Analysis of Soil Behavior in the Trial Embankment Zone N Using Geotechnical Instruments on the Semarang - Demak 1B Toll Road Work (STA: 4+200–4+600)

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***Abstract**. The soil condition in the trial embankment of the Semarang-Demak 1B (Middle Java, Indonesia) toll road project consists of a soft soil layer that tends to be very compressible, has low shear resistance, low permeability, and low carrying capacity. Therefore, soil improvement methods such as preloading and PVD installation are needed to accelerate the soil consolidation process. This study aims to evaluate the subsidence and stability of the groundsoil due to the load of the experimental stockpile. The research method was carried out by installing several geotechnical instruments, namely settlement plates, piezometers, and inclinometers to monitor soil response to the load of the heap. Observation data were analyzed to assess the magnitude of the decrease, pore pressure dissipation, and lateral movement of the soil. The results of the analysis show that the actual decline in the field is close to the predicted result of the calculation, with the degree of consolidation at most points having exceeded 90%. The lateral movement of the soil recorded by the inclinometer is still above the set tolerance limit of 375 mm. This indicates that the stack should require further evaluation, the average degree of consolidation reaching about 90.74%, which indicates that most of the excess pore pressure has been dissipated. The preloading and PVD methods have proven to be effective in speeding up the consolidation process.*

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1. INTRODUCTION

The Semarang - Demak Toll Road is divided into two sections, namely Section I (Semarang-Sayung) along 10.39 km and Section II (Sayung-Demak) along 16.01 km. Section 1 was built on the sea which functions as a sea embankment to overcome the tidal floods that often hit the North Java Coast National Road (Kaligawe - Sayung Road Section) and to overcome traffic congestion on the Pantura National Road, especially in the Kaligawe and Terboyo areas.

The Semarang-Demak 1B Toll Road Construction Project passes through coastal areas and swamps with soil conditions in the form of clay and silt. The subsoil at the study site tends to be very compressible, has low shear resistance, low permeability, and low carrying capacity. So that in these areas, toll roads are planned to build sea embankments. The construction of this sea embankment is expected to stem the tidal floods that often occur in the area.

One of the factors that need to be considered in soil stockpiling is the carrying capacity or strength of the soil. The strength of the base soil that will be used as a landfill area must meet the criteria for soil strength so that the landfill can be stable and able to bear the burden arising from landfilling. In the analysis of the fulfillment of the strength of this basic soil, there are two commonly used methods, namely the soil improvement method and the soil strengthening method. One method of soil improvement is through gradual hoarding by allowing the base soil layer to consolidate.

As the base soil layer consolidates, the strength of the soil will increase. The soil reinforcement method can be done through the addition of additional materials to the soil layer to increase the bearing capacity of the soil. Reinforcement can be done using bamboo mats, geotextiles, and preloading. In addition to the carrying capacity of the soil, the thing that also needs to be considered in hoarding is soil subsidence. Soil subsidence can occur due to the load of the backfill and consolidation that occurs in the clay soil layer.

In this study, a trial embankment analysis containing a layer of clay soil will be carried out using instrumentation. The analysis was carried out using the soil improvement method through gradual hoarding and the installation of prefabricated vertical drain (PVD) and through the soil reinforcement method using a bamboo pile mat system. A calculation of land subsidence that occurs due to the load from the heap will also be carried out.

This paper presents the results of trial testing of the embankment of sea embankment deposits in the N STA zone of 4+200 – 4+600 above soft soil. This embankment stability analysis aims to predict the subsidence of the bottom soil that will occur due to the burden of the embankment trial. For this reason, monitoring was carried out and geotechnical instrument data was obtained in the form of inclinometer, piezometer, and settlement plate data. The results of this monitoring are compared with the empirical formula carried out in planning to determine the degree of consolidation that occurs. The research location is situated at the Semarang–Demak 1B Toll Road Project (STA 4+200–4+600) in Central Java, Indonesia (Figure 1).

Figure 1. Study Location The Semarang - Demak 1B Toll Road Work (STA: 4+200–4+600)

2. METHODOLOGY

This research is included in the type of experimental research with a model scale in the laboratory. The research was carried out in several laboratories, namely the Bio-Process Laboratory, the Construction Materials Test Laboratory, and the Stone and Concrete Laboratory, Bandung State Polytechnic. The flow chart of this research can be seen as shown in Figure 2.

