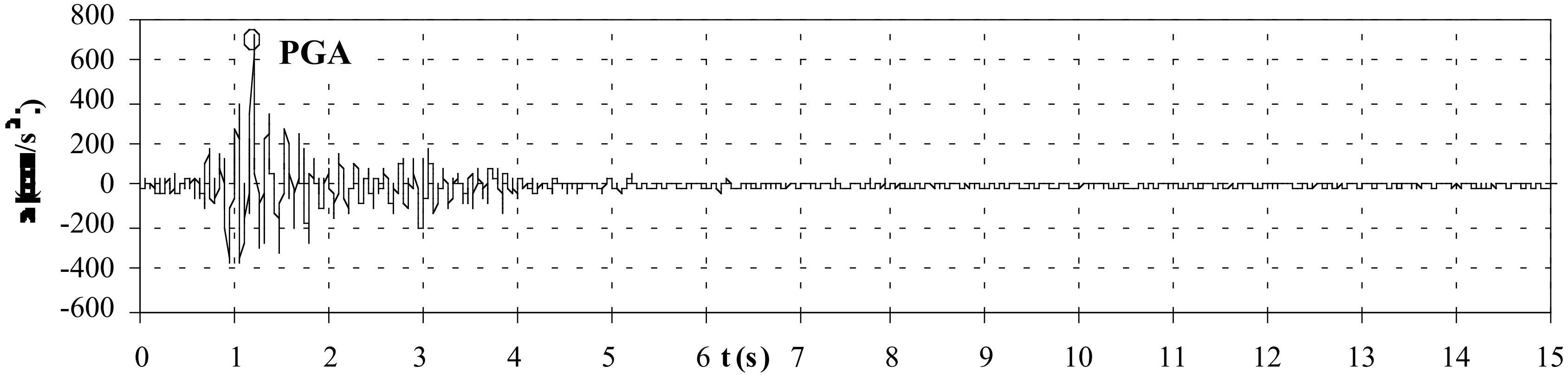
PARAMETERS CHARACTERIZING THE SEISMIC DEMAND

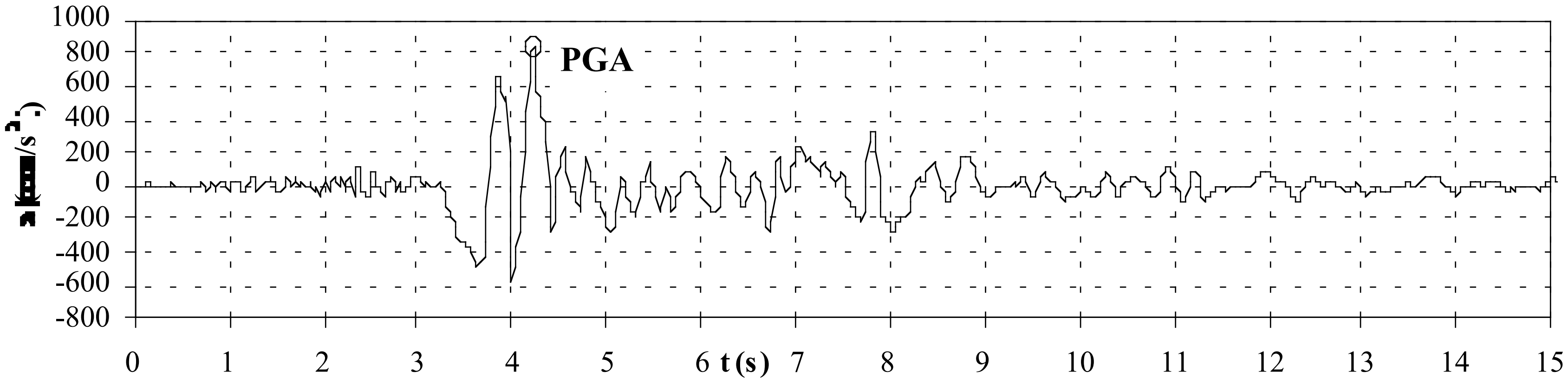
FOR

EARTHQUAKE DAMAGE SCENARIO EVALUATION

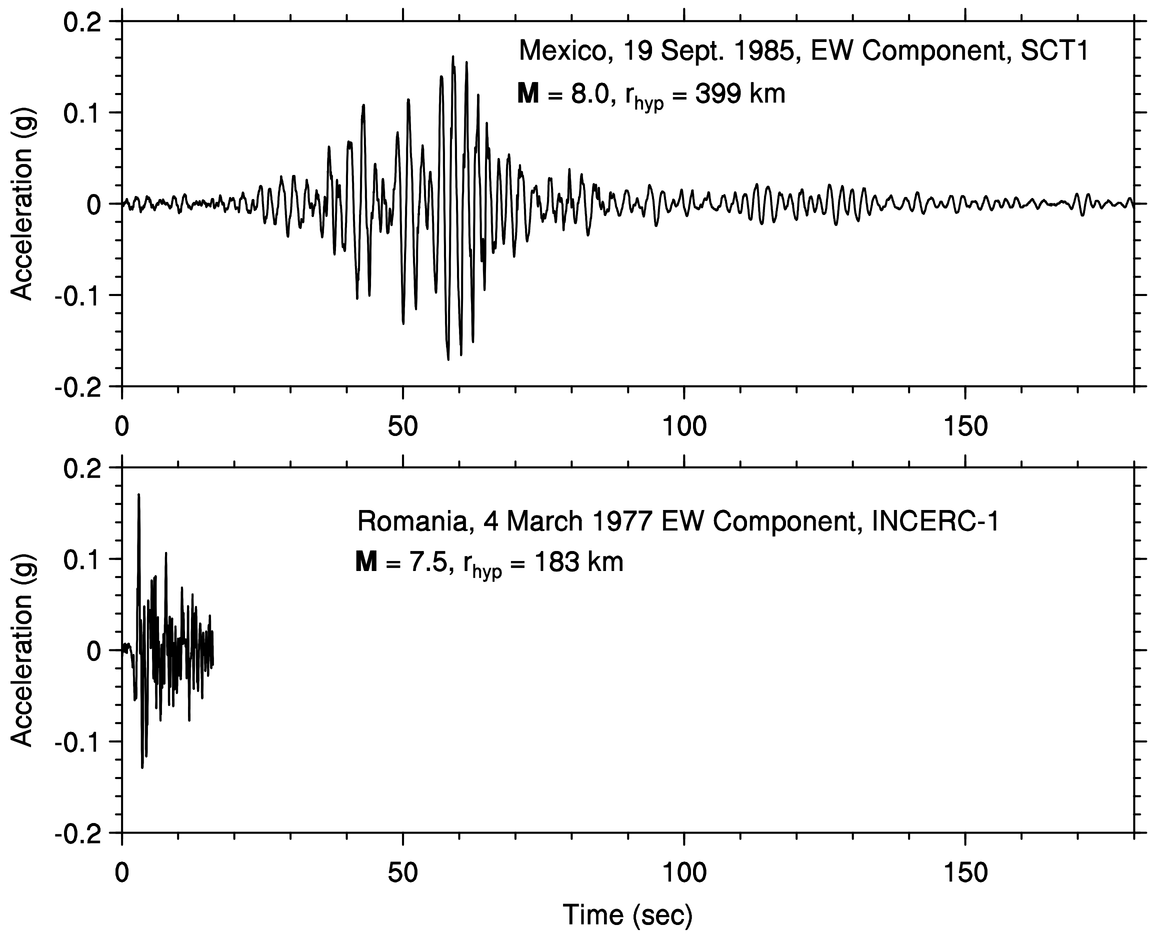
PGA as a demand parameter…



Acceleration time history. Rocca NS record.
1971 Ancona earthquake
(ML=4.7)



