

De beoordeling van schade aan gebouwen

The assessment of damage to buildings

Living On Soft Soils – Work Package 3.2

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What damage can subsidence do to buildings?

Damage can be defined as a physical harm that **alters** the **functionality**, the **usefulness** and the **economical values** of a structure, from its initial state.

Aesthetic damage



Functional damage



Structural damage



Damage to masonry buildings

Different drivers induce ground movements (or settlements) that affect the existing structures:

- The intensity (how much?)
- The rate (time development) (how fast?)
- The soil heterogeneity (how variable?)
- The cause (by what?)

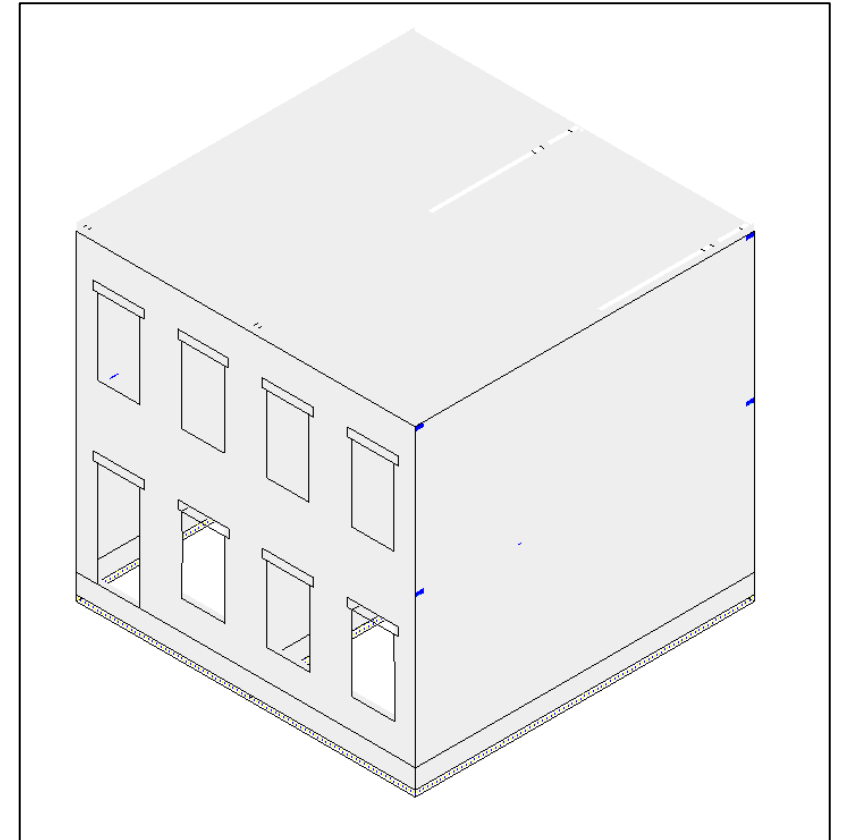
The response of the structure (the observed damage) depends on how the structure, the foundation system and the subsurface interact.

“Subsidence” or **“settlement”**?

“Process X” or **“Process Y”**?

It’s probably a combination!

The building does not know that, but still get damaged...

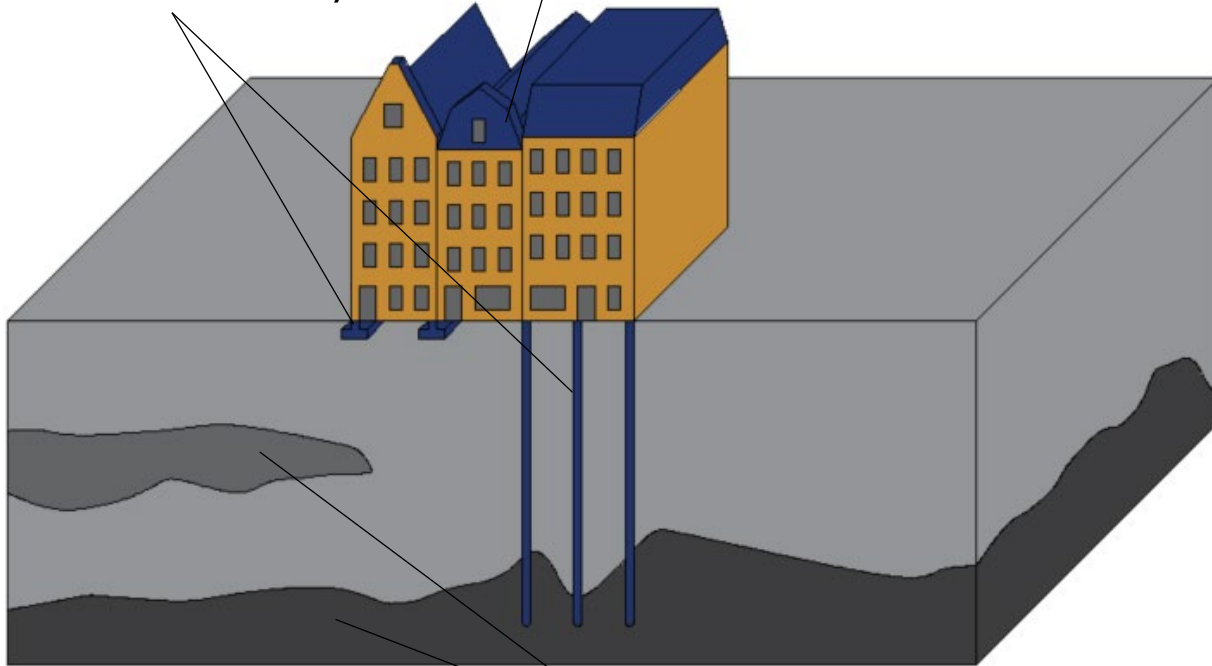


An example of how the damage develops in a masonry building due to settlements. The colored areas indicate the damage.

