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Numerical analysis of framed building response to tunnelling induced ground movements

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ABSTRACT

Tunnelling in congested urban area may inevitably induce ground movement causing damage to adjacent surface buildings. Past research usually oversimplified surface structure as an equivalent elastic beam, which is unable to represent behaviour of a framed building realistically due to frame action. In this study, a series of numerical analyses were conducted to investigate the behaviour and damage mechanism of a framed building with individual footing due to tunnelling induced ground movements. Nonlinear behaviour of the infilled wall and the interfaces between soil-structure and between frame-wall were explored to interpret the complex interaction effects in the system. A non-uniform deformation around the tunnel was applied to simulate the realistic tunnelling induced ground movements while the distribution of initial ground stiffness affected by building weight was reproduced by a user defined nonlinear constitutive model. The different responses in terms of angular distortion, horizontal strain and smeared crack pattern of the framed building subject to scenarios with different ground stiffness, interface parameters and different frame infill configurations were evaluated. The results can be practically used to assess the performance of framed building subject to different ground deformation conditions resulting from tunnelling. The presented analysis provided a useful background for properly understanding and prioritizing those factors having a significant effect on the response of framed building to tunnelling induced ground movements.

1. Introduction

Ground movements induced by tunnelling can lead to damage of the adjacent buildings. One of the important purposes for the prediction of tunnelling induced ground movement is to assess the potential adverse impact on the adjacent structures. This environmental impact becomes one of the issues of great importance for tunnelling in urban areas.

The behaviour of the ground and nearby structures due to tunnelling generally leads to a complex soil-structure interaction problem. In the conventional methods of assessing building damages, the building was subjected to a free-field settlement profile and it was assumed to follow the ground movements and to be weightless [1]. Notable studies indicate that not only the tunnelling induced settlement impacts the existing adjacent buildings, but the existing buildings affect the tunnelling induced ground movement profiles as well, due to the factors such as relative stiffness, relative position, building weight and characteristics etc. [2–7]. These results are mainly obtained from an assumption that the building is represented by an equivalent elastic Timoshenko beam. The use of such an equivalent elastic beam to study the soil-structure interaction would be appropriate if the building deformation is dominated by the wall behaviour, such as for brick wall building or masonry buildings. However, as the framed building deformation is dominated by the frame action, the behaviour of the framed building cannot be represented by the simple equivalent elastic beam. Although Mair and Taylor [8] suggest to estimate the framed building stiffness by simply summing the individual bending stiffness of all the floor slabs and Potts and Addenbrooke [7] suggest to calculate the framed building stiffness using the parallel axis theorem, it is obvious that both methods cannot take account of the frame action. Moreover, the stiffness modification factor for frame presented by Goh and Mair [9] also cannot take account of the effects of infilled wall on the frame action. In fact, since the frame is generally infilled with wall or panel, there is a significant interaction between the frame and the infill-wall which may have beneficial or adverse effect on the structure response [10]. Such infills used for the reinforced concrete frame structure can significantly enhance both the stiffness and strength of the surround frame [11]. Hence, it is essential to consider the influence of wall-frame interaction in assessing the tunnelling effects on the

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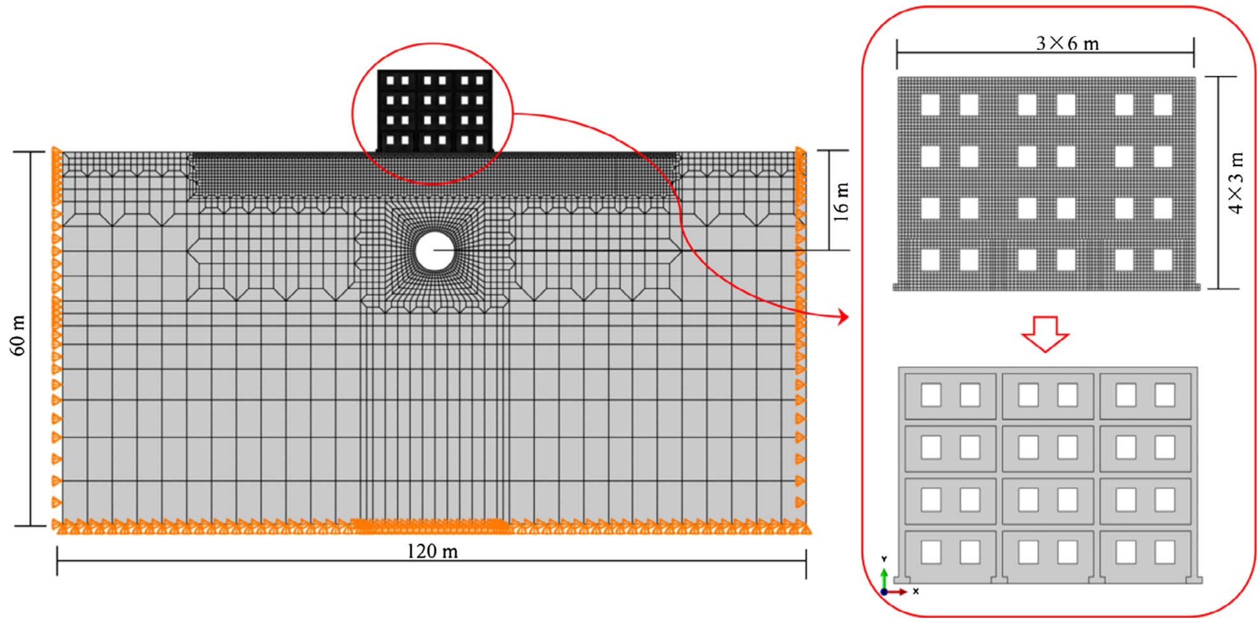

