Research Article

Scattering of Antiplane SH Waves by Complex Landforms

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The multiple scattering of SH waves by isosceles triangular hill, semicircle depression, and isosceles trapezoidal hill in the solid half-space is studied. The complex model is divided into multiple subdomains by using the region matching method, then the wave functions in each subdomain are constructed by using the fractional-order Bessel function, and finally, the infinite algebraic equations for solving the unknown coefficients in the wave function are established by using the multipolar coordinate technique and the complex function method according to the boundary conditions. Fourier series is used to solve the unknown undetermined coefficients. The results show that due to the multiple reflections of the incident wave between complex landforms, surface displacement amplitude is affected by the incident angle, incident frequency, and the distance between the isosceles triangular hill, semicircle depression, and isosceles trapezoidal hill. It is found that when the incident frequency increases, there is a certain amplification effect between the hills and the depression. When the wave is incident horizontally, there is a certain “barrier” effect between hills and depression, and when the distance between the hills and depression reaches a certain level, the “barrier” effect will reach a stable value.

1. Introduction

In recent years, the research [1–4] on seismology has been widely valued by seismologists at home and abroad, which continuously and vigorously develops in the fields of crustal upper mantle structure and tectonic detection, natural earthquake prediction and disaster prevention, engineering building detection, energy survey, and other fields, which profoundly affects the politics, economy, and military of human society. Among all the factors affecting earthquakes, it has been confirmed that local landform is the most important factor causing seismic hazard or earthquake local changes, so correctly studying and analyzing the effect rule of landform on earthquake has essential engineering application value in seismology and earthquake. How to enhance comprehensive seismic capacity, effectively reduce the seismic hazard, and ensure the safety of life and property in the event of an earthquake to the greatest extent becomes an important topic for the majority of seismology researchers.

At present, based on the classical elastic wave theory [5–7], previous studies mainly focus on single landform aspects, such as single sag, deposit, and raised landform. Many scholars have studied these problems deeply and gained many valuable results. These studies have a reference significance of engineering to a certain extent. Trifunac [8–10] studied the nature of surface motion in and around a semicylindrical canyon, a semicylindrical alluvial valley, and a semieliptical alluvial valley under the case of incident plane SH waves. This study qualitatively explained some vibrating characteristics of long and deep alluvial valleys. Lee [11] studied the 2D scattering and diffraction of plane SH waves by a semiparabolic cylindrical canyon in an elastic half-space for the cases of SH waves coming from the side of the half-space toward the front of the canyon. Lee [12] presented a closed-form analytic solution of two-dimensional scattering and diffraction of plane SH waves by a semicylindrical hill with a semicylindrical concentric tunnel inside an elastic half-space by using the cylindrical wave function expansion method. Qiu [13] studied the antiplane response of an isosceles triangular hill to incident SH waves based on the method of complex function and by using a moving coordinate system. Yuan [14, 15] studied the
problem of scattering of plane SH waves by a semicylindrical hill in an otherwise homogeneous, isotropic, and elastic two-dimensional half-space by using the series of wave functions and a new expansion technique and then presented a closed-form solution of two-dimensional scattering of plane SH waves by a cylindrical canyon of circular-arc cross section in a half-space by using the wave functions expansion method. Francisco [16] explained a boundary method developed by Herrera in connection with wave scattering and studied the application to the scattering of the SH wave by surface irregularities. Qi [17, 18] studied the problem of the scattering of SH wave by the isosceles triangular hill in the right-angle plane given by using the methods of complex function and multiple coordinate and the scattering of SH wave in a half-space with oblique semieliptical notches. Tsaur [19] studied the dynamic antiplane problem of an elliptic-arc canyon in the comer of an elastic quarter space by using the method of wave function expansions and the method of images. Wang [20] studied the seismic response of a tunnel lining structure embedded in a thick expansive soil stratum. Shyu [21] proposed a novel strategy for the investigation of displacement amplitude near and along symmetric dikes embedded in a thick expansive soil stratum. In this paper, based on the accurate region matching method, the model is divided into four regions as shown in Figure 1: region 1 contains three semicircular canyons at the half-space boundary, region 2 contains an isosceles triangular hill and a semicircular bottom region, region 3 contains a fan-shaped domain formed by a trapezoidal side boundary, and region 4 contains a semicylindrical domain formed by the trapezoidal upper boundary. Because of many subdomains, the multipolar coordinate technique is used to construct the wavefield expressions in each subdomain. In region 1, the wave functions \( w^A \), \( w^C \), and \( w^D \) which satisfy the condition of no traction at the horizontal boundary are constructed. In region 2, the fractional-order Bessel function standing wave \( w^A \) satisfying the condition of no traction at the triangular isosceles boundary was constructed. In region 3, the divergent wave \( w^F \) and the cohesiv wave \( w^f \) satisfying the condition of no traction at the isosceles trapezoidal side were constructed. Finally, in region 4, the cohesive wave \( w^r \) satisfying the condition of no traction at the upper horizontal boundary was constructed. According to the continuous condition of displacement and stress of boundary \( s_p \), \( s_d \), and \( s_e \) and the nontraction conditions of boundary \( s_s \), a set of infinite algebraic equations will be obtained by introducing multipolar coordinates and complex function method. The amplitude of surface displacement of complex terrain is obtained by a numerical example. In this paper, the effects of different incident angles, incident frequency, size of the isosceles triangular mountain and isosceles trapezoid mountain, size of semicircle basin, and distance between mountains and basin on ground motion are studied. This study provides a theoretical reference for seismic mitigation and engineering construction planning of complex landforms.

