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Proposed Speedy Moisture Test Calibration Chart on Indonesian Road Embankments

Soebagio[1], D. S. Raharja[2*], U. Khatulistiani[3]

[1,2*,3]*Civil Engineering Department, Faculty of Engineering,*

Wijaya Kusuma Surabaya University, Surabaya, Indonesia.

Email: [1]soebagio@uwks.ac.id, [2*]raharja.ds@uwks.ac.id, [3]utari.kh@uwks.ac.id.

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A B S T R A C T

Embankment construction is generally carried out using borrow materials. The water content of embankment material significantly affects the compaction quality. Measuring water content in the field typically uses a speedy moisture test (SMT) because the process is simple, and the result is obtained immediately. The accuracy level of the SMT is relatively high. However, it still needs to be corrected using a calibration chart for a more precise measurement. This research aims to determine the accuracy of the SMT tool compared to the standard oven-dry method, especially on borrow materials in East Java. The experimental method was used with soil samples from Pasuruan and Mojokerto borrow. Standard index properties tests and soil compaction tests were conducted to determine soil type and obtain optimum water content. The water content varies in several levels and is measured using SMT and oven-dry methods. The regression was performed to make a correlation, while RMSE and simple paired T-test were conducted to investigate the accuracy level of the correlation chart from this research, respectively. It was found that the soil samples used met the requirements as embankment soil (SW and SM). The proposed calibration chart is presented with the SMT-corrected water content equation ($w_{SMT-corrected} = 0.9815 w_{SMT} - 1.4323$)*. This equation has a coefficient of determination (*R^2*) equal to 0.95, which mean a very strong relationship. The proposed calibration chart performs well according to RMSE, which is equal to 2.41 and paired T-test result. This proposed calibration chart can be widely used in road embankment practice in Indonesia.*

1. Introduction

Infrastructure development in Indonesia run fast in recent years, with highways, airports, dams, and public transport facilities becoming the main programs to be realized by the government. Sixty-eight toll routes had been constructed in Java, Sumatera, Kalimantan, and

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Sulawesi with 2545 km length per September 2022, and twenty-seven toll routes with 1813 km length are under construction [1]. All those infrastructures will require embankment construction to reach the design elevation. Embankment construction generally uses selected soil material that passes the standard requirements screening. Depending on the soil embankment materials, this selected soil will spread out and compact using compactor vehicles, which are roller or vibro roller. The quality control of soil embankment can be done by evaluating the parameters, including dry density, compaction energy and saturation degree [2] [3], California Bearing Ratio (CBR) [4], subgrade modulus by performing static plate load test (Plate Bearing test) [5] [6], and dynamic cone penetration (DCP) index [7]. The dry density parameters are the most popular applied in the field [8] [9]. The standard requirement for the degree of dry density accepted for soil embankment is 95% of optimum laboratory dry density (γ_{dry}) obtained from standard or modified compaction proctor test. Another soil parameter that must be measured to get the dry density is soil water content (w). The water content of embankment material significantly affects the compaction quality [10] [11]. Water content is crucial in compaction quality control because it will significantly impact the dry density parameter. So, measuring the water content accurately is crucial to provide precise dry density parameters, which become the main parameter in the acceptance criteria of a soil embankment work.

Water content measurement in the field varies, including gravimetric chemical using calcium carbide gas pressure tester, electrical impedance gauge, and nuclear method [12]. The nuclear method has been the most applied tool for compaction control and direct water content measurement because of its simple application and precision [13]. Unfortunately, Zorluer *et al.* found that water content measurement from the nuclear method is more variable than the conventional method [14]. Several countries have paid attention to this topic and conducted research, especially about device effectiveness comparison for determining field soil moisture content, like Austin [15], the United States [16], and Washington D.C. America [17]. A couple of methods available have recently become popular to estimate moisture content by using machine learning [18] or deep learning [19]. However, the speedy moisture test (SMT) has become Indonesia's most popular tool for measuring field water content.

