Analysis of RC buildings under earthquakes with arbitrary orientations.

Results and Challenges

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The angle of seismic incidence in the seismic safety assessment procedure of individual buildings

- Eurocode 8 Part 3 (deterministically-oriented approach)

4stage procedure:

1) Limit State/s
2) Level of knowledge
3) Structural analysis
4) Safety verifications

- PBEE framework (Probabilistic approach)

$$\lambda(L)=\int\int\int G(L\,|\,\mathrm{DM})\cdot dG(DM\,|\,EDP)\cdot dG(EDP\,|\,IM)\cdot dP(\mathrm{IM})$$

Decision!

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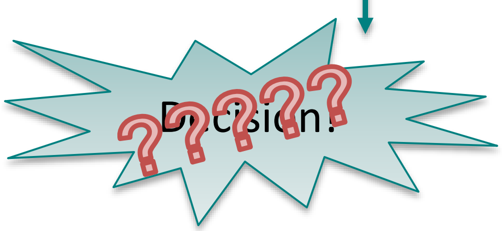

Problems integrating the critical angle

- Practical
  - ✓ EDP
  - ✓ Frequency content
  - ✓ Seismic intensity
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Inexistent techniques to predict the critical angle.

Analytical procedure proposed for LFA.

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Overall performance of a realistic 3D structure and compliance (or not) with a Limit State.

Unique demand parameter able to characterize the global response of the structure:

Proposed framework to define a global demand parameter

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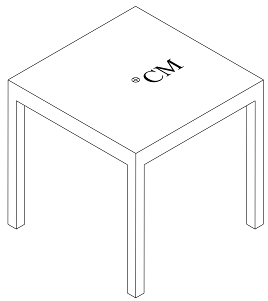
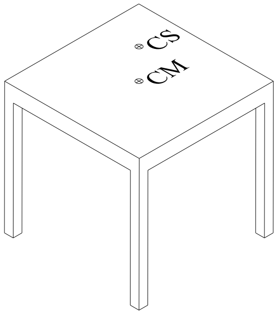
Critical angle of incidence in LFA





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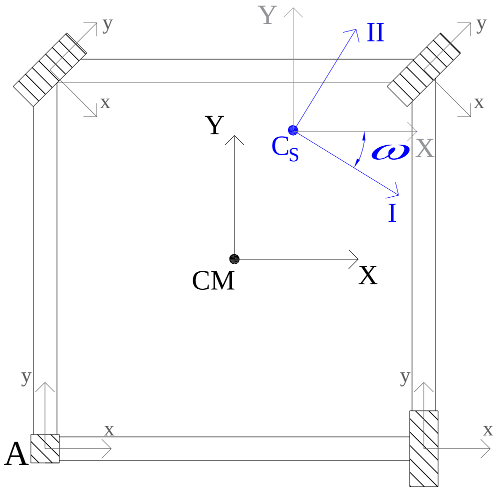

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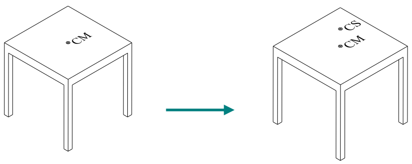

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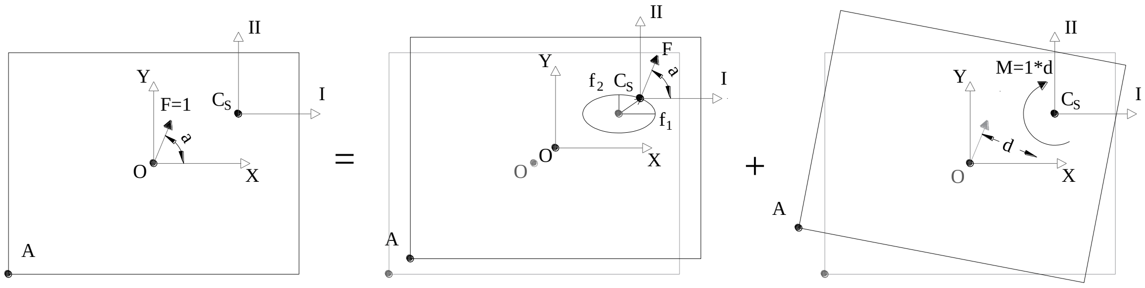

