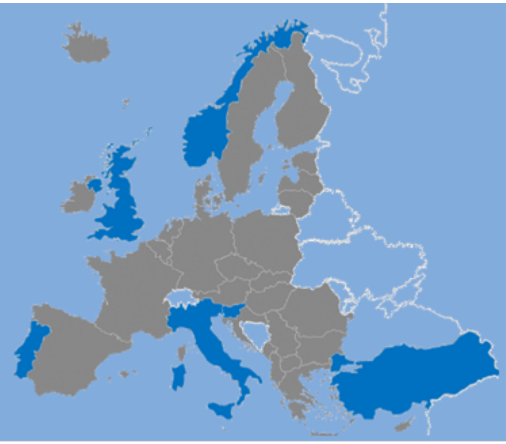
European Commission

Horizon 2020
European Union funding
for Research & Innovation

liquefACT



EARTHQUAKE INDUCED LIQUEFACTION RISK:
HOLISTIC ASSESSMENT AND MITIGATION

Wednesday 20th June 2018 - 11:30-13:00

ROOM: CR2 (building M2 - Thessaloniki Concert Hall/16ECEE Conference Venue)

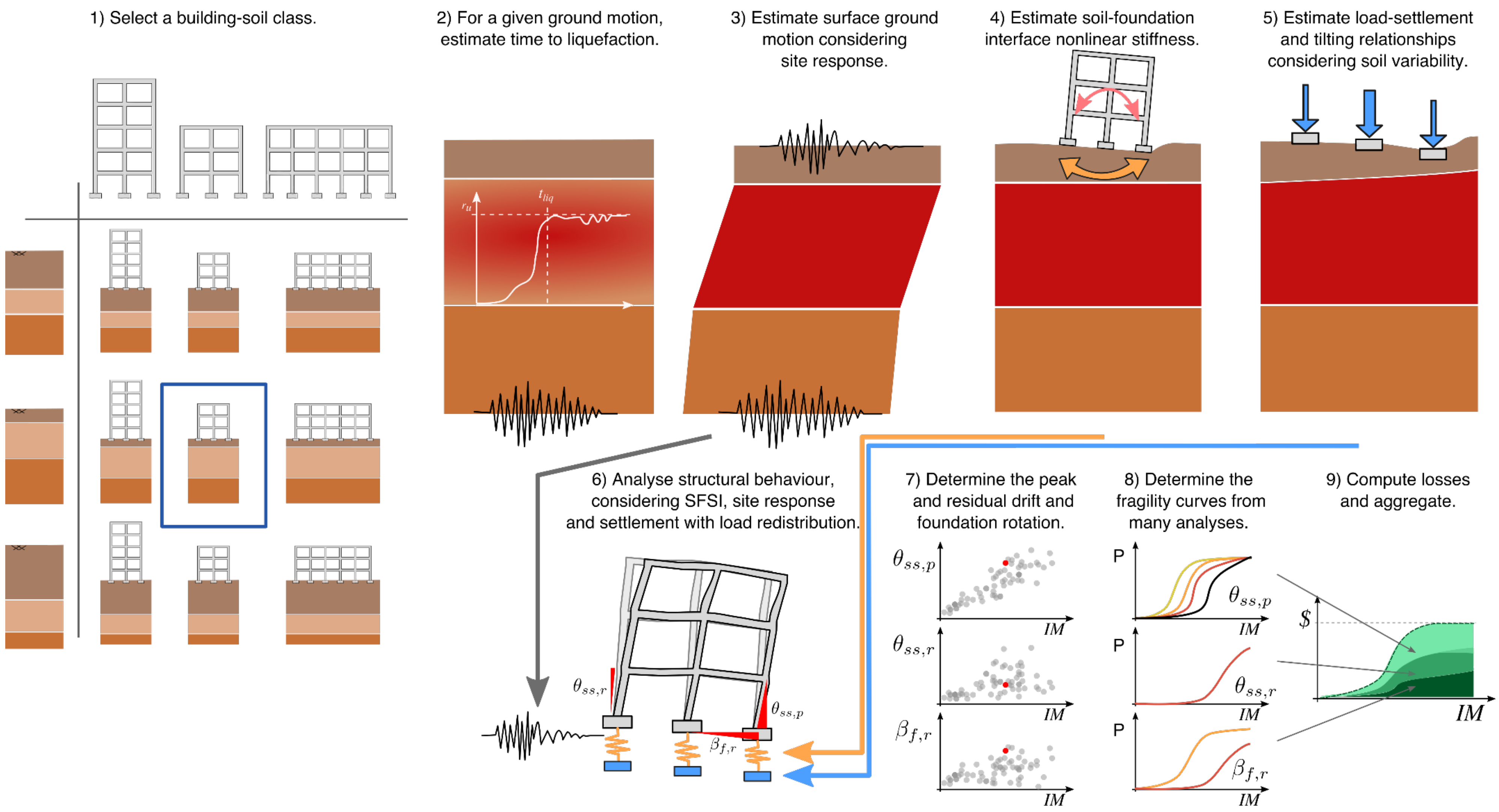
Liquefaction vulnerability of structures and infrastructures on liquefiable deposits

