SEISMIC EVALUATION METHODS FOR BUILDINGS IN DEVELOPING COUNTRIES

by

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Objective

This study on seismic performance evaluation of existing buildings is meant to serve as a precursor to the implementation of performance-based earthquake engineering for RC structures in Peru.

Propose an appropriate evaluation method of structures to be used in Peru and others developing countries.

2

Contents

Evaluation Method
Non-linear Static Procedures (NSPs)

Capacity Spectrum Method (CSM)
- **Determining Capacity (Pushover analysis)**
- **Determining Demand (elastic response spectram)**

Modification proposed by Chopra & Goel
- **Determining Demand (inelastic systems considering constant ductility curves)**

Evaluation of existing building
Capacity: Nonlinear Static Analysis (Pushover)
Demand: Elastic Spectrum (reduced by damping)
Inelastic Spectrum (Constant-Ductility curves)

Conclusions

3

Introduction

Peruvian code states:

The structure neither should collapse nor cause serious damage to people due to severe earthquakes.

The structure should endure moderate earthquakes that could happen during its service life and it is acceptable damage within the specified limits.

There are two levels of seismic demand and two qualitative levels for damage of the structure, however there are two uncertainties to comply this:

The values of the earthquakes are not specified.

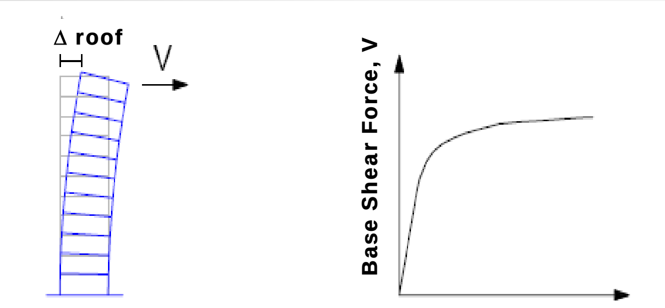
The description of damages is not well explained.

4

Calculation of Capacity

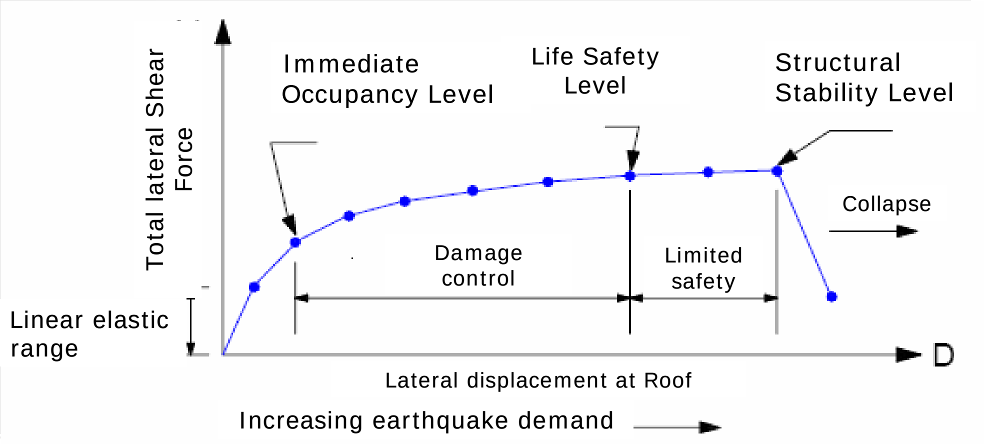
Nonlinear Static Analysis (Pushover)

Approximates how structures behave after exceeding their elastic limit.



