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Spatial Interpolation of Unconfined Compressive Strength for Soft Bangkok Clay Via Random Technique and Modified Inverse Distance Weight Method

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ABSTRACT

The basic of the inverses distance weight method has been improved by many researches. Not only power parameter but also sensitivity, anisotropy ratio, anisotropy angle and searching radius are incorporated to the model. In addition the cross validation processes is introduced to filter the best parameters for the observed data. To further develop, this study proposes a simple technique and a small modification of the IDW (modified IDW (mIDW)) function but increase ability to improve the estimation results. First, the random technique can be added in cross validation searching step to receive the possibly best parameters to better represent the natural phenomena of the interested areas. Second, with mIDW a coefficient of anisotropy angle parameter is modified to respond the anisotropy effect. The modified IDW is added a coefficient call geographic modification, to reflect the anisotropy angle parameter.

This study uses 164 bore holes with 23 layers data for Bangkok to test the model. This study evaluates four models: IDW, Tomczak IDW (Tomczak, 1998), mIDW, and Cubic Spline. With the random technique the observed data patterns that are feed to the searching parameters step reveal the best parameters to imitate the natural phenomena of the area. This study finds mIDW model is better than IDW, Tomczak IDW, and Cubic Spline. The root means square errors of the study case decreases numerously from the worst random to best random case by 11 %.

1. Introduction

Soil engineering properties are required for many kinds of civil engineering works such as

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road, building and dam design. Soil samples are collected and some testing might be carried out in-situ such as the standard penetration, vane shear test, etc. The collected samples are sent to a laboratory for other necessary testing such as sieve analysis, Atterberg's limits testing, unit weight, unconfined compression test, etc. Getting the summary of testing result is costly and time consuming. Also for one site location, only one or two soil borings will be assigned and used to represent soil properties of the whole area. For a particular case, soil strata at some locations are quite rapidly changed. Therefore, only two soil borings may not be able to represent soil engineering properties of the area, as these properties will be vastly deviated from actual properties. With misapprehension of soil properties/strata-profile, engineers can do wrong in foundation design. This in turn may impose great risk to the entire project. In a case of preliminary and feasibility study stage, if possible, it is necessary to have a good confident of engineering soil properties with only small spending.

All of these cases have inspired to this study in applying spatial analysis to gain and affirm knowledge of soil engineering properties through spatial interpolation, by using sampling data in the areas.

2. Literature Review

To understand the natural phenomena of soil engineering properties many mathematics modeling for estimating unsampled data are studied and classified to non-geostatistic, geostatistics and hybrid system (Li and Heap , 2008, Horpibulsuk et al., 2004: 2007). The inverses distance weight method is one of non-geostatistic models that has been used and commented such as Dumitru et al. (2013) addressed in their study the IDW method is not suitable for the area that have high different of elevation. Robinson and Metternicht (2006) and Göl et al. (2017) evaluated the spatial interpolation techniques, geostatistics and non-geostatistic included the IDW, to estimate soil property, pH and soil organic carbon respectively. They found not only one method outperform for all aspect of test both number and type of variable. De Mesnard (2013) was commented on the zero distance effect. If the estimating points are closed to some sampled points, the remotely sampled points not effect to the estimate value. In addition, in development aspect the IDW was developed and improved continuously since 1968 by Shepard (1968). Tomczak (1998) introduced the IDW automation system with anisotropy examined. The parameters of the IDW will be calculated by cross-validation and also the confidence on the estimated value be calculated by jackknife approach. The anisotropy parameter is enhanced with the flow direction of the river (Merwade et al., 2006). The distance in the IDW model is switched with an elliptical distance.

The sampling location and number also affect the estimation values (Webster and Oliver, 2007; Kanevski, 2013). Unfortunately soil boring locations and number can be assigned only in a project no relationship between projects to another project. The locations of a construction project will be located by investors, associated with their economic growth.

This study proposes a simple technique with a small modification of the IDW model but more ability to improve the estimation results. Firstly the random technique, it can be added in parameters searching step to receive the parameters that more represents the natural phenomena of the interesting area. Secondly a coefficient of anisotropy angle parameter will be modified to respond the anisotropy effect.

