Numerical Prediction vs Measured Lateral Movements of An Unstable Slope Before and After Reinforcement by Two Rows of Bored Piles – A Case Study in Kalimantan Indonesia

Fadlli As-Shidiqqy, Endra Susila[2], Andhika Sahadewa[3]

[1]Master of Engineering Program, Department of Civil Engineering, Institut Teknologi Bandung
[2]Assistant Profesor, Department of Civil Engineering, Institut Teknologi Bandung
[3]Assistant Profesor, Department of Civil Engineering, Institut Teknologi Bandung

fadllishidiq@gmail.com, endra@si.itb.ac.id, sahadewa@ftsl.itb.ac.id

ABSTRACT: This paper discusses the behaviors of an unstable slope in Kalimantan Indonesia, before and after installation of reinforcement by two rows of bored piles. Horizontal movements were noticed several months after completion of construction on a pile slab structure built on clays with fairly steep slope conditions. An instrumentation system of an inclinometer was installed following the noticed movement, to monitor lateral movements of the embankment. Data from the installed inclinometer shows that slow movement had occurred continuously and had caused the pile slab structure to move. For a quick mitigation, a group of bored piles were selected to reinforce the slopes. To study the behaviors, a finite element modeling was performed. A Professional software called PLAXIS was utilized. To model the field conditions, the back analysis method was performed to study the condition and to refine parameters obtained from field soil investigation. The models were carried out using peak and residual soil parameters. The results were next compared with the movement behavior of the movement monitored by the installed inclinometer. The selected soil parameters were the ones that matched the most the behavior of the inclinometer monitoring results. Next, an analysis of the deformation behavior that occurs due to the reinforcement of the soil and its slab structure was carried out. Furthermore, the results will be compared with the results of monitoring using an inclinometer, so that the treatment carried out was verified. This study found that the selected reinforcement system can effectively stabilize the unstable slope. This study also found, the selected numerical model could capture the behaviors of the unstable slopes (deformation and failure plane) and could predict the behaviors of reinforced slopes.

Keywords: Slope Stability, Reinforcement, inclinometer, mitigation, residual, bored pile, PLAXIS, prediction lateral movement by modelling

1 INTRODUCTION

In one project in Kalimantan, a pile slab structure has been built, with the reason that the location has a subgrade position or the existing land is very far below the planned elevation, the soft soil area is quite deep, and has limited land because this location is close to residential areas. local. In planning the pile slab construction, embankment is used as a reinforcement for the pile slab leg area. The embankment at the foot of the pile slab is done to smooth the slopes. Initially the construction did not experience any problems, but after a few months, when it rained, causing the pile slab construction to experience movement, an inclinometer was installed to monitor the movement in the lateral direction (procedure in SNI 3404-2008).

After the inclinometer is installed, the readings from the inclinometer show daily movements, as evidenced by the pile slab that is cracked due to the large lateral force of the soil being pushed.

After re-investigation at this location was carried out using the SSP (Steel Sheet Pile), as well as a trial of piling in the field, but the piling did not go smoothly because the SSP could only enter at a depth of ±5 m and the SSP also shifted after a few days later. Seeing this, it is necessary to re-investigate. To assist the investigation, modeling was used using PLAXIS 2D and PLAXIS 3D software, as well as to confirm the results of the analysis compared to monitoring using an inclinometer. As the handling and mitigation of the collapse in the pile slab construction, it is planned to use soldier pile reinforcement to hold the soil in order to minimize the lateral forces that occur due to soil thrust.

In the planning analysis of the soldier pile, there are several aspects that need to be considered in order to get efficient and effective results, namely the dimensions, installation position, and installation pattern of the soldier pile, which will later produce the results that make the smallest lateral movement. The pattern variation that is carried out is to try with 1 row of bored piles with a space of 2 m from the axle to the axle, with a cap on it, then if the lateral movement is still large enough then do it with 2 rows of bored piles with parallel pattern variations. Meanwhile, variations in the position of the bored pile installation will be carried out with several trials with different distances from the pile slab location. This is taken into account because if the distance is too close to the pile slab position, it is possible to disturb the pile slab structure, but if the distance is too far, it will allow soil movement in the space or space between the pile slab locations to the bored pile point. Then it will be done with 2 variations of the distance, namely 10 m to 15 m. To get a safety factor value > 1.5 in accordance with the requirements of SNI 8460-Geotechnics 2017.

