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Two Lessons Learnt in Defining Intersections and Interfaces in Numerical Modeling with Plaxis

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Abstract**—**This paper is going to discuss two issues encountered in using PLAXIS. Both issues were monitored during application of PLAXIS to estimate the excavation-induced displacement. Column Soil Mixing (CSM) was applied to stabilise the excavation. It was understood that the estimated excavation induced deformation at the top of the CSM blocks highly depends on the material type defining pavement material adjacent to the CSM blocks. Cohesive material for pavement will result in the unrealistic connection between pavement and CSM even by defining an interface element. To find the most realistic approach, the interface defined in three different manners (1) no interface elements were applied (2) a non-cohesive soil layer was defined between pavement and CSM block to represent the friction between these materials (3) built-in interface elements in PLAXIS was used to define the boundary between the pavement and the CSM block. The result showed that the option 2 would result in more realistic results. The second issue was in the modelling of the contact line between the CSM block and an inclined layer underneath. The analysis result showed that the excavation-induced deformation highly depends on how the PLAXIS user defines the contact area. It was understood that if the contact area had defined as a point in which CSM block had intersected the layer underneath the estimated lateral displacement of CSM block would be unrealistically lower than the model in which the contact area was defined as a line.

Keywords**—**PLAXIS, FEM, CSM, excavation-induced deformation.

I. Introduction

EXCAVATION changes the stress state and results in deformation around the excavated area. In urban areas, it is crucial to estimate excavation induced deformation. Numerical modellings like Finite Element Method (FEM) are commonly used to excavation-induced deformations. PLAXIS is known as common FEM software in engineering practice. To avoid misinterpretation of the result, it is important to carefully review the analysis results. This paper presents two examples of misinterpretation which might happen in the excavation and soil stabilisation modelling using numerical modeling packages like PLAXIS [1]. In 2003, numerical simulation of construction staging of deep urban excavations was commonly used to estimate induced ground deformations [2]. In 2006, Ong et al. studied comparisons of finite element modelling of a deep excavation using 2-D finite element software, SAGE-CRISP and PLAXIS [3], [4]. In 2014, scientists studied the behavior of tie back sheet pile wall in deep excavation with PLAXIS, and results of the study indicate that sheet pile wall method is viable to limit ground movements due to the excavation [5]. Also, the parametric study demonstrates that considerable reduction in wall deformations, and bending moments can be achieved and safe excavation to greater depths is possible with the introduction of tie back sheet pile wall support system [5].

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II. Geometry and Material Properties

Fig. 2 demonstrates geometry and stratigraphy for the model. Furthermore, material properties for two constitutive models and material properties for hardening soil model have been shown in Tables I and II, respectively.

TABLE I
MATERIAL PROPERTIES (MOHR-COLUMB MODEL AND LINEAR ELASTIC MODEL)

Item	Unit	Pavement	CSM	Layer (2)	Layer (3)
Material model	-	LE	MC	MC	MC
Drainage type	-	D	UB	UB	D
Unstaturated Unit Weight	kN/m³	20	18	15.5	19
Staturated Unit Weight	kN/m³	20	18	15.5	19
Undrained Strength	kN/m²	-	250	39	-
Effective Cohession	kN/m²	-	-	-	0
Effective Friction Angle	°	-	-	-	40
Dilation Angle	°	-	-	-	0
Elastic Modulus	MN/m²	20,000	60	12	80
Poisson's Ratio		0.2	0.3	0.3	0.3

TABLE II
MATERIAL PROPERTIES (HARDENING SOIL MODEL)

Item	Unit	Layer (1)
Material model	-	HS
Drainage type	-	D
Unstaturated Unit Weight	kN/m³	16.5
Staturated Unit Weight	kN/m³	16.5
Undrained Strength	kN/m²	-
Effective Cohession	kN/m²	0.0
Effective Friction Angle	°	30
Dilation Angle	°	0.0
HS Model-E_{50}	MN/m²	9
HS Model -E_{oed}	MN/m²	9
HS Model -E_{ur}	MN/m²	27
HS Model -m	-	0.453

As it can be seen in Table II, some parameters for HS model are as follows:

- E_{50} = Secant stiffness in standard drained triaxial test in the HS model
- E_{oed} = Tangent stiffness for primary oedometer loading in the HS model

- E_{ur} = Triaxial unloading/reloading stiffness in the HS model
- M= Power for stress-level dependency of stiffness in the HS Model