2. Problem Description

The half-space model composed of an isosceles triangle, an isosceles trapezoid, and a semicircular depression is shown in Figure 1. The horizontal surface boundary is \( s_1 \), the convex vertex of the isosceles triangle is \( \alpha_1 \), the hypotenuse boundary is \( s_2 \), the height is \( h_1 \), the center point of the bottom side is \( o_1 \), and the length of the bottom side is \( 2L_1 \). The center of the semicircle depression is \( o \) and the radius is \( R \). The intersection point of isosceles trapezoid oblique edge is \( s_3 \), the oblique edge is \( s_4 \), the upper boundary is \( s_5 \), the center point of the upper boundary is \( o_3 \), the length of the upper edge is \( 2L_3 \), the center point of the bottom edge is \( o_4 \), the length of the bottom edge is \( 2L_2 \), the height is \( h_2 \), and the height of the intersection point of isosceles trapezoid oblique edge is \( h_3 \) from the upper boundary. Based on the idea of dividing regions, three auxiliary boundaries \( s_p, s_d, \) and \( s_e \) are introduced, which satisfy the continuity of stress and displacement at the auxiliary boundary. The model is divided into four regions as shown in Figure 1: region 1 is a half-space with three semicircular depressions at the horizontal boundary; region 2 is an isosceles triangle convex and semicircular bottom region; region 3 is a closed fan-shaped region formed by two semicircular curves; region 4 is an elastic semicircle. The six coordinate systems are
According to the small deformation theory, without considering the physical force, the elastic dynamic equation can be expressed as
\[(\lambda + \mu)\nabla (\nabla \cdot u) + \mu \nabla^2 u = \rho \ddot{u},\]
\[u = \text{Re}\{(u, v, w)\exp(-i\omega t)}\],
where \(\nabla\) is the vector differential operator, \(u\) is the displacement vector, \(\rho \ddot{u}\) is the inertia term, and \(\lambda\) and \(\mu\) are Lame constants.

In this paper, the SH wave is studied. Considering the antiplane displacement, then \(u = v = 0\). By substituting formula into (2) and (1) and omitting the time harmonic factor \(\exp(-i\omega t)\), the Helmholtz equation can be obtained as
\[\nabla^2 w + k^2 w = 0.\]

Three polar coordinate systems \((r, \theta), (r_1, \theta_1)\), and \((r_2, \theta_2)\) are defined in region 1, with a center point of \(o, o_1\), and \(o_2\) as shown in Figure 2. The total wavefield can be decomposed into the total scattered wavefield \(w^s\) and free displacement field \(w^{sr}\) by auxiliary boundaries \(s_b\) and \(s_d\) and semicircular sag boundary \(s_c\). The total wavefield can be expressed as follows:
\[w_1 = w^{sr} + w^r.\]

The incident wave field \(w^i\) and the reflected wavefield \(w^r\) generated by the horizontal boundary \(s\) are as follows:

\[w^i = w_0 \exp(ik[y \sin \alpha - x \cos \alpha]),\]
\[w^r = w_0 \exp(ik[y \sin \alpha + x \cos \alpha]).\]

The total scattered wave field can be divided into
\[w^s = w^B + w^C + w^D.\]

At the horizontal boundary, the three scattered wavefields satisfy the condition of no traction, which are expressed as follows:

\[\begin{align*}
\text{This paper} & \quad \text{Reference [16]} \\
\h_1/L_1 = 0.75 & \quad h_1/L_1 = 0.75 \\
\h_1/L_1 = 0.5 & \quad h_1/L_1 = 0.5 \\
\h_1/L_1 = 0.25 & \quad \ldots h_1/L_1 = 0.25
\end{align*}\]
\[ w^B(r_1, \theta_1) = w_0 \sum_{m=0}^{\infty} B_m H_m^{(1)}(kr_1)(\exp(i m \theta_1) + (-1)^m \exp(-i m \theta_1)), \]

\[ w^C(r, \theta) = w_0 \sum_{m=0}^{\infty} C_m H_m^{(1)}(kr)(\exp(i m \theta) + (-1)^m \exp(-i m \theta)), \]

\[ w^D(r_2, \theta_2) = w_0 \sum_{m=0}^{\infty} D_m H_m^{(1)}(kr_2)(\exp(i m \theta_2) + (-1)^m \exp(-i m \theta_2)). \]

Among them, when \( \theta_1 = \pm \pi/2 \), then \( \tau^B_{\theta_1} = \mu/r_1 \partial w^B/\partial \theta_1 = 0 \). When \( \theta = \pm \pi/2 \), then \( \tau^C_\theta = \mu/r \partial w^C/\partial \theta = 0 \). When \( \theta = \pm \pi/2 \), then \( \tau^D_{\theta_2} = \mu/r_2 \partial w^D/\partial \theta_2 = 0 \). \( H_m^{(1)}(\cdot) \) is the first \( m \)-order Hankel function and satisfies the radiation conditions. \( B_m, C_m, \) and \( D_m \) are the unknown undetermined coefficients.

The polar coordinate system \((r_3, \theta_3)\) is defined in the region and the center point is \( o_3 \). Region 2 is a closed region consisting of auxiliary boundary \( s_b \) and isosceles triangle boundary \( s_c \). The scattered wave \( w^A \) is constructed in the closed region, and the condition of no traction at the free boundary \( s_c \) is satisfied; that is, when \( \theta_3 = \pm \tan(L_2/h_2) \), then \( \tau^A_{\theta_3} = \mu/r_3 \partial w^A/\partial \theta_3 = 0 \). The scattered wave is as follows:

\[ w^A(r_3, \theta_3) = w_0 \sum_{m=0}^{\infty} A_m(I_m p_2)(kr_3)(\exp(i m \theta_3) + (-1)^m \exp(-i m \theta_3)), \]

where \( p_2 = \pi/(2 \arctan(L_2/h_2)) \). \( A_m \) is the unknown undetermined coefficient.

The polar coordinate system \((r_4, \theta_4)\) is defined in region 3 and the center point is \( o_4 \). Due to the construction of two semicircular auxiliary boundaries \( s_d \) and \( s_e \), there are cohesive wave \( w^E \) and divergent wave \( w^E \) in the closed region. Therefore, the cohesive wave and the divergent wave need to satisfy the traction-free boundary condition of the isosceles trapezoidal oblique edge \( s_f \); that is, when \( \theta_4 = \pm \theta_0 \), then \( \tau^E_{\theta_4} = \mu/r_4 \partial w^E/\partial \theta_4 = 0 \), and \( \tau^E_{\theta_4} = \mu/r_4 \partial w^E/\partial \theta_4 = 0 \). The cohesive wave \( w^E \) is shown in formula (12) and the divergent wave \( w^E \) is shown in formula (13):

\[ w^E(r_4, \theta_4) = w_0 \sum_{m=0}^{\infty} F_m(I_m p_2)(kr_4)(\exp(i m \theta_4) + (-1)^m \exp(-i m \theta_4)), \]

\[ w^E(r_4, \theta_4) = w_0 \sum_{m=0}^{\infty} E_m H_m^{(1)}(kr_4)(\exp(i m \theta_4) + (-1)^m \exp(-i m \theta_4)), \]

where \( p_2 = \pi/2 \theta_0 \). \( F_m \) and \( F_m \) are the unknown undetermined coefficients.