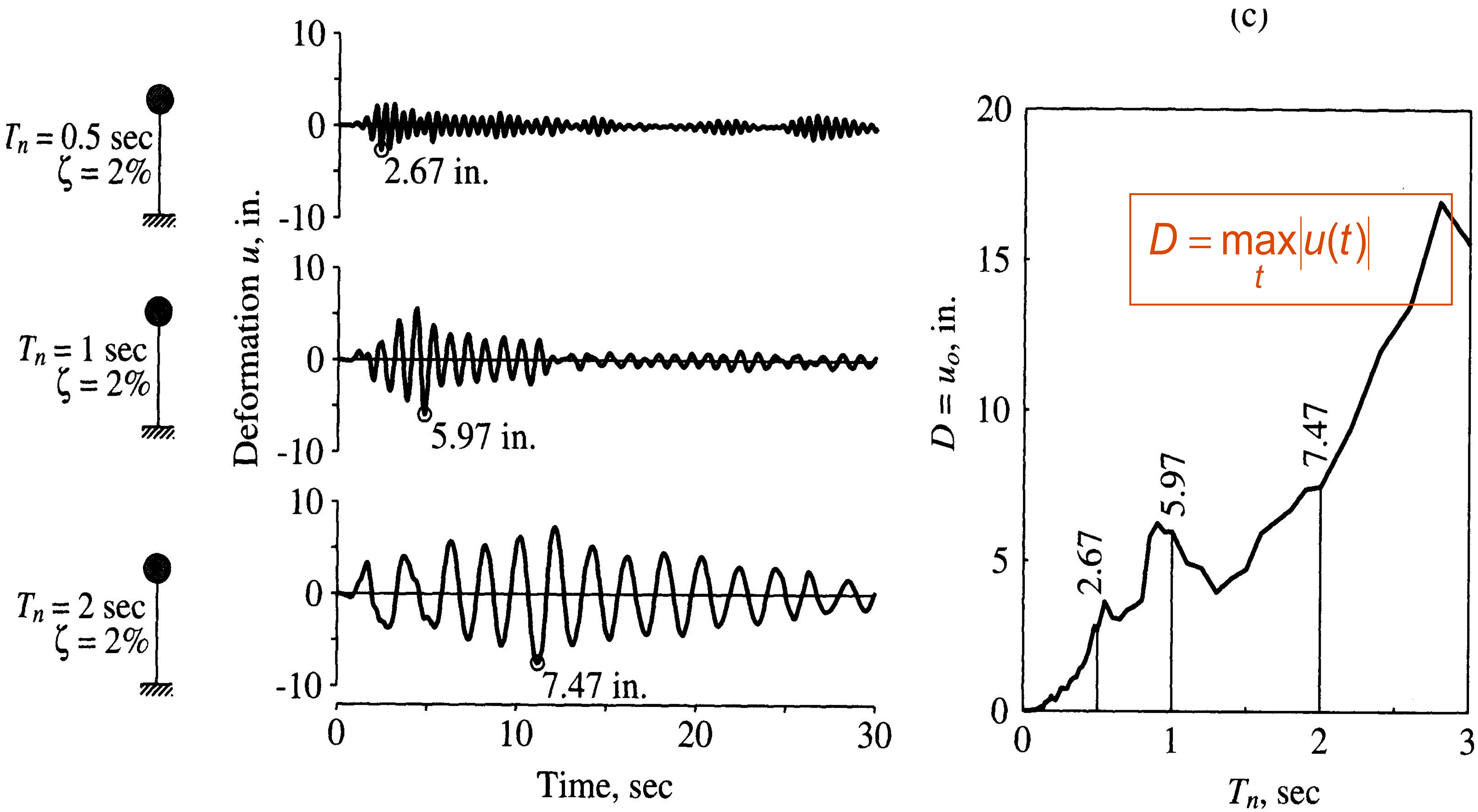
Acceleration time history. Sylmar N360 record.
1994 Northridge earthquake
(Mw=6.7)



Response spectra

A response spectrum is a plot of maximum response (e.g. displacement, velocity, acceleration) of SDF systems to a given ground acceleration versus systems parameters (T_n , ξ).

EXAMPLE **:** Deformation response spectrum for El Centro earthquake



$$D = \max_t |u(t)|$$

Response spectra

Deformation, pseudo-velocity and **pseudo-acceleration** response spectra can be defined and ploted on the same graphs

Peak Deformation $D = \max|u(t)|$

Peak Pseudo– velocity $V = \omega_n D$

Peak Pseudo– acceleration $A = \omega_n^2 D$

ω_n : natural circular frequency of the SDF system.

COMBINED D-V-A SPECTRUM

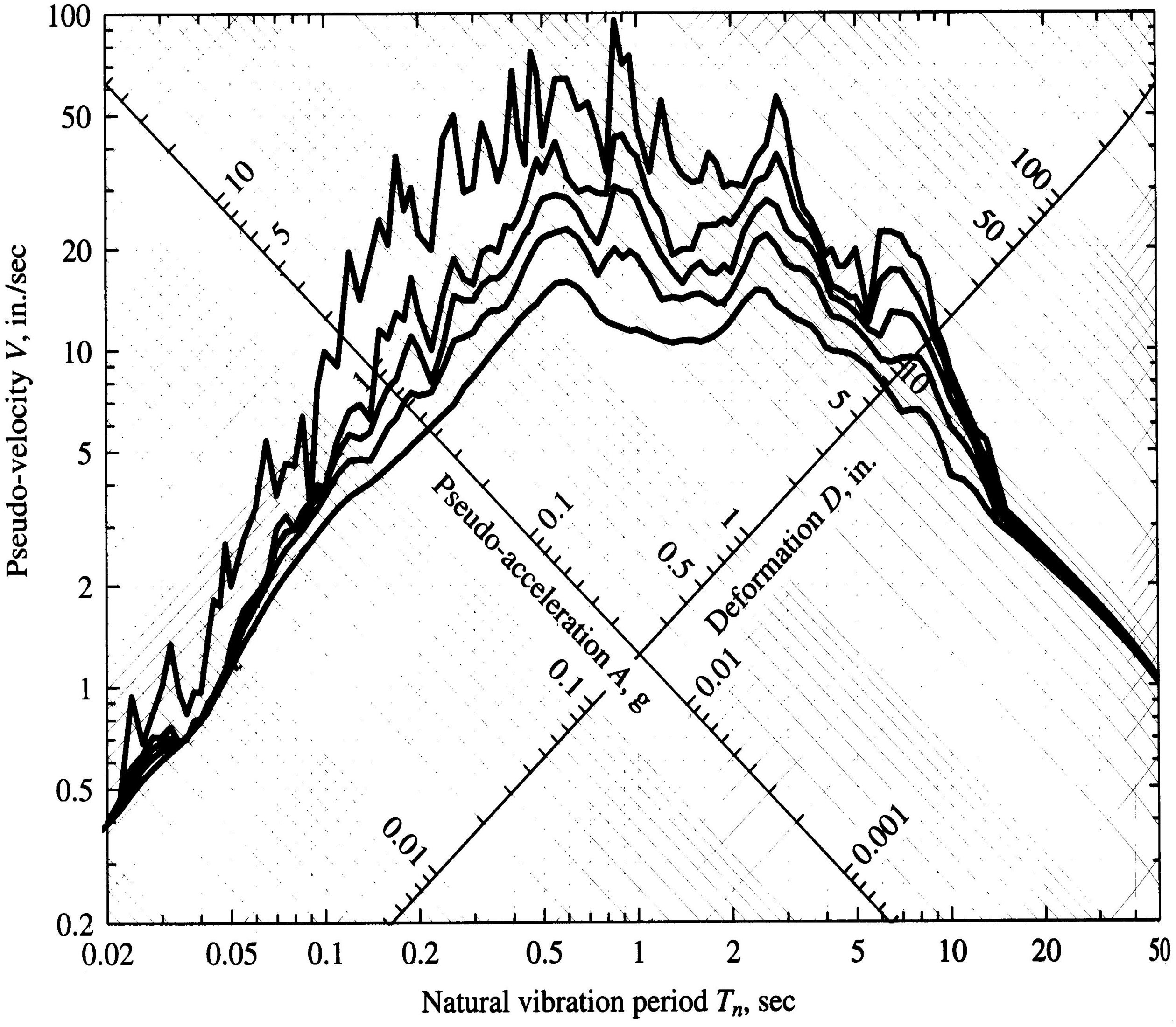
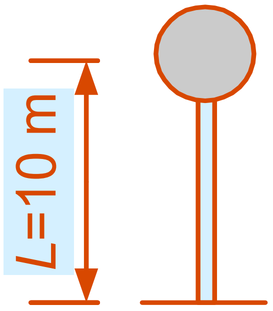


Figure 6.6.4 Combined *D–V–A* response spectrum for El Centro ground motion; ζ = 0, 2, 5, 10, and 20%.

EXAMPLE

A water tank is subjected to the El Centro earthquake. Calculate the maximum bending moment during the earthquake.



m = 10000 kg

k = 98.7 kN/m

ξ = 2%

$$\omega_n = \sqrt{\frac{k}{m}} = 3.14 \text{ rad/s} \text{ ® } T_n = \frac{2\pi}{\omega_n} = 2 \text{ s}$$

$$\text{Spectrum} \rightarrow \begin{cases} D = 7.47 \times 25.4 = 190 \text{ mm} \\ A = 0.191 \times 9.81 = 1.87 \text{ ms}^{-2} \end{cases}$$

