STATE OF THE ART AND STATE OF THE PRACTICE FOR ENERGY DISSIPATION AND SEISMIC ISOLATION OF STRUCTURES IN MEXICO

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Casa abierta al tiempo

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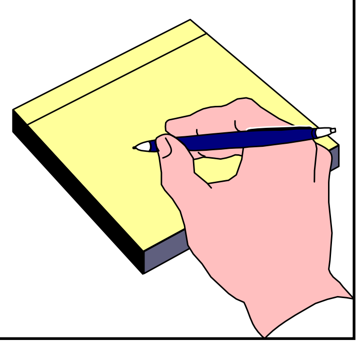
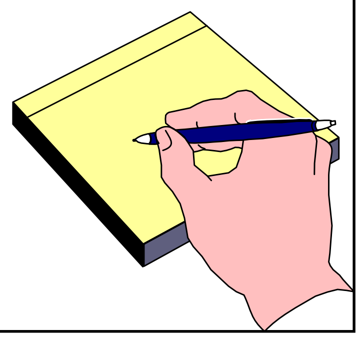
FULBRIGHT

OUTLINE

- Principles
- Experimental Research
- Analytical Research
- Applications
- Remarks



Principles



Fundamental Principle

$$E = E_e + E_k + E_h + E_d$$

- **It is not economic to resist strong earthquakes relying exclusively in “clean” energies (E_e & E_k) that causes no damage to structures.**

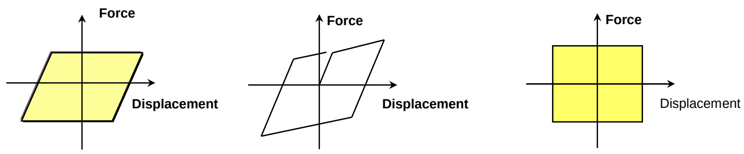
$$E_e = \int_0^u ku(t)du; \qquad E_k = \int_0^u m\ddot{u}(t)du$$

- **In traditional earthquake-resistant design philosophy of the 70s-80s, E_h has been (ab)used, so substantial damage is expected in common structural resisting elements (“dirty” energy).**

- **Passive energy dissipation maximizes E_d and/or concentrates E_h in special elements (seismic fuses), so most common structural elements are expected to remain undamaged. Therefore, it is a wiser and semi-clean (semi-dirty) strategy. However, it requires solid knowledge of structural concepts (dynamics and configuration).**

Passive Energy Dissipators

- One crude classification
  - Displacement dependent

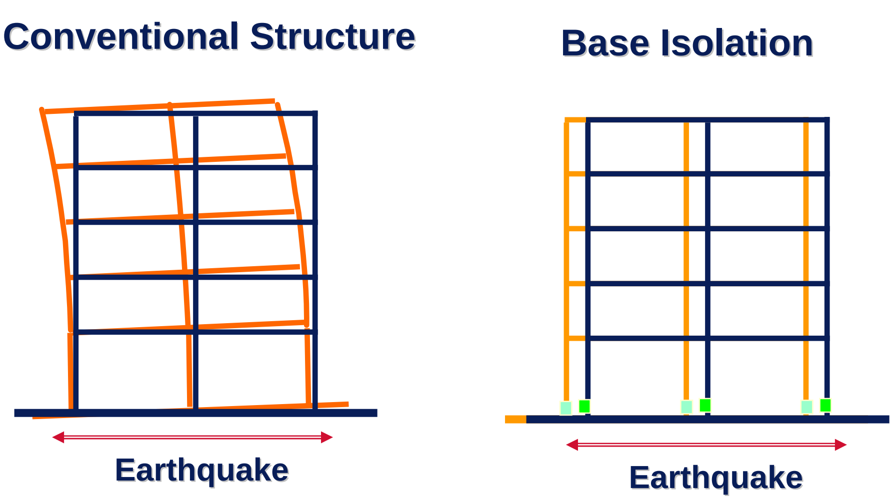


Hysteretic behavior (i.e., metals) — Friction-Extrusion

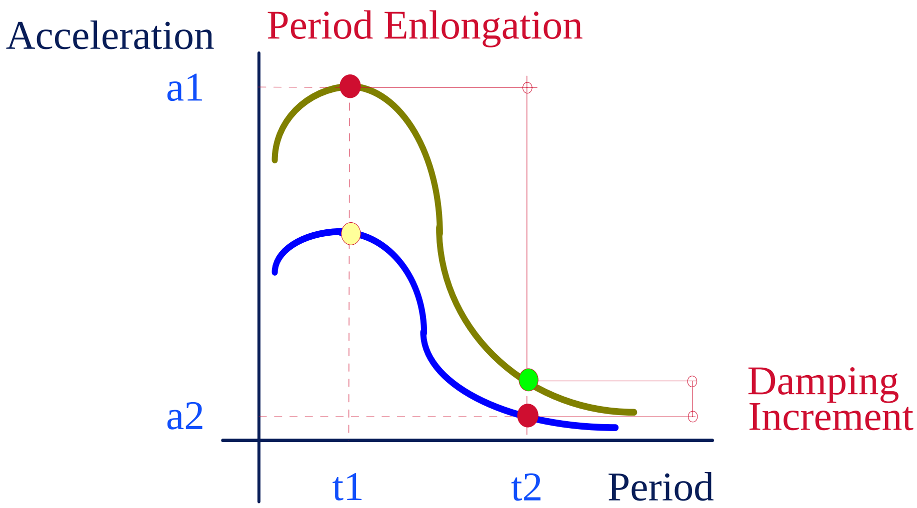
  - Velocity dependent

Viscoelastic materials — Viscous dampers (fluids)

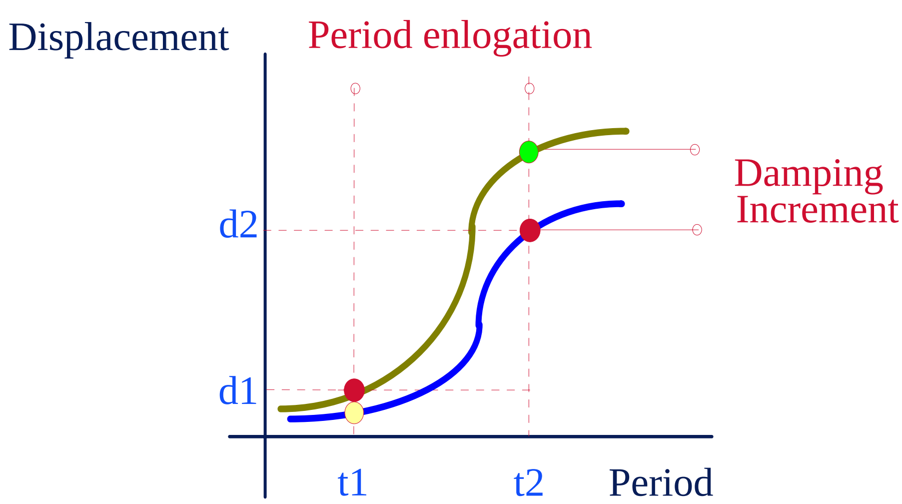
Base Isolation



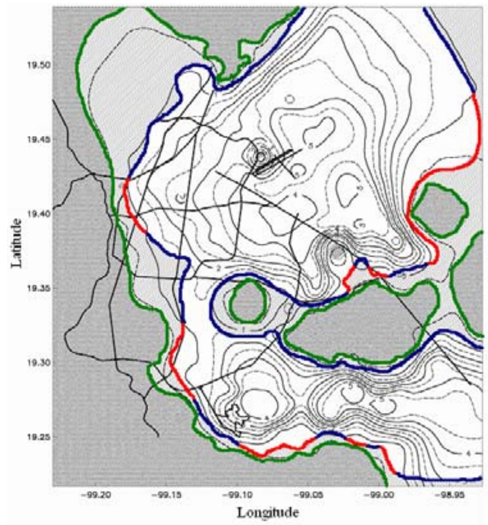
Seismic Isolation (Firm Soils or Rock)