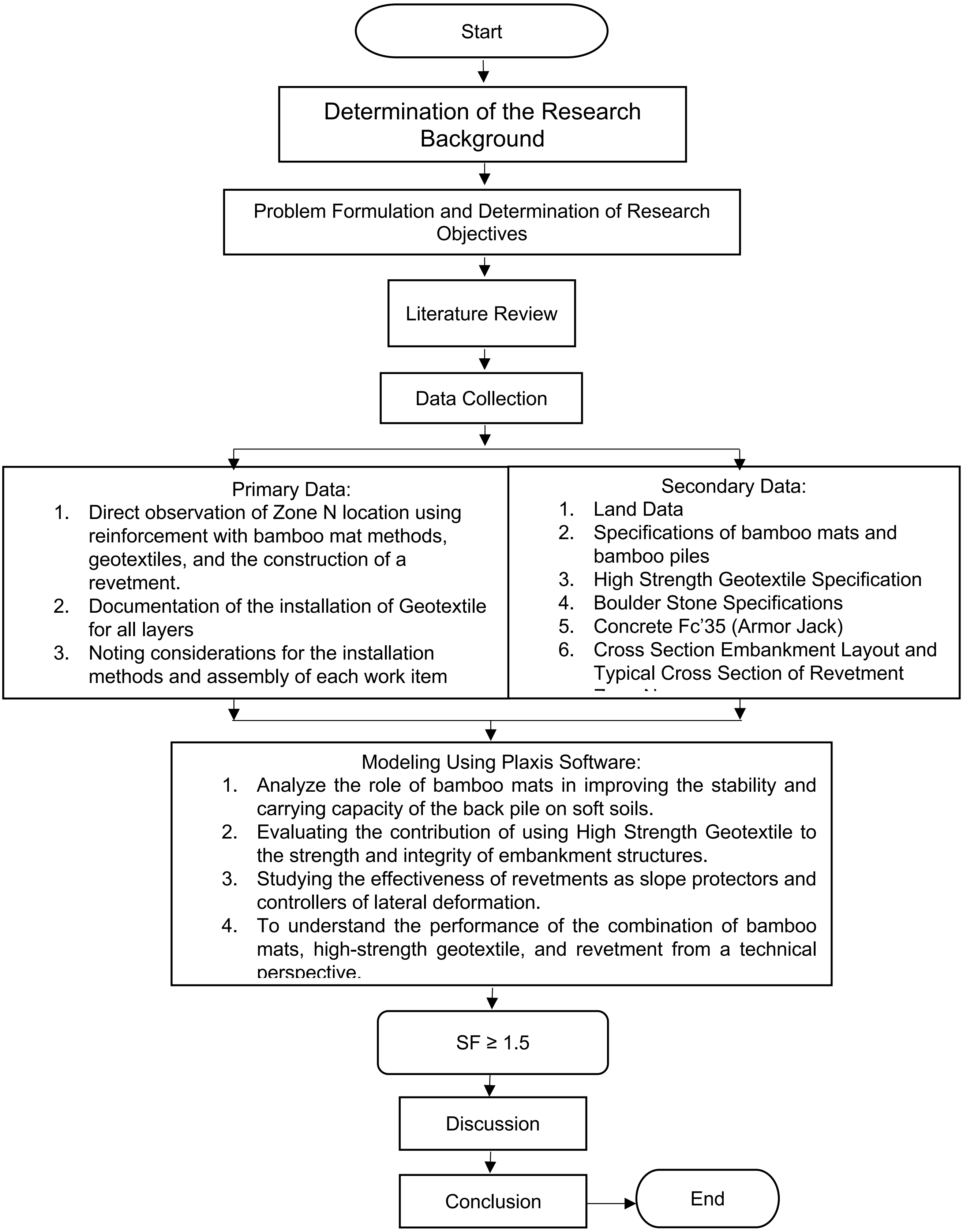

Figure 2. Flowchart

3.RESULT AND DISCUSSION

3.1. Preliminary Material Test Results

The results of preliminary testing are carried out to ensure that the concrete constituent materials meet the standards so that the mix design can be achieved and in accordance with the planned quality.