$$(\text{obs}: \ A = \omega_n^2 D)$$

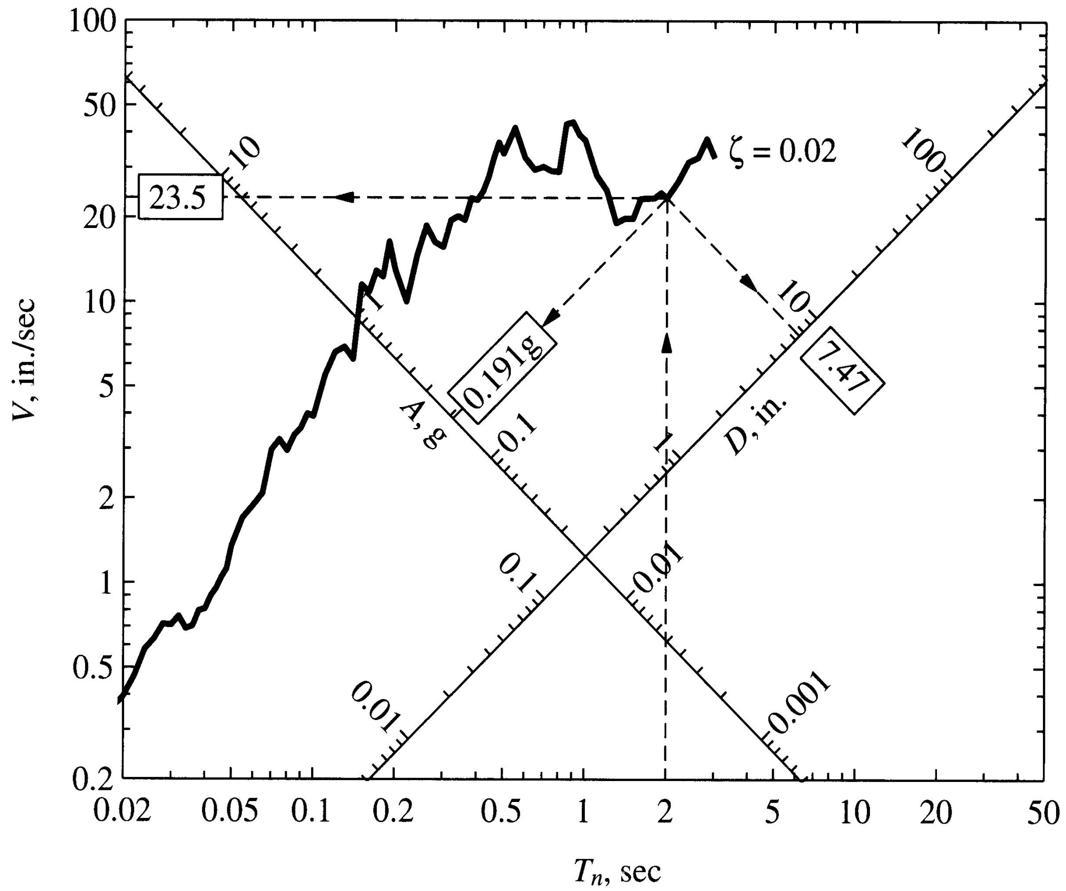
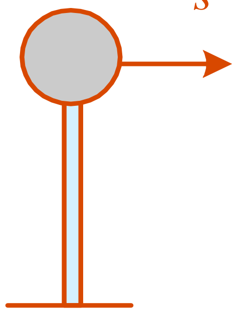
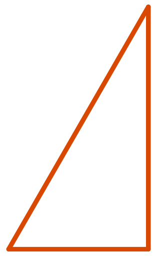


Figure 6.6.3 Combined D–V–A response spectrum for El Centro ground motion; $\zeta = 2\%$.

$$f_s = k \cdot D = 18.7 \text{ kN}$$





$$M_{\text{max}} = 187 \text{ kNm}$$

When the equivalent static force has been determined, the internal forces and stresses can be determined using statics.

Response spectrum characteristics

General characteristics can be derived from the analysis of response spectra.

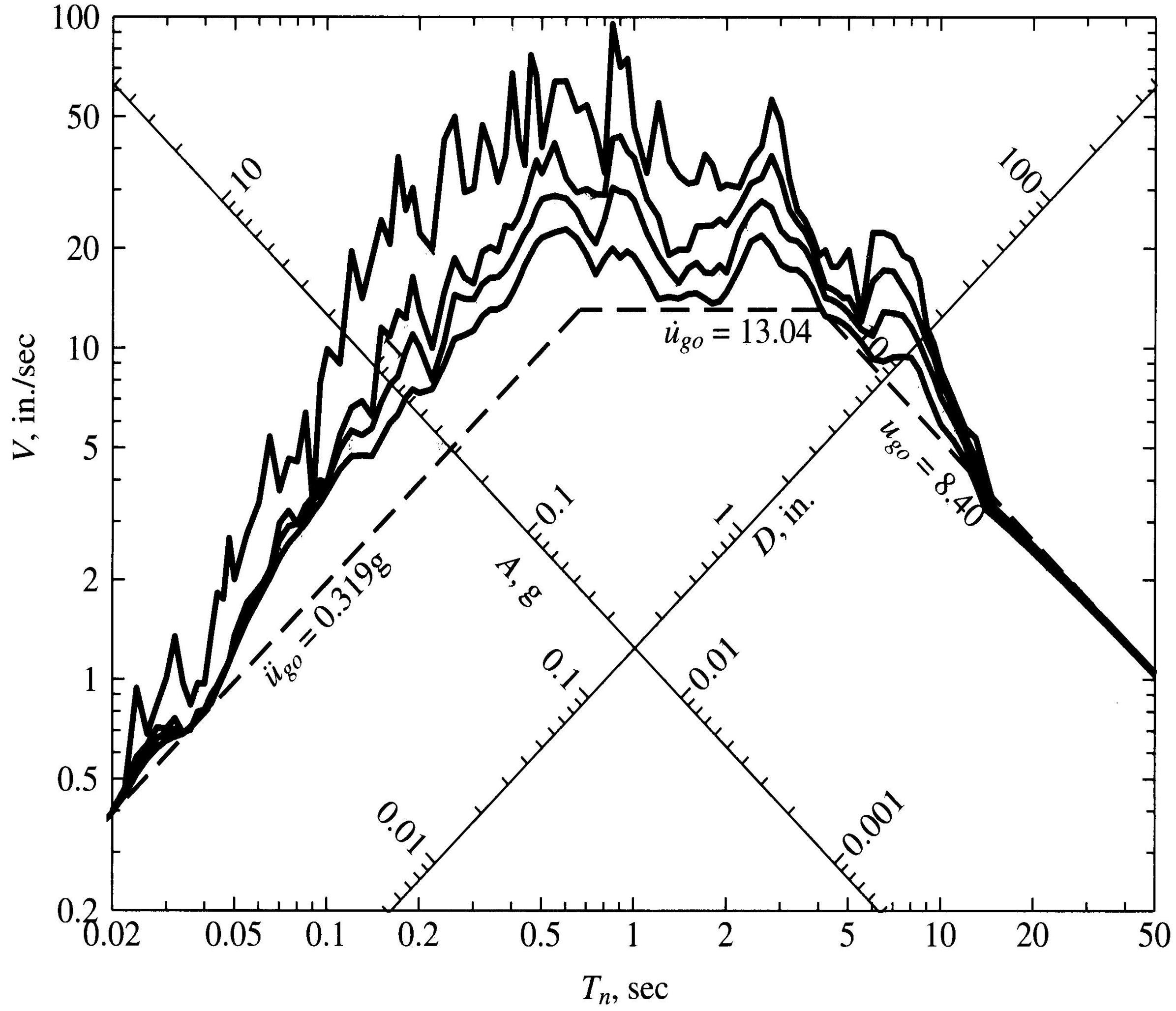


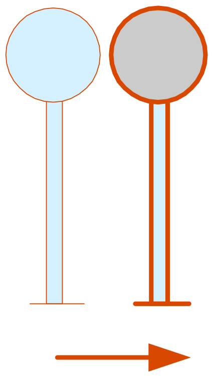
Figure 6.8.1 Response spectrum (ζ = 0, 2, 5, and 10%) and peak values of ground acceleration, ground velocity, and ground displacement for El Centro ground motion.

$$T_n = 2\pi\sqrt{m/k}$$

$T_n < 0.03$ s : rigid system

no deformation

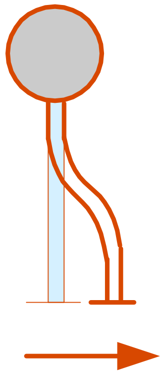
$u(t) \approx 0 \rightarrow D \approx 0$



$T_n > 15$ s : flexible system

no total displacement

$u(t) = u_g(t) \rightarrow D = u_{go}$



The spectrum can be divided in 3 period ranges :

$T_n < 0.5$s : acceleration sensitive region

$0.5 < T_n < 3$s : velocity sensitive region

$T_n > 3$s : displacement sensitive region

Elastic design spectrum

Problem: how to ensure that a structure will resist future earthquakes.