Knowledge gaps

Structure variability (e.g. materials, geometries)

Different foundations system



The subsoil is not homogeneous

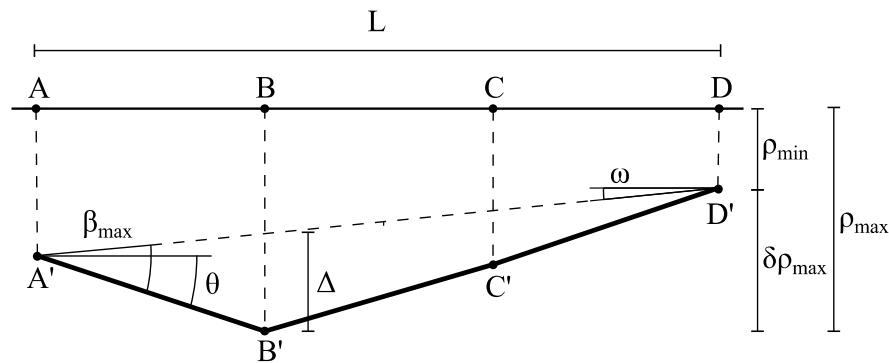
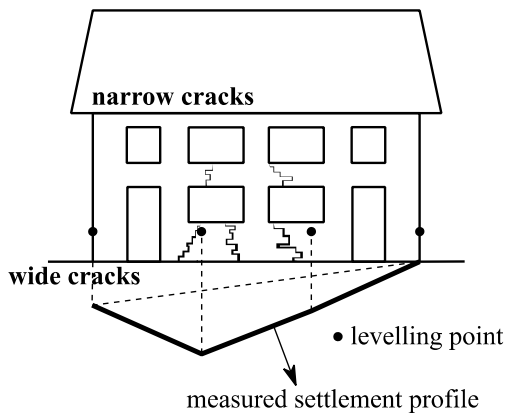
Proper regional or countrywide damage assessment analyses **require technical knowledge** of the behaviour of structures exposed to the hazard (subsidence).

There is a need for better insight into the vulnerability of the buildings (**linking building damage to subsidence**), **considering the variability of the buildings'** features (within the building or compared to other buildings) and the **heterogeneity of the subsoil**.

Existing relationships between the ground settlements and the building damage, which have been typically proposed as guidelines, **may not be suitable** for the damage assessment procedures for Dutch buildings.

Starting from observations of existing-structures...

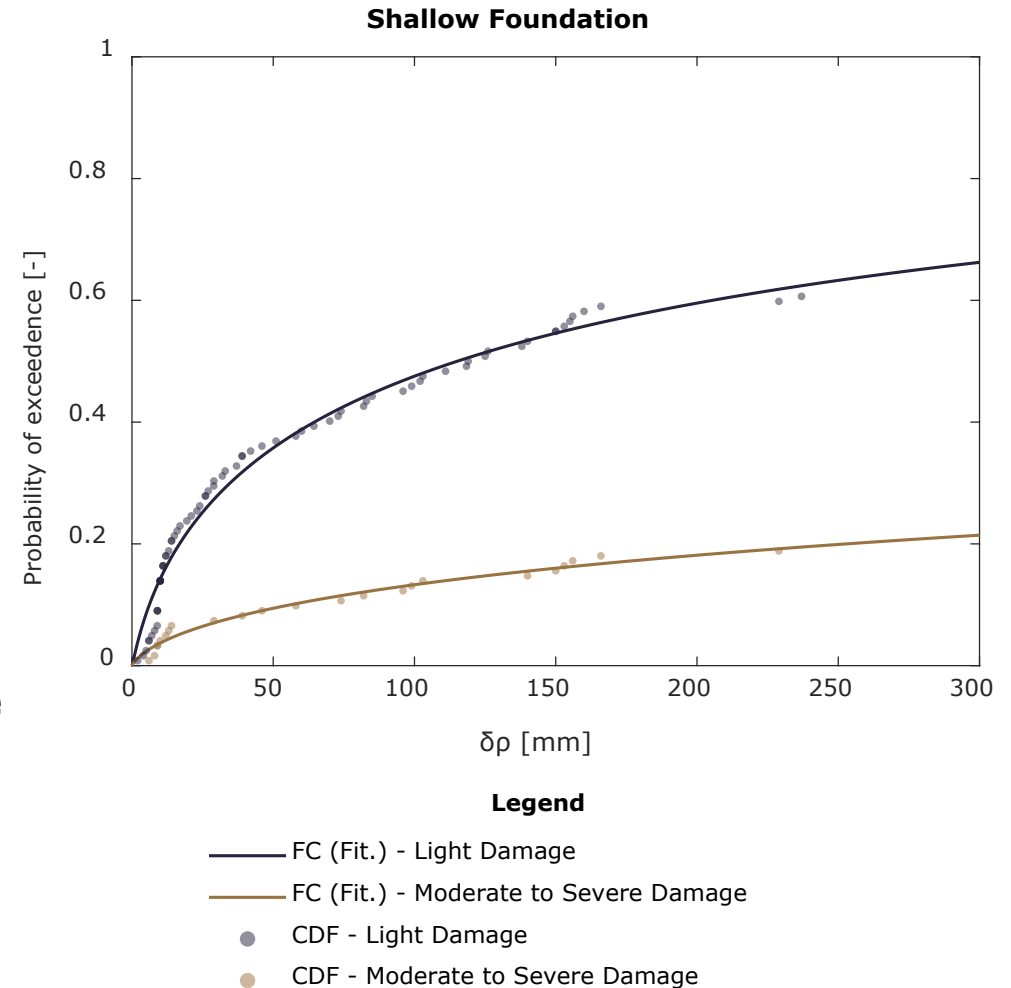
386 field surveys over different Dutch provinces were collected and then categorized by foundation system and observed damage.



