CONSTRUIR EN ACERO
UNA NECESIDAD DEL FUTURO
SIMPOSIO 2018

DISEÑO SíSMICO POR DESEMPEÑO PARA EDIFICOS EN ALTURA
PERFORMANCE-BASED SEISMIC DESIGN FOR TALL BUILDINGS

JOHN VIISE – ASSOCIATE PRINCIPAL, THORNTON TOMASETTI

ASIMET 80 AÑOS
Transformar para Crecer

ICHA
CORPORACIÓN
INSTITUTO CHILENO
DEL ACERO


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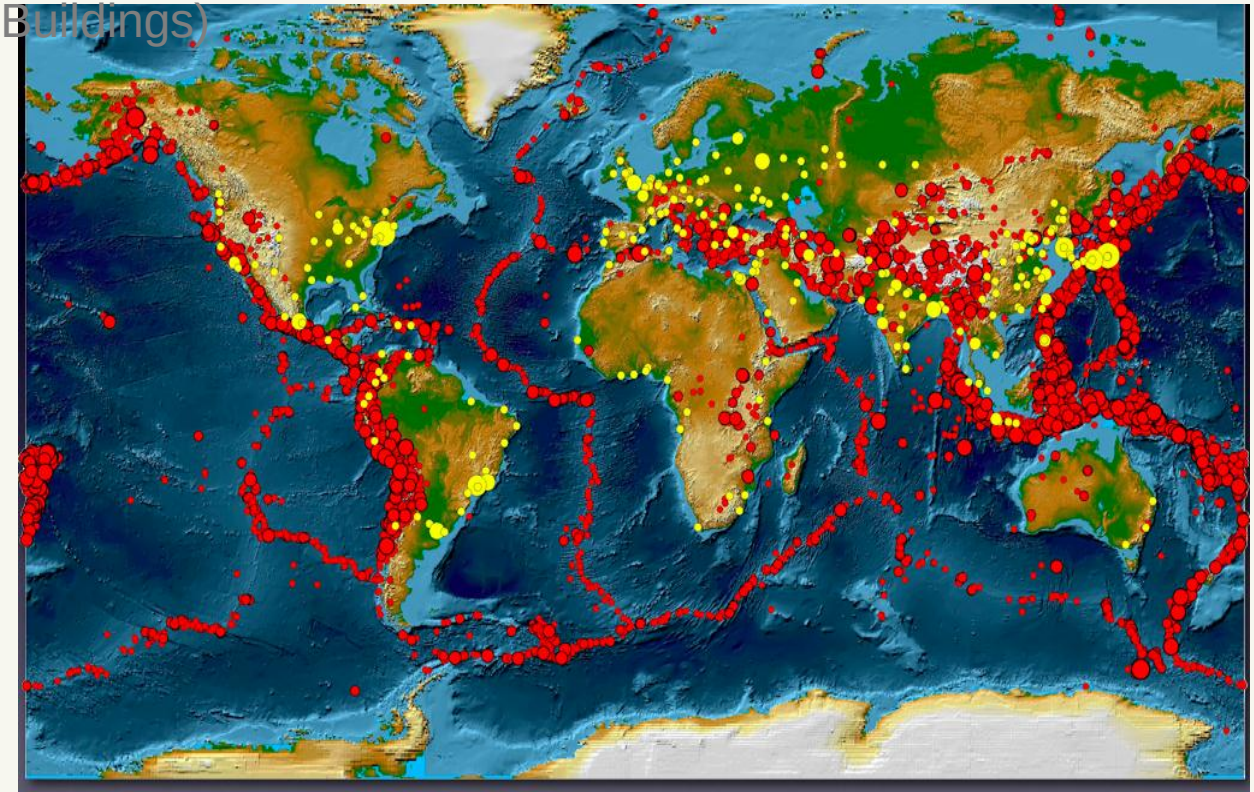
DSPD Para Edificios en Altura (PBSD of Tall Buildings)



all earthquakes (red) M ≥ 5.5; cities (yellow) with population > 1000000

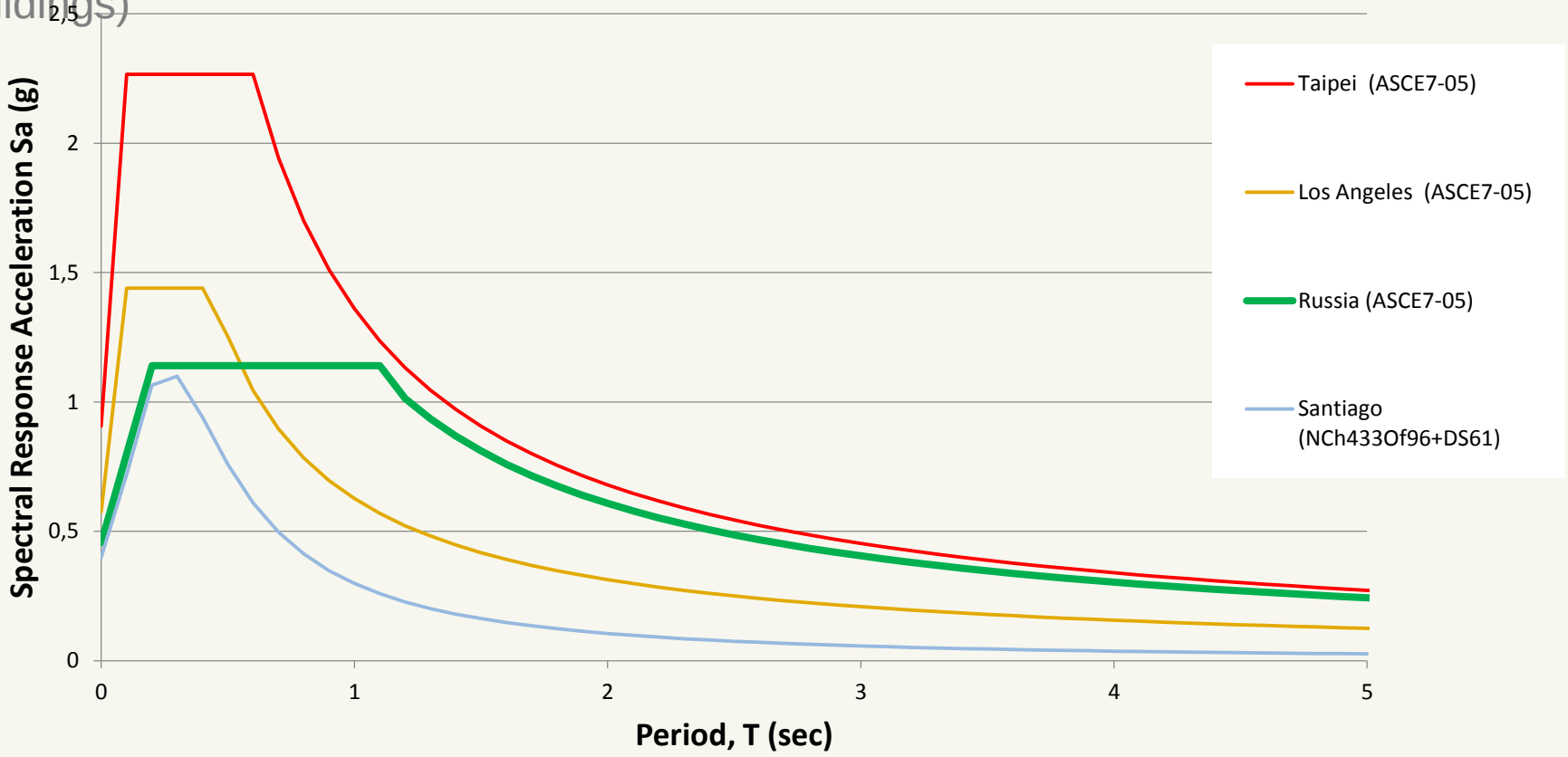
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

1987 Pudong District
Shanghai, China

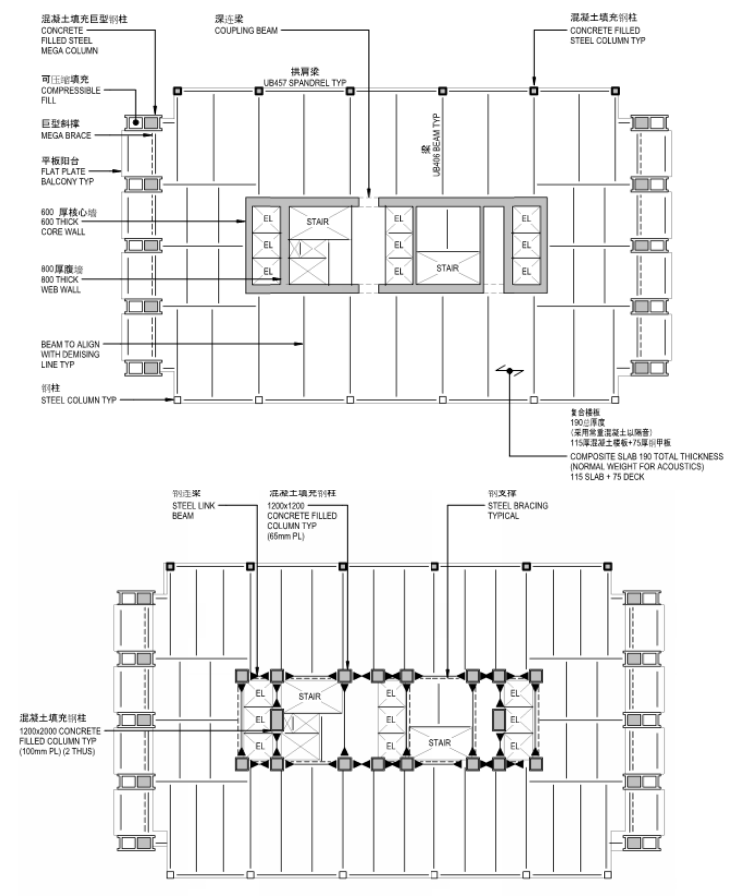
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

2013 Pudong District
Shanghai, China

DSPD Para Edificios en Altura (PBSD of Tall Buildings)



DSPD Para Edificios en Altura (PBSD of Tall Buildings)



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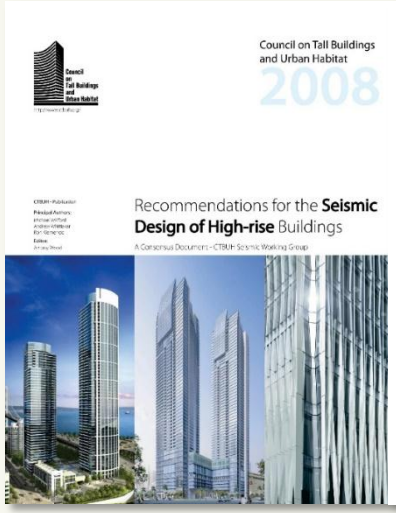
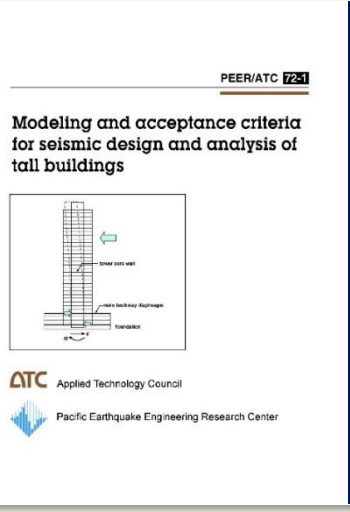
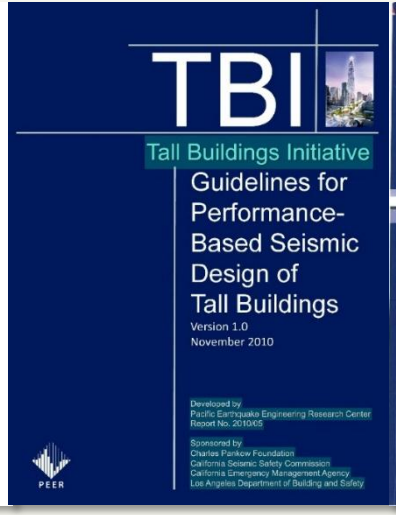


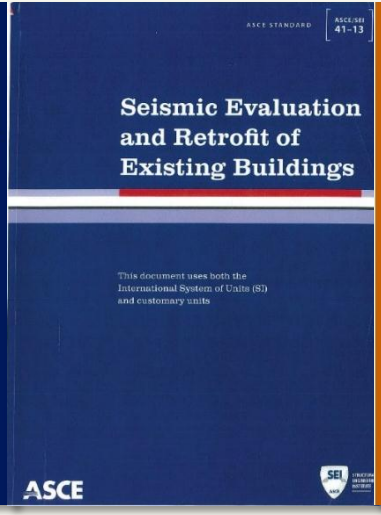
2008



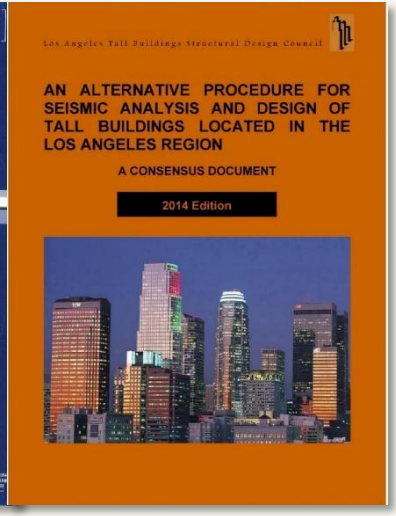
2010



2010, 2017



2013, 2017



2014, 2017

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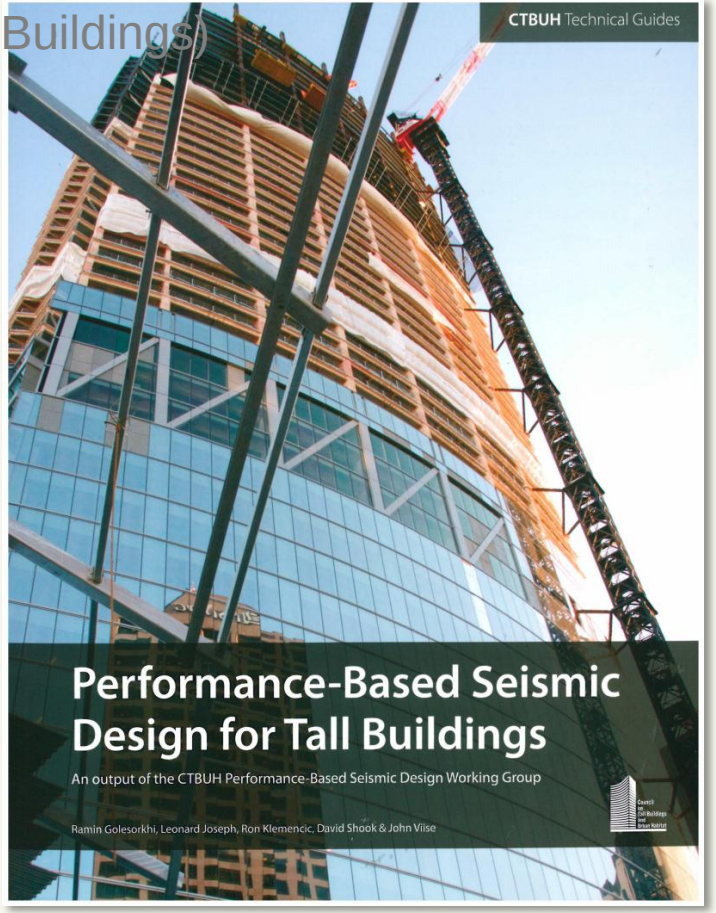


Co-Chair
Ron Klemencic

Co-Chair
John Viise

Ramin Golesorkhi

Neville John Mathias

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Qué Publicar y Por Qué? What to Publish and Why?

- El diseño basado en los códigos tiene sus limitaciones (Code-based design has limitations)
- Los edificios en altura son especiales: (Tall buildings are unique)
  - Periodos largos (Long Periods)
  - Efectos significativos de los modos altos (Higher mode effects significant)
  - Efectos significativos debidos a P-Δ (Significant P-Δ effects)
  - Acogen altas ocupaciones y tienen mayor impacto en caso de fallo (Large occupancy and greater impact of failure)
- Los avances computacionales hacen el uso del análisis no linear más práctico (Computing advances make nonlinear analysis more practical)
- **Escasos ejemplos de diseño publicados (Minimal design examples published)**

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Ventajas prácticas (What is it Good For?)