3. Procedure

3.1 Methodology

The foundation mathematical model for IDW is given as

$$P_j = \sum_{i=1}^{n_j} \lambda_{ij} P_{ij} \quad (1),$$

where $P_{ij}$is interesting value of sampled point i refer unsampled point j as Figure 1. The λ_{ij} is weighting distance as proposed by Tomczak (1998) as Equation (2).

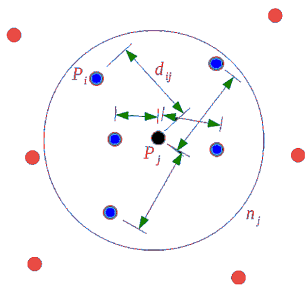

Figure 1: Unsampled point j within sampled points i that have n_j number.

From Tomczak (1998) the effective distance is

$$\lambda_{ij} = \frac{1/(d'_{ij}+\delta)^p}{\sum_{i=1}^{n_j} 1/(d'_{ij}+\delta)^p} \quad (2),$$

where $d'_{ij}$is the effective distance which is formulated by:

$$d'_{ij} = \sqrt{A_{xx} * \Delta x^2 + A_{xy} * \Delta x * \Delta y + A_{yy} * \Delta y^2} \quad (3)$$

with

$$A_{xx} = \left[\frac{cos(\theta)}{\rho}\right]^2 + [-sin(\theta)]^2 \quad (4)$$

$$A_{xy} = 2 * \left[\frac{cos(\theta)}{\rho} * \frac{sin(\theta)}{\rho} + (-sin(\theta) * cos(\theta))\right] \quad (5)$$

$$A_{yy} = [cos(\theta)]^2 + \left[sin\frac{(\theta)}{\rho}\right]^2 \quad (6).$$

Figure 2 illustrates concept of equation 2-5 where ρ is anisotropy ratio (a/b). In isotropic case ρ equals 1. Anisotropy angle θ is measured from x axis, as in Figure 2.

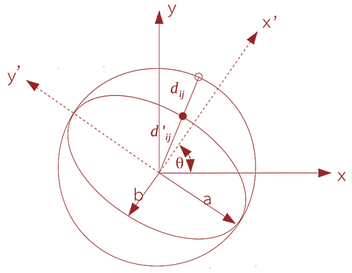

Figure 2: The concept of effective distance and anisotropy.

