NUMERICAL STUDY OF SOFT SOIL IMPROVEMENT USING PREFABRICATED VERTICAL DRAIN IN PASER AIRPORT EAST KALIMANTAN, INDONESIA

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ABSTRACT

In this article, the effect of using Prefabricated Vertical Drain as a soil improvement on the time it takes for consolidation to settle in the construction of runway embankments at Paser Airport, East Kalimantan, Indonesia using numerical methods will be discussed. Based on the Indonesian Soft Soils Distribution Map and the results of the Standard Penetration Test conducted the runway area is dominated by soft clay to a depth of 24 meters. The characteristics of soft soils have low shear strength, high compressibility and low permeability which can cause large settlements over a long period of time. In numerical analysis, Prefabricated Vertical Drain is combined with preloading to speed up consolidation time. Based on the analysis results, the minimum pore pressure condition before soil improvement is reached within 36.36 years, whereas after soil improvement, the time for settlement is significantly reduced to 0.17 years or 63.22 days. The preloading height is calculated so that the final embankment elevation is reached when the settlement has been completed. Manual analysis was performed to obtain a comparison of the duration of settlement using numerical methods.

Keywords: Prefabricated Vertical Drain, Soft Soil, Airport, Embankment, Finite Element Method

1. INTRODUCTION

According to the Indonesian Soft Soil Distribution Map issued by the Ministry of Energy and Mineral Resources of the Republic of Indonesia, part of East Kalimantan, especially in Tanah Grogot district of Paser regency is dominated by soft clay [1]. The construction of runway embankment of Paser Airport which is in Tanah Grogot district if not careful carries a risk of potential failure. This is due to the soft clay soil has such poor characteristics which are low bearing capacity or low shear strength, high compressibility index (0.10 – 1.15), a very low permeability which can cause large consolidation settlements over a long period of time and slope instability [1]–[7]. The soft soil distribution map of East Kalimantan province can be seen in Figure 1.

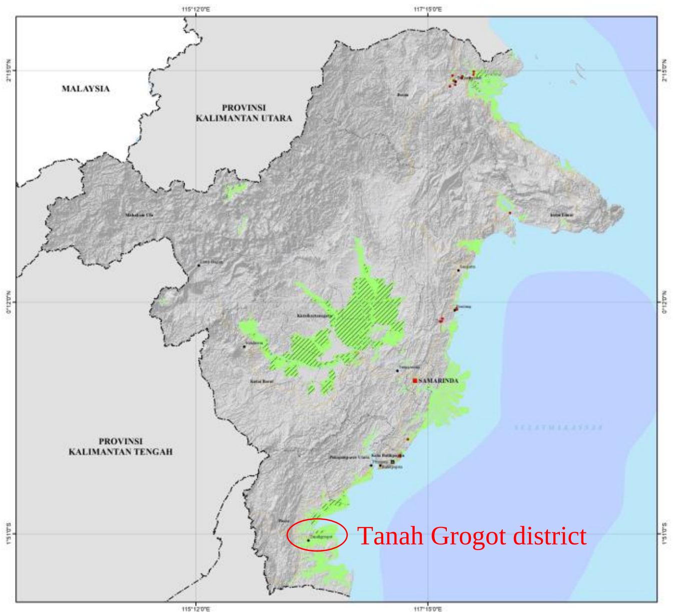

Figure 1. Soft soil distribution map of East Kalimantan province [1]

The construction of Paser Airport is designed to have a 2090-meters runway and 150-meters long landing strip. With the presence of Paser Airport, the distance and travel time from Balikpapan city or another city/region to Paser regency can decreased and can increase the economic growth in Paser regency. Paser Airport were design to handle domestic flight and will be upgraded to handle international flight later. The layout of Paser Airport can be seen in Figure 2.

