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ABSTRACT

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The results of an investigation of the directional properties of waves scattered from rough surfaces are presented. The bi-static scattering of ultrasonic waves has been measured for planar surfaces of different known roughness, and the average differential scattering cross section computed. The value of the acoustic measurements is considered from the viewpoint of validation of electromagnetic theories of scattering.

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OMNIDIRECTIONAL SCATTERING OF ULTRASONIC WAVES FROM ROUGH SURFACES OF KNOWN STATISTICS WITH APPLICATION TO ELECTROMAGNETIC SCATTERING

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Introduction

In the investigation of electromagnetic radiation phenomena, it has often proven useful to conduct acoustic model experiments in cases where the analogous electromagnetic problem presents difficulties not easily or conveniently solved. This has been done successfully in the study of antennas [1] and in the areas of scattering in turbulent media [2] and from rough surfaces [3]. The areas of investigation are restricted, however, by the scalar nature of the acoustic waves, and the study of polarization effects is necessarily excluded. An important application of model experimentation is then the study of electromagnetic phenomena for which polarization is not important. Another, perhaps more important, application, and the one considered here, is the verification of theories for which the acoustic and electromagnetic forms have common foundations.

The model experiments described here were performed to investigate the characteristics of omnidirectional scatter from rough surfaces. The scattering surfaces were constructed to be smooth

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enough to satisfy the conditions of the Kirchhoff theory of scattering [4], and the experiments, therefore, provide information useful for the verification of this theory.

Technique of Experiment

The characteristics of omnidirectional scatter were investigated by measuring bi-statically the average differential scattering cross section [5], σ_o, as a function of the set of angles (ϕ_o, ϕ_1, ϕ_2) (see figure #1) and the parameters describing the rough surfaces. At the frequency used, the surfaces were sufficiently rough to achieve a near-complete conversion to scatter power. In this case, the average power received is

$$<P> = \iint_S \frac{P_t G_t(\Psi_t)}{4\pi r_t^2} \sigma_o \frac{\lambda^2 G_r(\Psi_r)}{4\pi r_r^2} dA \qquad (1)$$

where: $<P>$ is the configuration average of the received power

$G_r(\Psi_r)$ and $G_t(\Psi_t)$ are the gain functions of the acoustic transducers

λ is the wavelength

S is the illuminated area

P_t is the transmitted power

The transducers used were of high directivity (6° between half power points) permitting the approximation to be made that σ_o is constant over the illuminated area; using this in eq. (1) gives

$$<P> = \sigma_o \iint_S \frac{P_t G_t(\Psi_t)}{4\pi r_t^2} \frac{\lambda^2 G_r(\Psi_r)}{4\pi r_r^2} dA \qquad (2)$$

The measurement of σ_o was done by measuring $<P>$ over an ensemble of rough surfaces and evaluating the integral over the illuminated area (thereby accounting for "aperture effect") as a function of the angles (ϕ_o, ϕ_1, ϕ_2).

The experiments were performed in a water tank of dimensions (6' x 8' x 11') (see figure 2). Because of the proximity of the tank wallsand the surface of the water, it was necessary to use a pulse modulated oscillator, which operated at a frequency of one megacycle (λ = 1.5 millimeters in water). The pulse width of the modulation was sufficiently long to establish a beam width limited condition [6] and the transmitted power in eq.s (1) and (2) is a constant in time. The ensemble of rough surfaces was obtained by rotating the rough surface targets (shown in figure 2) through the transducer beam thereby generating the fading signal from which the average power was calculated.

Two planar rough surfaces with different reflectivities and surface roughnesses were constructed. One of these was made by striking mild steel sheet randomly with a ball peen hammer. The other surface was made by flowing grout over a sand surface thereby producing a smooth surface with reflectivity different from steel. The surface roughnesses were determined by making sampled height measurements using a depth gauge mounted on a machined surface. From these measurements the sample distribution of heights and sample autocorrelation function of both surfaces were calculated.

These are shown in figures 3 and 4. The waves of the sample autocorrelation functions are fit, approximately, by the Gaussian function

$$r = e^{-\left(\frac{x}{L}\right)^2}$$

however, near the origin a three halves power function gives better agreement. The sample distribution functions are seen to be approximately Gaussian.