Xavier Romão, Maxim Millen

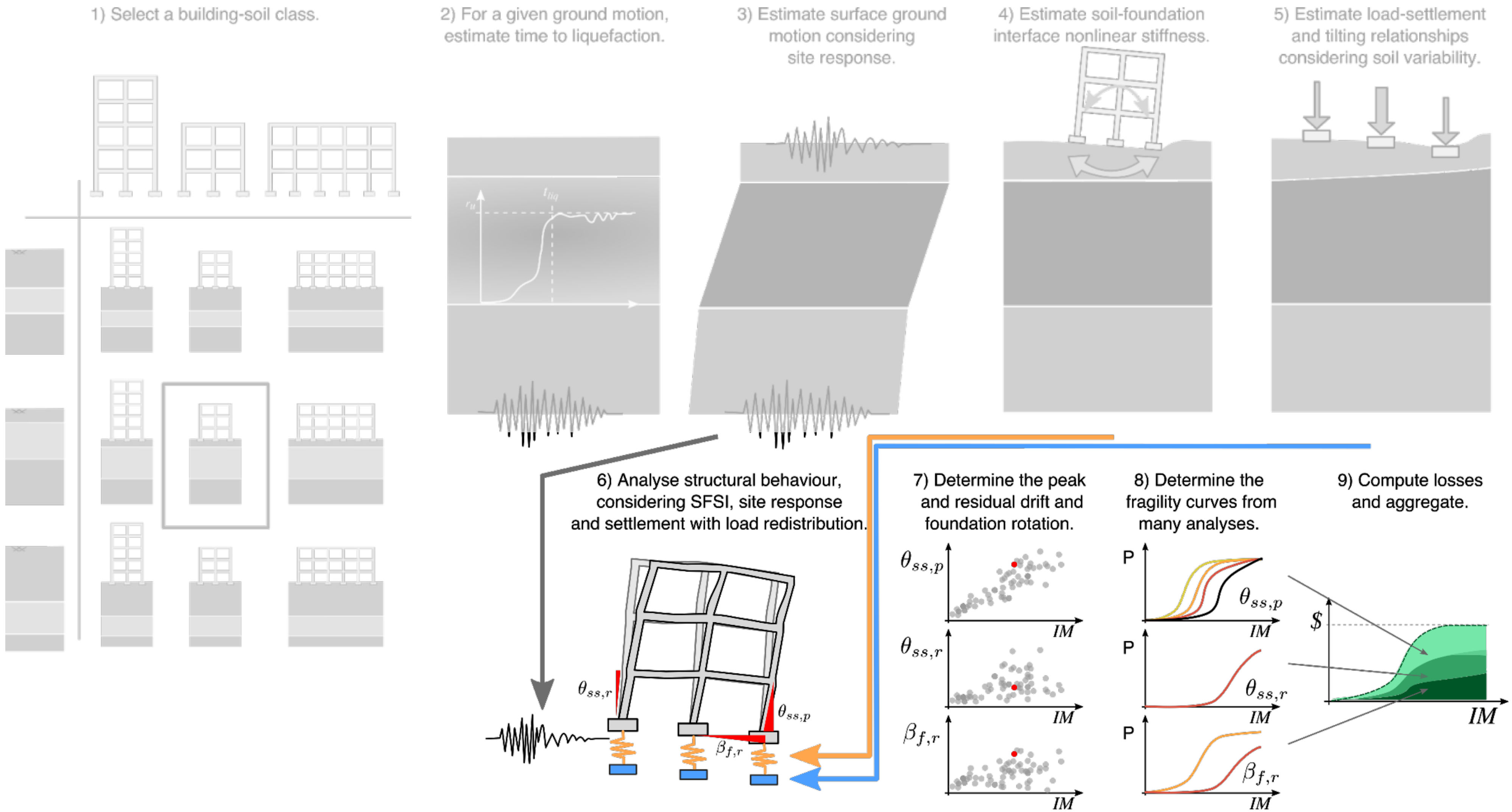
UNIVERSITY OF PORTO

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

QUANTIFYING BUILDING PERFORMANCE

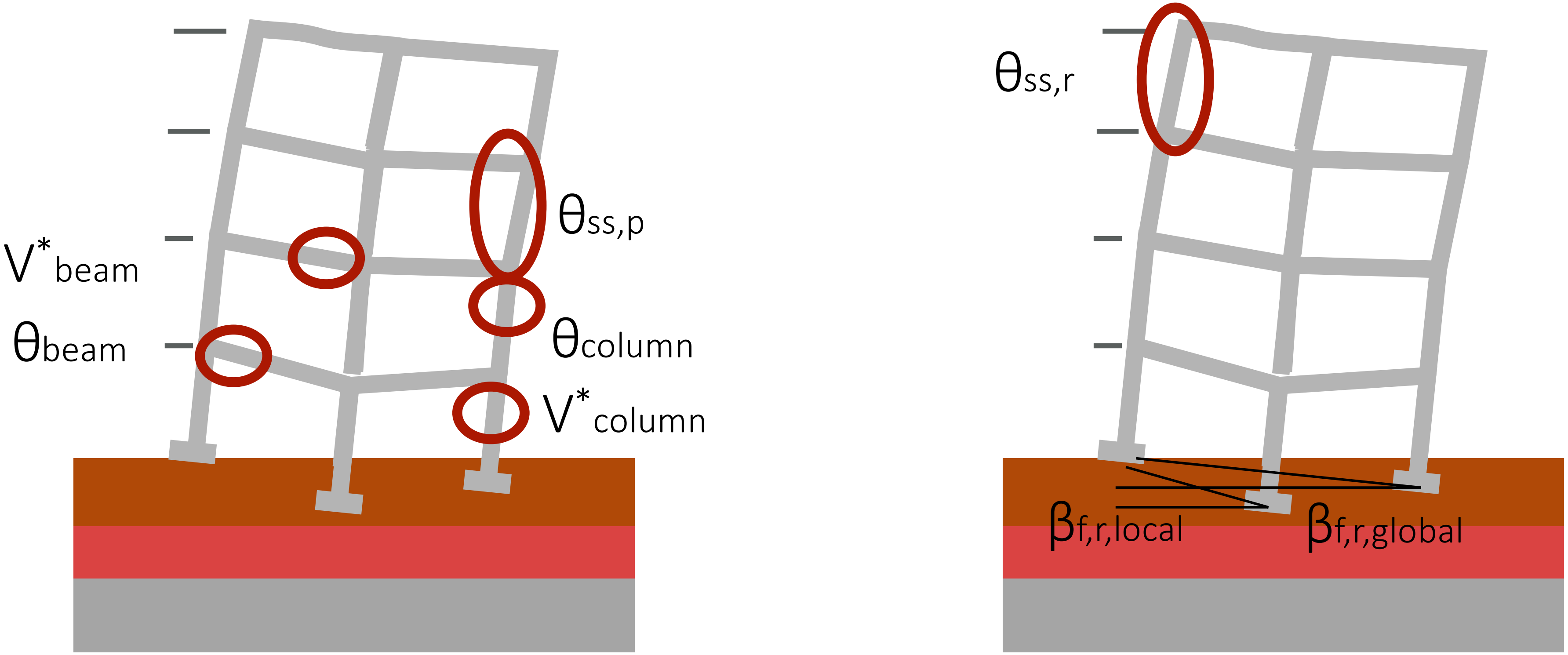


QUANTIFYING BUILDING PERFORMANCE



QUANTIFYING BUILDING PERFORMANCE

Engineering Demand Parameters (EDPs) and modelling framework



Dynamic performance EDPs:

Maximum chord rotation θ, shear force, V* and interstorey drift $\theta_{ss,p}$

Residual performance EDPs:

Maximum residual interstorey drift $\theta_{ss,r}$ and residual rotation of the foundation $\beta_{f,r}$

