Assessment of subsidence induced damage on masonry buildings

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Why is it challenging to assess damage on buildings?

The potential consequences of ground settlements associated with subsidence phenomena include direct damage in the form of cracking in masonry buildings. However, evaluating and predicting the 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 (Costa et al., 2020).

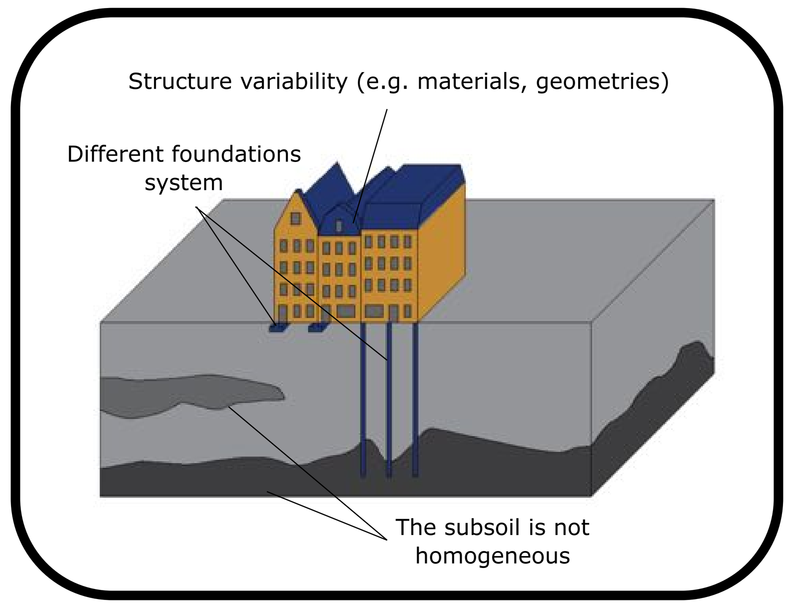

Fig. 1 – The structure-foundation-soil system: an illustration of the uncertainties and large variability related to the structural and soil features.

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).

Which parameters can be used to assess the damage?

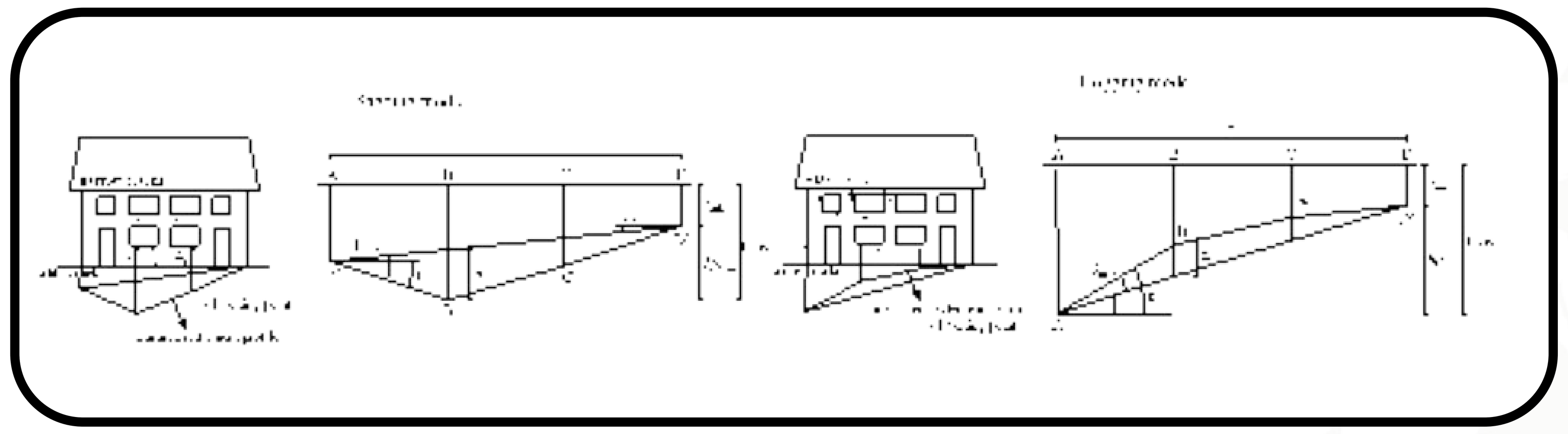

Fig. 2 – Typical building damages for sagging and hogging profiles and the definitions of the settlement parameters: maximum settlement ρ_{max}, minimum settlement ρ_{min}, differential settlement $\delta\rho_{max}$, rotation θ, relative rotation (or angular distortion) β, deflection Δ, deflection ratio Δ/L and tilt ω.