The polar coordinate system \((r_5, \theta_5)\) is defined in region 4 and the center point is \( o_5 \). Region 4 is a closed region composed of a semicircular auxiliary boundary \( s_g \) and a horizontal boundary \( s_g \). A cohesive wave \( w^G \) is constructed in the closed region, and the cohesive wave needs to satisfy the traction-free boundary condition of the horizontal boundary \( s_g \); that is, when \( \theta_5 = \pm \pi/2 \), then \( \tau^G_{\theta_5} = \mu/r_5 \partial w^G/\partial \theta_5 = 0 \). The cohesive wave \( w^G \) is as follows:

\[ w^G = w_0 \sum_{m=0}^{\infty} G_m(J_m(kr_5)(\exp(i m \theta_5) + (-1)^m \exp(-i m \theta_5))), \]

where \( G_m \) is the unknown undetermined coefficient.

According to the stress and displacement continuity of the auxiliary boundaries \( s_b, s_d, s_e \), and \( s_g \) and the traction-free condition of the semicircular depression boundary \( s_s \), the boundary equations for solving the unknown undetermined coefficients \( A_m, B_m, C_m, D_m, E_m, F_m, G_m \) are determined. The boundary conditions are as follows:
The infinite algebraic equations with unknown undetermined coefficients can be solved by substituting the wavefield functions in each subdomain into the boundary conditions (15).

4. Complex Function

The expression of the wavefield in each subdomain has been given, and the boundary equations for solving unknown undetermined coefficients have been determined. It is worth noting that the wave field expressions of each subdomain are established in their respective polar coordinates, but the solution of each boundary equation needs to be unified between the polar coordinates \((r, \theta)\), \((r_1, \theta_1)\), and \((r_2, \theta_2)\). At present, some studies use the addition formula to transform the coordinates. However, the physical model of complex landforms studied in this paper is relatively complex, so the addition formula theorem in isosceles triangle mountain, isosceles trapezoid mountain, and semicircle depression need to be derived again, which will bring a lot of calculation. Therefore, we use the complex function method to transform the coordinates of each subdomain, which will not only ensure the accuracy of the calculation but also greatly reduce the amount of calculation. In this paper, while defining the main coordinate system \((x, y)\), \((x, y)\), five subcoordinate systems \((x_j, y_j)\), \((x_j, y_j)\), \((x_j, y_j)\), \((x_j, y_j)\), \((x_j, y_j)\) are also defined. However, by using the multipolar coordinate method, the transformation between each complex coordinate system can be easily obtained. The transformation equations are as follows:

\[
z = z_1 - iL_4 = z_2 + iL_5 = z_3 - h_4 + iL_5 = z_4 - h_2 + iL_5 = z_5 - h_1 - iL_4.
\]

In the above equation, \(h_1, h_2, \) and \(h_4\), respectively, represent the vertical distance between the subcoordinate system \((z_3, \overline{z})\), \((z_3, \overline{z})\), and \((z_3, \overline{z})\) and the main coordinate system \((z, \overline{z})\). \(L_4\) is the horizontal distance between the subcoordinate system \((z_5, \overline{z})\), \((z_5, \overline{z})\) and the main coordinate system \((z, \overline{z})\). \(L_5\) is the horizontal distance between the subcoordinate system \((z_5, \overline{z})\), \((z_5, \overline{z})\) and the main coordinate system \((z, \overline{z})\).

The expression of Helmholz equation (3) in the main complex coordinate system is as follows:

\[
\frac{\partial^2 w}{\partial z^2} + \frac{1}{4} k^2 w = 0.
\]

The corresponding stress expressions are as follows:

\[
\begin{align*}
\tau_{xz} &= i\mu \left( \frac{\partial w}{\partial \bar{z}} + \frac{\partial \bar{w}}{\partial z} \right), \\
\tau_{\bar{z}z} &= -i\mu \left( \frac{\partial \bar{w}}{\partial \bar{z}} - \frac{\partial w}{\partial z} \right).
\end{align*}
\]

In the complex coordinate system \((z, \overline{z})\), according to the transformation relationship between coordinates in equation (16), the incident wavefield in equation (5) and the reflected wavefield in equation (6) can be expressed as

\[
\begin{align*}
w^i(z, \overline{z}) &= w_0 \sum_{m=-\infty}^{\infty} (-i)^m J_m(k|z|) e^{im\alpha} \left( \frac{z}{|z|} \right)^m, \\
w^r(z, \overline{z}) &= w_0 \sum_{m=-\infty}^{\infty} (i)^m J_m(k|z|) e^{-im\alpha} \left( \frac{z}{|z|} \right)^m.
\end{align*}
\]

The total free field \(w^{ir}\) can be expressed as

\[
w^{ir}(z, \overline{z}) = w_0 \sum_{m=-\infty}^{\infty} (i)^m J_m(k|z|) \left( (-1)^m e^{im\alpha} + e^{-im\alpha} \right) \left( \frac{z}{|z|} \right)^m.
\]

Under the condition that the total free field radial stress satisfies the condition of no traction on the horizontal boundary, the expression of the total free field radial stress in a complex coordinate system \((z, \overline{z})\) is as follows:
\[ r_{rz}^{i \gamma}(z, \bar{z}) = \frac{\mu k w_0}{2} \sum_{m=-\infty}^{\infty} (i)^m (J_{m-1}(k|\bar{z}|) - J_{m+1}(k|\bar{z}|)) \left( (-1)^m e^{i\max} + e^{-i\max} \right) \left( \frac{z}{|z|} \right)^m. \] (21)