QUANTIFYING BUILDING PERFORMANCE

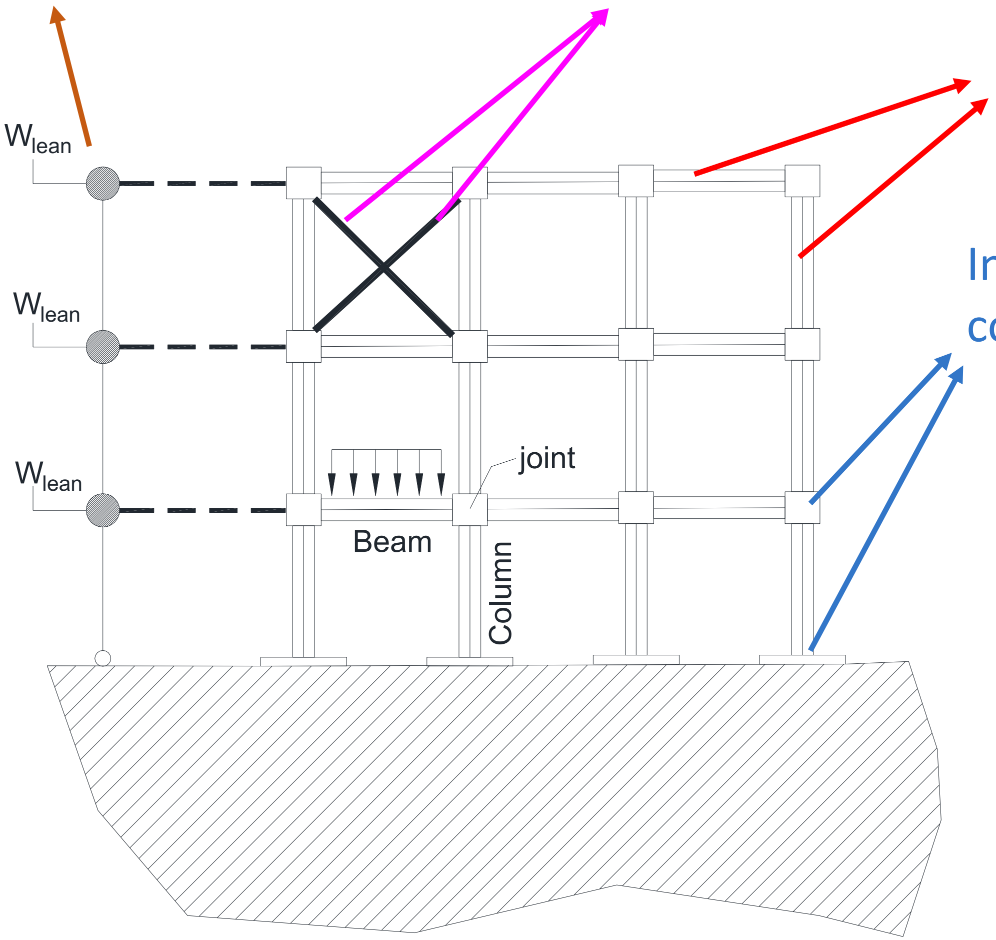
Engineering Demand Parameters (EDPs) and modelling framework

Leaning column accounting for global P-Δ effects

Nonlinear struts for the infills

Elastic beam-column elements

Inelastic behaviour concentrated in “hinges”



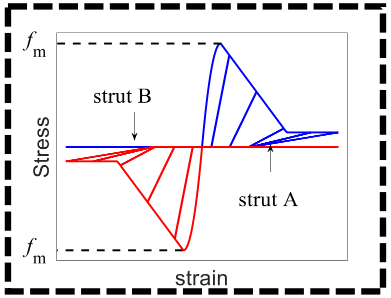
Modelling framework developed in OpenSees:
2D inelastic frames accounting for soil-structure interaction and liquefaction induced damage

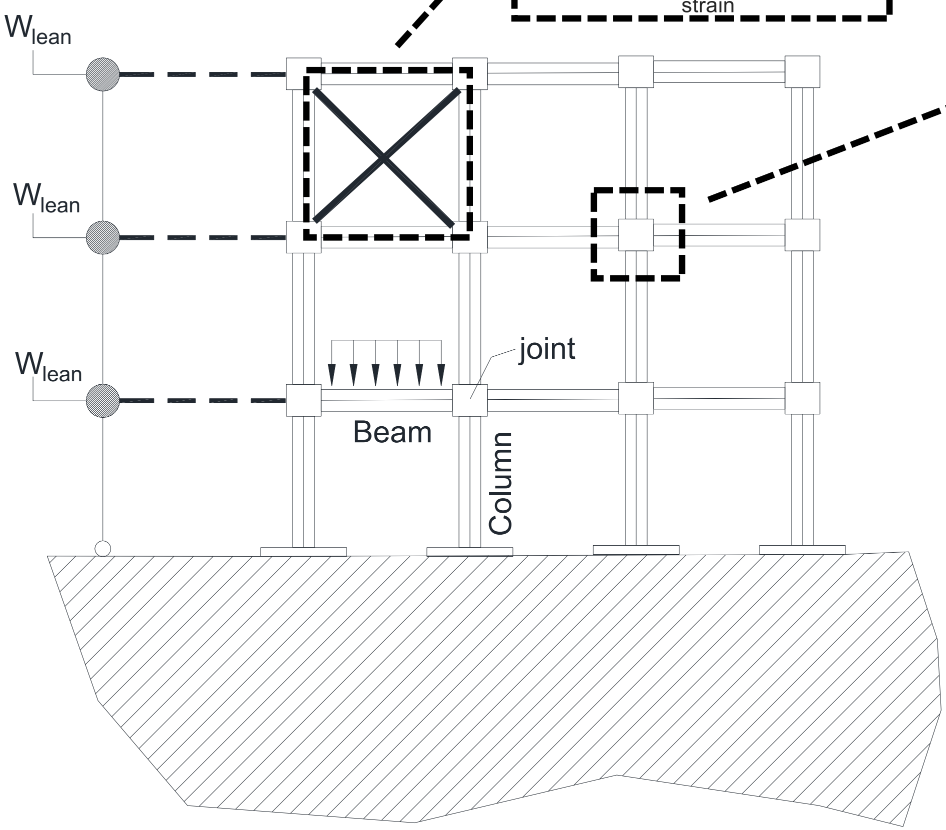
QUANTIFYING BUILDING PERFORMANCE

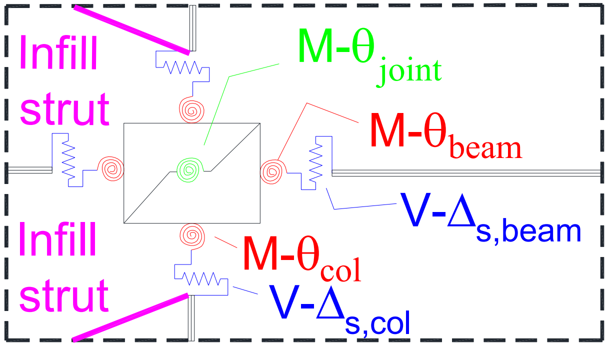
Engineering Demand Parameters (EDPs) and modelling framework

