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Re-evaluation of PIZ and SIZ due to Deep Excavation

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CHAPTER 1
INTRODUCTION

1.1 Background

Urban developments of a city are highly supported by recent technologies and studies. These developments such as deep excavation, tunneling, and retaining walls are increasing as time goes by. Such projects may cause additional problems to their surrounding buildings. Settlements that are induced during deep excavation process have become a challenge for civil engineers for this whole time. High-quality soil testing, retaining wall design process, excavation simulation, and reliable monitoring system are essential to ensure the safety of the project itself and units around it. Ou and Hsieh (2011) showed a simplified method in determining the influence zone of settlements induced by deep excavation called Primary Influence Zone (PIZ) and Secondary Influence Zone (SIZ). However, recent research shows that this method is not suitable for some cases.

Finite Element Method (FEM) has been widely used to simulate deep excavation cases to predict wall deformation and surface settlement. This study used PLAXIS 2D to predict the ground settlement of an excavation case. As for the soil models, Hypoplasticity Clay (HC) Model is used for the clay layer and Hardening soil model is used for the sand layer.

The case history being used is Core Pacific City (CPC) Shopping Mall, Taipei, Taiwan. From the result of TNEC case (Ou & Hsieh, 2011), the determination of PIZ method fits well with the simulation result. However, for CPC case which is located 300 meters away from TNEC case, the method differs much from the simplified method. Based on the soil investigation result, the soil layer on CPC case is similar to TNEC case, which is Sungshan layer overlaying Chingmei gravel formation (Hwang et al., 2007), with some differences in the thickness of the layers.

1.2 Research Objective

The objective of this study is to create parametric studies of CPC deep excavation case using PLAXIS 2D. The parametric studies include three parameters: Excavation width (B), excavation depth (He), and friction angle (φ) of the gravel layer. Although deep excavation is also closely related to wall deformation, this study will focus on the surface settlement induced by the excavation. The surface settlement will be compared to its monitoring data as well as the simplified PIZ determination method. Based on the results, the factors that influence PIZ which leads to abnormal results can be concluded.

1.3 Report Structure

Following this chapter, the structure of this Report is as follows:

Chapter 2 provides background theories and references about the surface settlement induced by deep excavation. The theory Primary Influence Zone (PIZ) and Secondary Influence Zone (SIZ) will also be explained here.

Chapter 3 provides the introduction of CPC case including geological condition, soil investigation result, structural data, and monitoring data.

Chapter 4 provides the numerical simulation result of CPC case as well as all the parametric studies using PLAXIS 2D. The results of the numerical simulation are compared with the monitoring data and the simplified PIZ determination method.

Chapter 5 provides the discussion results of all the parametric study cases and how it influences the PIZ and SIZ. Finally, conclusion of this study will be stated.

CHAPTER 2
LITERATURE REVIEW

2.1 Surface Settlement Induced by Deep Excavation

Deep excavation induces wall deformation and surface settlement. As for surface settlement, Hsieh and Ou (1998) categorized ground surface settlement shapes/types into spandrel type and concave type, refer to figure 2.1. Spandrel type of surface settlement is related to cantilever type of wall deformation while concave type of surface settlement is related to deep inward type of wall deformation. In general, excavation in soft clay leads to a deep inward movement of wall deflection and concave type of ground settlement. On the other hand, excavation in sandy soil or stiff clay induced less deflection on the retaining wall and the spandrel type of ground settlement is more likely to happen.

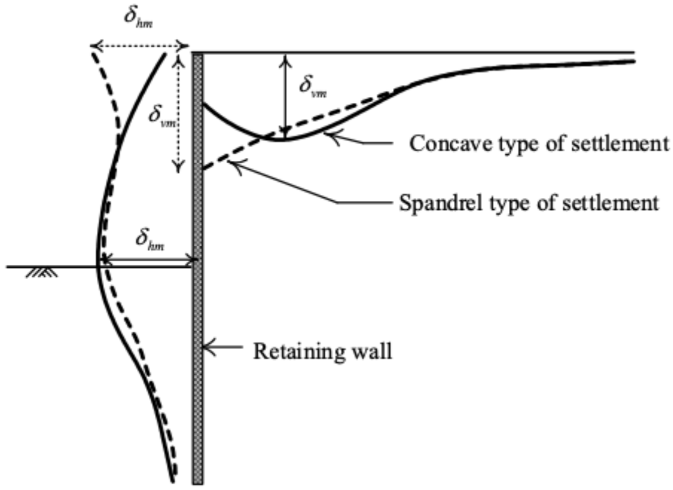

Figure 2.1 Concave and Spandrel Type of Settlement

Peck's method (1969) can estimate the surface settlement at various distances behind the retaining wall. Soil is classified into 3 types according to the characteristics. Type 1 is sandy and soft to stiff clayey soil. Type 2 is very soft to soft clayey soil either to a limited depth of clayey soil below the excavation bottom or to a significant depth of clayey soil below the excavation bottom but $N_b < N_{cb}$. Type 3 is very soft to soft clayey soil to a significant depth below the excavation bottom and $N_b \geq N_{cb}$. N_b is the stability number of soil and N_{cb} is the critical stability number against basal heave.

Clough and O’Rourke (1990) proposed different types of settlement envelope for different soils. Excavation in sandy or stiff clayey soil tends to produce triangular surface settlement and the maximum settlement is located near the retaining wall, refer to figure 2.2. Excavation in soft to medium clayey soil will produce a trapezoidal envelope of settlement, refer to figure 2.3.

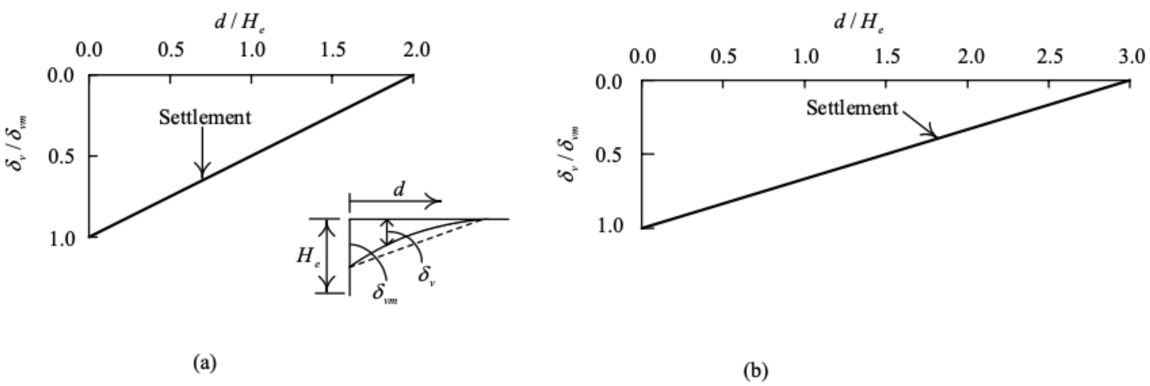

Figure 2.2 Clough and O’Rourke’s method of triangular surface settlement in (a) sand (b) stiff clayey soil

