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Comparison of analytical and finite-element method for modelling excavations

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ABSTRACT: Modeling excavations is a critical aspect of geotechnical engineering, with analytical methods and finite element methods (FEM) being used primarily. Analytical methods offer simplified one-dimensional solutions, providing quick insights into system behavior. However, they often fall short in capturing complex interactions inherent in real-world scenarios. In contrast, FEM enables to simulate complex geometries and boundary conditions by discretizing the domain into finite elements. This approach, while more computationally intensive, yields more accurate and comprehensive results. Usually, engineering practices have relied on one of these methods, limiting the ability to cross-verify results and understand the nuances of each approach. To bridge this gap, a software tool DCB2Plaxis has been developed to automatically convert analytical models from 2D DC-Excavation-Pit into FEM models compatible with Plaxis 2D. This tool enables engineers to seamlessly show between modeling paradigms and to facilitate comparative analyses. In this paper, a comprehensive analysis was conducted by applying both analytical and FEM approaches to various excavation pit scenarios with similar geometry and boundary conditions. This comparative study revealed that while analytical methods provide expedient evaluations suitable for preliminary assessments, they may oversimplify complex soil-structure interactions and fail to account for factors such as elastic-plastic material behaviors. Conversely, FEM offers a more robust framework capable of modeling intricate conditions, including staged construction processes and varying material properties, leading to more reliable predictions of deformation and earth pressure distribution. Also, groundwater in excavations can be modeled more realistically with Plaxis.The integration of this DCB2Plaxis tool into engineering workflows enhances the understanding of the strengths and limitations inherent in both analytical and FEM approaches. It empowers engineers to select the most appropriate method based on project-specific requirements. This advancement underscores the importance of leveraging multiple modeling techniques to achieve optimal, sustainable design and safety outcomes in excavation projects

KEYWORDS: Excavation pit, Analytical methods, FEM, Plaxis, constitutive model.

1 INTRODUCTION

Supported excavations are common in urban infrastructure and are typically designed using either simplified analytical approaches or numerical finite-element (FE) analyses. Analytical methods—implemented in tools such as DC-Pit—are fast and practical for preliminary sizing, but they idealize soil behavior and interaction, which can bias predictions of wall actions and ground movements. FE software such as PLAXIS 2D addresses these issues by modeling staged construction, soil–structure interaction, and alternative constitutive laws, at the cost of additional modeling effort. In routine practice, this has meant that cross-checking an analytical design with FE required rebuilding the model, discouraging systematic comparisons on real projects.

To eliminate this barrier, we developed DCB2Plaxis, a Python-based converter that reads DC-Pit input (and, when available, output) files and automatically generates a one-to-one PLAXIS 2D model. Geometry, boundary conditions, groundwater levels, and the entire construction sequence are transferred, while soils can be assigned Mohr–Coulomb (MC), Hardening Soil (HS), or Hardening Soil Small-strain (HSS) models with user-specified stiffness parameters. Retaining systems (sheet-pile, Grider plank wall, diaphragm, and bored-pile walls), anchors/props, and grout bodies are instantiated with properties mapped from DC-Pit, and optional settings are exposed through a simple GUI. The intent is to minimize manual input while still allowing engineers to review and adjust the generated model where project-specific judgment is needed.

Using this workflow, we assembled three real-project case studies that span a flexible sheet-pile system (one anchor level), a diaphragm wall (three props), and a bored-pile wall (five props). For each case, we analyze three FE variants—HSS, MC with $E=E_{50}$, and MC with $E=E_{ur}$ —to quantify the influence of constitutive model and stiffness selection. Soil parameters are taken from geotechnical investigation reports. The comparisons focus on retaining-structure response (normal force N, bending moment M, shear force Q, and horizontal displacement U_x) and earth-pressure distributions at key stages.

