Curso de Diseño de Estructuras Sismorresistentes

Quinta Parte

Análisis y Diseño Simplificado de Edificios Basado en Desplazamientos

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STANFORD UNIVERSITY

OBJETIVOS DE ESTA PARTE DEL CURSO

1. Hacer un breve de observaciones de efectos de sitio, con énfasis en suelos muy blandos como los de la zona blanda de la ciudad de México o de la ciudad de Guayaquil;
2. Presentar la enorme diferencia en formas espectrales de movimientos registrados en suelo blando;
3. Presentar factores de reducción para estructuras cimentadas en suelo blando;
4. Presentar cocientes de desplazamientos inelásticos a elásticos para estructuras cimentadas en suelo blando.

Ejemplos de Documentación de Efectos de las Condiciones del Suelo en el Nivel de Daño

- MacMurdo noted that during the ***1819 Runn of Cutch, India earthquak***e buildings on soil were more affected than those on rock
- The effect of soil conditions on the intensity of ground motions was also presented by Wood in 1908 in his study of the distribution of damage and apparent intensity of shaking during the ***1906 San Francisco earthquake***.
- Multiple authors noted important effects of soil conditions on building and pipeline performance in the ***1923 Kanto earthquake in Japan***.

Ejemplo de Estudio Análitico de Efectos de Suelo Blando

4. Relation between the Nature of Surface Layer and the Amplitudes of Earthquake Motions.

By Kiyoshi KANAI,

Earthquake Research Institute.

(Read Dec. 18, 1951.—Received Dec. 20, 1951.)

$$\rho_n \frac{\partial^2 u_n}{\partial t^2} = \left(\mu_n + \xi_n \frac{\partial}{\partial t}\right) \frac{\partial^2 u_n}{\partial z^2} \cdot [n=1, 2, 3]$$

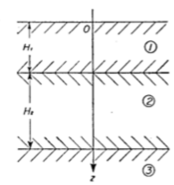


Fig. 1.

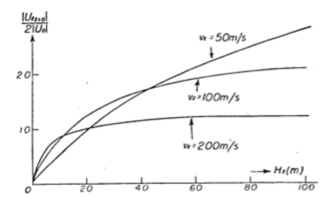


Fig. 2. The case of $\xi_2 = 10^6$ C.G.S., $\rho_2 = 1.5$, $\rho_3 = 2.25$, $v_3 = 1.7$ km/sec, $p = 2\pi/T = 2\pi/(4H_2/v_2)$.

27 de Julio de 1957

http://simerida.com/img/Angel%20de%20la%20independencia%2001.gif

27 de Julio de 1957

(Source: Steinbrugge collection, NISEE, UC Berkeley)

Primera evidencia instrumental de los efectos de sitio

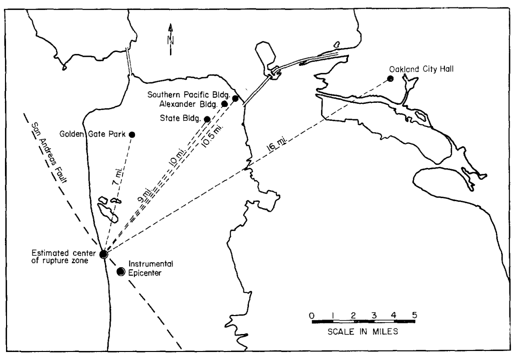


Fig. 1. Location of U.S.C.G.S. strong motion accelerometer stations relative to San Andreas Fault—San Francisco earthquake of March 22, 1957.

(After Idriss and Seed, 1968)

Primera evidencia instrumental de los efectos de sitio

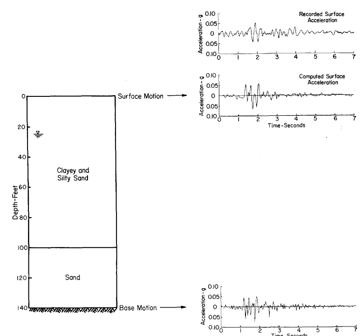


Fig. 9. Recorded and computed surface accelerations—Alexander Building site.

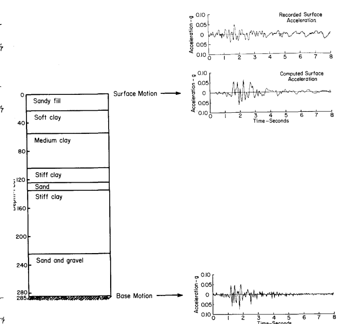


Fig. 12. Recorded and computed surface accelerations—Southern Pacific Building site.

(After Idriss and Seed, 1968)

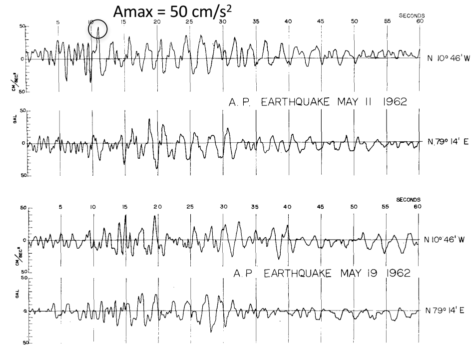
Sismos de Mayo de 1962

APPENDIX 1—INSTRUMENTAL CHARACTERISTICS OF THE FOUR EARTHQUAKES STUDIED

Date (Mexico City)	Coordinates of the Epicenter	Distance of the Epicenter to the Accelerograph	Focal Depth	Modified Mercalli Intensity	Magnitude	Reference
December 10, 1961	20.1°N 99.1°W	80 km	15 km	4–5	5	Figueroa (1963)
May 11, 1962	16.6°N 99.4°W	330 km	30 km	6–7	6.7	Figueroa (1963)
	17.0°N 99.7°W	—	25 km	—	7–7¼	USCGS (1962)
May 19, 1962	17.3°N 99.4°W	240 km	30 km	6	6.5	Figueroa (1963)
	17.2°N 99.5°W	—	20 km	—	7–7¼	USCGS (1962)
November 30, 1962	17.3°N 99.4°W	250 km	25 km	4–5	5½	Figueroa (1963)
	17.4°N 99.6°W	—	51 km	—	5¼–5½	USCGS (1963)

(After Bustamante, 1964)

Sismos de Mayo de 1962

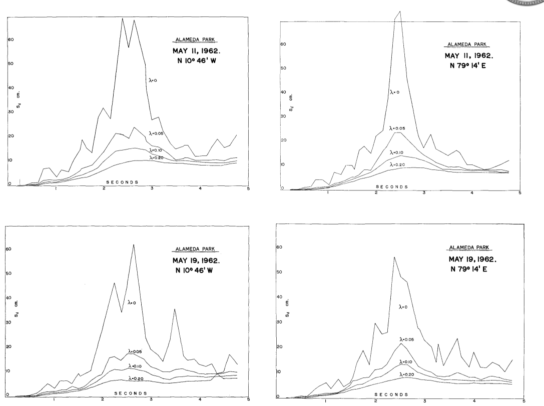


(After Zeevaert, 1964)

Sismos de Mayo de 1962

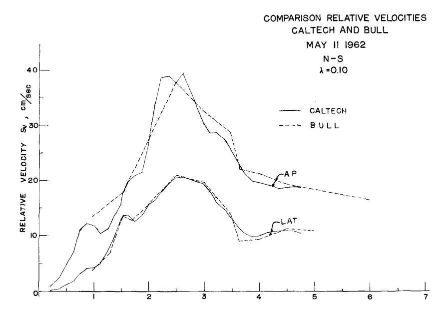
Mayo 11, 1962
M6.7
330 km

Mayo 19, 1962
M6.5
240 km



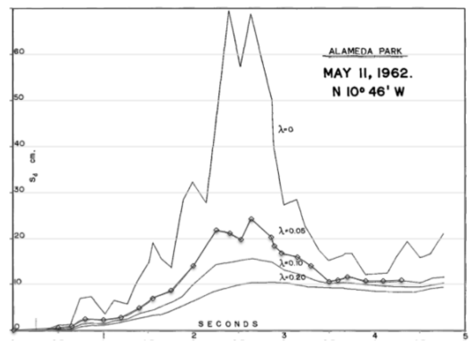
(After Zeevaert, 1964)