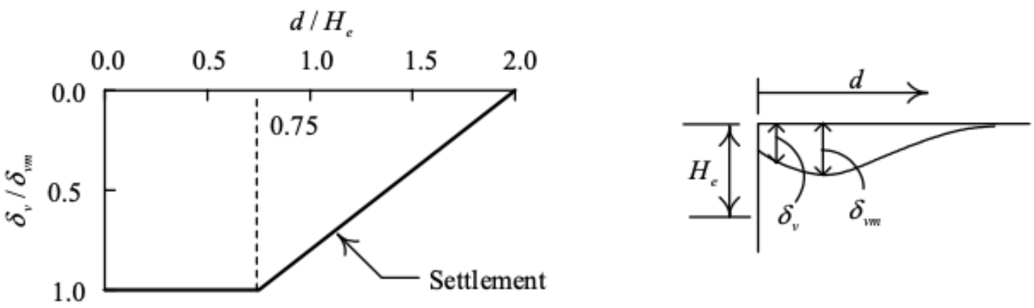

Figure 2.3 Clough and O’Rourke’s method of trapezoidal surface settlement soft to medium clayey soil

2.2 Basal Heave due to Deep Excavation

Base shear failure is defined as the condition when the shear stress generated in most of the soil below the excavation bottom reaches the shear strength. As a result, the soil will be subjected to a certain amount of displacement or heave which leads to the failure of entire excavation bottom. This phenomenon can occur both in sandy or clayey soil. This failure in clayey soil is called “basal heave” or “plastic heave”.

2.3 Primary Influence Zone (PIZ) and Secondary Influence Zone (SIZ)

Influence zone is defined as the distance behind the retaining wall where buildings nearby receive influence due to excavation process. Primary influence zone (PIZ) have steeper settlement curve which means high influence to nearby buildings. On the other hand, the curve for Secondary influence zone (SIZ) is gentler and the influence to nearby buildings is less. As excavation starts, settlement begin to occurs and as the excavation stage goes deeper, the PIZ will be more visible due to maximum settlement induced. The maximum settlement will increase as the excavation goes deeper, but the PIZ will not be enlarged.

Ou and Hsieh (2011) stated that PIZ is approximately equal to twice the excavation depth and the SIZ is approximately as large as the PIZ. In total, there are 4 factors affecting the PIZ: H_e, B, H_f, and H_g, where H_e is excavation depth, B is excavation width, H_f is depth of soft clay bottom, and H_g is depth of the rock-like soil.

Excavation in soft clay may induced basal heave and that potential basal heave failure surface can be assumed as the PIZ for wide excavations, in which $\sqrt{B^2 + {H_e}^2} > 2H_e$. Since basal heave occurs in soft clay rather than silt, sand, and stiff clay, H_f is also introduced to describe the limitation of the potential basal heave failure. If the soft clay has a limited thickness, the potential basal heave surface failure will be tangential to the bottom of the soft clay. This comes up to an equation $PIZ_1 = \min(H_f, B)$, a schematic representation is shown in figure 2.4.

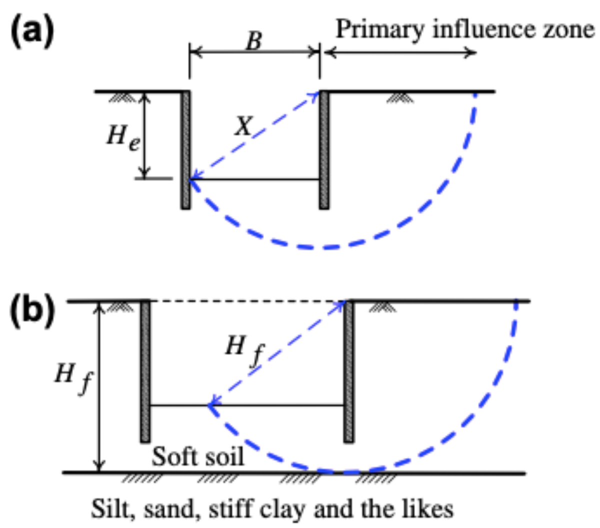

Figure 2.4 Schematic representation of possible PIZ_1 restricted to basal heave

Active failure may occur during the early stage of an excavation and not restricted to certain kind of clay or sand, unlike basal heave failure that only occurs on soft clay. For narrow excavation, in which $\sqrt{B^2 + {H_e}^2} \leq 2H_e$, if the soil profile is not restricted to a rock-like soil, the active failure zone is approximately equal to twice the excavation depth, which is stated earlier. If a rock-soil layer is shallow enough to strict the soil movement, the range of the active failure zone will be approximately the same as the depth pf the rock-like soil (H_g). The second equation is as stated as $PIZ_2 = \min(2H_e, H_g)$, a schematic representation is shown in figure 2.5. The PIZ is then defined as $PIZ = \max(PIZ_1, PIZ_2)$, a simple flowchart is shown in figure 2.6.

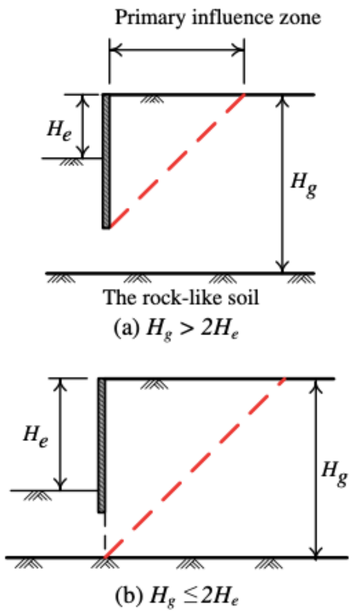

Figure 2.5 Schematic representation of possible PIZ_2 from the active failure zone