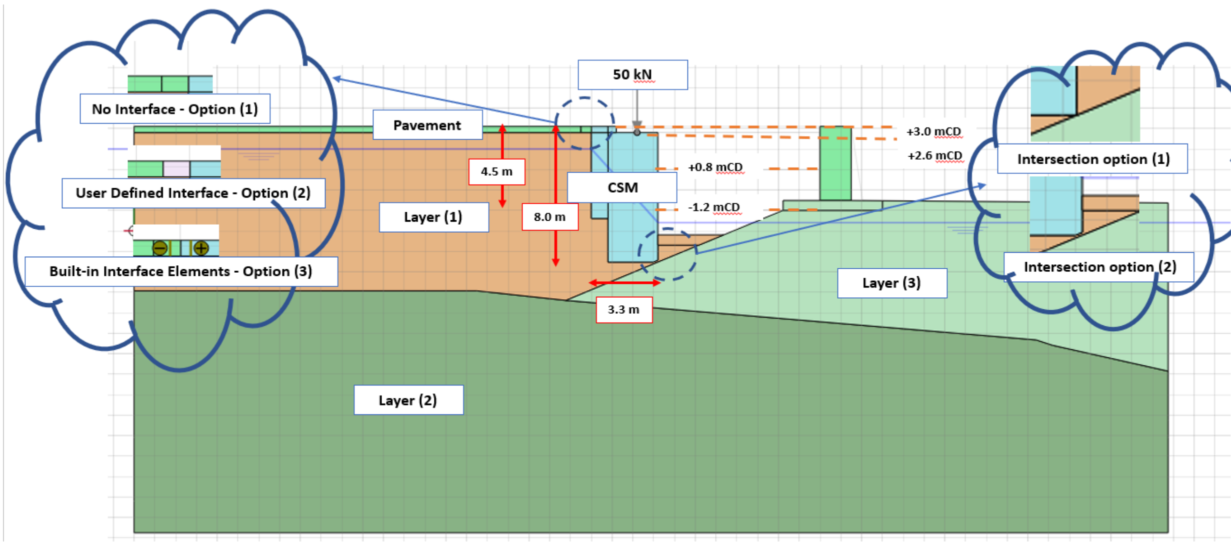

Fig. 1 Geometry and stratigraphy

III. Stage Construction

The following construction methodology is envisaged and has been incorporated into PLAXIS:

- Excavate existing pavement (from ~2.2 mCD to 2.6 mCD) and removing overlying pavement material.
- Construct CSM blocks – refer to Fig. 1.
- Install an inclinometer in the middle of the CSM block closer to the excavation.
- Carry out a staged excavation to the base of the trench (-0.2 mCD). In the FE model, excavation was broken down into three stages:
- Stage I: excavate the trench from +2.6 mCD down to +0.8 mCD, refer to Figs. 1and 2.
- Stage II: excavate from +0.8 mCD to -1.2 mCD, refer to Fig. 1 and Fig. 2.Stage III: excavate from -1.2 mCD to -the base of the trench.
- Apply gantry load (50 kN).

IV. Comparing Different Interface Options

As can be seen in the left side of Fig. 1, the boundary between the existing pavement layer and the CSM blocks can be defined in three different ways:

- Option (1) – no interface element would be defined, and the boundary between CSM block and the existing pavement would be defined by a geometry line.
- Option (2) – a user defined zone would be defined between CSM block and the existing pavement, to manipulate the friction between the CSM block and its adjacent existing pavement. To reach to a friction coefficient of 0.5, the friction angle of this zone should be defined equal to 25 deg. Other properties would be identical to the properties of the pavement.
- Option (3) – the PLAXIS built-in interface element would be used and interface reduction factor (Rint) of defined in the material properties assigned to the pavement, and CSM block.

A. No Interface Option (1)

Fig. 2 shows the deformation expected assuming option (1), and Fig. 3 shows the lateral deflection predicted by PLAXIS after each stage of construction as specified in section III.

As it can be seen in Figs. 2 and 3, the top of the CSM would be hinged to the pavement layer adjacent to it, which is not expected in actual CSM block. This also unrealistically reduced the lateral deflection in Fig. 3.