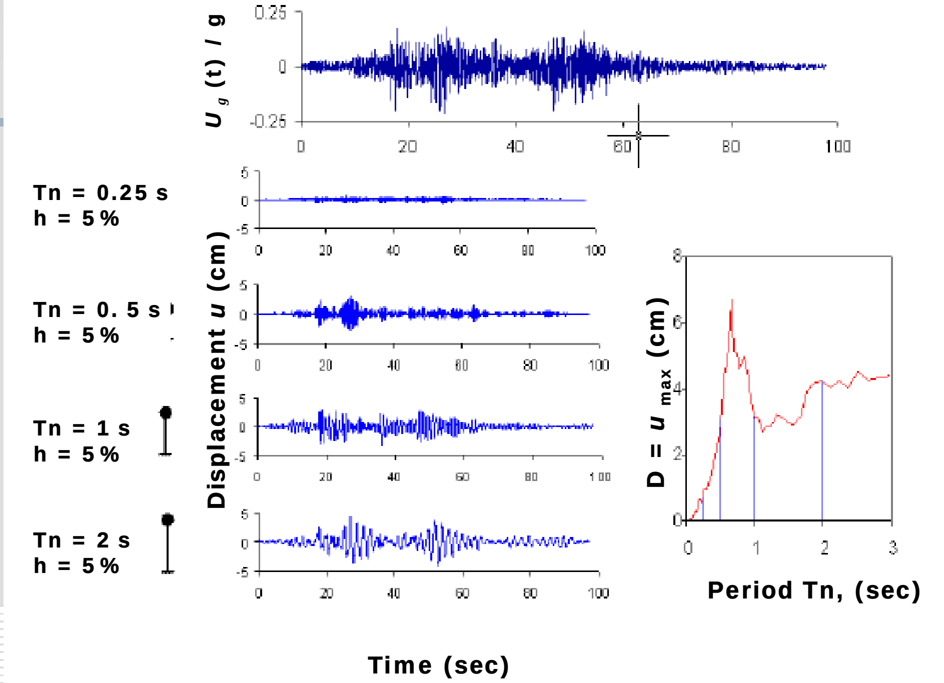
5

Characteristics of Capacity Curve

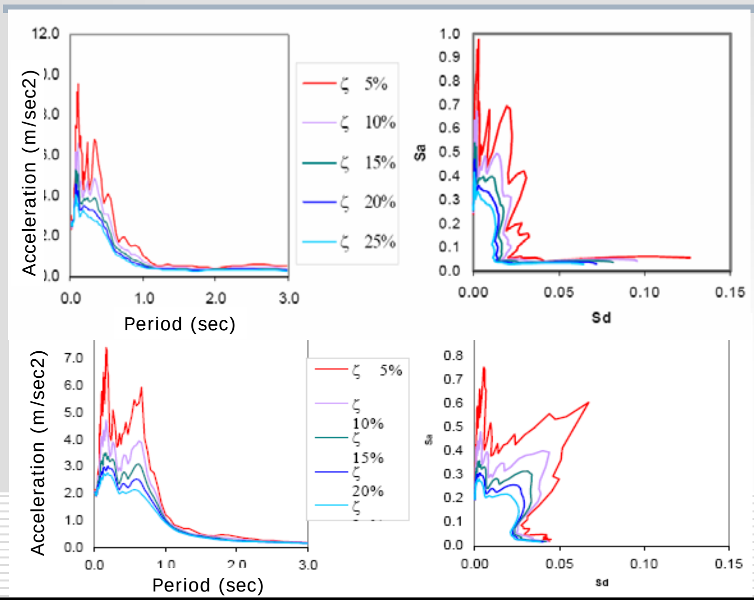


6

Deformation Response Spectrum



Elastic Response Spectrum

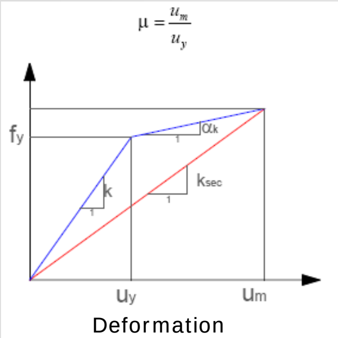


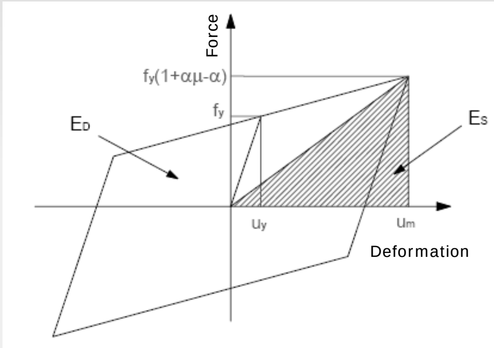
Earthquake, 1966

Earthquake, 1974

8

Equivalent elastic spectrum





$$\hat{\zeta}_{eq} = \zeta + \zeta_{eq}$$

$$T_{eq} = T_n\sqrt{\frac{\mu}{1+\alpha\mu-\alpha}}$$

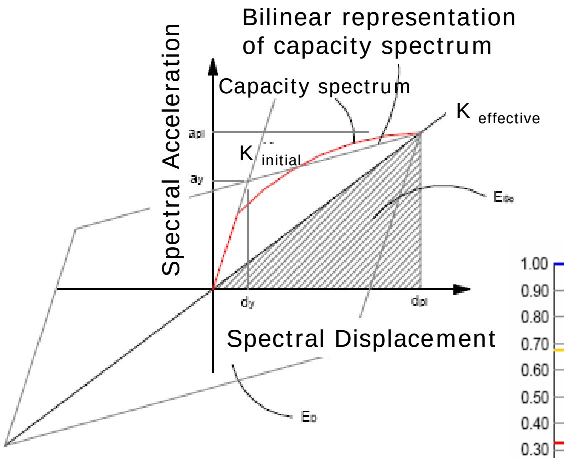
$$\zeta_{eq} = \frac{2(\mu-1)}{\pi\mu}$$

ATC – 40

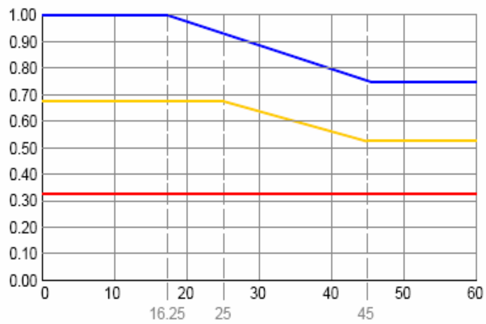
Performance objectives

Desired building performance level for given earthquake ground motion. It is described by designating the maximum allowable damage state for an identified seismic hazard.

Capacity Spectrum- Equivalent Lineal System