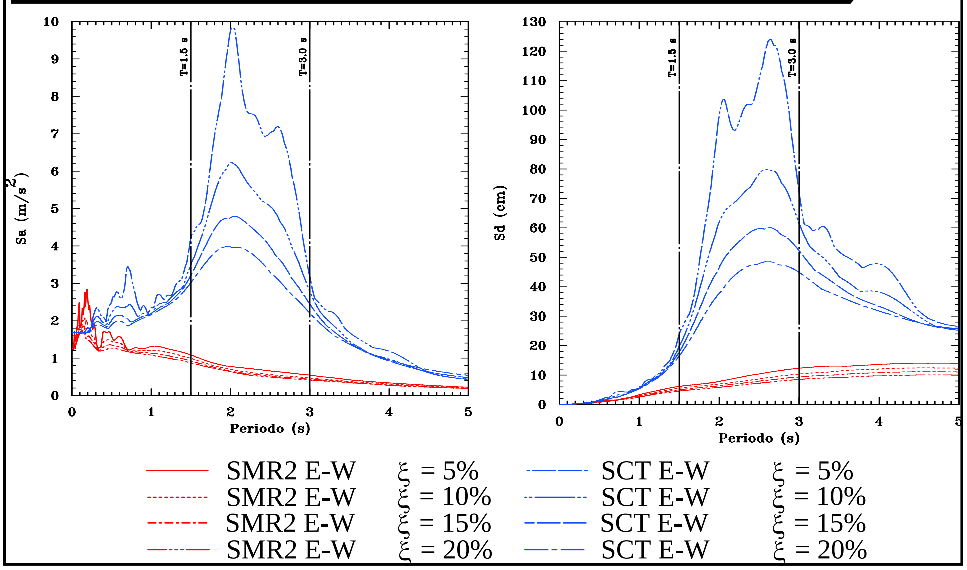
Seismic Isolation (Firm Soils or Rock)



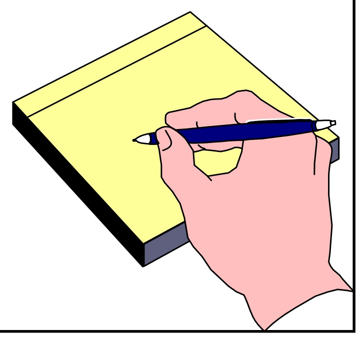
Why base isolation is not a good idea for soft soils as those found in the lakebed region of Mexico City?



Firm Soils (SMR2) vs Soft Soils (SCT)



Experimental Research



Experimental, Base Isolation

- Rolling Base Isolation system proposed by González-Flores: First one, conducted in 1964 at UNAM, shaking table test.

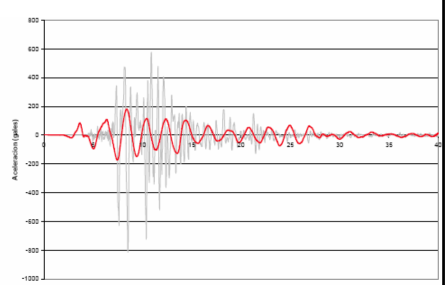
http://nisee.berkeley.edu/visual_resources/steinbrugge_collection.html

Experimental, Base Isolation

- GT-BIS System: Mexican development by Garza-Tamez whose shaking table tests were conducted at Illinois in 1992 (paid by Garza).

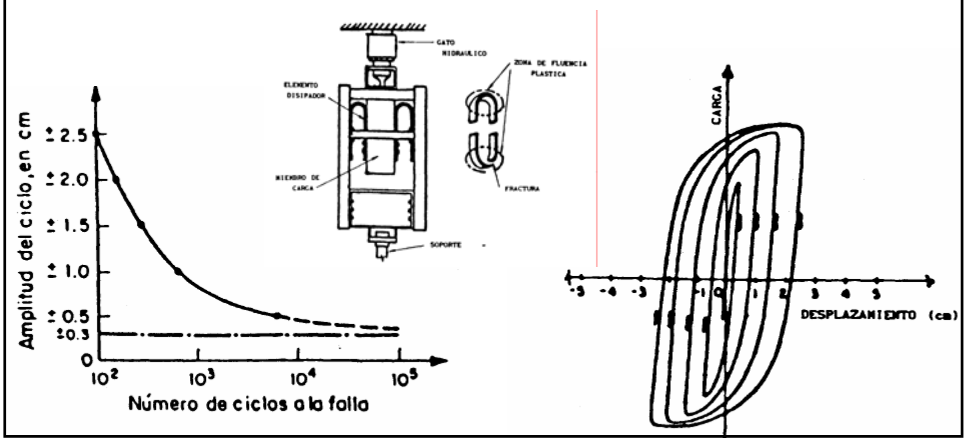
Experimental, Base Isolation

- Friction isolation system for low-income housing tested by Yeomans *et al.* (2006) at ITESM. Acceleration record: Kobe (1995).



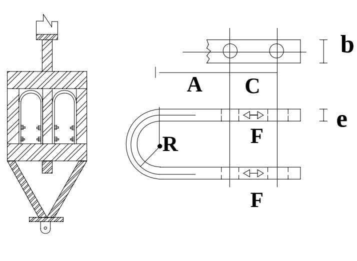
Experimental, Energy Dissipation

- U-shaped mild steel strip elements (“DS elements”). Cyclic testing at UNAM (Aguirre and Sánchez, 1989-1992). Similar to those studied by Kelly.



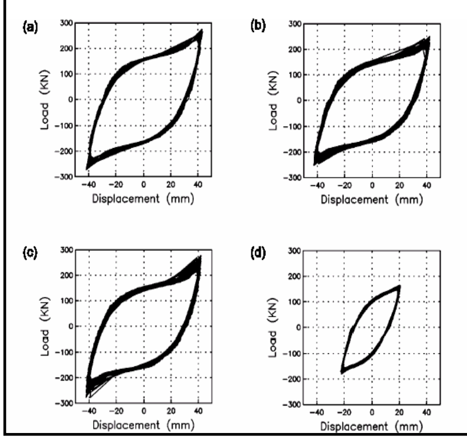
Experimental, Energy Dissipation

- U-shaped mild steel strip elements (“DS elements”). Shaking table tests at UNAM by González-Alcorta (1992-1994).



Experimental, Energy Dissipation

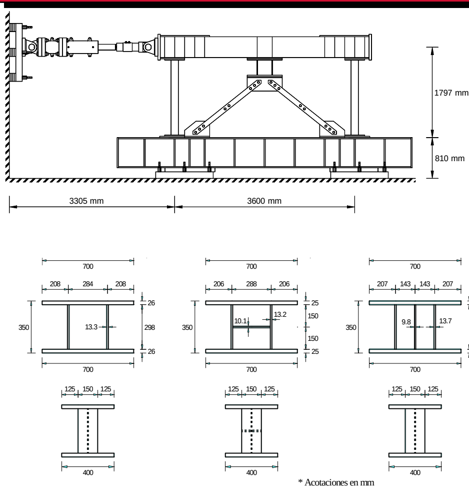
- Cyclic tests of simply-supported plates in bending, know as DV device, proposed by Jorge Ortega and tested at UNAM by Escobar *et al.* (1998-1999)

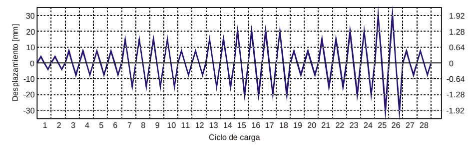


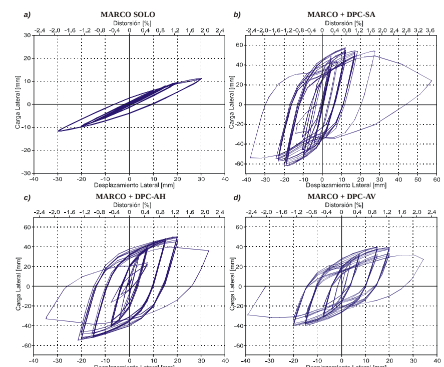
Experimental, Energy Dissipation

- Low Yield Steel Shear Panel Devices (LYSSP) tested at Cenapred by Óscar López-Bátiz and Fernando Aparicio (2002-2003)

Experimental, Energy Dissipation







Experimental, Energy Dissipation

- Pseudo-static cyclic tests of a two-story RC waffle flatslab building model retrofitted with a flexible steel device (FSD) mounted in concentric bracing by *Vera et al.* (2000) at UAEM.