Procedimientos de diseño que pueden establecer el nivel de desempeño para: (Design Procedures that can set desired performance for:)

- Seguridad para la vida (Minimo exigido por el código) (Life Safety (Code minimum))
- Recuperar la ocupabilidad (Restore Occupancy)
- Limitar el coste de las reparaciones (Limit Repair Costs)

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Práctica Estándar Internacional (International Standard Practice)

Estados Unidos + ASCE 7-16

- DSPD históricamente utilizado para refuerzos estructurales (ASCE 41) (PBSD retrofit history)
- DSPD es un proceso en dos etapas (PBSD process two-step)
- Cálculo lineal con factores R (factores sísmicos de reducción) (Code linear analysis with R-values (seismic reduction factors))
- El código impone un sistema de límites de altura (Code system height limits)

China

- DSPD para edifcios que rebasan los límities (altura) (PBSD for buildings are over-limit (height))
- DSPD es un proceso en dos etapas(Two-step design process PBSD)

Eurocode 8

- Cálculo lineal con factores sísmicos de reducción (Code linear analysis with seismic reduction factors)
- Sin límite de altura y sin mención del DSPD (No height limits and no mention of PBSD)

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Sismicidad (Intensidad y Frecuencia) (Seismicity (Intensity and Frequency))

P = Probabilidad de Excederse en una vida de n años = $P = 1 - (1 - P_a)^n$ (Probability of Exceedance in a life of n years)
P_a = Probabilidad Annual de Excederse (Annual Probability of Exceedance)
Periodo de Retorno = $1/P_a$ (Return Period)
n = 50 años (years)

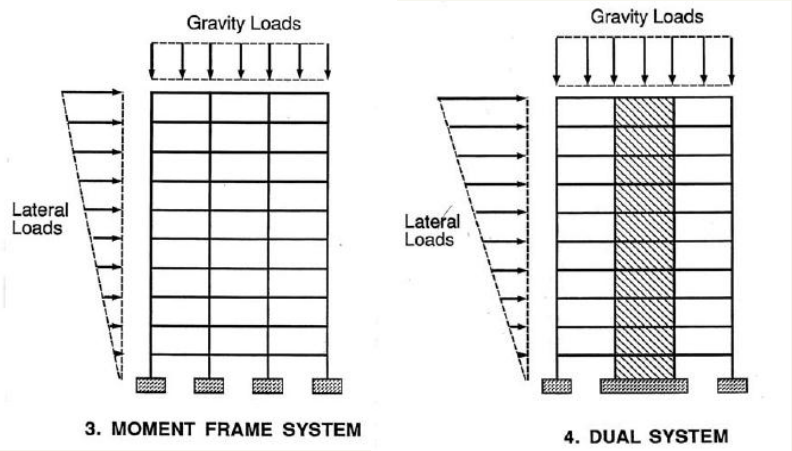
Sismo Moderado o de Diseño (DE = 2/3MCE) – Codigo (Moderate or Design Level Earthquake - Code)
Periodo de Retorno = 475 años (Return Period = 475 years)

Sismo Frecuente o de Servicio (SLE) – PBSD Etapa 1 (Frequent or Service Level Earthquake – PBSD Step 1)
Frecuente: Periodo de Retorno = 50 años (**Frequent:** Return Period = 50 years)
SLE: Periodo de Retorno = 43 años (**SLE:** Return Period = 43 years)

Sismo Raro o Máximo Considerado (MCE) – PBSD Etapa 2 (Rare or Maximum Considered Earthquake – PBSD Step 2)
Raro: Periodo de Retorno = 2000 años (**Rare:** Return Period = 2000 years)
MCE: Periodo de Retorno = 2475 años (**MCE:** Return Period = 2475 years)

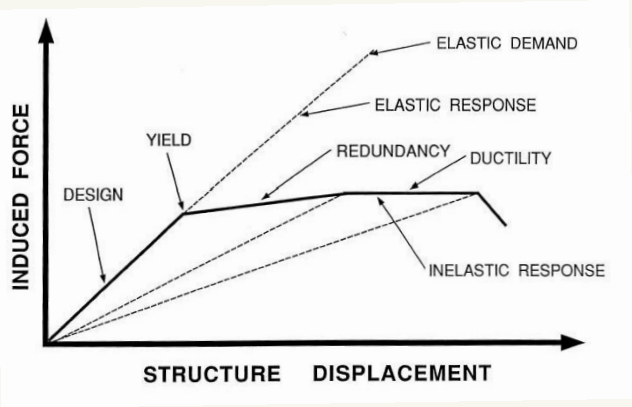
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Límites del Diseño Convencional (Limits of Conventional Design)



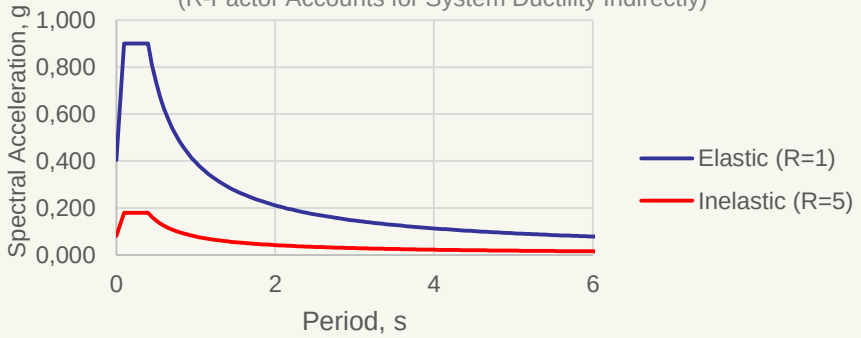
Selección del Sistema Estructural
(Structural System Selection)

+



Resultados Experimentales
(Experimental Results)

El factor de reducción R tiene en cuenta la ductilidad del sistema de forma indirecta
(R-Factor Accounts for System Ductility Indirectly)



DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Límites del Diseño Convencional – Restricciones en Altura (Limits of Conventional Design – Height Restrictions)

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, R[a]	Overstrength Factor, Ω_0[g]	Deflection Amplification Factor, C_d[b]	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category B	C	D[d]	E[d]	F[e]
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls[l, m]	14.2	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls[l]	14.2	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls[l]	14.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls[l]	14.2	1½	2½	1½	NL	NP	NP	NP	NP
5. Intermediate precast shear walls[l]	14.2	4	2½	4	NL	NL	40[k]	40[k]	40[k]
6. Ordinary precast shear walls[l]	14.2	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4	3½	2½	2¼	NL	NL	NP	NP	NP
9. Ordinary reinforced masonry shear walls	14.4	2	2½	1¾	NL	160	NP	NP	NP
10. Detailed plain masonry shear walls	14.4	2	2½	1¾	NL	NP	NP	NP	NP
11. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP
12. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
13. Ordinary reinforced AAC masonry shear walls	14.4	2	2½	2	NL	35	NP	NP	NP
14. Ordinary plain AAC masonry shear walls	14.4	1½	2½	1½	NL	NP	NP	NP	NP
15. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	14.5	6½	3	4	NL	NL	65	65	65

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Límites del Diseño Convencional – Más de 80 sistemas definidos y aun así…

(Limits of Conventional Design – 80+ Systems defined and still…)

TABLE 12.2-1 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE–RESISTING SYSTEMS

Seismic Force–Resisting System	ASCE 7 Section where Detailing Requirements are Specified	Response Modification Coefficient, R[a]	System Overstrength Factor, Ω_0[g]	Deflection Amplification Factor, C_d[b]	Structural System Limitations and Building Height (ft) Limit[c]				
					Seismic Design Category				
					B	C	D[d]	E[d]	F[e]
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls	14.2 and 14.2.3.6	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls	14.2 and 14.2.3.4	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls	14.2 and 14.2.3.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls	14.2 and 14.2.3.1	1½	2½	1½	NL	NP	NP	NP	NP
5. Intermediate precast shear walls	14.2 and 14.2.3.5	4	2½	4	NL	NL	40[f]	40[f]	40[f]
6. Ordinary precast shear walls	14.2 and 14.2.3.3	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4 and 14.4.3	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4 and 14.4.3	3½	2½	2¼	NL	NL	NP	NP	NP
9. Ordinary reinforced masonry shear walls	14.4	2	2½	1¾	NL	160	NP	NP	NP
10. Detailed plain masonry shear walls	14.4	2	2½	1¾	NL	NP	NP	NP	NP
11. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP
12. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
13. Light-framed walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1, 14.1.4.2, and 14.5	6½	3	4	NL	NL	65	65	65
14. Light-framed walls with shear panels of all other materials	14.1, 14.1.4.2, and 14.5	2	2½	2	NL	NL	35	NP	NP
15. Light-framed wall systems using flat strap bracing	14.1, 14.1.4.2, and 14.5	4	2	3½	NL	NL	65	65	65
B. BUILDING FRAME SYSTEMS									
1. Steel eccentrically braced frames, moment resisting connections at columns away from links	14.1	8	2	4	NL	NL	160	160	100
2. Steel eccentrically braced frames, non-moment-resisting, connections at columns away from links	14.1	7	2	4	NL	NL	160	160	100
3. Special steel concentrically braced frames	14.1	6	2	5	NL	NL	160	160	100
4. Ordinary steel concentrically braced frames	14.1	3¼	2	3¼	NL	NL	35[f]	35[f]	NP[f]
5. Special reinforced concrete shear walls	14.2 and 14.2.3.6	6	2½	5	NL	NL	160	160	100
6. Ordinary reinforced concrete shear walls	14.2 and 14.2.3.4	5	2½	4½	NL	NL	NP	NP	NP
7. Detailed plain concrete shear walls	14.2 and 14.2.3.2	2	2½	2	NL	NP	NP	NP	NP
8. Ordinary plain concrete shear walls	14.2 and 14.2.3.1	1½	2½	1½	NL	NP	NP	NP	NP
9. Intermediate precast shear walls	14.2 and 14.2.3.5	5	2½	4½	NL	NL	40[f]	40[f]	40[f]
10. Ordinary precast shear walls	14.2 and 14.2.3.3	4	2½	4	NL	NP	NP	NP	NP
11. Composite steel and concrete eccentrically braced frames	14.3	8	2	4	NL	NL	160	160	100
12. Composite steel and concrete concentrically braced frames	14.3	5	2	4½	NL	NL	160	160	100
13. Ordinary composite steel and concrete braced frames	14.3	3	2	3	NL	NL	NP	NP	NP
14. Composite steel plate shear walls	14.3	6½	2½	5½	NL	NL	160	160	100
15. Special composite reinforced concrete shear walls with steel elements	14.3	6	2½	5	NL	NL	160	160	100
16. Ordinary composite reinforced concrete shear walls with steel elements	14.3	5	2½	4½	NL	NL	NP	NP	NP
17. Special reinforced masonry shear walls	14.4	5½	2½	4	NL	NL	160	160	100
18. Intermediate reinforced masonry shear walls	14.4	4	2½	4	NL	NL	NP	NP	NP
19. Ordinary reinforced masonry shear walls	14.4	2	2½	2	NL	160	NP	NP	NP
20. Detailed plain masonry shear walls	14.4	2	2½	2	NL	NP	NP	NP	NP
21. Ordinary plain masonry shear walls	14.4	1½	2½	1¼	NL	NP	NP	NP	NP

TABLE 12.2-1 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE–RESISTING SYSTEMS (continued)

Seismic Force–Resisting System	ASCE 7 Section where Detailing Requirements are Specified	Response Modification Coefficient, R[a]	System Overstrength Factor, Ω_0[g]	Deflection Amplification Factor, C_d[b]	Structural System Limitations and Building Height (ft) Limit[c]				
					Seismic Design Category				
					B	C	D[d]	E[d]	F[e]
22. Prestressed masonry shear walls	14.4	1½	2½	1¾	NL	NP	NP	NP	NP
23. Light-framed walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1, 14.1.4.2, and 14.5	7	2½	4½	NL	NL	65	65	65
24. Light-framed walls with shear panels of all other materials	14.1, 14.1.4.2, and 14.5	2½	2½	2½	NL	NL	35	NP	NP
25. Buckling-restrained braced frames, non-moment-resisting beam-column connections	14.1	7	2	5½	NL	NL	160	160	100
26. Buckling-restrained braced frames, moment-resisting beam-column connections	14.1	8	2½	5	NL	NL	160	160	100
27. Special steel plate shear wall	14.1	7	2	6	NL	NL	160	160	100
C. MOMENT-RESISTING FRAME SYSTEMS									
1. Special steel moment frames	14.1 and 12.2.5.5	8	3	5½	NL	NL	NL	NL	NL
2. Special steel truss moment frames	14.1	7	3	5½	NL	NL	160	100	NP
3. Intermediate steel moment frames	12.2.5.6, 12.2.5.7, 12.2.5.8, 12.2.5.9, and 14.1	4.5	3	4	NL	NL	35[h,i]	NP[h]	NP[i]
4. Ordinary steel moment frames	12.2.5.6, 12.2.5.7, 12.2.5.8, and 14.1	3.5	3	3	NL	NL	NP[h]	NP[h]	NP[i]
5. Special reinforced concrete moment frames	12.2.5.5 and 14.2	8	3	5½	NL	NL	NL	NL	NL
6. Intermediate reinforced concrete moment frames	14.2	5	3	4½	NL	NL	NP	NP	NP
7. Ordinary reinforced concrete moment frames	14.2	3	3	2½	NL	NP	NP	NP	NP
8. Special composite steel and concrete moment frames	12.2.5.5 and 14.3	8	3	5½	NL	NL	NL	NL	NL
9. Intermediate composite moment frames	14.3	5	3	4½	NL	NL	NP	NP	NP
10. Composite partially restrained moment frames	14.3	6	3	5½	160	160	100	NP	NP
11. Ordinary composite moment frames	14.3	3	3	2½	NL	NP	NP	NP	NP
D. DUAL SYSTEMS WITH SPECIAL MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES	12.2.5.1								
1. Steel eccentrically braced frames	14.1	8	2½	4	NL	NL	NL	NL	NL
2. Special steel concentrically braced frames	14.1	7	2½	5½	NL	NL	NL	NL	NL
3. Special reinforced concrete shear walls	14.2	7	2½	5½	NL	NL	NL	NL	NL
4. Ordinary reinforced concrete shear walls	14.2	6	2½	5	NL	NL	NP	NP	NP
5. Composite steel and concrete eccentrically braced frames	14.3	8	2½	4	NL	NL	NL	NL	NL
6. Composite steel and concrete concentrically braced frames	14.3	6	2½	5	NL	NL	NL	NL	NL
7. Composite steel plate shear walls	14.3	7½	2½	6	NL	NL	NL	NL	NL
8. Special composite reinforced concrete shear walls with steel elements	14.3	7	2½	6	NL	NL	NL	NL	NL
9. Ordinary composite reinforced concrete shear walls with steel elements	14.3	6	2½	5	NL	NL	NP	NP	NP
10. Special reinforced masonry shear walls	14.4	5½	3	5	NL	NL	NL	NL	NL
11. Intermediate reinforced masonry shear walls	14.4	4	3	3½	NL	NL	NP	NP	NP
12. Buckling-restrained braced frame	14.1	8	2½	5	NL	NL	NL	NL	NL
13. Special steel plate shear walls	14.1	8	2½	6½	NL	NL	NL	NL	NL

