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ANALYSIS OF SCATTERING FROM OIL FILM ON SEA SURFACE WITH A MODEL OF STRATIFIED MEDIUM WITH SLIGHTLY ROUGH INTERFACES

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ABSTRACT

A model of stratified medium with slightly rough interfaces is presented for analysis of scattering from oil film on sea surface. Because the thickness of oil film is considered, the model is more realistic than that raised in other paper in which only single rough surface is assumed. In this paper the coupled differential equations are derived and solved by full wave approach, and the simple expressions of back scattering cross section for oil film on sea surface have been obtained. According to these expressions some curves are given for different thickness of oil film. It is shown that the results obtained by the present model are in better agreement with the experimental data than those obtained by the single surface model.

INTRODUCTION

The problem of remote sensing of oil film on sea surface has been studied extensively. In previous work [1] the model of a single rough sea surface was used to treat the problem by perturbation approach, in which the effect of thickness

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of oil film was neglected. However, in actual cases the oil film always has some thickness; therefore, more accurate model is needed for practical applications. In the paper, a model of stratified medium with slightly rough interface is presented for analyzing the scattering of oil film on sea surface. Because the oil film structure is considered as multilayered structures of arbitrary thickness. It is obvious that the present model is more realistic than the single surface model.

In the paper, the coupled diferential equations for the scattering problem are derived and solved by means of full wave approach. The simple expressions of backscattering cross section of oil film on sea surface are obtained. The scattering characteristics of different oil film thicknesses are calculated. It is shown that the scattering characteristics are quite different for different thicknesses. A practical example is calculated with different models. Due to considering effect of the thickness of oil film, the results obtained by present model are in better agreement with experimental data than those obtained by the single surface model, and the utility of the present model is justified.

THEORETICAL ANALYSIS

The geometrical configuration of an oil film on sea surface is illustrated in Fig.1. The oil film structure consists of three regions. Let ε_0, ε_1 and ε_2 are complex permittivity of upper medium (air), middle medium (oil film), and lower medium (sea), respectively, and $\mu_0 = \mu_1 = \mu_2$ is assumed. The upper interface (air / oil film) and lower interface (oil film / sea) are defined by random functions as: $z = \zeta_{01}(x,y)$ and $z = \zeta_{12}(x,y)$. The distance between upper and lower interface is $H_1(x,y) = \zeta_{01}(x,y) - \zeta_{12}(x,y)$, and Ho is the mean of H_1, i.e. $Ho = \langle H_1 \rangle$.

In the analysis, the transverse electric and megnetic fields are expaned by the basis functions into vertically and horizontally polarized waves as:

$$\vec{E}_T(x,y,z) = E_x \hat{a}_x + E_z \hat{a}_z \tag{1a}$$
$$= \sum_{k_z} \int_{-\infty}^{\infty} dk_x \left(E^V(y,k_x,k_z)\vec{e}_T^V + E^H(y,k_x,k_z)\vec{e}_T^H \right)$$

$$\vec{H}_T(x,y,z) = H_x \hat{a}_x + H_z \hat{a}_z \tag{1b}$$
$$= \sum_{k_z} \int_{-\infty}^{\infty} dk_x \left(H^V(y,k_x,k_z)\vec{h}_T^V + H^H(y,k_x,k_z)\vec{h}_T^H \right)$$

where, the superscripts V and H are used to denote vertically and horizontally polarized waves, respectively. The symbol $\sum_{k_z}$ in Eqs. (1a) and (1b) denotes the summation over the entire wavenumber spectrum k_z consisting of the radiative $(0 < k_{z0} < \infty)$, lateral $(0 < k_{zl} < \infty)$, and surface-

