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SEPARATION OF ELECTRODE AND POLARIZATION MEDIUM IMPEDANCES IN TWO-TERMINAL MEASUREMENTS

By

M. M. Judy

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SEPARATION OF ELECTRODE AND POLARIZATION MEDIUM IMPEDANCES IN TWO TERMINAL-MEASUREMENTS

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Abstract

Separation of the impedance due to interfacial polarization and that due to sample polarization from the total impedance obtained in two-terminal measurements follows from an equation linear in the sample length.

Taking the electrical analogue of a two-terminal cell containing a polarizable medium to be two impedances in series, Z_e the impedance due to polarization at the interface between electrodes and sample and Z_m the impedance of the sample, the total impedance Z of the cell is written as

$$Z = Z_e + Z_m . \tag{1}$$

Parallel capacitance and parallel resistance are assumed to electrically represent the sample. Upon writing R_e and $-\omega I_e$ for the real and imaginery parts of Z_e and considering a sample of length L, relative dielectric constant ϵ/ϵ_0 and resistivity ρ then equation (1) for the total impedance is written as

$$Z = \left[R_e + \left(\frac{\rho/A}{1+\omega^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2\rho^2}\right)L\right] - i\omega\left[I_e + \left(\frac{\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)\epsilon_0/A}{1+\omega^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2\rho^2}\right)L\right] \tag{2}$$

Equation (2) was applied to data taken over the frequency range 10^2 to 10^6 Hz, using cells of various lengths; one cell having polished-platinum electrodes (typically strongly polarizing), and another cell having platinized-platinum electrodes (typically weakly polarizing or "reversible"); both cells contained various earth materials or 10^{-3} N NaCl solution. Reasonable values of ϵ/ϵ_0 and ρ were obtained for all materials. Furthermore, good agreement between values of

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ABSTRACT

Separation of the impedance due to interfacial polarization and that due to sample polarization from the total impedance obtained in two-terminal measurements follows from an equation linear in th sample length.

Taking the electrical analogue of a two-terminal cell containing a polarizable medium to be two impedances in series, Z_e the impedance due to polarization at the interface between electrodes and sample and Z_m the impedance of the sample, the total impedance Z of the cell is written as

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$$Z = \left[R_e + \left(\frac{\rho/A}{1 + \omega^2\left(\frac{\epsilon}{\epsilon_o}\right)^2 \epsilon_o^2 \rho^2}\right)L\right] - i\omega\left[I_e + \left(\frac{\rho^2\left(\frac{\epsilon}{\epsilon_o}\right)\epsilon_o/A}{1 + \omega^2\left(\frac{\epsilon}{\epsilon_o}\right)^2 \epsilon_o^2 \rho^2}\right)L\right] \quad . \tag{2}$$

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INTRODUCTION

Whenever an external electric field is applied between nonreversible electrodes that are immersed in a polarizable medium, such as most earth materials containing ground water, polarization occurs at the electrode-medium interface. This interfacial polarization is characterized by a barrier layer at the interface comprised of partially immobilized ions. The barrier layer is of the order of 10^{-7} meters in thickness. It may be electrically represented as an impedance. Therefore, the measured impedance in two-terminal measurements consists of the impedance characteristic of the barrier layer superimposed upon the impedance characteristic of the medium. The values of the real and imaginary terms of the impedance of the barrier layer are, in general, functions of the electrode material, electrode surface, electrode surface area, nature of the medium, temperature, and functions of the frequency of the applied field, and these values are time dependent in magnitude.1/

1/ Some excellent reviews and discussions on interfacial polarization and its effects are:

Collett, L. S., 1959, Laboratory investigation of overvoltage in Overvoltage research and geophysical application: New York, Pergamon Press, p. 50-71.

Von Hippel, A. R., 1954, Dielectrics and waves: New York, John Wiley and Sons.

Waite, J. R., 1954, A phenomenological theory of overvoltage for metallic particles in Overvoltage research and geophysical application: New York, Pergamon Press, p. 22-28.

Attempts at eliminating or reducing the interfacial polarization or the magnitude of the impedance of the barrier layer, which will hereafter be called the electrode impedance, have centered around electrodes that are physically and chemically "reversible" with respect to the medium in contact with the electrodes. Examples are cells using Ag•AgCl electrodes with the chloride ion in aqueous solution or platinized-platinum electrodes that are routinely used in the measurement of the resistivity of solutions at higher frequencies ($\geq 10^3$ Hz).

Recent work aimed at reducing the polarization effects when making two-terminal measurements on earth materials involved the use of platinized-platinum electrodes with pads of moist blotter paper impregnated with silver and silver nitrate interposed between the electrodes and the sample (Scott and others, 1964). They found in measurements on various earth materials that apparent relative dielectric constants calculated from data on samples of different lengths of the same material showed good agreement. This agreement was interpreted as evidence of negligible electrode polarization in their electrode system.

Prior to investigating the polarization exhibited by various earth materials it was decided to perform the present work that would effect quantitative separation of the electrode and sample impedances and to determine the actual polarization impedances involved in attempting to obtain more quantitative data than heretofore reported.

Separation of electrode and medium impedances

Since the electrode impedance is localized at the interface the total impedance Z of the two-terminal system can be written as a series combination of electrode and sample impedances,

$$Z = Z_e + Z_m \tag{1}$$

where Z_e and Z_m are, respectively, the electrode and medium impedances. Generally, these impedances will be complex. Writing R_e and $-\omega I_e$, respectively, for the real and imaginary parts of Z_e and taking the electrical analogue of the medium to be a capacitance and a resistance in parallel, equation (1) may be written as

$$Z = \left[R_e + \frac{R_m}{1+\omega^2 R_m^2 C_m^2}\right] - i\omega\left[I_e + \frac{R_m^2 C_m}{1+\omega^2 R_m^2 C_m^2}\right] \tag{2}$$

If the medium is of constant cross-sectional area A (which is also the electrode area) and of length L, the resistance and capacitance of the medium may be written, neglecting fringing, as

$$R_m = \rho \frac{L}{A}$$

and

$$C_m = \left(\frac{\epsilon}{\epsilon_0}\right)\epsilon_0 \frac{A}{L}$$

where ρ and (ϵ/ϵ_0) are the resistivity and relative dielectric constants, respectively, of the medium; and ϵ_0 is the permittivity of vacuum, 8.85×10^{-12} farads/meter. In general, the resistivity and relative dielectric constant of the medium are both functions of the frequency of the applied electric field for earth materials. These expressions for R_m and C_m when substituted into equation (2) yield for the total impedance Z

$$Z = \left[R_e + \left(\frac{\rho/A}{1+\omega^2\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2} \right) L \right] \tag{3}$$

$$-i\omega \left[I_e + \left(\frac{\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)\epsilon_0/A}{1+\omega^2\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2} \right) L \right]$$

in which the real and imaginary parts are linear in the length L and approach R_e and I_e, respectively as L approaches zero. Thus, if the real and imaginary parts of the total impedance are determined for various sample lengths, application of equation (3) allows separation of contributions of the electrodes and medium.

If the equivalent parallel capacitance and conductance of the cell are experimentally determined, the left-hand side (the total impedance) of equation (3) may be written as

$$Z = \frac{R}{1+\omega^2C^2R^2} - i\omega\frac{R^2C}{1+\omega^2C^2R^2}, \tag{4}$$

where C and R are the equivalent parallel capacitance and resistance, respectively. Equating the real and imaginary parts of equations (3) and (4) obtains

$$\frac{R}{1+\omega^2C^2R^2} = R_e + \left(\frac{\rho/A}{1+\omega^2\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2} \right) L \tag{5}$$

and

$$\frac{R^2 C}{1+\omega^2 R^2 C^2} = I_\epsilon + \left(\frac{\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)\epsilon_0/A}{1+\omega^2\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2}\right)L \qquad (6)$$

With the substitutions

$$B_R = \frac{\rho/A}{1+\omega^2\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2} \qquad (7)$$

and

$$B_C = \frac{\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)\epsilon_0/A}{1+\omega^2\rho^2\left(\frac{\epsilon}{\epsilon_0}\right)^2\epsilon_0^2} \qquad (8)$$

equations (5) and (6) may be rewritten as

$$\frac{R}{1+\omega^2 R^2 C^2} = R_e + B_R L \qquad (9)$$

and as

$$\frac{R^2 C}{1+\omega^2 R^2 C^2} = I_\epsilon + B_C L. \qquad (10)$$

Experimental work

To investigate the practicability of using equation (3) in separating electrode and medium impedances, measurements of equivalent parallel capacitance and conductivity were made using a two-terminal cell and samples of different lengths at a constant temperature of

32.2°C over the frequency range 10^2 to 10^6 Hz and the data fitted by equations (9) and (10). Measurements were made using both polished-platinum and platinized-platinum electrode pairs. The former is typically nonreversible but the latter is commonly used as a reversible electrode system.

The earth materials used are listed in table 1. The alluvium and topsoil were chosen as materials which could be expected to exhibit large relative dielectric constants, and the quartz-10^{-3} N NaCl mixture was chosen as one that could be expected to exhibit moderately large constants. The 10^{-3} N NaCl solution was chosen as a material capable of good sample reproducibility from run to run.

Sample cell

The cell used is shown in figure 1. It was of constant area (9.58×10^{-4} m^2) along its length. The length could be varied by using silicone rubber gaskets and lucite spacers. The electrodes were washed in deionized water before each run. Deionized water or 10^{-3} N NaCl was added by pipette and the mixture thoroughly mixed before packing the cell. The cell was hand-packed in the same way for each run.

It is estimated that water contents and sample densities were reproduced within ±3 percent for each run. A vernier caliper with 10^{-4} meter least-count was used to determine the sample length.

Prior to the start of each run the filled cell was held at 32.2±0.1°C in a temperature bath (Model Number 4-8600, American Inst. Co.) for 18 hours or until the equivalent parallel capacitance or resistance were time-independent in magnitude. During the electrical measurements the cell was held at the same temperature.

Electrical measurements

The equipment used for the electrical measurement was the same as that described by Scott (Scott and others, 1964). For the electrical measurements between 10^2 and 10^4 Hz a Hewlett Packard Audio Oscillator, Model 201CR, was used to drive a Wayne-Kerr Universal Bridge, Model B-221 with stated accuracies of 0.2 percent and 0.25 percent of the reading on all conductance and capacitance ranges. During high frequency measurements (10^4 to 10^6 Hz) a Hewlett Packard Test Oscillator, Model 650A was used to drive a Wayne-Kerr Radio Frequency Bridge.

During both low and high frequency measurements a Rhode and Schwartz type UBM tunable indicating-amplifier was used as a null indicator. At frequencies greater than 5×10^5 Hz, the upper frequency limit of the amplifier, the tuning stages of a Hallicrafter Model S-108 receiver were used to amplify the bridge output and the 4.55×10^5 Hz IF signal from the receiver was fed to the amplifier (or null indicator).

Data reduction

The data for each electrode-medium system at the frequencies investigated were fitted by computer to the linear equations (9) and (10) by the least-squares method. Values of ϵ/ϵ_0 and ρ at each measurement frequency were calculated from the computed values of B_c and B_R by use of equations (7) and (8). Also, values for R_e and I_e were obtained as the intercepts in equations (9) and (10).

Values of the apparent relative dielectric constants and resistivities at each measurement frequency for the shortest, longest, and for an intermediate specimen length were calculated from the parallel equivalent capacitance and resistance for each cell using

$$C = \left(\frac{\epsilon}{\epsilon_0}\right) \epsilon_0 \frac{A}{L} \tag{11}$$

and

$$R = \rho \frac{L}{A} \tag{12}$$

From the data obtained using cells containing alluvium and with either polished-platinum or platinized-platinum electrodes, values of the series equivalent capacitance of the cell, C_s, were calculated at each measurement frequency for all specimen lengths using

$$\frac{1}{\omega C_s} = \frac{\omega R^2 C}{1 + \omega^2 R^2 C^2} \tag{13}$$

The value of the equivalent series resistance of the cell, $\mathcal{R}_s$, was also calculated by use of

$$\mathcal{R}_s = \frac{\mathcal{R}}{1+\omega^2 C^2 \mathcal{R}^2} \tag{14}$$

Results and Discussion

It was possible to fit the data for all measurements at all frequencies by the linear equations (9) and (10). Experimental points and curves calculated by equations (9) and (10) are shown on figures 2 through 21 for the cells with polished- and platinized-platinum electrodes containing alluvium. The scatter of the data points about the computed curves of the quantity $R/(1+\omega^2C^2R^2)$ (figs. 11 and 21) or the equivalent series resistance of the cell is seen to be small and in general decreases with increasing frequency. Comparison of data points with the computed curves of the quantity $R^2C/(1+\omega^2C^2R^2)$ shows less scatter at higher than at lower frequencies (figs. 2 through 10 and 12 through 20).

It is felt that the linear equations (9) and (10) adequately represent the experimental data; and that the scatter of the data points about the computed curves is attributed to variations in $\mathcal{R}_e$ and $\mathcal{I}_e$ arising from the inability to exactly reproduce the electrode surfaces, water content, and density from run to run; and that separation of electrode and sample impedances has been effected so that the values of ϵ/ϵ_0 and ρ obtained by the linear curve-fitting are characteristic of the material in most instances to well within order of magnitude.

The following comments support the foregoing conclusions:

(1) The effect of variations in electrode surface reproducibility is probably the greatest cause of the scatter in the experimental points. This conclusion is based on the presence of scatter in the values of ϵ/ϵ_0 and ρ for the cells containing only the 10^{-3} N NaCl solution (figs. 28, 29, 36, and 37) which is as pronounced as the scatter in the data for earth materials. The difficulty in reproducing electrode surfaces and the effect of surface changes on the electrical properties of the sample--electrode interface are discussed in the literature (Jones and Christian, 1935; Jones and Bollinger, 1935; Jaffé and Rider, 1952). These workers have found that anything which influences the effective surface area, the thickness of the barrier layer, and the ionic population of the barrier layer affects the measured capacitance and resistance of the cell. Often cells will have to be held at constant temperature for hours until measured values of capacitance and resistance become time-independent. The time-dependence of the electrical properties of the cell is strongly indicative of kinetic changes in the barrier layer which eventually yield a kinetically stable layer structure.

(2) The values of ϵ/ϵ_0 and ρ obtained through the linear reduction of the data for each material using both polished- and platinized-platinum electrodes agree reasonably well (figs. 22 through 37 and tables 2 through 17). Agreement is particularly good for those materials having large values of ϵ/ϵ_0. Furthermore, the values of the apparent relative dielectric constant for the different materials, calculated by equation (11) from data taken when using platinized-platinum electrodes and different cell lengths cluster closely together and approximate closely the values calculated by use of equations (8) and (10). However, those values of the apparent relative dielectric constant calculated from data taken when using polished-platinum electrodes and different cell lengths tend to be arranged in order according to the length of the cell and to differ from the value calculated by linear curve fitting. The good agreement between values of the apparent dielectric constant and those values of the constant calculated by use of equations (8) and (10) from the data taken using the platinized-platinum electrodes is expected as the platinized-platinum electrodes are more nearly reversible, by virtue of their extensive surface area, than are the polished-platinum electrodes. The values of the apparent resistivity at each frequency of measurement calculated for the cells consisting of alluvium-polished-platinum electrodes, alluvium-platinized-platinum electrodes, and topsoil-polished-platinum electrodes, decrease with increasing length and approach the value calculated

by linear curve fitting. This reduction is expected because as the sample length increases the magnitude of $\mathcal{R}_e$ becomes small when compared with the magnitude of the sample-resistance; thus the value of the cell-resistance approximates the true sample-resistance. The reversal of the aforementioned order of decreasing values of the apparent resistivities with increasing sample length for the other materials is felt to be due to nonreproducibility of the electrode surfaces from run to run.

(3) A value of approximately 70 ohm-meters for the resistivity of the 10^{-3} N NaCl solution at 32.2°C was obtained using equations (7) and (9) and was calculated by equation (12) from the data taken from cells with polished- and platinized-platinum electrodes. This value compares favorably with the value of 71 ohm-meters calculated by linear extrapolation between values at 18°C and 25°C (Glasstone, 1959). Values of the relative dielectric constant of the order of 70 for the 10^{-3} N NaCl solution were obtained at higher frequencies by linear curve-fitting of the data from both cells. These values compare favorably with the value of approximately 78.5 obtained by the following calculations as outlined by Smyth (1955). First, the dielectric constant of water at 32.2°C was calculated using the first order temperature-correction $T/T_0 = 78.54 [1 - 4.60 \times 10^{-3} (t - 25°C)]$. Second, the ionic lowering-correction of 11×10^{-3} for a 10^{-3} N NaCl solution was calculated. These combine algebraically to give approximately 78.5 for the relative dielectric constant of the solution.

(4) The values of the equivalent series capacitance C_s and resistance R_s of the cells (with polished- and platinized-platinum electrodes containing alluvium) calculated according to equations (13) and (14) and shown in figures 38 through 41 exhibit expected behavior with increasing frequency. It is seen particularly on figure 38 for the cell with polished-platinum electrodes that at lower frequencies, values of C_s for the various lengths tend to cluster while at higher frequencies the values disperse in order of increasing length. These characteristics arise from the relatively larger values of I_e at lower frequencies that override the decrease in capacitance with increasing length; while at the higher frequencies the geometric capacitance of the cell predominates. The clustering of values of C_s at lower frequencies for the cell using platinized-platinum is not so pronounced because its characteristic I_e is typically small and the geometric or sample capacitance is the predominant term in the cell capacitance. The same frequency-dependence of C_s has been found by Jaffé and Rider (1952) in studies of metal electrode-aqueous solution systems.

(5) The magnitudes of I_e and R_e (tables 18 through 21) decrease with increasing measurement-frequency for all cells studied. Such behavior is typical as the interfacial polarization varies inversely with the frequency of the applied field. The negative values of I_e and R_e are attributed to the presence of scatter in the data that was caused by nonreproducibility in electrode surface and sample characteristics.

It is proposed that the present investigation be continued and directed toward the following:

(1) Examination of representative earth materials to determine the effects of mineralogy, water content and salinity, and temperature on sample dielectric constants and conductivity with frequency. The examination of earth materials containing minerals such as clay, which are capable of a high degree of polarization, is considered desirable.

(2) Methods to enhance electrode and sample reproducibility should be studied.

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Table 1.--Materials used in electrical study

Material	Description
1. Quartz	-150 mesh fraction of crushed pegmatitic quartz which had been repeatedly leached with $3HNO_3$: 2HCl and conc HCl. Contained 20.4 vol percent 10^{-3}N NaCl and packed to density $\rho = 1.43$ Kg/m^3.
2. Alluvium	-80 mesh fraction of an alluvium from southern Nevada. Buff in color, siliceous to slightly calcareous with detrital fragments of zeolite and welded tuff, quartz and feldspar grains, lithics of carbonate and volcanics. Contained 28.9 vol percent distilled H_2O and packed to density $\rho = 2.02$ Kg/m^3.
3. Topsoil	-63 mesh fraction of a topsoil from central Colorado. Dark gray to brown, humic, unctuous, silty to clayey with few sand grains. Contained 24.7 vol percent distilled H_2O and packed to density $\rho = 1.73$ Kg/m^3.
4. NaCl solution	10^{-3} N. made using deionized water.

Table 2.--Comparison of apparent relative dielectric constants ϵ/ϵ_o calculated for alluvium using polished-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		1.25×10^{-2} m	3.47×10^{-2} m	5.67×10^{-2} m
1.00×10^{2}	-1.46×10^{3}	2.98×10^{5}	1.80×10^{5}	1.04×10^{5}
5.00×10^{2}	1.17×10^{4}	2.58×10^{4}	2.22×10^{4}	1.68×10^{5}
1.00×10^{3}	7.50×10^{3}	1.06×10^{4}	9.58×10^{3}	8.73×10^{4}
5.00×10^{3}	2.15×10^{3}	1.91×10^{3}	2.02×10^{3}	2.11×10^{3}
1.00×10^{4}	1.20×10^{3}	9.53×10^{2}	1.08×10^{3}	1.13×10^{3}
5.00×10^{4}	2.85×10^{2}	2.23×10^{2}	2.43×10^{2}	2.72×10^{2}
1.00×10^{5}	1.96×10^{2}	1.26×10^{2}	1.40×10^{2}	1.75×10^{2}
5.00×10^{5}	6.82×10^{1}	4.88×10^{1}	6.07×10^{1}	6.14×10^{1}
1.00×10^{6}	6.02×10^{1}	3.93×10^{1}	4.68×10^{1}	5.21×10^{1}

Table 3.--Comparison of apparent relative dielectric constants ϵ/ϵ_0 calculated for alluvium using platinized-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		1.25×10^{-2} m	3.49×10^{-2}	5.58×10^{-2}
1.00×10^{2}	4.94×10^{4}	5.32×10^{4}	5.22×10^{4}	5.16×10^{4}
5.00×10^{2}	1.25×10^{4}	1.30×10^{4}	1.37×10^{4}	1.28×10^{4}
1.00×10^{3}	7.01×10^{3}	7.22×10^{3}	7.70×10^{3}	7.15×10^{3}
5.00×10^{3}	1.89×10^{3}	1.85×10^{3}	2.07×10^{3}	1.89×10^{3}
1.00×10^{4}	1.06×10^{3}	9.75×10^{2}	1.17×10^{3}	1.06×10^{3}
5.00×10^{4}	2.53×10^{2}	2.51×10^{2}	2.83×10^{2}	2.51×10^{2}
1.00×10^{5}	1.74×10^{2}	1.43×10^{2}	1.63×10^{2}	1.65×10^{2}
5.00×10^{5}	6.88×10^{1}	5.53×10^{1}	6.63×10^{1}	6.51×10^{1}
1.00×10^{6}	5.99×10^{1}	4.28×10^{1}	5.27×10^{1}	5.40×10^{1}

Table 4.--Comparison of relative dielectric constants ϵ/ϵ_0 calculated for topsoil using polished-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		1.06×10^{-2} m	3.24×10^{-2} m	5.47×10^{-2} m
1.00×10^2	1.08×10^6	8.70×10^5	5.86×10^5	7.13×10^5
5.00×10^2	2.47×10^4	9.89×10^4	5.69×10^4	7.06×10^4
1.00×10^3	1.27×10^4	3.61×10^4	2.16×10^4	2.68×10^4
5.00×10^3	2.12×10^3	3.14×10^3	2.67×10^3	3.06×10^3
1.00×10^4	9.29×10^2	1.35×10^3	1.07×10^3	1.26×10^3
5.00×10^4	2.34×10^2	1.67×10^2	2.18×10^2	2.32×10^2
1.00×10^5	1.02×10^2	8.87×10^1	1.34×10^2	1.38×10^2
5.00×10^5	3.40×10^1	3.68×10^1	4.74×10^1	1.17×10^2
1.00×10^6	3.13×10^1	3.04×10^1	3.59×10^1	6.58×10^1

Table 5.--Comparison of apparent relative dielectric constants ϵ/ϵ_0 calculated for topsoil using platinized-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		1.10×10^{-2} m	3.45×10^{-2} m	5.45×10^{-2} m
1.00×10^{2}	8.27×10^{4}	1.26×10^{5}	9.66×10^{4}	8.87×10^{4}
5.00×10^{2}	1.25×10^{4}	1.92×10^{4}	1.64×10^{4}	1.34×10^{4}
1.00×10^{3}	5.69×10^{3}	8.95×10^{3}	8.34×10^{3}	6.16×10^{3}
5.00×10^{3}	1.36×10^{3}	1.30×10^{3}	1.75×10^{3}	1.38×10^{3}
1.00×10^{4}	6.89×10^{2}	9.08×10^{2}	8.13×10^{2}	7.31×10^{2}
5.00×10^{4}	1.01×10^{2}	1.83×10^{2}	2.39×10^{2}	1.16×10^{2}
1.00×10^{5}	6.15×10^{1}	1.73×10^{2}	1.59×10^{2}	5.46×10^{1}
5.00×10^{5}	3.97×10^{1}	7.20×10^{1}	8.14×10^{1}	4.62×10^{1}

Table 6.--Comparison of apparent dielectric constants ϵ/ϵ_o calculated for quartz with 10^{-3} N NaCl using polished-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		1.25×10^{-2} m	3.24×10^{-2} m	5.45×10^{-2} m
1.00×10^2	1.76×10^3	3.40×10^3	2.20×10^3	1.96×10^3
5.00×10^2	2.48×10^2	3.83×10^2	2.98×10^2	2.70×10^2
1.00×10^3	1.24×10^2	1.70×10^2	1.40×10^2	1.29×10^2
5.00×10^3	3.92×10^1	4.49×10^1	4.11×10^1	4.05×10^1
1.00×10^4	5.71×10^0	3.76×10^1	3.03×10^1	1.19×10^1
5.00×10^4	8.08×10^0	2.33×10^1	2.82×10^1	1.01×10^1
1.00×10^5	8.62×10^0	2.19×10^1	2.65×10^1	1.11×10^1
5.00×10^5	1.16×10^1	1.96×10^1	2.43×10^1	1.37×10^1
1.00×10^6	1.28×10^1	1.86×10^1	2.35×10^1	1.46×10^1

