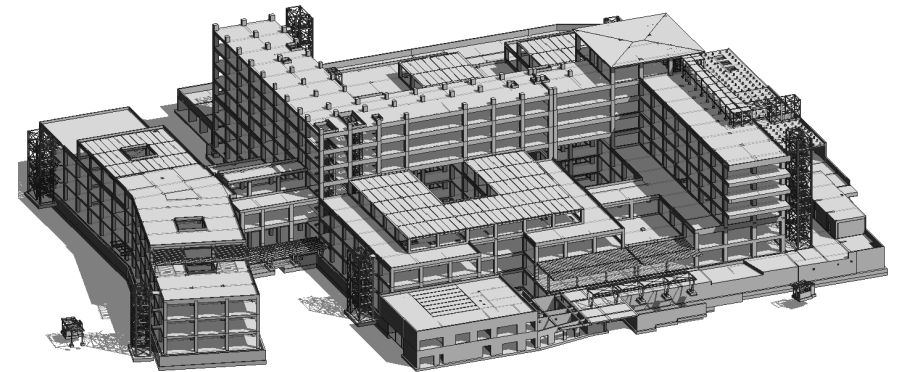


HOSPITAL FÉLIX BULNES (2017)



- **Ubicación:** Cerro Navia, Santiago
- **Superficie:** 130.000 m²
- **Número de pisos:** 11 pisos sobre el nivel de aislación y 3 subterráneos
- **SPS:** 264 aisladores elastoméricos, 74 deslizadores, 94 disipadores viscosos de 150 ton; $\xi = 11\%$; $D_{TM} = 29.2 \text{ cm}$
- **Período:** $T = 4,1s$; $\frac{V_b}{W} = 4\%(R = 1)$

HOSPITAL MARGA-MARGA (2019)



- **Ubicación:** Valparaíso
- **Superficie:** ~ 94.000m²
- **Número de pisos:** 4 (19m) y 8 en la torre (34m)
- **Dimensiones en planta:** 120m x 128m
- **SPS:** 252 aisladores elastoméricos y 64 deslizadores
- **Nivel de aislación:** subterráneo
- **Estructura:** marco intermedio, Capítulo 21, ACI
- **Períodos:** $T_x = 3.39s$, $T_y = 3.47s$

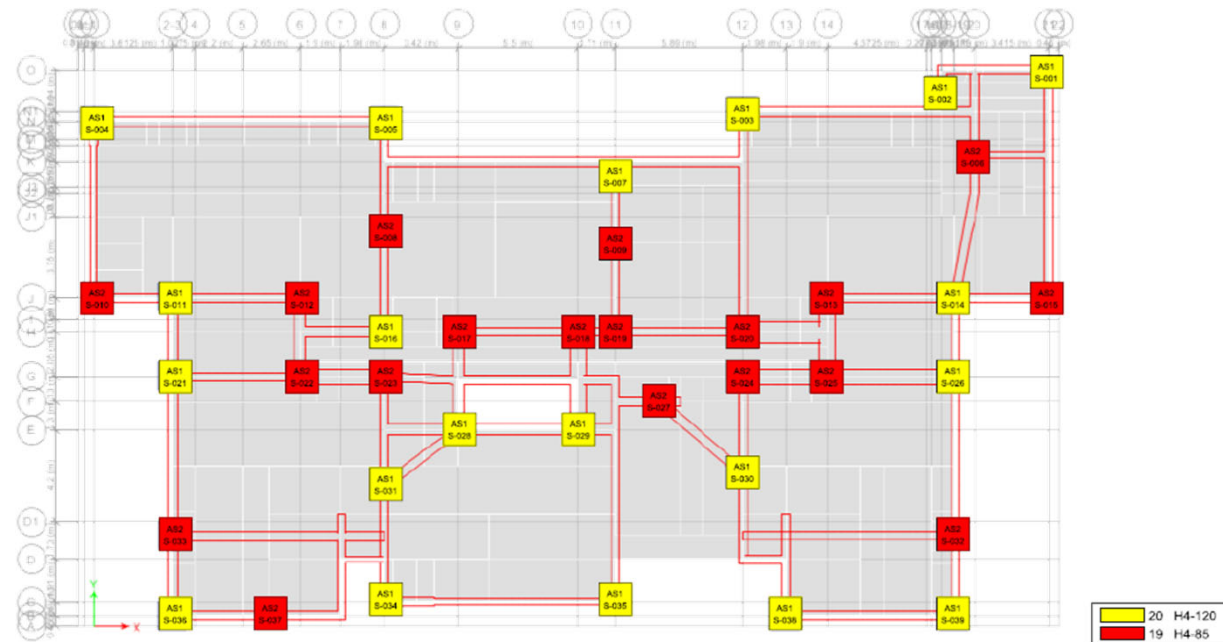
EDIFICIO RIMINI (2020)

Interfaz de
Aislamiento

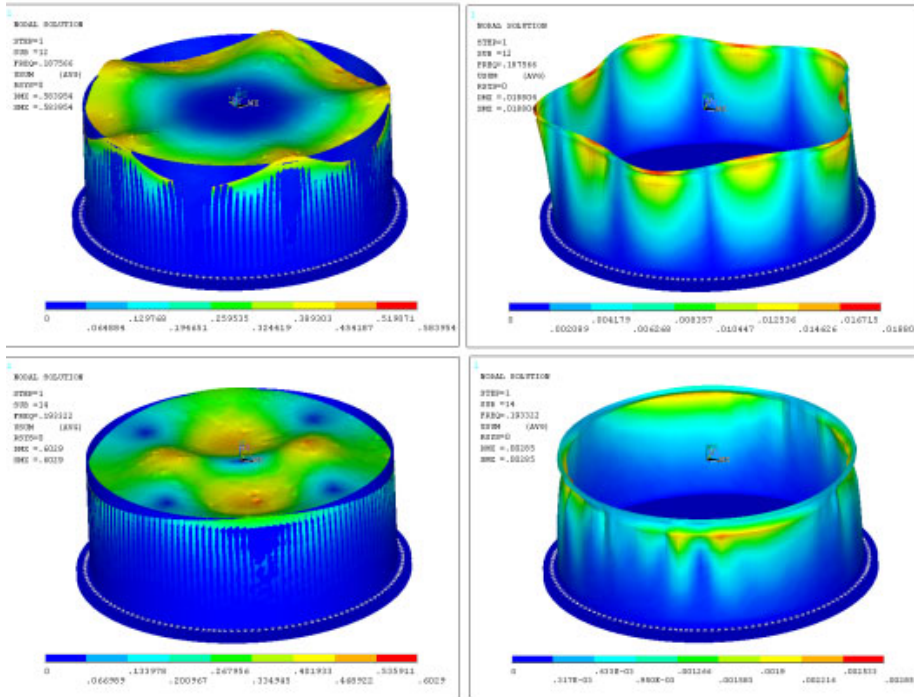


Edificio más alto con aislación en Latinoamérica

- **Ubicación:** Antofagasta
- **Superficie:** 26.500 m²
- **Número de pisos:** 35 sobre el nivel de aislación (32+3 subterráneos)
- **SPS:** 39 aisladores elastoméricos
- **Períodos:** $T_x = 3,72s$; $T_y = 3,74s$



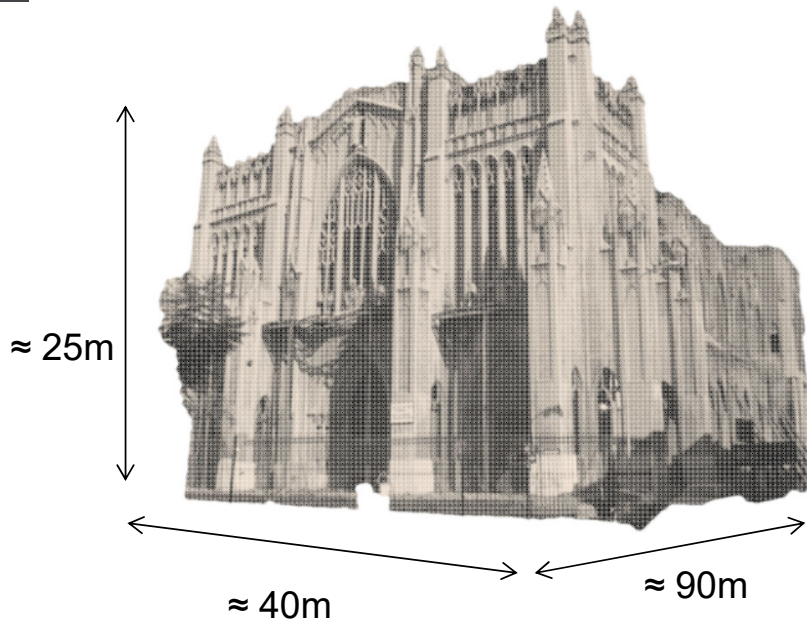
GNL MEJILLONES (2011)