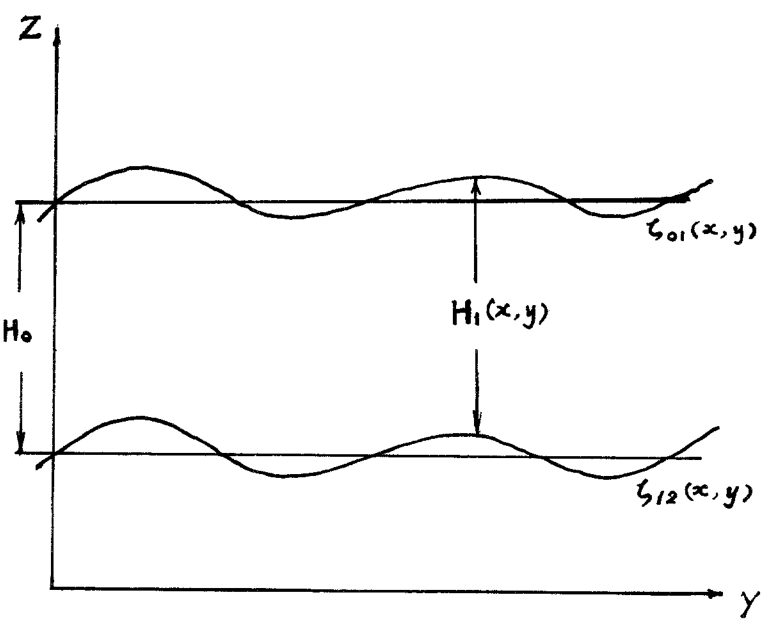

Fig.1 Schematic of the oil film on sea surface.

wave terms k_{zs} [2]. The explicit expressions for the basis functions $\vec{e}_T^P$ and $\vec{h}_T^P$ have been given in earlier work [2]. On substituting the complete expansion into the Maxwell's equations and making use of the biorthogonal relationships for the basis functions, the Green's theorem, and the exact boundary conditions, the following first-order coupled differential equations for the forward and backward wave amplitudes a^P and b^P are obtained in terms of the transmission and reflection scattering coefficients $S_{PQ}^{\alpha\beta}$ as well as the excitation expressions A^P and B^P as follows [2]:

$$-\frac{da^P}{dy}-jk_y'a^P=\sum_Q\sum_{k_z}\int_{-\infty}^{\infty}dk_x\left(S_{PQ}^{BA}a^Q+S_{PQ}^{BB}b^Q\right)-A^P \tag{2a}$$

$$-\frac{db^P}{dy}+jk_y'b^P=\sum_Q\sum_{k_z}\int_{-\infty}^{\infty}dk_x\left(S_{PQ}^{AA}a^Q+S_{PQ}^{BB}b^Q\right)+B^P \tag{2b}$$

where

$$a^P=\frac{1}{2}\left(E^P+H^P\right) \tag{2c}$$

$$b^P=\frac{1}{2}\left(E^P-H^P\right) \tag{2d}$$

in which the superscripts P and Q denote either vertical polarization V or horizontal polarization H.

The first-order iterative solutions for the wave amplitudes a^P and b^P are obtained by neglecting the transmission and reflection scattering coefficients in equation (2a) and (2b). These first-order solutions are substituted in the right side of equation (2a) and (2b), and the resulting equations are solved to get the second-order iterative solution for the wave amplitudes. The second-order iterative solutions are used in complete expansions for electromagnetic field, and the desired iterative solutions for the scattered radiation fieldes are then determined by means of the steepest descent method. The expressions of scattered field are derived for the case in which the source and receiver are far from the irregular boundarys.

To simplify the problem, following three are assumed: (a) upper and lower interface have same fluctuation, i.e. H_1=Ho, (b) the spectral density of random rough surface is that of the sea surface, which is defined by $W(p,q)= K\,(p^2+q^2)^{-K_2}$, (c) the surface is slightly rough. Then the formula of the incoherent scattering cross section per unit for the oil film on sea surface can be expressed by

$$\sigma_{PQ} = \sigma^{I}_{PQ}\, g_{PQ} \tag{3}$$

Where σ^{I}_{PQ} is the backscattering cross section for single rough surface (corresponding to KoHo$\Rightarrow\infty$), which is same as the results obtained in other paper [1]. g_{PQ} is a factor for stratified medium with slightly rough interfaces, which is main result of the paper different from others. σ^{I}_{PQ} is defined as:

$$\sigma^{I}_{PQ} = K_1 C_0^{i4} S_0^{i-K_2} \alpha_{PQ} \qquad P,Q = V \text{ or } H \tag{4}$$

where

$$\alpha_{VV} = \left| \frac{(\varepsilon_{1r}-1)[(\varepsilon_{1r}-1)S_0^{i2}+\varepsilon_{1r}]}{\varepsilon_{1r}C_0^{i}+\sqrt{\varepsilon_{1r}-S_0^{i2}}} \right|^2 \tag{5a}$$

$$\alpha_{HH} = \left| \frac{(\varepsilon_{1r}-1)}{C_0^{i}+\sqrt{\varepsilon_{1r}-S_0^{i2}}} \right|^2 \tag{5b}$$

$$\alpha_{VH} = \alpha_{HV} = 0 \tag{5c}$$

and g_{ll} is given by:

$$g_{ll} = \left| \frac{(1+A_1^{ll} e^{B_1} + A_2^{ll} e^{2B_1})}{(1+A_3^{ll} e^{B_1})^2} \right|^2 \qquad l = V \text{ or } H \tag{6}$$

where

$$A_1^{VV} = \frac{4\varepsilon_{1r}(\varepsilon_{2r}-\varepsilon_{1r})(\varepsilon_{1r}-S_0^{i2})(\varepsilon_{1r}\varepsilon_{2r}+S_0^{i2}(\varepsilon_{2r}-\varepsilon_{1r}))}{(\varepsilon_{1r}-1)(\varepsilon_{1r}+S_0^{i2}(\varepsilon_{1r}-1))(\varepsilon_{2r}\sqrt{\varepsilon_{1r}-S_0^{i2}}+\varepsilon_{1r}\sqrt{\varepsilon_{2r}-S_0^{i2}})} \tag{7a}$$

$$- \frac{2(\varepsilon_{2r}-\varepsilon_{1r})(\varepsilon_{1r}C_0^{i2}-S_0^{i2})}{(\varepsilon_{1r}+S_0^{i2}(\varepsilon_{1r}-1))(\varepsilon_{2r}\sqrt{\varepsilon_{1r}-S_0^{i2}}+\varepsilon_{1r}\sqrt{\varepsilon_{2r}-S_0^{i2}})}$$

$$A_2^{VV} = \left(\frac{\varepsilon_{2r}\sqrt{\varepsilon_{1r}-S_0^{i2}} - \varepsilon_{1r}\sqrt{\varepsilon_{2r}-S_0^{i2}}}{\varepsilon_{2r}\sqrt{\varepsilon_{1r}-S_0^{i2}} + \varepsilon_{1r}\sqrt{\varepsilon_{2r}-S_0^{i2}}} \right)^2 \tag{7b}$$

$$A_3^{VV} = \frac{(\varepsilon_{1r}C_0^{i} - \sqrt{\varepsilon_{1r}-S_0^{i2}})(\varepsilon_{2r}\sqrt{\varepsilon_{1r}-S_0^{i2}} - \varepsilon_{1r}\sqrt{\varepsilon_{2r}-S_0^{i2}})}{(\varepsilon_{1r}C_0^{i} + \sqrt{\varepsilon_{1r}-S_0^{i2}})(\varepsilon_{2r}\sqrt{\varepsilon_{1r}-S_0^{i2}} + \varepsilon_{1r}\sqrt{\varepsilon_{2r}-S_0^{i2}})} \tag{7c}$$

$$A_1^{HH} = \frac{2(\varepsilon_{1r}-\varepsilon_{2r})(2(\varepsilon_{1r}-S_0^{i2})+(1-\varepsilon_{1r}))}{(1-\varepsilon_{1r})(\sqrt{\varepsilon_{1r}-S_0^{i2}}+\sqrt{\varepsilon_{2r}-S_0^{i2}})} \tag{7d}$$

$$A_2^{HH} = \left(\frac{\sqrt{\varepsilon_{1r}-S_0^{i2}} - \sqrt{\varepsilon_{2r}-S_0^{i2}}}{\sqrt{\varepsilon_{1r}-S_0^{i2}} + \sqrt{\varepsilon_{2r}-S_0^{i2}}} \right)^2 \tag{7e}$$

$$A_3^{HH} = \frac{(C_0^{i} - \sqrt{\varepsilon_{1r}-S_0^{i2}})(\sqrt{\varepsilon_{1r}-S_0^{i2}} - \sqrt{\varepsilon_{1r}-S_0^{i2}})}{(C_0^{i} + \sqrt{\varepsilon_{1r}-S_0^{i2}})(\sqrt{\varepsilon_{1r}-S_0^{i2}} + \sqrt{\varepsilon_{2r}-S_0^{i2}})} \tag{7f}$$

$$B_1 = -j\sqrt{\varepsilon_{1r}-S_0^{i2}}\ (2k_0H_0) \tag{7g}$$

Where θ_i is incident angle, $C_0^i=\cos\theta_i$, $S_0^i=\sin\theta_i$, K_1 and K_2 are parameters of sea surface. $ko=\omega\sqrt{\mu_0\varepsilon_0}$.

NUMERICAL CALCULATIONS

we have obtained the formulae of the backscattering cross section for oil film on slightly rough sea surface as given in Eqs. (3)-(7). Some numerical results are given here.