$$\beta_{eff} = \kappa\beta_0 + 5$$



Capacity Spectrum Method

Japanese expressions:

$$M = \frac{\left(\sum m_i \delta_i^t\right)^2}{\sum m_i \delta_i^{t2}} \qquad S_a = \frac{Q}{M} \qquad S_d = \frac{\sum m_i \delta_i^{\,2}}{\sum m_i \delta_i}$$

δ: displacement

ATC-40 expressions:

$$PF_1 = \left[\frac{\sum_{i=1}^{N} w_i \phi_{i1} / g}{\sum_{i=1}^{N} \left(w_i \phi_{i1}^2\right) / g}\right] \qquad \alpha_1 = \frac{\left[\sum_{i=1}^{N} w_i \phi_{i1} / g\right]^2}{\left[\sum_{i=1}^{N} \left(w_i \phi_{i1}^2\right) / g\right]\left[\sum_{i=1}^{N} \left(w_i\right) / g\right]} \qquad S_a = \frac{V/W}{\alpha_1} \qquad S_d = \frac{\Delta_{roof}}{PF_1 \phi_{roof,1}}$$

ϕ_i: amplitude of mode i

12

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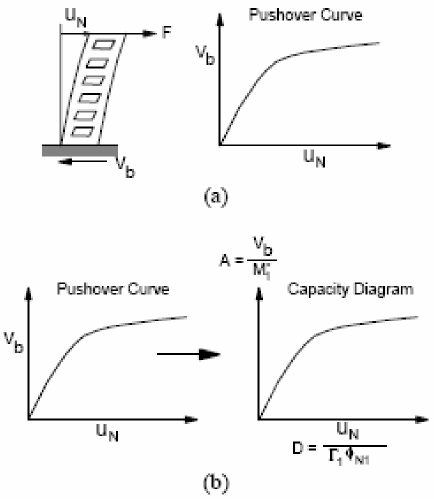

