DeepEX 2D and 3D FEM Verification Part 3

Taipei Nation Enterprise Center excavation (Lim et al 2010)

The top-down constructed excavation of the Taipei Nation Enterprise Center (TNEC) is simulated with DeepEX 2D and 3D FEM and the predicted results from the numerical models are compared with the actual measured wall displacement and the numerical model results. The TNEC structure is an 18-story building and has five basement levels while the site occupies an area of about 3,500 m2. The depth of the excavation was 19.7 m, with dimension of diaphragm wall was 90 cm thick and 35 m deep. The groundwater level was at a depth of 2.0 m below the ground surface. The plan view of the overall excavation is illustrated in Figure 1a and the top-down construction sequence is illustrated in Figure 1b.

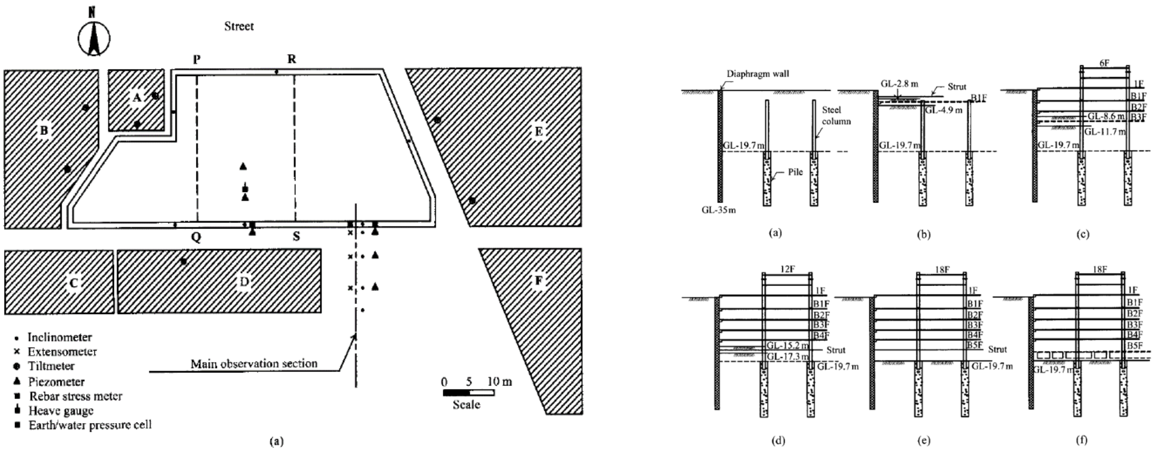

Figure 1: TNEC top-down excavation as presented in [Ou et al 2000]

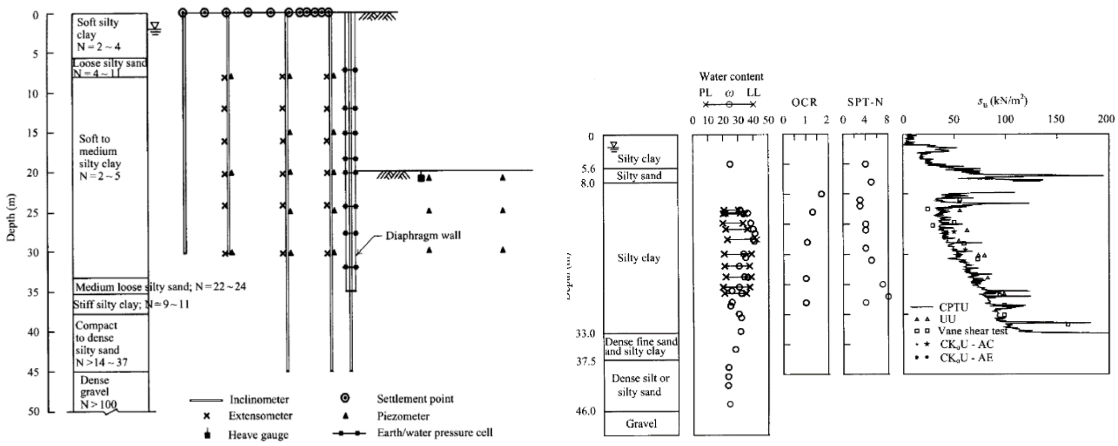

Figure 2: TNEC top-down excavation – soil properties as presented in [Ou et al 2000]

