



IMPLEMENTATION OF EARTH CONDUCTIVITY EXPERIMENT TO EVALUATE UNDERGROUND PARAMETERS

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ABSTRACT

Ground conductivity is a well-known parameter since it is commonly used for the grounding system for the building. However, the effect of solar variation to the ground conductivity is not well interrogated by the society. Thus, earth conductivity (EC) experiment is implemented to investigate the pattern of underground conductivity based on the layer of the soil as internal factor and based on solar variation as external factor. The measurements are taken using resistivity meter Chauvin Arnoux C.A 6471 to obtain the underground conductivity data. Since there are many other factors that affects the reading such as type of soil and salt contents, the measurements are conducted at the same survey site. Besides, the measurement applies 2 methods which are Wenner and Schlumberger method. The preliminary result from this small scale experiment has revealed the optimal range soil depth in the survey area and it shows good correlation between underground conductivity and solar variation. Details of the analysis will be discussed throughout this paper.

Keywords: wenner array, schlumberger array, underground resistivity, solar variation.

INTRODUCTION

In electrical engineering field, ground is the reference point in an electrical circuit from which voltages are measured, which is also a common return path for electric current, or a direct physical connection to the earth. Underground resistivity is a measurement on how much the soil could resist the flow of electricity. It is one of a critical factor in designing any systems that rely on passing and flowing current through the ground's surface. Electrical circuits may be connected to ground (earth) for several reasons. In powered equipment, the exposed metal parts are connected to ground to prevent user contact with dangerous voltage, if there is any electrical insulation fails [1]. Underground resistivity is very important to take into account in determining the design of the grounding system for new installations of any buildings. The most ideal location to place the grounding system is the one with the lowest possible resistance. Criteria that can affect the underground resistivity are the soil composition, moisture content and temperature [2]. Soil is basically inhomogeneous and the resistivity of the soil will always vary. Resistivity of the ground is a prime factor which affects the efficiency of a grounding system [3]. Mapping the underground resistivity is the process of determining the subsurface resistivity distribution of soil by conducting some measurements and experiments on the ground surface.

To measure the resistivity of the soil, there are several types of configuration in which the electrodes may be arranged, with the spacing chosen to match the needs. Each electrode configuration has its own advantages and disadvantages, depending on the type of survey. The Wenner array is one of the configurations where it is very useful for resolving the differing resistivity of subsurface layers. Wenner array is a highly symmetric form of the more general Schlumberger array, but the main drawback

of this array is the large amount of work required to deploy the electrodes in the array [4].

The soil resistivity value is depending to some great variation due to temperature, moisture and chemical content. Testing of underground resistivity has been applied in various contexts like detection of anomalous materials of soils, detection of soil type and rock, landfill, solute transfer delineation and groundwater exploration [2]. Factors such as efficiency of the measuring technique, maximum probe depths, length of cables required, cost and ease of interpretation of the data need to be considered to choose the best array for measurement. In the Wenner method, all four electrodes are moved for each test with the spacing between each adjacent pair remaining the same. Wenner method was found suitable for resistance survey study compared to others various methods because of its ability to define depth of penetration at study area by manipulate the spacing between two current electrodes and allows user to control probe spacing. The depth penetration of the electrodes is less than 5% of the separation to ensure that the approximation of point sources, required by the simplified formulae, remains valid [5]. Plus, the Wenner array is most susceptible to lateral variation effects because all four electrodes are moved after each reading. When the current electrode's spacing is increased, the deeper skin depth will be penetrated to measure the soil resistivity [6]. The moisture content in soils containing free charged particle that responsible for the current flows can largely affects the conduction of current in soils. The resistance to currents flowing in all soil types depends directly upon soil temperature, moisture content and salt content.

Solar variation is the variation position of the Sun at the fixed observing position. These positions of solar are varies all the time as the Earth is rotates and moving on its axis. The rotation of Earth is taken 24 hour to



complete with respect to the sun and 23 hours 56 minutes and 4 seconds with respects to the star [7]. Therefore, with the changes of day and night time, it is expected to influence the terrestrial parameters which will be explored in this paper. Both methods; Wenner and Schlumberger arrays are being conducted to see the relationship between solar variation and the underground conductivity. The spacing of electrode will first be defined to identify the optimal value of spacing to match the purpose of the experiment. The data obtained has been plotted and several graphs were then illustrated and compared.

