Assessment of subsidence induced damage to masonry buildings

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Introduction

Evaluating and predicting damage to buildings in subsiding areas is a complex task that requires associating the vulnerability of exposed structures with the intensity of the subsidence hazard.

Damage assessment analyses require detailed information of the features of the exposed buildings (e.g. material of construction, geometry, type of foundation system), and of the subsurface system on which they are resting, which leads to intrinsic uncertainties when dealing with a large number of buildings (Ferlisi et al., 2019, Saeidi et al., 2012).

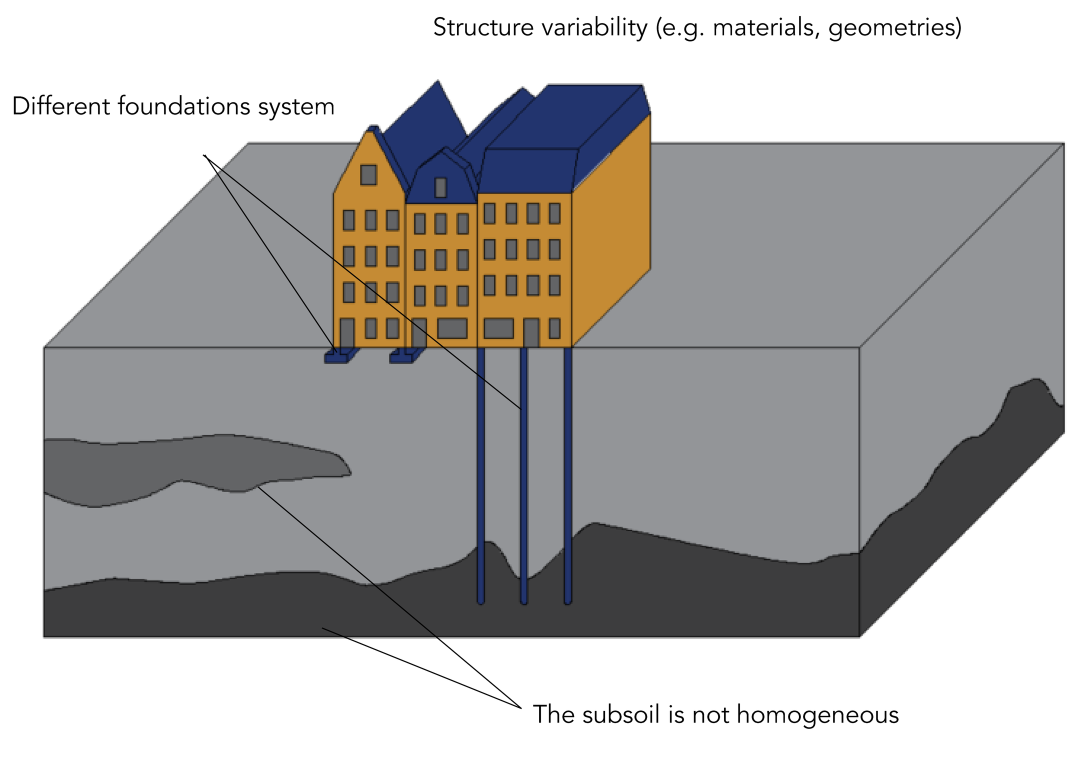

Figure 1. The structure-foundation-soil system: an illustration of the uncertainties and large variability related to the structural and soil features.

Subsidence-damage to buildings

During and just after their construction, structures typically experience settlements which can continue throughout the first few decades (DeJong, 2016) and are not necessarily a symptom of deficiencies.
However, when a structure is unable to accommodate the ground displacements, cracking of structural or non-structural elements alike, tilting and distortions are likely to occur, leading to a loss of cosmetic, functional, durability or structural functionality aspects.

In the heavily urbanised coastal-deltaic plain of the Netherlands, (masonry) buildings often rest on heterogeneous soil that includes peaty, clayey and silty strata, which predisposes the occurrence of creep settlements over very long times.

The use of empirical data of existing buildings

To obtain an empirical picture, a rich dataset was collected in a digital database comprising 386 surveyed masonry buildings located in the Netherlands, 122 of which rest on shallow foundations and 264 on piled foundations. The analyses allowed for the retrieval of empirical fragility functions; These display the probability of reaching or exceeding damage as a function of a settlement-related parameter (e.g. differential settlement in Fig.2).