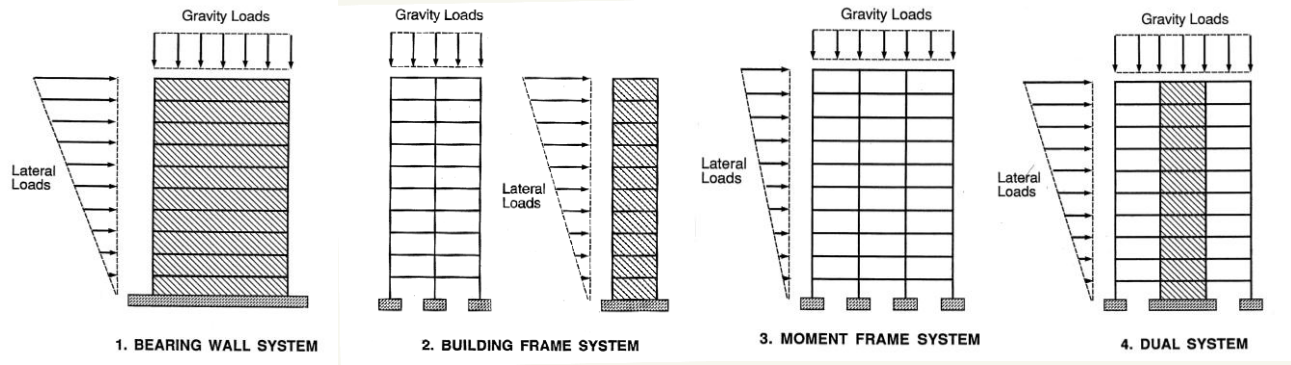
TABLE 12.2-1 DESIGN COEFFICIENTS AND FACTORS FOR SEISMIC FORCE–RESISTING SYSTEMS (continued)

Seismic Force–Resisting System	ASCE 7 Section where Detailing Requirements are Specified	Response Modification Coefficient, R[a]	System Overstrength Factor, Ω_0[g]	Deflection Amplification Factor, C_d[b]	Structural System Limitations and Building Height (ft) Limit[c]				
					Seismic Design Category				
					B	C	D[d]	E[d]	F[e]
E. DUAL SYSTEMS WITH INTERMEDIATE MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES	12.2.5.1								
1. Special steel concentrically braced frames[f]	14.1	6	2½	5	NL	NL	35	NP	NP[h,k]
2. Special reinforced concrete shear walls	14.2	6½	2½	5	NL	NL	160	100	100
3. Ordinary reinforced masonry shear walls	14.4	3	3	2½	NL	160	NP	NP	NP
4. Intermediate reinforced masonry shear walls	14.4	3½	3	3	NL	NL	NP	NP	NP
5. Composite steel and concrete concentrically braced frames	14.3	5½	2½	4½	NL	NL	160	100	NP
6. Ordinary composite braced frames	14.3	3½	2½	3	NL	NL	NP	NP	NP
7. Ordinary composite reinforced concrete shear walls with steel elements	14.3	5	3	4½	NL	NL	NP	NP	NP
8. Ordinary reinforced concrete shear walls	14.2	5½	2½	4½	NL	NL	NP	NP	NP
F. SHEAR WALL-FRAME INTERACTIVE SYSTEM WITH ORDINARY REINFORCED CONCRETE MOMENT FRAMES AND ORDINARY REINFORCED CONCRETE SHEAR WALLS	12.2.5.10 and 14.2	4½	2½	4	NL	NP	NP	NP	NP
G. CANTILEVERED COLUMN SYSTEMS DETAILED TO CONFORM TO THE REQUIREMENTS FOR:	12.2.5.2								
1. Special steel moment frames	12.2.5.5 and 14.1	2½	1¼	2½	35	35	35	35	35
2. Intermediate steel moment frames	14.1	1½	1¼	1½	35	35	35[h]	NP[h,l]	NP[h,l]
3. Ordinary steel moment frames	14.1	1¼	1¼	1¼	35	35	NP	NP[h,l]	NP[h,l]
4. Special reinforced concrete moment frames	12.2.5.5 and 14.2	2½	1¼	2½	35	35	35	35	35
5. Intermediate concrete moment frames	14.2	1½	1¼	1½	35	35	NP	NP	NP
6. Ordinary concrete moment frames	14.2	1	1¼	1	35	NP	NP	NP	NP
7. Timber frames	14.5	1½	1½	1½	35	35	35	NP	NP
H. STEEL SYSTEMS NOT SPECIFICALLY DETAILED FOR SEISMIC RESISTANCE, EXCLUDING CANTILEVER COLUMN SYSTEMS	14.1	3	3	3	NL	NL	NP	NP	NP

[a]Response modification coefficient, R, for use throughout the standard. Note R reduces forces to a strength level, not an allowable stress level.
[b]Reflection amplification factor, C_d, for use in Sections 12.8.6, 12.8.7, and 12.9.2
[c]NL = Not Limited and NP = Not Permitted. For metric units use 30.5 m for 100 ft and use 48.8 m for 160 ft. Heights are measured from the base of the structure as defined in Section 11.2.
[d]See Section 12.2.5.4 for a description of building systems limited to buildings with a height of 240 ft (73.2 m) or less.
[e]See Section 12.2.5.4 for building systems limited to buildings with a height of 160 ft (48.8 m) or less.
[f]Ordinary moment frame is permitted to be used in lieu of intermediate moment frame for Seismic Design Categories B or C.
[g]The tabulated value of the overstrength factor, Ω_0, is permitted to be reduced by subtracting one-half for structures with flexible diaphragms, but shall not be taken as less than 2.0 for any structure.
[h]See Sections 12.2.5.6 and 12.2.5.7 for limitations for steel OMFs and IMFs in structures assigned to Seismic Design Category D or E.
[i]See Sections 12.2.5.8 and 12.2.5.9 for limitations for steel OMFs and IMFs in structures assigned to Seismic Design Category F.
[j]Steel ordinary concentrically braced frames are permitted in single-story buildings up to a height of 60 ft (18.3 m) where the dead load of the roof does not exceed 20 psf (0.96 kN/m^2) and in penthouse structures.
[k]Increase in height to 45 ft (13.7 m) is permitted for single story storage warehouse facilities.

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

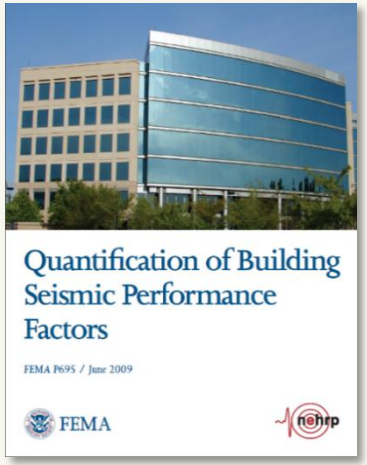
Límites del Diseño Convencional – Constantes R, C_d, Ω_0 (Limits of Conventional Design – R, C_d, Ω_0 values)



R?

¿Por qué?

(Why?)



DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Límites del Diseño Convencional (Limits of Conventional Design)

Problemas con la constante R: (Issues with R-values)

- Cualitativo (Qualitative)
- Menos Directo (Less direct)
- Menos Preciso (Less accurate)
- Menor Libertad de Sistemas (Less freedom of systems)
- Dificultad para incorporar las nuevas tecnologías (Difficult to incorporate new technologies)
- Puede ser mas costoso (Can make more costly)

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

Secuencia de Diseño – Aproximación en Dos Etapas– Comprobación para Cargas a Nivel de Servicio (Frecuente)

(Design Procedure – Two Step Approach – Check for SLE (Frequent) Loading)

- Sismo de Nivel de Servicio (Periodo de retorno de 43-50 años) (Service Level EQ (43-50 year return period))
- Análisis con Espectro de Diseño, sin reducciones (R=1) (Response Spectrum Analysis (RSA), no reductions (R=1))
- Los components estructurales serán verificados usando: (1) resistencia especificada (2) sin factores de reducción de la resistencia (3) valores de rigidez de nivel de servicio (Structural components will be checked using: (1) specified strengths, (2) no strength reduction factors, and (3) serviceability stiffness values)
  - $1.0D + L_{exp} + 1.0\ E_x + 0.3\ E_y$
  - $1.0D + L_{exp} + 1.0\ E_y + 0.3\ E_x$
- Los Ratios Demanda/Capacidad (DCR) deben satisfacer los siguientes límites: (Demand/Capacity Ratios (DCR) satisfy the following thresholds:)
  - Elementos Controlados por Deformación DCR ≤ 1.50 (Deformation Controlled Elements)
  - Elementos Controlados por Fuerzas DCR ≤ 0.70 (Force Controlled Elements)
- Máxima deriva de entrepiso (h/200) (Inter-story drift maximum)

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

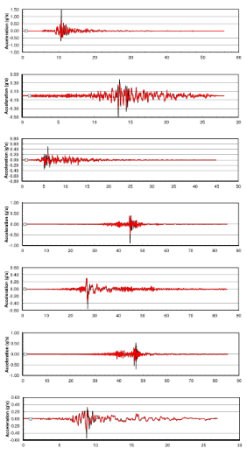
Secuencia de Diseño – Aproximación en Dos Etapas – Comprobación para Cargas MCE_R (raro)

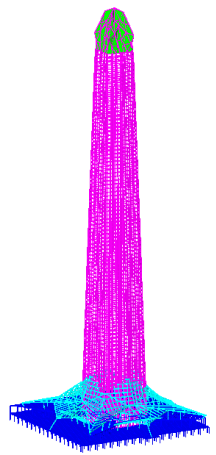
(Design Procedure – Two Tiered Approach – Check for MCE_R (Rare) Loading)

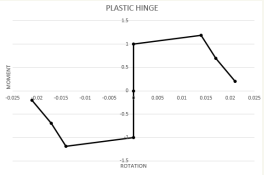
- Sismo Raro (periodo de retorno de 2000-2475 años) (Rare Level EQ (2000-2475 year return period))
- Análisis No Lineal de Respuesta Histórica (Nonlinear Time History Analysis)
- No-linealidad del material modelada (Material nonlinearity modeled)
- Los components estructurales serán verificados usando: (1) resistencia esperada (2) sin factores de reducción de la resistencia (3) valores de rigidez (Structural components will be checked using: (1) expected strengths, (2) no strength reduction factors, and (3) stiffness values)
  - $1.0D + L_{exp} + 1.0\ E$
- Los Ratios Demanda Capacidad (DCR) deben satisfacer los siguientes límites: (Demand Capacity Ratios (DCR) satisfy the following thresholds:)
  - Controlados por Fuerzas (Críticos) DCR ≤ 1.0/1.5 (Force Controlled (Critical))
  - Controlados por Fuerzas (No críticos) DCR ≤ 1.00 (Force Controlled (Non-critical))
  - Los Elementos controlados por deformaciones deben MINIMAMENTE satisfacer los límites de comportamiento para la Prevención del Colapso (CP), generalmente LS (Deformation Controlled elements must MINIMALLY satisfy Collapse Prevention (CP) performance thresholds, generally LS)
- Máxima deriva de entrepiso (h/33) (Inter-story drift maximum)

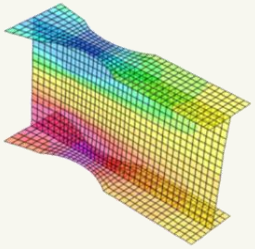
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

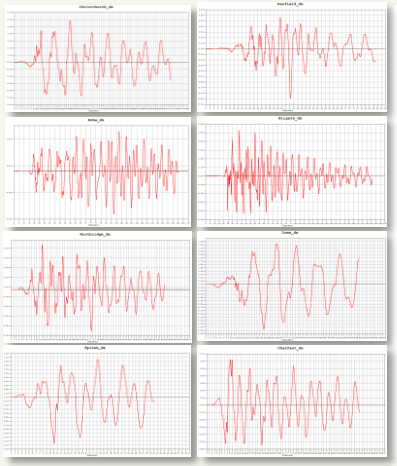
¿Qué es? (What is it?)











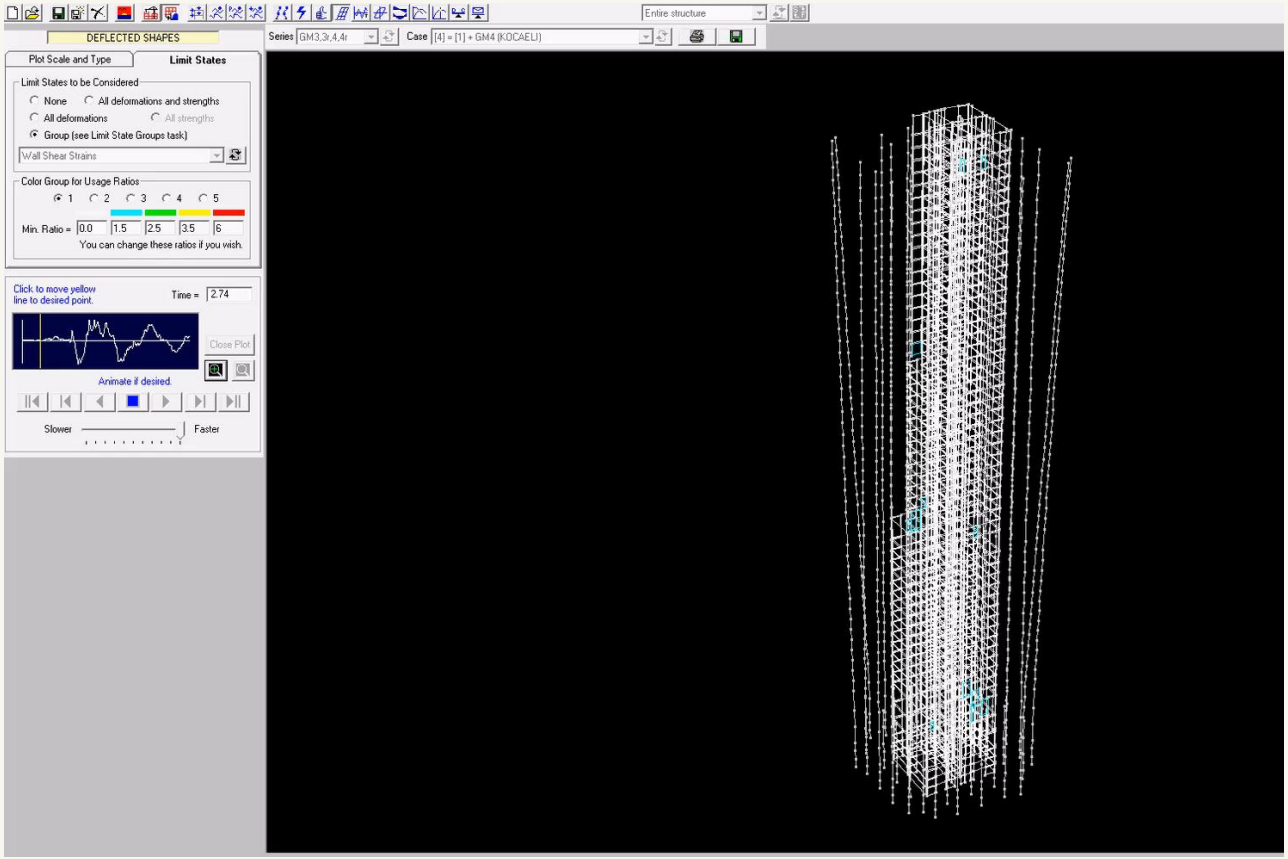
REGISTRO DE ACELERACIONES DEL SUELO
(GROUND ACCELERATION RECORDS)

MODELO DE ANÁLISIS NO LINEAL
(NON-LINEAR ANALYSIS MODEL)

SIMULACIÓN SÍSMICA COMPLETA
(FULL EARTHQUAKE SIMULATION)

