Evaluation of Undrained Shear Strength (cu) using CPT Data

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Abstract. A number of mechanical cone penetration tests (CPT) have been carried out within a 70 m by 70 m area of the Southern Tangerang District in order to evaluate of the small-scale variation of undrained shear strength (c_u) of a medium-stiff to very-stiff and overconsolidated clay. The tests were conducted at a grid spacing of either one from 15 to 50 metres, were taken to a typical depth of (1) one to 5 (five) metres. Measurement of cone tip resistance and sleeve friction were recorded at intervals of 200 mm. This paper examines only the results of CPT tests to determine the undrained shear strength (c_u), and applies the technique of spatial statistics is an analysis which takes the effect of spatial in its analysis. In spatial statistics, it can use spatial interpolation techniques of Ordinary Kriging (OK) and Inverse Distance Weighted (IDW) to obtain the other some points or grids information in area study by using CPT data. These methods can evaluate true of c_u values from triaxial test results based on both methods. In this research, the accuracy of method in the estimation process is reviewed based on Root Mean Square Error (RMSE).

Keywords: medium-stiff, overconsolidated, clay, shear strength, geostastistic.

1. Introduction

A site selected in the area of Southern Tangerang sizes 70 m by 70 m, at the study area relatively has low contour and near by Cisadane river; Location of site as shown in Fig. 1, has the coordinate position around 6°19'30 "- 6°22'12" South Lattitude (SL) and 106°38'24"-106°41'06" East Longitude (EL). Topographically, the study area and its surroundings are located at an altitude between 44 m to 88 m above the average sea level. The study area is included in the Cisauk sub-district, closing to Setu regency, Banten Province, West Java Province. Specifically, the location of this road is adjacent to the Cisadane river and drainage channels from housing around this road.

Much of Southern Tangerang district is underlain by a medium – stiff to very-stiff layers or overconsolidated clay as Tangerang clay which was deposited during the Miocene-Pleistoscene period (Bojongmanik to Serpong formations) (Bemmelen, 1949) shown Fig. 1. The Tangerang clay is locally significant because at this location exists an important access road between Kranggan to Suradita (Lintas Selatan road) with very heavy traffic and many type of moda transporation. Tangerang clay layers located relatively closes to ground surface, is free of fill and previous construction; is clear access to site; and is easy to be reached from public services.

2. Research method

2.1. Cone penetration test (CPT) data

In order to accurately undrained shear strength (c_u) data for shallow foundation system until 4.0 m depth to reinforce soil must obtain a large number of field and or laboratory test results. However, a few data sample are conducted only randomly and very irregular locations. Cone penetration test (CPT) by virtue of its continuous and simultaneous recording of cone tip resistance (q_c) and sleeve friction (f_s) is able to provide for evaluating the c_u value. Several study were performed by Orchant et al., 1988. Coefficient of variation for the CPT is in the range between 5 – 5%, and the CPT has a very low random testing errors than laboratory triaxial test. It was largely reasons that the CPT was used to evaluate the spatial variability of the Tangerang clay.

Soil mechanics and Foundation Laboratory of Civil Engineering Department, State Polytechnic of Jakarta has carried out some mechanical cone penetration tests (CPT); and sampling of disturbed and undisturbed was implemented. All soil layers obtained and observed by the core boxes of disturbed sample were compared to CPT data, and classified by CH and MH. Typical of CPT data is shown as Fig. 2. The depth of penetrometer is decided to an accuracy of 0.5%. Measurement of cone resistance, sleeve friction and depth were recorded at every 200 mm increments of the penetrometer travel.

