Vacuum Preloading of Soft Clays on the Sumatra Toll Road in Indonesia – Field Monitoring Records vs. Numerical Modelling Results

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Abstract. The vacuum preloading method was utilized to improve soft soil Trans Sumatera Toll Road Project. This paper presents a study result of numerical modelling of the behaviours of vacuum preloading which was verified by a field monitoring result. Numerical modelling of vacuum preloading was performed in three steps based on permeability conversion. PVD's model was carried out by considering the smear zone and discharge capacity. Vacuum suction was modelled as a negative pressure along with the PVD. The Modified Cam–Clay model was selected to simulate soft clay soils. Effects of vacuum distribution (constant and linearly decreased) along the PVD were investigated. Prediction from this model such as settlement, pore water pressure, and lateral displacement was compared to actual field data. The degree of consolidation was estimated by using an empirical calculation based on pore water pressure in the field. This paper shows that the results of the numerical modelling were comparable to the actual field data. This study found that modelling vacuum with a linearly decreased pressure along the PVD resulted the closest to field data. This study also found that a vacuum pressure with a constant along the PVD still resulted in reasonable prediction.

1. Introduction

The development of infrastructure in Indonesia, especially the construction of toll roads was growing so rapidly. The construction of toll roads built on soft soil creates problems. Soft soil had a long time settlement when it carried loads. It had a low bearing capacity, too. Therefore, it needs a soil improvement method. There is a problem when it needs so much backfill material, the quarry is hard to find. Site with difficult access, bringing backfill material will cause other problems too. Soil improvement with vacuum preloading method was the right choice. Vacuum pressure of -80 kPa is equivalent to 4-5 m of embankment if we used 16 kN/m^3 soil unit weight.

Software with the finite element method was used to modelled vacuum preloading. In much literature, the finite element method is quite powerful in modelling the vacuum preloading method. This research focuses on modelling the soil improvement of vacuum preloading. Prediction from this model such as settlement, pore water pressure, and lateral displacement was compared to actual field data.

2. Geotechnical Condition

A very soft to soft silty clay layer was found 7.5 m in thickness from the ground surface. There was loose to compact clayey sand from 7.5 m to 12 m depth. The soft soil was found in 12 to 18.5 m depth again with soft to medium consistency. The target of soil improvement is between the ground surface and this layer. Compact silty sand and very stiff to hard sandy clay were found up to 27.5 m in depth and until the end of drilling, respectively.