Sismos de Mayo de 1962



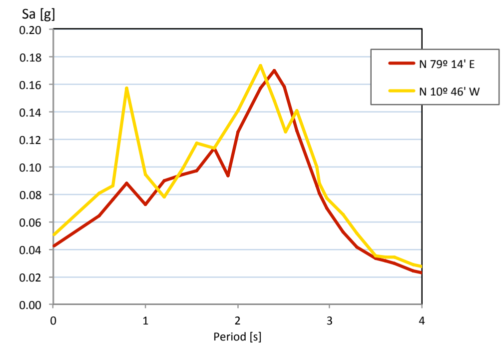
"The spectrum amplitudes of the AP accelerograms were found to be consistently larger than those of the LAT site only 600 meters distant." (After Zeevaert, 1964)

Sismos de Mayo de 1962

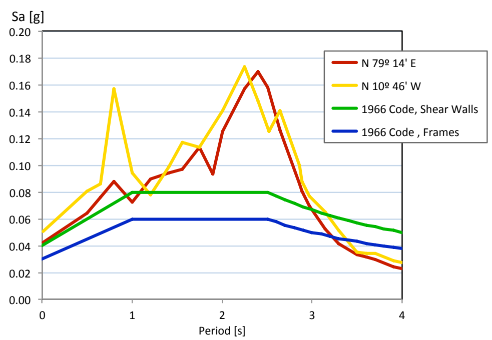


(After Zeevaert, 1964)

Sismos de Mayo de 1962

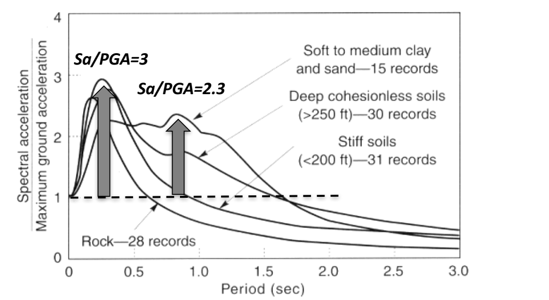


Espectros del sismo del 11 de Mayo de 1962 en la Alameda vs espectros de diseño de 1966



(After Zeevaert, 1964)

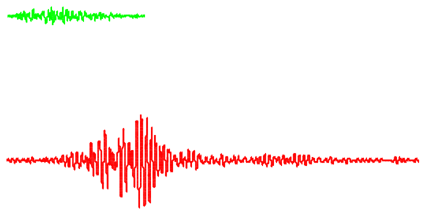
Estado del Arte sobre efectos de sitio a finales de los 70's y principios de los 80's



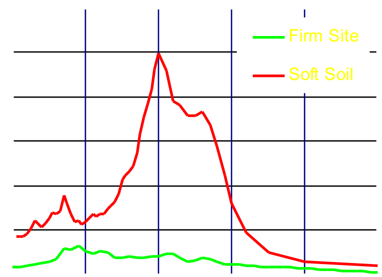
(After Seed et al. 1976)

Dichos estudios no reflejaban las características de los espectros de respuesta calculados a partir de registros de suelo blando!!!

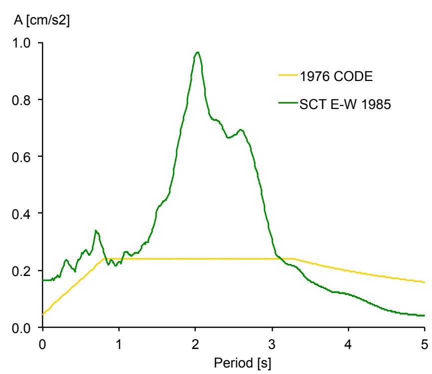
1985 Mexico City:



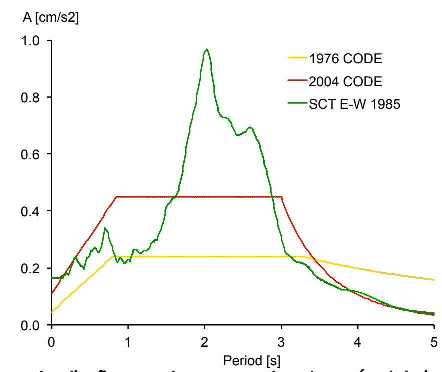
1985 Mexico City:



Espectro de Respuesta SCT-EW-85 vs Espectro de Diseño



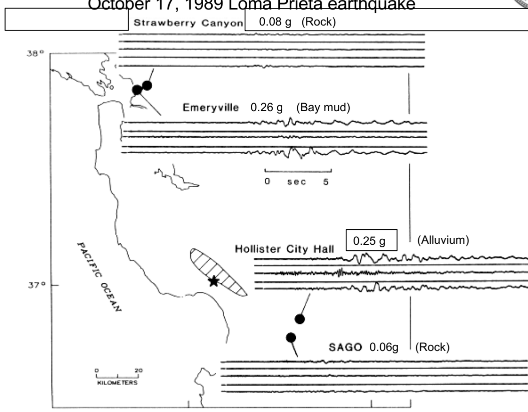
Espectro de Respuesta SCT-EW-85 vs Espectro de Diseño



Los espectros de diseño, aun los propuestos después del sismo, tampoco reflejaban las características de los espectros de respuesta calculados a partir de registros de suelo blando!!!

EFFECT OF SITE CONDITIONS

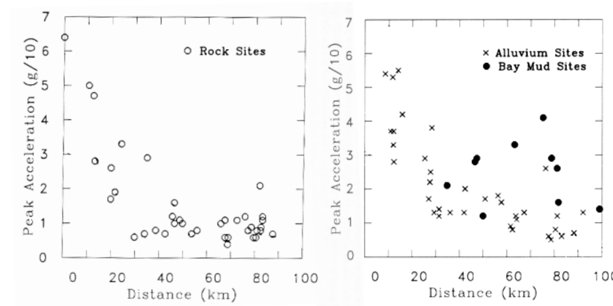
October 17, 1989 Loma Prieta earthquake



(Modified from Boore et al. 1990)

EFFECT OF SITE CONDITIONS

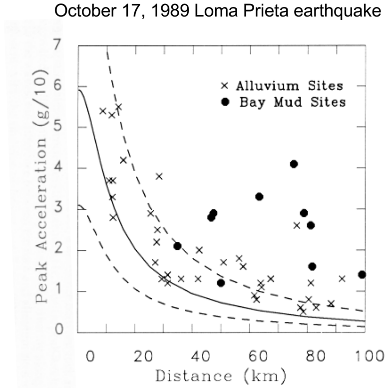
October 17, 1989 Loma Prieta earthquake



(Modified from Boore et al. 1990)

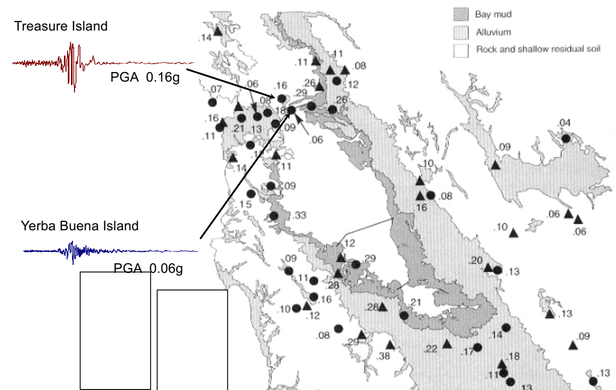
EFFECT OF SITE CONDITIONS

October 17, 1989 Loma Prieta earthquake



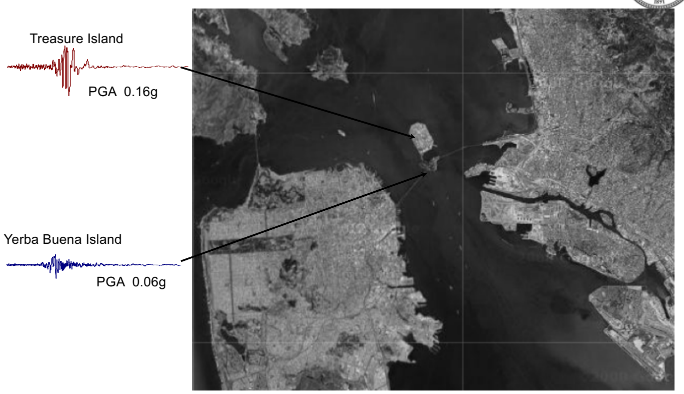
(After Boore et al. 1990)