The analysis carried out for this treatment is using the finite element or numerical method with the help of the PLAXIS 2D plane strain software which aims to produce output in the form of interactions that occur in the pile slab due to soil thrust after the reinforcement of the soldier pile. After handling the analysis and the construction is done, it is necessary to check the movement in the field, using the confirmation or monitoring method by installing an inclinometer. These results can be compared approximately 1 month after the installation of the inclinometer, if the results of the inclinometer are not very different from the planning results, then the confirmed planning can be considered correct prediction behavior of movement soil and pile using numerical methods.

2 PROBLEM DESCRIPTION

The review area in the case study used in this research is located in Kalimantan with a pile slab construction. The thing that is used in the research review is the area of the embankment foot which is used as reinforcement to stiffen the pile slab. This is done because the elevation of the pile slab foot area can be said to be steep and allows lateral movement to occur. After the arrival of the rainy season, there was a large enough movement that caused the fracture of one of the pile slabs. The movement is then monitored using an inclinometer to determine the location of the depth where the movement occurred, and the pattern of the movement. To find out and confirm the latest data related to soil at the site, field tests in the form of N-SPT, and laboratory tests can be used as comparisons and complementary data. After that, it will be analyzed the reinforcement that will be applied with the recommendation of reinforcement in the form of bored pile. After that, the modeling conditions in PLAXIS for prediction of deformation and behaviour to determine the value of deformation after using reinforcement compared to the actual conditions, for know how accurate the prediction deformation and behaviour by PLAXIS.

3 GEOTECHNICAL CONDITIONS

The soil at this location is sedimentary soil or commonly called alluvial when viewed from the geological map of the area (ISBN.978-602-9105-80-3), so that at this location it is possible to have deep soft soil. When conducting soil investigations in the field and laboratory, it can be seen that the soft soil depth is about 14 m, in the area near the toe of the plate, as shown in the image below. It can also be seen in the image below that the red line is the movement of the inclinometer monitoring that occurs to a depth of approximately 14 m, as shown in Figure 1.