Bed-joint levelling measurements (lintvoegwaterpassing) + damage level

=> Four damage parameters (*differential settlement $\delta\rho$, rotation θ , angular distortion β and deflection ratio Δ/L*);

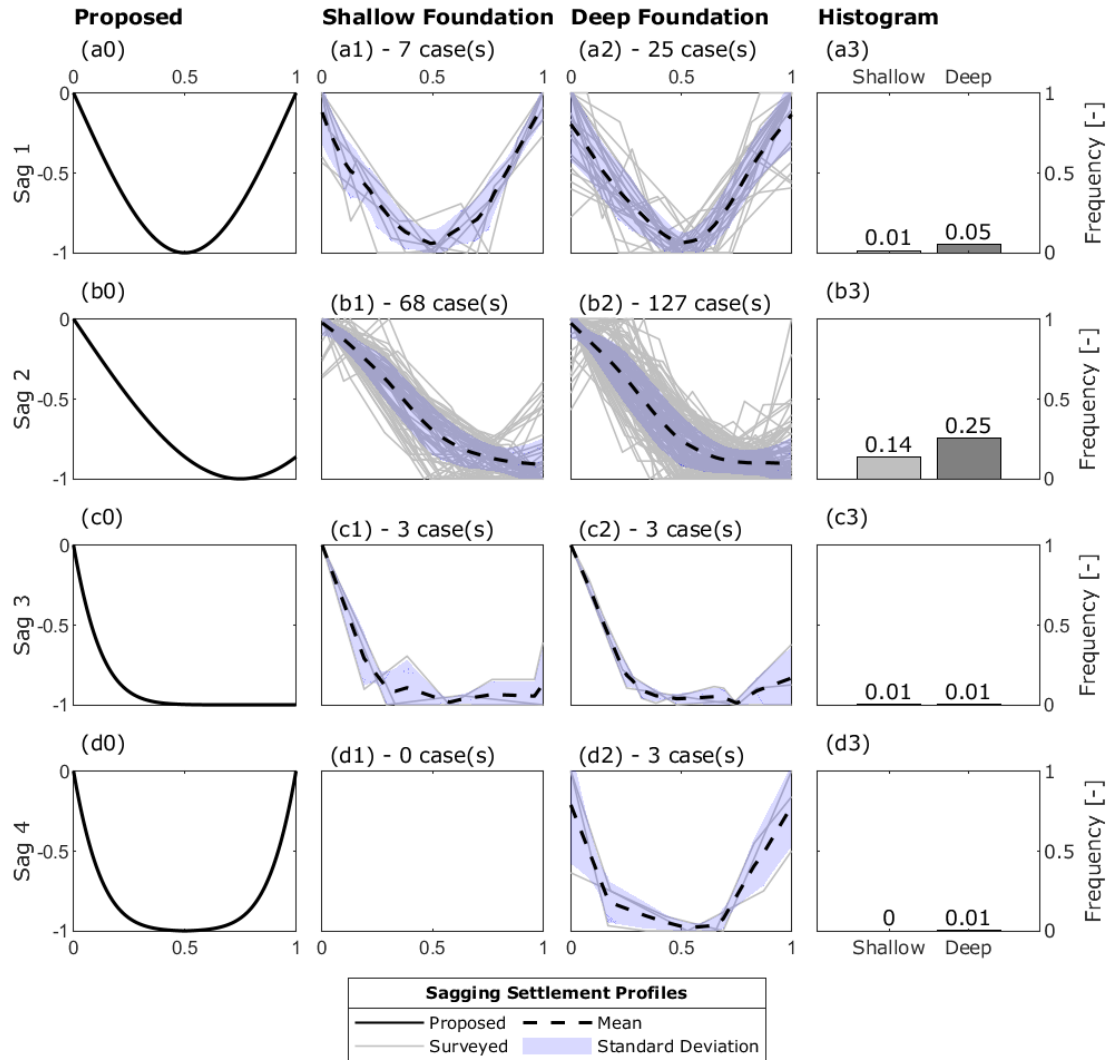
=> **Fragility curves** (probabilistic relationships between the building damage and the settlement);