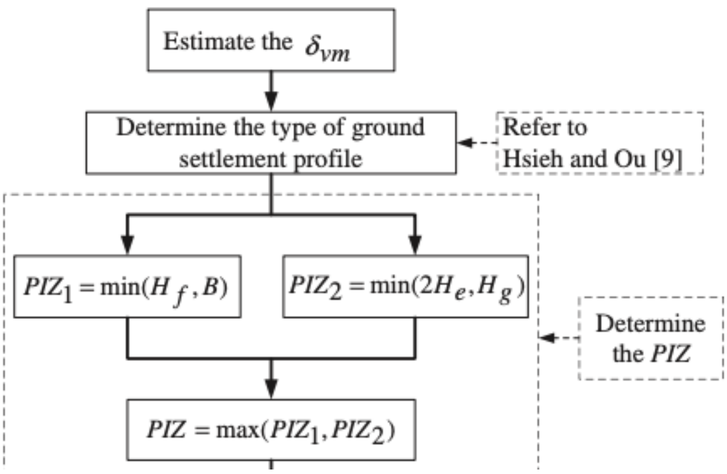

Figure 2.6 Flowchart of PIZ determination

CHAPTER 3
INTRODUCTION OF DEEP EXCAVATION CASE

3.1 The Excavation Case of Core Pacific City (CPC) Shopping Mall Construction

Core pacific City shopping mall was built in 1998 and established in 2001. It is a 12-storey building with 7-level basement. At that time, this building is considered as the largest mall in Southeast Asia in terms of floor area. The excavation depth is 31.68 m, which is also the deepest excavation at that time in Taiwan. The construction of the basement used top-down method with the deepest level of 31.68 m. 1500 mm diaphragm wall is used as the retaining wall system with 52 m depth. Figure 3.1 shows the CPC site plan.

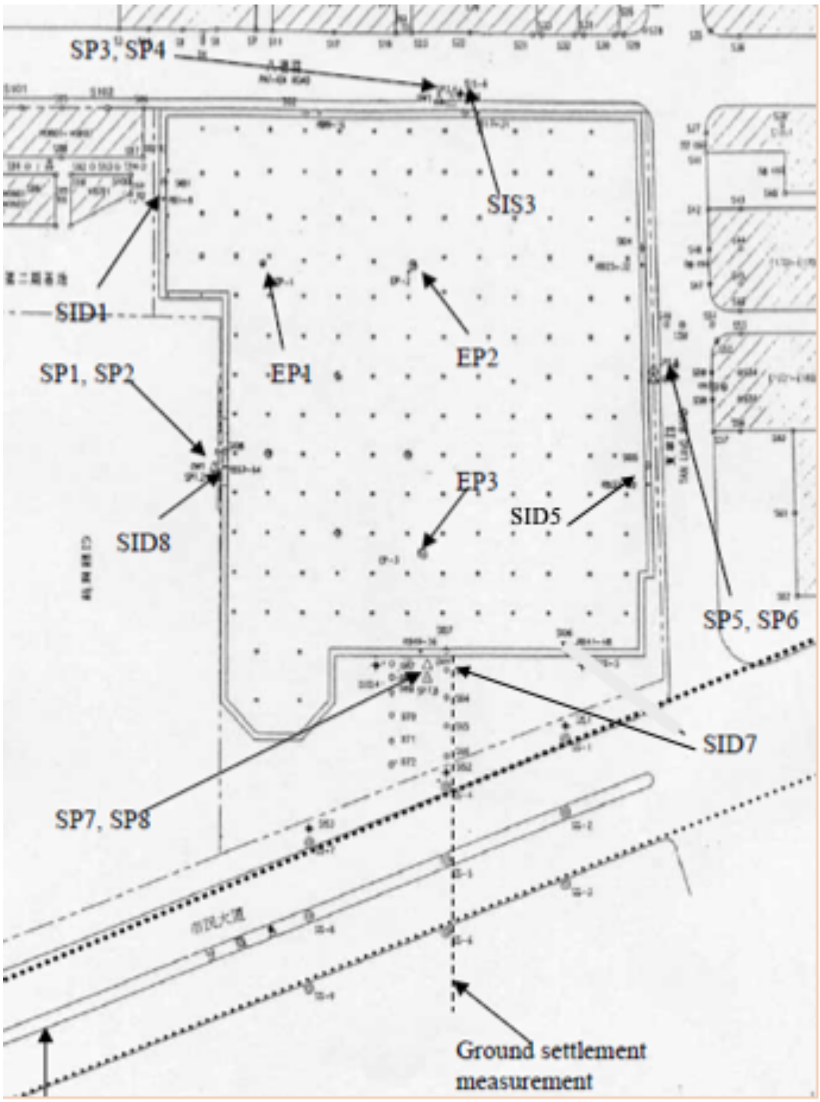

Figure 3.1 CPC Site Plan

3.2 Soil Condition of CPC

The location of CPC is not far from TNEC, approximately 300 m southwest away from TNEC. The soil profile of CPC is based on Sungshan layer formation and Chingmei gravels. Figure 3.2 shows a schematic representation of CPC soil profile with depth and the diaphragm wall. The toe of the diaphragm wall was installed in a layer that is hard enough to avoid toe movement of the wall.

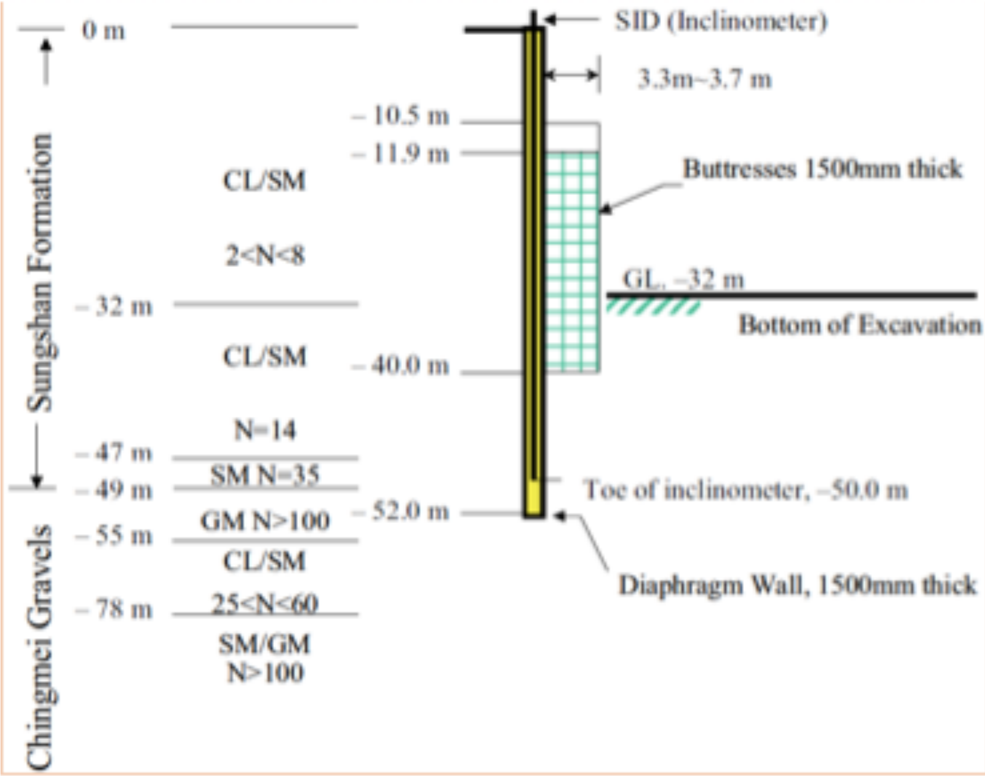

Fig 3.2 CPC Soil Profile with Depth and Diaphragm Wall

3.3 Excavation Support System

As mentioned before, CPC used top-down construction method. Floor slabs are constructed from the 1F until B7F with a total of 8 floor slabs. The floor slab thickness is not uniform and some adjustment is made due to data limitation. One adjustment is setting the floor slab thickness of 1F and B1F to 0.15 m which is the same as B2F floor slab. Steel struts were also used to support the excavation system. The detail of the floor slabs and struts formation are shown in figure 3.3. This construction is completed approximately 868 days and the sequence of the CPC site is shown in table 3.1.