The elastic design spectrum is obtained from ground motions data recorded during past earthquakes at the site or in regions with near-similar conditions

EXAMPLE

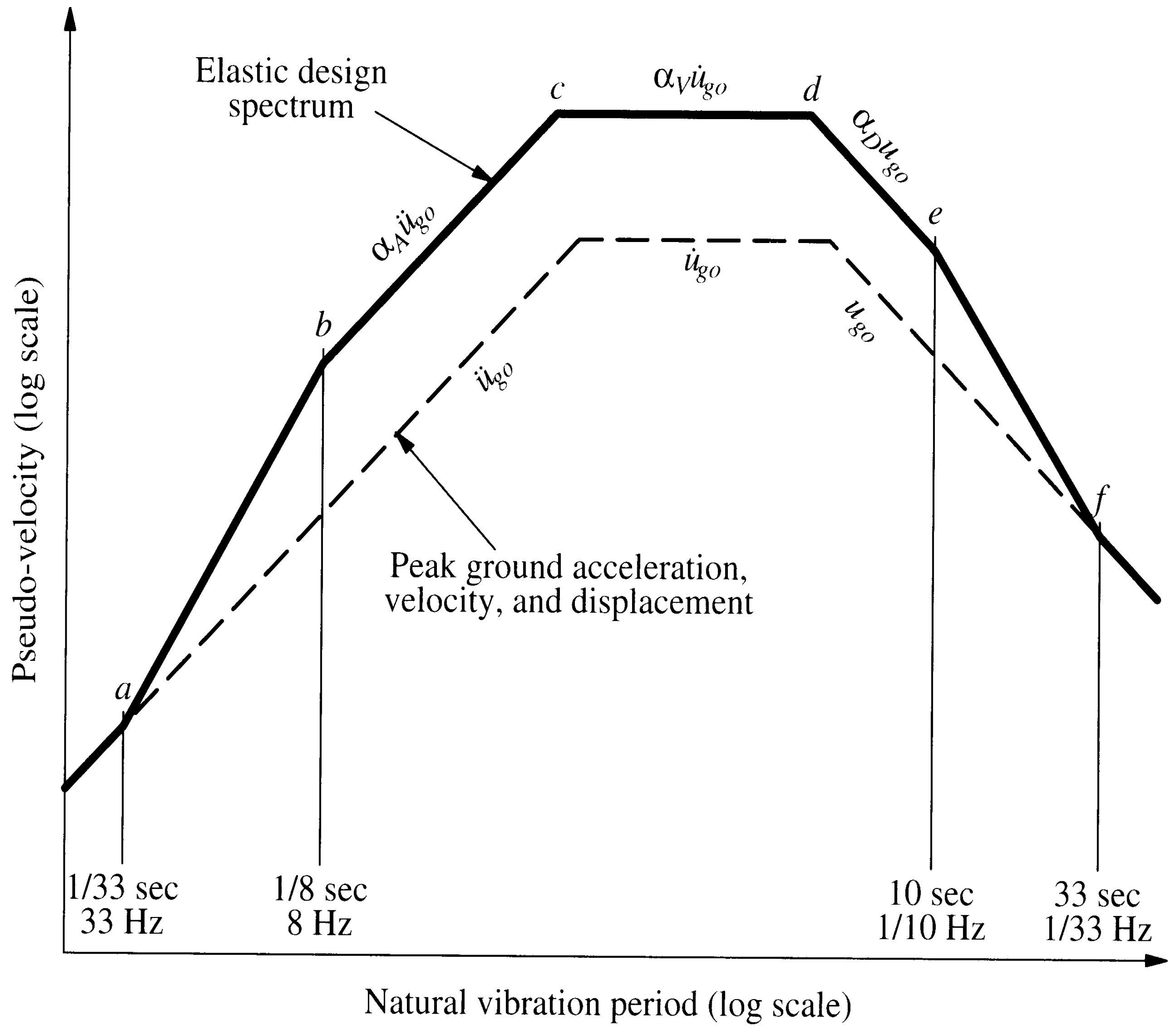


Figure 6.9.3 Construction of elastic design spectrum.

EPA

Realizing the limitation of using peak instrumental values, since damage can not be related only to the peak values, but it may require the occurrence of several repeated cycles, Applied Technology Council (1978) ATC introduced the concept of effective peak acceleration, EPA.

The effective peak acceleration EPA is defined as the average spectral acceleration over the period range 0.1 to 0.5 s divided by 2.5 (the standard amplification factor for a 5% damping spectrum), as follows:

$$\mathrm{EPA} = \frac{\bar{S}_{pa}}{2.5}$$

where is the mean pseudo-acceleration value. The empirical constant 2.5 is essentially an amplification factor of the response spectrum obtained from real peak value records. Thus EPA is correlated with the real peak value, but not equal to nor even proportional to it. If the ground motion consists of high frequency components, EPA will be obviously smaller than the real peak value.

It represents the acceleration which is most closely related to the structural response and to the damage potential of an earthquake. The EPA values for the two records of Ancona and Sylmar stations are 205 cm/s^2 and 774 cm/s^2 respectively, and describe in a more appropriate way, than PGA values, the damage caused by the two earthquakes.

Duration

Several observations derived from analyses of strong motion records of recent earthquakes indicate the considerable influence of the duration on the cumulative damage of the structures. For example, time histories with high amplitudes but short duration can be associated to moderate damages compared to ground motion with lowest amplitude but with longest duration. Moreover, it is well known that the major drawback in the use of elastic response spectra is the neglecting of the duration.

Different approaches have been taken to the problem of evaluating the duration of strong motion in an accelerogram. The bracketed duration (Bolt, 1973) is defined as the time between the first and the last exceedances of a threshold acceleration (usually 0.05g). Among the different duration definitions that can be found in the literature, one commonly used is that proposed by Trifunac e Brady (1975):

$$t_D = t_{0.95} - t_{0.05}$$

where $t_{0.05}$ and $t_{0.95}$ are the time at which respectively the 5% and 95%, of the time integral of the history of squared accelerations are reached, which corresponds to the time interval between the points at which 5% and 95% of the total energy has been recorded.

Arias Intensity

The Arias Intensity (Arias, 1969), IA, is defined as follows:

$$I_A = \frac{\pi}{2g} \int_0^{t_t} a_g^2(t)\, dt$$

where t_t and a_g are the total duration and ground acceleration of a ground motion record, respectively. The Arias intensity has units of velocity. IA represents the sum of the total energies, per unit mass, stored, at the end of the earthquake ground motion, in a population of undamped linear oscillators.

Arias Intensity, which is a measure of the global energy transmitted to an elastic system, tends to overestimate the intensity of an earthquake with long duration, high acceleration and broad band frequency content. Since it is obtained by integration over the entire duration rather than over the duration of strong motion, its value is independent of the method used to define the duration of strong motion.

Housner Intensity

Housner (1952) defined a measure expressing the relative severity of earthquakes in terms of the area under the pseudo-velocity spectrum between 0.1 and 2.5 seconds. Housner's spectral intensity IH is defined as:

$$I_H = \int_{0.1}^{2.5} S_{pv}\left(T,\xi\right) dT = \frac{1}{2\pi} \int_{0.1}^{2.5} S_{pa}\left(T,\xi\right) T \, dT$$

where S_{pv} is the pseudo-velocity at the undamped natural period T and damping ratio ξ, and S_{pa} is the pseudo-acceleration at the undamped natural period T and damping ratio ξ. Thus, Housner's spectral intensity is the first moment of the area of S_{pa} $(0.1<T<2.5)$ about the S_{pa} axis, implying that the Housner spectral intensity is larger for ground motions with a significant amount of low frequency content.

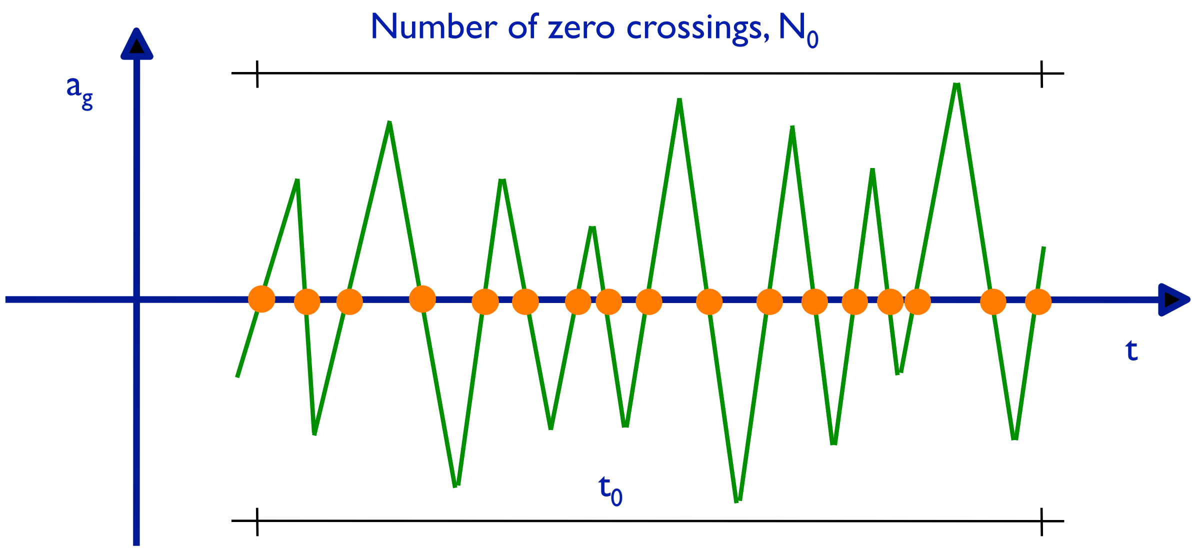
The IH parameter captures important aspects of the amplitude and frequency content in a single parameter, however, it does not provide information on the strong motion duration which is important for a structural system experiencing inelastic behaviour and yielding reversals.

