



COMPARATIVE NUMERICAL ANALYSIS OF SURCHARGE EFFECTS ON A CANTILEVER SHEET PILE WALL IN STIFF CLAY

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Abstract: Cantilever sheet pile walls rely on passive resistance below the excavation level and are therefore sensitive to nearby surface loads. This study evaluates the combined effects of surcharge magnitude and distance on a 4 m deep excavation supported by a 9 m long steel sheet pile wall in homogeneous stiff clay. A two-dimensional plane-strain model was developed in PLAXIS 2D. The clay was represented by a drained Mohr-Coulomb model, while the wall was modelled as an elastic plate with interface elements on both sides. Uniform 4 m wide surcharges of 50 and 100 kPa were applied at normalised distances x/H of 0, 0.5, 1.0 and 2.0. A no-surcharge model was also analysed. The excavation was modelled as a staged construction process with four successive 1 m excavation stages, and stability was evaluated using the strength reduction method. When the 100 kPa surcharge started immediately behind the wall, the maximum wall displacement, maximum bending moment and excavation-induced surface settlement reached 31.0 mm, 107.3 kN m/m and 11.2 mm, respectively, while the factor of safety fell to 1.40. Moving the same load to $x/H = 2.0$ reduced the displacement and bending moment by 54% and 78%, and increased the factor of safety to 2.10. For the 50 kPa series, the wall displacement approached the no-surcharge condition once x/H reached 0.5, whereas the bending moment approached the reference value more gradually and became comparable at $x/H = 2.0$. The results show that increasing the surcharge distance substantially reduces wall deformation. However, the factor of safety remains lower than the no-surcharge value, even when the deformation response becomes comparable to the reference case.

Keywords: Cantilever sheet pile wall, Stiff clay, Surface surcharge, PLAXIS 2D, Bending moment, Factor of safety

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Received: July 15, 2026

Accepted: August 17, 2026

Published: September 15, 2026

Cite as: Turan, C. (2026). Comparative numerical analysis of surcharge effects on a cantilever sheet pile wall in stiff clay. *Black Sea Journal of Engineering and Science*, 9(5), 2621-2628.

1. Introduction

Cantilever sheet pile walls are widely used to support shallow and moderately deep excavations where anchors or internal props are impractical. Their lateral resistance is developed primarily through soil-wall interaction and the passive resistance mobilised along the embedded portion of the wall (USACE, 1994). In clayey ground, the stability of such walls is closely related to the mobilisation of soil shear strength and the wall embedment ratio (Keawsawasvong et al., 2023). Surcharge loads applied near the excavation can alter the stress state and the mobilisation of soil resistance, thereby affecting wall deformation, bending moment, ground movement, and overall stability (Debnath and Pal, 2023).

In urban excavations, the retained ground is frequently subjected to surcharge loads originating from adjacent buildings, foundations, traffic, stored materials, and construction equipment. Such loads increase the lateral stresses acting on the wall and may lead to greater wall displacement, bending moment, and ground movement. The surcharge effect is controlled not only by its magnitude but also by the width and location of the

loaded area, as these parameters govern the transmission of additional stresses through the retained soil towards the wall. Nandi and Choudhury (2022) showed that surcharge intensity, strip width, and distance from the wall significantly affect the response of embedded cantilever walls. Akan (2023) similarly reported that the distance of the surcharge from the wall can be more influential than its intensity and loaded width, particularly when the load is positioned close to the excavation.

Experimental evidence further demonstrates the importance of surcharge location. Aparna and Samadhiya (2020) observed that the adverse effects of a strip footing on the response of the model sheet pile wall were most pronounced when the footing was located within the active failure region. Both wall deflection and ground settlement decreased as the footing was located farther from the excavation face. Comparable trends have been reported in numerical investigations. Singh and Chatterjee (2020) found that wall deflection and ground settlement decreased with increasing surcharge distance, whereas both responses increased with surcharge magnitude. Debnath and Pal (2023) similarly reported



that wall deflection, bending moment, and ground settlement were greatest when the surcharge was applied close to the wall and decreased substantially with increasing distance from the wall.