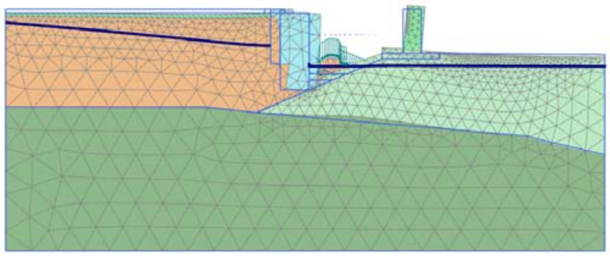

Fig. 2 No Interface-Option (1)

A. User Defined Interface – Option (2)

As the second option discussed before, a zone has been defined between CSM block and the existing pavement. The material properties of the intermediate zone have been defined similar to pavement properties with a different friction angel of 25 deg. This intermediate zone represents the interface properties between CSM and the pavement.

Results have been shown in Figs. 4 and 5. As it can be seen, the maximum lateral deflection is ~36 mm, which is almost two times of the maximum deflection in the first option ~19 mm (refer to Fig. 3). Moreover, the unrealistic hinge has been removed. This shows that this option reflects actual condition more realistically.

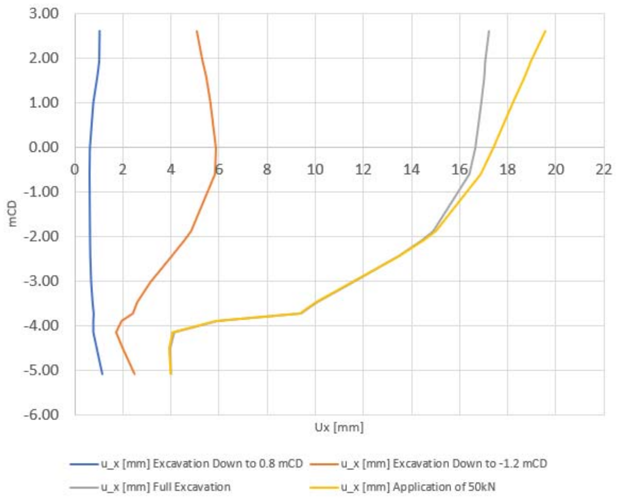

Fig. 3 Lateral deflection estimated at the location of the inclinometer, refer to section III

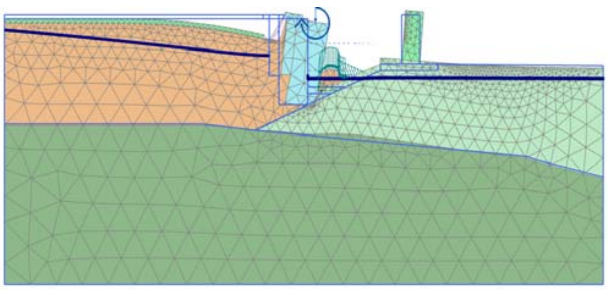

Fig. 4 User defined zone - option (2)

B. Built-in Interface Element Option (3)

In the third option, the PLAXIS built in interface element, has been used. As shown in Fig. 6, the unrealistic hinge is appeared, like option (1) in Fig. 2. Consequently, the lateral deflection reported in Fig. 7 is also similar to Fig. 3.

V. Comparing Different Intersection Options

A. Intersection Option (1)

It is known that some of the ground improvement machinery, e.g. cutter soil mix equipment would be refused when they reach a large soil particles. Herein, it has been assumed that the layer 3 is a soil layer with large particle in a way that the CSM rigs would be refused when it intersects with layer 3.

Intersection between the CSM block and layer 3, in theory, will happen in a point as shown in intersection option (1), refer to Fig. 1. However, in real practice, the intersection would be more like the option (2) refer to Fig. 1.

Fig. 8 shows the result for intersection option (1), which is comparable to Fig. 4 that, in all previous analysis, the intersection option (2) has been used. As can be seen in Fig. 9, the maximum lateral deflection in theory would unrealistically decrease by almost 20% (from ~36 mm to ~30 mm), refer to Figs. 5 and 9, respectively.

