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The comparison of the safety zone in the vicinity of marine clay treatment areas with and without surcharge and vacuum preloading

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ABSTRACT

One of the important parameters that should be considered in designation of weak clay and peats treatment systems is the influence zone wherever there are infrastructures or sensitive buildings in the vicinity of the treatment area. Since large vertical and horizontal displacements occur in these treatment systems, the soil around the project undergoes large strains that should be accounted for in project planning prior to finalization of the treatment system. The treatment systems for weak clays and peats are often a combination of prefabricated vertical drains plus vacuum and/or surcharge preloading. For investigation of the impact of preloading agents, and FEM simulation of two case histories were performed. One the project incorporates the combination of surcharge and vacuum preloading while the other one consisted of only vacuum preloading without surcharge embankment. Based on the verified models, different scenarios were introduced for comparison of impact of the vacuum and preloading agents on the magnitude of the influence zone. Regarding the impact of surcharge embankment, it was shown that reducing the height of surcharge can drastically reduce the influence zone in both numerical simulations. The application of vacuum preloading as the only preloading agent has decreased the influence zone drastically and for urban areas or places that sensitive infrastructures exist might be an ideal option for similar cases. Regarding the impact of magnitude of vacuum pressure on the influence zone it was shown that application of a stable high vacuum pressure can significantly reduce the diameter of the influence zone. For every project that includes the treatment of weak clay or peat stratums, based on the material and sensitivity of nearby structures and infrastructures, the maximum allowable strains should be determined prior to designation of the treatment system to avoid unpredicted damage by qualified consultants.

1. Introduction

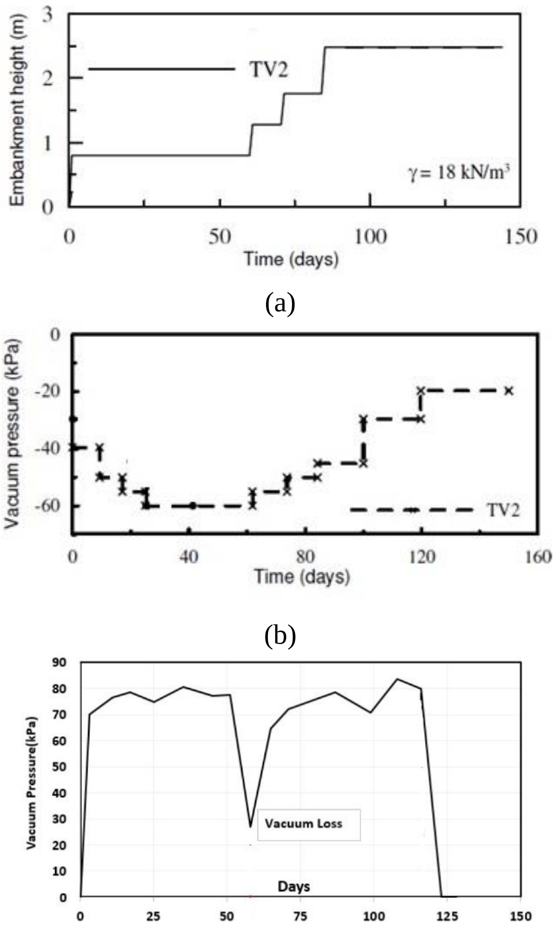
Due to the rapid propagation of urban areas and industrial facilities especially in coastal regions and places that were considered unsuitable before for any kind of construction, the treatment and reinforcement of weak soil stratums becomes an evitable part of the development plans[2, 3]. Marine weak clays and loose peats are two common types of soils that are mostly encountered. One of the popular methods for treatment of such soils is the application of PVDs and vacuum and surcharge preloading. The systems are a combination of all these methods and sometimes each one of them individually. As a result of huge vertical and lateral displacements that occur in such treatment systems, one of the important issues that should be considered along with the efficiency of such systems is the existence of sensitive infrastructures and structures, especially in urban areas where there is a condensed volume of pipelines and cables. Based on the material and tolerance of such pipelines or trenches, the maximum allowable shear strains should be determined prior to the designation of the treatment system. Based on the allowable strains, the influence zone can be determined by FEM or analytical approach.

