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Investigation of Soft Soil Deformation due to Excavation Work at Sungai Kesang, Johor using PLAXIS 2D

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Abstract: Sungai Kesang is located between the south of Malacca and Johor. The problem started during excavation work for construction of bypass river causes nearby house experienced cracked and damaged. To investigate the displacement behaviour due to excavation work, several cases or models of excavation were modelled using numerical analysis software (PLAXIS 2D). Many factors were considered such as different values of slope angles excavation, the groundwater level, and the load (house) from the adjacent work. There are 27 models were proposed for this investigation where the width of the excavation is 23 m and the depth of the excavation is four (4) meters and the excavation rate is assumed as two (2) meters per week. The soil displacement and the pore pressure dissipation were measured within a one-year duration. From 27 of the proposed models, only 9 models were completed successfully or safe and the rest models were fail due to soil collapse. This study concludes that the excavation in soft soil is not affected by the changes of groundwater level and the load but is only affected by the changes of slope angle. The excavation can be performed when the slope angle is less than 30°.

Keywords: Soft Soil, Excavation, Plaxis 2D

1. Introduction

Soft soil or soft ground is a soil that likely to fail or causing excessive settlement once the structure constructed over it. It is very spacious where it has its own problems. This type of soil typically has a low shear strength, highly compressible and low permeability [1]. Usually, the shear strength will be less than 40 kPa and surprisingly can be molded by light finger pressure [2].

Excavation can be defined as any man-made cut, cavity, trench or depression on the soil which is formed by the removal of soil in the Earth's surface. Any excavations in soft soil can be a great challenge due to the large lateral loads that requires a support from the shoring system. Besides that, potential for large deformation could be one of the challenges as well and their impacts on existing structures. Due to the potential large deformations, excavation in soft soil in town areas will create public involvement especially stakeholders [3].

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Basically, to select and design the excavation system, the primary controlling factors will include, (1) soil type and soil strength parameters, (2) groundwater conditions, (3) slope protection, (4) side and bottom stability, and (5) vertical and lateral movements of adjacent areas and effects on existing structures [4]. As for soft soil, the factors will be a bit different.

Previous studies revealed that these factors will affect the behaviour of excavation in soft soils that must be understood so that a safe and economical design will be achieved. The factors include (1) basal stability and its effect on strut loads and excavation induced deformations, (2) stability of the base against hydrostatic uplift, (3) excavation induced deformation and their potential for adversely impacting adjacent structures, (4) sources of ground deformation from construction activities other than the actual excavation and bracing processes, (5) control of groundwater and (6) recent construction innovation support and ground improvement [3].

Finite element analysis is a crucial tool for recent research and the design will be conducted by computer software called PLAXIS. This software is widely used finite element program for geotechnical engineering [5]. This research is to investigate the deformation of soft soil due to excavation work. The study also furthered by determine the possible causes of the deformed soft ground.

Usually, geotechnical design of a project relies on conventional design method, the finite element method plays an important role in the analysis of deformations, stability and the influence on the surrounding structures [6]. Over the last 15 years, the users of finite element programs working in engineering and contracting firms has been significantly increased. The engineers need to know how to select right models and their parameters for a certain application. Before going into soil models, aspect of real soil behaviour should be focused first because this will become the basis to evaluate the possibilities and limitations of some existing models for geotechnical engineering applications [7].

PLAXIS 2D is a program that used for two-dimensional analysis based on finite element method. It is very useful computer software in analysing geotechnical engineering and design problem such as deformation, settlement, stability and groundwater flow in soil. PLAXIS 2D was first developed in 1987 at Delft University of Technology. Its initial purpose is to develop an easy-to-use 2D finite element code for the analysis of river embankments on soft soil of the lowland of Hollands [8].

PLAXIS software was continuously developed and was extend to cover most area of geotechnical engineering field [9]. In 1998, PLAXIS 2D for window was released for commercial purposes. In 2010, the PLAXIS 3D software was developed due to continuously grow of technology and new knowledge from researchers in the field of geo-mechanic and numerical method [10].

1.1 Problem statement

This research is to investigate the possible causes behind those cracks and damages. One thing for sure, the damages occurred that relates to the damage is the soil at the construction site. The deformation of the soil during the construction that affect the nearby residential should not be happening after the procedure like Soil Investigation (SI) had been conducted. In this study, the investigation was carried out by using PLAXIS 2D software to simulate the event happened in Sungai Kesang. By doing this, the possible causes of the soil deformation could be analysed and be known.