Table 7.--Comparison of apparent dielectric constant ϵ/ϵ_0 calculated for quartz with 10^{-3} N NaCl using platinized-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		1.28×10^{-2} m	4.06×10^{-2} m	5.39×10^{-2} m
1.00×10^{2}	1.02×10^{3}	1.36×10^{3}	1.27×10^{3}	1.11×10^{3}
5.00×10^{2}	2.33×10^{2}	2.38×10^{2}	2.56×10^{2}	2.37×10^{2}
1.00×10^{3}	1.28×10^{2}	1.24×10^{2}	1.38×10^{2}	1.28×10^{2}
5.00×10^{3}	4.47×10^{1}	4.53×10^{1}	4.67×10^{1}	4.53×10^{1}
1.00×10^{4}	3.44×10^{1}	3.32×10^{1}	3.41×10^{1}	3.45×10^{1}
5.00×10^{4}	7.08×10^{0}	2.79×10^{1}	1.16×10^{1}	1.21×10^{1}
1.00×10^{5}	1.25×10^{1}	2.34×10^{1}	1.42×10^{1}	1.51×10^{1}
5.00×10^{5}	1.92×10^{1}	1.99×10^{1}	1.77×10^{1}	1.83×10^{1}
1.00×10^{6}	1.69×10^{1}	2.04×10^{1}	1.79×10^{1}	1.83×10^{1}

Table 8.--Comparison of apparent relative dielectric constants ϵ/ϵ_0 calculated for 10^{-3} NaCl solution using polished-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		4.74×10^{-3} m	2.40×10^{-2} m	8.95×10^{-2} m
1.00×10^2	5.86×10^3	8.33×10^5	1.00×10^5	2.74×10^4
5.00×10^2	1.43×10^2	5.40×10^4	5.52×10^3	1.44×10^3
1.00×10^3	8.18×10^1	1.61×10^4	1.62×10^3	4.17×10^2
5.00×10^3	7.94×10^1	9.88×10^2	2.01×10^2	6.86×10^1
1.00×10^4	6.58×10^1	3.24×10^2	1.37×10^2	5.80×10^1
5.00×10^4	3.68×10^1	5.92×10^1	7.41×10^1	5.12×10^1
1.00×10^5	5.49×10^1	4.80×10^1	7.30×10^1	5.02×10^1
5.00×10^5	6.20×10^1	4.36×10^1	7.53×10^1	5.99×10^1
1.00×10^6	6.88×10^1	3.24×10^1	8.01×10^1	6.67×10^1

Table 9.--Comparison of apparent relative dielectric constants ϵ/ϵ_o calculated for 10^{-3} NaCl solution using platinized-platinum electrodes

Frequency (sec^{-1})	From equation 10	From individual cell data for lengths equal to:		
		3.91×10^{-3} m	4.97×10^{-3} m	9.65×10^{-3} m
1.00×10^{2}	9.87×10^{0}	1.05×10^{4}	5.65×10^{3}	3.08×10^{3}
1.00×10^{3}	5.92×10^{0}	2.38×10^{2}	1.15×10^{2}	5.79×10^{1}
1.00×10^{4}	5.77×10^{1}	8.20×10^{1}	7.94×10^{1}	6.27×10^{1}
1.00×10^{5}	7.82×10^{1}	7.34×10^{1}	7.65×10^{1}	7.72×10^{1}
1.00×10^{6}	7.08×10^{1}	7.26×10^{1}	7.65×10^{1}	7.72×10^{1}

Table 10.--Comparison of resistivities ρ calculated for alluvium using polished-platinum electrodes. Values are given in ohm-meters

Frequency (sec^{-1})	From equation 9	From individual cell data for lengths equal to:		
		1.25×10^{-2} m	3.47×10^{-2} m	5.67×10^{-2} m
1.00×10^{2}	3.55×10^{1}	4.99×10^{1}	4.43×10^{1}	3.91×10^{1}
5.00×10^{2}	3.52×10^{1}	4.84×10^{1}	4.33×10^{1}	3.85×10^{1}
1.00×10^{3}	3.50×10^{1}	4.79×10^{1}	4.29×10^{1}	3.82×10^{1}
5.00×10^{3}	3.43×10^{1}	4.67×10^{1}	4.21×10^{1}	3.75×10^{1}
1.00×10^{4}	3.40×10^{1}	4.62×10^{1}	4.16×10^{1}	3.71×10^{1}
5.00×10^{4}	3.35×10^{1}	4.51×10^{1}	4.06×10^{1}	3.65×10^{1}
1.00×10^{5}	3.34×10^{1}	4.46×10^{1}	4.04×10^{1}	3.62×10^{1}
5.00×10^{5}	3.23×10^{1}	4.36×10^{1}	3.92×10^{1}	3.52×10^{1}
1.00×10^{6}	3.20×10^{1}	4.25×10^{1}	3.67×10^{1}	3.47×10^{1}

Table 11.--Comparison of resistivities ρ calculated for alluvium using platinized-platinum electrodes. Values are given in ohm-meters

Frequency (sec^{-1})	From equation 9	From individual cell data for lengths equal to:		
		1.25×10^{-2} m	3.49×10^{-2} m	5.58×10^{-2} m
1.00×10^{2}	3.91×10^{1}	4.60×10^{1}	4.05×10^{1}	4.14×10^{1}
5.00×10^{2}	3.86×10^{1}	$4.55 \times 10-1$	4.00×10^{1}	4.08×10^{1}
1.00×10^{3}	3.84×10^{1}	4.51×10^{1}	3.97×10^{1}	4.05×10^{1}
5.00×10^{3}	3.77×10^{1}	4.42×10^{1}	3.89×10^{1}	3.97×10^{1}
1.00×10^{4}	3.74×10^{1}	4.37×10^{1}	3.86×10^{1}	3.94×10^{1}
5.00×10^{4}	3.68×10^{1}	4.24×10^{1}	3.78×10^{1}	3.86×10^{1}
1.00×10^{5}	3.65×10^{1}	4.19×10^{1}	3.72×10^{1}	3.82×10^{1}
5.00×10^{5}	3.57×10^{1}	4.09×10^{1}	3.62×10^{1}	3.74×10^{1}
1.00×10^{6}	3.58×10^{1}	4.02×10^{1}	3.59×10^{1}	3.73×10^{1}

Table 12.--Comparison of resistivities ρ calculated for topsoil using polished-platinum electrodes. Values are given in ohm-meters

Frequency (sec^{-1})	From equation 9	From individual cell data for lengths equal to:		
		1.06×10^{-2} m	3.24×10^{-2} m	5.47×10^{-2} m
1.00×10^{2}	3.45×10^{1}	7.99×10^{1}	3.28×10^{1}	4.17×10^{1}
5.00×10^{2}	3.16×10^{1}	6.06×10^{1}	3.08×10^{1}	3.77×10^{1}
1.00×10^{3}	3.12×10^{1}	5.72×10^{1}	3.04×10^{1}	3.68×10^{1}
5.00×10^{3}	3.05×10^{1}	5.35×10^{1}	2.97×10^{1}	3.54×10^{1}
1.00×10^{4}	3.07×10^{1}	5.29×10^{1}	2.99×10^{1}	3.54×10^{1}
5.00×10^{4}	3.00×10^{1}	5.18×10^{1}	2.93×10^{1}	3.46×10^{1}
1.00×10^{5}	2.97×10^{1}	5.15×10^{1}	2.90×10^{1}	3.44×10^{1}
5.00×10^{5}	2.91×10^{1}	5.02×10^{1}	2.87×10^{1}	3.39×10^{1}
1.00×10^{6}	2.86×10^{1}	4.93×10^{1}	2.86×10^{1}	3.32×10^{1}

Table 13.--Comparison of resistivities ρ calculated for topsoil using platinized-platinum electrodes. Values are given in ohm-meters

Frequency (sec^{-1})	From equation 9	From individual cell data for lengths equal to:		
		1.10×10^{-2} m	3.45×10^{-2} m	5.45×10^{-2} m
1.00×10^{2}	2.63×10^{1}	2.00×10^{1}	2.13×10^{1}	2.49×10^{1}
5.00×10^{2}	2.61×10^{1}	1.99×10^{1}	2.11×10^{1}	2.48×10^{1}
1.00×10^{3}	2.60×10^{1}	1.98×10^{1}	2.11×10^{1}	2.50×10^{1}
5.00×10^{3}	2.58×10^{1}	1.96×10^{1}	2.09×10^{1}	2.50×10^{1}
1.00×10^{4}	2.55×10^{1}	2.05×10^{1}	2.08×10^{1}	2.43×10^{1}
5.00×10^{4}	2.55×10^{1}	1.98×10^{1}	2.08×10^{1}	2.42×10^{1}
1.00×10^{5}	2.55×10^{1}	1.94×10^{1}	2.07×10^{1}	2.42×10^{1}
5.00×10^{5}	2.94×10^{1}	1.92×10^{1}	2.06×10^{1}	2.40×10^{1}

Table 14.--Comparison of resistivities ρ calculated for quartz with 10^{-3} NaCl solution using polished-platinum electrodes. Values are in ohm-meters

Frequency (sec^{-1})	From equation 9	From individual cell data for lengths equal to:		
		1.25×10^{-2} m	3.24×10^{-2} m	5.45×10^{-2} m
1.00×10^{2}	1.05×10^{3}	6.79×10^{2}	7.61×10^{2}	1.01×10^{3}
5.00×10^{2}	1.04×10^{3}	6.74×10^{2}	7.55×10^{2}	1.00×10^{3}
1.00×10^{3}	1.00×10^{3}	6.72×10^{2}	7.55×10^{2}	1.00×10^{3}
5.00×10^{3}	1.05×10^{3}	6.69×10^{2}	7.51×10^{2}	9.95×10^{3}
1.00×10^{4}	1.03×10^{3}	6.67×10^{2}	7.50×10^{2}	9.97×10^{3}
5.00×10^{4}	1.04×10^{3}	6.63×10^{2}	7.45×10^{2}	9.91×10^{3}
1.00×10^{5}	1.04×10^{3}	6.60×10^{2}	7.44×10^{2}	1.00×10^{3}
5.00×10^{5}	1.12×10^{3}	6.36×10^{2}	7.17×10^{2}	1.05×10^{3}
1.00×10^{6}	1.09×10^{3}	6.09×10^{2}	6.83×10^{2}	1.03×10^{3}

Table 15.--Comparison of resistivities ρ calculated for quartz with 10^{-3} N NaCl solution using platinized-platinum electrodes. Values are given in ohm-meters

Frequency (sec^{-1})	From equation 9	From individual cell data for lengths equal to:		
		1.28×10^{-2} m	4.06×10^{-2} m	5.39×10^{-2} m
1.00×10^{2}	6.55×10^{2}	5.99×10^{2}	6.29×10^{2}	6.32×10^{2}
5.00×10^{2}	6.52×10^{2}	5.97×10^{2}	6.26×10^{2}	6.30×10^{2}
1.00×10^{3}	6.51×10^{2}	5.96×10^{2}	6.25×10^{2}	6.29×10^{2}
5.00×10^{3}	6.48×10^{2}	5.95×10^{2}	6.22×10^{2}	6.26×10^{2}
1.00×10^{4}	6.47×10^{2}	5.93×10^{2}	6.20×10^{2}	6.25×10^{2}
5.00×10^{4}	6.44×10^{2}	5.95×10^{2}	6.23×10^{2}	6.25×10^{2}
1.00×10^{5}	6.51×10^{2}	5.91×10^{2}	6.29×10^{2}	6.25×10^{2}
5.00×10^{5}	6.30×10^{2}	5.65×10^{2}	6.26×10^{2}	6.37×10^{2}
1.00×10^{6}	6.91×10^{2}	5.24×10^{2}	6.08×10^{2}	6.10×10^{2}

Table 16.--Comparison of resistivities ρ calculated for 10^{-3} N NaCl solution using polished-platinum electrodes. Values are given in ohm-meters

Frequency ($\sec^{-1}$)	From equation 9	From individual cell data for lengths equal to:		
		4.74×10^{-3} m	2.40×10^{-2} m	8.95×10^{-2} m
1.00×10^{2}	6.03×10^{1}	4.61×10^{1}	5.73×10^{1}	6.17×10^{1}
5.00×10^{2}	6.02×10^{1}	4.21×10^{1}	5.68×10^{1}	6.16×10^{1}
1.00×10^{3}	6.03×10^{1}	4.17×10^{1}	5.67×10^{1}	6.16×10^{1}
5.00×10^{3}	6.02×10^{1}	4.11×10^{1}	5.67×10^{1}	6.15×10^{1}
1.00×10^{4}	6.03×10^{1}	4.11×10^{1}	5.67×10^{1}	6.16×10^{1}.
5.00×10^{4}	6.06×10^{1}	4.13×10^{1}	5.67×10^{1}	6.16×10^{1}
1.00×10^{5}	6.05×10^{1}	4.13×10^{1}	5.67×10^{1}	6.17×10^{1}
5.00×10^{5}	6.13×10^{1}	4.13×10^{1}	5.69×10^{1}	6.26×10^{1}
1.00×10^{6}	6.17×10^{1}	4.09×10^{1}	5.66×10^{1}	6.27×10^{1}

Table 17.--Comparison of resistivities ρ calculated for 10^{-3} N NaCl solution using platinized-platinum electrodes. Values are given in ohm-meters

Frequency ($\sec^{-1}$)	From equation 9	From individual cell data for lengths equal to: 3.91×10^{-3} m	4.97×10^{-3} m	9.65×10^{-3} m
1.00×10^{2}	7.39×10^{1}	5.99×10^{1}	6.67×10^{1}	6.87×10^{1}
1.00×10^{3}	7.39×10^{1}	5.96×10^{1}	6.65×10^{1}	6.86×10^{1}
1.00×10^{4}	7.39×10^{1}	5.93×10^{1}	6.63×10^{1}	6.85×10^{1}
1.00×10^{5}	7.42×10^{1}	5.93×10^{1}	6.67×10^{1}	6.86×10^{1}
1.00×10^{6}	8.12×10^{1}	5.84×10^{1}	6.59×10^{1}	6.82×10^{1}

Table 18.--Values of R_e and I_e calculated by equations (9) and (10) from data for alluvium using polished- and platinized-platinum electrodes

Frequency (sec^{-1})	R_e Polished Pt ohm	R_e Platinized Pt ohm	I_e Polished Pt $farad^{-1} \cdot sec^2$	I_e Platinized Pt $farad^{-1} \cdot sec^2$
1.00×10^2	2.24×10^2	5.35×10^1	8.738×10^{-2}	3.27×10^{-3}
5.00×10^2	2.11×10^2	5.15×10^1	4.79×10^{-3}	8.62×10^{-4}
1.00×10^3	2.06×10^2	5.13×10^1	1.97×10^{-3}	4.67×10^{-4}
5.00×10^3	1.98×10^2	4.71×10^1	2.44×10^{-4}	1.01×10^{-4}
1.00×10^4	1.95×10^2	4.53×10^1	1.05×10^{-4}	4.59×10^{-5}
5.00×10^4	1.83×10^2	3.61×10^1	1.932×10^{-5}	1.19×10^{-5}
1.00×10^5	1.80×10^2	3.16×10^1	3.09×10^{-6}	-1.49×10^{-6}
5.00×10^5	1.77×10^2	2.79×10^1	3.64×10^{-6}	-8.89×10^{-6}
1.00×10^6	1.70×10^2	1.60×10^1	1.53×10^{-6}	-2.19×10^{-6}

Table 19.--Values of R_e and I_e calculated by equations (9) and (10) from data for topsoil using polished-and platinized-platinum electrodes

Frequency (sec^{-1})	R_e Polished Pt ohm	R_e Platinized Pt ohm	I_e Polished Pt $farad^{-1} \cdot sec^2$	I_e Platinized Pt $farad^{-1} \cdot sec^2$
1.00×10^{2}	2.36×10^{2}	-1.18×10^{2}	-1.37×10^{-1}	-2.34×10^{-3}
5.00×10^{2}	1.96×10^{2}	-1.16×10^{2}	2.28×10^{-2}	-2.12×10^{-4}
1.00×10^{3}	1.83×10^{2}	-1.16×10^{2}	6.92×10^{-2}	-5.16×10^{-5}
5.00×10^{3}	1.68×10^{2}	-1.15×10^{2}	5.07×10^{-4}	-4.15×10^{-5}
1.00×10^{4}	1.56×10^{2}	-1.04×10^{2}	1.68×10^{-4}	-1.49×10^{-5}
5.00×10^{4}	1.60×10^{2}	-1.10×10^{2}	9.52×10^{-4}	2.50×10^{-6}
1.00×10^{5}	1.62×10^{2}	-1.14×10^{2}	1.05×10^{-5}	4.73×10^{-7}
5.00×10^{5}	1.63×10^{2}	-2.97×10^{2}	4.90×10^{-6}	-2.93×10^{-6}
1.00×10^{6}	1.62×10^{2}		2.99×10^{-6}	

Table 20.--Values of R_e and I_e calculated by equations (9) and (10) from data for quartz and 10^{-3} N NaCl using polished- and platinized-platinum electrodes

Frequency (sec^{-1})	R_e Polished Pt ohm	R_e Platinized Pt ohm	I_e Polished Pt $farad^{-1} \cdot sec^2$	I_e Platinized Pt $farad^{-1} \cdot sec^2$
1.00×10^2	-6.09×10^3	-1.18×10^3	-6.42×10^{-2}	9.29×10^{-3}
5.00×10^2	-6.07×10^3	-1.17×10^3	-1.46×10^{-2}	-1.13×10^{-3}
1.00×10^3	-6.04×10^3	-1.17×10^3	-8.94×10^{-3}	-9.85×10^{-4}
5.00×10^3	-6.00×10^3	-1.16×10^3	-3.39×10^{-3}	-3.83×10^{-4}
1.00×10^4	-1.09×10^4	-1.16×10^3	2.65×10^{-3}	-4.20×10^{-4}
5.00×10^4	-6.08×10^3	-1.09×10^3	6.27×10^{-4}	6.15×10^{-4}
1.00×10^5	-6.42×10^3	-1.23×10^3	2.68×10^{-4}	1.48×10^{-4}
5.00×10^5	-7.24×10^3	-5.72×10^2	-9.23×10^{-4}	-2.26×10^{-4}
1.00×10^6	-2.24×10^3	-1.78×10^2	-7.21×10^{-4}	3.12×10^{-4}

Table 21.--Values of R_e and I_e calculated by equations (9) and (10) from data for 10^{-3} N NaCl using polished- and platinized-platinum electrodes

Frequency (sec^{-1})	R_e Polished Pt ohm	R_e Platinized Pt ohm	I_e Polished Pt $farad^{-1} \cdot sec^2$	I_e Platinized Pt $farad^{-1} \cdot sec^2$
1.00×10^2	-3.52×10^1	-4.50×10^1	6.99×10^{-2}	1.12×10^{-3}
5.00×10^2	-4.01×10^1		4.00×10^{-3}	
1.00×10^3	-4.65×10^1	-4.60×10^1	1.12×10^{-3}	2.37×10^{-5}
5.00×10^3	-4.36×10^1		6.87×10^{-5}	
1.00×10^4	-4.90×10^1	-4.70×10^1	3.21×10^{-5}	6.93×10^{-7}
5.00×10^4	-4.82×10^1		2.08×10^{-5}	
1.00×10^5	-4.95×10^1	-4.70×10^1	3.76×10^{-6}	4.79×10^{-6}
5.00×10^5	-5.89×10^1		-1.61×10^{-7}	
1.00×10^6	-6.38×10^1	-4.92×10^1	-3.42×10^{-6}	-5.03×10^{-6}

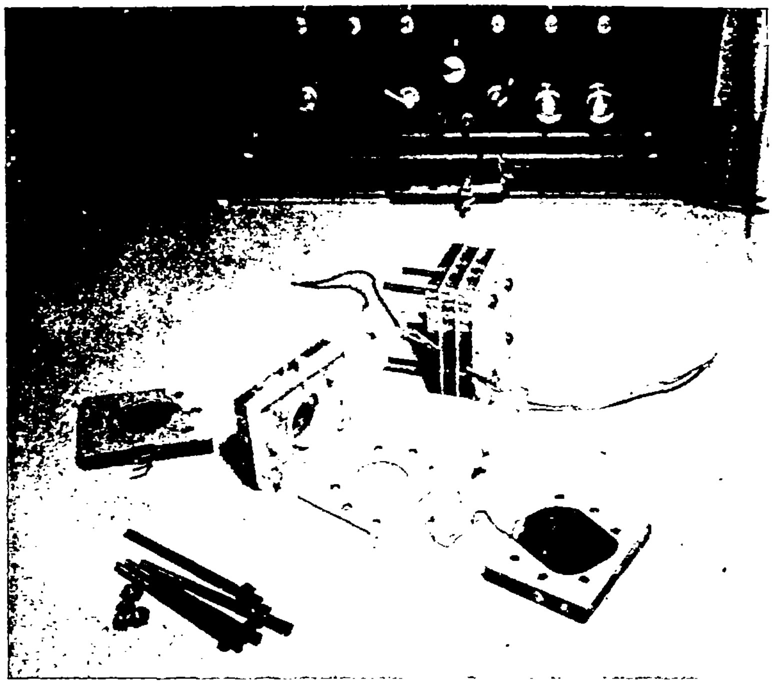

Figure 1.--The cell used to determine the parallel equivalent capacitance and conductance of various materials. An assembled cell is shown in upper center of picture.

