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# Using a Displacement-Based Approach for Loss Assessment of Urban Areas

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DBELA

DISPLACEMENT-BASED  
EARTHQUAKE LOSS  
ASSESSMENT

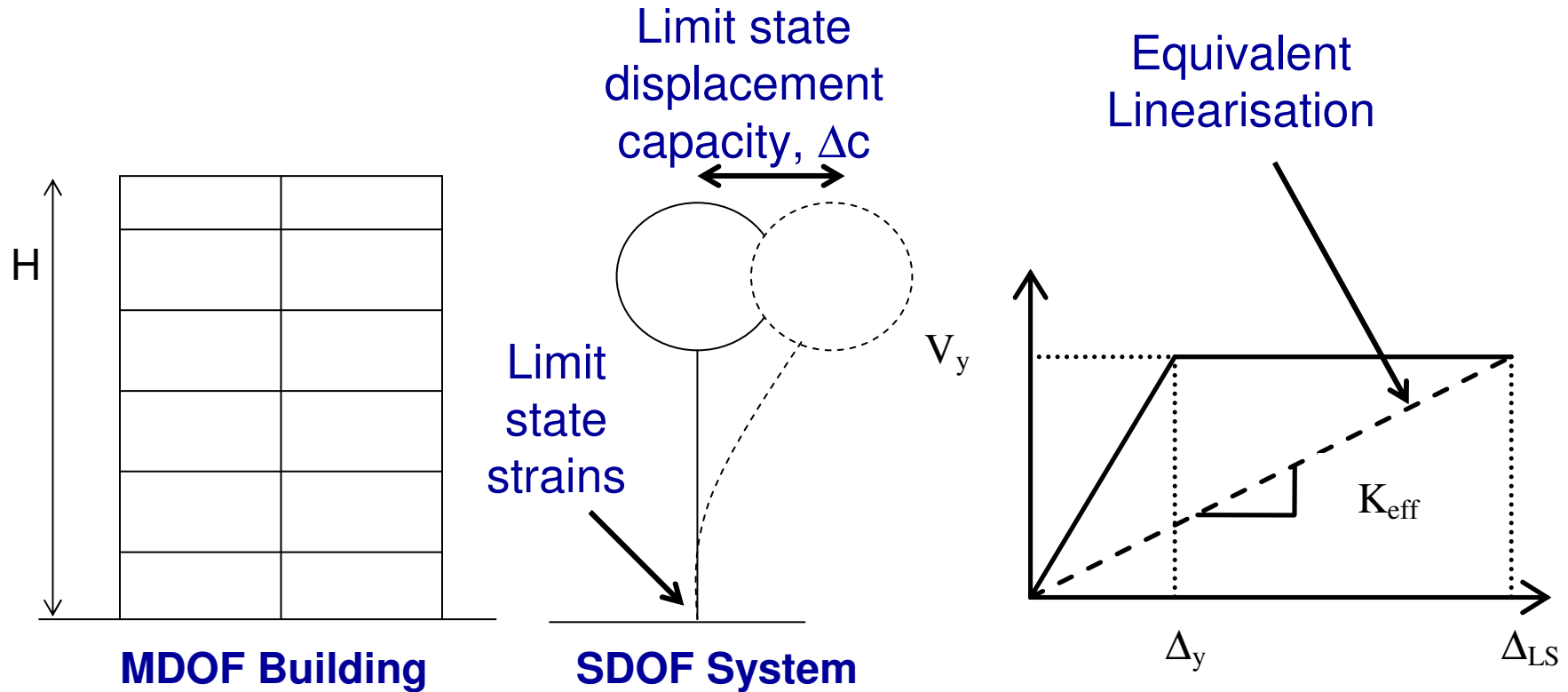
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**DEMAND** – overdamped **DISPLACEMENT RESPONSE SPECTRA** relate displacement demand of a SDOF system to its fundamental period of vibration

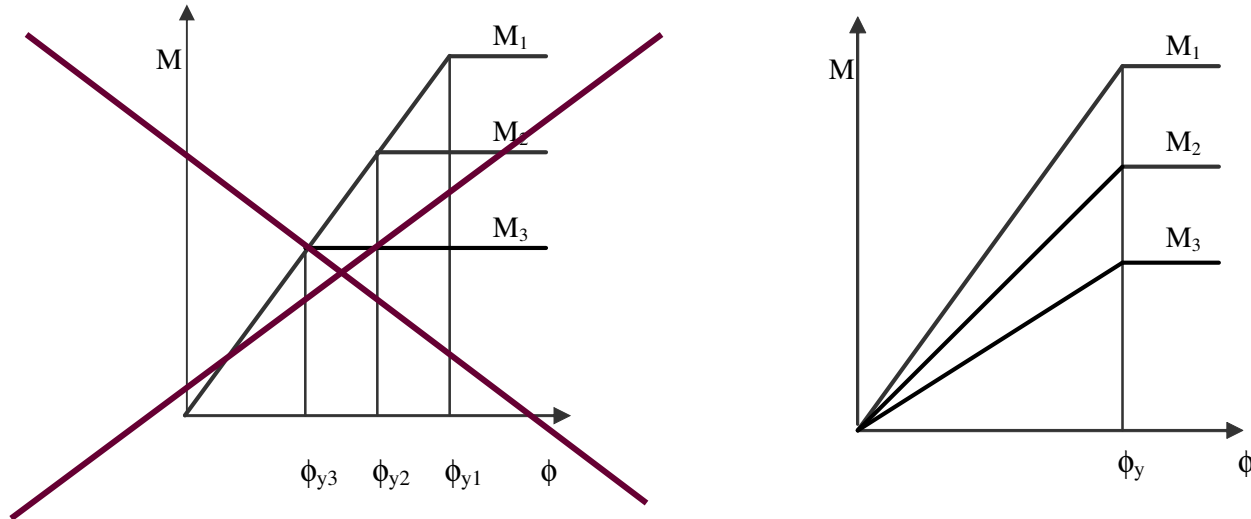
- n Relationship between the frequency content of the ground motion and dominant period of the buildings

- n Correlation of this ground motion parameter to damage

**BUILDING CLASS CAPACITY** – mechanics-derived equations to relate limit state displacement capacity of SDOF system to its fundamental period of vibration