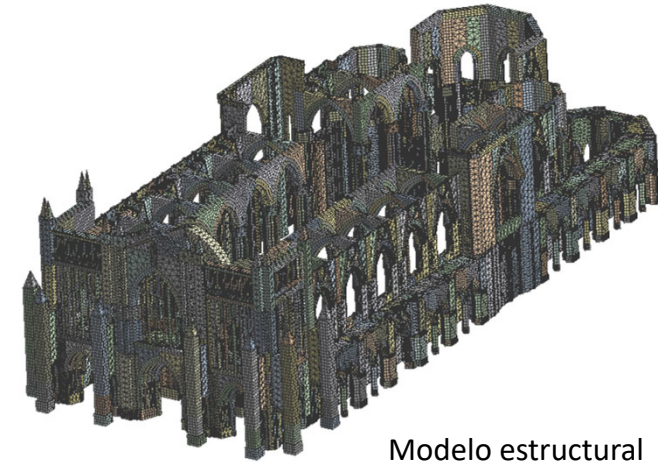
- **Ubicación:** Mejillones, Chile
- **Dimensiones:** $h = 50m$, $D = 90m$
- **Peso máximo:** 160.000 ton
- **SPS:** 501 aisladores elastoméricos
- **Período:** $T = 2,5s$



BASÍLICA DEL SALVADOR (2020)

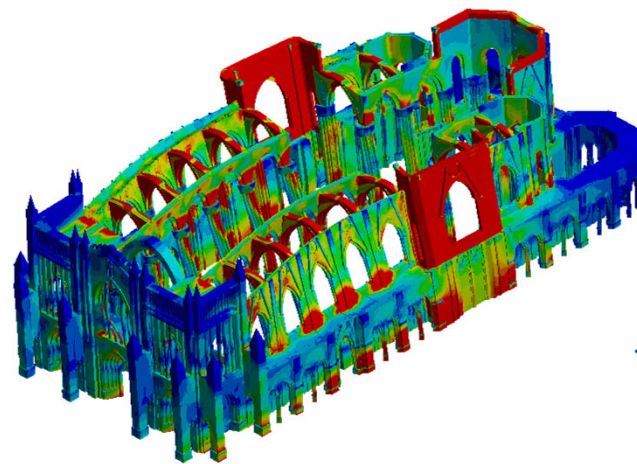


Escaneo laser

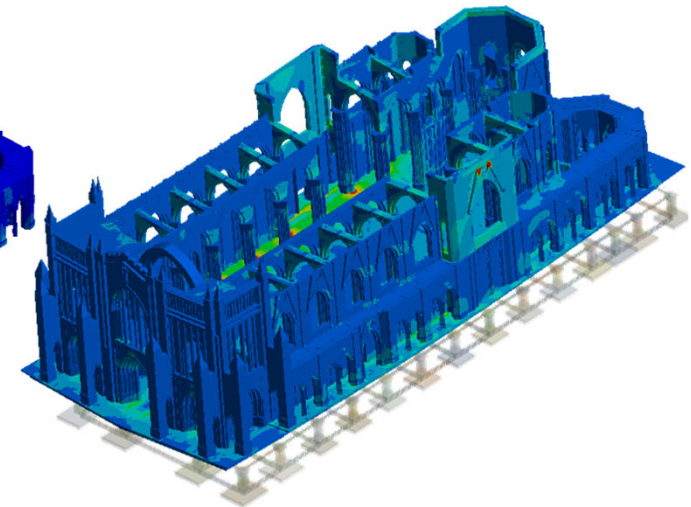


Modelo estructural

- Construida entre 1873-1892
- Mampostería no reforzada
- Fundaciones de mampostería
- Muros exteriores conectados con columnas interiores con arcos de mampostería
- Diseño inadecuado para un país sísmico



Modelo actual



Modelo aislado

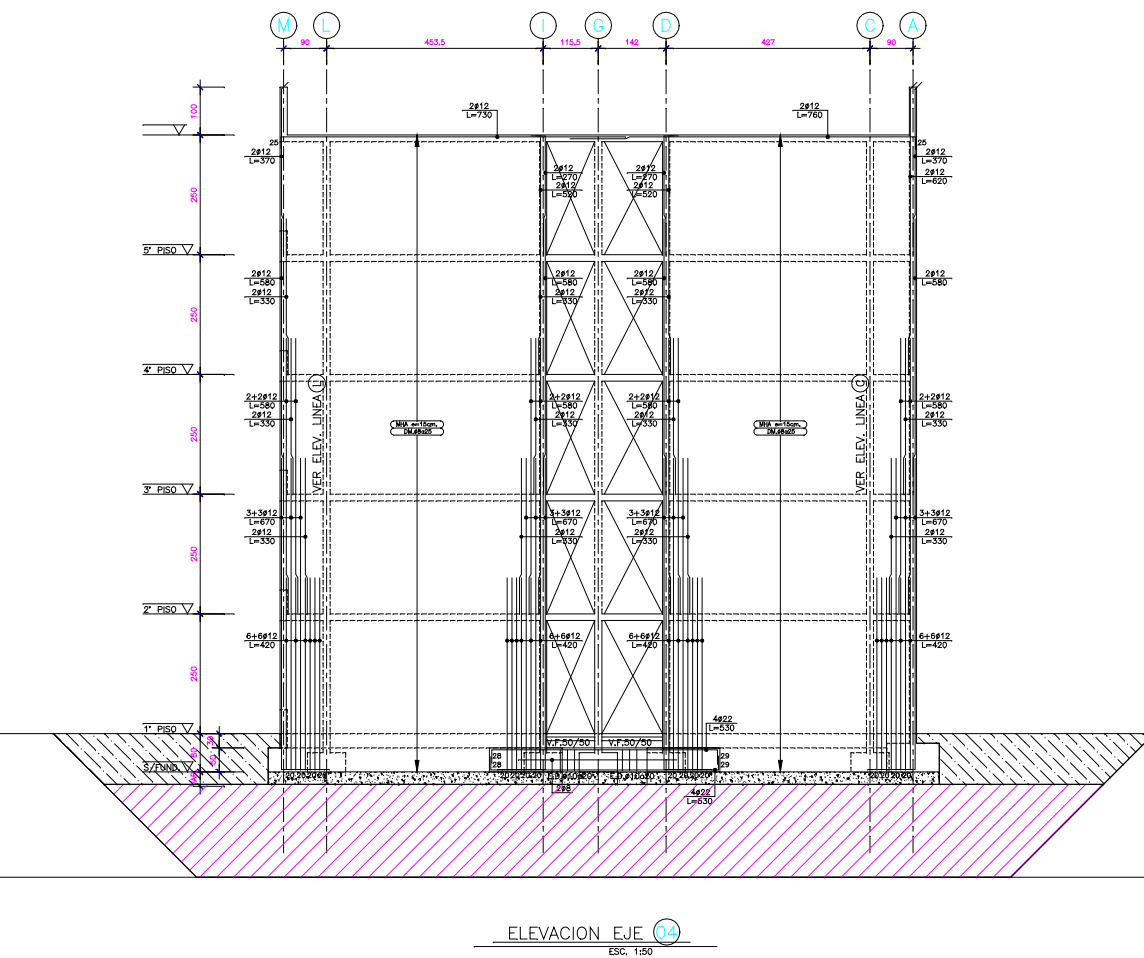
PANIAHUE VIVIENDAS SOCIALES (2012)



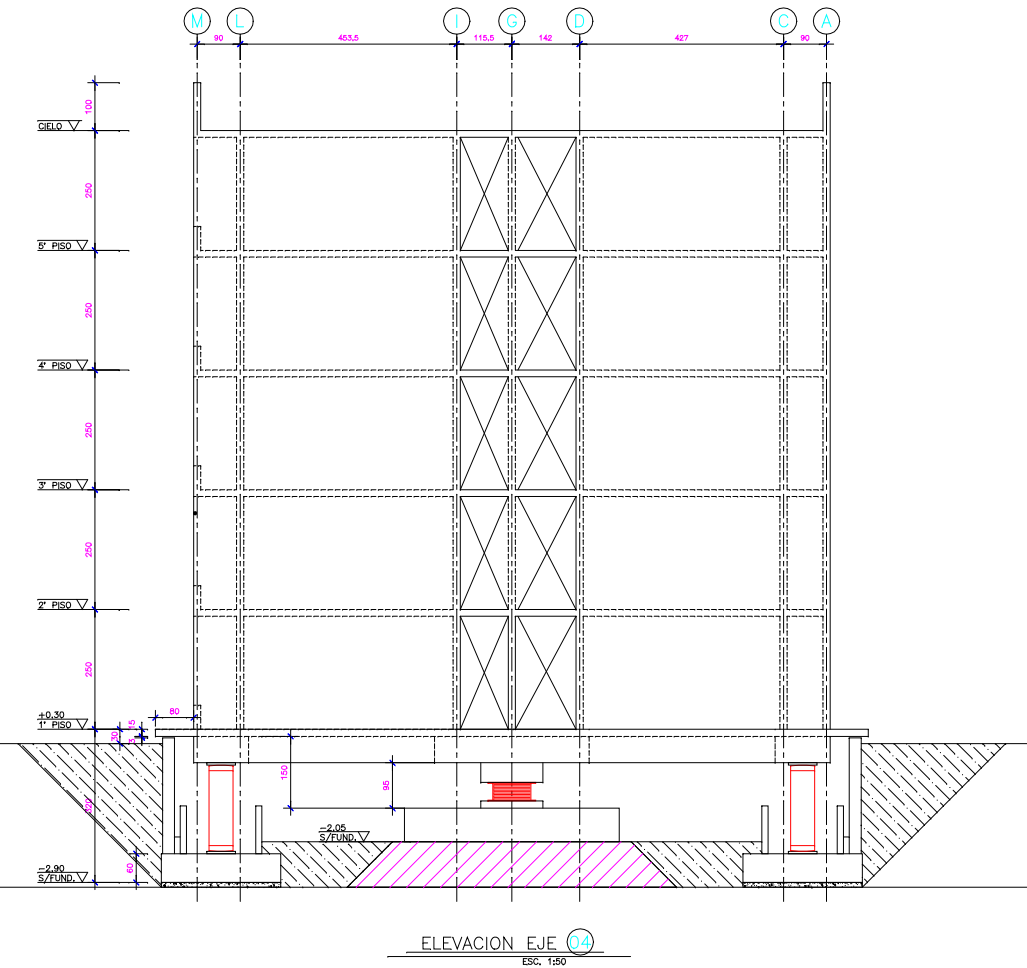
- **Ubicación:** Santa Cruz, Chile
- **Características:** 8 bloques de 4 pisos cada uno. Total: 192 viviendas sociales
- **Superficie:** 26.500 m²
- **SPS:** 39 aisladores elastoméricos
- **Períodos:** $T_x = 3,72s$, $T_y = 3,74s$