Full/partial infills

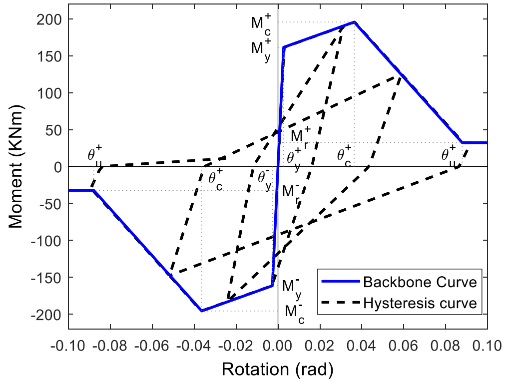
2 struts/infill (compression-only)



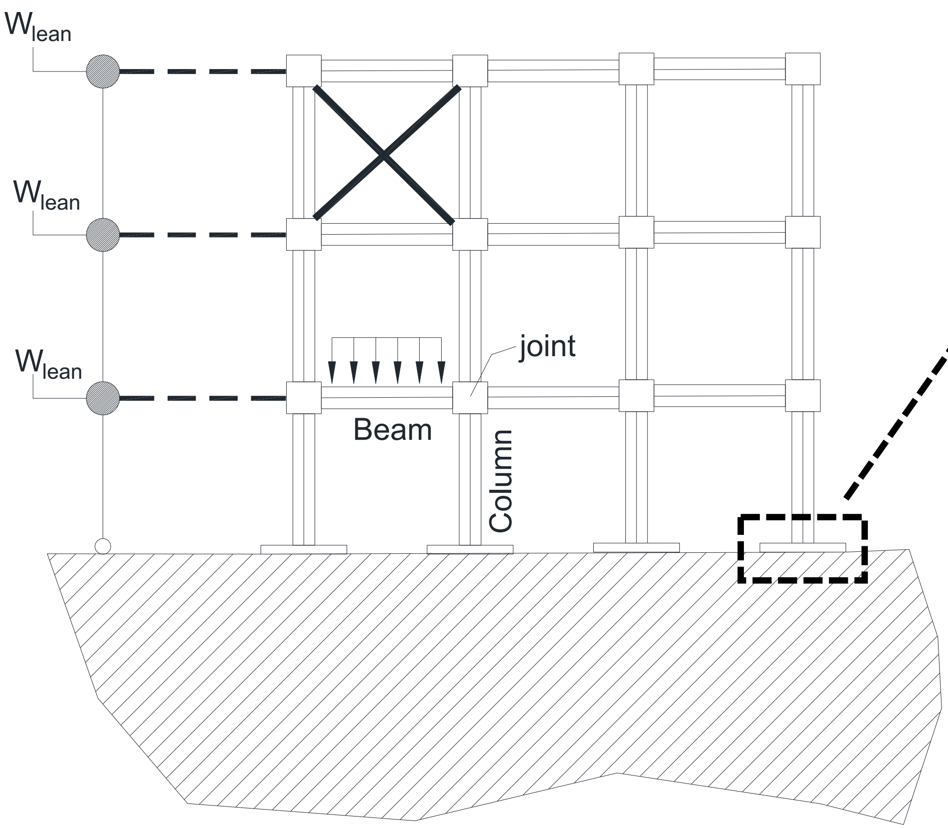


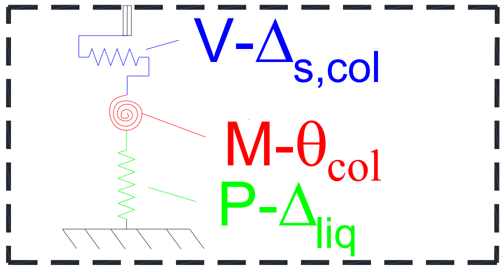


Nonlinear hysteresis for M-θ (includes stiffness and strength degradation)

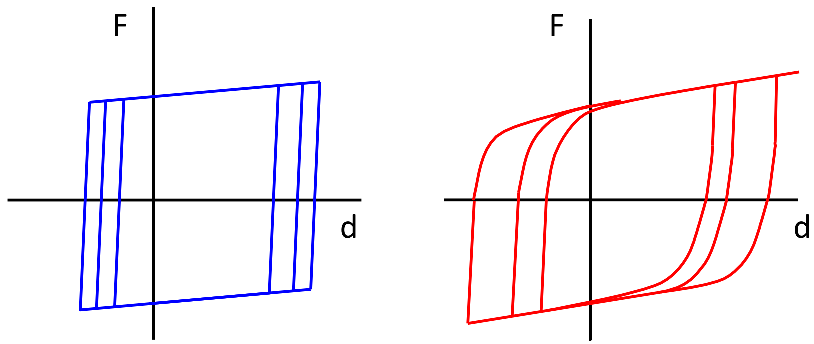


QUANTIFYING BUILDING PERFORMANCE
Engineering Demand Parameters (EDPs) and modelling framework



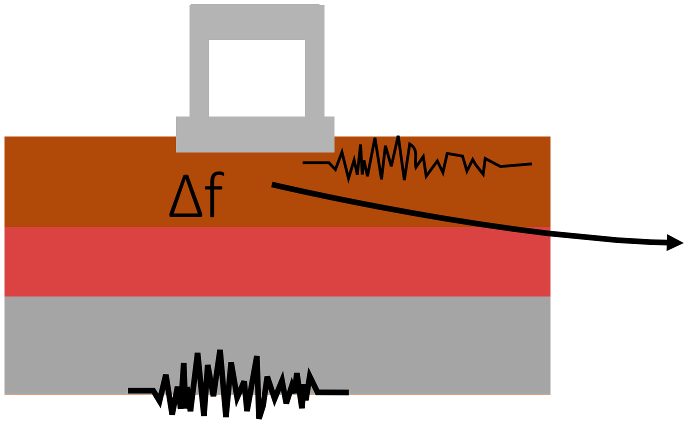


Nonlinear hysteresis for soil-structure interaction spring $P\text{-}\Delta_{liq}$