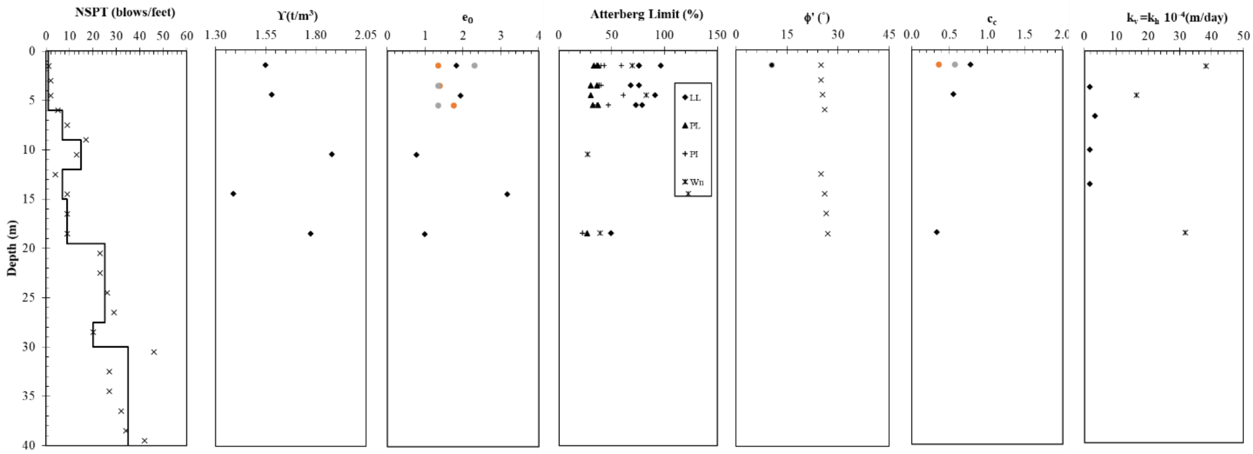


Figure 1 Soil Parameter vs Depth

Table 1 Soil Parameter Design

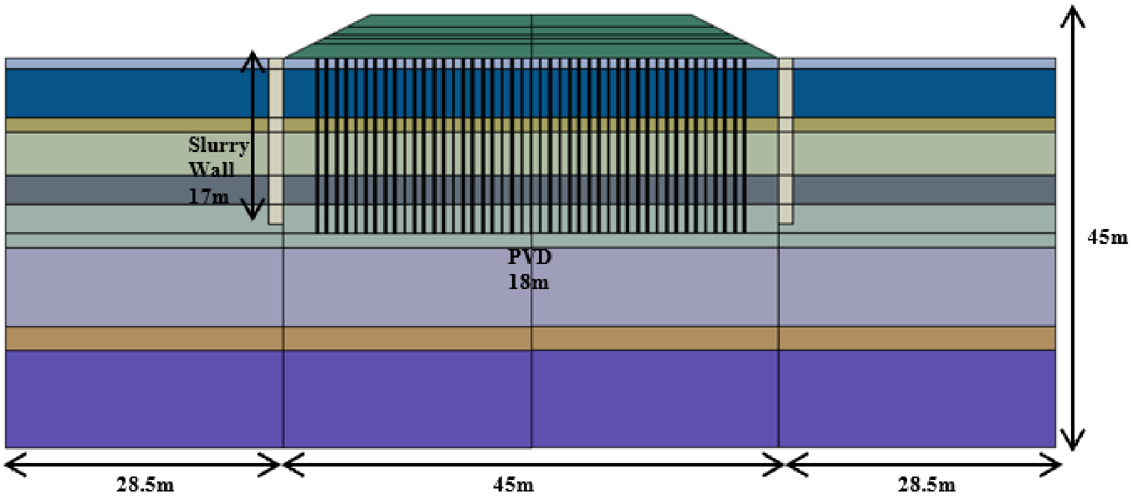
Soil Type	Depth (m)			Υ_{sat} (kN/m^3)	M	e_0	ν	κ	λ	k_h (m/day)
Slurry wall	0	-	17	13	0.98	3	0.4	0.08	0.5	2.59E-03
Silty clay	0	-	6	15.5	0.98	1.94	0.35	0.034	0.339	1.74E-04
Silty clay	6	-	7.5	15.8	0.98	1.82	0.35	0.024	0.239	1.77E-04
Clayey sand	7.5	-	12	18.44	1.67	0.77	0.3	-	-	8.64E-03
Silty clay	12	-	15	15.8	0.98	1.82	0.35	0.024	0.239	1.77E-04
Silty clay	15	-	19.5	17.7	0.98	1.82	0.35	0.014	0.143	3.28E-04
Silty sand	19.5	-	27.5	18	1.67	0.77	0.3	-	-	8.64E-03
Sandy clay	27.5	-	30	18	1.2	0.99	0.35	0.002	0.022	3.28E-04
Sandy clay	30	-	40	19	1.2	0.99	0.35	0.002	0.022	3.28E-04