Results

Measurements of σ_o were made as a function of the azimuthal angle, ϕ_o, for a range of values of the depression angles ϕ_1 and ϕ_2. Figures 5 and 6 show curves of σ_o against ϕ_o for variation of the depression angles when they are both equal. Figures 7 and 8 show the variation of σ_o against ϕ_o when the depression angle ϕ_1 is fixed at 40° and ϕ_2 is allowed to vary. The curves for both surfaces are similar in shape and the difference in the surfaces is shown, largely, by the relative amplitudes of the curves. An important feature which is common to the curves of figures 5 and 6 is the near-constancy of σ_o in the specular direction ($\phi_1 = \phi_2$, $\phi_o = 0$).

Summary and Conclusions

The measurement of the scatter of acoustic waves provides a basis for determining the validity of theories for the prediction of the analogous electromagnetic scatter as all electromagnetic scatter theories also take an acoustic form. The omnidirectional measurement of σ_o gives a complete description of the scattering (no restriction on angles of incidence or observation) and therefore affords the opportunity to make a more rigorous test of theory validity. The experiments described here are especially useful for this purpose as the scattering surfaces are of known roughness. A prediction of the experimental results based on the Kirchhoff approximation has been made and will be reported on at a later time.

cknowledgements

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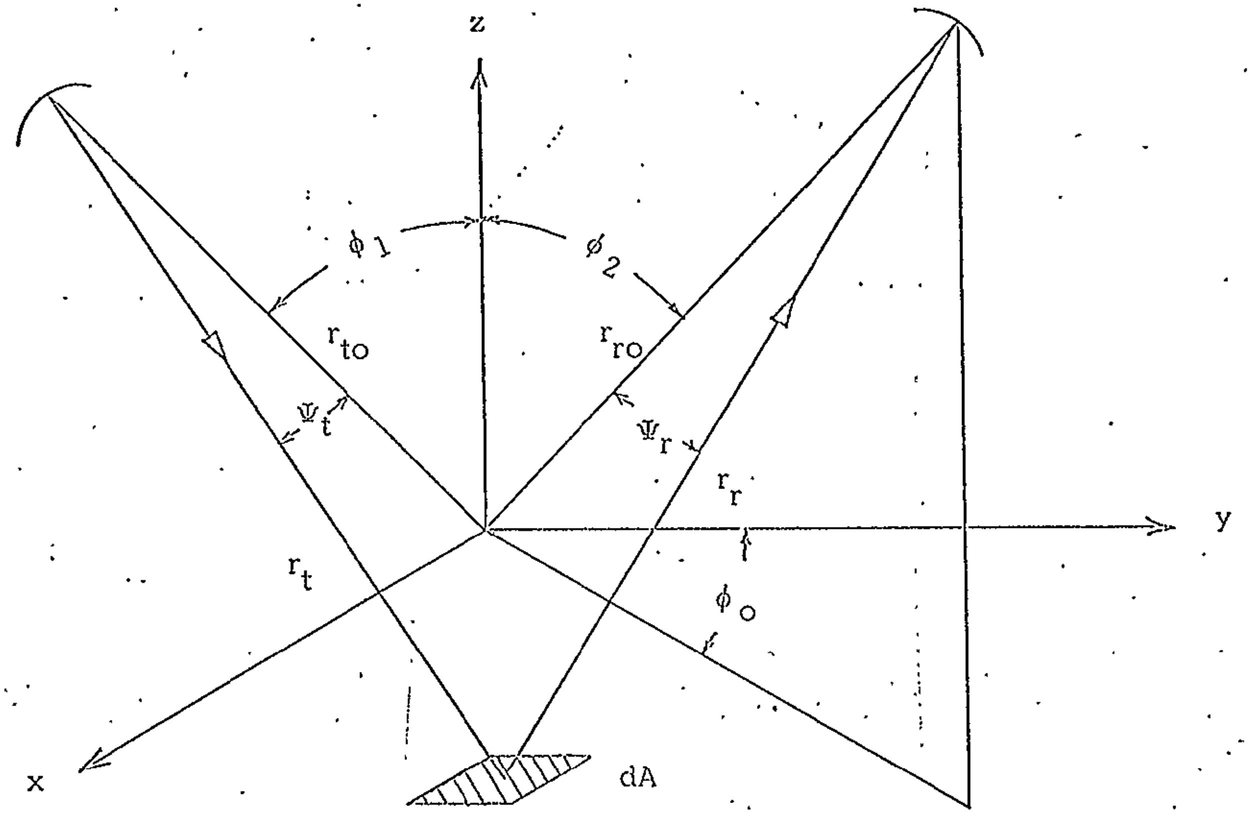
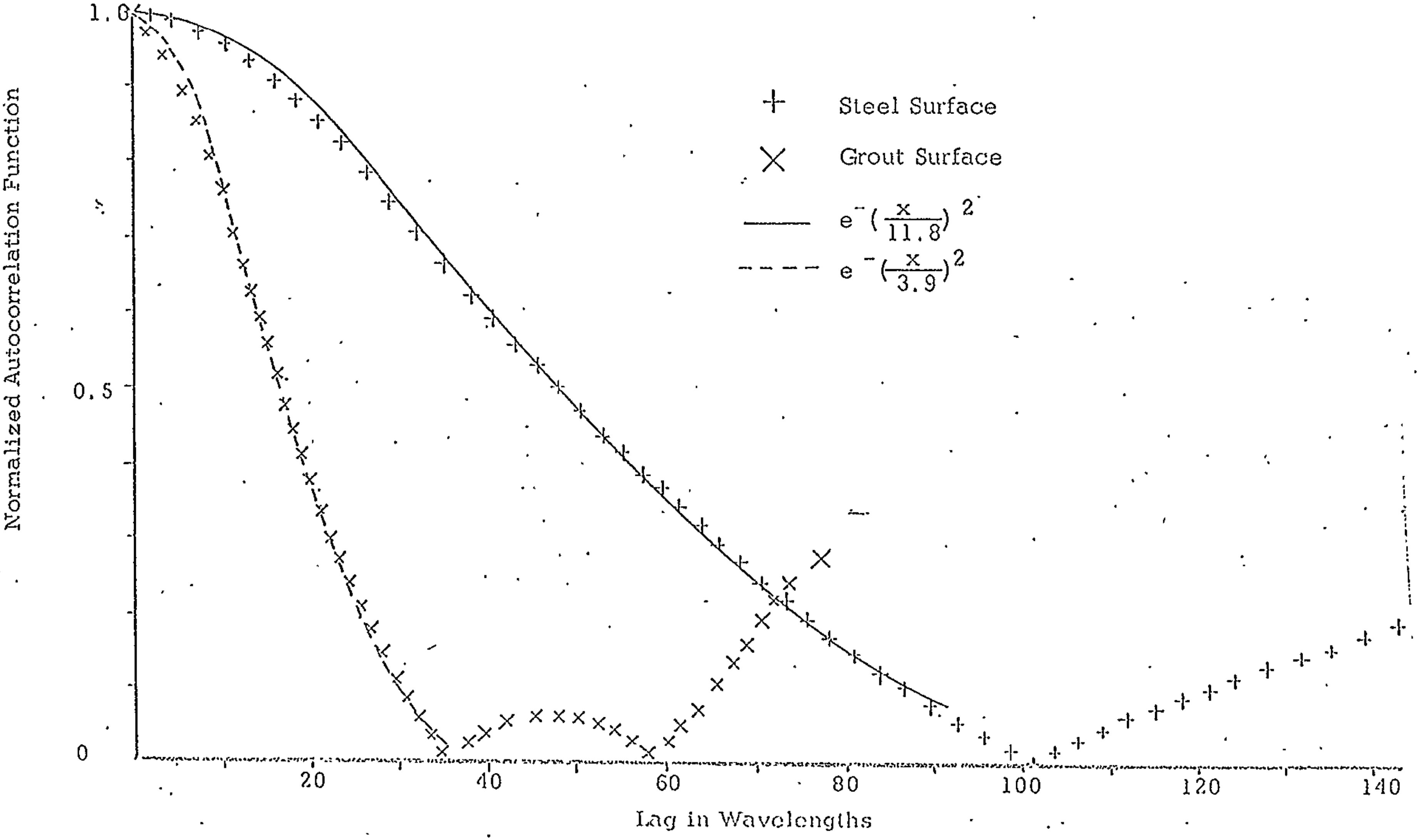