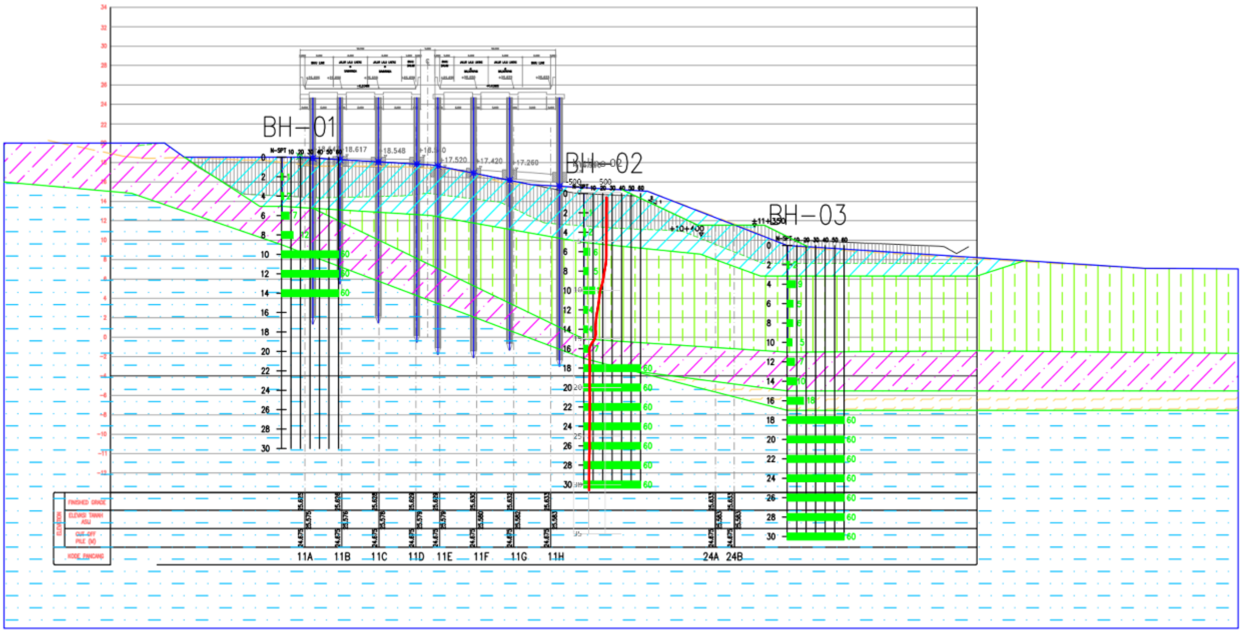


Figure 1. Soil stratification and cross section

4 ANALYSIS METHOD

In finding the initial condition, parameter soil should be interpreted, it is done by describing the soil layer according to the N-SPT value and soil classification, then the N-SPT value is correlated to the parameter value in the modeling with additional laboratory test results as a comparison or as a reinforcement in determining parameters (Burt Look, 2007). Beside that's, parameter values must adjust to the field condition, it is necessary to verify the soil parameter model, which is done by making an initial model with a failure condition or safety factor ≤ 1 (SNI 8460-2017 Geoteknik) which is a requirement of the back analysis method to show that the modeled conditions have reached collapse, so that the soil parameters used can be said to be in accordance with the conditions that occur in the field. In addition, the deformation values in the field are also used as a comparison with the analysis using the PLAXIS software. If the deformation that occurs is the same as the field conditions, the modeled parameters can be followed up with an analysis of the treatment plan that will be applied.

5 SELECTION OF SOIL PARAMETERS

To verify the model in adjusting the geometry and soil parameters, running is carried out by adjusting the field conditions or conditions where the soil experiences movement according to field conditions by using monitoring in the form of an inclinometer that is installed and has a safety factor value equal to one or a critical condition and will precisely move. For more details on the condition of the critical safety factor can be seen in Figure 2 in 2D model, and Figure 3 in 3D Model.

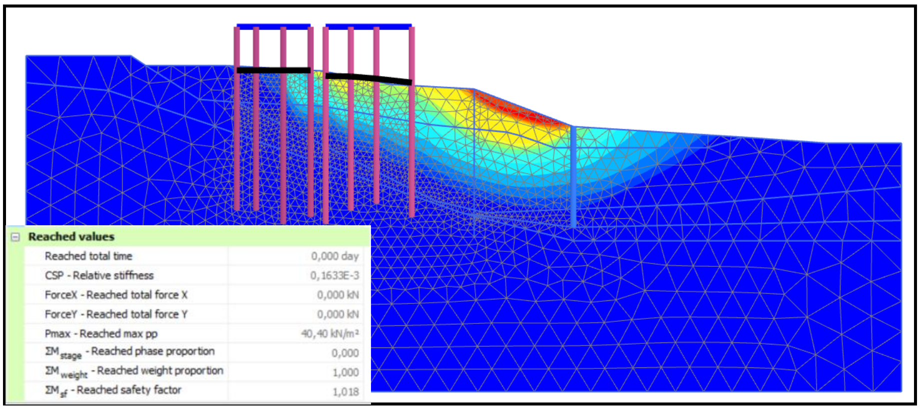


Figure 2 *Safety factors* PLAXIS 2D model

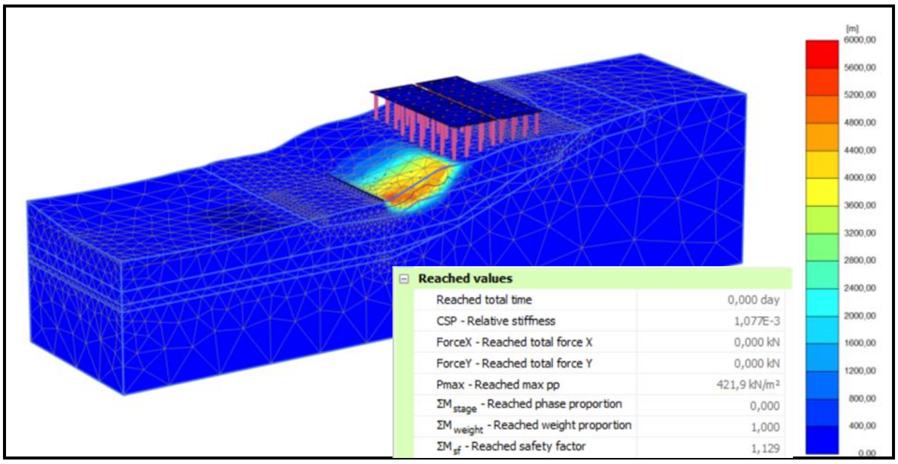


Figure 3 *Safety factor* model PLAXIS 3D

From the model we get safety factor in critical condition, for 2D model the value is 1,022 and from 3D model value of safety factors is 1,129. The difference value can happen because the model 3D has different contours in longitudinal direction.

