Construction of Design Response Spectrum – The Chilean way

EPS 256

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Seismic design of structures

* When you are designing an earthquake resistant structure some important questions are:

- How to estimate the maximum forces generated by the earthquake?

- What is this earthquake to be considered?

Seismic design of structures

* In USA there is probabilistic approach. For each specific site you define a Maximum Considered Earthquake (MCE) (an event with a 2% probability of exceedence in 50 years or a Tr = 2475 years). The design earthquake is 2/3 the MCE.

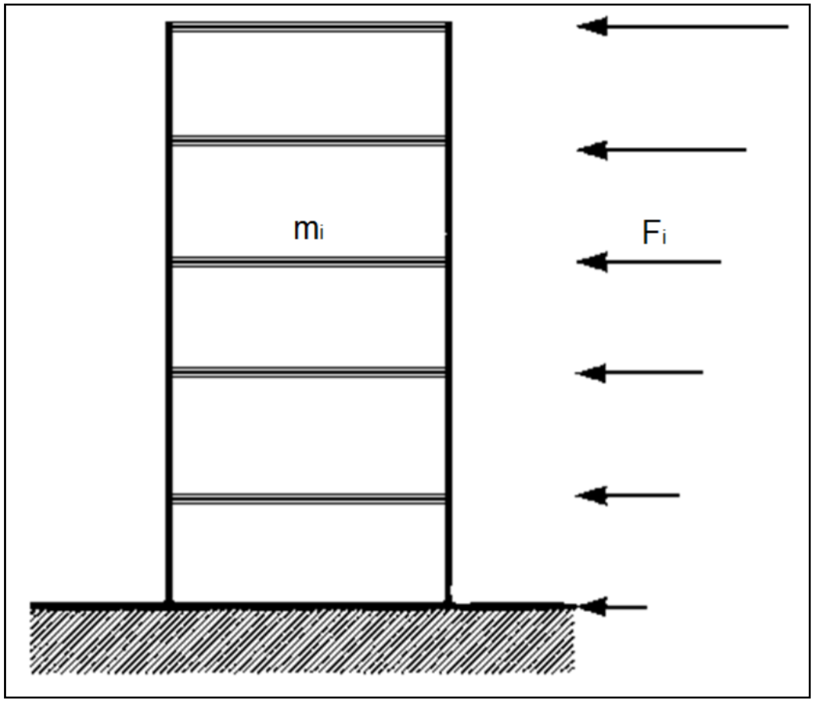
* In Chile the approach is deterministic. The design earthquake corresponds to the biggest earthquake recorded (for the current code is the 03/03/1985, Mw = 7.8 event)

Seismic analysis

* There are three ways “to apply” the seismic action:

1. *Static.*
2. *Time history analysis.*
3. *Modal spectral analysis (most used).*

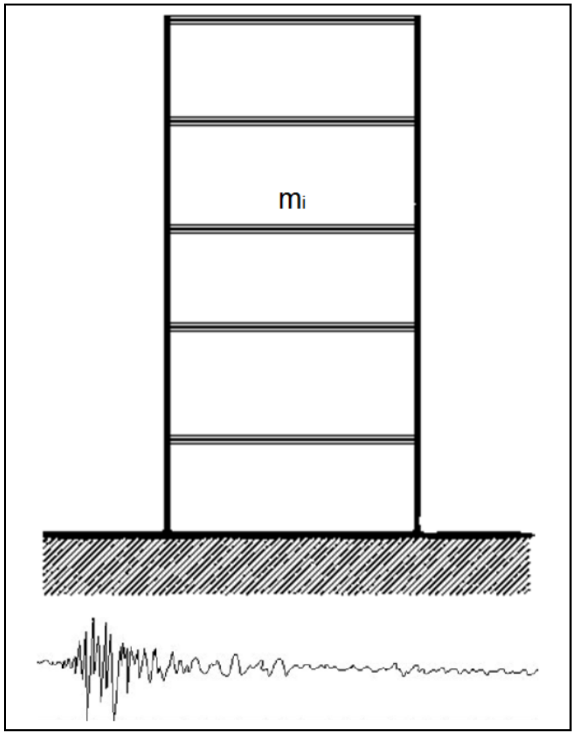
Seismic analysis - Static



* Used in the past years or for structures of less than 5 stories and in certain seismic zones.

* It assumes that the seismic deformations increases linearly with the height (first mode).

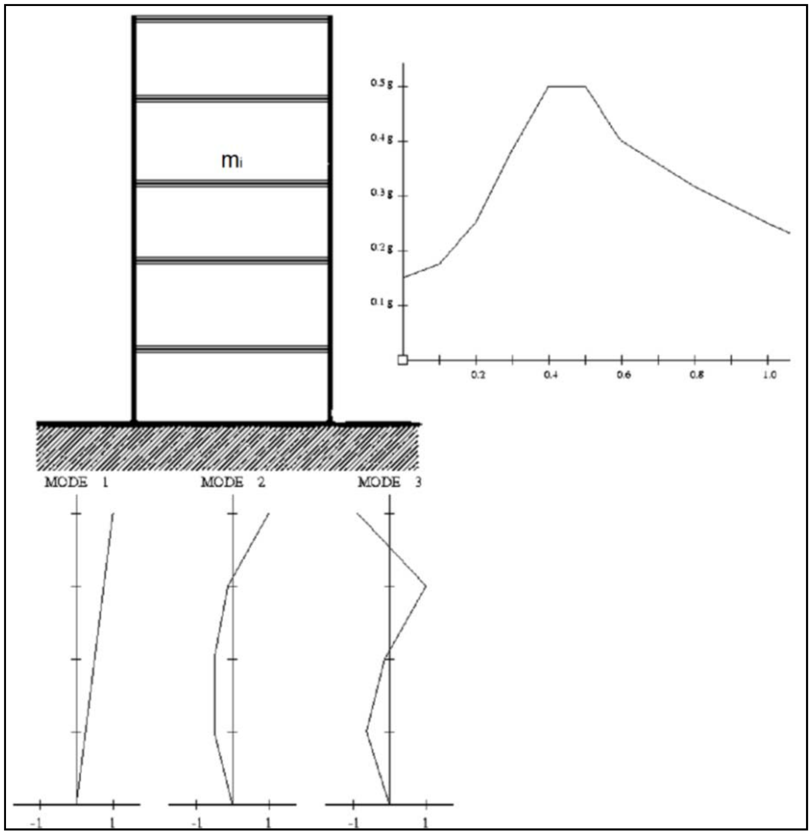
Seismic analysis – Time history analysis