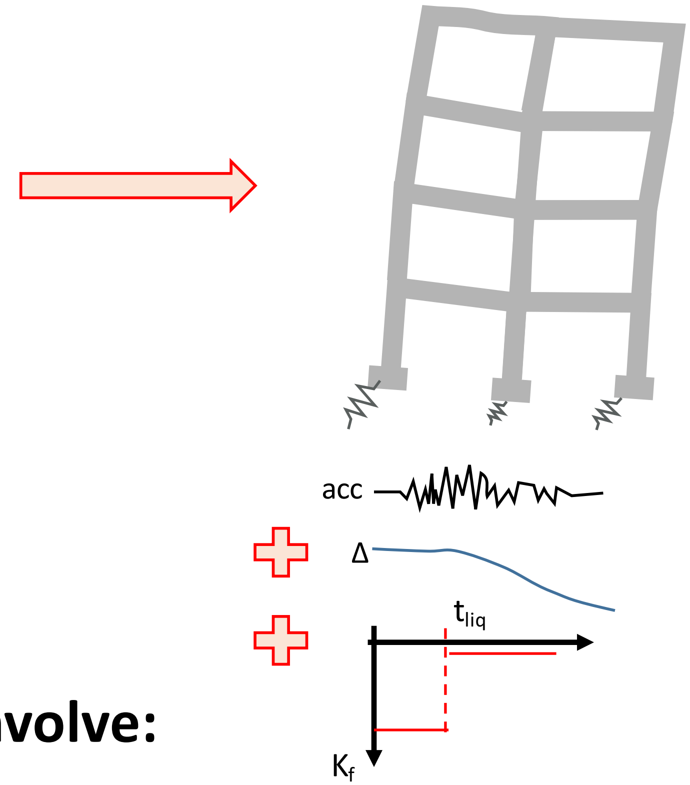
Steel01 model SteelMP model

QUANTIFYING BUILDING PERFORMANCE
additional modifications to the modelling/analysis framework



Time series of:
- Settlement
- Stiffness
- Surface shaking

Estimate of t_{liq}



Model the soil system (FLAC analyses)

Dynamic analyses of the OpenSees model involve:

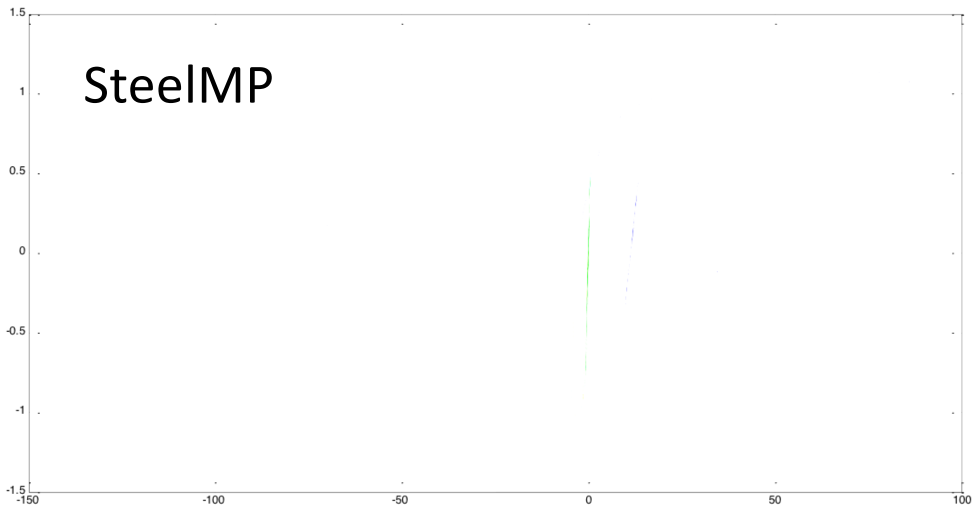
Ground motion filtered by the selected soil profile

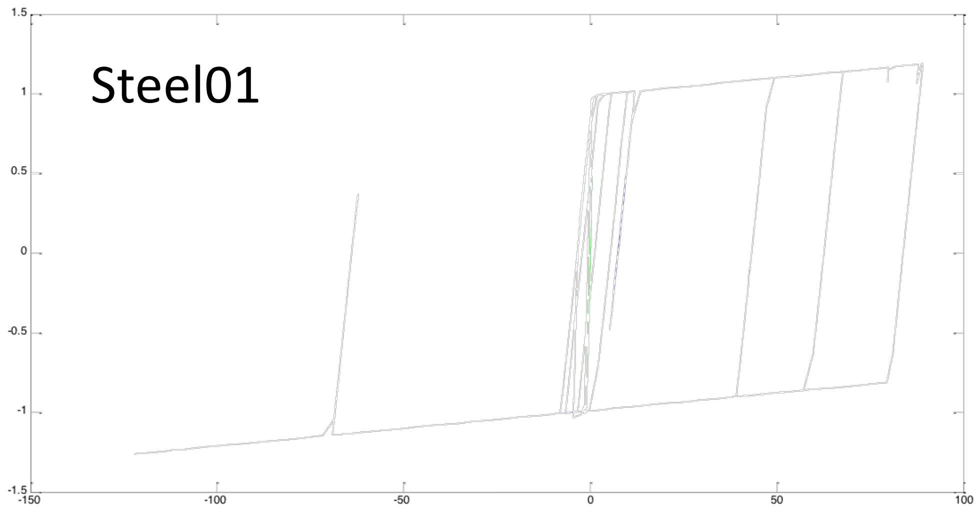
Time series of imposed displacements at the supports acting simultaneously with the ground motion (determined from soils spring settlement & expected settlement)

Reduction of the stiffness of soil springs K_f after t_{liq} to reflect the stiffness evolution

QUANTIFYING BUILDING PERFORMANCE
analysing the performance of the SFSI spring model

Performance test: in a test frame, at a certain time instant of the dynamic analysis, reduce the stiffness of the SSI spring model to 10% of the initial value in 10 steps at a certain time instant, using the 2 models (Steel01 and SteelMP)