SOLUCION AISLADA VS BASE FIJA

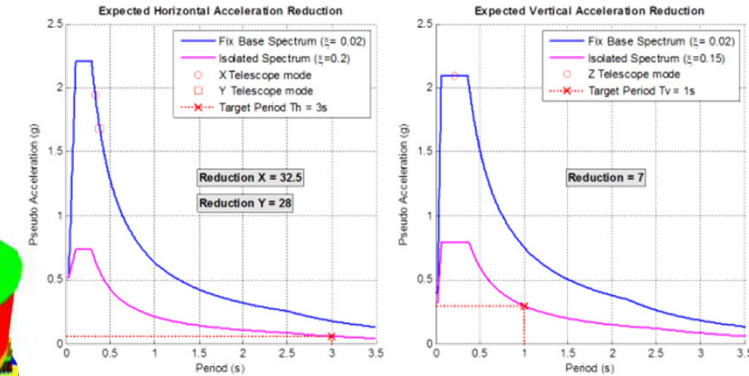
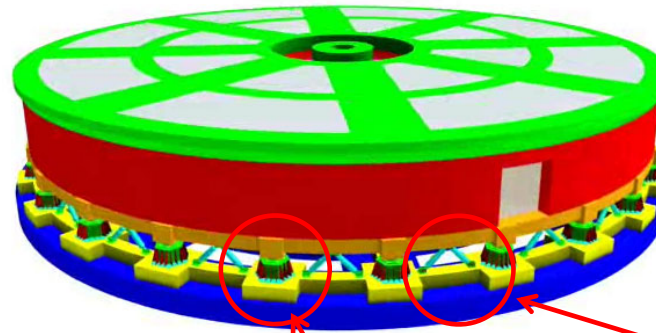
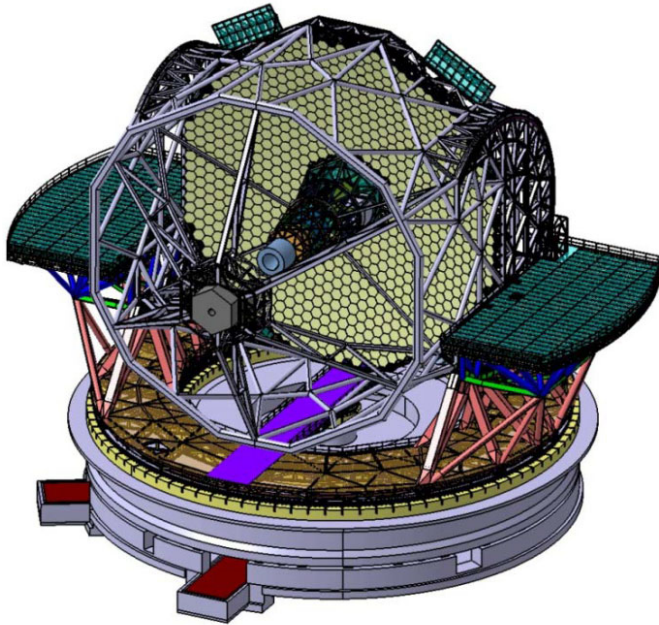


Convencional



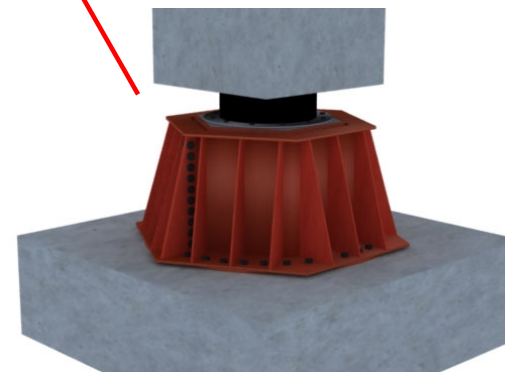
Aislado

TELESCOPIO EELT (ESO)

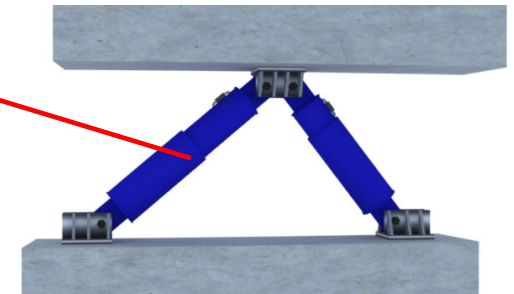


Proyecto

- Diseño conceptual de un sistema de aislación 3D
- Capaz de mantener al telescopio restringido durante operación normal
- El sistema de restricción debe lograr variaciones menores a 5% de las principales frecuencias de la estructura con base fija (objetivo 2%)
- Máxima aceleración durante un sismo: 0.26g



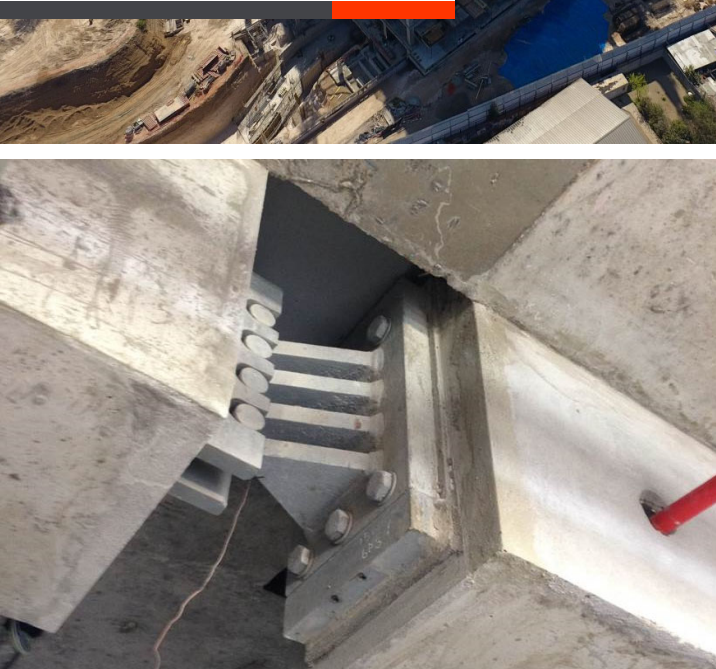
Aisladores elastoméricos



Disipadores viscosos

(Fuente: Sirve S.A.)

DISIPACION DE ENERGIA



SEISMIC PROTECTION SYSTEMS

FUNDAMENTAL CONCEPT

I.