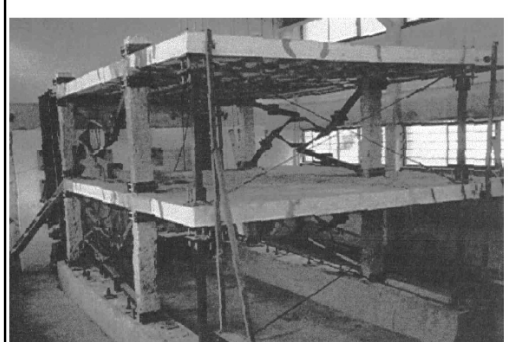


Figura12 Historia carga desplazamiento marco interior

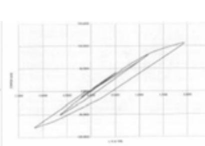
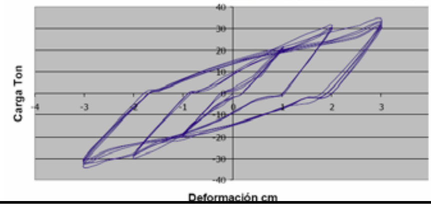


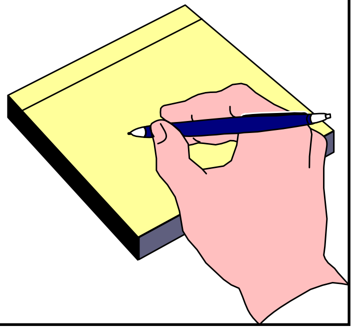
Figura 13 Historia carga desplazamiento marco exterior

Experimental, Energy Dissipation

- **Cyclic tests of a of a simply supported plate of variable section (SSPVS) by *Vera et al.* (2006) at UAEM.**

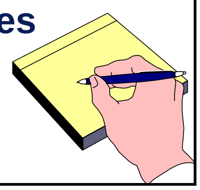


Analytical Research



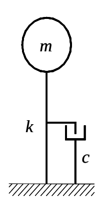
Passive Energy Dissipation

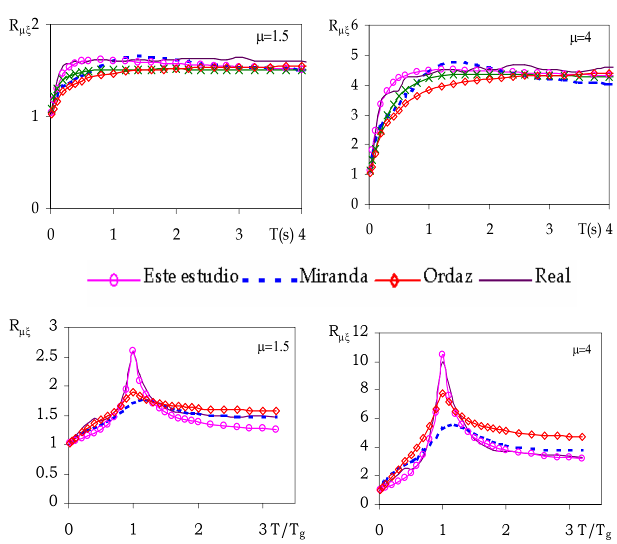
- Parametric studies using SDOF systems
- Studies using MDOF systems
- Proposals for the analytical modeling of specific devices
- Evaluation and validation of models used for nonlinear analyses
- Reliability and optimization of structures with passive energy dissipation devices
- Design procedures and guidelines
- Studies for bridges



Parametric SDOF studies

- Arroyo and Terán (2002)
- Firm Soils

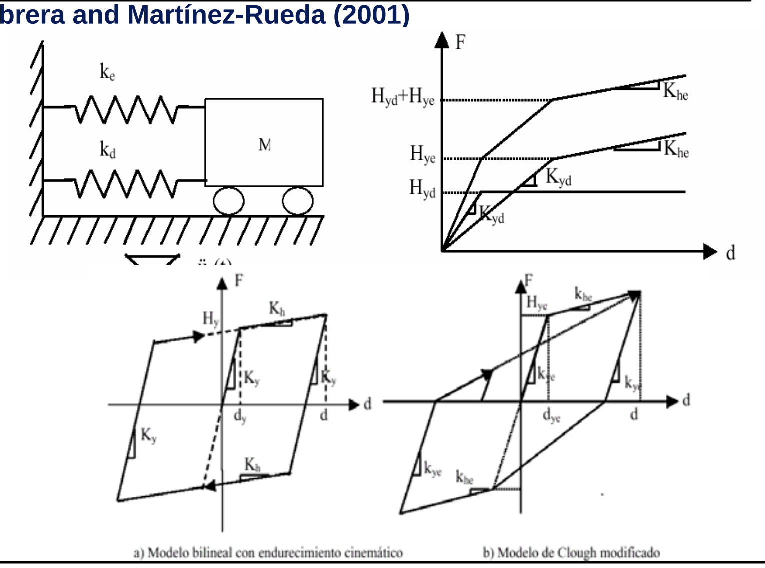




- Soft Soils

Parametric SDOF studies

- Cabrera and Martínez-Rueda (2001)



Parametric SDOF studies

- Cabrera and Martínez-Rueda (2001)

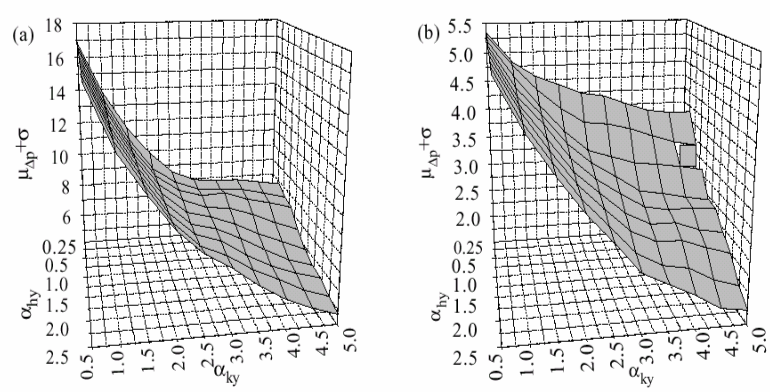
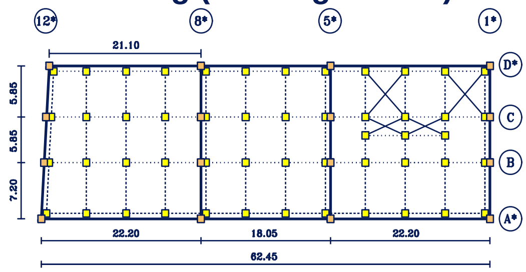
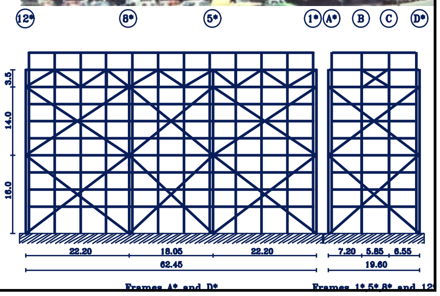


Figura 4. Demandas de ductilidad promedio más la desviación estándar para estructuras con C_y=0.1, Z=2, T_y=0.2 seg (a) y C_y=0.1, Z=2, T_y=0.6 seg (b) analizadas con el modelo bilineal.

Retrofit Strategies: Bracing vs Dissipators

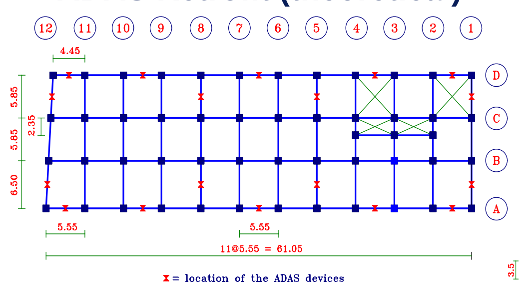
- Bracing (existing retrofit)