EFFECT OF SITE CONDITIONS

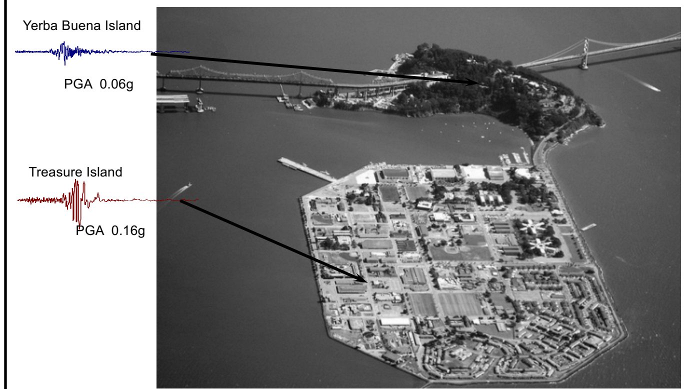


(After Seed et al, 1990)
(After Kramer, 1996)

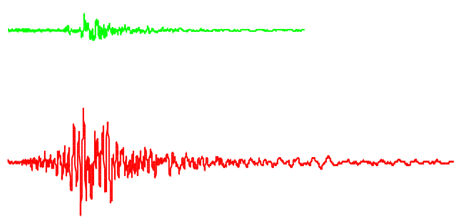
EFFECT OF SITE CONDITIONS



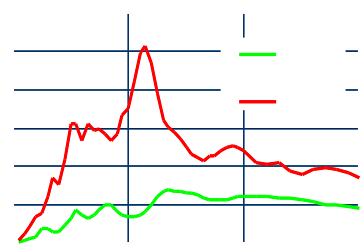
EFFECT OF SITE CONDITIONS

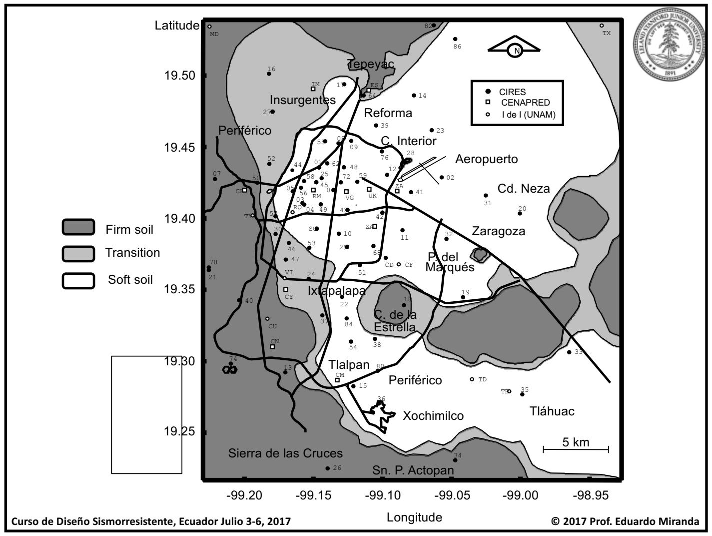


1989 Bay Area:



1989 Bay Area:




Latitude
19.50
19.45
19.40
19.35
19.30
19.25
Firm soil
Transition
Soft soil
CIRES
CENAPRED
I de I (UNAM)
Tepeyac
Insurgentes
Reforma
Periférico
C. Interior
Aeropuerto
Cd. Neza
Zaragoza
P. del Marqués
Ixtapalapa
C. de la Estrella
Tlalpan
Periférico
Xochimilco
Tláhuac
Sierra de las Cruces
Sn. P. Actopan
5 km
-99.20
-99.15
-99.10
-99.05
-99.00
-98.95
Longitude
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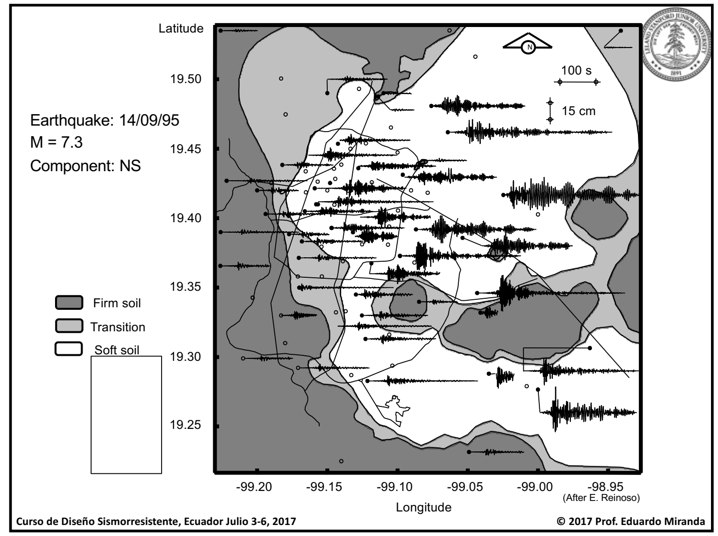
Latitude
Earthquake: 14/09/95
M = 7.3
Component: NS
19.50
19.45
19.40
19.35
19.30
19.25
100 s
15 cm
Firm soil
Transition
Soft soil
-99.20
-99.15
-99.10
-99.05
-99.00
-98.95
(After E. Reinoso)
Longitude
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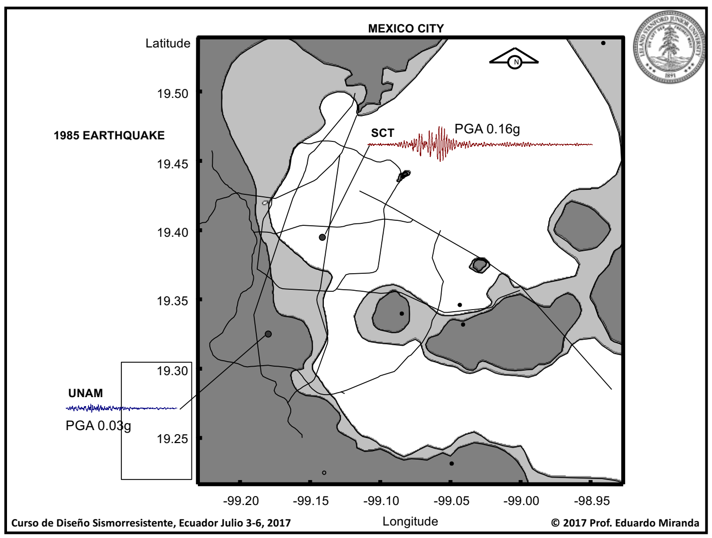
MEXICO CITY
Latitude
19.50
1985 EARTHQUAKE
19.45
19.40
19.35
19.30
19.25
SCT
PGA 0.16g
UNAM
PGA 0.03g
-99.20
-99.15
-99.10
-99.05
-99.00
-98.95
Longitude
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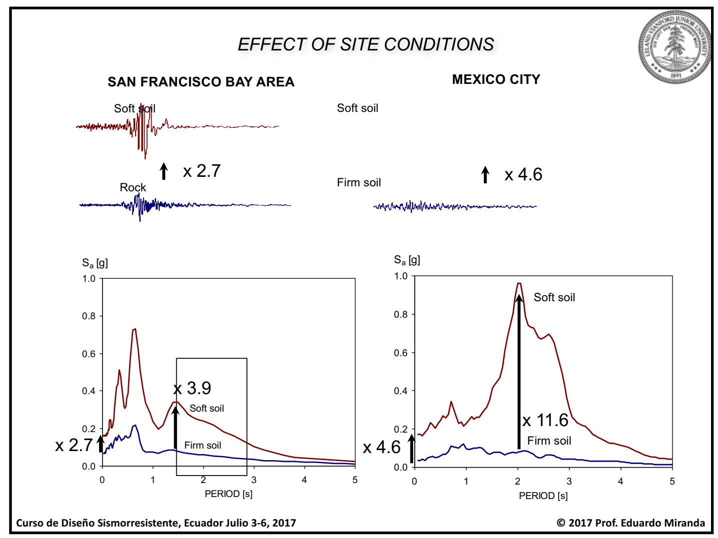
EFFECT OF SITE CONDITIONS
SAN FRANCISCO BAY AREA
MEXICO CITY
Soft soil
x 2.7
Rock
Soft soil
x 4.6
Firm soil
Sa [g]
x 3.9
Soft soil
Firm soil
x 2.7
PERIOD [s]
Sa [g]
Soft soil
x 11.6
Firm soil
x 4.6
PERIOD [s]
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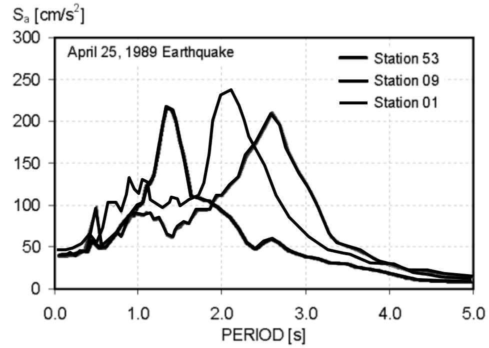
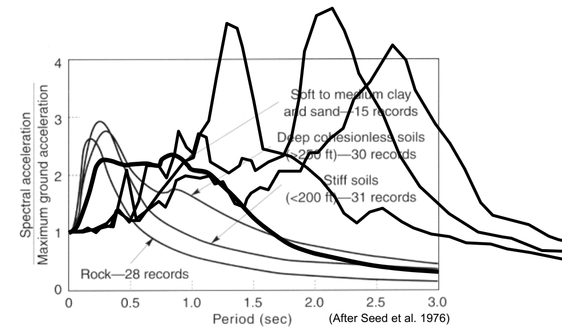
Variaciones en espectros de respuesta en zona de lago