The general form of the EOM with seismic protections system (SPS) is

$$M\ddot{u} + C\dot{u} + Ku + L^T f_d(v, \dot{v}) = -Mr\ddot{u}_g$$

$\ddot{u}, \dot{u}, u$ are the acceleration, velocity, and displacement of the mass

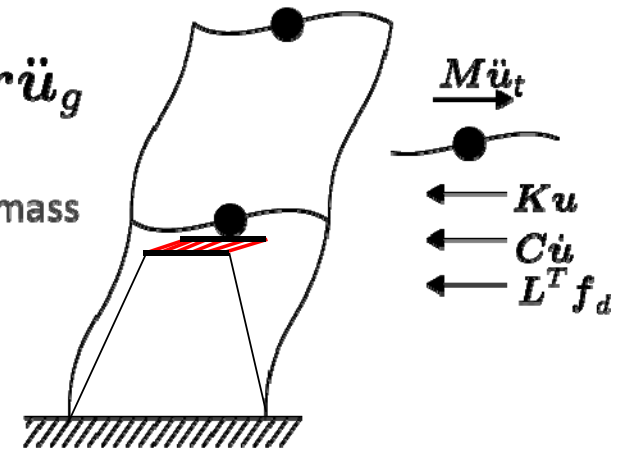
M, C, K are the mass, damping, and stiffness matrices

r is the influence vector of the input

f_d is the vector of SPS forces

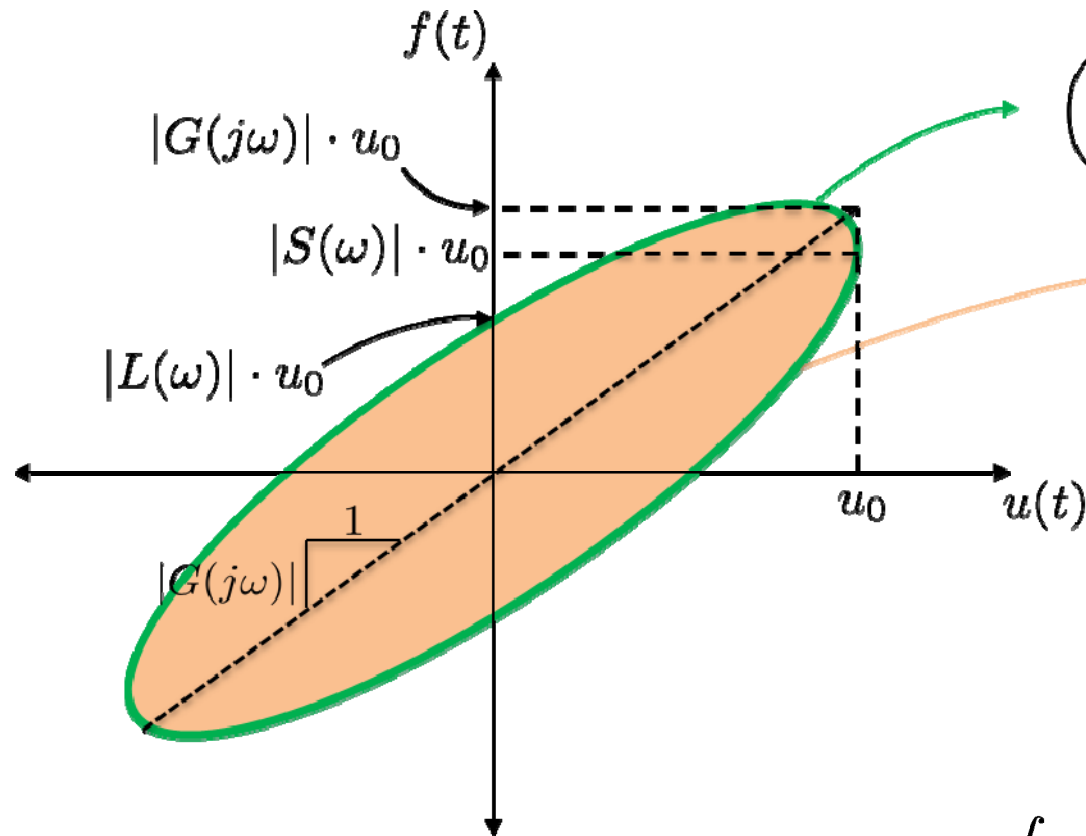
L^T is the kinematic transformation from the local SPS deformations to the global dofs

$v, \dot{v}$ are the local displacement and velocity of the SPS d.o.f which depend on $u, \dot{u}$ respectively



$$\underbrace{\frac{1}{2} \dot{u}_t^T(\tau) M \dot{u}_t(\tau) \Big|_0^t}_{E_k(t)} + \underbrace{\int_0^t \dot{u}^T(\tau) C \dot{u}(\tau) d\tau}_{E_v(t)} + \underbrace{\frac{1}{2} u_t^T(\tau) K u(\tau) \Big|_0^t}_{E_s(t)} + \underbrace{\int_0^t \dot{u}^T(\tau) L^T f_d(\tau) d\tau}_{E_d(t)} = \underbrace{\int_0^t \dot{u}_g^T(\tau) r^T M \ddot{u}_t(\tau) d\tau}_{E_i(t)}$$

DISIPACION DE ENERGIA EN SL Y NL



$$\left(\frac{u(t)}{u_0}\right)^2 + \left(\frac{f(t) - S(\omega) \cdot u(t)}{L(\omega) \cdot u_0}\right)^2 = 1$$

$$E_d = \pi u_0^2 \cdot |L(\omega)|$$

Cuadrática en desplazamiento

Caso Lineal

Note:

$$L(\omega) = |G(j\omega)| \cdot \sin(\phi)$$

$$S(\omega) = |G(j\omega)| \cdot \cos(\phi)$$

$$E_d = \oint f(t) \cdot du \longrightarrow$$

$$\xi_d = \frac{E_d}{4\pi W_s}$$

Caso General

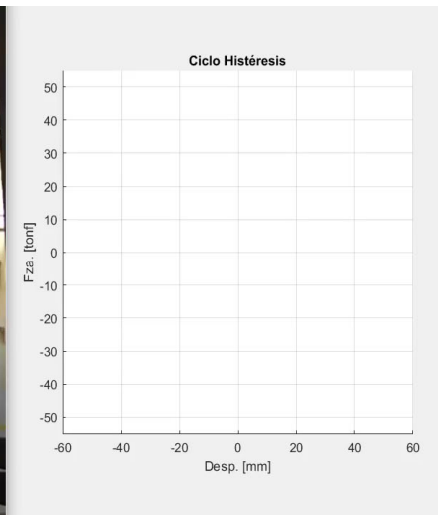
ECUADOR: HOSPITAL

DISIPACIÓN METÁLICA

Características

- Reforzamiento de hospital existente
- 308 TADAS de 30 ton (+/- 45 mm) y 80 TADAS de 50 ton (+/- 55 mm)
- Instalados en arriostramientos tipo Chevron
- Ensayados en Laboratorio DICTUC

Hospital, Ecuador

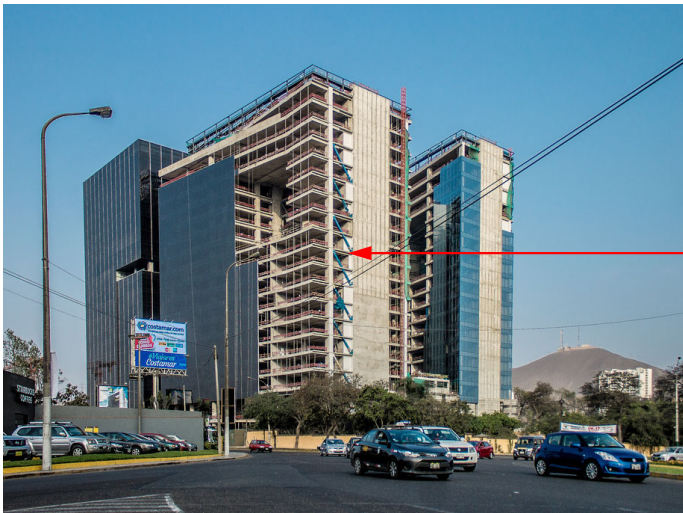


EDIFICIO PANORAMA

DISIPACIÓN VISCOSA

Características

- 78 VD's fabricados en Chile para un complejo de dos edificios en Perú
- $C = 1,745 \text{ kN} \cdot \left(\frac{s}{m}\right)^\alpha$ con $\alpha = 0.3$
- Max. fuerza: 1,275 kN, recorrido: $\pm 50 \text{ mm}$
- 1,600 kJ de capacidad de disipación de energía