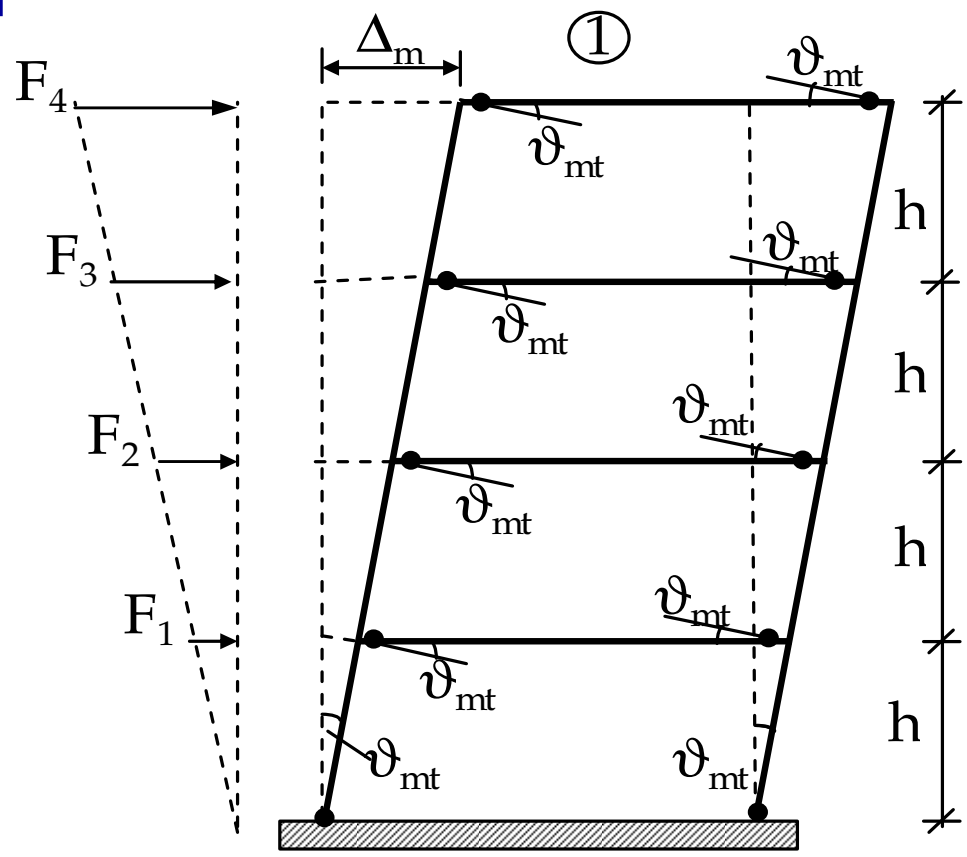
## Direct Displacement-Based Design principles



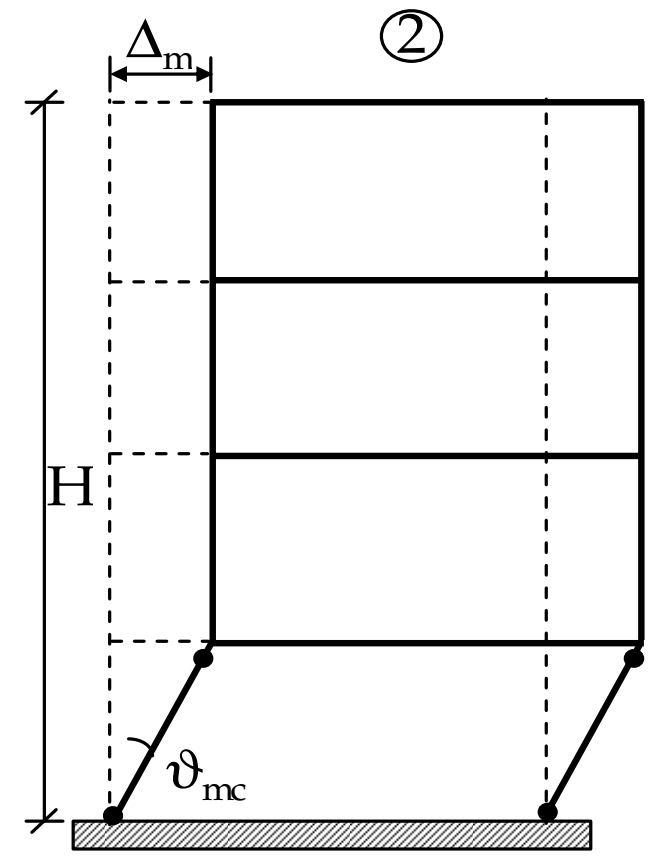
$\Delta c = f(\text{Height, geometrical properties, limit state strains})$

Period =  $f(\text{Height})$

$\therefore \Delta c = f(\text{Period, geometrical properties, limit state strains})$



Beam-sway



Column-sway

## EXAMPLE OF PRE-YIELD CAPACITY EQUATIONS

BEAM SWAY

$$\Delta_{Sy} = 0.5ef_h H_T \varepsilon_y \frac{l_b}{h_b}$$

COLUMN SWAY

$$\Delta_{Sy} = 0.43ef_h H_T \varepsilon_y \frac{h_s}{h_c}$$

PERIOD-HEIGHT  
RELATIONSHIP

$$T_y = 0.1H_T$$

## EXAMPLE OF POST-YIELD CAPACITY EQUATIONS

### BEAM SWAY

$$\Delta_{SLsi} = 0.5ef_h H_T \varepsilon_y \frac{l_b}{h_b} + 0.5(\varepsilon_{C(Lsi)} + \varepsilon_{S(Lsi)} - 1.7\varepsilon_y) ef_h H_T$$