A calibration chart should accompany the application of SMT to get good results [20]. Oman studied water content measurement of various types of granular soil in Minnesota using SMT and oven-dry methods. The result indicates that the SMT result tends to be higher than the oven-dry method but there is a strong correlation between the two methods [21]. Berney IV

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et al. investigate various moisture content devices' effectiveness, accuracy, and repeatability. The result shows that the SMT has become the most effective in terms of repeatability but has the worst accuracy among other devices [22]. Similarly, Alleman *et al*. found that the SMT overestimated the moisture content compared to an oven-dry method by 1.25%. However, after the calibration chart is performed, the water content value of SMT becomes reliable[23]. Several studies have studied speedy moisture content's effectiveness, accuracy, and repeatability and developed calibration charts to correct this. Additionally, calibration charts are developed for common soil types. Meanwhile, for specific soil material for road embankments, especially in Indonesia, further calibration charts are required to provide precise results. Unfortunately, no research or study has been conducted regarding this calibration chart for specific Indonesian borrow materials.

This research aims to determine the accuracy of the Speedy Moisture Test (SMT) tool compared to the oven-dry method, especially on borrow materials in East Java. Based on this, an equation will be obtained that can be used to create a calibration chart. It is hoped that the results of this research can provide suggestions for calibration charts that can be widely used in road embankment practices in Indonesia.

2. Research Method

This research uses an experimental method with soil samples from two borrow materials in East Java. The samples obtained were then tested for index properties and compaction tests by following Indonesia's national standards (SNI) and American Standard Testing and Materials (ASTM). The test results are used to classify the soil sample based on the Unified Soil Classification System (USCS) and determine the water content variation. There are 20 variations of water content measured by oven-dry method and SMT tools. Using the regression method, the fifteen samples are used as training data to build a calibration chart. Next, an equation will be obtained for measuring the error level using five other samples. Error level measurement uses root mean square error (RMSE). In addition, a paired t-test will be carried out.

2.1 Materials

This research was conducted with two soil samples from the Prigen borrow pit in Pasuruan, Ngoro borrow pit in Mojokerto. Both borrow pits are strategically positioned to supply soil embankments material for Toll Road construction as drawn by the thick yellow line in **Figure 1**.

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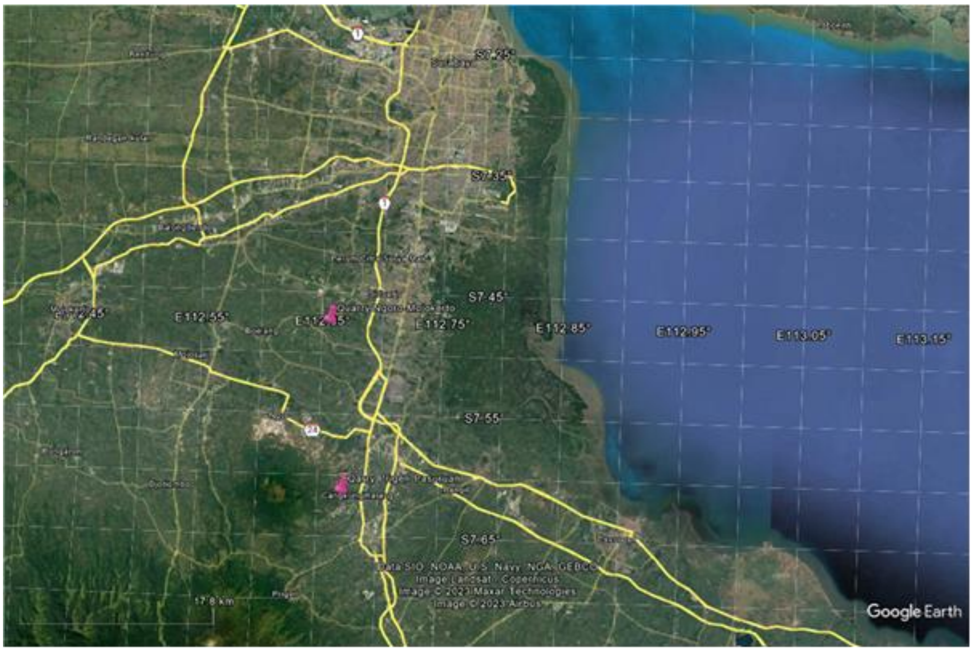

Source: Earth.google.com

Figure 1. Maps that Point Out the Location of Borrow Materials Mining Studied.