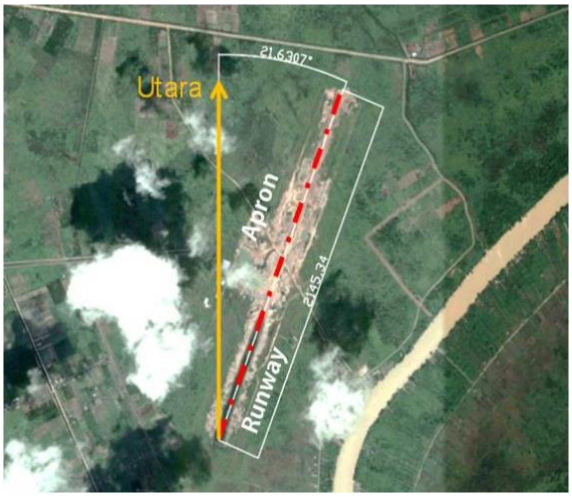

Figure 2. Paser Airport layout

Geotechnical drillings and Standard Penetration Tests are performed to determine the depth and characteristics of soft soil in Paser Airport area. Based on the results of field investigation a very soft to medium stiff clay layer is found from the elevation of 0 to 24-meters deep with Ground Water Level is found at elevation of -1 meter. The result of field investigation can be found in Table 1.

Table 1. Field investigation result

Elevation (m)	N_{SPT}	Soil description	Consistency
0 – 8	1.4	Clay	Very soft
8 – 18	4.67	Sandy clay	Soft
18 – 22	10.5	Clay	Medium
22 – 24	18	Clay	Medium
24 – 39	37.5	Clay	Stiff
39 – 40	57	Sand	Very dense

Based on Indonesian Standard for Geotechnical Design Requirement (SNI 8460:2017), one method of soil improvement that suited very well for a soft clay layer (clay or silt to sandy silt with particle size from 0.1 – 0.0001 mm) is using Prefabricated Vertical Drain (PVD) combined with soil preloading. This system combination has the goal of shortening the pore water flow path because by preloading the soil will be compressed then by using PVD, the pore water flow can move horizontally can be seen in Figure 3. In addition, the use of PVD combined with preloading aims to reduce the settlement after construction, accelerate consolidation by reducing the path length of excess pore water pressure dissipation, increase stability (by increasing the effective stress in the soil), and reduce/mitigate liquefaction effects [3], [8]–[11].

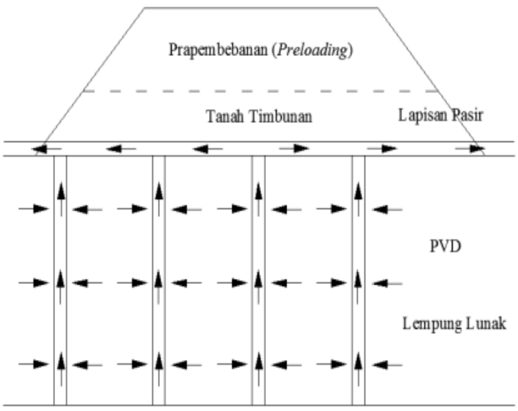

Figure 3. PVD and preloading system (Hardiyatmo, 2022)

This study aims to evaluate the effectiveness of PVD and preloading in reducing consolidation time on soft soil of Paser Airport numerically. The preloading height is calculated so that the final embankment elevation is reached when the settlement has been completed.

2. METHODS

The whole soil improvement analysis will be based on Indonesian Standard for Geotechnical Design Requirement (SNI 8460:2017). Plain-strain model of embankment and soft soil layer modelled by finite element method using Plaxis 2D software. The geotechnical parameters used in this research are obtained from the field investigation in airport area. The condition of before and after soil improvement modelled to determine the effectiveness of the use of PVD and preloading. The total stress of preloading load will be calculated so that the final embankment elevation is reached when the settlement has been completed. Manual analysis also will be carried out so obtain the comparison result to numerical analysis.

3. RESULT AND DISCUSSION

3.1 Parameter

The cross section of runway of Paser Airport can be seen in Figure 4. The final elevation of runway embankment (embankment height) is 2.5-meters with top and bottom width are 18-meters and 66.55-meters. The material used for embankment must meet the criteria based on General Specification by the Ministry of Public Works of Republic of Indonesia which has CBR > 10% and Plasticity Index < 6%. The parameter for embankment can be found in Table 2 and the parameter for runway pavement are presented in Figure 5.

Table 2. Embankment parameters

Parameter	Unit	Value
Density, γ	kN/m^3	19
E_{50} ref	kN/m^2	40000
E_{oed} ref	kN/m^2	40000
E_{ur} ref	kN/m^2	120000
φ	^{o}	27.5
$k_x = k_y$	m/day	7.128

The parameters for soft clay layer are obtained through several correlation formula, tables, and curves from geotechnical drilling and Standard Penetration Test result. The geotechnical parameter for soil layer can be found in Table 3.