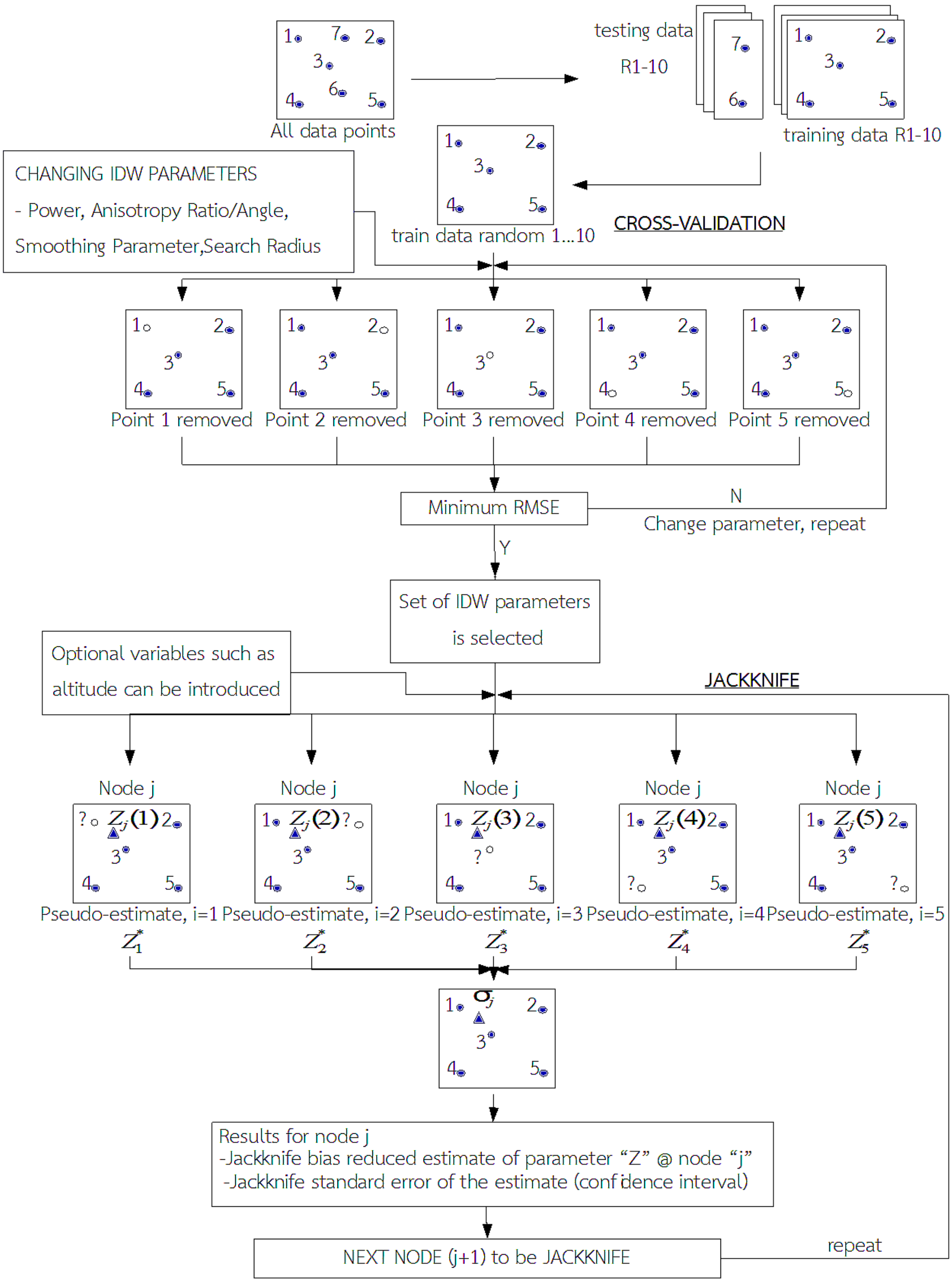

Figure 3: The cross-validation and jackknife procedure of Tomczak (1998) with random technique.

The random technique takes observed data at random ten times. Each time, random data is divided to training and testing group with 75% and 25%. The training group is used to train the model or searching for parameters in Tomczak (1998) procedures. The testing group is used to calculate root means square errors of the selected parameters (Figure 3).

Another form of equation 2 is coordinate transform with coefficient ρ can be given as

$$N' = \frac{-sin(\theta)E}{\rho} + cos(\theta)N$$
$$E' = \frac{cos(\theta)E}{\rho} + sin(\theta)N \quad (7).$$

Then,

$$d_{ij} = \sqrt{N'^2 + E^2} \quad (8)$$

with the proposed modification

$$N' = \frac{\frac{-sin(\theta)E}{\rho} + cos(\theta)}{\eta} \quad (9)$$

where η is the geometry modifier as shown in Figure 4.

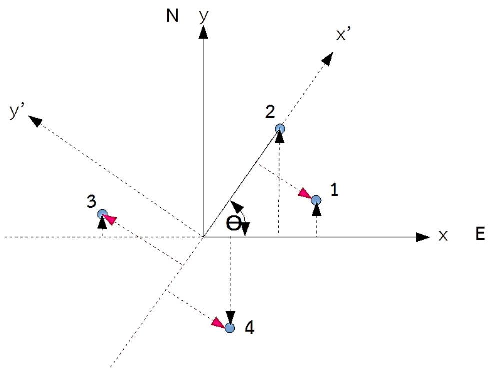

Figure 4: The black arrows are distance from E to points orΔN.
The red arrows are distance from E after transformation.

If the distance from E of any points is shorter after the axis is rotated, it cause that points are more effect to the estimate value in that direction conversely the distance longer, causes less effect. The value of η is given as

$$\eta = \Delta N / \Delta N' \quad (10)$$

Also the results will be compared with the cubic spline model that recommend in Phothong and Witchayangkoon (2015).