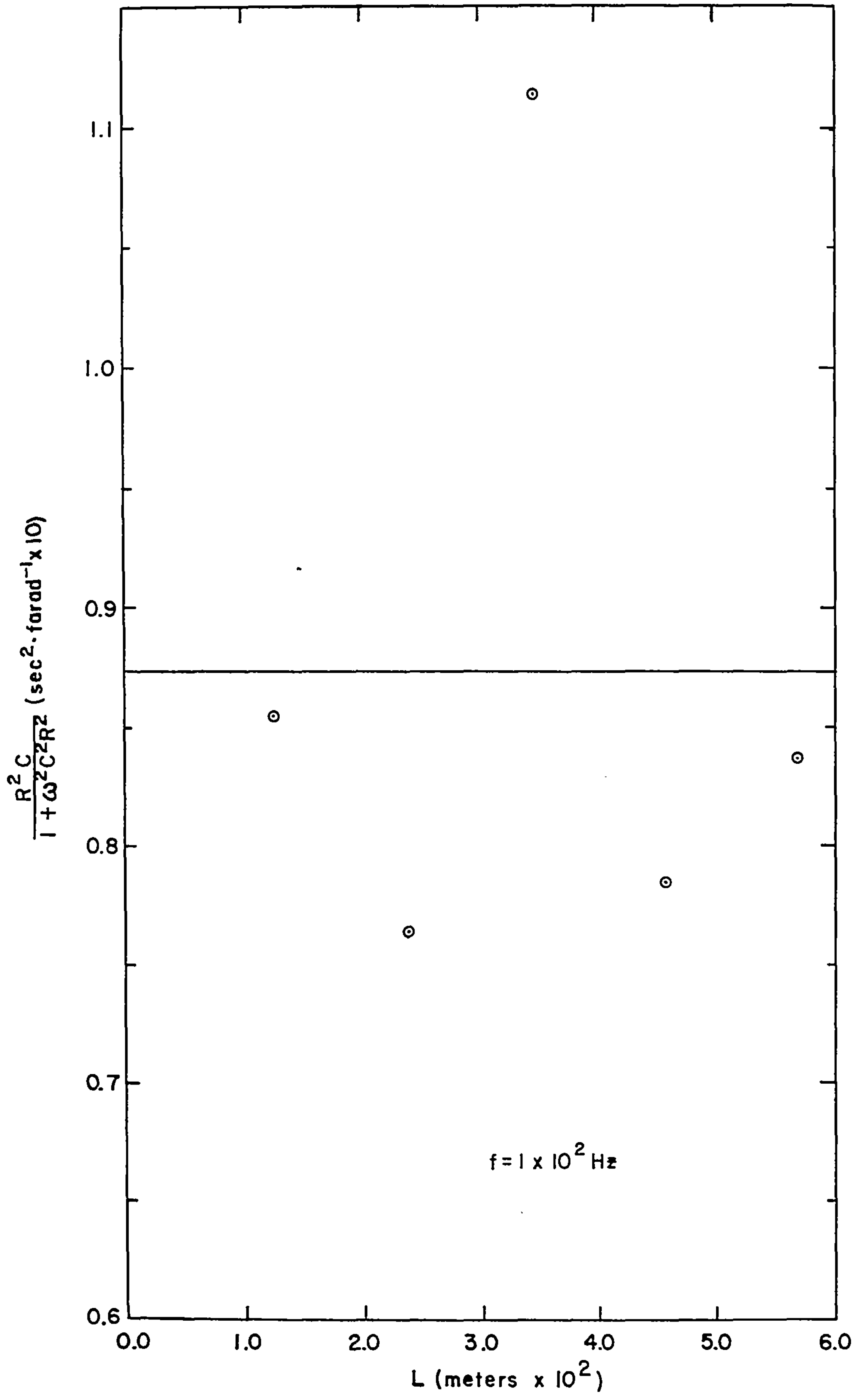

Figure 2.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

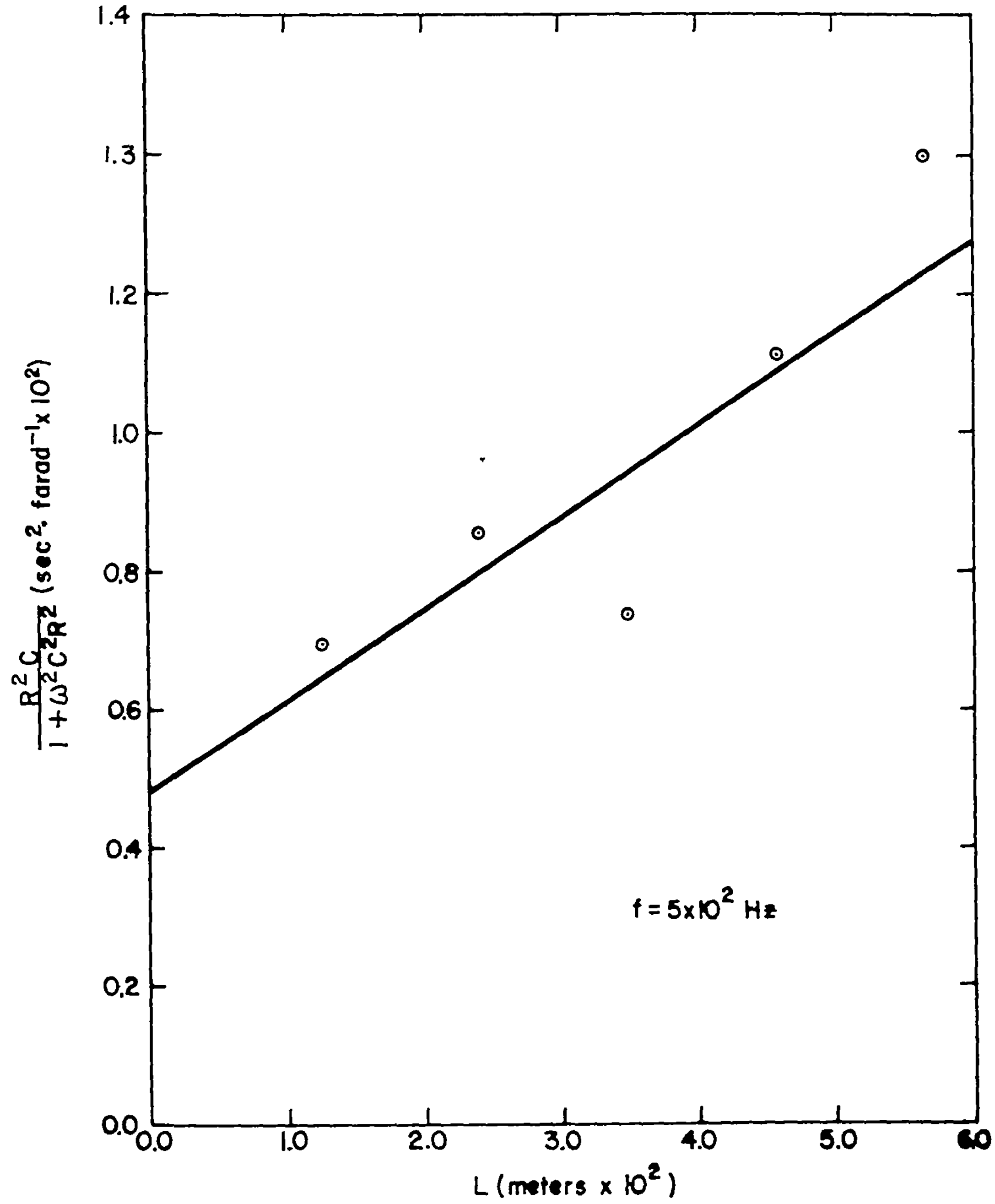

Figure 3.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

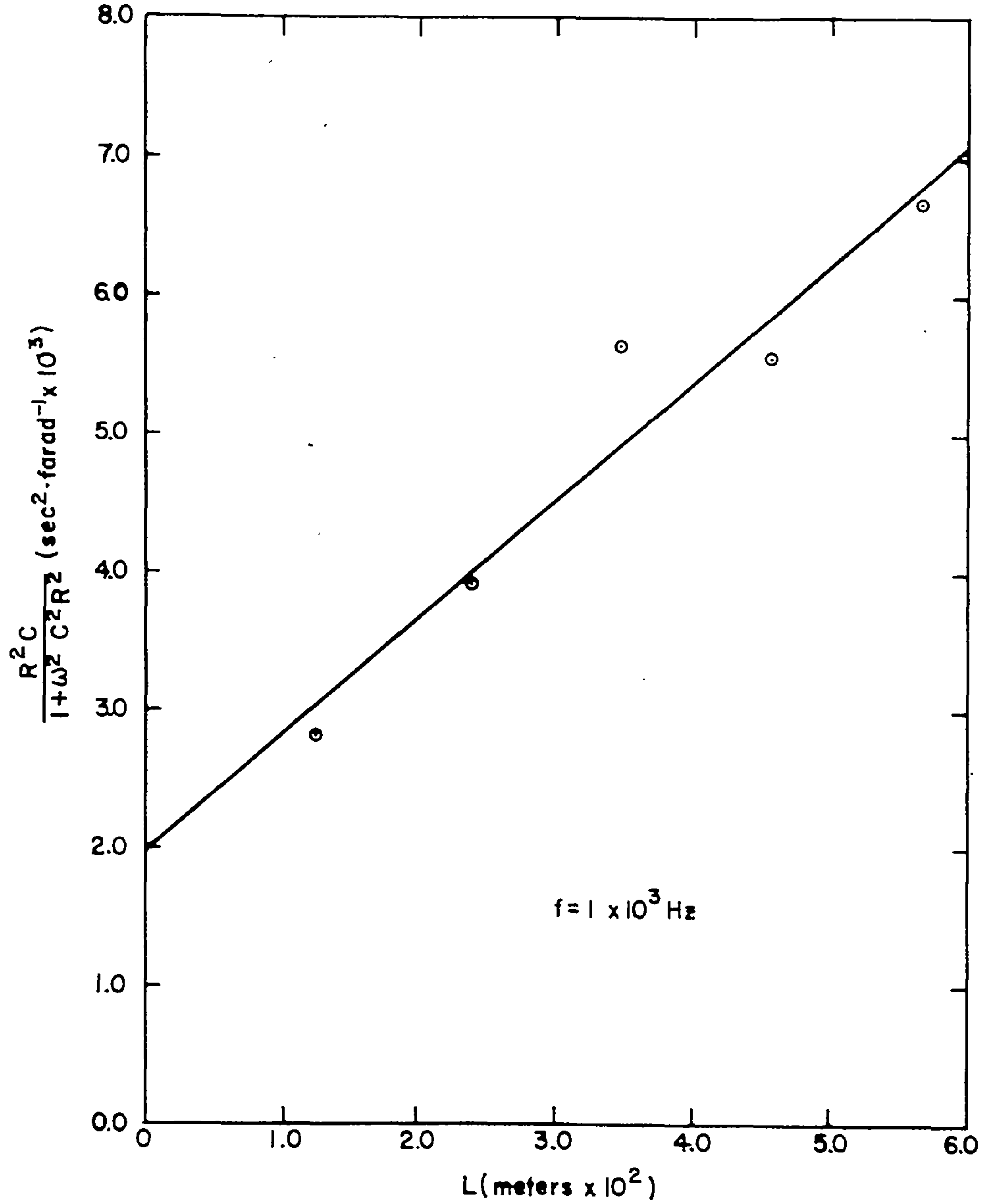

Figure 4.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

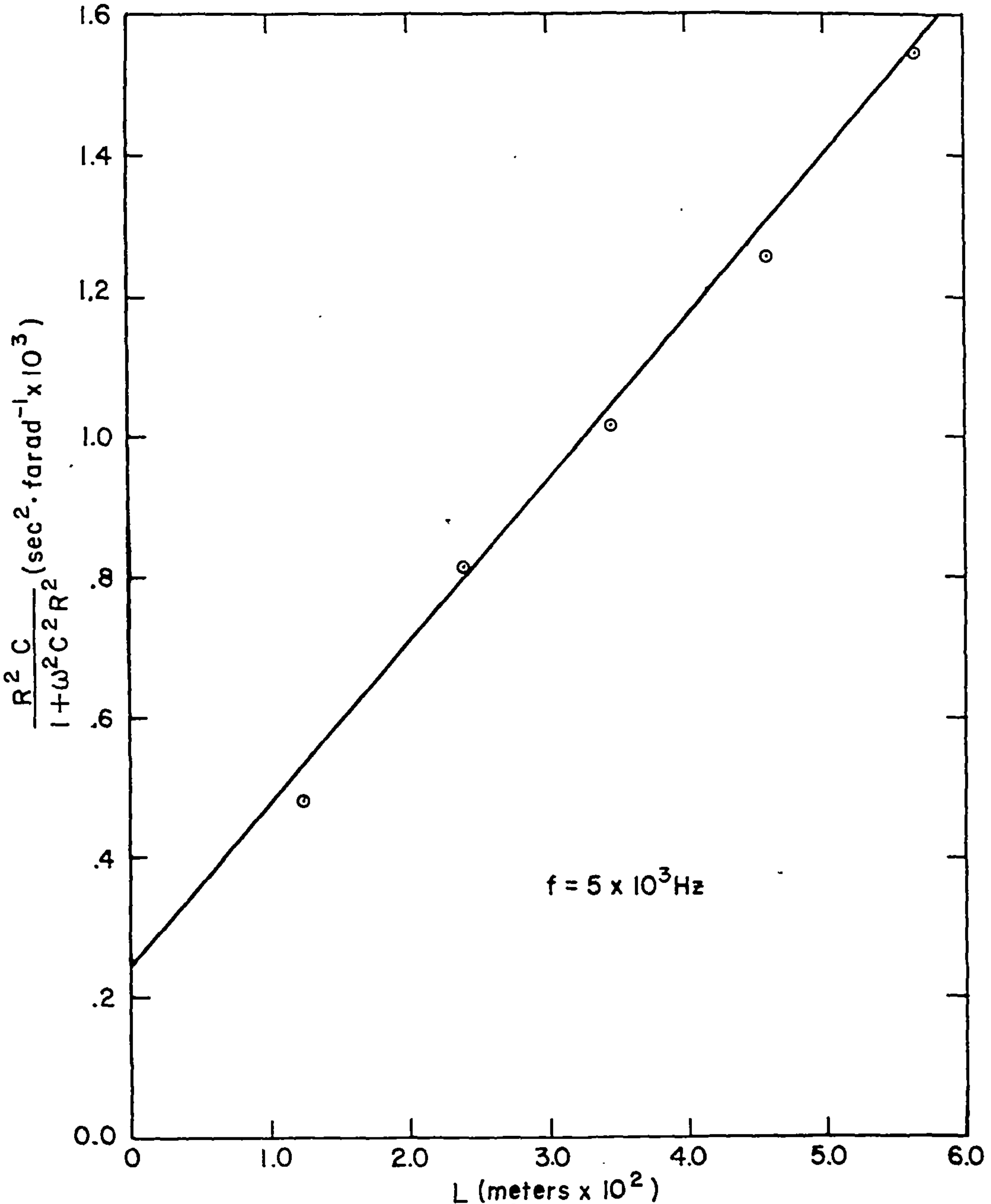

Figure 5.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

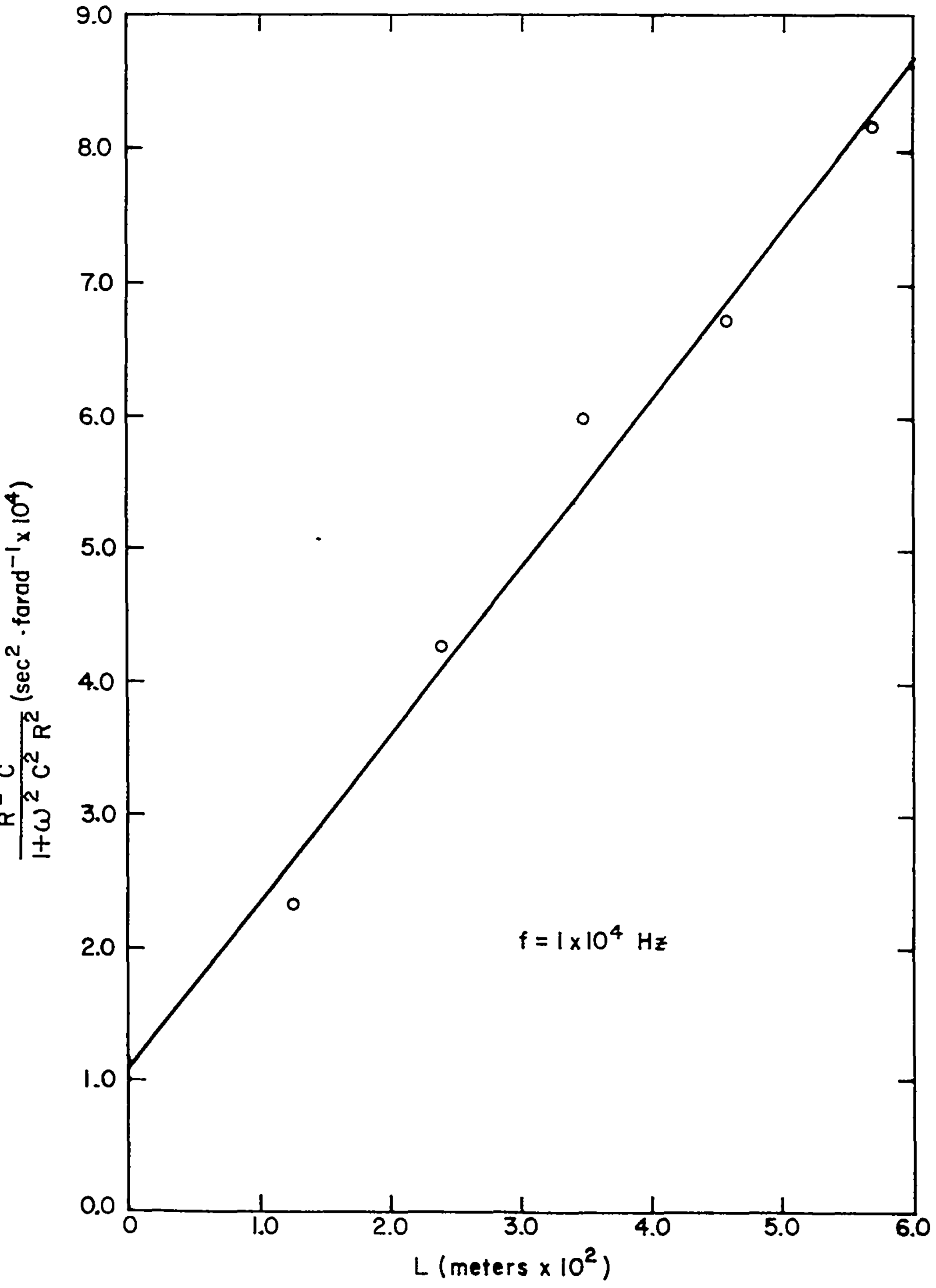

Figure 6.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

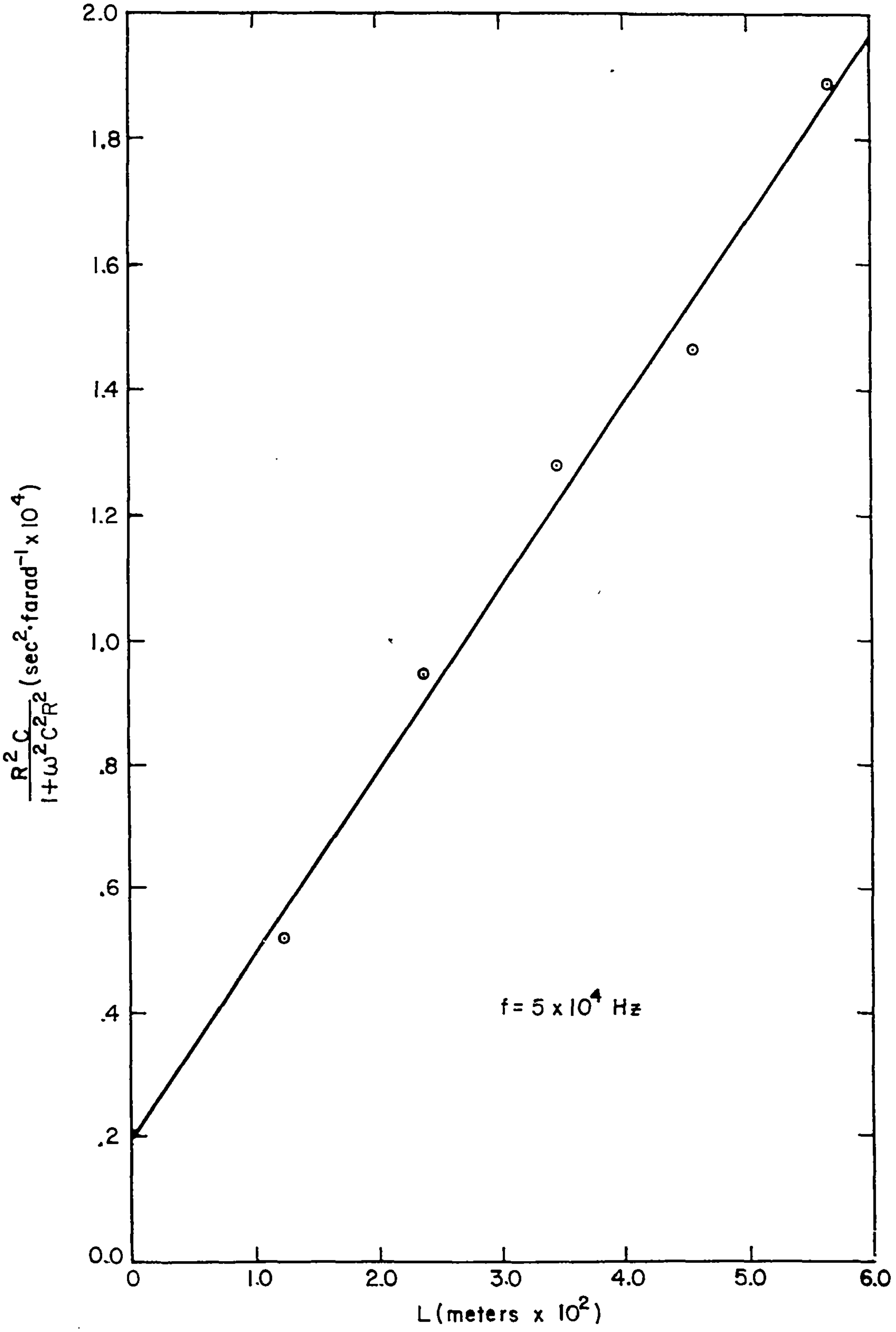

Figure 7.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

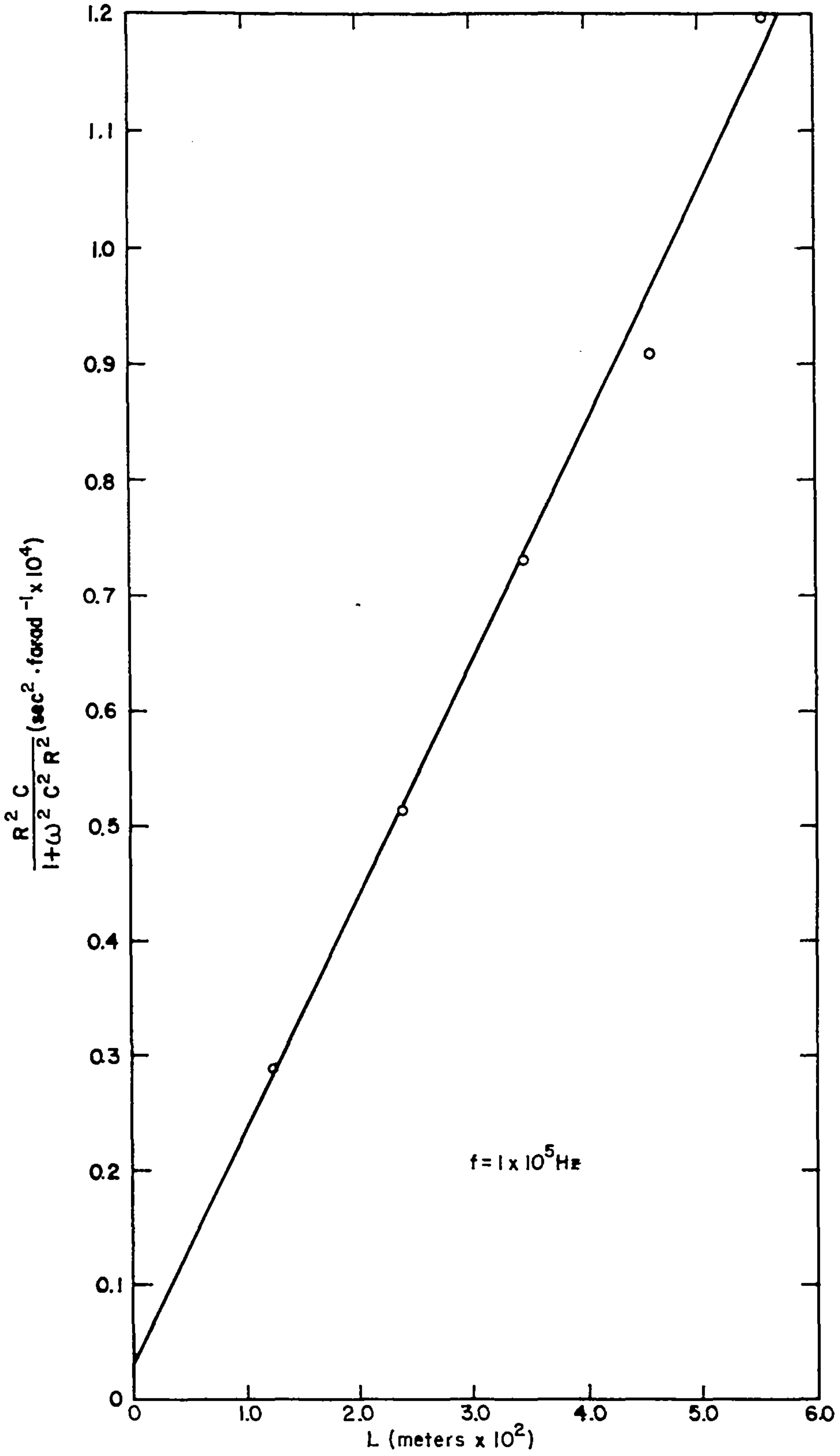

Figure 8.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

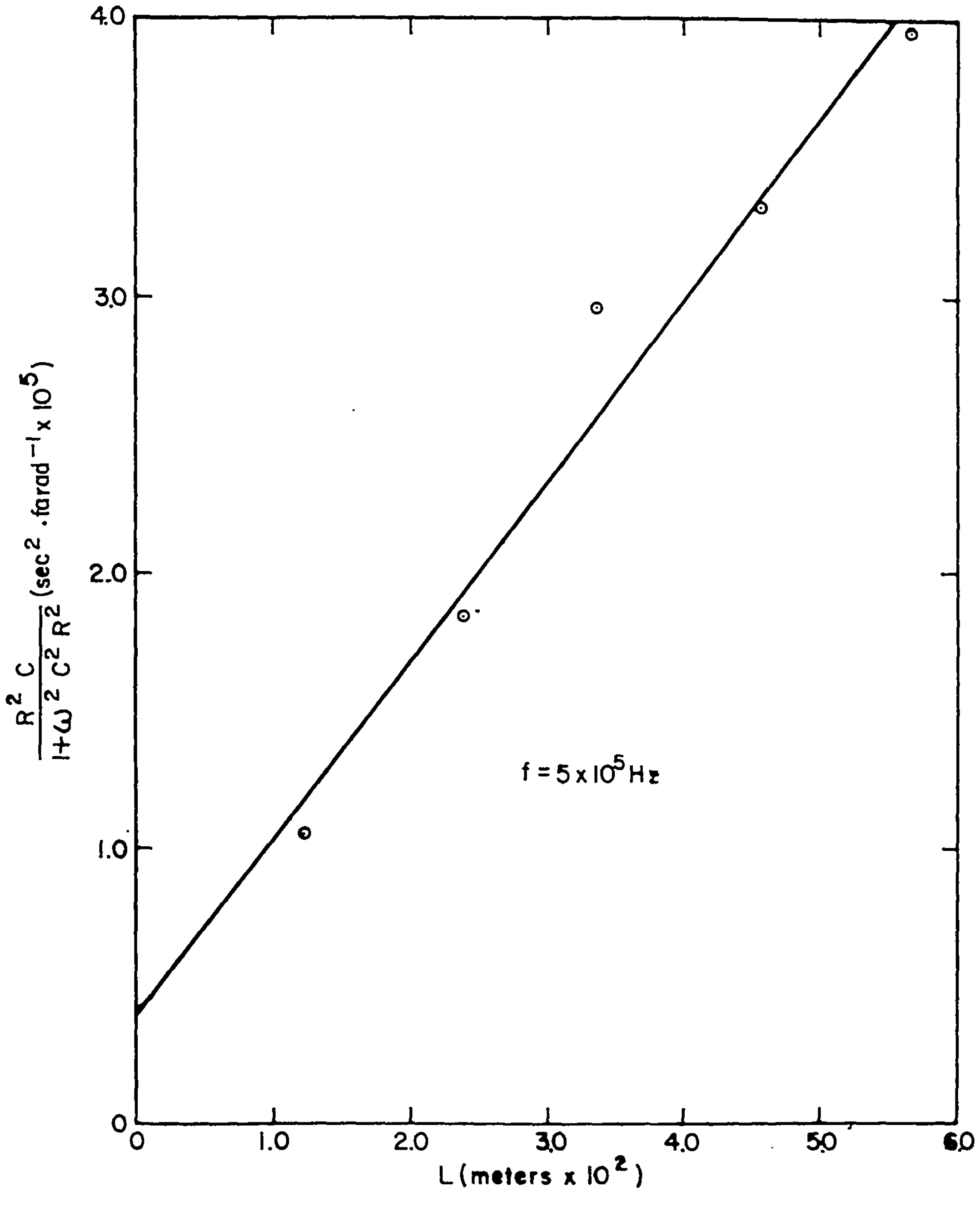

Figure 9.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

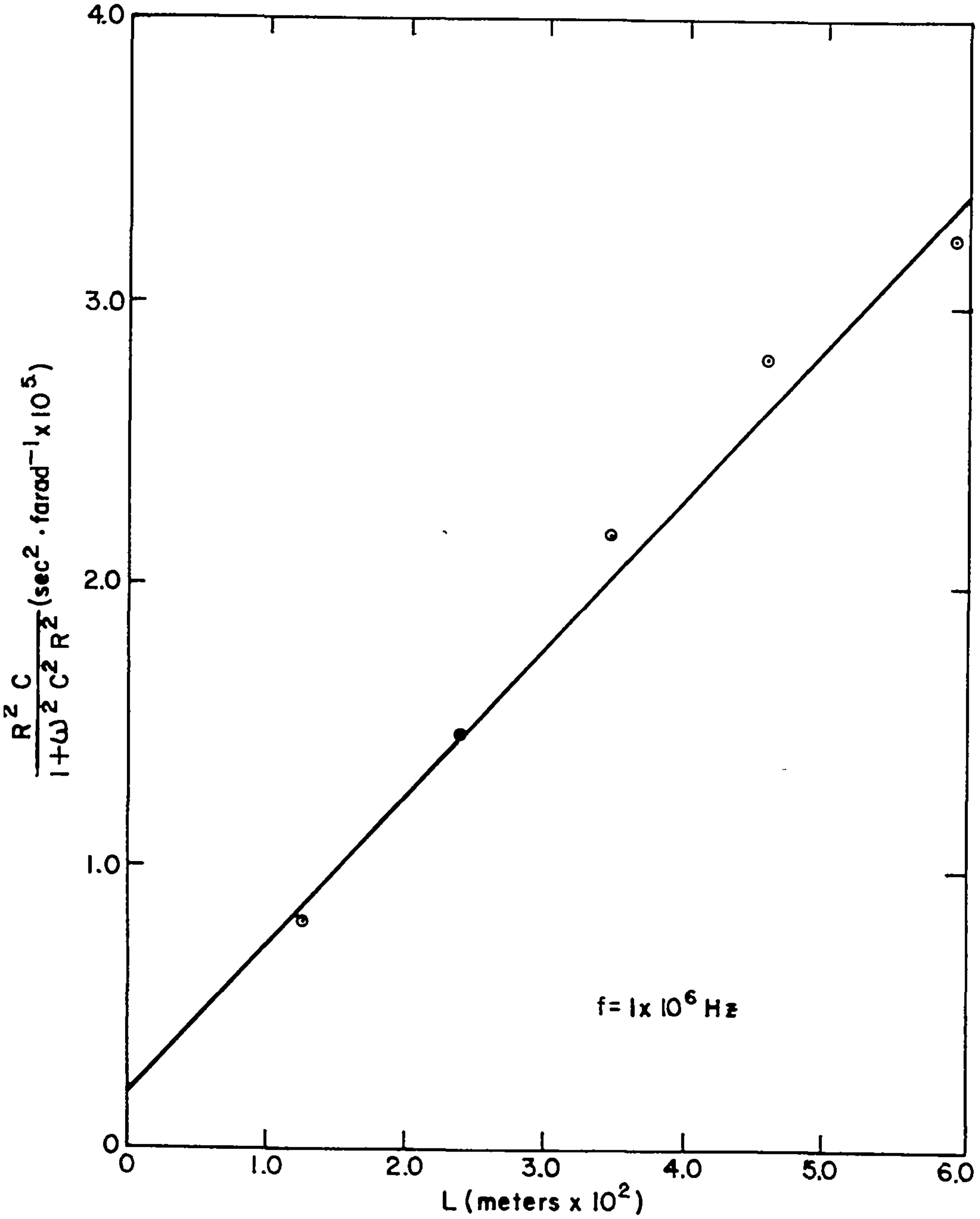

Figure 10.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with polished-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

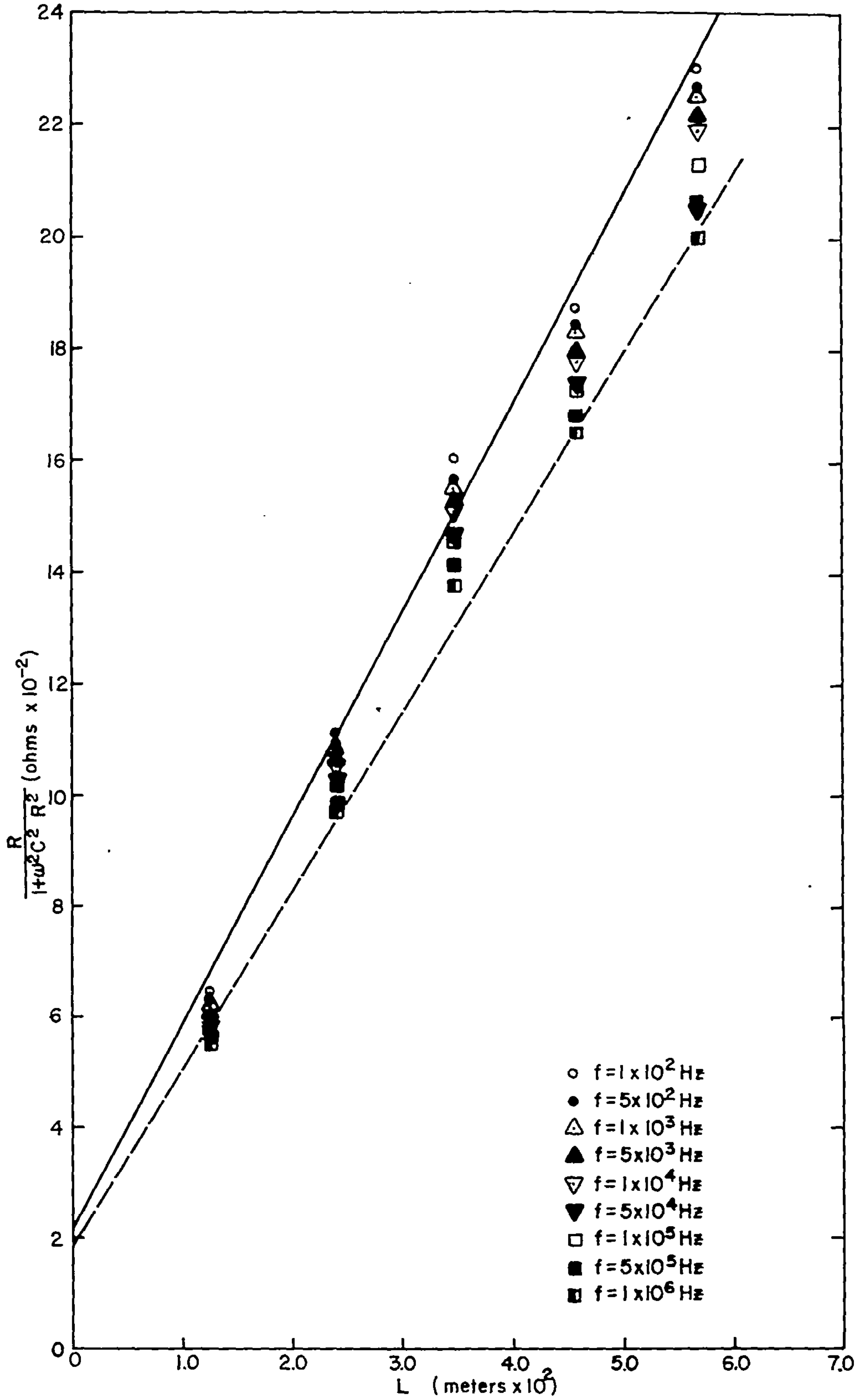

Figure 11.--Values of $R/(1+\omega^2C^2R^2)$ at frequencies 1 x 10^2 to 1 x 10^6 Hz for five sample lengths of the cell with polished-platinum electrodes containing alluvium. The solid and dashed curves were calculated using Equation (9) from data taken at 1 x 10^2 and 1 x 10^6 Hz respectively.