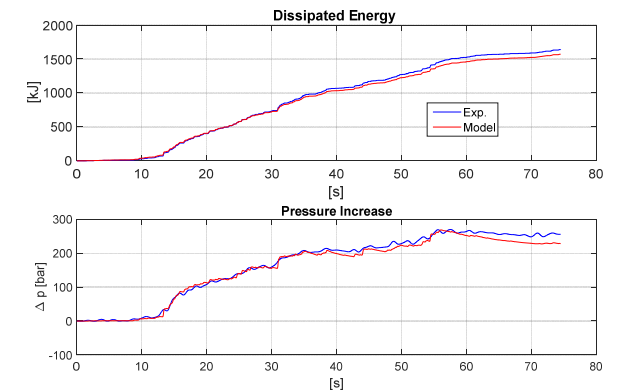
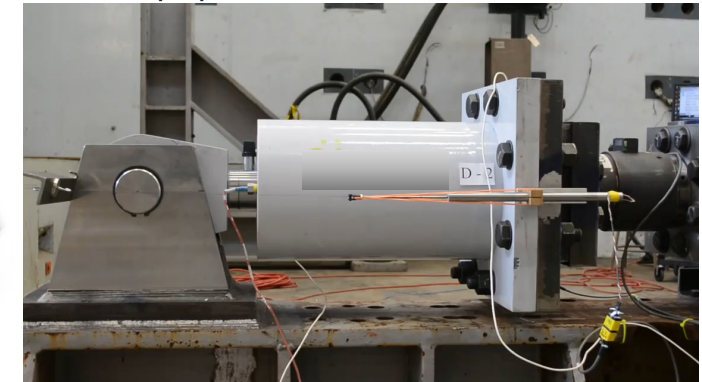
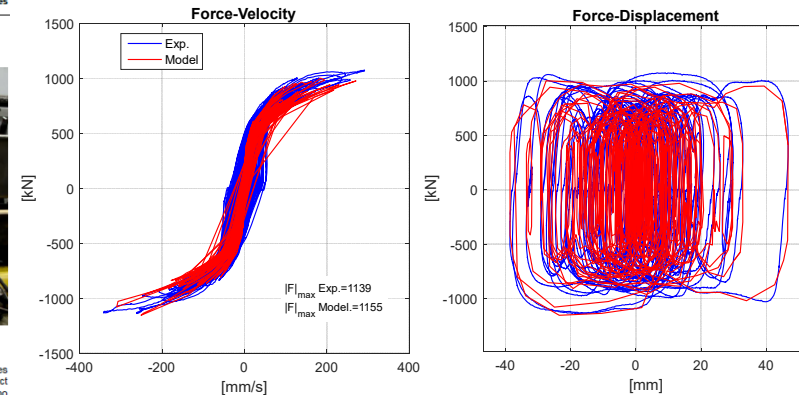
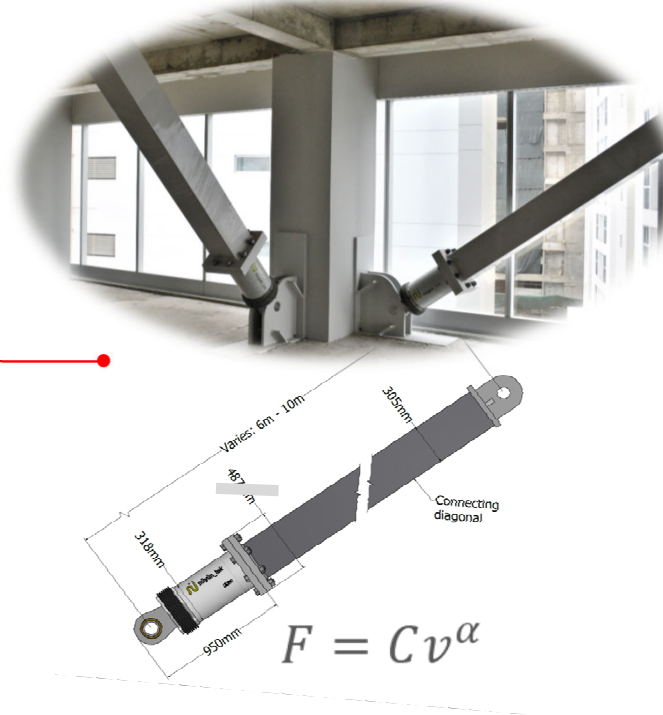
ATLSS ENGINEERING RESEARCH CENTER
Lehigh University
Imbit Laboratories

Finally, Figure 3 shows the damper mounted in the test system at the Lab.



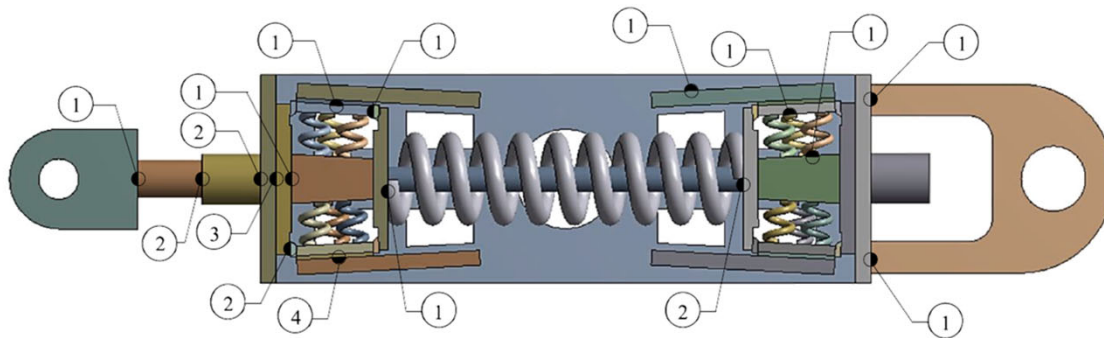
Figure 3: Damper 14059-001 mounted in the test system.

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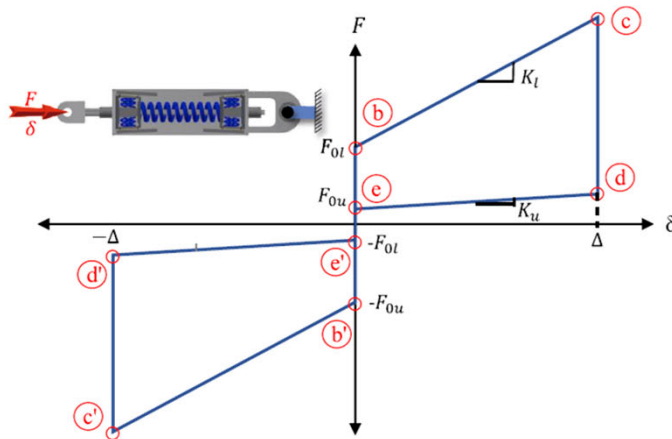


SISTEMAS AUTOCENTRANTES

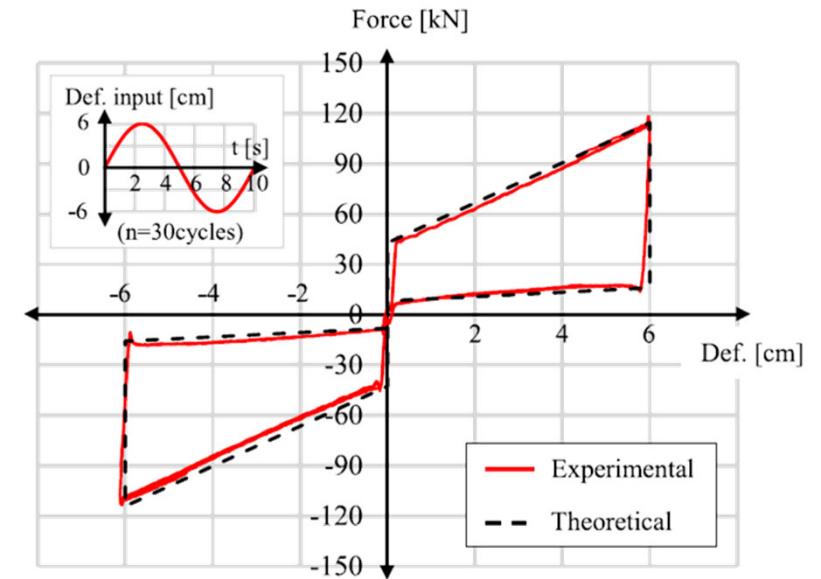
FRICCIÓN



- ① Bonded contact ② No separation contact ③ Frictionless contact ④ Frictional contact
 Contact face
 Target face



- (a) Unloaded device (before the damper works)
 (b) Imminent motion of left friction wedge
 (c) Maximum displacement Δ of left friction wedge
 (d) Reverse motion of left friction wedge
 (e) Left friction wedge at initial preload condition
 (a') Imminent motion of right friction wedge
 (b') Maximum displacement Δ of right friction wedge
 (c') Reverse motion of right friction wedge
 (d') Right friction wedge at initial preload condition



Westenenk et al. (2019)

ESTRUCTURAS PREFABRICADAS

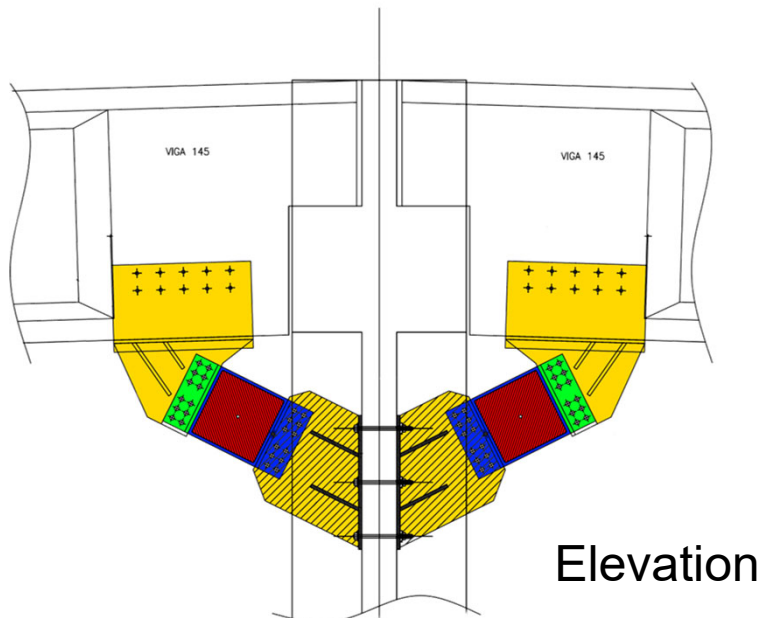


OBJETIVOS DEL MEJORAMIENTO ESTRUCTURAL

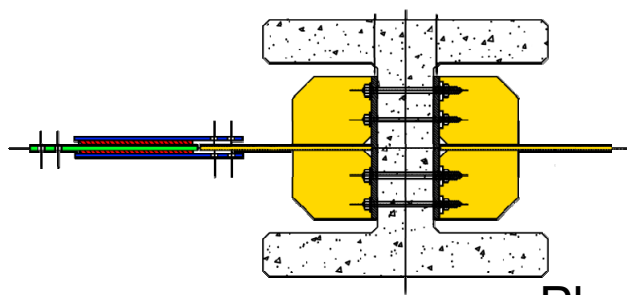
- Asegurar la integridad y operación del difragma de techo
- Cumplir con el diseño por capacidad en las conexiones a través de incluir disipadores viscoelásticos.
- Solución estructural:
 - Disipadores friccionales en arriostres de techo
 - Uniones viga-columna con disipación



