THE EFFECT OF THE USE PREFABRICATED VERTICAL DRAIN (PVD) ON SOFT SOIL CONSTRUCTION OF BANDUNG CITY ROAD WITH FINITE ELEMENT ANALYSIS

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ABSTRACT

Soft soil has low permeability and high-water content that can cause soil subsidence and persistent consolidation time. Soil improvement will be able to minimize the subsidence and lengthy consolidation process by installing a combination of preloading and PVD. The effect of the installation of PVD and preloading was analyzed using Finite Element Analysis. An equivalence between plane strain and axisymmetric was formulated to obtain a 2D finite element analysis that was closer to field conditions. The equivalent equation between axisymmetric and plane strain has been proposed by the Indraratna Method. This study aims to determine the stress-strain behavior, pore water pressure, and stability in the use of PVD as well as the effect of the smear zone. The results indicated that using a combination of preloading and PVDs allowed the soil to reach the end of consolidation faster with a time difference of 1,015 days with the installation of a triangle pattern whose distance between PVDs was 1.5 m. Meanwhile, the effect of the smear zone indicated that the greater the permeability value of the smear zone, the smaller the degree of total consolidation that occurred. This was indicated by a decrease of 430 mm in 97 days. The degree of total consolidation was directly proportional to the decreased value in a certain time. Therefore, if the subsidence is greater, the value of the total consolidation degree will follow.

Keywords: Finite Element Analysis, Prefabricated Vertical Drain, Soft Soil

1. INTRODUCTION

Based on soil investigation analysis, Summarecon Bandung City possess soft soil content which has more water and air than solid soil particles. The construction of malls, residential areas, shop houses, offices, and other facilities are built on this soft soil.

In this study, an investigation was carried out in the Mall area which focused on road construction as shown in Figure 1. Many soil improvement methods have been proposed and applied in soft soil locations to increase their bearing capacity and minimize anticipated settlement [1]. With low strength and high compressibility, it is crucial to make improvements to avoid excessive settlement and prevent stability failure.

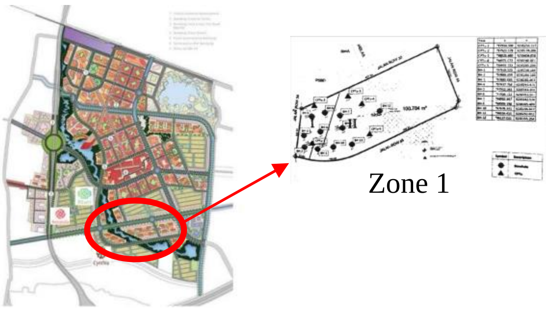

Figure 1. Kota Summarecon Bandung Area Development

Therefore, it is necessary to study how the behavior of embankment construction is related to stress-strain, pore water pressure, and stability, to determine the effect of using PVD on soft soil by applying the finite element method and to consider the smear zone effect using the Indraratna and Redana approach, 1998.

2. LITERATURE

Soft soil is divided into several types, namely silt, clay, organic soil, and sandy soil. Silts have low undrained shear strength, which is around 10 – 20 kPa for soft silts, while 4 – 10 kPa for very soft silts. The level of plasticity is low and has a high permeability so that the consolidation settlement occurs quickly. Clay soil is a cohesive soil that has a fine grain size smaller than 0.002 mm, low permeability, high capillary water increase, high compressibility so that the consolidation process takes place slowly [2]. Meanwhile, organic soil (peat soil) usually smells like rotting plants or wood. This soil is called peat soil when the organic level reaches more than 75% and has a very high natural water content. Peat soil is one of the most difficult soils to improve. Sandy soil is categorized as soft soil if it is in a loose state and has an N-SPT value of less than 10. Based on field tests, physically soft soil can be squeezed easily by the fingers.

2.1 Soft Soil Improvement

2.1.1 PVD *(*Prefabricated Vertical Drain*)*

Prefabricated Vertical Drain is a tool used for drainage using synthetic materials. The channel is made vertical which serves to shorten the path of pore water and accelerate the dissipation of pore water in the soil. This vertical drainage uses a plastic sheet combined with a core material polypropylene which has high mechanical strength. While the wrapping layer is a material in the form of geotextiles.

