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*Research Article*

# Settlement Analysis of Pipe Culvert Situated in Soft Clay Treated with Prefabricated Vertical Drains

**Adamu Beyene Negesa**

*Department of Civil Engineering, Jimma Institute of Technology, Jimma University, Jimma, Ethiopia*

Correspondence should be addressed to Adamu Beyene Negesa; adams.180@yahoo.com

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Engineering structures built on soft and compressible soils are often subjected to a long-lasting consolidation settlement. It is difficult to achieve an acceptable level of consolidation during the first few years/days of operation. Similarly, the culvert structure provided at station km 159 + 112 of the Awash-Kombolcha-Hara Gebeya Railway Project, Ethiopia, was situated along the route traversing soft clay ground of significant thickness. For the intention of reducing consolidation time and lessening the precarious impact of the postconstruction settlement, the soft clay ground was treated with preloading and prefabricated vertical drains. However, the culvert structure is currently undergoing consolidation settlement with varying magnitudes. The vertical deformation of the culvert site is monitored using settlement gauges installed at the site. Monitoring of the site continued for 120 days to track the extent of ground deformation at the culvert site. However, because of environmental and technical factors like calibration and alignment errors, the settlement instrument readings may be exposed to uncertainties, which may probably affect the safety of the culvert structure. Hence, the study is primarily aimed at evaluating the field deformation performance of the culvert structure for 120 days of the consolidation period through numerical analysis and comparing the result with the site settlement monitoring data. The critical effect of wick drain and some key parameters (fill thickness and wick drain spacing) were also scrutinized. Finite element-based numerical modeling was conducted by using the 2D GeoStudio/SigmaW package, and the Modified Cam Clay Constitutive model was adopted. The conducted numerical analysis revealed that the finite element result has good agreement with the field settlement monitoring data with only 0.0305 m maximum deviation in which the numerical analysis result remained greater for majority of the consolidation time. It can also be inferred that granular fill thickness and wick drain spacing were the key parameters impacting the settlement of the culvert structure.

## 1. Introduction

The compressible nature of soft soils makes them prone to geotechnical problems like bearing capacity failure, lateral displacement, and consolidation settlement. The low shear strength of these soils needs significant improvement as their natural bearing capacity is very low. These soft and compressible soils are also often subjected to long-term consolidation settlement because of the low rate of drainage experienced by the soils. Hence, in the past, developers had the option of passing over sites with soft and compressible soil conditions. This is done to overcome settlement problems encountered during the postconstruction phase as well as higher project costs incurred at the foundation level [1, 2].

Soft soils having poor engineering properties exhibit a large amount of long-lasting settlement, which is a threat to the stability of structures supported by these grounds. Despite the poor engineering performance of soft soils, an increasing need of construction necessitates direct usage of these grounds as foundation through applying any appropriate improvement technique rather than passing over sites with soft soil. In such cases, soil improvement techniques such as preloading with wick drains can be adopted to provide adequate bearing capacity, facilitate subsoil drainage, and minimize total and differential settlements encountered [3–6].

Similarly, some researchers [7–10] reviewed that preloading with prefabricated vertical drains is generally adopted to accelerate the rate of consolidation and to minimize settlement of the treated area under future dead and live loads. Preloading increases the bearing capacity of soil and also reduces the compressibility of weak ground by making the soil to consolidate. The drainage path is reduced by using prefabricated vertical drains so that the shortest path is taken by the pore water to dissipate. Likewise, in order to significantly reduce structural settlement in soft ground, the setting of pile foundations is also one of the most effective and feasible methods applied, especially when soft soil covers a narrow parcel of land [11, 12].

The prediction of settlements for embankments situated on soft soils is important to prevent the excessive settlement of the constructed structures within a shorter duration of time. Settlement of embankments over soft soils is a major problem encountered in maintaining railway facilities. The challenges to accurately predict the total and rate of consolidation settlements are partly due to the uncertainties in field conditions, laboratory testing, interpretations of laboratory test data, and assumptions made in the development of the one-dimensional consolidation theory. Hence, there is a need to investigate methods to better predict the settlement of embankments on soft soils by using numerical analysis. The settlement results obtained through site monitoring and from numerical analysis have to be compared to evaluate the safety of the structures resting on soft ground with regard to settlement [13].