The disturbed soil samples were taken in a particular amount, which will be enough for performing all of the soil laboratory testing, including index properties, compaction test, and water content measurement by SMT and oven-dry method. The sample from borrow materials mining fields that comply with the requirements of General Specification of Toll Road in subchapter S4.05 will be used to measure water content by using SMT and oven-dry method. The requirements of borrowed materials are the soil not categorized as OL, OH, Pt, or high plasticity CH, according to the USCS [24].

2.2 Testing Methods

Ten samples were used at each location (Mojokerto and Pasuruan) with different water contents. This research is executed in the laboratory using an SMT apparatus and a standard laboratory oven. The SMT water content measurement procedure follows the guidance from ASTM D4944-18, while the oven-dry method follows the procedure from ASTM D2216-10 as control variables in measuring soil water content. In the first stage, an index properties soil test is done to determine the soil type using USCS and then continued with a standard proctor compaction test to determine the maximum dry density and optimum water content.

The water content of the soil sample will be varied in several levels and intervals to obtain a good variation of water content measurement data by using SMT and oven-dry methods (see **Figure 2**).

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(a) (b)

Source: Research Documentations

Figure 2. (a) Oven-dry Water Content Measurement and (b) SMT Water Content Measurement

2.3 Statistic Approach for Correlations

The water content data that has been obtained will be plotted in a scatter chart with SMT measurement on the X axis and oven-dry measurement on the Y axis. Then will utilize linear regression analysis to develop a correlation between SMT versus oven-dry water content as expressed in determination coefficient parameters (R^2). This parameter indicates that the variables studied have strong or weak relationships, and the value varies from 0 to 1. The R^2 value close to 0 indicates no relationship between variables, while the value close to 1 indicates a very strong relationship between variables [25]. R^2 (<0.5) indicates a weak relation between the predictor variable(s) and the response variable. While R^2 (<0.8 and >0.5) indicates a moderately weak relationship, which is there is substantial error variation (possibly caused by a large measurement spread), and R^2 (>0.8) indicates a strong relationship [26]. The equation of R^2 is as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{m}\left(X_i - Y_i\right)^2}{\sum_{i=1}^{m}\left(\bar{Y}_i - Y_i\right)^2} \quad (1)$$

Where X_i is the variable on the x-axis as the predicted *i* value and the Y_i variable on the y-axis as the actual value used as control variables [25].

The verification process was conducted by paired T-test to see the degree of significance from using the calibration chart [27]. This T-test can still be applied in a very small sample [28]. The paired T-test analysis can be conducted using IBM SPSS Statistics [29], [30]. The paired T-test was performed twice; first is between w_{oven} and w_{SMT}, and second is between w_{oven} and $w_{SMT-corrected}$. The paired T-test, sometimes known as the dependent sample T-test, is

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a statistical process to determine whether the mean difference between two sets of observations equals zero [31]. Like many statistical procedures, the paired sample t-test has two competing hypotheses: the null hypothesis (H_0) and the alternative hypothesis (H_1). The null hypothesis assumes that the true mean difference between the paired samples is zero ($\mu_d = 0$). In contrast, the alternative hypothesis assumes that the true mean difference between the paired samples is not equal to zero ($\mu_d \neq 0$) as the expression of two-tailed analysis. This T-test can be conducted if the sample is normally distributed. Some methods to verify the normality distribution include skewness, kurtosis, the Kolmogorov-Smirnov (KS) test, and visually showing the histogram chart [32]. The sample data are categorized as normally distributed if the skewness value is between +1 to -1m, the kurtosis value <2, the KS from calculation < KS, which is obtained from the table, and the line distribution on the histogram chart shows the normal shape or symmetric [27].