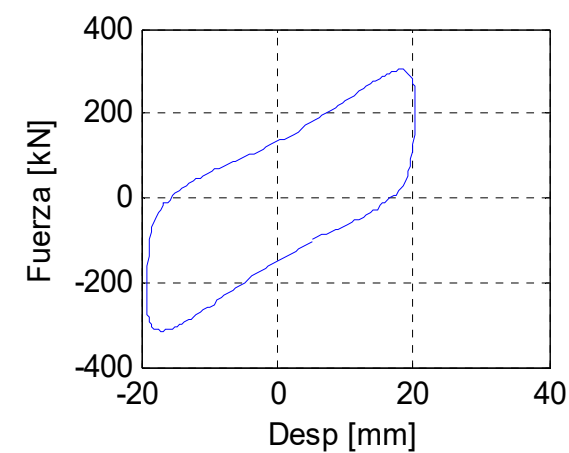
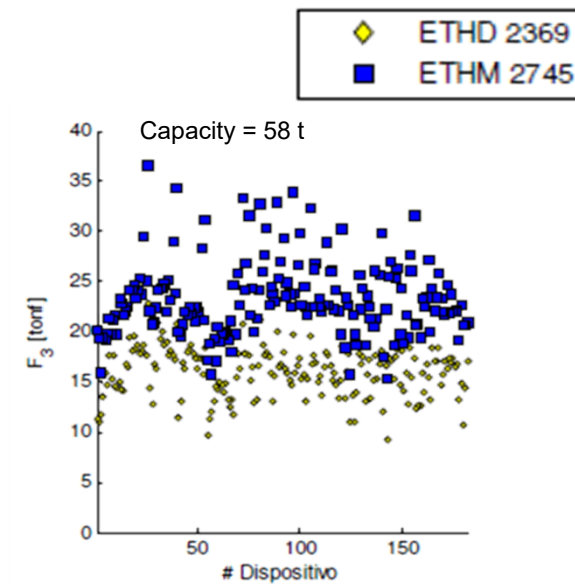
CONEXIONES VISCOELÁSTICAS



Elevation

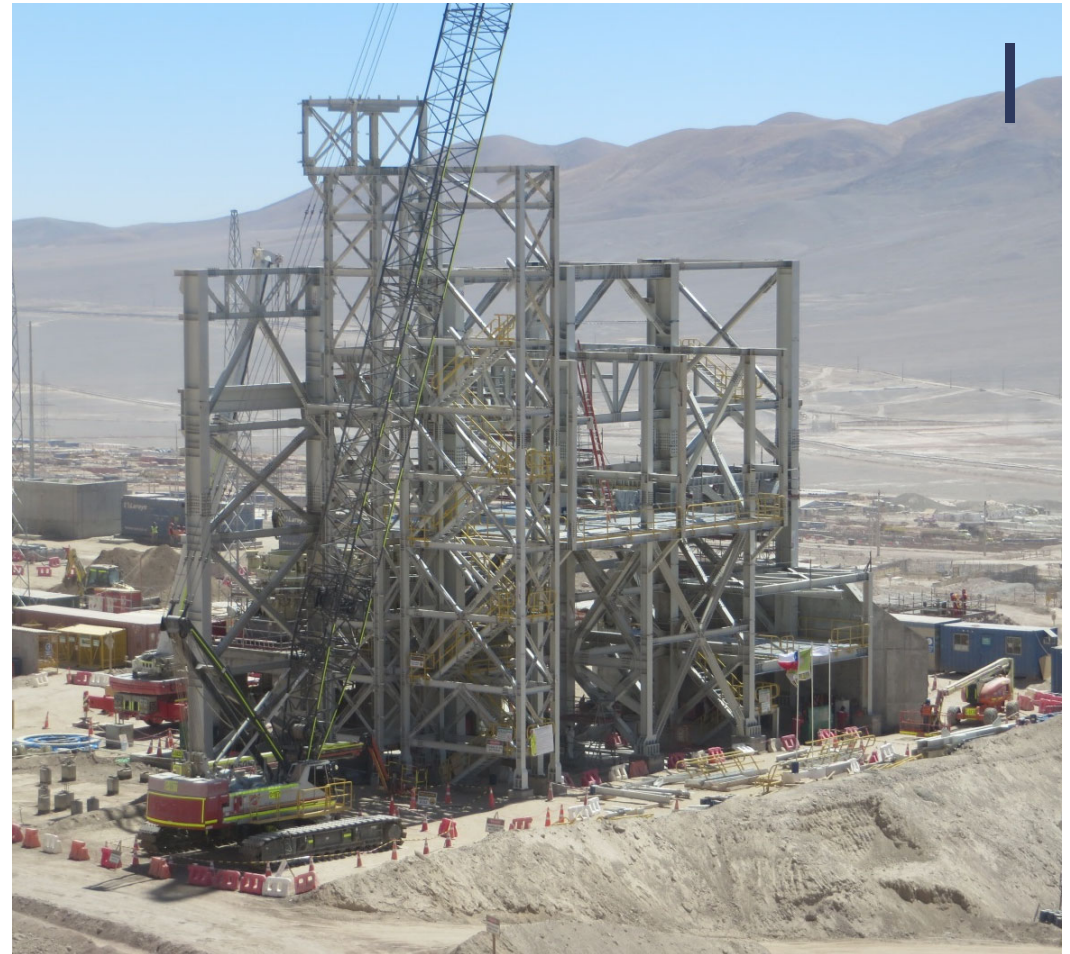
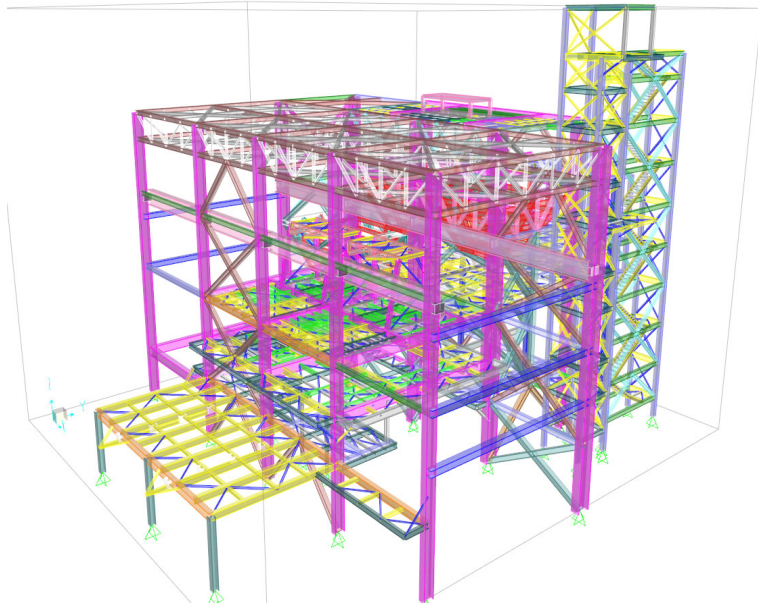
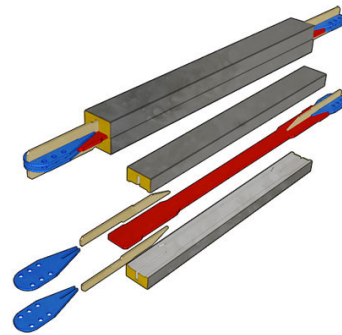
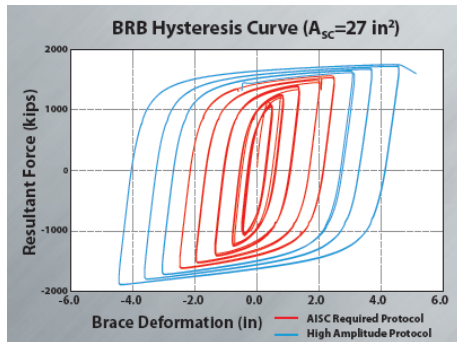


Plan view



TOSTADOR DE MOLIBDENO (CODELCO, 2016)