According to the site investigation findings illustrated in Figure 2, stratigraphic condition at the site can be described as follows:

The first layer is soft silty clay, which ranges from ground surface level 0.0m to−5.6 m and whose N-value is around 2 ~ 4. The second layer, from -5.6 m to −8.0 m, loose silty fine sand with N-values between 4 ~ 11 and ϕ' = 28°. The third layer, from −8.0 m to −33.0m, is again soft silty clay whose N-value is around 2 ~ 5 and the PI is within the range of 9 ~ 23, with an average value of 17. This layer is the one which most affects excavation behaviour. The fourth layer, ranging from −33.0 m to −35.0 m, is medium dense silty fine sand with N-value between 22 and 24 and ϕ' = 32°. The fifth layer is medium soft clay, ranges from −35.0 m to −37.5 m, N-value between 9 ~ 11. The sixth layer is medium dense to dense silt or silty fine sand; ranges from −37.5 m to −46.0m, N = 14~ 37 and ϕ' = 32°. Below the sixth layer is dense Chingmei gravel soil and N is above 100.

For the construction stage sequence an exhaustive list of the construction stages according to Ou et al 200 is presented in Figure 3:

Table 3.3 Excavation process of TNEC

Stage	*Day*	*Excavation activities*
	−29 ~	Installed devices outside of the excavation zone, including in-soil inclinometers, extensometers, observation wells, and electronic piezometers
	1–89	Constructed the diaphragm wall, including installation of the earth/water pressure cells, in-wall rebar strain meters, and in-wall inclinometers
	89–147	Constructed piles and the steel columns
	147–155	Installed devices inside of the excavation zone, including the piezometers and heave gauges
1	156–162	Excavated to the depth of GL-2.80 m
2	164–169	Installed struts H 300 × 300 × 10 × 15 at the depth of GL-2.0 m. The preload of each strut = 784.8 kN
3	181–188	Excavated to the depth of GL-4.9 m
4A	217	Constructed B1F floor slab at the depth of GL-3.5 m
4B	222–238	Dismantled the first level of strut and constructed the 1F floor slab. Started the construction of the superstructure
5	233–255	Excavated to the depth of GL-8.6 m
6	279	Constructed the B2F floor slab at the depth of GL-7.1 m
7	318–337	Excavated to the depth of GL-11.8 m
8	352	Constructed the B3F floor slab at the depth of GL-10.3 m
9	363–378	Excavated to the depth of GL-15.2 m
10	400	Constructed the B4F floor slab at the depth of GL-13.7 m
11A	419–423	Excavated the central zone to the depth of GL-17.3 m
12A	425–429	Installed struts H 400 × 400 × 13 × 21 at the depth of GL-16.5 m in the central zone. The preload of each strut = 1177 kN
11B	430–436	Excavated the side zones to the depth of GL-17.3 m
12B	437–444	Installed struts H 400 × 400 × 13 × 21 in the two side zones at the depth of GL-16.5 m. The preload of each strut = 1177 kN
13	445–460	Excavated to the depth of GL-19.7 m
	457	Finished the superstructure
14	464–468	Cast the foundation slab
15	506–520	Constructed the B5F floor slab at the depth of GL-17.1 m
16	528	Dismantled the second level of struts

Figure 3: TNEC top-down excavation as presented in [Ou et al 2000]

2D Finite Element model in Deepex

A 2D finite element model was constructed with DeepEX FEM and the wall displacement results were compared with both the measured data and the previously published numerical simulation of the TNEC excavation with Plaxis 2D (Lim et al 2010). In the Lim et al paper, multiple constitutive laws are utilized on the simulation of the undrained cohesive layers of the excavation (MMC, small strain SH, SH etc) while cohesionless soils are all modelled with the Mohr coulomb constitutive law. In the current comparison the soil hardening constitutive law is selected as the most adequate among the different implementations. The soil material properties used in both the DeepEX 2D and DeepEX 3D models are illustrated in table 3-I.

