FORO INTERNACIONAL DE MICROZONIFICACION SISMICA DE SANTA FE DE BOGOTA

ANALISIS Y SELECCION DE SEÑALES SISMICAS PARA DISEÑO DE ESTRUCTURAS

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MAYO 2006

ESTUDIO DE MICROZONIFICATION SISMICA DE SANTAFE DE BOGOTA

INGEOMINAS Y LA U. DE LOS ANDES EN 1994-1997

ESTABLECIO

- MAPA GEOLOGICO DE LA CIUDAD A ESCALA 1:50.000
- MAPA TECTONICO Y FUENTES SISMICAS PARA DISEÑO EN BOGOTA
- CARACTERIZACION DE LOS MATERIALES IN-SITU
- MAPA DE MICROZONIFICACION SISMICA A ESCALA 1:50.000
- MAPAS DE VULNERABILIDAD SISMICA DE EDIFICACIONES E INFRAESTRUCTURA

SE DEFINIERON 3 FUENTES SISMICAS

1) FUENTE LEJANA - ZONA DE SUBDUCCION
   Ms = 8; DISTANCIA = 400 KM
   ACELEROGRAMA DEL SISMO DE MICHOACAN 9/19/85
   REGISTRO EN LA UNAM

2) SISMO FRONTAL - CORDILLERA ORIENTAL
   M = 7.2 Ms; D = 60 KM
   ACELEROGRAMA SINTETICO BASADO EN EL
   REGISTRO DEL ROSAL - SISMO DE TAURAMENA - 19/1/95
   Ms = 6.5; D = 100 KM

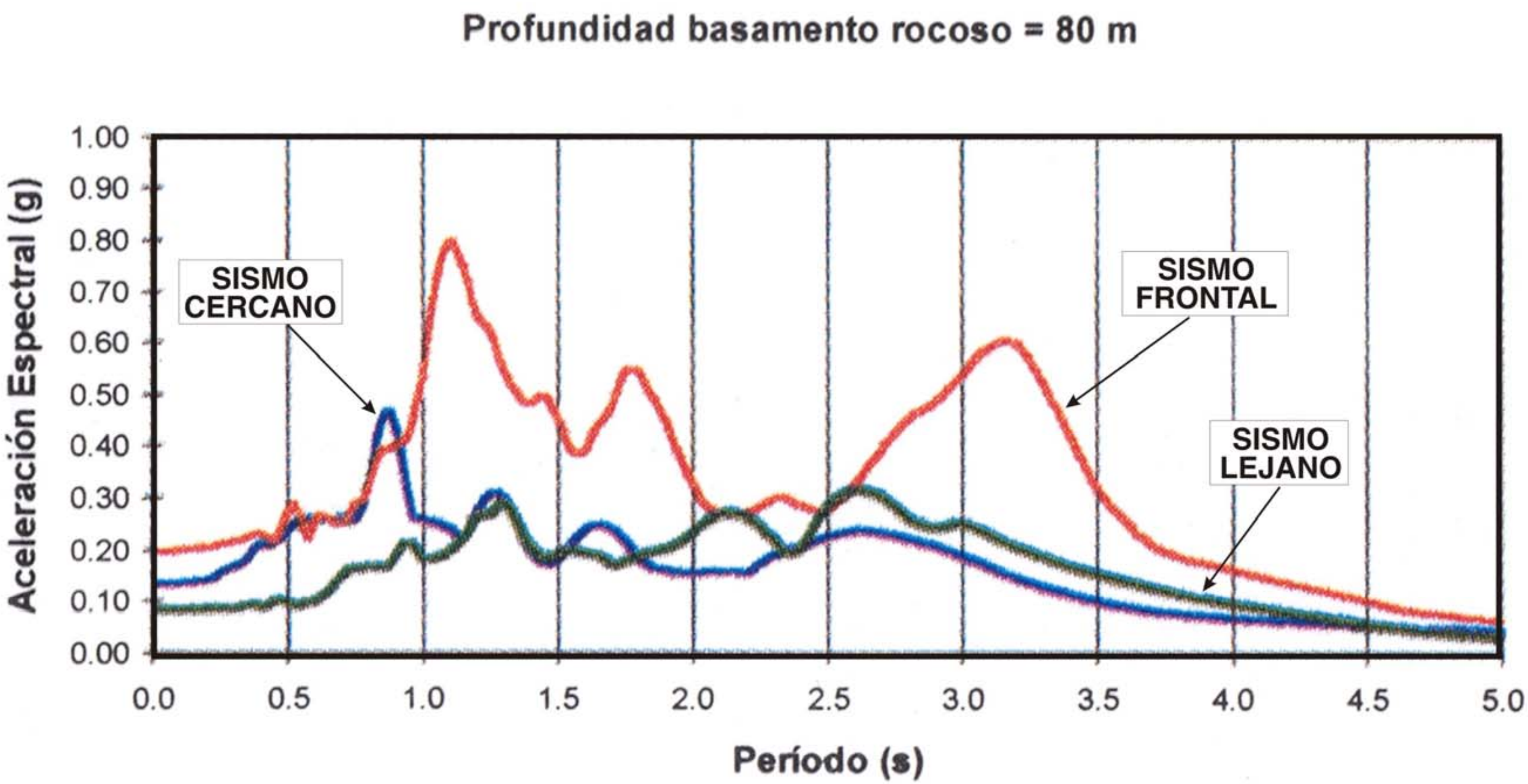
3) FUENTE LOCAL - FALLAS LA CAJITA, MOCHUELO
   ACELEROGRAMA DE CORRALITOS - SISMO DE LOMA PRIETA
   Ms = 7.0 a D = 10 KM; a = 0.6 g
   PARA BOGOTA a = 0.25 g - MISMO CONTENIDO FRECUENCIAL

LAS 3 FUENTES NO TIENEN EL MISMO NIVEL DE AMENAZA NI DE ACTIVIDAD

A) PERIODOS DE RETORNO DIFERENTE

B) UNOS ACELEROGRAMAS REALES
Y OTROS SINTETICOS

C) CERTEZA SOBRE ACTIVIDAD SISMICA
EN CADA FUENTE ES DIFERENTE



ESPECTROS DE RESPUESTA DE LAS FUENTES SISMICAS

LA PROBLEMATICA

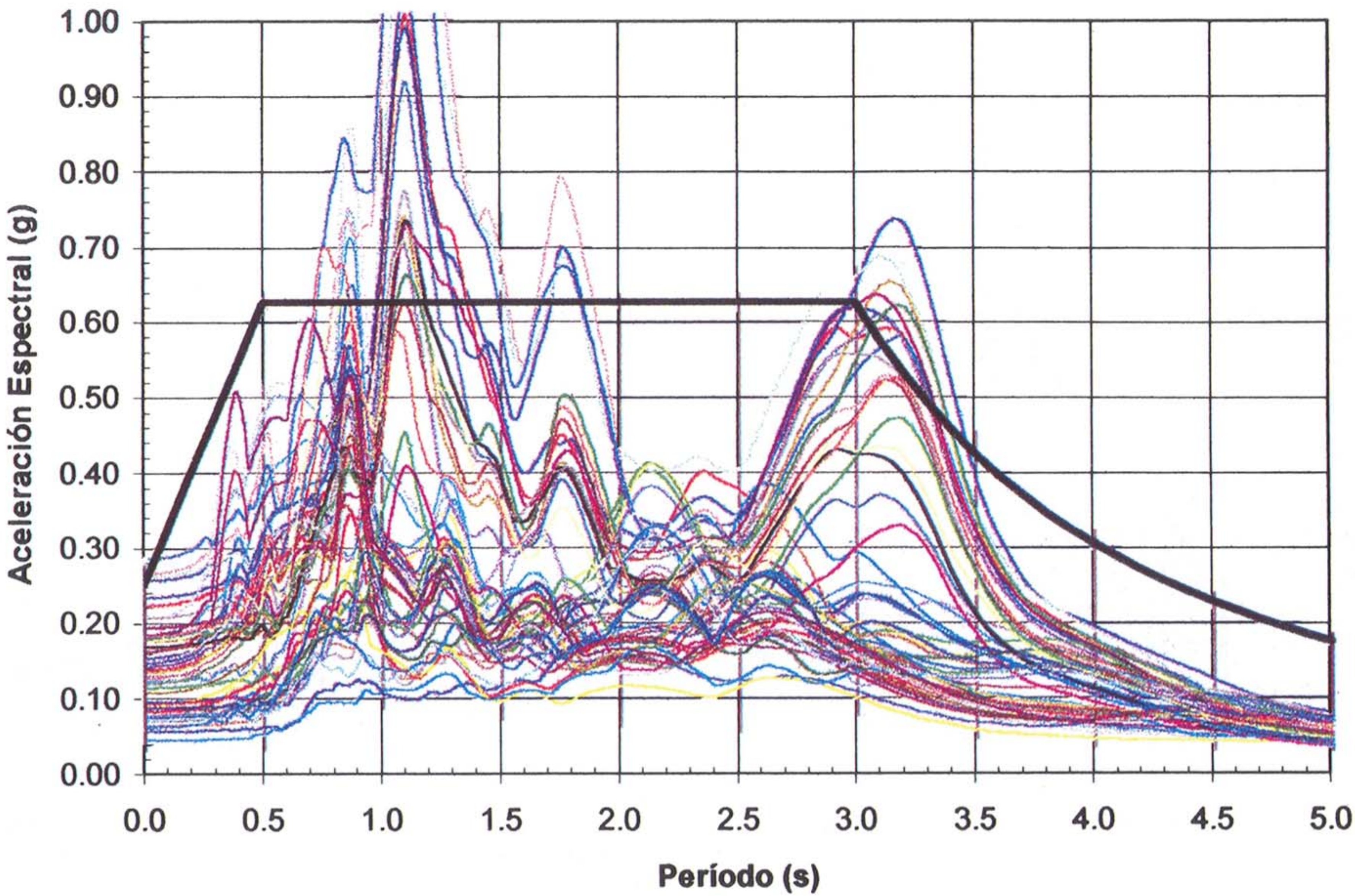
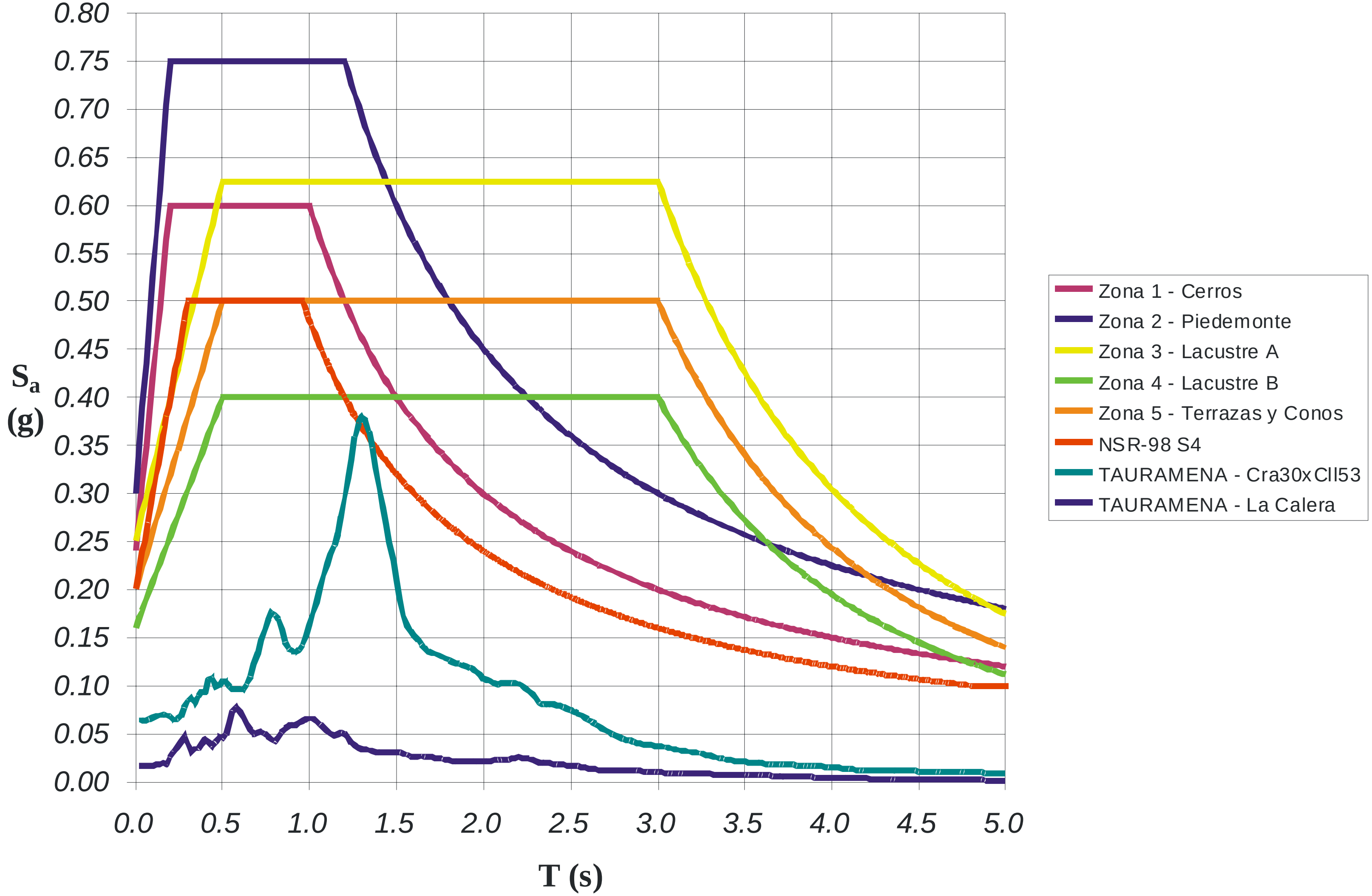
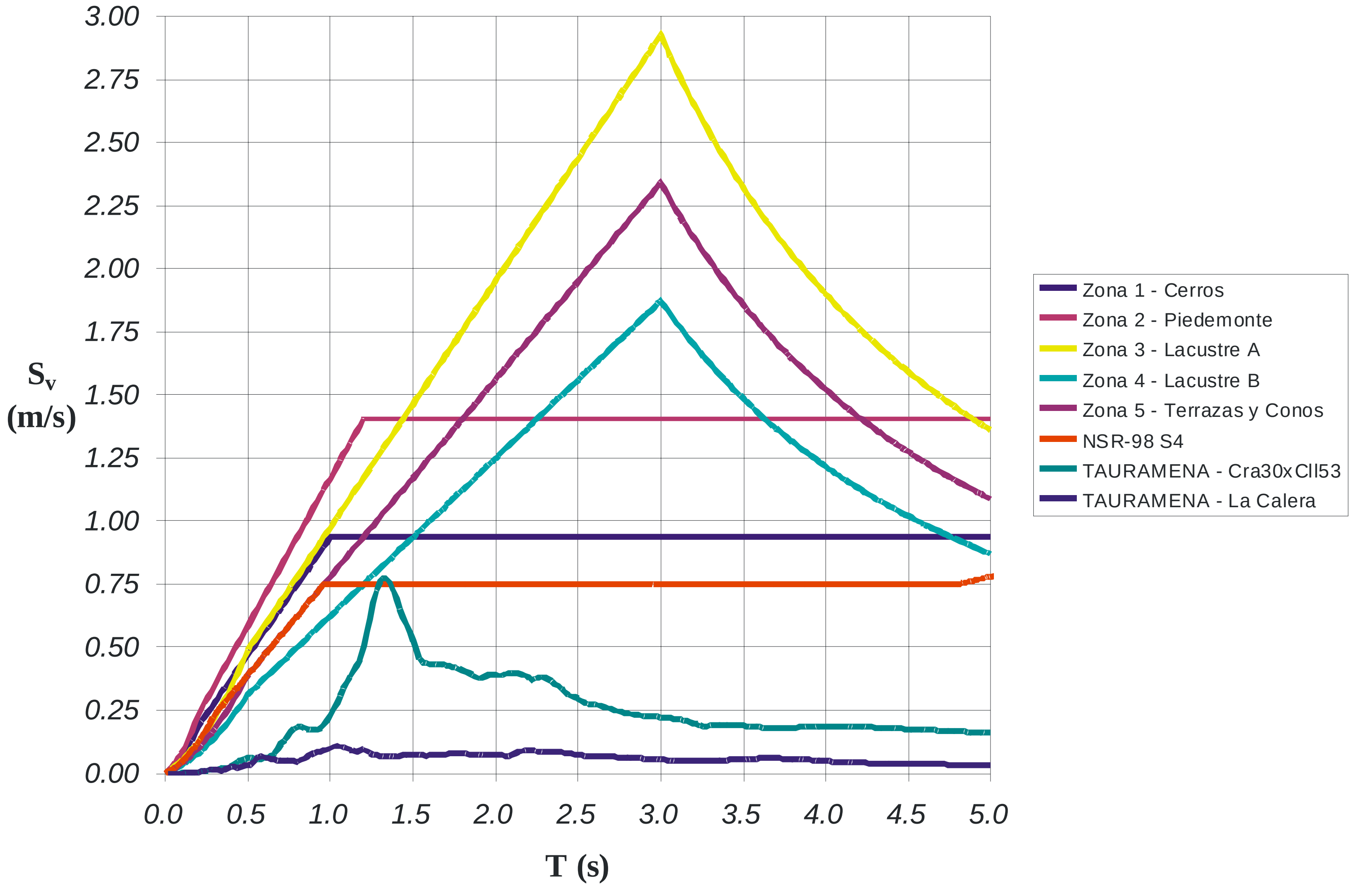