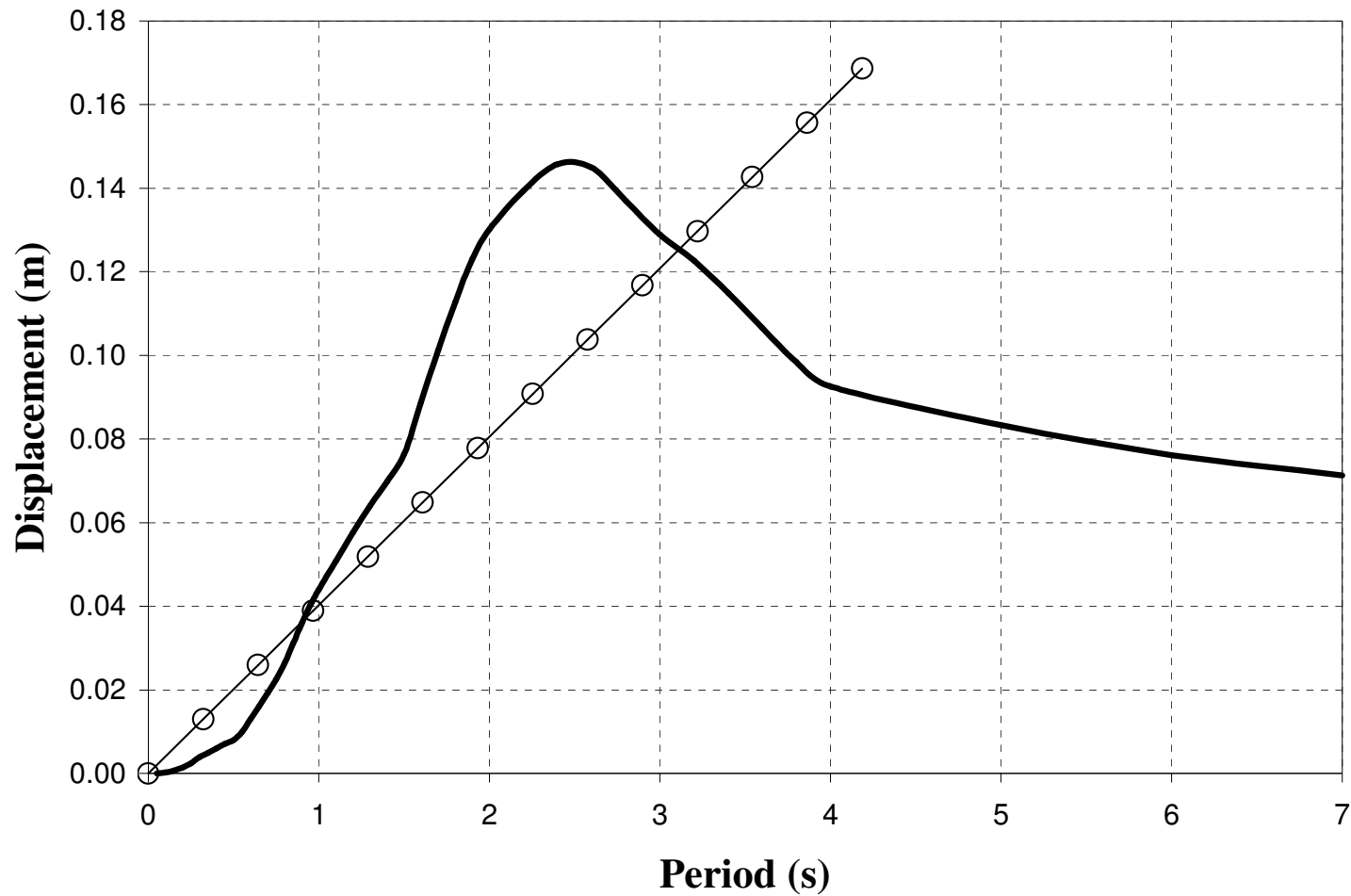
### COLUMN SWAY

$$\Delta_{SLsi} = 0.43ef_h H_T \varepsilon_y \frac{h_s}{h_c} + 0.5(\varepsilon_{C(Lsi)} + \varepsilon_{S(Lsi)} - 2.14\varepsilon_y) h_s$$

### PERIOD-HEIGHT RELATIONSHIP

$$T_{Lsi} = T_y \sqrt{\mu_{Lsi}}$$

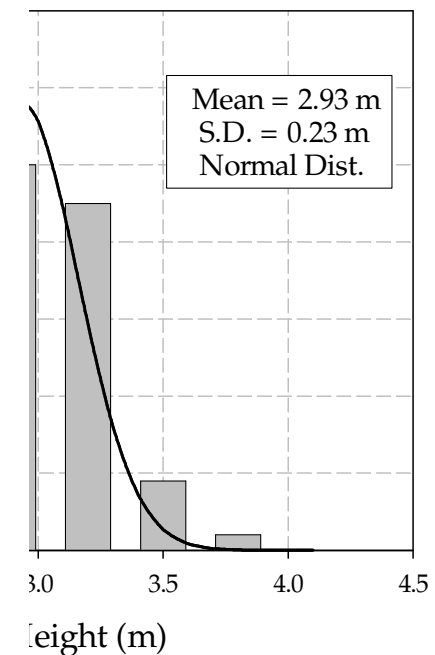
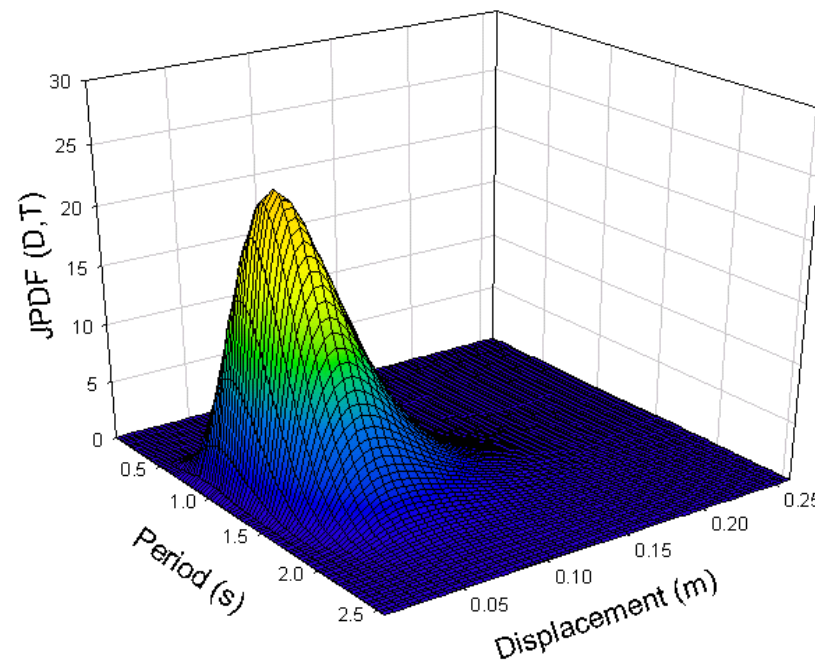
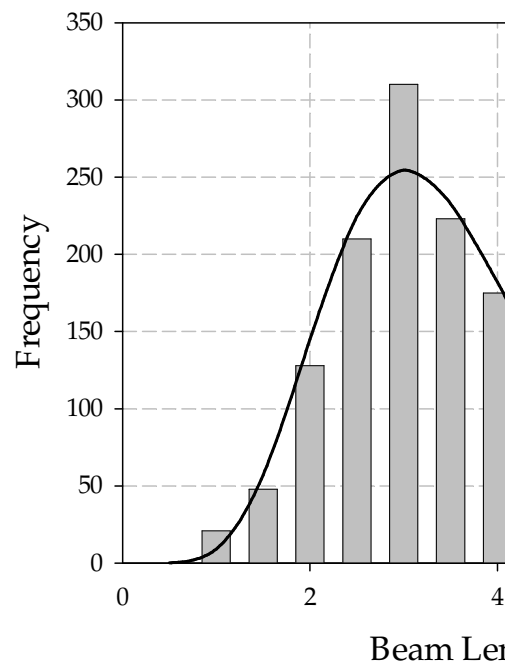
IF DEMAND > CAPACITY  
FAILURE OF LIMIT STATE