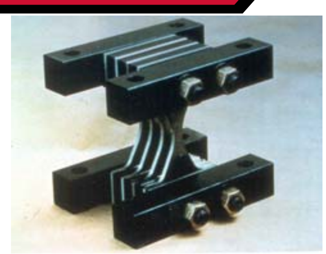


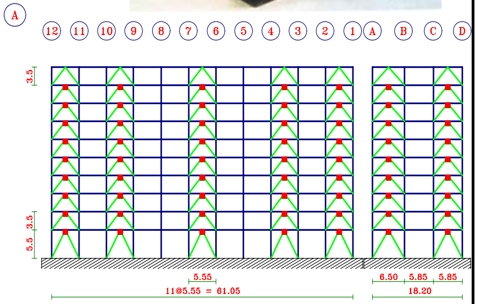


Retrofit Strategies: Bracing vs Dissipators

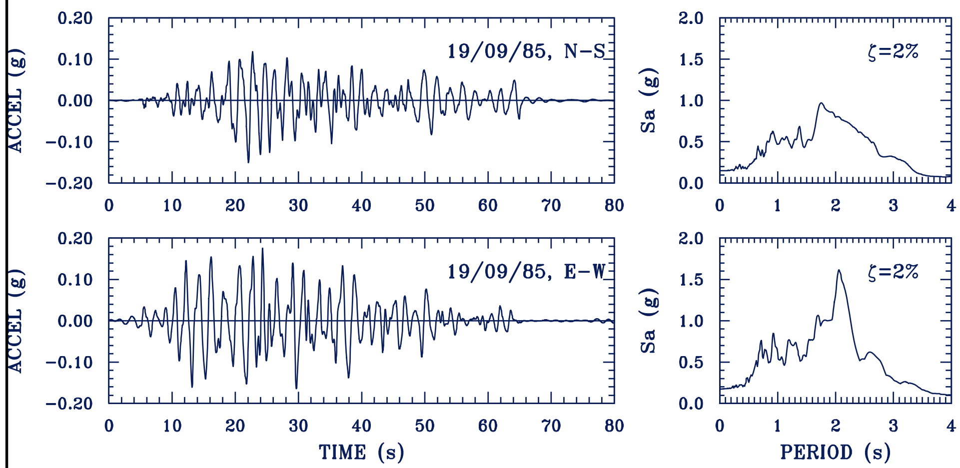
- ADAS Retrofit (theoretical)





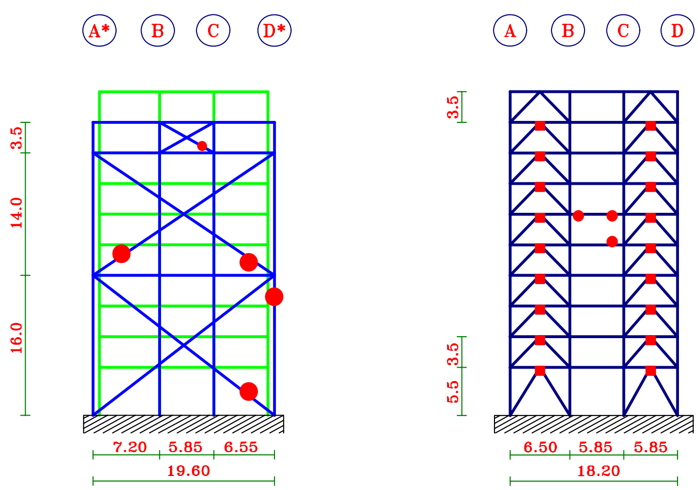


- Artificial site records, M_s=8.1 earthquake



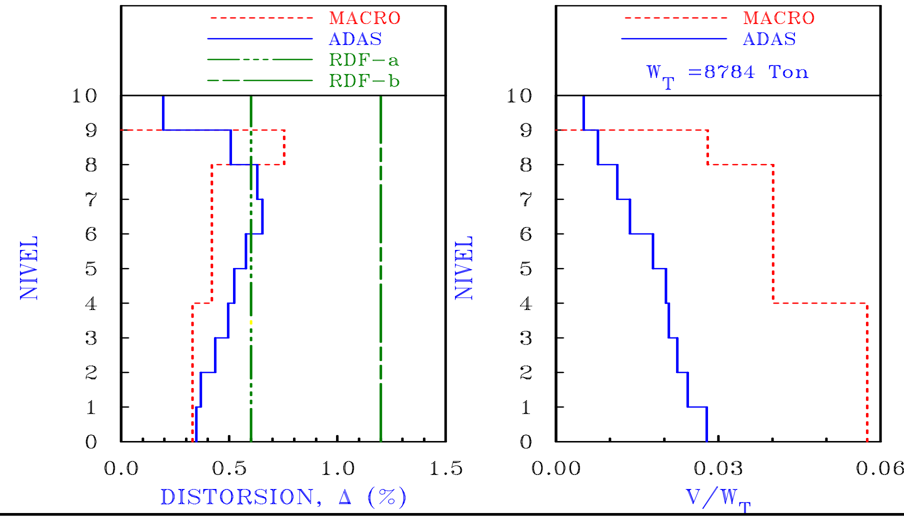
Comparison: CBFs vs ADAS

- Yield mapping

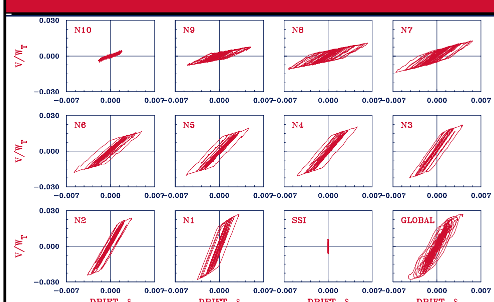


Comparison: CBFs vs ADAS

- Response envelopes

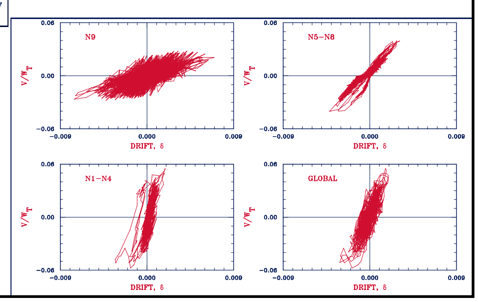


Comparison: CBFs vs ADAS



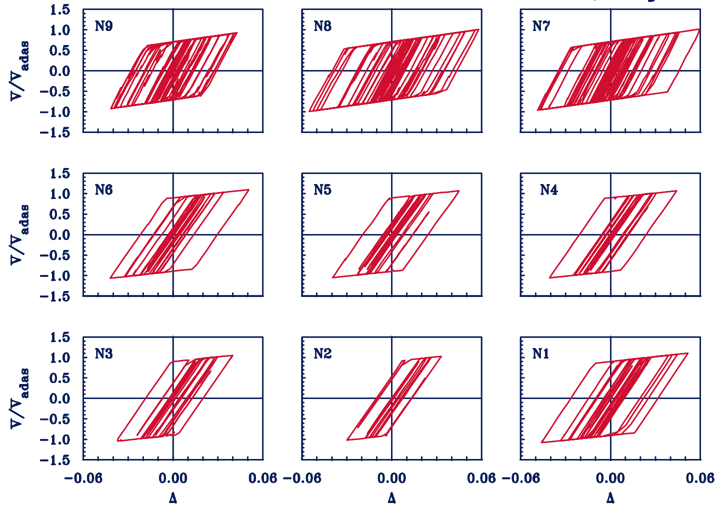
- Interstory Hysteresis curves, ADAS retrofit

- Interstory Hysteresis curves, Macro CBF retrofit



Comparison: CBFs vs ADAS

- Hysteresis curves for ADAS located in frame 8, bay A-B



Retrofit Strategies: Bracing vs Dissipators

- Park España Building: CBF (existing) vs DS

Comparison: Bracing vs DS

- Artificial acceleration site record, M_s=8.1 earthquake

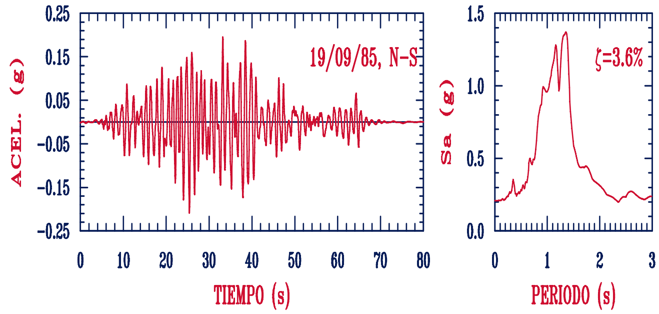
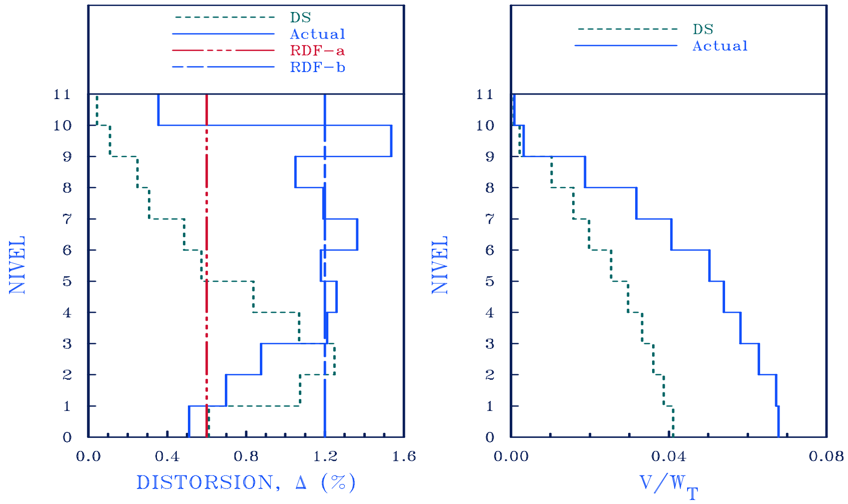