METHODOLOGY

This study is starting with a series of measurements to get the raw data of underground resistivity using both Wenner and Schlumberger arrays. The configurations of these arrays are shown in Figure-1 and Figure-2.

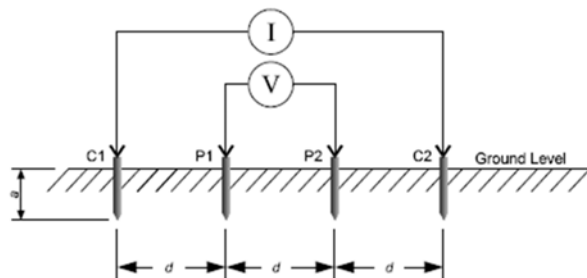


Figure-1. Wenner array configuration.

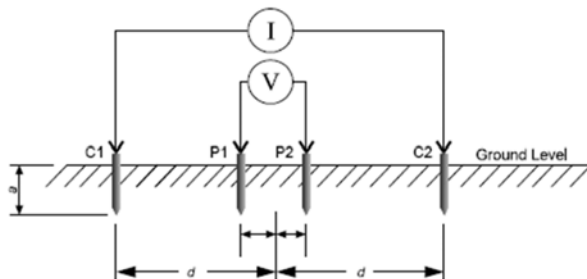


Figure-2. Schlumberger array configuration.

Wenner method is consists of four electrodes (as shown in Figure-1 that been arranged with the same distance between each electrodes [8]. While for Schlumberger array (Figure-2), the spacing between the inner electrodes is smaller than the outer electrodes. The math used to analyse the electrical signals from the Schlumberger array is the same as that for the Wenner array. The difference between the two arises through the geometric factor. The calculation for the underground apparent resistivity, ρ_w (Wenner array) and ρ_s (Schlumberger array) consists of different equations as expressed in Equation. (1) and Equation. (2).

$$\rho_w = 2\pi\alpha R \quad (1)$$

$$\rho_s = \frac{\pi L^2 R}{2l} \quad (2)$$

where α = probe spacing (m), R = measured resistance (Ω), L = distance from center to outer probes (m) and l = distance from center to inner probes (m).

A series of measurements were taken using the resistivity meter Chauvin Arnoux C.A 6471 as presented in Figure-3 and Figure-4 to measure the ground resistivity. The resistivity was measured using 2 different methods which are Wenner and Schlumberger method. Plus, in order to study the relation between the underground resistivity and solar variation, the optimal electrode's distance is first needed to be identified. Therefore, the experiment is divided into two parts; 1) measurement the underground resistivity with different electrode's spacing and 2) underground conductivity measurement due to solar variation.

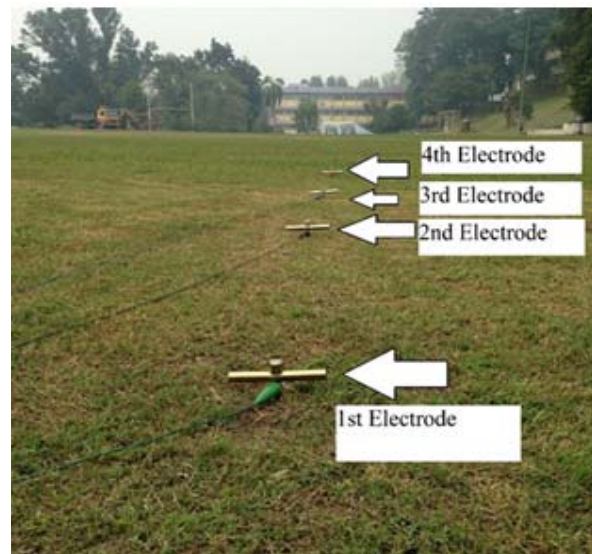


Figure-3. 4-point electrodes.