The scattered wavefield \( w^B \) in equation (8) can be expressed in the complex coordinate system \((z, \bar{z})\) as

\[ w^B(z, \bar{z}) = w_0 \sum_{m=0}^{\infty} B_m H_m^{(1)}(k|z + iL_4|) \left( \frac{z + iL_4}{|z + iL_4|} \right)^m + (-1)^m \left( \frac{z + iL_4}{|z + iL_4|} \right)^{-m}. \] (22)

The corresponding radial stress is as follows:

\[ r_{rz}^B(z, \bar{z}) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} B_m \left( H_m^{(1)}(k|z + iL_4|) \left( \frac{z + iL_4}{|z + iL_4|} \right)^m - (-1)^m H_m^{(1)}(k|z + iL_4|) \left( \frac{z + iL_4}{|z + iL_4|} \right)^{-m} \right) e^{i\theta} + \]
\[ + (-1)^m H_m^{(1)}(k|z + iL_4|) \left( \frac{z + iL_4}{|z + iL_4|} \right)^{-m} e^{-i\theta} - H_m^{(1)}(k|z + iL_4|) \left( \frac{z + iL_4}{|z + iL_4|} \right)^{m+1} e^{-i\theta}. \] (23)

The scattered wavefield \( w^C \) in equation (9) can be expressed in the complex coordinate system \((z, \bar{z})\) as

\[ w^C(z, \bar{z}) = w_0 \sum_{m=0}^{\infty} C_m H_m^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^m + (-1)^m \left( \frac{z}{|z|} \right)^{-m}. \] (24)

The corresponding radial stress is as follows:

\[ r_{rz}^C(z, \bar{z}) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} C_m \left( H_m^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^m - (-1)^m H_m^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^{-m} \right) e^{i\theta} + \]
\[ + (-1)^m H_m^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^{-m} e^{-i\theta} - H_m^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^{m+1} e^{-i\theta}. \] (25)

The scattered wavefield \( w^D \) in equation (10) can be expressed in the complex coordinate system \((z, \bar{z})\) as

\[ w^D(z, \bar{z}) = w_0 \sum_{m=0}^{\infty} D_m H_m^{(1)}(k|z - iL_5|) \left( \frac{z - iL_5}{|z - iL_5|} \right)^m + (-1)^m \left( \frac{z - iL_5}{|z - iL_5|} \right)^{-m}. \] (26)
The corresponding radial stress is as follows:

\[
\tau_{rz}^D (z, \bar{z}) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} D_m \left( \lim_{k \to 0} \frac{H_{m+1}^{(1)}(k|z-iL_5|)}{z-iL_5} \right)^{m-1} e^{-i\theta} - (-1)^m \lim_{k \to 0} \frac{H_{m+1}^{(1)}(k|z-iL_5|)}{z-iL_5} e^{-i\theta} \]  

\[
+ (-1)^m \lim_{k \to 0} \frac{z-iL_5}{z-iL_5} \tau_{rz}^{(1)}(k|z-iL_5|) e^{-i\theta} - H_{m+1}^{(1)}(k|z-iL_5|) e^{-i\theta}).
\]

In the complex coordinate system \((z_1, \bar{z}_1)\), according to the transformation relationship between coordinates in equation (16), the total free field \(u^{j+\tau}\) in formula (21) can be expressed as

\[
w^{j+\tau}(z_1, \bar{z}_1) = w_0 \sum_{m=-\infty}^{\infty} (i)^m J_m(k|z_1-iL_4|) \left( (-1)^m e^{in\alpha} + e^{-in\alpha} \right) \left( \frac{z_1-iL_4}{z_1-iL_4} \right)^m.
\]

The corresponding total free field radial stress is as follows:

\[
\tau_{rz}^{j+\tau}(z_1, \bar{z}_1) = \frac{\mu k w_0}{2} \sum_{m=-\infty}^{\infty} (i)^m \left( J_{m-1}(k|z_1-iL_4|) - J_{m+1}(k|z_1-iL_4|) \right) \left( (-1)^m e^{in\alpha} + e^{-in\alpha} \right) \left( \frac{z_1-iL_4}{z_1-iL_4} \right)^m.
\]

The scattered wavefield \(w^A\) in equation (11) can be expressed in the complex coordinate system \((z_1, \bar{z}_1)\) as

\[
w^A(z_1, \bar{z}_1) = w_0 \sum_{m=0}^{\infty} A_m J_{mp_1}(k|z_1+h_1|) \left( \frac{z_1+h_1}{z_1+h_1} \right)^{mp_1} \left( z_1+h_1 \right)^{-mp_1}.
\]

The corresponding radial stress is as follows:

\[
\tau_{rz}^A = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} A_m \left( J_{mp_1-1}(k|z_1+h_1|) \right)^{mp_1} e^{-i\theta} - (-1)^m J_{mp_1+1}(k|z_1+h_1|) \left( \frac{z_1+h_1}{z_1+h_1} \right)^{-mp_1} e^{i\theta} \]  

\[
+ (-1)^m J_{mp_1-1}(k|z_1+h_1|) \left( \frac{z_1+h_1}{z_1+h_1} \right)^{-mp_1} e^{-i\theta} - J_{mp_1+1}(k|z_1+h_1|) \left( \frac{z_1+h_1}{z_1+h_1} \right)^{mp_1} e^{-i\theta}.
\]

The scattered wavefield \(w^B\) in equation (8) can be expressed in the complex coordinate system \((z_1, \bar{z}_1)\) as

\[
w^B(z_1, \bar{z}_1) = w_0 \sum_{m=0}^{\infty} B_m H_m^{(1)}(k|z_1|) \left( \frac{z_1}{z_1} \right)^m \left( \frac{z_1}{z_1} \right)^{-m}.
\]
The corresponding radial stress is as follows:

\[
\tau_{rz}^B(z_1, z_1) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} B_m \left( H_{m-1}^{(1)}(k|z_1|) \left( \frac{z_1}{|z_1|} \right)^{m-1} e^{i\theta_1} - (-1)^m H_{m+1}^{(1)}(k|z_1|) \left( \frac{z_1}{|z_1|} \right)^{m+1} e^{-i\theta_1} \right) + (-1)^m H_{m-1}^{(1)}(k|z_1|) \left( \frac{z_1}{|z_1|} \right)^{m-1} e^{i\theta_1} - H_{m+1}^{(1)}(k|z_1|) \left( \frac{z_1}{|z_1|} \right)^{m+1} e^{-i\theta_1} \right).
\]