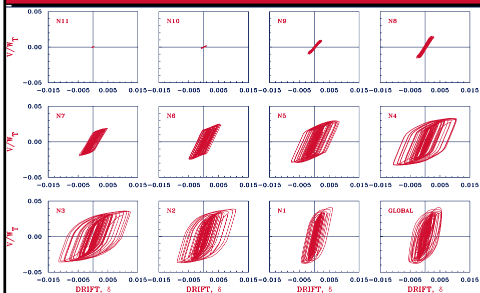
Tabla 6. Resumen de los análisis dinámicos no lineales para los modelos de Parque España							
Modelo	W (t)	$T_{N\text{-}S}$ (s)	Desplazamientos máximos (cm)			Demanda máxima (μ)	
			N3	N4	Azotea	Entrepiso	Global
Actual	1752.7	1.10	6.87	10.48	34.79	5.5 (N8)	4.5
DS	1752.7	1.24	8.65	11.61	19.36	4.5 (N3)	2.5

Comparison: Bracing vs DS

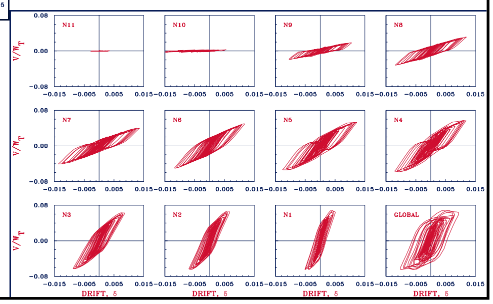
- Peak response envelopes



Comparison: Bracing vs DS



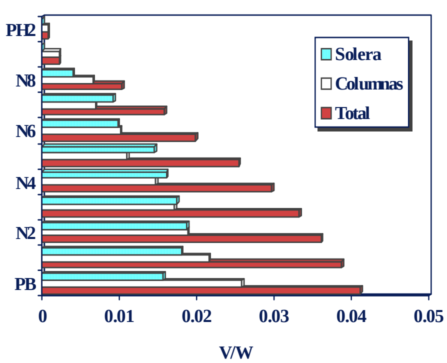
- Interstory hysteresis curves, frames with DS



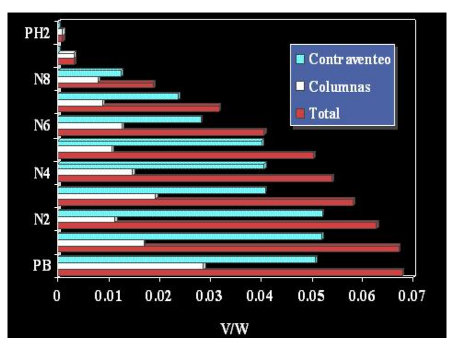
- Interstory hysteresis curves, existing CBFs

Comparison: Bracing vs DS

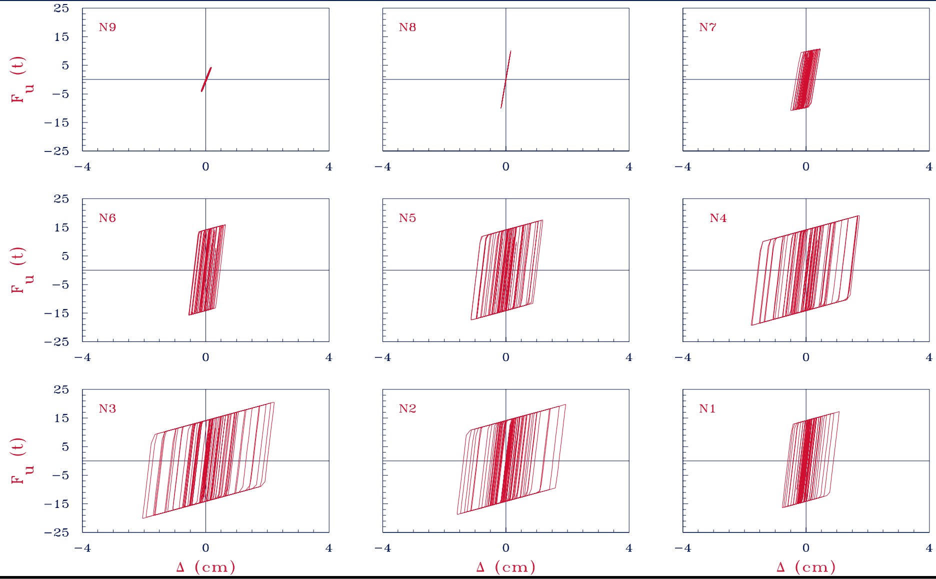
- Shear, frames with DS devices



- Shear, frames with existing CBF



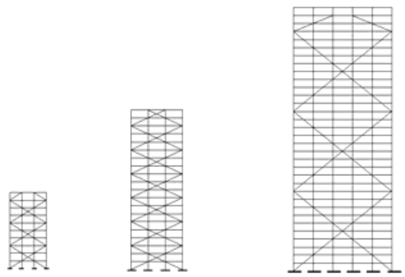
Hysteresis, DS devices



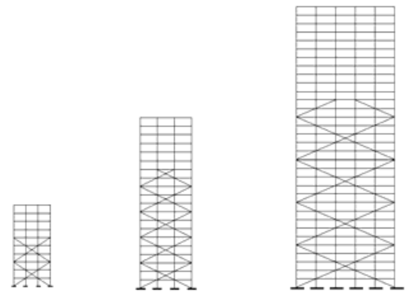
Comparison: Bracing vs Energy Dissipation

- Montiel and Ruiz (2000)

- CBFs
- Passive Energy Dissipation

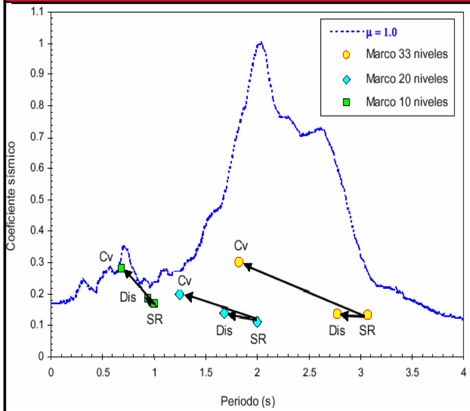


a) Marco de 10 niveles b) Marco de 20 niveles c) Marco de 33 niveles

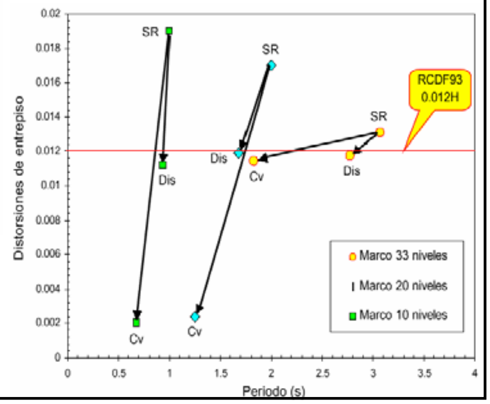


a) Marco de 10 niveles b) Marco de 20 niveles c) Marco de 33 niveles

Comparison: Bracing vs Energy Dissipation

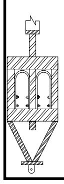
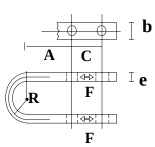


- Montiel and Ruiz

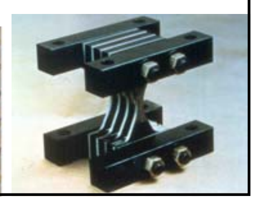


Analytical, Energy Dissipation

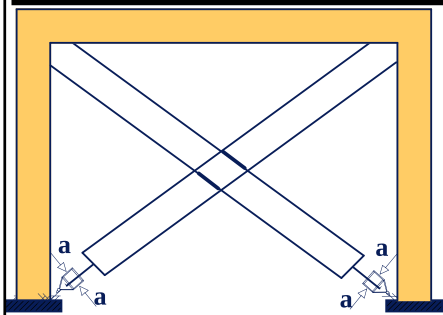
- **Proposals for the analytical modeling of specific devices**
  - **DS device: Aguirre and Sánchez (1989, 1992), Tena-Colunga (1998, 2000), Terrones *et al.* (2002)**
  - **ADAS device: Tena-Colunga (1997)**
  - **DV device: Fernández *et al.* (1999), Escobar *et al.* (2002)**
  - **SSPVS device: Vera *et al.* (2006)**