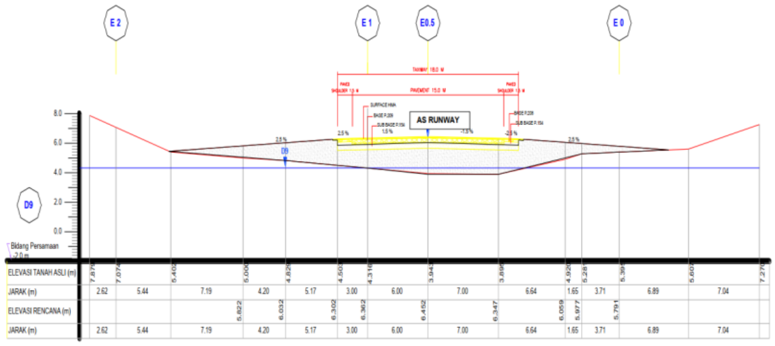

Figure 4. Runway embankment cross section

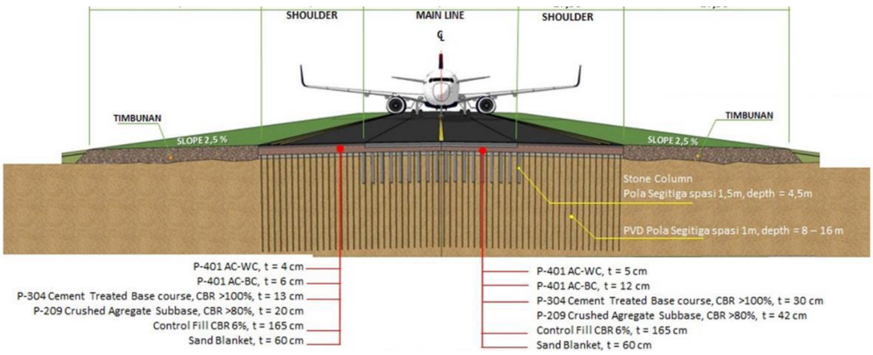

Figure 5. Runway pavement cross section and thicknesses

3.2 Preloading and settlement calculation

The total settlement of soil layer is calculated using Giroud method for elastic settlement, as in Eq. (1) and Terzaghi method for one dimensional consolidation settlement for normally consolidated soil as in Eq. (2). The result of settlement calculations of each iteration of embankment height are presented in Table 4.

$$S_i = q \sum \frac{h_i}{E_i} \quad (1)$$

$$S_c = \frac{Cc}{1+e_0} H \log\left(\frac{P_0+\Delta P}{P_0}\right) \quad (2)$$

Table 3. Soil parameters

Elev. (m)	γ (kN/m^3)	c (kN/m^2)	φ (°)	E (kN/m^2)	μ	e_0	Cc	Cv (m^2/year)
0 – 8	15.50	12.50	20	2172.696	0.18	1.33	0.317	2.088
8 – 18	16.80	16.00	21	3425.059	0.22	1.04	0.231	2.604
18 – 22	17.00	22.50	22	6600	0.25	0.63	0.108	3.154
22 – 24	17.50	37.78	23	11455.77	0.3	0.56	0.087	12.812

Table 4. Embankment final elevation calculation

$H_{initial}$ (m)	Preloading Stress (kN/m^2)	S_{total} (m)	H_{final} (m)
2.5	47.5	1.594	0.906
4	76	3.229	1.436
5	95	4.083	1.709
6	114	4.944	1.967
7	133	5.812	2.213
8	152	6.685	2.449

From calculation result it was found that the initial height of embankment is 9.134-meters to obtain the embankment final elevation 2.5-meters with the total settlements of soil is 6.685-meters. The time it takes for consolidation to settle is calculated using consolidation coefficient, as in Eq (3). With average Cv of 2.723 m2/year the time for consolidation to complete (U = 90%) was 44.84 years.

$$t = \frac{T_v H^2}{C_v} \quad (3)$$

3.3 Soil improvement analysis using PVD

The PVD installation design is carried out in a triangular and rectangular pattern with the distance intervals (s) used, namely 1-m, 1.5-m, 2-m, 2.5-m, and 3-m. The layout of each pattern can be seen in Figure 6. The type of PVD used is 100 mm wide and 3 mm thick, installed to a depth of 18 m. The result of consolidation time (t90) of each variable is compared in the Table 5 and Figure 7.