Table 3-I

Name	Constitutive Model	OCR	C (Kpa)	ϕ	E50 (Kpa)	Eoed (Kpa)	V	m	Pref (Kpa)	Eur/ E50
L1 Soft clay	Soil hardening	4	1	30	4574	4574	0.2	1	100	3
L2 - silty sand	Mohr Coulomb	1	0.1	30	68351	-	0.3	-	-	-
L3a silty clay	Soil hardening	1.8	1	29	9375	9375	0.2	1	100	3
L3b silty clay	Soil hardening	1.5	1	29	9375	9375	0.2	1	100	3
L3c silty clay	Soil hardening	1.2	1	29	15300	15300	0.2	1	100	3
L4 - dense sand	Mohr Coulomb	1	0.1	33	265000	-	0.3	-	-	-
L5- dense silt	Mohr Coulomb	1	0.1	35	300247	-	0.3	-	-	-
L6 - gravel	Mohr Coulomb	1	0.1	40.7	200000	-	0.35	-	-	-

The exact support stiffness properties, wall diaphragm properties, water table location etc can be found in (Lim et al 2010) and (Ou et al 2000). The final stage of the 2D finite element model in DeepEX is illustrated in Figure 4.

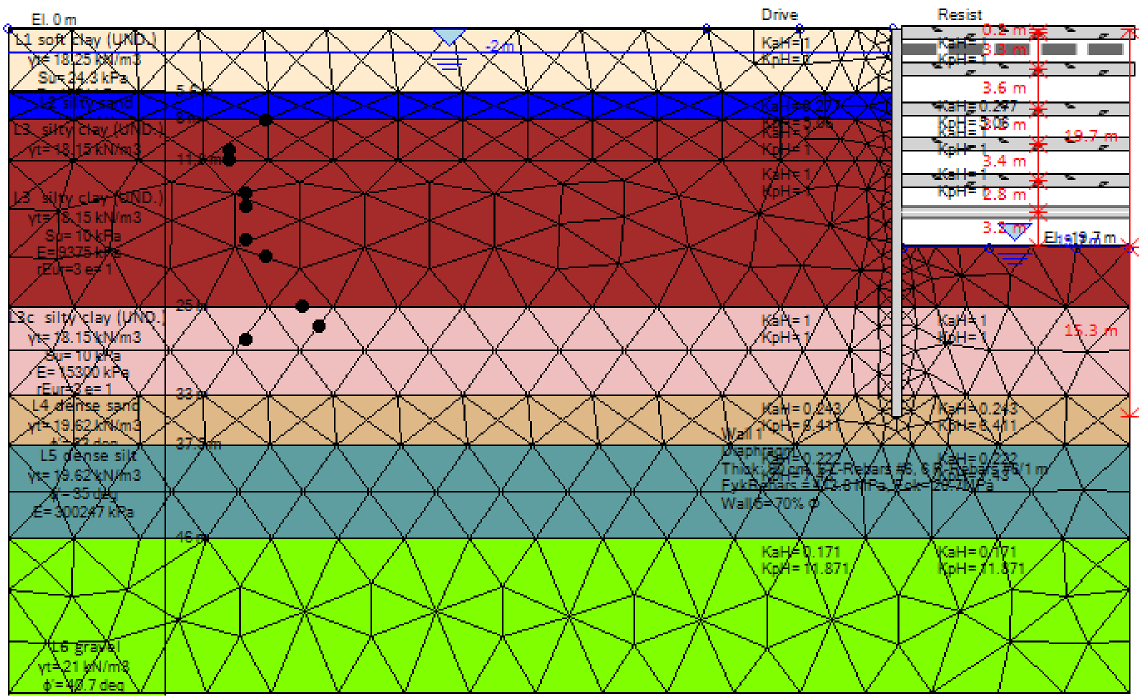

Figure 4: 2D model constructed in DeepEX – final construction stage

The lateral displacement results of the diaphragm wall for each excavation stage, starting from stage 3 and up to stage 7, are illustrated in Figure 5 for the DeepEX 2D model, the Plaxis 2D results presented in [Lim et al 2010] and the actual measured displacement of the walls published in [Ou et al 2000]. The same wall displacements isolated for each individual stage are illustrated in Figure 6.