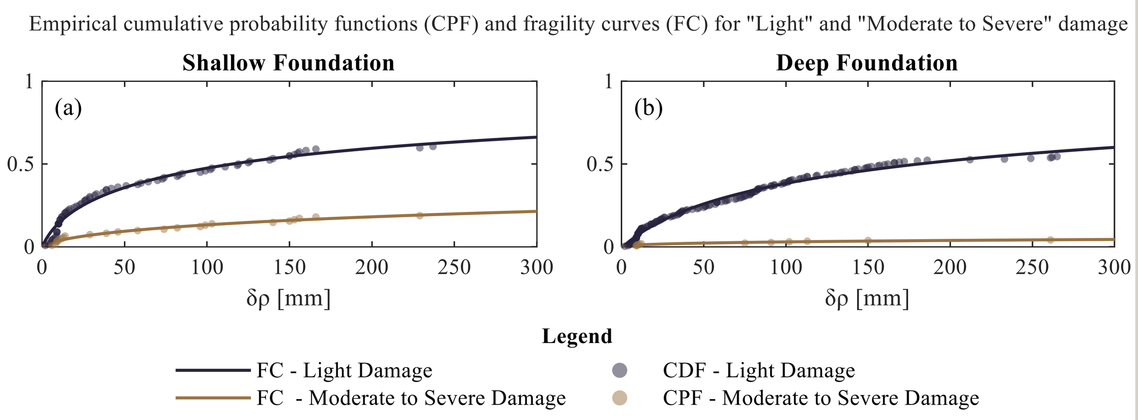

Figure 2. Fragility curves of buildings resting on shallow or deep foundations for all the differential settlement δρ. "**Light damage**" refers to aesthetic damage characterized by very fine/fine cracks up to 5 mm. "**moderate to severe damage**" implies moderate and severe damage that could affect the serviceability of the building or be associated with a risk for the structural safety (from: Prosperi et al., 2023).

Recurrent settlement shapes

Different subsidence drivers lead to unpredictable settlement shapes affecting the existing structures. Levelling measurements allow to trace back the settlement profiles along the façade of the buildings.
The available manual levelling readings for all the surveyed buildings made it possible to identify the recurrent settlement shapes (which are fitted by Gaussian shapes).