3.1. Data Borlog

This research was carried out on the STA 4 + 200 to STA 4 + 600 section in the Trial Embankment Section 1B project, Semarang. Soil investigation data was obtained from five drill points (BH-01 to BH-05) along the section (Table 1)

Table 1. Recapitulation of Borlog Results

Soil Characteristics	BH-01	BH-02	BH-03	BH-04	BH-05
Very Soft Clay	5-15 m	-	5-25 m	5-20 m	-
Soft Clay	15-35 m	5-30 m	25-30 m	20-35 m	5-35 m
Firm Clay	35-45 m	30-40 m	30-50 m	35-50 m	35-50 m
Stiff Clay	45-50 m	40-50 m			

3.2. Data Sondir

At the research site, soil conditions at a depth of 0–6 m are a surface layer consisting of soft deposits (mud and mud) with unstable characteristics. Therefore, The interpretation of the results of the Cone Penetration Test (CPT) at point SM.1 is focused starting from a depth of 6 m, where the soil layer begins to show a more representative consistency to the behavior of the road foundation foundation. The recapitulation of the Cone Penetration Test (CPT) results can be seen in the following Table 2 :

Table 2. Recapitulation of Sondir Test Results (CPT)

SM.1		
Characteristic	Depth	qc kg/cm^2
Clay is very soft	6.0 – 10.4	1 - 2
Clay is very soft to soft	10.4 – 31.2	2 - 8
Soft clay to stiff	31.2 – 34.0	8 - 20

3.3. Piled Up Data

The Zone N Stack is carried out in 6 stages of construction. The first three stages use sand material, which functions as a drainage layer as well as the initial load (preloading). This stage is intended to accelerate the dissipation of pore water pressure through PVD and reduce the risk of instability.

Furthermore, the next three stages use selected fill materials until they reach the planned pile height. The division per stage is not only based on the volume of the stockpile, but also considers the response of the base soil to the load monitored through settlement plates, piezometers, and inclinometers.

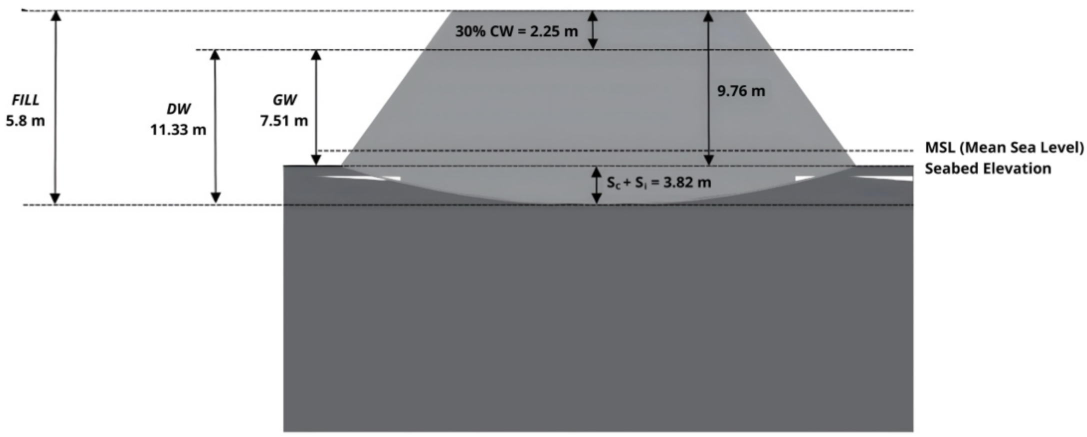

Figure 3. Sketch of The Embankment Trial

Table 3. Results of Preloading and Settlement Calculation Analysis

Construction Fill Height	Settlement Compensation		Total Preload Height	Total Embankment Stack Height
	Elastic	Consolidation		
7.51	1.0	2.82	2.25	13.58

Based on the design shown in Figure 2, the height of the embankment construction in zone N is 7.51 m. However, due to the foundation soil being a soft layer with significant consolidation potential, the embankment planning also takes into account additional height as a settlement compensation, as shown in Table 3.

3.4. Settlement Plate Analysis

Settlement Plate data is in the form of land subsidence data on the basis of whether the land is still declining or has experienced a final settlement. To find out the prediction of the final decline of each Settlement Plate, it is done using the Asaoka Method. The following is a graph of the final settlement determination on SP-32 (Figure 4).