Nguyen et al [4] performed a finite element analysis for analysis of a treatment system that incorporates vacuum and surcharge preloading as the remediation agent, for determination of the influence zone for a project where cracks were observed in the vicinity of the treatment area. Tashiro et al [5] constructed a test embankment for the investigation of large deformation that could have occurred in construction of the main embankment and ran a coupled soil-water analysis for prediction of deformations. The field data and simulations were used for planning counter-measures in the designation of the main embankment. Liu et al [6] proposed a direct relationship between maximum value of the lateral displacement (ELD) and the distance from the treated area boundary, considering the length of the prefabricated vertical drain for estimation of influence zone in treatment incorporating vacuum preloading for a case study. Since every project has its own unique specifications, the proposed relation by [6] can only give a firsthand estimation as they themselves announced and more precise calculation should be done prior to the finalization of the design process.

In this paper a FEM approach is applied for the investigation of the impact of surcharge embankment and vacuum preloading on the diameter of the influence zone for soil treatment systems. Two case studies were modeled and verified and based on these models various scenarios were introduced for comparison of various combinations of incorporating parameters on the influence zone.

2.Material and Methods

Two case histories are introduced and verified in order to investigate the effect of the surcharge and vacuum preloading on the diameter of the safe zone in the premier of treatment area. The first case history is the TV2 test embankment that was built in international Bangkok airport for the investigation of vacuum preloading along with PVDs and surcharge. The second one is the soil treatment project that was accomplished for the construction of a residential complex that was situated beside the coastal area using PVDs and vacuum preloading. Both case histories were constructed on weak stratums of weak Bangkok clay that is very unsuitable for infrastructure construction issues as a result of low shear strength[1, 7]. In both mentioned case histories, the soil treatment was inevitable. For Bangkok airport the combination of vacuum and surcharge preloading was used, while in the residential complex project only vacuum preloading was used and there was no surcharge embankment[8]. Since the surcharge preloading was absent in one the case histories, it was used as a measure to investigate the effect of surcharge preloading on safe zone perimeter. The procedure of finite element (FE) modelling is complex and was done by the authors in Pardsouie et al [9, 10] that can be accessed by readers for detailed information. More details and specifications regarding TV2 test embankment and the residential complex construction and instrumentation can be accessed in Bergado et al [11, 12] and in chaiyaput et al [7]. Fig 1a and 1b shows the application of surcharge and vacuum preloading in TV2 and fig 1c shows the application of vacuum preloading in residential complex vs time.



(c)

Figure 1. (a) the sequence of the construction of TV2 embankment vs time (b) the application of vacuum preloading in TV2 vs time (modified after [13]) (c) the application of vacuum preloading in residential complex vs time (modified after [8])

Fig 2 shows the soil profile section of the TV2 embankment.

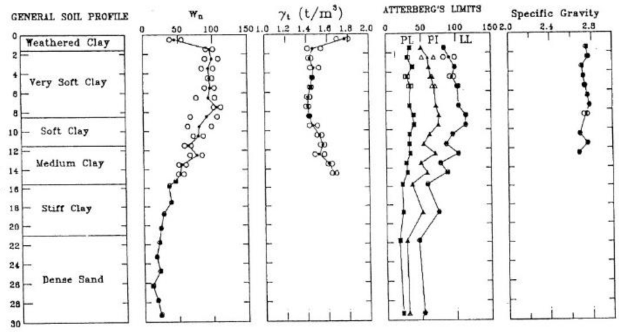
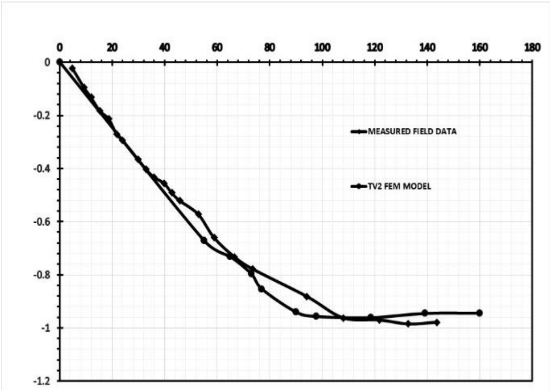
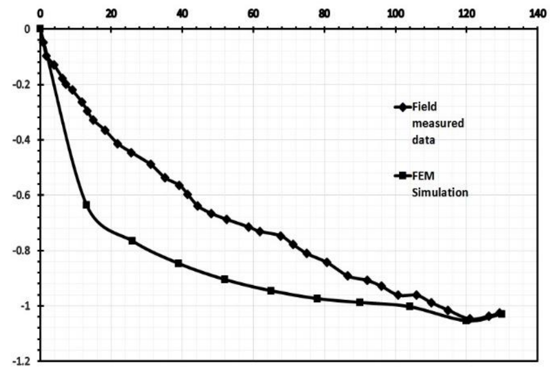