3. Description

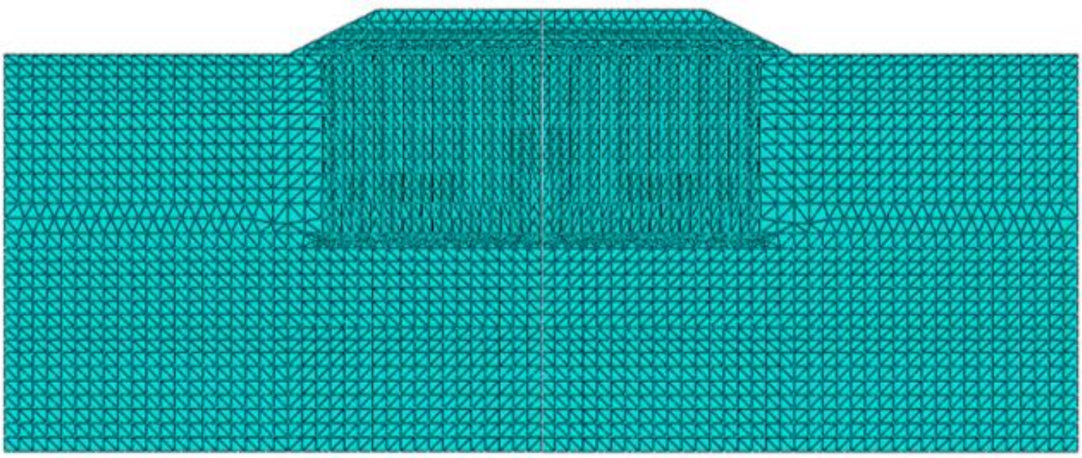
Soil investigation and laboratory data were used to interpret index and engineering properties for each layer of soil. Soft soils were improved by PVD combined with vacuum preloading. PVD had 18.5 m in length, spaced 1 m with a rectangular installation pattern. Sealing walls were installed surrounding the improvement area. It had 1 m in width and 17 m in length. The sand platform was laid on the ground surface with 1.5 m of height. A backfill 3.5 m high was required to reach the design elevation. Vacuum pressure was used as a preloading by utilising atmospheric pressure. It used – 80 kPa for the analyses. Vacuum preloading method on soft clays was carried out for 128 days. Stage construction model following field monitoring records.

4. Numerical Modelling

Software-based on finite element method, ABAQUS 2D 6.13-1 is used to modelled vacuum preloading method. Analyses were carried out under plane strain conditions by converting permeability equivalent from axisymmetric flow conditions to plane strain conditions. It used an empirical equation (Indraratna, et al, 2021). The geometry model was drawn based on as-built drawings. Mesh type element was used CPE6MP (6 nodes modified quadratic plane strain triangle, pore pressure, hourglass control).



(a)



(b)

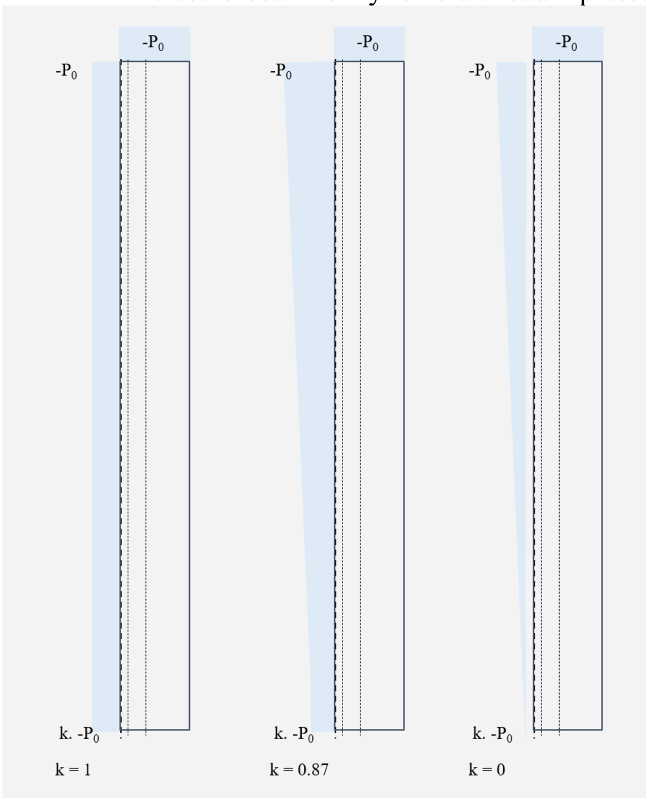
Figure 2 Models: (a) Geometry and (b) Meshing