1.2 Research objectives

The aims of this study were to model several cases of excavation with condition that might contribute to the soil deformation, to investigate the behaviour of excavation with the proposed cases and to compare and recommend the best condition for excavation in soft soil.

2. Materials and Methods

In order to achieve the objectives of the research, there are some steps that need to be done. These steps are crucial because it contain detailed procedures and better understanding of the process and work flow. After reading and understanding of the suitable literature materials, the appropriate material models had been selected and the parameters required for analysis also specified

2.1 Data collection

The data was obtained from the flood mitigation project in Sungai Kesang, where it will be used to simulate the condition at the site. The data collected were the borelog which shows the soil profile at the site, the location of the borehole and Standard Penetration Test (SPT)-N value of different stratigraphy soil layers.

2.2 Methods

The PLAXIS 2D able to simulate the problem in plane strain condition especially when modelling the simple excavation, slope stability and embankment construction. In this study, the PLAXIS 2D version 2015 was used for modelling of soft soil excavation. The Mohr-Coulomb model was used for Sandy clay layer and the Soft Soil model were used for clay layer since this model able to give more accurate results. The settlement and excess pore water pressure behaviour were analysed.

2.2.1 Soil parameters

For this study, all the soil parameters were in undrained condition because this model simulate the behaviour for short term condition (immediately after construction) where it is more critical than the long term performance. The detailed parameters of each soil layer for this research shown in Table 1.

Table 1: Soil parameters

Material	Clay	Sandy Clay
Material model	Soft Soil Model	Mohr-Coulomb Model
Material behaviour	Undrained (A)	Undrained (B)
γ_{unsat} (kN/m^3)	16.0	15.0
γ_{sat} (kN/m^3)	18.0	18.0
Young's Modulus, E' (kN/m^2)	-	3400
Poisson ratio, v'	-	0.33
Cohesion, c'_{ref} (kN/m^2)	1.0	-
$S_{u,ref}$ (kN/m^2)	-	5.0
Friction angle, ϕ (°)	25.0	-
ψ' (°)	0.0	-
κ^*	0.0085	-
λ^*	0.03	-
Initial void ratio, e_{int}	1.0	0.5

2.2.2 Modelling procedures

The maximum horizontal axis, X_{max} was set to 150 m, the minimum horizontal axis, X_{min} was set to 0.0 m, maximum vertical contour (y-axis), Y_{max} was set to 10.0 m and minimum vertical contour (y-axis), Y_{min} was set to -50.0 m. As for the model type, the Plane Strain model with 15-noded elements is selected to produce accurate results.

The proposed model was created using "Create soil polygon" tool according to the coordinate as shown in Figure 1 to Figure 3. After created the rectangle shape, the "Cut polygon" tools was used to create the excavation area. To create the load as a surcharge, choose "Create line load". The line load then put onto the model following the coordinate. As for the value of the load, double click on line load then on the "Selection explorer" tab on the left, set the value -10.00 in "$q_{y,start,ref}$" and "$|q_{y,start,ref}|$".

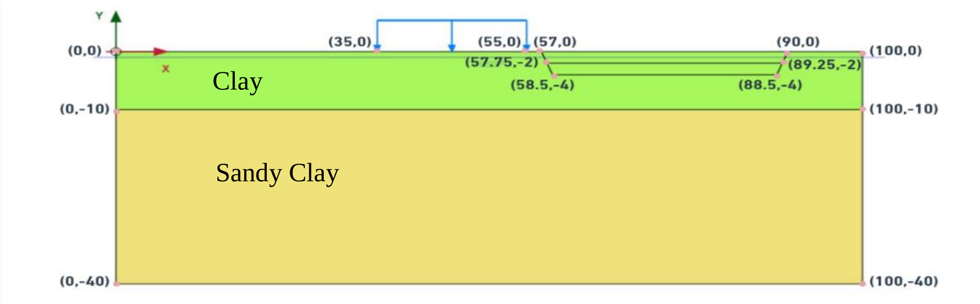

Figure 1: Model geometry for excavation work (70° slope angle)