In the back analysis method, in addition to the value of the safety factor that reaches a critical value, the deformation in the modeling must also be able to resemble or approach the inclinometer monitoring in the field. Figure 4 shows that the movement of the inclinometer monitoring results using PLAXIS 2D and 3D modeling.

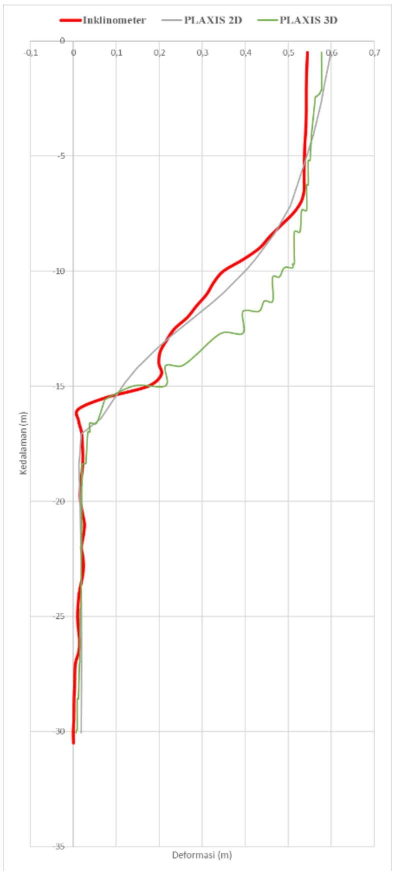


Figure 4 Deformation comparison of the inclinometer with the PLAXIS model

From the results of calculations using the PLAXIS software, parameter values are obtained that are close to the original conditions in the field by fulfilling several criteria, namely the SF value ≤ 1 and the movement is equal to or close to the horizontal movement of the inclinometer monitoring results in the field which can be seen in table 1. In determining soil parameters that has collapsed, it is more appropriate to use the residual condition parameter, meaning that the parameter obtained must be correlated with the residual condition. Then the parameter values from the reanalysis will be compared with the correlation parameters obtained in the residual condition. The following parameter values for the difference in residual and back analysis parameter values are shown in table 2.

Table 1 Parameters result from back analysis adjustment

Soil Layer	Type	γ_{unsat} [kN/m^2]	γ_{sat} [kN/m^2]	k_x [m/day]	k_y [m/day]	E' [KPa]	v (nu)	C'_{ref} [KPa]	ϕ' [^{0}]
Layer 1 (Soft soil) (N = 2)	Undrained A	12	16	8,64x10-4	8,64x10-4	2475	0,3	1,1	16
Layer 2 (Sandy Clay, Medium) (N = 6)	Undrained A	16	18	8,64x10-4	8,64x10-4	4000	0,28	3,3	15
Layer 3 (Medium-stiff Clay) (N = 9)	Undrained A	16	18	8,64x10-4	8,64x10-4	11137	0,28	4,95	27
Layer 4 (Stiff Clay) (N = 18)	Undrained A	16	18	8,64x10-4	8,64x10-4	22275	0.28	10	25
Layer 5 (Very stiff Clay) (N = 60)	Undrained A	18	20	8,64x10-4	8,64x10-4	73150	0.28	33	30

Table 2 Comparison of effective phi values (Φ')

Soil Layer	Φ' [^{0}] Peak	Φ' [^{0}] Residual	Φ' [^{0}] Back Analysis
Layer 1	23	17	16
Layer 2	22	14	15

Based on table 2, it can be seen that the difference in the value of the shear angle parameter in the back analysis results with the correlation parameter for residual conditions is not significantly different, the difference is only around 1°, while the difference for peak conditions is around 7°.

6 ANALYSIS OF SLOPE REINFORCEMENT

Analysis of slope reinforcement can be done by obtaining models and parameters that describe field conditions. The selection of the handling method is carried out by adjusting to the case that occurs. From several handling stability and slope stability reinforcement, the possible reinforcement is reinforcement using bored pile.