* You find the response of the structure (internal forces) as a function of time for a specific ground motion.

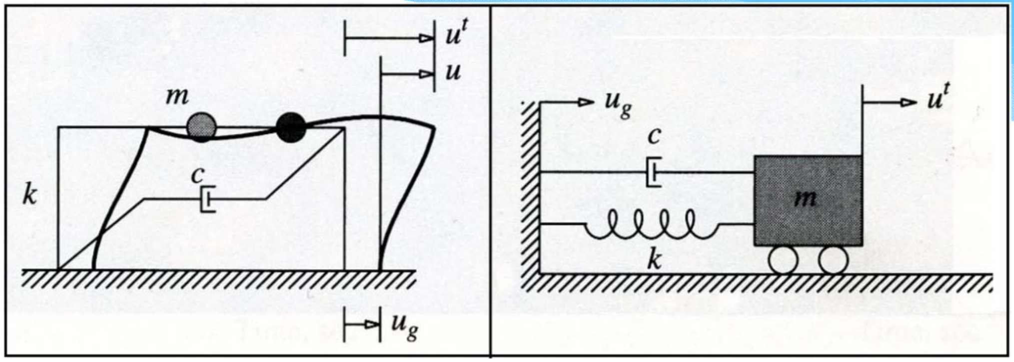
* It requires to have the accelerogram of the design earthquake or have several representative accelerograms of big earthquakes.

Seismic analysis – Modal spectral analysis



- It defines the seismic behavior of the structure as the superposition of n-modes of vibration.
- It requires to define a Design Response Spectrum, in general, a spectrum of pseudo-accelerations.

Seismic analysis – Modal spectral analysis – One DOF system

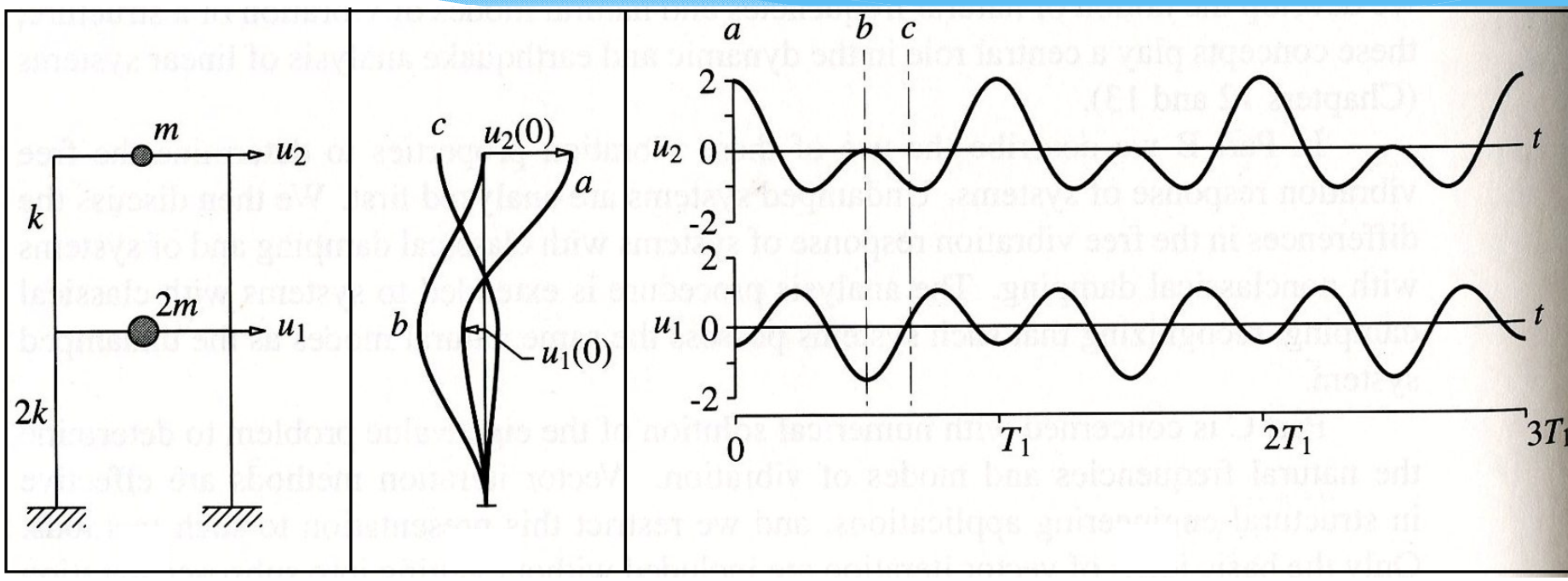


$$m * \ddot{u}(t) + c * \dot{u}(t) + k * u(t) = -m * \ddot{u}_g(t)$$

$$\ddot{u}(t) + 2 * \xi * \omega_n * \dot{u}(t) + {\omega_n}^2 * u(t) = -\ddot{u}_g(t) \quad \text{; Eq.(1)}$$