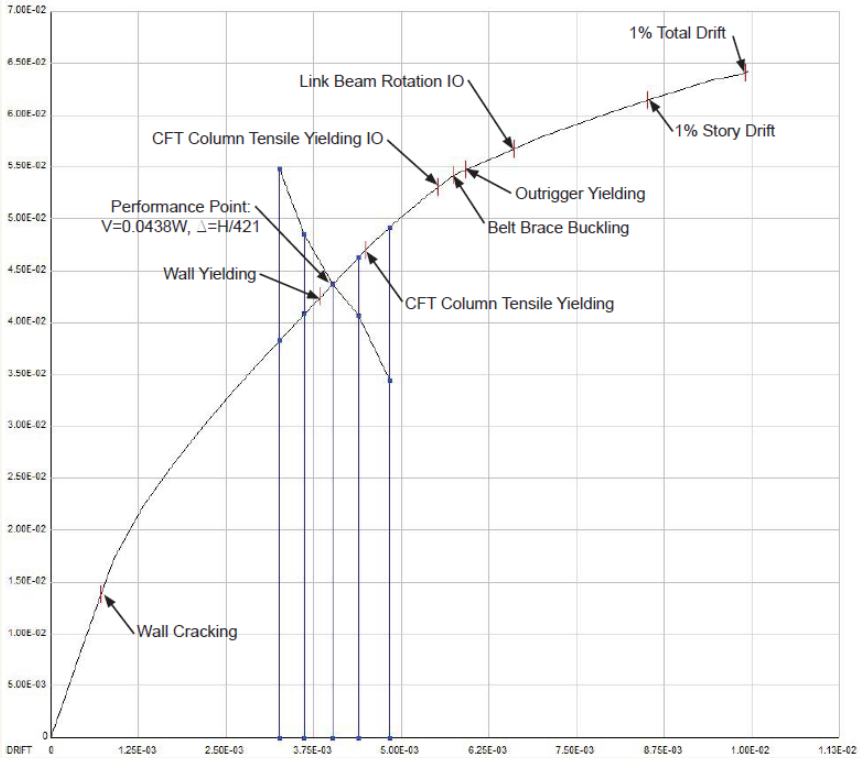
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

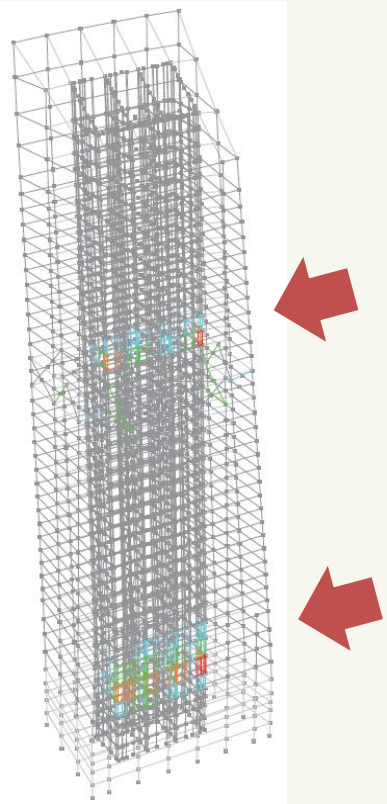
Ejemplo de Análisis No Lineal de Respuesta Histórica (Non-linear Response History Analysis Example)



DSPD Para Edificios en Altura (PBSD of Tall Buildings)

¿Qué elementos disipan energia en caso de un terremoto significativo? What Elements Dissipate Energy in a Significant Seismic Event?



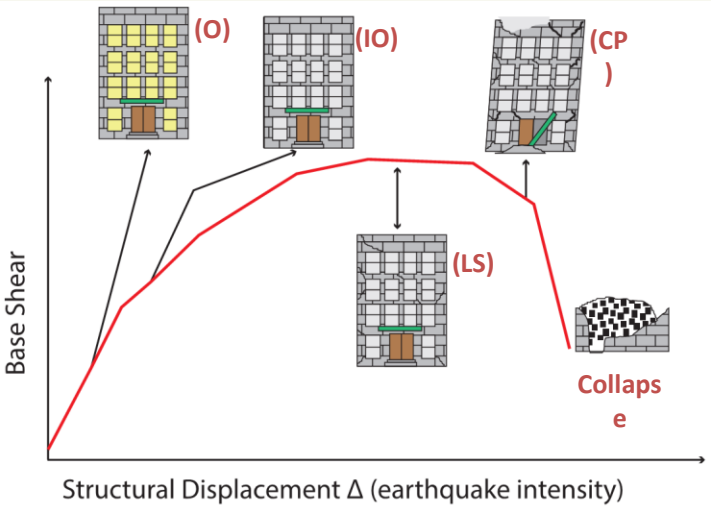


Elementos Controlados por Deformación vs Controlados por Fuerzas

(Deformation Controlled vs Force Controlled Elements)

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

No Linealidad del Material – Usar ASCE41 y Ensayos del Material para el Modelo
(Material Nonlinearity – Use ASCE 41 and Material Testing for Direct Modeling)



Operacional (O - Operational) = Los elementos de emergencia permanecen funcionales; daños menores
(Backup utility services maintain functions; very little damage)

Uso Inmediato (IO - Immediate Occupancy) = El edificio permanence seguro para ser ocupado; reparaciones menores
(The building remains safe to occupy; repairs are minor)

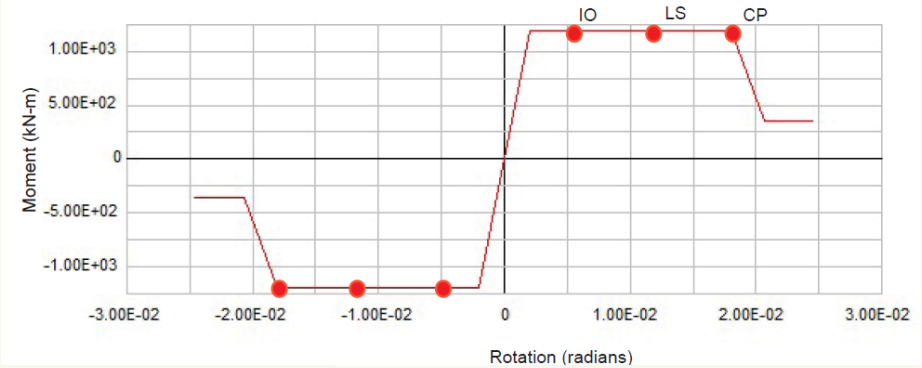
Riesgo para la vida - (LS - Life Safety) = La estructura permanece estable y con capacidad significativa; los daños de riesgo no estructurales son limitados
(Structure remains stable and has significant reserve capacity; hazardous nonstructural damage is controlled)

Prevención del Colapso (CP - Collapse Prevention) = El edificio se mantiene en pie, pero en el límite; cualquier daño adicional puede causar el colapso
(The building remains standing, but only barely; any additional damage may cause collapse)

Colapso (Collapse) = Autoexplicado (Self-explanatory)

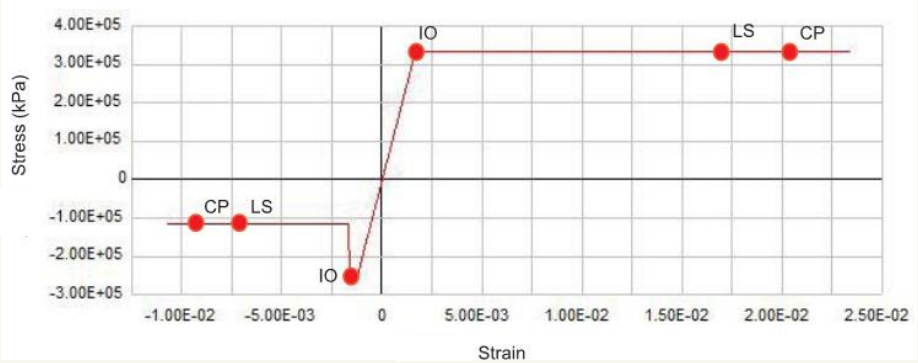
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

No Linealidad del Material – ASCE41 y Ensayos del Material (Material Nonlinearity – ASCE 41 and Material Testing)



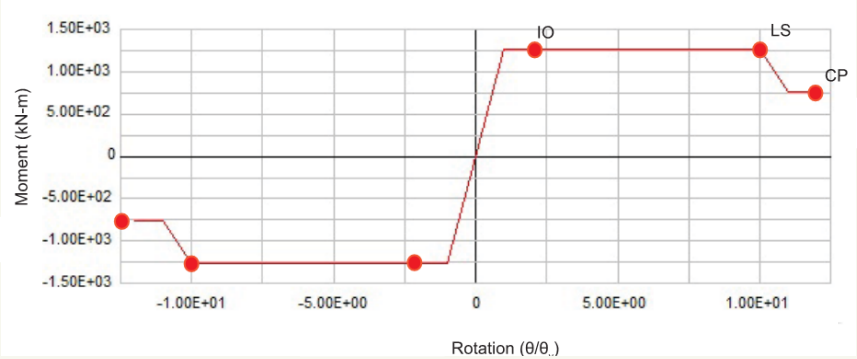
Modelo para Viga de Acoplamiento en Hormigón Armado

(Conventionally Reinforced Link Beam Model)

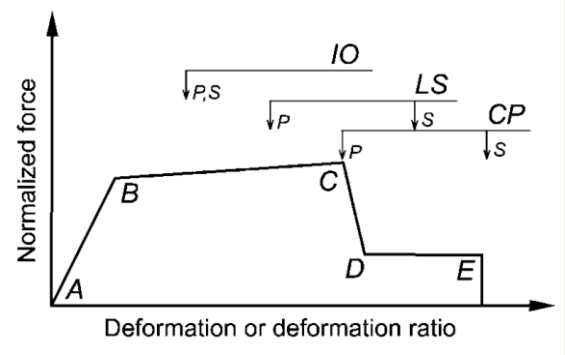


Modelo para Arriostramiento Simple en Acero

(Simple Steel Brace Model)



Modelo Para Viga de Acero (Steel Frame Beam Model)



Criterio de aceptación (Acceptance Criteria Illustration)

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

1. Valoración más precisa del comportamiento (More accurate assessment of performance)
2. Uso de sistemas previamente restringidos por su altura (Use of previously height-restricted structural systems)
3. Flexibilidad para utilizar nuevas tecnologías (Flexibility to use new technology)

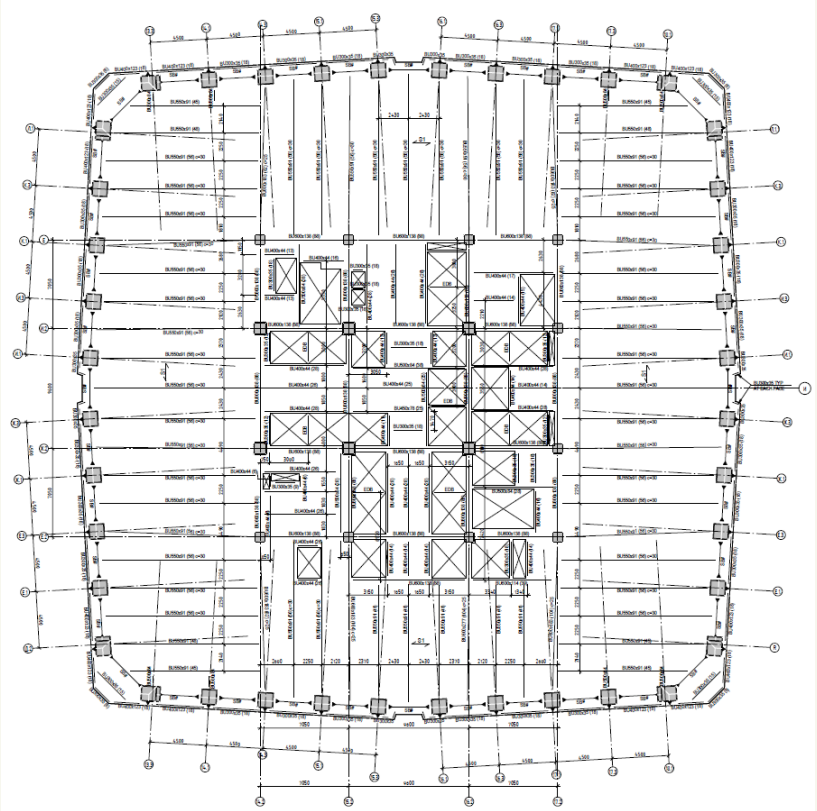
Russia (1)

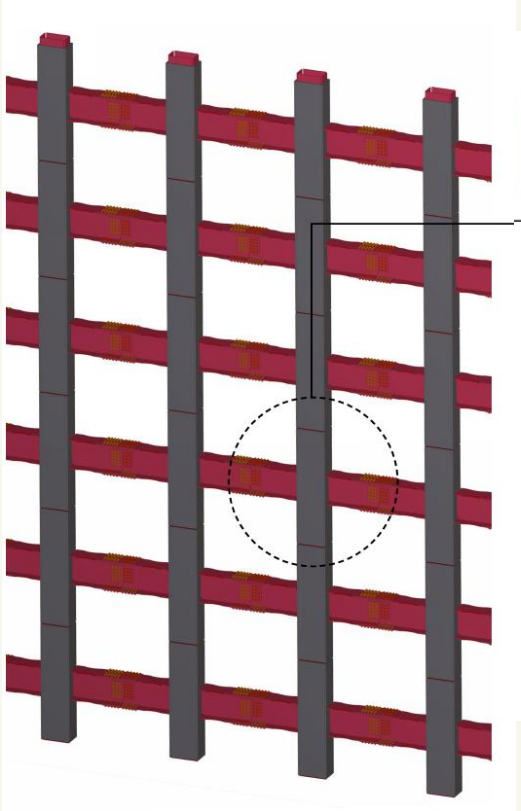
Los Angeles, CA USA (2)

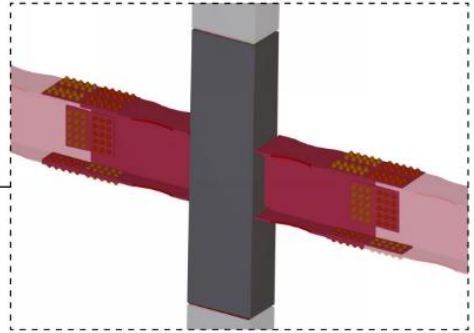
China (3)

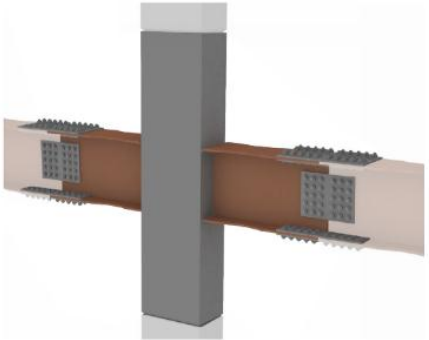
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)









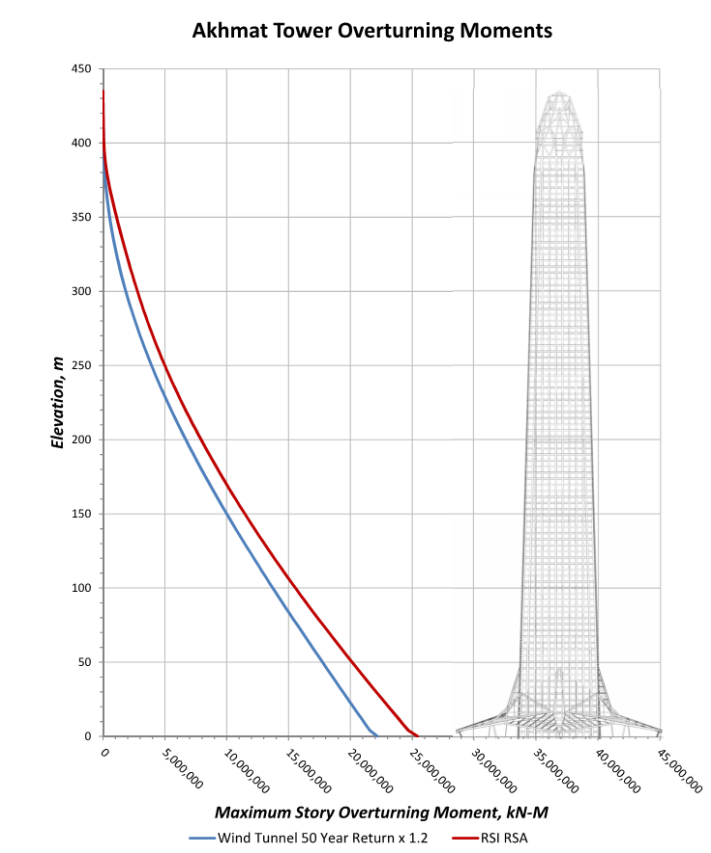
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