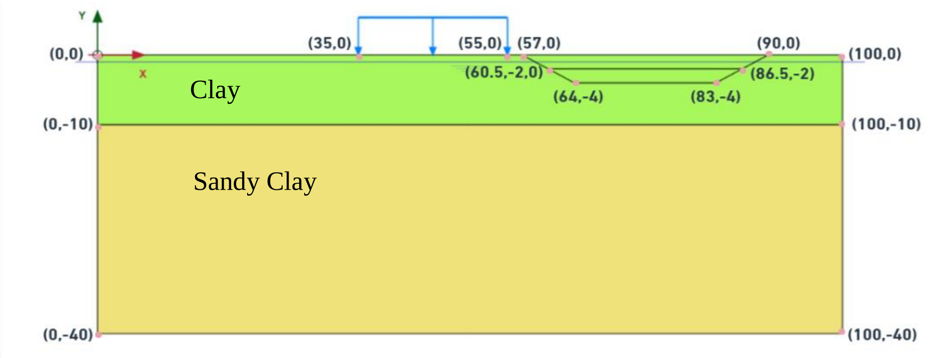

Figure 2: Model geometry for excavation work (30° slope angle)

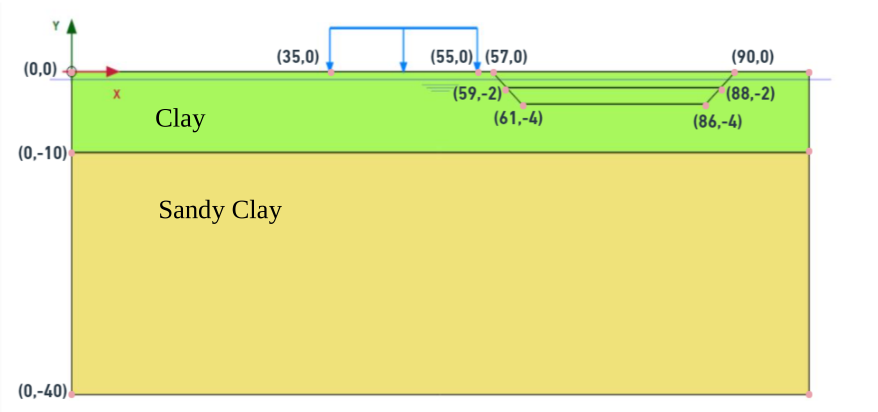

Figure 3: Model geometry for excavation work (45° slope angle)

The subsoil consist of 2 layers which are Clay soil and Sandy Clay soil. After defining the soil properties, input data of the material inside the designated soil layers was keyin. After the geometry model has been fully defined, the geometry has to be divided into finite elements in order to perform the finite elements calculation. This can be done by clicking the "Generate mesh" in the "Mesh" tab. Choosing medium mesh should be fine as very fine mesh will lead to excessive calculation times.

In order to define ground water level in FEM analysis, click on the "Flow condition" tab. To model the changes of the groundwater level, the ground water level line at 1 m, 2 m and 4 m below the surface were sketch .

In the calculation stage, the excavation was divided into 2 phases. The time interval for each excavation phase was assumed as 7 days. The depth of the excavation is 2 m for both phases. The total time taken for both excavation phases was 14 days. After the excavation phases, a consolidation period of 365 days was introduced to allow the dissipation of excess pore pressure. The total duration to complete the process was 379 days.

At initial phase, the excavation was deactivated because excavation phase is not yet started during initial phase. Then, K_o procedure was chosen for calculation type in this phase when the initial soil surface is horizontal. This is to direct the generation of initial effective stresses, pore pressures and state parameters. As for loading type, “Staged construction” was chosen.

At phase 1, the first excavation layer was activated. For the general parameters, the calculation type chosen was “Consolidation” and the loading type was “Staged construction”. This type of calculation made to generate and analyse the deformation and excess pore pressure. The time interval was set to 7 days. Phase 2 involved the activation of second excavation layer. The general parameter was defined as same as previous phase, which total days for Phase 1 and Phase 2 were 14 days.

After both layers of excavation had been done, the simulation will undergo the consolidation phase. The general parameters for this phase was “Consolidation” for calculation type and “Staged construction” for loading type. The value of time interval was 365 days.

The point coordinate for total ground surface settlement analysis were A(57,0), B(55,0), C(50,0), D(45,0), E(40,0) and F(35,0) as shown in Figure 3.15 (a). Whereas for excess pore pressure, the point coordinate were K(47.49,-4.26), L(47.43,-5.32), M(47.49), and N(46.66,-7.53).