FIGURA 3.23 ESPECTROS DE RESPUESTA Y DE DISEÑO ZONA 3 - LACUSTRE A



0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
S_a
(g)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
T (s)
Zona 1 - Cerros
Zona 2 - Piedemonte
Zona 3 - Lacustre A
Zona 4 - Lacustre B
Zona 5 - Terrazas y Conos
NSR-98 S4
TAURAMENA - Cra30xCll53
TAURAMENA - La Calera



3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
S_v
(m/s)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
T (s)
Zona 1 - Cerros
Zona 2 - Piedemonte
Zona 3 - Lacustre A
Zona 4 - Lacustre B
Zona 5 - Terrazas y Conos
NSR-98 S4
TAURAMENA - Cra30xCll53
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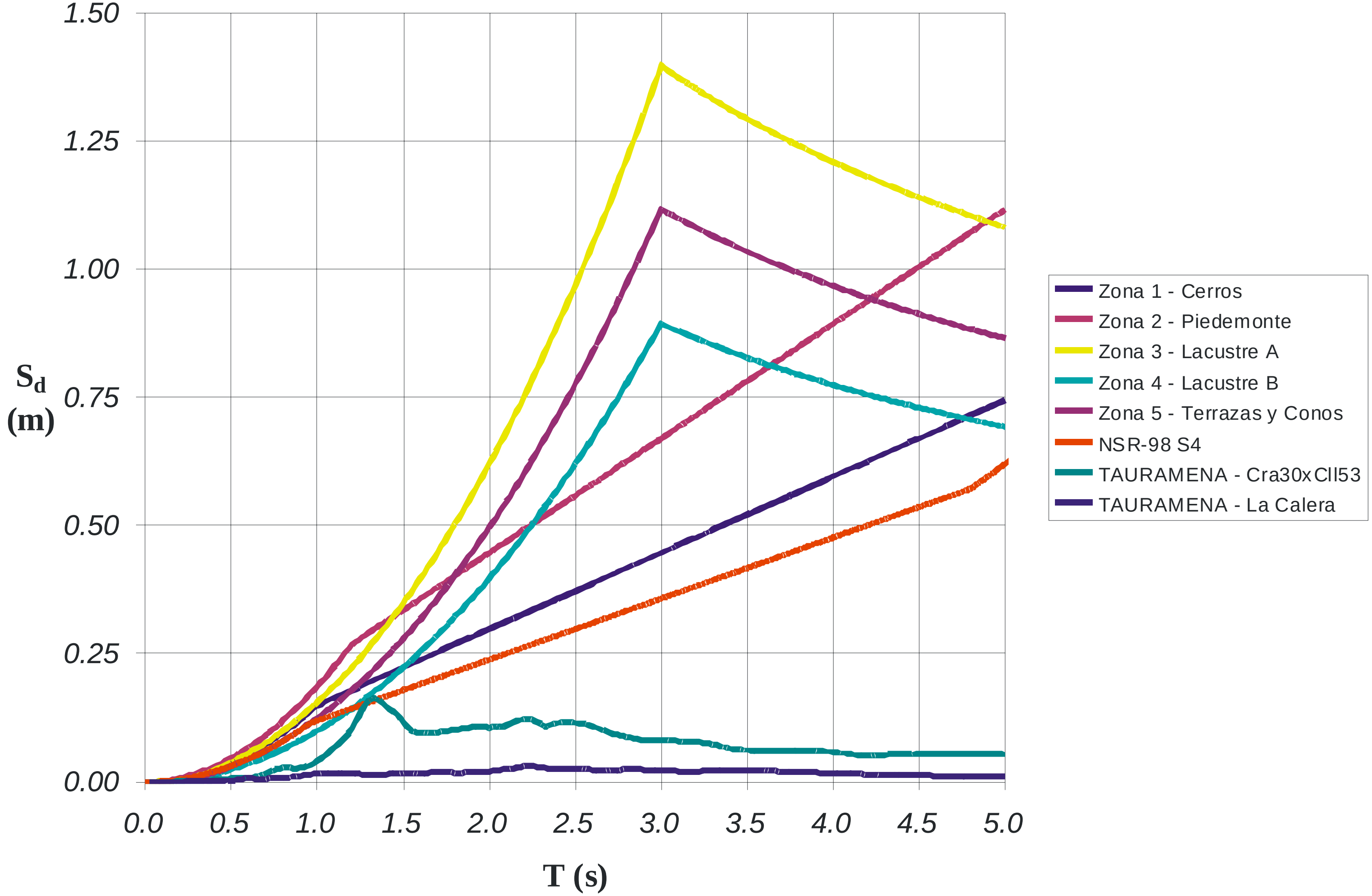
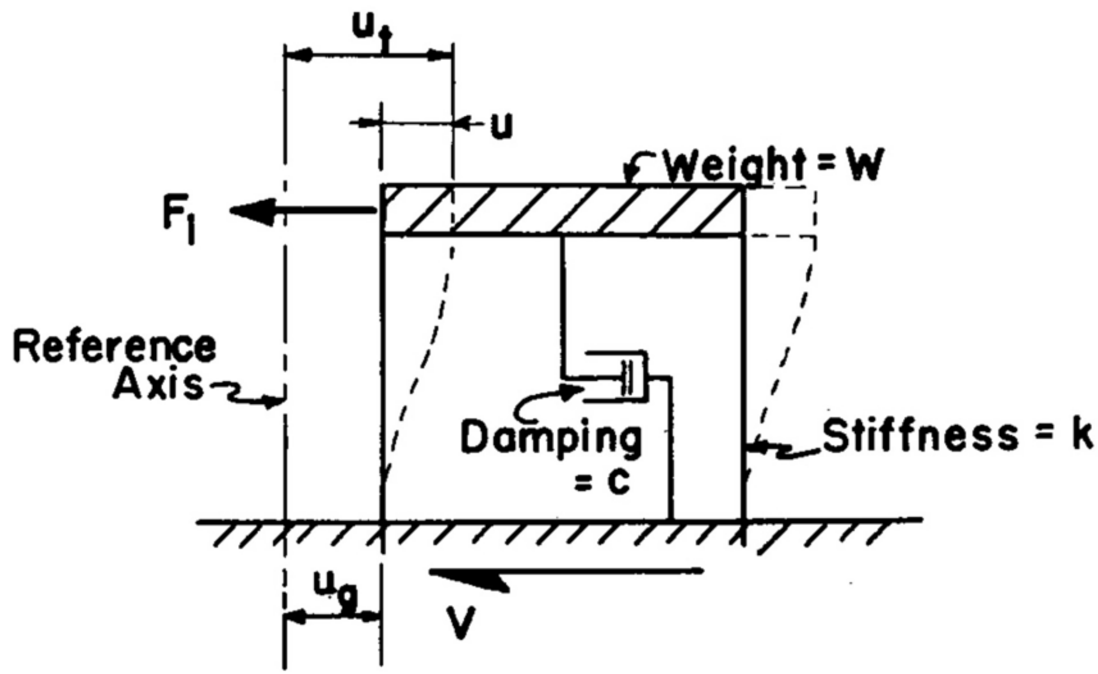
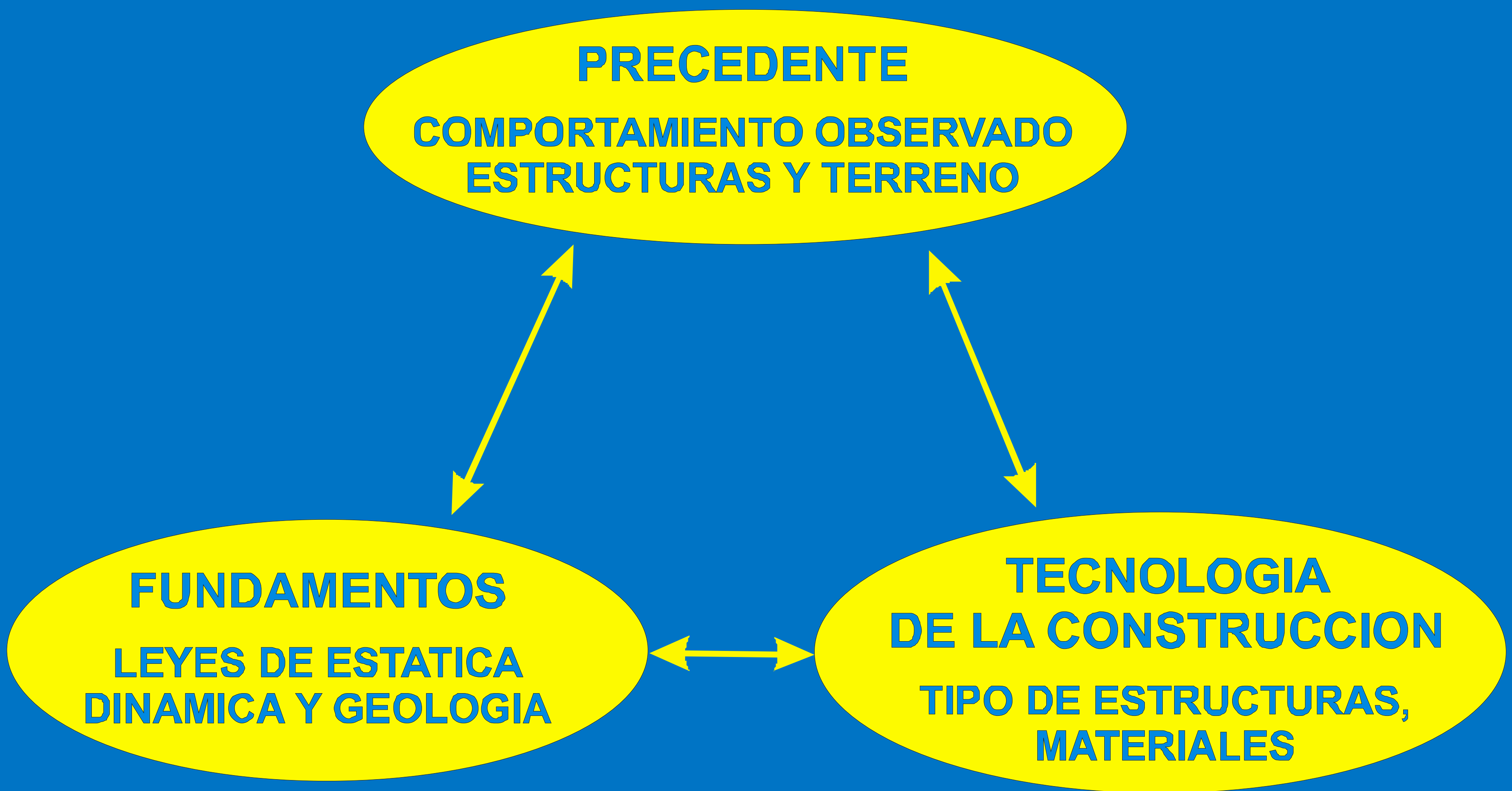