We plot the backscattering cross section for the case of $\varepsilon_{1r}=2.06-j0.021$, $\varepsilon_{2r}=58.11-j28.86$, and $K_1=0.003$, $K_2=5.5$, as a function of θ_i and koHo in Fig.2(a) and (b). It has been seen that when ko Ho increases the curves approach the curve of σ_{pq}^{I} (corresponding to koHo$\Rightarrow\infty$), when koHo decreases the curves approach the curve of koHo =0. for different koHo the curves appear great differences. It indicated that the return power from the lower interface always affects the total power. that is why Ho, as a important parameter in calculating the scattering problem, should be considered for general case.

Fig.3 gives the scattering characteristics of oil film on sea surface, which are calculated with different models. The solid line shows the results calculated by present model, and the dotted line denotes the results obtained by the single surface model [1] and "x" denotes the experimental points given in [1]. The good agreement between theoretical and experimental results justifys that the present model is more reasonable than single surface model for the oil film scattering problem.

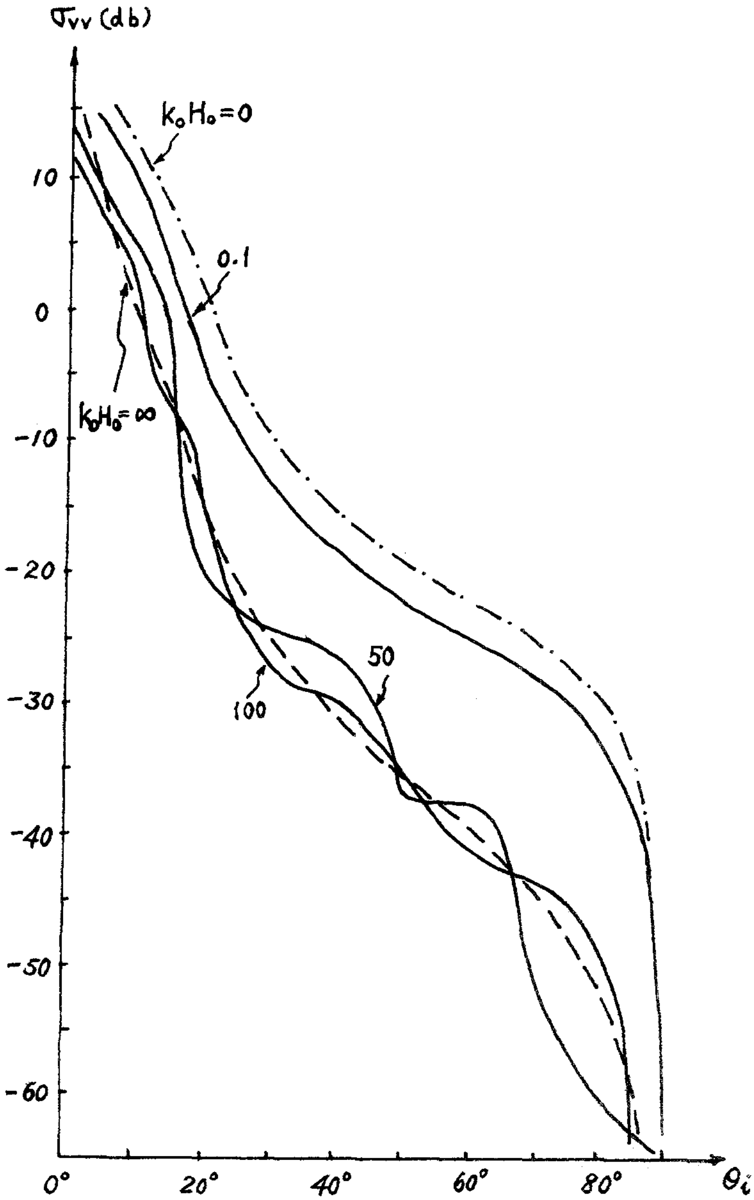

Fig.2 (a) Variation of σ_{vv} with incident angle.