3. Results and Discussion

There were in total 27 cases that had been modelled differently for this research. Every case contained different condition that had been discussed earlier. The only thing that remained unchanged were the soil parameters and the soil profile.

Table 2: Summary of analysis of result

Case	Slope angle (°)	GWT (m)	Remarks
Surcharge 10 kN/m^2			
1	45	1	Failed at Consolidation (Phase 3)
2	30	1	Success
3	70	1	Failed at Excavation 2 (Phase 2)
4	45	2	Failed at Consolidation (Phase 3)
5	30	2	Success
6	70	2	Failed at Excavation 2 (Phase 2)
7	45	4	Failed at Consolidation (Phase 3)
8	30	4	Success
9	70	4	Failed at Excavation 2 (Phase 2)
Surcharge 20 kN/m^2			
10	45	1	Failed at Excavation 2 (Phase 2)
11	30	1	Success
12	70	1	Failed at Excavation 2 (Phase 2)

13	45	2	Failed at Excavation 2 (Phase 2)
14	30	2	Success
15	70	2	Failed at Excavation 2 (Phase 2)
16	45	4	Failed at Consolidation (Phase 3)
17	30	4	Success
18	70	4	Failed at Excavation 2 (Phase 2)
Surcharge 30 kN/m^2			
19	45	1	Failed at Excavation 1 (Phase 1)
20	30	1	Success
21	70	1	Failed at Excavation 1 (Phase 1)
22	45	2	Failed at Excavation 2 (Phase 2)
23	30	2	Success
24	70	2	Failed at Excavation 1 (Phase 1)
25	45	4	Failed at Excavation 2 (Phase 2)
26	30	4	Success
27	70	4	Failed at Excavation 2 (Phase 2)

Total of 9 cases were successfully calculated. Meaning to say in PLAXIS 2D, the 9 cases do not show any signs of soil body collapsed. However, the rest of the cases, the calculation failed when there are error of "soil body collapse" appear in the analysis.. The failure between each case were varies such as failed during Excavation 1 (Phase 1), Excavation 2 (Phase 2) and Consolidation (Phase 3).

3.1 Total Ground Surface Settlement

In FEM analysis, the coordinate point was selected for generating the total ground surface settlement data as previously mentioned. The suitable coordinate was selected because the loading is concentrated below the surcharge load and the tip of excavation.

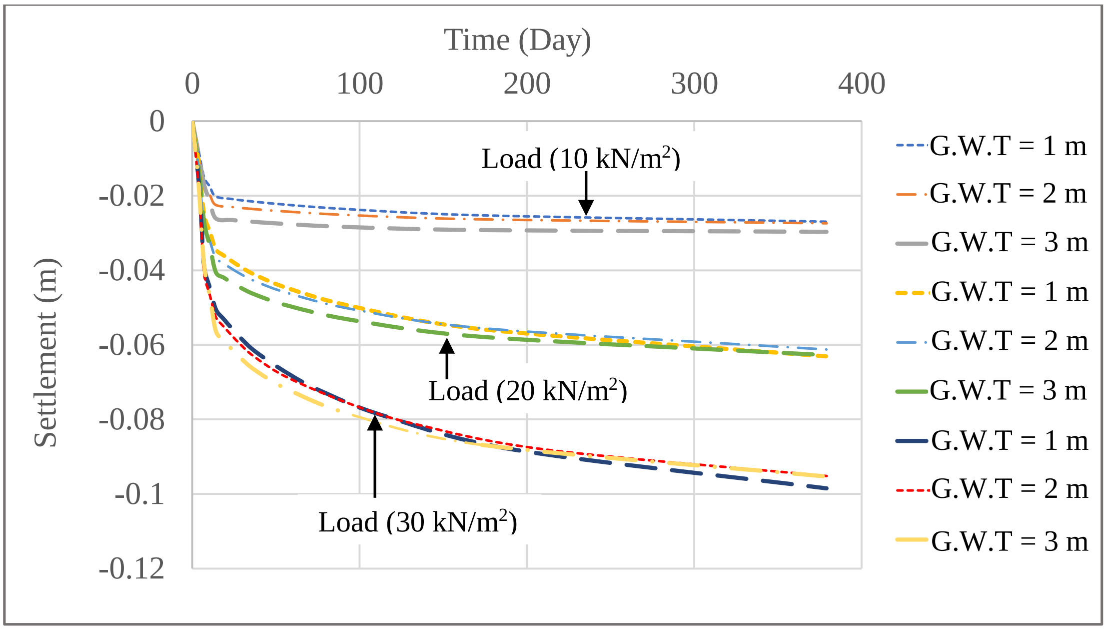

Figure 4: The effect of load and groundwater level on the settlement behaviour

Figure 4 shows the effect of the load and groundwater table on the displacement due to excavation work. It shows that the higher the imposed load, the higher the settlement occur. The changes of the groundwater level did not affect significantly the settlement.

