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An Investigation into a Shoring Method to Support Buildings Adjacent to Excavations

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ABSTRACT: Underpinning and Shoring are widely used for supporting the buildings adjacent to excavations all over the world. “Inclined Struts” is one of the traditional excavation methods to support buildings adjacent to excavations. In this method, some inclined struts which are connected to the bottom of the excavation and to the wall, column, or foundation of adjacent buildings are used. Provided that the inclined struts are connected to a load bearing member, such as a wall or column of the adjacent structure, the traditional method can be considered as a type of Shoring. Although this method has been used for years, it has been poorly investigated. Herein, the common configurations of the traditional excavation were numerically simulated. Comparing simulation results, the paper suggests that struts should be allied to the foundation of the adjacent building in order to minimize the ground surface displacements. Finally, governing mechanism of the traditional excavation is revealed.

1. INTRODUCTION

A major concern during the planning and excavation of underground construction is the impact of construction related to ground movement on adjacent building and utilities. During excavation and support of open-cuts, changes in the state of stress in the ground mass around the excavation and loss of ground occur. These changes in stress and ground losses are typically expressed in the form of vertical and horizontal ground movements. The ground movements, in turn cause any structures by the affected ground to translate, rotate, deform, and possibly damage.
Shoring and underpinning are frequently-used method in all over the world. Shoring is a form of temporary support which can be given to existing buildings adjacent to excavation to avoid damage to neighbouring structures. Similarly, Underpinning is another temporary support for existing buildings next to excavations. Generally, the main objective of underpinning works is to transfer the load carried by a foundation from its existing bearing level to a new level at a lower depth.
Amongst several types of supporting structures next to excavations, one type of shoring method, called “Inclined Strut”, is widely used in different areas (e.g., Iran). Despite the excessive use of “Inclined Strut” method, adequate researches have not been conducted about it. Besides, International references have not adequately point out to this method.
This paper intends to (1) introduce the “Inclined Strut” method, (2) perceive the governing mechanism of this method (3) present some suggestions to improve this method.
Moreover, there are not adequate international resources concerning the mechanism of shoring and underpinning. Therefore, the presented analytical study in this paper could enrich shoring and underpinning resources.

2. INCLINED STRUTS METHOD

Inclined Strut can be considered as shoring or underpinning. Shoring is a form of temporary support for structures adjacent to excavations to prevent excessive deformation of the structure. There are three basic system of shoring, used to support existing structures adjacent to an excavation, as follows:

1- Dead shoring
2- Raking shoring
3- Flying shoring

As described by Chudley and Greeno [1], "Dead shoring system is used primarily to carry vertical loadings. Raking shoring system is used to support a combination of vertical and horizontal loadings. Flying shoring system is an alternative to raking shoring to give a clear working space at ground level." And underpinning is another kind of temporary support for buildings next to excavations. Underpinning works is to transfer the load carried by a foundation from its existing bearing level to a new level at a lower depth.
Inclined Struts method is a traditional method which is widely used to support structures adjacent to excavations. In this method, wood or steel “struts” are used to connect the wall and or columns of adjacent structure to the bottom of excavation (as shown in Fig. 1), so Inclined Struts can be categorized as raking shoring method. Raking shoring method could be converted to flying shoring when the excavation is narrow and two opposite building adjacent to excavations are fairly close.
Traditional raking shoring could be considered as underpinning when the upper end of the strut is connected to the foundation of adjacent structures.

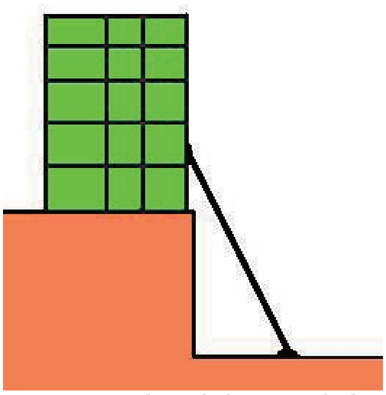
Figure 1 Traditional Shoring method

3. NUMERICAL ANALYSIS

To find the underlying mechanism of Inclined Struts and to improve this method, numerical analysis has been used in the presented study. A number of most common configurations of Inclined Struts method were modelled using Fast Lagrangian Analysis of Continua, FLAC [2].The results were compared and ones which leaded to the least excavation-induced deformation introduced.