Fig. 1. Meshed FE model.

Table 1
Details of framed building with individual footing.

Category	Structure	Story	Footing	Bay	Analysis type
Building info	Infilled frame[a]	4 m × 3 m	1 m × 1 m × 0.4 m	3 m × 6 m	Plane stress
Beam & column[b]	0.4 m * 0.4 m, identical section				Plane stress
Masonry infill	0.25 m in thickness				Plane stress
Opening	1.2 m × 1.4 m (L × H)				–
Soil & tunnel	SSD-Elastic soil model/non-uniformly deforming tunnel				Plane strain

[a] Infilled frame varying the position relating to the tunnel induced settlement profile, and the infill configurations.
[b] Beam and column sections are identical in order to evaluate the distinct responses between them.

adjacent framed building.

On the one hand, numerical modelling requires imparting realistic ground movements to the building. The ground movement can be obtained with the non-uniform tunnel convergence pattern method [12]. It is suggested that a no tension interface between the soil and structure is necessary to simulate the soil-structure interaction [13], which highlights the relative movements such as slip and separation are consent between the soil and the building elements. However, once the tunnelling induced ground movement cannot integrally impart to the building foundation, not only detachment but also embedment would be occurred between the soil and structure [14–16]. On the other hand, soil-structure interaction calls for engaging the buildings to take their own stiffness and strength in resisting any deformation due to external action [14]. The equilibrium of the buildings is maintained by the stiffness itself and the stabilizing force provided by the soil ground. Meanwhile, the underlying soil is bearing the loads from the existing surface buildings, and as a result, the initial stress regime has already been significantly changed compared to the free field [4]. However, it is well known that the soil stiffness is dependent on the mean effective stress level and the soil strain level [17,18]. Therefore, the initial soil stiffness of the soil under the building is related not only to the soil weight but also to the overloaded building weight as well. The redistribution of the building weight and soil initial stiffness resulting from the tunnelling induced ground movement should be considered for interpreting the complex soil-structure interaction. Moreover, as pointed out by Burland and Wroth [19] and Goh and Mair [9] that the deformation mechanism of the building is different in the sagging or hogging zone, hence the building response should be studied related to the convexity or concavity of the displacement profile, respectively.

Numerical simulation is an efficient tool in modelling the tunnelling-soil-building interaction because the tunnel, the soil and the building can all be encompassed by one model. The development in computational technology impels many authors to investigate the problem of tunnelling-soil-building interaction with numerical methods. In some analyses, the buildings are modelled as an elastic shell at the surface [5], an equivalent beam [20,6], or a bare frame [9,21], while in some other analyses the buildings are modelled as a masonry facade wall [22] or a frame with discrete element infills [23]. In the former group analysis the buildings are greatly simplified, while in the latter group the structures are imposed with an assumed convex settlement profile, thereby they cannot account for the tunnelling induced Gaussian curve type displacement profile which normally shows itself with convex and concave parts.

This paper aims to investigate the response of the framed building, founded on shallow foundations, to the tunnelling induced ground movement. Finite element analysis considering the interaction of soil-structure and wall-frame, and the realistic distribution of initial ground stiffness is used to identify the complex nonlinear interaction in the