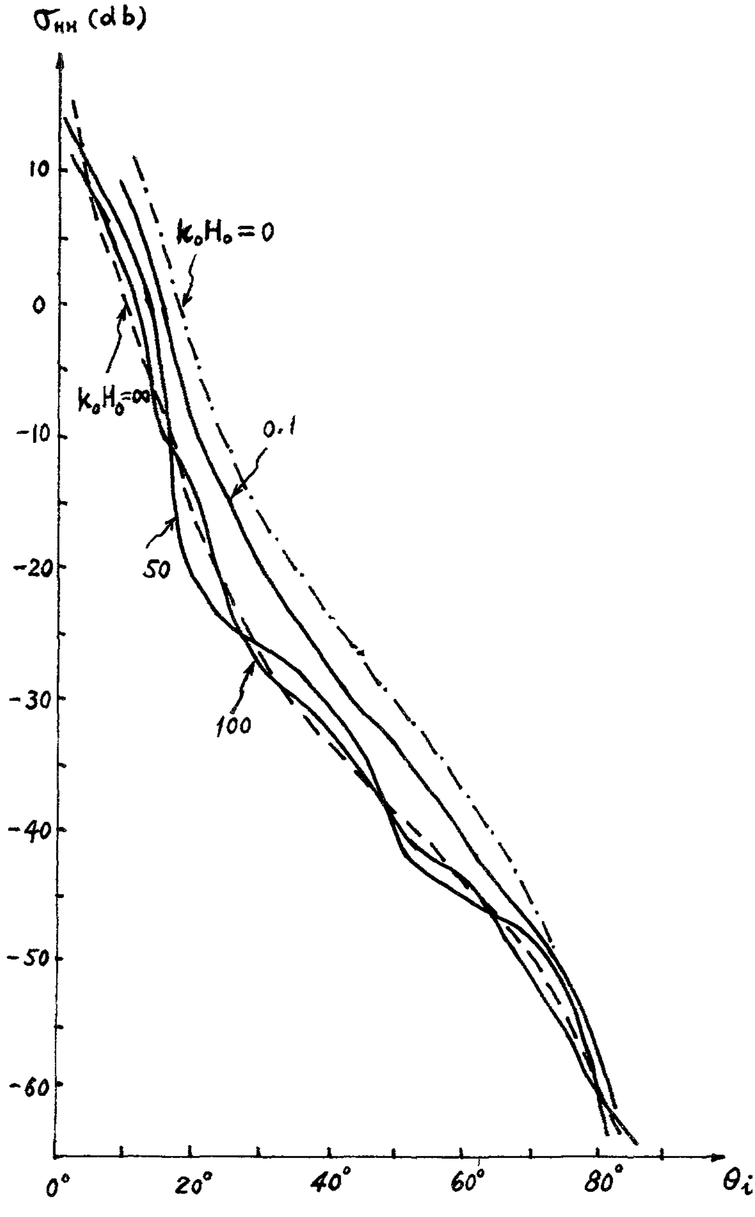

Fig.2 (b) Variation of σ_{HH} with incident angle.

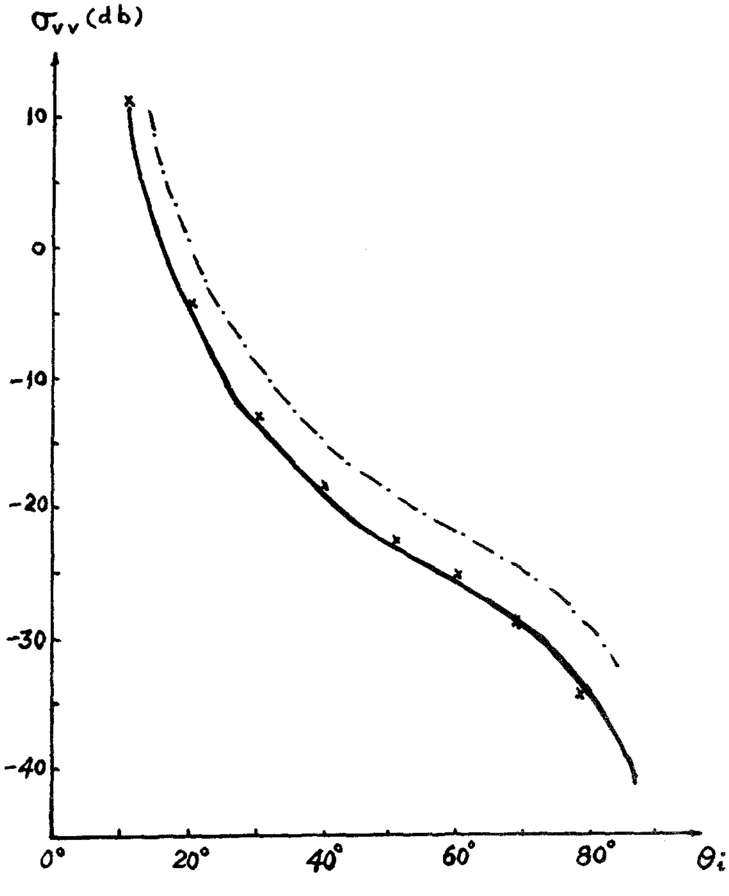

Fig.3 Comparison between two different models.

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