* Where:
  * $T_n = \frac{2*\pi}{\omega_n}$: Natural period of vibration
  * $\xi = \frac{c}{2*m*\omega_n}$: *Damping ratio*
  * $\ddot{u}_g(t)$: Ground acceleration

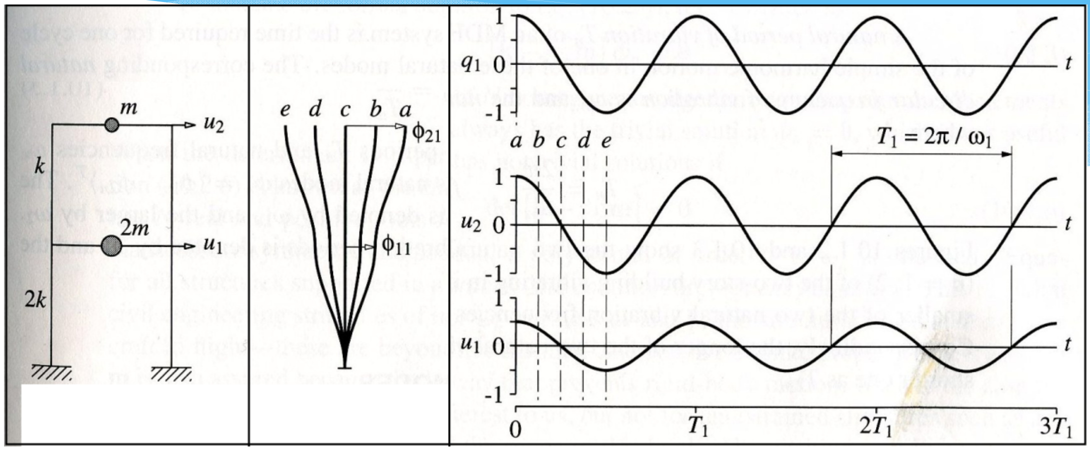
Seismic analysis – Modal spectral analysis – MDOF system

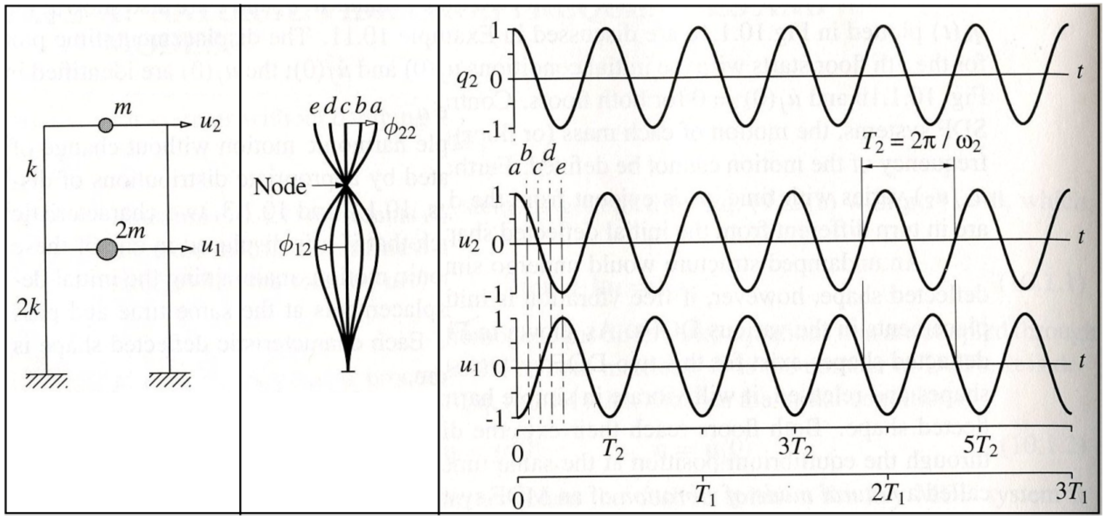


$$[M] * \overrightarrow{\ddot{u}(t)} + [C] * \overrightarrow{\dot{u}(t)} + [K] * \overrightarrow{u(t)} = -[M] * \vec{\imath} * \ddot{u}_g(t)$$

$$\ddot{q}_n(t) + 2 * \xi_n * \omega_n * \dot{q}_n(t) + \omega_n{}^2 * q_n(t) = -\Gamma_n * \ddot{u}_g(t)$$

Seismic analysis – Modal spectral analysis – MDOF system





Seismic analysis – Modal spectral analysis

* Now, it is necessary to construct the design response spectrum.

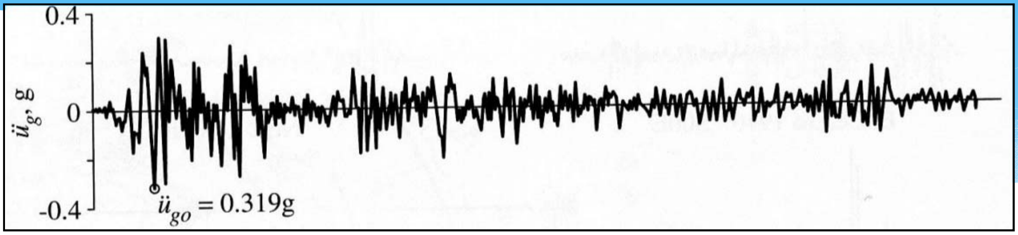
* A plot of the peak value of a response quantity (eg. acceleration) as a function of the natural vibration period of the system is called the response spectrum for this quantity.