(33)

The scattered wavefield \(w^C\) in equation (9) can be expressed in the complex coordinate system \((z_1, z_1)\) as

\[
w^C(z_1, z_1) = w_0 \sum_{m=0}^{\infty} C_m H_m^{(1)}(k|z_1 - iL_4|) \left( \frac{z_1 - iL_4}{|z_1 - iL_4|} \right)^m + (-1)^m \left( \frac{z_1 - iL_4}{|z_1 - iL_4|} \right)^m.
\]

(34)

The corresponding radial stress is as follows:

\[
\tau_{rz}^C(z_1, z_1) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} C_m \left( H_{m-1}^{(1)}(k|z_1 - iL_4|) \left( \frac{z_1 - iL_4}{|z_1 - iL_4|} \right)^{m-1} e^{i\theta_1} - (-1)^m H_{m+1}^{(1)}(k|z_1 - iL_4|) \left( \frac{z_1 - iL_4}{|z_1 - iL_4|} \right)^{m+1} e^{-i\theta_1} \right) + (-1)^m H_{m-1}^{(1)}(k|z_1 - iL_4|) \left( \frac{z_1 - iL_4}{|z_1 - iL_4|} \right)^{m-1} e^{i\theta_1} - H_{m+1}^{(1)}(k|z_1 - iL_4|) \left( \frac{z_1 - iL_4}{|z_1 - iL_4|} \right)^{m+1} e^{-i\theta_1} \right).
\]

(35)

The scattered wavefield \(w^D\) in equation (10) can be expressed in the complex coordinate system \((z_1, z_1)\) as

\[
w^D(z_1, z_1) = w_0 \sum_{m=0}^{\infty} D_m H_m^{(1)}(k|z_1 - i(L_4 + L_5)|) \left( \frac{z_1 - i(L_4 + L_5)}{|z_1 - i(L_4 + L_5)|} \right)^m + (-1)^m \left( \frac{z_1 - i(L_4 + L_5)}{|z_1 - i(L_4 + L_5)|} \right)^m.
\]

(36)

The corresponding radial stress is as follows:

\[
\tau_{rz}^D(z_1, z_1) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} D_m \left( H_{m-1}^{(1)}(k|z_1 - i(L_4 + L_5)|) \left( \frac{z_1 - i(L_4 + L_5)}{|z_1 - i(L_4 + L_5)|} \right)^{m-1} e^{i\theta_1} - (-1)^m H_{m+1}^{(1)}(k|z_1 - i(L_4 + L_5)|) \left( \frac{z_1 - i(L_4 + L_5)}{|z_1 - i(L_4 + L_5)|} \right)^{m+1} e^{-i\theta_1} \right) + (-1)^m H_{m-1}^{(1)}(k|z_1 - i(L_4 + L_5)|) \left( \frac{z_1 - i(L_4 + L_5)}{|z_1 - i(L_4 + L_5)|} \right)^{m-1} e^{i\theta_1} - H_{m+1}^{(1)}(k|z_1 - i(L_4 + L_5)|) \left( \frac{z_1 - i(L_4 + L_5)}{|z_1 - i(L_4 + L_5)|} \right)^{m+1} e^{-i\theta_1} \right).
\]

(37)

In the complex coordinate system \((z_2, z_2)\), according to the transformation relationship between each coordinate in equation (16), the total free field \(w^{izr}\) in formula (21) can be expressed as

\[
w^{izr}(z_2, z_2) = w_0 \sum_{m=-\infty}^{\infty} (i)^m f_m(k|z_2 + iL_5|) \left( (-1)^m e^{i\alpha_m} + e^{-i\alpha_m} \right) \left( \frac{z_2 + iL_5}{|z_2 + iL_5|} \right)^m.
\]

(38)
The corresponding total free field radial stress is as follows:

\[
\tau^{tr}_{rz}(z_2, \zeta_2) = \frac{\mu k w_0}{2} \sum_{m=-\infty}^{\infty} (i)^m \left( J_{m-1}(k|z_2 + iL_3|) - J_{m+1}(k|z_2 + iL_3|) \right) \left( -1 \right)^m e^{i\alpha_m} + e^{-i\alpha_m} \left( \frac{z_2 + iL_3}{z_2 + iL_3} \right)^m.
\]  

(39)

The scattered wavefield \(w^B\) in equation (8) can be expressed in the complex coordinate system \((z_2, \zeta_2)\) as

\[
w^B(z_2, \zeta_2) = w_0 \sum_{m=0}^{\infty} B_m H^{(1)}_m(k|z_2 + i(L_4 + L_5)|) \left( \frac{z_2 + i(L_4 + L_5)}{z_2 + i(L_4 + L_5)} \right)^m + (-1)^m \left( \frac{z_2 + i(L_4 + L_5)}{z_2 + i(L_4 + L_5)} \right)^{m-1}.
\]  

(40)

The corresponding radial stress is as follows:

\[
\tau^B_{rz}(z_2, \zeta_2) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} B_m \left( H^{(1)}_m(k|z_2 + i(L_4 + L_5)|) \left( \frac{z_2 + i(L_4 + L_5)}{z_2 + i(L_4 + L_5)} \right)^{m-1} + (-1)^m H^{(1)}_{m+1}(k|z_2 + i(L_4 + L_5)|) \left( \frac{z_2 + i(L_4 + L_5)}{z_2 + i(L_4 + L_5)} \right)^{m-1} \right) e^{i\phi_l}.
\]  

(41)

The scattered wavefield \(w^C\) in equation (9) can be expressed in the complex coordinate system \((z_2, \zeta_2)\) as

\[
w^C(z_2, \zeta_2) = w_0 \sum_{m=0}^{\infty} C_m H^{(1)}_m(k|z_2 + iL_3|) \left( \frac{z_2 + iL_3}{z_2 + iL_3} \right)^m + (-1)^m \left( \frac{z_2 + iL_3}{z_2 + iL_3} \right)^{m-1}.
\]  