Figure 2. soil profile and a brief geotechnical properties of Bangkok airport treatment area (after [11])

Figure 3 shows the verifications of the FEM models vs measured data of the settlements in the field for both case histories (measured data from [8, 13]. As it can be seen for the residential complex the FEM model over predicts the settlement quantities where the final settlement was estimated correctly. This might be attributed to the delay stress transferred for fine grained soil that were reported by [14-16]. Since the mechanism of the transference of vacuum preloading to the soil structure is completely different from surcharge embankment, the inaccuracy of the hydraulic modifier function as stated by [10] might also be the reason for overestimation of the settlement curve.



(a)



(b)

Figure 3. the verification of the two case histories FEM models for settlement vs time (a) TV2 after 160 days (b) residential complex after 130 days

Based on the verified TV2 FEM, simulations were carried out for different situations as the cases with surcharge and PVDs, vacuum preloading and PVDs, and the case with the application of an ideal constant 60 kPa vacuum preloading for comparison of the different scenarios. Fig 4 shows the schematic view of the TV2 model used in the analysis.

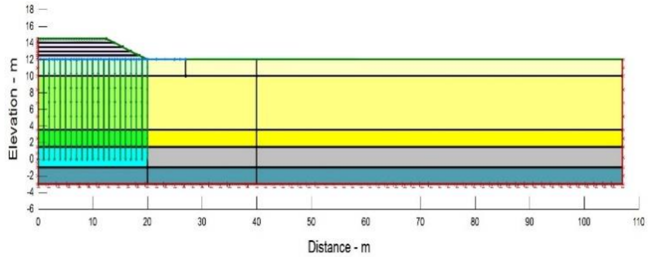


Figure 4. The schematic view of the TV2 model

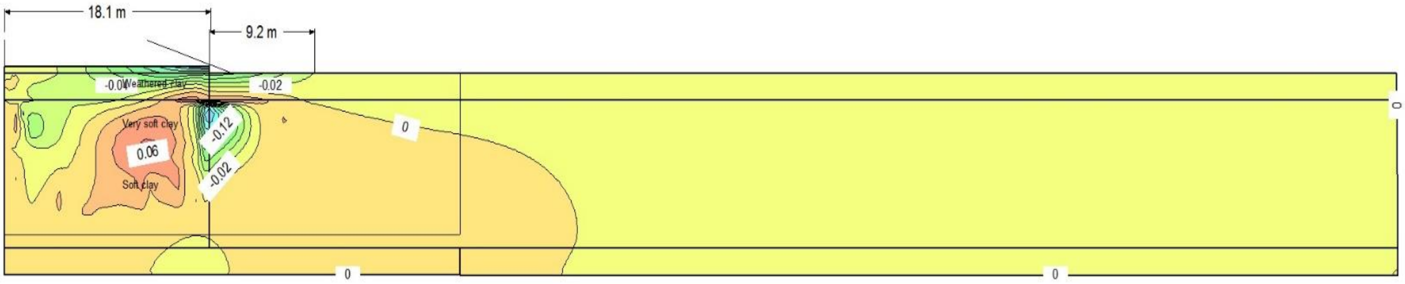
3. Results and discussions

3.1. The impact of the surcharge embankment

3.1.1. Residential complex

As it can be seen in figure 5, the influence zone for the verified model is only 9.2 m, which is a very low value in comparison to other cases while for the case with equivalent surcharge it has increased to 55.8 m. Based on the figure 6, the equivalent surcharge for the residential case history is an embankment that is 5 m height which has been built in 130 days and remained for another 370 days without PVDs. The assumed case with equivalent surcharge demonstrates the high efficiency of the vacuum preloading even in the absence of surcharge embankment. The application of vacuum preloading as the only preloading agent has decreased the influence zone drastically and for urban areas or places that sensitive infrastructures exist might be an ideal option for similar cases.