Figure 2 (above) shows the geometry and mesh model that was carried out in the analysis. The left and right sides were assigned a boundary displacement on the horizontal axis with zero value (Ux = 0), respectively. In addition, vertical axis boundary displacement was set to zero value (Ux = Uy = 0). PVD was modelled as a cluster. It assigned a boundary pressure as a place for vacuum pressure. It was modelled by considering smear zone and discharge capacity. Vacuum suction pressures were modelled as a boundary pore pressure along with the PVD. Modified Cam – Clay (MCC) was used to modelling of soft clays. The sand platform and backfill were modelled as a soil cluster.

This research was carried out with vacuum pressure variations along with the PVD. In detail (Figure 3):

- Case A : constant vacuum pressure;
- Case B Measurement : decreased accordance to pore water pressure records; and

- Case C : decreased linearly to zero vacuum pressure.



(a) (b) (c)

Figure 3 Vacuum Pressure Modelling: (a) Case A, (b) Case B Measurement, and (C) Case C

5. Result

5.1. Settlement

In general, due to 13% vacuum pressure different, Case A (R^2 = 0.71) and Case B Measurement (R^2 = 0.71) were similar predict surface settlement response. On the other hand, Case C (R^2 = 0.92) predict the lowest among the three analyzed cases. Models with a large vacuum pressure distribution along the PVD were the closest predicted surface settlement until day 70th. Otherwise, Case C was closer to filed monitoring records until day 128th. Both settlements at 5 m and 10 m depth field data were closest to the Case B Measurement model (R^2 = 0.64 to 0.93).