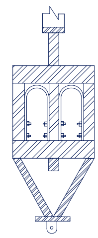



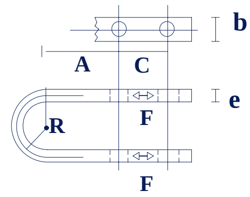




DS Devices





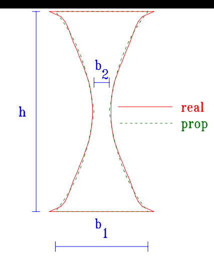


$$K_{DDE} = K_{DS} = n(0.297\sigma_u b) \qquad K_2 = 0.032K_{DS}$$

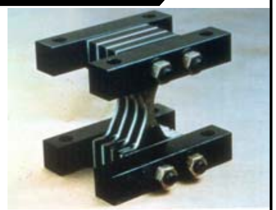
$$F_u = F_{uDS} = n(0.07\sigma_u be) \qquad F_y = 0.756F_{uDS}$$

$$\Delta_y = 0.1782\,e \qquad \Delta_u = 2e$$

ADAS Devices



$$\Delta_y = \frac{V_{ADAS}}{K_{ADAS}}$$



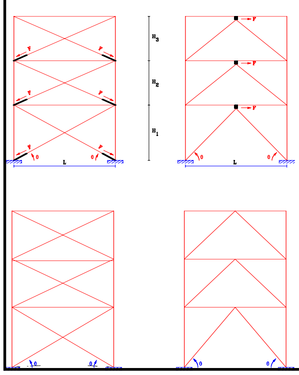
$$K_{DDE} = K_{ADAS} = n\frac{f_{66}}{f_{22}f_{66} - f_{26}^2} \qquad F_u = V_{ADAS} = n\left(\frac{\sigma_y(b_1 - b_2)t^2}{2h}\right)$$

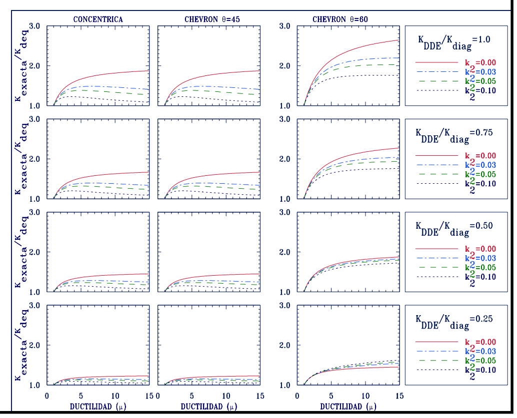
$$f_{22} = \frac{12}{Et^3}\left\{\frac{h^3}{2b_1\, ln(b_1/b_2)}\left[\frac{b_1}{b_2}\left(\frac{1}{2} + \frac{1}{[ln(b_1/b_2)]^2}\right) - 1 - \frac{1}{ln(b_1/b_2)} - \frac{1}{[ln(b_1/b_2)]^2}\right]\right\} + \frac{78h}{25Etb_1\, ln(b_1/b_2)}\left(\frac{b_1}{b_2} - 1\right)$$

$$f_{26} = \frac{12}{Et^3}\left\{\frac{h^2}{2b_1\, ln(b_1/b_2)}\left(\frac{b_1}{b_2} - 1\right)\right\} \qquad f_{66} = \frac{12}{Et^3}\left\{\frac{h}{b_1\, ln(b_1/b_2)}\left(\frac{b_1}{b_2} - 1\right)\right\}$$

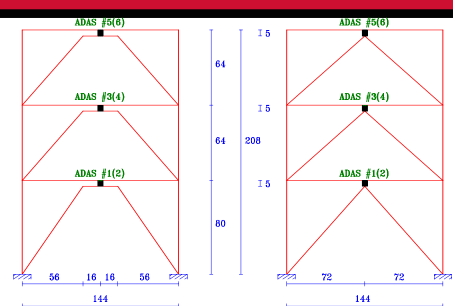
Analytical, Energy Dissipation

- Evaluation and validation of models used for nonlinear analyses
  - Tena-Colunga (2000, 2002)
  - Amateco and Escobar (2006)



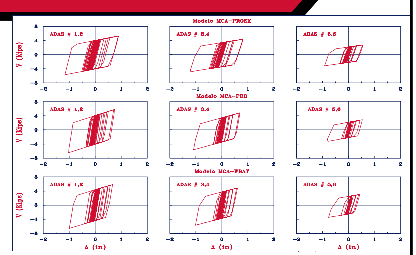


Validation of analytical models

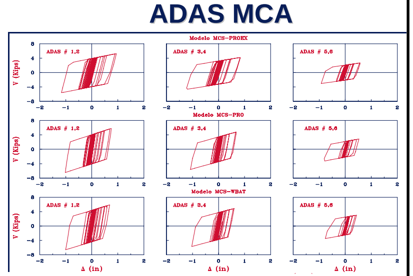


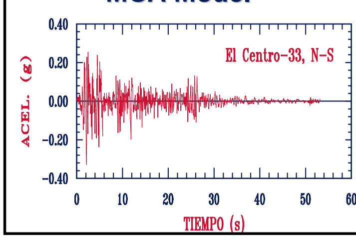
MCA Model

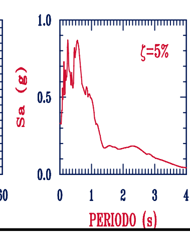
MCS Model



ADAS MCA



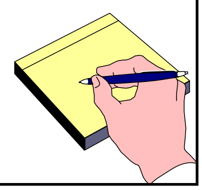




ADAS MCS

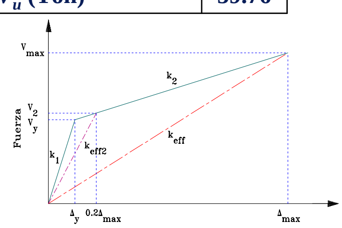
Base Isolation

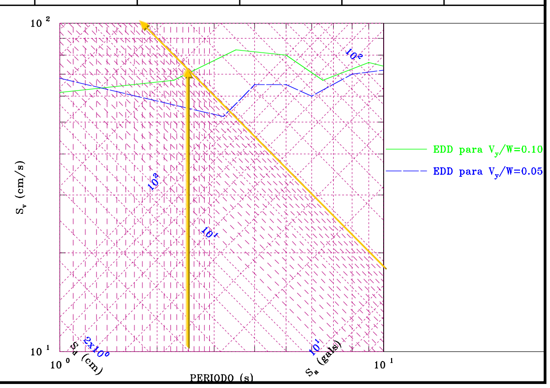
- Studies for buildings using equivalent SDOF models
- Studies for buildings using equivalent frame models
- Studies for buildings using 3D models
- Parametric studies
- Design procedures and guidelines
- Studies for existing applications
- Studies for new developments
- Studies for bridges



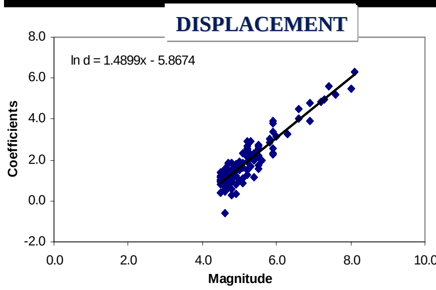
Design of the isolation system for a school building, considering bidirectional effects, using CSDS

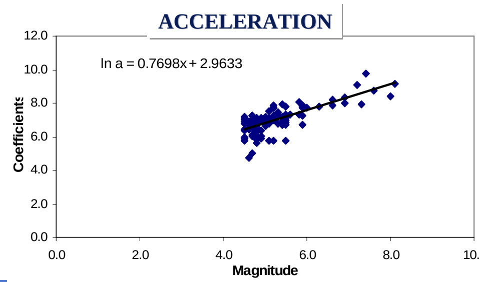
			Iter. 1	*Iter. 2*	*Iter. 3*	*Iter. 4*	*Iter. 5*
T_I (s)	2.5	α	0.6	0.484	0.513	0.506	0.508
W (Ton)	1530	k_1 (Ton/cm)	8.21	10.59	9.99	10.14	10.10
$\beta = V_y/W$	0.10	k_2 (Ton/cm)	0.82	1.06	1.00	1.01	1.01
D (cm) (EDD)	28	Δ_y (cm)	3.11	2.41	2.55	2.51	2.52
D_{2D}=D+0.3D (cm)	36.4	Δ_y/D_{2D}	0.085	0.066	0.070	0.069	0.069
N_{ais}	6	α_c	0.484	0.513	0.506	0.508	0.507
k_{min} (Ton/cm)	9.85						
k_{ef} (Ton/cm)	1.64						
V_y (Ton)	25.50						
V_u (Ton)	59.76						