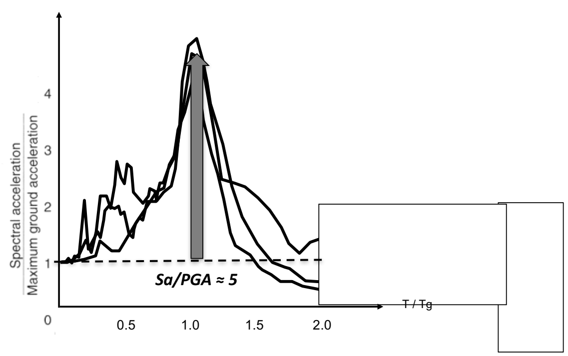
Elastic response spectra at three soft sites in Mexico City



Comparación con las recomendaciones de Seed et al. para el diseño de estructuras en suelos blandos

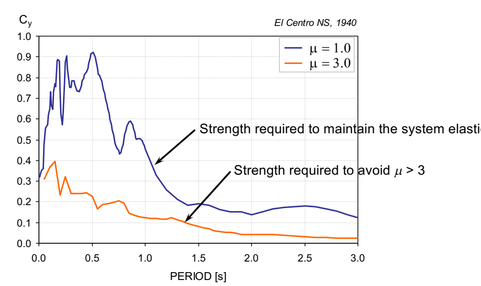


Propuesta de binormalización espectral



INELASTIC STRENGTH SPECTRA

Inelastic spectra, by definition, are smaller than their elastic counterpart.



Estimación de fuerzas laterales con fines de diseño

Con fines de diseño, podemos estimar ordenadas espectrales no lineales a partir de factores de reducción Q' (R en muchos otros países)

$$F_y = \frac{S_a}{R} W$$

$$F_y = \frac{S_a}{Q'} W$$

Espectros no lineales calculados de registros de suelos blandos

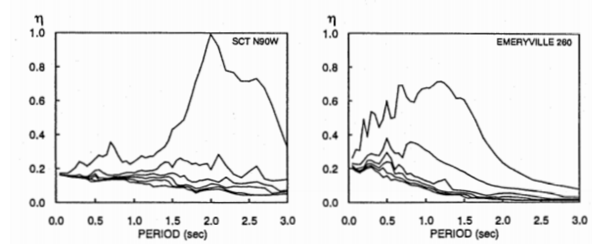


FIGURE 1. Normalized inelastic strength demands (μ=1,2,3,4,5,6).

Factor de Reducción de Resistencia

El factor de reducción por comportamiento no lineal (Q' o R) se define como el cociente de la resistencia lateral necesaria para permanecer en intervalo elástico entre la resistencia lateral necesaria para controlar la demanda de ductilidad a un cierto nivel.

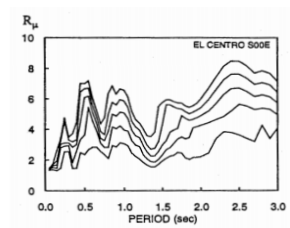
$$Q' = R_\mu = \frac{F_y(\mu = 1)}{F_y(\mu = \mu_t)}$$

O bien

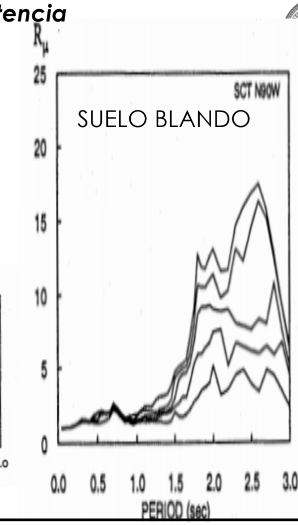
$$Q' = R_\mu = \frac{C_y(\mu = 1)}{C_y(\mu = \mu_t)}$$

Factor de Reducción de Resistencia

SUELO FIRME

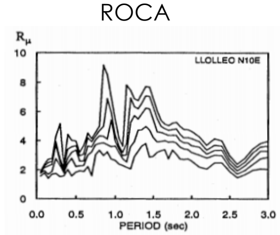


SUELO BLANDO

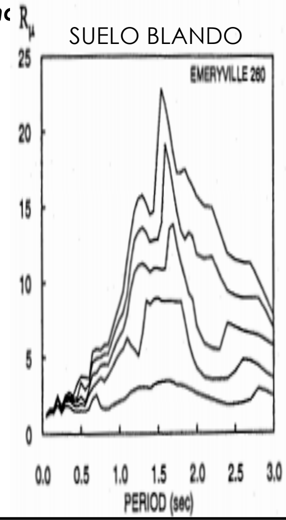


Factor de Reducción de Resistenc

ROCA



SUELO BLANDO



Una observación importante:

Obtener una buena estimación del espectro de respuesta elástico NO ES SUFICIENTE CON FINES DE DISEÑO SISMORRESISTENTE para estructuras cimentadas en suelos muy blandos

Mi primera propuesta de investigación ☺

SMIP91 Seminar Proceedings

EVALUATION OF STRUCTURAL RESPONSE FACTORS USING GROUND MOTIONS RECORDED DURING THE LOMA PRIETA EARTHQUAKE

Eduardo Miranda
Research Engineer, Earthquake Engineering Research Center
University of California at Berkeley

Vitelmo V. Bertero
Professor, Earthquake Engineering Research Center
University of California at Berkeley

ABSTRACT

Present procedures of defining seismic design forces are based on the use of elastic spectra reduced by a response modification factor which only depends on the type of structural system. This paper summarizes the results of an analytical study concerning strength reduction factors. Strength demand and strength reduction spectra were computed using simplified elastic and inelastic bilinear SDOF structural models and 36 ground motions recorded during the 1989 Loma Prieta earthquake. Special emphasis was given to the influence of local site conditions. Results show that strength reduction factors are significantly affected by the level of inelastic deformation, the period of vibration and by local site conditions.

Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Suelos Blandos

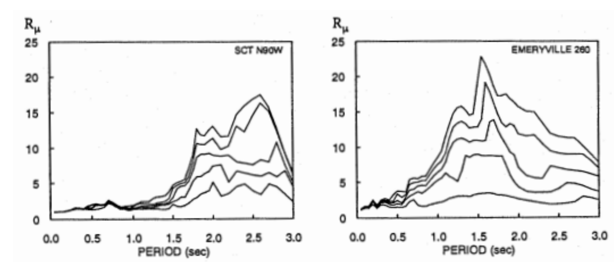
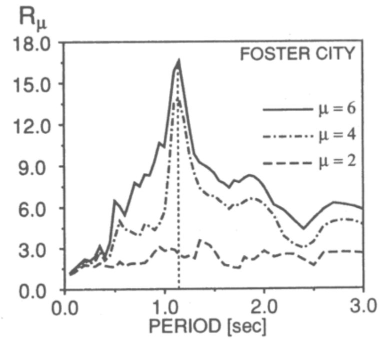


FIGURE 2. Strength reduction factors (μ=6,5,4,3,2).

Podíamos aprender y usar resultados de la Cd de México para la Región de la Bahía de SF y viceversa !!!

Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Suelos Blandos



Mi tercer artículo en una revista arbitrada ☺

SITE-DEPENDENT STRENGTH-REDUCTION FACTORS

By Eduardo Miranda[1]

ABSTRACT: Strength-reduction factors that are used to reduce linear elastic design spectra to account for the hysteretic energy dissipation of the structure are evaluated. The paper presents a summary of results of a statistical analysis of strength-reduction factors computed for single-degree-of-freedom systems undergoing different levels of inelastic deformation when subjected to a relatively large number of recorded earthquake ground motions. Special emphasis is given to the influence of soil conditions. Results indicate that for a given displacement ductility demand, the use of period-independent reduction factors is inadequate. Soil conditions can have an important effect on strength-reduction factors, particularly in the case of soft-soil sites. It is recommended that strength-reduction factors to be used in design be specified as a function of the period and inelastic capacity of the structure, and of at least two types of soil conditions—one for rock and relatively firm sites and another for soft-soil sites. Following these recommendations, simplified expressions to compute strength-reduction factors are proposed.

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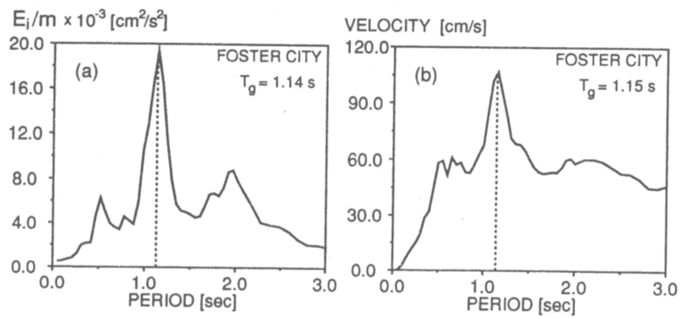
Periodo Predominante del Movimiento de Terreno, T_g



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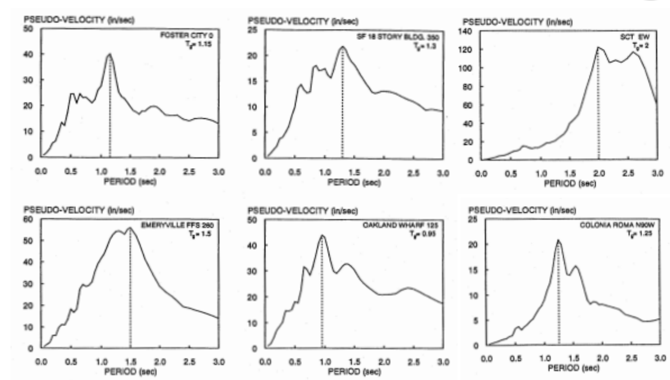
Periodo Predominante del Movimiento de Terreno, T_g



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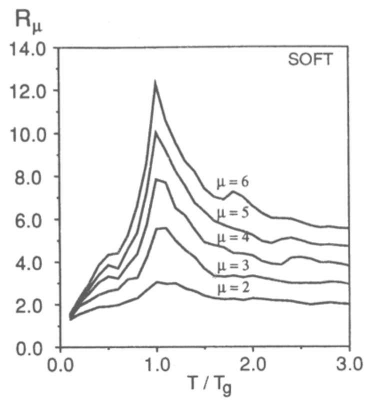
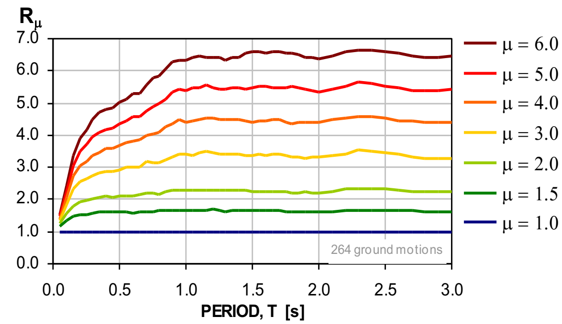
Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Suelos Blandos en Función de T/T_g



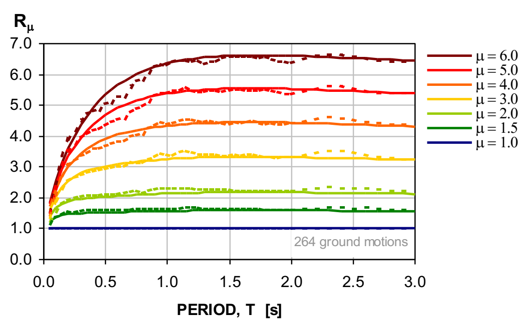
Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

STATISTICAL RESULTS ON STRENGTH REDUCTION FACTORS



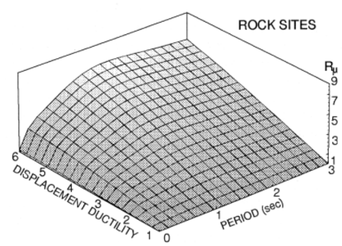
Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

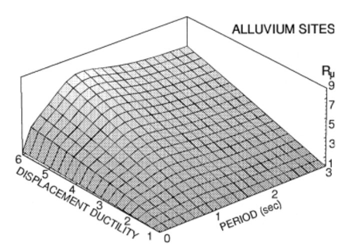
STATISTICAL RESULTS ON STRENGTH REDUCTION FACTORS



Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

Miranda 1991





Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Suelos Blandos en Función de T/T_g

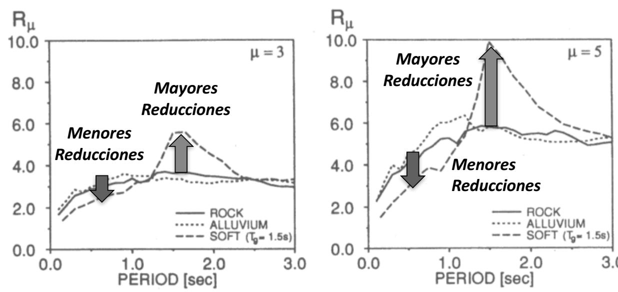
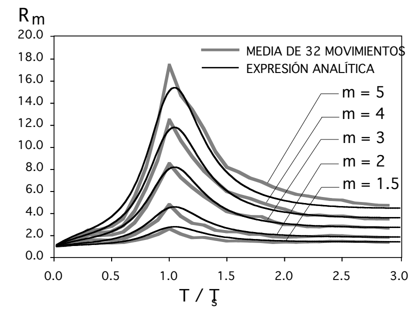