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3.2 Data Sampling

The soil engineering property in this case study is unconfined compressive strength (Su). This data obtains from 164 soil boring logs within the Bangkok province as Figure 5, with sampled size 1198 numbers. The sampled data scatter in 23 soil layers from 1.5 to 18.25 meters in depth.

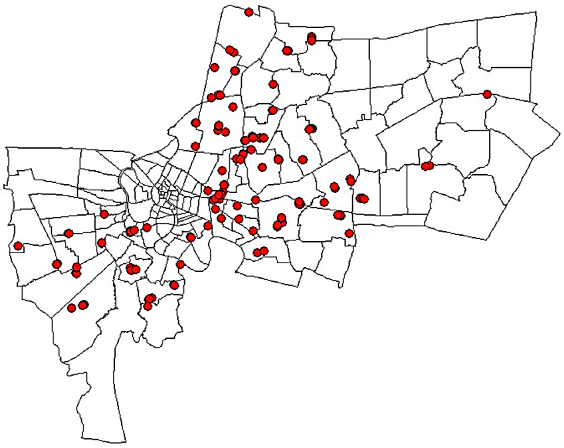

Figure 5: The 164 soil bore holes location in Bangkok

The sampled data will be feed to cross-validation processes to search for parameters . If the process is searching for the power parameter, the anisotropy ratio will set to 1 and the anisotropy angle set to 0. The smoothing parameter (set to 0) and searching radius (use all data) are not considered in this study. After the power is chosen the anisotropy ratio is run with range 1 to 10 step 0.5. The anisotropy angle is run in the last step, with range 0 to 170 degrees with 10 degrees step. All searching processes are run by both IDW by Tomczak (1998) and mIDW models.

3.3 Results & Discussion

The results of cross-validation process of the first random are shown in Table 1. The parameter at layer 19 will be selected to test the model by related testing data. The training data are known data in the IDW equation. The estimating locations are the testing data locations. The rmse of testing data will be calculated to compare the respondent of each model. The results are shown in Table 2.

If the random technique has been applied to layer 19, the different power searching results will illustrate on Figure 6. With the same random technique the anisotropy ratio and angle are shown in Figures 7 -8.

In Table 1 shows the results from cross-validation processes. The most frequent seen values of the power and anisotropy column are 1 that are selected from criteria the minimum rmse. The one value of the power parameter and the anisotropy ratio mean the results are only average by distance or ordinary the IDW and all direction have same properties respectively. On the other hand the layer 19 shows obvious results of all parameters. This indicates the collected data have a pattern that can be the best represented. However the random technique can reveal the best pattern of sampled data with lowest rmse. An example is the power parameter as in Figure 6 using data at random ten times yielding the same graph shape, each with a minimum value. The third random produces the lowest the rmse as shown in Table 3. In addition, with the all parameters the modified IDW shows the best rmse in Table 5, same as Layer 11 on Table 6.

Table 1: cross-validation of data in each layers with the first random

Number	Depth, m.	Power	Anisotropy Ratio	Anisotropy Angle
		TIDW/mIDW	TIDW/mIDW	mIDW
1	1.5	1	1	150
2	3	1	1	30
3	3.25	1	1	10
4	4.5	1	1	0
5	4.75	1	1	40
6	6	1	1	70
7	6.25	1	1	90
8	7.5	1	1	40
9	7.75	2	1	50
10	9	1	1	100
11	9.25	1	1	30
12	10.5	1	2	50
13	10.75	1	4.5	70
14	12	1	1	50
15	12.25	1	1	0
16	13.5	1.5	1	150
17	13.75	1	1	10
18	15	1	2.5	0
19	15.25	1.5	3.5	170
20	16.5	1	1	50
21	16.75	1	1	170
22	18	1	1	0
23	18.25	1	1	80