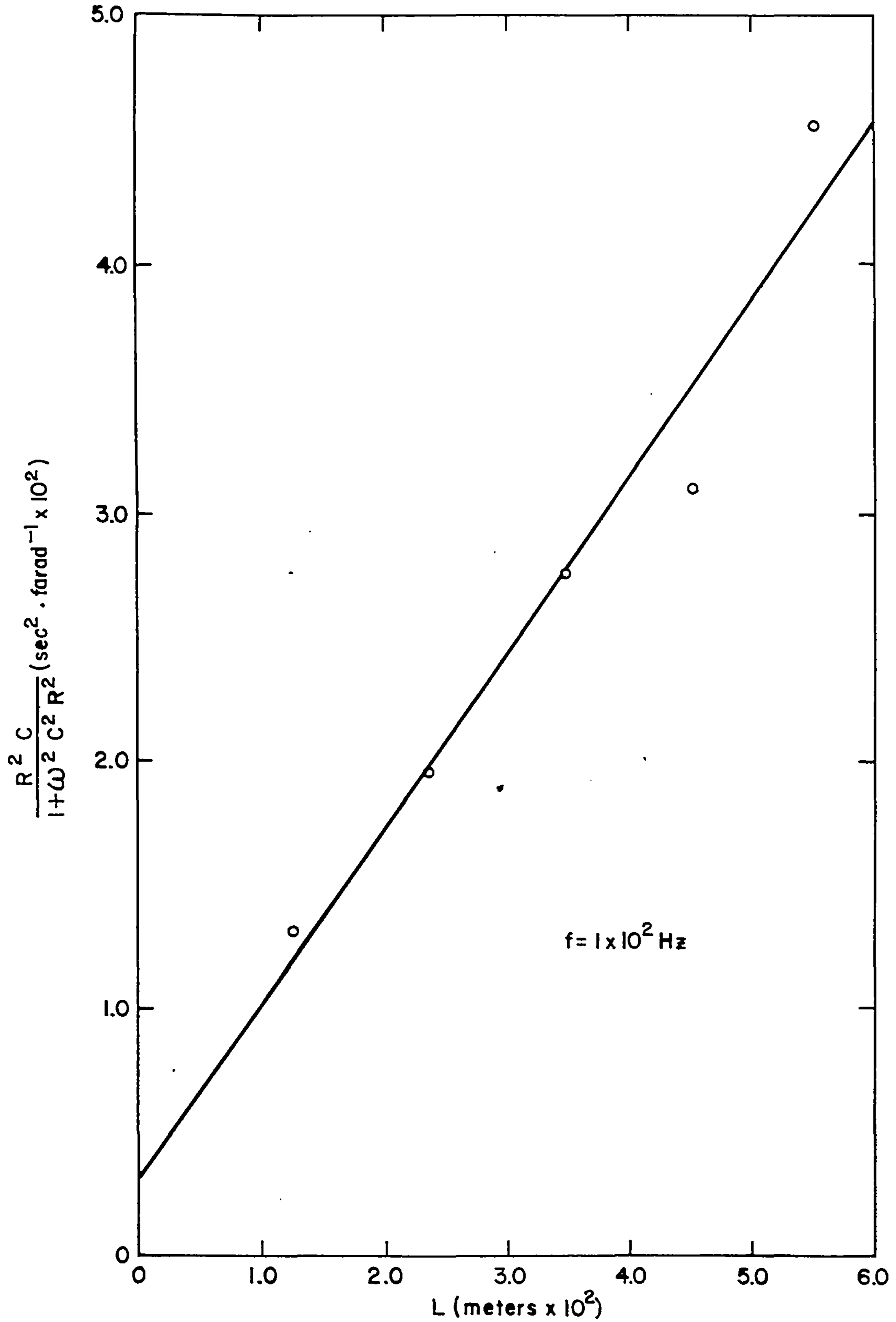

Figure 12.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

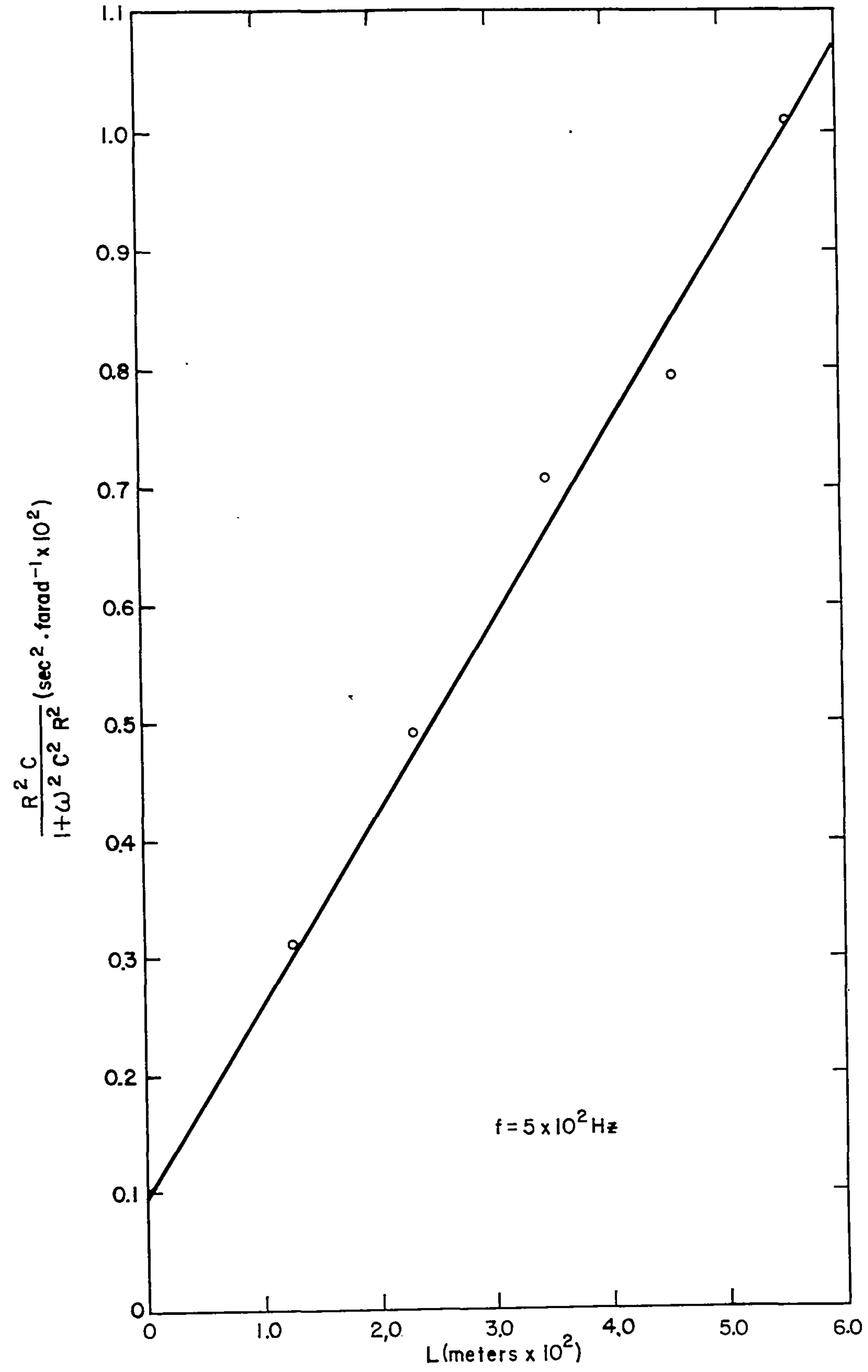

Figure 13.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

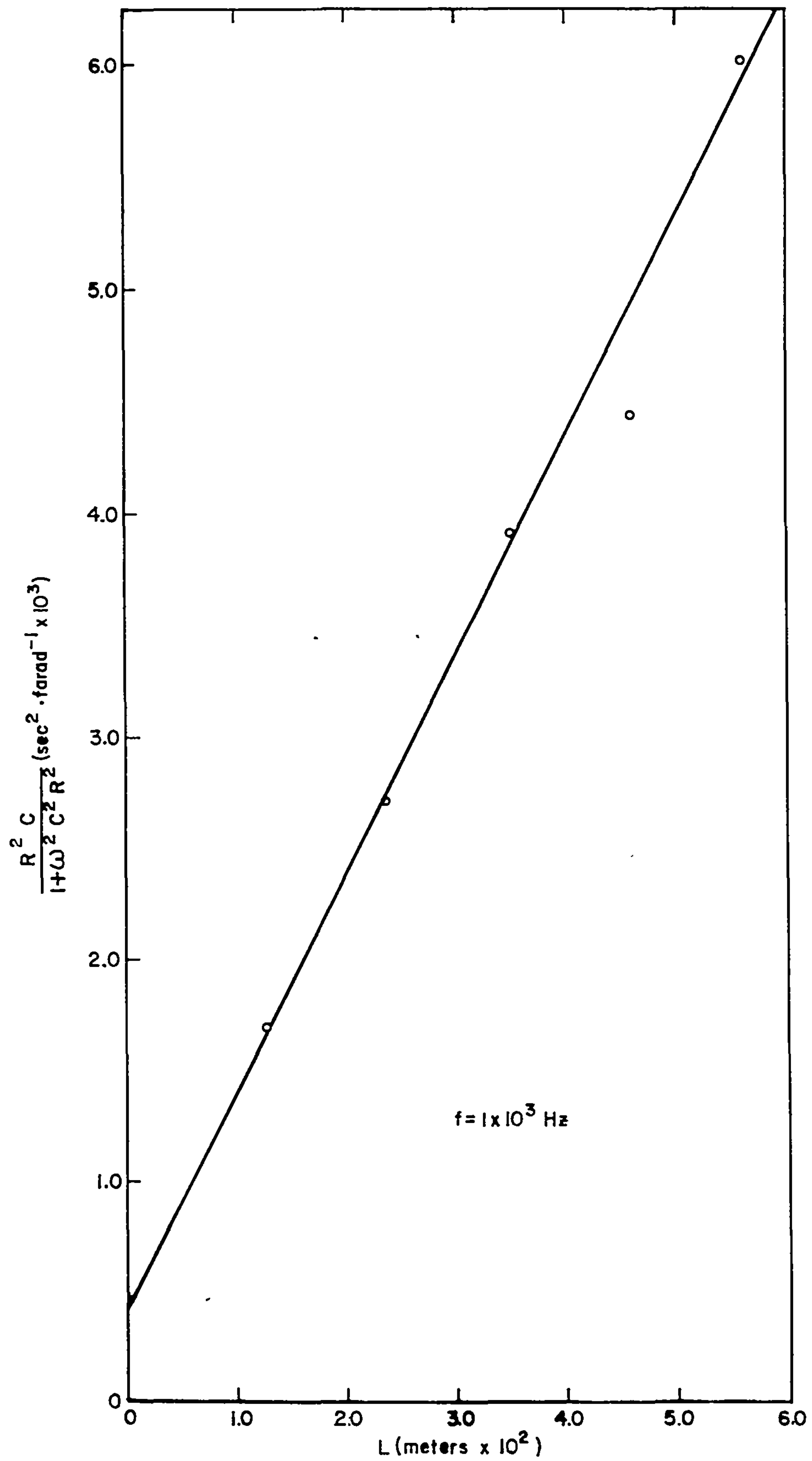

Figure 14.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

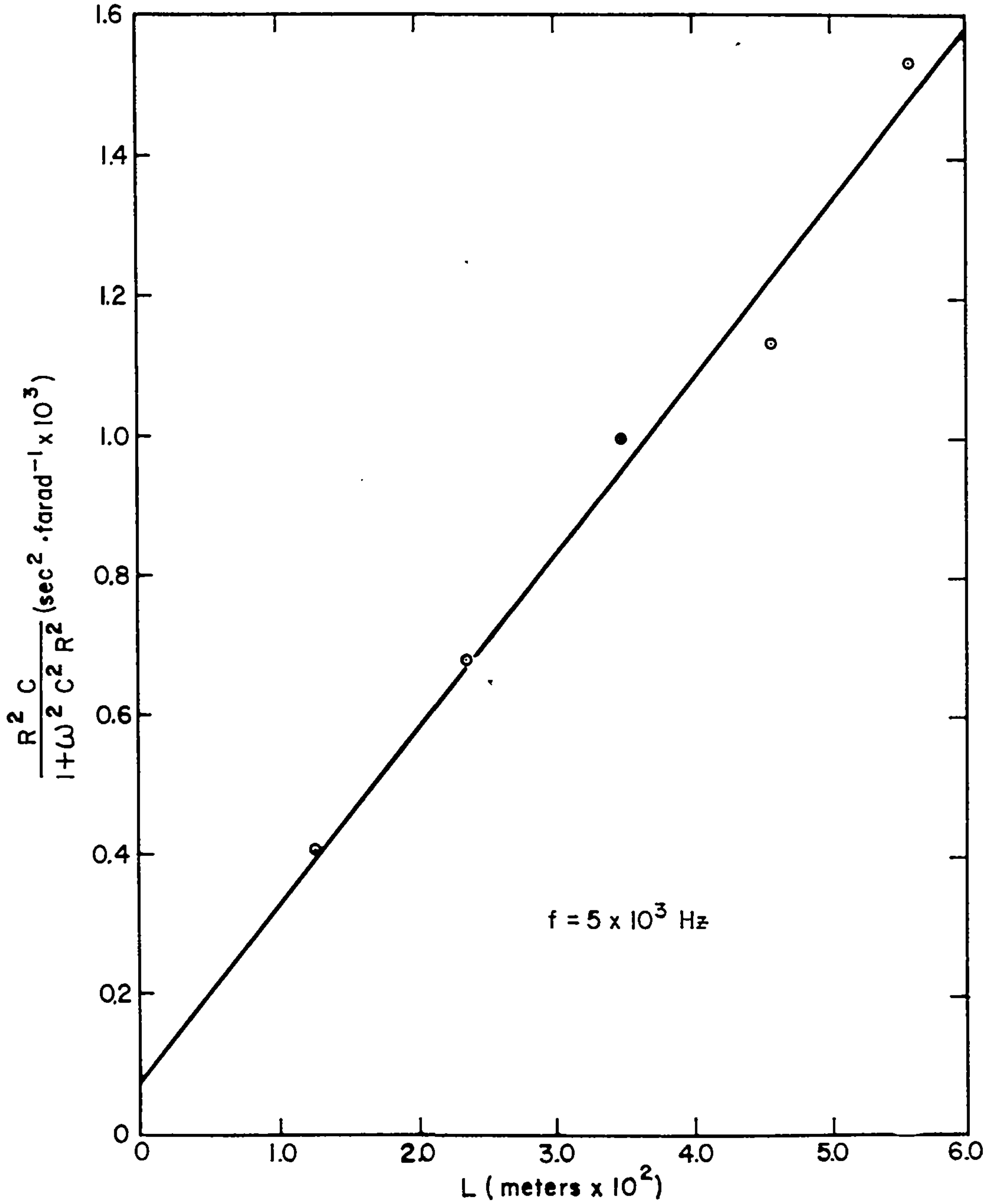

Figure 15.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

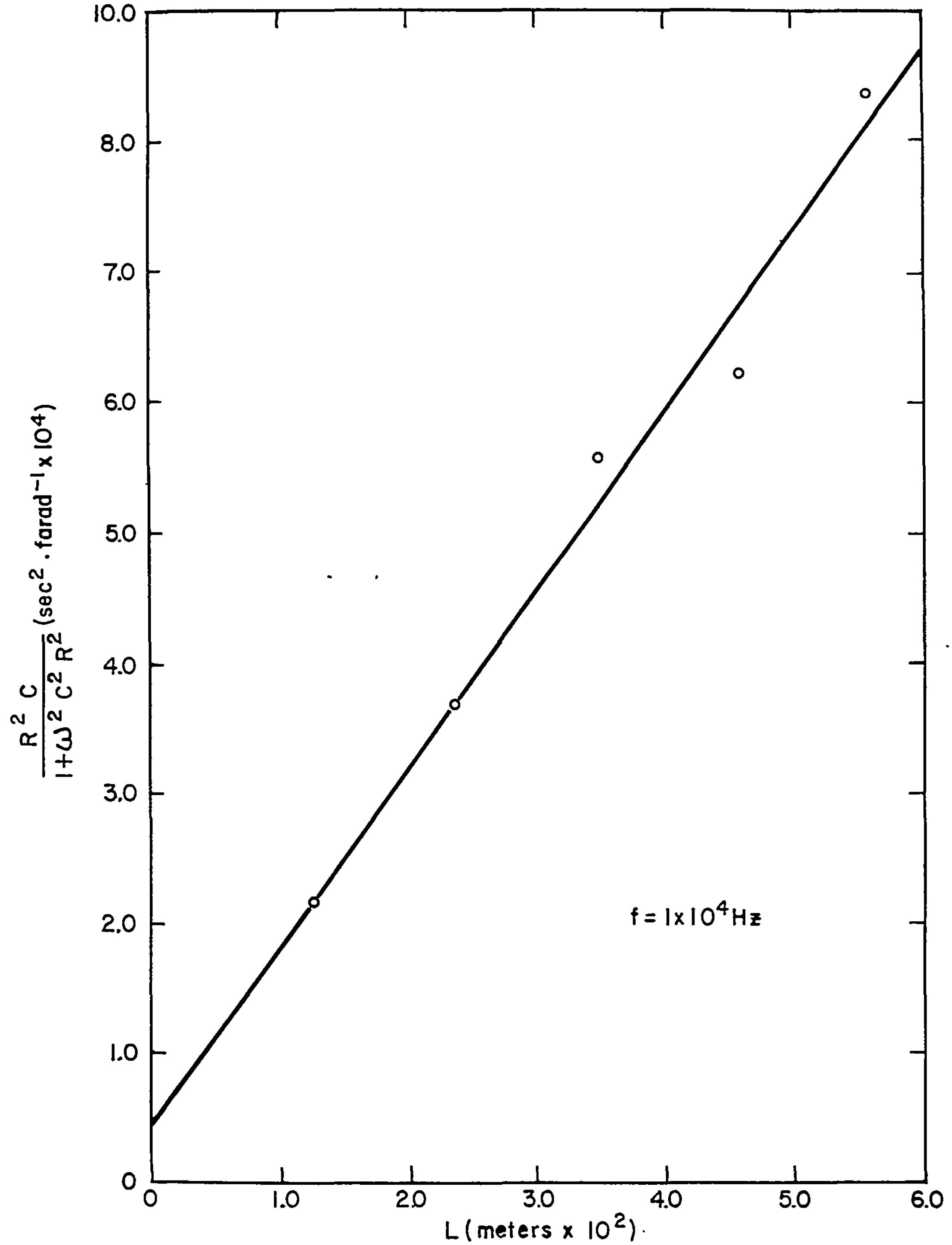

Figure 16.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

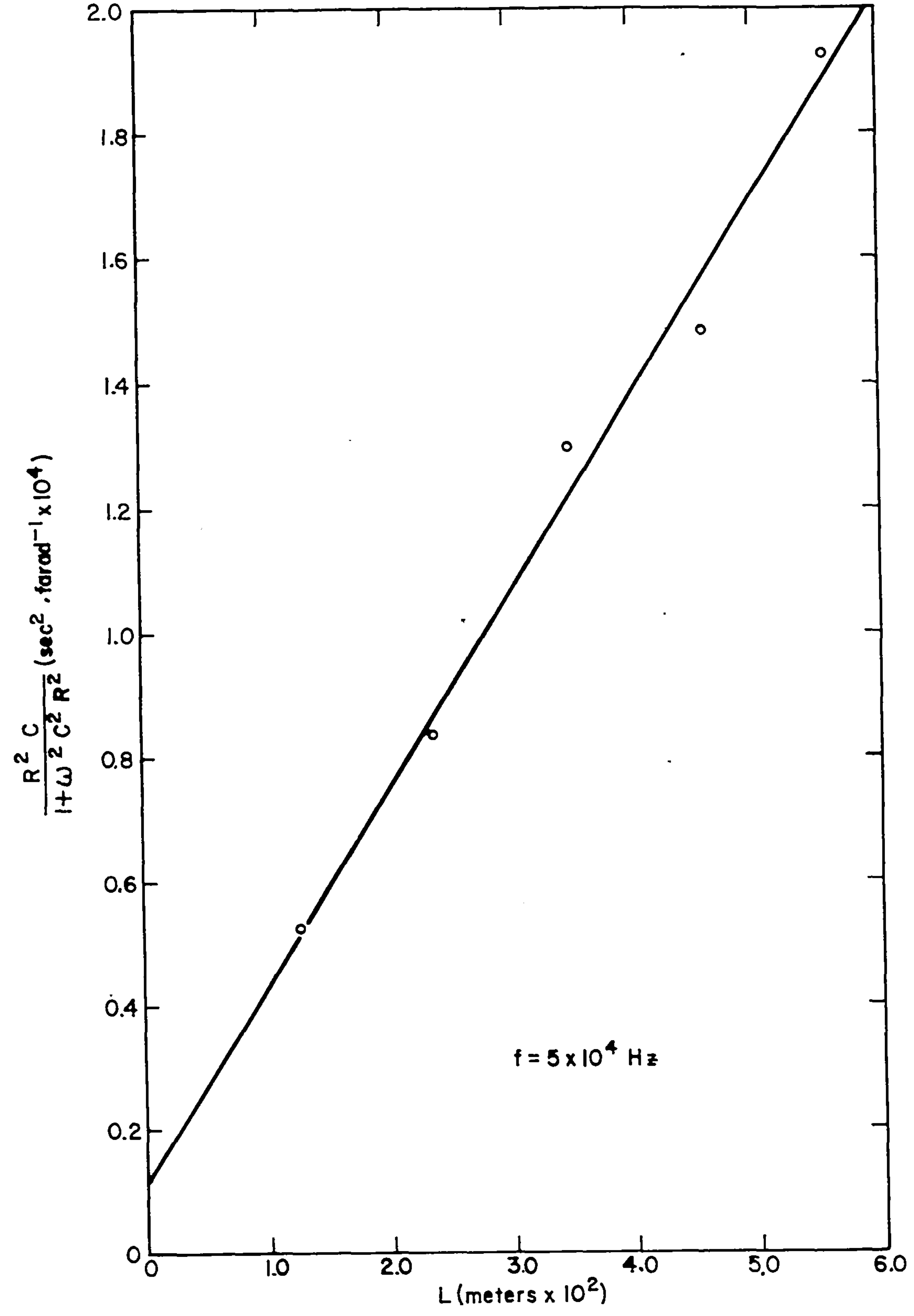

Figure 17.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

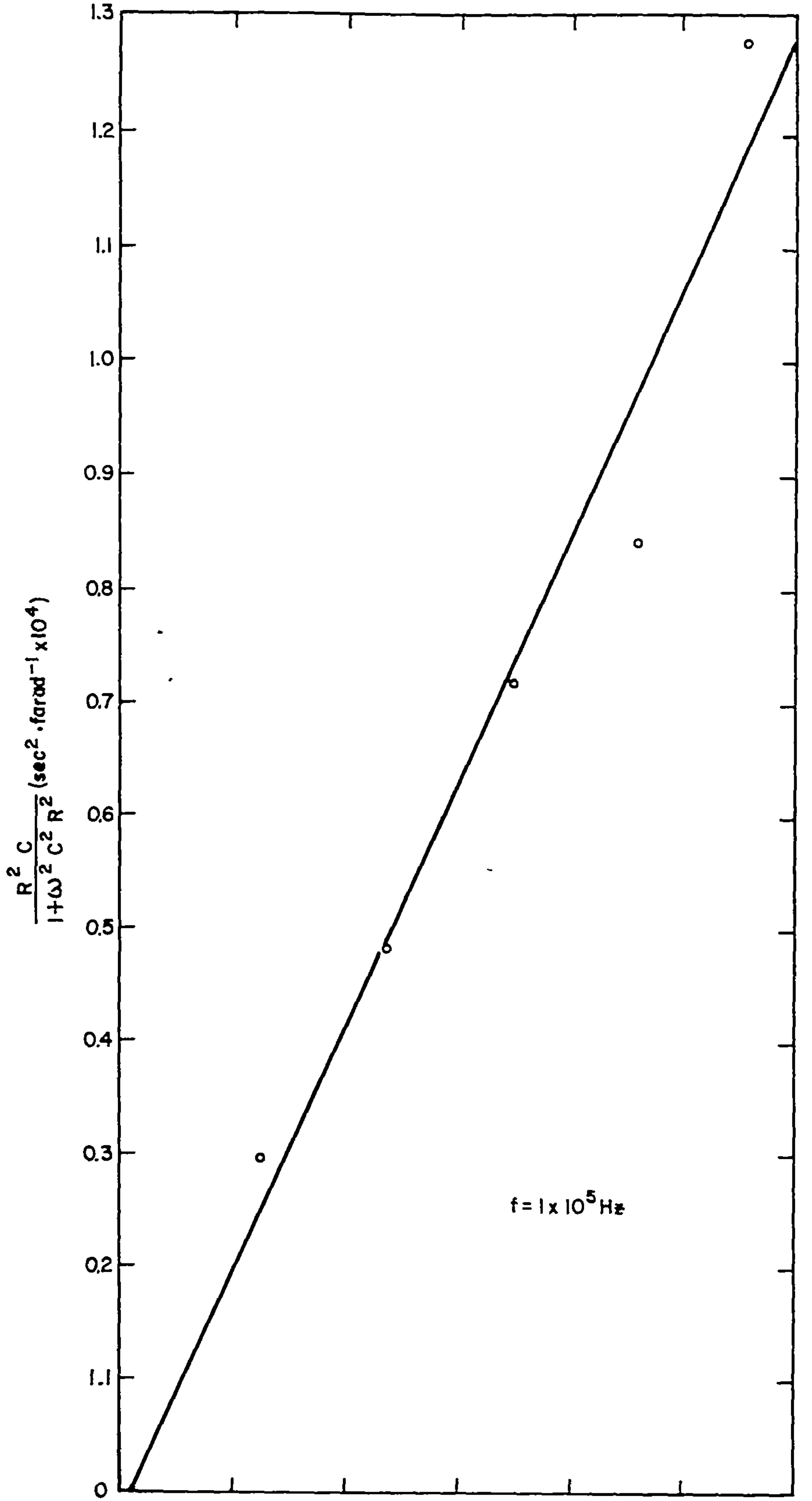

Figure 18.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

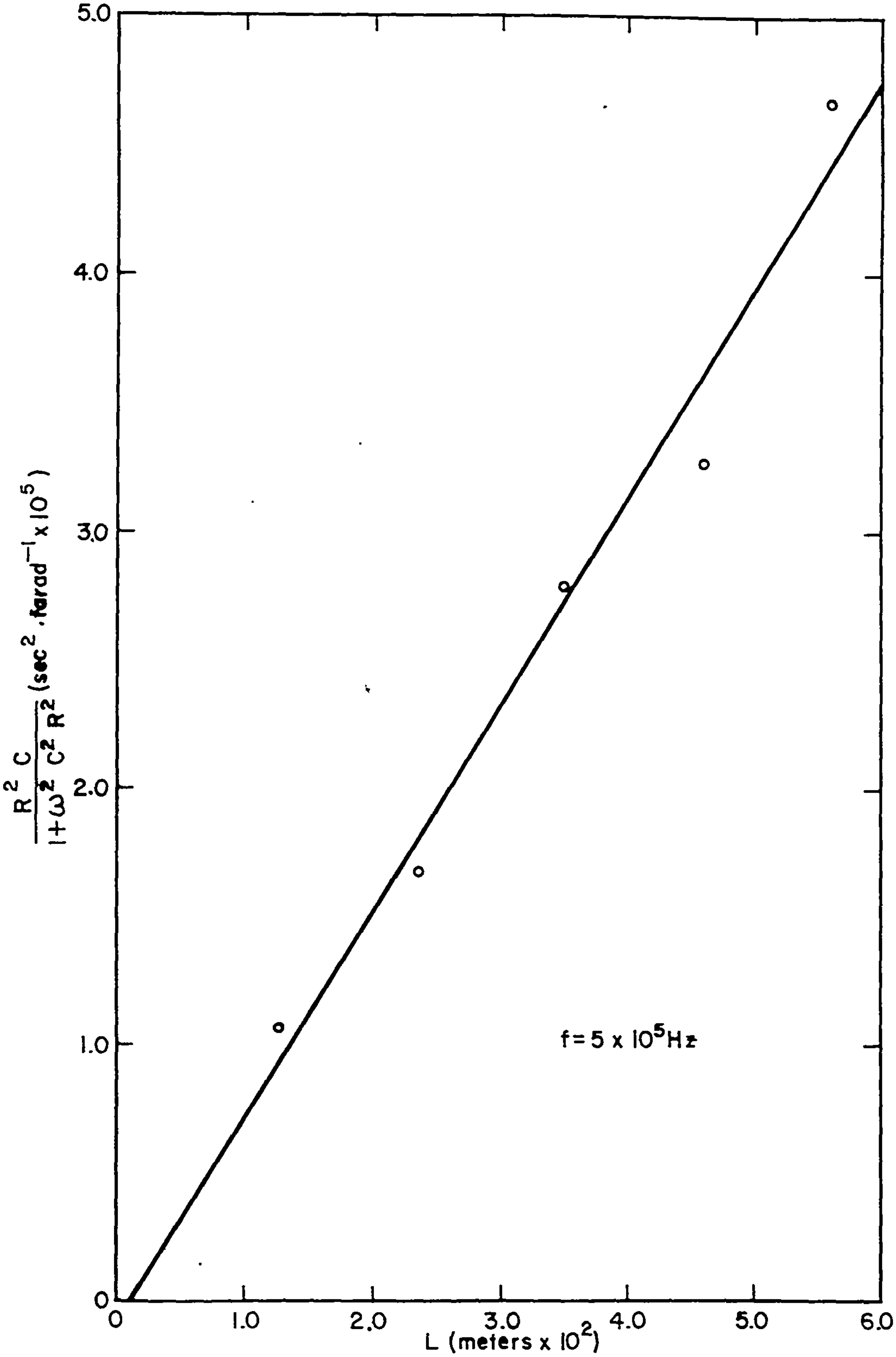