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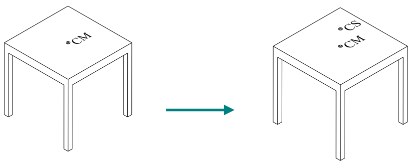

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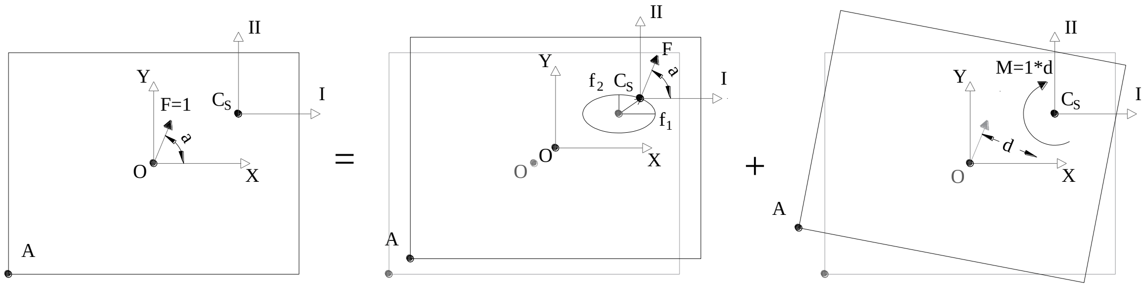

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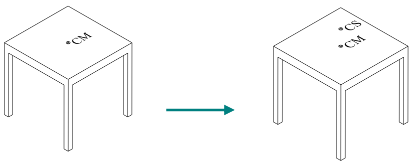
$$T_{unc}(\alpha) = \frac{T_I \cdot T_{II}}{\sqrt{\cos(\alpha)^2 \cdot T_{II}{}^2 + \sin(\alpha)^2 \cdot T_I{}^2}}$$

Critical angle of incidence in LFA



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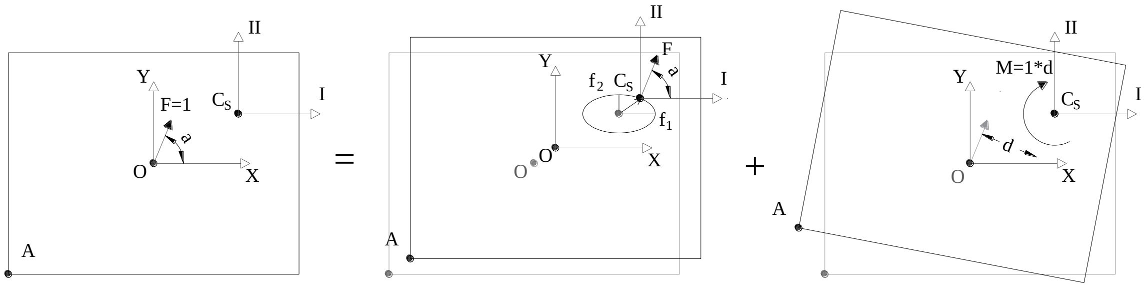

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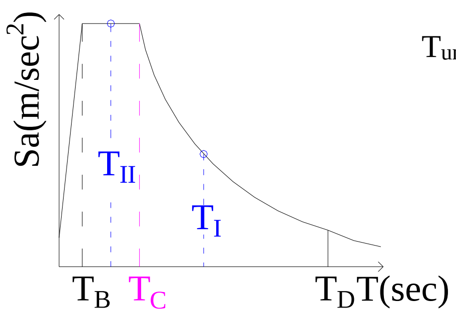
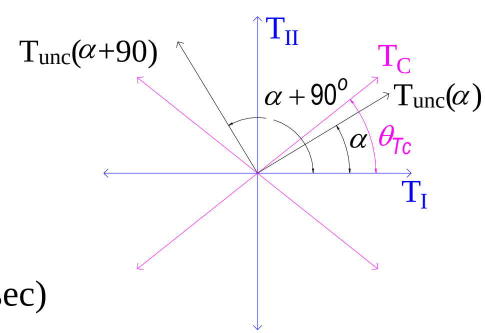
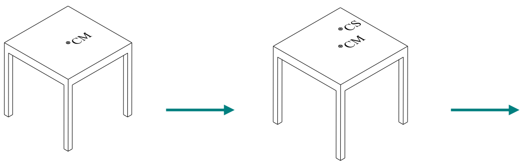