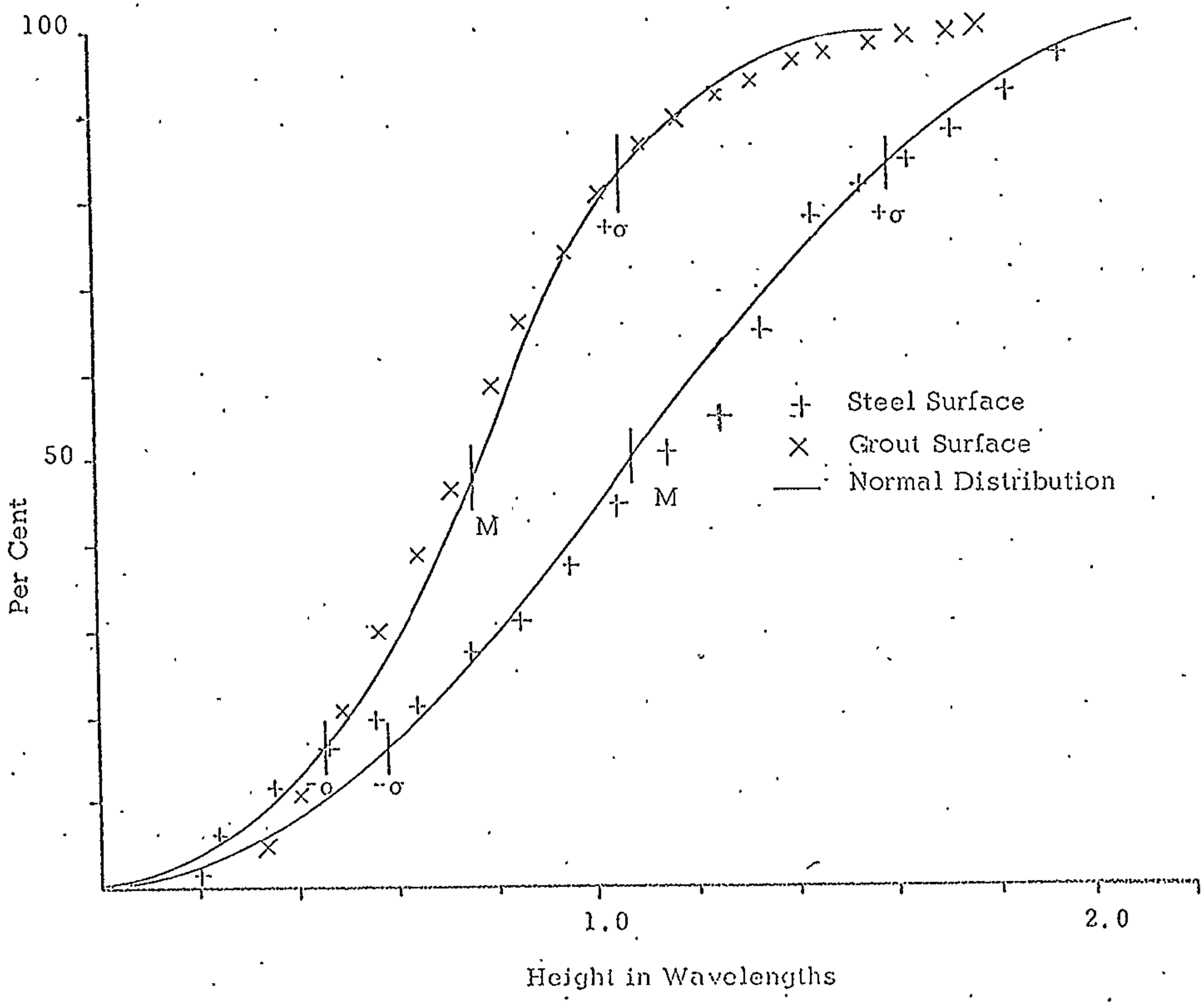
GEOMETRY OF BI-STATIC SCATTERING

FIGURE 1



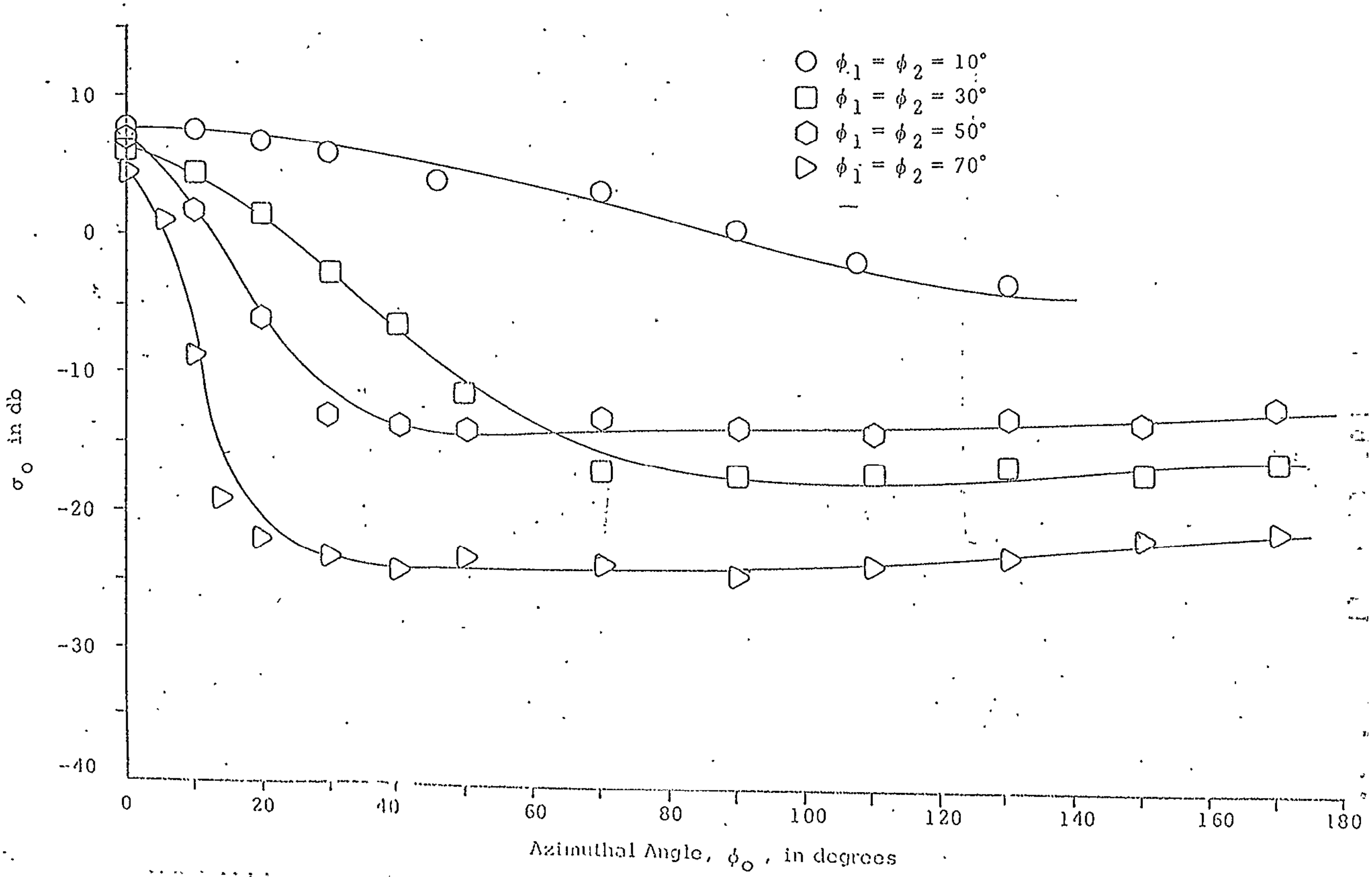
SAMPLE AUTOCORRELATION FUNCTIONS

FIGURE 3



DISTRIBUTION OF SURFACE HEIGHTS FOR THE STEEL AND GROUT SURFACES

FIGURE 4



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