The settlement analysis of soft soils by using an analytical approach is usually vulnerable to uncertainties. It is time-consuming and exhaustive in order to complete the settlement analysis of the soft soils covering large areas, especially in the presence of prefabricated vertical drains [13, 14]. Similarly, some scholars [13, 15] point out that field settlement measurements obtained through instrumentation systems installed at construction sites sometimes do not give the exact deformation value of soft soil or the structure overlying the soil. The reason is that the accuracy of these measurements is affected by environmental factors like temperature variation, humidity, and rainfall and technical problems like calibration and alignment errors on site. In relation to this, many scholars [16–18] pointed out that in the process of soft ground treatment by the drainage consolidation method, problems such as movement of fine particles with water flow and temperature variation directly affect the rate of consolidation.

To this end, it was reported [19–21] that it is technically advised if the designs and analyses made in areas of soft ground consider the empirical data not only from the field monitoring and analytical approaches but also from the numerical analysis results. Therefore, the current study is aimed at evaluating the deformation performance of a culvert structure situated on a soft clay foundation treated with a wick drain along with the Awash-Kombolcha-Hara Gebeya Railway Project, Ethiopia (station km 159 + 112) through conducting finite element-based numerical modeling. This could be carried out through a comparison of the numerical analysis results with the field monitoring settlement data. Besides, the significant effect of wick drain on the vertical deformation of soft soils will be assessed.

## 2. Materials and Methods

*2.1. Test Field and the Soil Formation.* The Awash-Kombolcha-Hara Gebeya Railway Project is under construction with the intention of connecting Awash and Hara Gebeya towns, covering a total length of 390 km. This research was conducted on the culvert structure provided at station km 159 + 112 of the project, with an approximate geographical location of 10°21′0″ N and 39°55′60″ *E*, which is about 274 km from Addis Ababa city (metropolis of Ethiopia). The ground formation of the area is composed of thick, saturated soft clay soils characterized by dark gray-black clay of more than 10 m in thickness on the surface, underlain by brown clay, and interrupted by rhyolitic rock outcrops. The dark clay is conspicuously thick at the specific study area (station km 159 + 112 of the project), with a groundwater table close to the surface. Hence, this segment of the route needs special concern and attention since the proposed culvert structure is situated within the route traversing the area predominantly covered with soft and compressible clay soils. The culvert was generally constructed on embankments overlying thick clay deposits treated with prefabricated vertical drains (wick drains) not to entirely discard the massive soft layer through the conventional excavation trend.

Removal of the extremely thick, unsuitable soft clay soil entirely through excavation is unpractical and not effective cost-wise. Therefore, special ground treatment with preloading and a prefabricated vertical drain was applied to the site ahead of starting the routine construction activities of the culvert. In relation to this, the soft clay soil was treated with vertically installed wick drains at a spacing of 1.3 m that can reduce the drainage path in a lateral direction and hence perpetuate the consolidation of the saturated soft clay soil before the construction gets started.

Groundwater was encountered at shallower depths in majority of the boreholes by the time soil site investigation was conducted. The standard penetration test result demonstrated that the culvert site in the study displayed high groundwater and more than 10 m of thick, soft, saturated cohesive soil deposits. As depicted in Figure 1, the groundwater table displayed at the time of boring is located at a depth of 1 m below the naturally existing ground surface. The geotechnical investigation conducted with the help of standpipe piezometers also revealed that there was no groundwater table fluctuation observed along the route. The model geometry considered for numerical simulation in this study is a direct implication of the existing vertical profile of the ground formation depicted in Figure 1. The standard penetration test result depicted in Figure 1 reveals the vertical profile of the soil formation at the culvert site over a depth of about 20 m with respect to penetration resistance. Within the stated depth of exploration, three layers of soil having similar origins (clay) were known to appear. As indicated, the resistance of the formation against penetration varies with the depth in which it undergoes an acute increase as depth increases. The top layer falls to very soft to soft clay, whereas the consecutive bottom layers have characteristics of silty clay to very stiff clay.