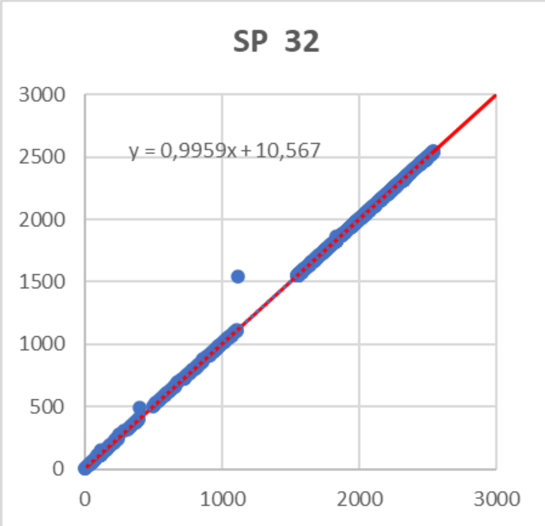

Figure 4. SP-32 Final Settlement Determination Curve

The calculation of the determination of the total final compression is taken as an example in the SP-32. On the SP-32 final settlement determination curve An equation is obtained from the graph that has been created. From this equation, the value of the total settlement can be determined as follows:

y = 0.9959 x + 10.567
y = 2577.32 x
y = x
x = 2577.32mm (1)

So that the total final settlement value in SP-32 is 2577.32 mm. After the prediction of the final total settlement is obtained, the remaining settlements in the field can be known in the following way:

Sc final settlement plate reading = 2513 mm
Final settlement = 2577.32 mm
Settlement balance = Final settlement – Settlement reading
= 2577.32 – 2513
= 74.11 mm (2)

The remaining settlement that occurred was 74.11 mm.

The remaining compression on the other Settlement Plate can be seen in Table 4.

Table 4. The Rest of The Settlement at The Settlement Plate Point

No	Settlement Plate	Cumulative Settlement in the Field	Final Settlement Prediction	Settlement Balance
		$S_{c(t)}$ (mm)	S_c (mm)	mm
1	SP-25	1190	1264.10	74.11
2	SP-26	3152	3413.27	261.27
3	SP-27	5335	5696.97	361.97
4	SP-28	6185	7133.20	948.20
5	SP-29	6347	7853.81	1506.81
6	SP-30	5995	6960.40	965.40
7	SP-31	5098	5381.52	283.52
8	SP-32	2513	2577.32	64.32

So from the results above, it can be seen that the remaining size of the decline in each Settlement Plate is estimated to be around 64.32 mm – 1056.81 mm.
The degree of consolidation U is the ratio between the consolidated settlement that has occurred at a certain time Sc(t) to the total settlement that will occur S(c). This equation can be expressed as follows (Das & Sobhan, 2018):

U = Sc(t) / Sc (3)

And the actual degree of consolidation in SP-32 that occurred, as follows:

U = Sc(t) / Sc
U = 2513 / 2577.32 = 97.5% (4)

So the degree of consolidation in SP-32 is 97.5%. The degree of consolidation on other Settlement Plates can be seen in Table 5.

Table 5. Degree of Consolidation at The Settlement Point

No	Settlement Plate	Cumulative Settlement in the Field	Final Settlement Prediction	Actual Degree of Consolidation
		$S_{c(t)}$ (mm)	S_c (mm)	%
1	SP-25	1190	1264.10	94.1
2	SP-26	3152	3413.27	92.3
3	SP-27	5335	5696.97	93.6
4	SP-28	6185	7133.20	86.7
5	SP-29	6347	7853.81	80.8
6	SP-30	5995	6960.40	86.1
7	SP-31	5098	5381.52	94.7
8	SP-32	2513	2577.32	97.5

Based on the results of the settlement plate consolidation degree reading in Table 5, the actual consolidation degree value is mostly above 90%, which indicates that the primary consolidation process is almost complete. This condition indicates that the subsoil has undergone significant improvements in mechanical properties.

However, the SP-29 consolidation value is still relatively low (80.8%) so special attention or extension is needed preloading time for consolidation to reach the target. Overall, these results show that the soil improvement method with preloading and PVD installation is effective in accelerating the consolidation of soft soils so that the subsoil layer can be considered stable enough to support the construction of road embankments. The following is a graph of the decline in the Settlement Plate pile presented in Figure 5.