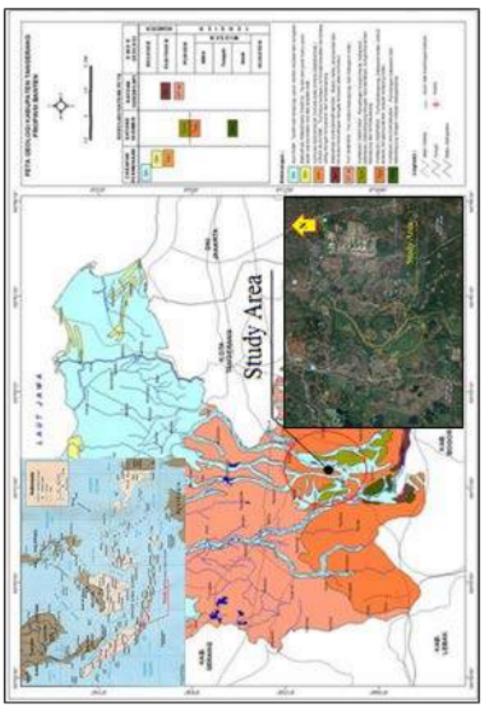

Figure 1. Study area and geology map for Tangerang District (Bemmelen, 1949) and location of access road of Suradita-Kranggan

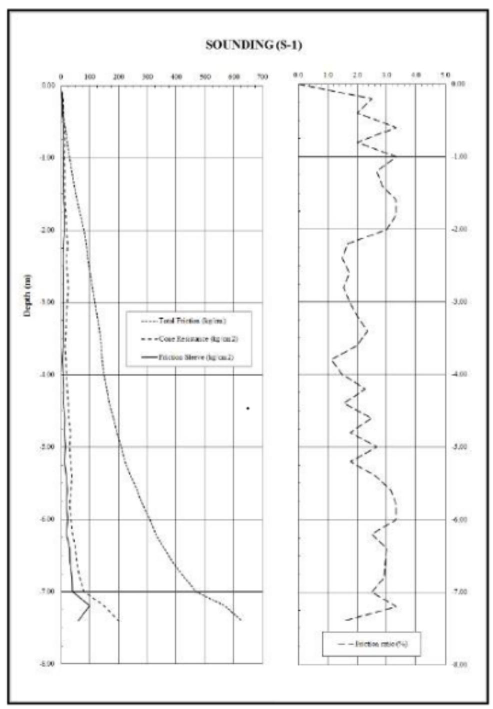

Figure 2. Typical CPT data results (S-1).

The layout of cone penetration tests (CPT), 6 (six) in all, is shown in Fig. 3. The cone penetrations were arranged at an area of 70 m by 70 m in a grid where tests located, the letters A – H and 1 – 8 indicating the grid reference. In addition, all tests were carried out in a cross formation, each test of CPT was located at 10 m to 25 m centres. Table 1 shows the results of triaxial laboratory tests. Visual inspection of these cores indicated that Tangerang clay is overlain by alluvium soil layers consisting of red – brown and sandy clay as shown as from core box (Fig. 4). The standard penetration tests (SPT) and sampling were driven to a depth of 10.0 m below ground level by a mechanical mounted drilling rigs. During this time period, weather condition were relatively constant and it is assumed that measurements data obtained by the CPT do not include variations due to climatic change. It was observed only the undrained shear strenght (c_u) values at the depth 4.0 m of all CPT data for a shallow foundation design as an alternative of reinforcement of soil foundation in supporting the rigid pavement structure since the road was always damaged in the winter season.

Table 1. Triaxial undisturbed sample test results

SOIL MECHANIC AND FOUNDATION LABORATORY
DEPARTMENT OF CIVIL ENGINEERING
STATE POLYTECHNIC OF JAKARTA (PNJ)

SUMMARY OF LABORATORY TEST DATA FOR PROJECT
PENINGKATAN JALAN SURADITA-KRANGGAN, CISAUK, TANGERANG, PROPINSI BANTEN
JAWA BARAT