Previous studies have addressed the analysis and optimisation of cantilever sheet-pile walls in cohesionless soils. For example, Babu and Basha (2008) developed a reliability-based optimisation framework for cantilever sheet-pile walls embedded in sandy soils. By contrast, studies focusing on walls embedded in clay remain relatively limited. Keawsawasvong et al. (2023) investigated the stability factors of cantilever sheet-pile walls in clay using the finite-element strength-reduction method, whereas Maitra and Singh (2026) developed a simplified analytical procedure for walls retaining cohesive backfill subjected to uniform surcharge loading. These studies highlight the combined importance of clay strength, wall embedment and surcharge loading. However, the simultaneous evaluation of wall deformation, bending response, ground settlement and global stability within the same staged-excavation model has received less attention. Such a comparison is important because serviceability and stability indicators may approach the no-surcharge condition at different rates as the surcharge setback increases.

The present study addresses this gap by investigating a cantilever steel sheet pile wall supporting a 4 m deep excavation in homogeneous stiff clay. To represent the long-term response to a sustained surcharge that is present before and throughout excavation, the clay is analysed under drained effective-stress conditions. Short-term undrained excavation behaviour is therefore outside the scope of the present study. A systematic numerical programme is conducted to quantify the combined effects of surcharge magnitude and distance from the wall. Surcharge pressures of 50 and 100 kPa are applied at four different setback distances, and a corresponding no-surcharge model is adopted as the reference case. This framework provides a consistent basis for directly comparing the influence of surcharge magnitude and setback distance. The response is evaluated in terms of maximum horizontal wall displacement, maximum wall bending moment, maximum ground-surface settlement behind the excavation, and global factor of safety. Particular attention is given to the rate at which these response measures approach the no-surcharge condition as the distance between the loaded area and the wall increases. The outcomes of the study reveal whether serviceability and stability responses diminish at comparable rates and provide a clearer basis for evaluating the placement of surcharge loads adjacent to cantilever-supported excavations.

2. Materials and Methods

2.1. Geometry and Boundary Conditions

The numerical model represented an unsupported cantilever wall in plane strain. The excavation depth was

$H = 4$ m and the embedded length below the excavation level was $D = 5$ m, giving $D/H = 1.25$ and a total wall length of 9 m (Figure 1). A 4 m excavation depth and staged excavation procedure are consistent with the representative cantilever wall model reported by Kawa et al. (2019). The selected dimensions also fall within the range commonly associated with cantilever sheet pile applications, which are generally used for excavations of limited height (Aparna and Samadhiya, 2020; Debnath and Pal, 2023).

The numerical domain was 40 m wide and 20 m deep. Approximately 25 m of soil was retained behind the wall and 15 m was located on the excavation side (Figure 1). The lateral boundaries were fixed in the horizontal direction and remained free vertically. The base was fixed in both horizontal and vertical directions. The domain was selected so that the main displacement field remained away from the lateral and lower boundaries.

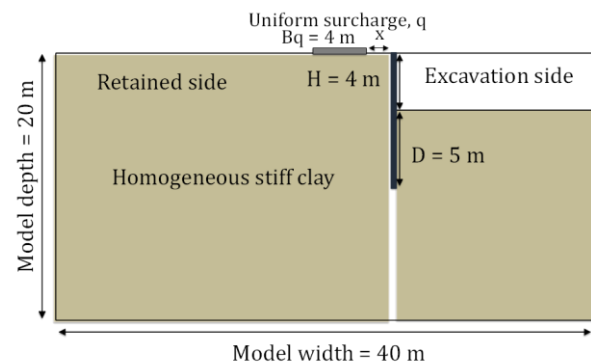


Figure 1. Idealised model geometry, boundary conditions and surcharge definition.

2.2. Soil Model and Parameters

The soil was idealised as a homogeneous stiff clay under drained conditions to represent long-term effective-stress behaviour. The Mohr-Coulomb model was adopted to provide a consistent and transparent framework for the parametric comparisons. The stiffness and strength values were selected by rounding the drained parameters reported for stiff Bangkok clay by Surarak et al. (2012). The same Mohr-Coulomb parameters were retained in all analyses to ensure that the observed differences resulted solely from surcharge magnitude and location. The adopted soil parameters are summarised in Table 1. No groundwater table was included in the model. The dilation angle was set to zero, which is appropriate for the idealised clay response considered here.