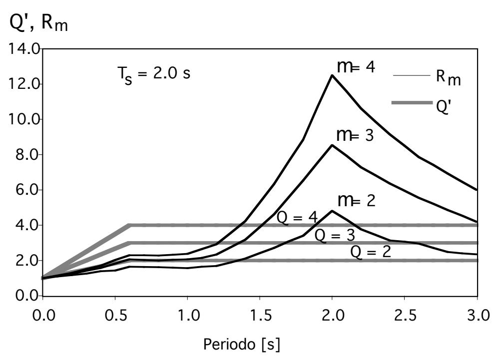
FIG. 9. Influence of Local Site Conditions on Strength-Reduction Factors

Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Suelos Blandos en Función de T/T_g



Factor de Reducción de Resistencia Calculados a Partir de Registros Obtenidos en Suelos Blandos en Función de T/T_g

Comparación con los factores de reducción de los reglamentos de 1976, 1987, 2004 (actual)



Recomendaciones de Factor de Reducción de Resistencia para Estructuras Cimentadas en Suelos Blandos

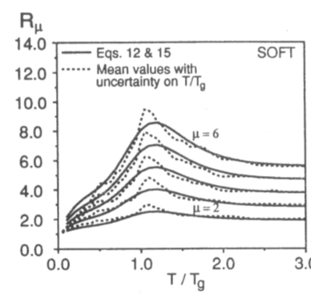
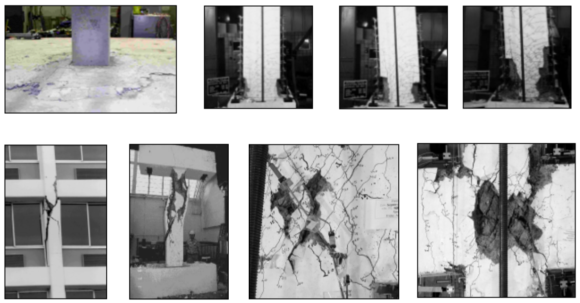


FIG. 14. Mean Strength-Reduction Factors of Soft Soil Sites Considering 10% Error in Estimation of T/T_g Ratio Compared to those Computed Using Eqs. (12) and (15)

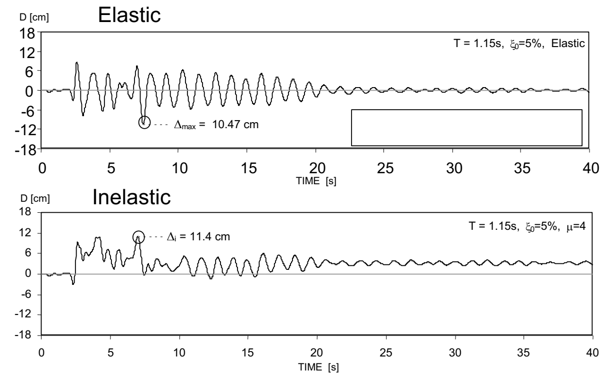
Con $R_\mu(\mu,T/Tg)$ mejoramos nuestra estimación de fuerzas lateral de estucturas en suelo blando



Pero que produce este daño ?

Fuerzas o Deformaciones ?

Demandas de Desplazamiento en Sistemas Elásticos e Inelásticos



$$C = \frac{\Delta_i}{\Delta_e}$$

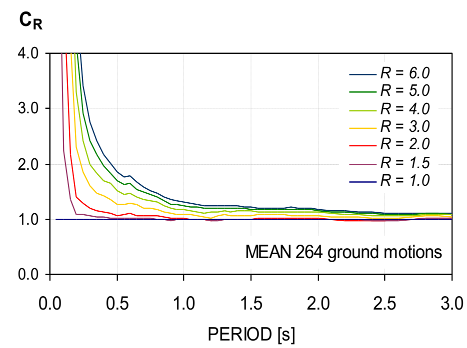
Demandas de Desplazamiento en Sistemas Elásticos e Inelásticos

Si conocemos estos cocientes entonces es posible obtener una estimación de la demanda de desplazamiento en el sistema con comportamiento no lineal a partir de la demanda en el sistema elástico utilizando la siguiente expresión

$$\Delta_i = C_R \cdot \Delta_e = C_R \cdot S_d$$

Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

Mean constant relative strength inelastic displacement ratios:



Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

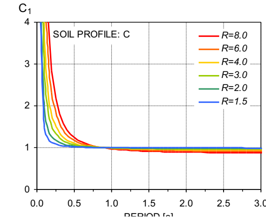
Approximate C_R (Ruiz-Garcia and Miranda 2003)

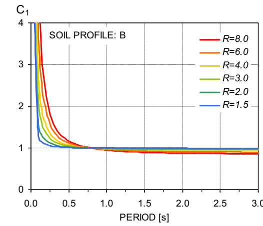
$$C_R = 1 + \left[\frac{1}{a(T/T_s)^b} - \frac{1}{c} \right](R-1)$$

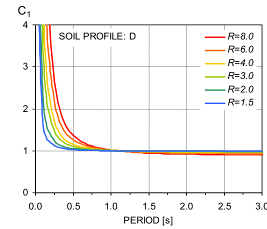
Site class	*a*	*b*	*c*	T_s [s]
B	42	1.60	45	0.75
C	48	1.80	50	0.85
D	57	1.85	60	1.05

Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

Approximate C_R
(Ruiz-Garcia and Miranda 2003)







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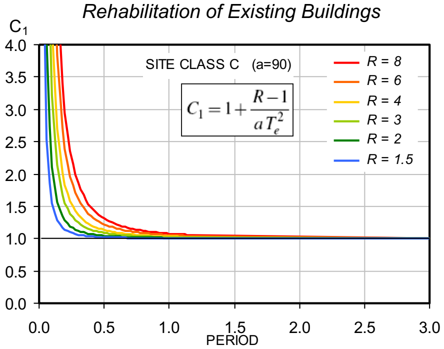
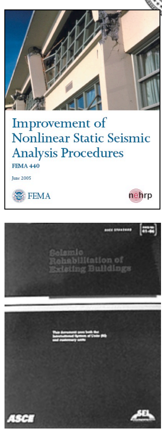
Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

ASCE/SEI 41-06 Standard for *Seismic Rehabilitation of Existing Buildings*





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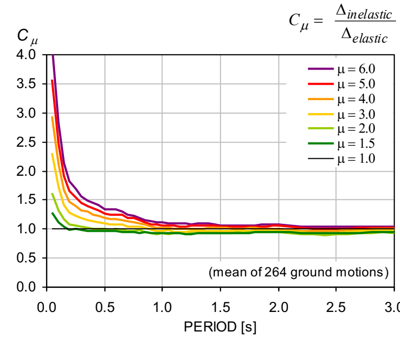
Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme

Mean inelastic displacement ratios:

$$C_\mu = \frac{\Delta_{inelastic}}{\Delta_{elastic}}$$



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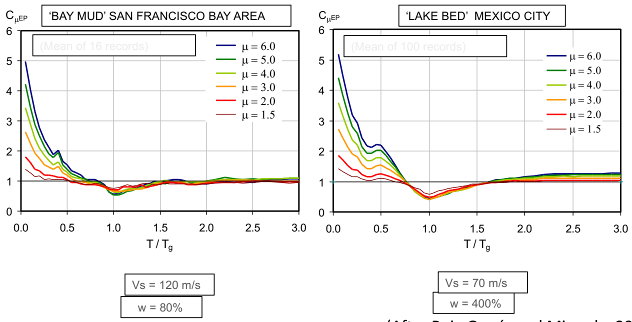
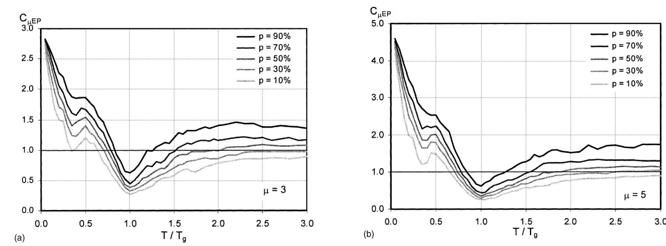
Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Suelo Blando