BORE HOLE No.	DEPTH (m)	USCS	G_s	MATERIAL PROPERTIES						ATTERBERG LIMIT			PARTICLE SIZE DISTRIBUTION				TRIAKSIAL UU		CONSOLIDATION		
				w_s (%)	γ_m (gr/cm^3)	γ_d (gr/cm^3)	e	n	S_r (%)	LL (%)	PL (%)	PI (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	c (kg/cm^2)	ϕ (°)	C_v (cm^2/sec)	C_c	P_c (kg/cm^2)
(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)	(U)	(V)
BH-01	- 4.00 to - 4.50	CH	2.689	68.23	1.542	0.917	1.930	0.66	94.85	56.03	27.53	28.50	2.0	11.0	23.0	64.0	1.396	0.25	4.1E-02	0.21	1.59
BH-02	- 4.00 to - 4.50	CH	2.690	57.58	1.598	1.014	1.650	0.62	93.71	60.01	24.59	35.42	1.0	11.0	25.0	63.0	1.291	0.32	1.3E-02	0.24	1.65
BH-03	- 4.00 to - 4.50	CH	2.684	55.6	1.622	1.042	1.570	0.61	94.75	58.01	18.79	39.22	0.0	7.0	22.0	71.0	1.361	0.31	3.0E-03	0.37	0.83
BH-04	- 4.00 to - 4.50	MH	2.663	53.49	1.657	1.080	1.500	0.60	96.35	64.72	32.97	31.75	0.0	2.0	76.0	22.0	1.272	0.33	3.0E-03	0.31	0.77
BH-05	- 4.00 to - 4.50	MH	2.661	39.85	1.764	1.261	1.110	0.53	95.61	59.30	33.79	25.51	0.0	5.0	71.0	24.0	1.268	0.35	5.0E-03	0.32	1.11

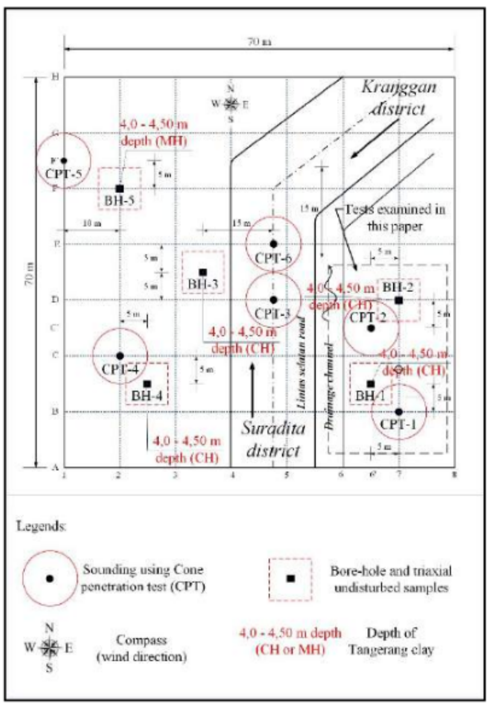

Figure 3. Layout of cone penetration test (CPT) and depth of triaxial undisturbed samples

Figure 4. Typical of core box (e.g. BH-02)

2.2. *Undrained shear strength (c_u) and cone factor (N_k)*

As undrained shear strength (c_u) depend on testing method (Mayne et al, 2009), it is important to define which c_u is in use. Empirical correlations have been used to estimate the undrained shear strength of clays (Baligh et al, 1980); mostly based on Terzaghi's bearing capacity theory (1943) rewritten as the relationship between the undrained shear strength of a clay (c_u) and the cone tip resistance (q_c) by the following:

$$c_u = \frac{q_c - \sigma_{vo}}{N_k} \tag{1}$$

σ_{vo} is the overburden pressure, and N_k is the cone factor.

The wide scatter in the N_k values in literature shows that no single value of the N_k covers all types of clays, test conditions and penetrometers (Schmertmann, 1975); as demonstrated by Stark and Delshaw (1990). At the time of recording of mechanical penetration tests, some triaxial laboratory tests were carried out from BH-01 to BH-06 at the depth of 4.0 metres to 4.50 metres to find the value of c_u. Even value of N_k is not known with great precision, since it is difficult to determine the value of N_k of CPT. However, CPT field data is better than laboratory triaxial data Lunne et al (1976) stated that the value of N_k is 15 to 20 for overconsolidated clays, number of 15 was selected on this research. It is well known that many data from triaxial laboratory tests have inaccuracies or errors rather than CPT test results. Thus, the resulting CPT data will be used to validate triaxial data at a depth of 4.0 meters. Begemann (1965) suggested that range of c_u values from medium – stiff to very – stiff clay is 2.5 to 20 t/m^2 or 0.25 kg to 2.0 kg/cm^2 based on correlation between consistency and cone resistance of CPT.