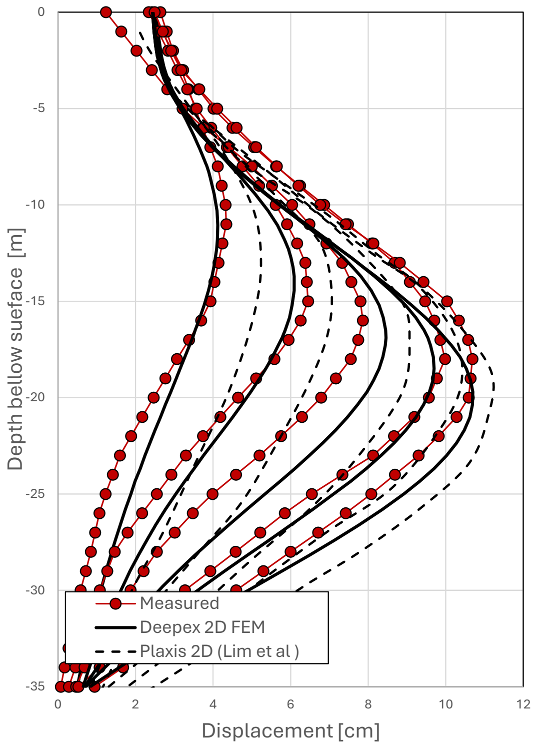

Figure 5: 2D model constructed in DeepEX – all monitored excavation stages

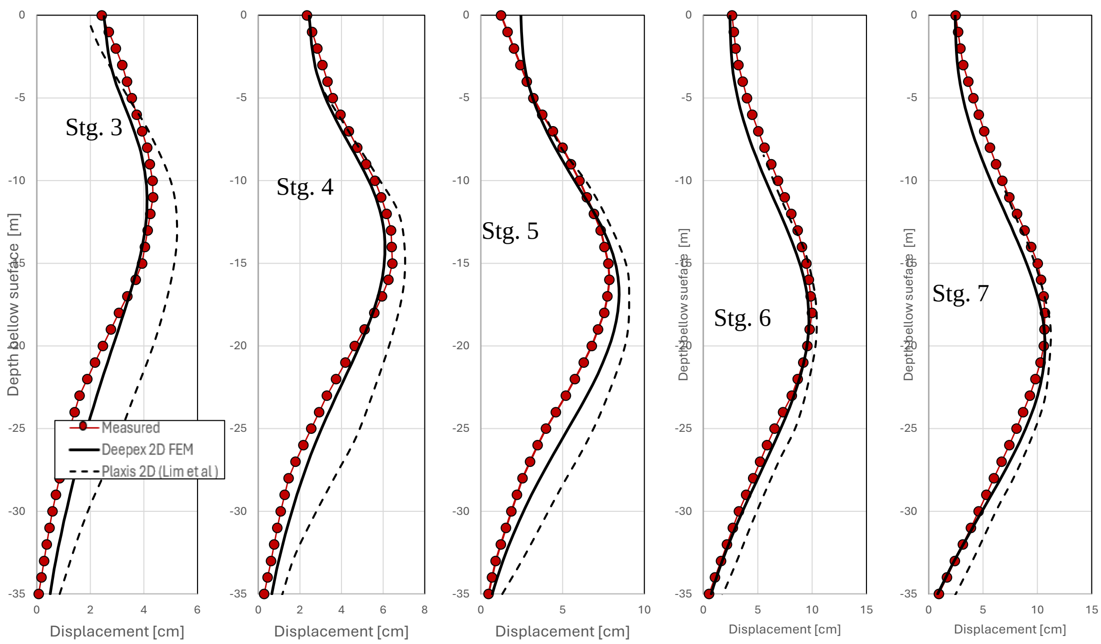

Figure 6: 2D model constructed in DeepEX – individual comparison of each construction stage

3D Finite Element model in DeepEX

As the final step in this evaluation process of DeepEX, a 3D finite element model (FEM) has been developed to simulate the TNEC excavation. While plane strain conditions are a legit assumption given the elongated shape of the excavation and the continuous nature of the slab supports at each excavation step, a 3D model was constructed regardless of the above, for reasons of completion. The constructed 3D FEM model is illustrated in Figure 7.