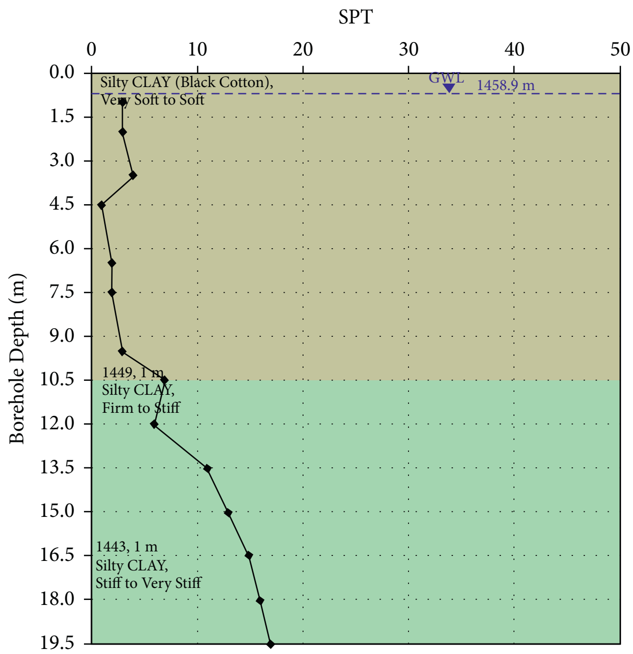



Figure 1: The soil profile at the culvert site, station km 159 + 112 (SPT vs. borehole depth).

*2.2. Culvert Site Monitoring.* Culvert site monitoring was done to scrutinize the extent and magnitude of excess movements and/or deformations encountered and to take appropriate preventive measures. It is a good management tool used to provide continuous feedback on the deformation progress of the soft clay foundation. At the culvert site, immediately after the accomplishment of granular material fill, the site monitoring was being carried out using an instrument called settlement gauge, which was installed at the culvert site. The construction site monitoring phase lasted more than 120 days by taking settlement readings on a weekly basis. In order to compensate for the lateral and vertical isotropy in the embankment fill and existing soft clay, measurements were taken at eight different representative points at the culvert site. The settlement gauge, installed near the culvert site, was used to read a fill settlement and deformation of the soft clay at a set time interval for all selected points. This study covers the model and simulation of soft clay with that of fill material layers in order to investigate the settlement and consolidation scenario that happened at the culvert site over the time duration of 120 days by using Coupled Sigma/W Analysis so that it remains possible to compare the numerical analysis result with that of field monitoring data.

### *2.3. The Numerical Analysis*

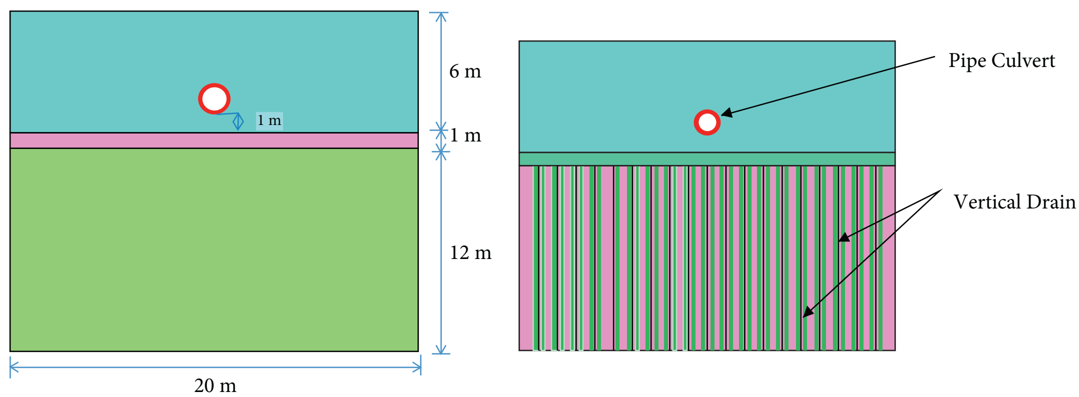
*2.3.1. Model Geometry.* The generation of the finite element model with Sigma/W begins with the creation of a geometry model, which is the representation of the problem of interest. Accordingly, the overall thickness of the soil model geometry considered for the simulation was 19 m tick by 20 m wide soil formation as depicted in Figure 2(a). In order to incorporate the effect of sequential loading of granular fill materials on the adjacent close vicinity of the culvert site, a wider soil zone was considered for the simulation of the model. The model geometry encompasses 12 m of thick, naturally existing, saturated soft clay soil, 1 m horizontal sand drain used to facilitate the horizontal water dissipation, and 6 m of naturally selected granular fill (as recommended for the construction).