Table 5. Comparison of PVD distance and pattern to consolidation time

Interval (m)	Triangular Pattern t_{90} (day)	Rectangular Pattern t_{90} (day)
1	48.18	57.6
1.5	127.77	152.07
2	251.64	298.68
2.5	422.85	501.03
3	643.8	761.91

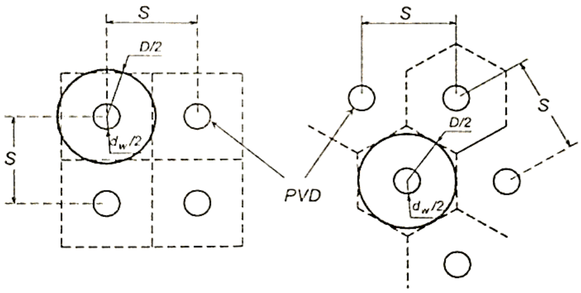

Figure 6. PVD rectangular and triangular patterns

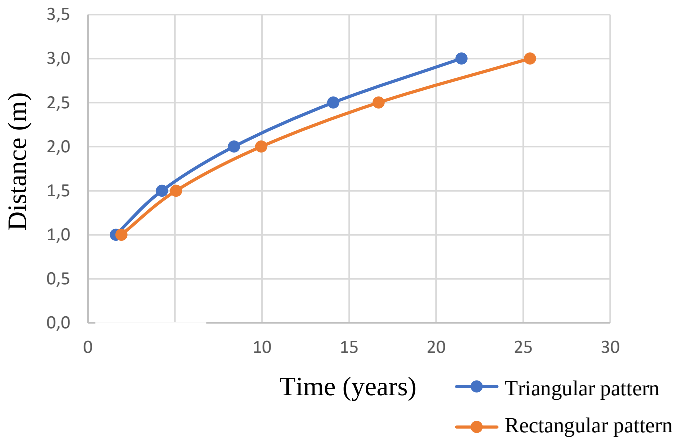

Figure 7. Relationship between the PVD interval and consolidation time

From the calculation PVD with triangular pattern resulting in faster consolidation time than rectangular pattern. This is due to PVD with triangular pattern are more efficient in placement so it can cover more area than rectangular pattern. The higher the gap or interval between PVD, the time it takes for consolidation to settle are longer.

3.4 Numerical Analysis

Numerical analyses are carried out using Finite Element Method with the help of Plaxis 2D software. The parameters used in this analysis are the same with the parameters used in analytical analysis as for embankment and soil parameters, are presented in Table 2 and Table 3. The numerical analysis was conducted with 3 conditions, namely the existing condition if no soil improvement was implemented, and the use of PVD with interval 1-m and 2-m. The embankment height used in numerical analysis is 2.5-meter based on the cross section of runway. Analysis conducted by Plaxis 2D using stage construction method, where the embankment was implemented gradually. The result of plastic analysis and consolidation analysis of existing condition can be seen in Figure 8 and Figure 9 respectively.