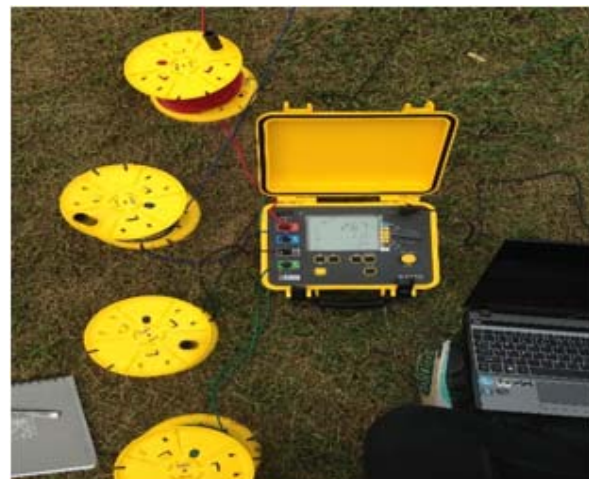


Figure-4. C.A 6471 resistivity meter.



Optimal electrode's spacing for underground resistivity measurement

In order to identify the optimal electrode's distance to characterize the underground resistivity due to solar variation, the experiment using both arrays, Wenner and Schlumberger were conducted with different distances of 3, 6, 9, 12 and 15m. The measurement takes place at Padang Pusat Sukan UiTM Shah Alam throughout the project, to ensure that the type of soil is always the same. The measurements are then conducted repeatedly for several days to determine the normal pattern of underground conductivity at this location.

Ground resistivity and solar variation

For Wenner array, the spacing between the electrodes is fixed to 3m. For the configuration of Schlumberger array, the distance between the outer dipole is 3m which is same as the distance between the dipoles in Wenner configuration. The best condition for this resistivity meter (C.A 6471) to measure underground resistivity using Schlumberger array is when the maximum spacing between inner electrodes is 40% of outer electrodes space [9]. Therefore, distance for the inner electrodes of Schlumberger configuration is 1m which is 33.33% from the outer electrodes distance. The details for the measurement are as shown in the Table-1.

Table-1. Details of ground resistivity measurement.

Parameters	Wenner	Schlumberger
Date	3, 4 and 5 May 2016	
Venue	UiTM Shah Alam Sports Centre soccer field	
Time	8.00am-9.30pm (in every 30 minutes)	
Electrode's distance	3, 6, 9 12 and 15 m	

The sequence experiment is conducted at the same location, day and time for both arrays in order to minimize the parameters that can affect the underground resistivity value such as the underground salt and moisture content, environment's temperature and the weather. The readings of the underground resistivity are measured in every 30 minutes during the time interval.

RESULTS AND DISCUSSIONS

The soil resistivity shows a considerable and predictable variation with different spacing, depth and also the solar variation which represents the day and night time. The measurements for both arrays (Wenner and Schlumberger) on different electrode's spacing and solar variation is analysed and is illustrated in the several graphs using MATLAB software.

Optimal electrode's spacing for underground resistivity measurement

The overall results for the Wenner method are shown in Figure-5. The measurements were conducted repeatedly to get the almost same pattern. These 5

readings are the most accurate and in the same pattern in all measurements that is being conducted. From the graph, it shows that the soil resistivity value is decreasing along the spacing of 3m to 6m. This result explains that the soil layer is inhomogeneous for this certain depth. The value of soil resistance in the soil spacing in between 3m to 6m is lower than the greater depth. Thus, it shows that the measurement for greater spacing is more important in this type of soil. While the reading of underground conductivity from 6m onward shows the increasing pattern, meaning that the type of soil in this layer is almost homogenous.

As seen in the Figure-6, the results from Schlumberger method are almost the same pattern as Wenner method. The values obtained in the measurement is varies just about $\pm 3\Omega m$ from the Wenner method. The measurement for Schlumberger method is easier than Wenner method and it does not require repetitive measurement. This method is more suitable in measuring the soil resistivity in several different depths and spacing [10] compared to Wenner method.

From the obtained results, the effective way to measure soil resistivity or to create electrical rod grounding system is 6m onwards of depth. In overall, the resistivity value that starts from 6m is directly proportional to the spacing as displayed from the graph.