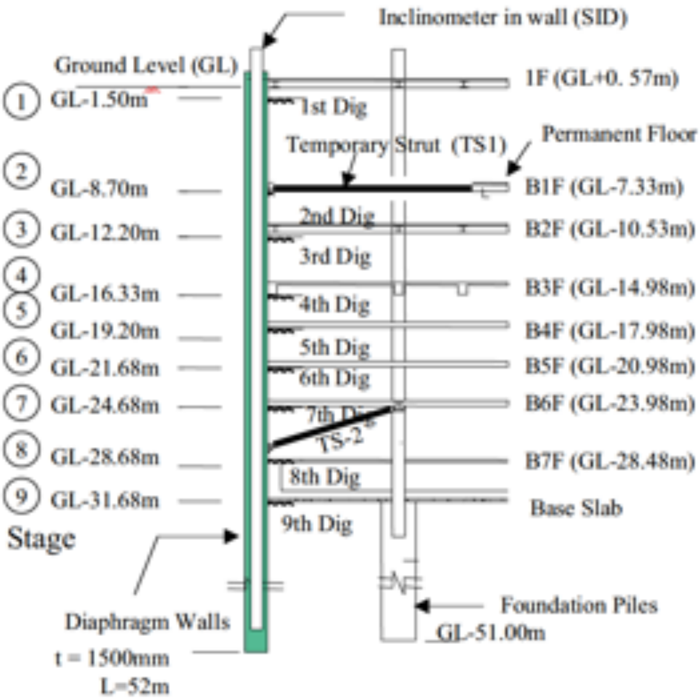

Figure 3.3 Floor Slabs and Struts Details

Construction Stage	Construction Operation	Construction Period		Day No
		From	To	
I	Construction of Diaphragm Wall	06/03/98	22/09/98	0- 165
II	Installation of piles and kingpost steel columns	23/07/98	15/01/99	104- 287
III	Installation of barrettes foundations beneath a spherical structure	31/07/98	13/02/99	112- 307
IV	Excavation to 0.88m bgl	03/03/99	15/03/99	325- 340
V	Casting of 1F slab	12/03/99	12/05/99	337- 398
VI	Excavation to 9.0m bgl	13/05/99	24/06/99	399- 441
VII	Casting of B1F slab	09/06/99	09/08/99	426- 487
VIII	Excavation to 12.3m bgl	01/08/99	21/08/99	479- 499
IX	Casting of B2F slab	13/08/99	01/10/99	491- 540
X	Excavation to 16.7m bgl	27/09/99	26/10/99	537- 566
XI	Casting of B3F slab	10/10/99	19/11/99	550- 589
XII	Excavation to 19.5m bgl	26/11/99	19/12/99	596- 619
XIII	Casting of B4F slab	03/12/99	09/01/00	603- 639
XIV	Excavation to 22.5m bgl	01/01/00	21/01/00	630- 651
XV	Casting of B5F slab	09/01/00	14/02/00	639- 674
XVI	Excavation to 25.5m bgl	14/02/00	10/03/00	647- 698
XVII	Casting of B6F slab	21/02/00	03/04/00	654- 695
XVIII	Excavation to 28.5m bgl	13/04/00	18/05/00	705- 740
IXX	Casting of B6 invert props	28/04/00	02/06/00	720- 755
XX	Excavation to 31.7m bgl	25/05/00	25/07/00	747- 808
XXI	Casting of B7F slab	23/06/00	31/10/00	776- 868

Table 3.1 Excavation Sequence of CPC

CHAPTER 4

NUMERICAL SIMULATION OF CPC CASE AND PARAMETRIC STUDY

4.1 Input for CPC Numerical Model

Site plan, soil profile, supporting system, and sequences are introduced in chapter 3. This simulation is created with PLAXIS 2D. For the clay layers, HC model in undrained A condition which are being used with the same source of TNEC oedometer test results from Teng (2011). For the sandy layers, Hardening Soil model is used in drained condition. Gravel layers are also using Hardening Soil Model. The 4 parameters affecting the PIZ used for the CPC case is shown in figure 4.1.

CPC		TNEC	
B:	120.0 m	B:	43.0 m
H_e:	31.7 m	H_e:	19.7 m
H_f:	77.5 m	H_f:	33.0 m
H_g:	77.5 m	H_g:	46 m

Figure 4.1 4 CPC and TNEC Parameters That Affects PIZ Determination

4.2 PLAXIS Model of CPC Case

The model uses cross section between SID-8 and SID-5 and simulated as 50 m with 100 m distance behind diaphragm wall, refer to figure 4.2 for SID mapping. The excavation is simulated until 82 m depth. There are 4417 soil elements and 35627 nodes used in this simulation. Figure 4.3 shows the CPC model in PLAXIS 2D. Soil profile input details are shown in figure 4.4.