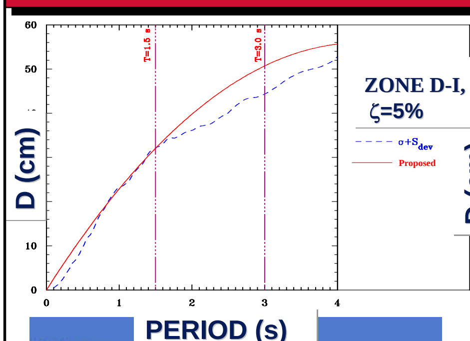


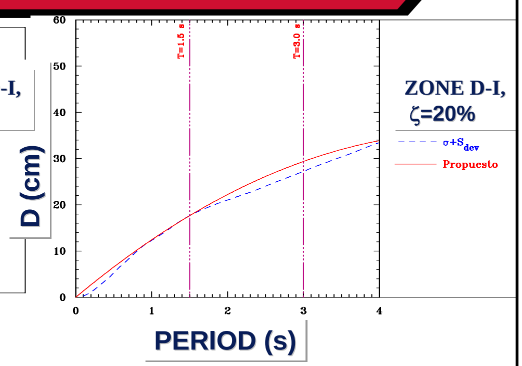
Updated Attenuation Laws





Displacement Design Spectrum for Zone D-I



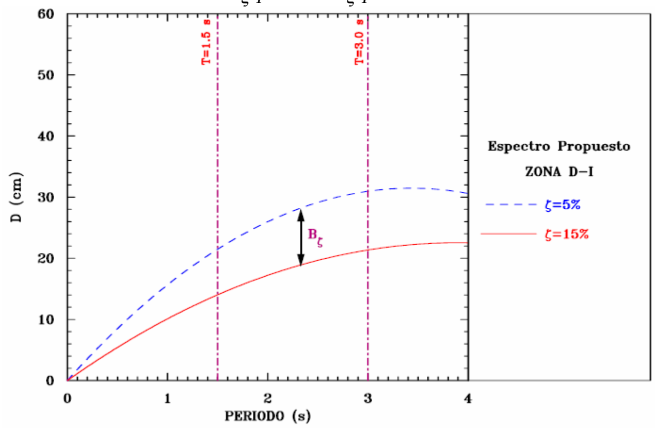


$$D = a_1 T_I - a_2 T_I^2$$

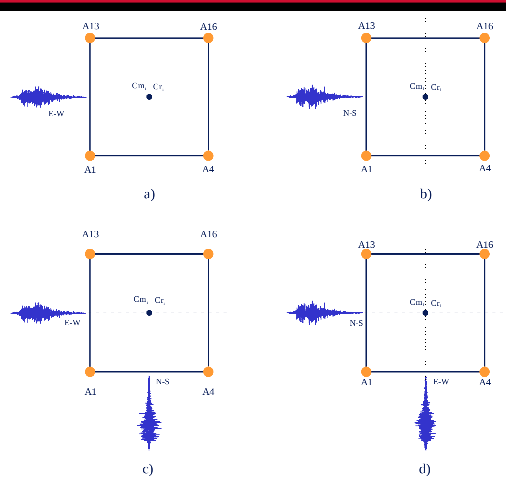
Alternate Method

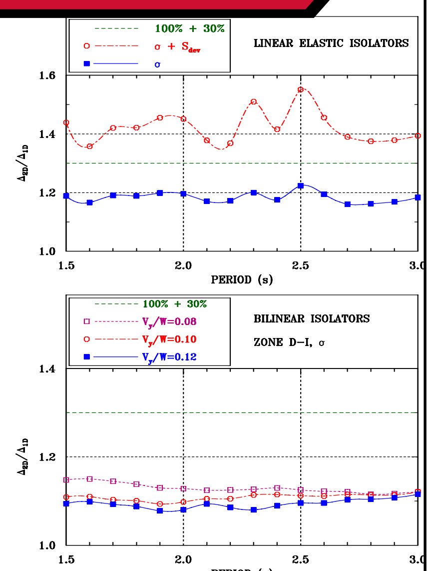
$$D = \left(\frac{T_I}{2\pi}\right)^2 \frac{S_a}{B_\zeta}$$

$$B_\zeta = \frac{a_{1_{\zeta 5}} - a_{2_{\zeta 5}} T_I}{a_{1_{\zeta I}} - a_{2_{\zeta I}} T_I}$$



Directional Effects

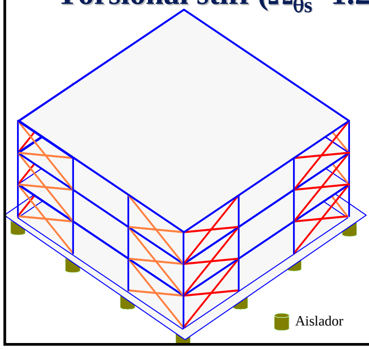




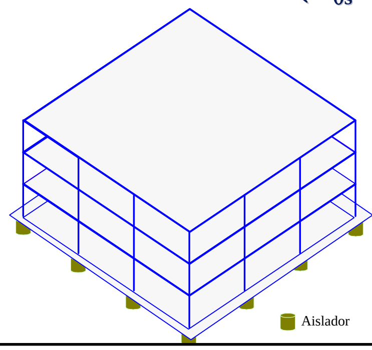
Torsional Effects

- Unidirectional and bidirectional eccentricities (mass and stiffness) in the superstructure.
- Unidirectional and bidirectional stiffness eccentricities in the isolation system.
- T_I/T_s= 1.25, 2, 3, 8 $\qquad \Omega_{\theta s}$=0.8, 1.2

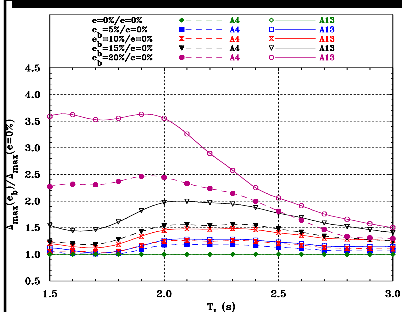
Torsional stiff ($\Omega_{\theta s}$=1.2)



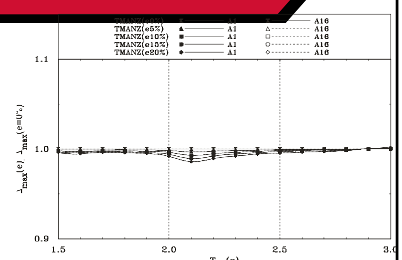
Torsional flexible ($\Omega_{\theta s}$=0.8)



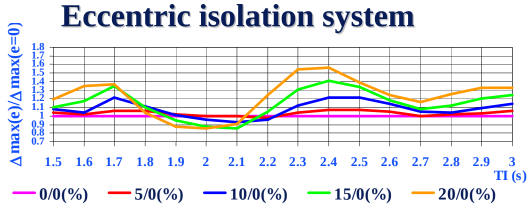
Torsional Effects (T_I/T_s=8, $\Omega_{\theta s}$=1.2, TMANZ)