Table 2: cross-validation of data in each layers with the first random

Layer 19, Testing

Number	N	E	Depth	Su	IDW	TIDW	GIDW	CSPLINE
1	1527533	674208	15.25	99.5	46.443093	46.368559	46.368738	56.52935
2	1507554	660360	15.25	32.6	44.234356	44.246782	44.246177	26.36278
3	1527267.1	671969.07	15.25	17.8	48.282706	48.852508	48.890603	33.411835
4	1520337	685636	15.25	75.7	55.033261	56.328767	56.148871	63.227268
5	1510107	663475	15.25	41.9	55.994246	56.320272	56.345146	22.913048
6	1516205	650970	15.25	49.5	52.620001	52.667682	52.668256	47.134003
7	1527273.82	671991.2	15.25	16.5	48.379444	48.815873	48.850826	33.411835
8	1529027	668833	15.25	19.8	26.03412	25.945848	25.951248	13.911095
9	1528987	668831	15.25	21.7	26.262952	26.470962	26.494569	13.911095
10	1518479	655225	15.25	19.7	61.853788	58.671512	59.513632	46.842564
11	1531221	670509	15.25	27.3	30.176933	29.646483	29.618862	28.583748
12	1508379	660478	15.25	12.1	32.95253	32.01035	32.069092	26.873676
13	1526105	672699	15.25	61	70.462945	70.400366	70.446245	34.316494
14	1518438	683012	15.25	32.9	32.881271	33.072547	32.985765	48.043964
				RMSE	23.755696	23.345283	23.470414	18.7656872

With the criteria minimum rmse the interesting parameters can be read from the graph and shown in Table 3. The random number 3 produces the best rmse.

Table 3: The parameters searching from layers 19 with the third random.

Layer	Depth, m.	Power	Anisotropy Ratio	Anisotropy Angle
		TIDW/mIDW	TIDW/mIDW	mIDW
19	15.25	1.5	2	20

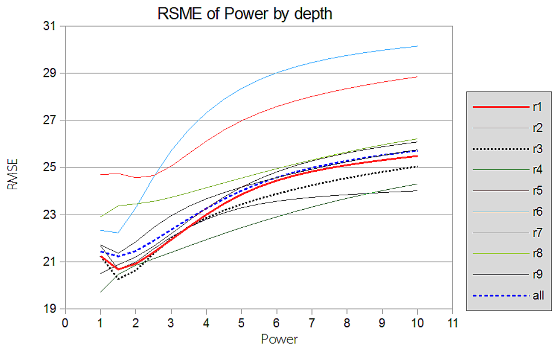

Figure 6: The power searching of layer 19, using data at random ten times in succession.

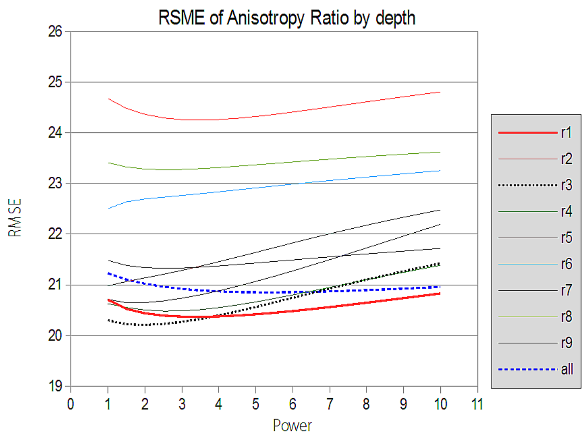

Figure 7: The anisotropy ratio searching of layer 19, using data at random ten times in succession.

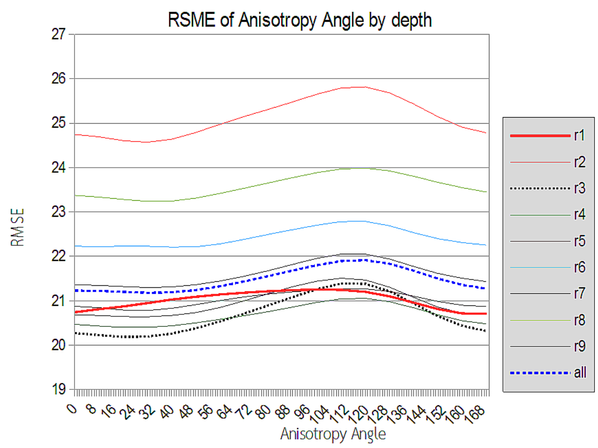

Figure 8: The anisotropy angle searching of layer 19, using data at random ten times in succession.