Figure 19.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

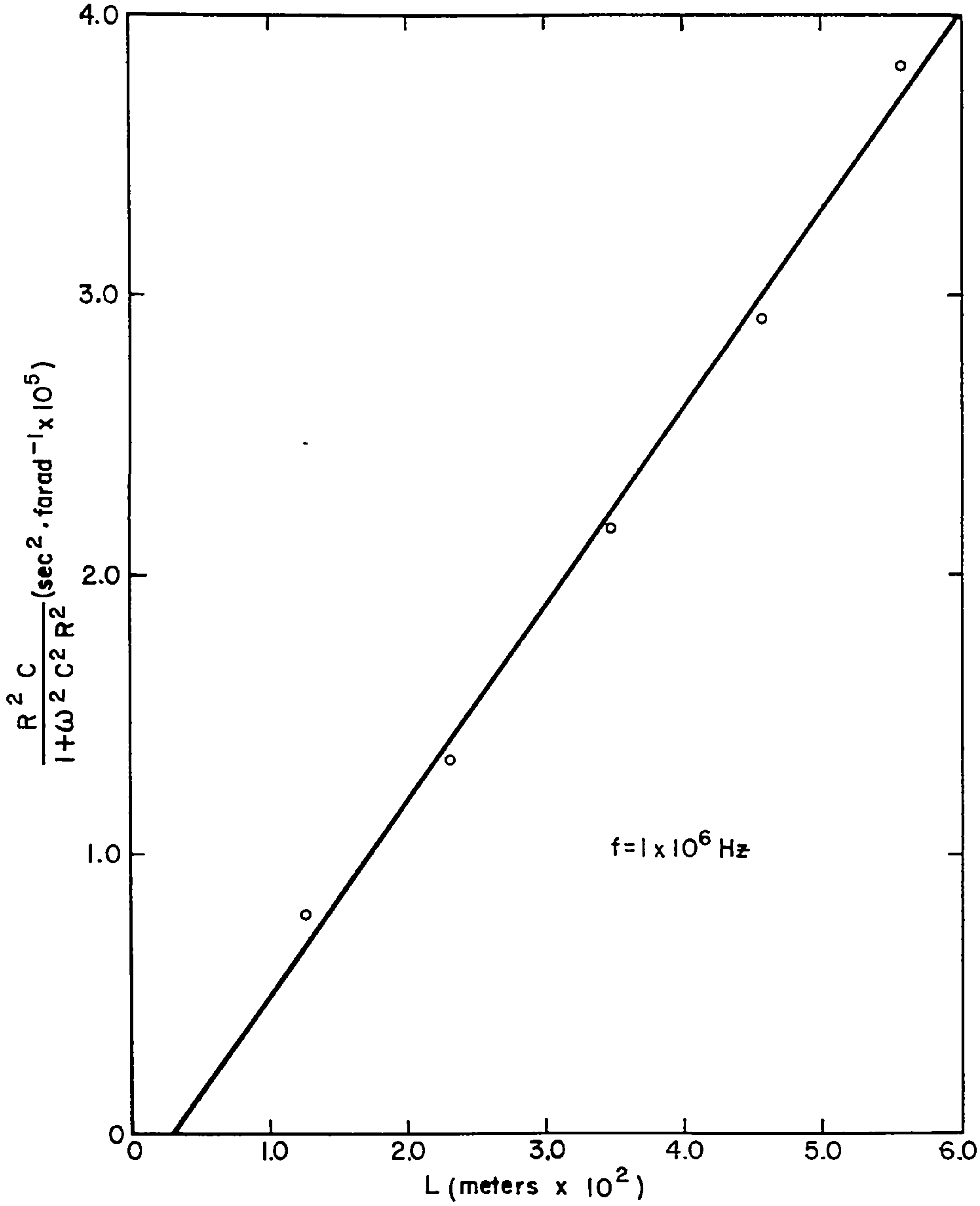

Figure 20.--The quantity $R^2C/(1+\omega^2C^2R^2)$ as a function of the sample length for the cell with platinized-platinum electrodes containing alluvium. The curve was computed by use of Equation (10).

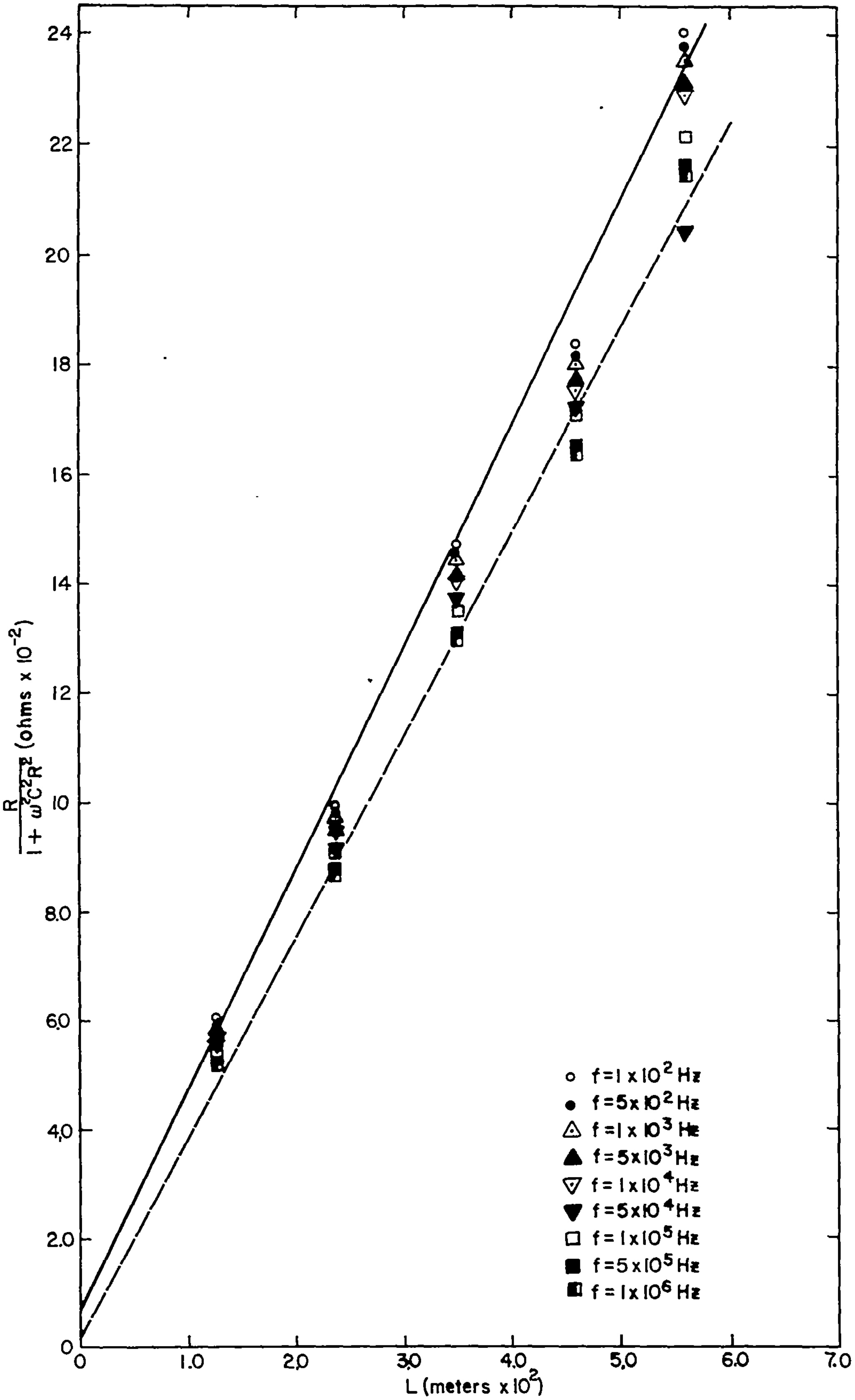

Figure 21.--Values of $R/(1+\omega^2C^2R^2)$ at frequencies 1 x 10^2 to 1 x 10^6 Hz for five sample lengths of the cell with platinized-platinum electrodes containing alluvium. The solid and dashed curves were calculated using equation (9) from data taken at 1 x 10^2 and 1 x 10^6 Hz respectively.

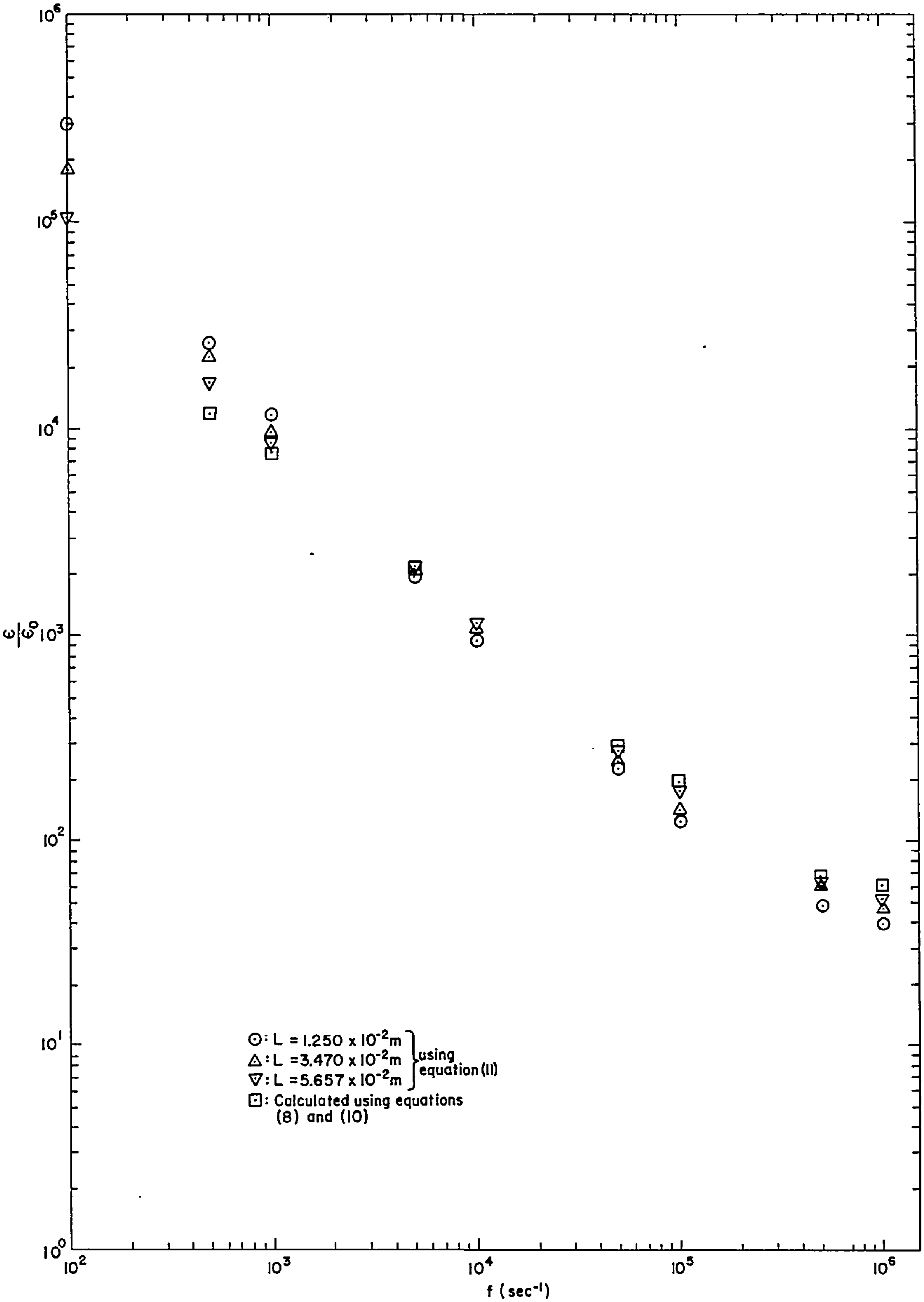

Figure 22.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with polished-platinum electrodes containing alluvium.