2.3. *Geostatictics and spatial variability analysis*

Analysis of the spatial variability of undrained shear strength, has almost exclusively developed by Li and White (1987). Similar to the autocorrelation function of random variables, the semivariogram requires stationarity, that is, the semivariogram depends on the separaration and not on the locality of the pairs. As a result, if a drift, or trend, exists in the data. Before the interpolation model is used, it is necessary to know in advance how accurate the model is used. Procedure of cross validation method is to eliminate one data and use the remaining samples as data to predict the data that is removed using the model. If the trend is substracted from regionalised variable, the residuals will themselves be a regionalised variable and will have local mean values of zero.

There are several theoretical semivariogram models including spherical, exponential, gaussian, linear, hole effect, etc. (Rota 2007). Stages of data analysis using Ordinary Kriging (Krige, 1951; Duval et al, 1955) developed by some researchers. The semivariogram is calculated in the direction different, semivariogram sometimes generate several different parameters from some of these directions, it was called anisotropic semivariogram (Armstrong, 1998). Anisotropic semivariogram can be distinguished into 2 types, such as: geometry and zonal anisotropics. The main factor influencing accuracy of Inverse Distance Weighted (IDW) is Power parameter (Yasreby et al, 2009). The smaller the RMSE value of a model indicates that the model is more accurate. Furthermore, The CPT data is used to selected semivarogram model. Then, the selected semivariogram will be used to determine the value of c_u at a depth of 4.0 m and find the c_u values at the other coordinate points in Fig. 3.

3. Results

In this section, the results of the descriptive analysis will be explained in the c_u data. Then, the application of the ordinary kriging method for estimation of c_u according to Fig. 3. The data used is processed using GS$^+$ software packages to calculate the experimental semivariogram value and also to estimate the location which is not sampled. Microsoft Excel is used to create a display the data of CPT at the depth of 4.0 m. The results of CPT data would be evaluated by using Equation (1) and N_k of 15.

3.1 Descriptive analysis

Descriptive analysis is used to observed generally a picture of CPT data in general. Descriptive analysis used in c_u data consists of average, median, variance, standard deviation, maximum value, minimum value, and range. Results of descriptive analysis shows in Table 2. From table 2, it can be identified that the average and standard deviation values have no a significant difference between all depths from recorded at every 200 mm increments of the penetrometer travel and depth of 4.0 m, but instead the variance and range values have more significant differences. Obviously, it can be realized that there are differences in the amount of data from the results of CPT investigations significantly.

3.2 Ordinary kriging method

The steps for applying the method ordinary kriging is as follows:

1. Examination of data stationary

   Observation for data stationary are carried out by making a plot of the distribution of the yield points survey measurements of c_u. In the method ordinary kriging data is required stationary data. Data stationary will not indicate in a certain trend. The following is the results of the distribution survey point plotted of c_u results.

   a. Observation value plotted versus X-axis (Easting) (also see Fig. 3) as shown as Fig. 5.

Table 2. Descriptive analysis of c_u results for all depths of CPT data (in kg/cm^2) by recorded at every 200 mm increments of the penetrometer travel and depth of 4.0 m

Descriptive analysis	**All depths**	**Depth of 4.0 m**
Number of data	120	6
Average	1.279	1.588
Median	1.212	1.577
Deviation standard	0.578	0.503
Variance	0.334	0.253
Maximum	3.030	2.377
Minimum	0.269	0.844
Range	2.762	1.533

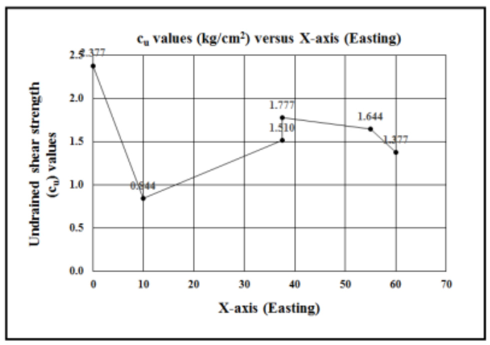

Figure 5. Plot of observation of CPT data in 2 – dimensional at the depth of 4.0 m versus X-axis (Easting).

   b. Observation value plotted against absis (Northing) (also see Fig. 3) as shown as Fig. 6. Figs. 5 and 6 show that the observation plot of CPT data values versus both axes (Easting & Northing) has no tendency certain trends.

   c. 3 – dimensional plotting of CPT data at depth of 4.0 m as shown as Fig. 7. Based on Figs. 5, 6 and 7 show that the measurement of CPT data has no specific trends. Thus, it can be classified as a stationary data.