It should be mentioned that for surcharge preloading the displacement is 0.05 cm outward while for the case that includes only vacuum preloading the displacement is -0.02 inward. This issue was also reported by chai et al [17, 18]. The vacuum pressure unlike surcharge preloading causes an inward movement toward the center of treatment area and as a result, a balanced combination of surcharge and vacuum preloading might be a good option for designers where there is a great concern regarding lateral movement and the diameter of the influence zone.



(a)

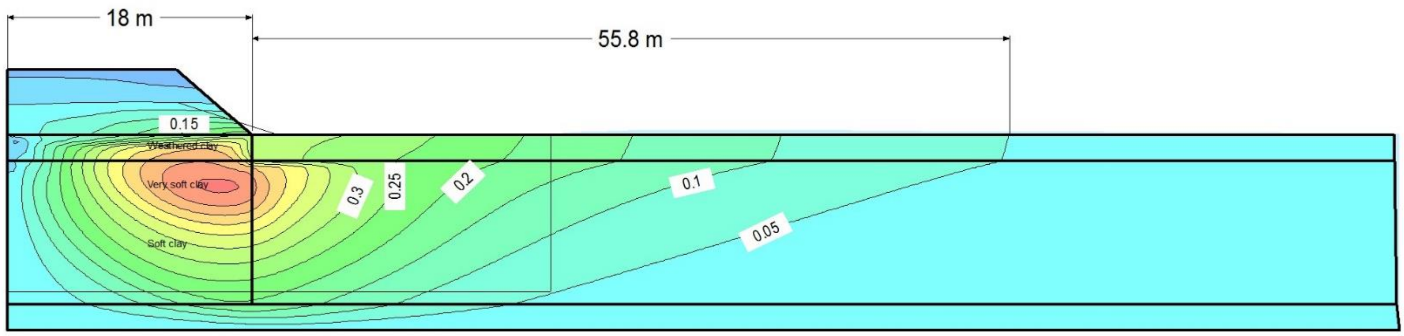


Figure 5. The contour diagram of the x-displacement of the perimeter of the residential complex treatment area (a) verified case study after 130 days (b) the equivalent surcharge embankments after 500 days

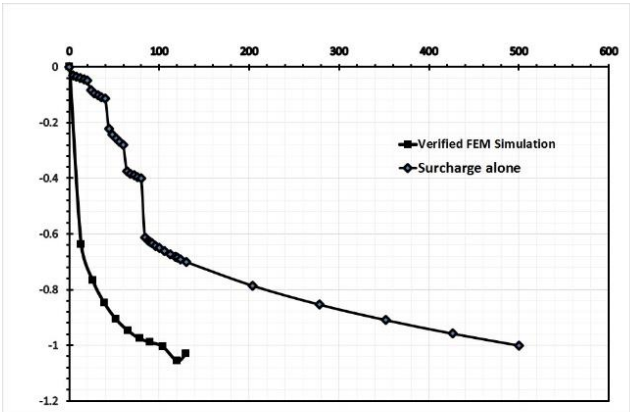
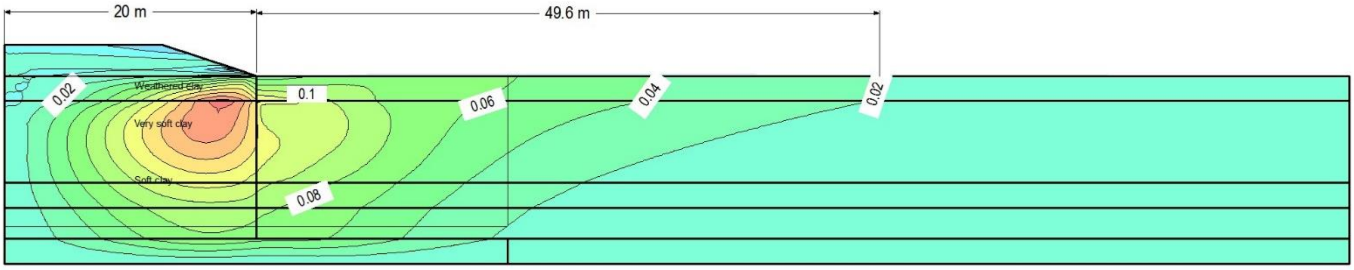