# UNCERTAINTY & VARIABILITY CAPACITY

Probabilistic distributions assigned to each parameter in equation (e.g. Normal / Lognormal)

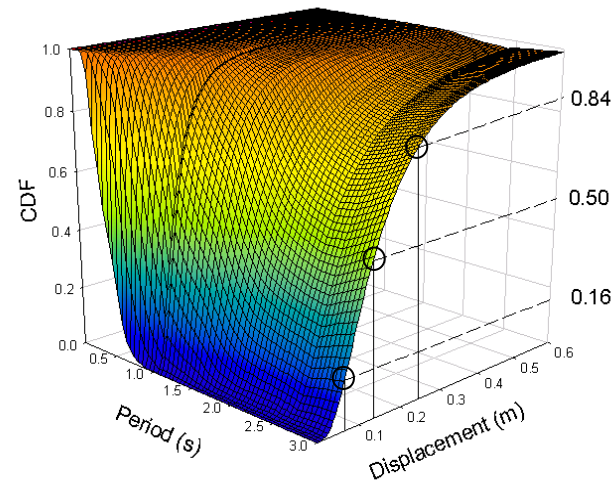
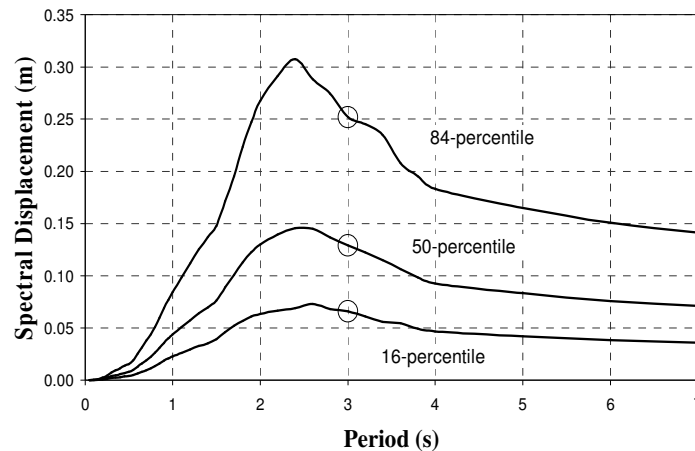
FORM – Produce the JPDF of displacement capacity and period



# UNCERTAINTY & VARIABILITY

DEMAND – single scenario earthquakes

Cumulative distribution function computed using logarithmic standard deviation at each period



## Reliability Formula

$$P_f = \int \int_{x \ y} [1 - F_D(x/T_{LSi} = y)] \cdot f_{\Delta_{LSi} T_{LSi}}(x, y) dx dy$$

## DAMAGE BANDS (% of buildings)

SLIGHT – % slight =  $1 - P_{f1}$

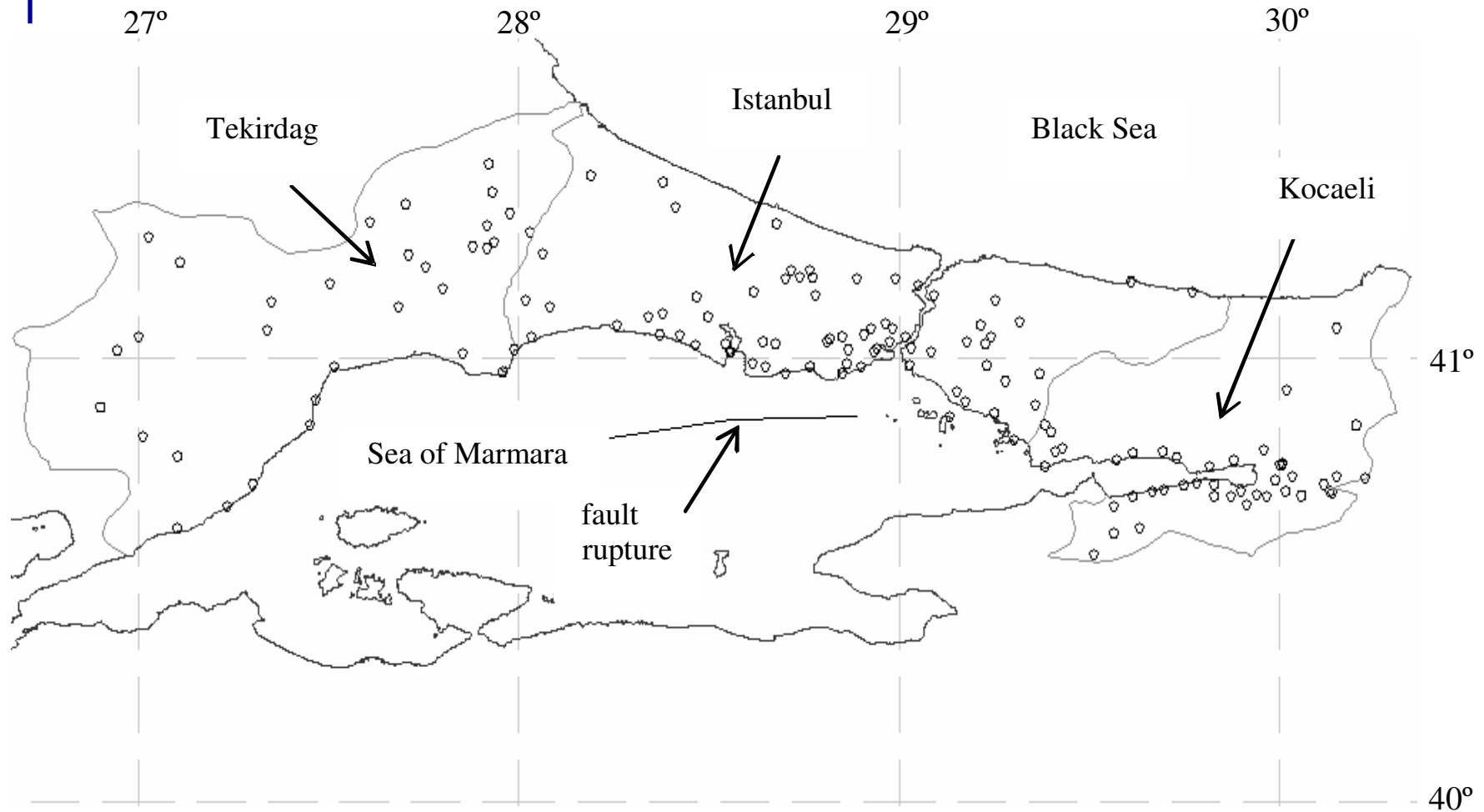
MODERATE – % moderate =  $P_{f1} - P_{f2}$