The circular pipe culvert was provided within the granular fill material at a depth of 3.58 m from the top of the model geometry. Similarly, 1 m and 3.58 m of compacted gravel fill was provided below and above the pipe culvert, respectively. The pipe culvert provided at the site has an external diameter of 1.42 m and an internal diameter of 1.32 m with a surface thickness of 10 cm. The reinforced concrete pipe culvert provided is detected as a hollow structural beam floating over the soil region in the Sigma/W algorithm. The load induced by the culvert (self-weight) was manually calculated and entered as a stress boundary condition. The inelastic interface developed between the reinforced concrete culvert and the surrounding soft soil is detected by the mechanical and physical properties of the two materials. At the culvert site, the ground improvement technique using prefabricated vertical drains was undertaken. The sole purpose of this drain system is to shorten the drainage path of the pore water from a low permeable layer to the provided sand drainage layer, thereby accelerating the rate of primary consolidation or the process of settlement. Accordingly, prefabricated vertical drains of 12 m length were installed, which is up to the bottom end of the soft clay soil layer as illustrated in Figure 2(b). The wick drain installation was situated in a square pattern with a center-to-center spacing of 1.3 m. Material properties of the soil layers used for the numerical modeling are included in Table 1. Besides, Tables 2 and, 3, respectively, represent the specifications of a pipe culvert and wick drain materials.

*2.3.2. The Analysis Process.* For the numerical analysis taken in this study, a Geostudio (Sigma/W) finite element package was used. The plane stress 2D element was adopted in the finite element program to simulate the soft soil improved with wick drain, granular fill, and the pipe culvert as well. The Modified Cam Clay Constitutive model was applied for simulation of the soft clay layer, whereas the Mohr–Coulomb Soil model was applied to simulate properties of the embankment fills (granular fill and sand drain).

Basically, three different analyses were made in this study to simulate the soil mass properties which are as follows: (a) in situ analysis to establish initial stress conditions, (b) load-deformation analysis to simulate fill placement, and (c) coupled analysis to simulate the generation and dissipation of excess pore-water pressures in addition to deformations.

In this study, the in situ analysis that is formulated specifically for establishing the initial stresses and strain conditions was undertaken for the existing soft clay of twelve meters thick. This was done because most classes of problems will require initial stresses before proceeding with a load-deformation or coupled stress and strain. The initial stresses are only the result of gravity and represent the




(a) (b)

Figure 2: (a) The overall dimension of the soil model geometry considered for the numerical analysis. (b) Illustration of installed perforated vertical drain and the circular pipe culvert.

Table 1: Material properties used for the numerical model.

| Parameters | Soft clay | Sand drain | Gravel fill |
|---|---|---|---|
| Elastic modulus (MPa) | 6 | 30 | 80 |
| Poisson's ratio | 0.45 | 0.30 | 0.25 |
| Friction angle ($^{o}$) | 0 | 36 | 40 |
| Cohesion (kPa) | 40 | 0 | 0 |
| Dilation angle ($^{o}$) | 0 | 6 | 10 |
| Unit weight (kN/$m^3$) | 16 | 18.6 | 20 |
| Coefficient of permeability (m/s) | $10^{-7}$ | $10^{-6}$ | $10^{-4}$ |
| Compression index, $C_c$ | 1.3 | — | — |
| Recompression index, $C_r$ | 12 | — | — |
| Slope of critical state line, M | 0.179 | — | — |
| Lambda, $\lambda$ | 0.1486 | — | — |
| Kappa, $\kappa$ | 0.00956 | — | — |
| Initial void ratio, $e_o$ | 0.351 | — | — |
| Layer thickness (m) | 12 | 1 | 6 |

Table 2: The material properties of the pipe culvert.

| Parameters | Values |
|---|---|
| External diameter, $D$ (m) | 1.42 |
| Internal diameter, $d$ (m) | 1.32 |
| Elastic modulus, $E$ (GPa) | 40 |
| Cross-sectional area, a ($m^2$) | 0.2152 |
| Moment of inertia, MI ($m^4$) | 0.1012 |
| Thickness, $t$ (m) | 0.1 |

Table 3: Specification of the installed wick drains.

| Drain parameters | Values |
|---|---|
| Spacing, Ds (m) | 1.3 |
| Length (m) | 12 |
| Diameter of drain influence zone, $D$ (m) | 1.469 |
| Thickness of the drain (m) | 0.068 |
| Average discharge capacity ($m^3$/year) | 157 |

equilibrium state of the undisturbed soil. Hence, the initial stresses considered were the self-weight of the soil and groundwater.

