

# NOTES ON HIGH HORIZONTAL STRESS GENERATION AND POST PROCESSING FOR DEEP EXCAVATION SHORING WALL USING PROGRAM PLAXIS 2D

Bo Xu and Qijing Yang  
*Arcadis Pacific Australia Pty Ltd*

<https://doi.org/10.56295/AGJ6125>

## ABSTRACT

With recent advancement of computer technology and software engineering, numerical modelling is becoming an essential tool to carry out a soil structure interaction analysis of a shoring system for deep excavation. This technical note has been prepared to provide specific approaches for a shoring system design of a deep excavation in Sydney using commercially available software Plaxis. The first part of this note covers a method of generating high in-situ horizontal stresses in Plaxis model, which are usually presented in Sydney Sandstone and Shale formation. The second part presents a useful tool for post-processing of analysis results from Plaxis 2D for soil structure interaction analysis of shoring walls for deep excavation.

## 1 INTRODUCTION

Numerical modelling using commercially available software Plaxis has been widely used in geotechnical engineer, including the Sydney Sandstone and Shale where high locked-in in-situ horizontal stresses are often present. The default option in Plaxis 2D for high in-situ stress within rock is to apply a homogenous initial stress state in the model with the filed stress option. Where there is a case with horizontal stresses increase with depth it would require the user to physically define the input for each element with depth. This is often found inconvenient, hence there is a need to develop a methodology for auto-generation of the high in-situ horizontal stresses for Plaxis modelling.

During the detailed design of M4 East project (WestConnex Stage 1B) in Sydney and construction process in 2015, the authors developed an approach to generating the in-situ high horizontal stresses in rock using an applied volume strain when program Plaxis 2D and Plaxis 3D are used. Since successful application of this approach, it has subsequently been widely adopted by many practicing geotechnical engineers for Plaxis modelling over the past 10 years, notably Sydney Metro Northwest and Sydney Metro City, Sydney West Metro, Western Sydney Airport Metro, New M5 Motorway, M4-M5 Link and Rozelle Interchange in Sydney and Melbourne Metro in Melbourne. The first part of this note will set out the details of how this methodology can be used for ease of reference.

It is very important to have efficient communications between geotechnical and structural engineers for shoring wall design of a deep excavation. The role of geotechnical engineers is often to carry our soil and structure interaction analysis and then pass the analysis results to structural engineers to carry out the structural design such as reinforced concrete structure or steel members such as steel props and waler beams.

Preparation of the analysis results for the shoring walls sounds simple but could be a very time-consuming process, especially nowadays the construction sequences or stages are becoming increasingly complex under urban development environment. When many construction stages (for example, more than 30 analysis stages) are modelled in the numerical analysis, the load path transfer will become very complex and therefore the critical stages where the design can be focused on will become less obvious. This situation always present technical challenges to the geotechnical engineers who are responsible for providing analysis results such as bending moment, shear force, axial force and deflection within the retaining wall structures which are modelled by the plate elements in Plaxis.

The second part of this note introduces the geotechnical automation works we are currently undertaking within Arcadis to streamline the interaction process between geotechnical and structural engineers for cut and cover structure design. This process is currently being used for multiple infrastructure the projects across Australia and has been proved useful. This note is to share the approach and written scripts with the geotechnical colleagues who may wish to use for their future projects.

## 2 MODELLING METHODOLOGY AND PROCEDURES

The high in-situ stresses have been well recognised from the construction of tunnels and caverns in Sydney Region, with some of the published works by Enever (1990), Pells (1990) and McQueen (2004). The high in-situ horizontal stresses have often caused the shear movements along the bedding planes, joints or sheared zones, which, in turn, result in damages

to the installed support system such as rock bolts or shotcrete in tunnels and deep excavations. Therefore, it is essential to simulate this high horizontal stress properly when a numerical modelling is undertaken.

In the Sydney region, the rock classification system (Class I to Class V) proposed by Pells et al. (1998) is commonly adopted for Hawkesbury Sandstone and Ashfield Shale, based on rock strength, defect spacing, and the presence of allowable seams.

Typical in-situ horizontal stresses in Sydney Sandstone Class I/II are commonly recommended to be as follows:

$$\sigma_h = (1.5 \sim 2.5) + 2\sigma_v \text{ (MPa)} \quad (1)$$

where  $\sigma_h$  is the horizontal stress while  $\sigma_v$  is the vertical stress. Equation (1) shows that the recommended in-situ horizontal stresses within Class I/II rocks consists of two parts: (1) constant component of 1.5 ~2.5 MPa within the rock and (2) linearly increased component of with depth,  $2\sigma_v$ , which is related to the vertical stresses within the rock mass.

It should be pointed out that gravity loading method in PLAXIS 2D cannot generate in-situ stress with  $k_0$  greater than 1 because the value of  $k_0$  is directly related to the Poisson's ratio,  $\nu$ , by the following equation:

$$k_0 = \nu / (1 - \nu) \quad (2)$$

An alternative method based on volumetric strain is therefore proposed to generate the exact in-situ horizontal stress distribution within rock mass as recommended in Equation (1). This method is based on the following relationship between the stress and strain obeying Hooke's Laws for the rock mass and can be used to generate the additional horizontal stress,  $\sigma_{xx}$ , which is the first component,  $\sigma_h$ , of Equation (1). Modification of Poisson's ratio will be required as discussed in Step 2 below.

$$\sigma_{xx} = E\varepsilon_{xx} + \nu(\sigma_{yy} + \sigma_{zz}) \quad (3)$$

where E is Young's modulus,  $\sigma_{yy}$  and  $\sigma_{zz}$  are horizontal stress in y and z directions, respectively,  $\varepsilon_{xx}$  is the horizontal strain in x direction.

The detailed procedures to generate high in-situ horizontal stresses within rock mass are described as follows:

Step 1: Generating the initial in-situ horizontal stresses within rocks with adopting  $k_0$ -procedure and  $k_0$  value of 2 (the second component of Equation-1).