3.1. Numerical Simulation and Input Data

The inclined struts and adjoining building were modelled using beams (a type of structural element in FLAC). Mohr-Coulomb constitutive model was chosen for soil elements. The parameters of soil and structural elements have been shown in Table 1.

Table.1: The parameters of soil and structural elements used in numerical modelling

Parameters	units	amount
Moment Interia	m^4	4.80E-05
Beam cross section	m^2	4.80E-03
ν	-	0.35
γ_{soil}	kN/m3	20
H	m	8
E_{steel}	kN/m^2	2.0E+08
E_{soil}	kN/m^2	8.0E+04

To minimize boundary effects, the vertical boundary at the far ends was set 80 m away (almost 10 times of excavation's width) from the centre of excavation, Fig.2. It, therefore, was assumed to be free in vertical direction and restricted in horizontal direction. The bottom horizontal boundary was restricted in the both horizontal and vertical directions. The boundary condition and the discretization of the medium for modelling is shown in Fig. 3.

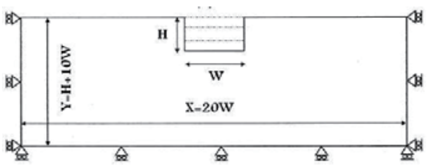

Figure 2 boundary condition of the numerical model

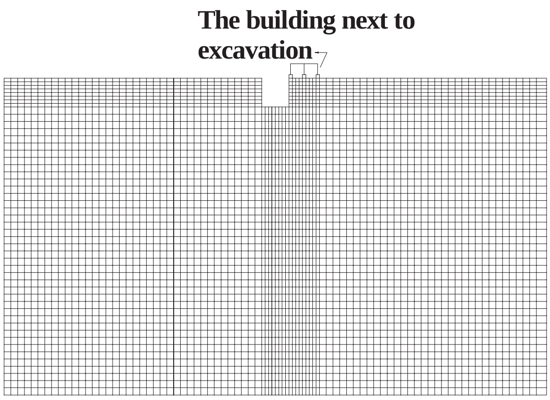

Figure 3 the discretization of the medium for modeling

3.2. Modelling Stages

Firstly, the in-situ horizontal and vertical stresses were generated. Initial in-situ horizontal and vertical stresses are as follows.

$$\sigma_y = \gamma h$$

$$\sigma_x = K_0 \sigma_y$$

Which γ is the soil density, K_0 is the coefficient of earth pressure at-rest, and σ_y and σ_x are the vertical and horizontal initial stresses at depth of h respectively.

Secondly, it was assumed that an eight-floor building was located next to the excavation. The depth of modelled excavation (H) was considered to be 8 m since it is a typical depth when the traditional Inclined Struts method is used.

The width of excavation (W) and also the width of neighboring building (L) were assumed equal to 8m in the models as a number of researchers consider H/L and H/W equal to one in their studies.(e.g., [3])

Thirdly, excavation stages are modelled according to common excavation procedures. Boundaries between the stages are modelled by geometry lines and on the basis of considered order for excavating as described later in this paper. Restrained areas in geometry lines are omitted, according to the desired excavation stages.

3.3. Modelling adjacent buildings

Neighbouring building was modelled in seven different ways. Fig. 4 is illustrated these ways. The results of modelling were compared on the basis of excavation–induced displacement in ground surface and excavation's wall deformations.