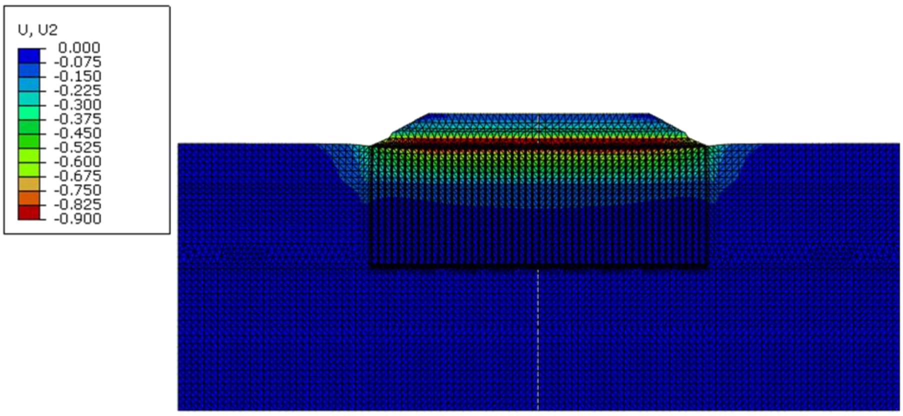


Figure -4 ABAQUS Result: Settlement Contour

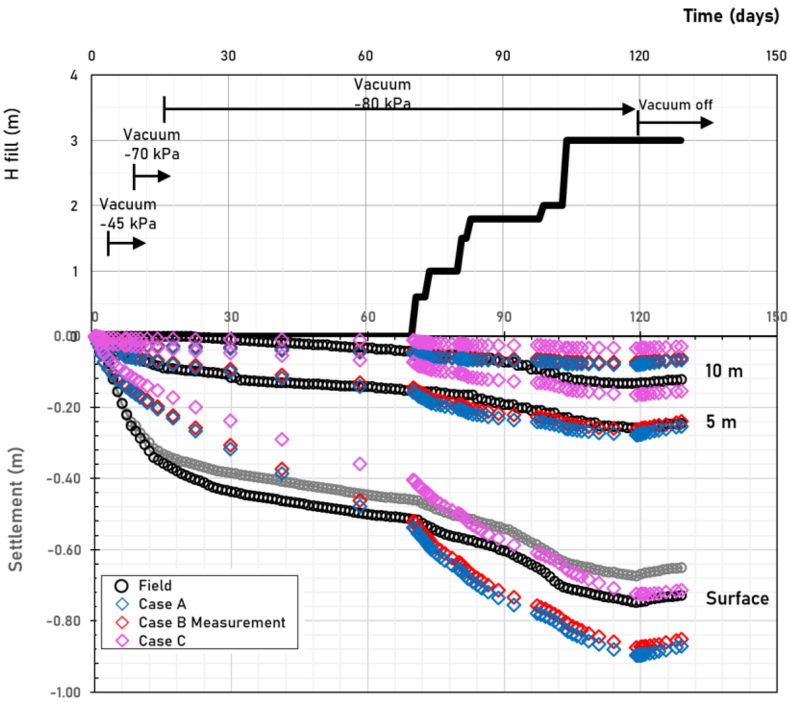


Figure 5 Settlement Graph: Numerical Modelling (ABAQUS) vs Field Monitoring

5.2. Pore Water Pressure

As well as settlement response, distribution vacuum pressure's value affected pore water pressure dissipation which can be seen in Figure 3. Therefore, the largest vacuum distribution, Case A and Case B Measurement produced the closest pore pressure response. While Case C resulted in a lower pore water pressure response than the two cases before.

Before and after the backfill, the closest prediction response was the Case B Measurement model (R^2 = 0.74 to 0.93). The anomaly occurred at a 5 m depth, which Case A was closer to the pore water pressure monitoring after the backfill (R^2 = 0.94)