(42)

The corresponding radial stress is as follows:

\[
\tau^C_{rz}(z_2, \zeta_2) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} C_m \left( H^{(1)}_m(k|z_2 + iL_3|) \left( \frac{z_2 + iL_3}{z_2 + iL_3} \right)^{m-1} + (-1)^m H^{(1)}_{m+1}(k|z_2 + iL_3|) \left( \frac{z_2 + iL_3}{z_2 + iL_3} \right)^{m-1} \right) e^{i\phi_l}.
\]  

(43)

The scattered wavefield \(w^D\) in equation (10) can be expressed in the complex coordinate system \((z_2, \zeta_2)\) as

\[
w^D(z_2, \zeta_2) = w_0 \sum_{m=0}^{\infty} D_m H^{(1)}_m(k|z_2|) \left( \frac{z_2}{z_2} \right)^m + (-1)^m \left( \frac{z_2}{z_2} \right)^{m-1}.
\]  

(44)
The corresponding radial stress is as follows:

\[
\tau_{rz}^{D}(z_2, \bar{z}_2) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} D_m \left( H_{m-1}^{(1)}(k|z_2|) \left( \frac{z_2}{|z_2|} \right)^{m-1} e^{i\theta_2} - (-1)^m H_{m+1}^{(1)}(k|z_2|) \left( \frac{z_2}{|z_2|} \right)^{m+1} e^{-i\theta_2} \right) + (-1)^m H_{m-1}^{(1)}(k|z_2|) \left( \frac{z_2}{|z_2|} \right)^{m+1} e^{-i\theta_2} - H_{m+1}^{(1)}(k|z_2|) \left( \frac{z_2}{|z_2|} \right)^{m+1} e^{-i\theta_2}. \tag{45}\]

The cohesive wave field \( w^F \) in equation (12) can be expressed in the complex coordinate system \((z_2, \bar{z}_2)\) as

\[
w^F(z_2, \bar{z}_2) = w_0 \sum_{m=0}^{\infty} F_m I_{mp_2}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{mp_2} + (-1)^m \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{-mp_2}. \tag{46}\]

The corresponding radial stress is as follows:

\[
\tau_{rz}^{F}(z_2, \bar{z}_2) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} F_m \left( I_{mp_2-1}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{mp_2-1} e^{i\theta_2} - (-1)^m I_{mp_2+1}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{-mp_2-1} e^{-i\theta_2} \right) + (-1)^m I_{mp_2-1}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{-mp_2-1} e^{-i\theta_2} - I_{mp_2+1}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{mp_2+1} e^{-i\theta_2}. \tag{47}\]

The divergent wavefield \( w^E \) in equation (13) can be expressed in the complex coordinate system \((z_2, \bar{z}_2)\) as

\[
w^E(z_2, \bar{z}_2) = w_0 \sum_{m=0}^{\infty} E_m H_{mp_2}^{(1)}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{mp_2} + (-1)^m \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{-mp_2}. \tag{48}\]

The corresponding radial stress is as follows:

\[
\tau_{rz}^{E}(z_2, \bar{z}_2) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} E_m \left( H_{mp_2-1}^{(1)}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{mp_2-1} e^{i\theta_2} - (-1)^m H_{mp_2+1}^{(1)}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{-mp_2-1} e^{-i\theta_2} \right) + (-1)^m H_{mp_2-1}^{(1)}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{-mp_2-1} e^{-i\theta_2} - H_{mp_2+1}^{(1)}(k|z_2 + h_2|) \left( \frac{z_2 + h_2}{|z_2 + h_2|} \right)^{mp_2+1} e^{-i\theta_2}. \tag{49}\]

In the complex coordinate system \((z_3, \bar{z}_3)\), according to the transformation relationship between coordinates in equation (16), the cohesive wave field \( w^F \) in equation (12) can be expressed as
\[ w^E(z_3, \bar{z}_3) = w_0 \sum_{m=0}^{\infty} F_m J_{m p_2}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{m p_2} + (-1)^m \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{-m p_2}. \]  

(50)

The corresponding radial stress is as follows:

\[ \tau^E_{rz}(z_3, \bar{z}_3) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} F_m \left( J_{m p_2-1}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{m p_2-1} e^{i \theta_3} - (-1)^m J_{m p_2+1}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{-m p_2+1} e^{-i \theta_3} \right). \]  

(51)

The divergent wavefield \( w^E \) in equation (13) can be expressed in the complex coordinate system \((z_3, \bar{z}_3)\) as

\[ w^E(z_3, \bar{z}_3) = w_0 \sum_{m=0}^{\infty} E_m H^{(1)}_{mp_2}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{m p_2} + (-1)^m \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{-m p_2}. \]  

(52)

The corresponding radial stress is as follows:

\[ \tau^E_{rz}(z_3, \bar{z}_3) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} E_m \left( H^{(1)}_{mp_2-1}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{m p_2-1} e^{i \theta_3} - (-1)^m H^{(1)}_{mp_2+1}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{|z_3 + h_3|} \right)^{-m p_2+1} e^{-i \theta_3} \right). \]  

(53)

The cohesive wavefield \( w^G \) in equation (14) can be expressed in the complex coordinate system \((z_3, \bar{z}_3)\) as

\[ w^G(z_3, \bar{z}_3) = w_0 \sum_{m=0}^{\infty} G_m J_{m}(k|z_3|) \left( \frac{z_3}{|z_3|} \right)^{m p_2} + (-1)^m \left( \frac{z_3}{|z_3|} \right)^{-m p_2}. \]  

(54)

The corresponding radial stress is as follows:

\[ \tau^G_{rz}(z_3, \bar{z}_3) = \frac{\mu k w_0}{2} \sum_{m=0}^{\infty} G_m \left( J_{m-1}(k|z_3|) \left( \frac{z_3}{|z_3|} \right)^{m-1} e^{i \theta_3} - (-1)^m J_{m+1}(k|z_3|) \left( \frac{z_3}{|z_3|} \right)^{-m-1} e^{i \theta_3} + (-1)^m J_{m-1}(k|z_3|) \left( \frac{z_3}{|z_3|} \right)^{-m+1} e^{-i \theta_3} \right). \]  