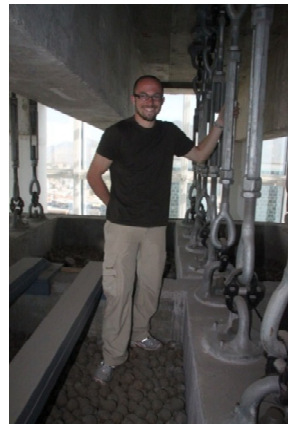
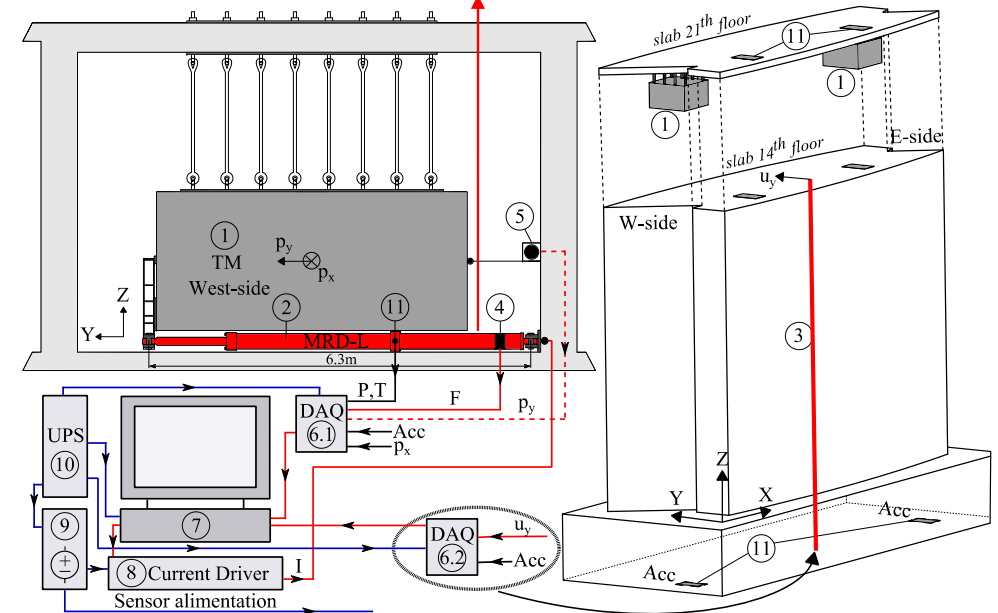
DIAGONALES DE PANDEO RESTRINGIDO



AMS + Amortiguador MR



- **Ubicación:** Las Condes, Santiago
- **Años de ejecución:** 2005-2006
- **Materialidad:** Hormigón armado
- **Sistema estructural:** estructura mixta de muros (núcleo) y marcos
- **Número de pisos:** 22
- **Número de subterráneos:** 6
- **Superficie:** 50.000 m²
- **SPS:** 2 AMS de aproximadamente 160 ton cada uno y un disipador magneto-reológico en el piso mecánico



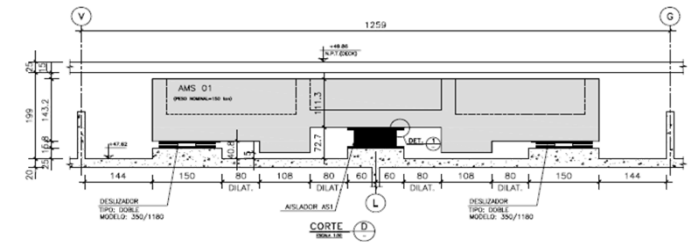
AMS SOBRE AISLADORES



Geocentro Agustinas - Aconcagua

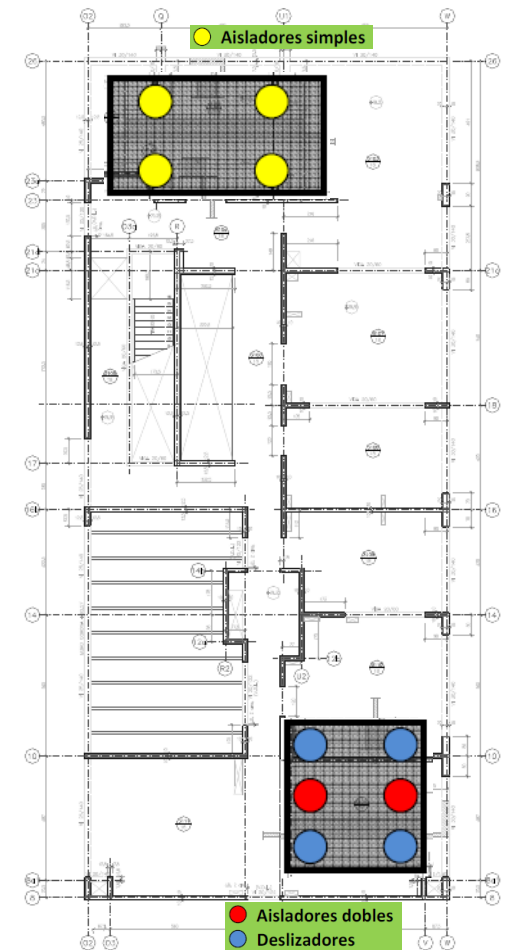
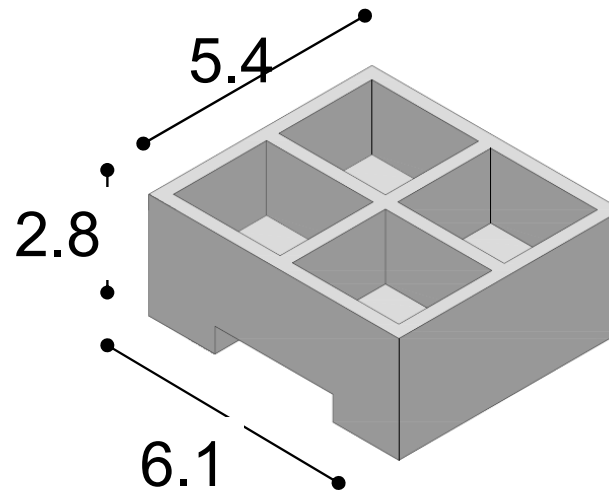
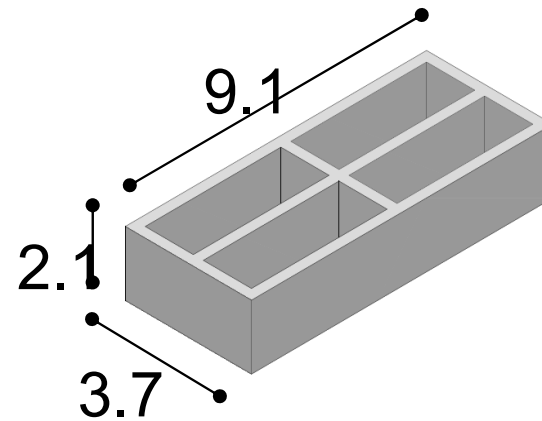


Parque San Damián - MPC



Las Condes Capital - Armas

AMS SOBRE AISLADORES



SEASCAPE TOWER, NZ (2017)

AMS + DISIPADORES VISCOSOS

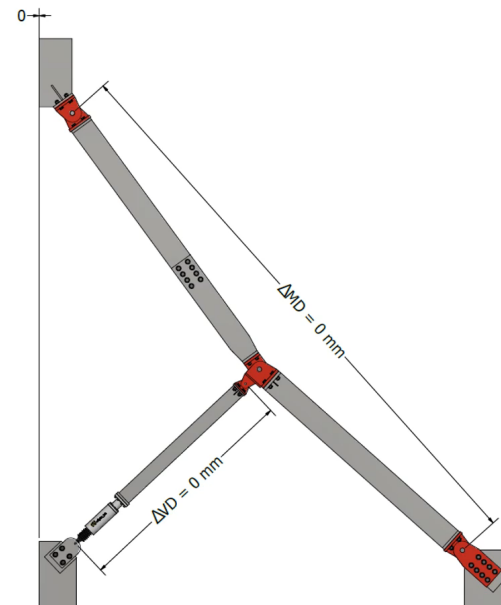
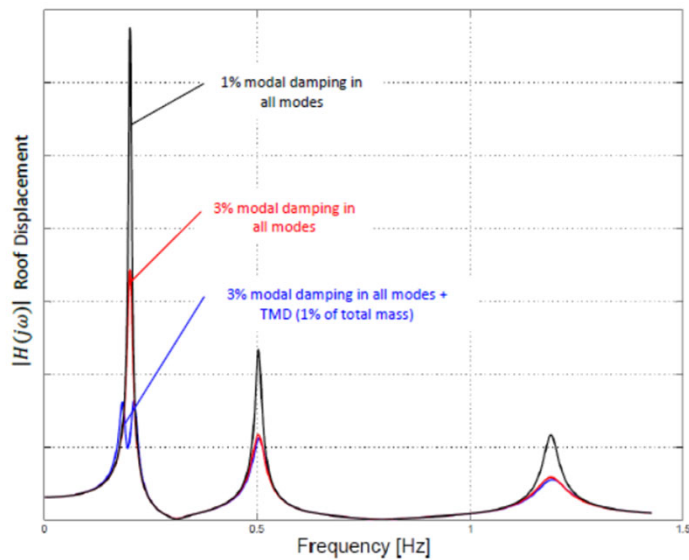
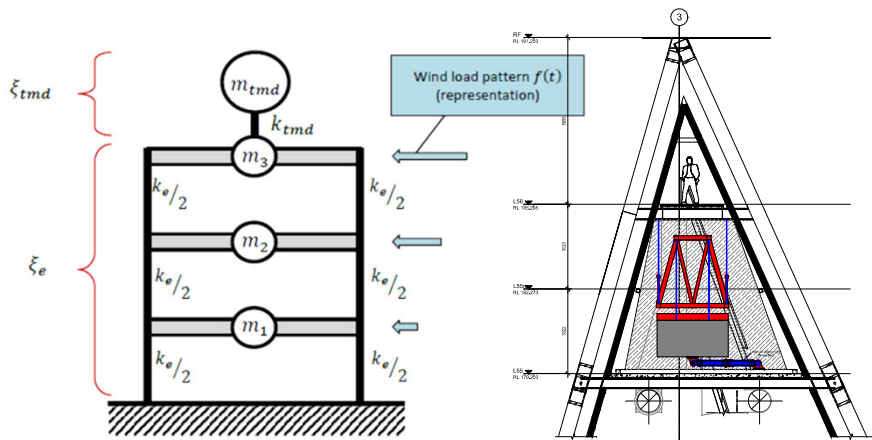