Table 1. Stiff clay parameters used in the numerical analyses

Parameter	Value
Unsaturated unit weight (γ_{unsat}) (kN/m ³)	17
Saturated unit weight (γ_{sat}) (kN/m ³)	19
Young's modulus (E) (kPa)	14,000
Poisson's ratio (ν)	0.35
Effective cohesion (c') (kPa)	30
Effective friction angle (ϕ') (°)	26
Dilation angle (ψ) (°)	0
Constitutive model	Mohr-Coulomb
Drainage condition	Drained

2.3. Sheet Pile and Soil-Wall Interface

The sheet pile was represented by an AZ24-700 S355GP steel profile rather than an equivalent reinforced-concrete wall. It was modelled as a linear-elastic plate element per metre width of wall. The plate properties were based on the AZ24-700 section used by Tornborg et al. (2023). The adopted normal stiffness, flexural rigidity, unit weight, and Poisson's ratio are listed in Table 2. Interface elements were assigned to both sides of the plate to allow relative movement and stress transfer between the steel wall and the clay. An interface reduction factor of $R_{\text{inter}} = 0.67$ was adopted on both sides of the wall, consistent with values used in previous PLAXIS studies of sheet-pile-soil interaction (Nguyen et al., 2023; Keawsawasvong et al., 2023).

Table 2. Sheet pile and interface properties

Property	Value
Normal stiffness (EA) (kN/m)	3.70×10^6
Flexural rigidity (EI) (kNm ² /m)	1.17×10^5
Unit weight of plate (w) (kN/m/m)	1.30
Poisson's ratio (ν)	0.20
Interface reduction factor (R_{inter})	0.67

2.4. Surcharge Cases and Construction Stages

A 4 m wide uniform surface surcharge was applied on the retained side. The distance x was measured from the wall to the nearest edge of the loaded strip. Two surcharge intensities, $q = 50$ and 100 kPa, were examined at $x/H = 0, 0.5, 1.0$ and 2.0 . For $H = 4$ m, these ratios correspond to distances of $0, 2, 4$ and 8 m, respectively. For the case designation, S denotes the surcharge condition, the following number indicates the surcharge intensity in kPa, and R represents the normalised surcharge distance, defined as $R = x/H$. For example, $S50-R0.5$ corresponds to a 50 kPa surcharge applied at $x/H = 0.5$, or $x = 2$ m (Table 3). A no-surcharge analysis was used as the reference. The same geometry, wall section, soil properties, mesh setting and excavation sequence were used in every case. This ensured that the comparisons isolated the effects of surcharge magnitude and distance. Initial stresses were generated using the K_0 procedure.

The surcharge was then activated and allowed to reach equilibrium. This sequence was intended to represent a pre-existing surcharge that was present before excavation and remained active throughout all excavation stages. The plate and interface elements were subsequently activated prior to excavation, without explicitly modelling the sheet-pile installation process. Displacements were reset after wall activation so that the reported surface settlements represented additional movement generated during excavation rather than settlement caused by the initial application of the surcharge. Excavation was carried out incrementally in four successive 1 m stages. The final excavation stage was followed by a strength-reduction analysis to determine the factor of safety.

Table 3. Analysis matrix showing the actual and normalised surcharge distances

Case	Surcharge q (kPa)	Distance x (m)	x/H
Reference	0	-	-
S50-R0	50	0	0.0
S50-R0.5	50	2	0.5
S50-R1	50	4	1.0
S50-R2	50	8	2.0
S100-R0	100	0	0.0
S100-R0.5	100	2	0.5
S100-R1	100	4	1.0
S100-R2	100	8	2.0

2.5. Mesh and Output Quantities

A very fine finite-element mesh was adopted throughout the study. As shown in Figure 2, local refinement was concentrated around the sheet-pile wall, the excavation zone and the surcharge area, where larger stress and displacement gradients were expected. The same mesh-generation settings were retained in all cases to ensure consistency among the analyses. Although a separate mesh-sensitivity study was beyond the scope of the present investigation, the adopted very fine and locally refined mesh provided a consistent basis for the comparative evaluation. The model dimensions were sufficient to prevent significant displacement contours from reaching the lateral and bottom boundaries. The principal service response quantities were the maximum horizontal displacement of the plate, the maximum absolute bending moment and the maximum downward surface displacement on the retained side. The factor of safety was obtained from the strength reduction analysis.