$$F(\alpha) = \begin{cases} m \cdot 2.5 \cdot a_g \cdot S \cdot \eta \cdot \dfrac{T_C}{T(\alpha)} & , \text{ for } 0 \le \alpha \le \alpha_{T_C} \\ m \cdot 2.5 \cdot a_g \cdot S \cdot \eta & , \text{ for } \pi - \alpha_{T_C} \le \alpha \le \alpha_{T_C} \\ m \cdot 2.5 \cdot a_g \cdot S \cdot \eta \cdot \dfrac{T_C}{T(\alpha)} & , \text{ for } \pi - \alpha_{T_C} \le \alpha \le \pi + \alpha_{T_C} \\ \ldots \end{cases}$$

Critical angle of incidence in LFA



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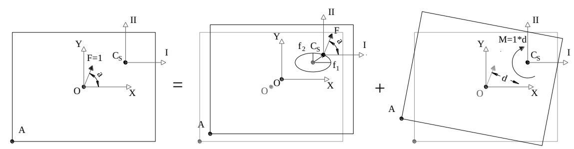

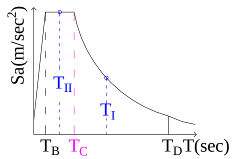

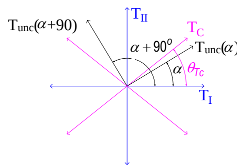

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Combination of the two orthogonal components using a directional combination rule,

e.g. a percentage λ combination rule:

$$u^A(\alpha)=\sqrt{\left(F(\alpha)\cdot u^A_{I,"1"}(\alpha)\pm\lambda\cdot F(\alpha+\frac{\pi}{2})\cdot u^A_{I,"1"}(\alpha+\frac{\pi}{2})\right)^2+\left(F(\alpha)\cdot u^A_{II,"1"}(\alpha)\pm\lambda\times F(\alpha+\frac{\pi}{2})\cdot u^A_{II,"1"}(\alpha+\frac{\pi}{2})\right)^2}$$

or the SRSS:

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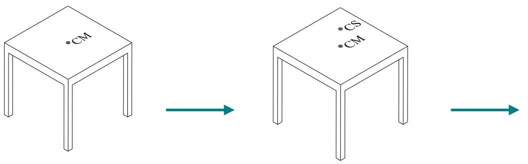
Critical angle of incidence in LFA



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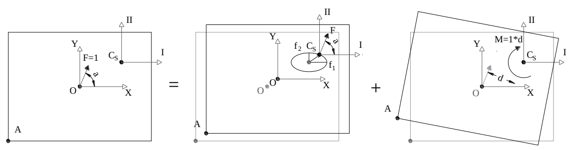

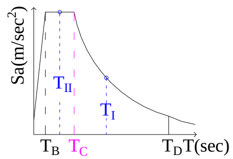

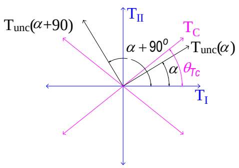

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Maximize to get the critical angle:

$$\boxed{\frac{du^A(\alpha)}{d\alpha}=0 \quad\rightarrow\quad \alpha_{crit}}$$

Problems integrating the critical angle

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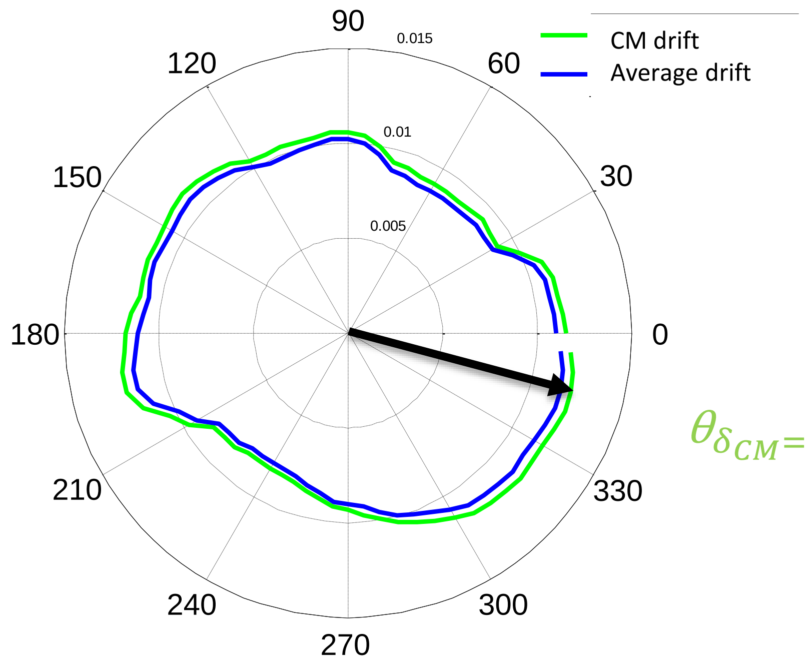
Unique demand parameter able to characterize the global response of the structure:

Proposed framework to define a global demand parameter

Global structural 3D response: Preliminary results

- Definition of one demand parameter able to describe the average global response: **Initial approach**

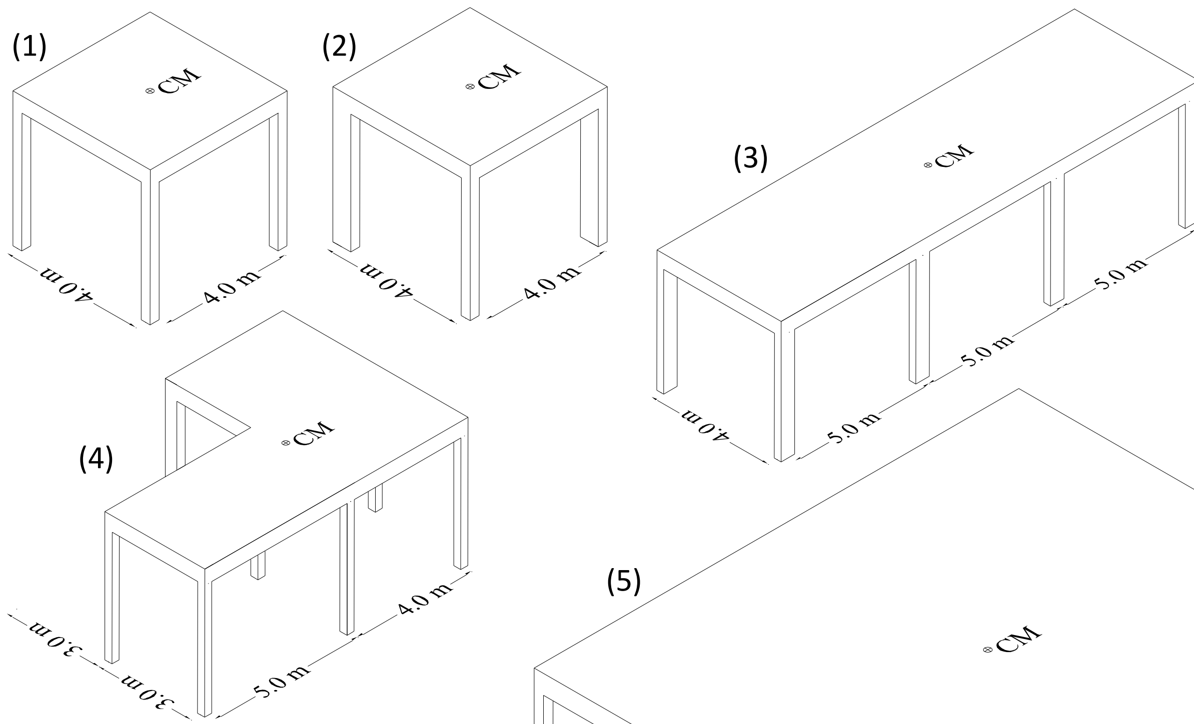
  - ✓ Proposed parameter: drift of the Centre of Mass, dr_{CM}
  - ✓ Global response: Average drift of all columns, dr_{ave}
  - ✓ Hypothesis: Both response parameters attain their maximum value for the same angle of seismic incidence, $\theta_{dr_{CM}=\max} = \theta_{dr_{ave}=\max}$