Additional verification is also performed using RMSE. RMSE is a standard metric that roots the mean-square of difference value between observation and prediction values. RMSE is widely used to evaluate the quality of a mathematics model [33]. The equation of RMSE is as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2} \qquad (2)$$

Where, n is the number of samples, y_i is the value of the observations in the order i $\left(i = 1, 2, ..., n\right)$, and $\hat{y}_i$ is the value of the predictions in the order i. The value of RMSE equal to zero is the best value that shows the predictions value perfectly represents the observational value, while the plus infinity value (+∞) is the worst [25].

3. Results and Discussion

3.1 Laboratory Test Result

The laboratory test result of the first soil sample from Pasuruan has a specific gravity value of 2.53 and grain size distribution dominated by sand 47.63 %, gravel 40.90 %, silt 10.20 %, and clay particles 1.27 %. The Atterberg limit test agrees well with the grain size distribution result. The percentage of sand and gravel is more than 50 %, and a small percentage of clay particles makes the soil have no plasticity. Therefore, this soil can be categorized as well graded sand with gravel with symbol SW.

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Table 1. Result of Index Properties and Standard Proctor Compaction Test.

No.	Parameters	Units	Pasuruan Borrow	Mojokerto Borrow
1	Specific Gravity	-	2.53	2.65
2	Grain size distribution			
	- Gravel	%	40.90	15.73
	- Sand	%	47.63	55.97
	- Silt	%	10.20	14.93
	- Clay	%	1.27	13.37
3	Atterberg Limit			
	- Liquid limit	%	NP	35.97
	- Plastic limit	%	NP	25.83
	- Plasticity Index	%	NP	10.15
4	Soil Classification	USCS	SW	SM
5	Standard Proctor			
	- Maximum dry unit weight	gr/cm^3	1.66	1.83
	- Optimum water content	%	14.52	14.37

Source: Laboratory Test Results.

The second soil sample from Mojokerto has a specific gravity value of 2.65, and grain size distribution is dominated by sand at 55.97 %, gravel 15.73 %, silt 14.93 %, and clay particles 13.37 %. The Atterberg limit test shows a good agreement with grain size distribution result, even the percentage of sand and gravel is more than 50 %, but the percentage of clay particles is more than 10%, so the soil still has low plasticity. The liquid limit value is 35.97 %, and the plastic limit value is 25.83 %, so the plasticity index value is LL-PL equal to 10.15 %. Therefore, this soil can be categorized as silty sand with the symbol SM.

The detailed result of the soil index properties test is presented in **Table 1**. The index propertied test result for both samples shows that the soil type complied with the standard requirements as soil embankment because materials were not categorized as CH, OH, OL, and Pt [24].

3.2 Correlation Using Linear Regression

Figure 3 shows that the value of R^2 between SMT versus the oven-dry method is 0.95, which means that there is a very strong relationship between both variables. Therefore, theoretically, this calibration chart could be applied to correct SMT pressure gauge dial reading so the water content value will be much closer to the exact or real water content as measured by the oven-dry method. The equation in **Figure 3** can be rewritten as follows:

$$w_{SMT-corrected} = 0.9815 w_{SMT} - 1.4323 \quad (3)$$

Where $w_{SMT-corrected}$ denotes the SMT water content measurement after correction with the calibration chart and w_{SMT} is the SMT water content direct reading of pressure gauge.