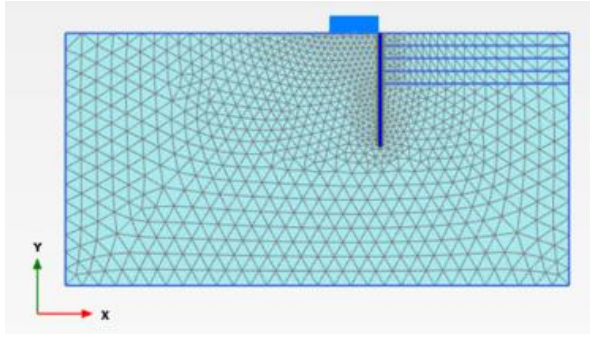


Figure 2. Finite-element mesh with local refinement around the sheet-pile wall and surcharge area.

3. Results and Discussion

3.1. Summary of numerical results

Table 4 presents the response quantities obtained at the final 4 m excavation stage for the reference model and the eight surcharge cases. To distinguish the effects of surcharge magnitude and distance, the wall displacement, bending moment, excavation-induced surface settlement and factor of safety are discussed separately in the following sections.

3.2. Maximum horizontal wall displacement

Figure 3 shows the variation of maximum horizontal wall displacement with normalised surcharge distance. For the 50 kPa series, the maximum wall displacement in S50-R0 was 17.2 mm, which was 21.8% greater than the no-surcharge value of 14.1 mm. In S50-R0.5, the displacement decreased to 14.0 mm. The values obtained for S50-R0.5, S50-R1 and S50-R2 differed from the reference value by less than 2%, indicating that the wall displacement had effectively reached a response plateau once x/H reached 0.5.

The 100 kPa series exhibited a substantially stronger response when the surcharge was located close to the wall. In S100-R0, the maximum displacement reached 31.0 mm, representing increases of 119.5% relative to the reference case and 80.2% relative to S50-R0. The displacement remained above the reference value in S100-R0.5, where it was 18.3 mm, but approached the no-surcharge response in S100-R1. No meaningful additional change was observed in S100-R2. These results indicate that the surcharge influence zone governing wall displacement increased with surcharge magnitude.

Table 4. Numerical results at the final 4 m excavation stage.

Case	Maximum wall u_x (mm)	$ M _{\max}$ (kN m/m)	$S_{\max}$ (mm)*	FoS
Reference	14.1	20.2	4.03	3.08
S50-R0	17.2	54.6	4.07	1.89
S50-R0.5	14.0	37.1	4.06	2.06
S50-R1	14.0	28.1	4.05	2.25
S50-R2	14.1	21.6	4.03	2.65
S100-R0	31.0	107.3	11.2	1.40
S100-R0.5	18.3	54.5	4.05	1.57
S100-R1	14.0	36.2	4.03	1.75
S100-R2	14.1	23.3	4.03	2.10

* $S_{\max}$ is the additional excavation-induced settlement after the displacement reset following wall installation.

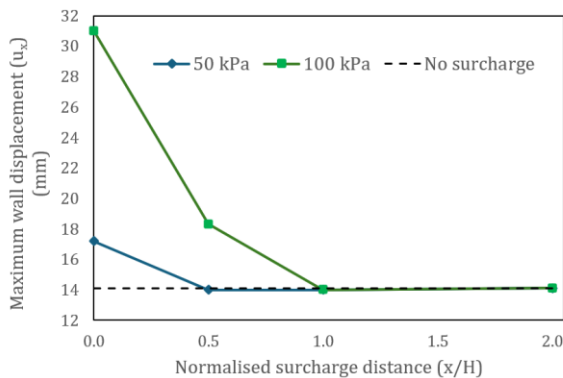


Figure 3. Variation of maximum horizontal wall displacement with normalised surcharge distance. The dashed line denotes the no-surcharge value.

The reduction in wall displacement with increasing surcharge distance agrees with the experimental

observations of Aparna and Samadhiya (2020) and with the numerical trends reported by Singh and Chatterjee (2020), Nandi and Choudhury (2022), Debnath and Pal (2023) and Akan (2023). The present results further demonstrate that the normalised distance required for the wall displacement to approach the no-surcharge response depends on the applied surcharge intensity.