Step 2: Immediately after Step 1, plastic analysis stage is then carried out with assigning a specified horizontal volume strain  $\varepsilon_{xx}$  to Sandstone/Shale Class I/II rock layers in the model. Additional horizontal stresses (the first component of Equation-1) will be then generated and added onto the existing in-situ horizontal stresses calculated from the first step within the soils and rocks. The input value for the horizontal volume strain value will need to be calculated based on the following equation:

$$\varepsilon_{xx} = 1 / \{E(\sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz}))\} \quad (4)$$

A very small value should be adopted for the Poisson's ratio for the rock (Class I/II) materials in order to reduce the effects from other stress components. For example, additional horizontal stress of 1.5 MPa corresponds to a horizontal strain of 0.075% for the rock with Young's modulus of 2000 MPa. It should be pointed out that the Poisson's ratio needs to be reset to the typical value of 0.2 for the subsequent analyses after the generation of in-situ stresses.

The modelling workflow outlined in this paper was originally developed in 2015 during detailed design development for the M4 East project, WestConnex Stage 1B in Sydney, Australia. It is worth noting that a similar approach was presented in a technical post for Plaxis Modelling by Bentley Systems (2024). This paper provides the theoretical background and derivation of the equations based on Hooke's law, together with a more comprehensive description of the detailed procedures and worked examples. As such, this paper provides a useful technical reference in geotechnical numerical modelling.

### 3 WORKED EXAMPLE

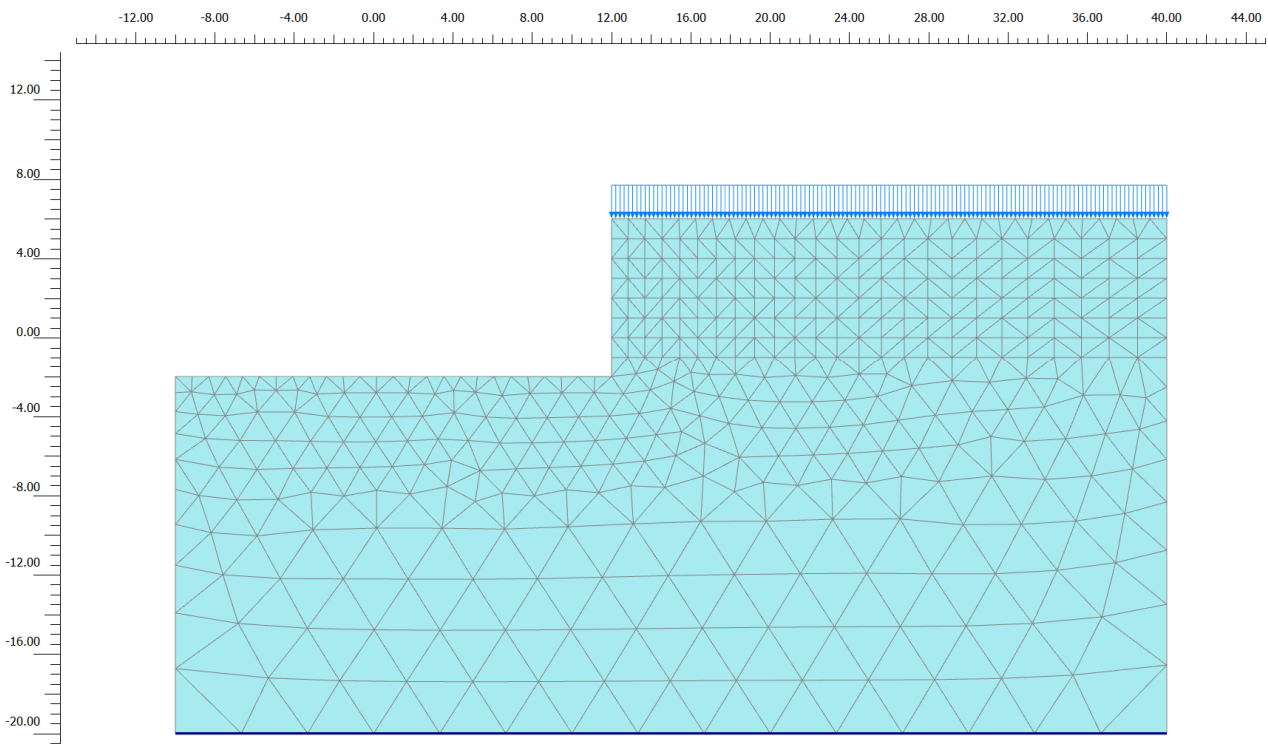
A worked example problem has been used to demonstrate the application of the proposed method for deep excavation into Sandstone/Shale Class I/II rock mass. The strength and deformation parameters used for the rock mass are summarised in the table below:

**Table 1: Input parameters for rock mass**

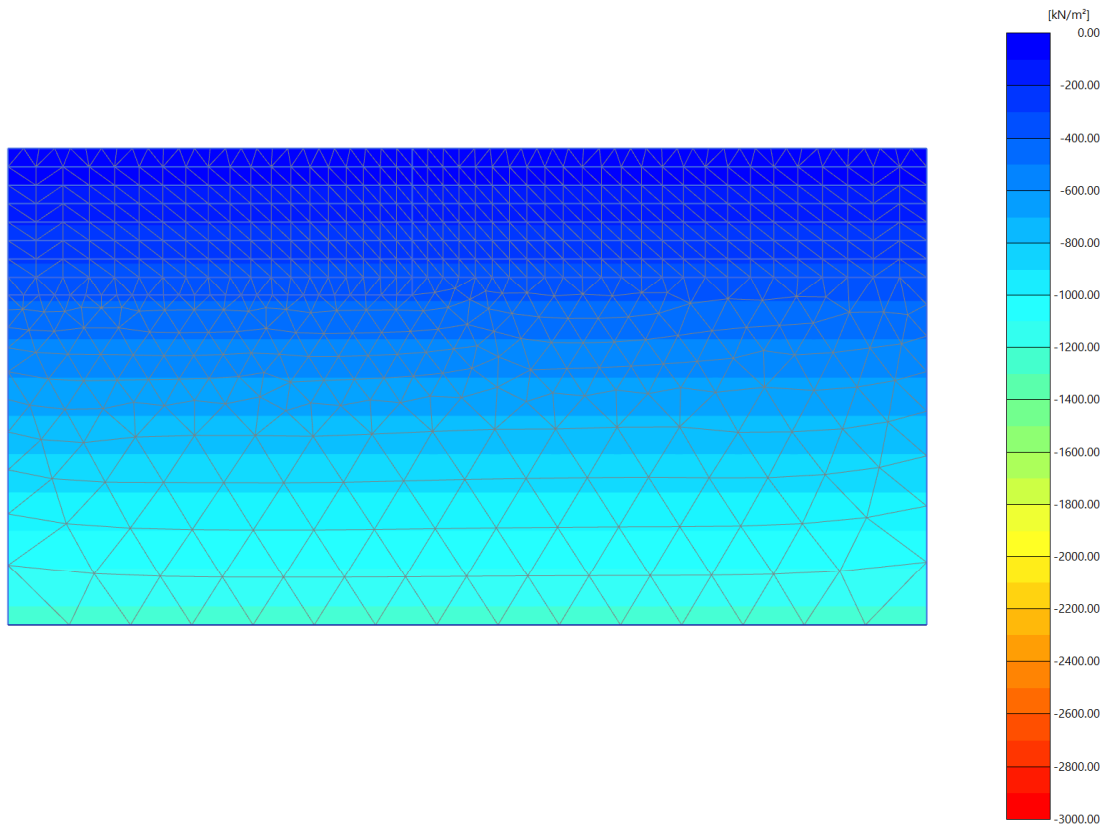
Unit weight (kN/m <sup>3</sup> )	Effective cohesion (kPa)	Effective angle of friction (deg)*	Young's modulus (MPa)	Poisson's ratio	Tensile strength (kPa)
24	500	36	2000	0.2	50

The geometry of the deep excavation into Class I/II rocks with high in-situ horizontal stressed is shown in Figure 1. The total excavation depth is 8 m in this analysis case and a 20 kPa surcharge is applied at the ground surface. Figure 2 shows the distribution of in-situ horizontal stresses within the rock from the first step (Step 1) of the in-situ stress generation procedure. The in-situ horizontal stresses are calculated by multiplying the vertical stresses with the specified  $k_0$  value ( $k_0=2$  for this case). Note that the in-situ horizontal stress is 0 at the ground surface from this step. Figure 3 shows the in-situ horizontal stress distribution from the second step (Step 2) after the volume strain in the horizontal direction is applied. It can be seen that the in-situ horizontal stress is 1500 kPa at the ground surface (this cannot be obtained by using  $k_0$ -procedure alone) and increases linearly with the depth.

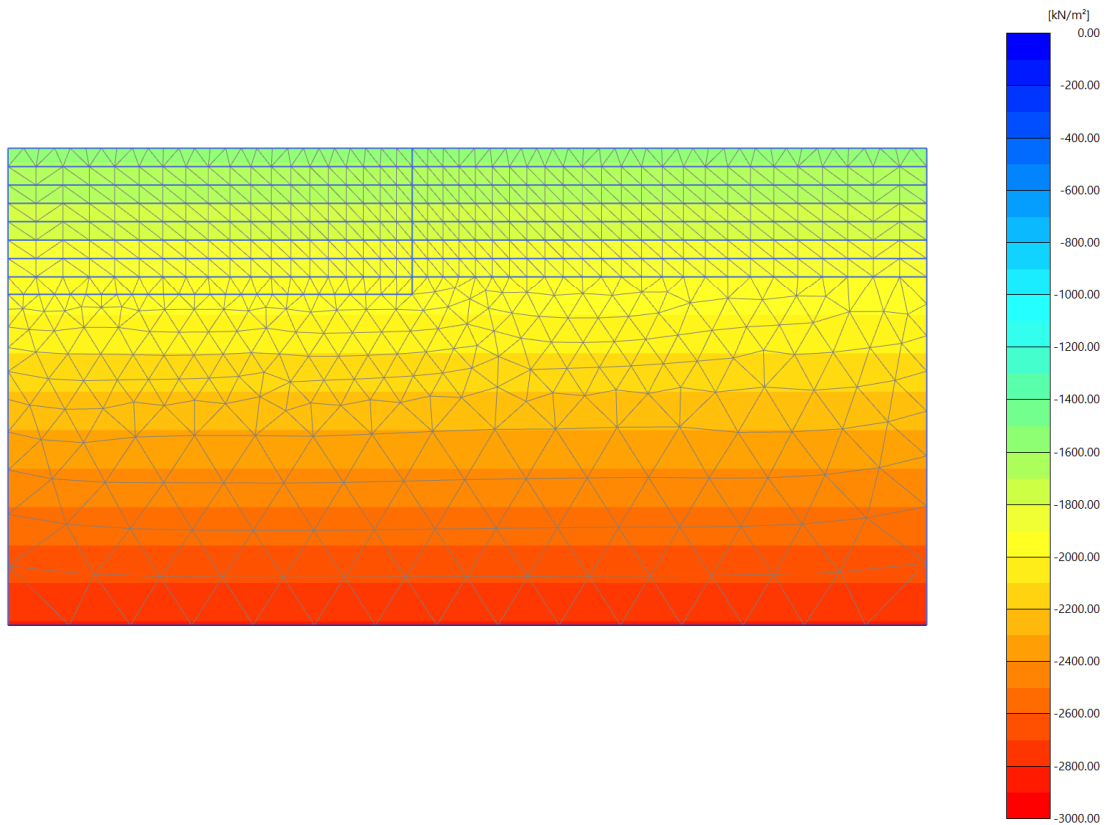
Figure 4 shows the comparison results between the recommended linear relationship and analysis results from PLAXIS 2D based on the proposed volume strain approach. It can be seen that in-situ horizontal stresses commonly encountered in Sydney can be correctly modelled in PLAXIS 2D through the proposed volumetric strain approach.