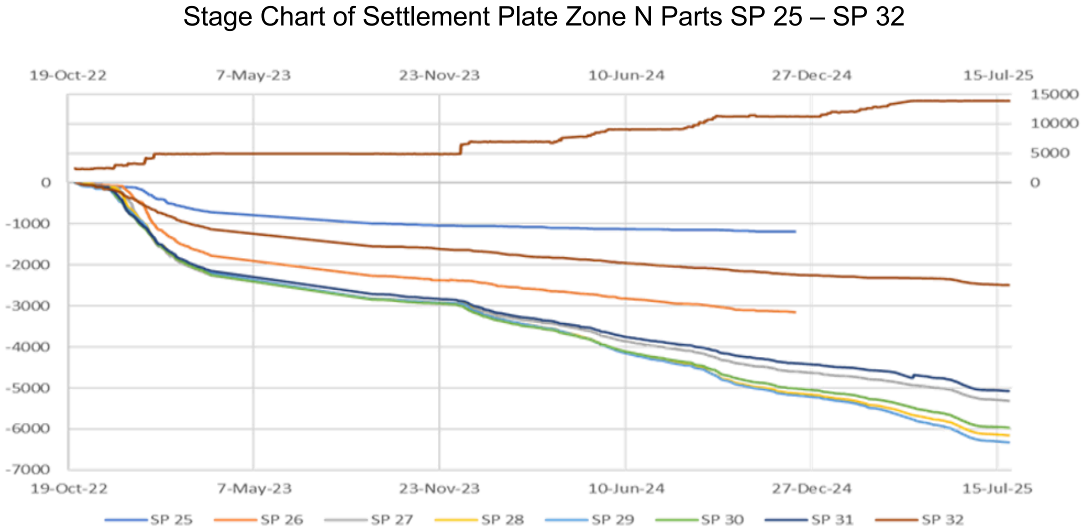

Figure 5. Stage Chart of Settlement Plate Zone N Parts SP 25 – SP 32

3.5. Inclinometer Analysis

In the Semarang-Demak Toll Embankment Trial project, several inclinometers were installed, including INC-03 which functions to monitor the lateral shift of soft soil due to the load of the heap and the consolidation process. The magnitude of the displacement on the INC - 03 chart (Figure 5) can be seen in Table 6 for Displacement Lateral INC-03

Table 6. Table Displacement Lateral INC-03

Project : TOL SEMARANG-DEMAK (TRIAL EMBANKMENT ZONA N)
Inclinometer # : INC 03
Probe Orientation : A+/A-
Area :
Top Casing Elev. : +2.876
: Free standing pipe (unused data)

Date of Reading : 23 June 2025 -
Tested by : Bagus, Nugi, H
Base Reading Date : 19 November