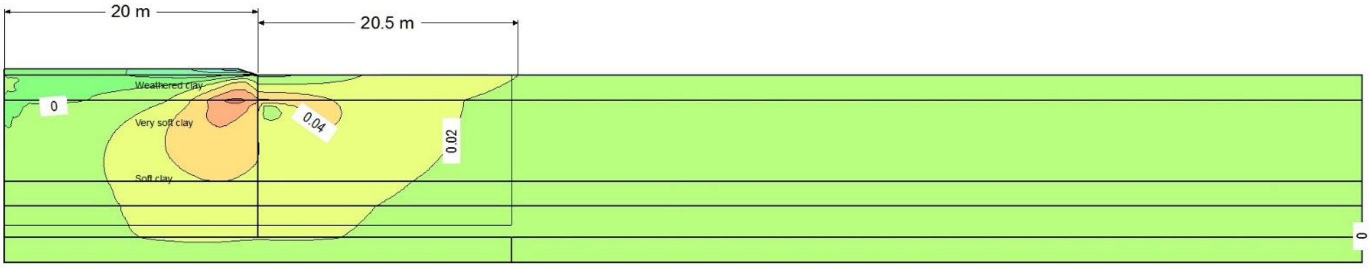
Figure 6. the comparison of the settlement curves of verified FEM model vs time with equivalent surcharge load

3.1.2. TV2 test embankment

In order to compare the impact of surcharge preloading a case has been defined based on the TV2 verified model that lacks the surcharge embankment. The settlement curve and influence zone for the defined case are shown in figure 8 and 7b. For the case of TV2 with 2.4 m surcharge and variable vacuum pressure vs time as it was shown in figure 1a and 1b, the influence zone is equal to 49.6 m while for this case in the absence of surcharge preloading, the influence zone is equal to 20.5 m (figure 7a and 7b). In figure 8 it can be seen that by omission of the surcharge embankment the final settlement has reduced from 1.27 to 0.73 m. The applied vacuum pressure in the case of TV2 was not a constant and stable pressure unlike the residential complex and for TV2 case the lateral displacements have positive values. Although the settlement is lesser in comparison to the TV2 verified FEM simulation in figure 7b, the magnitude of final settlement is 42 percent smaller.



(a)



(b)

Figure 7. The contour diagram of the x-displacement of the perimeter of the TV2 treatment area (a) FEM verified model (b) The case without surcharge preloading

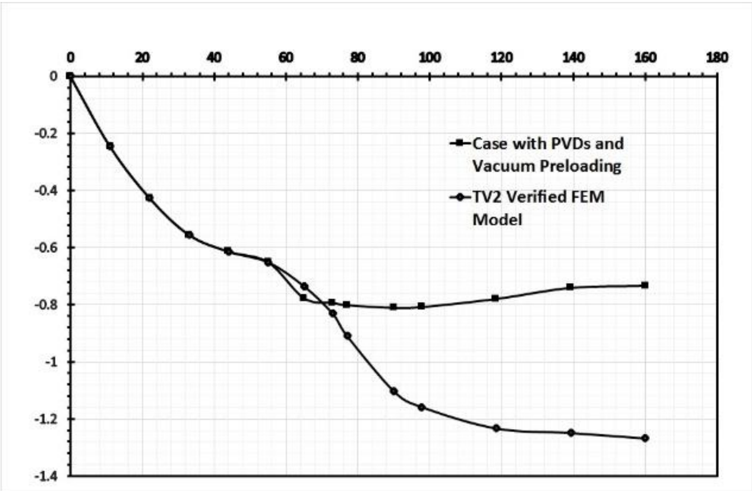
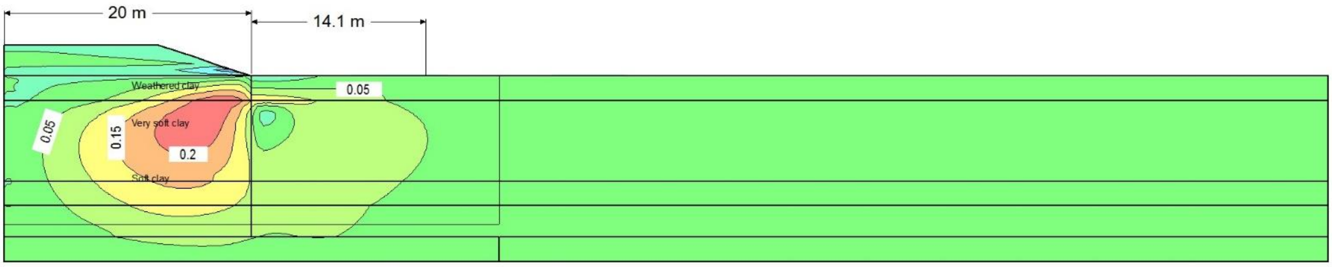