**Figure 1: Mesh generated by Plaxis 2D**



**Figure 2: In-situ horizontal stress contours generated in Step 1 using  $k_0$  procedure**



**Figure 3: Horizontal stress contours generated by Plaxis 2D**

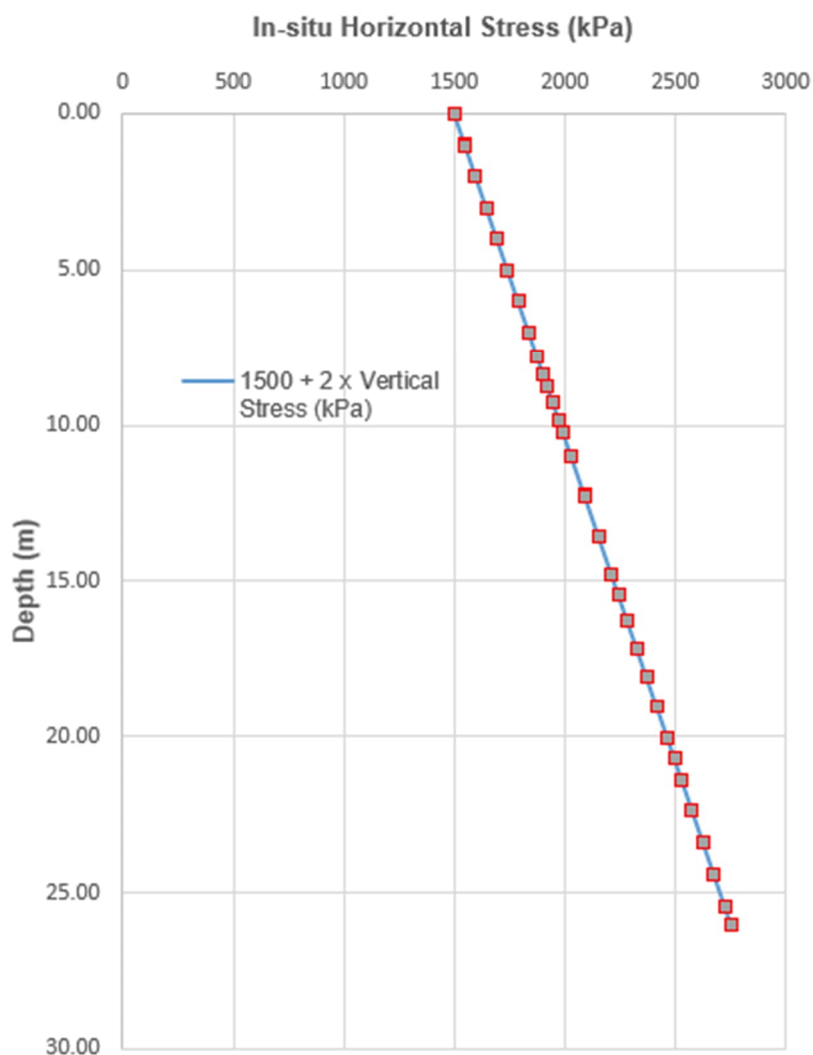


Figure 4: Comparisons of in-situ horizontal stresses from the recommended linear relationship and analysis results from PLAXIS 2D based on the proposed volume strain approach

#### 4 POSTPROCESSING OF PLAXIS 2D ANALYSIS RESULTS

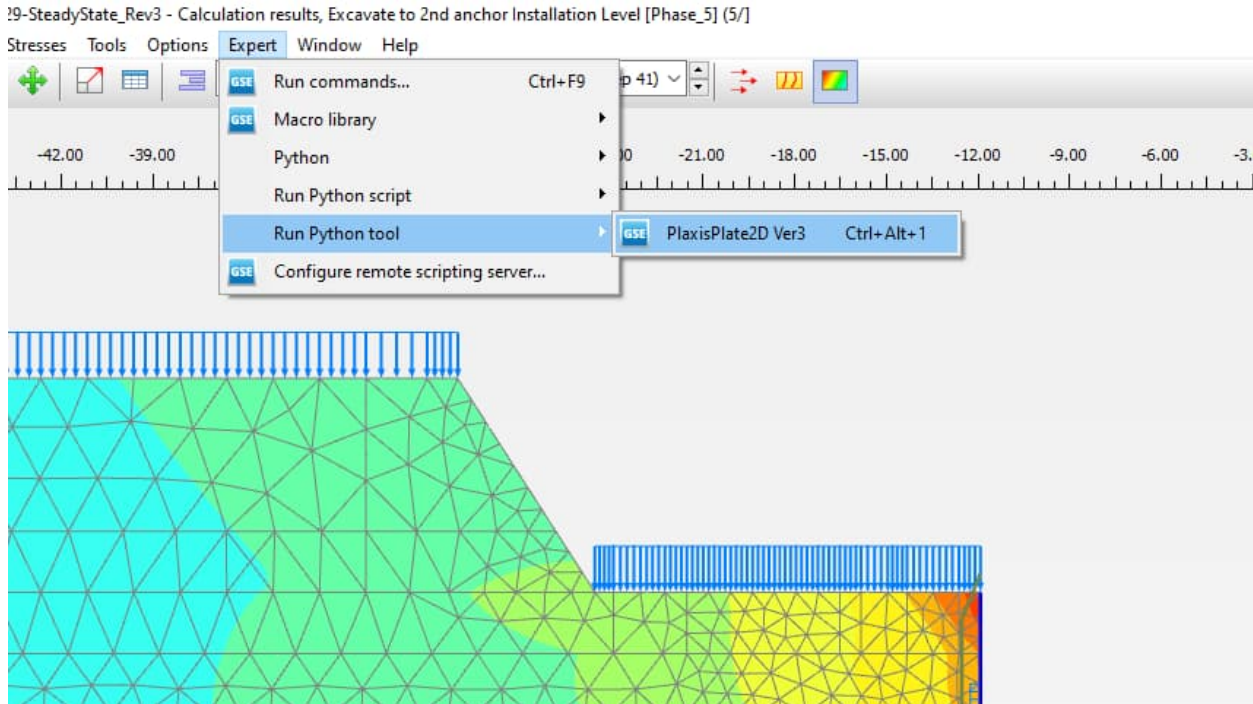
Post processing of Plaxis 2D analysis results for the shoring wall for deep excavations could be a time-consuming task when multiple construction stages are required for simulation. As part of geotechnical automation innovation process, a python-based tool named PlaxisPL2D has been developed to streamline the post-processing of analysis results from Plaxis 2D.