EXTENSIVE – % extensive =  $P_{f2} - P_{f3}$

COMPLETE – % complete =  $P_{f3}$

MEAN DAMAGE RATIO – weights applied to each damage band to give composite measure of damage: ratio between cost of repair/retrofit to cost of rebuilding

# SENSITIVITY STUDY – SEA OF MARMARA, TURKEY

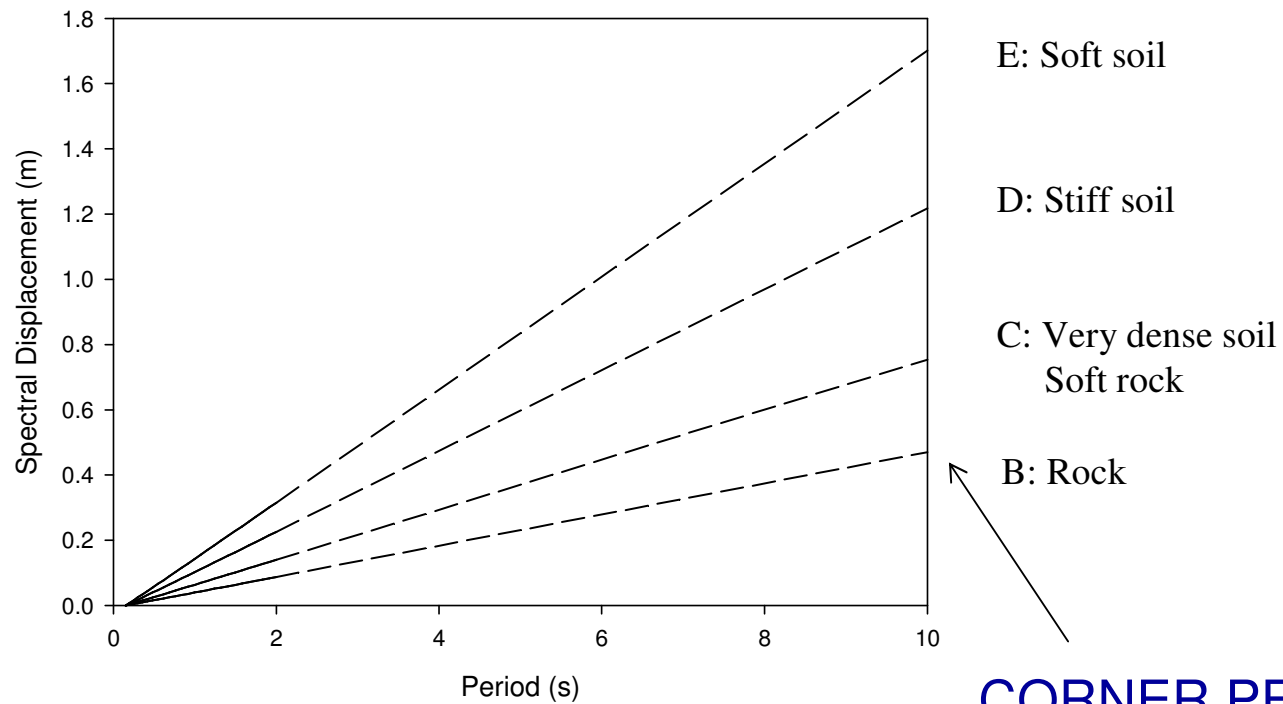


Erdik *et al.* (2004) fault segmentation model,  $M_w = 7.2$

Building Stock Data – 2000 Building Census

# BASE MODEL - GROUND MOTION PREDICTION EQUATION

Boore *et al.* (1997)