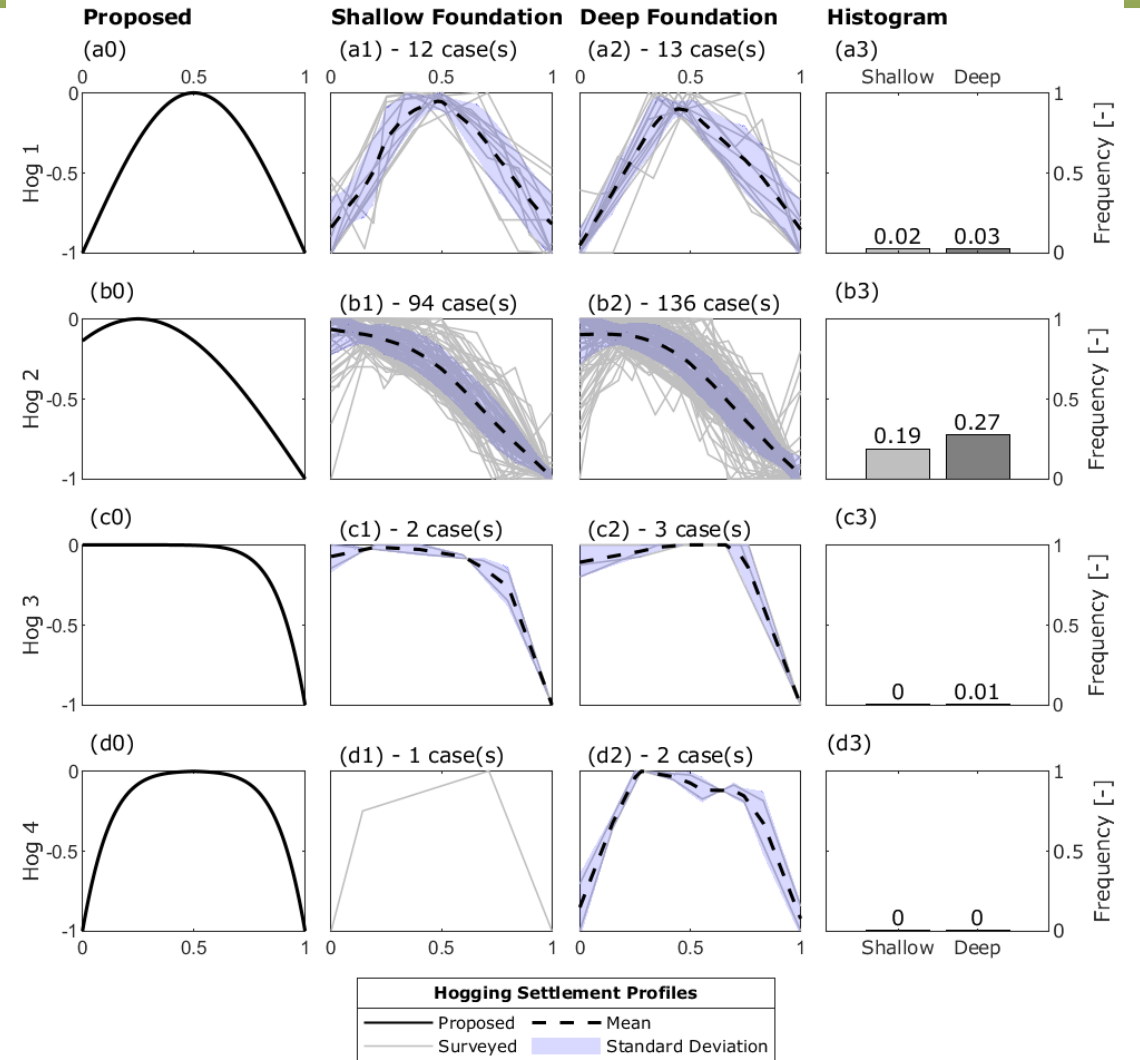
Recurrent settlement shapes

All the bed-joint measurements were classified into eight recurrent settlement shapes, allowing to observe the most recurrent ones.

Recurrent sagging settlement profiles - 233 cases of the 499 classified.