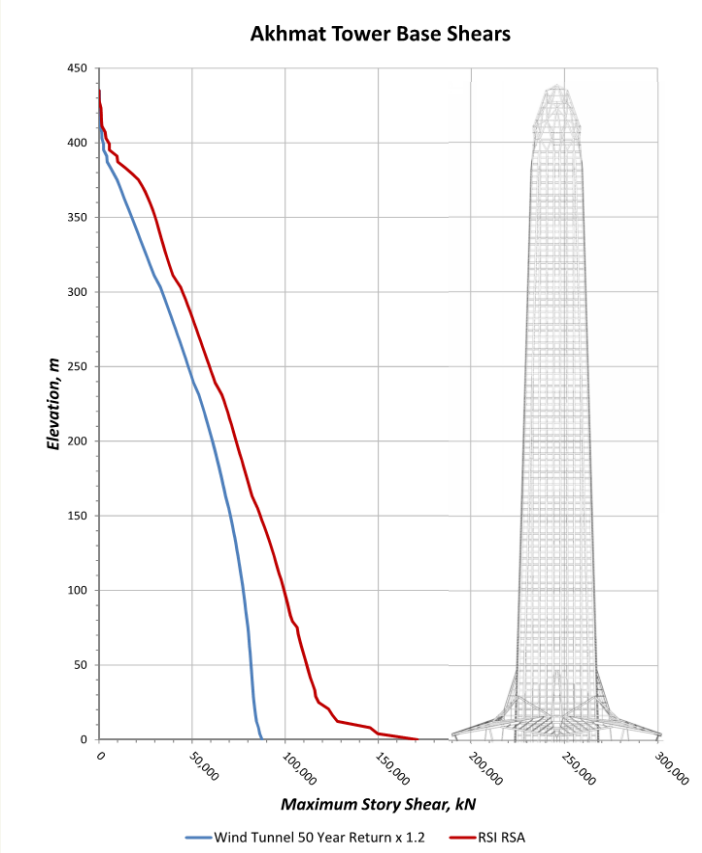
1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)

- Torre con Tubo de Marcos Especiales (SMF): (Tower Tube Special Moment Frame)
  - Columnas (Columns): S690 (100 max)
  - Vigas (Beams): C390 (50 max)
- Forjado (Floor Framing): C345
- Losa (Tower Raft): B75 / 60 MPa
- Pilotes (Tower Piling): B40 / 32 MPa

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

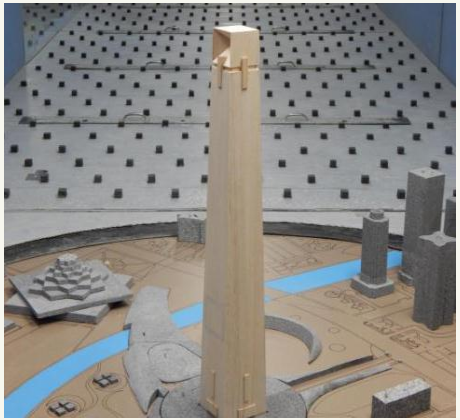
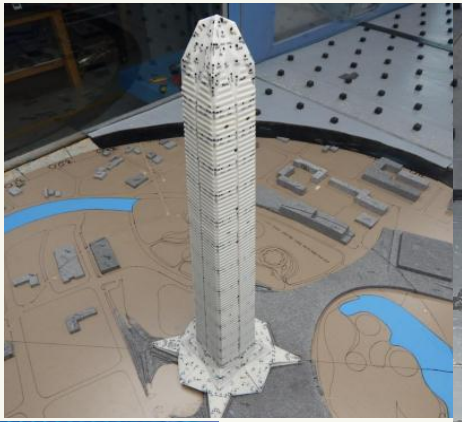
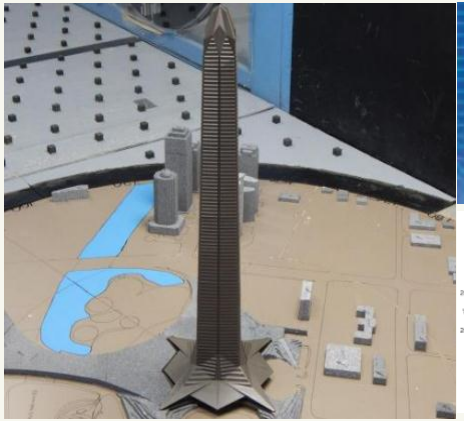
1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)

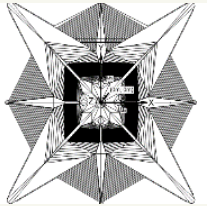
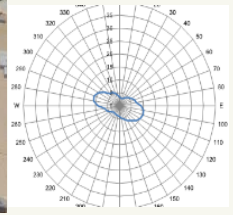
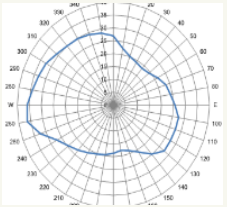
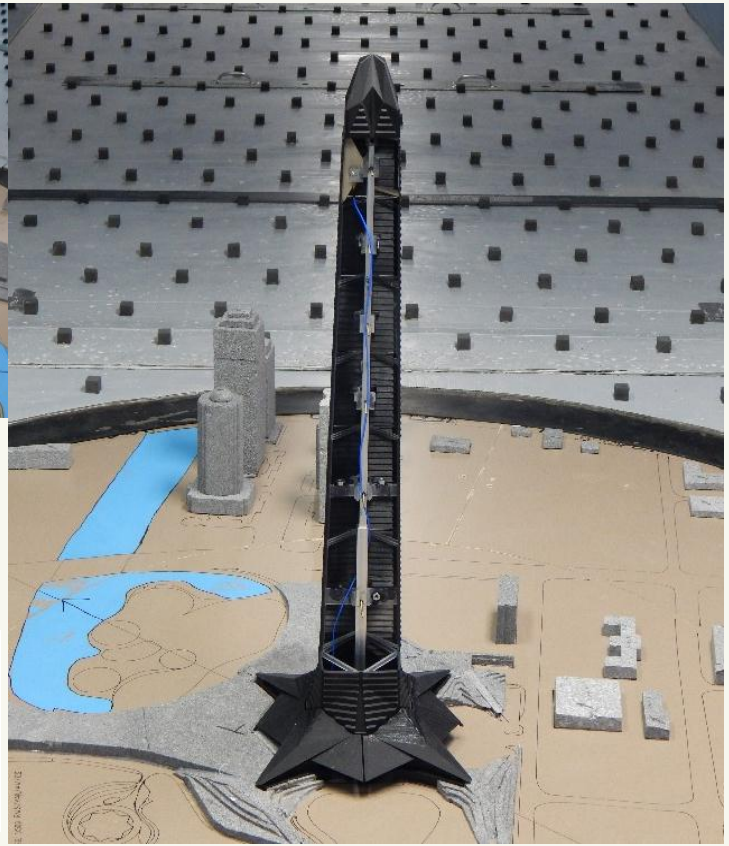




DSPD Para Edificios en Altura (PBSD of Tall Buildings)

1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)

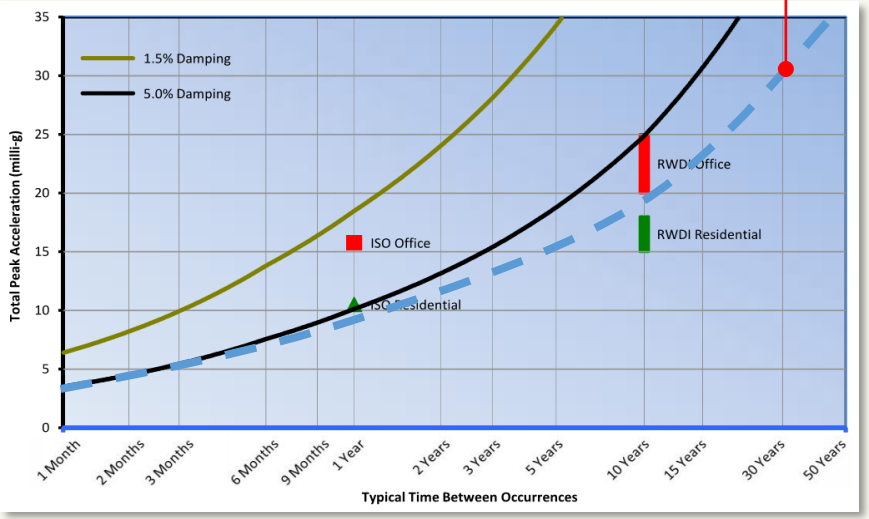






DSPD Para Edificios en Altura (PBSD of Tall Buildings)

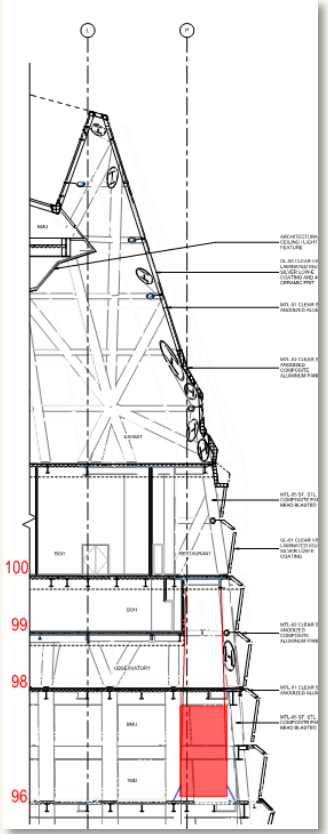
1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)

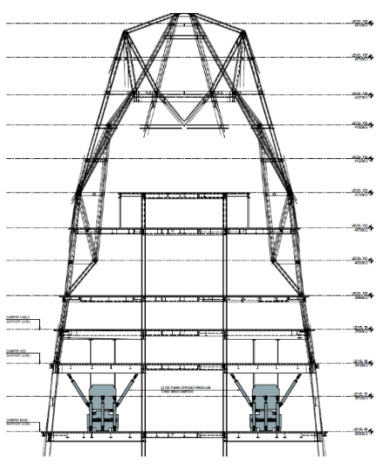
Reducción - Resultados del Test Aerolástico

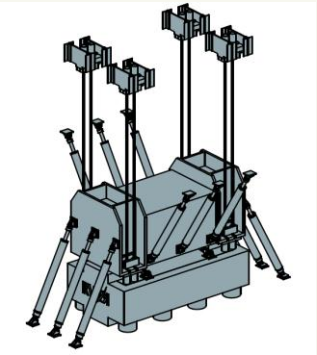
Reduction – Aeroelastic Test Results



Return Period (Years)	Peak Accelerations[2] (milli-g) Total - [X, Y and torsional components]		Peak Torsional Velocities (milli-rads/sec)		
	1.5% Damping	5.0% Damping	1.5% Damping	5.0% Damping	CTBUH[5] Criteria
1	18 - [18, 11, 0.73]	10 - [9.7, 5.9, 0.40]	0.1	0.1	1.5
5	34 - [33, 19, 1.1]	19 - [18, 11, 0.61]	0.2	0.1	-
10	45 - [44, 23, 1.3]	25 - [24, 13, 0.72]	0.2	0.1	3

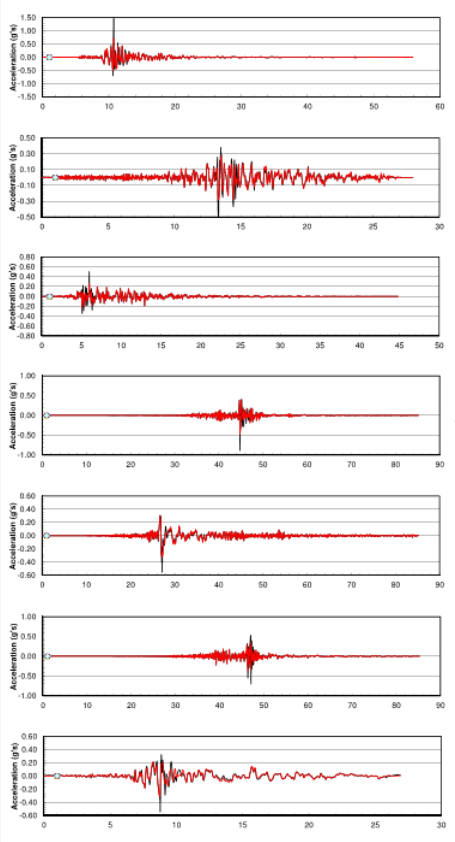


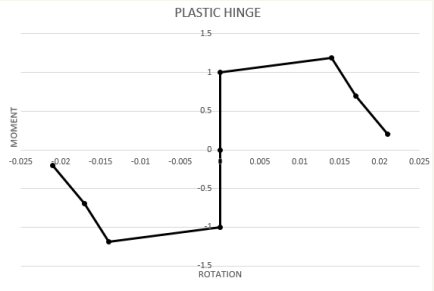


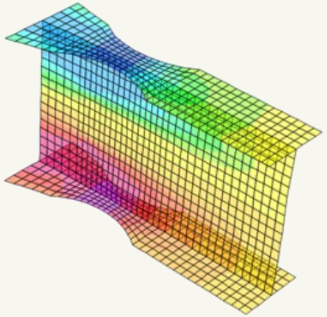


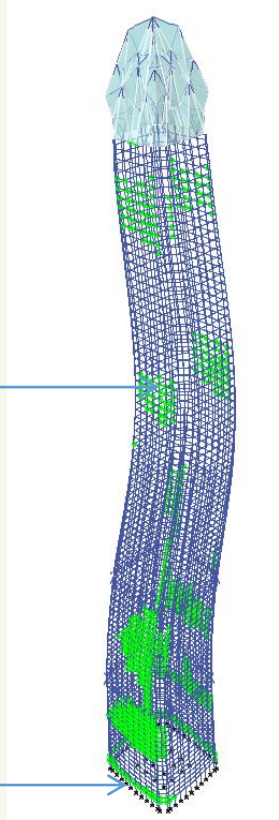
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)





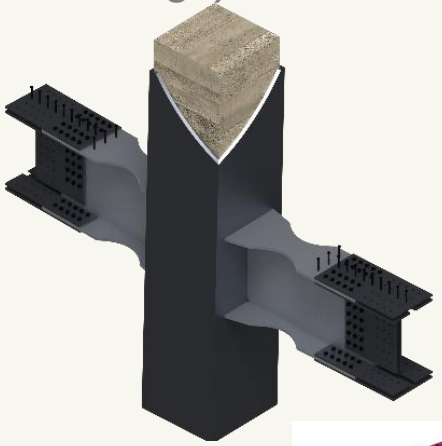


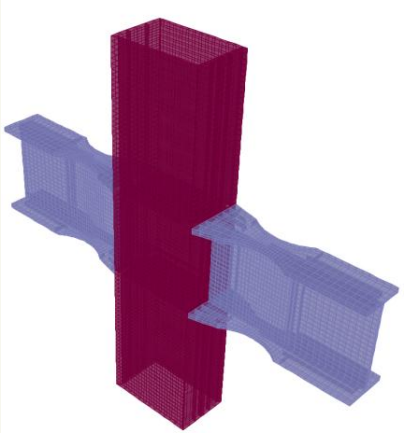


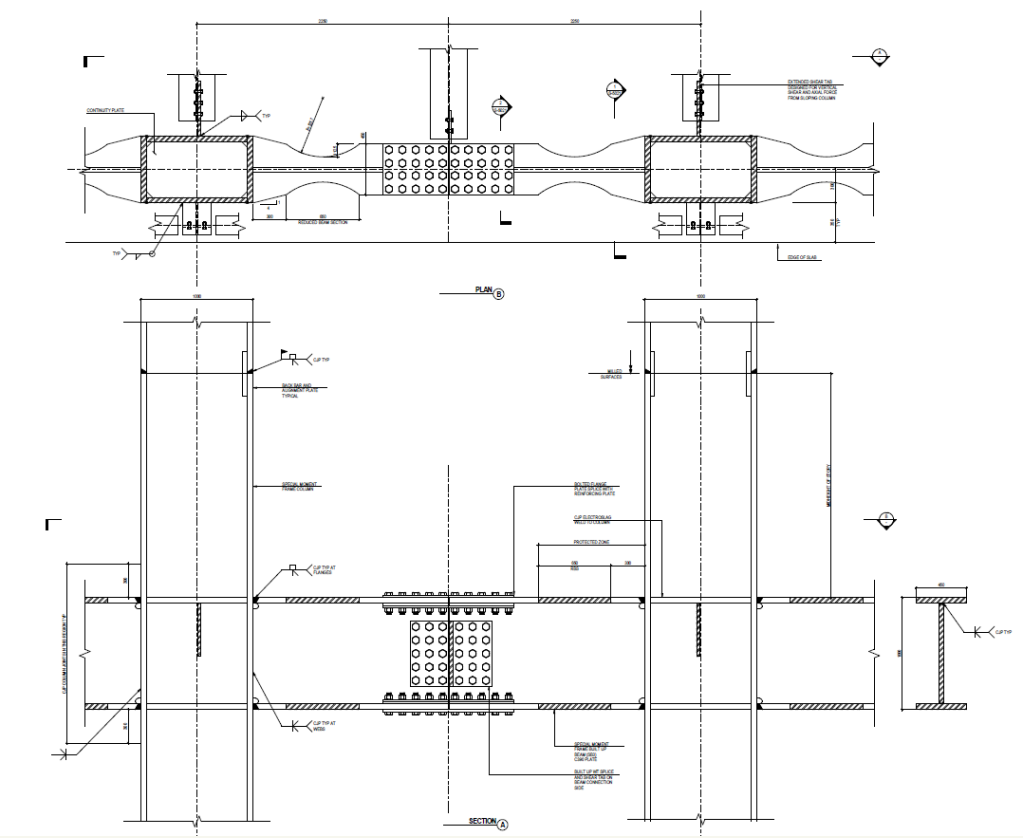
46826 STEPS

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)