Elev.	Depth	Base Reading	Displacement													
			23/06/25	24/06/25	25/06/25	26/06/25	27/06/25	28/06/25	29/06/25	30/06/25	01/07/25	02/07/25	03/07/25	04/07/25	05/07/25	06/07/25
m	m	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
2.376	0.50	0.00	-175.26	-181.64	-179.54	-180.21	-183.99	-181.23	-179.23	-179.03	-181.00	-185.54	-184.58	-182.71	-195.83	-189.64
1.876	1.00	0.00	-152.06	-154.49	-154.39	-153.76	-158.01	-154.78	-154.81	-153.60	-154.93	-159.43	-158.33	-157.88	-164.34	-162.76
1.376	1.50	0.00	**-640.26**	**-643.05**	**-642.70**	**-641.68**	**-644.56**	**-642.10**	**-642.39**	**-641.63**	**-641.69**	**-645.66**	**-645.09**	**-645.24**	**-648.13**	**-648.68**
0.876	2.00	0.00	-566.45	-569.51	-569.30	-567.91	-569.91	-567.78	-568.50	-567.70	-567.23	-571.01	-570.69	-571.00	-572.48	-573.63
0.376	2.50	0.00	-529.90	-533.14	-533.19	-531.83	-533.39	-531.39	-532.18	-531.36	-530.65	-534.36	-533.93	-534.51	-535.86	-536.68
-0.124	3.00	0.00	-496.74	-499.84	-499.91	-498.56	-500.06	-498.00	-499.01	-497.96	-497.25	-500.93	-500.49	-501.08	-502.49	-503.28
-0.624	3.50	0.00	-461.64	-464.73	-464.75	-463.58	-464.96	-462.85	-464.01	-462.80	-462.05	-465.55	-465.10	-465.56	-467.20	-467.74
-1.124	4.00	0.00	-431.11	-434.26	-434.19	-433.15	-434.41	-432.43	-433.55	-432.23	-431.59	-434.81	-434.44	-434.84	-436.54	-436.93
-1.624	4.50	0.00	-401.05	-404.11	-403.90	-402.91	-404.28	-402.23	-403.44	-402.04	-401.30	-404.43	-404.14	-404.65	-406.25	-406.70
-2.124	5.00	0.00	-355.45	-358.48	-358.25	-357.31	-358.80	-356.66	-357.84	-356.41	-355.83	-358.56	-358.45	-358.95	-360.69	-360.79
-2.624	5.50	0.00	-323.17	-326.08	-325.75	-324.90	-326.46	-324.24	-325.39	-324.05	-323.39	-326.01	-325.96	-326.51	-328.23	-328.10
-3.124	6.00	0.00	-304.26	-307.44	-307.13	-306.39	-307.86	-305.58	-306.78	-305.60	-304.48	-307.44	-307.30	-307.91	-309.50	-309.24
-3.624	6.50	0.00	-297.51	-300.60	-300.29	-299.61	-301.11	-298.79	-299.90	-298.88	-297.63	-300.73	-300.40	-301.11	-302.61	-302.30
-4.124	7.00	0.00	-289.23	-292.30	-292.18	-291.39	-292.68	-290.56	-291.55	-290.44	-289.30	-292.33	-292.10	-292.83	-294.31	-294.09
-4.624	7.50	0.00	-269.33	-271.50	-271.49	-270.71	-271.85	-269.83	-270.81	-269.73	-268.64	-271.39	-271.29	-272.10	-273.46	-273.29
-5.124	8.00	0.00	-247.06	-249.35	-249.25	-248.48	-249.50	-247.54	-248.55	-247.44	-246.33	-249.05	-249.04	-249.86	-251.11	-250.86
-5.624	8.50	0.00	-222.79	-225.06	-224.96	-224.23	-225.09	-223.19	-224.11	-223.04	-222.05	-224.66	-224.68	-225.39	-226.78	-226.33
-6.124	9.00	0.00	-202.94	-205.29	-205.20	-204.28	-205.26	-203.18	-204.28	-203.20	-202.04	-204.83	-204.85	-205.45	-206.71	-206.31
-6.624	9.50	0.00	-184.66	-187.03	-186.96	-185.96	-186.98	-184.90	-186.06	-184.91	-183.79	-186.55	-186.60	-187.10	-188.38	-187.91
-7.124	10.00	0.00	-169.91	-172.23	-172.18	-171.16	-172.10	-170.06	-171.15	-170.10	-169.04	-171.70	-171.81	-172.31	-173.49	-173.06
-7.624	10.50	0.00	-164.33	-166.59	-166.50	-165.59	-166.29	-164.41	-165.36	-164.33	-163.29	-166.05	-166.01	-166.51	-167.49	-167.19
-8.124	11.00	0.00	-165.74	-167.98	-167.91	-167.01	-167.64	-165.71	-166.75	-165.80	-164.68	-167.35	-167.28	-167.83	-168.73	-168.45
-8.624	11.50	0.00	-168.84	-170.98	-170.94	-170.03	-170.70	-168.65	-169.85	-168.88	-167.76	-170.41	-170.43	-170.85	-171.81	-171.49