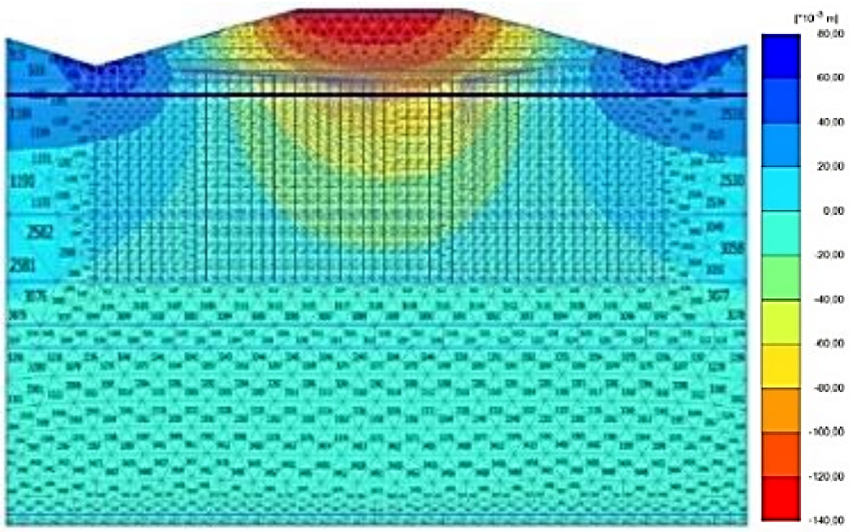

Figure 8. Plastic analysis of existing condition before soil improvement

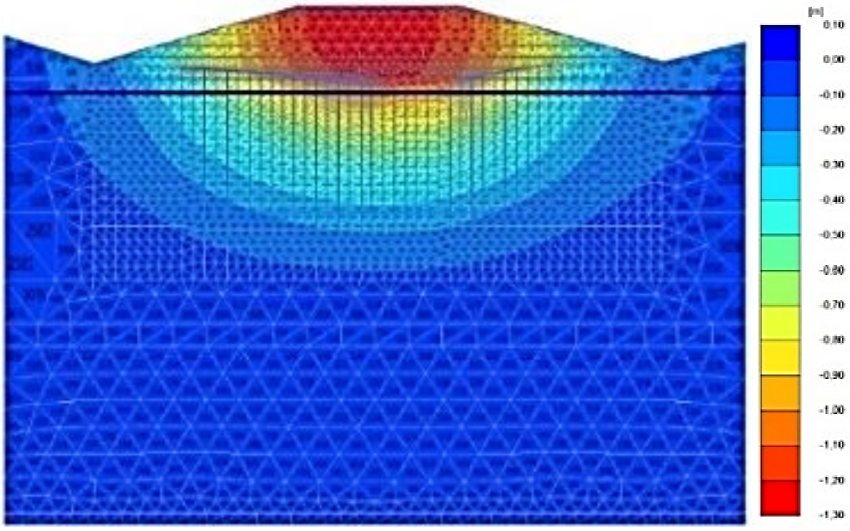

Figure 9. Consolidation analysis of existing condition before soil improvement

The result of existing condition before soil improvement using PVD show the displacement that occur of plastic analysis and consolidation analysis were 0.1351-meter and 1.281-meter respectively, with total displacement or settlement is 1.416-meter compared to manual calculation using analytical method is 1.594-meter. The time it takes for consolidation to complete is 13270 days or 36.36 years compared to manual calculation is 44.84 years. The result of consolidation analysis after soil improvement was implemented with the interval of PVD 1-meter and 2-meter can be seen in Figure 10a and Figure 10b respectively.

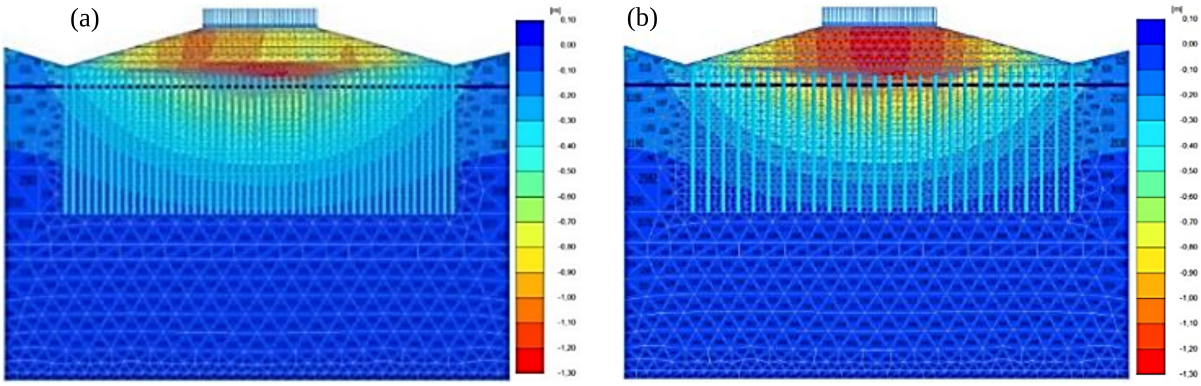

Figure 10. Consolidation analysis after soil improvement with (a) 1-meter interval and (b) 2-meter interval

The result of soil improvement analysis using numerical method shows that the use of PVD did not affect the amount consolidation settlement of each model significantly, which are 1.221-meter for 1-meter PVD interval and 1.228-meter for 2-meter PVD intervals compared to condition before soil improvement which Is 1.281-meter. However, the consolidation time of improved soft soil decrease significantly from 36.36 years to only 63.22 days or 0.173 years when using 1-meter PVD interval. The use of PVD with 2-meter interval show no increasing or decreasing in consolidation time with 63,54 days or 0.174 years. The relationship between excess pore pressure and time it takes to consolidate is presented in Figure 12.