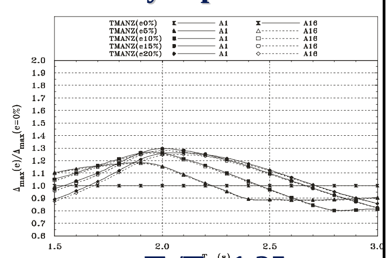
Eccentric isolation system



Stiffness eccentricity superstructure

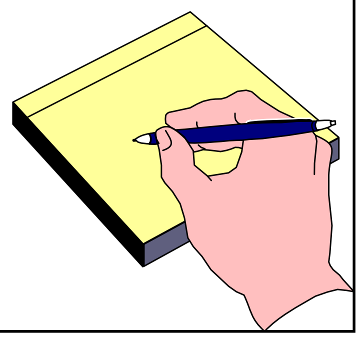


Mass eccentricity superstructure



T_I/T_s=1.25

Applications



Applications, Base Isolation

Table 1 Base isolation projects built in Mexico

Project Name	*Type*	*Isolation System*	*Place*	*Year*
Legaria Secondary School	Building (N)	Rollers by González-Flores	Mexico City	1974
Legaria Church	Building (N)	Rollers by González-Flores	Mexico City	1980
Hidalgo-San Rafael Bridge	Bridge (N)	LRB	Mexico-Querétaro Highway	1994
Printing press of the Reforma Newspaper	Machinery-Equipment (N)	GT-BIS	Mexico City	1994
Mural Newspaper	Building (N)	GT-BIS	Guadalajara	1998
Infiernillo II Dam Bridge	Bridge (N)	Multi-rotational sliding bearings	Infiernillo Dam, Michoacán	2002
Acueducto Patria	Bridge (N)	LRB	Guadalajara	2006
Tijuana Urban Bridge	Bridge (N)	LRB	Tijuana	2006

Analytical, Base Isolation

- **Studies for existing applications**
  - **Sosa and Ruiz (1992) presented an analytical study for the school building in Mexico City isolated with the rolling base-isolation device proposed by Gonzalez-Flores.**

http://nisee.berkeley.edu/visual_resources/steinbrugge_collection.html

Analytical, Base Isolation

- **Studies for existing applications**
  - Garza-Tamez and Foutch (1994) described the isolation of the floor slab supporting the printing press of the Reforma Newspaper in Mexico City, located in near-firm soil conditions (T_I= 6 s).
  - Silva and Garza-Tamez (2004) presented the acceleration records obtained during the June 15, 1999 Tehuacán earthquake (M=6.5).

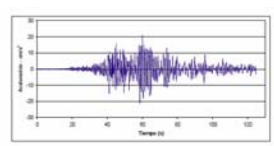


Figura 15. Acelerograma registrado en el suelo firme bajo la nave de prensa aislada del periódico REFORMA.

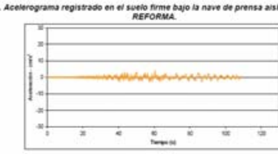
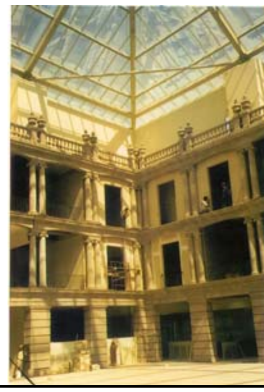
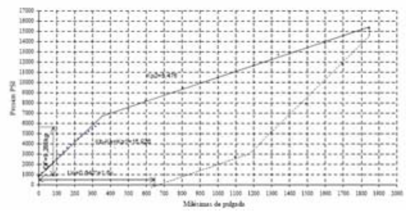


Figura 16. Acelerograma registrado en la estructura aislada del periódico REFORMA.

Analytical, Base Isolation

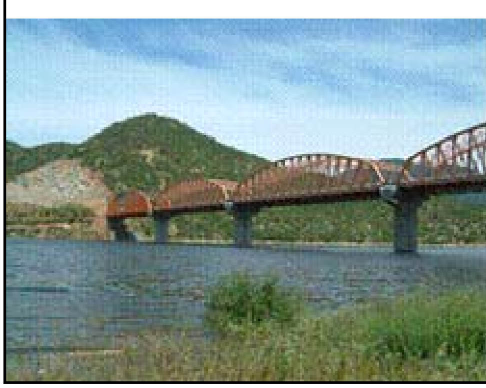
- **Studies for existing applications**
  - Garza-Tamez and Silva (1999) presented the design of the GT-BIS isolation system for the press building of the Mural Newspaper in Guadalajara, the first application of the GT-BIS system to isolate a building structure. The design was checked with a *in-situ* pushover test described in Silva and Garza-Tamez (2004)

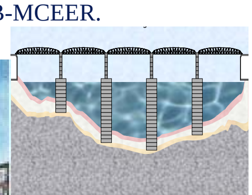




Analytical, Base Isolation

- **Studies for existing applications**
  - Gómez-Martínez *et al.* (2001-2003) presented the research study conducted to implement base isolators in one of the truss bridges that cross Infiernillo Dam in Michoacán State. The device used to isolate Infiernillo Dam Bridge II was a multi-rotational sliding bearing tested at UB-MCEER.





Applications, Energy Dissipation

Table 2 Passive energy dissipation projects built in Mexico

Building Name	*Type & Number*	*Device*	*Place*	*Year*
Izazaga 38-40	Retrofit (1)	ADAS	Mexico City	1989
Cardiology Hospital	Retrofit (1)	ADAS	Mexico City	1990
20 de Noviembre Hospital	Retrofit (5)	SBC (Slotted Bolted Connections)	Mexico City	1992-1994
IMSS Headquarters (Reforma 476)	Retrofit (3)	ADAS	Mexico City	1993-1997
3M Headquarters	New (1)	Viscoelastic Dampers (VED)	Mexico City	1996-1997
TMM Warehouse	New (3)	ADAS	Acapulco	1997
SAGAR	Retrofit (1)	DV	Mexico City	1999
La Jolla	New (3)	ADAS	Acapulco	1999
Torre Monterrey	Retrofit (1)	ADAS	Mexico City	2002
Torre Mayor	New (1)	Taylor	Mexico City	2003
Córdoba	Retrofit (1)	ADAS	Mexico City	2004
Romanza	New (1)	ADAS	Acapulco	2005
Nautilus	New (1)	ADAS	Acapulco	2005
Fray Servando	Retrofit (1)	Taylor	Mexico City	2005
Mar Azul	New (1)	ADAS	Acapulco	2006
Total of buildings	25			

Applications, Energy Dissipation

- **Retrofit of Cardiology Hospital with ADAS devices, Mexico City**

Applications, Energy Dissipation

- Retrofit of 20 de Noviembre Hospital with Slotted Bolted Connections (SBC), Mexico City

Applications, Energy Dissipation

- Retrofit of IMSS Headquarters with ADAS devices, Mexico City

Applications, Energy Dissipation

- 3M Headquarters with Viscoelastic dampers, Mexico City



Applications, Energy Dissipation

- Retrofit of SAGAR building with DV devices, Mexico City



Applications, Energy Dissipation

- 19 La Jolla Apartments at Acapulco with ADAS devices

Applications, Energy Dissipation

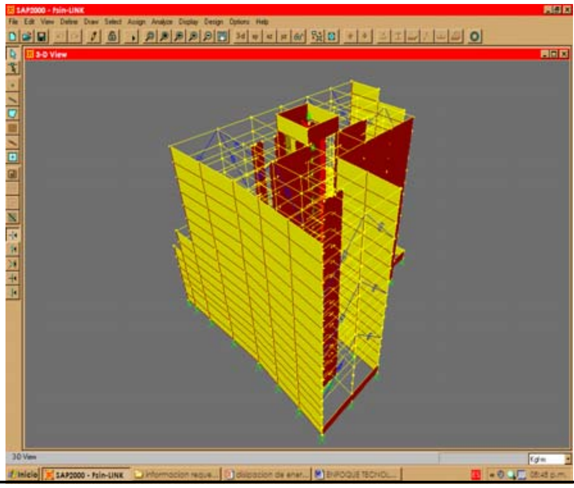
- Retrofit of Torre Monterrey with ADAS devices, Mexico City

Applications, Energy Dissipation

- Torre Mayor, Taylor dampers, Mexico City

Applications, Energy Dissipation

- Retrofit of Fray Servando building with Taylor dampers, Mexico City



Applications, Energy Dissipation

- Residencial Mar Azul, Acapulco

Concluding Remarks

- Mexico has already an important research experience in passive energy dissipation and seismic isolation.
- However, the number of applications is relatively small for the size of the country and the knowledge that Mexican structural engineers already have in this area.

Concluding Remarks

- As in many other countries, it seems that the absence of an official building code that addresses completely the design of base-isolation and energy dissipation brakes potential applications.
- There are already complete guidelines available (Ruiz 2002, Tena-Colunga 2004, 2005), but they are not yet included in the most important building codes, such as Mexico’s Federal District Code (RCDF) or the Manual of Civil Structures (MOC).

Concluding Remarks

- The updated version for the Manual of Civil Structures (MOC) will include specific guidelines for the design of structures with passive energy dissipation devices and base isolation. This updated version is in progress and is scheduled to be presented in 2008.
- It is hoped that the updated version for MOC will help trigger applications of passive energy dissipation within the country.