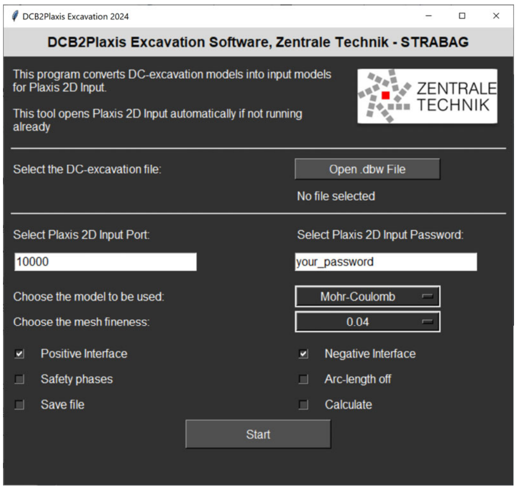
Results indicate that internal forces from FE can be higher or lower than analytical values depending on the mobilized stiffness regime, whereas U_x is consistently most sensitive to constitutive model choice. DC-Pit pressure envelopes show layer-by-layer kinks, while PLAXIS produces stage-dependent, continuous distributions that reflect arching, plasticity, and support interaction. Collectively, the findings underline known limitations of analytical schemes for serviceability predictions and highlight the practical importance of selecting an appropriate constitutive law (HSS over MC) and credible stiffness inputs when assessing excavation performance.

The paper is organized as follows: Section 2 details the DCB2Plaxis tool and model mapping; Section 3 describes the study cases and analysis setup; Section 4 presents retaining-structure and earth-pressure comparisons; Section 5 discusses the implications for practice and Section 6 summarizes key conclusions.

2 DCB2PLAXIS TOOL

DCB2Plaxis is a Python-based converter that communicates with PLAXIS 2D via the Remote Scripting Interface. It reads DC-Pit input (.dbw) and, when available, output (.erw2) files, and automatically builds a staged PLAXIS model. The key steps are:

1. Import DC-Pit data (geometry, loads, water levels, and construction stages).
2. Material assignment via a dialog, where the user selects the soil constitutive model and completes any parameters do not present in DC-Pit.
3. Model generation in PLAXIS (geometry, interfaces, and staged construction created 1:1).
4. Run & export (optional automatic calculation and export of results for comparison).



DCB2Plaxis Excavation 2024

DCB2Plaxis Excavation Software, Zentrale Technik - STRABAG

This program converts DC-excavation models into input models for Plaxis 2D Input.

This tool opens Plaxis 2D Input automatically if not running already

ZENTRALE TECHNIK

Select the DC-excavation file: Open .dbw File

No file selected

Select Plaxis 2D Input Port: 10000

Select Plaxis 2D Input Password: your_password

Choose the model to be used: Mohr-Coulomb

Choose the mesh fineness: 0.04

☑ Positive Interface
☑ Negative Interface
☐ Safety phases
☐ Arc-length off
☐ Save file
☐ Calculate

Start

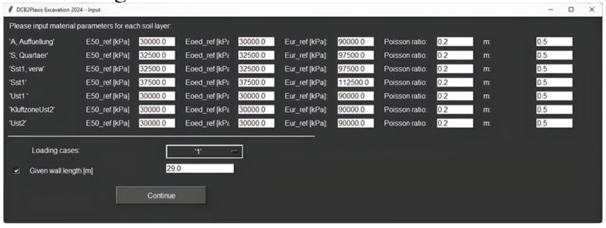
Figure 1. DCB2Plaxis first input window.

The following items are transferred from DC and generated in Plaxis automatically:

- Geometry. Soil stratigraphy; retaining structures (sheet-pile, Grider plank wall, diaphragm wall, bored-pile wall); anchors, grout bodies and props; excavation levels; exterior/interior slopes; and stage-wise groundwater levels. Model boundaries are set by default to ±50 m from the wall, which is adequate for most excavations (users may adjust if required).
- Loads. Line and point loads on the ground surface or retaining walls. Anchor pre-stressing are also transferred.
- Construction sequence. Each excavation or dismantling step becomes a PLAXIS calculation phase with the same activation/deactivation logic as in DC-Pit.
- Materials. Wall, soil, anchors/props, and grout bodies are instantiated with parameters mapped from DC-Pit and/or completed by the user (see § 2.3).

Because DC-Pit does not store full constitutive data needed for FEM, DCB2Plaxis provides a controlled mapping:

- Soils. Friction angle (φ), cohesion (c), wall–soil interface friction, unit weights (dry/submerged), and permeability (if present) are imported. The user then chooses one of:
    - Mohr–Coulomb (MC): supply E (Young's modulus) and ν (Poisson's ratio).
    - Hardening Soil (HS) or Hardening Soil small-strain (HS-small/HSS): supply E_{50}^{ref}, E_{oed}^{ref}, E_{ur}^{ref}, ν, and m. The reference pressure p^{ref} is assumed as 100 kPa. For HSS, G_0^{ref} and $\gamma^{0.7}$ are assumed with editable defaults. The soil-material input dialog is shown in Figure 2.