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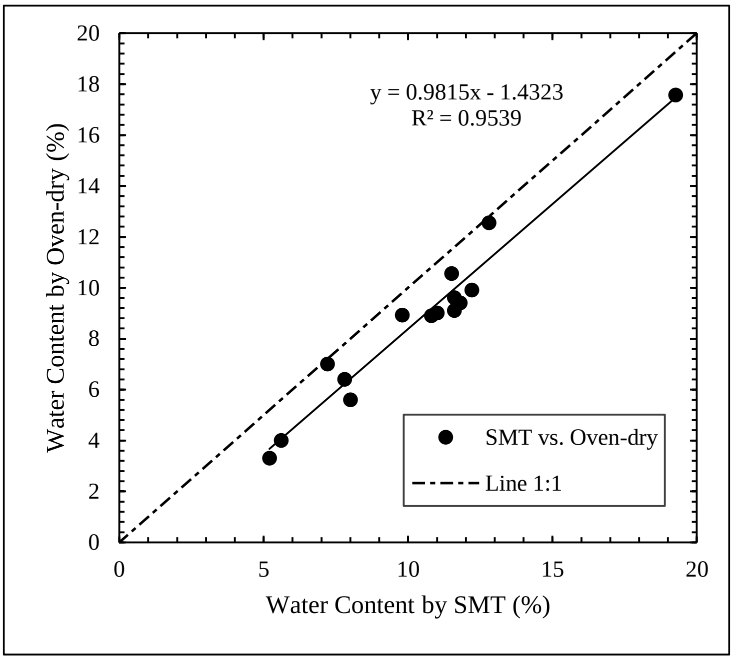

Source: Analysis Result as Proposed Calibration Chart.

Figure 3. Proposed Calibration Chart Between SMT Versus Oven-dry Water Content Measurement

Table 2. Previous Equations of $w_{SMT-corrected}$

Source	Equation	R^2	Soil Type Sample (USCS)	Country
Current Research	$w_{SMT-corrected} = 0.9815 w_{SMT} - 1.4323$	0.95	SW and SM	Indonesia
Berney IV *et al.* (2012)	$w_{SMT-corrected} = 0.7504 w_{SMT} - 0.3672$	0.81	ML, SP, SP-SC, and GP-GM	Washington D.C.
Oman (2004)	$w_{SMT-corrected} = 0.89 w_{SMT} + 0.76$	0.77	Not mentioned	Minnesota

Source: Previous Research [22], [21]

A comparison of various equations $w_{SMT-corrected}$ are presented in **Table 2**. The R^2 value from previous research shows a moderate relationship [21] and a moderate to strong relationship [22]. This research provides the highest R^2 = 0.95, which several factors could cause. The possibility is that the soil type used in this research consists of SW and SM, while Berney IV *et al.* (2012) consist of four types of soil [12], and Oman (2004) consists of various soil types even though it is not stated using USCS but by using grading number [21]. However, one similarity among that research is that all the soil types used comply with the requirement as toll road embankment materials in Indonesia.

3.3 Equation Verification Using RMSE and T-test

The equation obtained is verified on five testing data using RMSE with the value 0.48 (see **Table 3**). This value shows that the equation proposed has a small error or the corrected

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value of SMT water content is close to the actual water content. This result is not only in line with the result of Berney IV *et al.* (2012) but also gives a better equation where the RMSE is 2.41. It means the value is small enough and provides no significant error. So, the proposed equation is verified to produce a good result.

Table 3. Data of water content measurement using oven-dry, SMT, and SMT-corrected **Eq. 2**.

ID	w_{oven}	w_{SMT}	$w_{SMT-corrected}$	Squared error
P2	2.7	3.8	2.30	0.16
P6	5.3	7.3	5.73	0.18
M7	8.6	9.6	7.99	0.37
M9	10.1	12.4	10.74	0.41
M-9	14.67	16.2	14.47	0.04
			RMSE	0.48

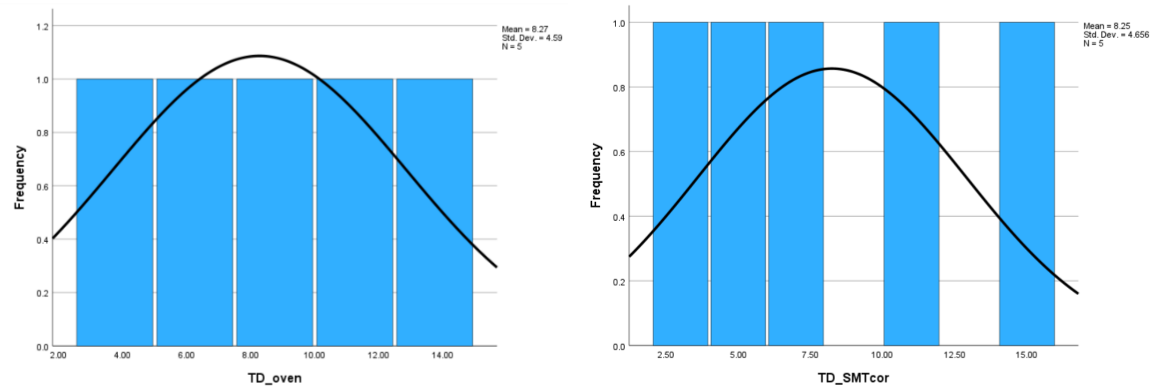
Source: Laboratory Test Results and Analysis.

