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Sensitivity study on tunnelling induced damage to a masonry façade

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ABSTRACT

Assessing the potential damage caused by soil subsidence to masonry structures is essential for the successful realisation of underground projects in urban areas. The damage assessment procedures need to take into account the highly non-linear behaviour of the structural materials, characterised by brittle cracking and consequent stress redistribution, and the important effect of soil–structure interaction. This paper presents the results of a sensitivity study performed on a 2D finite element model that was validated through comparison with experimental results. The study investigates the effect of openings, material properties, building weight, initial damage, normal and shear behaviour of the base interface and applied settlement profile. The results assess quantitatively the major role played by the normal stiffness of the soil–structure interaction and by the material parameters defining the quasi-brittle masonry behaviour.

1. Introduction

This paper investigates the effect of selected structural and geotechnical parameters on the response of masonry buildings subject to tunnelling-induced settlements.

Tunnelling activity in urban areas is growing, with a consequent higher risk of induced ground settlements that can cause damage on existing surface structures. The prediction of damage risk and the design of mitigation measures to protect the building, when necessary, requires a complete understanding of the interaction between the structure and the subsiding soil. The mutual influence of building and ground responses is made more complex by the fact that both the masonry and the soil exhibit a non-linear relation between the applied displacements and the induced deformations.

Observations deduced from measurements of soil and structure displacements in actual tunnelling projects [1] has been essential to validate and improve empirical-analytical [2,3] and numerical based [4] assessment methods. These methods have been included in complete staged procedures that represent the most common approaches currently used in practice to predict the potential building damage [5,6].

The simplification of the problem to physical models that can be tested under controlled laboratory conditions is another fundamental method of investigation. Researchers adopted different solutions to preserve the prototype relationship between material strains and stresses in scaled model testing: the use of geotechnical centrifuges [7], the controlled reduction of material strength [8] or the amplification of static loads [9]. In addition to offering a deeper insight into the simulated mechanisms, experimental tests can be used to validate numerical models [6,10]. By including non-linear constitutive laws to describe the material behaviour, numerical models enable to reproduce the response of the structure and its interaction with the ground [6,10–15].

In this research, a numerical model previously validated through comparison with experimental results is used to investigate a wide range of possible scenarios. A sensitivity study performed on a 2D finite element model of a façade subject to differential settlements aims to assess quantitatively the influence of openings, material parameters, loading conditions, interaction properties and settlement troughs (Fig. 1). An important outcome of this research is the quantitative assessment of the structural damage in terms of cracking and distortions, as a function of the parameter variations. These results can be used to develop a comprehensive damage classification system that correlates the main building characteristics with the risk of being damaged by a certain ground deformation [16].

2. Numerical model

The adopted 2D numerical model reproduces the experiment described in [9] and it is shown in Fig. 2. In the laboratory test,

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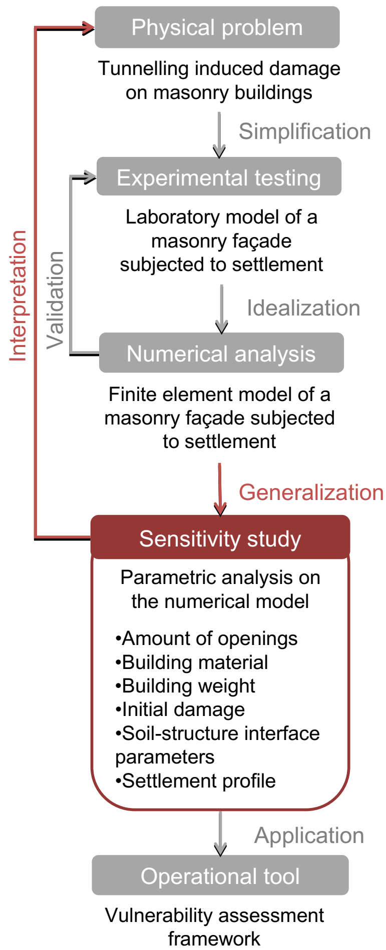

Fig. 1. Paper content (in red) and research overview. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

a 1/10th scaled masonry façade was subjected to self-weight and to a vertical load of 12.2 kN, distributed in 35 application points, which replicate the prototype stress field. Single bricks were removed at the location of the applied loads and wooden lintels were inserted above the openings. The façade was supported by a H-shaped steel profile with two hinges and one fixed constraint. A controlled hogging deformation was applied to the structure by pulling downwards the left end of the steel profile. A rubber layer simulating the soil–structure interaction was inserted between the façade and the steel beam.