DCB2Plaxis Excavation 2024 - Input

Please input material parameters for each soil layer:

'A, Auffuellung'	E50_ref [kPa]	30000.0	Eoed_ref [kPa	30000.0	Eur_ref [kPa]:	90000.0	Poisson ratio:	0.2	m:	0.5
'S, Quartaer'	E50_ref [kPa]	32500.0	Eoed_ref [kPa	32500.0	Eur_ref [kPa]:	97500.0	Poisson ratio:	0.2	m:	0.5
'Sst1, verw'	E50_ref [kPa]	32500.0	Eoed_ref [kPa	32500.0	Eur_ref [kPa]:	97500.0	Poisson ratio:	0.2	m:	0.5
'Sst1'	E50_ref [kPa]	37500.0	Eoed_ref [kPa	37500.0	Eur_ref [kPa]:	112500.0	Poisson ratio:	0.2	m:	0.5
'Ust1 '	E50_ref [kPa]	30000.0	Eoed_ref [kPa	30000.0	Eur_ref [kPa]:	90000.0	Poisson ratio:	0.2	m:	0.5
'KluftzoneUst2'	E50_ref [kPa]	30000.0	Eoed_ref [kPa	30000.0	Eur_ref [kPa]:	90000.0	Poisson ratio:	0.2	m:	0.5
'Ust2'	E50_ref [kPa]	30000.0	Eoed_ref [kPa	30000.0	Eur_ref [kPa]:	90000.0	Poisson ratio:	0.2	m:	0.5

Loading cases: '1'

☑ Given wall length [m] 29.0

Continue

Figure 2. DCB2Plaxis second input window.

- Retaining walls. Stiffnesses from DC-Pit are converted automatically to the corresponding volume/plate properties in PLAXIS (no user input required).
    - Bored-pile and diaphragm walls are modeled as volume elements with a dummy plate for force and displacement read-out.
    - Sheet-pile and Girder plank walls are modeled as plate elements.
- Anchors/Props. Horizontal spacing and axial stiffness are imported; elements are created and activated per stage (no user input required).
- Grout bodies. Modeled as Embedded Beams with spacing, diameter, and stiffness transferred from DC-Pit. Axial skin resistances are initialized with reasonable defaults and can be edited if needed.

All the above material parameters can be edited in Plaxis after the model transfer.

The following options need to be set by users:

- Mesh fineness (global target size).
- Interfaces: add/activate positive/negative interfaces.
- Safety phases: optionally append a safety (ϕ-c reduction) analysis.
- Arc-length control: enable/disable (the "Arc-length off" option disables it).
- Save/Calculate: save the PLAXIS model and/or run calculations automatically.
- Loading cases: if multiple DC-Pit load cases exist, select which to transfer.
- Given wall length: if unchecked, the wall length from DC-Pit input is used; if checked, the default becomes the maximum required length from DC-Pit output, which the user can override.

The tool minimizes manual data entry and can build, mesh, save and (optionally) compute the PLAXIS model end-to-end. Nevertheless, users should review the generated model—boundary extents, mesh density around structural features, soil parameters, and stage activation—to ensure plausibility for the specific project context.

3 STUDY CASES

Three real-project cases with differing support systems were selected to cover a representative range of deep-excavation configurations and loading conditions. The DC-Pit and PLAXIS 2D models for each case are shown in Figures 3–5, and the main characteristics are summarized below.

Table 1. Benchmark Cases.

Case	Retaining system	Support	Excavation depth [m]
1	Sheet pile wall	1 × anchor	6.65
2	Diaphragm wall	3 × props	19.67
3	Bored pile wall	5 ×props	21.00

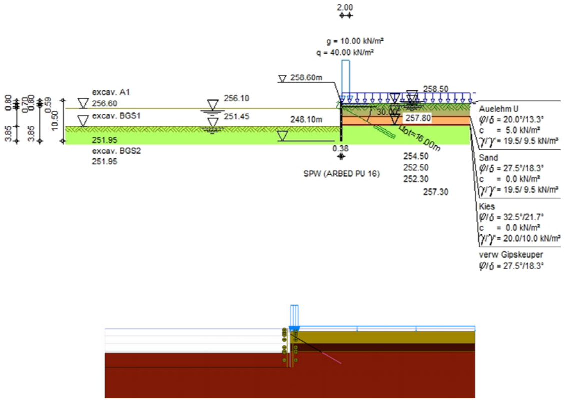


Figure 3. DC-Pit and Plaxis 2D model for Sheet pile wall case.