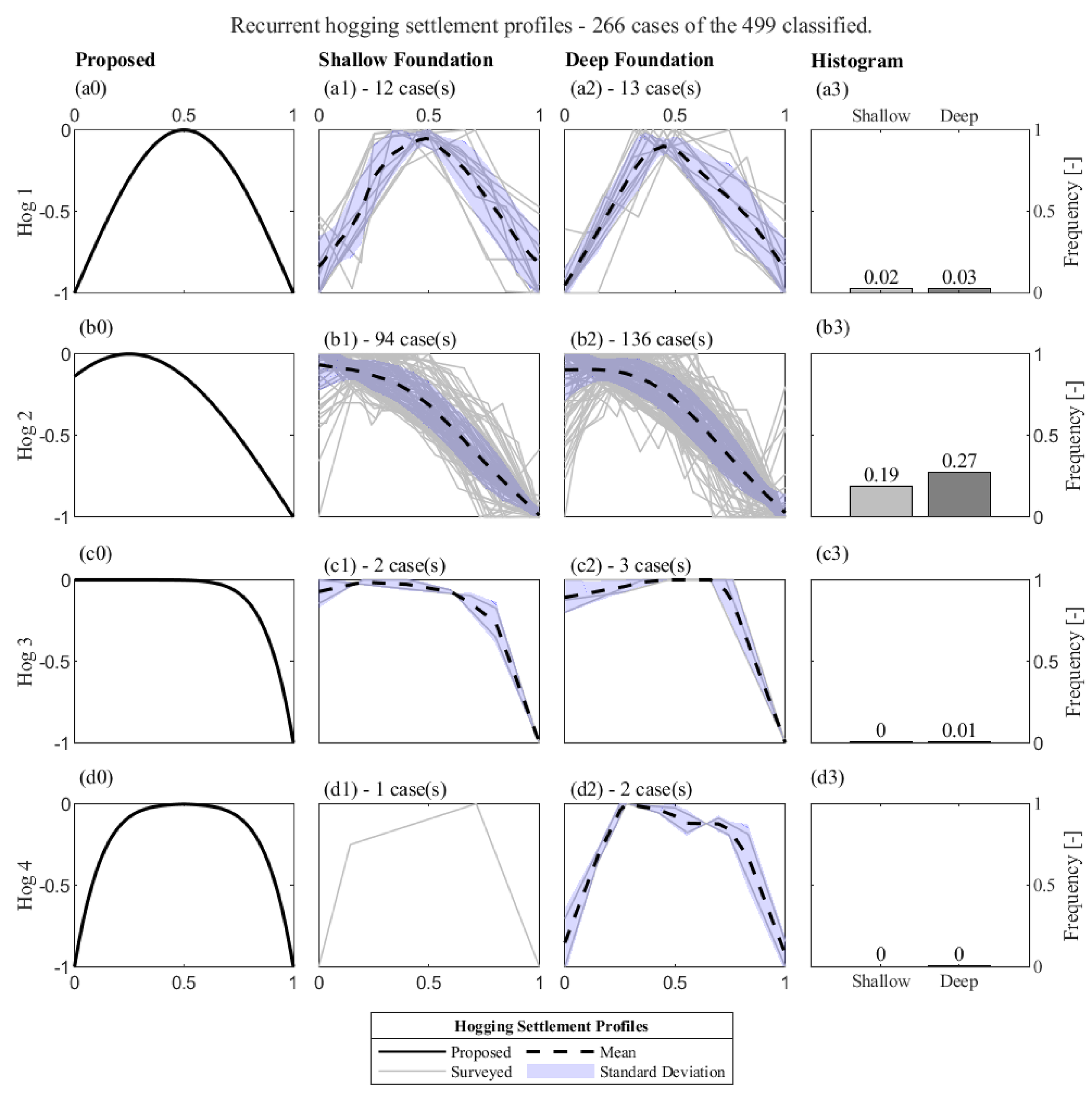

Figure 3. Nondimensional hogging settlement profiles of the considered surveyed buildings: from (a0) to (d0) Proposed settlement profiles; Settlement profile for: from (a1) to (d1) for buildings on shallow foundations, and from (a2) to (d2) for buildings on deep foundations. The number of cases for each foundation system is indicated on top of each bin from (a3) to (d3) (from: Prosperi et al., 2023).

Numerical simulations for settlement-induced damage

The measurements of full-scale structures are crucial to improve the existing relationships between ground movements and building damage (Son and Cording, 2005). However, the lack of detailed information of the exposed structure and subsurface limits the generalization of conclusions.
Numerical models provide a reliable alternative to evaluate the effect of variability of the employed parameters, representing different controlled variations (e.g. different settlement shapes).