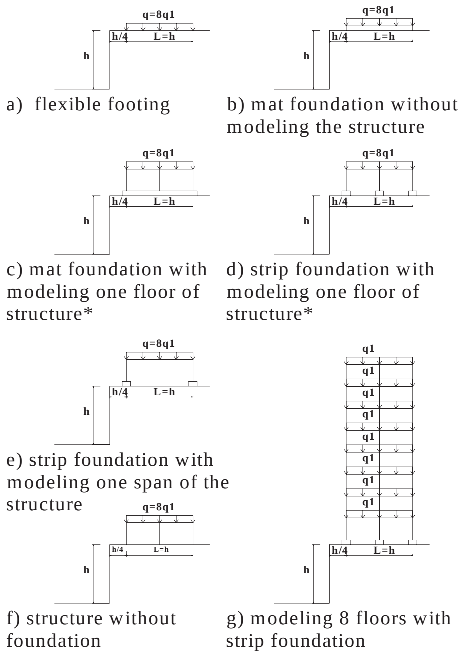

Figure 4 seven modelling types examined for structural modelling of neighbouring buildings

Eventually, the comparison led to the following results:

1. If foundation of adjoining structure is not simulated, it will lead to a trivial difference in calculated displacements. However, it is recommended to model foundation.
2. Considering a mat foundation for the adjoining structure, will reduce excavation-induced deformation in excavation wall and ground surface. Therefore strip footing, which leads to worse condition, was considered.
3. Modelling all the floors of structure does not have a considerable effect on the results.

Therefore, the 7-D type (as shown in Fig. 4) was considered for adjoining structure simulation. It models foundation as strip footing and consider the first storey of neighbouring building. The upper storeys are considered as loads exerted on the first floor.

3.4. Struts Configuration Studied

Eight most common configurations of excavation procedure used in traditional shoring method have been shown in Fig. 5. In the first configuration, the excavation is constructed in one stage (5(a)). Afterward struts have been installed and connect the roof of structure to the bottom of excavation. In 5(b) cross-section, similar to 5(a) one excavation was completed in one stage, but struts have been connected to the foundation of adjoining structure. As can be seen in the Fig. 5 the merely difference between 5(a) and 5(c) cross-sections is the stage of excavation, which is consist of two stages in 5(c). 5(d) cross-section is constructed in two stages and after completing the excavation struts connect the first roof of structure to the bottom of excavation. In 5(e) and 5(f) cross-sections, after fulfilling the first stage of exaction the struts are installed and finally the second stage of excavation is constructed. The only difference between these configurations is in the locations where struts are allied with the adjoining structure. The 5(g) cross-section shows occasions, when Raking shoring alters to Flying shoring. Finally, 5(h) shows a very rare type of traditional method. In this configuration the foundations of adjoining structure connect to each other with a grade beam.

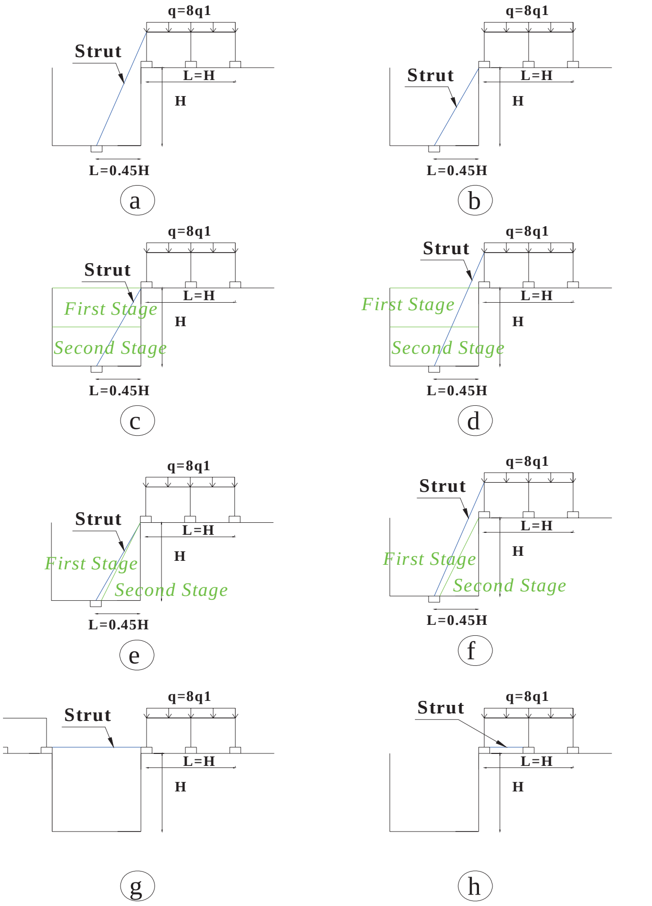

Figure 5: several most common configurations of excavation procedure used in traditional shoring method. (a) Inclined struts connected to the first floor after full excavation. (b) Inclined struts connected to the footing after full excavation. (c) Inclined struts connected to the footing after full excavation done in two stages. (d) Inclined struts connected to the first floor after full excavation, done in two stages. (e) Inclined struts connected to footing after the first stage of excavation, done in two stages. (f) Two adjacent footing of neighbouring building are fully connected. (g) flying shoring.