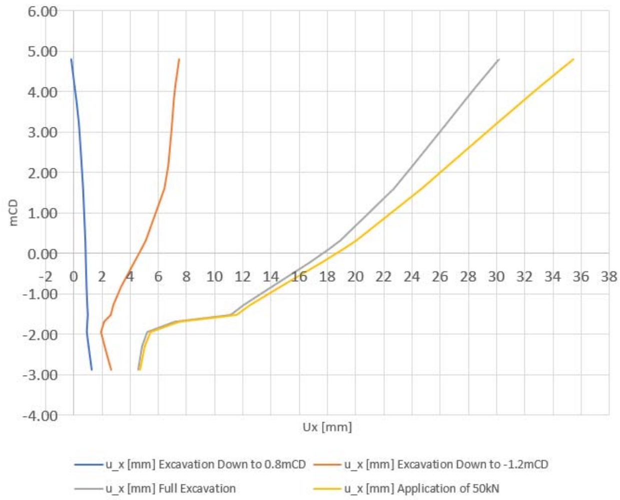

Fig. 5 lateral deflection estimated at the location of the inclinometer, refer to section III

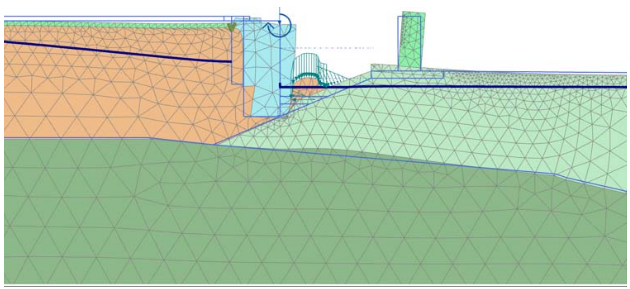

Fig. 6 Built-in interface-option (3)

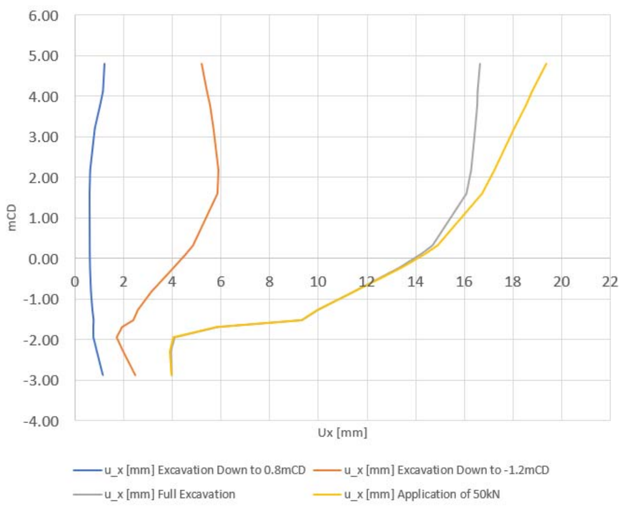

Fig. 7 Lateral deflection estimated at the location of the inclinometer, refer to section III

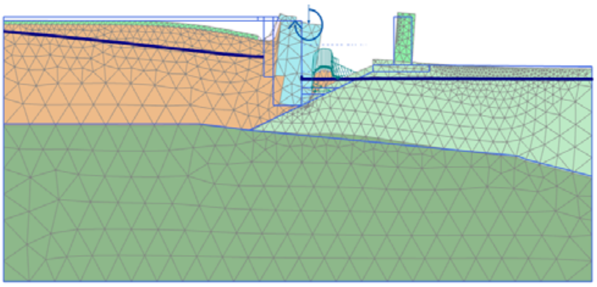

Fig. 8 Intersection option (1)

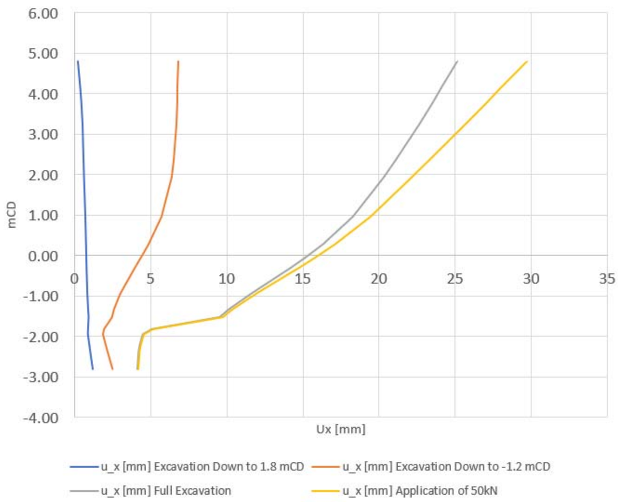

Fig. 9 Lateral deflection estimated at the location of the inclinometer, refer to Section III

VI. Conclusion

In real practice, it is of great importance to scrutinize the result and carefully review the outputs to find and remove the unrealistic assumptions similar to the mentioned examples and simulate the actual condition as accurate as possible.

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