The relationship between settlement time and pore water pressure, shows the consolidation completed when the excess pore water pressure reaches 1 kPa or t_{90}. The use of PVD as soil improvement significantly reduce the consolidation time, this is due to the path length of excess pore water pressure dissipation has been reduced, so that water can travel horizontally rather than vertically from the very bottom of soft soil layer to ground surface. Meanwhile, the relationship between settlement and consolidation time in Figure 13 shows the same total settlement before and after the soil improvement but using PVD can decrease the consolidation time.

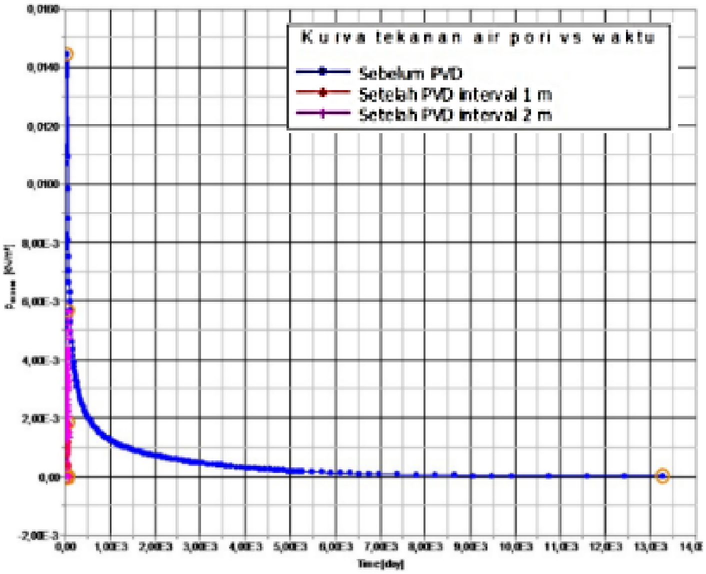

Figure 12. The relationship curve of excess pore water pressure versus time

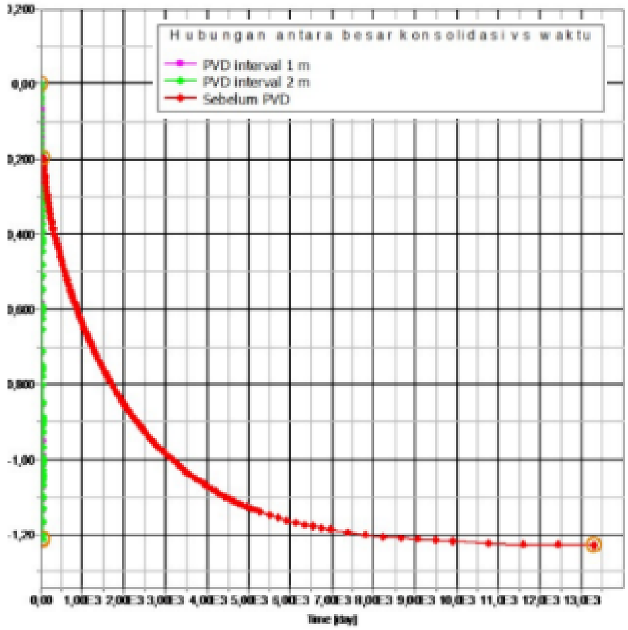

Figure 13. The relationship curve of settlement versus time

4. CONCLUSION

Based on numerical and analytical analysis to determine the effectiveness of the use of PVD as soil improvement shows that PVD can reduce the consolidation time very significantly from 44.84 years to 48.18 days or 0.132 years using analytical calculations and from 36.36 years to 0.173 years using finite element method when using 1-meter PVD interval. The use of PVD did not affect the amount of total settlement occurred on soft soil, but the higher the preloading stress applied the larger and faster consolidation to completed.

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