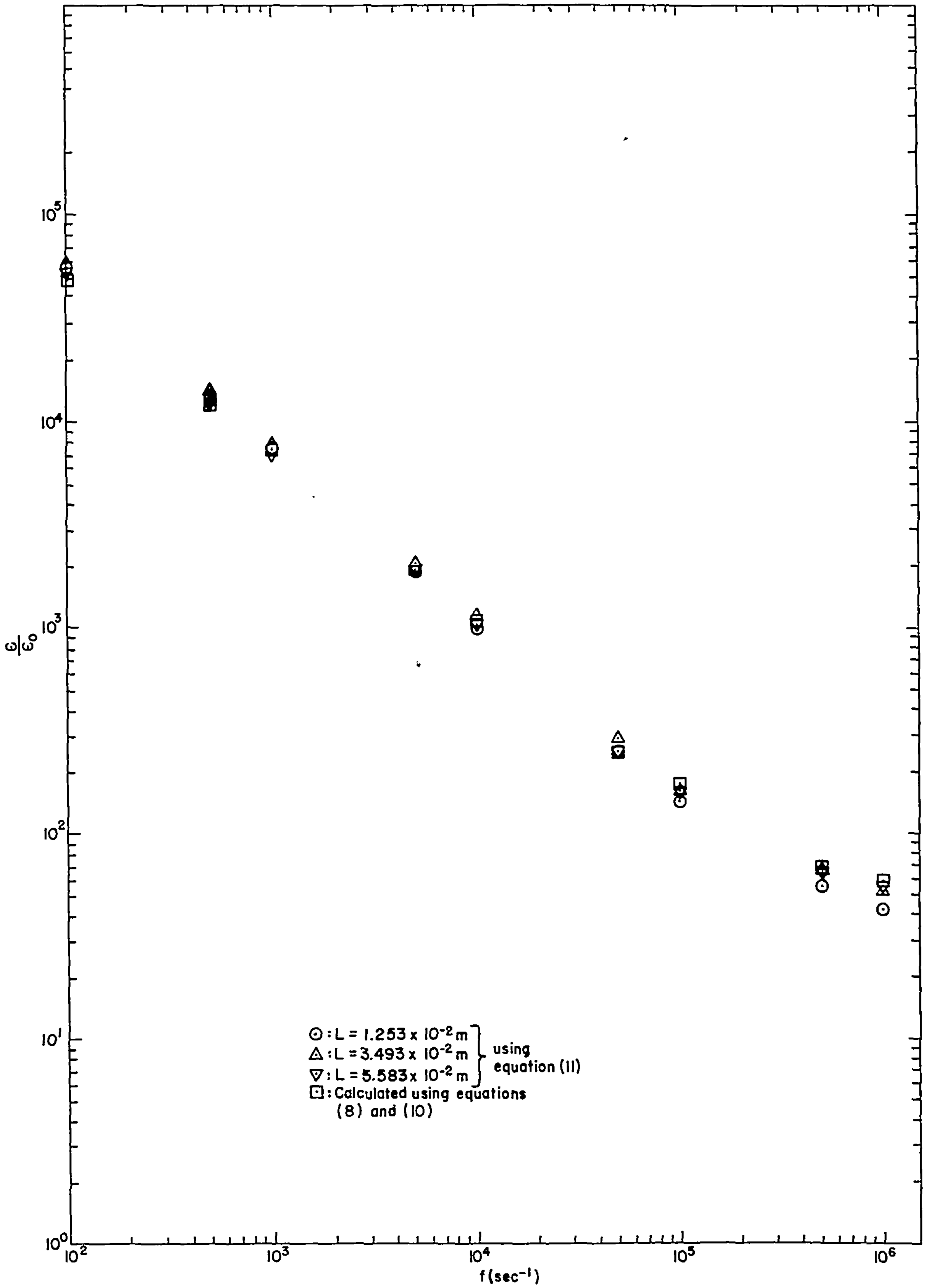

Figure 23.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with platinized-platinum electrodes containing alluvium.

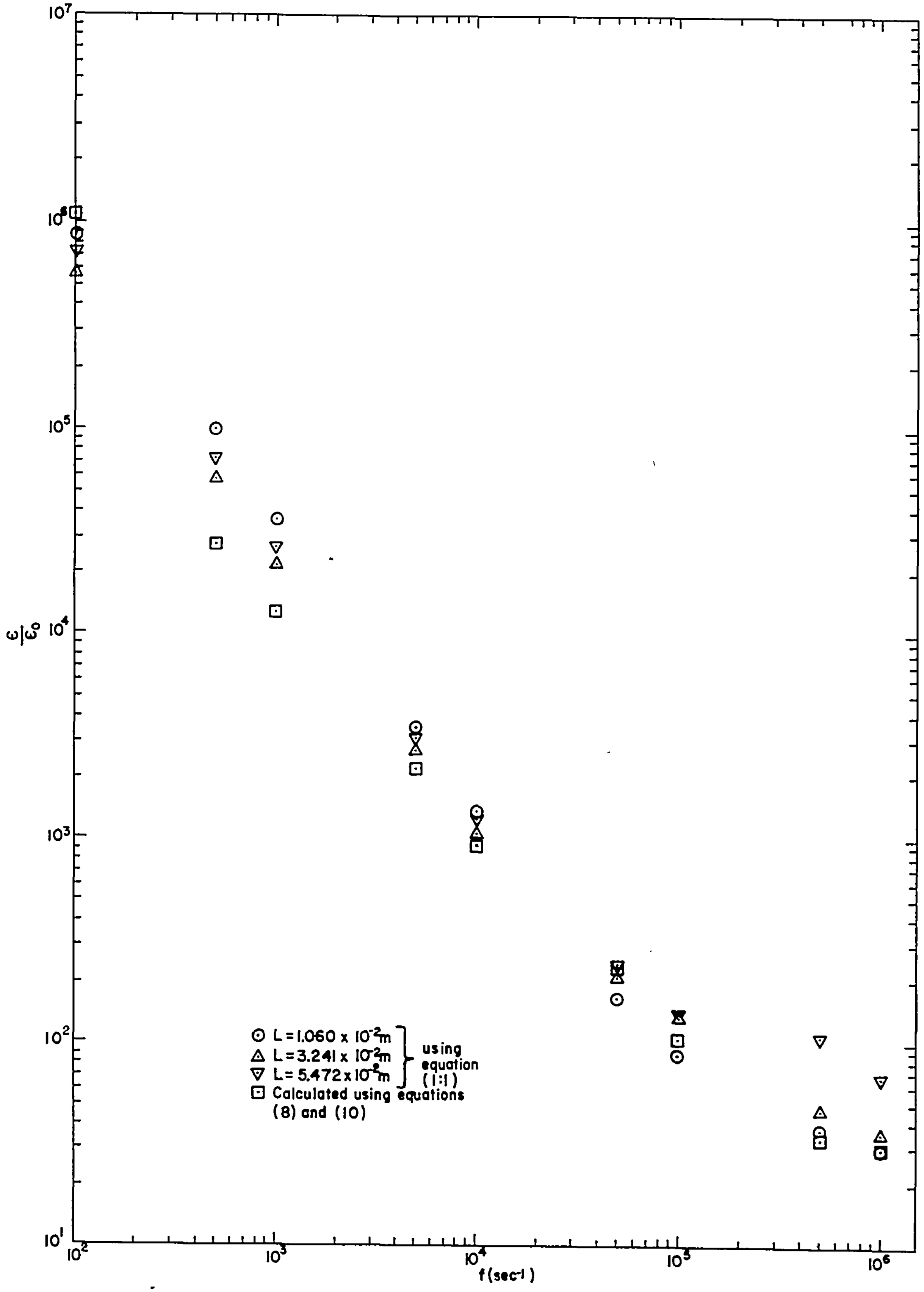

Figure 24.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with polished-platinum electrodes containing topsoil.

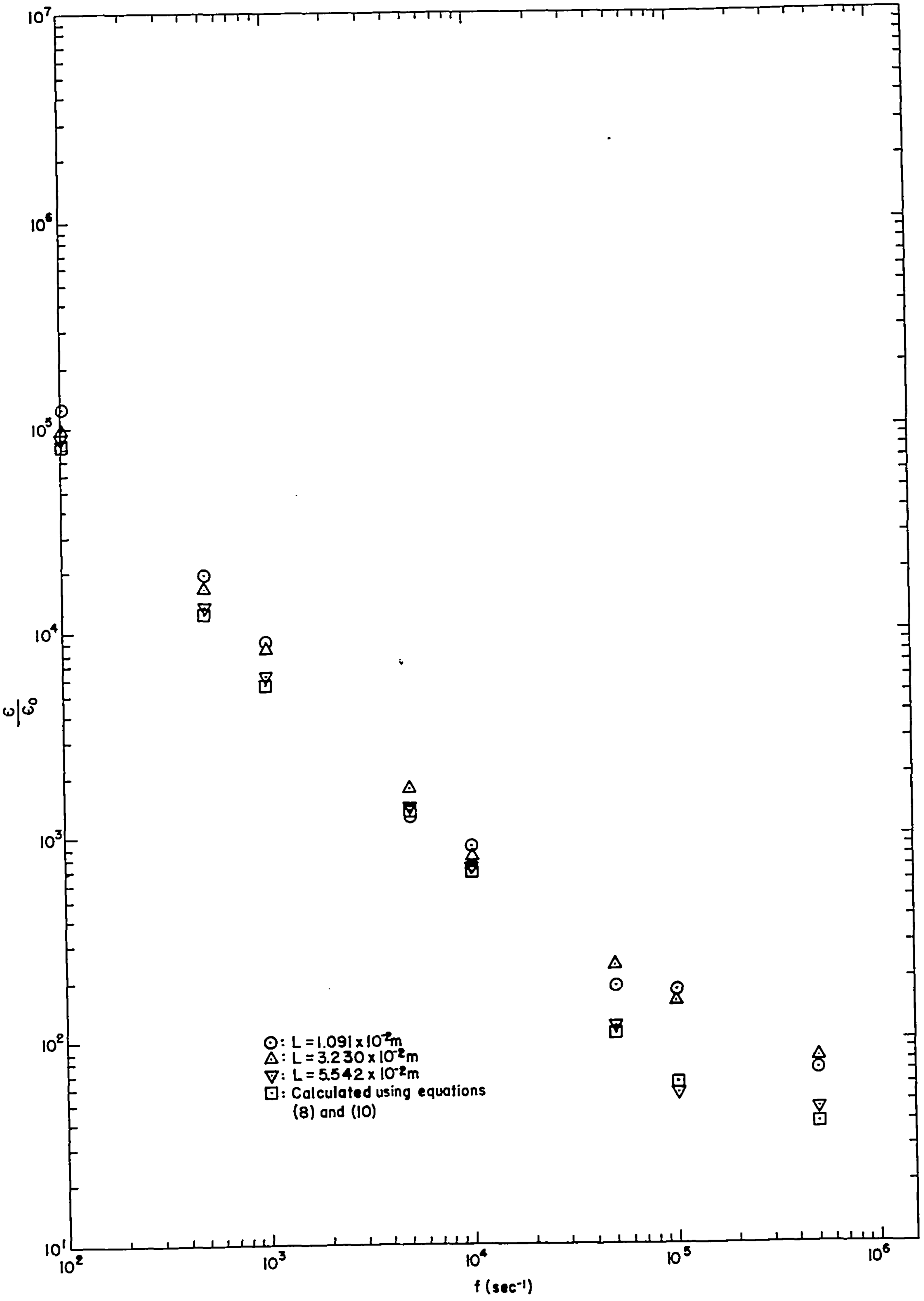

Figure 25.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with platinized-platinum electrodes containing topsoil.

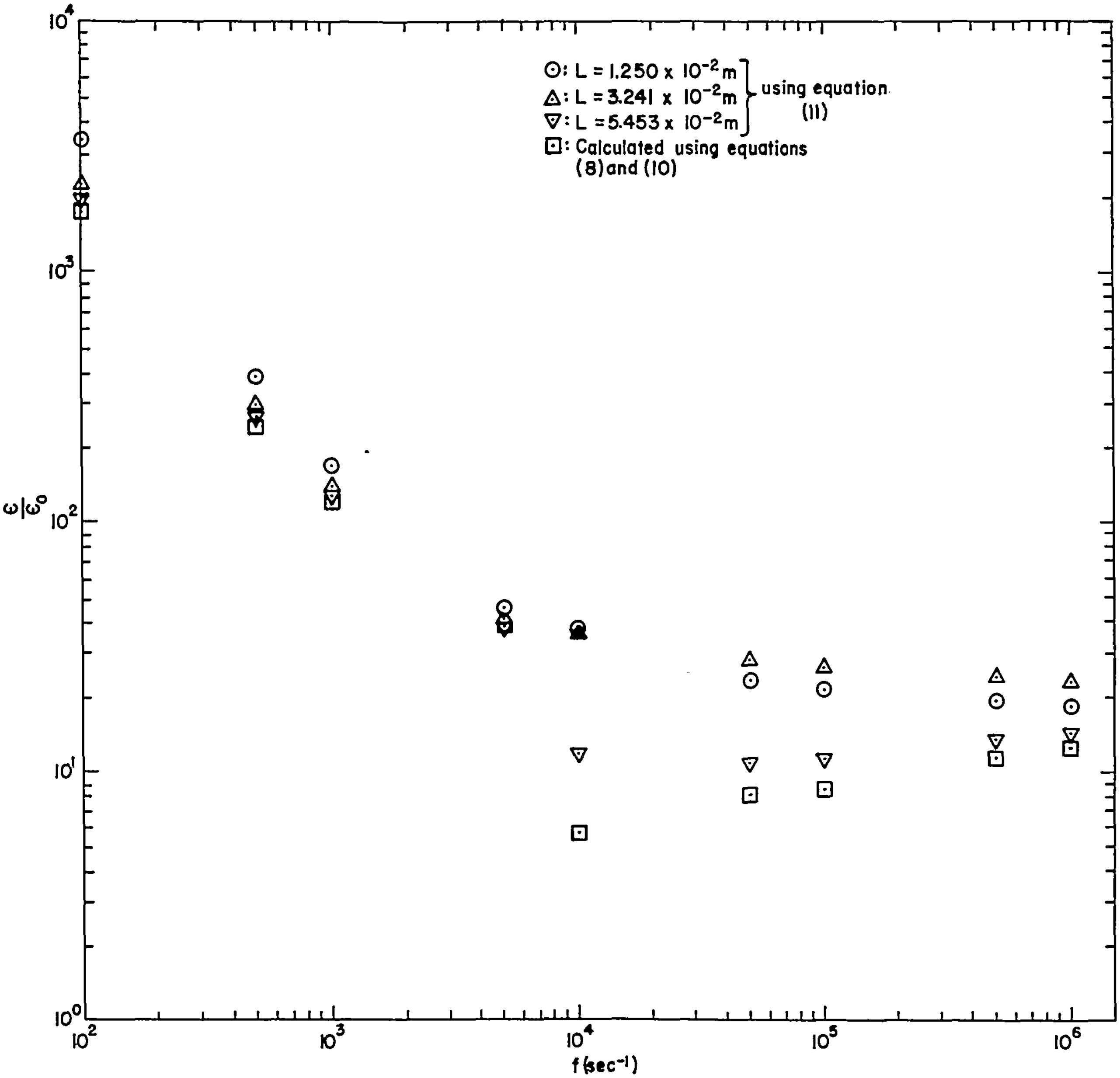

Figure 26.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with polished-platinum electrodes containing quartz with 10^{-3} N NaCl.

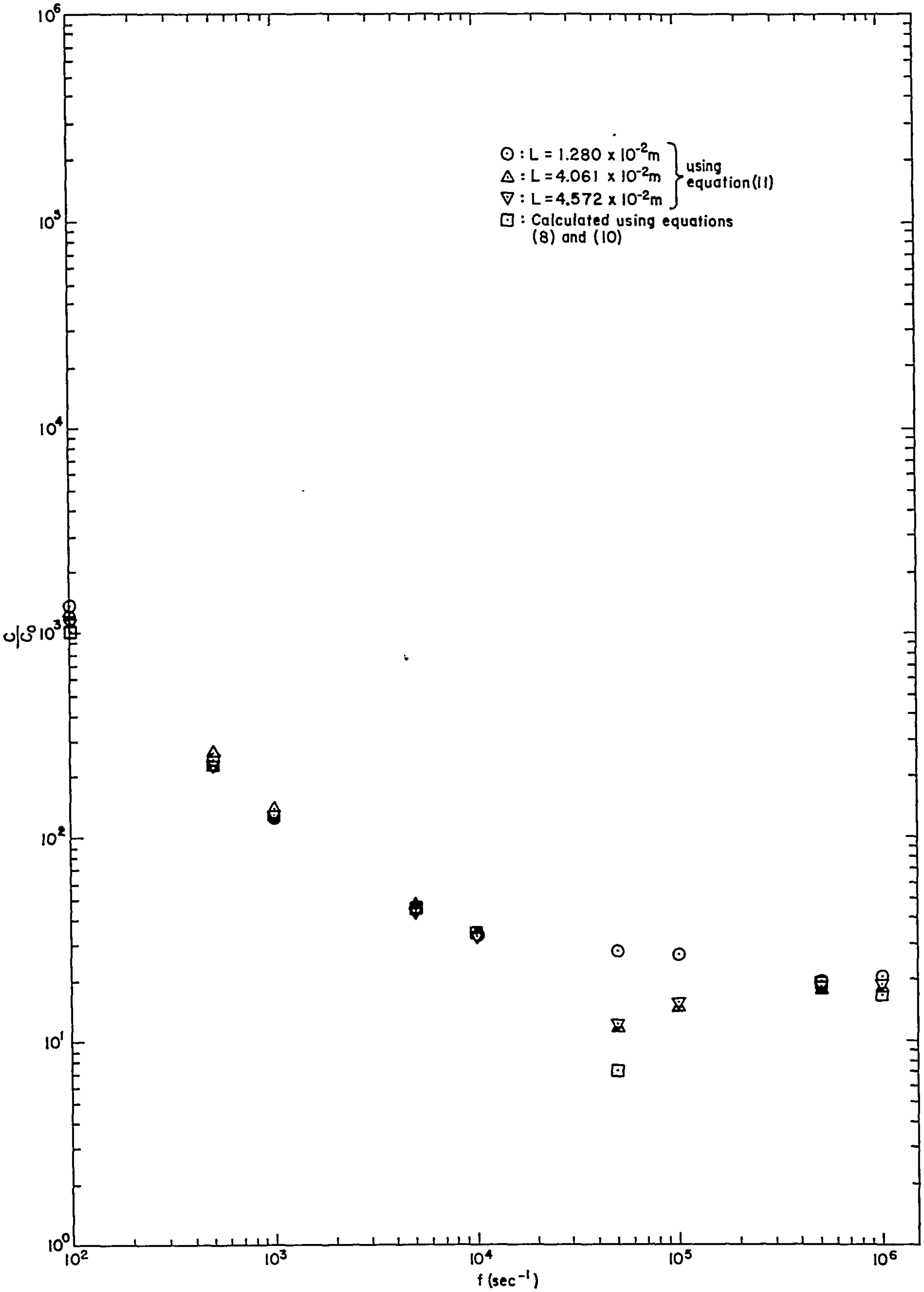

Figure 27.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with platinized-platinum electrodes containing quartz with 10^{-3} N NaCl.

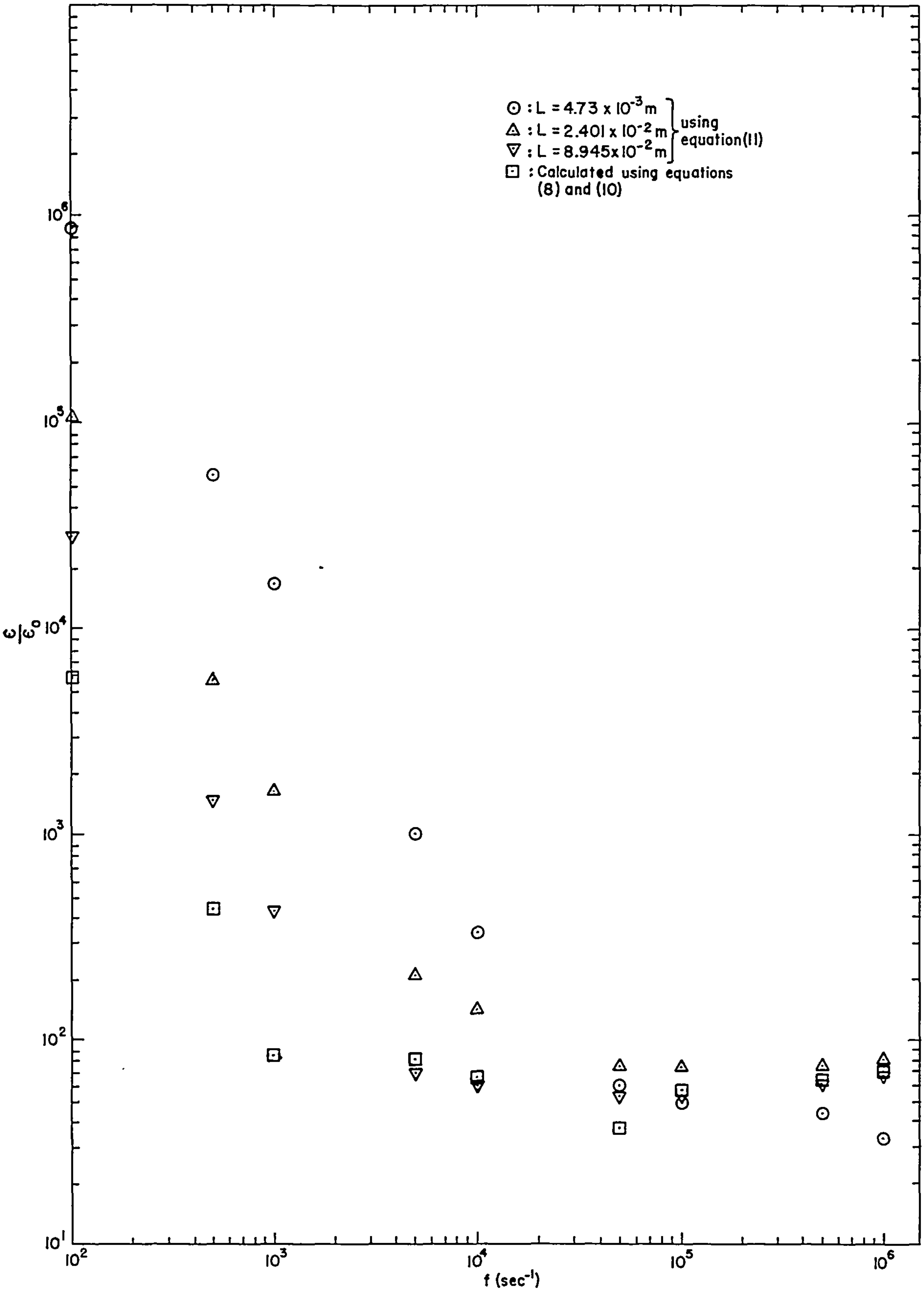

Figure 28.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with polished-platinum electrodes containing 10^{-3} N NaCl.