(After Ruiz-García and Miranda, 2004)

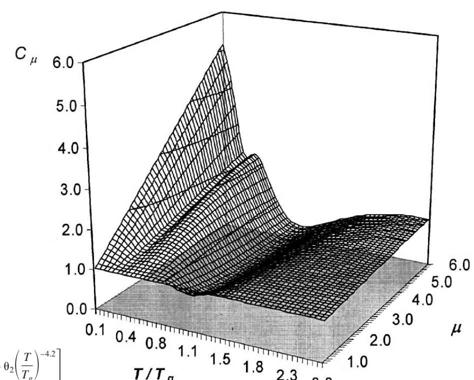
Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Suelo Blando

Cocientes de desplazamientos para diferentes niveles de probabilidad de excendencia



(After Ruiz-García and Miranda, 2004)

Recomendaciones de Diseño para estimar Desplazamientos Laterales de Estructuras en Suelo Blando

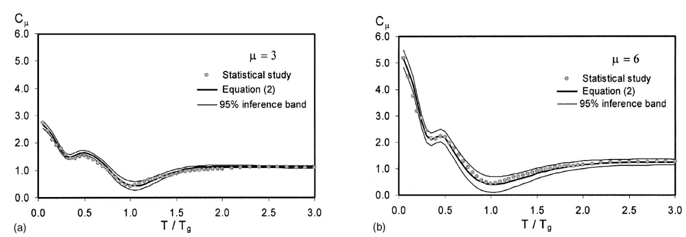


$$\tilde{C}_\mu = 1 + (\mu-1)\left[\theta_1 + \theta_2\left(\frac{T}{T_g}\right)^{-4.2}\right] + \theta_3(\mu-1)^{0.5}\left(\frac{T_g}{T}\right)\exp\left[\left(2.3-\frac{32}{\mu}\right)\left(\ln\left\{\frac{T}{T_g}\right\}-0.1\right)^2\right] - 0.08\left(\frac{T_g}{T}\right)\exp\left[-70\left(\ln\left(\frac{T}{T_g}+0.67\right)\right)^2\right] \quad (2)$$

(After Ruiz-García and Miranda, 2004)

Recomendaciones de Diseño para estimar Desplazamientos Laterales de Estructuras en Suelo Blando

Comparación de Estudios Estadísticos con la Expresión Propuesta



(After Ruiz-García and Miranda, 2004)

Dos Formas de Calcular los Cocientes de Desplazamientos

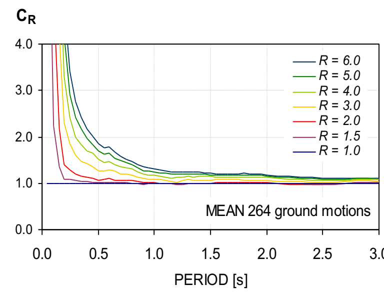
$$C_\mu = \frac{\Delta_i}{\Delta_e} = \frac{\Delta(\mu = \mu_t)}{\Delta(\mu = 1)}$$

Su cálculo requiere de iteración

$$C_R = \frac{\Delta_i}{\Delta_e} = \frac{\Delta(R = R_t)}{\Delta(R = 1)}$$

Su cálculo NO requiere de iteración pero además tienen muchas otras ventajas

Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Roca o Suelo Firme



Inelastic displacement ratios for evaluation of structures built on soft soil sites

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[1] *Graduate School of Civil Engineering, Universidad Michoacana de San Nicolás de Hidalgo, Edificio C, Planta Baja, Cd. Universitaria, 59610 Morelia, México*
[2] *Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305-4020, U.S.A.*

SUMMARY

This paper summarizes the results of a comprehensive statistical study aimed at evaluating peak lateral inelastic displacement demands of structures with known lateral strength and stiffness built on soft soil site conditions. For that purpose, empirical information on inelastic displacement ratios which are defined as the ratio of peak lateral inelastic displacement demands to peak elastic displacement demands are investigated. Inelastic displacement ratios were computed from the response of single-degree-of-freedom systems having 6 levels of relative lateral strength when subjected to 118 earthquake ground motions recorded on bay-mud sites of the San Francisco Bay Area and on soft soil sites located in the former lake-bed zone of Mexico City. Mean inelastic displacement ratios and their corresponding scatter are presented for both ground motion ensembles. The influence of period of vibration normalized by the predominant period of the ground motion, the level of lateral strength, earthquake magnitude, and distance to the source are evaluated and discussed. In addition, the effects of post-yield stiffness and of stiffness and strength degradation on inelastic displacement ratios are also investigated. It is concluded that magnitude and distance to the source have negligible effects on constant-strength inelastic displacement ratios. Results also indicate that weak and stiffness-degrading structures in the short spectral region could experience inelastic displacement demands larger than those corresponding to non-degrading structures. Finally, a simplified equation obtained using regression analyses aimed at estimating mean inelastic displacement ratios is proposed for assisting structural engineers in performance-based assessment of structures built on soft soil sites.

Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Suelo Blando

$$C_R = \frac{\Delta_i}{\Delta_e} = \frac{\Delta(R = R_t)}{\Delta(R = 1)}$$

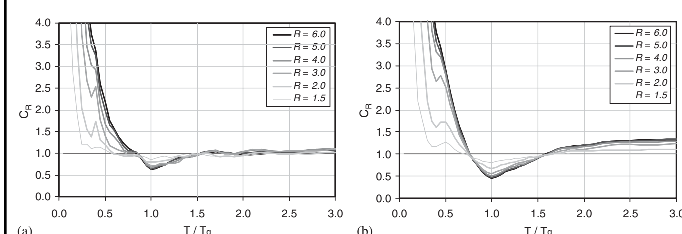


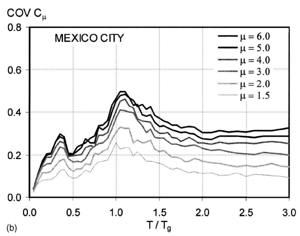
Figure 3. Mean inelastic displacement ratios computed for: (a) the San Francisco Bay Area ground motion set (mean of 18 ground motions); and (b) the Mexico City ground motion set (mean of 100 ground motions).

(After Ruiz-García and Miranda, 2006)

Variabilidad/Dispersión de los Cocientes de Desplazamientos Calculados a Partir de Registros Obtenidos en Suelo Blando

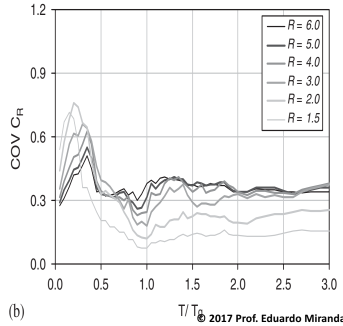
Ductilidad Constante

$$C_\mu = \frac{\Delta_{inelastic}}{\Delta_{elastic}}$$

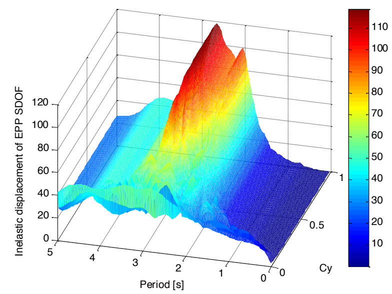


Resistencia Relativa Constante

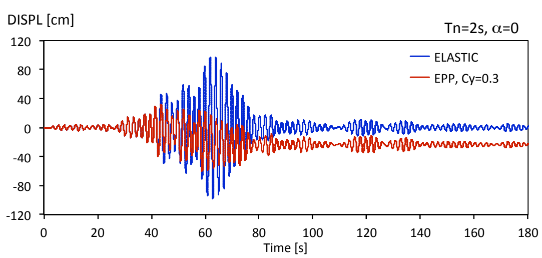
$$C_R = \frac{\Delta_i}{\Delta_e} = \frac{\Delta(R = R_i)}{\Delta(R = 1)}$$