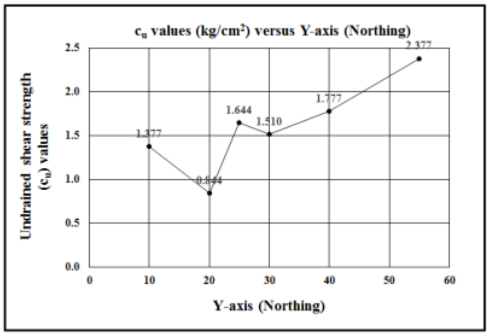

Figure 6. Plot of observation of CPT data in 2 – dimensional at the depth of 4.0 m versus Y-axis (Northing).

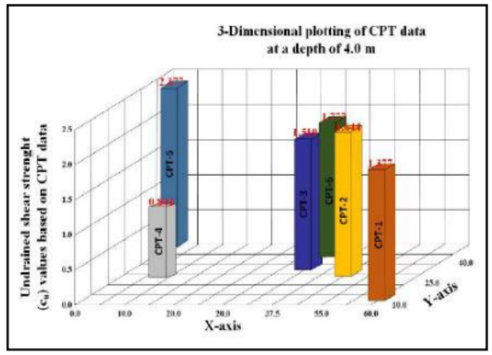

Figure 7. Plotting of observation CPT data in 3 – dimensional at the depth of 4.0 m.

2. Calculation of experimental variogram
   From c_u measurement based on CPT data, experimental semivariogram was analyzed with using GS$^+$ software based on 4 direction. The direction used is North – South $\theta = 0^o$, Northeast –Southwest $\theta = 45^o$, West – East $\theta = 90^o$, Southeast – Northwest $\theta = 135^o$. Active lag and interval distances used in this study are 70 m and 10 m, respectively according to Fig. 3. Direction tolerance used in this study was more or less 22.5^o. Based on the results of the experimental semivariogram calculation, an experimental semivariogram plotted from 4 directions was used as follows:

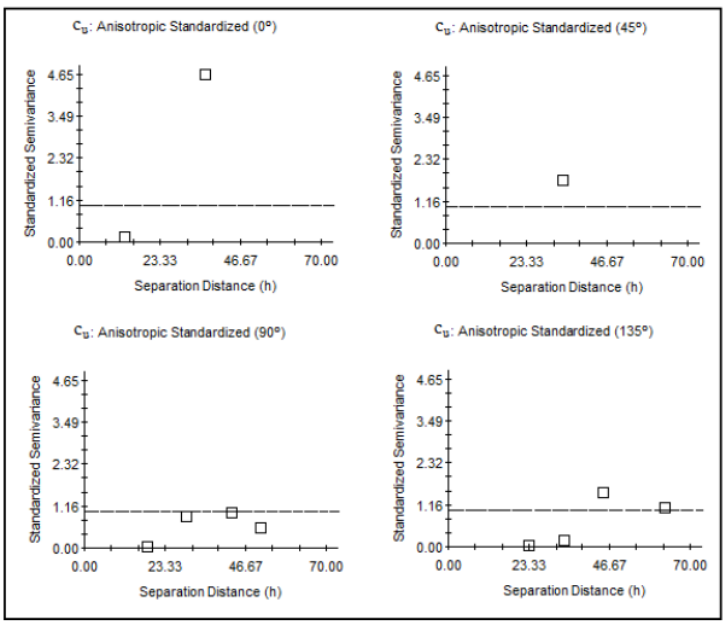

Figure 8. Plotting of experimental semivariogram

The theoretical semivariogram model used as a comparison in this study is spherical model; exponential; and Gaussian models, as shown as Table 3. Based on the results cross validation calculation, RMSE value of the three models is shown in Table 4.

Table 3. Parameters belonging to the variogram models at depth of CPT 4.0 m

Model	Nugget	Sill	Range
Spherical	0.000100	0.259200	44.8000
Exponential	0.000100	0.313200	86.1000
Gaussian	0.000100	0.271200	40.3568

Table 4. RMSE calculation results for semivariogram model

No.	Model	RMSE
1.	Spherical	0.476
2.	Exponential	0.333
3.	Gaussian	0.455

Based on Table 4, the results of RMSE calculation from three models shows that the model spherical and exponential models were models best for estimation of c_u data in the area of Tangerang clay. The spherical and exponential models produces the value of the RMSE not significantly different, that is equal to 0.476 and 0.455.