CSM: (a) Pushover curve, (b) Conversion of pushover curve to capacity spectrum

13

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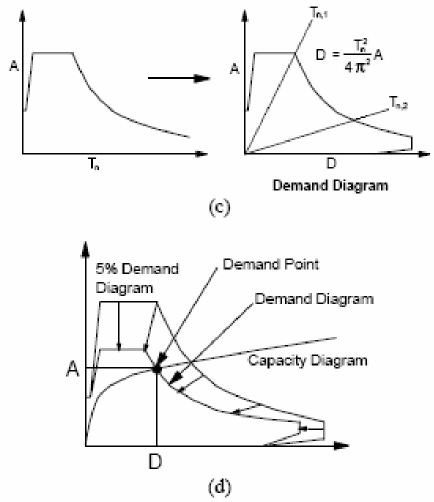

(c) conversion of elastic response spectrum from standard format to A-D format, (d) determination of displacement demand

14

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Deformation limits

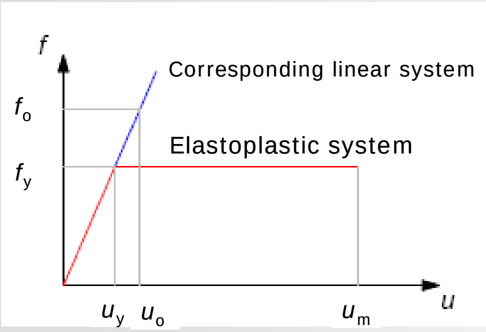
	Performance level			
Interstory drift limit	Immediate occupancy	Damage control	Life safety	Structural stability
Maximum total drift	0.01	0.01 – 0.02	0.02	0.33 Vi/Pi
Maximum inelastic drift	0.005	0.005 – 0.015	No limit	No limit

Vi: total calculated lateral shear force in story i

Pi: total gravity load at story i

Constant-Ductility curves

The force-deformation relation for a structure is idealized by an elastic-perfectly plastic force-deformation relation.



u_y = Yield deformation

u_o = Deformation of the corresponding linear system

u_y = Maximum displacement

f_y = Yield strength

f_o = Earthquake-induced resisting force

Hysteretic model for constant-ductility curves

Constant-ductility inelastic spectra attempts to reproduce actual nonlinear structural response by means of an elasto-plastic representation of the system. In this way, energy dissipated through hysteresis comes explicitly modeled, with only a relatively small viscous damping quantity (usually not more than 5%) is added to the system, to somehow represent non-hysteretic energy dissipation mechanisms. the post-yield hardening ratio can be made to vary between 0.0 and 1.0 (the default is 0.0, i.e. no hardening, hence ***elasto-perfectly plastic system***).

17

Hysteretic model for constant-ductility curves

Comment:

We do not use degrading models like Takeda or Ramberg. This kind of models can not be used because the spectral analysis does not take into consideration the degradation as function of the cyclic behavior.

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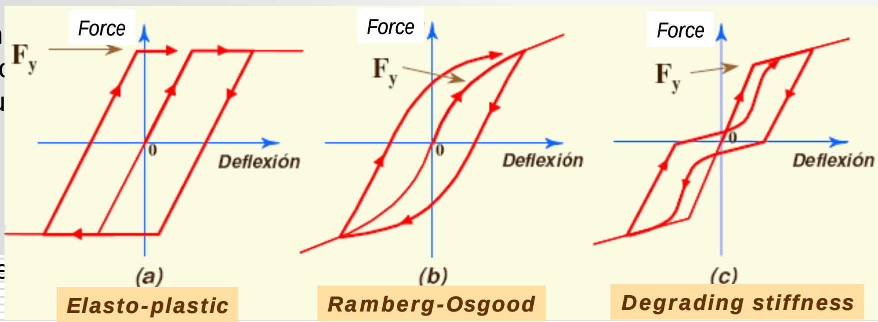