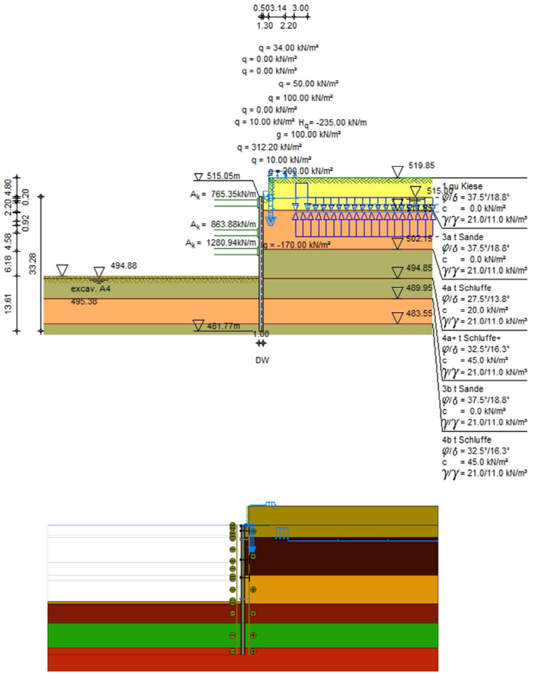


Figure 4. DC-Pit and Plaxis 2D model for Diaphragm wall case.

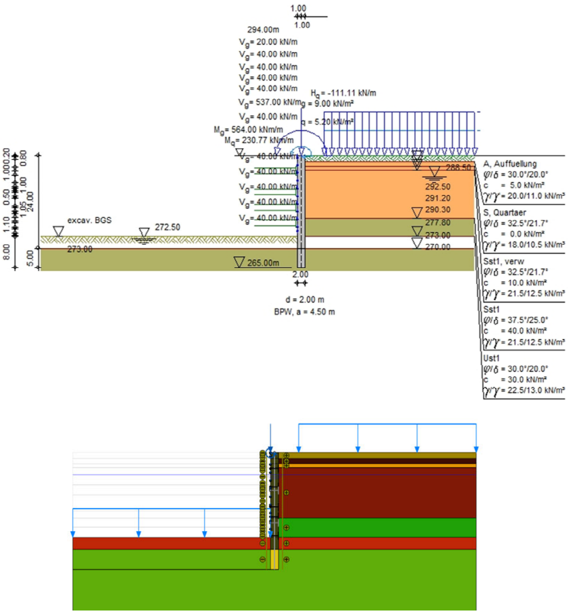


Figure 5. DC-Pit and Plaxis 2D model for Bore pile wall case.

For each case, the PLAXIS model was generated directly from the corresponding DC-Pit file using DCB2Plaxis. Geometry, boundary conditions, groundwater levels, and stage sequencing were transferred 1:1.

To assess the influence of constitutive behavior and stiffness selection, three FEM variants were analyzed per models: 1) HSS (HS-small); 2) MC with $E=E_{50}$; and 3) MC with $E=E_{ur}$.

The three cases span flexible (sheet-pile) to stiff (diaphragm, bored-pile) systems under complex loading and staging. They are considered to be representative for different types of deep excavations.

4 RESULTS COMPARSION

4.1 *Retaining structure results*

For each case, we compare DC-Pit and Plaxis results for the retaining structures: normal force (N), bending moment (M), shear force (Q), and horizontal displacement (U_x). Although results exist for all construction phases, we present only the most informative stages. For Case 1, the final construction phase is shown; for Cases 2 and 3, three excavation stages and one final dismantling stage are included (Figures 6–8).