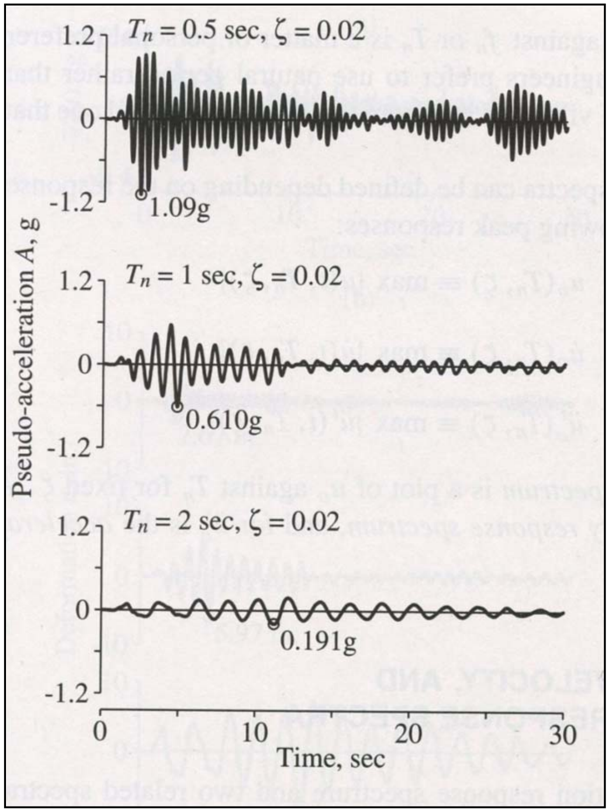
* This response spectrum will depend on the damping ratio and the ground motion selected.

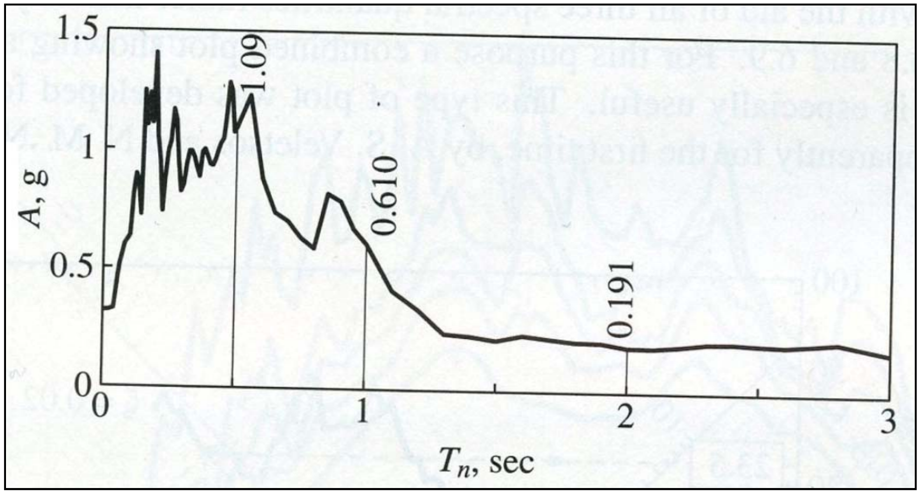
Seismic analysis – Modal spectral analysis

* For a fixed value of damping ratio (eg. ξ = 5%) and for a given ground motion (eg. El Centro 1940) we have to procedure as follow:
* For each value of T_n, we have to solve equation (1) and find the maximum value of $u(\ddot{t})$, $u(\dot{t})$ and $u(t)$ asociated with this period.
* Then, we have to repeat the procedure for another value of T_n, for the whole range of interest.
* Finally we plot in the x-axis the period and in the y-axis the quantity respectively.