**CORNER PERIOD =  
12.6 SECONDS  
 $M_w = 7.2$**

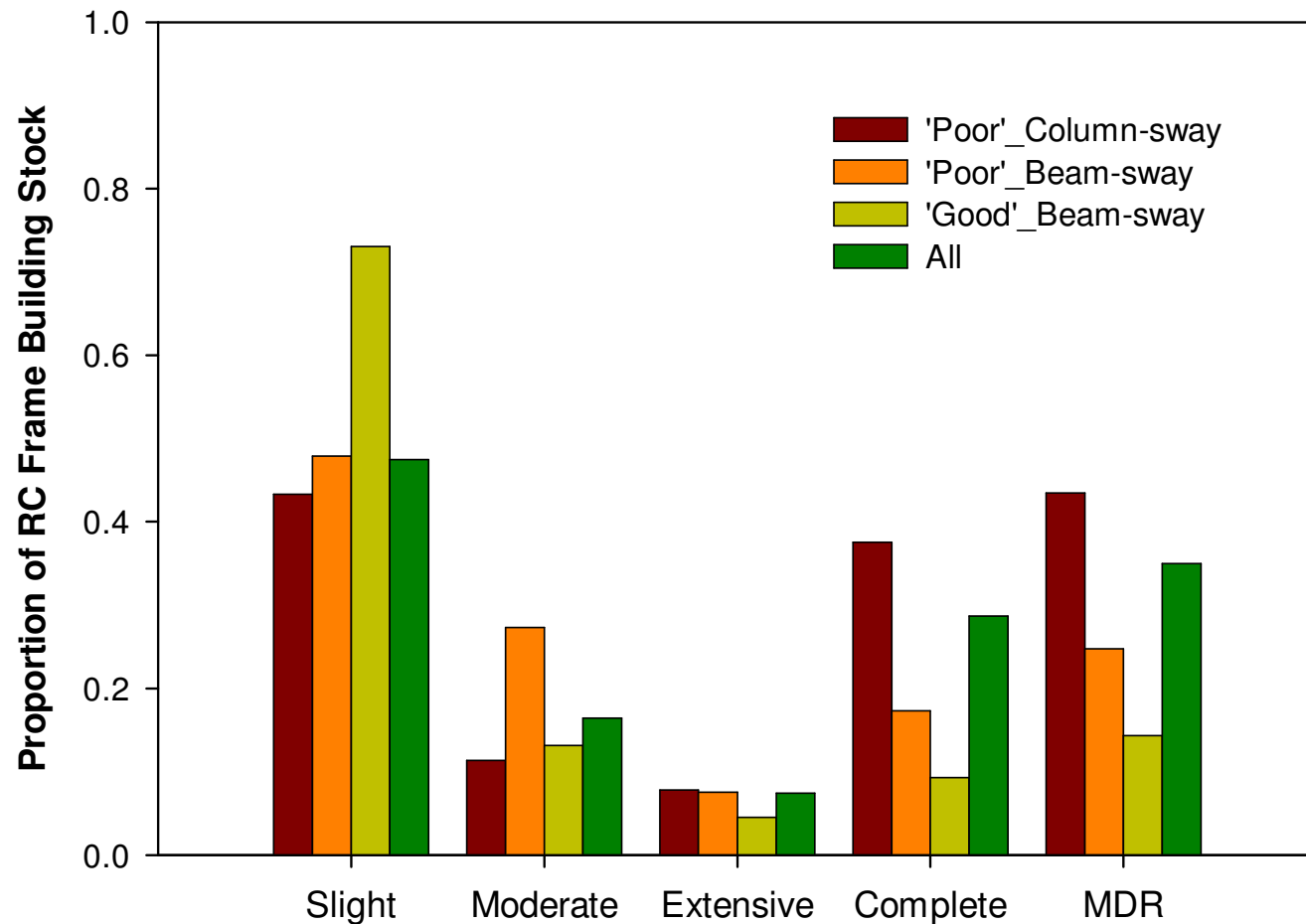
NEHRP GUIDELINES:  $T_{VD} = 10^{\frac{M_w - 5}{2}}$

# BASE MODEL – CAPACITY

(Poor, Column-sway frames)

Capacity Parameter	Mean value	Coefficient of variation	Probabilistic Distribution
Ground floor storey height	3.6 m	35%	Lognormal
Column section depth	0.6 m	35%	Lognormal
Beam length	4.0 m	25%	Lognormal
Beam depth	0.55 m	10%	Lognormal
Steel yield strength	263 MPa	10%	Normal
Limit state 2 concrete strain, $\epsilon_{c3}$	0.45 %	50%	Lognormal
Limit state 2 steel strain, $\epsilon_{s3}$	1.25 %	50%	Lognormal
Limit state 3 concrete strain, $\epsilon_{c2}$	0.75 %	50%	Lognormal
Limit state 3 steel strain, $\epsilon_{s2}$	2.25 %	50%	Lognormal