With the use of PVD, water will flow horizontally in the soil so that the horizontal/radial direction becomes very dominant, this will shorten the time for the consolidation process. To reduce land settlement due to consolidation during construction, the use of PVD is generally accompanied by preloading which exceeds the final post-construction load [3].

2.1.2 PVD Installation

In the process of installing Prefabricated Vertical Drain (PVD), a rectangular iron pipe (mandrel) is needed which functions to avoid damage to the PVD. A tool to assist with the PVD installation process is called a mandrel. The size of this rectangular iron or mardel greatly affects the amount of soil damage around the PVD due to the installation process which greatly affects the magnitude of the smear effect that occurs with the larger the size of the mardel, the greater the damage. For the width of mandrel ranges from 40-150 mm and this size must be larger than the size of the PVD used so that the PVD can fit into the mandrel.

Estimated time required for the PVD installation process is between 1-5 minutes and assisted by a machine to move the mandrel up and down as quickly as possible.

2.2 Finite Element Method

The finite element method is a numerical procedure for obtaining solutions to problems found in technical analysis using the element discretization approach [4]. Criticization is the process of modeling a structure/object by dividing it into a number of small elements (finite elements) that are connected in nodes and are used by elements as boundaries of the structure or object. In the finite element method, the equation and the whole system is formed by combining the equations of the elements.

Modeling vertical drain in the analysis using a drain element that has an infinite permeability value. During the consolidation analysis, the drain element provides a zero excess pore pressure condition at all points in the channel. The drain element can be activated or not to determine the effect of using the drain element. Finite element analysis on soft soils usually uses the plane strain assumption. However, in the case of the field, consolidation around the vertical drain uses axisymmetric. An equivalence between plane strain and axisymmetric is made to obtain a 2D finite element analysis that is closer to field conditions The equivalent equation between axisymmetric to plane strain has been proposed by the Indraratna Method.

The sensory method, which is the most complex model because of its accuracy with parallel drain walls, is by modeling *v*ertical drain and smear effect zone. This method separates each smear and no smear zone by differentiating the horizontal permeability coefficient values. Indraratna adopted Hird's method for the calculation of permeability conditions without smear zone.

As the equation below:

No Smear Zone Effect

$$\frac{k_{hp}}{k_h} = \frac{0.67}{[\ln(n) - 0.75]} \quad (1)$$

With Smear Effect

$$\frac{k_{hp}'}{k_h} = \frac{\beta}{\frac{k'_{hp}}{k_{hp}}\left[\ln\left(\frac{n}{s}\right) + \left(\frac{k_h}{k_s}\right)\ln(s) - 0.75\right] - \alpha} \quad (2)$$

$$\alpha = \frac{2(n-s)^3}{3(n-1)n^2} \quad (3)$$

$$\beta = \frac{2(s-1)[3n(n-s-1)+(s^2+s+1)]}{3(n-1)n^2} \quad (4)$$

where K_{hp} is the horizontal permeability of the undisturbed zone where s is the distance between vertical drain and K_h is the horizontal permeability, n is the distance ratio. k_{hp}' is the horizontal permeability of the disturbed zone.

2.3 Road

2.3.1 Pavement Layer

Road pavement is a construction built on a subgrade layer that serves to support traffic loads. There are generally two types of road construction, namely:

a. Flexible pavement
b. Rigid pavement

2.3.2 Traffic Load

According to Sukirman [7], road pavement construction receives traffic loads which are transferred through vehicle wheels. The amount of the transferred load depends on the total weight of the vehicle, the configuration of the axle, the contact area between the wheels and the pavement, the speed of the vehicle, and so on. Thus the effect of each vehicle on the damage caused is not the same. Therefore it is necessary to have a standard load so that all other loads can be equivalent to the standard load. The standard load is 18000 lb (8.16 tons) of double wheeled single axle load [7].

3. RESEARCH METHOD

3.1 Research Location

This study was conducted on the Summarecon Bandung Area Mall construction project on the road construction.

3.2 Stages and Procedures Of Analysis

The stages and procedures of analysis were as follows:

1. Library research
2. Data collection
3. Data analysis
4. Discussion

3.3 Data Collection Technique

To determine the parameters used in the analysis, secondary data in the form of laboratory data were used. The stages of analysis were as follows:

1. secondary data collection in the form of laboratory test results and borlog results,
2. planned load analysis,
3. calculation of evidence required for soil improvement using the evidence of the length of the consolidation process,
4. soil improvement using a combination of PVD and preloading and considering the smear zone,
5. finite element analysis using the Indraratna Method on conditions without PVD and with PVD as well as conditions considering the smear zone, and
6. analysis of stress-strain relationship, soil pore water pressure, and slope stability.