Destructiveness potential factor

Araya & Saragoni (1984) proposed the destructiveness potential factor, P_D, that considers both the Arias Intensity and the rate of zero crossings, ν_0 and agrees with the observed damage better than other parameters. The destructiveness potential factor, which simultaneously considers the effect of the ground motion amplitude, strong motion duration, and frequency content on the relative destructiveness of different ground motion records, is defined as:

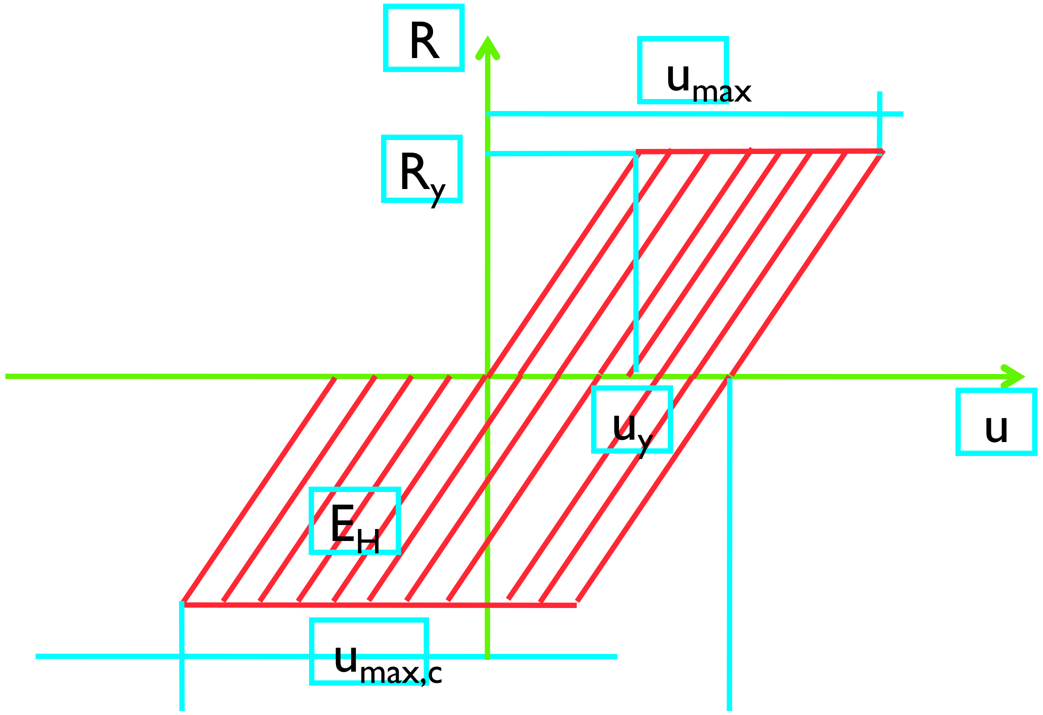
$$P_D = \frac{\pi}{2g} \frac{\int_0^{t_0} a_g^2(t)\,dt}{\nu_0^2} = \frac{I_A}{\nu_0^2} \qquad \nu_0 = \frac{N_0}{t_0}$$

where t is the time, a_g is the ground acceleration, $\nu_0 = N_0/t_0$ is the number of zero crossings of the acceleration time history per unit of time, N_0 is the number of the crossings with the time axis, t_0 is the total duration of the examined record (sometimes it could be a particular time-window), and IA is the Arias intensity.



Ductility

In current seismic regulations, the displacement **ductility** ratio μ is generally used to reduce the elastic design forces to a level which implicitly considers the possibility that a certain degree of inelastic deformations could occur. To this purpose, employing numerical methods, constant ductility response spectra were derived through non-linear dynamic analyses of viscously damped SDOF systems by defining the following two parameters:



$$\mu = \frac{u_{max}}{u_y} \qquad C_y = \frac{R_y}{mg}$$

$$\eta = \frac{R_y}{m\ddot{u}_{g(max)}} = \frac{C_y}{\ddot{u}_{g(max)}/g}$$

where R_y is the **yielding resistance**, m is the mass of the system, and $\ddot{u}_{g(max)}$ is the maximum ground acceleration.

The parameter C_y represents the structure's **yielding seismic resistance coefficient** and η expresses a system's **yield strength** relative to the maximum inertia force of an infinitely rigid system and reveals the strength of the system as a fraction of its weight relative to the peak ground acceleration expressed as a fraction of gravity.

Input Energy

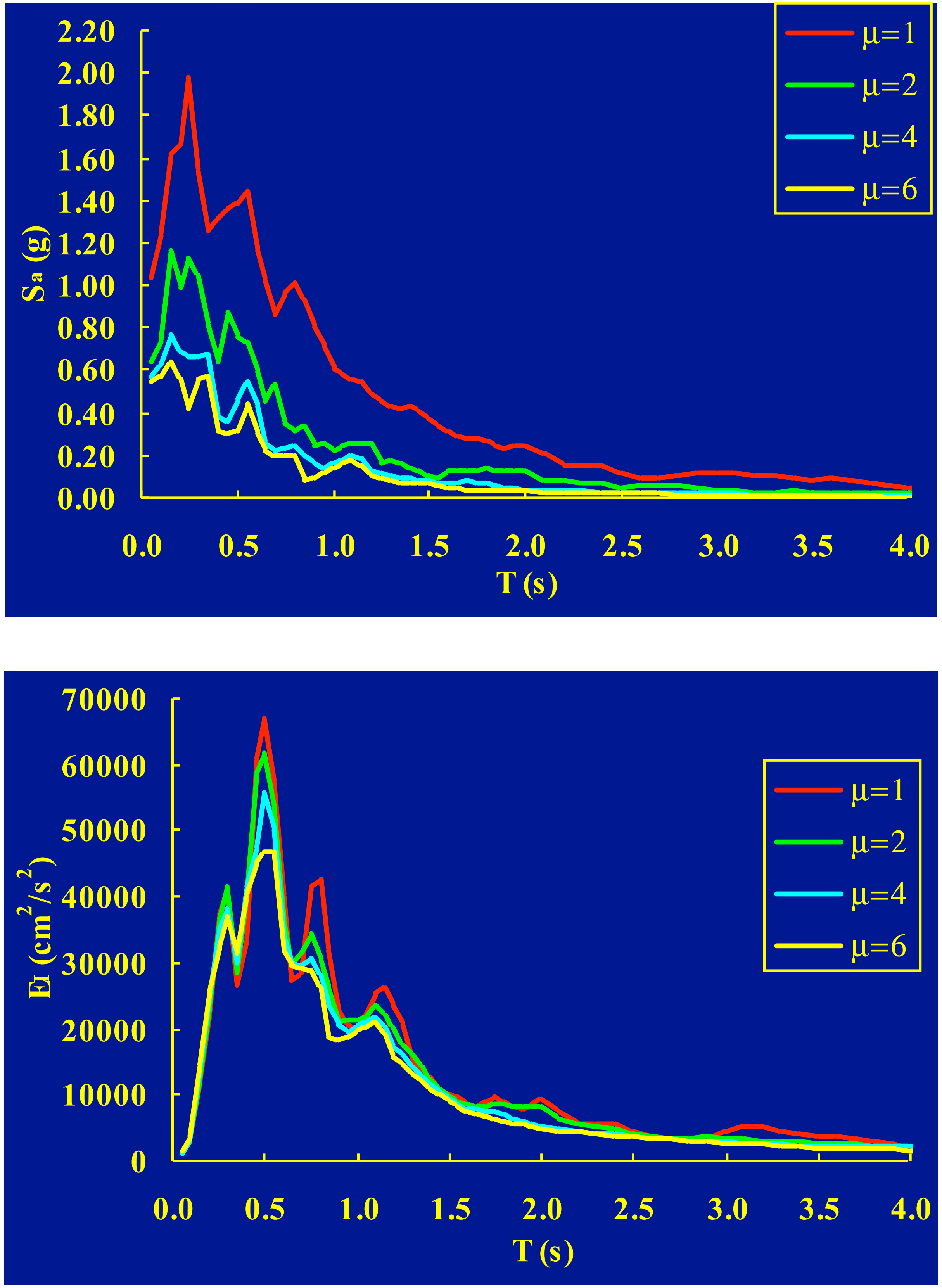
The elastic and inelastic (in terms of displacement ductility) response spectra are not sufficient for the estimation of the damage potential of the earthquake ground motion because they do not give a precise description of the quantity of the energy that will be dissipated through hysteretic behaviour; in the inelastic case they give only the value of the maximum ductility requirement. To overcome this problem other ductility definitions, e.g. hysteretic or cyclic ductility, were introduced.