3.3. Bending Moment Response

The maximum bending moment exhibited a stronger dependence on surcharge distance than the maximum wall displacement. In the 50 kPa series, the maximum absolute bending moment decreased progressively from 54.6 kN m/m in S50-R0 to 37.1, 28.1 and 21.6 kN m/m in S50-R0.5, S50-R1 and S50-R2, respectively. Moving the surcharge from $R = 0$ to $R = 2$ reduced the maximum bending moment by 60.5%. The moment in the adjacent surcharge case was 170.1% greater than the no-surcharge value of 20.2 kN m/m, whereas the farthest

case exceeded the reference by only 6.8%. Thus, the response of the 50 kPa series progressively approached the no-surcharge condition as the loaded strip was moved away from the wall.

A more pronounced distance-dependent reduction was observed in the 100 kPa series. The maximum absolute bending moment decreased progressively from 107.3 kN m/m in S100-R0 to 54.5, 36.2 and 23.3 kN m/m in S100-R0.5, S100-R1 and S100-R2, respectively. Moving the surcharge from $R = 0$ to $R = 2$ reduced the maximum bending moment by 78.3%. Relative to the no-surcharge moment of 20.2 kN m/m, the flexural demand in S100-R0 was 431.2% higher, while the value in S100-R2 remained only 15.3% above the reference. Notably, although the maximum wall displacement in S100-R1 had already approached the no-surcharge response, its bending moment remained 79.2% above the reference value. This finding indicates that the flexural demand approached the no-surcharge condition more gradually than the maximum wall displacement. The maximum bending moment in the 100 kPa series was 96.6% greater than that in the 50 kPa series at $R = 0$, but this difference decreased to approximately 8.0% at $R = 2$. The effect of

surcharge intensity on flexural demand therefore diminished as the loaded strip was moved farther from the wall.

Figure 4 presents the bending moment distributions along the wall. Despite the considerable differences in magnitude, the profiles retained a similar overall shape, and the peak moment consistently occurred close to the excavation level. The surcharge therefore amplified the existing flexural response without substantially changing the location of the peak moment or the general form of the distribution. Increasing R mainly reduced the magnitude of the moment over the wall length, with the distributions increasingly resembling the no-surcharge profile. This trend agrees with Nandi and Choudhury (2022), who demonstrated that surcharge intensity and distance affect the structural response of embedded cantilever walls, and with Debnath and Pal (2023), who reported a substantial reduction in bending moment as the surcharge, was positioned farther from the wall. It is also consistent with Akan (2023), who highlighted the importance of surcharge position in governing cantilever-wall response.

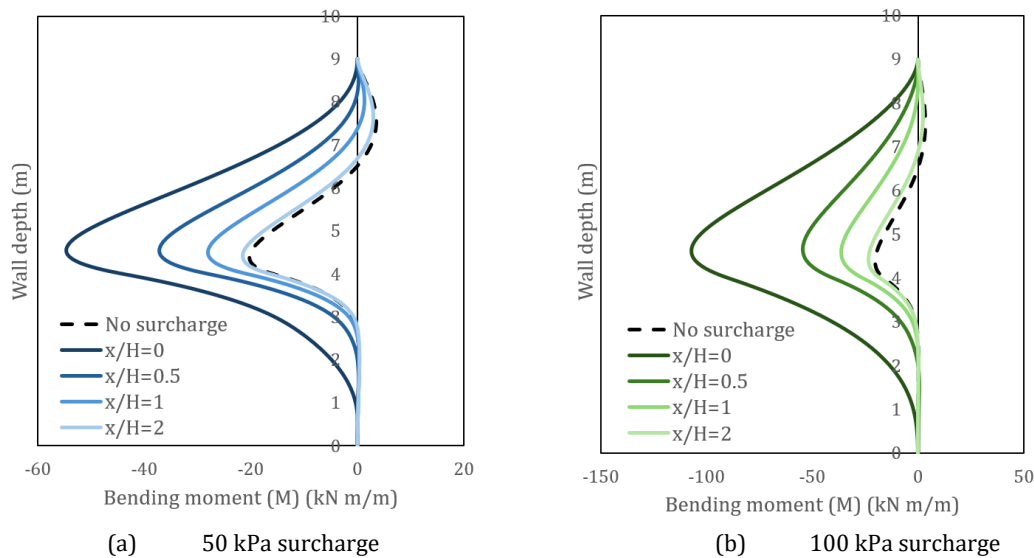


Figure 4. Bending moment distributions along the wall for the (a) 50 and (b) 100 kPa surcharge series.