Figure 8. the comparison of the settlement curves of verified FEM model vs time with the case on the absence of surcharge preloading

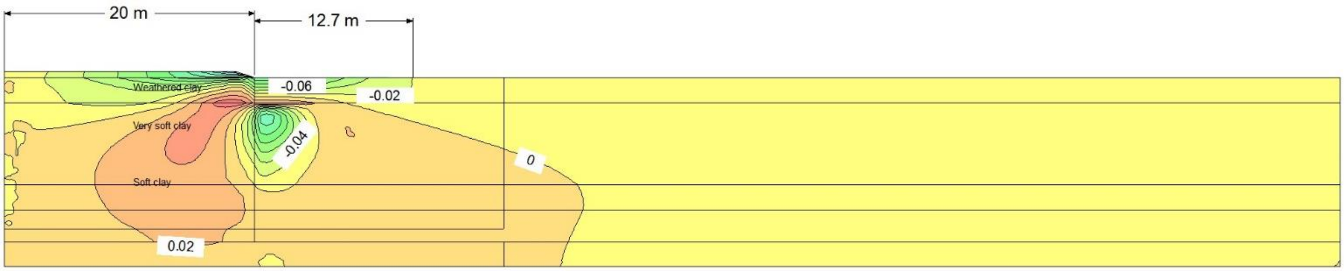
3.2. The impact of the magnitude of vacuum preloading

3.2.1. TV2 test embankment

Figure 9a illustrates the TV2 case with a constant ideal 60 kPa vacuum pressure in combination with 2.4 m surcharge preloading. The influence zone for this case is 14.1 m that is drastically reduced in comparison to the verified TV2 case that had a 49.6 m influence zone (figure 7a). It is clear that a stable vacuum preloading can significantly reduce the diameter of the influence zone. For the case of constant 60 kPa pressure in the absence of surcharge preloading for TV2, the influence zone is 12.7 m and the displacement is towards the center of the embankment as it is shown in figure 9b. The exclusion of the surcharge embankment has reduced the influence zone by 1.4 m while the final settlement has reduced from 1.92 to 1.44 m. The final settlement with stable vacuum pressure in the absence of surcharge embankment is still higher than the verified TV2 model (1.44 in comparison to 1.26). This case shows the great impact of a stable vacuum preloading in overall system efficiency and reduction of the influence zone for such treatment systems.



(a)



(b)

Figure 9. The contour diagram of the x-displacement of the perimeter of the TV2 treatment area (a) TV2 FEM model with constant 60 kPa vacuum preloading (b) The case with constant 60 kPa vacuum preloading in the absence of surcharge preloading

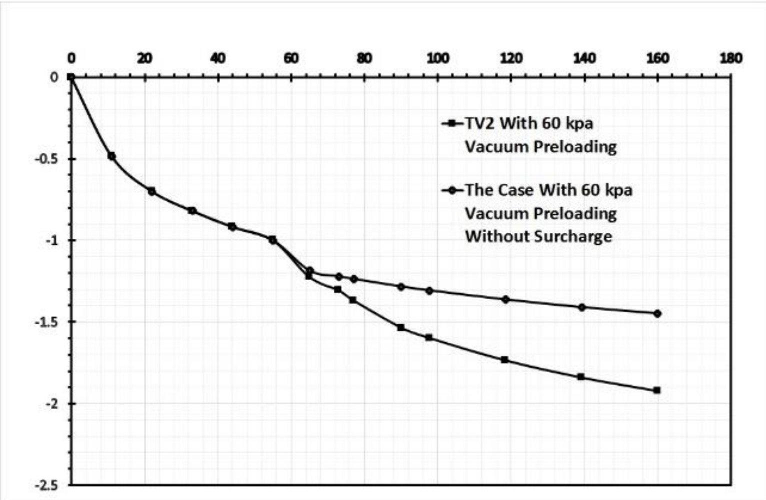


Figure 10. the comparison of the settlement curves of TV2 FEM model with 60 kPa vacuum preloading vs the case with 60 kPa vacuum preloading in the absence of surcharge preloading