Among all the different parameters proposed for defining the damage potential, perhaps the most promising is the Earthquake Input Energy (E_I) and associate parameters (the damping energy E_ξ and the plastic hysteretic energy E_H) introduced by Uang & Bertero (1990). This parameter considers the inelastic behavior of a structural system and depends on the dynamic features of both the strong motion and the structure.
The formulation of the energy parameters derives from the following balance energy equation (Uang & Bertero, 1990), where (E_I) is the input energy, (E_k) is the kinetic energy, (E_s) is the elastic strain energy:

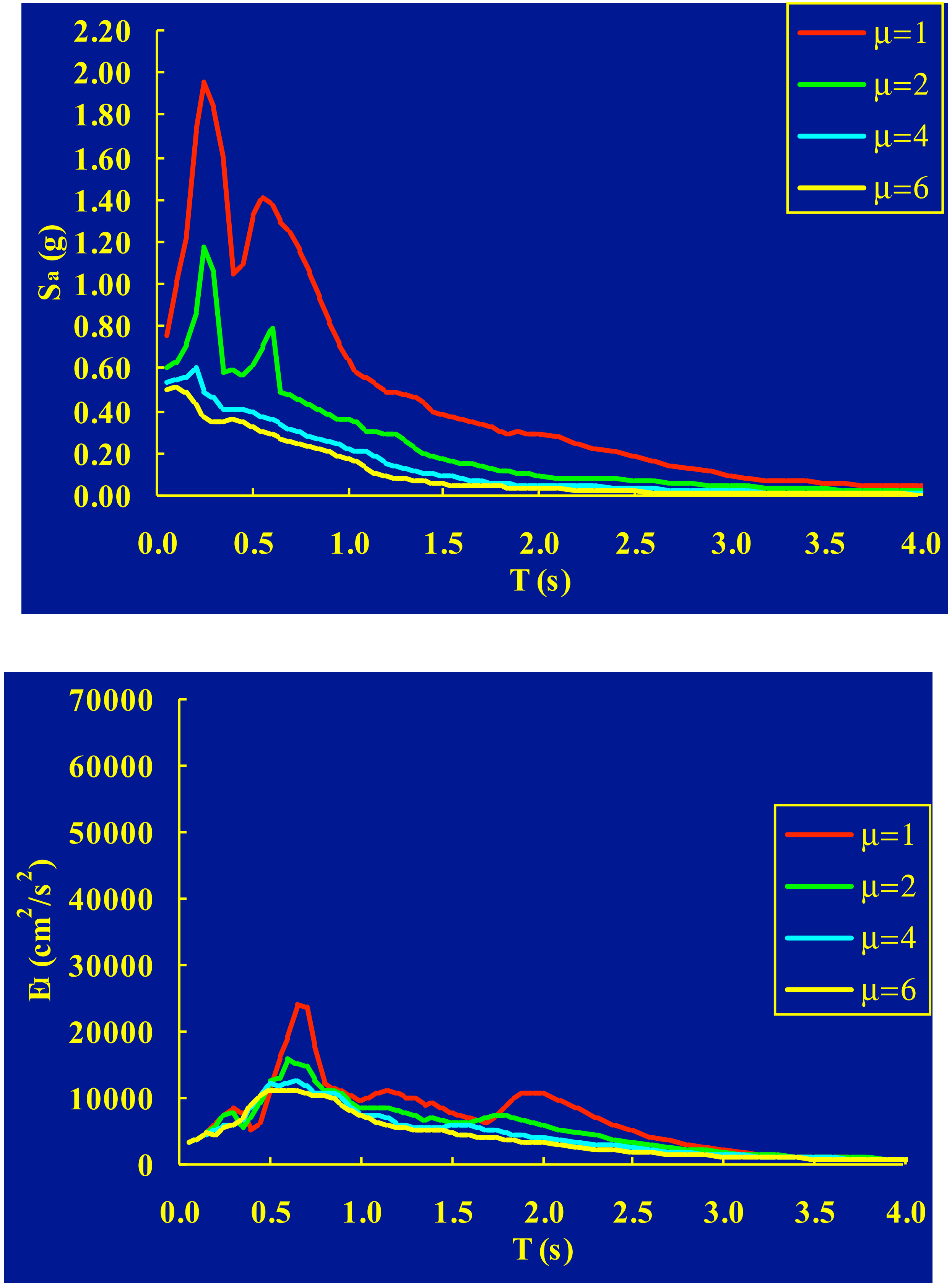
$$E_I = E_k + E_\xi + E_s + E_H$$

EI represents the work done by the total base shear at the foundation displacement.

Comparison



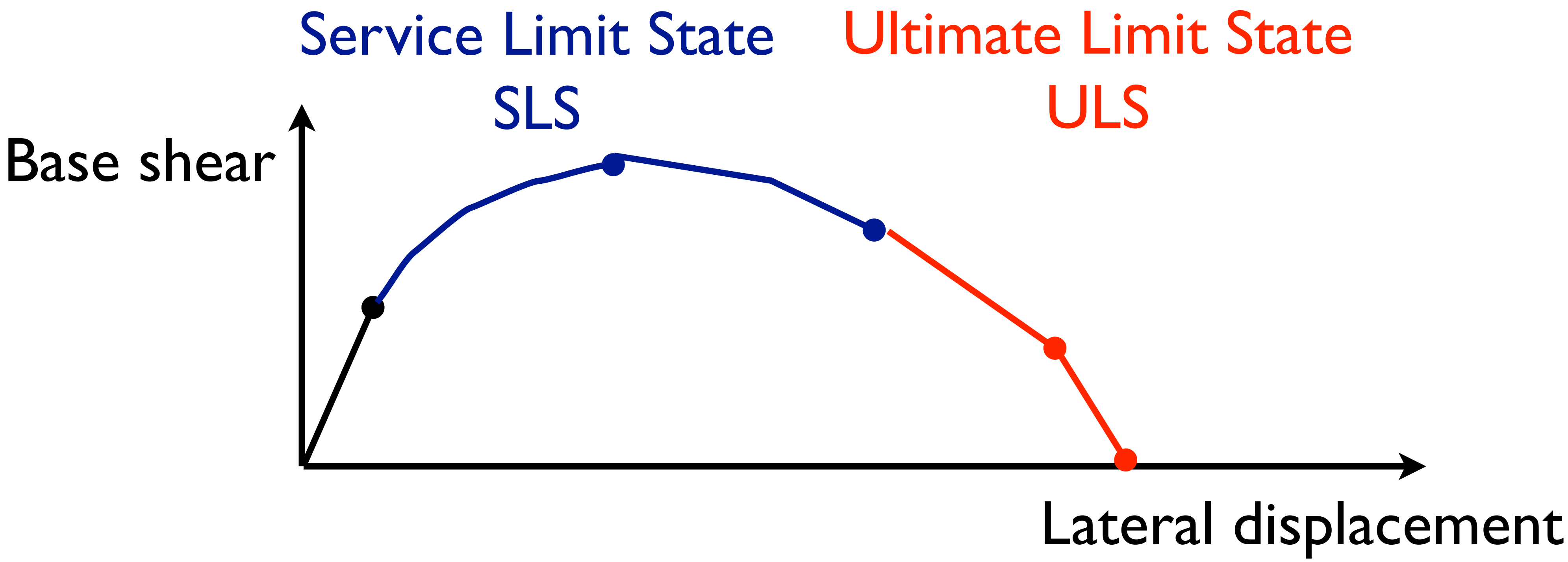
Chile Earthquake 1985
LLOLLEO N10, M=7.8, D_f=33 km



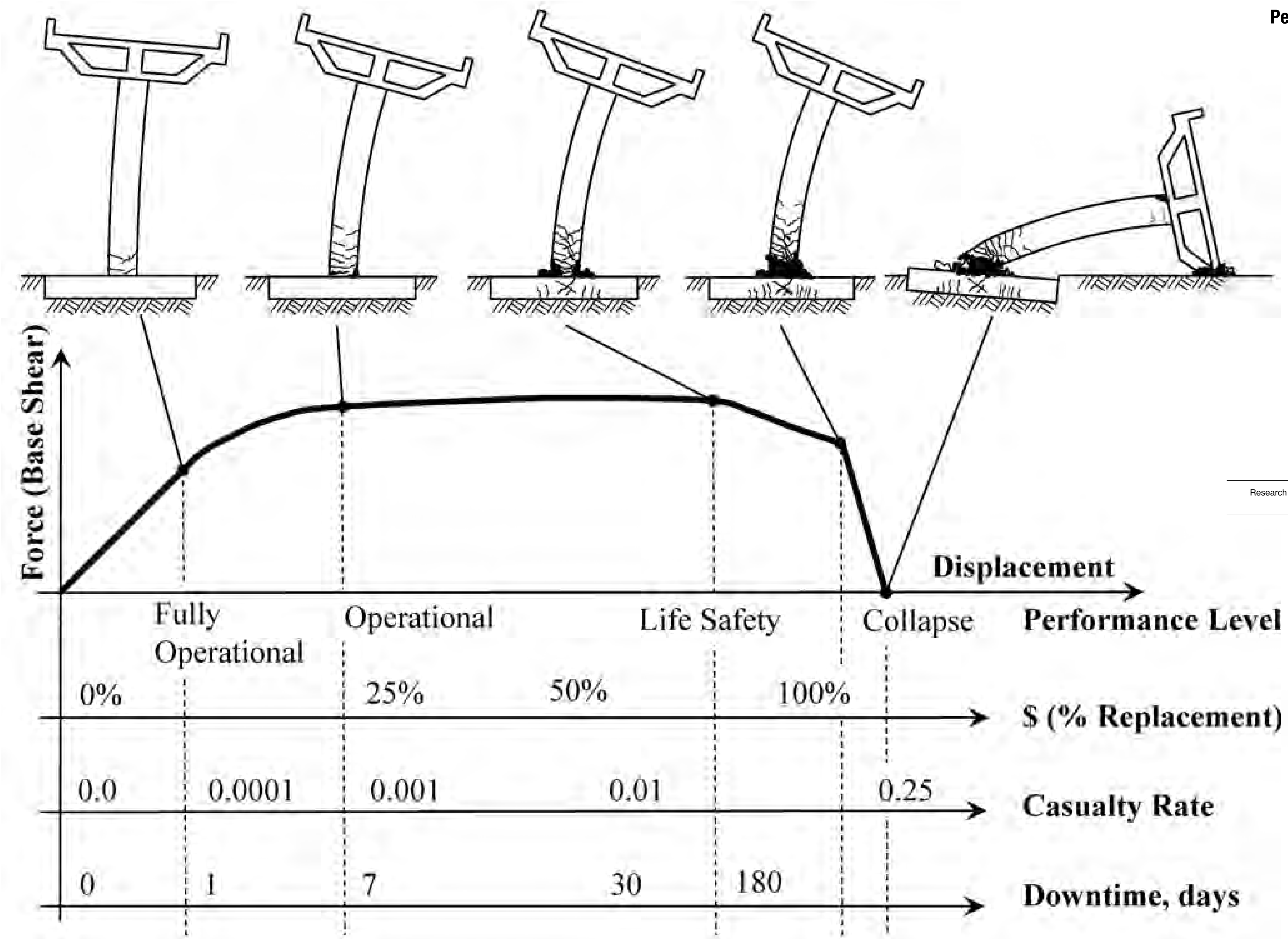
San Salvador Earthquake 1986
CIG N90, M=5.4, D_f=1.6 km