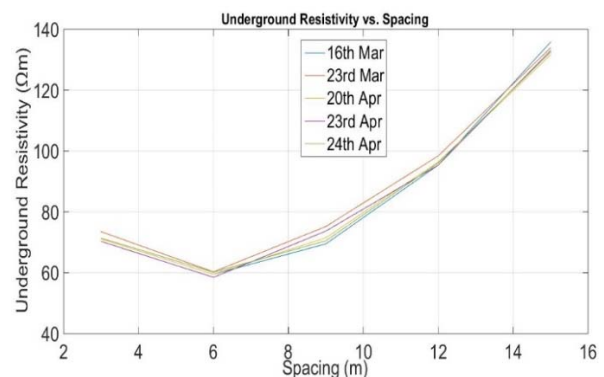


Figure-5. Overall graph of underground resistivity (Ωm) with different electrode's spacing (m) for Wenner method.

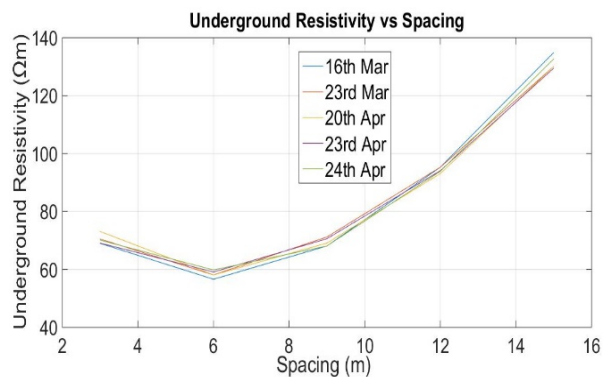


Figure-6. Overall graph of underground resistivity (Ωm) with different electrode's spacing (m) for Schlumberger method.



Based on theory, the readings between Wenner and Schlumberger method have not shown big different since certain parameters that have to be taken into account during the measurement such as type of soil, time and distance are the same. It is therefore suggested that within this range of electrode spacing (3-15m), despite of any arrays, the values of underground resistivity are almost same.

In overall, it can be seen that there are 2 types of underground resistivity pattern; from 3-6m and from 6m onwards. This pattern reveals the type of soil in this survey site consists of 2 different layers. Starting from 6m onwards, the resistivity value is gradually increased where it shows the normal pattern of resistivity value within the same type of soil. The resistivity of a material is a measure of how well the material retards the flow of electrical current and it vary tremendously from one material to another. The resistivity of a material maybe combined with reasoning along geologic lines to identify the materials that constitute the various underground layers as illustrated in Figure-7 [4]. Therefore, the results from EC experiment are in good agreement with the theoretical study.

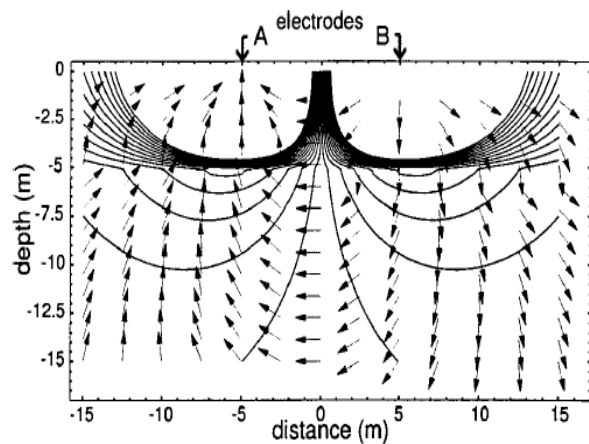


Figure-7. Current flow and equipotential surfaces between two electrodes in a level field with inhomogeneous subsurface structure. The boundary between the two materials in this example is at a depth of $z=5$ m [4].

Table-2 represents the average measurement of soil resistivity between these two methods is varies by $\pm 3\Omega\text{m}$ values. The variations of the values are not much, so the theory between these two methods is proven right.

Table-2. Comparisons of the average value of soil resistivity between Wenner and Schlumberger method.

Method/ Spacing	Average value of soil resistivity (Wenner) (Ωm)	Average value of soil resistivity (schlumberger) (Ωm)
3m	71.48	70.36
6m	59.6	58.34
9m	72.08	69.42
12m	96.34	94.36
15m	133.36	131.46

Ground resistivity and solar variation

For this experiment, raw data are taken from the measurements of ground resistivity in 3 days which are 3rd, 4th and 5th May 2016. For each day, the ground resistivity was measured using both Wenner and Schlumberger method. The experiment is conducted at the same pace with fixed electrode's distance of 3m throughout the project.