By using PlaxisPlate2D, engineers and geotechnical professionals can quickly export and present the analysis results from Plaxis 2D in a desirable format by reducing significant amount of the post analysis processing time. Furthermore, PlaxisPlate2D will eliminate potential human errors of repeated data processing. PlaxisPlate2D is written in Python, which is a powerful and widely used programming language, and it is specifically designed for deep excavation analysis where plate elements are used to model the shoring walls. PlaxisPL2D can be made available free upon request via an email to the authors.

PlaxisPlate2D can be directly run from the Plaxis output program as shown in Figure 5. Some of the key features and benefits from PlaxisPlate2D are summarised as follows:

- PlaxisPlate2D extracts the Plaxis 2D analysis results for all the plate elements and node-to-node anchors/structs within the model and present the results in professionally designed charts and tables which can be directly used in the design report or for the presentation.
- The extracted results will be automatically stored in a single Microsoft Excel Spreadsheet file.

- It generates charts for the results of displacement, bending moment, shear force and axial force of plate elements with depth/level for all the analysis stages.
- It can be used for the analysis and design for various deep excavation problems where the retaining walls are modelled with plate elements.
- It automatically generates the summary table which presents the results of the calculated actions in wall and associated ground anchors for every analysis stage.



**Figure 5: PlaxisPlate2D tool within Plaxis 2D output program**

The user interface for this tool is shown in Figure 6. The required inputs to extract the plate results are summarised as below:

- X coordinate of the vertical plate member in Plaxis 2D. Note that this tool only can extract the results for one continuous vertical plate member only. Currently, it does not support the horizontal and inclined plate members,
- Min Y coordinate of the vertical plate member in Plaxis 2D. This represents the lowest point for the vertical plate member. This does not need to be within the plate member and can be below the vertical plate member. The tool will automatically check the valid plate elements which are above this point.
- Max Y coordinate of the vertical plate member in Plaxis 2D. This represents the highest point for the vertical plate member. This does not need to be within the plate member and can be above the vertical plate member. The tool will automatically check the valid plate elements which are below this point.
- Port ID. This is the port ID used when the Plaxis remote scripting server is started.
- Password: This is the password used when the Plaxis remote scripting server is enabled.
- Plate name: This is the plate name which can be defined by the users before the result extraction. This name will be included into the Excel spreadsheet file.
- Select folder: This is to select the folder where the extracted data file will be saved to. Clicking the button of “Browse” will help to select the folder as the user wishes. The user can directly enter the full folder path.
- Spreadsheet name: This is the name of the Excel spreadsheet file created by PlaxisPlate2D.

The result extraction progress will be displayed under the “Progress” section when the “Start Importing” button is clicked.