The complex interplay among the subsoil, superstructure and foundation system (as shown in Fig. 1) leads to different settlement configurations (e.g., "sagging" and "hogging" in Fig. 2) (Ferlisi et al., 2019, Peduto et al., 2021).
In the state of art, different parameters are appraised in their capacity to effectively describe the relationship between the intensity of the settlement configuration and the induced damage (e.g., differential settlement, rotation, angular distortion (or relative rotation) and deflection ratio in Fig.2).

The assessment of the performance of the above-mentioned parameters in damage assessment analyses is required to define a hazard metric suitable for the assessment and/or forecast of the damage on a large number of buildings.

The use of empirical data of existing buildings

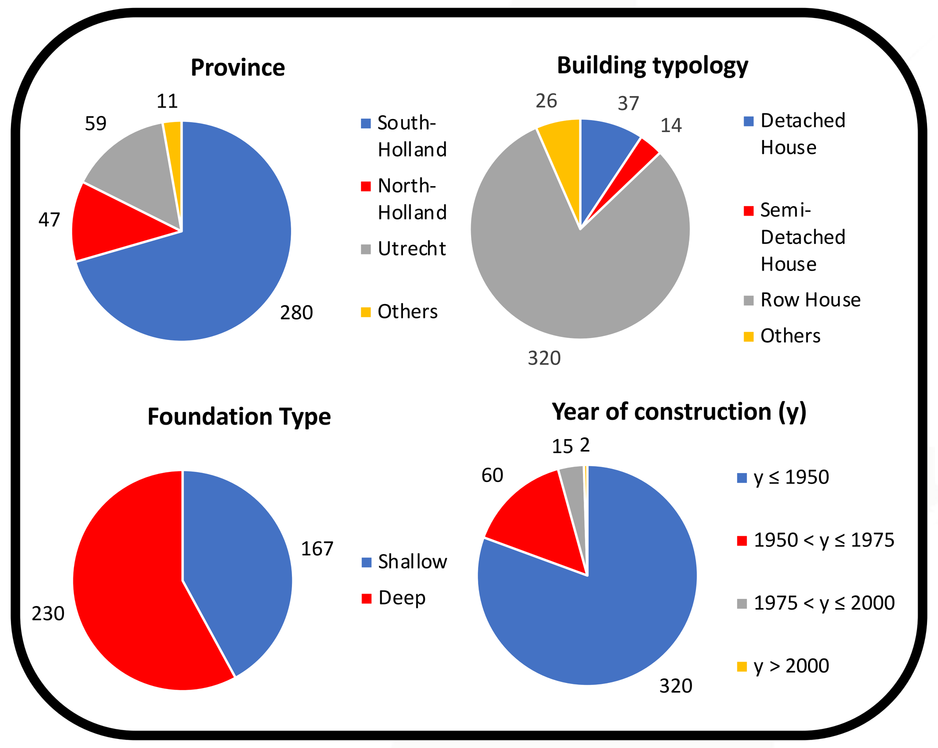

Fig. 3 – Summary of building data distinguished by location, building typology, foundation type and damage level.

To obtain an accurate, empirical picture, a rich dataset was collected in a digital database (Prosperi et al., 2022) comprising 397 surveyed masonry buildings, 167 of which rest on shallow foundations and 230 on piled foundations. The information of these buildings were recorded during different survey campaigns over different Dutch provinces (Fig. 3).

Methodology

The surveys cases included both undamaged (D0 in Tab. 1) and damaged masonry buildings (D1, D2 and D3 in Tab. 1). Four parameters (i.e., differential settlement, rotation, relative rotation and deflection ratio) selected as representative of the intensity of the subsidence phenomena causing the damage on buildings, were computed for each building, starting from the available bed joint levelling along the building façades. The collected bed-joint levelling measurements for each building allowed to trace back the settlements affecting the building. The four parameters were used to generate probabilistic relationship in the form of fragility curves. Fragility curves (e.g., see Fig 4.b) allow to retrieve the relationship between the damage severity level and a hazard intensity parameter for a given structural typology. Fragility curves display the probability of reaching or exceeding a specific degree of damage as a function of a settlement-related demand parameter. (e.g. differential settlement in Fig.4)

Tab. 1 – Damage classification system (adapted from: Burland and Wroth, 1974).

Damage level	Damage class	Approx. crack width (mm)
D0	Negligible	Up to 0.01 mm
D1	Very slight	Up to 1mm
D2	Slight	Up to 5 mm
D3	Moderate	5 to 15 mm

Conclusion

The obtained results are expected to be useful to assess and predict the built heritage vulnerability and, in turn, to be a valuable input to the consequential evaluation of subsidence risk adaptation and mitigation strategies for masonry buildings. The generated fragility curves may be applied to assess the probability of damage over multiple buildings, although the assessment may be limited by the variety of structure typologies, the loading conditions, the source of deformation measurements and the damage classification method adopted.