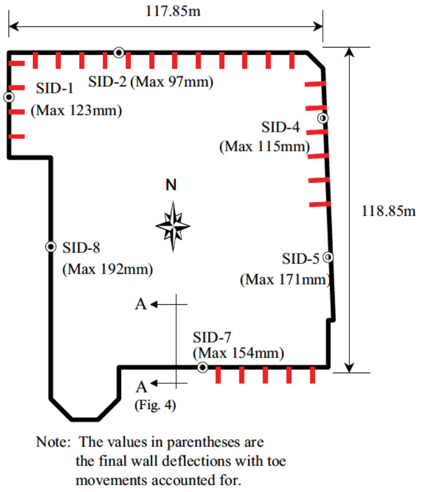

Figure 4.2 SID Mapping for PLAXIS Model

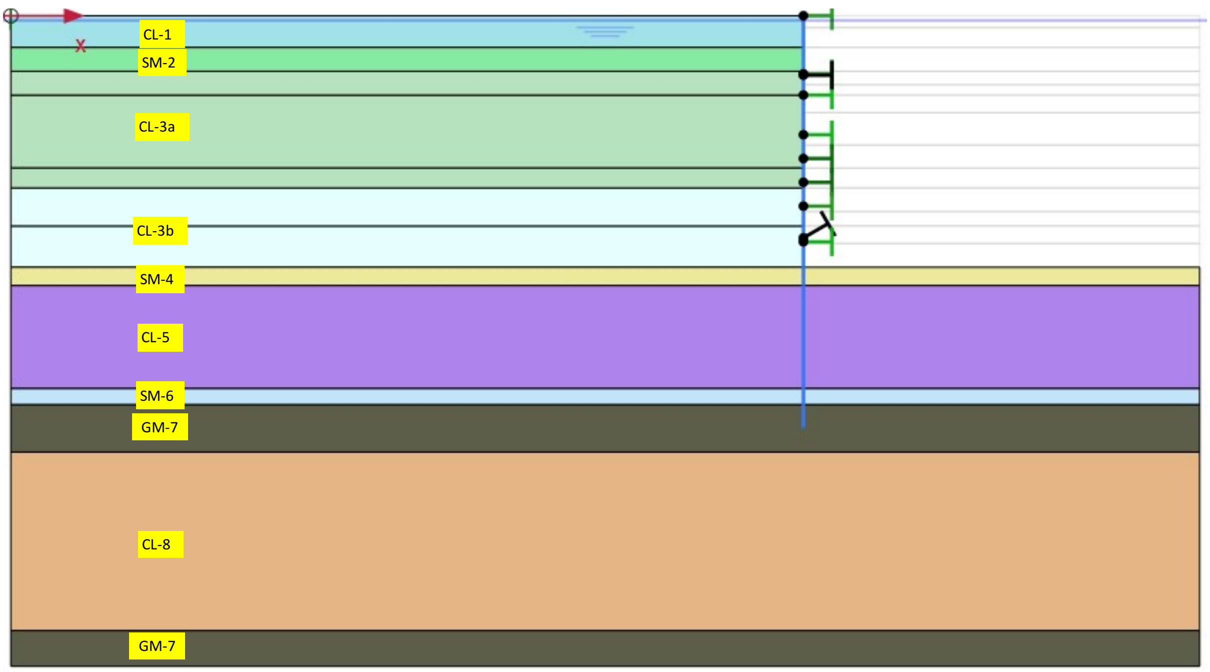

Figure 4.3 CPC Model in PLAXIS 2D

Parameter	Unit	Layer				Source
		SM-2	SM-4	SM-6	GM-7	
Depth	m	4-7	31.7-34	47-49	49-55	Hwang et al. (2007)
γ_{unsat}	kN/m³	19	19.3	20.3	21.9	
γ_{sat}	kN/m³	19	19.3	20.3	21.9	
e_{init}		0.74	0.69	0.67	0.63	TNEC parameter
N_{SPT}		8	23	26	>100	Hwang et al. (2007)
c'	kPa	1		5		
φ'	°	32	33	35	46	
E_{ur}^{ref}	kPa	47420	30130	67540	518700	TNEC parameter
E_{50}^{ref}	kPa	15810	10040	22510	172900	
E_{oed}^{ref}	kPa	15810	10040	22510	121000	
m		0.5				
$\gamma_{0.7}$		10^{-5}			[redacted]	
G_0^{ref}	kPa	46423	85093	92718		
k_x	m/day	0.52				
k_y	m/day	0.26				
K_0		0.47	0.455	0.43	0.28	Calculated using Jacky (1994)

Parameter	Unit	Layer					Source
		CL-1	CL-3		CL-5	CL-8	
Depth	m	0-4	7-21.7	21.7-31.7	34-47	55-77.5	Hwang et al. (2007)
γ_{unsat}	kN/m³	19	18.4	19	19.5	19	
γ_{sat}	kN/m³	19	18.4	19	19.5	19	
e_{init}		0.74	1.05		0.69	0.69	TNEC parameter
φ_c	°	31		32	36	38	Hwang et al. (2007)
p_r	kPa	20					Trial and error
λ^*		0.06			0.05		
κ^*		0.01			0.012	0.015	
N		1					TNEC parameter
ν_{pp}		0.1					
α_G		1					
R		1×10^{-4}					
βr		0.135					
χ		0.7					
G_{vh0}		437					
n_g		0.66					
m_{rat}		0.5					
e or OCR		14	11.3		11		
k_x	m/day	10^{-7}					
K_0		0.99	0.485	0.47	0.455		Calculated using Jacky (1994)

Figure 4.4 CPC Soil Parameter Input for Sandy Layers (Left) and Clayey Layers (Right)

For the excavation case sequence, all steps will be calculated in "consolidation" calculation type. Dewatering is impossible because the excavation is done in clayey layer, therefore the excavated soil cluster will be set to "set cluster dry". Ground water level of CPC case is located on GL -0.6 m. To match the water pressure diagram to the monitoring data, "set cluster to interpolate water pressure" setting is set because there was a water pressure dropdown in GL -10.0 m until GL -33.0 m (CL-3 Layer). Layers below GL -33.0 are all set to use water level at GL -13.0 m. The water pressure setting of CPC case in PLAXIS model is shown in figure 4.5. The details of the construction sequences are summarized in table 4.1.