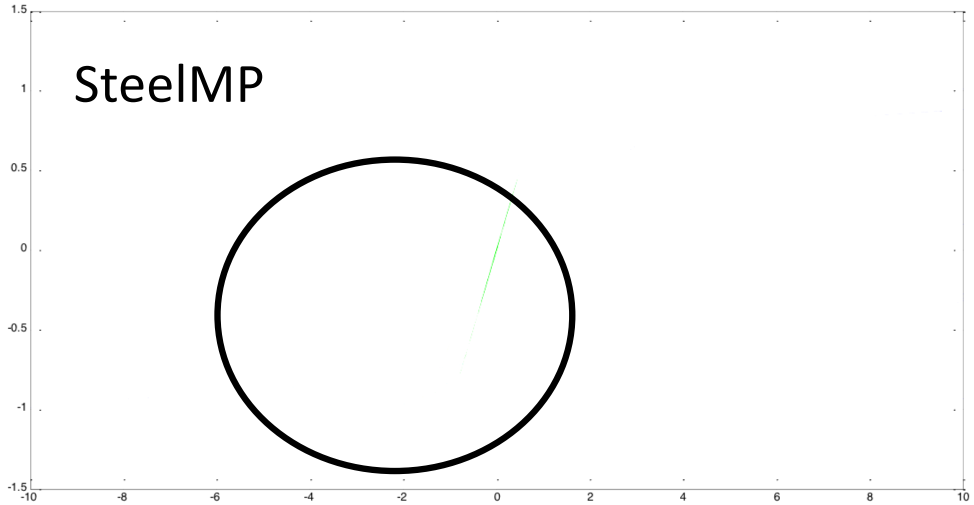


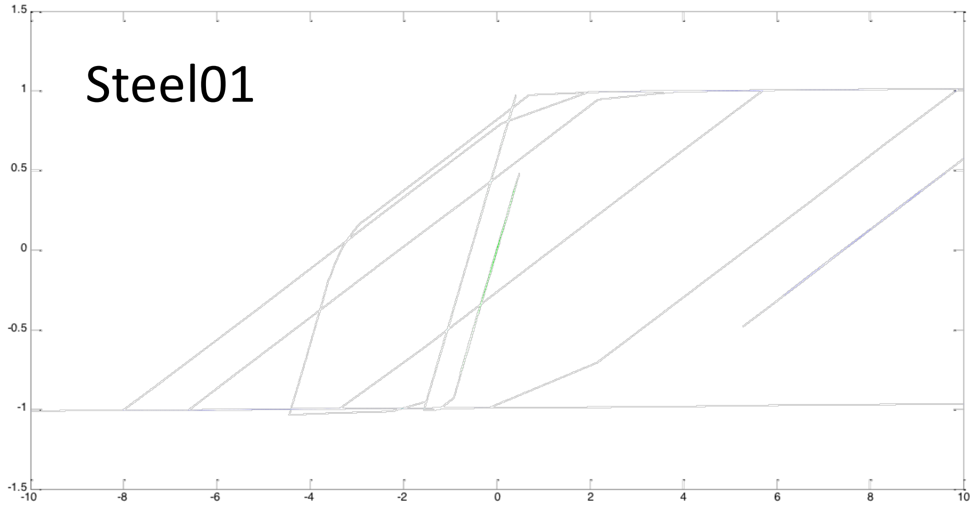


Green – response before changing the stiffness
Red – response when stiffness is changing
Blue – response after changing the stiffness

Outside obvious differences between the 2 models, the response seems ok in both cases, but a closer look reveals some issues

QUANTIFYING BUILDING PERFORMANCE
analysing the performance of the SFSI spring model



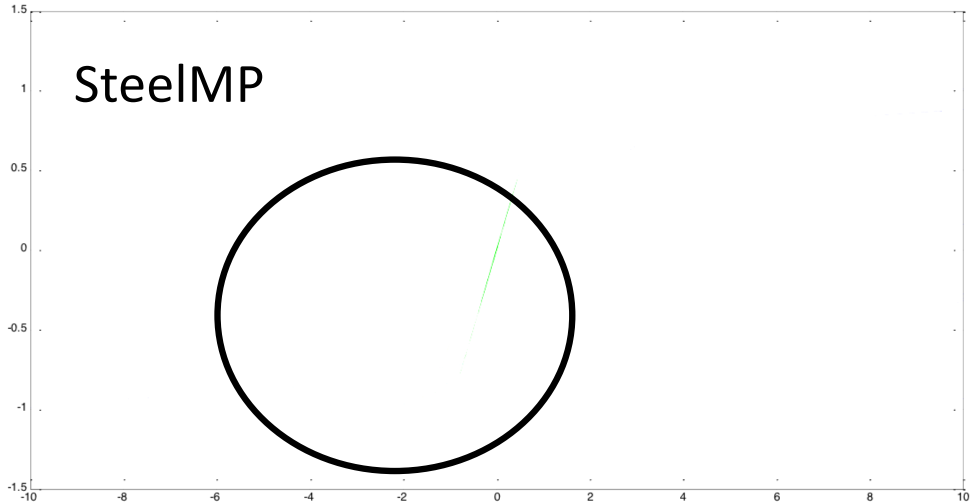


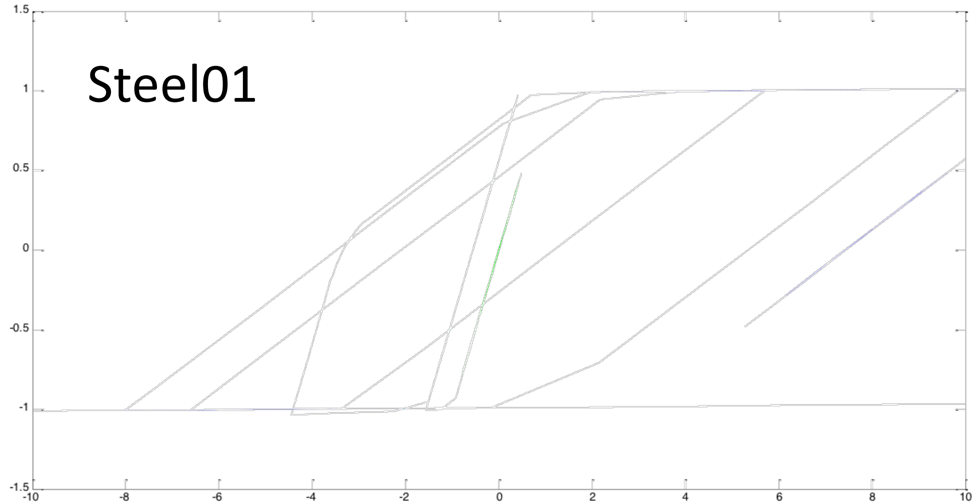
Green – response before changing the stiffness
Red – response when stiffness is changing
Blue – response after changing the stiffness

The **response of SteelMP is inconsistent**. It is clear when we compare the change from the green to the red curve in both models: when the stiffness change starts in SteelMP, there is a strange jump in the response; **but the response is able to get back on track after the stiffness change is over**.