1.50
1.25
1.00
0.75
0.50
0.25
0.00
S_d
(m)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
T (s)
Zona 1 - Cerros
Zona 2 - Piedemonte
Zona 3 - Lacustre A
Zona 4 - Lacustre B
Zona 5 - Terrazas y Conos
NSR-98 S4
TAURAMENA - Cra30xCll53
TAURAMENA - La Calera



$$V_{max} = \frac{W}{g}\,\frac{2\pi}{T}\,S_V$$

Si T = 2 SEGUNDOS y S_V = 2.0 M/S

$$V_{max} = \frac{W}{9.8\ M/S^2} \times \frac{2 \times 3.14}{2\ S} \times 2.0\ \frac{M}{S} = 0.65\ W$$



BASES PARA PREPARAR UN CODIGO SISMICO

EL PRECEDENTE

DE SEÑALES SISMICAS EN DEPOSITOS BLANDOS

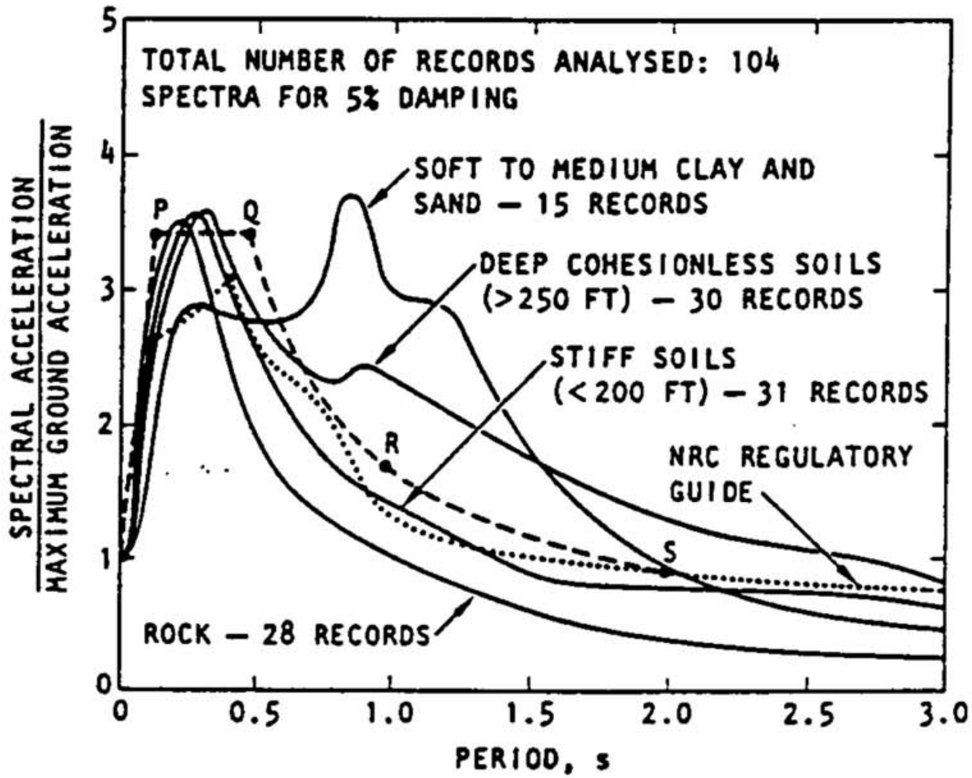


Figure 25. 84th percentile spectra for different site conditions.

Spectral Acceleration Amplification Factors for 5% Damping

One Sigma (84.1%)			Median (50%)		
Point	Period (sec)	S_a / a_{max}	Point	Period (sec)	S_a / a_{max}
P	0.1	3.4	A	0.1	2.7
Q	0.5	3.4	B	0.5	2.7
R	1.0	1.7	C	1.0	1.2
S	2.0	0.85	D	2.0	0.6

LOMA PRIETA - MAGNITUDE 7.1
17/10/89

Table 6-2. *Peak accelerations, velocities and displacements for selected recorded ground motions. The peak accelerations listed in this table are "Volume II" accelerations.*

Station	Distance (km)	Component	Peak Acceleration	Peak Velocity (cm/sec)	Peak Displacement (cm)
Corralitos	5	EW	.478	47.5	11.5
		NS	.629	55.2	9.5
		VERT	.439	18.6	7.77
Gilroy No. 1	10	EW	.442	33.8	6.32
		NS	.435	31.9	6.49
		VERT	.210	14.5	5.15
UC Santa Cruz	20	EW	.409	21.2	6.81
		NS	.441	21.2	6.61
		VERT	.331	12.0	6.72

(ROCK SITES CLOSE)

LOMA PRIETA - MAGNITUDE 7.1
17/10/89

Station	Distance (km)	Component	Peak Acceleration	Peak Velocity (cm/sec)	Peak Displacement (cm)
Diamond Heights	76	EW	.113	14.3	4.31
		NS	.098	10.5	2.83
		VERT	.043	6.68	1.36
Rincon Hill	79	EW	.090	11.6	4.88
		NS	.080	7.34	2.62
		VERT	.029	3.97	1.85
Pacific Heights	80	EW	.061	14.3	4.88
		NS	.047	9.88	3.08
		VERT	.031	5.93	2.25
Telegraph Hill	81	EW	.092	9.59	2.76
		NS	.052	6.50	1.43
		VERT	.033	3.30	1.91
Cliff House	83	EW	.108	21.0	6.4
		NS	.075	11.2	3.70
		VERT	.062	7.51	1.57

(ROCK SITES - SAN FRAN.)

LOMA PRIETA - MAGNITUDE 7.1
17/10/89

0

0'-40' FILL

BAY MUD
Vs=150ft/sec TO
40'-120' Vs=450 ft/sec

• V. DENSE SANDS

• STIFF TO HARD CLAYS
100'-500'

ROCK

Station	Distance (km)	Component	Peak Acceleration	Peak Velocity (cm/sec)	Peak Displacement (cm)
APEEL No. 2	47	133	.227	35.9	5.68
		043	.277	53.1	10.4
		VERT	.086	7.79	1.06
Foster City	48	EW	.283	45.4	14.7
		NS	.257	31.8	6.28
		VERT	.103	8.38	3.57
SF Airport	64	EW	.332	29.3	5.92
		NS	.235	26.5	5.05
		VERT	065	5.27	1 77
Emeryville	81	EW	.260	41.1	8.21
		NS	.214	21.5	3.75
		VERT	.060	5.00	.80
2-Story Building, Oakland	76	290	.243	37.9	8.05
		200	.191	20.0	3.92
		VERT	.144	6.19	1.30
Outer Harbor Wharf, Oakland	76	305	.271	42.3	9.17
		035	.287	40.8	9.88
		VERT	.066	10.5	1.83

(SOFT SOIL)

LOMA PRIETA - MAGNITUDE 7.1
17/10/89

Station	Distance (km)	Component	Peak Acceleration	Peak Velocity (cm/sec)	Peak Displacement (cm)
Yerba Buena Island (ROCK)	79	EW	.067	14.7	4.12
		NS	.029	4.61	1.39
		VERT	.028	4.22	1.13
Treasure Island (SOIL)	81	EW	.159	33.4	12.2
		NS	.100	15.6	4.48
		VERT	.016	1.16	1.15

3.3 2.38 3.3 2.3 3.2 2.96

LOMA PRIETA - MAGNITUDE 7.1
17/10/89

Station	Distance (km)	Component	Peak Acceleration	Peak Velocity (cm/sec)	Peak Displacement (cm)
Telegraph Hill	81	EW	.092	9.59	2.76
		NS	.052	6.50	1.43
		VERT	.033	3.30	1.91

(ROCK SITE - SAN FRAN.)