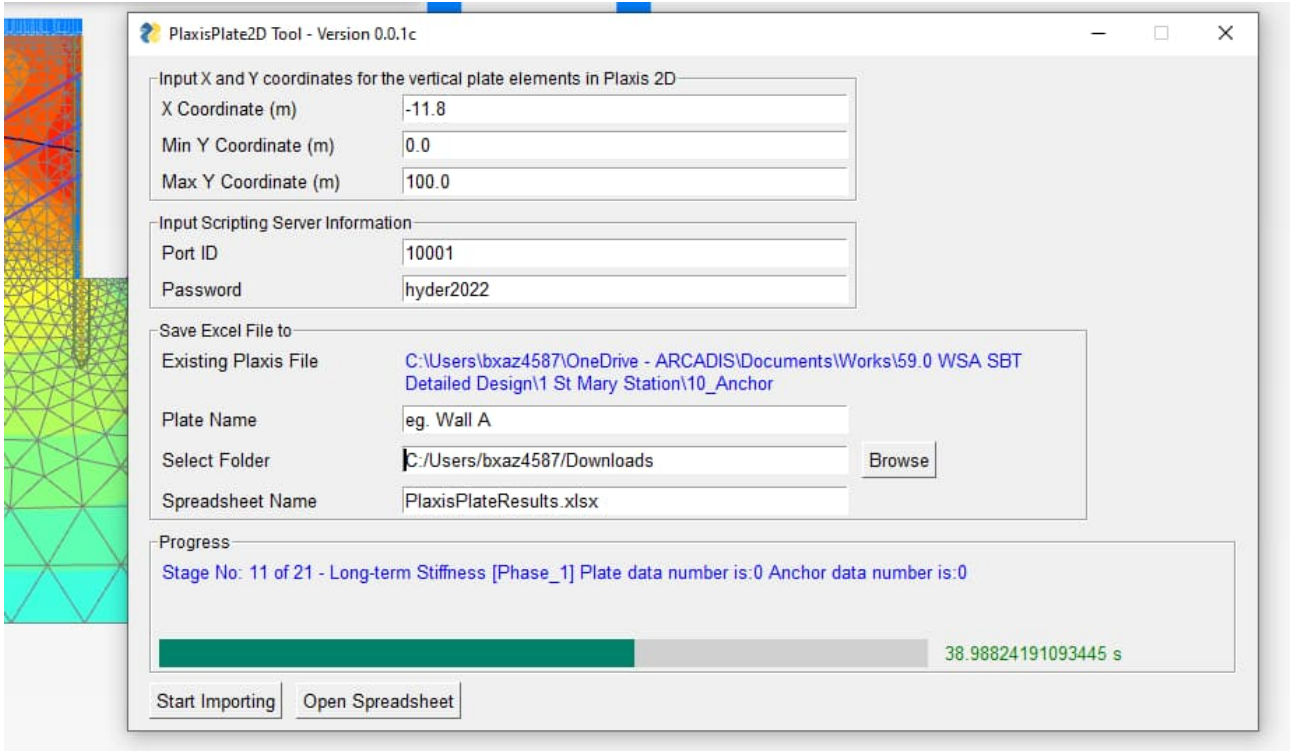


Figure 6: PlaxisPlate2D user interface

A typical spreadsheet output is shown in Figure 7. Multiple sheets are included in the spreadsheet file. The first three sheets are “About”, “Summary” and “Plots”, followed by individual sheets which includes the detailed results for each analysis stage. “About” sheet shows the general information for the selected plates and the output file.