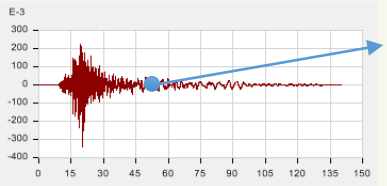




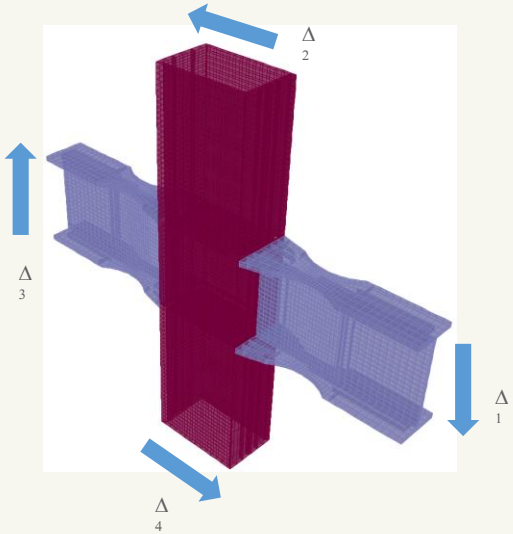
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

1. Valoración más precisa del comportamiento (Rusia) (More accurate assessment of performance)

Kobe Earthquake

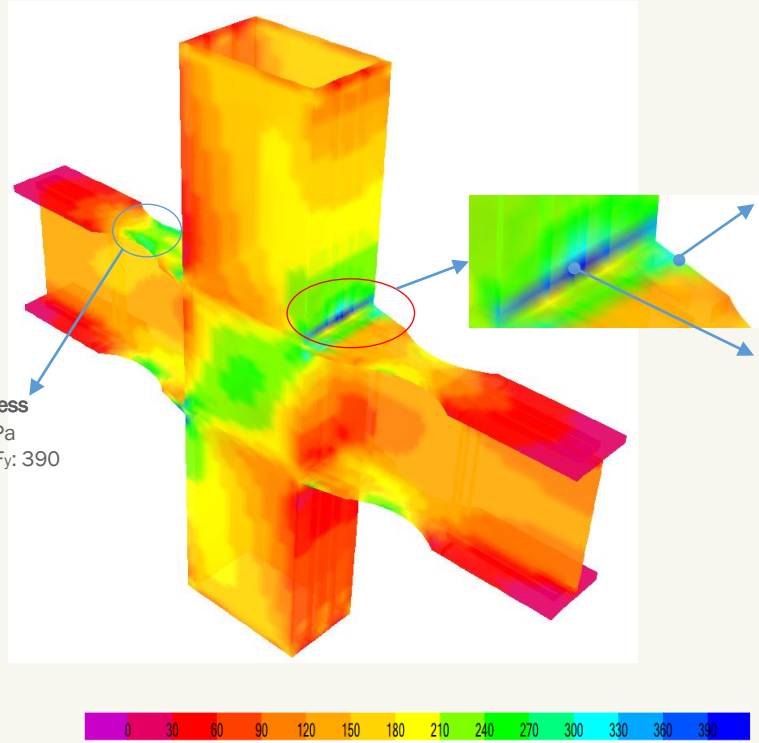


Time Step 52.96sec When Maximum Joint Rotation Observed



Node Rotation at Peak Response

Δ1 (mm)	2.1
Δ2 (mm)	5.2
Δ3 (mm)	1.9
Δ4 (mm)	5.6



Max RBS Stress
RBS: 275 MPa
Beam Plate Fy: 390 MPa

Max Beam Flange Stress

Beam Flange: 325 MPa
Beam Plate Fy: 390 MPa

Max Column Face Stress

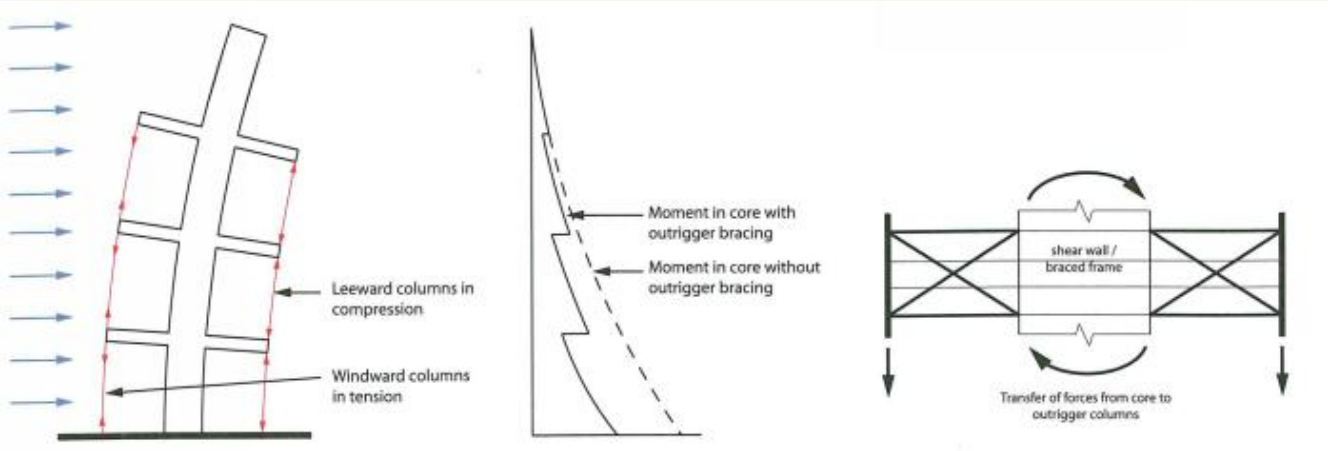
Column Face: 420 MPa
Column Plate Fy: 690 MPa

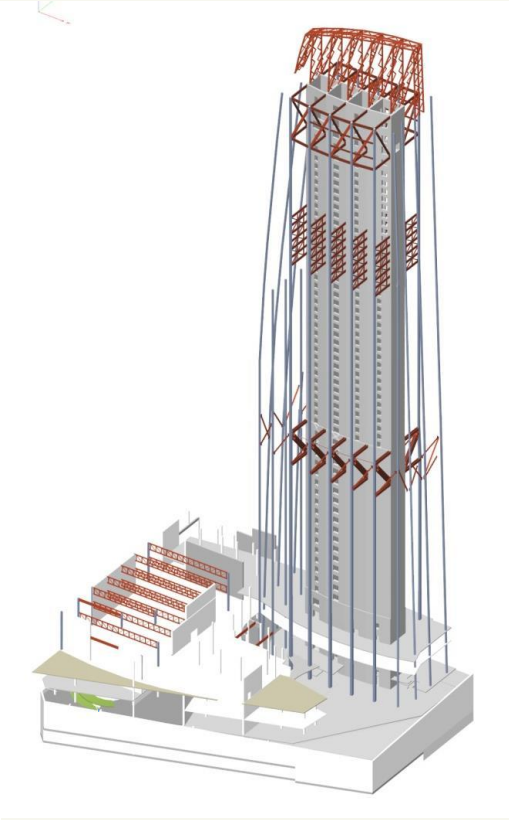
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

2. Uso de sistemas estructurales previamente restringidos en altura (Los Angeles, CA – USA)

Use of previously height-restricted structural systems

- Muros del núcleo en hormigón (Concrete core walls)
- Columnas tubulares de acero rellenas de hormigón (Concrete filled steel box columns)
- Forjado mixto (Composite steel floor framing)
- **BRBs en tres zonas con outriggers (BRBs in three outrigger zones)**
- **Diagonalización de dos niveles con outriggers (Belt trusses at two outrigger zones)**



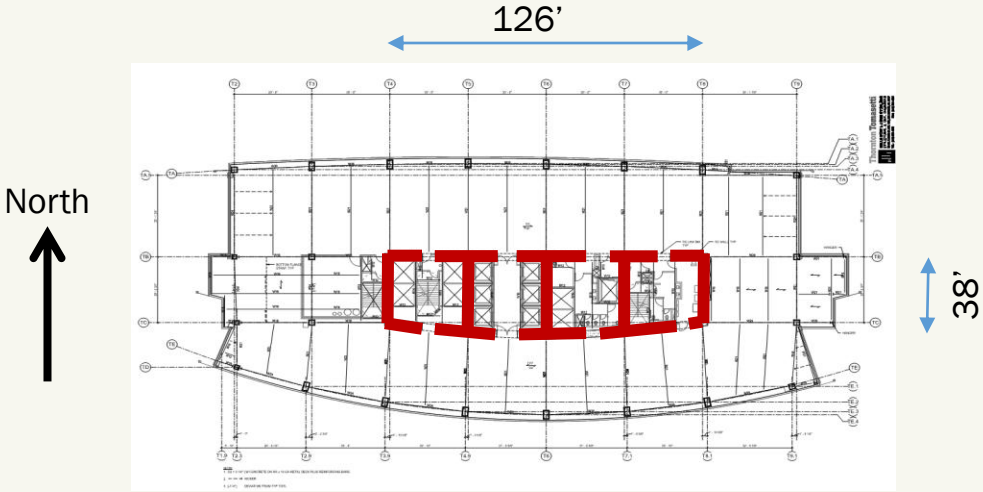


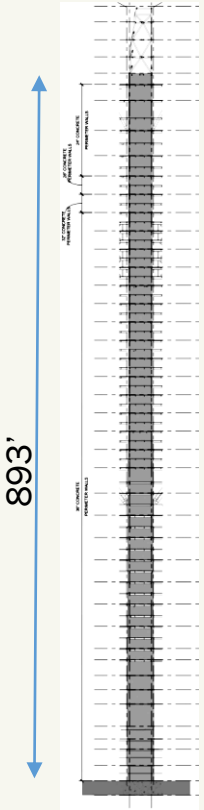
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

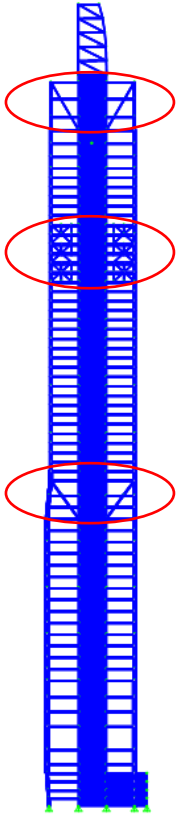
2. Uso de sistemas estructurales previamente restringidos en altura (Los Angeles, CA – USA)

Use of previously height-restricted structural systems

- Altura del núcleo = 893’ = 272m (Core height)
- Núcleo (E-W) = 893’/126’= 272m/38m = 7 (Core)
- Núcleo (N-S) = 893’/38’= 272m/12m = 23.5 (Core)
- Outriggers (N-S)
  - 38’ (12m) a 108’ (33m) (8:1) (38 to 108 feet)



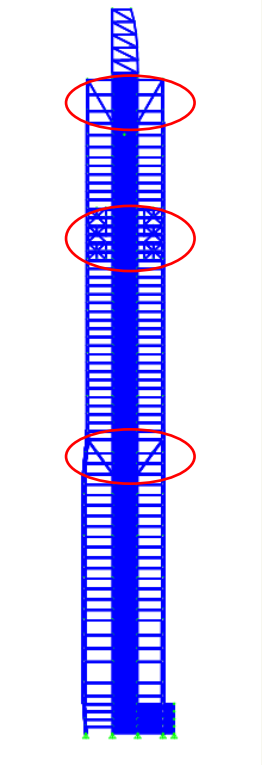




DSPD Para Edificios en Altura (PBSD of Tall Buildings)

2. Uso de sistemas estructurales previamente restringidos en altura (Los Angeles, CA – USA)

Use of previously height-restricted structural systems

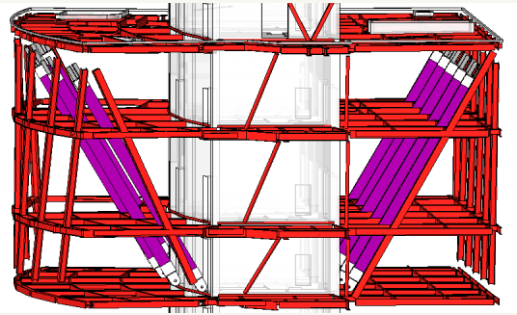


DSPD Para Edificios en Altura (PBSD of Tall Buildings)

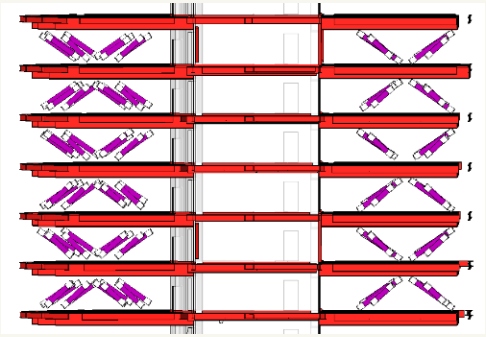
2. Uso de sistemas estructurales previamente restringidos en altura (Los Angeles, CA – USA)

Use of previously height-restricted structural systems

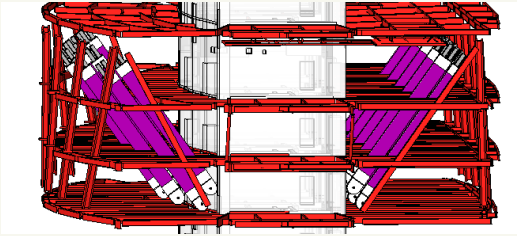
- Las diagonals de los outriggers son BRBs
  (Outrigger diagonals are BRBs)
- Relativamente nuevo (Relatively new)
  - 1970's: Invención en Japón (Japan invention)
  - '94 Northridge: 1er uso en USA (US adoption)
- En tres localizaciones (Three sets)
  - 170 BRBs total