The most effective configuration of struts as shown in Fig. 5, several configurations of struts were studied and compared. To find the most effective configuration, it is essential to firstly consider the effects of ground movement on buildings.

Settlement damage to masonry buildings was addressed by Burland and Wroth [3] and Burland et al [4], who introduced a damage classification system. In a development Boscardin and Cording [5] illustrated the importance of direct horizontal extension in initiating damage. Fig. 9 illustrates the combination of angular distortion; define in this case as the maximum change in slope angle the "beam" or "wall", and horizontal strain. Damage categories were based on the criteria suggested by Skempton and Macdonald [6] and work of the U.K. National Coal Board [7]. Fig. 7 was derived for building with length (L) to height (H) ration of 1 in terms of horizontal strain and angular distortion (β). In fact, angular distortion is the maximum change in slope along the beam or the slope at the supports.

A later modification of the critical strain approach by Burland [8] induced lateral strain based on the work of Boscardin and Cording [5] and adapted different values of critical strain to reflect different damage categories, as illustrated by Fig. 7. However this approach was limited to the case of $L/H = 1$. The both Fig. 6 and Fig. 7 were used in this paper to discuss the result of numerical analysis.

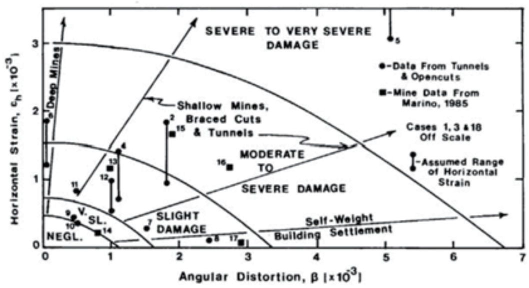

Figure 6 relationship between angular distortion, horizontal strain, and damage category Boscardin and Cording [5]

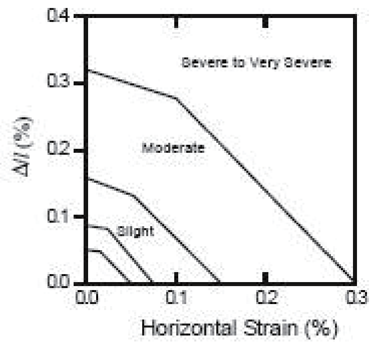

Figure 7 relationships between damage category, horizontal strain and deflection ratio (Δ/L) which is defined as maximum deflection between the beam deflection line and the straight line between the two end points (chord) divided by the chord length, Burland [8]

To find the most effective configuration displacement of ground surface was carefully considered. Fig. 8 compares excavation-induced displacement of ground surface as a result of eight mentioned traditional excavation procedures. As can be seen in the Fig. 5, 5(a) and 5(b) configurations differ only in the location where strut connected to the adjacent structure. According to Fig. 8 and Fig. 9, lateral displacement (horizontal displacement) induced using 5(a) was more than that in 5(b) although in terms of vertical displacement both of them were the same. On the ground that the soil on the bottom of excavation heaves after excavation, the strut conveys this protrusion to the adjacent structure. Owing to this fact, dividing the excavation procedure into two stages, as shown in 5(c) to 5(f), reduces the vertical excavation-induced displacements. As a case in point, 5(c) configuration resulted in less lateral displacement (horizontal displacement) in comparison with 5(b). Moreover, this was the same regarding 5(a) and 5(d). Furthermore, dividing the excavation procedure into two stages causes less vertical displacement. In fact, 5(c) and 5(d) configurations triggered less vertical displacement in compared with 5(a) and 5(b). Excavation-induced excavation in 5(c) and 5(d) are similar to 5(e) and 5(f) respectively. To sum up, 5(e) and 5(c) are recommended. However, excavation procedures shown in 5(e) and 5(f) seem to be simpler in terms of construction. Not surprisingly, using horizontal struts decreases the lateral displacement (horizontal displacement). Nevertheless, horizontal struts can not transfer a portion of the load of the adjoining buildings to the bottom of excavation. Indeed, unlike 5(a) to 5(f) configurations, 5(g) and 5(h) can not compensate for the loss of load bearing capacity of adjacenet buildings' foundation caused by excavation.