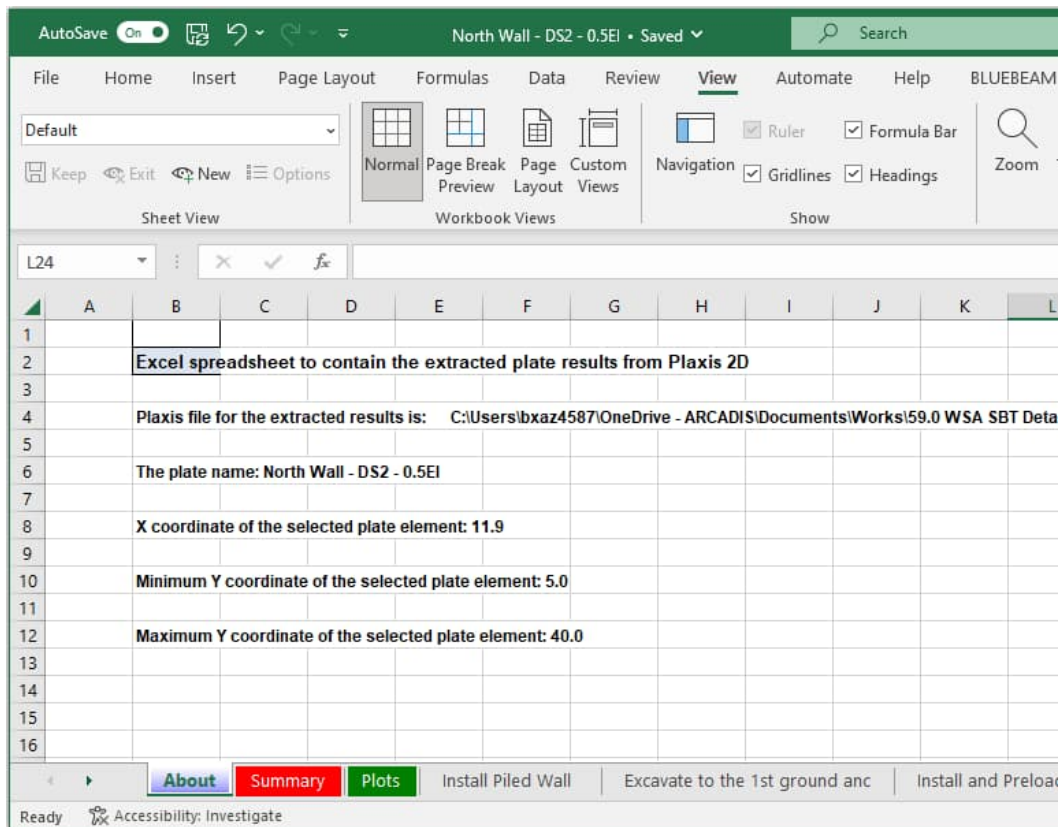


Figure 7: PlaxisPlate2D output file – “About” sheet

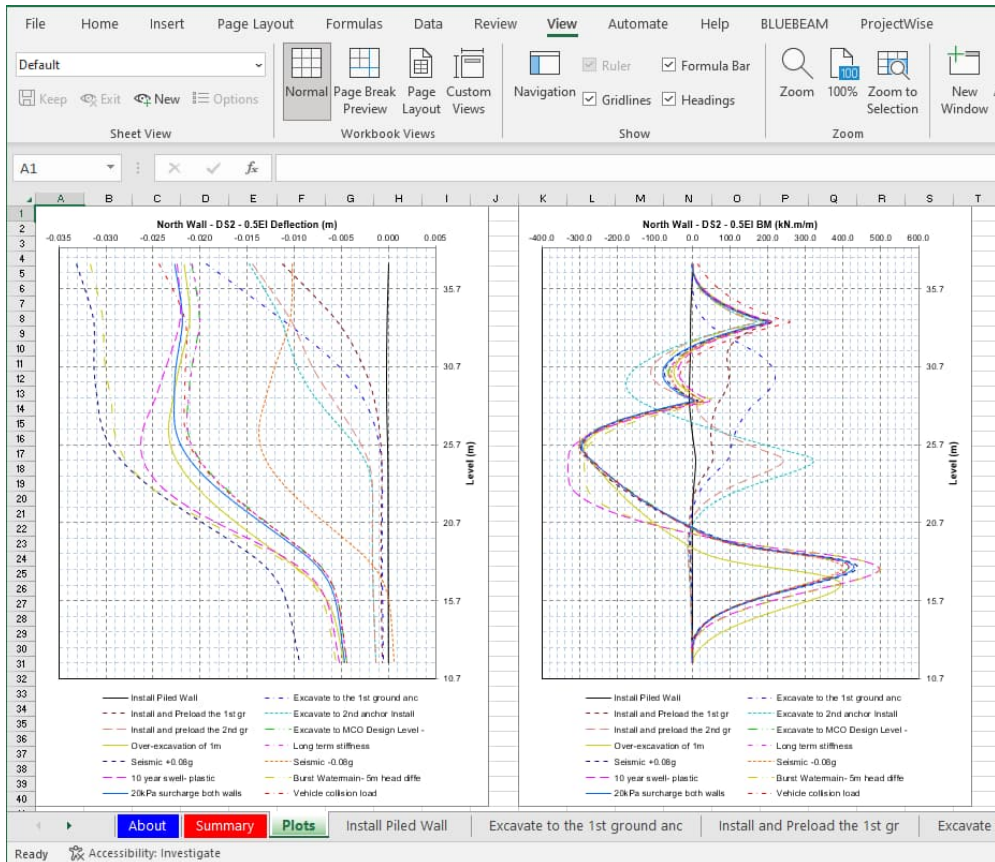
**NOTES ON HIGH HORIZONTAL STRESS GENERATION AND POST PROCESSING FOR DEEP EXCAVATION SHORING WALL USING PROGRAM PLAXIS 2D**  
**XU AND YANG**

Figure 8 shows the “Summary” sheet which presents the summarised results of the calculated actions in wall and associated ground anchors (which shares the same X coordinate with the plate) for every analysis stage for this example case. The minimum and maximum values are also provided.

No	Construction Stages	North Wall - DS2 - 0.5EI								Ground Anchor	
		Deflection (m)		Bending Moment (kN.m/m)		Shear Force (kN/m)		Axial Force (kN/m)		Anchor @ 33.55 m RL	Anchor @ 28.5 m RL
		min	max	min	max	min	max	min	max	(kN)	(kN)
1	Initial Stress Based on K0 [InitiaPhase]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	Original ground surface [Phase_1]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	Install Piled Wall [Phase_2]	0.000	0.000	-8.7	9.0	-3.9	6.1	-49.3	0.0	NA	NA
4	Excavate to the 1st ground anchor level [Phase_3]	-0.019	-0.001	-4.8	218.6	-45.7	78.5	-50.0	68.5	NA	NA
5	Install and Preload the 1st ground Anchor [Phase_4]	-0.011	-0.001	-7.2	209.6	-117.9	127.8	-176.1	28.7	800.0	NA
6	Excavate to 2nd anchor installation Level [Phase_5]	-0.015	-0.001	-177.7	321.3	-173.1	164.8	-334.7	36.5	895.3	NA
7	Install and preload the 2nd ground anchor [Phase_6]	-0.014	-0.001	-110.9	240.3	-166.0	133.5	-427.5	18.0	875.8	600.0
8	Excavate to MCO Design Level - RL 18.7 m [Phase_8]	-0.021	-0.004	-298.5	412.9	-190.0	361.3	-1105.7	0.1	941.6	848.8
9	Over-excavation of 1m [Phase_10]	-0.023	-0.005	-288.2	393.1	-188.4	345.7	-1133.6	0.1	940.9	853.6
10	Long term stiffness [Phase_11]	-0.021	-0.004	-297.7	413.3	-189.7	357.6	-1097.3	0.1	946.6	858.3
11	Seismic +0.08g [Phase_12]	-0.033	-0.009	-295.5	435.5	-193.4	361.8	-1198.7	0.2	902.6	819.9
12	Seismic -0.08g [Phase_13]	-0.014	0.001	-302.6	395.1	-186.2	332.9	-966.4	0.1	1011.9	928.3
13	10 year swell-plastic [Phase_7]	-0.028	-0.005	-330.8	495.4	-201.3	335.4	-1108.6	2.3	958.8	909.4
14	Burst Watermain- 5m head differential [Phase_14]	-0.032	-0.006	-288.9	500.0	-196.3	339.7	-1215.7	2.0	1035.1	977.6
15	20kPa surcharge both walls [Phase_8]	-0.023	-0.005	-294.2	427.1	-187.0	360.0	-1152.5	0.1	946.9	859.3
16	Vehicle collision load [Phase_15]	-0.024	-0.004	-290.2	416.5	-195.8	359.9	-1113.9	0.0	970.7	867.5
<b>Extreme Values</b>		<b>-0.033</b>	<b>0.001</b>	<b>-330.8</b>	<b>500.0</b>	<b>-201.3</b>	<b>361.8</b>	<b>-1215.7</b>	<b>68.5</b>	<b>1035.1</b>	<b>977.6</b>

**Figure 8: PlaxisPlate2D output file – “Summary” sheet**

Figure 9 shows the plots for deflection, bending moment of the plate member against the reduced level. The results for all the analysis stages modelled are included.