10 BRBs (Levels 70-73)



120 BRBs (Levels 53-59)



40 BRBs (Levels 28-31)

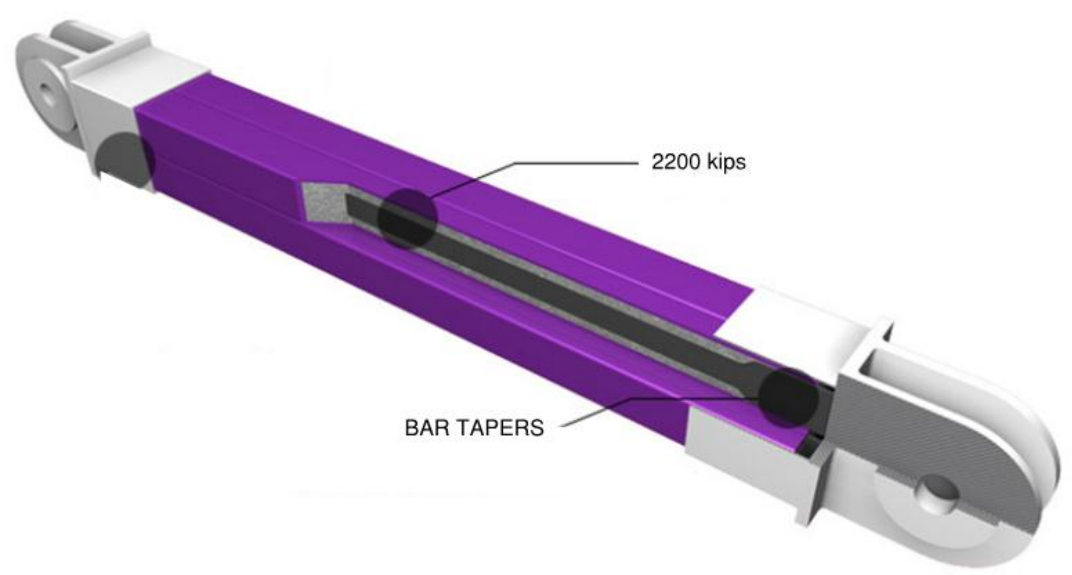
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

2. Uso de sistemas estructurales previamente restringidos en altura (Los Angeles, CA – USA)

Use of previously height-restricted structural systems

¿Por qué usar arriostramientos de pandeo restringido (BRBs)? **Why use Buckling Restrained Braces (BRBs)?**

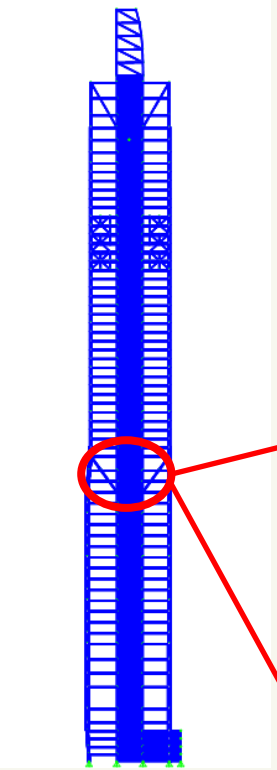
- Componentes (Components)
  - Núcleo de acero (Steel core)
  - Camisa exterior (Outer sleeve)
- Limita las fuerzas (Caps forces in critical elements)
  - Columnas (Columns)
  - Muros de transmisión (Wall panel zones)
  - Conexiones (Connections)
  - Cimientos (Foundations)
- Permite elementos largos sin arriostramiento (Allows long unbraced lengths)
  - Arquitecturas dramáticas (Dramatic architecture)

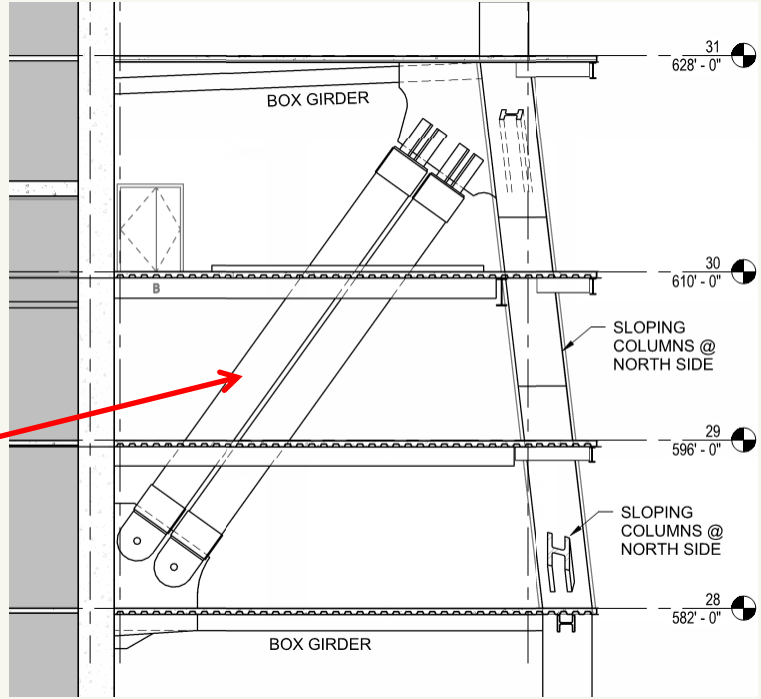


DSPD Para Edificios en Altura (PBSD of Tall Buildings)

2. Uso de sistemas estructurales previamente restringidos en altura (Los Angeles, CA – USA)

Use of previously height-restricted structural systems





4 X 2200 kips each = 8800 kips / location

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

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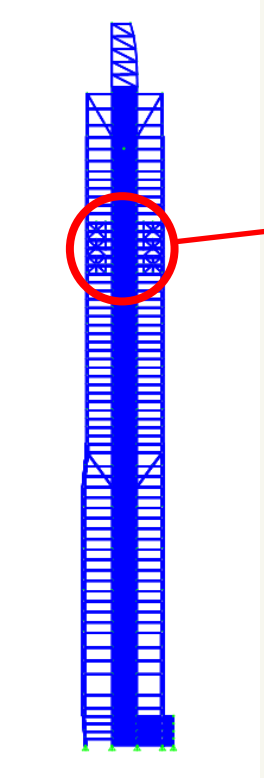
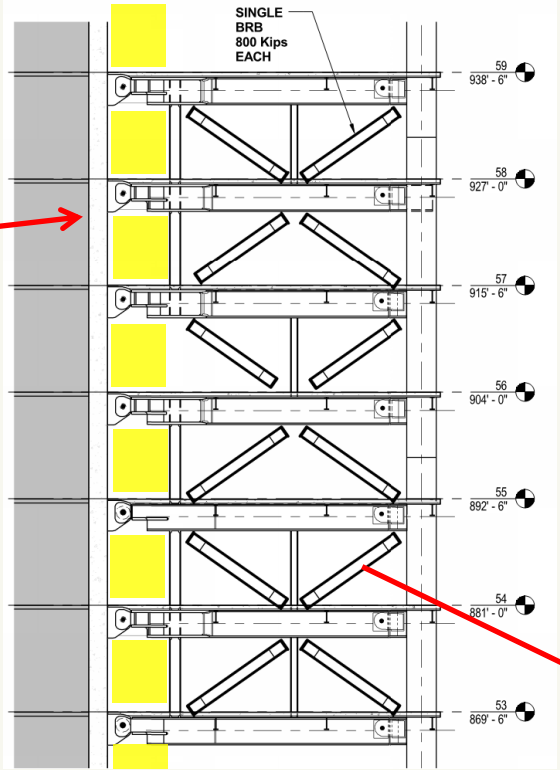
Use of previously height-restricted structural systems





800 kips each

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

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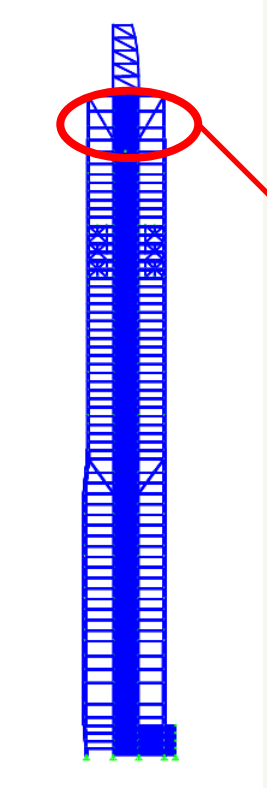
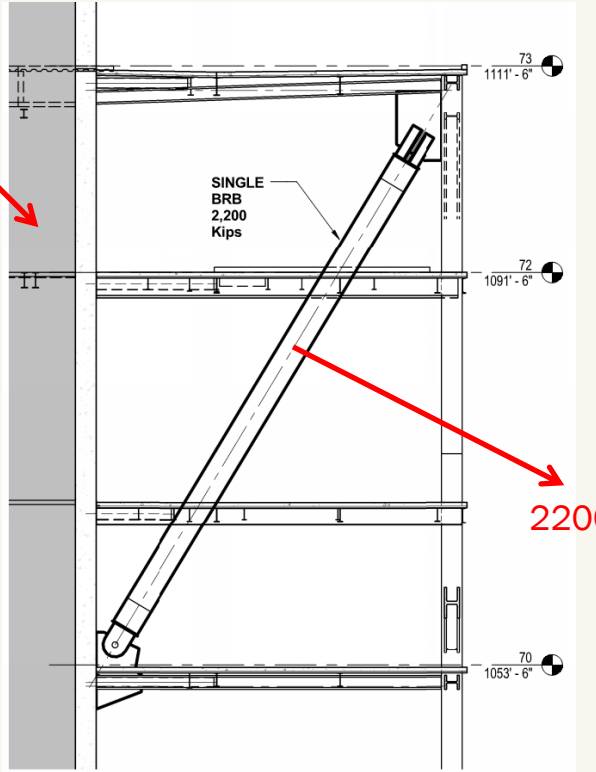
Use of previously height-restricted structural systems





2200 kips each

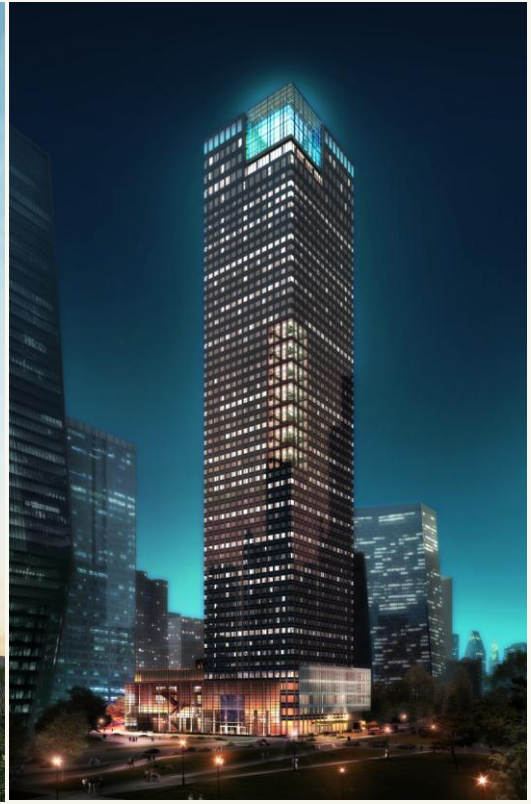
DSPD Para Edificios en Altura (PBSD of Tall Buildings)

2. Uso de sistemas estructurales previamente restringidos en altura (Los Angeles, CA – USA)

   Use of previously height-restricted structural systems

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

3. Flexibilidad para usar nuevas tecnologías (China) (Flexibility to use new technology)



DSPD Para Edificios en Altura (PBSD of Tall Buildings)

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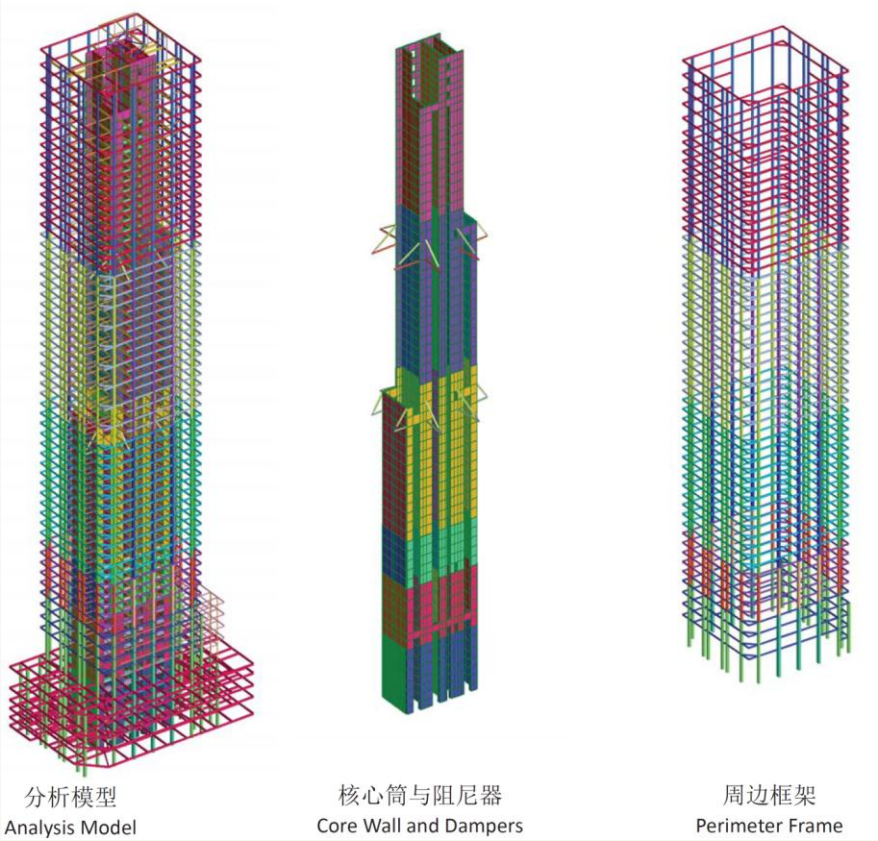

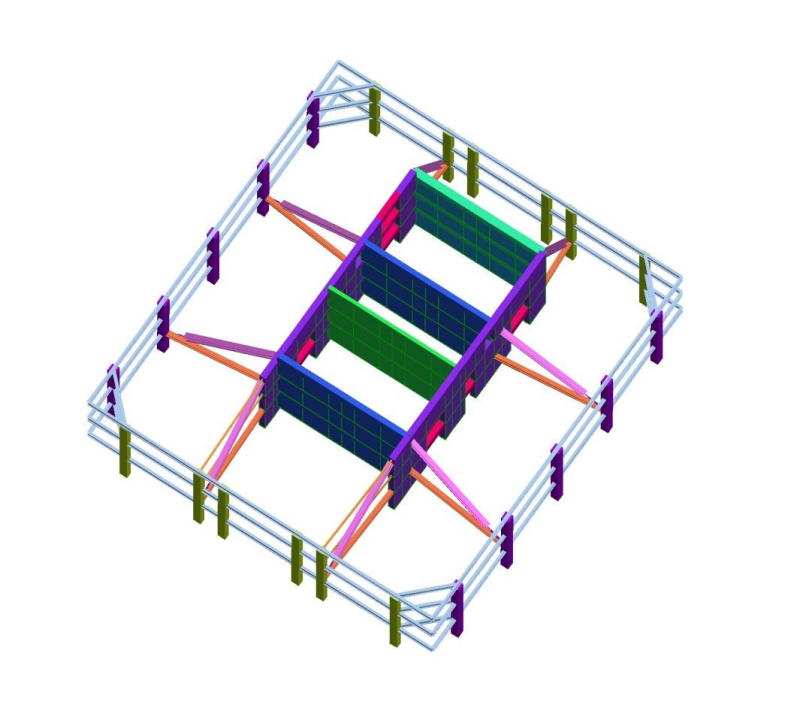

Amortiguadores en el Nivel Mecánico Superior
(Dampers at Upper Mechanical Level)

DSPD Para Edificios en Altura (PBSD of Tall Buildings)

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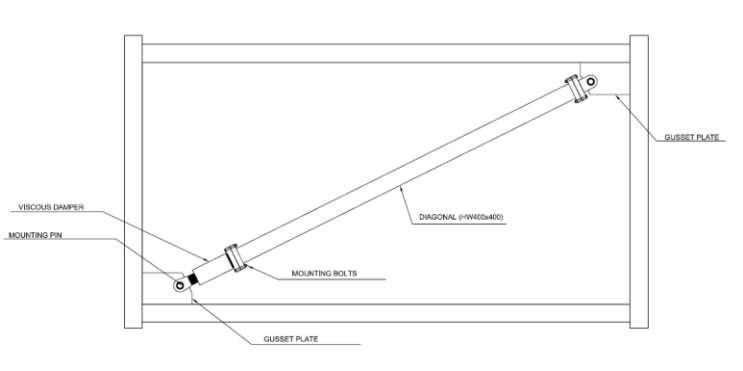