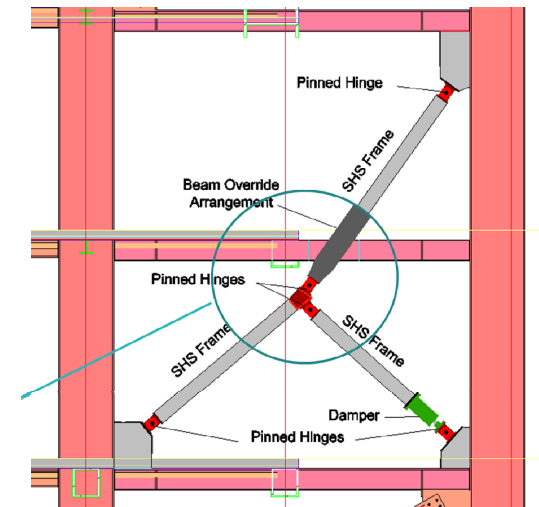
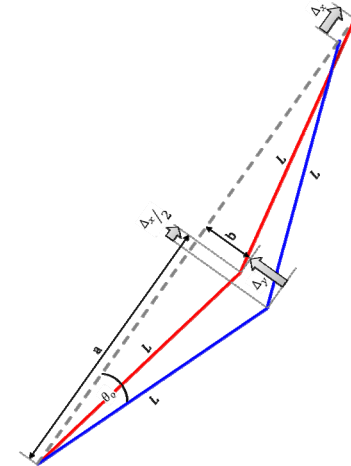
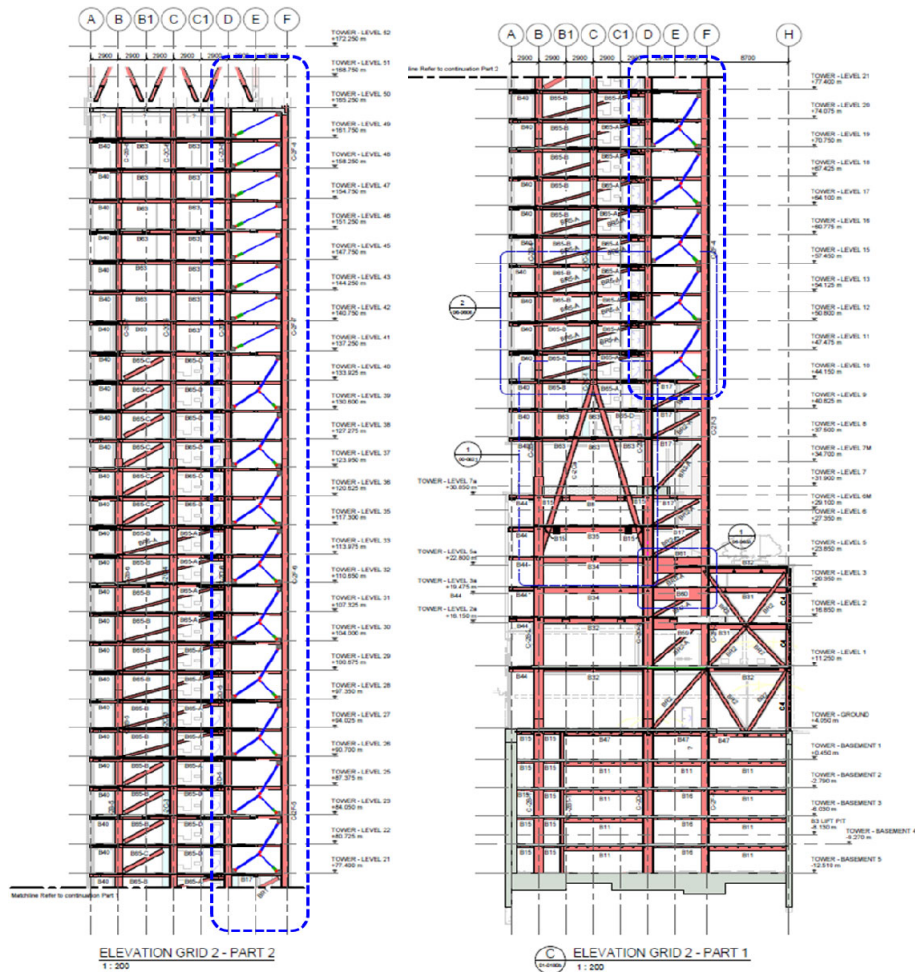
Table 1: Results for non-linear and probabilistic analyses

Type	Criterion	Maximum allowable Limit	Damping Configuration Results		
			36VDs (Arrangement II)	36VDs + 150Ton TMD (Arrangement VII)	28 VDs (Arrangement VI)
Occupant Comfort Performance Objectives					
1 year return period Peak Acceleration	W.H. Melbourne (1988)	10.2 milli-g	10.48 milli-g	7.15 milli-g	11.01 milli-g
1 year return period Peak Acceleration	ISO 10137 (2007) for residential towers	7.7 milli-g	10.48 milli-g	7.15 milli-g	11.01 milli-g
1 year return period Peak rotational velocity	Isyumov (1995)	1.5 milli-rad/s	1.43 milli-rad/s	1.06 milli-rad/s	1.51 milli-rad/s
Total Structural Equivalent Damping Objectives					
Required total damping (inherent + added damping)	Mode 1 (X)	3.0%	1.9%	4.9%–5.9%	1.7%
	Mode 2 (Y)	3.0%	2.9%	3.9%–4.9%	2.3%
	Mode 3 (Rz)	3.0%	3.9%	3.2%	3.8%

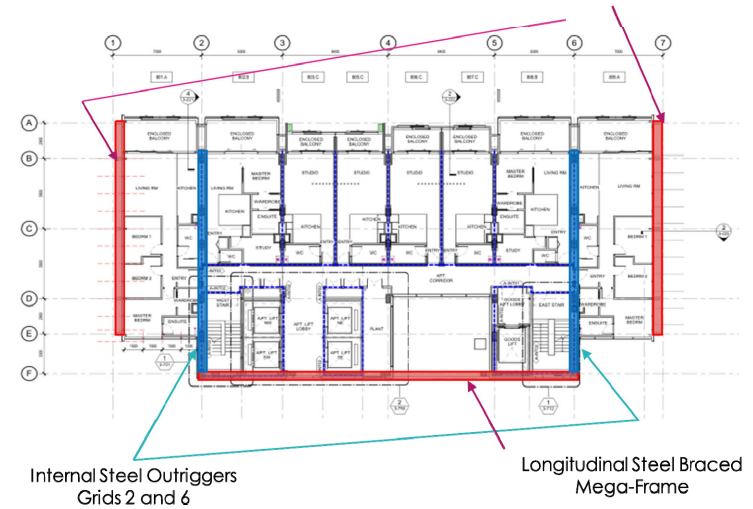


SEASCAPE TOWER, NZ (2017)

AMS + DISIPADORES VISCOSOS



External Steel Braced Mega-Frames



COSTOS (CHILE) DE SPS (1 UF $\approx$ 37 USD)

SPS	Reducción sísmica	Desde	Hasta	Unidad	Comentario
Aislación	70 a 90%	~0.00	1.20	UF/m ²	Solución con los mejores resultados de protección. Su implementación permite la optimización de la estructura, efecto incluido en este rango de costos. Aplicable para razones de aspecto Altura máxima / Ancho mínimo $\leq$ 3. Requiere intervención en el nivel donde se instalan los aisladores y soluciones para el GAP de aislamiento (40cm aprox.)
Disipación	20 a 40%	0.10 0.45	0.40 0.85	UF/m ²	Solución con resultados aceptables de protección, con mejor desempeño en edificios altos y flexibles. Normalmente requiere importantes intervenciones en la fachada, más fácil de aceptar en edificios de oficinas. Actualmente se está trabajando en soluciones mejor adaptadas para edificios residenciales (arriba: disipadores metálicos; abajo: disipadores viscosos)
AMS	20 a 30%	3000	15000	UF (global)	Solución con las menores reducción sísmicas. Requiere mínima intervención arquitectónica solo en el nivel del techo. Las estructuras solo se ven afectadas en los últimos niveles.

*Costos de referencia estimados en base a proyectos recientes. Incluye costos directos de los dispositivos y materiales. No incluye costos de instalación ni otros costos indirectos.