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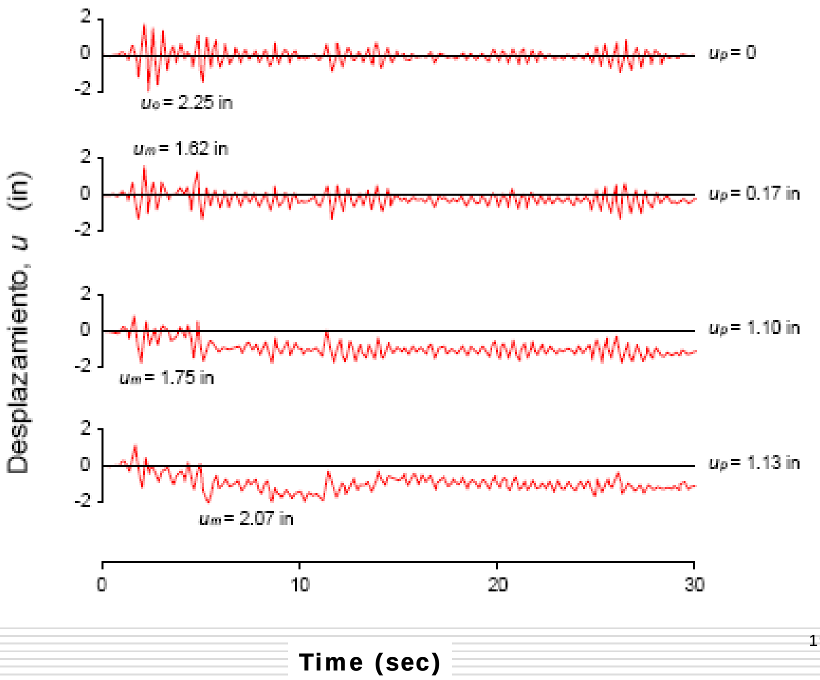
18

Constant-ductility curves



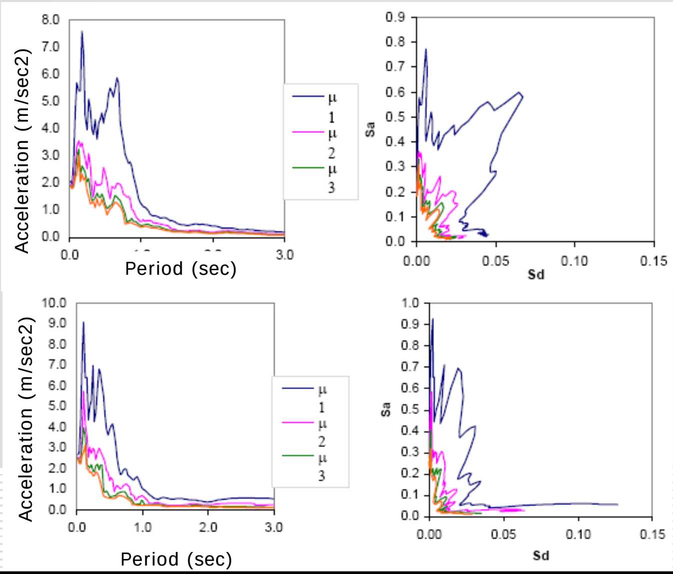
19

Construction of Constant-Ductility Spectrum

- Define ground motion u_g (t) and select the damping ratio for which the spectrum is to be plotted (5%).
- Select a value for Tn and determine the response of the elastic system. From u(t) determine u_o and $f_o = ku_o$.
- Determine the response of elasto-plastic system with Tn and damping and fy. Repeat the procedure varying fy to develop (fy,μ)