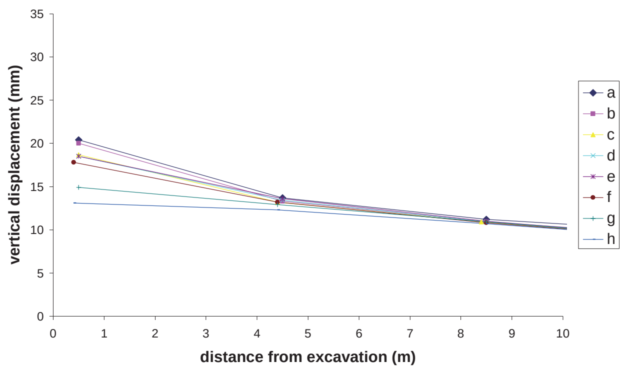

Figure 8 ground surface deformations predicted for 8 traditional excavation procedures

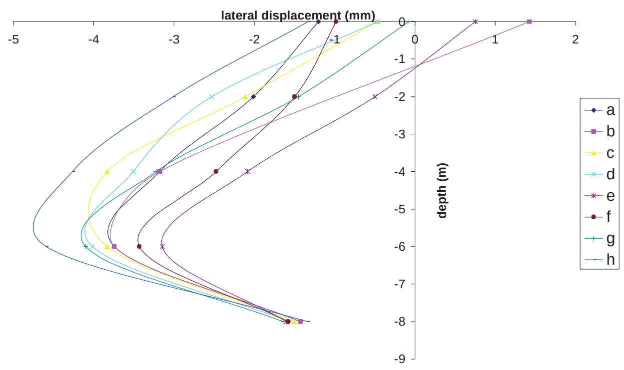

Figure 9 excavation's wall deformation predicted fo 8 traditional excavation procedure

4. THE GOVERNING MECHANISM OF "INCLINED STRUTS"

The result of numerical presented numerical models was carefully investigated and the distribution of stress and displacement were studied. As a result of mentioned studies, underlying mechanisms of "Inclined Struts" in traditional underpinning/shoring, shown in Fig. 1 and also Fig. 5(a) to 5(h), can be explained as follows:

1. The numerical simulation shows that struts will be more effective if they are connected to the foundation of adjoining structure. It was observed that Inclined struts convey a portion of building loads to the bottom of the excavation.
2. Inclined and horizontal Struts restrain the excavation-induced horizontal displacement and also tensile strain in the neighbouring building. Therefore, it reduces the damage of the building as Boscardin and Cording [5] presented a graph, shown in Fig. 6, which shows the importance of horizontal displacement.

The two above mentioned mechanisms are the beneficial effects of inclined struts on the adjacent building. However, flying shoring, as indicated in Fig. 5(g), could only present the second beneficial effect. Moreover, the connection of two adjacent footing, as shown in Fig. 5(h), does not show considerable beneficial impact.

5. CONCLUSION

a) A traditional shoring method, which is based upon the use of inclined struts, has been introduced and investigated.
b) The most effective configuration of "inclined Struts" method, which leads to the least excavation-induced displacement in adjacent building, has been proposed in Fig.5(e). This configuration is also minimizes damages to adjacent buildings, according to the criteria proposed by Boscardin and Cording [5] and Burland [8].
c) Finally, the key role of struts is to transfer a portion of foundation's force to the bottom of excavation as well as restraining the tensile strain in adjoining structure although it is likely to boost angular distortion.

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