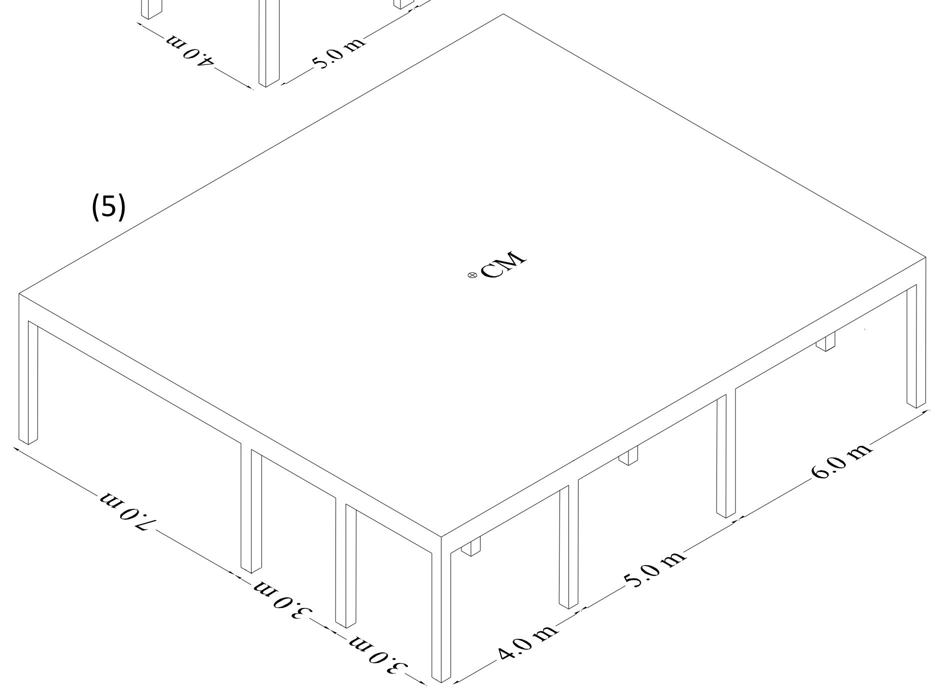


$\theta_{\delta_{CM}=\max} = \theta_{\delta_{ave}=\max}$

Global structural 3D response: Preliminary results

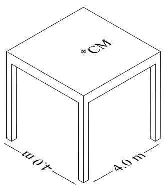
- Structures analyzed (plasticity lumped at member ends)

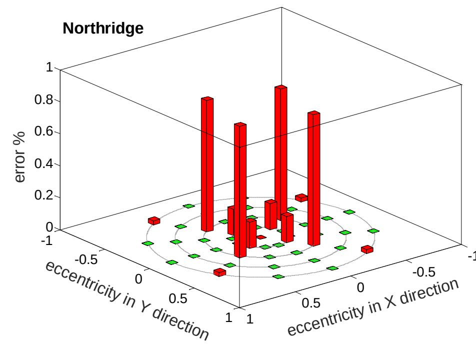


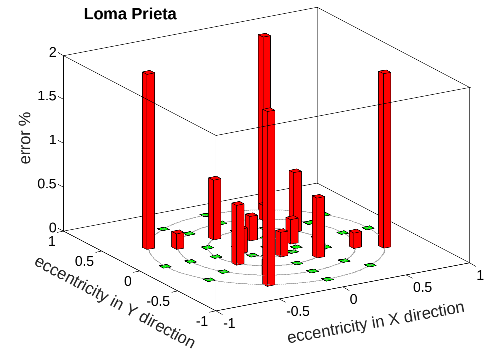


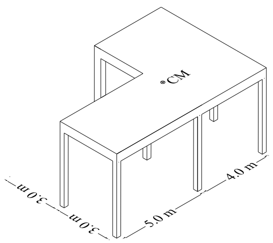
Structure No	Height (m)	Columns (cm)	Beams (cm)
1	4.0	25×25	25×50
2	4.0	25×25, 25×50	25×50
3	4.0	25×50	25×40
4	4.0	25×25, 25×40	25×50
5	4.0	40×40	25×60