# BASE MODEL DAMAGE PREDICTIONS



**MEAN DAMAGE  
RATIO (MDR)**

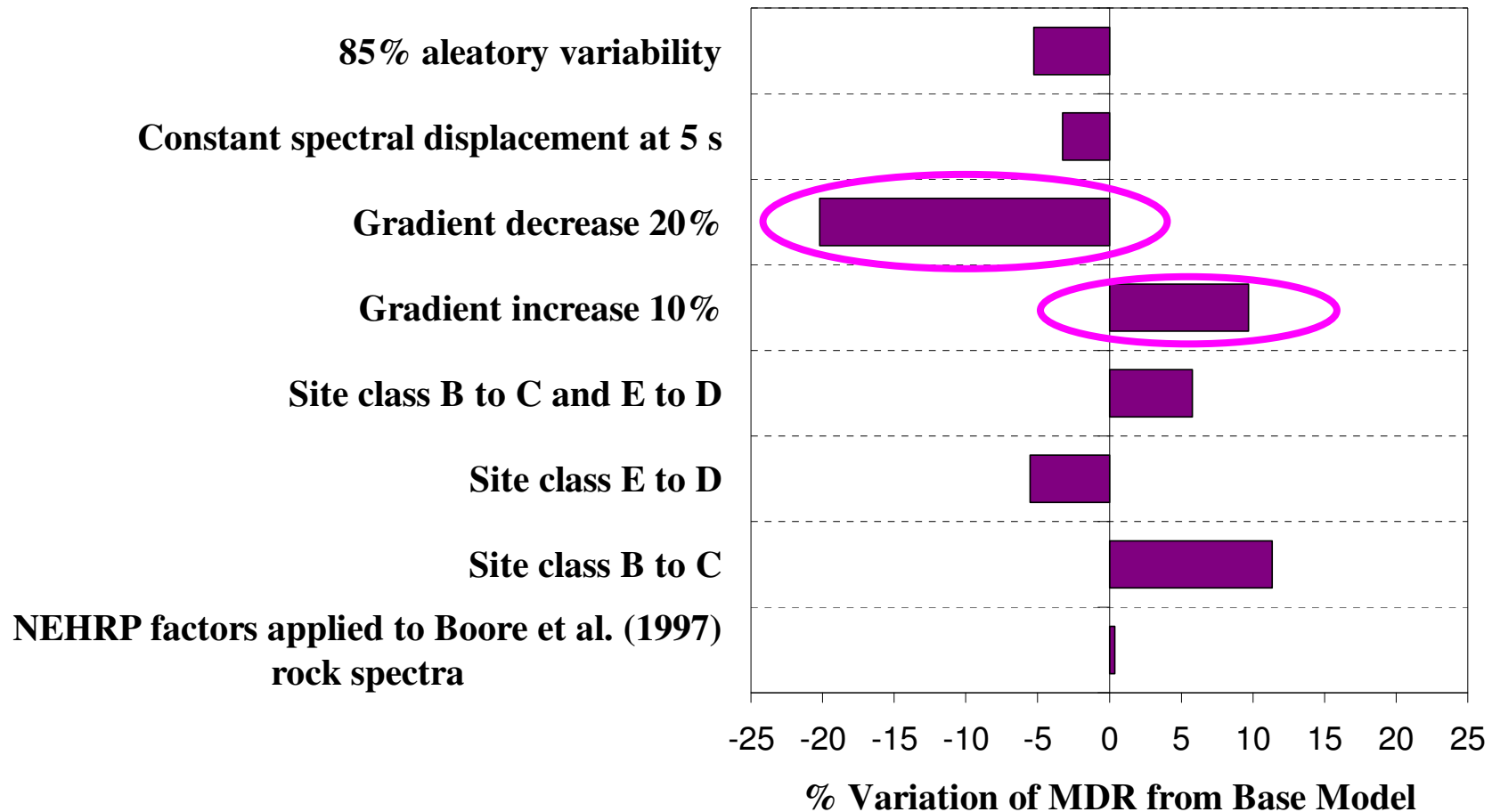
**2% SLIGHT**

**10% MODERATE**

**50% EXTENSIVE**

**100% COMPLETE**

# SENSITIVITY TO DEMAND VARIABLES



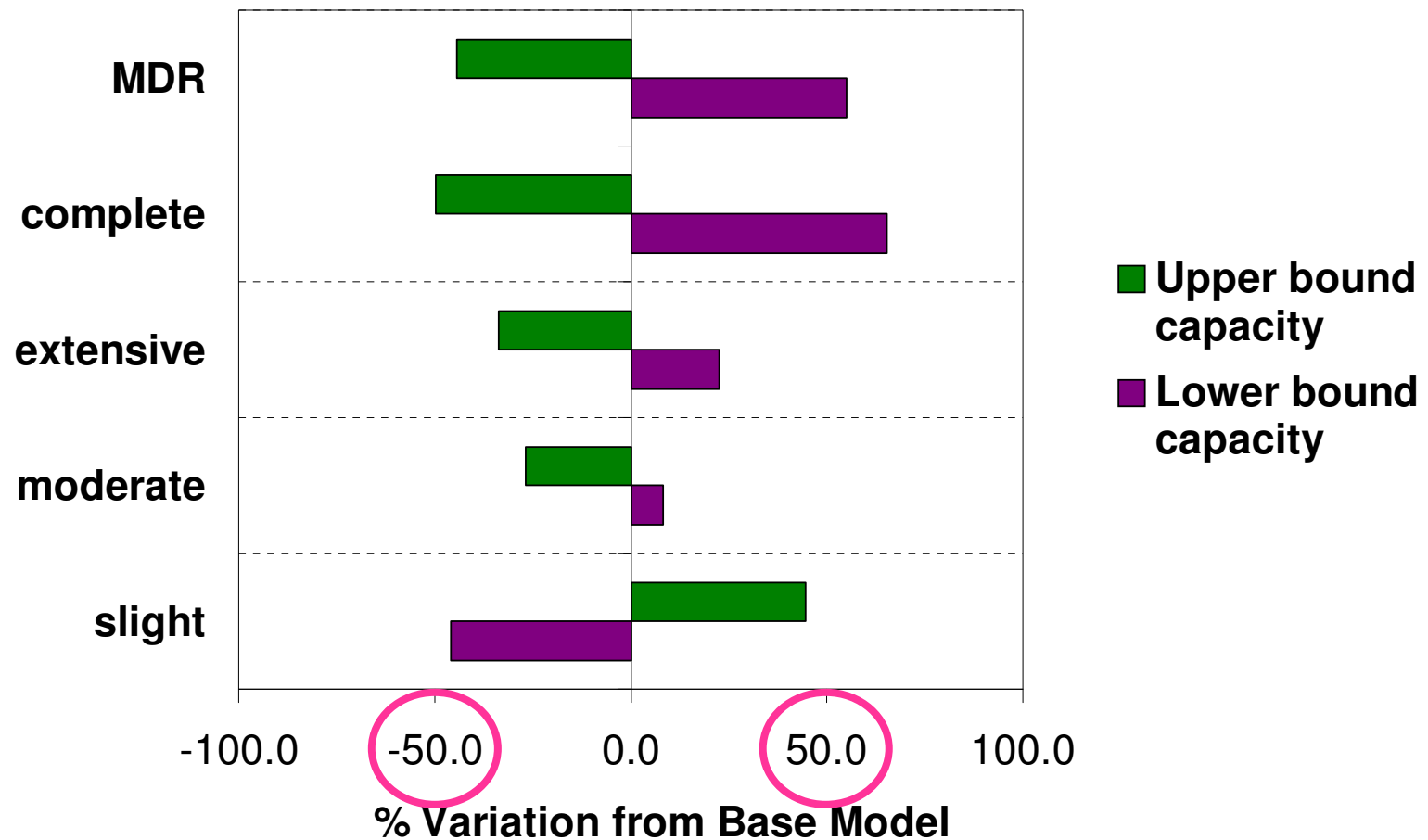
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## SENSITIVITY TO CAPACITY VARIABLES

Combined increase / decrease (10-20%) capacity parameters – upper bound / lower bound



# LOSS ASSESSMENT

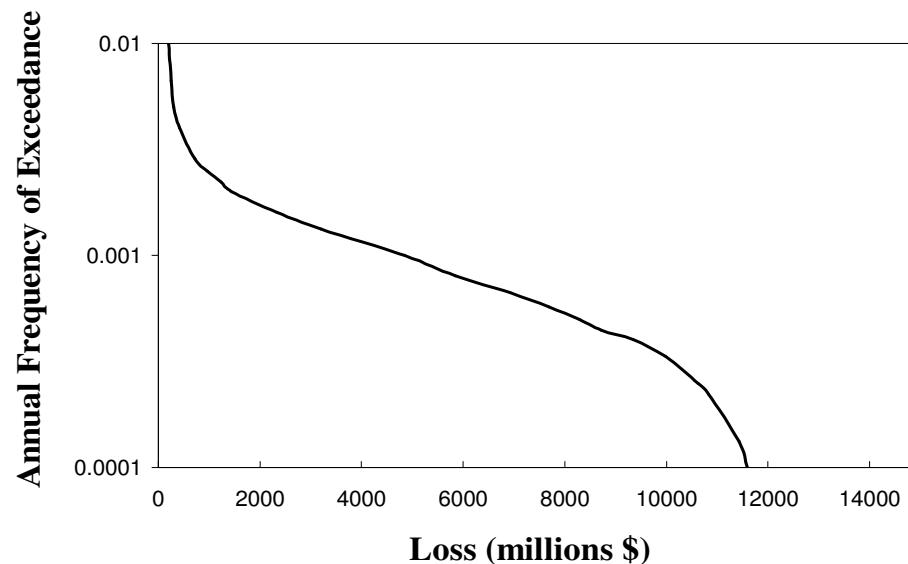
Single earthquake scenario – useful for disaster management, communicating seismic risk to public