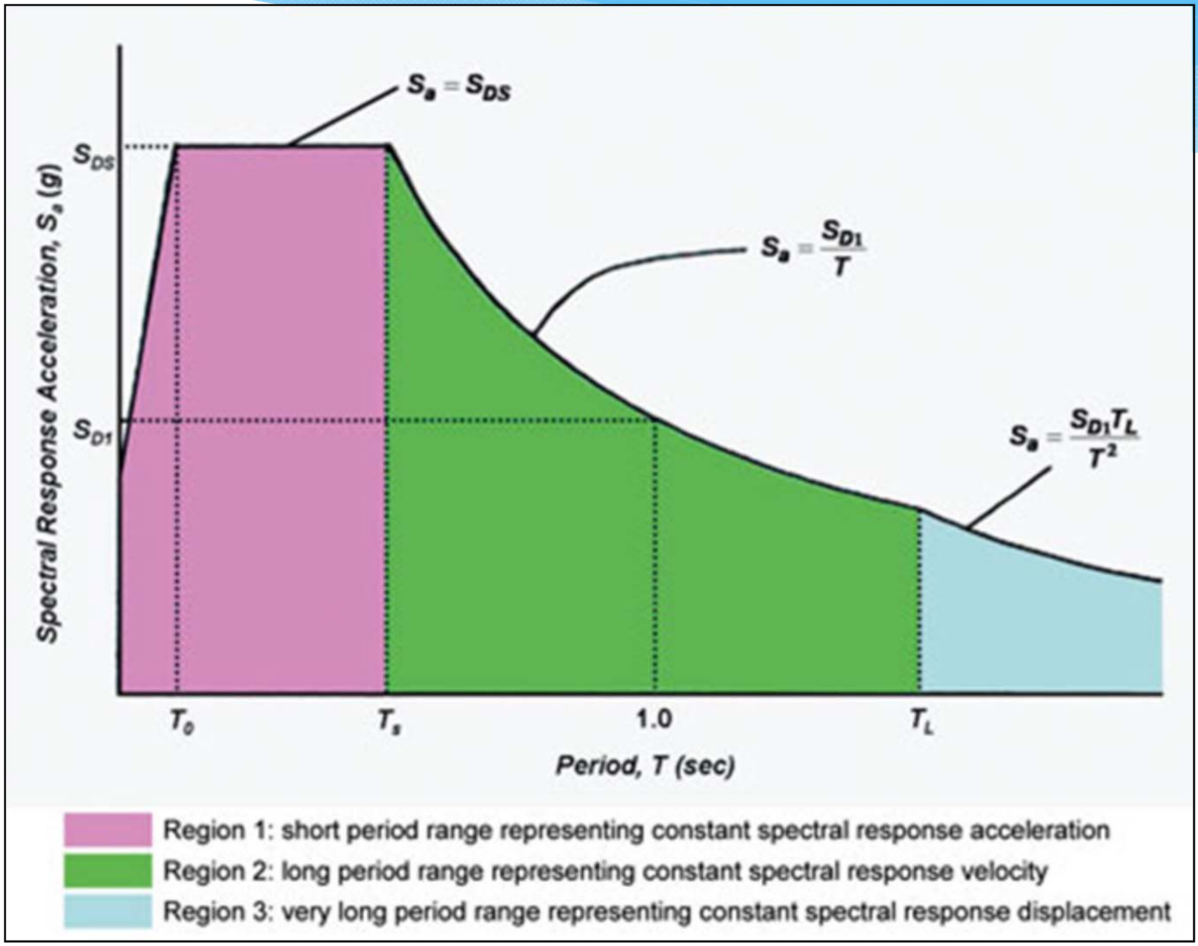
Pseudo-acceleration Response Spectrum







USA - Design Spectrum



Chile - Design Spectrum

* The Chilean seismic code NCh 433 of 96. mod. 2009 defines the design response spectrum (Pseudo-accel vs period).
* This spectrum were done taking as a start point normalized version of the response spectra obtained from different accelerograms recorded for the following earthquakes:
  * 10/16/81 (Ms = 6.8, 8 records)
  * 11/07/81 (Ms = 7.2, 14 records)
  * 03/03/85 (Ms = 7.8, 47 records)
  * 08/08/87 (Ms = 6.9, 6 records)

Chile - Design Spectrum

- The design spectrum is defined as:

$$Sa(T) = \frac{I * A_0 * \alpha}{R^*} \quad ; \quad \alpha = \frac{1 + r * \left(\frac{T}{T_0}\right)^p}{1 + \left(\frac{T}{T_0}\right)^q}$$

- Where:
  - I : Importance factor (1.2, 1.0 or 0.6)
  - A0: Effective acceleration of the ground (0.4*g, 0.3*g or 0.2*g)
  - R*: Reduction factor of the elastic response (inelastic factor)
- The Chilean design spectrum was done for a damping ratio of 5% (typical value for RC structures) and for 4 different types of soils (Soil I, II, III or IV).

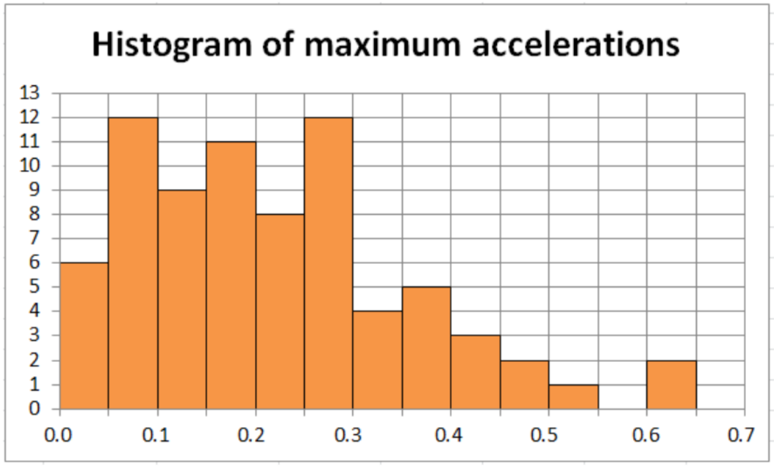
Chile - Design Spectrum

$$\alpha = \frac{1 + r * \left(\frac{T}{T_0}\right)^p}{1 + \left(\frac{T}{T_0}\right)^q}$$

- α is call the spectral amplification factor.
- This function was chosen because is the function that better minimize the error with respect to the mean spectrum.
- Note that if $T \to 0$ then $\alpha \to 1.0$ and if $T \to \infty$ then $\alpha \to 0$.
- In this expression $q > p$.
- α is determined statistically analyzing the values observed for the ratio Sa/a_{max}, where Sa is the linear acceleration response spectrum and a_{max} is the maximum acceleration of the corresponding accelerogram.