4. RESULTS AND DISCUSSION

The settlement and excess pore water pressure in this study were measured in the middle of the embankment with a depth of 17 m from the ground. In the trial area, PVD installation and preloading were carried out with a triangular pattern and the distance between PVDs was 1.5 m. Soil investigation at this location showed that the soil layer consisted of organic clay and silty clay with a depth of 25 m. Soil profile was obtained based on Test Drill data on the construction of the Kota Sumareccon Area Mall with N-SPT 10. The soil data under the embankment is selected from the Borehole data with the smallest value and is presented in **Table 1** below:

Table 1. Soil Parameters

Name	Embankment	Layer 1	Layer 2	Layer 3
		No PVD Usage		
γ_{unsat}	14	13.05	9.94	11.55
γ_{sat}	16	15.05	11.94	13.55
k_x	1.0	0.00864	0.00864	0.00864
k_y	1.0	0.00864	0.00864	0.00864
E_{ref}	3000	3000	3000	3000
ν	0.3	0.3	0.3	0.3
c_{ref}	1.0	9	12	12
φ	30	18	2	5
ψ	0.0	0.0	0.0	0.0
e_0	-	1.76	3.90	3.08
c_s	-	0.40	0.35	0.26

c_c	-	1.98	1.73	1.28
With Use of PVD Without Smear Zone effect				
$k(x)_{hp}$	1.0	0.00239	0.00239	0.00239
$k(y)_{hp}$	1.0	0.00864	0.00864	0.00864
With Use of PVD With Smear Zone effect				
$k(x)_{hp}$	1.0	0.00045	0.00045	0.00045
$k(y)_{hp}$	1.0	0.00864	0.00864	0.00864

4.1 Modeling of Vertical Drains

Technically, PVD is vertical bands made of synthetic material that is implanted using a crawler crane into soft soil, which then functions to absorb water and air in the soil until it comes out to the soil surface. In order to maximize the release of water and air, the soil is loaded in the form of sand. With PVD dimensions of 100mm x 4mm installed at a distance of 1.5m in a triangular pattern to a depth of 25m. The embankment soil used for the gradual embankment has a height of 5.5 m with 6 stages, for each stage it has a height of 1 m and the last stage is 0.5 m. The embankment height is based on the planned loading with an increase in soil elevation as high as 3m and the load from road construction is 13.15 kN/m2, so to get a final height of 3m, the planning height of the implementation embankment load is 5.5m. Loading modeling is presented in **Figure 2** below.

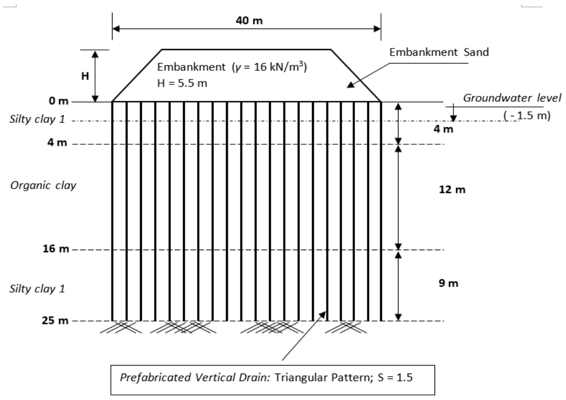

Figure 2. Geometry Modeling

In modeling using the Mohr – Couloumb (MC) model requires five parameters, namely Elastic Modulus, Poisson ratio, Friction Angle, Cohesion, and Dilantacy Angle. In this case study, the undrained method is used to model the behavior of soft soil and 3 kinds of permeability values are used, namely permeability without PVD, permeability with PVD without Smear Zone effect, and permeability with PVD + Semar Zone effect.