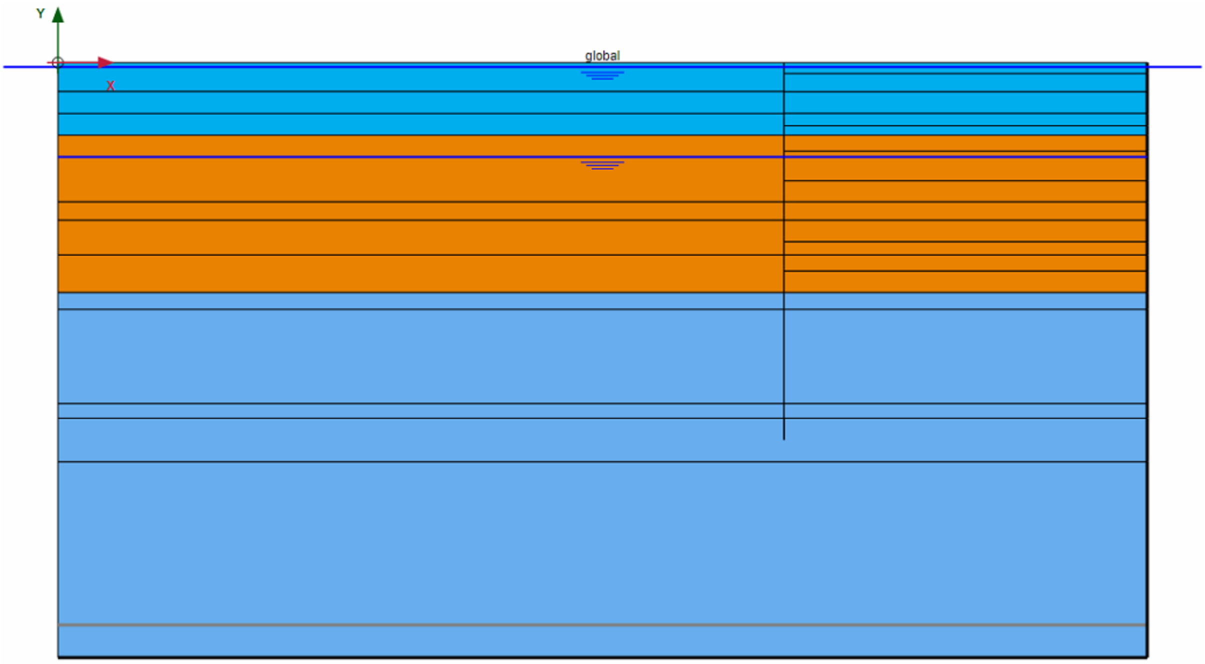

Figure 4.5 CPC Water Pressure Setting in PLAXIS 2D

Stage No.	Days	Activity
1	0-325	Diaphragm wall is activated
2	325-340	1^{st} stage of excavation (GL -1.5 m) Set cluster dry until GL -1.5 m
3	340-398	1F floor slab is activated (GL ±0.0)
4	398-441	2^{nd} stage of excavation (GL -8.7 m) Set cluster dry until GL -8.7 m Top strut is activated (GL -7.4 m)
5	441-487	B1F (GL -7.3 m) floor slabs are activated
6	487-499	3^{rd} stage of excavation (GL -12.2 m) Set cluster dry until GL -12.2 m

7	499-540	B2F (GL -10.5 m) floor slab is activated
8	540-566	4th stage of excavation (GL -16.3 m) Set cluster dry until GL -16.3 m
9	566-589	B3F (GL -15.0 m) floor slab is activated
10	589-619	5th stage of excavation (GL -19.2 m) Set cluster dry until GL -19.2 m
11	619-639	B4F (GL -18.0 m) floor slab is activated
12	639-651	6th stage of excavation (GL -21.7 m) Set cluster dry until GL -21.7 m Dewatering of layer SM-6 and GM-7 until water level GL -30.0 m
13	651-674	B5F (GL -21.0 m) floor slab is activated
14	674-698	7th stage of excavation (GL -24.7 m) Set cluster dry until GL -24.7 m B6F (GL -24.0 m) floor slab is activated
15	698-740	8th stage of excavation (GL -28.7 m) Set cluster dry until GL -28.7 m
16	740-755	Bottom strut is activated (GL -28.0 m)
17	755-808	9th stage of excavation (GL -31.7 m) Set cluster dry until GL -31.7 m
18	808-868	B7F (GL -28.5 m) floor slab is activated

Table 4.1 Construction Sequences of CPC case in PLAXIS 2D

From the simulation results, we can obtain the surface settlement along 100 m behind the wall. With the simplified PIZ determination method, the PIZ can be determined (Refer to figure 4.6) and calculations as well as graphing are done to create the d/PIZ-δ_v/δ_{vm} graph. The graph is then compared with the simplified method graph as in figure 4.7. Judging from the comparison, the maximum surface settlement of the final stage can be simulated well with the model, proved by the value of d/PIZ when $\delta_v/\delta_{vm} = 1$ is similar with the simplified method. However, the curve deviates after reaching the maximum settlement, which results to a wider curve compared with the simplified method. Therefore, parametric studies are made to identify the cause.

PIZ Simplified Determination Method for CPC Case:

$PIZ_1 = \min(H_f, B) = \min(77.5, 60) = 60$

$PIZ_2 = \min(2H_e, H_g) = \min(63.4, 77.5) = 63.4$

$PIZ = \max(PIZ_1, PIZ_2) = \max(60, 63.4) = 63.4$ m

Figure 4.6 PIZ Determination for CPC Case

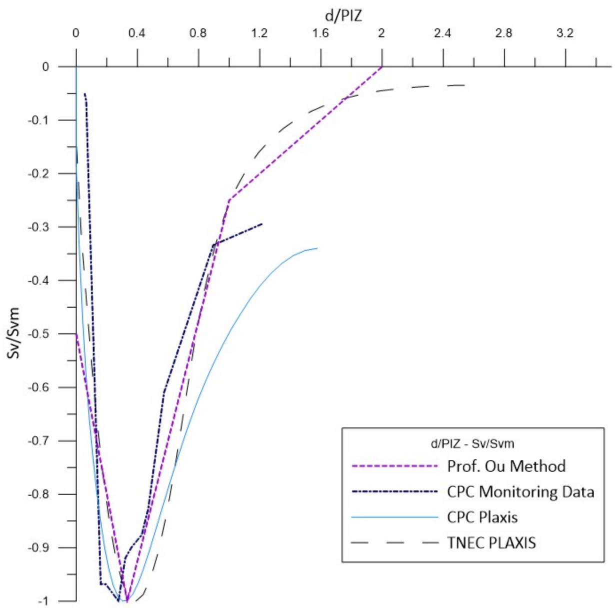

Figure 4.7 d/PIZ-δ_v/δ_{vm} graph of CPC case and Simplified PIZ Determination Method

4.3 Parametric Study

The simplified PIZ determination method involves a total of 4 parameters: H_f, H_g, B, and H_e. For the parametric studies, 3 parameters are modified: B, $\boldsymbol{\varphi}$' of gravel layer, and H_e. CPC case has an excavation width (B) of 100 m simulated and the B value will be modified into 3 values: 60, 120, and 200 m. The friction angle ($\boldsymbol{\varphi}$') of gravel layer in the original case is 46° and it will be modified into 3 values: 45°, 50°, and 55°. The original value of excavation depth (H_e) is 31.7 m and it will be modified into 3 values: 20, 25, and 30 m.

The first set of simulations is varying B value. The PLAXIS model is the same but modify the B value to 60, 120, and 200 m respectively. The result of the surface settlement graph is normalized to d/PIZ- δ_v/δ_{vm} graph. The result is shown in figure 4.8.