Chile - Design Spectrum

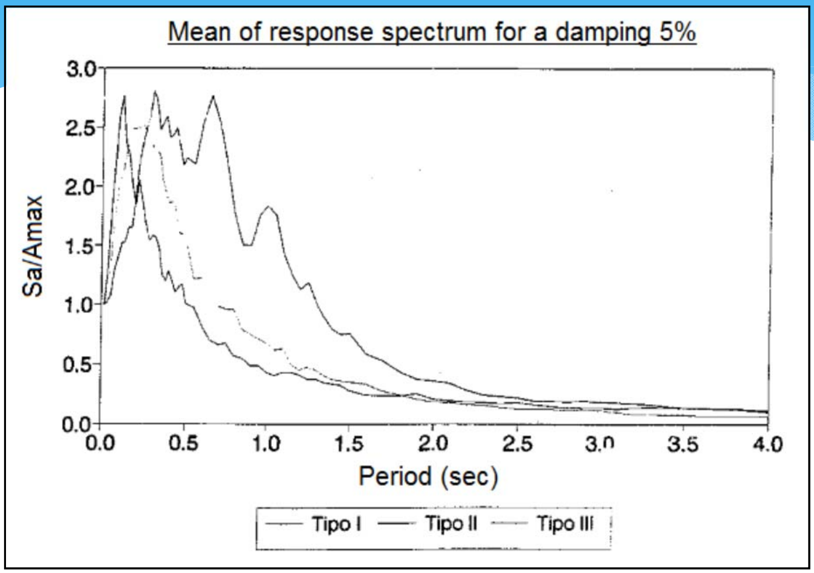
Epicentral distance (km)	Magnitude				Total
	Ms = 6.8 (10/16/81)	Ms = 6.9 (08/08/87)	Ms = 7.2 (11/07/81)	Ms = 7.8 (03/03/85)	
25 - 75	2	-	-	12	14
75 - 125	5	-	-	14	19
125 - 175	5	2	-	5	12
175 - 225	2	2	2	8	14
225 - 275	-	2	4	4	10
> 275	-	-	2	4	6



- For each of these records was computed the normalized response spectrum (Sa/amax).
- Then the mean and the standard deviation of Sa/amax for each period were computed.

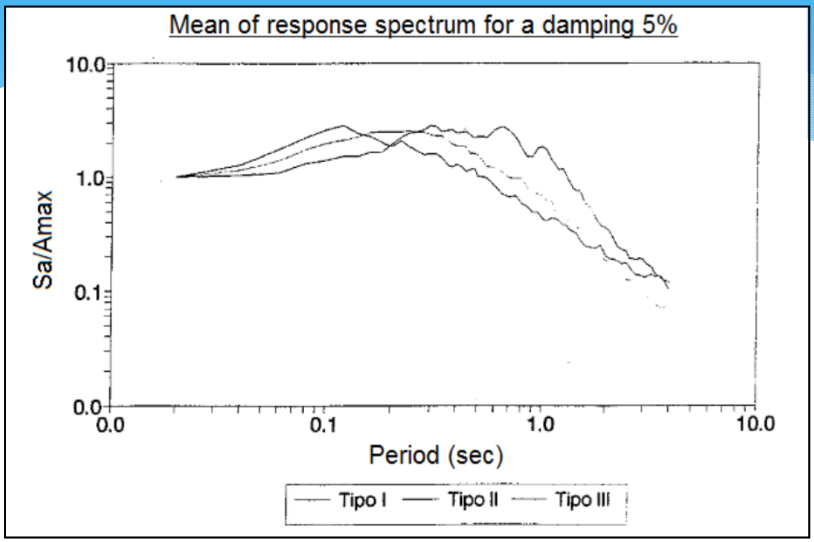
Type of soil	Magnitude				Total
	Ms = 6.8 (10/16/81)	Ms = 6.9 (08/08/87)	Ms = 7.2 (11/07/81)	Ms = 7.8 (03/03/85)	
I (Rock)	2	4	5	10	21
II (Hard soil)	6	2	9	27	44
III (Medium soil)	-	-	-	8	8
IV (Soft soil)	-	-	-	2	2
Total	8	6	14	47	75

Chile - Design Spectrum



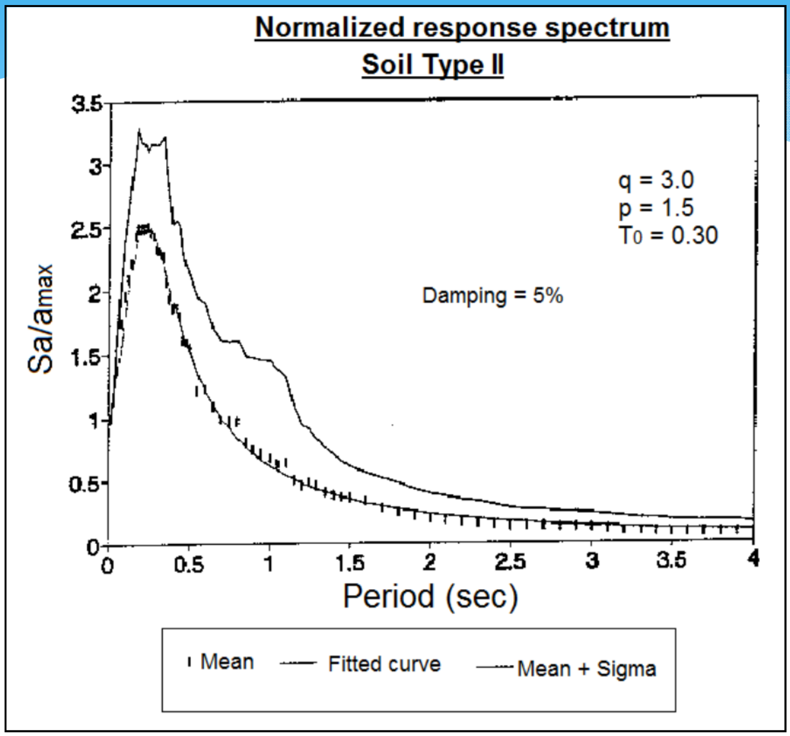
* The maximum amplification of the acceleration estimated over the mean curve is pretty similar for the 3 soils (2.75 for Soils I and III and 2.5 for Soil II).
* That is the reason why was adopted an unique value of r = 4.5, independent of the soil.
* With this value if T = To, α = 2.75.
* NOTE: Soil 3 is multimodal (2 peaks).