Station	Distance (km)	Component	Peak Acceleration	Peak Velocity (cm/sec)	Peak Displacement (cm)
Emeryville	81	EW	.260	41.1	8.21
		NS	.214	21.5	3.75
		VERT	.060	5.00	.80

(SOFT SOIL)

EVENTO	DEPOSITO	DIST.	VIBRACIONES DEL TERRENO			
		KM	a_{MAX} (g)	V_{MAX} (cm/seg)	d_{MAX} (cm)	$\frac{V^2_{MAX}}{a_{MAX}\,d_{MAX}}$
TAURAMENA (1995) INGEOMINAS COMPONENTE E-W M = 6.5	LACUSTRE	100	0.06	11	2.4	0.85
TAURAMENA (1995) EL ROSAL COMPONENTE E-W M = 6.5	ROCA	100	0.016	2.05	0.6	0.45
LOMA PRIETA (1989) TELEGRAPH HILL M = 7.1	ROCA	81	0.092	9.59	2.76	0.37
LOMA PRIETA (1989) EMERYVILLE M = 7.1	SUELO BLANDO	81	0.26	41.1	8.21	0.81

EVENTO	DEPOSITO	DIST. KM	VIBRACIONES DEL TERRENO a_{MAX} (g)	V_{MAX} (cm/seg)	d_{MAX} (cm)	$\frac{V^2_{MAX}}{a_{MAX}\, d_{MAX}}$
IMPERIAL VALLEY (1940) EL CENTRO COMPONENTE N-S M = 7.1	ALUVION	11 KM	0.35 g	33.4 cm/seg	20.9 cm	0.16
MEXICO SCT1 M = 8.1	SUELO BLANDO	~400 KM	0.17 g	60.5 cm/seg	21.9 cm	1.0

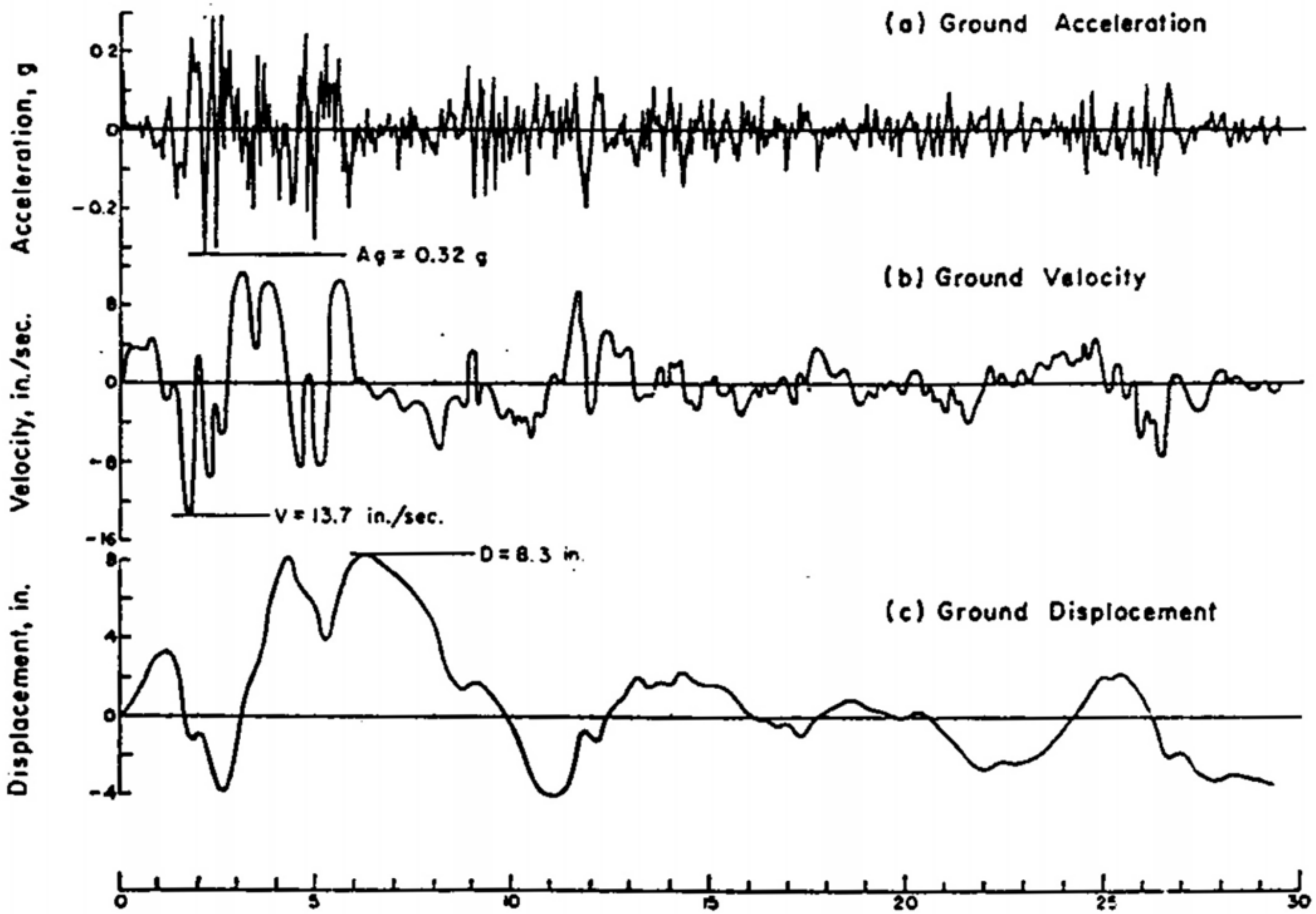
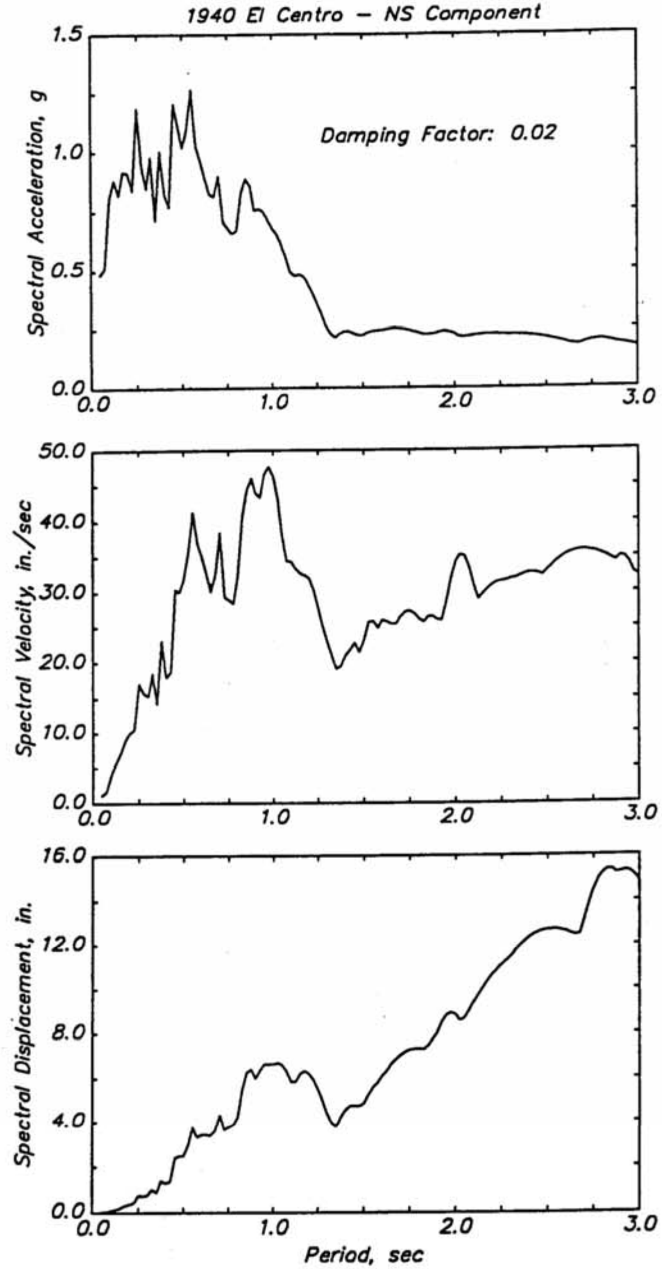