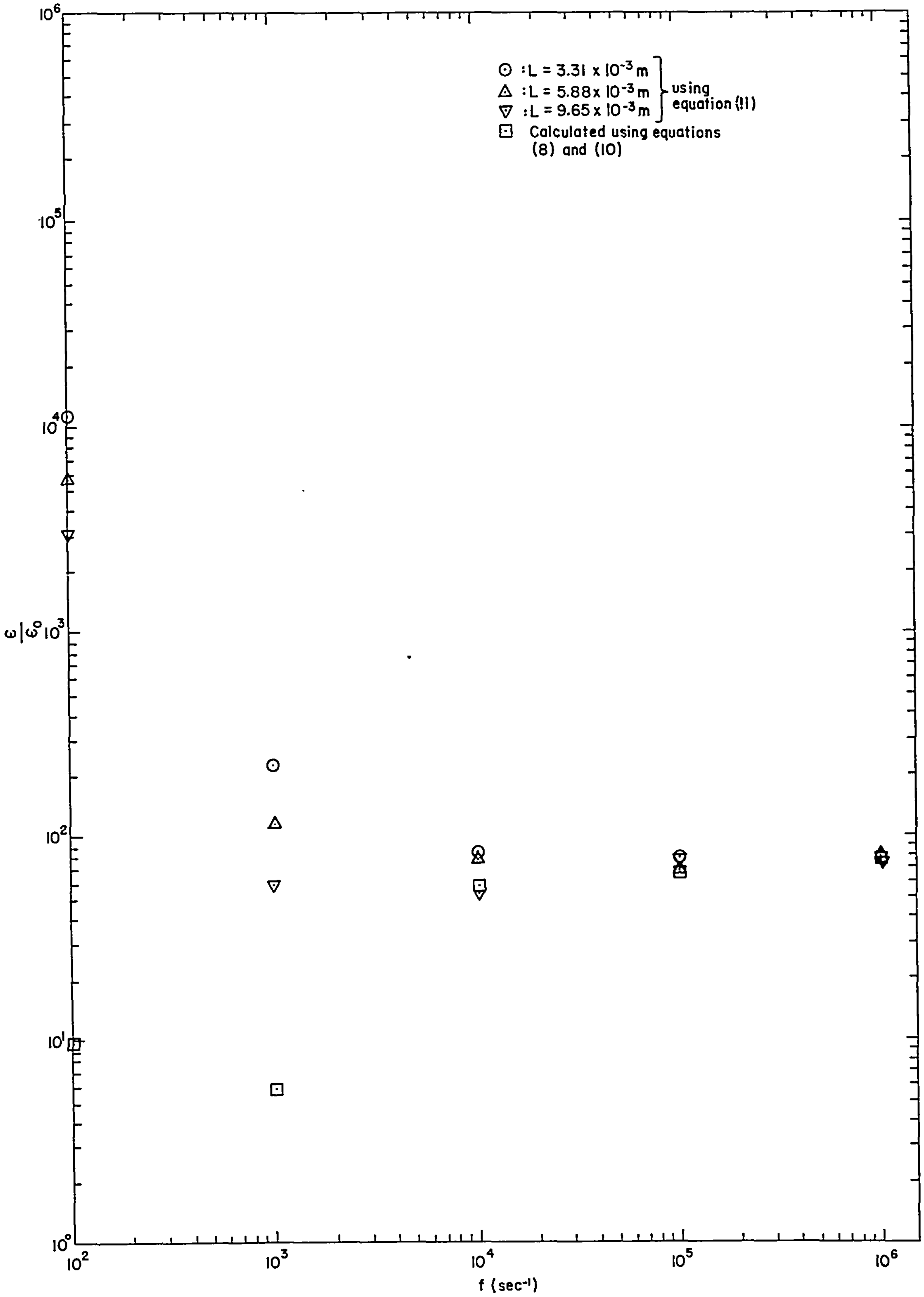

Figure 29.--The apparent relative dielectric constant calculated by use of Equation (11) and the relative dielectric constant calculated by use of Equations (8) and (10) for the cell with platinized-platinum electrodes containing 10^{-3} N NaCl.

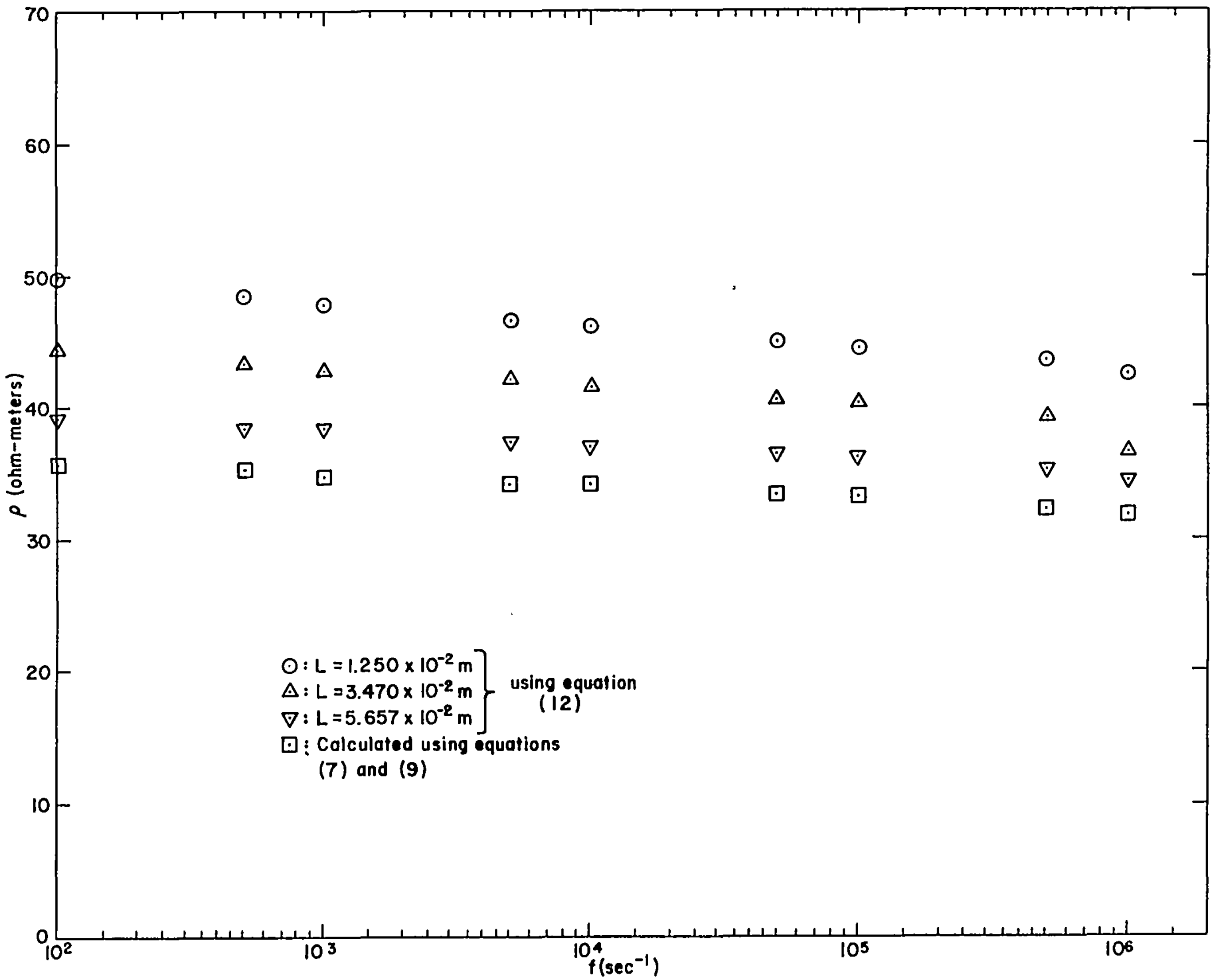

Figure 30.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with polished-platinum electrodes containing alluvium.

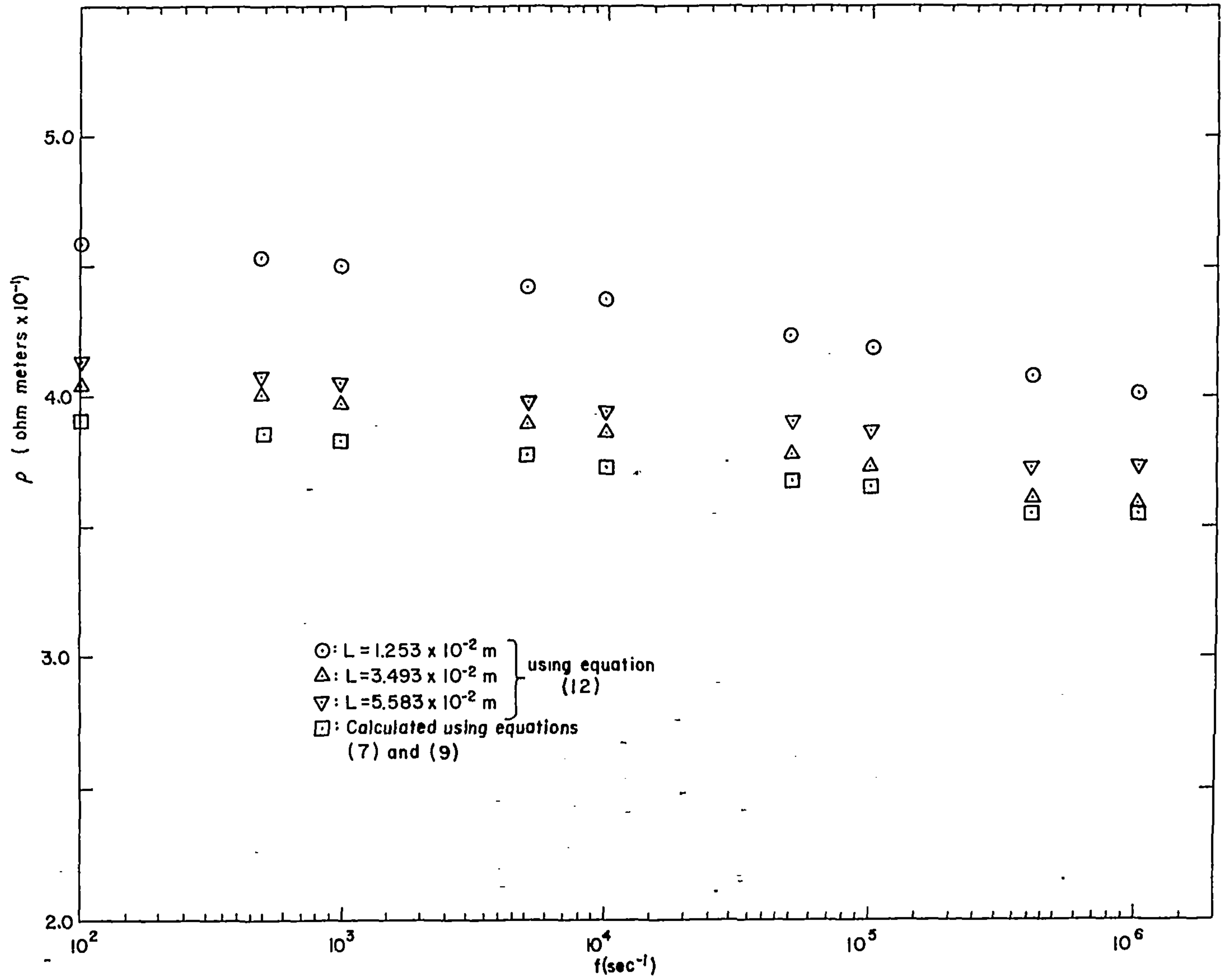

Figure 31.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with platinized-platinum electrodes containing alluvium.

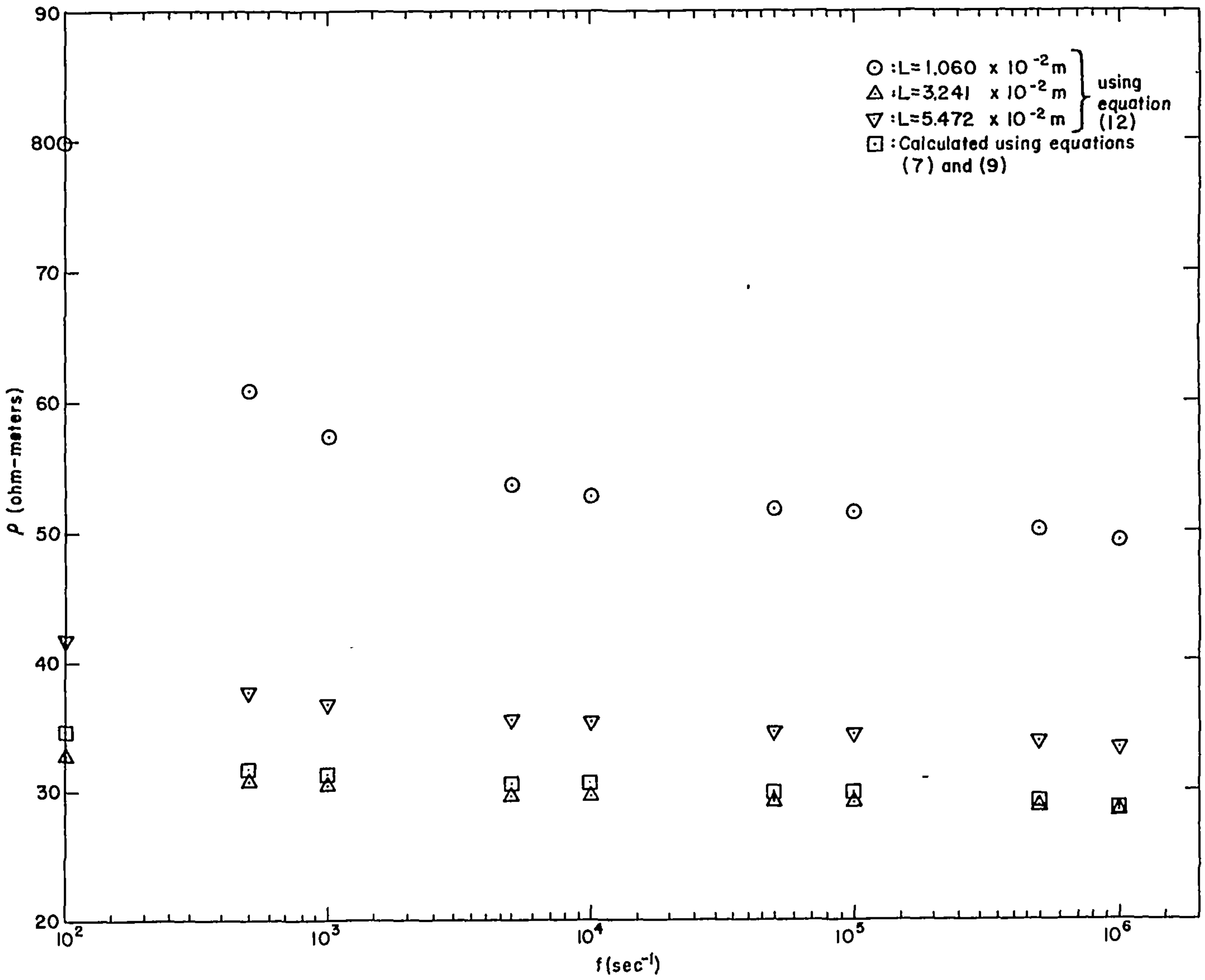

Figure 32.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with polished-platinum electrodes containing topsoil.

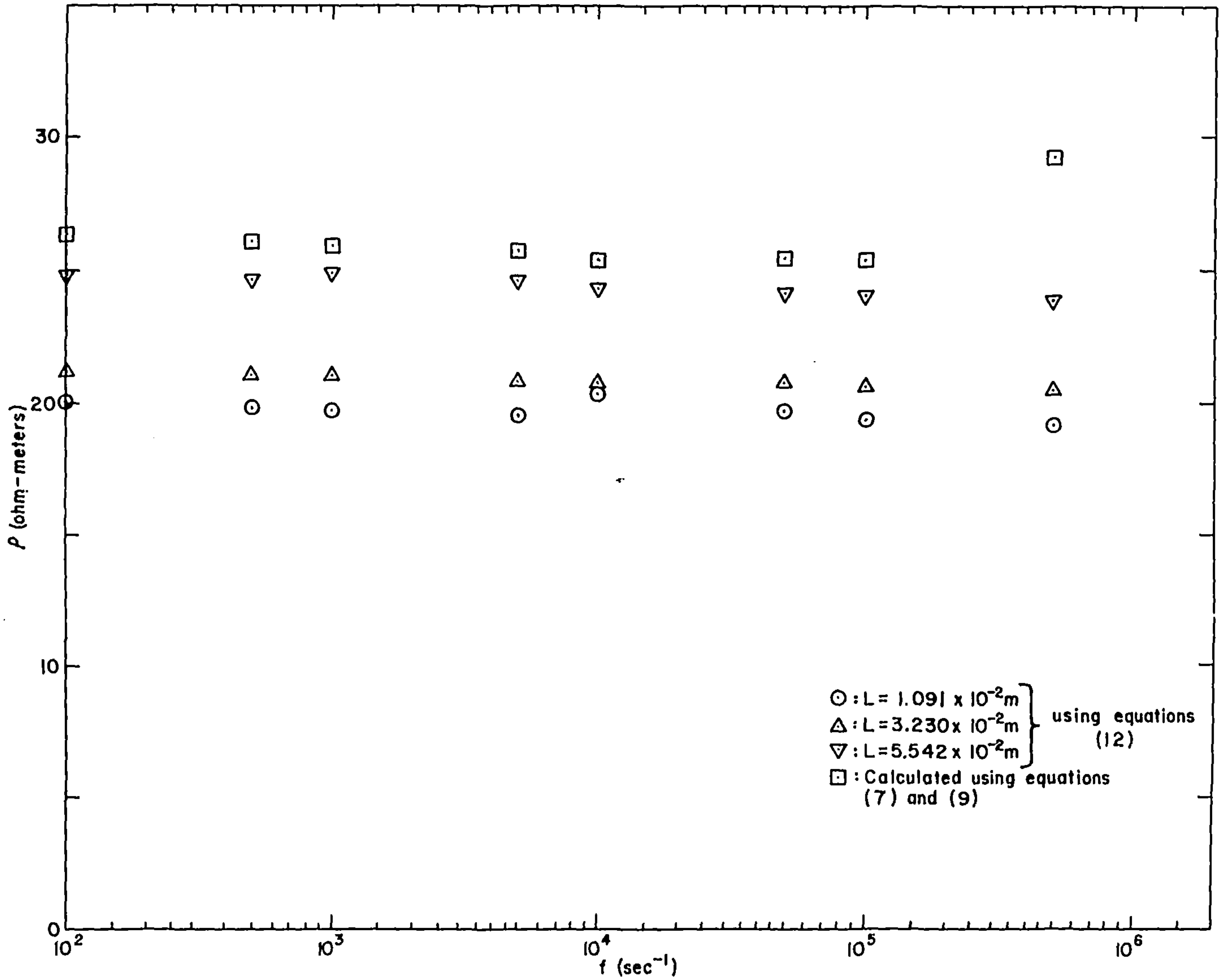

Figure 33.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with platinized-platinum electrodes containing topsoil.

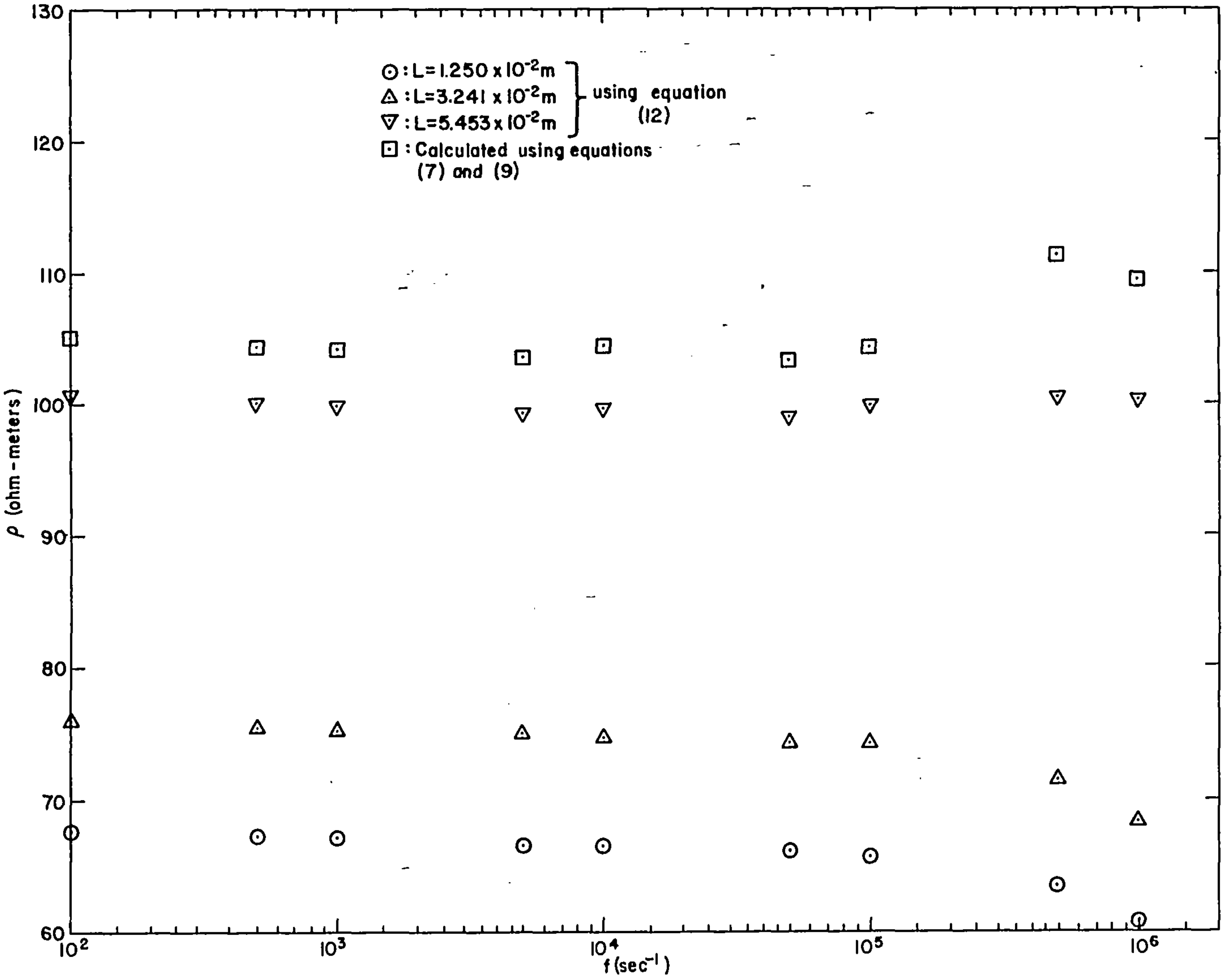

Figure 34.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with polished-platinum electrodes containing quartz with 10^{-3} N NaCl.

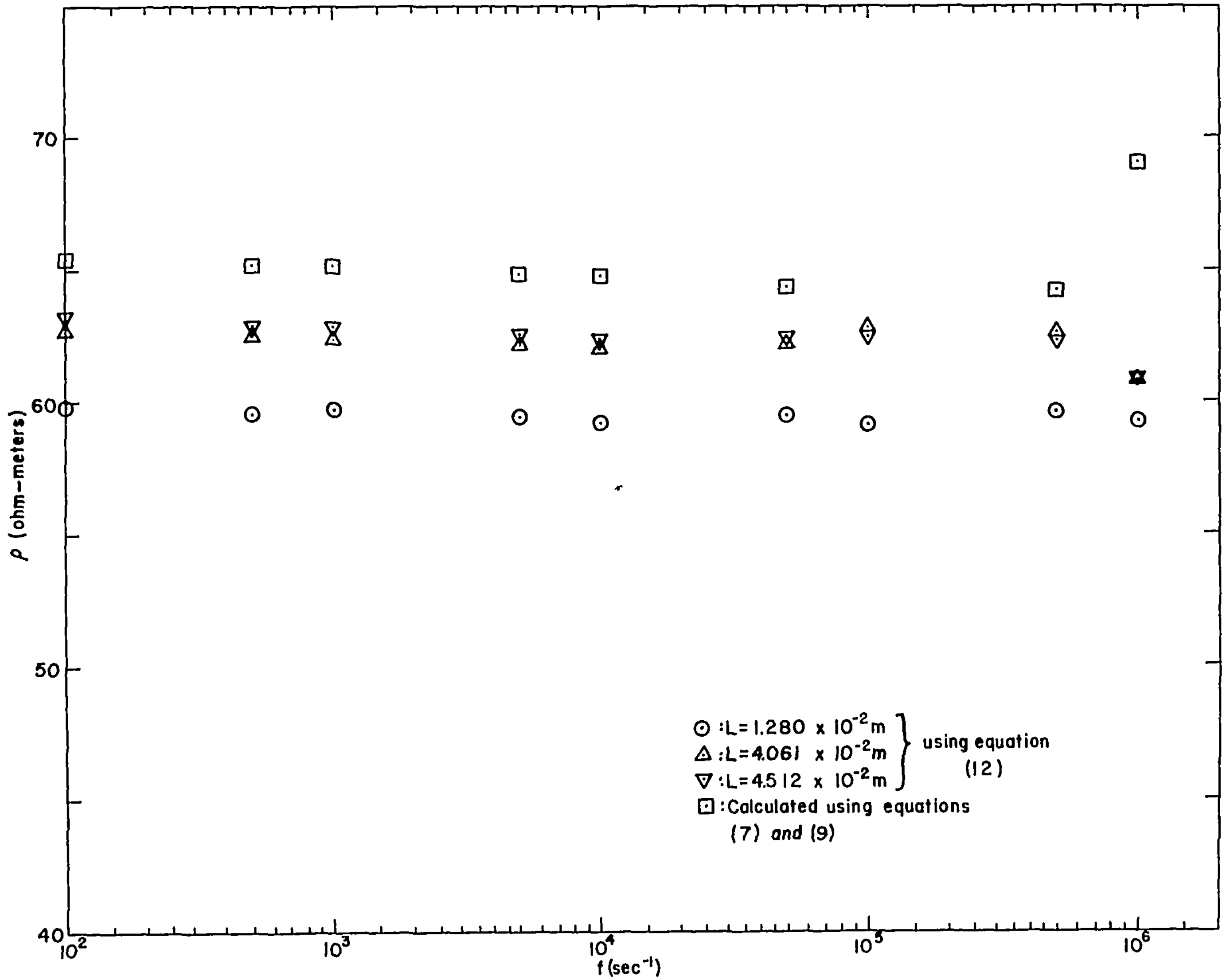

Figure 35.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with platinized-platinum electrodes containing quartz with 10^{-3} N NaCl.