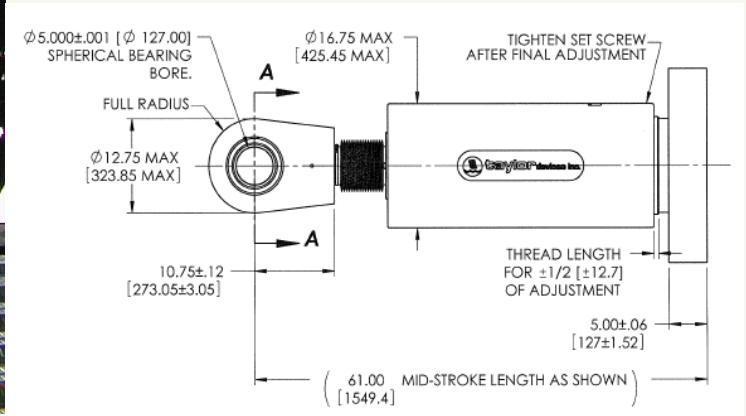

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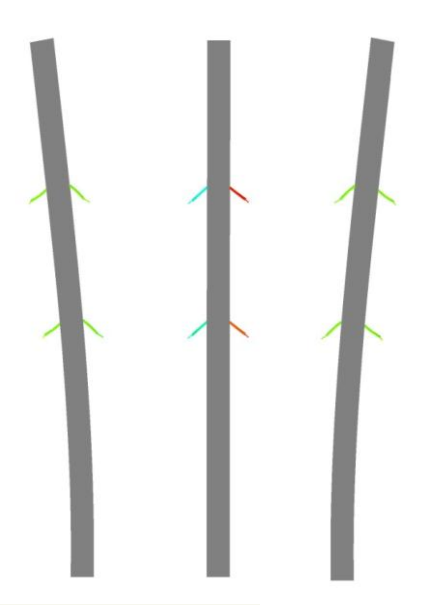
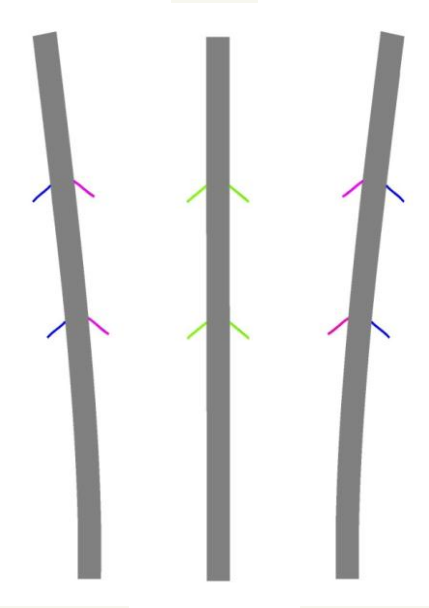
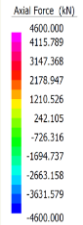




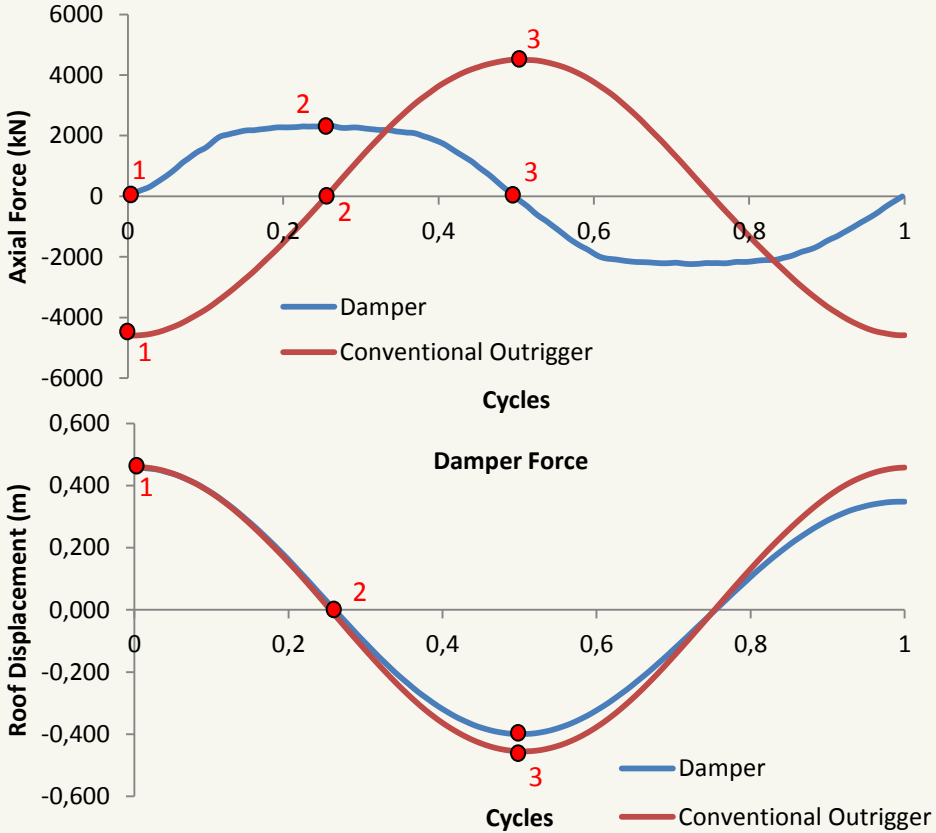


Point 1: 0 kN | Point 2: 2330 kN | Point 3: 0 kN

Damper Scheme

Point 1: 4500 kN | Point 2: 0 kN | Point 3: 4500 kN

Conventional Scheme



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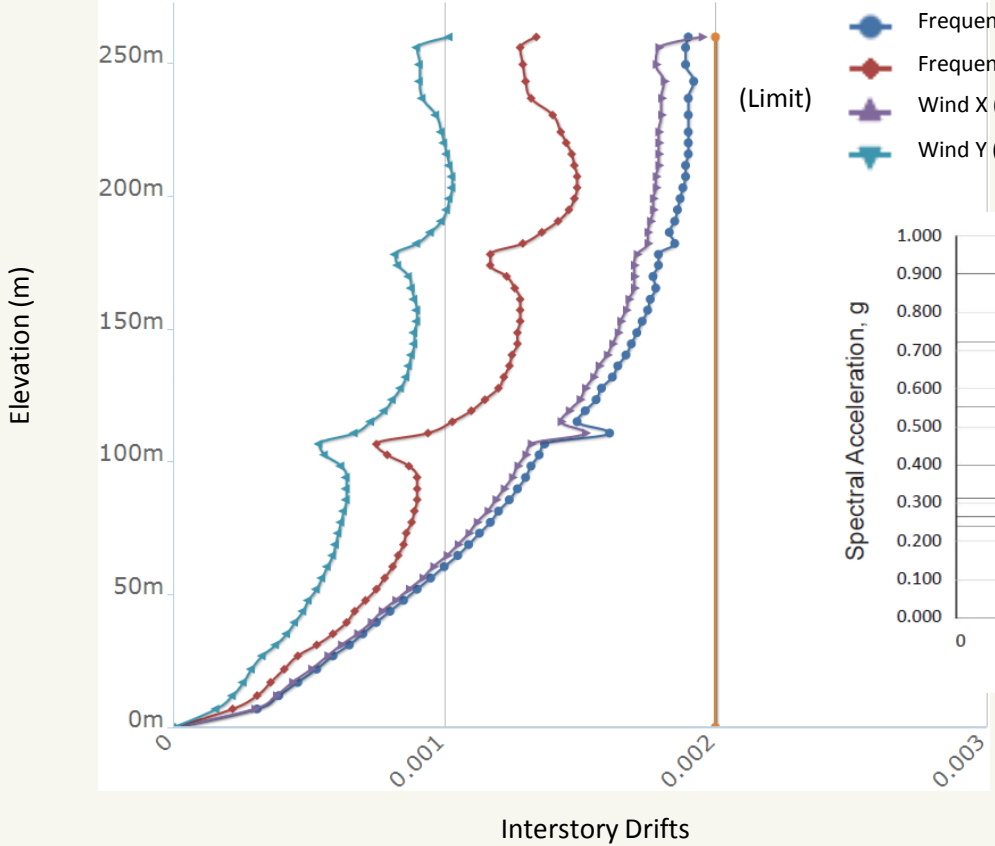

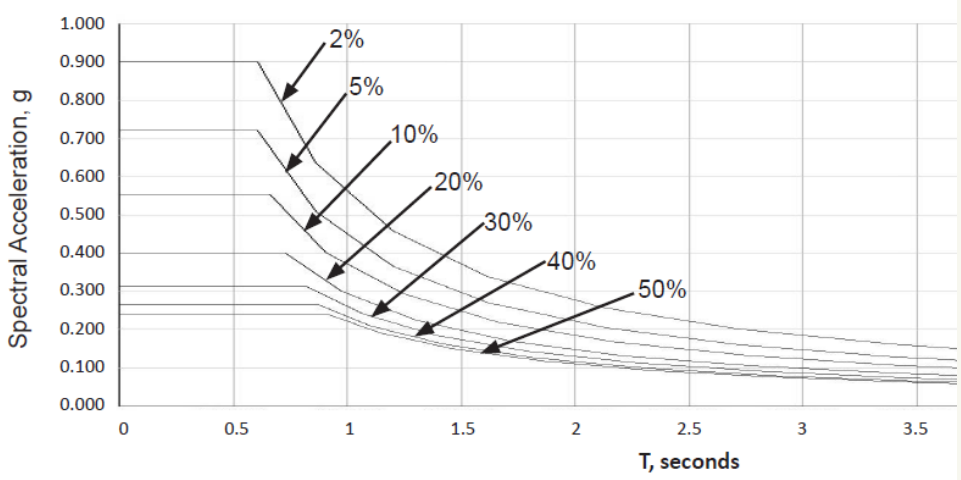

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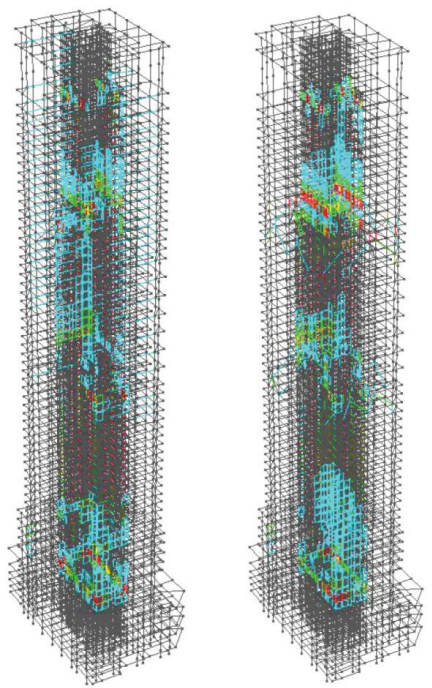
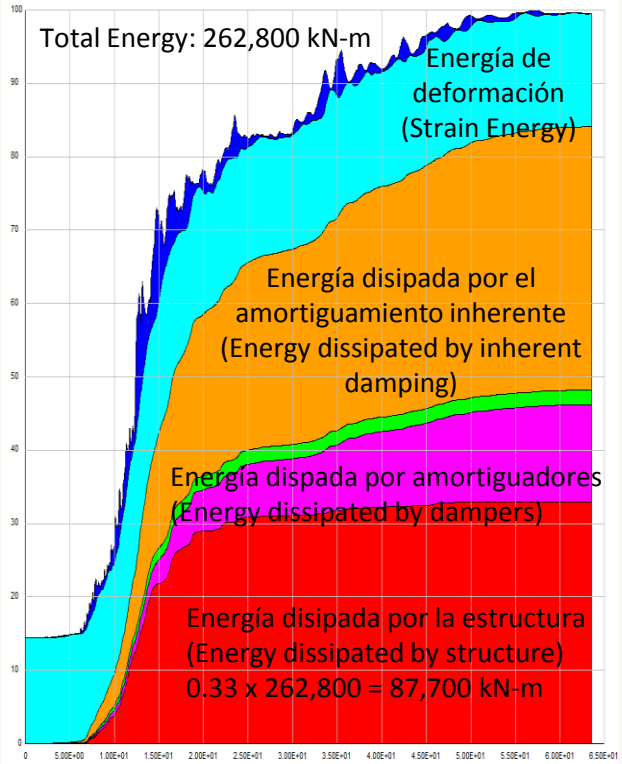


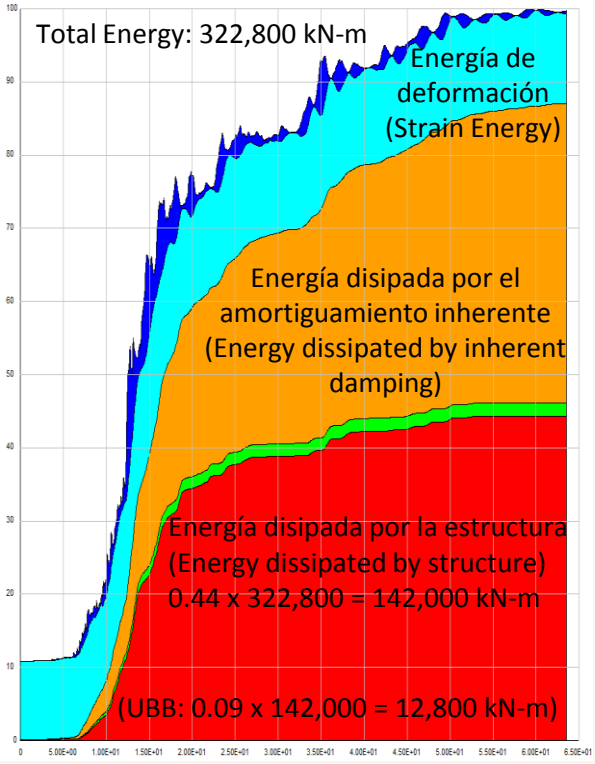
Damper Scheme UBB Scheme

Component **IO** Usage Ratio
Average of 7 sets of Rare TH Analysis



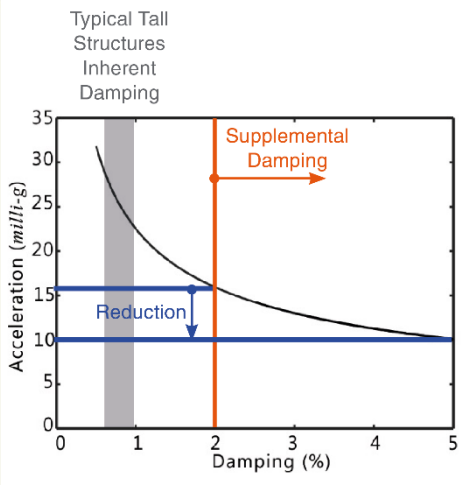
Time, s

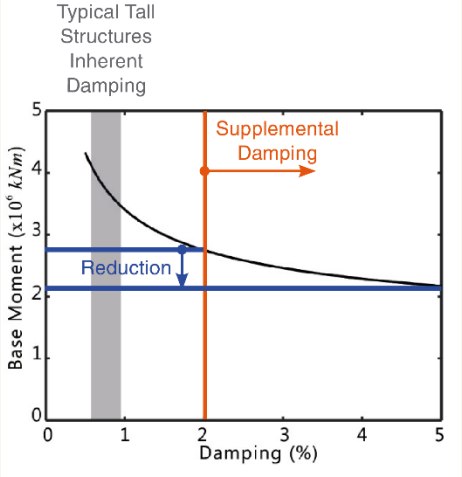
Dampers



Time, s

UBB Outriggers and Belt Truss


Typical Tall Structures Inherent Damping
Supplemental Damping
Reduction
Acceleration (milli-g)
Damping (%)
0
5
10
15
20
25
30
35
0
1
2
3
4
5


Typical Tall Structures Inherent Damping
Supplemental Damping
Reduction
Base Moment (x10^6 kNm)
Damping (%)
0
1
2
3
4
5
0
1
2
3
4
5


kinetica
VCD Hysteresis
Shear Force (kN)
Shear Displacement (mm)
1000
500
0
-500
-1000
-30
-20
-10
0
10
20
30


Cityview

CONSTRUIR EN ACERO
UNA NECESIDAD DEL FUTURO

SIMPOSIO 2018

GRACIAS

ASIMET 80 AÑOS
Transformar para Crecer

ICHA
CORPORACIÓN
INSTITUTO CHILENO
DEL ACERO