Reinforcement using bored piles will be carried out with several alternative installations if the initial alternative cannot withstand lateral forces and the value of the safety factor does not meet the requirements, the alternative is first to use a single row bored pile without benching, 1 row with benching, and 2 rows with benching. For more details, see at figure 5, Figure 6, and Figure 7.

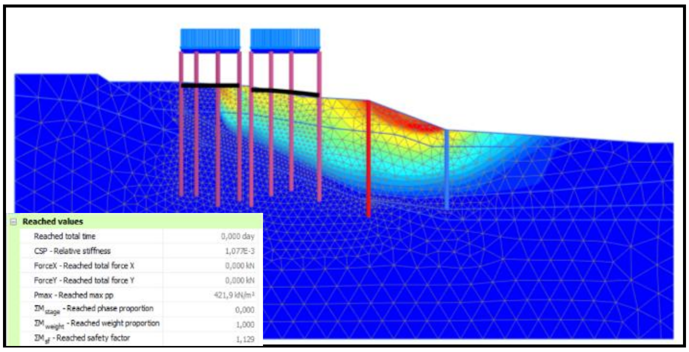


Figure 5 Calculated safety factors for static load conditions

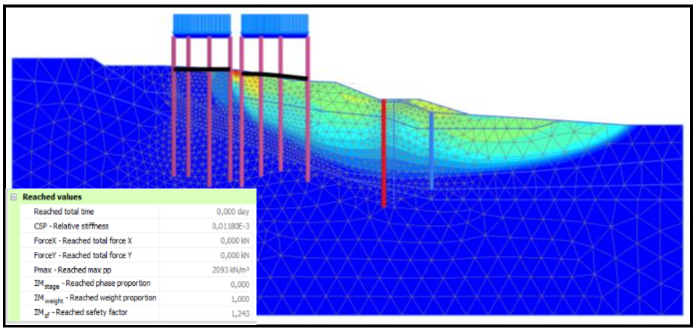


Figure 6 Calculated safety factors for static load conditions

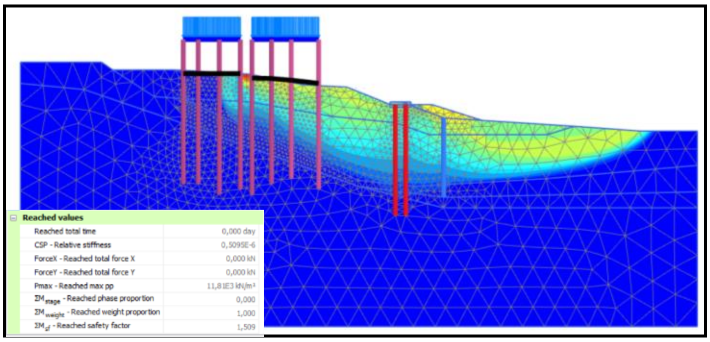


Figure 7 Calculated safety factors for static load conditions

From the results of the analysis above, the handling that meets the design criteria for the value of the safety factor is using a 2-line bored pile handling with a safety factor value of 1.509 > 1.5.

For dynamic analysis, Peak Ground Acceleration (PGA) get from spectrum desain in http://rsa.ciptakarya.pu.go.id/2021, the value acceleration for soft soil condition (SE) is 0,058 g. The result from PLAXIS we can see in the figure 8.