Fig. 1. El Centro, California, earthquake of 18 May, 1940, N–S component

ALUVION DENSO

Linear Response Spectra

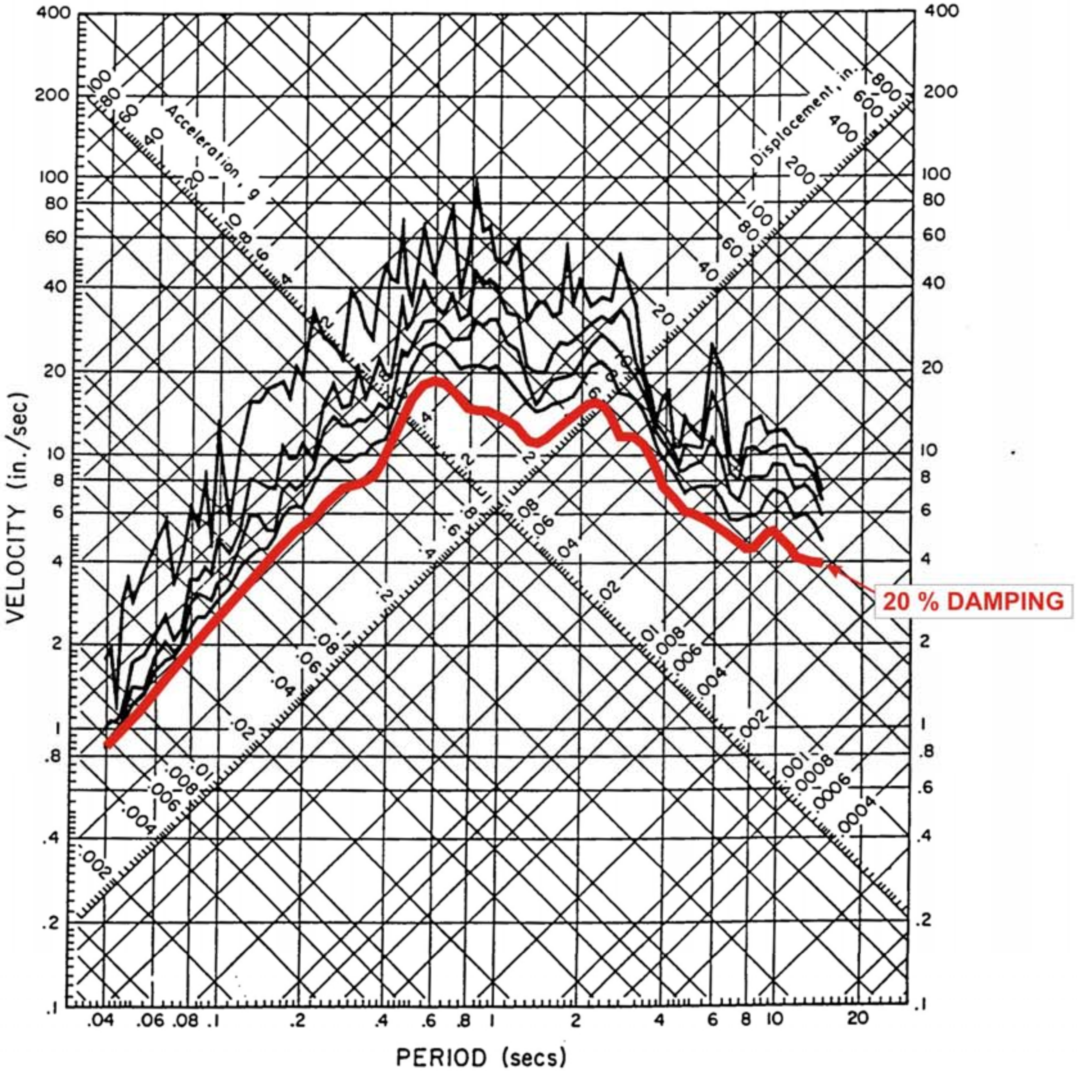


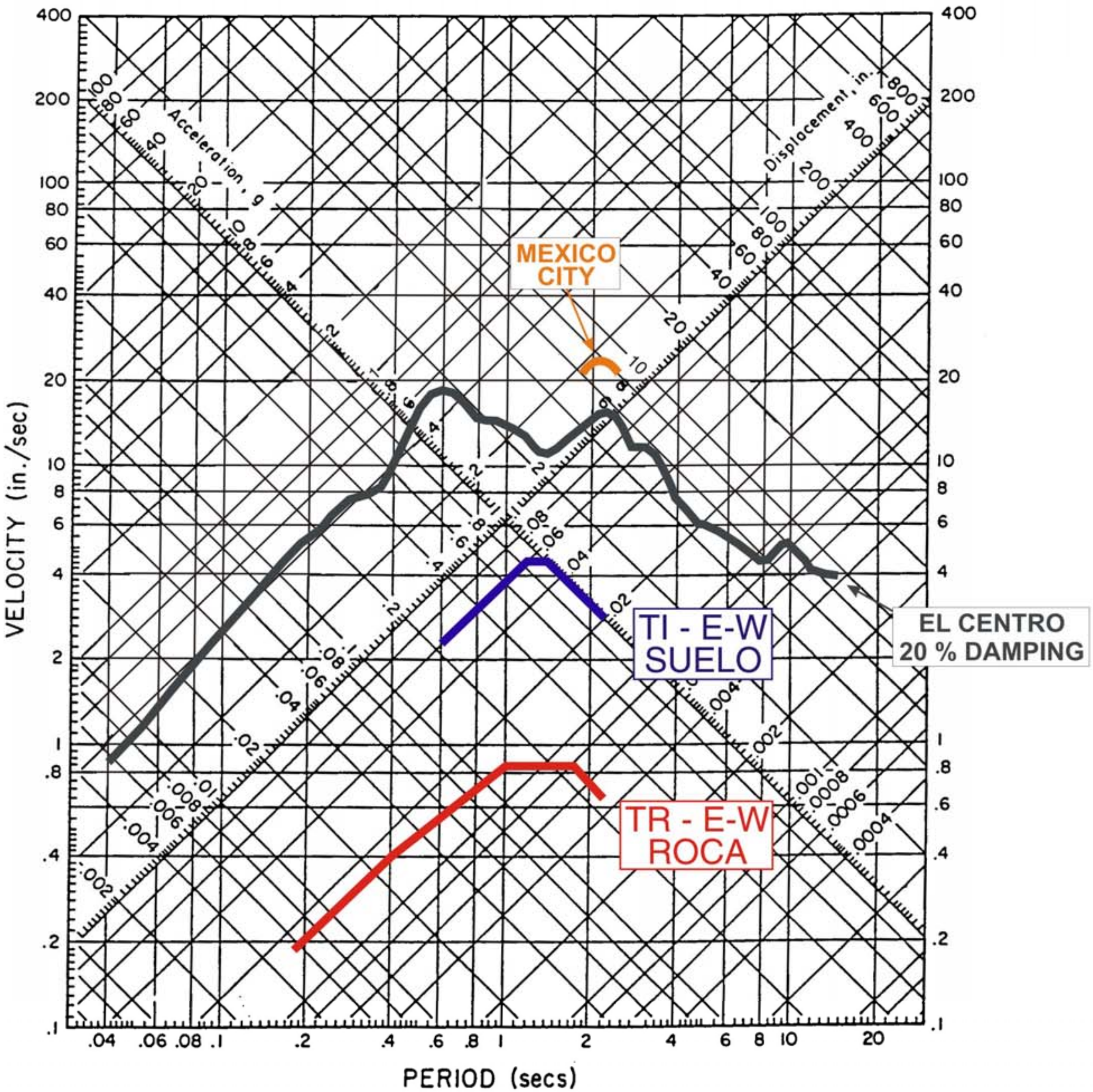
RESPONSE SPECTRUM

IMPERIAL VALLEY EARTHQUAKE MAY 18, 1940 - 2037 PST

IIIA001 40.001.0 EL CENTRO SITE IMPERIAL VALLEY IRRIGATION DISTRICT COMP SOOE

DAMPING VALUES ARE 0, 2, 5, 10 AND 20 PERCENT OF CRITICAL





MEXICO CITY
EL CENTRO 20 % DAMPING
TI - E-W SUELO
TR - E-W ROCA
VELOCITY (in./sec)
PERIOD (secs)
Acceleration, g
Displacement, in.

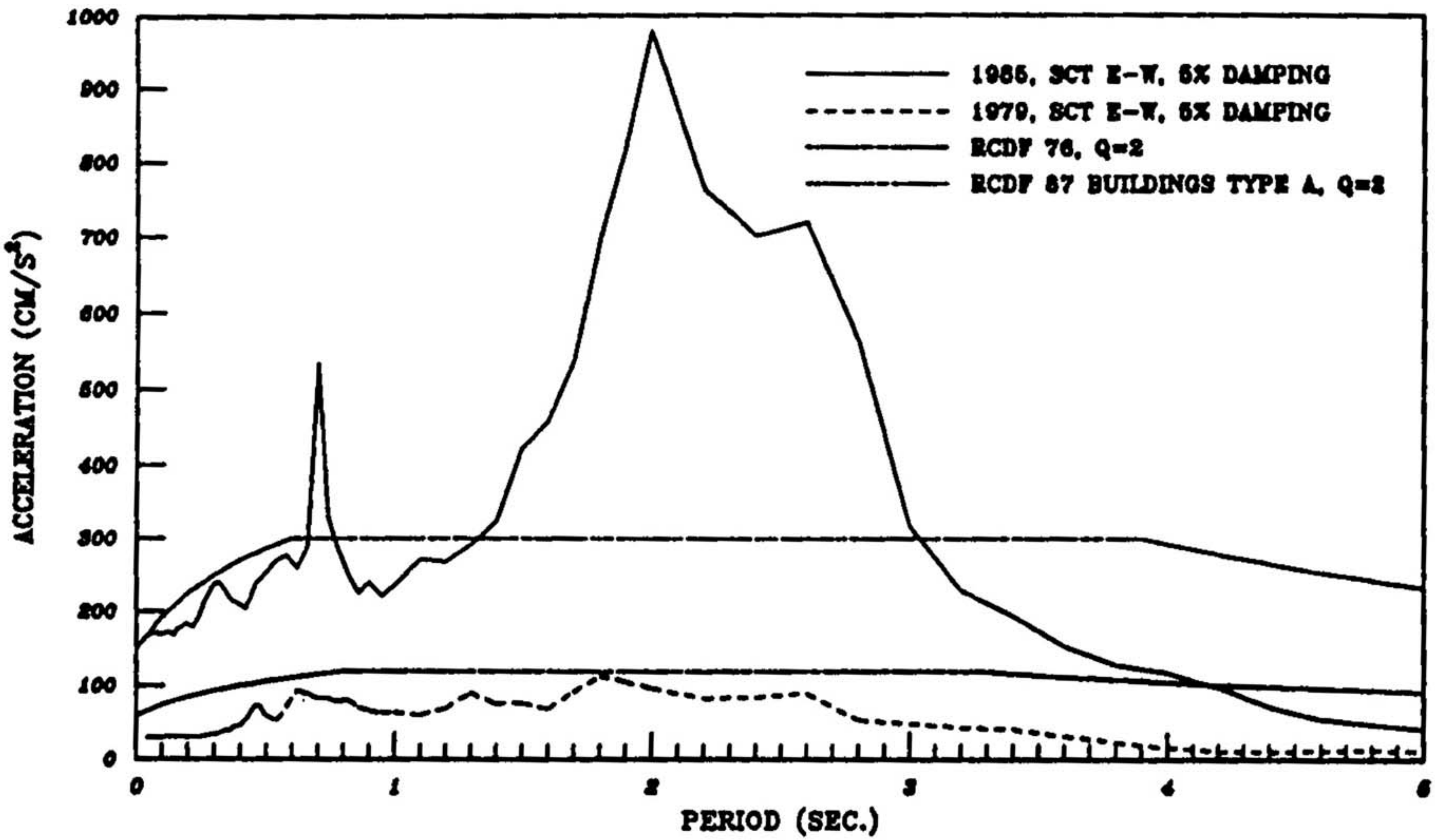
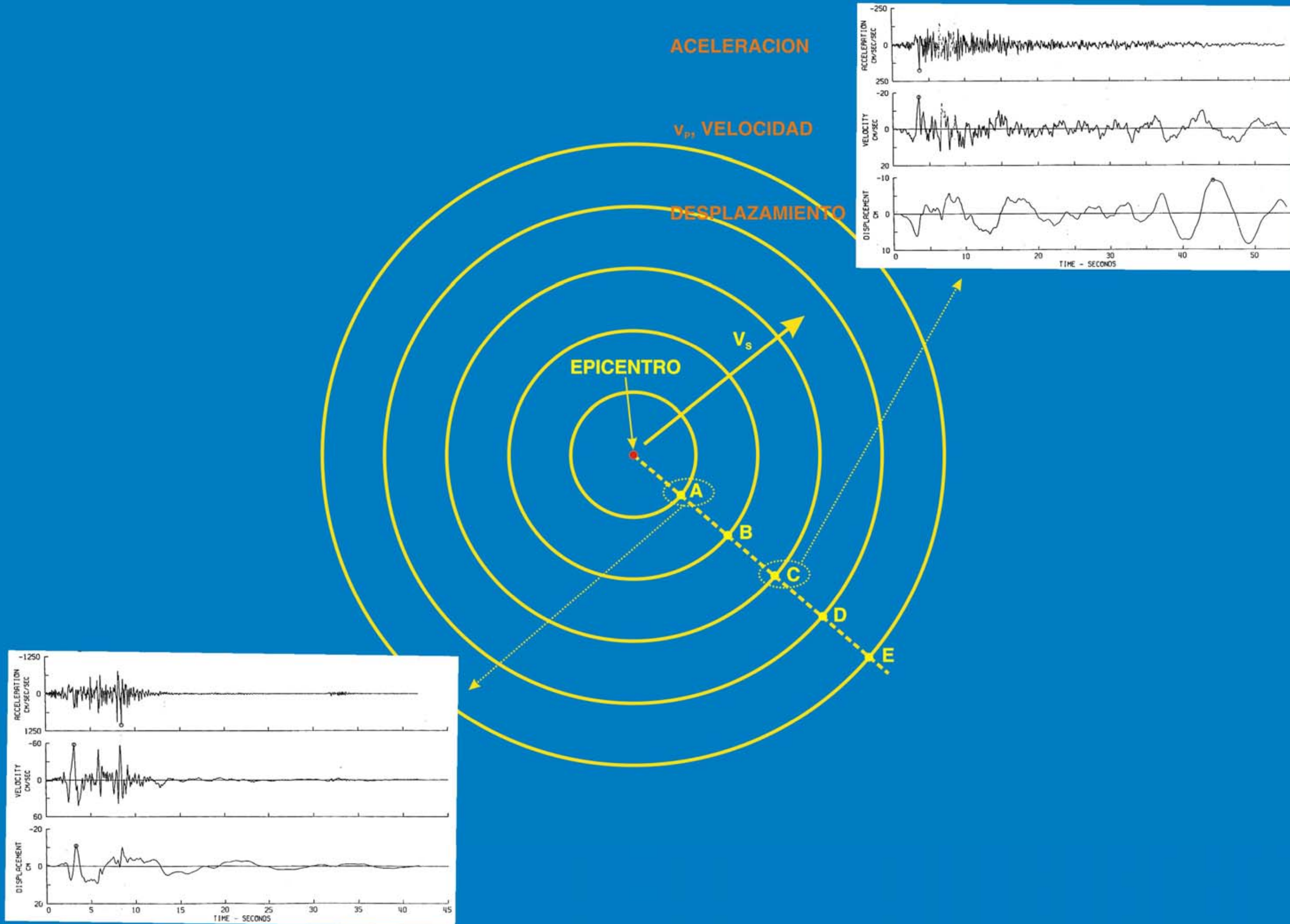