20

Constant-Ductility curves

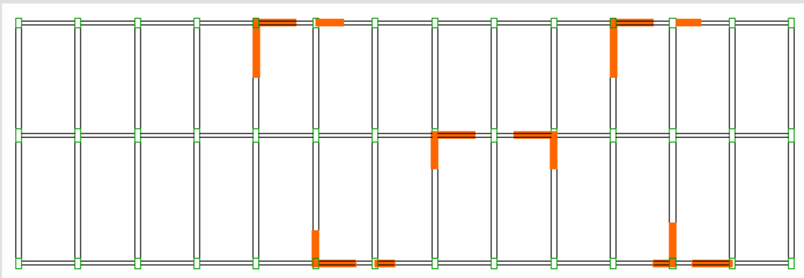


Earthquake, 1966

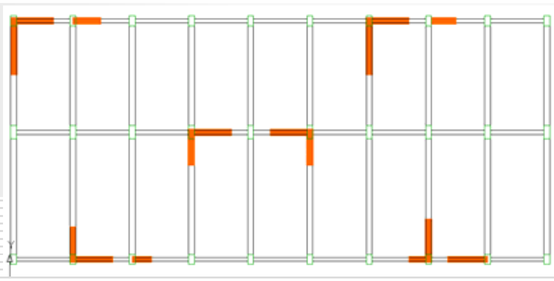
Earthquake, 1974

Existing building - Hospital Floor

(a)



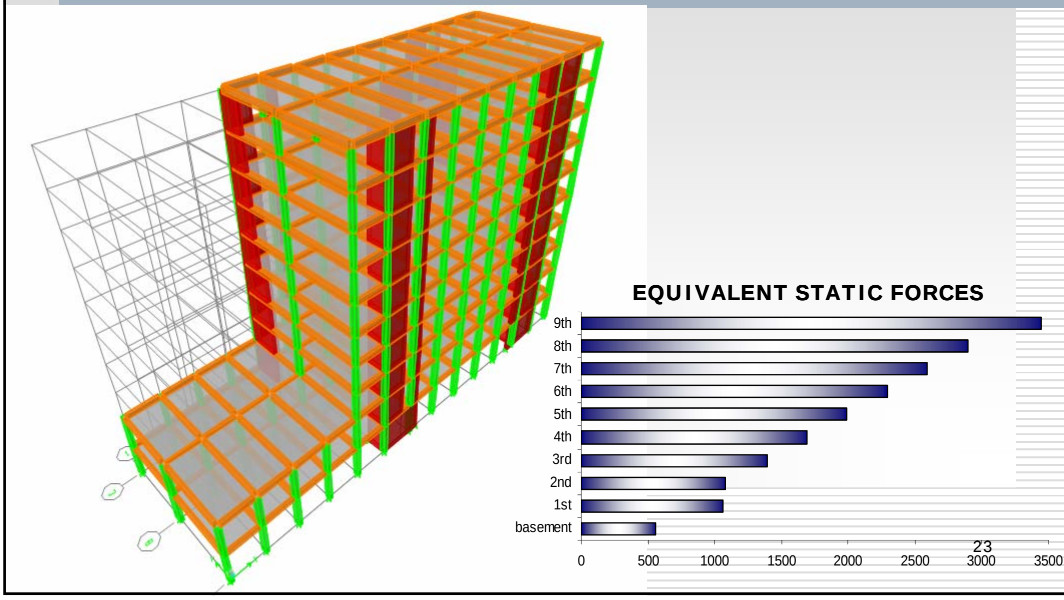
(b)



a) Plan Basement and 1st level

b) Plan 2nd – 9th levels

Existing building - Hospital

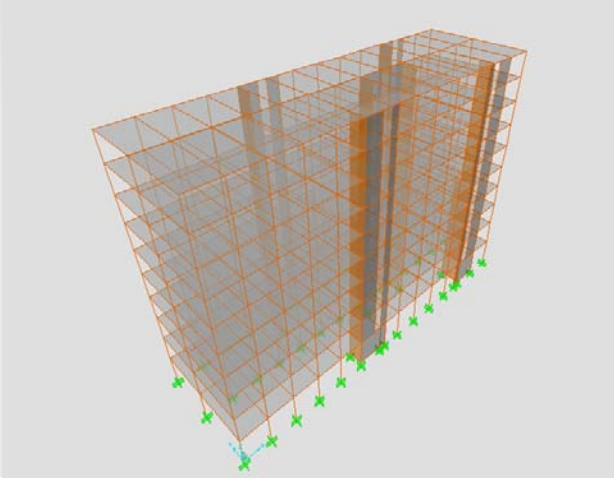


23

Existing building

Inelastic Model 3D to be evaluated using ETABS, CSI, Berkeley.