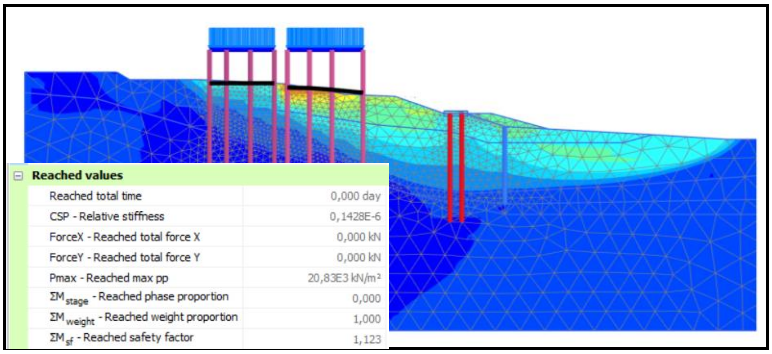
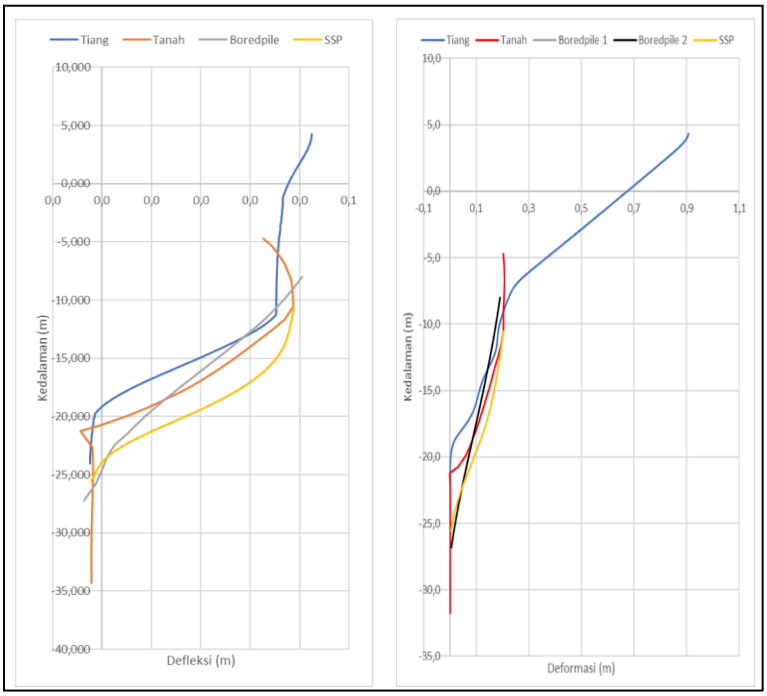


Figure 8 Calculated safety factors for static load conditions

From the results of the analysis above, the handling that meets the design criteria for the value of the safety factor is using a 2-line bored pile handling in dynamic load condition with a safety factor value of 1.123 > 1.1.

After an analysis that can meet the criteria of the safety factor is carried out, then an analysis of the deformation that occurs due to the influence of the bored pile reinforcement is carried out on the slab pile, as well as the soil at the review location. The behavior of the deformation movement that occurs between the soil and the pile and bored pile due to static and dynamic loads (pseudo-static method) can be seen in Figure 9.



(a) (b)

Figure 9. The behavior of lateral deformation on the soil that occurs due to (a) static load (b) dynamic load

For a recapitulation of the maximum deformation that occurs in each component can be seen in Table 3.

Table 3. Computed deformation values of each component

No.	Component	Deformation (m)			
		Initial condition	*No load*	*Load*	*Seismic Load*
1	Pile slab	0.6702	0.0013	0.0425	0.9072
2	Soil	0.5990	0.0020	0.0327	0.2022
3	*Bored Pile*	-	0.0020	0.0405	0.1905
4	SSP (*Steel Sheet Pile*)	0.6210	0.0020	0.0389	0.2039

7 CONCLUSIONS

Some conclusions that can be drawn from the results of the evaluation of these regression equations are:

- The difference between the peak shear strength parameters and the trial parameters from the field condition modeling is quite significant in angle friction, which is about 44% greater than the parameters obtained from the trial results. That's all can be done because condition after failure in the soil just have the residual strength.
- The difference in the shear strength parameter of the residual condition with the trial parameter from the field condition modeling is not significant, which is around 5%, then the parameter in the failure condition is the residual parameter of a soil
- The difference in deformation in the modeling of the residual parameter conditions with field conditions is not too significant with a difference in the deformation value of around 9%.
- The safety factor value for the critical condition of the 2D model is 1.018, and for the 3D model it is 1.1, this is due to the 3D effect which shows the actual conditions in the longitudinal direction have different elevations and geometries.
- The value of the safety factor in the handling of a single row bored pile at close range to the slab pile located on the slope produces an SF value of 1,1, handling a single row bored pile at a distance from the slab pile and installed between the slopes produces an SF value of 1,2 as well as in handling Bored pile of two rows a distance away from the slab pile and installed between the slopes produces an SF value of 1.5. Then it can be concluded that the treatment to be used is by using a 2-row bored pile

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