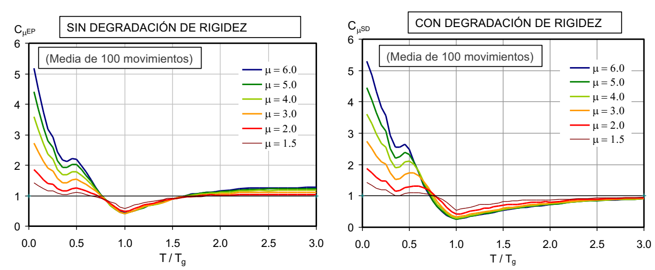
Efecto de la resistencia lateral en las demandas de desplazamiento



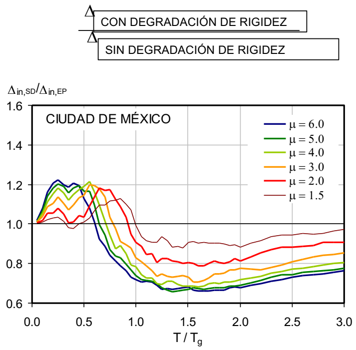
Efecto de la resistencia lateral en las demandas de desplazamiento



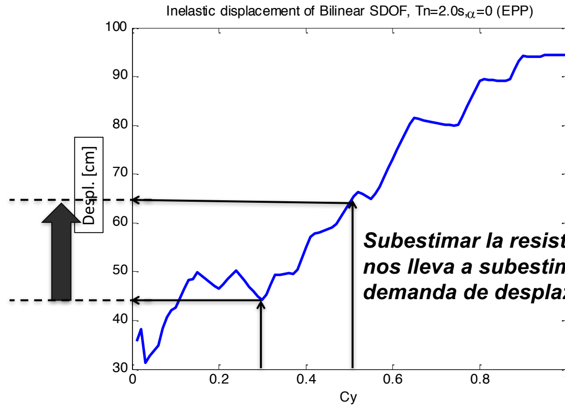
INFLUENCIA DEL COMPORTAMIENTO HISTERÉTICO



INFLUENCIA DEL COMPORTAMIENTO HISTERÉTICO

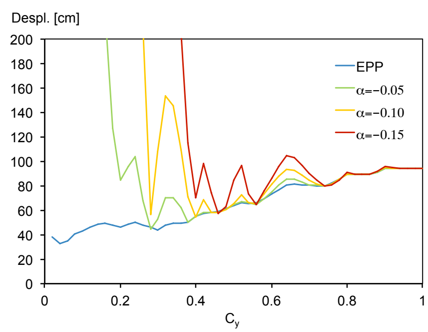


Efecto de la resistencia lateral en las demandas de desplazamiento



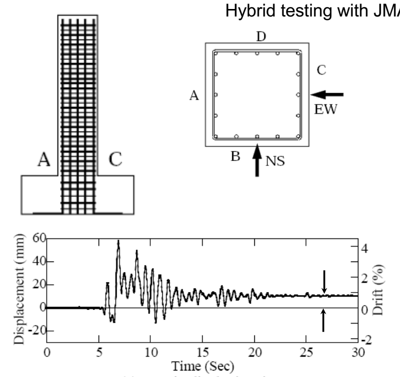
Subestimar la resistencia lateral nos lleva a subestimar la demanda de desplazamiento

Efecto de la resistencia lateral y la rigidez post-elástica en las demandas de desplazamiento



Importancia de las deformaciones residuales

Hybrid testing with JMA record



(a) Longitudinal Direction

(After Nagata, Kawashima, Watabe (2005))

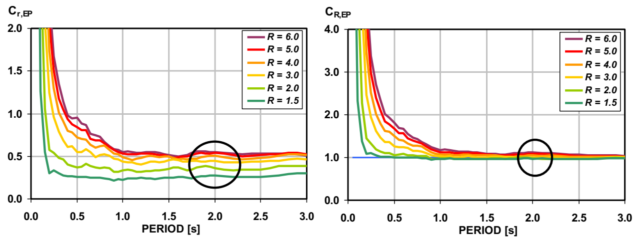
Estimación de las deformaciones residuales

RESIDUAL DISPLACEMENTS

C_r

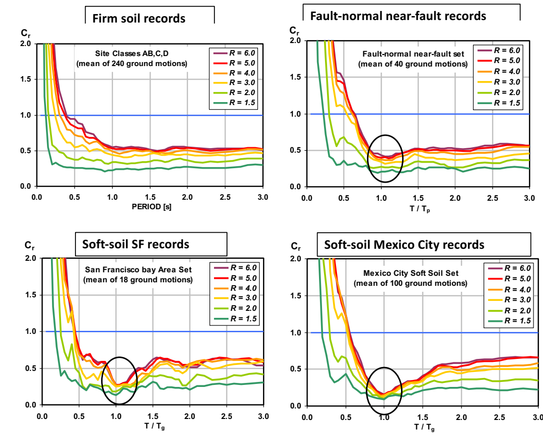
PEAK DISPLACEMENTS

C_R

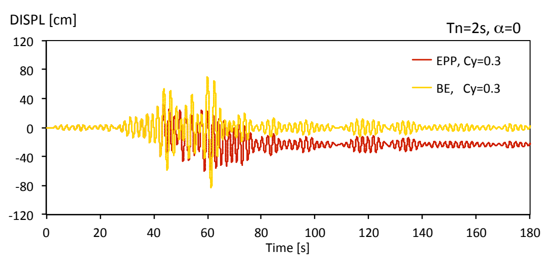


Residual displacement are more sensitive to strength than maximum (peak) displacements

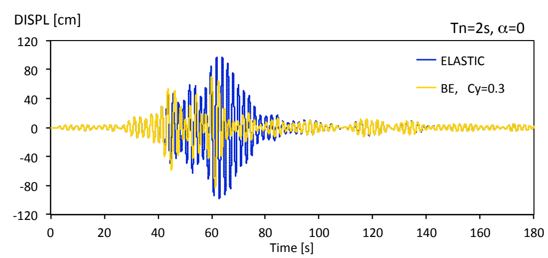
Estimación de las deformaciones residuales



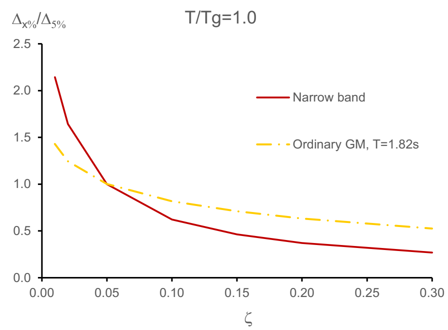
Demandas de desplazamiento en sistemas inelásticos con diferentes comportamientos histeréticos



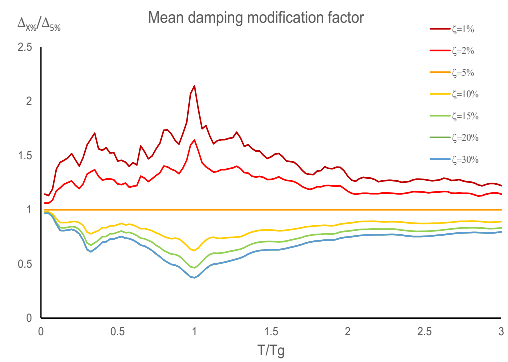
Demandas de desplazamiento en sistemas inelásticos con diferentes comportamientos histeréticos



Efecto del amortiguamiento en las demandas de desplazamiento para estructuras en suelo blando



Efecto del amortiguamiento en las demandas de desplazamiento para estructuras en suelo blando



Resumen y Conclusiones

Les he resumido brevemente los 30 años de aprendizaje de su servidor sobre la respuesta sísmica de estructuras cimentadas en suelos blandos

- Los movimientos de terreno sobre suelos muy blandos es muy diferente a los que ocurren en roca o depósitos de suelo blando
- No sólo los espectros de respuesta son muy diferentes sino muchos otros aspectos del diseño sismorresistente requieren ser modificados

PROF. EDUARDO MIRANDA