(55)
In equation (15), the continuous conditions of displacement and stress between regions 1 and 2, the continuous conditions of displacement and stress between regions 1 and 3, the continuous conditions of displacement and stress between regions 3 and 4, and the condition of no traction in the boundary of the semicircle depression can be expressed in the complex coordinate system as follows:

\[
\begin{aligned}
  w^A(z_1, \bar{z}_1) &= w^{ir}(z_1, \bar{z}_1) + w^B(z_1, \bar{z}_1) + w^C(z_1, \bar{z}_1) + w^D(z_1, \bar{z}_1), & |z_1| = L_1, \\
  \tau^A_r(z_1, \bar{z}_1) &= \tau^{ir}_r(z_1, \bar{z}_1) + \tau^B_r(z_1, \bar{z}_1) + \tau^C_r(z_1, \bar{z}_1) + \tau^D_r(z_1, \bar{z}_1), & |z_1| = L, \\
  w^D(z_2, \bar{z}_2) + w^f(z_2, \bar{z}_2) &= w^{ir}(z_2, \bar{z}_2) + w^B(z_2, \bar{z}_2) + w^C(z_2, \bar{z}_2) + w^D(z_2, \bar{z}_2), & |z_2| = L_2, \\
  \tau^D_r(z_2, \bar{z}_2) + \tau^f_r(z_2, \bar{z}_2) &= \tau^{ir}_r(z_2, \bar{z}_2) + \tau^B_r(z_2, \bar{z}_2) + \tau^C_r(z_2, \bar{z}_2) + \tau^D_r(z_2, \bar{z}_2), & |z_2| = L_2, \\
  w^d(z_3, \bar{z}_3) + w^f(z_3, \bar{z}_3) &= w^G(z_3, \bar{z}_3), & |z_3| = L_3, \\
  \tau^d_r(z_3, \bar{z}_3) + \tau^f_r(z_3, \bar{z}_3) &= \tau^G_r(z_3, \bar{z}_3), & |z_3| = L_3, \\
  \tau^{ir}_r(z, \bar{z}) + \tau^B_r(z, \bar{z}) + \tau^C_r(z, \bar{z}) + \tau^D_r(z, \bar{z}) &= 0. & |z| = R, \theta = \left(-\frac{\pi}{2}, \frac{\pi}{2}\right).
\end{aligned}
\]

By substituting the displacement field and stress field in each complex coordinate system into the boundary (56), the infinite algebraic equations can be obtained:

\[
\begin{aligned}
  \sum_{m=0}^{\infty} A_m \xi_m^{(11)} + \sum_{m=0}^{\infty} B_m \xi_m^{(12)} + \sum_{m=0}^{\infty} C_m \xi_m^{(13)} + \sum_{m=0}^{\infty} D_m \xi_m^{(14)} &= \sum_{m=-\infty}^{\infty} \xi_m^{(1)}, \\
  \sum_{m=0}^{\infty} A_m \xi_m^{(21)} + \sum_{m=0}^{\infty} B_m \xi_m^{(22)} + \sum_{m=0}^{\infty} C_m \xi_m^{(23)} + \sum_{m=0}^{\infty} D_m \xi_m^{(24)} &= \sum_{m=-\infty}^{\infty} \xi_m^{(2)}, \\
  \sum_{m=0}^{\infty} B_m \xi_m^{(32)} + \sum_{m=0}^{\infty} C_m \xi_m^{(33)} + \sum_{m=0}^{\infty} D_m \xi_m^{(34)} + \sum_{m=0}^{\infty} E_m \xi_m^{(35)} + \sum_{m=0}^{\infty} F_m \xi_m^{(36)} &= \sum_{m=-\infty}^{\infty} \xi_m^{(3)}, \\
  \sum_{m=0}^{\infty} B_m \xi_m^{(42)} + \sum_{m=0}^{\infty} C_m \xi_m^{(43)} + \sum_{m=0}^{\infty} D_m \xi_m^{(44)} + \sum_{m=0}^{\infty} E_m \xi_m^{(45)} + \sum_{m=0}^{\infty} F_m \xi_m^{(46)} &= \sum_{m=-\infty}^{\infty} \xi_m^{(4)}, \\
  \sum_{m=0}^{\infty} E_m \xi_m^{(55)} + \sum_{m=0}^{\infty} F_m \xi_m^{(56)} + \sum_{m=0}^{\infty} G_m \xi_m^{(57)} &= \sum_{m=-\infty}^{\infty} \xi_m^{(5)}, \\
  \sum_{m=0}^{\infty} E_m \xi_m^{(65)} + \sum_{m=0}^{\infty} F_m \xi_m^{(66)} + \sum_{m=0}^{\infty} G_m \xi_m^{(67)} &= \sum_{m=-\infty}^{\infty} \xi_m^{(6)}, \\
  \sum_{m=0}^{\infty} B_m \xi_m^{(72)} + \sum_{m=0}^{\infty} C_m \xi_m^{(73)} + \sum_{m=0}^{\infty} D_m \xi_m^{(74)} &= \sum_{m=-\infty}^{\infty} \xi_m^{(7)},
\end{aligned}
\]

where the expressions of \(\xi_m^{(f)}, \xi_m^{(k)}\), \(l = 11, 12, 13, 14, 21, 22, 23, 24, 32, 33, 34, 35, 36, 42, 43, 44, 45, 46, 55, 56, 57, 65, 66, 67, 72, 73, 74, k = 1, 2, 3, 4, 5, 6, 7\) in equation (58) are given in Appendix.

The Fourier series expansion method is used to solve the infinite algebraic equations. Multiply both sides of the infinite algebraic equation system by \(e^{-im\theta}\) and integrate on \((-\pi/2, \pi/2)\); then
The Fourier integral expression of the other functions is similar in form to equations (60) and (61). The system of equations (59) is an infinite algebraic equation system for solving unknown coefficients $A_m, B_m, C_m, D_m, E_m, F_m,$ and $G_m.$

### 5. Surface Displacement Amplitude

In order to study the interaction of antiplane SH waves among the isosceles triangular hill, semicircular basin depression, and the isosceles trapezoidal hill, it is necessary to discuss the influence of displacement amplitude on the frequency and incidence angle of incident SH wave and the influence of the distance between two hills and semicircle depression. The acceleration can be obtained if the displacement amplitude is obtained, which means that it can provide a better reference for seismic disaster mitigation for practical projects.