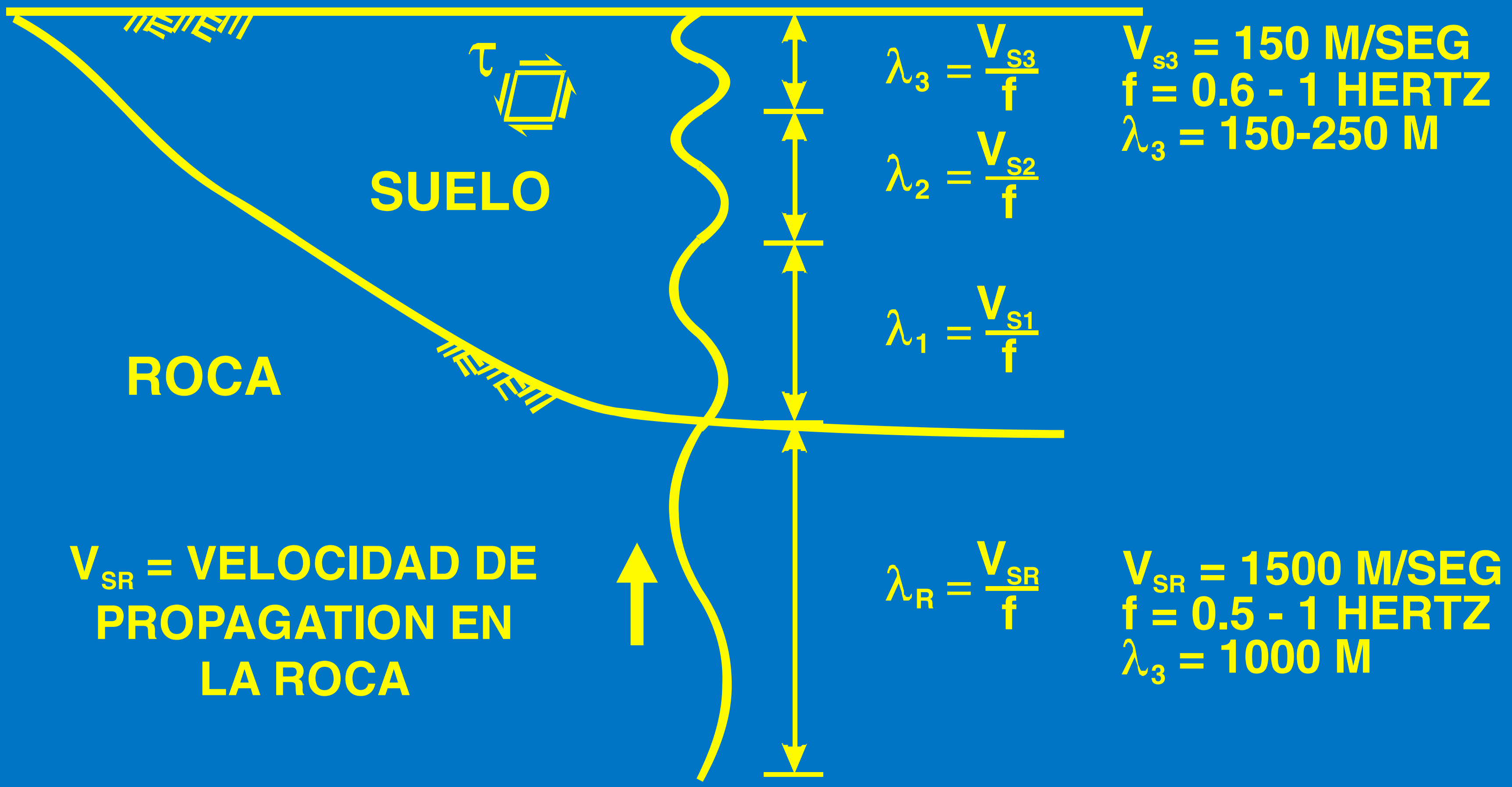
Figure 2 Acceleration response spectra and Mexico City design spectra for lake region

LOS FUNDAMENTOS

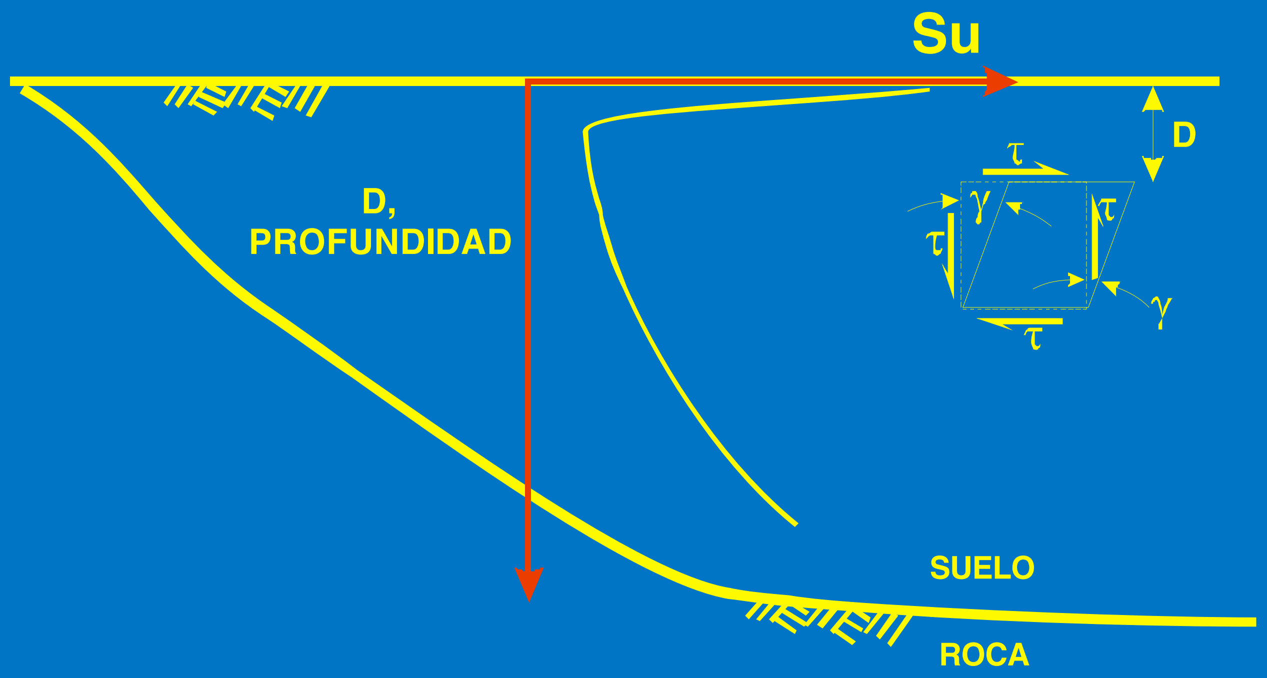
PRINCIPIOS DE PROPAGACION DE ONDAS DE ESFUERZO EN DEPOSITOS NATURALES



ACELERACION
v_p, VELOCIDAD
DESPLAZAMIENTO
EPICENTRO
V_S
A
B
C
D
E
ACCELERATION CM/SEC/SEC
VELOCITY CM/SEC
DISPLACEMENT CM
TIME - SECONDS



PROPAGATION DE ONDAS DE CORTE A TRAVES DEL TERRENO



RESISTENCIA AL CORTE, Su

τ = ESFUERZO DE CORTE

G = MODULO DE CORTANTE

γ = DEFORMACION UNITARIA

v_p = VELOCIDAD MAXIMA DEL TERRENO

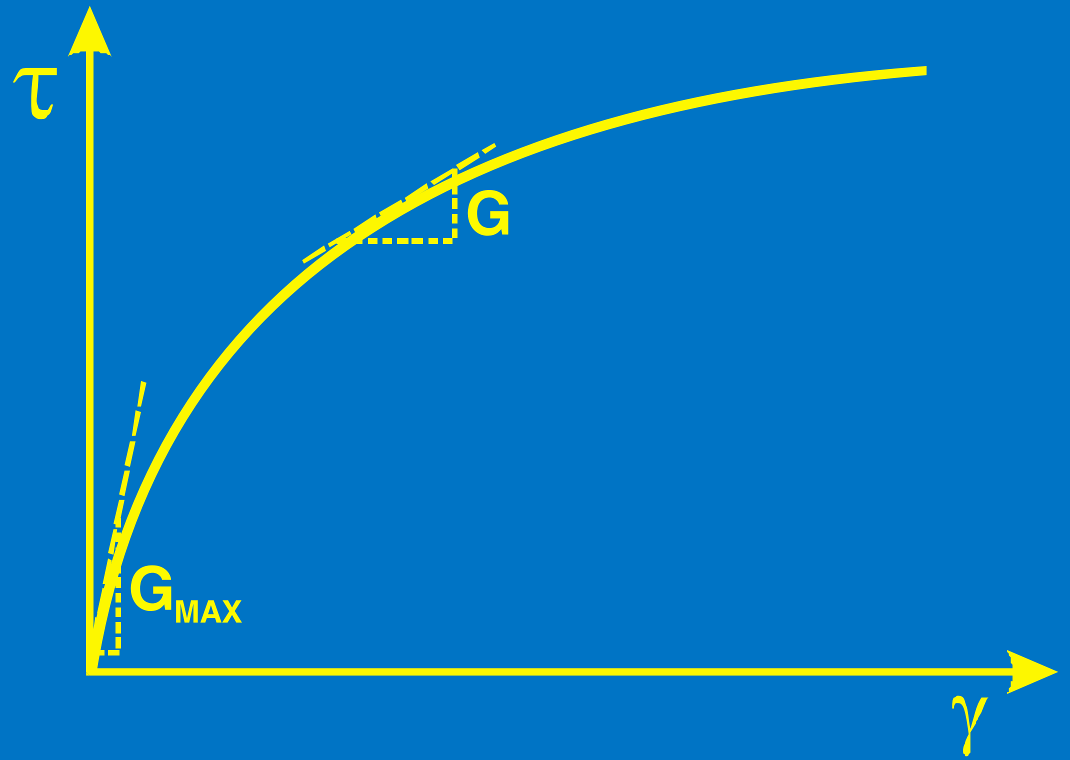
Vs = VELOCIDAD DE PROPAGACION

$$\tau = G\,\gamma$$

$$\gamma = \frac{v_p}{V_s}$$

$$\tau_{SIS} \leq Su$$

$$\therefore\ \tau_{SIS} = G\,\frac{v_p}{V_s}\ ; \qquad G\,\frac{v_p}{V_s} \leq Su$$



$$G_{MAX} = \frac{\gamma}{g} V_{SM}^{2} \qquad G = \frac{\gamma}{g} V_{S1}^{2}$$

$$\frac{G}{G_{MAX}} = \frac{\gamma/g \; V_{S1}^{2}}{\gamma/g \; V_{SM}^{2}} = \frac{V_{S1}^{2}}{V_{SM}^{2}}$$