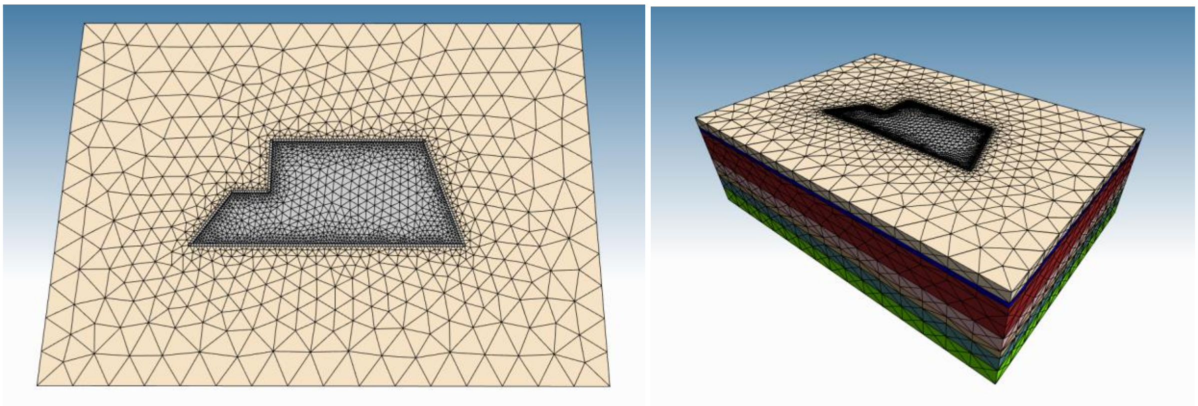

Figure 7: 3D model constructed in DeepEX – final construction stage

The lateral displacement results of the diaphragm wall for each excavation stage, starting from stage 3 and up to stage 7, are illustrated in Figure 8.

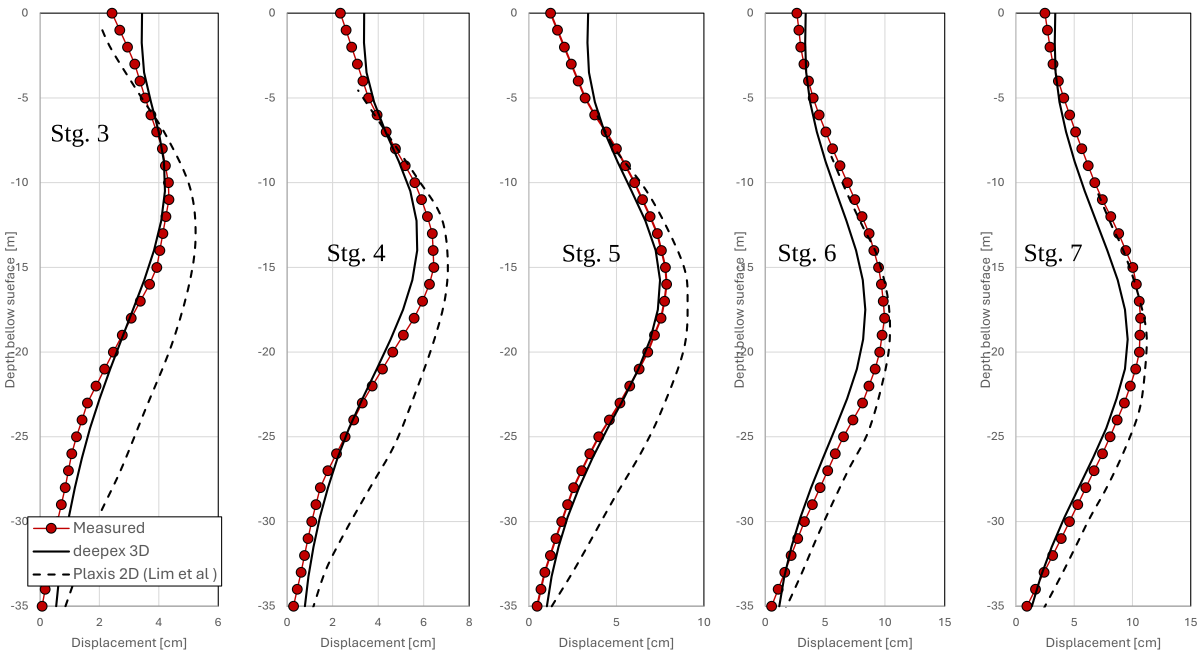

Figure 8: 3D model constructed in Deepex – individual comparison of each construction stage