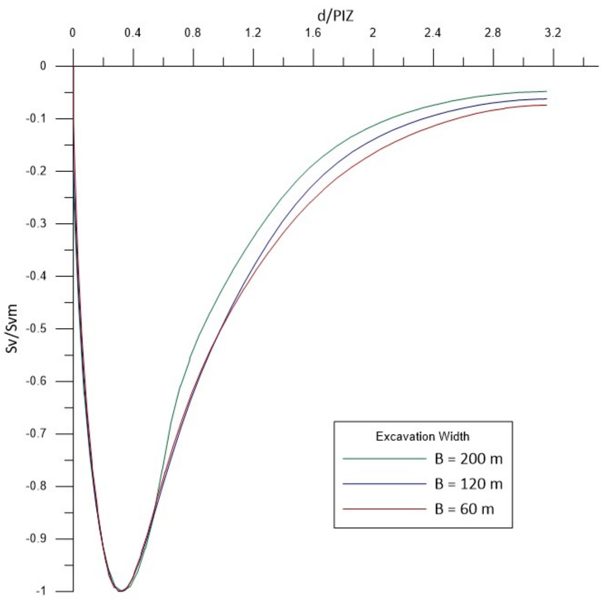

Figure 4.8 d/PIZ-δ_v/δ_{vm} graph of CPC case Varying B Value

The second set of simulations is varying ***φ***' of gravel layer. The PLAXIS model is the same but modify the ***φ***' of gravel layer value to 45,50, and 55 m respectively. The result of the surface settlement graph is normalized to d/PIZ- δ_v/δ_{vm} graph. The result is shown in figure 4.9.

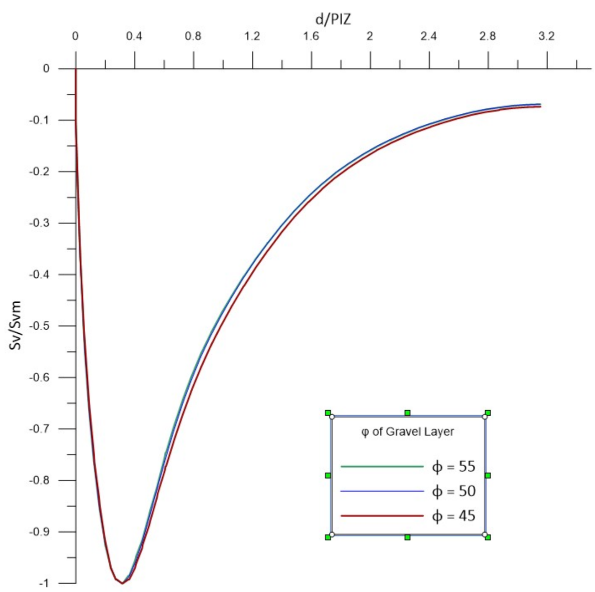

Figure 4.9 d/PIZ-δ_v/δ_{vm} graph of CPC case Varying ***φ***' Value of Gravel Layer

The third set of simulations is varying H_e value. The PLAXIS model is the same but modify the H_e value to 20, 25, and 30 m respectively. Due to changes in excavation depth, the diaphragm wall is also adjusted to a ratio of H_e : D_{wall} Depth = 1: 1.64 as shown in table 4.2.

The result of the surface settlement graph is normalized to d/PIZ- δ_v/δ_{vm} graph. The result is shown in figure 4.10.

Excavation Depth	**Diaphragm Wall Depth**
He = 20 m	32.808 m
He = 25 m	41.009 m
He = 30 m	49.211 m

Table 4.2 Diaphragm Wall Adjustment for PLAXIS Model

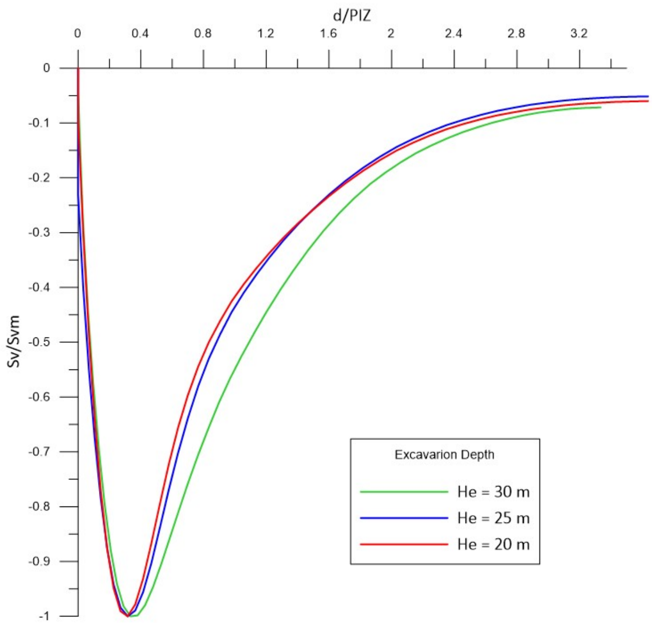

Figure 4.10 d/PIZ-δ_v/δ_{vm} graph of CPC case Varying H_e Value

The value of PIZ of all the cases are calculated and summarized in table 4.3. The second parameter which is the friction angle of the gravel layer is not included because it doesn't affect the PIZ result since the affecting parameters are H_f, H_g, B, and H_e. To conclude the result of all the simulations, we take the data at d/PIZ = 1 in terms of its normalized surface settlement and the 4 parameters: H_f, H_g, B, and H_e. The summarized table is shown at table 4.4.

Parameters	PIZ
Width B = 60 m	63.4 m
Width B = 120 m	63.4 m
Width B = 200 m	63.4 m
Depth He = 20 m	55 m
Depth He = 25 m	55 m
Depth He = 30 m	60 m

Table 4.3 PIZ Results of All Cases

	d/PIZ	Sv/Svm	B/He	Hf/He	Hg/He	B/Hf	B/Hg	Hf/Hg
B = 60m		0.492	1.893			1.091	0.774	
B = 120m		0.490	3.785	1.735	2.445	2.182	1.548	
B = 200m	1	0.421	6.309			3.636	2.581	0.710
He = 20m		0.417	3.000	2.750	3.875			
He = 25m		0.439	2.400	2.200	3.100	2.182	1.548	
He = 30m		0.549	2.000	1.833	2.583			
CPC	1	0.446	3.785	1.735	2.461	2.182	1.538	0.705
TNEC	1	0.258	2.183	1.675	2.335	1.303	0.935	0.717

B (m)	Gravel friction angle	d/PIZ	Sv/Svm	B/He	Hf/He	Hg/He	B/Hf	B/Hg	Hf/Hg
	45		0.492						
60	50		0.473	1.893			1.091	0.774	
	55		0.470						
	45		0.490						
120	50	1	0.483	3.785	1.735	2.445	2.182	1.548	0.710
	55		0.476						
	45		0.421						
200	50		0.416	6.309			3.636	2.581	
	55		0.412						

Table 4.4 Comparison of All Cases in Terms of the 4 Affecting Parameters

Based on the three set of simulations done, the affecting behavior is not identified yet. Therefore, an additional set of simulations is created to determine the possible factor of the deviated CPC d/PIZ- δ_v/δ_{vm} graph. In this simulation, we try to use TNEC parameter of B and H_e values on CPC case model. If the normalized d/PIZ curve is similar to the simplified method, this means the simplified PIZ determination method is limited to a certain He and B value. If the normalized d/PIZ curve still differs, the soil profile of the CPC case affects the curve. B value will be changed to 43.0 m and H_e value will be changed to 19.7 m. The soil profile and water pressure diagram remain changed. The result of the surface settlement graph is normalized to d/PIZ- δ_v/δ_{vm} graph and compared as shown in figure 4.11.