The parameters from Table 4 are put into any the IDW equation, the results shown in Table 5.

Table 5: The results using parameters from Table 4. Training and testing data from the third random.

Layer 19 random 3, Testing

IDW	TIDW	GIDW	CSPLINE
20.94097	21.00099	20.826826	27.2312666

With the same procedure, the layer number 11 at depth 9.25 meters can produce the parameters and results at Table 6.

Table 6: The parameters and results for layer 11.

Layer 11	Random5	Testing		
Power	AR	AA		
5	2	160		
IDW	TIDW	GIDW	GIDW2	CSPLINE
8.0733261	8.2501984	**8.0878867**	8.0177276	9.11346778

The inverses distance weighting method, frequency used by many researchers, is easy to use and understand as well as it can be modified to fit the interested phenomena. One of the most concerns for spatial interpolation is number and location of samples. With the random technique, the samples are randomly sampled and divided to training and testing data set. The training data set is used to calculate parameters that represent the variable of the area. The testing data uses to calculate the rmse of the model. In addition the modification of an anisotropy section of the IDW can fine tune the estimated results. The combination of both purposes method can increase accuracy of the estimation. It can produce the good results over the other model. From this study found the power parameter takes a great effect to the model, follow by the anisotropy ratio. The anisotropy angle does only fine tune the results.

4. Conclusion

The random technique and modified IDW can produce the good results over the other model. The random technique also can be used to find good patterns of sampling data to represent the area. The power parameter takes a great effect to the model, follow by the anisotropy ratio. The anisotropy angle is only fine tuning the results. In the future this proposed model can be developed to 3D and incorporated with random variable.

5. References

De Mesnard, L. (2013). Pollution models and inverse distance weighting: Some critical remarks, Computers & Geosciences 52 : 459-469.

Dumitru, P. D.; Plopeanu, M. and Badea, D. (2013). Comparative study regarding the methods of interpolation, 13 : 45-52.

Göl, C.; Bulut, S. and Bolat, F. (2017). Comparison of different interpolation methods for spatial distribution of soil organic carbon and some soil properties in the Black Sea backward region of Turkey, Journal of African Earth Sciences 134 : 85 - 91.

Horpibulsuk, S. and Rachan, R. (2004). Novel approach for analyzing compressibility and permeability characteristics of Bangkok clayey soils, : 3–8.

Horpibulsuk, S.; Shibuya, S.; Fuenkajorn, K. and Katkan, W. (2007). Assessment of engineering properties of Bangkok clay, 44 : 173-187.

Li, J. and Heap, A. D. (2008). A review of spatial interpolation methods for environmental scientists, .

Merwade, V. M.; Maidment, D. R. and Goff, J. A. (2006). Anisotropic considerations while interpolating river channel bathymetry, Journal of Hydrology 331 : 731 - 741.

Phothong, T. and Witchayangkoon, B. (2015). Estimation of Unconfined Compressive Strength by Spatial Interpolation Using Non-Geostatistical Methods and Artificial Neural Networks, American Transactions on Engineering & Applied Sciences 4(1): 49-56.

Robinson, T. and Metternicht, G. (2006). Testing the performance of spatial interpolation techniques for mapping soil properties, Computers and electronics in agriculture 50 : 97-108.

Shepard, D. (1968). A two-dimensional interpolation function for irregularly-spaced data, : 517-524.

Tomczak, M. (1998). Spatial interpolation and its uncertainty using automated anisotropic inverse distance weighting (IDW)-cross-validation/jackknife approach, Journal of Geographic Information and Decision Analysis 2 : 18-30.

Webster, R. and Oliver, M. A., 2007. Geostatistics for Environmental Scientists. Wiley, .

Kanevski, M. (Ed.), 2013. Advanced Mapping of Environmental Data (Geographical Information Systems). Wiley-ISTE,

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