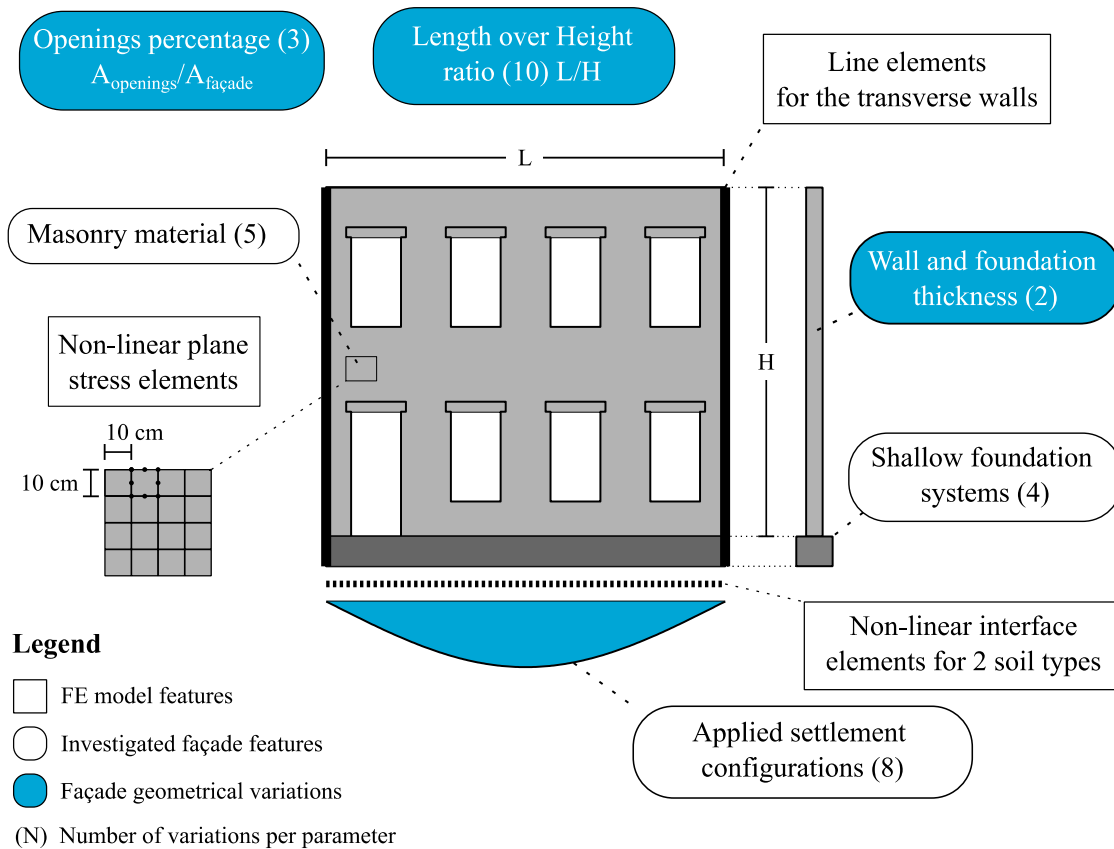
Recurrent hogging settlement profiles - 266 cases of the 499 classified.



Limitations of the empirical analyses

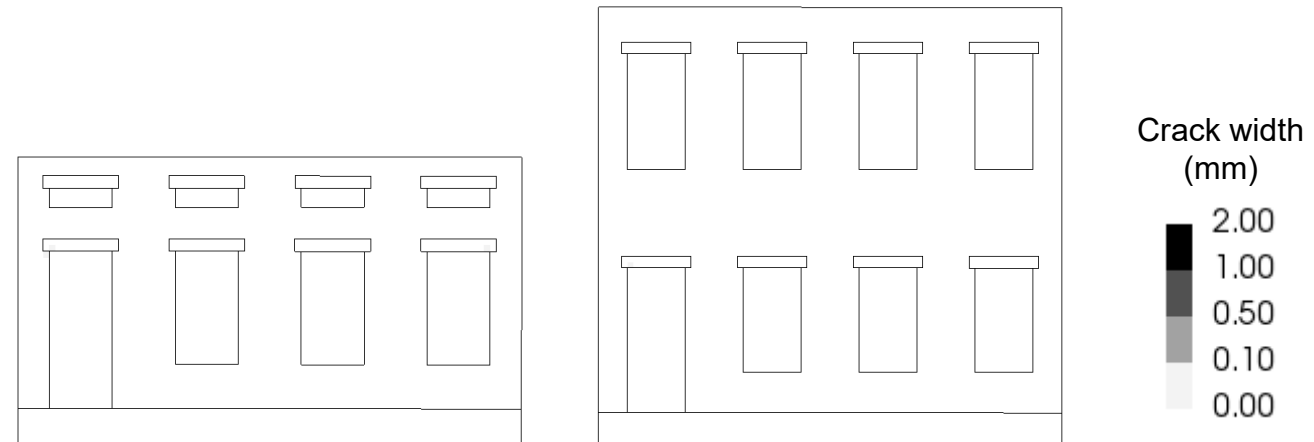
- The building dataset **may not represent a random sample** (in which every building in the Netherlands would have had the same probability of being selected and surveyed for the analyses);
- All the **visual damage** to the surveyed buildings was **assumed to be caused by the settlements**, while other possible contributing causes were disregarded;
- The **assessment of the damage** can be considered **slightly subjective** and depends on the experience, judgement and expertise of the analyst;