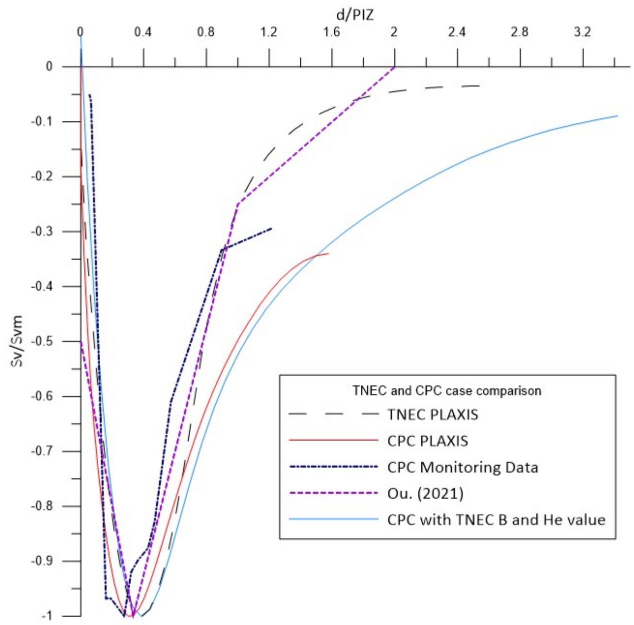

Figure 4.11 d/PIZ-δ_v/δ_{vm} graph of CPC case using TNEC case B and H_e Values

CHAPTER 5
DISCUSSION AND CONCLUSION

5.1. Discussion

Based on the first three set of parametric studies shown in chapter 4, some result from the graph can be pointed out. Referring to figure 4.8, from different value of B, deeper excavation leads to a narrower d/PIZ-δ_v/δ_{vm} curve, but all the three curves still differ from the simplified PIZ determination. Based on the second three set of parametric studies, figure 4.9 shows a similar behavior with different value of $\boldsymbol{\varphi}$' of the gravel layer. This can be concluded that friction angle of gravel layer doesn't have significant contribution to PIZ. The third set of the parametric studies shows different H_e values as in figure 4.10. A deeper excavation leads to a more deviated curve.

Table 4.4 shows the value of δ_v/δ_{vm} when d/PIZ = 1. Based on the simplified PIZ determination method, $\delta_v/\delta_{vm} = 0.25$ when d/PIZ = 1. The table shows the value of δ_v/δ_{vm} of the original CPC case and all parametric study cases ranges from 0.4 to 0.5 which is almost twice of the simplified method. To figure out the possible affecting parameters, 2 out of the 4 CPC parameters (H_f, H_g, B, and H_e) are normalized and compared with the TNEC case which is the base study of the simplified method. Comparing the parametric study cases, the summary of the ratios behavior is shown in figure 5.1. However, comparing both CPC and TNEC case, the ratios show a difference whenever B value involves. An additional simulation is then created. We try to modify the B and H_e value of CPC model to TNEC model. If the result of the d/PIZ-δ_v/δ_{vm} curve is similar to the simplified method, it can be concluded that the simplified method is valid to a certain value of B and H_e. If the curve still deviates from the simplified method, the soil property is the one affecting the deviation of the curve. A simple flowchart is provided in figure 5.2.

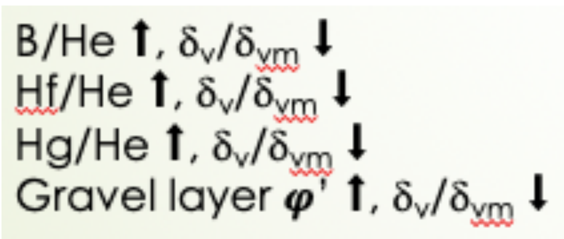

Figure 5.1 Summary of the ratios behavior when d/PIZ = 1

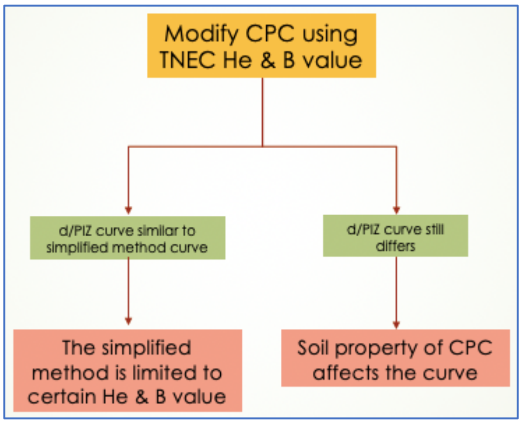

Figure 5.1 Flowchart of the additional simulation

The result of the additional simulation is similar to the original CPC case as in figure 4.11. Although CPC case has deeper and wider excavation compared with TNEC case, this simulation points out that the soil property of CPC case affects the deviation of the curve. CPC soil profile in figure 4.3 shows a thick layer of clay. Thicker layer of clay is most likely to leads to larger surface settlement. From the result, the secondary influence zone (SIZ) is plotted to be larger than the simplified method. In the simplified method, the distance of SIZ is roughly the same as PIZ. However, for this CPC case, the SIZ is enlarged up to 3 times of PIZ. As for the maximum surface settlement, the simplified method can still predict the CPC case well which means that the position of the maximum settlement is not primarily affected by the soil profile.

5.2. Conclusion

Based on this study, some points can be concluded:

1. From the parametric studies, deeper excavation (H_e) and narrower excavation (B) results to a more deviated d/PIZ-δ_v/δ_{vm} curve, while varying $\boldsymbol{\varphi}$' value of gravel layer doesn't have significant impact to the PIZ.

2. The maximum position of surface settlement behind the retaining wall can be predicted well with the simplified method regarding any kind of soil profile.

3. The distance of SIZ is effected by the thickness of the clay layer of the site, in which thicker layer induces larger settlement and affects the distance of SIZ up to 3 times of PIZ.

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