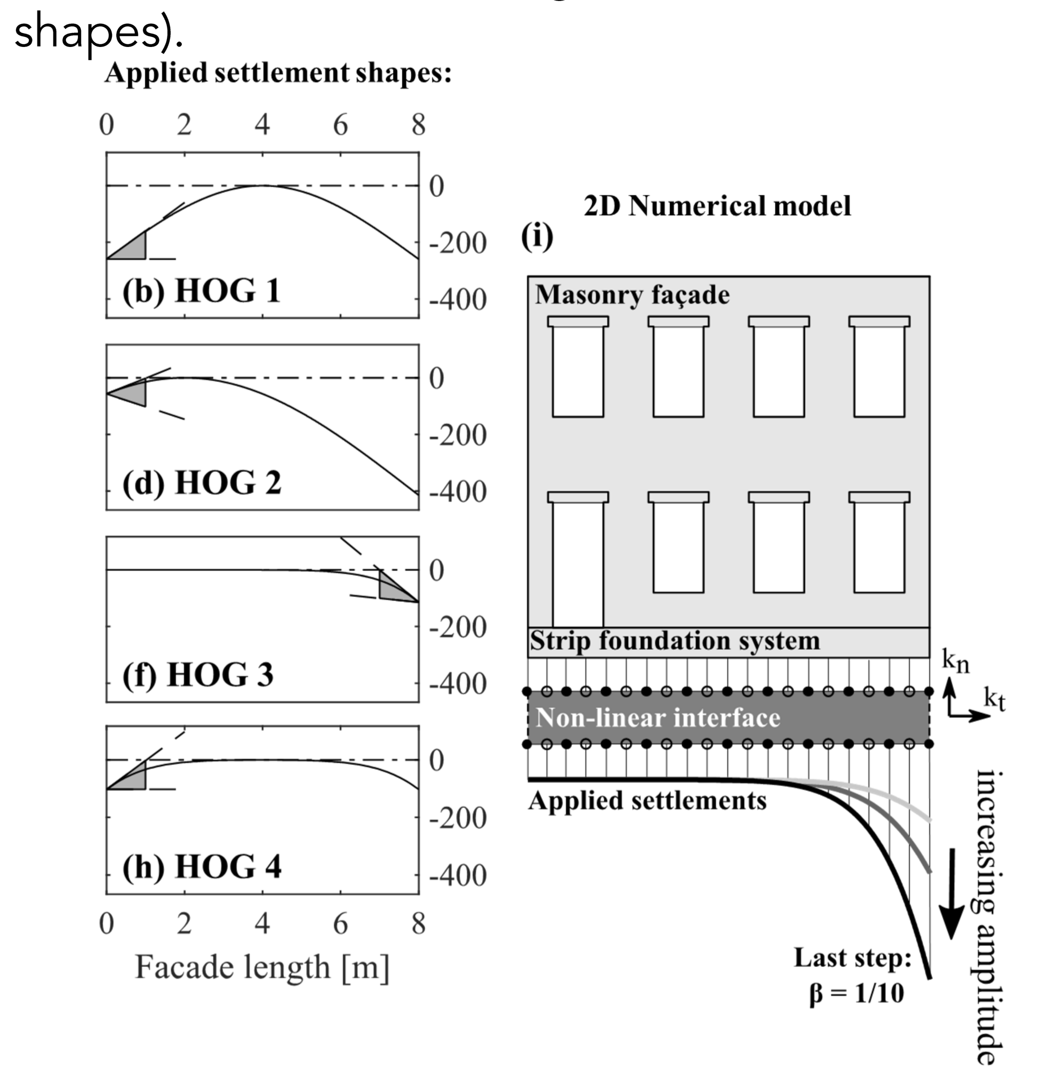

Figure 4. An example of numerical model of a masonry building subjected to four settlement shapes: HOG1, HOG2, HOG3, HOG4 from Fig. 2.

Methodology to characterize and quantify the damage

The results of the numerical analyses can be used to directly and objectively assess the extent of the induced damage in each wall of the building. The parameter Ψ in equation (1) proposed by Korswagen et al., 2019 is used to quantify the damage in the numerical models in one single scalar value:

$$\Psi = 2\, n_c^{0.15}\, \hat{c}_w^{0.3} \quad (1)$$

Where n_c is the number of cracks, $\hat{c}_w$ is the width-weighted and length averaged crack width (in mm).

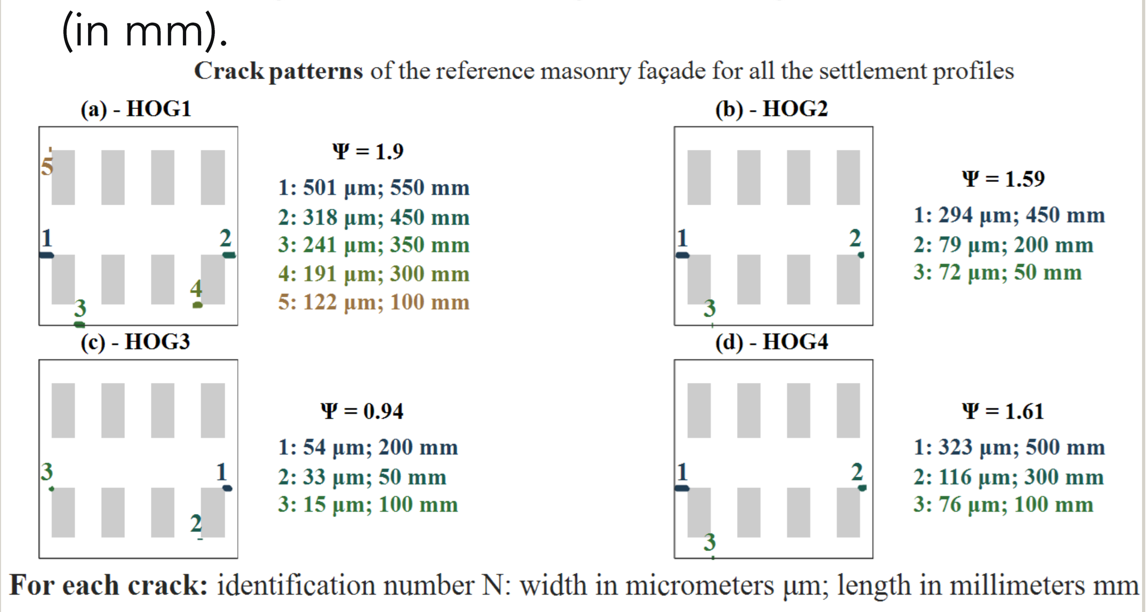

Figure 5. Crack patterns of the masonry façade for all the settlement profiles (HOG1 -4).

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