For the modeling done in this study, there were two layers of fill material considered, the sand drain and the gravel fill (twelve consecutive fills 0.5 m each), in addition to the wick drain and reinforced concrete pipe culvert. During the placement of these fill layers and pipe culvert, there was also a gradual increase in the imposed load, resulting in both lateral and vertical deformations of the foundation soil. The load-deformation analysis was done since there is an applied load of fills resulting in stress changes and displacements, as long as its primarily use is for simulation of fill placement and excavation construction procedures. In the case of a fill placement analysis, the weight of the fill was added to the model on the first load step that each fill layer is activated. Similarly, the coupled stress-pore pressure analysis was done by combining Sigma/W and Seep/W together in order to simulate both the soil mass deformation and the pore water pressure change. The coupled analysis enables solving of basic consolidation problems along with stress magnitudes developed because of loading. In this analysis, the seepage analysis is solved independently of the volume change analysis. The incremental change in pore-water pressures from the seepage solutions is used at each load step in the stress-deformation calculation in order to determine the change in effective stresses.

Regarding the numerical discretization, the GeoStudio algorithm ensures mesh compatibility within a region and for the most part ensures mesh compatibility across adjacent regions. It is possible to alter the size of the elements at a global level for the entire mesh, within any one or more regions, or along a line or around a point. Mesh density can also be specified as a real length unit, as a ratio of the global mesh size, or as the number of divisions along a line edge. Mesh size and density are the major factors contributing to the precision and accuracy of analyses in finite element-based modeling. In relation to this, the finer and denser meshes of unstructured type (quad and triangle mesh) were used immediately in the region surrounding the pipe culvert and medium-sized meshes of structured type (rectangular grid of quads) were used in the remaining regions.

*2.3.3. The Staged Construction Analysis.* The construction process of the culvert site encompasses a number of consecutive phases. For the finite element modeling made in this study, the whole culvert site construction work was divided into a number of stages just for the purpose of incorporating the effect of staged embankment loading. Accordingly, modeling of all phases of construction which is related to the sequential placement of each material layer was made to the necessary detail. As part of the culvert embankment, the 1 m thick sand drain and a total of 6 m thick granular fill with 12 cycles of fill placement (0.5 m each) were undertaken. The construction of the permanent embankment fill and surcharge loading was completed in a sequential process.

In order to simulate the field conditions, the permanent embankment load was modeled as a rectangular loaded area, considering the lateral fixation of the model geometry. The fill history was entered as a time and magnitude of the load, with the maximum magnitude equal to the unit weight of the fill multiplied by the fill height of each layer. Eventually, the surcharge was placed on top of the design fill so as to facilitate the rate of water dissipation from the soft clay.

## 3. Results and Discussion

*3.1. Comparison of the Finite Element Results with the Field Measurement Data.* The main aim of the study is to investigate the settlement performance of the culvert structure through numerical modeling and validate the results with field monitoring data. The field settlement monitoring data was obtained via the settlement gauge installed at the culvert site. The finite element result revealed that during the second thirty days of the consolidation process (from $30^{th}$ to $60^{th}$ day), the rate of vertical deformation observed in the soft clay was comparably larger. The slope of the vertical deformation vs. duration graph was observed to be steeper, which implies that there was a rapid dissipation of water from the soft clay during the referred time duration. However, the vertical rate of settlement was moderate during the first thirty days and during the last two months, with an indication of a gentle settlement time graph.

This has an implication that during the first month of the consolidation process, there was slow dissipation of pore water from the soft clay, resulting in a low rate of vertical settlement.

As illustrated in Figure 3, for the first thirty days of the consolidation process, a good agreement between the obtained numerical analysis results and the field measurement data was observed. However, for the remaining time duration, a little discrepancy between the results was considered, in which the numerical modeling settlement result remained greater with an average difference of 0.0095 m. The finite element analysis indicated that the maximum amount of vertical settlement encountered in the soft clay was 0.0453 m, whereas the field monitoring data revealed that the maximum settlement read from the settlement gauge at the center of the railway was 0.0324 m. Even though the difference between the two cases is insignificant, the conducted comparison guarantees the reliability of the field monitoring settlement data. Besides, the combined analysis of numerical model and field measurement data obviously helps to make timely and feasible engineering decisions. The findings of the study can apparently be an input for the decisions made by the project stakeholders regarding the deformation of the clay foundation as well.