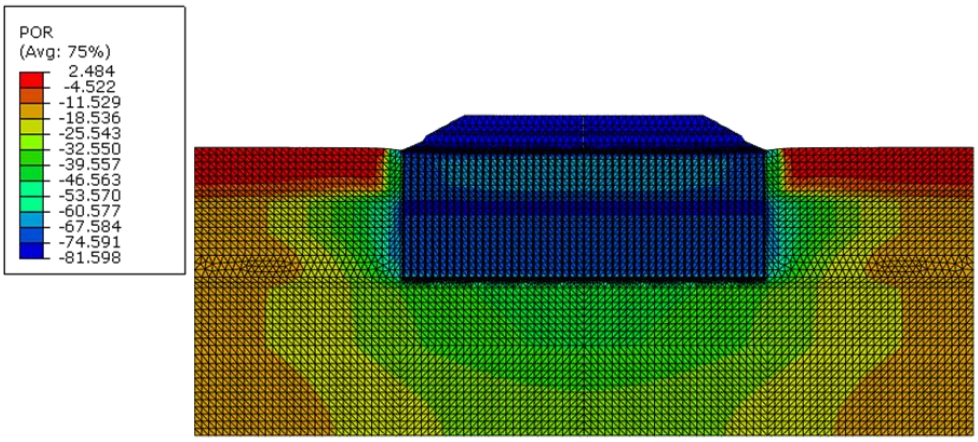


Figure 6 ABAQUS Result: Pore Pressure Contour

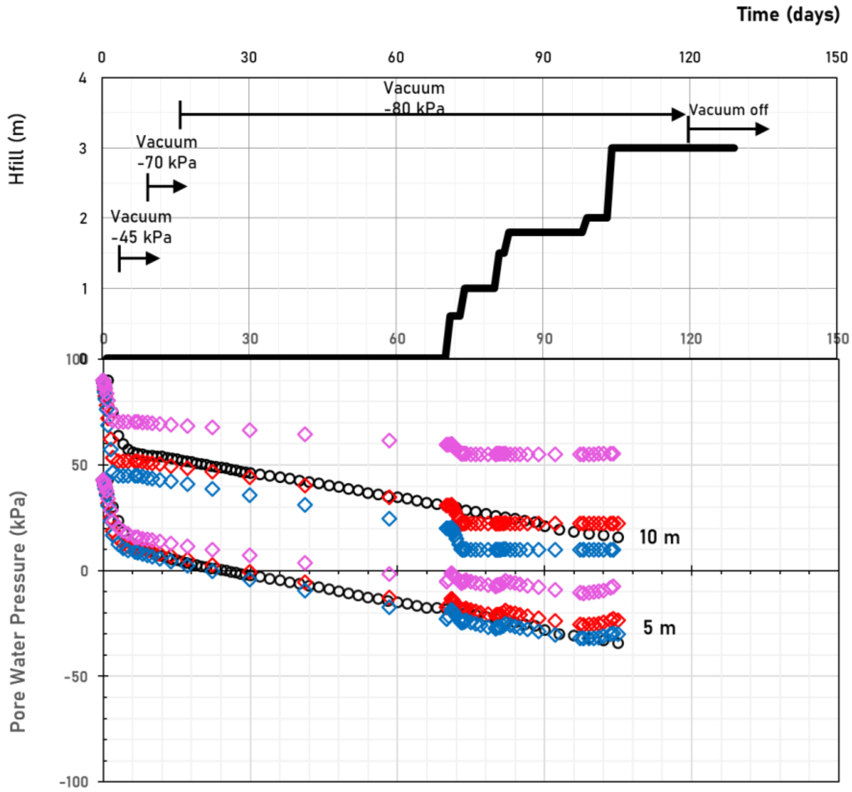


Figure 7 Pore Water Pressure Graph: Numerical Modelling (ABAQUS) vs Field Monitoring

5.3. Lateral Deformation

Case A was closest to both of field pattern and value of lateral deformation monitoring. The greater vacuum pressure, the bigger inward lateral deformation. At the same point, the most closely approximated field monitoring lateral deformation was Case B Measurement (R^2=0.74).