3.2 Excess Pore Pressure

In FEM analysis, the coordinate point was selected for generating excess pore pressure data as mentioned in previous chapter. The coordinate was selected because it directly underneath the surcharge load and also below every proposed ground water table value.

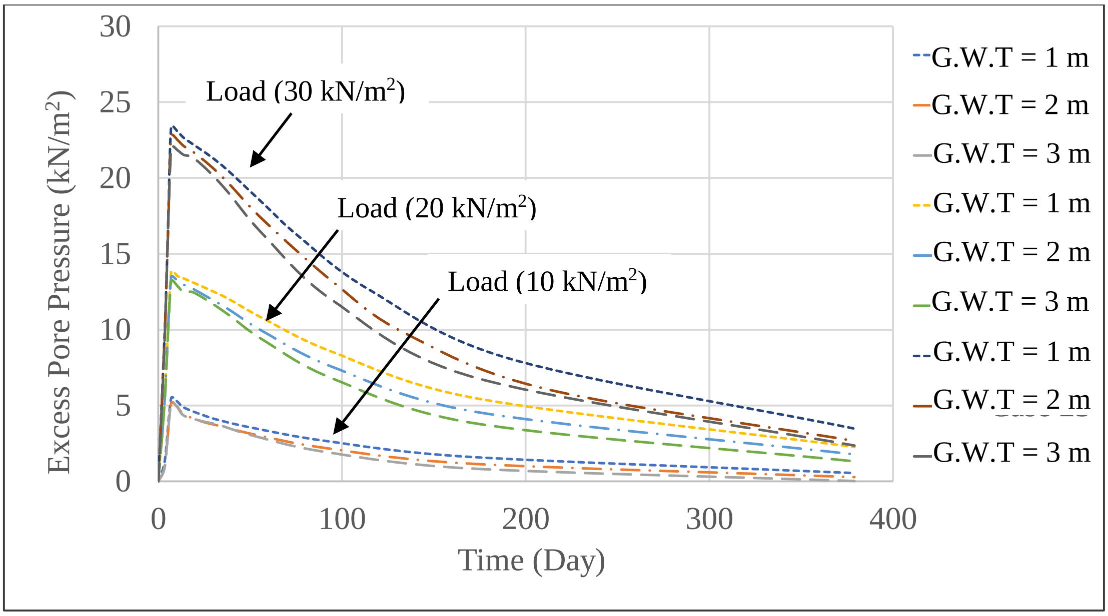

Figure 5: The effect of load and groundwater level on the excess pore pressure

From Figure 5, the highest value of excess pore pressure comes from the cases with 30 kN/m^2 of surcharge value. Besides that, ground water table with value of 1 m from surface also indicates the highest value of excess pore pressure which is case 20.