Deviation between the finite element method and field monitoring data with time is depicted in Figure 4. For majority of the considered consolidation duration, the numerical analysis result remains greater than the field measurement data.

However, the finite element settlement result fell below the field data during the third and fourth weeks of the consolidation time, and hence, the deviation remained positive, ranging from 0.000098 to 0.000653 m. This does not mean the loaded area undergoes upward deformation; rather, the entire zone was subjected to preloading and dead load experienced downward vertical deformation. Likewise, the deviation of the two cases ranges between -0.000377 and -0.0305 m for the remaining consolidation time. It can be inferred that the most significant deviation in values of vertical deformation between the two scenarios was recorded during the last week of the second month.

*3.2. Effect of Wick Drain on Vertical Deformation of Soft Clay.* The effect of prefabricated vertical drains on magnitude of vertical deformation of soft clay soils was clearly investigated. Simulation was made for both the soft clay soil improved with wick drain and the soft clay soil in the absence of wick drain by leaving other input parameters unaltered. The soft clay soil improved with wick drain underwent larger settlement than the soft clay soil not treated with wick drain.

As presented in Figure 5, the settlement of the soil mass near the pipe culvert overlying the soft clay layer improved with wick drain is much greater than the settlement that occurred when wick drain is not provided. This happened since the provision of wick drain leads to rapid dissipation of pore water from the soft clay soil and hence enforces the compression and settlement of the soil under loading. Accordingly, the maximum vertical deformation that resulted immediately below the pipe culvert (at the top of the sand drain) when using wick drain and in the absence of wick drain was 0.096 m and 0.064 m, respectively. For the soft clay soil to undergo 0.02 m vertical deformation, it takes twelve

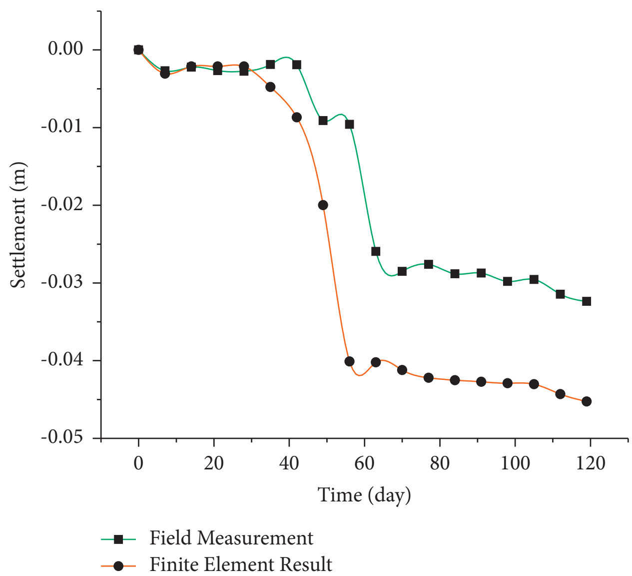



Figure 3: Comparison of site monitoring settlement data with the finite element result.

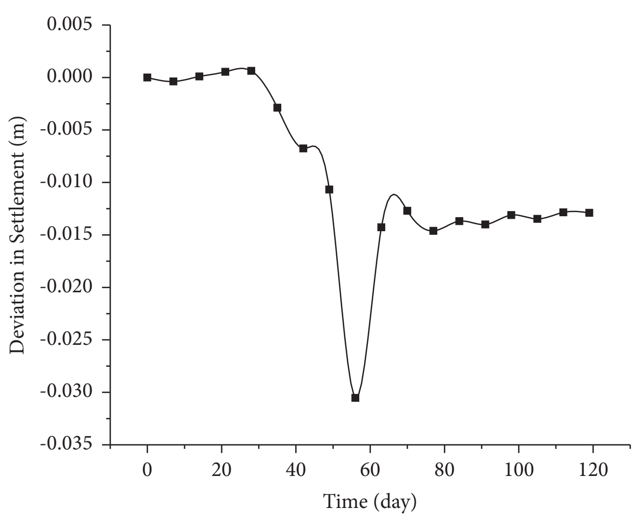



Figure 4: Deviation between the finite element and field measurement data.