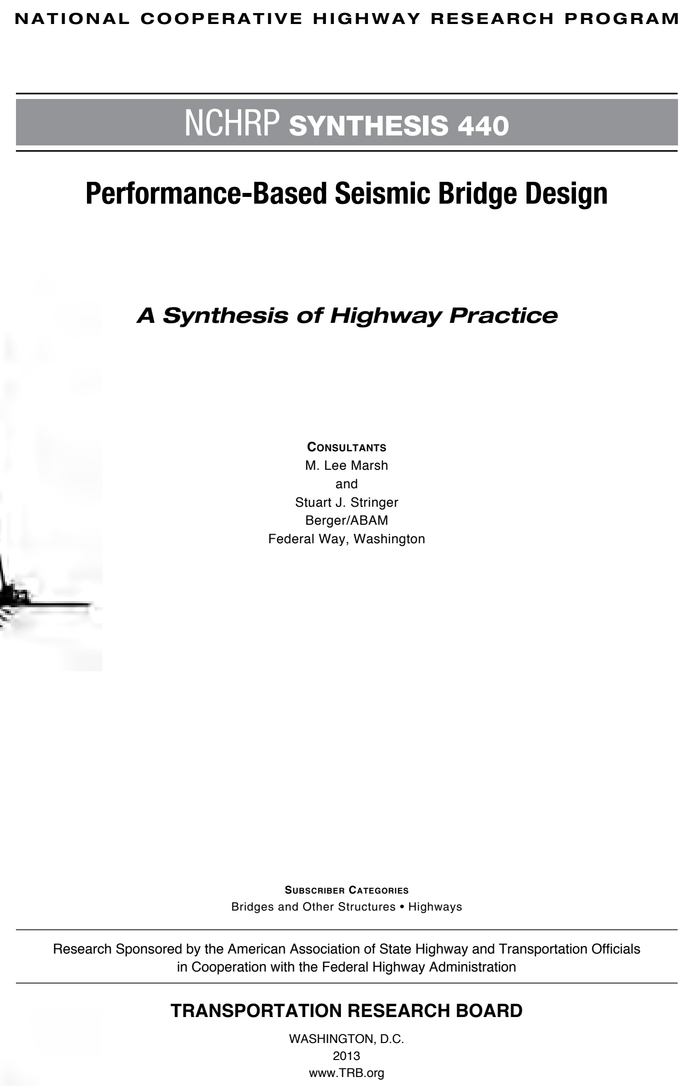
Performance Based Seismic Design

- Key elements of the implementation of PBSD:
  - definition of seismic design actions for multiple design levels
  - formats that are closely related to the structural and non-structural damage, that the PBSD framework specifically aims to control



Performance Based Seismic Design




NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP **SYNTHESIS 440**

Performance-Based Seismic Bridge Design

A Synthesis of Highway Practice

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and
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Subscriber Categories
Bridges and Other Structures • Highways

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in Cooperation with the Federal Highway Administration

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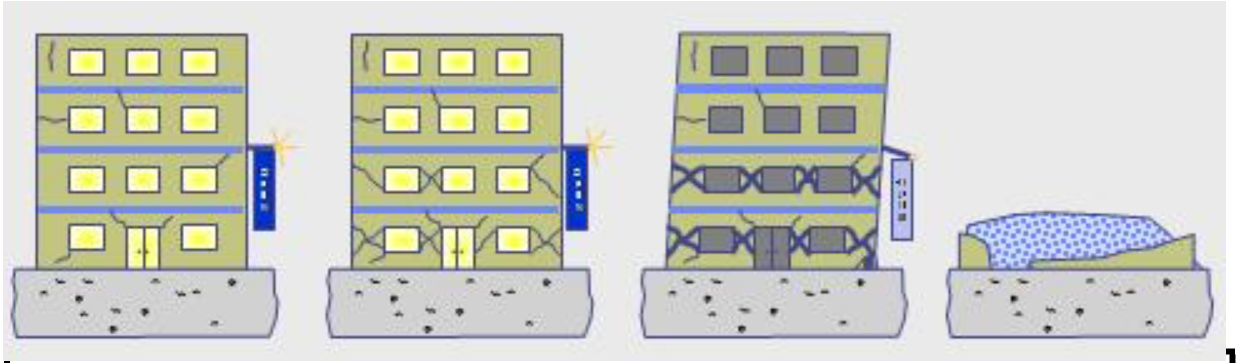
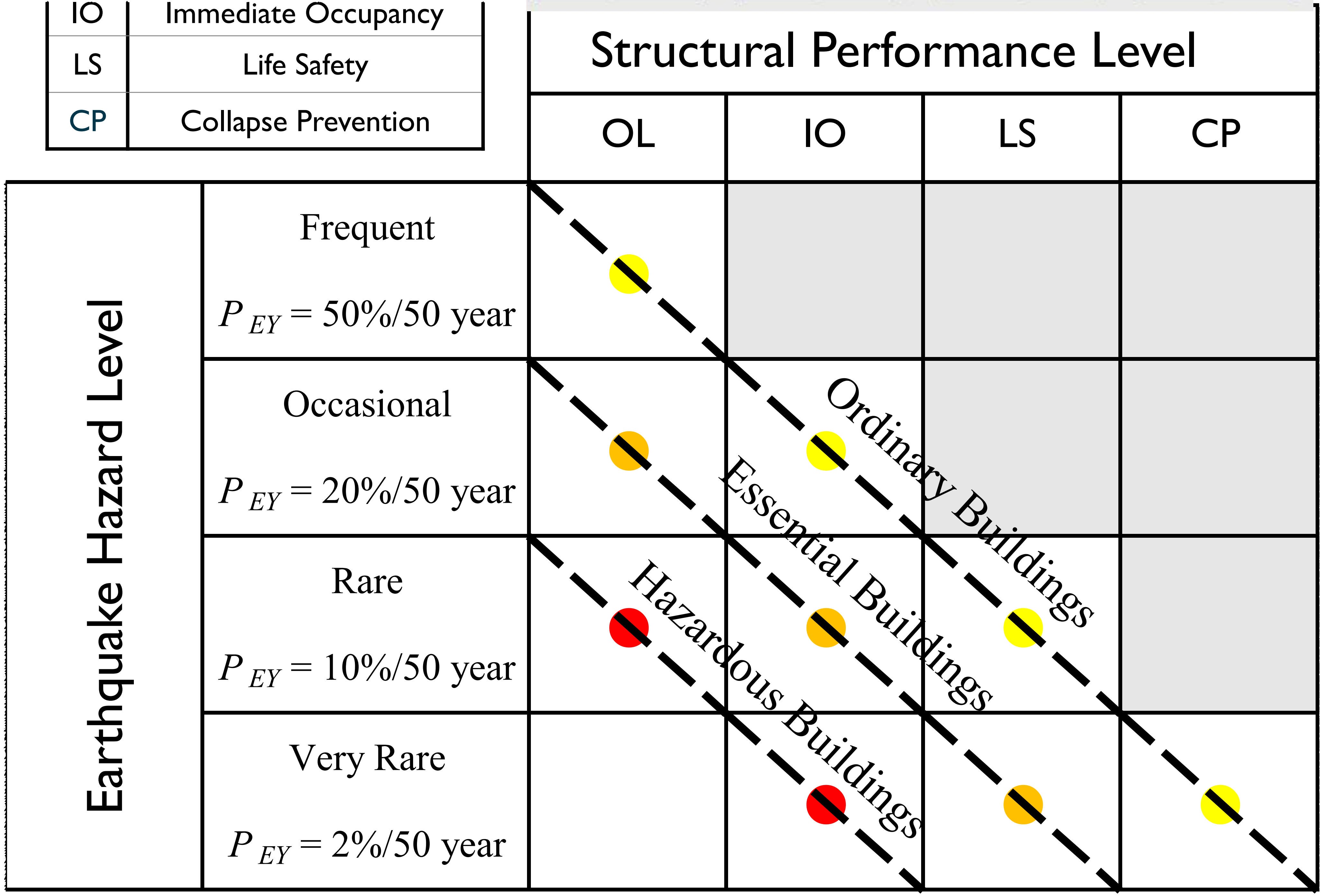
www.TRB.org

http://www.iitk.ac.in/nicee/wcee/article/2831.pdf

Earthquake Performance Level

OL	Operational Limit
IO	Immediate Occupancy
LS	Life Safety
CP	Collapse Prevention





Earthquake Hazard Level		Structural Performance Level			
		OL	IO	LS	CP
	Frequent $P_{EY} = 50\%/50$ year	🟡			
	Occasional $P_{EY} = 20\%/50$ year	🟠	🟡		
	Rare $P_{EY} = 10\%/50$ year	🔴	🟠	🟡	
	Very Rare $P_{EY} = 2\%/50$ year		🔴	🟠	🟡

PBD in Italy

- Stati Limite Ultimi (SLU)
  - Stato limite di salvaguardia della vita (SLV)
  - Stato limite di prevenzione del collasso (SLC)
- Stati Limite Esercizio (SLE)
  - Stato Limite di operatività (SLO)
  - Stato limite di danno (SLD)

https://it.wikipedia.org/wiki/Stato_limite

Italian code NTC18 - T_R

- Le probabilità di superamento nel periodo di riferimento P_{VR}, cui riferirsi per individuare l’azione sismica agente in ciascuno degli stati limite considerati, sono riportate nella Tab. 3.2.I.