3.3 Deformation pattern

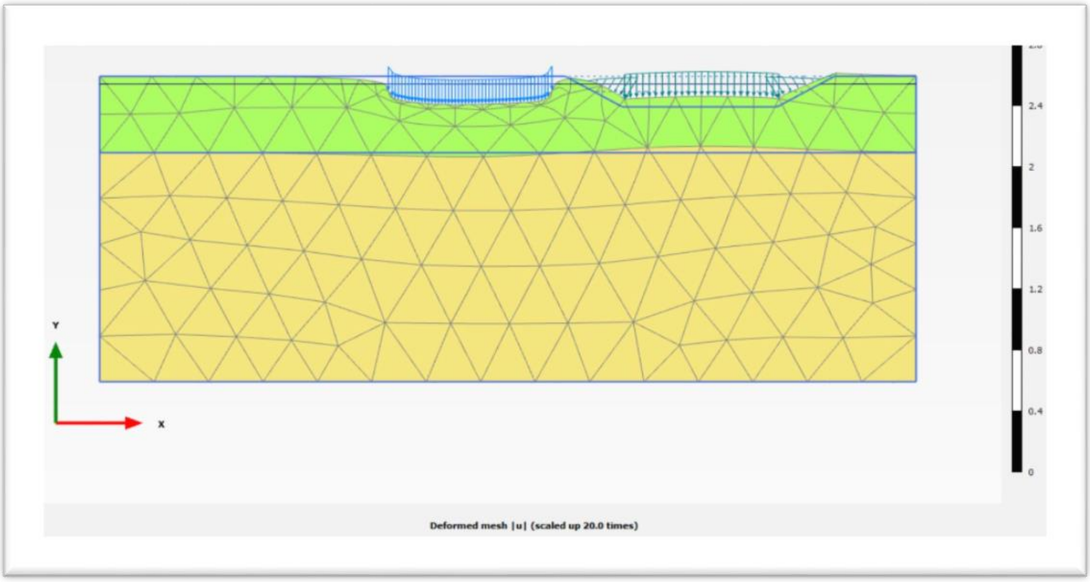

Figure 6: Deformation pattern from FEM analysis

The deformation pattern of the soil layers was shown in Figure 6 at Consolidation (Phase 3) from the FEM analysis. This deformation pattern is only for case 20. This is because it shows the highest value in settlement and excess pore pressure. The rest of the cases were almost the same as case 20. The maximum value generated for the deformed mesh was 0.186 m.

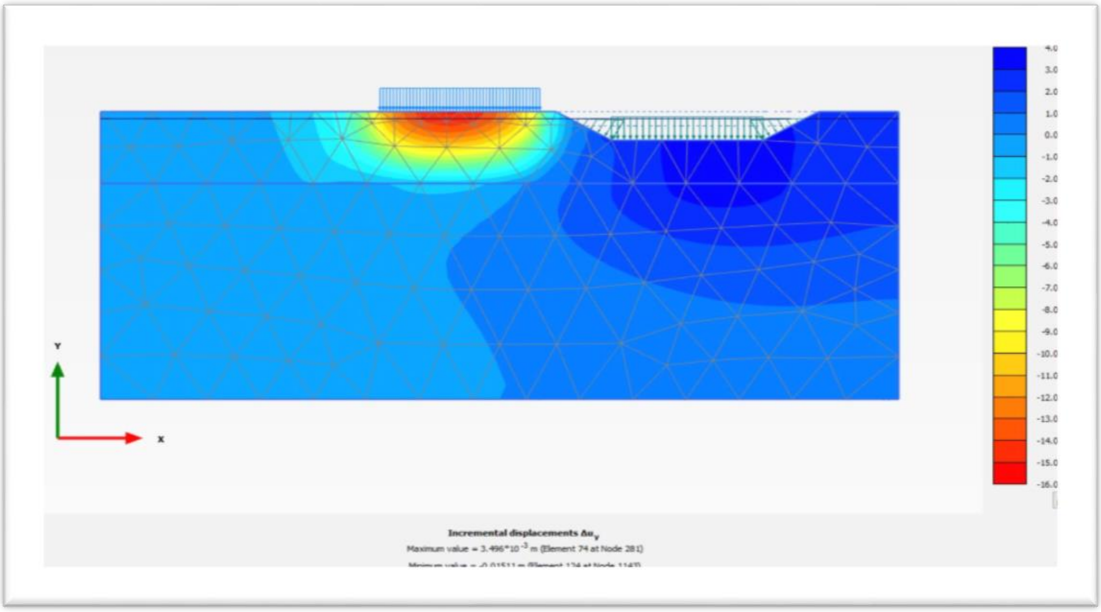

Figure 7: Deformation contour from FEM analysis

In Figure 7, the deformation contour of the of soil layers was shown. It also shows the Consolidation (Phase 3) for case 20. The maximum value of the incremental displacements was 3.496 x 10^{-3} m and the minimum value of incremental displacements was -0.01511 m.

4. Conclusion

In a summary, the structure close to the excavation work is stable due to excavation work when the excavated slope is less than 30°. This is due to its low stiffness and shear strength behaviour. The increment of the load adjacent the excavation work resulted in higher soil deformation. stability is not affected by the changes in groundwater level or the changes of the load adjacent to the excavation work. To make sure the river channel is stable during construction, the excavated slope should always less than 30°.

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