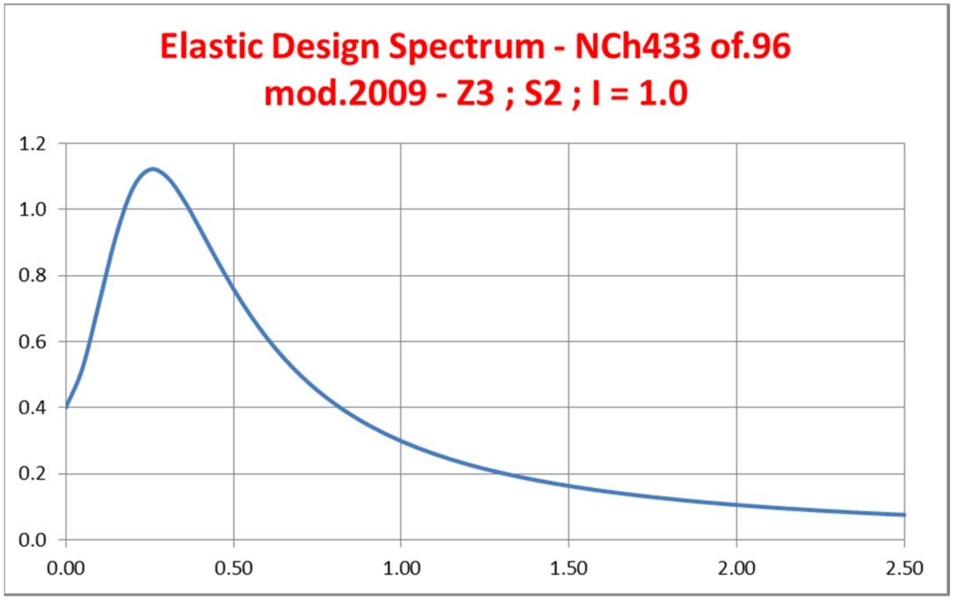
Chile - Design Spectrum



* The decreasing slope of the amplification curve for long periods increases when change from one soil to another, being soil 3 the one with the biggest decreasing slope.
* Therefore the difference q-p must increase with the change in the soil type.
* That is the reason for the selection of p = 2.0, 1.5 and 1.0 for soil types I, II and III, respectively (q = 3 for all).
* For soil IV the selection was arbitrary.