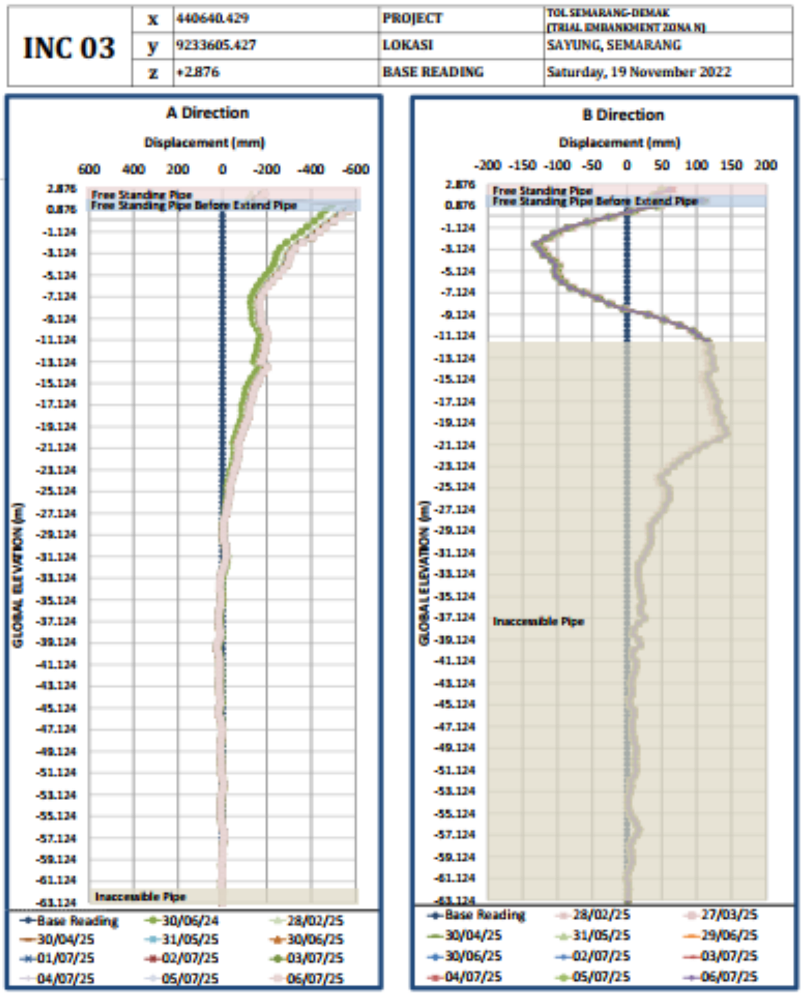

Figure 6. Displacement Chart INC-03
Source : PT Geotech Efatama

Inclinometer measurements were carried out at the INC-03 location with a top casing elevation of +2,876 m. The data in Figure 6 was read periodically from August 1, 2025 to August 10, 2025. The results of lateral displacement measurements showed that the dominant shift occurred in the A direction, with a maximum value of ±652 mm at a depth of about 1.5 m to 2.0 m from the ground level. The deformation pattern shows that the shallow layer of soft soil experiences the most significant movement due to the load of the heap. At deeper depths, the shift value is relatively smaller so that the main movement is focused on the shallow layer.

Meanwhile, in the B Direction, the maximum shift is only about 200 mm which can be seen in Figure 7, so it can be concluded that the main direction of lateral deformation is A Direction. The deformation pattern shows a shifting concentration in the shallow layer (depth -1.0 m to -5.0 m), which indicates the response of soft soils to the load of the backpile.

Based on the design criteria, with a planned stack height of 7.51 m, the permissible lateral displacement value according to the guidelines (OCDI, 2002) is about 375 mm (5% of the stack height), while according to NAVFAC (1986) it is limited to 500 mm. Thus, the actual measurement result of 652 mm has exceeded the design limit, indicating a significant lateral deformation in the soft soil. This condition confirms the need for further evaluation of the effectiveness of the soil improvement methods applied.

3.6. Piezometer Analysis

In the analysis of piezometer instrumentation, one of the methods used is the Yu & Chan (1979) method. This method was chosen because it was able to describe the average degree of soil consolidation based on pore water pressure reading data at various depths. The Yu–Chan method can combine actual field data with the theoretical pore water pressure distribution due to the load of the backpile. Thus, the results of the calculation are not only idealized, but also reflect real conditions in the field.

In Table 7, the pore water pressure due to the load of the backfill is still higher than the actual conditions in the field. This indicates that some of the pore pressure has been dissipated over time. The differences that still appear indicate that the consolidation process is still ongoing, especially in the upper soil layer.