The possibilities offered by numerical analyses



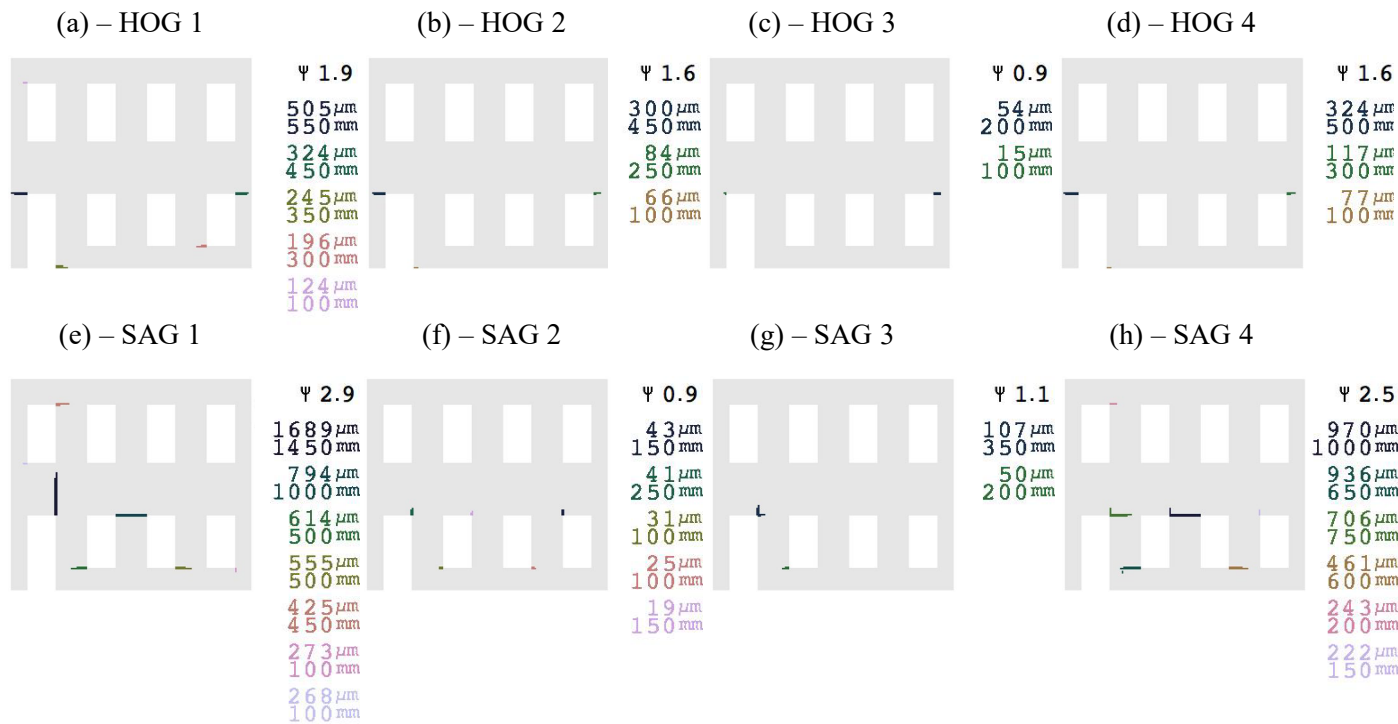
Numerical analyses:

- Represent **an alternative** when data of real structures are not available;
- Provide the opportunity to evaluate the effect of variability representing **different controlled variations**;
- Provide a reliable solution to **directly** and **objectively** quantify the **damage**;



Objectivity in the damage assessment

Crack patterns of the finite element models due to different settlement shapes



From the numerical simulation the damage can be taken directly and objectively, minimizing the need for judgment of the modeller.

(from Burland and Worth, 1975 and Korswagen et al. ,2019)

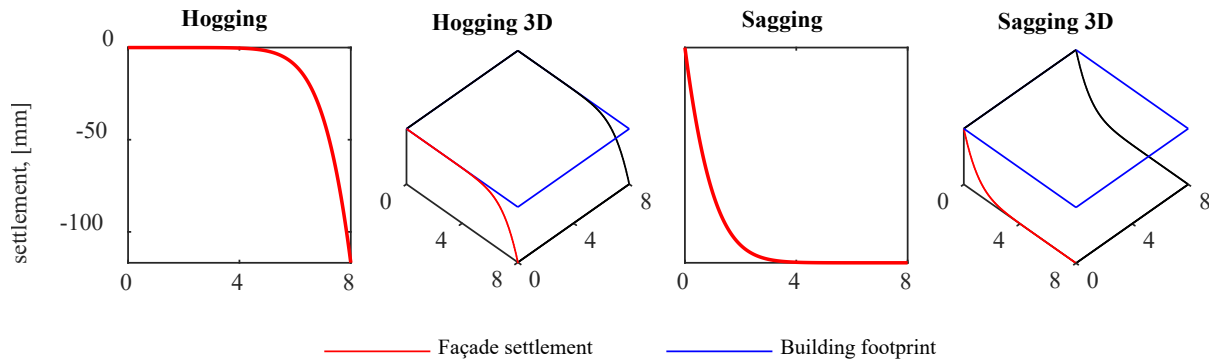
Damage level	Degree of damage	Approximate crack width	Parameter of damage
DL0	No Damage	Imperceptible cracks	$\Psi < 1$
DL1	Negligible	up to 0.1 mm	$1 \leq \Psi < 1.5$
DL2	Very slight	up to 1 mm	$1.5 \leq \Psi < 2.5$
DL3	Slight	up to 5 mm	$2.5 \leq \Psi < 3.5$

$$\Psi = \Psi (\text{number of cracks, cracks' width, cracks' length})$$

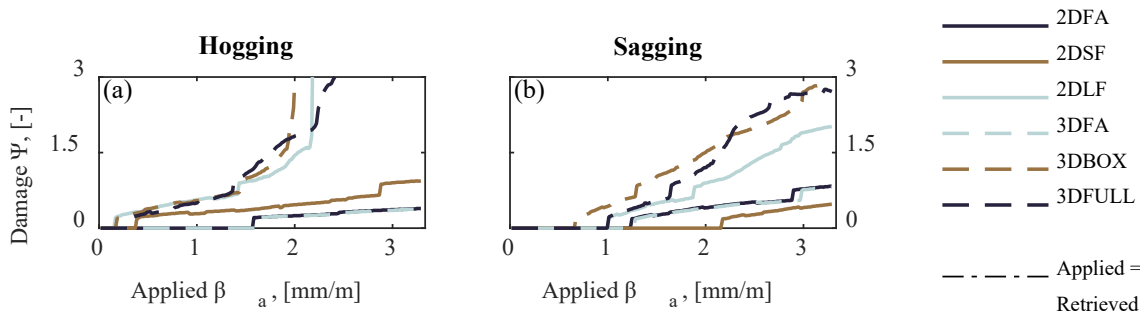
(from Korswagen et al. ,2019)