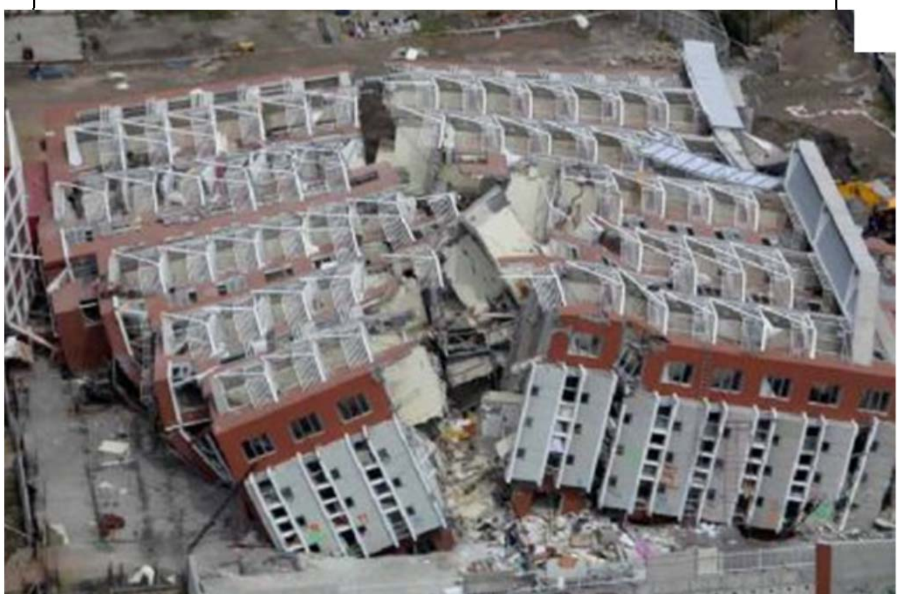
Chile - Design Spectrum



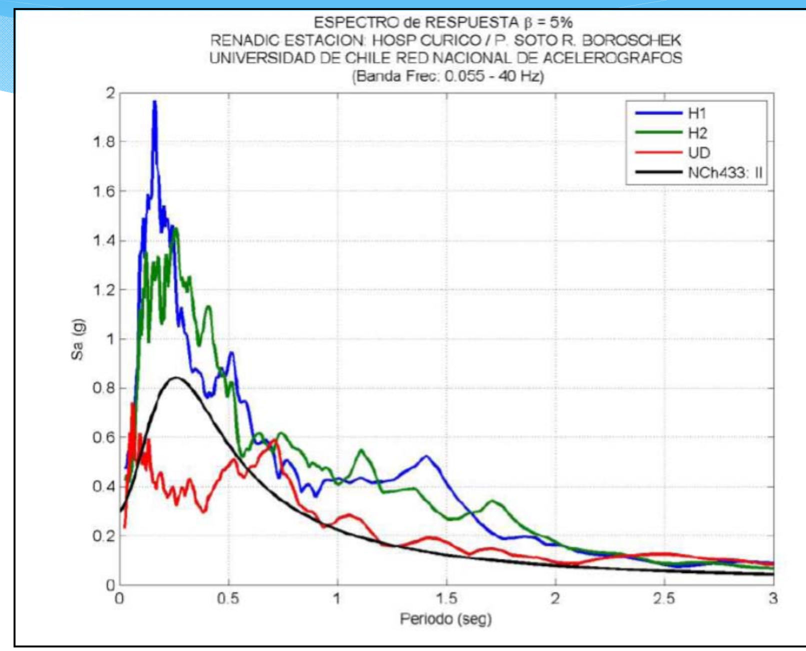


Chile - Design Spectrum

* What happened after the earthquake of 2010?



* It is necessary to define a MCE.



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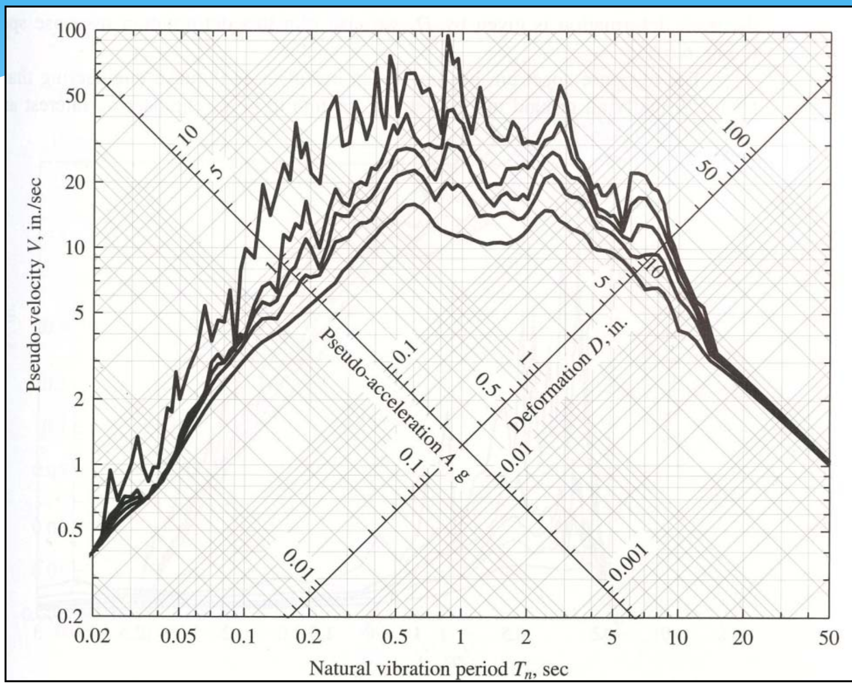
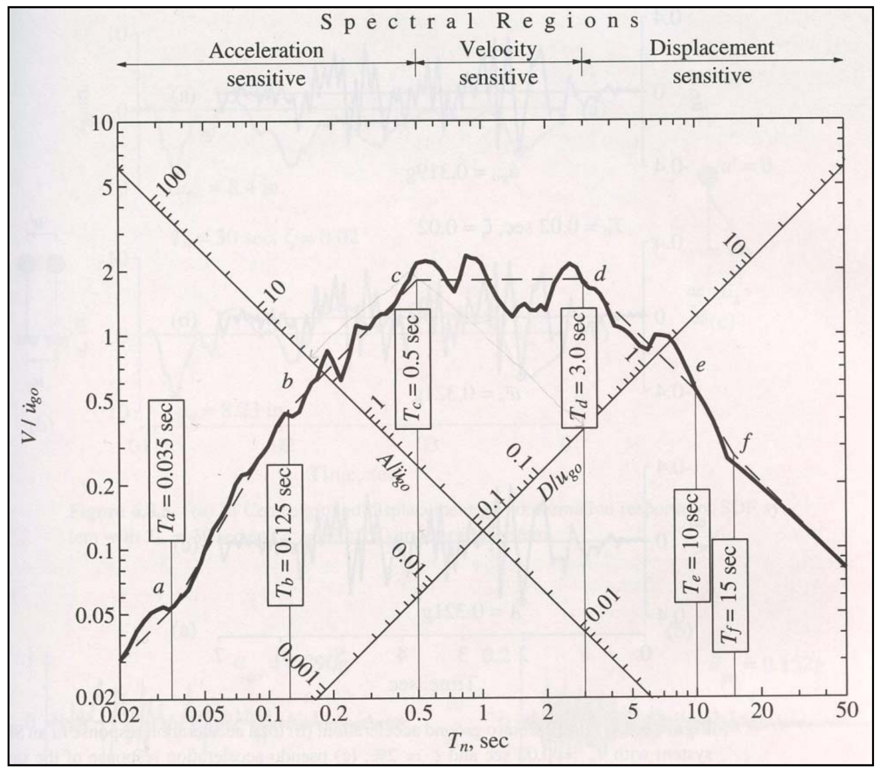
USA – Design spectrum





USA – Design spectrum