Table 7. Pore Water Pressure Analysis Results

Elevation	Elevation Correction	u0	ut	u0+Δσ	(u0+Δσ-ut)
-1.2	-1.2			171.57	
-4	-8.379	48.54	92.74	220.11	175.91
-14	-16.235	169.12	182.09	340.68	327.70
-34	-34.554	428.22	409.78	599.78	618.22
-39	-39.187	453.35	439.04	624.92	639.23
-44	-44.000	486.79	543.95	658.36	601.20
-49	-49.000	543.58	611.68	715.15	647.04
-54	-54	539.29	650.86	764.68	707.29

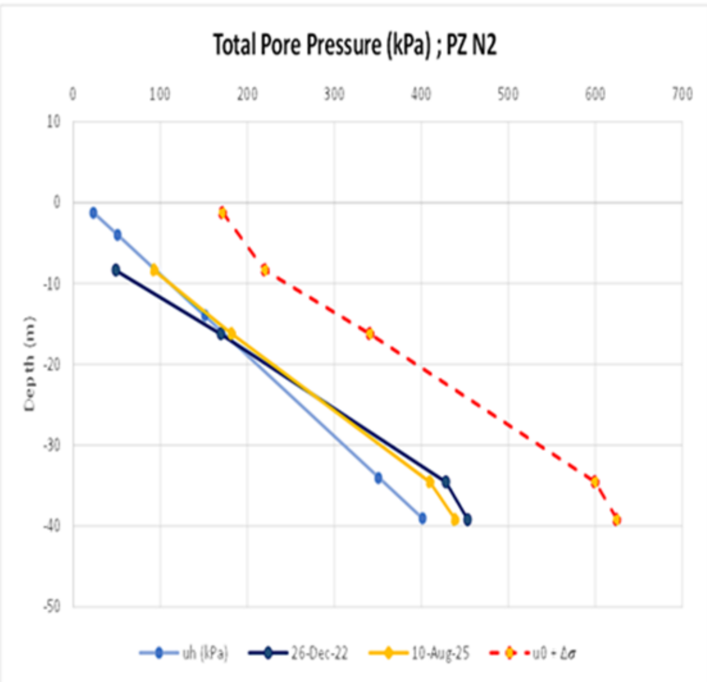

Figure 7. Piezometer Reading Result Graph

Meanwhile, Figure 7 shows the tendency of the field measurement curve to be closer to the theoretical curve. This confirms that the preloading applied successfully accelerates the dissipation of pore pressure. These conditions also indicate that the soil layer at a certain depth has undergone significant consolidation, although some parts still need additional time to reach full equilibrium.

Consolidation Degree Value
Up Date = 10-Aug-2025

6307.150 / 6950.462 = 90.74%

Figure 8. Consolidation Degree Value

The results of the analysis on the N2 piezometer until August 2025 show that the average degree of consolidation reaches around 90.74% (Figure 8), indicating that most of the excess pore water pressure has been dissipated. This indicates that soil improvement through preloading and PVD is effective in accelerating the consolidation process.

4. CONCLUSION

The subgrade condition on the Semarang–Demak 1B Toll Road STA 4+200 – 4+600 is dominated by soft to very soft clay with low bearing capacity, thus requiring appropriate soil improvement methods. Based on the analysis of settlement plate instrumentation readings, the degree of consolidation at most observation points has reached more than 90%, indicating that the subsoil condition is relatively stable. However, several points still show a lower degree of consolidation, suggesting the need for additional preloading time. Furthermore, piezometer data indicate that the average degree of consolidation has reached approximately 90.74%, which reflects that most of the excess pore water pressure has dissipated. This confirms that the application of preloading combined with Prefabricated Vertical Drains (PVD) has been effective in accelerating the soil consolidation process.

On the other hand, the inclinometer readings reveal that lateral soil movement remains a critical concern. Measurements at point INC-03 in the A direction indicate that the upper soft soil layer has undergone significant lateral deformation due to embankment loading, thus requiring further evaluation of the effectiveness of the implemented soil improvement methods. In addition, the recorded lateral displacement exceeds the allowable tolerance limits of 375 mm based on OCDI (2002) and 500 mm, indicating that the embankment condition still requires further assessment. Overall, the use of instrumentation such as settlement plates, piezometers, and inclinometers has proven effective in monitoring soft soil behavior. With a relatively high degree of consolidation achieved, the embankment at the study location can generally be considered safe to proceed to the next stage of construction, although careful monitoring and evaluation of lateral deformation remain necessary.

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