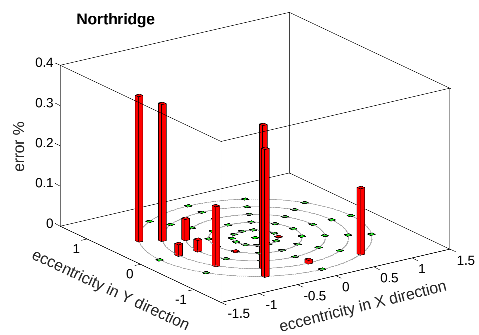
Global structural 3D response: Preliminary results

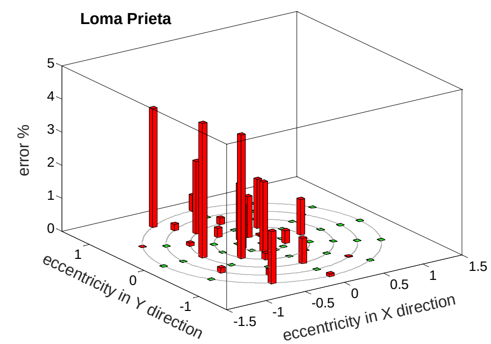


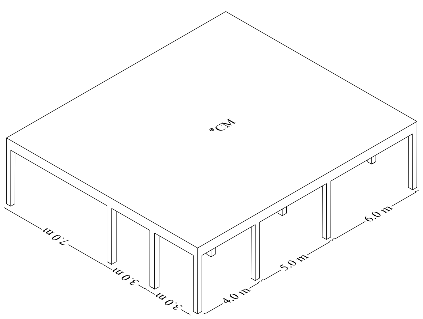


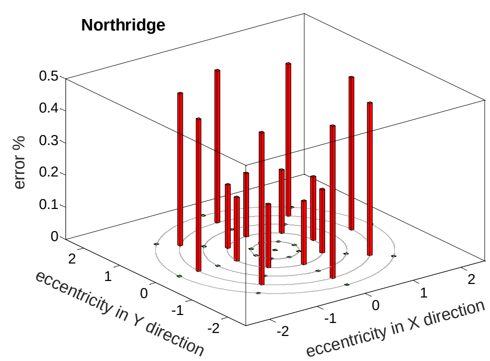


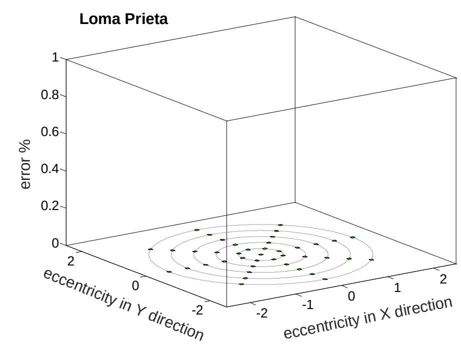












Global structural 3D response: revised approach

- Definition of one demand parameter able to describe the average global response: **revised approach being proposed**.

✓ Proposed parameter: the interstorey drift remains the main suspect for the global demand parameter.

✓ Global demand: in terms of structural losses.

✓ Hypothesis: Definition of a point where the structural loss, quantified based on its drift, is correlated to the total structural loss.

How:

- Determination of structural loss of a storey using an element-based approach based on chord rotation – loss functions (Haselton et al., 2008).
- Structural loss of a storey using empirical EDP – loss functions (Ramirez & Miranda, 2009).

Seismic safety assessment of 3D structures integrating the critical angle

- Practical → Procedures to determine the critical angle of incidence of a response parameter.

  e.g. methodology proposed for LFA.

- Conceptual → Definition of a response parameter able to describe global structural performance.

  e.g. interstorey drift expressing total structural loss

Maximizing the global response parameter with respect to the angle of incidence in order to obtain the total critical structural response.