3. Selection of the best interpolation method

Based on the results of cross validation calculations, it represented that the estimation results generated by the best model in the ordinary kriging method and the optimal power parameters in the IDW method as shown as Fig. 9. Table 5 indicates the results of cross validation calculations using the best models and optimal power parameters.

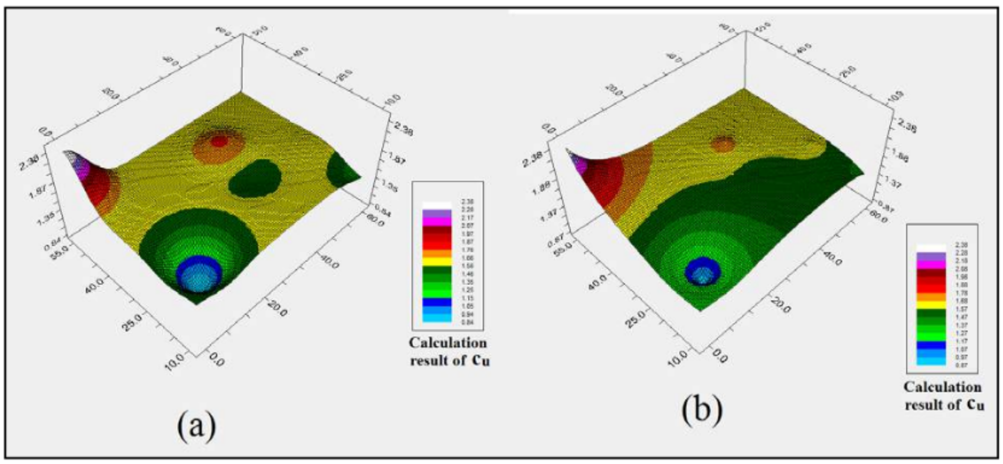

Figure 9. Results of cross validation calculations of c_u parameters at depth of 4.0 m generated by the best model in the ordinary kriging (a) and the optimal power parameters in the IDW (b) methods.

4. Conclusion and discussion

Some conclusion obtained by this research, these are:

1. According to the cross validation, there is no signifucantly difference between CPT and triaxial data results with using ordinary origing dan IDW methods as shown as Table 5. Table 5 shows conservatively that the c_u value from laboratory triaxial test are lower than in situ test of CPT.

Table 5. The results of cross validation calculations using the best models and optimal Power parameters

No.	Soil type	c_u based on the triaxial test results (kg/cm^2)	Estimated of c_u (kg/cm^2) by using Ordinary Kriging		Estimated of c_u (kg/cm^2) by using IDW
			Spherical	Gaussian	
BH-01	CH	1.396	1.52	1.52	1.52
BH-02	CH	1.291	1.62	1.62	1.58
BH-03	CH	1.361	1.59	1.59	1.57
BH-04	MH	1.272	1.20	1.20	1.30
BH-05	MH	1.268	1.74	1.74	1.79

2. The ordinary kriging method provides some estimation more accurate than IDW methods. It can be indicated by RMSE values obtained using ordinary kriging method equal of 0.476 dan 0.455 more minimum than RMSE values from optimal power parameters using IDW method equal of 0.481.
3. It was considered that the results obtained from 6 (six) data of CPT can evaluate 5 (five) data of the true triaxial values of this study can be useful for pre-evaluation of the subsurface strength in the area. The results of this study can be used to estimate undrained shear strenght related to the CPT and Triaxial test number inside the area. It should be underlined that, the database in this study should be broadened to increase the modelling ability of the method. Further tests should be conducted in northing and easting of the area for more reliable estimations of this parameter.
4. Generally, data – based geostatistics, and in particularly the semivariogram, has been shown to be a useful technique in the assessment of the range of correlation of the undrained shear strength of clays. However, a larger amount of data is still required to reduce errors in the preparation of soil parameters in design work. From Tangerang clay at depth of 4000 mm implies that samples are correlated within this range and should not be treated as uncorrelated random.

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