4.2 Embankment Load Planning

For planning on construction, the elevation on the ground level is raised as high as 3m. To determine the height of the embankment *preloading* and embankment height due to construction load and traffic load are as follows:

$$H = \frac{q_{bangunan}}{\gamma_{timbunan}} = \frac{13{,}15\ KN/m^2}{16\ KN/m^3} = 0{,}82\ m$$

Thus, the embankment height due to the building load and elevation increase is as high as

Hf = 3 + 0.82 = 3.82 m

to reach the final embankment height, the design embankment height is 5.5 m with a settlement value of 1.3 m.

4.3 New Road Planning

In this analysis, the type of collector road is selected which refers to the function of the road at that location so that it is known the thickness of the pavement layer that is used as a construction burden. The pavement structure and loads are presented below

- Pavement Arrangement:

- Laston = 7.5 cm
- Crushed stone – Class A (CBR 100) = 20 cm
- Crushed stone – Class B (CBR 80) = 24 cm

- Surface Coating: Laston

γ_1= 17 KN/m^3

Height = 0.075 m

$q_{building}$= γ_1 x height

= 17 KN/m^3 x 0.075 m

= 1,275 KN/m^2

- Top Foundation Layer: Crushed Stone – Class A

2= 23 KN/m3

Height = 0.20 m

$q_{building}$= 2 x height

= 23 KN/m3 x 0.20 m

= 4.60 KN/m2

- Lower Foundation Layer: Crushed Stone–Class B

γ_3= 22 KN/m^3

Height = 0.24 m

$q_{building}$= γ_1 x height

= 22 KN/m^3 x 0.24 m

= 5.28 KN/m^2

The highway construction load is 11.15 KN/m^2

The traffic load is assumed to be 2 KN/m^2
Total load 13.15 kN/m^2

4.5 Effect Of Application Of PVD's

In this analysis, to determine the effect of adding vertical drain on soft soil, modeled 2 conditions, namely with and without vertical drain. This will affect the process of removing excess soil pore water which affects the final time of consolidation. In the installation process of vertical drain, the land around vertical drain have trouble (smear zone) due to the width of the mandrel. Effect calculation smear zone using the method of Indraratna and Renada (1998) was also taken into account in this analysis [6].

4.5.1 Stress – Strain Behavior

The distribution of the total stress in the principal direction at the end of the construction is shown in **Figure 3.**

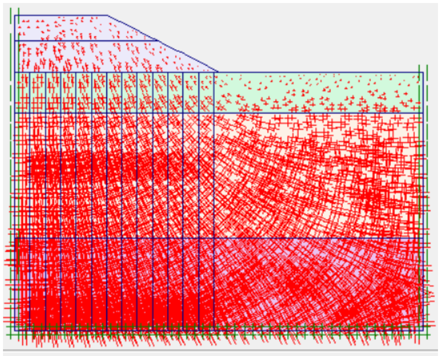

Figure 3. Total Stresses

Quantities can be assigned to any voltage point connected to a finite element network. The figure shows the total stress distribution where the extreme total main stress is – 369.01 kN/m^2 condition with vertical drain + Smear Zone effec*t*. For a comparison of the total stress values for several other conditions, it is shown in **Figure 4**.

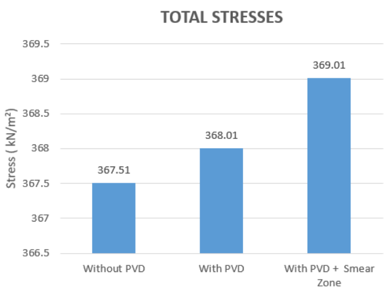

Figure 4. Comparison of Total Stress Values Curves in Various Conditions

4.5.2 Pore Water Pressure

The picture below shows that there is no vertical drain, the resulting pore water pressure does not decrease substantially, even after sufficient consolidation time. This is because the low soil permeability causes the pore water in the soil to be difficult to come out so it takes a long time for the final consolidation process. **Figure 5** shows the value of excess pore water pressure under conditions without using vertical drain.