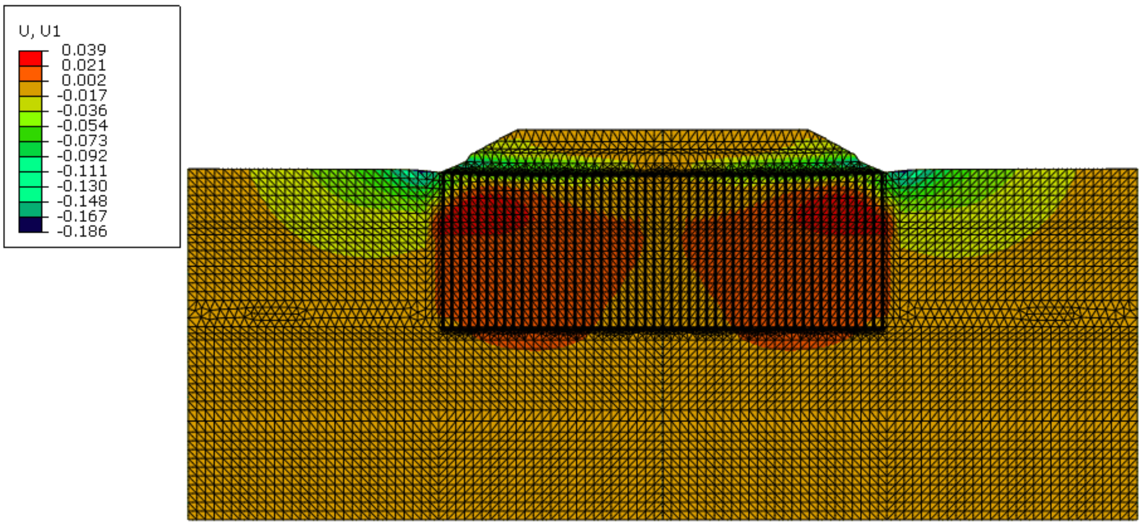


Figure 8 ABAQUS Result: Lateral Deformation Contour

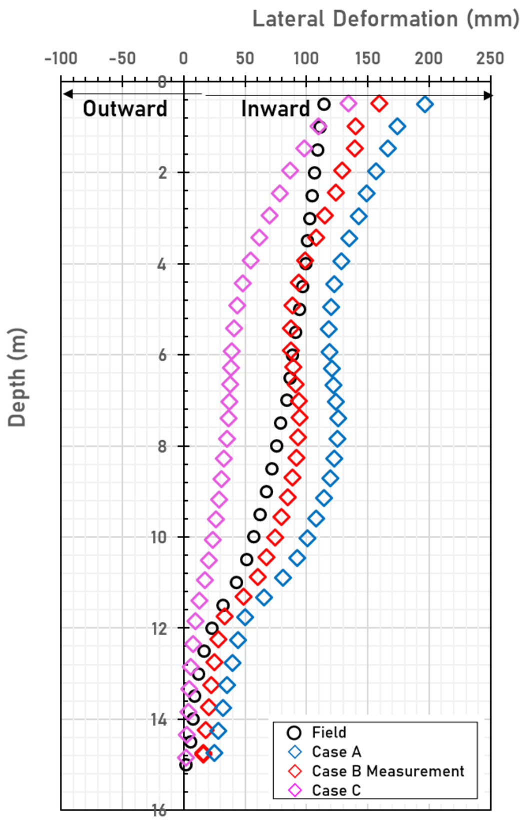


Figure 9 Lateral Deformation Graph: Numerical Modelling (ABAQUS) vs Field Monitoring

5.4. Degree of Consolidation
The degree of consolidation was estimated based on field pore water pressure monitoring (Chu et al, 2000). The study reached a 95% degree of consolidation.

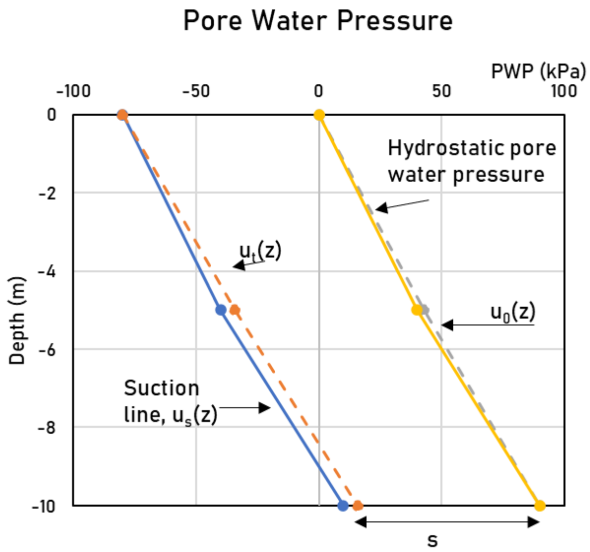


Figure 10 Pore Water Pressure vs Depth for Determined Degree of Consolidation Estimation

6. Conclusion
Surface settlement before backfill (until day 70th), Case A and Case B Measurement were closest to the data field (R^2 = 0.71 to 0.73). Otherwise, after backfill, Case C was closer (R^2 = 0.92). Settlement and pore water pressure prediction at 5 m and 10 m depth, lateral deformation was closest dominated by Case B Measurement model (R^2 = 0.93) as well as before and after backfill.

This paper shows that the results of the numerical modelling were comparable to the actual field data. This study also found that a vacuum pressure with a constant along the PVD still resulted in reasonable prediction. This can be seen from the vacuum data in the ground surface reduced linearly to 87% and distributed constant.

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