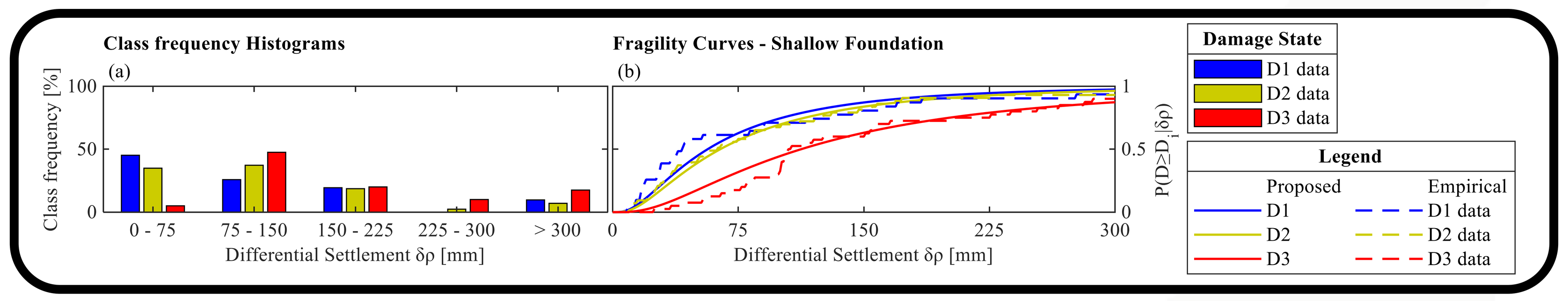

Fig. 4 – An example of the results for buildings on shallow foundations: (a) Class frequency of damage level for the differential settlement; (b) Fragility curves generated for the differential settlement.

Numerical simulations for settlement-induced damage

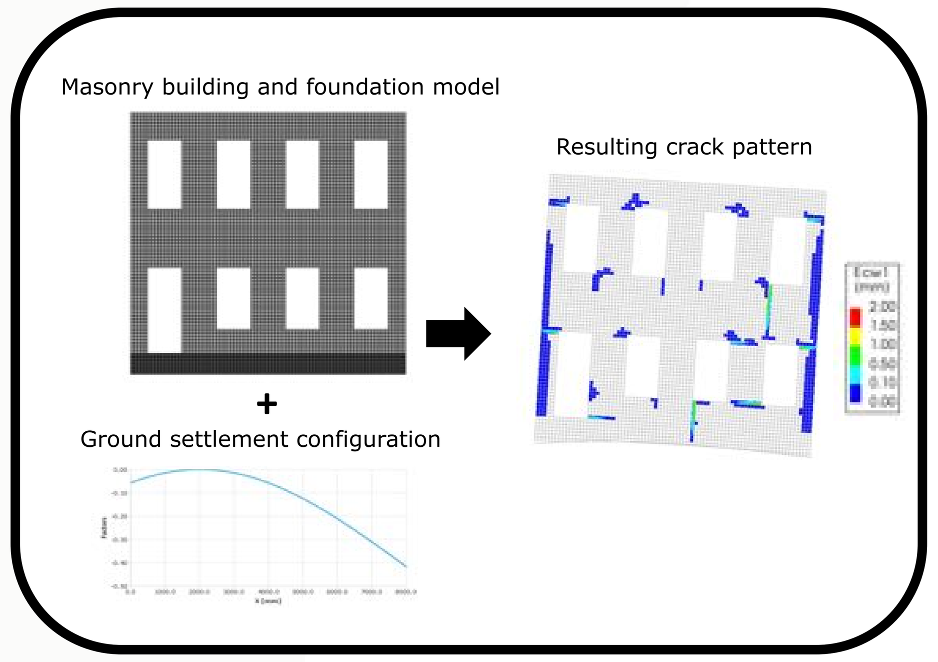

Fig. 5 – An example of the results of a numerical model for a masonry building subjected to a settlement configuration.
The building model includes a shallow foundation, and an interface to simulate the foundation-soil interaction. The imposed settlement (i.e., "hogging" settlement) leads to damage to the building. The amount (in terms of crack width, number and length) and the type of damage (in terms of crack pattern) can vary according to the features of the building and the shape and magnitude of the imposed deformations.

The lack of detailed information of the exposed structures (e.g. material, geometry, foundation type) and of the subsurface on which they rest represents a limit for the damage assessment analyses. Numerical analyses are being performed in order to directly and objectively quantify the damage. They also provide the opportunity to evaluate the effect of variability of the employed parameters representing different controlled variations, overcoming the lack of information (Sons and Cording, 2007).

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