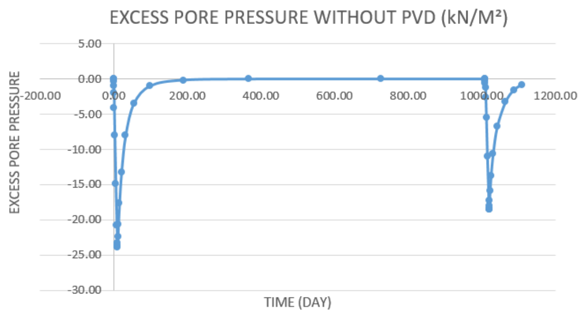

Figure 5. Excess Pore Pressure Values Without PVD

For **Figure 6** shows the different excess pore pressure conditions with PVD and smear zone

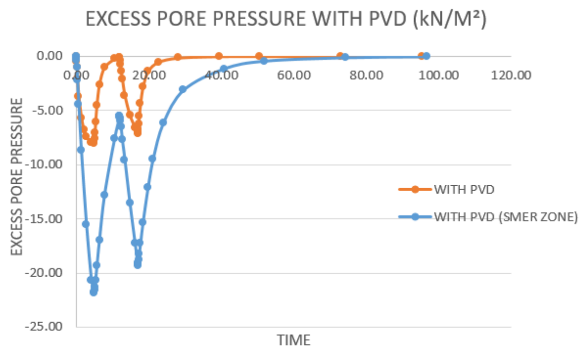

Figure 6. Excess Pore Pressure

The largest excess pore water pressure is 0.943 kN/m^2 in the negative direction (press). The largest pore water pressure occurs in conditions without using vertical drain seen in **Figure 7**. With the above data strengthen the statement that the effect of the smear zone on vertical drain is very influential on the consolidation time, since the calculation of the effect of the smear zone reduces the coefficient of soil permeability. Thus the time obtained under conditions without taking into account the effect of smear zone faster than entering the smear zone effect.

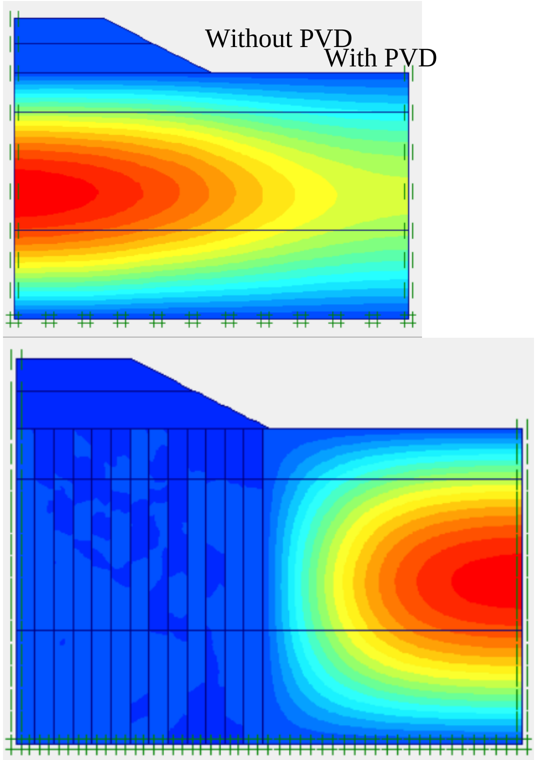

Figure 7. Distribution of Pore Water Pressure in Soil at the End consolidation

For the value of excess pore water pressure under various conditions, it can be seen in **Figure 8.** The maximum pore water pressure occurs in the early stages of construction. This shows one of the reasons why construction stages are important to evaluate.

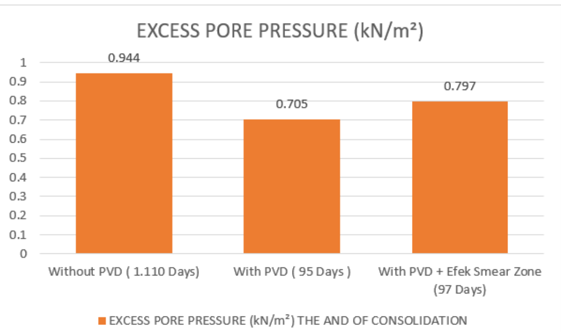

Figure 8. Excess Pore Pressure

4.5.3 Collapse Mechanism

Figure 9 shows the difference in settlement that occurs between the three soil conditions, namely the condition without PVD, the condition using vertical drian and conditions take into account the influence of smear zone. The settlement process in conditions without vertical drain is very slow, due to the absence of a short path for the exit of soil pore water. Meanwhile, with the use of vertical drain can shorten the distance of the exit of soil pore water, so that the final process settlement can happen more quickly. At the end settlement (430 mm) takes about 95 days under conditions not considering the effect of the Smear Zone, while conditions without vertical drain to reach the end of settlement takes 1110 days.