consolidation days in the absence of wick drain, whereas only three days are required when the clay soil is treated with wick drain. Similarly, for the soft clay soil to undergo 0.062 m vertical deformation, it takes seventy-five and forty-three consolidation days in the absence of wick drain and when using wick drain, respectively. Accordingly, during the considered consolidation period (one hundred twenty days), eighteen consolidation days were saved on average because of using wick drain. This has the implication that the soft clay treated with wick drain undergoes certain settlement value just eighteen days ahead of the soft clay foundation without wick drain. This finding is in good agreement with the work of [5] in which the properties of soft soil using preloading and prefabricated vertical drains were investigated. As a result, they concluded that the provision of prefabricated vertical drains at effective spacing plays both reinforcing and drainage

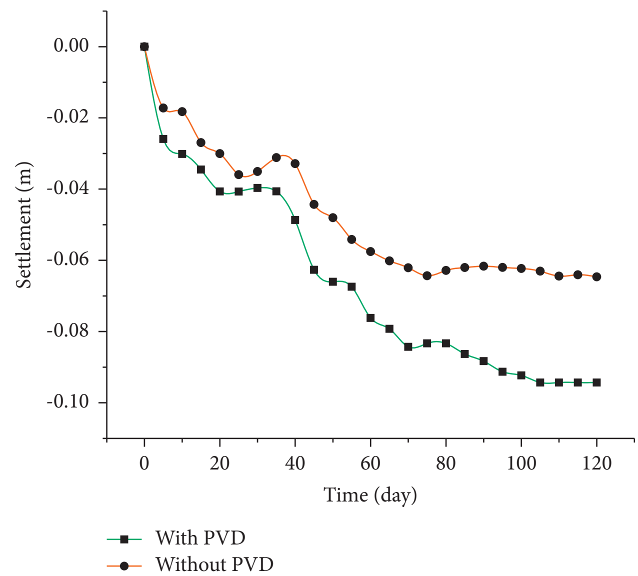



Figure 5: Settlement illustration (at a depth of 6 m) with and without wick drain.

roles in clay ground. However, the installation of a wick drain requires immense care since its efficiency directly depends on the spacing, installation mechanism, drain diameter, and treated depth of clay soil.

*3.3. Effect of Granular Fill Thickness.* To investigate the effect of fill thickness on the vertical deformations, three different fill thicknesses were considered for settlement that occurred around the periphery of the pipe culvert. The clear effect of granular fill thickness on vertical deformation of the culvert was hence investigated by varying the fill thicknesses and keeping the remaining parameters fixed. Figure 6 reveals that the amount of settlement observed in the model geometry decreases from the top to the bottom of the soil geometry depth-wise. Besides, as the thickness of the granular material fill increases, there is also an increment in the magnitude of settlement at different depths within the soil model geometry. When using 4 m, 5 m, and 6 m thick granular fills, the resulting maximum vertical deformations at the middle of the soft clay layer were 0.0330 m, 0.0381 m, and 0.0452 m, respectively, whereas the corresponding maximum settlements at the top of the granular fill were 0.085 m, 0.095 m, and 0.1 m, respectively. In the analysis of the effect of fill thickness on the rate of consolidation, the critical influence of fine particle migration on the efficiency and effectiveness of drains should not be undermined as its effect is so significant. Even though not dealt with in this study, the adverse impact of fine-grained particles' flow significantly affects drain efficiency and consolidation rate as well. According to [4], the interference of fine-grained soils hinders dissipation rate of pore water from low-permeability soil like clay. The particles migrate and fill up the flow pores, which leads to the possibility of fully blocking flow paths through time. Similarly, some scholars in [22, 23] pointed out that the suspension and solubility of fine particles is actually a factor of the nature of the constituent chemicals in the clay soil.

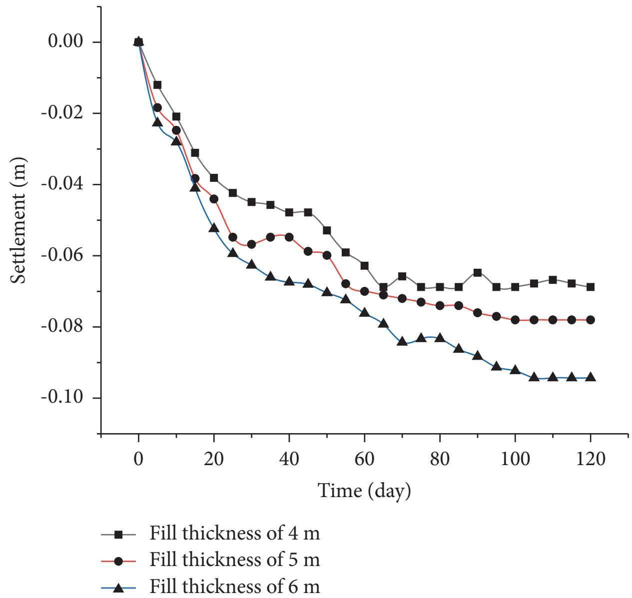



Figure 6: Settlement at the periphery of the pipe culvert (0.40 m below the pipe) for varying granular fill thicknesses.