Case 2, Diaphragm wall with 3 levels of props:

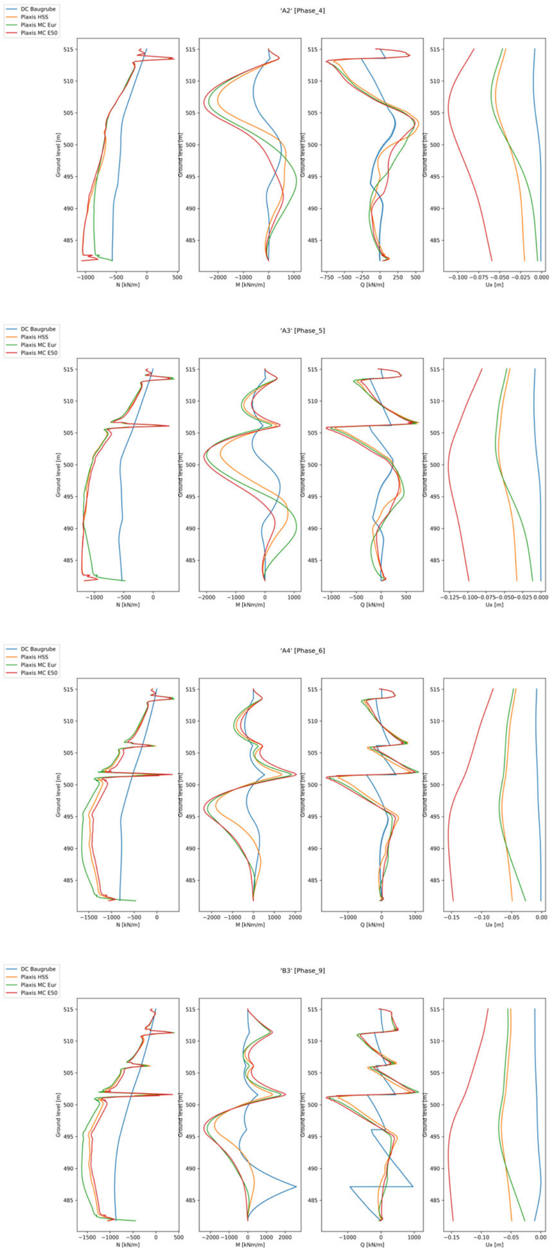


Figure 6. Retaining structure results comparison for Case 2.

Case 1, Sheet pile wall with 1 level of anchor:

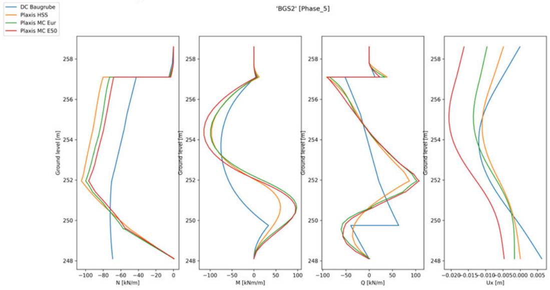


Figure 7. Retaining structure results comparison for Case 1.

Case 3, Bored pile wall with 5 level of props:

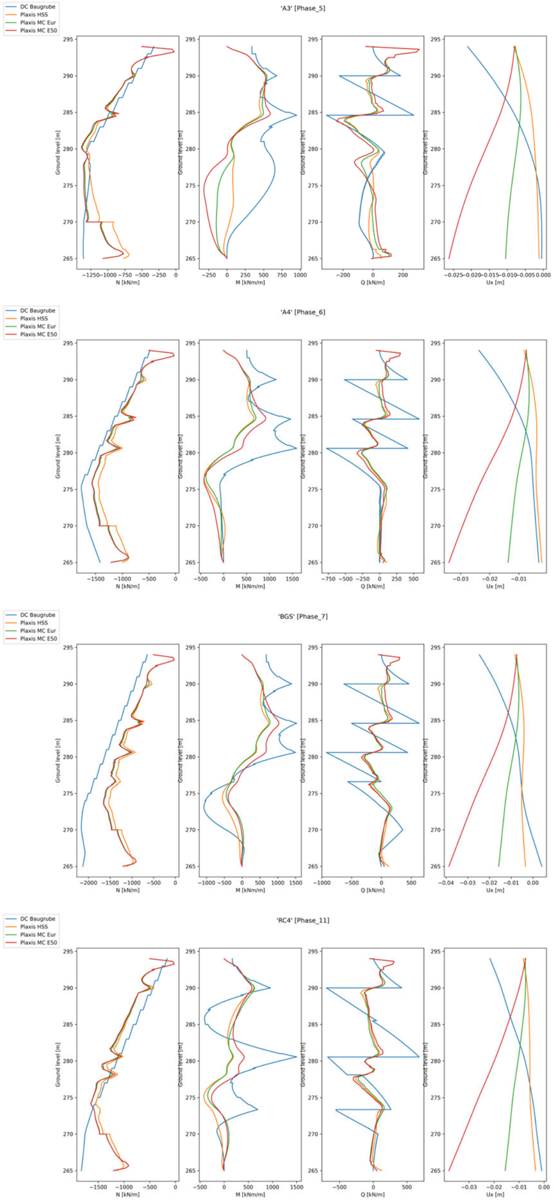


Figure 8. Retaining structure results comparison for Case 3.

For each case, internal forces in the retaining elements—normal force (N), bending moment (M), and shear (Q)—predicted by PLAXIS using HSS, MC–E_{50} and MC–E_{ur} are broadly consistent in magnitude and shape across stages. The principal divergence appears in horizontal wall displacement (U_x): as expected, MC–E_{50} yields the largest deflections, MC–E_{ur} and HSS gives similar deflections. These results are consistent with recent comparative studies showing that advanced models (HS/HS-small) better reproduce measured wall movements than Mohr–Coulomb, which tends to be optimistic for deformations (Dahal et al. 2024).

Comparisons with DC-Pit demonstrate that analytical results can be either higher or lower than FEM for internal forces, depending primarily on the effective stiffness regime mobilized in the FEM model. Lower soil stiffness (or more realistic stiffness degradation) in FEM shifts load to the wall and supports, increasing M and Q; stiffer profiles reduce these actions. This sensitivity underscores a key limitation of analytical formulations: they do not explicitly model stiffness nonlinearity or unloading–reloading behavior, which controls both the distribution and peak values of actions in staged excavation. Recent optimization and case-study papers likewise emphasize that reliable prediction of actions and deformations depends on constitutive model selection and parameter quality, with FEM enabling systematic sensitivity checks unavailable to closed-form methods (Arslan et al. 2025; Jürgens & Henke 2024).

Shape-wise, DC-Pit curves exhibit sharp kinks at layer interfaces, a direct consequence of layerwise pressure superposition and assumed distributions. FEM responses are smoother, because global equilibrium is solved with compatible deformations over the full soil–structure system; local extrema and inflections are redistributed as construction stages proceed and stiffness mobilizes. This stage-wise redistribution and interaction (e.g., between struts/anchors and the wall) is difficult to capture with analytical schemes, particularly when soils are heterogeneous, or stress histories vary with depth (Dahal et al. 2024).

4.2 *Earth pressure results*

We also compare the active and passive earth-pressure distributions along the retaining structures. In DC-Pit the earth pressure is directly exported from the result file, while in Plaxis, the earth pressure is integrated from the forces on the positive and negative interfaces. For each study case, DC-Pit and Plaxis outputs are aligned to the same key stages, and the essential comparisons are presented in Figures 9–11.

Case 1, Sheet pile wall with 1 level of anchor:

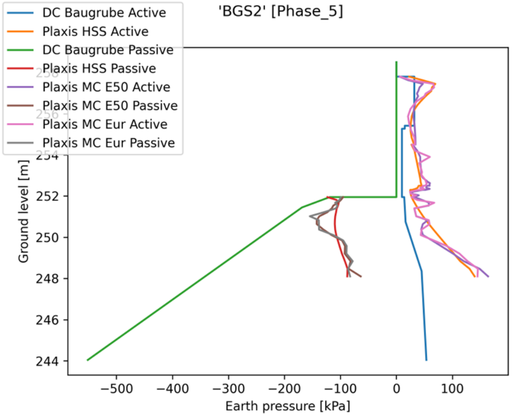


Figure 9. Earth pressure results comparison for Case 1.