3.4. Excavation-Induced Surface Settlement

Figure 5 presents the variation in maximum excavation-induced surface settlement (S_{max}) for the different surcharge cases. For the 50 kPa series, S_{max} varied only between 4.03 and 4.07 mm, with the maximum value obtained for S50-R0. The maximum deviation from the reference value was approximately 1.0%, indicating that the 50 kPa surcharge produced no appreciable change in the excavation-induced surface settlement, regardless of its position.

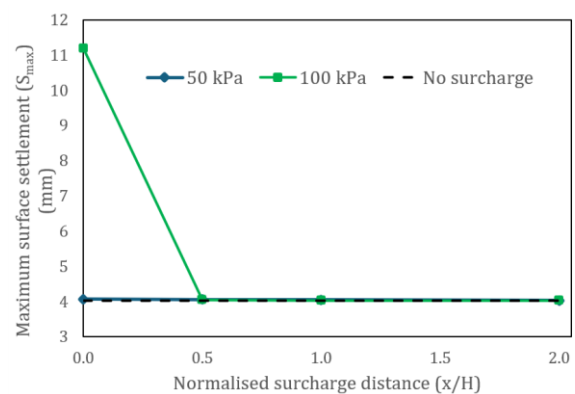


Figure 5. Variation of maximum excavation-induced surface settlement with normalised surcharge distance. The dashed line denotes the no-surcharge value.

A markedly different response was obtained for S100-R0, in which $S_{\max}$ reached 11.2 mm, approximately 2.8 times the reference value and substantially greater than the 4.07 mm obtained for S50-R0. Thus, increasing the adjacent surcharge from 50 to 100 kPa produced a disproportionately large increase in the additional surface settlement generated during excavation. This response suggests that the heavier surcharge in S100-R0 interacted more strongly with the excavation-induced deformation zone immediately behind the wall. Previous numerical studies have similarly shown that surcharge magnitude and position can significantly affect ground settlement and the deformation of cantilever sheet-pile walls, with the greatest effects generally occurring when the load is placed close to the wall (Singh and Chatterjee, 2020; Debnath and Pal, 2023).

Surface settlement returned to approximately the reference level over a shorter surcharge distance than wall displacement and bending moment. In S100-R0.5, $S_{\max}$ had already approached the reference value, whereas both wall response quantities remained above their corresponding reference values. A similar contrast was observed in the 50 kPa series. These results indicate that surcharge position had a stronger and more persistent influence on the lateral and structural response of the wall than on the maximum excavation-induced surface settlement. Accordingly, wall displacement, bending moment and surface settlement should be evaluated as distinct response measures (Debnath and Pal, 2023).

The reported $S_{\max}$ values represent incremental settlements developed during excavation while the surcharge remained active, rather than total settlements measured from the initial application of the surface load. Displacements were reset at the beginning of the excavation sequence (Bentley Systems, 2021). In field conditions, total settlement would comprise both the pre-excavation settlement associated with the surcharge and the additional settlement generated during excavation (Wang et al., 2022). For practical purposes, the reported $S_{\max}$ values should therefore be interpreted as excavation-induced increments rather than total field settlements. By excluding the pre-excavation displacement component, the adopted procedure provided a direct and consistent basis for comparing the excavation-stage effects of the 50 and 100 kPa surcharges. The settlement remained close to the reference value in all cases except S100-R0, where the adjacent 100 kPa surcharge produced a pronounced increase.

3.5. Factor of Safety

Figure 6 shows that the factor of safety increased consistently with surcharge distance for both load levels. For $q = 50$ kPa, FoS increased from 1.89 at $x/H = 0$ to 2.65 at $x/H = 2.0$. For $q = 100$ kPa, it increased from 1.40 to 2.10. The no-surcharge model remained the most stable case, with FoS = 3.08.