3.2.2. Residential complex

Although it might be assumed that only outward lateral displacement can cause the damage to structures and infrastructures in the vicinity of treatment areas, a stable high pressure vacuum has the potential for the similar impact like surcharge embankment as it is shown in figure 11. Figure 11 shows the influence zone in a case that a constant 80 kPa vacuum pressure was applied to the verified complex case where as it is shown in figure 1c, there were malfunctions and leakages in the air pressure system that was also reported by [8]. The influence zone has increased from 9.2 m in the verified FEM case to 18.5 m in the case with constant 80 kPa vacuum pressure. The final settlement for ideal constant pressure has increased from 1.05 to 1.15 m that is shown in figure 12. This case again shows the benefits of designation of a system that a balanced combination of surcharge and vacuum pressure be applied.

Figure 11. The contour diagram of the x-displacement of the perimeter of the residential complex treatment area with constant 80 kPa vacuum preloading

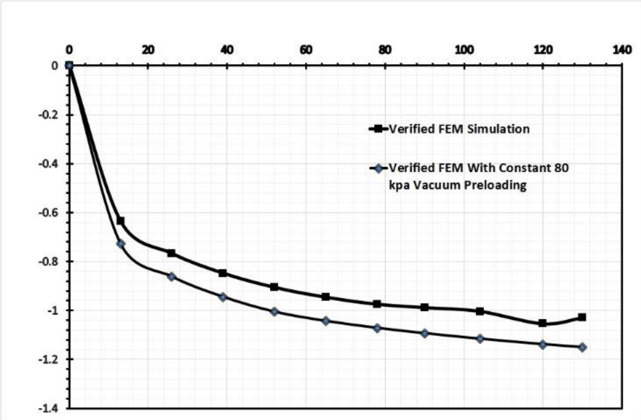


Figure 12. The comparison of the settlement curves of residential verified FEM model vs the verified case including constant 80 kPa vacuum preloading

4. conclusion

Two case histories were introduced and verified for investigation of the impact of surcharge embankment and vacuum preloading on the diameter of the influence zone; both were located on Bangkok marine clay. The first case history was TV2 that was a combination of vacuum pressure and surcharge embankment. The second case history was the application of vacuum preloading excluding the surcharge embankment. Based on the verified FEM simulation other cases were introduced as the equivalent surcharge embankment for residential complex and the application of ideal stable vacuum pressure for both residential and TV2 embankment.

Regarding the impact of surcharge embankment, it was shown that reducing the height of surcharge can drastically reduce the influence zone in both numerical simulations. For residential complex the assumed case with equivalent surcharge embankment demonstrates the high efficiency of the vacuum preloading even in the absence of surcharge embankment. The application of vacuum preloading as the only preloading agent has decreased the influence zone drastically and for urban areas or places that sensitive infrastructures exist might be an ideal option for similar cases. For the case of verified TV2 with 2.4 m surcharge and vacuum pressure vs time the influence zone is equal to 49.6 m while for the case in the absence of surcharge preloading, the influence zone decreased to 20.5 m.

Regarding the impact of magnitude of vacuum pressure on the influence zone it was shown that application of a stable high vacuum pressure can significantly reduce the diameter of the influence zone. It should be noted that like surcharge embankment, in the case of application of a constant 80 kPa vacuum pressure in residential complex the area of the influence zone propagates in the vicinity of the treatment area toward the center of the embankment and it is also creating danger for adjacent structures or infrastructures. Since vacuum pressure creates an inward displacement toward the center of embankment in contrast to surcharge embankment, a wise combination of surcharge and vacuum preloading might be a good option where there are sensitive infrastructures or structures if it be practically possible.

For every project that includes the treatment of weak clay or peat stratums, based on the material and sensitivity of nearby structures and infrastructures, the maximum allowable strains should be determined prior to designation of the treatment system to avoid unpredicted damage by qualified consultants. Finite element method is a powerful tool as shown in this article that can be utilized for modelling different and sophisticated scenarios.

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