Case 2, Diaphragm wall with 3 levels of props:

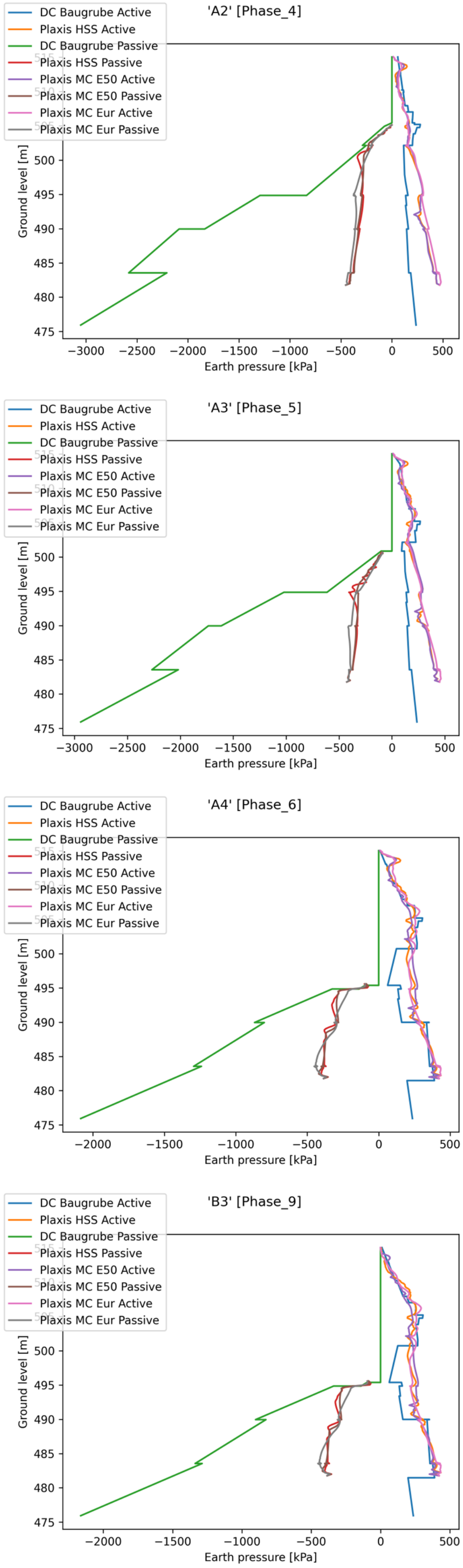


Figure 10. Earth pressure results comparison for Case 2.

Case 3, Bored pile wall with 5 level of props:

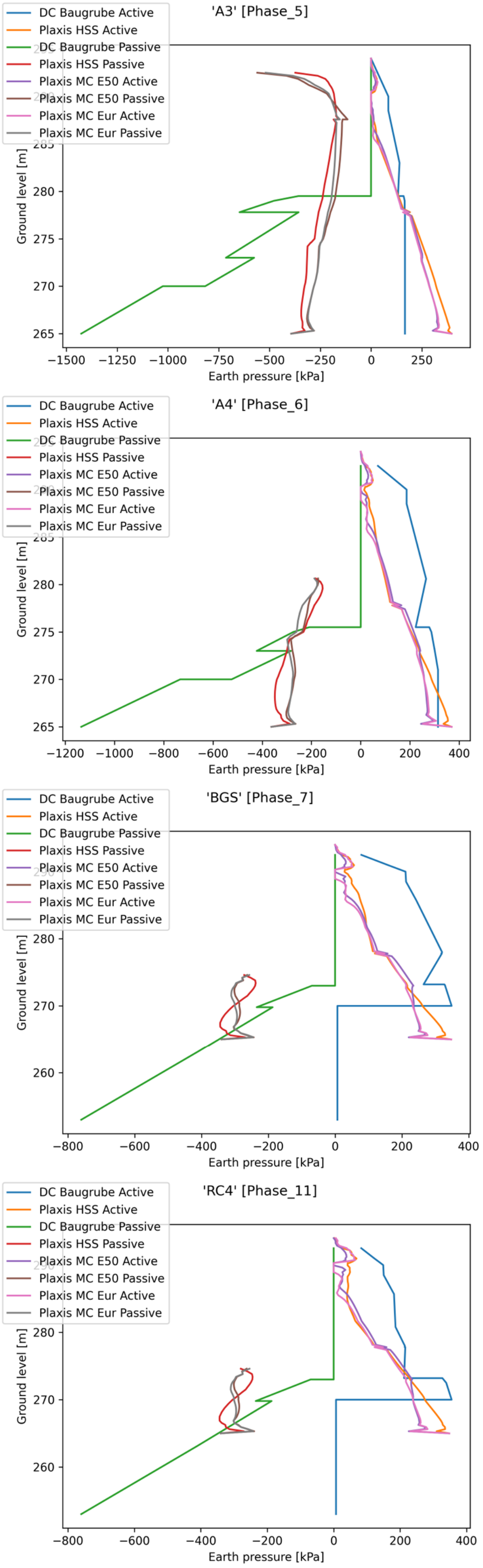


Figure 11. Earth pressure results comparison for Case 3.