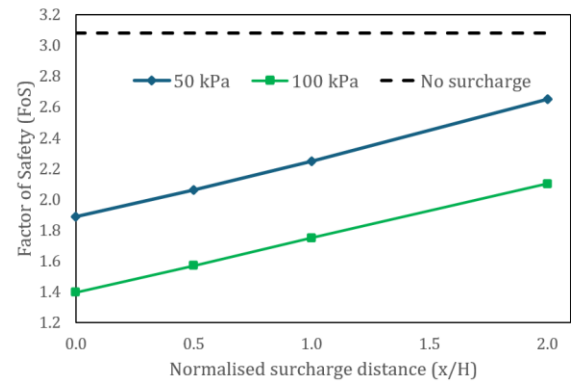


Figure 6. Variation of factor of safety with normalised surcharge distance. The dashed line denotes the no-surcharge value.

USACE (2003) indicates that a factor of safety of approximately 1.5 is typically regarded as a minimum acceptable value for slope stability under normal long-term loading conditions, although the appropriate value depends on the uncertainties involved and the consequences of failure. While this guidance was developed for slope-stability assessments, it provides a useful reference benchmark for interpreting the global strength-reduction factors obtained in the present analyses. Relative to this reference value, all cases except the 100 kPa surcharge applied immediately adjacent to the wall exhibited FoS values above 1.5. The FoS of 1.40 obtained for this case indicates a comparatively limited margin against instability and may therefore be regarded as a marginal stability condition. Moving the 100 kPa surcharge to $x/H = 0.5$ increased the FoS to 1.57, while greater distances provided progressively larger stability reserves. These results demonstrate that both surcharge magnitude and position strongly influence the available margin against overall instability. The observed trend is consistent with the mechanics of cantilever walls in clay. Passive resistance mobilised below the excavation level constitutes the principal stabilising mechanism, whereas additional loading on the retained side increases the driving action and reduces the available stability margin. Strength reduction analyses for cantilever walls in clay, such as those presented by Keawsawasvong et al. (2023), are therefore useful since they capture the complete soil-wall failure mechanism rather than relying on an individual structural response quantity.

3.6. Horizontal Displacement Contours

Figure 7 presents the horizontal soil displacement contours for the nearest and farthest surcharge positions at the final excavation stage. A common contour range was adopted for all cases to allow a consistent visual comparison of the displacement fields. The most pronounced response occurred when the 100 kPa surcharge was applied immediately adjacent to the wall. In this case, a localised high-displacement zone developed beneath the loaded surface and extended towards the wall and the excavation, accompanied by a

markedly steeper displacement gradient than in the other cases. This response is consistent with the direct influence of a near-wall surcharge on the deforming soil mass, as also observed in previous numerical investigations of surcharge-position effects on retaining-wall response (Debnath and Pal, 2023).

Moving the surcharge to $x/H = 2.0$ substantially reduced its influence on the displacement field. At this distance, the contours obtained for the two surcharge intensities became broadly similar, and the response was

concentrated mainly around the excavation and the embedded portion of the wall. This indicates that the deformation pattern in the far-field cases was governed predominantly by excavation-induced ground movement, whereas the adjacent 100 kPa surcharge directly intensified and extended the deforming zone. This case also corresponded to the lowest calculated FoS, indicating that the most pronounced service-stage deformation occurred in the case with the smallest stability reserve.