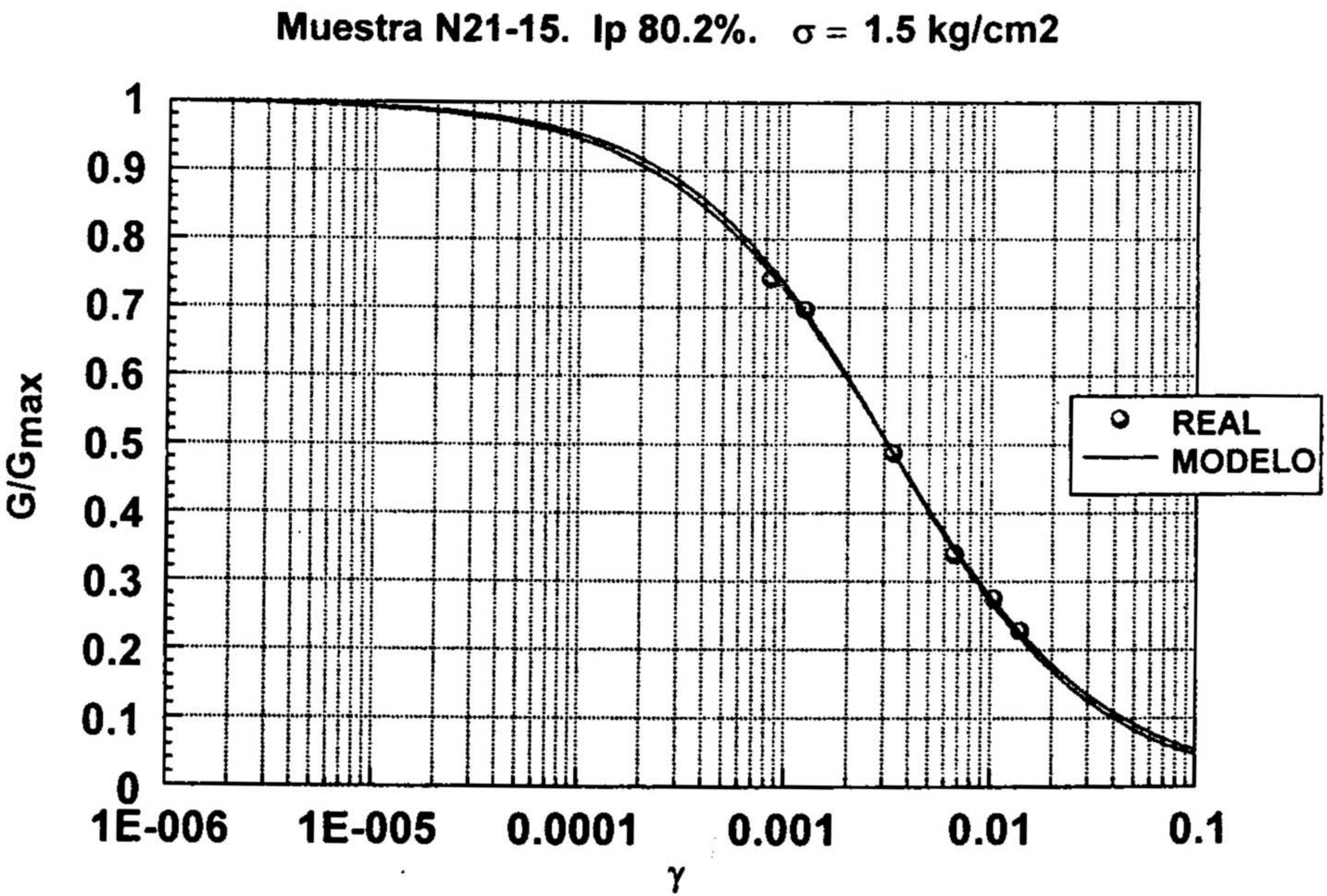
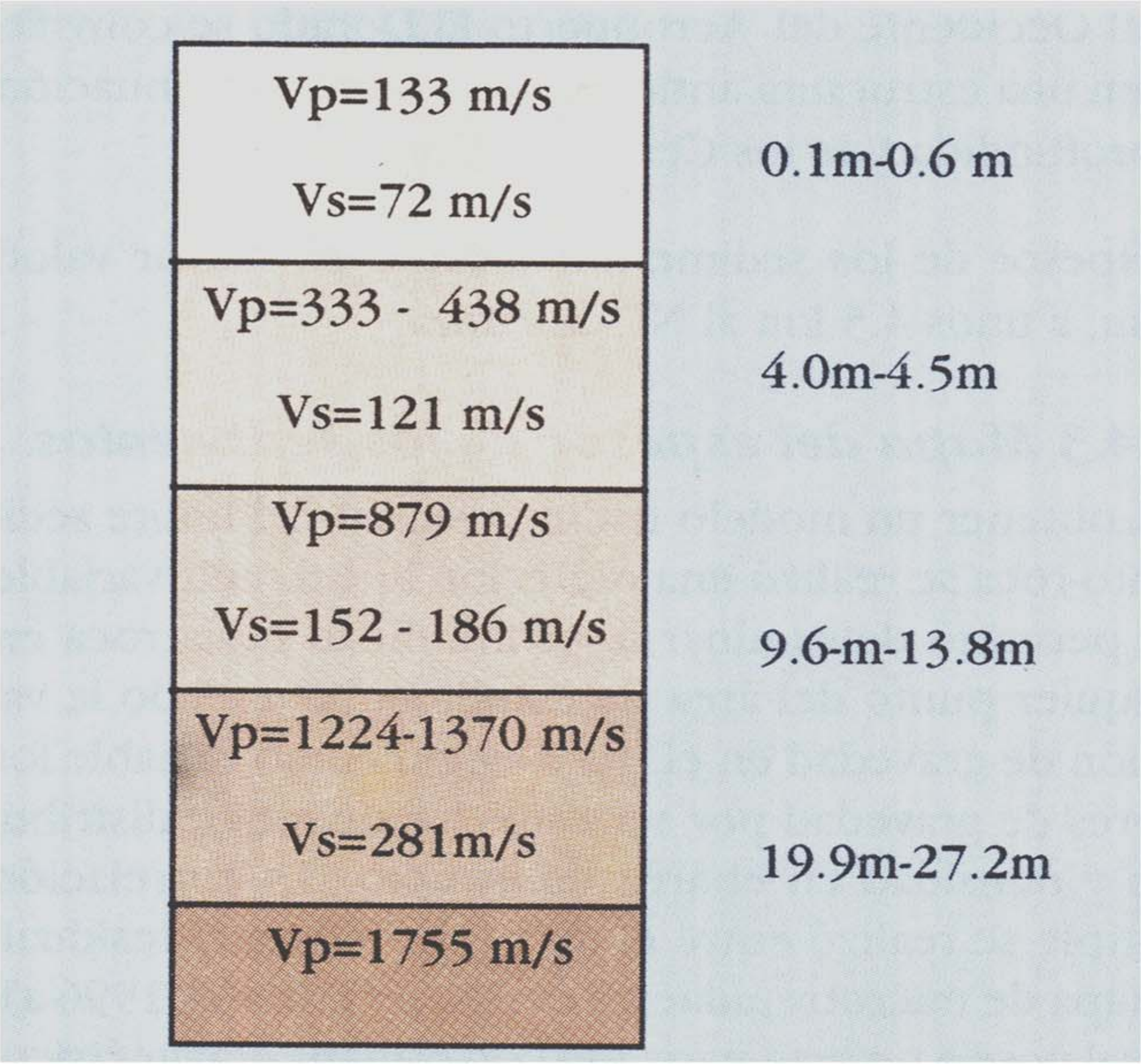


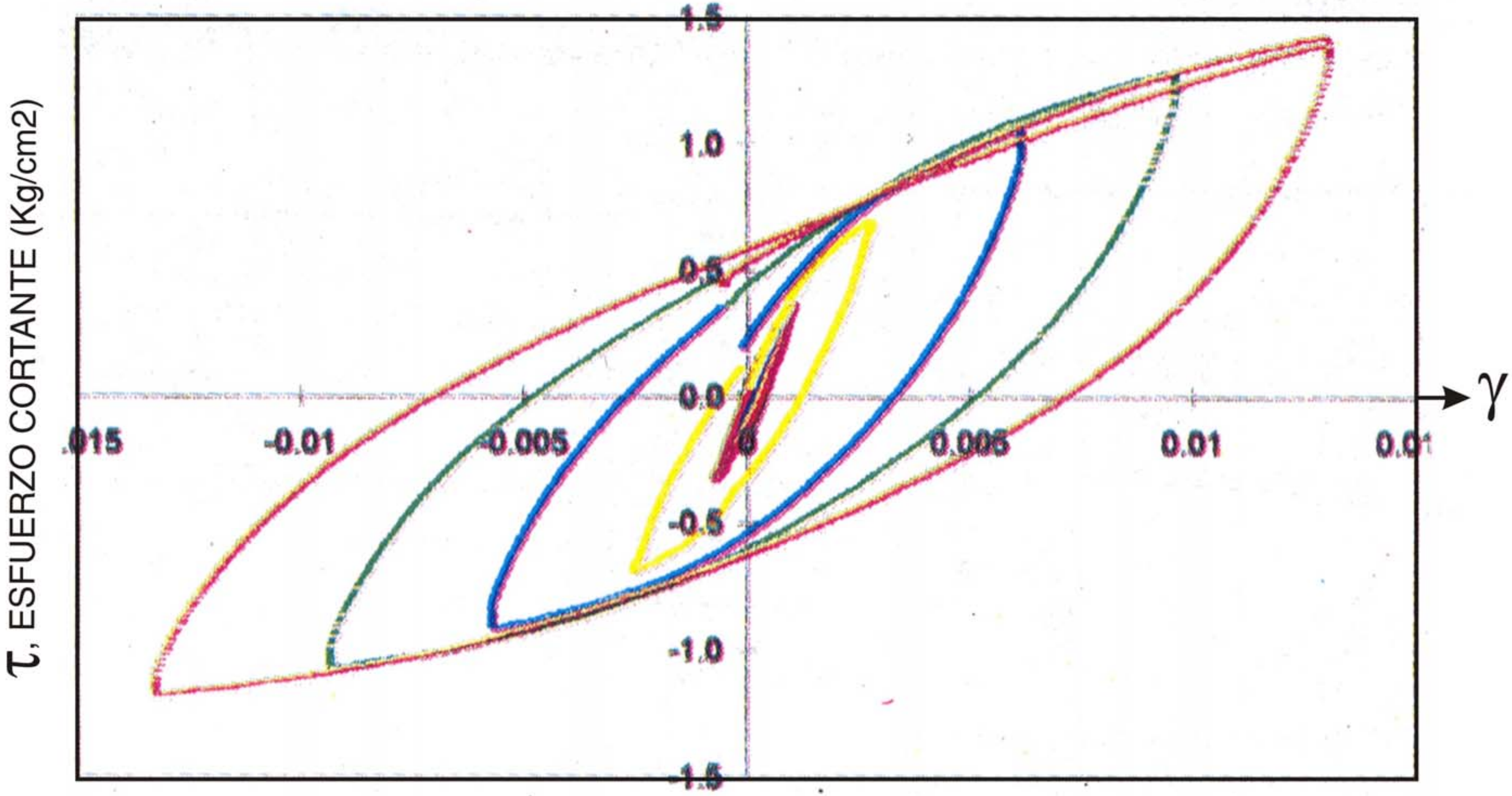
FIGURA 2.24 GRÁFICO DE CALIBRACIÓN DEL MODELO CONTRA ENSAYO DE LABORATORIO



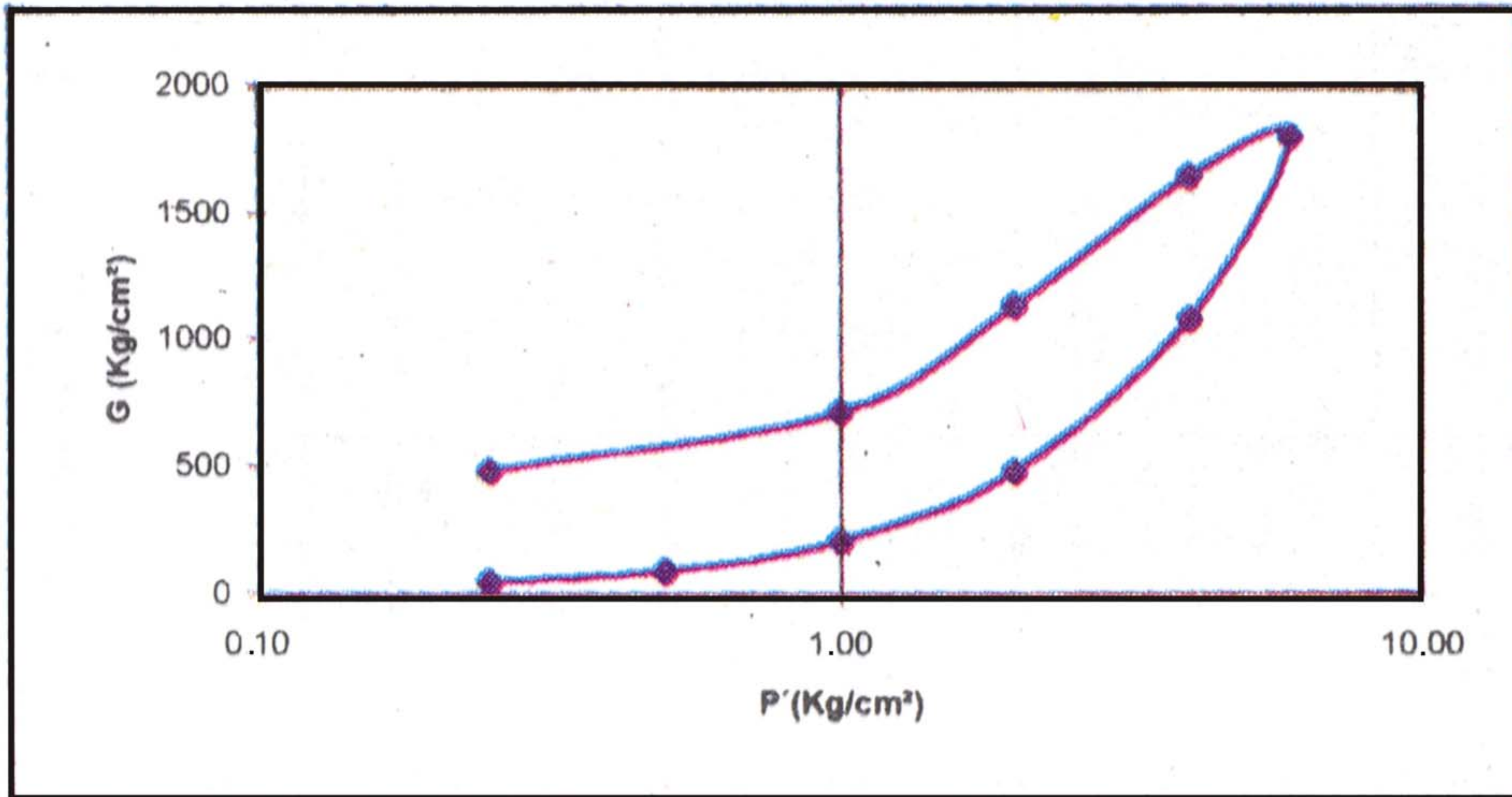
PERFIL DE VELOCIDADES DE PROPAGACION DE ESFUERZOS EN BOGOTA

MUESTRA N51-91-4

σ_3 = 5.0 Kg/cm^2 PROF = 93.8 M



RELACION ESFUERZO - DEFORMACION UNITARIA EN CORTE-BOGOTA



RELACION MODULO CORTANTE VERSUS CONFINAMIENTO EFFECTIVO. BOGOTA

DEPOSITO LACUSTRE BOGOTA

PROFUNDIDAD ~ 20 M

RESISTENCIA AL CORTE Su = 0.3 Kg/cm^2 (INGEOMINAS)