However, at that point, **the deformation of the spring is smaller with SteelMP than with Steel01** and **this difference in the deformation level is maintained until the end of the analysis**.

QUANTIFYING BUILDING PERFORMANCE
analysing the performance of the SFSI spring model





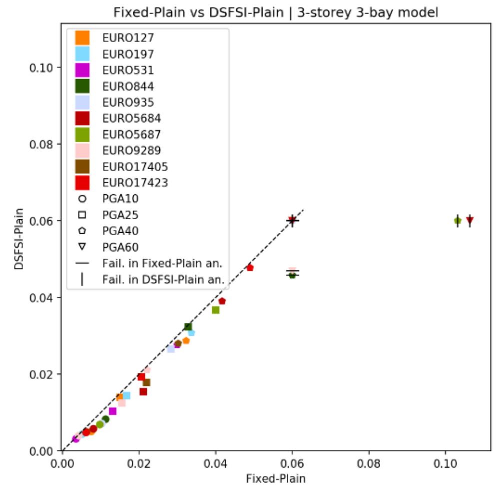
<u>Additional findings:</u>

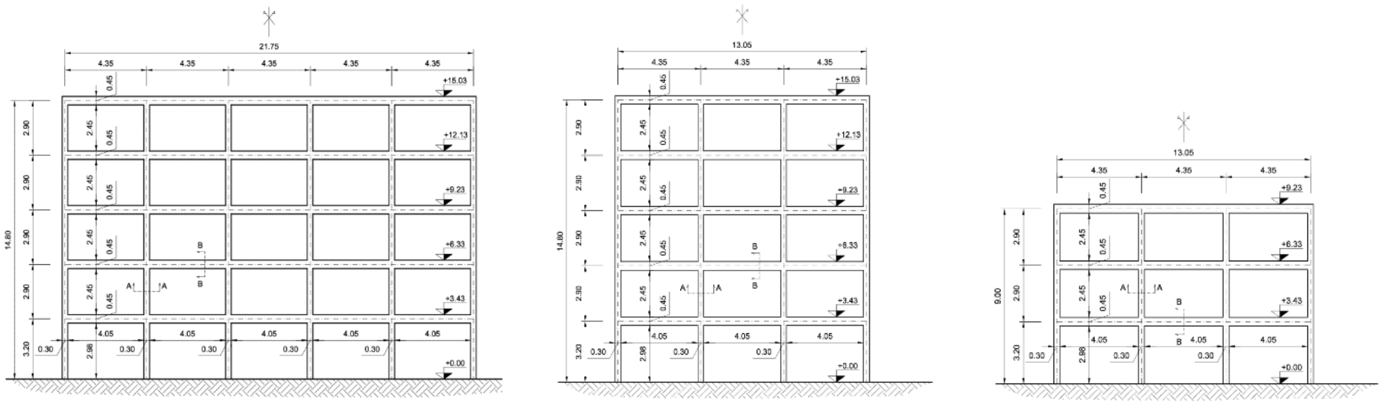
- Increasing the number of timesteps to achieve the desired stiffness reduction has no influence in the strange behaviour of SteelMP
- The strange behaviour of SteelMP only occurs if the stiffness change is performed when the spring is unloading
- The strange behaviour of SteelMP only occurs if the stiffness change is performed after the spring yields

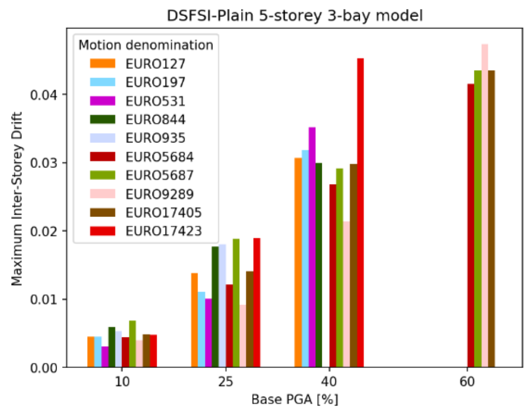
QUANTIFYING BUILDING PERFORMANCE
further sensitivity analyses

Several benchmark structures are currently being analysed to assess differences in the earthquake response for different conditions:

- Fixed supports vs supports with SFSI
- Normal ground motions vs filtered ground motions
- Uniform SFSI vs non-uniform SFSI
- Different models for SFSI
- …







SIMULATING PROBABILISTC BUILDING PERFORMANCE

Probabilistic building performance will account for:

- record-to-record variability (cloud analysis)
- uncertainty in the properties of the SFSI soil spring and t_{liq} (50 samples)
- building-to-building variability (100 building samples)

Development of a building model generator for creating multiple models of a certain building class

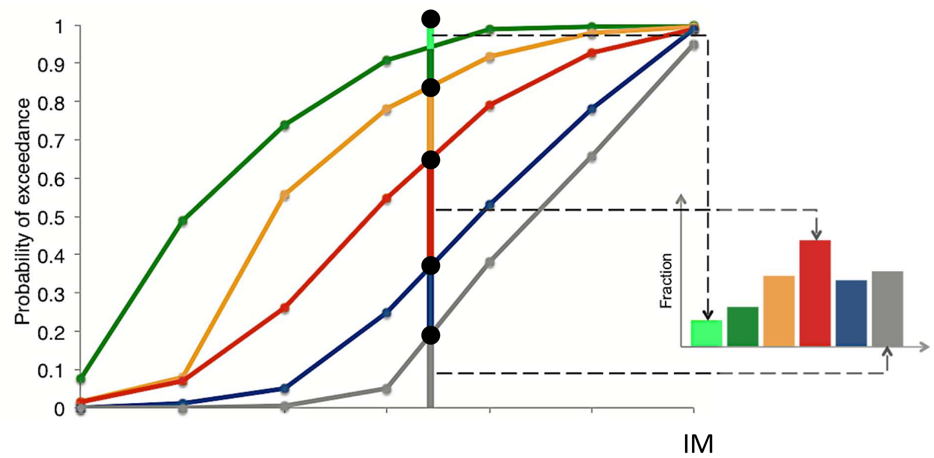
The building classes corresponds to gravity load designed RC frames with 1 to 5 storeys and 2 to 5 bays