ALL possible earthquake scenarios

insurance / reinsurance industry

Seismic code drafting committees

Loss versus annual frequency of exceedance



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## LOSS EXCEEDANCE CURVES

- n Need to perform a seismic hazard assessment of area and convolute results with vulnerability.
- n Aleatory variability modelled in hazard and thus removed from reliability formula.
- n **Inter-event** and **intra-event** components of aleatory variability need to be modelled separately in loss model.
- n Need to use **thousands of scenario earthquakes** (which can be generated using **Monte Carlo Simulation** in conjunction with **seismicity model**) to obtain **robust loss exceedance curves**.

## CONCLUSIONS / FUTURE RESEARCH

- n DBELA is a **MECHANICS-BASED** loss assessment methodology and the demand and capacity can be plotted on the same displacement-period plane.
- n Capacity equations can be **EASILY CALIBRATED** for different regions by adapting ( $\mu$ ,  $\sigma$ , **DISTRIBUTION**) of parameters.
- n Further developments:  
**INFILL PANELS, SHEAR FAILURE, other STRUCTURAL TYPES, improved parameters used in EQUIVALENT LINEARISATION, improvement of DISPLACEMENT SPECTRA** (especially at long periods).
- n **CALIBRATION** of the methodology and **COMPARISON** of results with damage data.



Thank you!



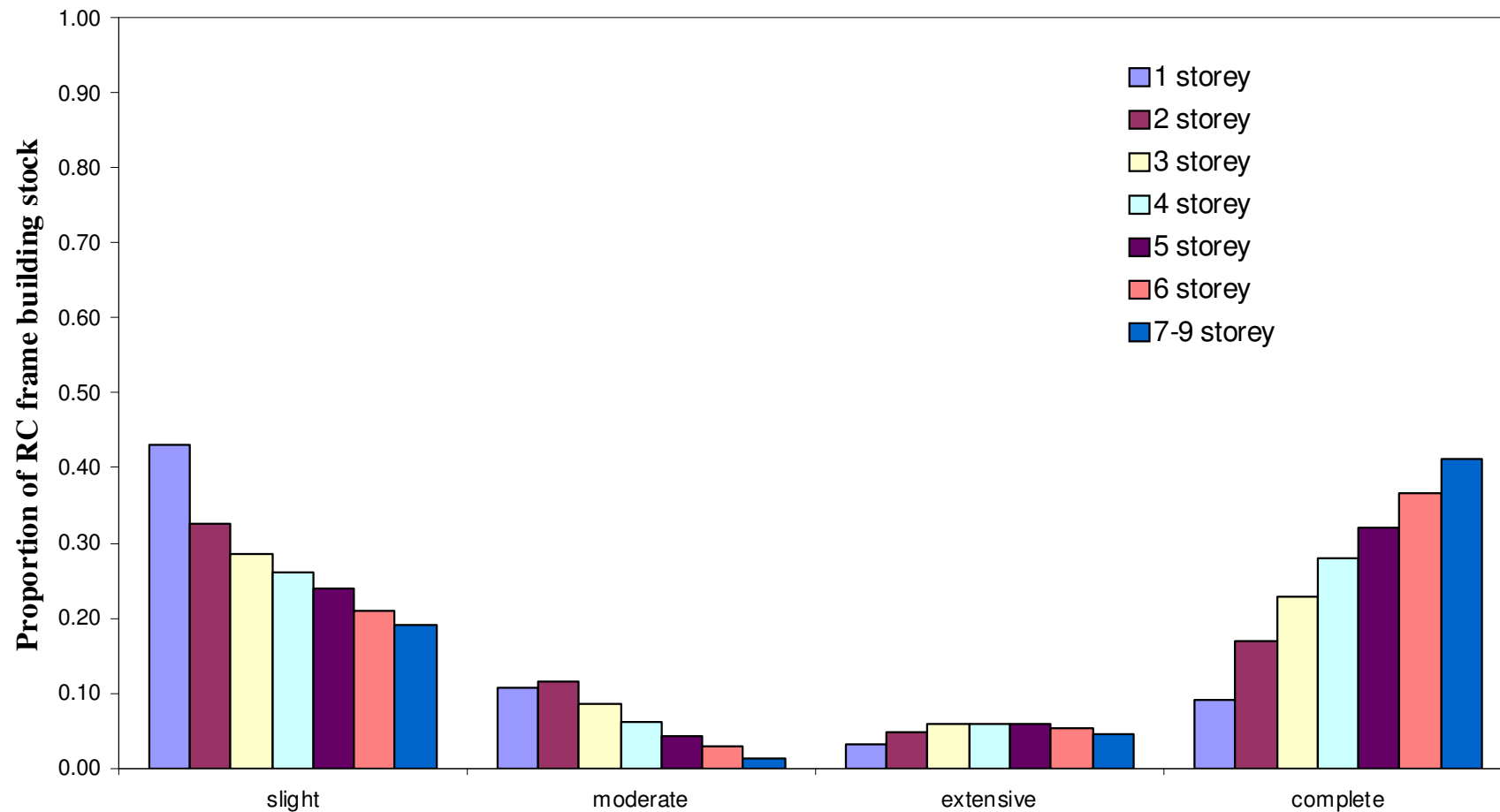


## CALIBRATION OF SEISMIC DESIGN CODES

Quantitative comparison of incremental cost of adding seismic resistance and the associated losses that can be avoided within an urban area

- n DBELA is ideal as structural parameters in displacement capacity equations can easily be adapted to model increasing levels of seismic resistance (e.g. stiffness and ductility).
- n Owners and regulators need to decide on a **minimum allowable resistance** of the building stock considering the return period of 'tolerable' levels of death, injury and persons rendered homeless.
- n Loss curves derived for various resistance levels of each building class are produced and compared with cost of resistance to define '**optimum**' resistance.

# BASE MODEL DAMAGE PREDICTIONS FOR EACH NUMBER OF STOREYS FOR POOR, COLUMN-SWAY



# SENSITIVITY TO GROUPING OF STOREY NUMBERS