Relationships between settlement and damage

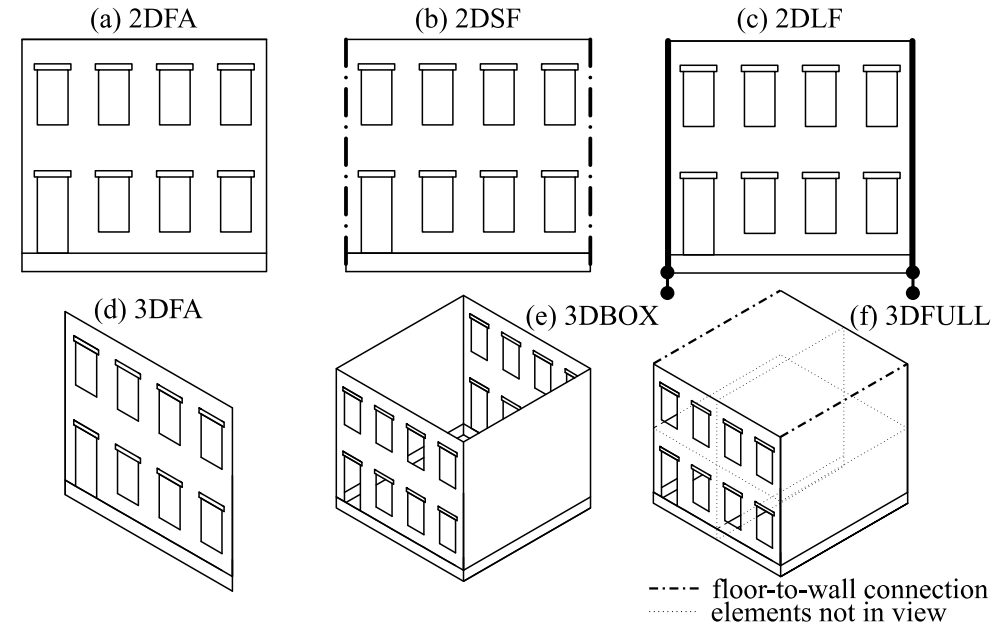
From the application of different settlement shapes...



...to the relationship between settlements and damage:



Different modelling options

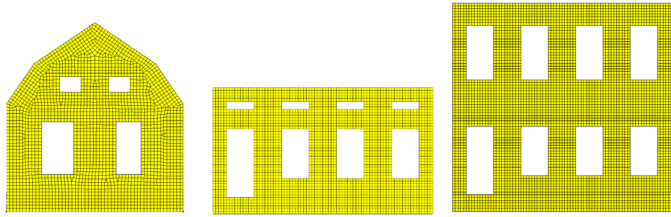


An example of one of the settlement-related parameters: the angular distortion

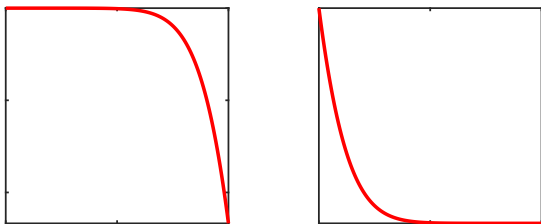
Numerical-based fragility curves: an example

Disclaimer: The results of this slide are not based on any calculation and just serve for illustration purposes.

Many building...



Many settlement profiles...