$\overline{\sigma}$v = 1.8 Kg/cm^2 (INGEOMINAS)

Vs_M = 280 M/S A DEFORMACIONES UNITARIAS MINIMAS

DEPOSITO LACUSTRE BOGOTA

PROCESO DE APROXIMACIONES SUCESIVAS

ASUMA UNA DEFORMACION UNITARIA DE CORTE γ

$$\gamma \sim 0.002; \longrightarrow G/G_{MAX} = 0.6 \longrightarrow \frac{Vs_1}{Vs_M} = \sqrt{0.6} = 0.77$$

$$\therefore Vs_1 = 0.77 \times 280 \text{ M/S} = 216 \text{ M/S}$$

G_{MAX} = 300 Kg/cm2 (FIG. 220 INGEOMINAS)

$$G = 300 \text{ Kg/cm}^2 \times 0.6 = 180 \text{ Kg/cm}^2$$

DEPOSITO LACUSTRE BOGOTA

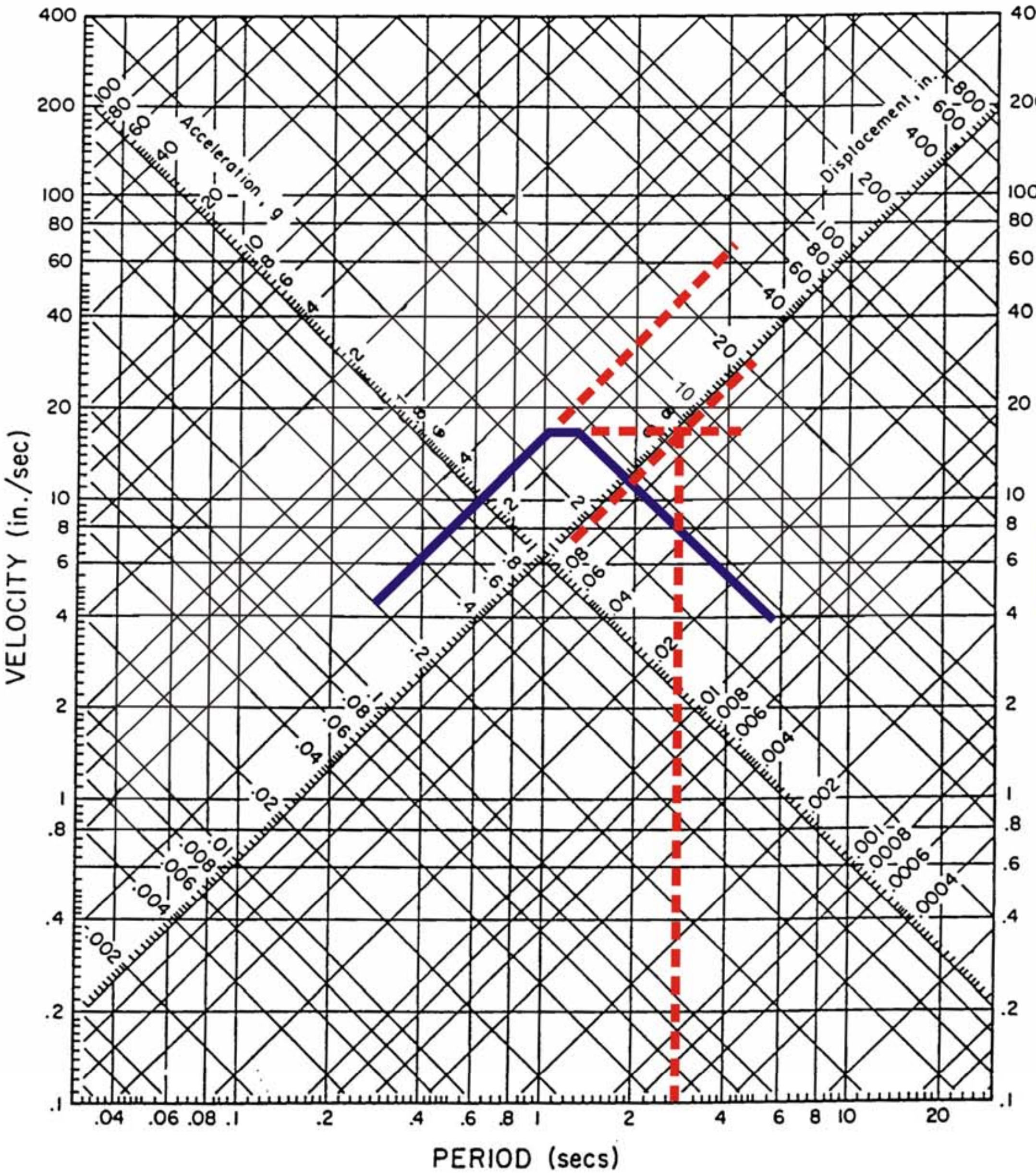
$\tau = Su$

$$\therefore 180 \text{ Kg/cm}^2 \times \frac{Vp}{216 \text{ M/S}} = 0.3 \text{ Kg/cm}^2$$

$$Vp = \frac{0.3 \text{ Kg/cm}^2}{180 \text{ Kg/cm}^2} \times 216 \text{ M/S} = 0.36 \text{ M/S} = 36 \text{ cm/S}$$

CONVERGENCIA

$$\gamma = \frac{Vp}{Vs} = \frac{0.36 \text{ M/S}}{216 \text{ M/S}} = 0.0017 \sim 0.002 \quad \underline{\textit{OK}}$$



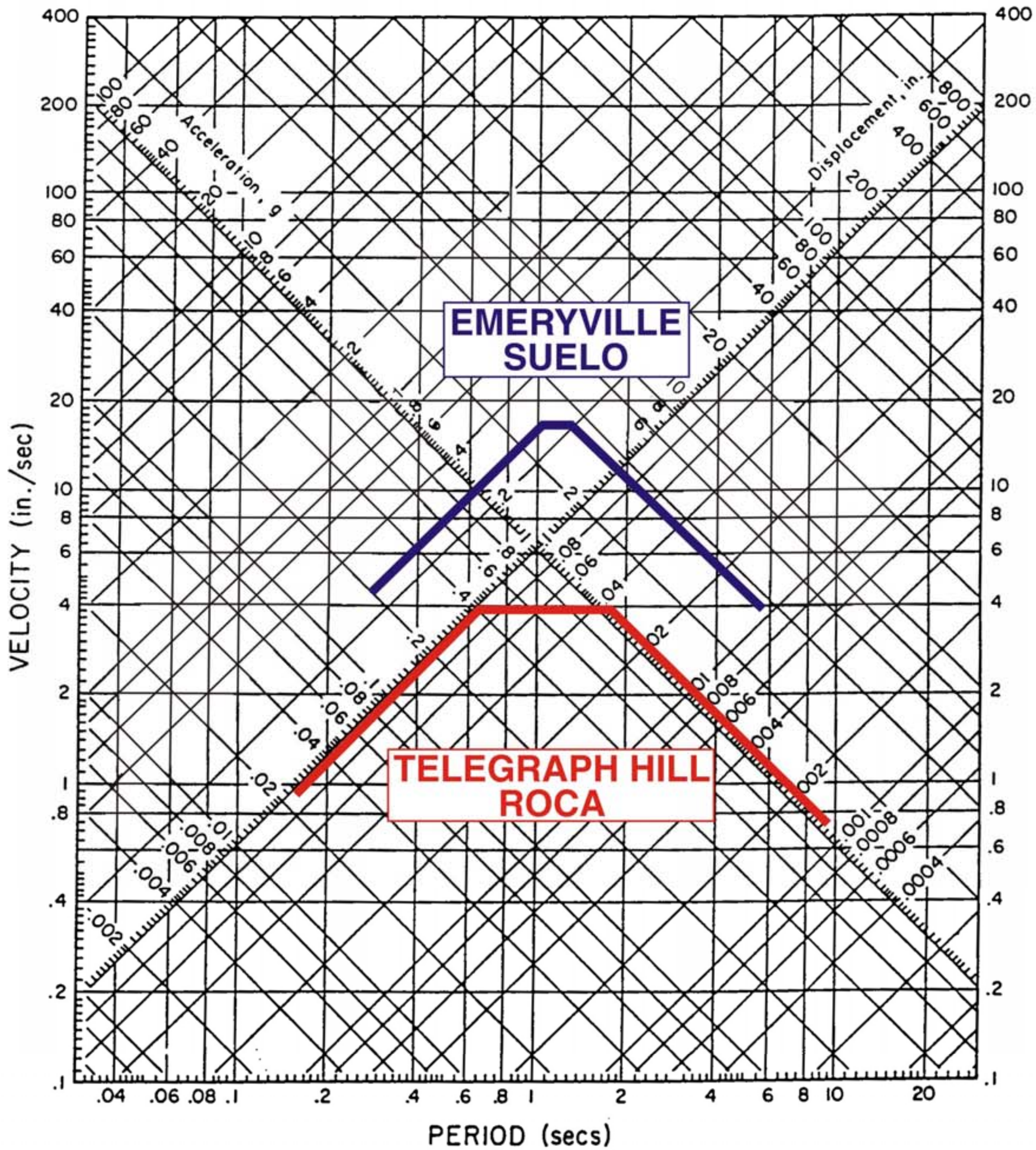
EMERYVILLE SUELO

LOS SUELOS BLANDOS DE BOGOTA

RESISTEN VELOCIDADES MAXIMA DE TERRENO
DE CERCA DE
$\bar{v}_P = 35$ cm/S

POR CONSIGUIENTE LAS ACELERACIONES
MAXIMAS DEL TERRENO A DIFERENTES PERIODOS
DE PUEDEN APROXIMAR ASI

V_{MAX}, cm/S	T, S	a_{MAX}, g
35	1.5	0.15g
35	2.0	0.11g
35	3.0	0.07g



EMERYVILLE
SUELO
TELEGRAPH HILL
ROCA
VELOCITY (in./sec)
PERIOD (secs)
Acceleration, g
Displacement, in.

LAS CONCLUSIONES

- USE ACELEROGRAMAS REALES PARA DISEÑO
  EVITE ACELEROGRAMAS SINTETICOS

- PARA EL SISMO FRONTAL EN BOGOTA SE SUGIERE

  A) EN ROCA USAR EL ACELEROGRAMA DE
  TELEGRAPH HILL, LOMA PRIETA
  - Ms = 7.1 @ D = 81 KM (ROCA)

  B) EN LOS DEPOSITOS DE SUELO (LACUSTRE,
  PIEDEMONTE) USE EL ACELEROGRAMA DE
  EMERYVILLE, LOMA PRIETA
  - Ms = 7.1 @ D = 81 KM (BAY MUD)

RECOMENDACIONES GEOTECNICAS PARA MEJORAR EL COMPORTAMIENTO ESTRUCTURAL DURANTE UN SISMO

- CONSTRUYAN SOTANOS PARA

A) ALIVIAR LOS ESFUERZOS DE CORTE EN EL SUELO

B) MINIMIZAR ASENTAMIENTOS DIFERENCIALES

C) ADUSTAR EL PERIODO DE LA ESTRUCTURA

D) PROVEER PARQUEADEROS EN BOGOTA