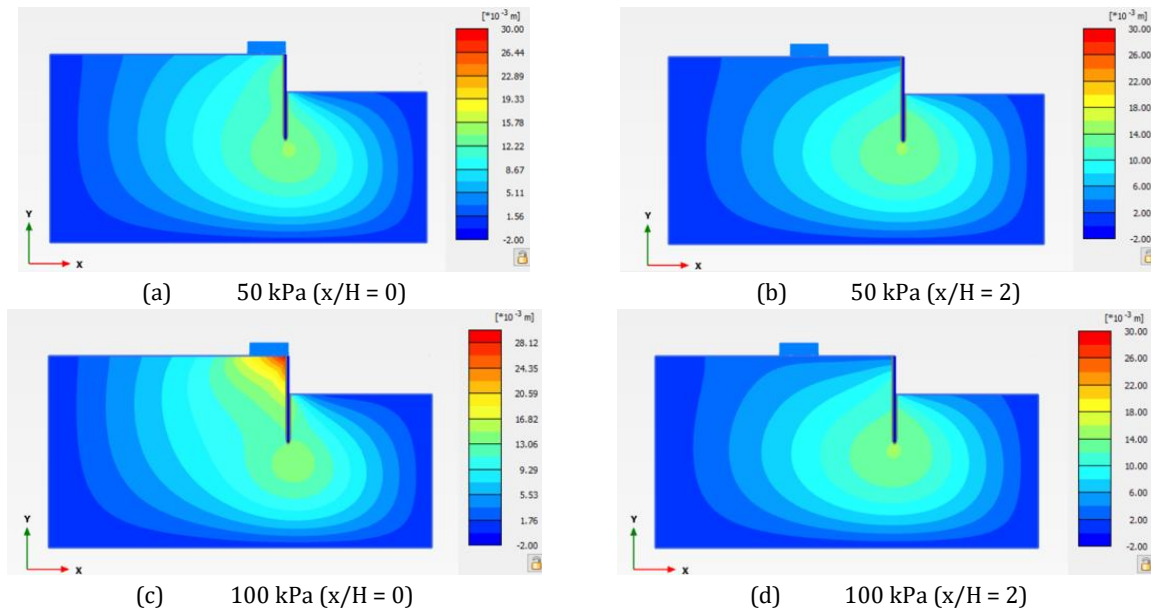


Figure 7. Horizontal soil displacement contours at the final excavation stage for the nearest and farthest surcharge positions: (a) 50 kPa, $x/H = 0$; (b) 50 kPa, $x/H = 2.0$; (c) 100 kPa, $x/H = 0$; and (d) 100 kPa, $x/H = 2.0$. A common contour range is used in all panels to facilitate direct comparison.

3.7. Practical Implications and Limitations

For the wall and soil conditions studied, locating the nearest edge of the surcharge at x/H of approximately 1.0 or greater was sufficient for the maximum wall displacement and excavation-induced settlement to approach the no-surcharge response. Bending moment also approached the reference condition with increasing distance, although it remained slightly above the no-surcharge value for both load levels at $x/H = 2.0$. The factor of safety remained below the reference value in every surcharge case. These observations indicate that, although increasing the surcharge setback substantially improves both deformation response and stability, the no-surcharge stability level is not fully recovered.

The numerical results are specific to the adopted wall geometry, clay properties and construction sequence. The assumption of a homogeneous clay profile and the exclusion of groundwater represent additional idealisations of the numerical model. Accordingly, the results should be extrapolated to layered deposits or groundwater-affected excavations with appropriate caution. In addition, the adopted Mohr-Coulomb model assumes constant stiffness and does not account for stress-dependent stiffness or enhanced small-strain

stiffness. The model was developed as a comparative parametric framework rather than as a calibration of a specific field or experimental case. Therefore, the absolute response values should be interpreted as model-dependent estimates, while the relative differences among the surcharge cases provide the primary basis for evaluating the influence of surcharge magnitude and position. Future studies may extend the present investigation by considering different soil profiles, groundwater conditions, wall geometries and surcharge configurations, as well as more advanced soil and interface modelling approaches.

4. Conclusions

This study aimed to evaluate the influence of surcharge magnitude and setback distance on the service response and stability of a cantilever sheet-pile wall in homogeneous drained clay. Based on the numerical analyses, the following conclusions were drawn:

- Surcharge position and magnitude strongly affected the wall response. The adjacent 100 kPa surcharge produced the most critical condition, with a maximum wall displacement of 31.0 mm, a bending moment of 107.3 kN m/m, a surface settlement of

11.2 mm and an FoS of 1.40. Moving the same surcharge to $x/H = 2.0$ reduced the wall displacement and bending moment by 54% and 78%, respectively, while increasing the FoS to 2.10. This demonstrates the substantial benefit of increasing the surcharge setback.

- The maximum wall displacement approached the no-surcharge response at approximately $x/H = 0.5$ for $q = 50$ kPa and $x/H = 1.0$ for $q = 100$ kPa. The bending moment decreased progressively over the full range of surcharge distances, indicating a more gradual sensitivity to setback.
- Except for the adjacent 100 kPa case, the excavation-induced surface settlement remained close to 4 mm, indicating that the additional settlement generated during excavation was limited for the remaining surcharge configurations.
- Increasing the surcharge setback substantially reduced deformation demand and improved stability. However, at $x/H = 2.0$, the wall displacement had nearly recovered to the no-surcharge response, whereas the FoS remained lower than the corresponding reference value. Deformation and strength-reduction results should therefore be considered together when assessing surcharge effects.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	C.T.
C	100
D	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100

C= concept, D= design, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required because this study did not involve human participants or animals.

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