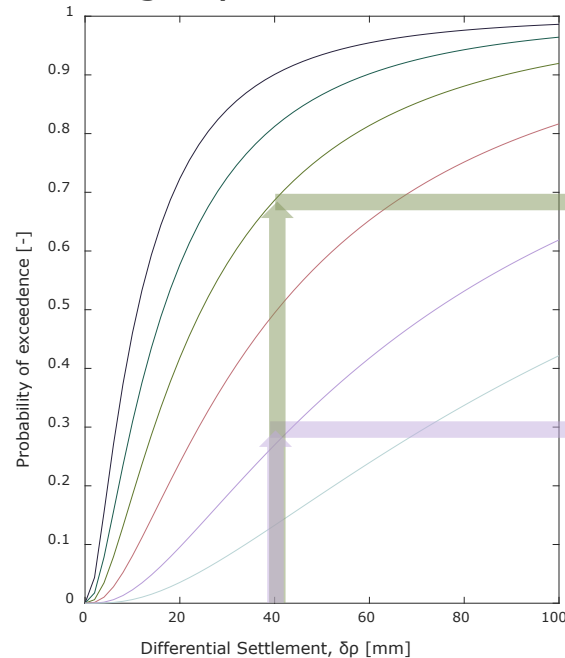


Façade settlement

Settlement parameters,
example: diff. settlement

$\delta\rho$

Fragility curves



70% probability
of $\psi = 1.5$

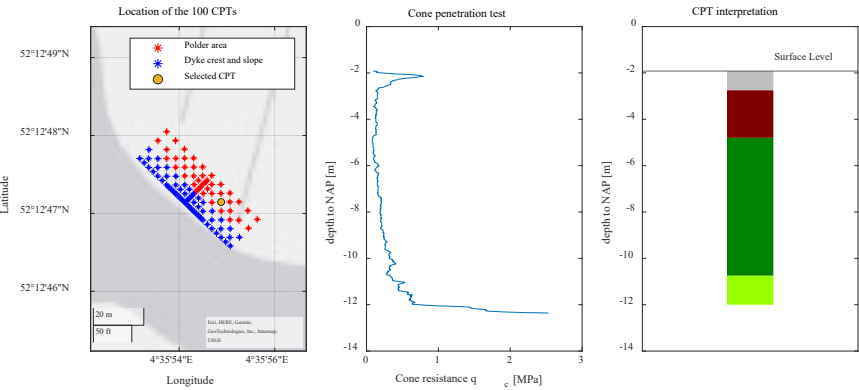
30% probability
of $\psi = 2.5$

50% probability of
damage class = 2



- No costs
- Low costs
- Average costs
- High costs
- Very high costs

Knowledge gaps and further developments: The role of the soil heterogeneity

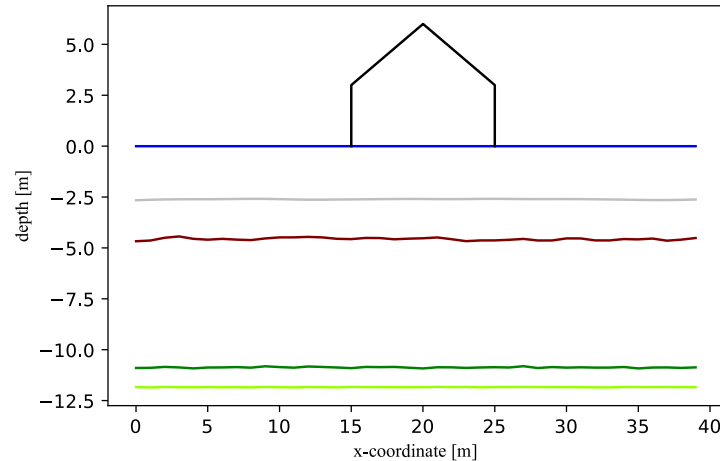


- What is the role of the soil heterogeneity at the scale of the single structure?
- If the soil heterogeneity has an important role, how common are particularly unfavourable soil conditions for existing buildings? Are there many “hotspots” in the country?

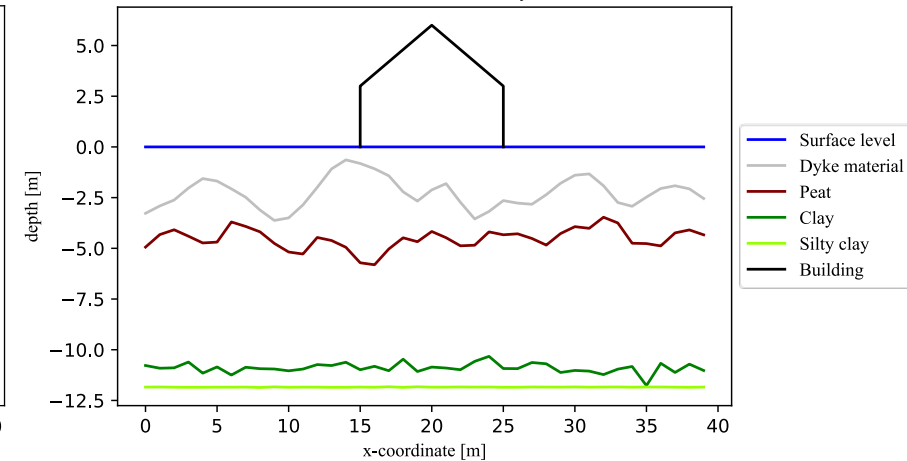
Homogeneous layers

Heterogenous layers

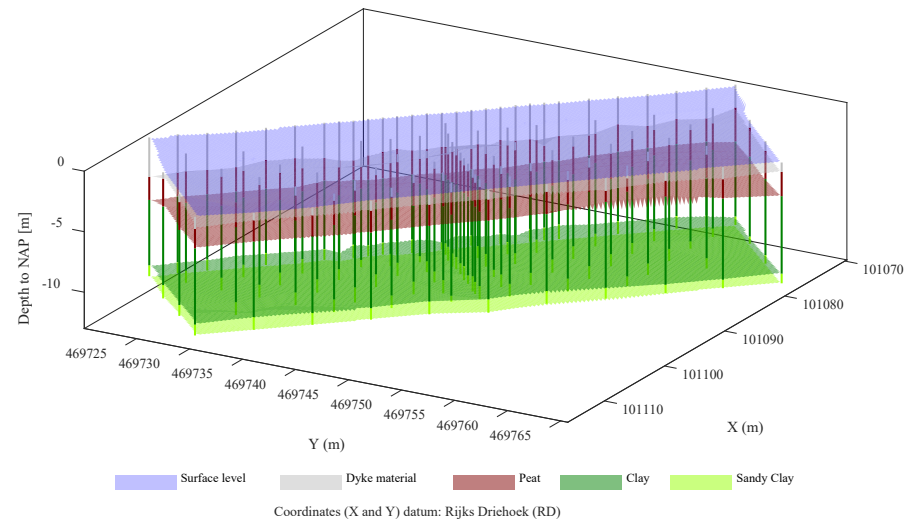
Realization n.1 for the Study area



Realization n.1 for the Study area



Surface plot of the layers' boundaries based on the CPTs' interpretation






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**Thank you for
your attention**

**Dank u voor uw
aandacht**