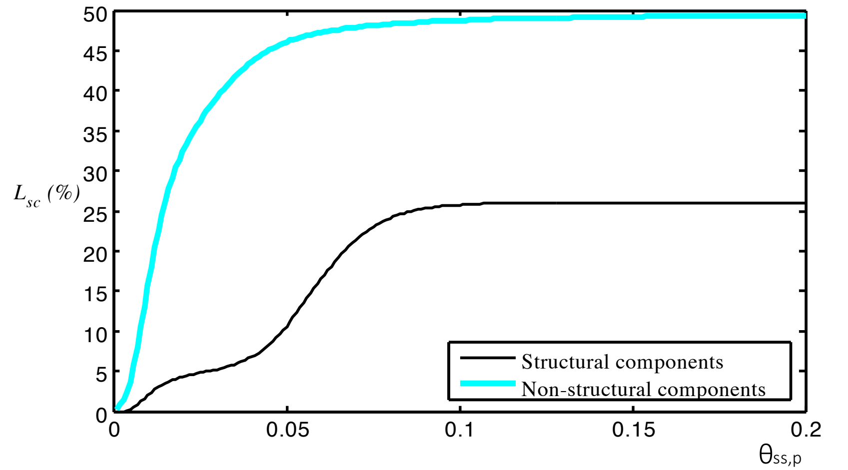
To establish fragility curves, performance levels are defined by:

- several maximum interstorey drift limits representing different levels of damage
- global collapse using one drift limit and accounting for “numerical” failure
- chord rotation and shear capacities (accounting for local failure; included in collapse cases)
- maximum residual interstorey drift limit
- reparability limits in terms of maximum foundation rotation (local and global)

LOSS QUANTIFICATION

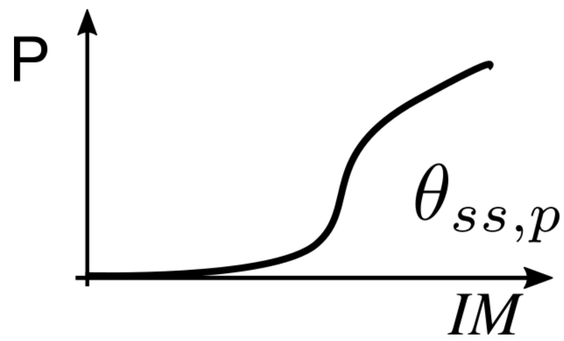
Fragility curves related with interstorey drift sensitive damage





Expected loss at a certain IM level, due to drift-related damage, given that the structure is repairable and didn't collapse

$$E\left(L_{\theta} \mid \bar{C} \cap R, IM_{i}\right) = \sum fr_{i} \times L_{i,\theta=\theta_{\lim}}$$

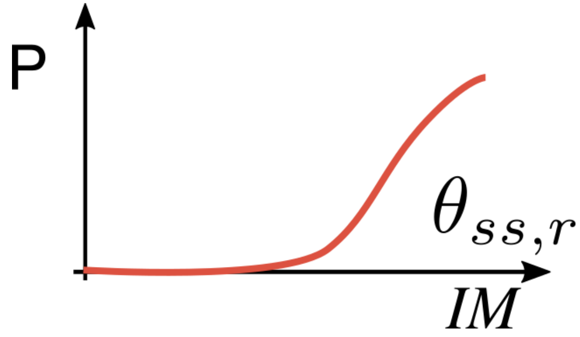


Fragility curve for collapse cases

$$p\left(C, IM_{i}\right)$$

$$E\left(L \mid C, IM_{i}\right) = 1$$

LOSS QUANTIFICATION

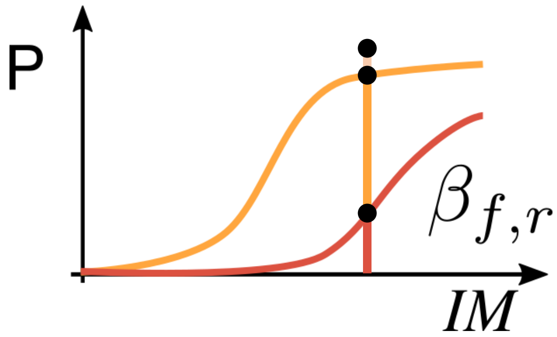


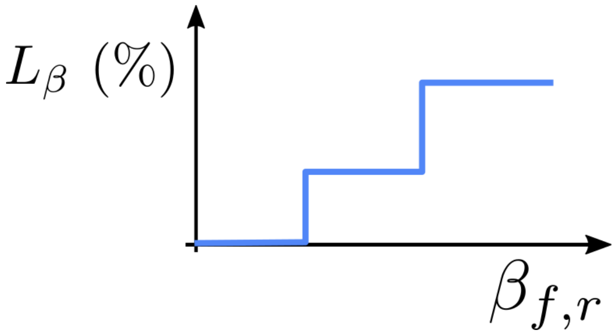
Fragility curve for residual drift (defines the limit of reparability and implies demolition)

$$p\left(D\,|\,\bar{C}, IM_i\right)$$

$$E\left(L\,|\,\bar{C}\cap D, IM_i\right)=1$$

$$or\ 1.05$$





Fragility curves for rotation at the foundation (defines limits of reparability and demolition)

$$E\left(L_{\beta_f}\,|\,\bar{C}\cap R, IM_i\right)=\sum fr_i \times L_{i,\beta_f=\beta_{f,\lim}}$$

LOSS QUANTIFICATION

Super structure-related loss

$$E_1(L \mid IM_i) = E(L_\theta \mid \bar{C} \cap R, IM_i) \times [1 - p(D \mid \bar{C}, IM_i)] \times [1 - p(C \mid IM_i)] + p(D \mid \bar{C}, IM_i) \times [1 - p(C \mid IM_i)] \times 1 + p(C \mid IM_i)$$

Loss = Repair + Demolition + Collapse

Foundation-related loss

$$E_2(L \mid IM_i) = E(L_{\beta_f} \mid \bar{C} \cap R, IM_i)[1 - p(D \mid \bar{C}, IM_i)] \times [1 - p(C \mid IM_i)]$$

Total expected loss

$$E(L \mid IM_i) = \min(E_1(L \mid IM_i) + E_2(L \mid IM_i); 1)$$