(according to ATC and FEMA)

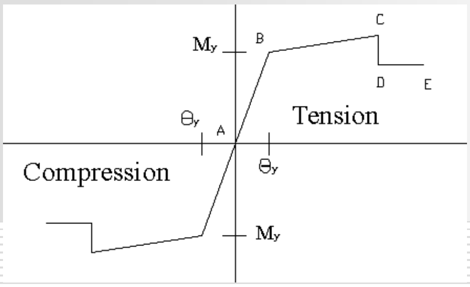


24

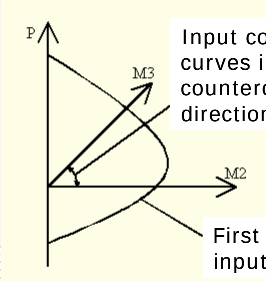
Considerations for 3D Model

Solicitations considered for nonlinear analysis:

- Shear force and bending moment (in the direction of major strength) for beams.
- Shear force and interaction of axial force and bending moments (in both directions) for columns.



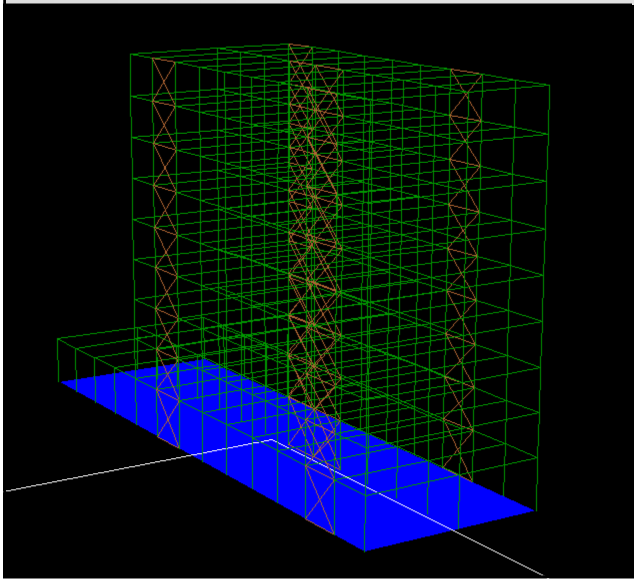
M-θ Diagram (beam/column)



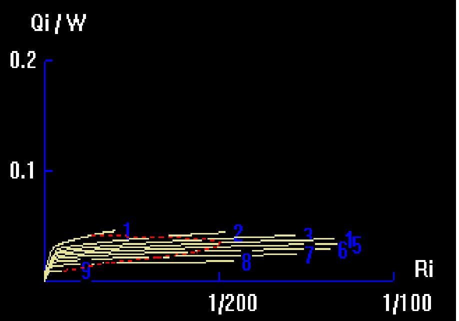
Interaction surface

25

Existing building



Pushover Analysis (STERA 3D)



Performance Point

Demand		ATC-40		Chopra & Goel	
		Sd	Sa	Sd	Sa
		cm	g	cm	g
Response Spectrum	Lima 1974	5.06	0.16	4.9	0.15
	Lima 1966	3.47	0.13	3.3	0.12

The obtained values seem to be not so different, but a dynamic analysis should be carried out to determine the accuracy of the calculation.

27

Conclusions

ATC-40 uses κ as approximation and defines A, B and C as behavior of the structure.

The improved procedure just presented gives the deformation value consistent with the selected inelastic response spectrum, while retaining the attraction of graphical implementation of ATC-40 Procedure A.

Both procedures are similar in the sense that the desired deformation is determined at the intersection of the capacity diagram and the demand diagram. However, the two procedures differ fundamentally in an important sense; the demand diagram used is different: constant-ductility demand diagram for inelastic systems in the modified procedure versus the elastic demand diagram in ATC-40 for equivalent linear systems.

28

Conclusions

The equivalent linear systems can be analyzed using the elastic design spectrum, however most existing rules for constructing elastic design spectra are limited to damping: 0 to 20% (Chopra)

29

Thanks for your kind attention

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30