Tab. 3.2.I – *Probabilità di superamento P_{V_R} in funzione dello stato limite considerato*

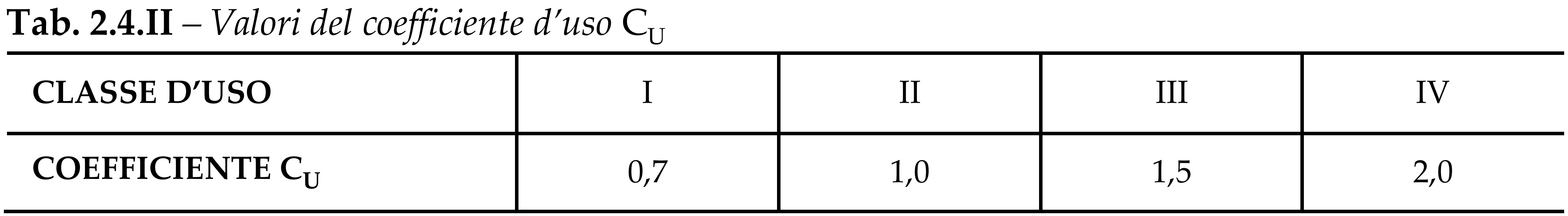
Stati Limite	**P_{V_R}: Probabilità di superamento nel periodo di riferimento V_R**	
Stati limite di esercizio	SLO	81%
	SLD	63%
Stati limite ultimi	SLV	10%
	SLC	5%

Per ciascuno stato limite e relativa probabilità di eccedenza P_{VR} nel periodo di riferimento V_R si ricava il periodo di ritorno T_R del sisma utilizzando la relazione:

$$T_R = -\frac{V_R}{\ln(1-P_{VR})} = -\frac{C_U V_N}{\ln(1-P_{VR})}$$

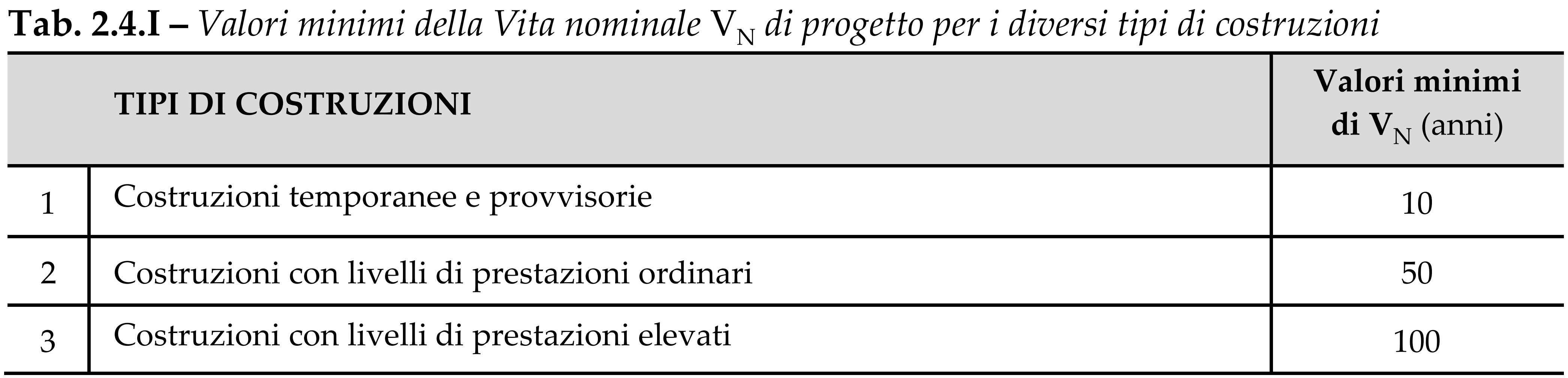
Italian code NTC18 - V_R e V_N

- Le azioni sismiche sulle costruzioni vengono valutate in relazione ad un periodo di riferimento V_R che si ricava, per ciascun tipo di costruzione, moltiplicandone la vita nominale di progetto V_N per il coefficiente d'uso C_U:



Tab. 2.4.II – *Valori del coefficiente d'uso* C_U

CLASSE D'USO	I	II	III	IV
COEFFICIENTE C_U	0,7	1,0	1,5	2,0



Tab. 2.4.I – *Valori minimi della Vita nominale* V_N *di progetto per i diversi tipi di costruzioni*

	TIPI DI COSTRUZIONI	**Valori minimi di V_N** (anni)
1	Costruzioni temporanee e provvisorie	10
2	Costruzioni con livelli di prestazioni ordinari	50
3	Costruzioni con livelli di prestazioni elevati	100

Italian code NTC18 - Classe d’uso

2.4.2. CLASSI D’USO

Con riferimento alle conseguenze di una interruzione di operatività o di un eventuale collasso, le costruzioni sono suddivise in classi d’uso così definite:

Classe I: Costruzioni con presenza solo occasionale di persone, edifici agricoli.

Classe II: Costruzioni il cui uso preveda normali affollamenti, senza contenuti pericolosi per l’ambiente e senza funzioni pubbliche e sociali essenziali. Industrie con attività non pericolose per l’ambiente. Ponti, opere infrastrutturali, reti viarie non ricadenti in Classe d’uso III o in Classe d’uso IV, reti ferroviarie la cui interruzione non provochi situazioni di emergenza. Dighe il cui collasso non provochi conseguenze rilevanti.

Classe III: Costruzioni il cui uso preveda affollamenti significativi. Industrie con attività pericolose per l’ambiente. Reti viarie extraurbane non ricadenti in Classe d’uso IV. Ponti e reti ferroviarie la cui interruzione provochi situazioni di emergenza. Dighe rilevanti per le conseguenze di un loro eventuale collasso.

Classe IV: Costruzioni con funzioni pubbliche o strategiche importanti, anche con riferimento alla gestione della protezione civile in caso di calamità. Industrie con attività particolarmente pericolose per l’ambiente. Reti viarie di tipo A o B, di cui al DM 5/11/2001, n. 6792, “Norme funzionali e geometriche per la costruzione delle strade”, e di tipo C quando appartenenti ad itinerari di collegamento tra capoluoghi di provincia non altresì serviti da strade di tipo A o B. Ponti e reti ferroviarie di importanza critica per il mantenimento delle vie di comunicazione, particolarmente dopo un evento sismico. Dighe connesse al funzionamento di acquedotti e a impianti di produzione di energia elettrica.

Italian code NTC18 - Azioni

CLASSIFICAZIONE DELLE AZIONI SECONDO LA VARIAZIONE DELLA LORO INTENSITÀ NEL TEMPO

- a) permanenti (G): azioni che agiscono durante tutta la vita nominale di progetto della costruzione, la cui variazione di intensità nel tempo è molto lenta e di modesta entità
- b) variabili (Q): azioni che agiscono con valori istantanei che possono risultare sensibilmente diversi fra loro nel corso della vita nominale della struttura
  - sovraccarichi;
  - azioni del vento;
  - azioni della neve;
  - azioni della temperatura.
- c) eccezionali (A): azioni che si verificano solo eccezionalmente nel corso della vita nominale della struttura;
  - incendi;
  - esplosioni;
  - urti ed impatti;
- d) sismiche (E): azioni derivanti dai terremoti.

Italian building code (NTC08/18)

- Seismic classification

  https://rischi.protezionecivile.gov.it/it/sismico/attivita/classificazione-sismica

- Seismic hazard

  http://esse1.mi.ingv.it

- NTC08 Seismic code (§ 2.*; 3.2; 7.*)

  https://www.gazzettaufficiale.it/eli/id/2008/02/04/08A00368/sg

- NTC18 Seismic code (§ 2.*; 3.2; 7.*)

  https://www.gazzettaufficiale.it/eli/gu/2018/02/20/42/so/8/sg/pdf

  https://www.gazzettaufficiale.it/eli/id/2019/02/11/19A00855/sg