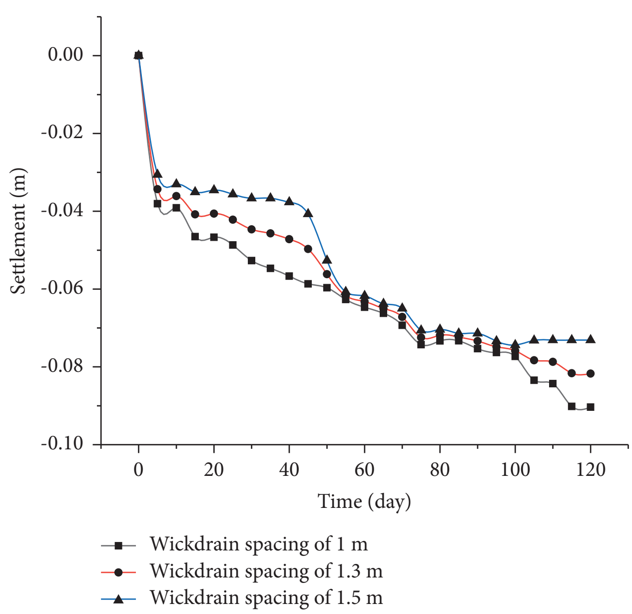



Figure 7: Effect of variation in PVD spacing on rate of consolidation of the clay soil.

*3.4. Effect of Wick Drain Spacing on Vertical Deformation.* In order to investigate the effect of wick drain spacing on vertical deformation and rate of consolidation, simulation was made for wick drain spacing of 1 m, 1.3 m, and 1.5 m by keeping other input parameters constant. Provision of a wick drain within soft clay is basically required to perpetuate the consolidation process of the soft clay soil. An increment in the spacing of the wick drain decreases the rate of consolidation of the soft clay soil, and hence, the consolidation process takes a long time to be accomplished. Besides, the vertical deformation that takes place within the soil mass would be long-lasting and gradual. As observed from Figure 7, the settlement magnitude of the three graphs shows a clear disparity in which larger deformation was observed when using 1 m spacing of the wick drain. This happened since the close placement of drains perpetuates the dissipation of water, as the main aim of using a wick drain is to reduce the drainage path within the soft clay. In addition, it was revealed that the maximum settlements encountered at the top of soft clay soil for wick drain spacing of 1 m, 1.3 m, and 1.5 m were 0.09 m, 0.081 m, and 0.076 m, respectively. This finding is visibly in line with the finding of [24] in which the consolidation rate of clay soil was analyzed for flexible pipes (drains) installed at a spacing of 1 m, 1.3 m, and 1.5 m. The resulting consolidation settlement was fastest of all for the drain spacing of 1 m and slowest for the drain installed at a spacing of 1.5 m.

## 4. Conclusion

During the considered site monitoring period (120 days), the magnitude of settlement occurred at the end of the 120 days when using the wick drain was less than the deformation witnessed in the absence of wick drain. In the first case scenario, any arbitrarily required deformation magnitude was basically achieved 18 days earlier (on average) than the latter one, which indicates 15% reduction in consolidation time. During the design and installation of wick drains in soft clay foundations, some of the essential factors to be given great consideration are the spacing at which the drain is installed and the thickness of the granular material fills. The closer the drains installed and the thicker the granular fill, the more rapid the rate of consolidation will be. Furthermore, a comparison made between the field settlement monitoring data and the numerical analysis result indicated that both results have good agreement with each other, showing the maximum and average difference of 0.0305 m and 0.00098 m, respectively, in which the numerical analysis result remained greater for majority of the considered consolidation time. Lastly, the development of good agreement between the culvert site monitoring and numerical analysis results can be a preliminary way to avoid a fear of overestimation or underestimation of the data generated from settlement gauges [25].

## Data Availability

All the data used to support the findings of this study are included in the manuscript.

## Conflicts of Interest

The author declares no conflicts of interest.

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