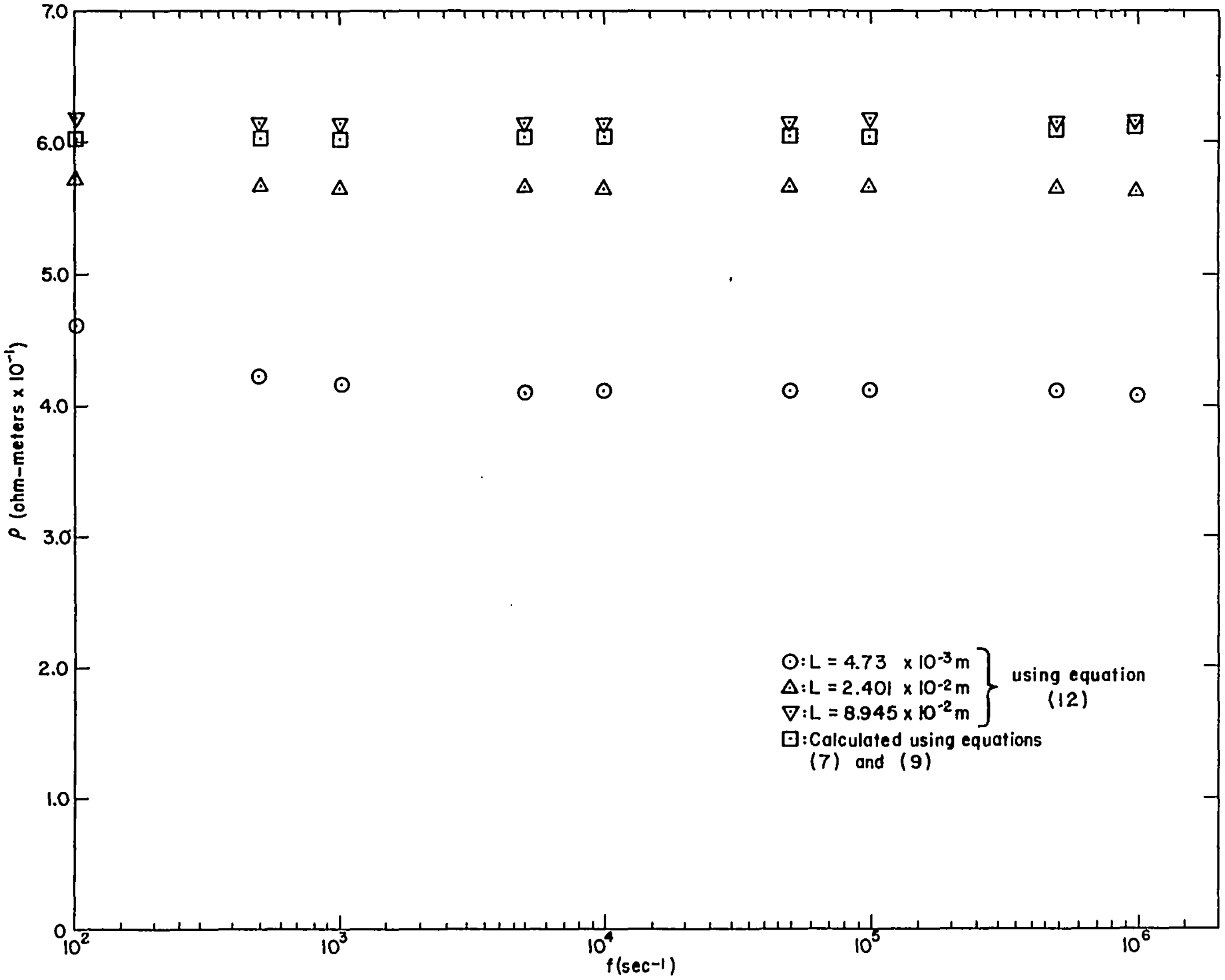

Figure 36.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with polished platinum electrodes containing 10^{-3} N NaCl.

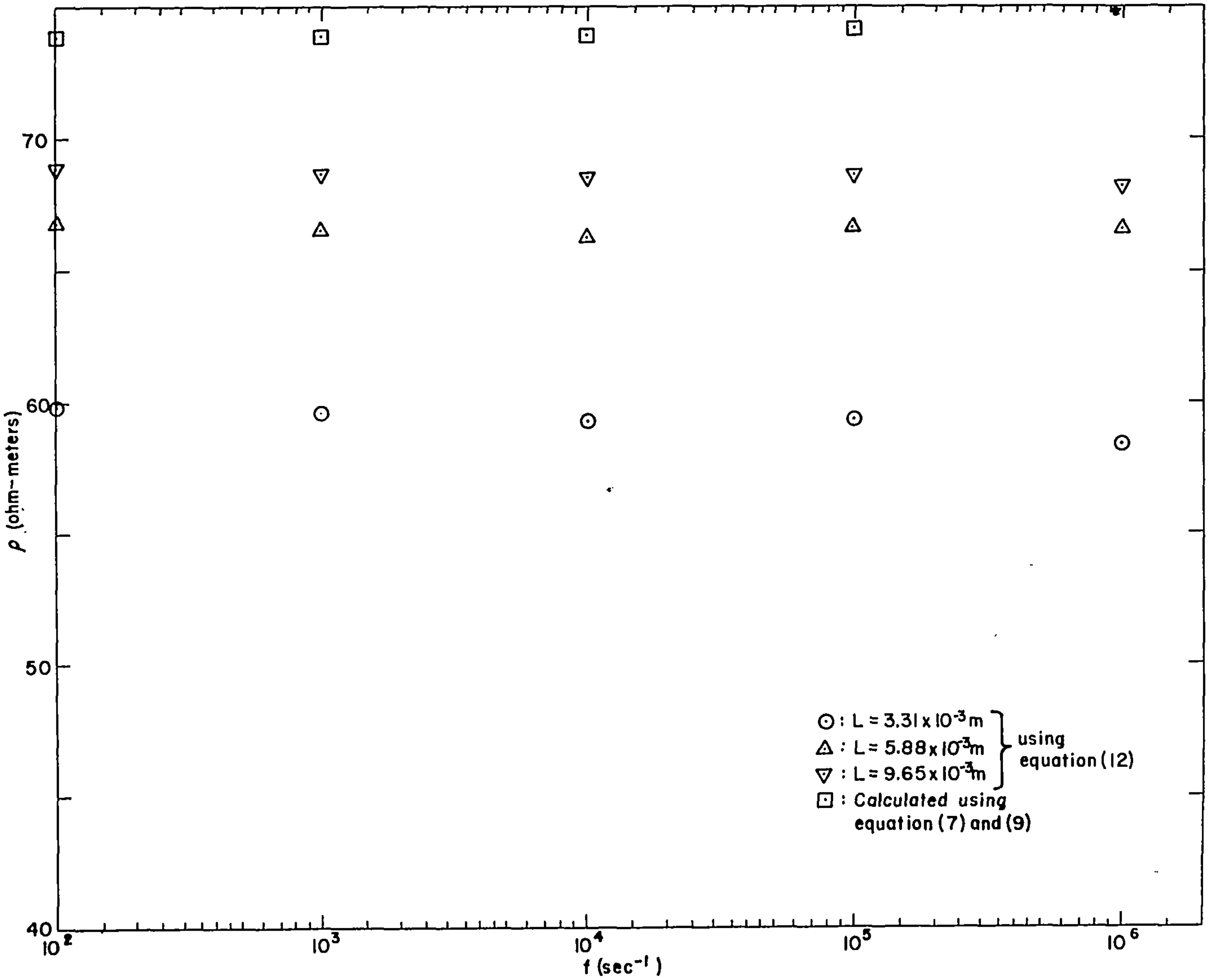

Figure 37.--The apparent resistivity calculated by use of Equation (12) and the resistivity calculated by use of Equations (7) and (9) for the cell with platinized-platinum electrodes containing 10^{-3} N NaCl.

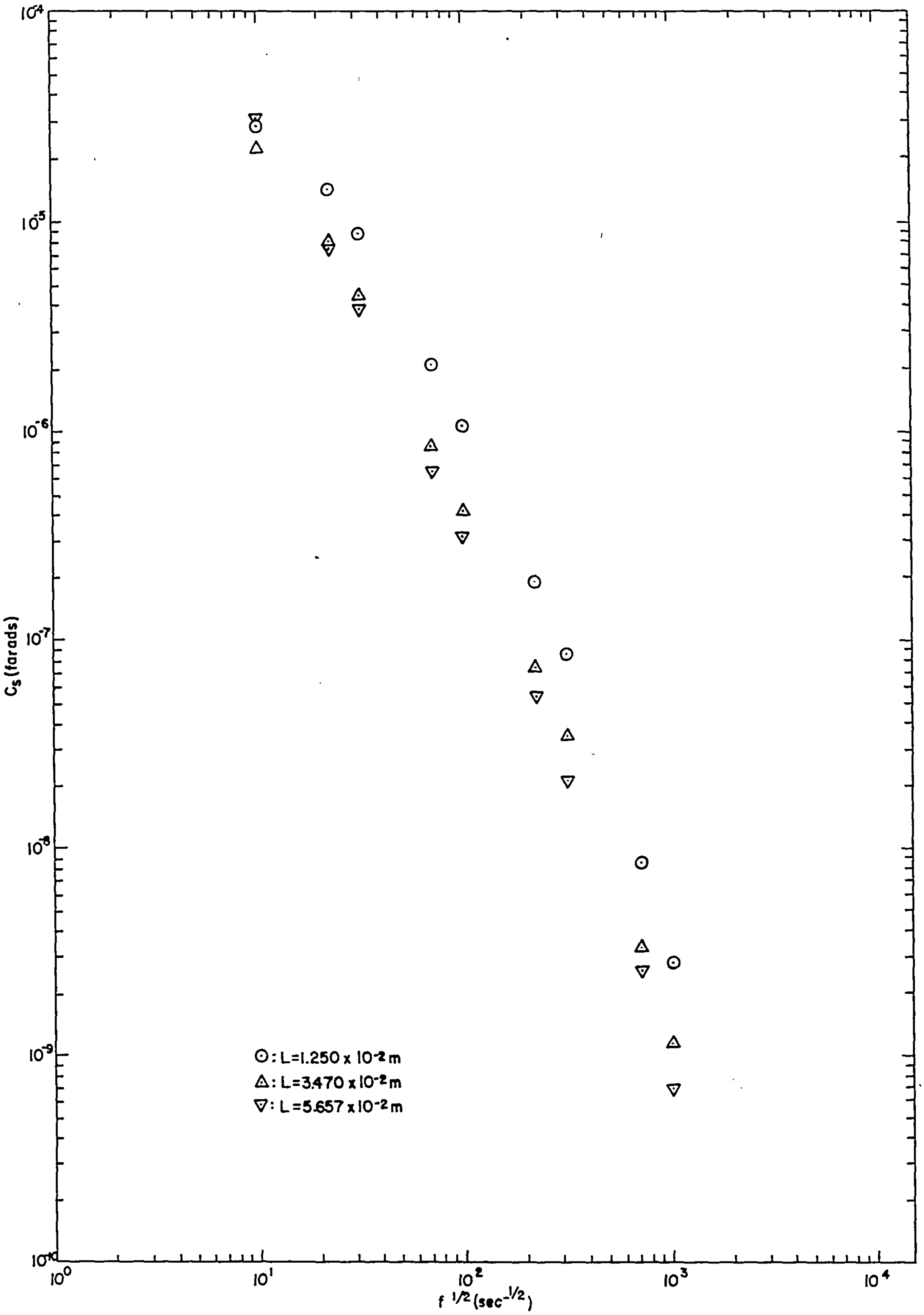

Figure 38.--Values of the series equivalent capacitance C_s for different lengths of the cell with polished-platinum electrodes containing alluvium.

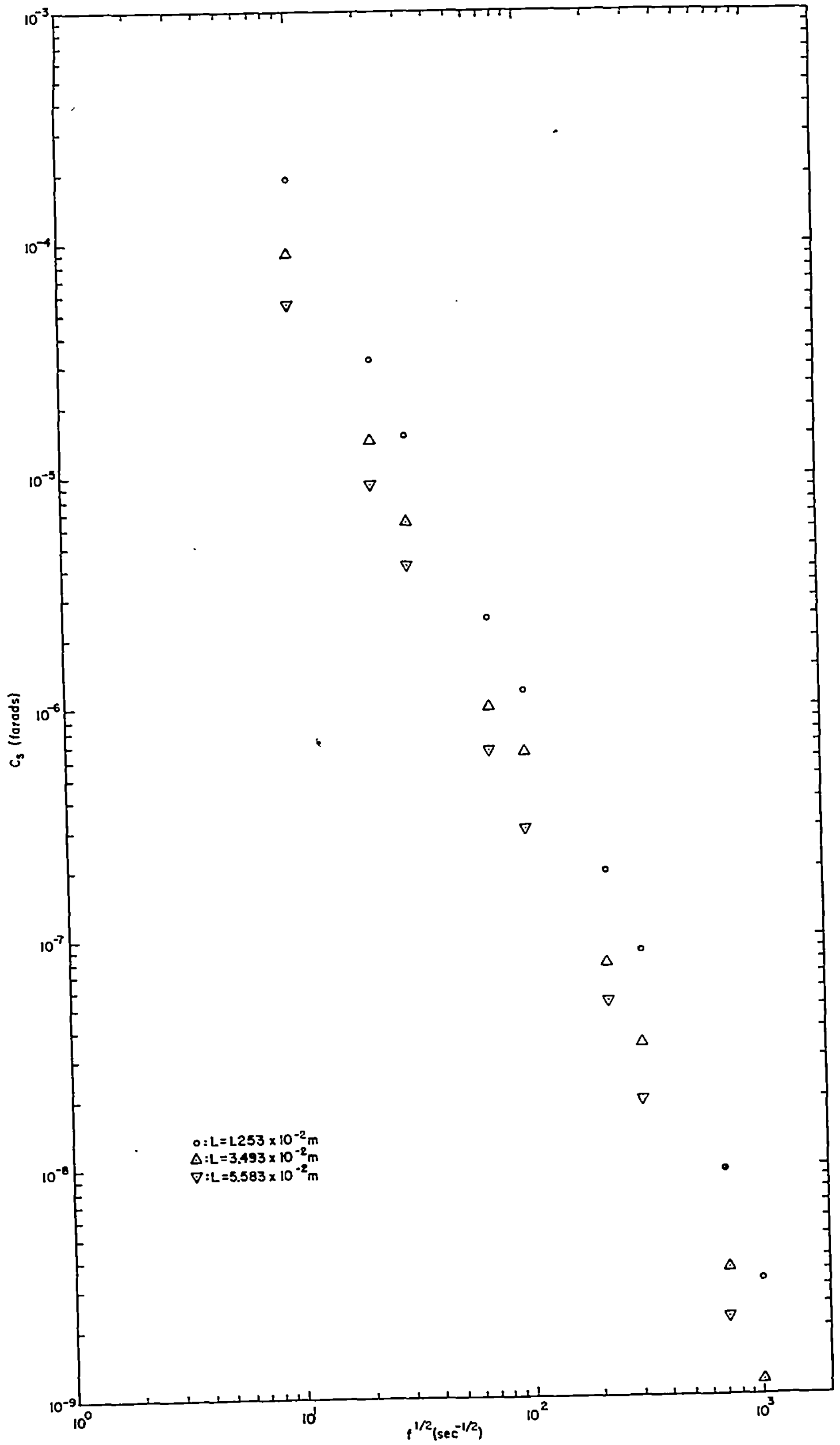

Figure 39.--Values of the series equivalent capacitance C_s for different lengths, of the cell with platinized-platinum electrodes containing alluvium.

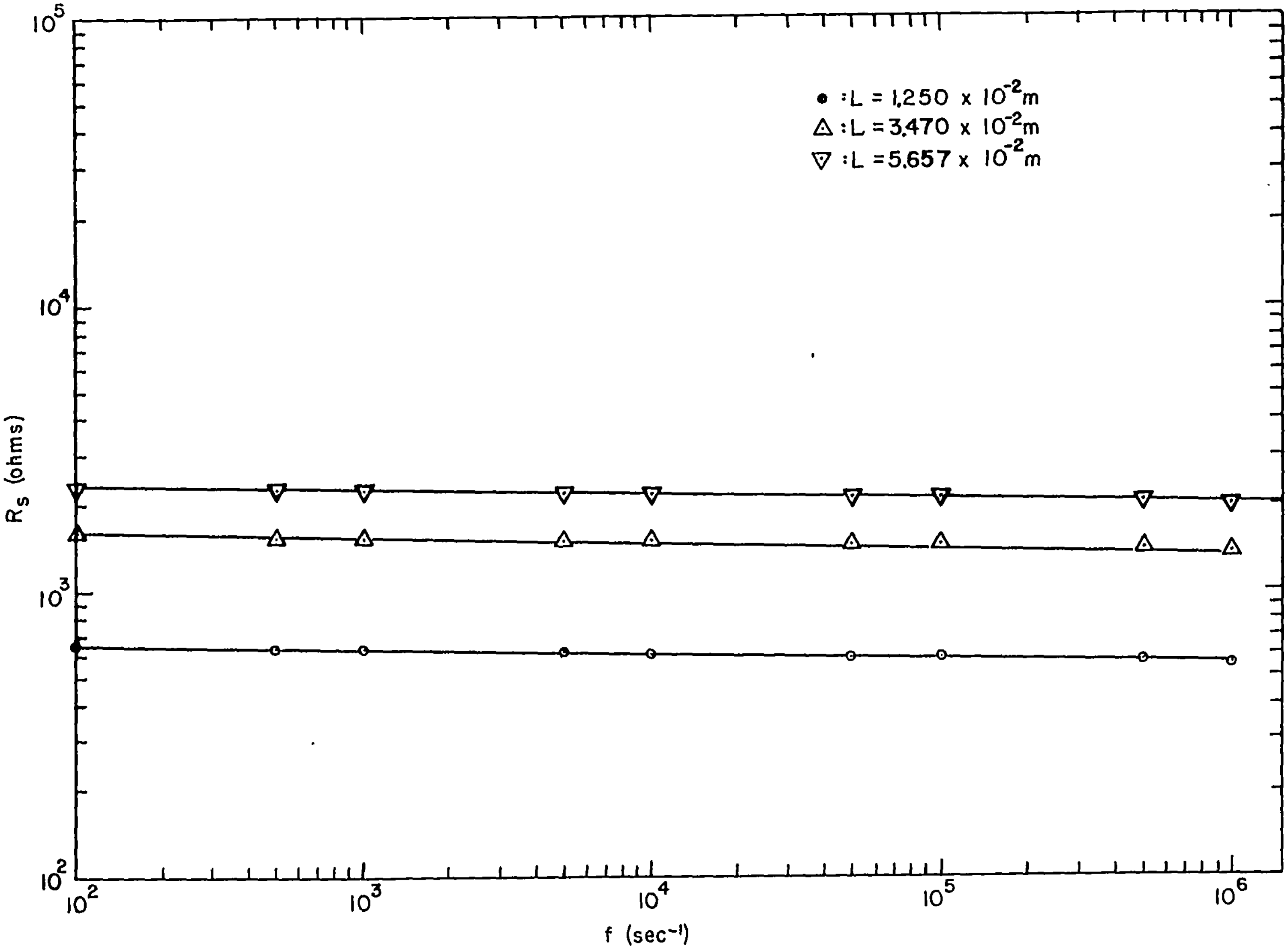

Figure 40.--Values of the series equivalent resistance R_s for different lengths of the cell with polished-platinum electrodes containing alluvium.

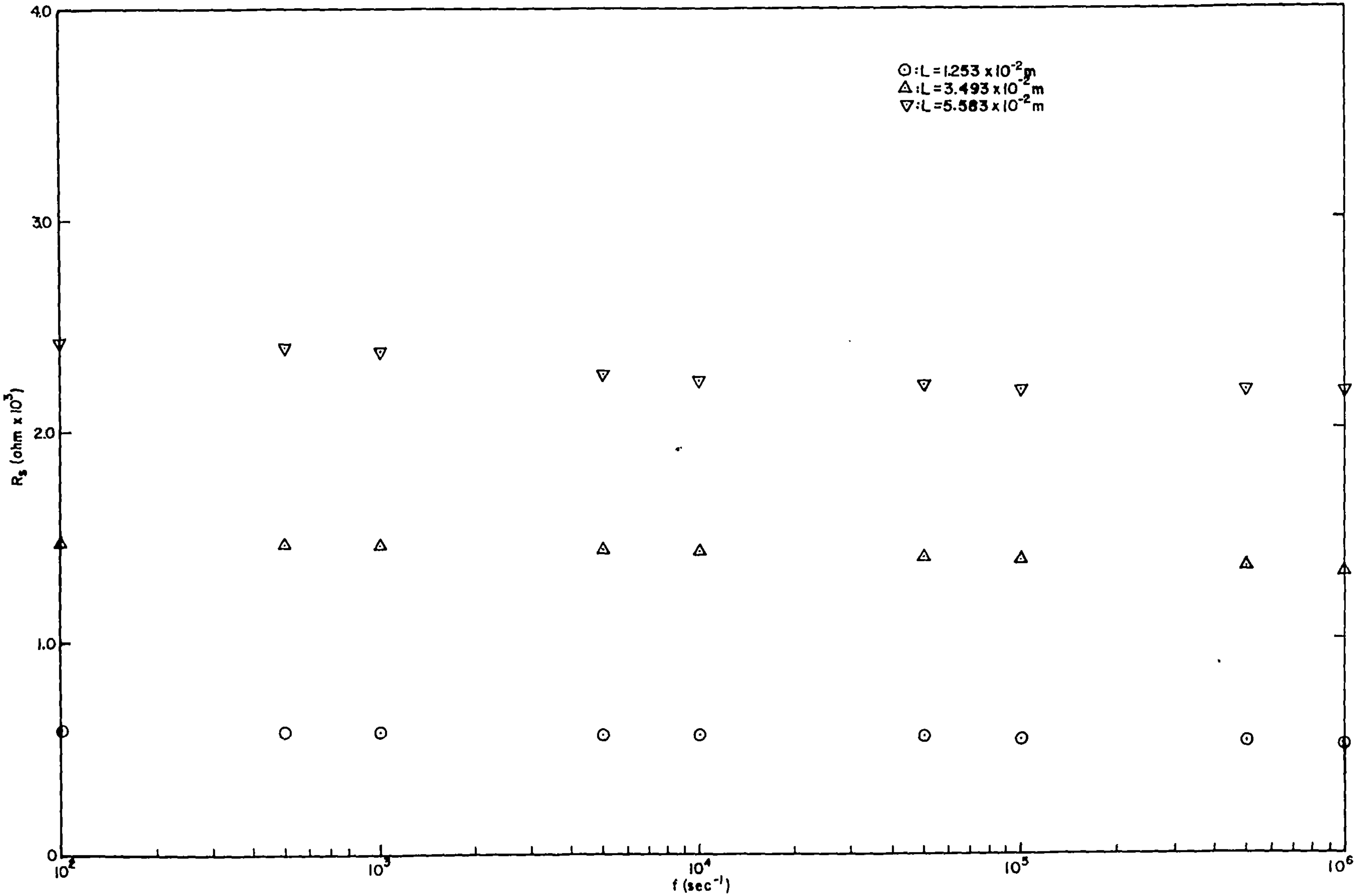

Figure 41.--Values of the series equivalent resistance R_s for different lengths of the cell with platinized-platinum electrodes containing alluvium.