Figure-8(a)-(c) represents the underground conductivity on 3rd, 4th and 5th May 2016 respectively for both arrays (blue line represents Wenner array and red line represent Schlumberger array). In general, the underground conductivity during this period shows the same pattern where the variation drops from 11am to 12pm before it reaches the lowest value during the noon (peak time) which is in between 12pm to 1.30pm. From 2 pm till night, the ground conductivity was increased slowly. This set of measurements also shows that there is no significance difference in underground conductivity measured by Wenner and Schlumberger arrays. The

reading of environment temperature and humidity is also measured for detail understanding on the variation of underground conductivity for each day and it is tabulated in Table-3.

Table-3. Comparisons of the average value of soil resistivity between Wenner and Schlumberger method.

	Average temperature ($^{\circ}\text{C}$)	Average humidity (%)
3rd May 2016	30.57	72.286
4th May 2016	32.07	63.6
5th May 2016	30.36	77.143

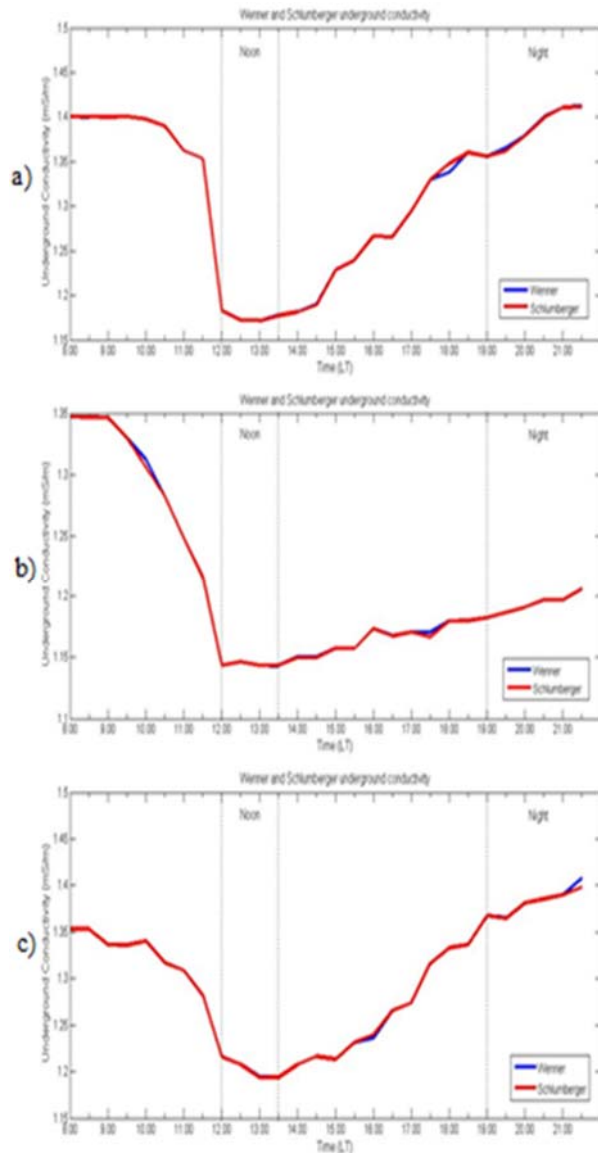


Figure-8. Wenner (blue line) and Schlumberger (red line) underground conductivity on a) 3rd May 2016, b) 4th May 2016 and c) 5th May 2016.

As mentioned in the analysis for figures above, the value of underground conductivity using the Wenner and Schlumberger method is almost identical because both of these methods have the same performance rate for the static measurements (with the same distance and the same place). For the measurements with the different distance and type of soil, the results between these two methods might have difference because the Schlumberger method is more sensitive to the changes in the distance while the Wenner method is more sensitive to the change in the soil properties.

From Figure-9, the lowest underground conductivity is during the noon (peak time). The peak time for three days of measurements is between 12pm to 1.30pm. Comparing these three days, the lowest

underground conductivity is on 4th May (red) which is 1.14mS/m. Peak time means that the position of the sun is at the peak on that day and for this study the peak time is between 12pm to 1.30pm for these 3 days. Malaysia is a country on equinox and it supposedly to have same day and night and the peak time is theoretically at 12pm. However, because of a few factors such as the refraction of the sunlight by the Earth's atmosphere that cause the sun edge to be appear at the horizon before the real upper edge of the sun appeared and the claim for the sunrise and the sunset time is when the first and last visibility of the sun from the horizon not when the center of the sun on horizon makes the sun peak time is ranging from 12pm to 1.30pm [11].