In the finite element model, the façade was modelled by 8-node plane stress elements with 3×3 points Gaussian integration schemes. A coaxial rotating crack model was applied to the masonry and a linear tension softening relation was assumed after cracking. The tension softening law was defined by the tensile strength f_t, the fracture energy G_f and the crack bandwidth h, which is related to the element size and equal to 11.8 mm. No damage criterion was assumed in compression and 6-node line interface elements characterised by no tension, assigned stiffness in compression and negligible stiffness in shear were inserted between the façade and the steel profile. The material parameters are listed in Table 1.

2.1. Model validation

Figs. 3 and 4 shows the results of the model validation in terms of displacements of selected points and in terms of crack pattern. The numerical and experimental curves match well throughout the entire simulation, suggesting the model ability to capture the settlement reduction due to the interface effect. Furthermore, the model is able to reproduce all the main cracks leading to the failure mechanisms described along with the experimental results. Further details about the numerical model and its validation can be found in [10].

2.2. Mesh and step size dependency

To evaluate the influence of the model discretization on the response, a mesh refinement study was performed. The reference

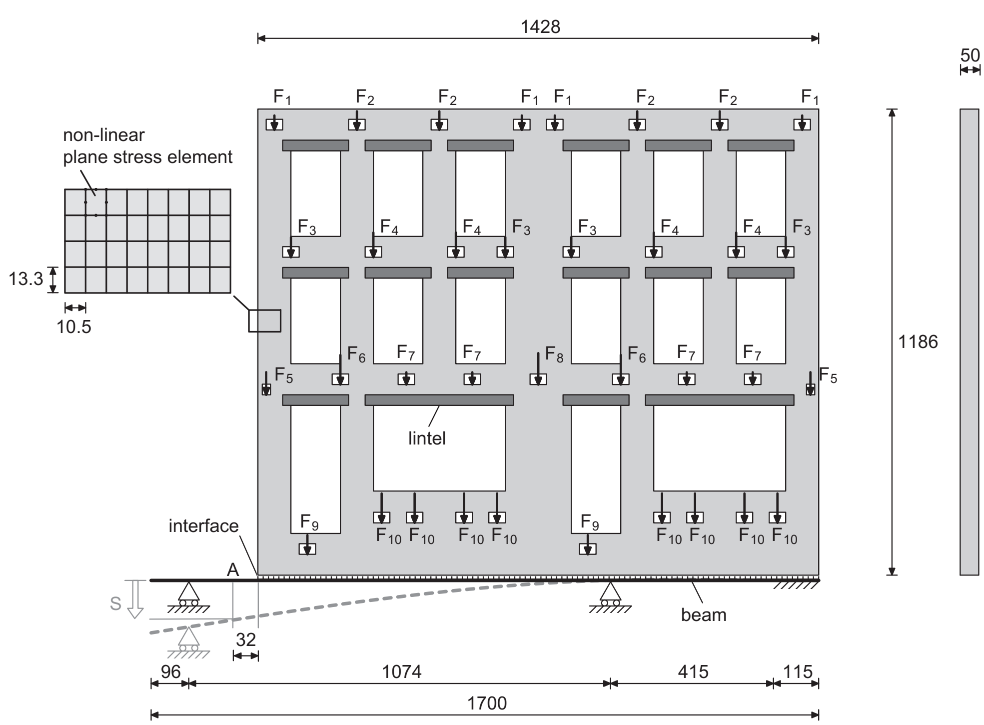

Fig. 2. Model of the scaled masonry façade. All dimensions are in mm.