**Figure 9: Typical PlaxisPlate2D output file – “Plots” sheet**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
		Y (m)	Ux (m)	M (kN.m/r)	SF (kN/m)	N (kN/m)	MAT	ELE							
1															
2	0	37.3	-0.0209	1.32E-13	-0.62812	0.142353	4	2							
3	1	37.1	-0.02084	0.105295	2.0027	-1.51746	4	2							
4	2	36.9	-0.02078	0.895625	5.945709	-3.39768	4	2							
5	3	36.7	-0.02072	2.531942	10.60631	-5.36482	4	2							
6	4	36.5	-0.02067	5.139232	15.46475	-7.33996	4	3							
7	5	36.31243	-0.02061	8.484075	20.23386	-9.27709	4	3							
8	6	36.12486	-0.02056	12.74569	25.2739	-11.3286	4	3							
9	7	35.93729	-0.0205	17.99211	30.70792	-13.5316	4	3							
10	8	35.74972	-0.02045	24.29872	36.66426	-15.9354	4	4							
11	9	35.56215	-0.0204	31.77021	43.06548	-18.534	4	4							
12	10	35.37458	-0.02035	40.47063	49.72051	-21.2894	4	4							
13	11	35.18701	-0.0203	50.4421	56.6233	-24.2012	4	4							
14	12	34.99944	-0.02025	61.72683	63.76186	-27.2728	4	7							
15	13	34.81826	-0.02021	73.99829	71.7645	-30.3862	4	7							
16	14	34.63708	-0.02017	87.74343	79.95591	-33.6581	4	7							
17	15	34.4559	-0.02014	102.9891	88.33375	-37.089	4	7							
18	16	34.27472	-0.02011	119.7627	96.88663	-40.6552	4	8							
19	17	34.09354	-0.02009	138.1039	105.6591	-44.4555	4	8							
20	18	33.91236	-0.02008	158.0617	114.6224	-48.3243	4	8							
21	19	33.73118	-0.02007	179.659	123.7647	-52.2569	4	8							
22	20	33.55	-0.02007	202.9186	-165.188	-229.728	4	12							
23	21	33.3	-0.02011	163.252	-152.202	-235.285	4	12							
24	22	33.05	-0.02016	126.826	-139.123	-240.877	4	12							
25	23	32.8	-0.02022	93.68391	-125.929	-246.51	4	12							
26	24	32.55	-0.02029	63.87165	-112.561	-252.204	4	14							
27	25	32.4125	-0.02033	48.90276	-105.212	-255.334	4	14							
28	26	32.275	-0.02038	34.94077	-97.8139	-258.483	4	14							

Figure 10: PlaxisPlate2D output file – detailed results for individual analysis stage

Figure 10 shows the typical detailed results for an analysis stage which are used in the plots as shown in Figure 9.

Some limitations associated with this tool are summarised as below:

- Only vertical plate elements are supported by this post processing tool.
- Ground anchors modelled by node-to-node anchors shall start from the selected plate elements. The starting point of the node-to-node anchor shall share the same X coordinate with the plate.
- No Excel spreadsheet file will be created if no plate elements within the defined range are present.
- Only deflection, shear force, bending moment and axial forces for plates and axial forces for node-to-node anchors are extracted by PlaxisPlate2D. No other results are included.
- PlaxisPlate2D does not support the old version of Plaxis 2D. The users need to ensure that Plaxis 2D Version 22 or later is already installed on the computer before this tool can be installed.

## 5 CONCLUSIONS

A simple procedure based on the volume strain approach has been proposed to generate the high in-situ horizontal stresses within Class I/II rocks for the cut and cover tunnel analyses of M4 East project in 2015. Since then, this approach has been widely used for many infrastructures project including Sydney Metro City, Sydney Metro Northwest, Rozelle Interchange, M6, Western Sydney Airport (SBT) and Melbourne Metro. The exact linear relationship of the in-situ horizontal stresses can be simulated by this approach in PLAXIS 2D analyses for the cut and cover tunnels. There is no need to divide the rock layers into a number of sub-layers with different  $K_0$  values to approximate the high in-situ horizontal stresses. It is a simple but more robust approach for the initial stress generation within the Class I/II rocks with high horizontal stresses. This approach also can be easily extended to model and rock having high horizontal stresses including Plaxis 3D modelling if required.

A Python based post processing tool has been developed for automatically extracting and presenting the analysis results from Plaxis 2D. This tool can achieve a great deal of time saving and avoiding the potential human errors in data processing. This tool has been successfully adopted on several major infrastructure projects in Australia, including Sydney Metro, Melbourne Metro, Western Sydney Airport (SBT), Sydney Metro West – Eastern Tunnelling Package, Suburban Rail Loop – Package C, and T2D Torrens to Darlington, consistently receiving very positive feedback. The tool can be made available upon request.

## 6 DISCLAIMERS

The authors, contributors and their respective organisations do not make any representation or warranty as to the accuracy, completeness, or suitability or otherwise of the information contained in this paper and shall have no liability to any person in connection therewith.

## 7 ACKNOWLEDGMENTS

This paper was developed through an actual project which was fully supported by Arcadis staff and the project managers.

### **CRedit authorship contribution statement**

**Bo Xu:** Conceptualisation, Software, Writing - original draft. **Qijing Yang:** Conceptualisation, Software, Writing - original draft, Writing – review and editing.

## 8 REFERENCES

- Bentley Systems. PLAXIS 2D 2024.2 Reference Manual. Bentley Systems International, Dublin, 2025.
- Bentley Systems (2024). A guide to correct initial stresses in rock structures. Bentley Communities / Bentley Technical Blog. [https://bentleysystems.service-now.com/community?id=kb\\_article&sysparm\\_article=KB0107800](https://bentleysystems.service-now.com/community?id=kb_article&sysparm_article=KB0107800)
- Enever, J. R., Alton, R. J. and Windsor, C. R. (1990) Stress regime in the Sydney Basin and its implications for excavation design and construction. Proc. 7<sup>th</sup> Australian Tunnelling Conference, Institution of Engineers Australia, Canberra. pp 49-59
- McQueen, L. B. (2004). In situ rock stress and its effect in tunnels and deep excavation in Sydney, Australian Geomechanics. Vol 39. No. 3.
- Pells, P. J. N. (1990) Stress and displacements round deep basements in the Sydney area. Proc. 7<sup>th</sup> Australian Tunnelling Conference, Institution of Engineers Australia, Canberra. pp 241-249.
- Pells, P.J.N., Mostyn, G. and Walker, B.F. (1998). Foundations on Sandstone and Shale in the Sydney Region. Australian Geomechanics, Vol 33. No. 3.