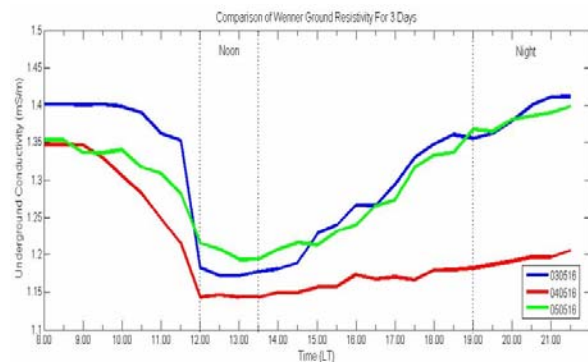


Figure-9. Comparison of Wenner underground conductivity for 3 days.

During the peak time, sun rays are at the hottest on that day since the solar radiation is directly hit the ground with the less refraction compared to when the sun is inclined with the ground. The less radiation refraction results in the less heat to be spread [11]. Therefore, this will make the underground moisture content drying more and thus increase the resistivity directly decreases the ground conductivity.

Besides, the result also indicates that the ground conductivity on 4 May 2016 (red) increases slower than other 2 days from the peak point through the night. Although the other parameters that might affect the ground conductivity such as distance and type of soil were constant, there are still a several factors such as the humidity and surrounding temperature that control the underground conductivity. On 3rd and 5th May 2016, the average surrounding temperature is 30°C and the average humidity is 72.286% and 77.143% respectively. On 4th May 2016, the average surrounding temperature and the humidity is 32.07°C and 63.6% respectively and it is 2.07°C higher than other days.

In general, the higher the moisture content, the lower the soil's resistivity is observed. Increasing the surround temperature will cause the surface of the ground is drying. Even the moisture from the lower layer of ground is permeate to the upper layer ground, the moisture will be dried in a little time will cause the moisture content of water to be decreased [12]. Lower moisture level in



ground will results in higher resistivity and based on the conductivity theories, the conductivity will decrease. Besides that, the humidity on that day also plays their roles. Higher humidity will result higher moisture contents on air. This will humidify the upper level of the ground and gives less pressure for the lower ground level where there is not huge different in the moisture level in both level [13]. Thus, it will increase the moisture contents in ground and increasing the ground conductivity accordingly. It is proven by results obtained on 3rd and 5th where the humidity is higher; the ground conductivity is higher than 4th May.

CONCLUSIONS

Soil resistivity measurement is one of the important critical factor in designing any systems or circuitry that rely on flowing current through the grounds' surface. It may have a different value with another type of soil and the criteria that may influence the value of soil resistivity is such as the temperature, the humidity and the salt contains in the soil. For the first experiment, it can be concluded that the readings of Wenner array and Schlumberger array are almost same for different electrode's distance. It shows that both arrays can be applied to measure the underground conductivity with different depth and soil type. Besides, the measurement obtained demonstrates that the soil in Padang Pusat Sukan UiTM Shah Alam consists of inhomogeneous subsurface; the upper layer from 3-6m and next layer is from 6m onwards. This experiment discovers that the optimal range depth of soil to study underground conductivity and solar variation should be from 6m onward since this layer is homogenous.

In the second experiment, it reveals that the ground conductivity is controlled by the variation of solar variation (day and night time). The lowest underground conductivity on these three days is during the peak time (12.00pm to 1.30pm). Among these three sets of measurements, the lowest underground is on 4th May. Besides, there are also several factors that control the ground conductivity which are surrounding temperature and humidity. Other than that, both of Wenner and Schlumberger method is suitable to use for the static measurements with the constant depth, distance and type of soil since it gives not much different in resistivity measurements result. This study can be improvised by replacing the 3m of electrode's spacing with the optimal range based on the first experiment. Besides, the period of the measurements also can be extending to 24 hours for future experiment. At the end of this project, a good understanding on the relationship between underground conductivity with the internal and external factors has been developed and the validity of this EC experiment has successfully proved.

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