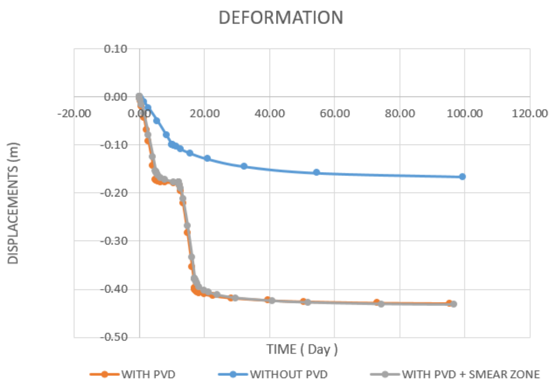

Figure 9. Deformation

The influence of the permeability of the smear zone effect on the magnitude of the settlement value of soft soil is very large. Permeability value under conditions considering the smear zone effect caused by the re-formation of the soil around the mandrel as a result of the installation process of vertical drain. The greater the damage to the soil that occurs, the magnitude of the settlement will automatically be smaller so that the time required will be longer. Soil settlement will increase when permeability smear zone it's getting smaller. Where the soil disturbance due to the vertical drain installation process is getting smaller, resulting in a faster land settlement [5].

From the results of this study it can be concluded that the greater the value of permeability of smear zone disturbed, the degree of total consolidation that occurs will be smaller. The degree of total consolidation is proportional to the magnitude of the decline that occurred over a certain period of time. Therefore, if the settlement is greater, the value of the degree of total consolidation will follow.

4.5.4 Analysis of Safety Factors

The safety factor analysis is made by assuming a reduction in the value of *phi –c*. The results of the analysis are shown in **Figure 10**.

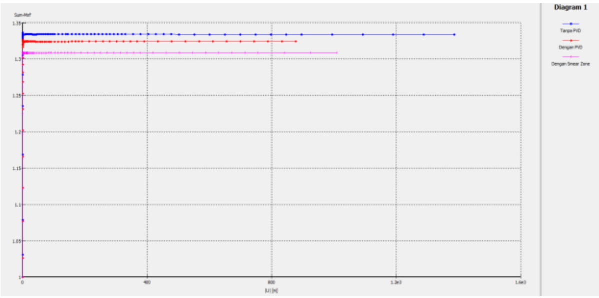

Figure 10. Safety Factors With Various Conditions

The safety factor value was obtained at the end of consolidation in conditions with and without safe PVD. And for conditions taking into account the effect of the Smear Zone, it is also safe.

5. CONCLUSION

The finite element method (FEM) is sufficient to provide a comprehensive evaluation of the embankment behavior analysis. Stress-strain distribution, pore water pressure, deformation and settlement predictions, and stability analysis can be obtained through computer program simulation models.

Based on the results of the analysis, it can be concluded that:

1. The result of the settlement using 1.5 m PVD indicated that it took 95 days to reach 90% consolidation and the decrease value was -430 mm, whereas it took longer (97 days) for conditions considering the smear zone with the same decrease value.
2. The relationship between stress and strain that occurred indicated that changes in soil conditions resulted in an increase in the stress value. This was characterized by the initial stress value without improvement of 367.51 kN/m^2, whereas in the improved soil conditions, the stress value was 368.01 kN/m^2. Conditions considering the smear zone affected the value of stress, which increased with a value of 369.01 kN/m^2.
3. The condition of excess pore water pressure at the end of consolidation indicated that it only took 95 days for the use of PVD with a final pore water pressure of 0.705 kN/m^2. Meanwhile, the condition without PVD took 1,110 days to reach pore water pressure of 0.944 kN/m^2. However, it took two days longer to consider the smear zone condition compared to without any consideration.
4. The safety factor in each condition obtained different values. These values indicated a safe condition and that prevented the landslide on the heap. The value of the safety factor without PVD was 1.3340 and with the addition of PVD was 1.3085.

The effect of permeability of smear zone effect to the magnitude of the decline is very influential. The result of the analysis is the greater the permeability value of the disturbed smear zone, the smaller the degree of total consolidation that occurs.

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