Across the three study cases, earth-pressure envelopes from DC-Pit show piecewise transitions at soil-layer boundaries that reflect idealized active/passive assumptions. PLAXIS results, by contrast, evolve continuously with staging, exhibiting realistic arching and stress redistribution toward the toe and between support levels as plasticity develops and stiffness degrades. This behavior aligns with recent numerical investigations where FEM captured earth-pressure shifts and compatible wall deformation profiles that analytical methods could not reproduce without ad hoc adjustments (Jürgens & Henke 2024).

Moreover, the chosen constitutive law materially affects the pressure profile. HSS concentrate and release pressures in a way that tracks stiffness mobilization at small strains, producing lower peak pressures with more distributed support reactions relative to MC for the same geometry and phasing. This is consistent with studies showing HSS better matching monitoring data for both wall deflection and ground settlement, while MC (and by extension many analytical approximations) underestimates deformation demand and can misplace pressure resultants. Where adjacent assets are present, recent 2D/3D FEM case studies have validated parameter sets against instrumentation and demonstrated realistic pressure–deformation coupling across stages—capabilities that exceed what layerwise analytical approaches can deliver (Dahal et al. 2024).

5 DISCUSSIONS

The three case studies confirm a complementary but asymmetric role for the two approaches. Analytical calculations in DC-Pit are efficient for early sizing and rapid option screening; however, they cannot represent stress-dependent stiffness, unloading–reloading, or the stage-wise redistribution of actions. FEM in PLAXIS captures these effects naturally and therefore becomes essential whenever serviceability limits (wall deflection or ground settlement) control the design, stratigraphy is heterogeneous, or geometry/support layouts are nonstandard.

Across all cases, internal force envelopes (N, M, Q) from FEM variants were broadly comparable, whereas horizontal displacement (U_x) was strongly model-dependent. The practical implication is that the constitutive model and stiffness inputs dominate serviceability predictions, and calibration against investigation data should be prioritized.

Layerwise active/passive superposition in DC-Pit produces piecewise pressure diagrams with kinks at strata interfaces. The FEM solutions are continuous and evolve with each construction step, reflecting arching, plasticity, support activation, and toe restraint. This difference explains why internal actions may align while U_x diverges: pressure redistribution during phasing is captured by FEM but only approximated in analytical schemes.

6 CONCLUSIONS

Automation enables like-for-like comparisons. DCB2Plaxis tool transfers geometry, boundary conditions, groundwater levels, and construction phases 1:1 from DC-Pit to PLAXIS, eliminating manual re-modelling and allowing direct, auditable comparisons on real projects.

Analytical methods are expedient but intrinsically limited. They encode simplified pressure schemes and cannot represent soil stiffness nonlinearity, unloading–reloading, or stage-wise interaction. As a result, internal forces may be over- or under-estimated, and deformations are often unconservative, especially in flexible systems and heterogeneous profiles.

Constitutive model choice governs serviceability predictions. In FEM, HS-small consistently provide more realistic wall deflections and ground settlements than MC, which tends to be optimistic for movements. Selecting HS/HS-small is therefore recommended for serviceability checks, while MC may be reserved for early scoping.

Parameter quality matters as much as model form. Case studies highlight that action and deformation predictions are highly sensitive to stiffness inputs; calibrated parameters from site investigations should be used, and sensitivities run to bracket uncertainty—tasks that are straightforward in FEM and impractical with closed-form methods.

For deep or urban excavations, nearby structures, complex stratigraphy, or demanding serviceability limits, FEM is essential to capture earth-pressure redistribution and soil–structure interaction through staging. Recommended workflow for practice is the following: use DC-Pit for preliminary sizing and options, then verify critical variants in FEM via DCB2Plaxis, with HSS and parameter ranges reflecting site investigation data; where feasible, calibrate against monitoring.

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