The second verification is performed using a T-test, which requires the normality check first. The normality assumption check was performed on the testing data (TD) of oven-dry, SMT, and SMT corrected. **Table 4** shows the detail of the normality check result, where the skewness value is between +1 and -1, the kurtosis value is less than 2, the KS statistic is smaller than the KS table, and the normality line inside the histogram chart (**Figure 4**) shows the symmetric shape. So, the testing data is complying with the normality assumption.

Table 4. Result of Paired T-test of Two Paired Variables.

Parameter	TD Oven-dry	TD SMT	TD SMT Corrected
Skewness	0.294	0.125	0.126
Kurtosis	-0.315	-0.471	-0.473
KS Statistic	0.127	0.119	0.122
KS Table	0.668	0.668	0.668

Source: IBM SPSS Summary Result.



(a) (b)

Source: IBM SPSS Analysis Results.

Figure 4. Histogram Chart of Testing Data with the Normality Line Display.

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Table 5 provides the statistical summary of three data that will be evaluated. The first paired T-test results, between oven-dry testing data versus SMT measurement, show a clear difference significantly with a P-value less than or equal to (≤) 0.05 (< 0.001), so the null hypothesis is rejected, and the alternative hypothesis is accepted which mean there is a significant difference between variables tested. Meanwhile, the second paired T-test results, between oven-dry testing data versus SMT corrected, show a low significance with a P-value equal to 0.931 (> 0.05), so the null hypothesis is accepted, and the alternative hypothesis is rejected, which means there are no significant differences between variables (see **Table 6**).

Table 5. Statistic Data of Sample Data Training.

No	Sample name	Mean	N	St. Deviation	St. Dev. Error
1	TD oven	8.2740	5	4.589	2.053
2	TD SMT	9.8600	5	4.743	2.121
3	TD SMTcorrected	8.2460	5	4.656	2.082

Source: IBM SPSS Analysis Results.

Table 6. Summary Result of T-test Data for Two Pair Testing Data.

No	Parameter	TD Oven-dry vs. SMT	TD oven-dry vs. SMTcorrected
1	Paired Differences		
	- Mean	-1.586	0.0280
	- Std. Deviation	0.562	0.539
	- Std. Error Mean	0.251	0.241
	- 95% Confidence Level of the Differences - Lower	-2.284	-0.641
	- 95% Confidence Level of the Differences - Upper	-0.888	0.697
2	t	-6.309	0.116
3	df	4	4
4	Significance		
	- One-side P	0.002	0.457
	- Two-side P	0.003	0.913
5	Cohen's d	-0.327	0.006

Source: IBM SPSS Analysis Results.

Therefore, according to this paired T-test result, the proposed calibration chart to make corrections on SMT direct reading performs well. This result agrees with the study from Berney et al., which found that SMT needs a multiplied chart conversion of the measurement data to level the accuracy and SMT is the most precise instrument compared to other water content measurement tools [22].

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4. Conclusion

It was found that the soil samples used met the requirements as embankment soil (SW and SM). A calibration chart has been proposed with the SMT-corrected water content equation ($w_{SMT-corrected} = 0.9815 w_{SMT} - 1.4323$). This equation has a coefficient of determination (R^2) equal to 0.95, which means a very strong relationship. The proposed calibration chart performs well according to RMSE, which is equal to 2.41 and paired T-test result. This proposed calibration chart can be widely used in road embankment practice in Indonesia.

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