In region 1, the total displacement field is $w_1$, which can be expressed as

$$w_1 = w^r + w^h + w^A + w^D.$$  \hspace{1cm} (61)

In region 2, the total displacement field $w_2$ can be expressed as

$$w_2 = w^A.$$  \hspace{1cm} (62)

In region 3, the total displacement field $w_3$ can be expressed as

$$w_3 = w^r + w^F.$$  \hspace{1cm} (63)

In region 4, the total displacement field $w_4$ can be expressed as

$$w_4 = w^G.$$  \hspace{1cm} (64)

Equations (62)–(65) can also be expressed as

$$w_j = |w_j|e^{i(\omega - \psi_j)} \quad j = 1, 2, 3, 4,$$  \hspace{1cm} (65)

where $|w_j|$ is the displacement amplitude and $\psi_j$ is the phase angle.

The dimensionless frequency of an incident wave can be expressed as

$$\eta = \frac{2R}{\lambda} = \kappa \frac{R}{\sqrt{\pi}}$$  \hspace{1cm} (66)

where $\lambda$ is the wavelength of the incident wave.

### 6. Numerical Calculation and Analysis

Because horizontal boundary $s$ and semicircular concave boundary $s_4$ are no traction boundary, the precision of the analytical method can be tested using the residual
dimensionless stress on the surface of the basin. In this paper, taking the truncation of the Fourier series \( m = n = 20 \) is enough to make the residual dimensionless stress reach \( 10^{-3} \). The amplitude of incident wave under all computation conditions is \( w_0 = 1 \). What needs to be pointed out in our calculation model is that the incident wave, reflected wave, and scattered wave are all expressed at the origin \( o \) while the standing wave in the isosceles triangle is expressed at the origin \( o_3 \) and the standing waves in the isosceles trapezoid are all expressed at the origin \( o_1 \) and \( o_4 \) expansion which means that there is an isosceles triangle hill on the left side of the semicircular depression and an isosceles trapezoid hill on the right side of the semicircular depression.

To confirm the correctness of complex model wave function construction and calculation results in this paper, the model is first reduced to only contain the isosceles triangle hill bulge, and the isosceles triangle hill size data is set according to the literature [16]. \( h_3/L_0 \), that is the ratio of the height of the isosceles triangle to the base is 0.75, 0.5, and 0.25, respectively. The incident wave frequency is set to \( \eta = 0.5 \), and the incidence angle is set to \( \alpha = 0^\circ \). As shown in Figure 2, the computation result of the complex landforms model reducing isosceles triangle hill model is nearly the same as the literature [16]. Then, the complex landforms model is reduced to only contain semicircular depression, and the semicircular depression size is set according to the literature [9]. The radius of the semicircular depression is set to \( R = 1 \), the incident wave frequency is set to \( \eta = 0.5 \), and the incidence angles are set to \( 0^\circ, 30^\circ, 60^\circ, \) and \( 90^\circ \). As is shown in Figure 3, the computation result of the complex landforms model reducing semicircular depression is nearly the same as the literature [9]. Finally, the complex landforms model is reduced to only contain the isosceles trapezoid hill, and the isosceles trapezoid hill size data is set according to the literature [21]. The top side radius of the isosceles trapezoid is set to \( L_3 = 0.5 \). The bottom side radius of the isosceles trapezoid is set to \( L_1 = 1 \), and the incident angles are \( 0^\circ, 30^\circ, 60^\circ, \) and \( 90^\circ \). As shown in Figure 4, the computation result of the complex landforms model reducing the isosceles trapezoid is nearly the same as the literature [21]. The abovementioned reducing model computation confirms the accuracy and applicability of the method in this article.

To research the interaction between complex landforms, the amplitude of surface motion at different points is very important. Through numerical calculation, we can judge how far the distance between the mountains is, and the influence between the mountains will be ignored. In this paper, because we suppose that encouragement contains an SH wave with an amplitude of 1, without the isosceles triangle hill, the semicircular depression, and the isosceles trapezoid hill, the amplitude of ground motion will fluctuate around 2.

In Figure 5, we set the radius of the base of the isosceles triangle hill, the radius of the semicircular depression, and the radius of the base of the isosceles trapezoid hill \( L_1 = R = L_2 = 1 \). The distance between the center point of the isosceles triangle hill and the center point of the semicircular depression is \( L_4 = 3 \). The distance between the center point of the isosceles trapezoid hill and the center point of the semicircle depression is \( L_3 = 3 \). The top radius of the isosceles trapezoid hill is \( L_3 = 0.5 \). The height of the isosceles triangle hill is \( h_1 = 1 \), and the height of the isosceles trapezoid hill is \( h_4 = 0.5 \). To research the surface displacement amplitude of complex landforms, four cases \( \eta = 0.5, 1, 1.5, 2 \) are taken to research incidence angle \( \alpha = 0^\circ, 45^\circ, 90^\circ \) condition. It can be
seen obviously in Figure 5 that complex landforms coupling site has a significant impact on seismic waves. Unity site reaction depends on the incidence frequency and incidence angle. As shown in Figure 5(a), when $\eta = 0.5$, and under the circumstance that the wave is incident vertically $\alpha = 0^\circ$, the displacement amplitude of the top of the isosceles triangle hill (near $x/R = -3$) is small, which is only around 2.5. When the wave is incident horizontally $\alpha = 90^\circ$, the displacement amplitude of the top of the isosceles triangle hill (near $x/R = -3$) reaches 4, which shows that when the wave is incident horizontally, the displacement amplitude of the isosceles triangle hill will be affected by right semicircular depression and tends to increase. When the wave is incident vertically $\alpha = 0^\circ$, the displacement amplitude of the semicircular (near $x/R = 0$) is close to 0. The hills on the left and right sides show a "barrier" effect on the semicircular depression, the displacement amplitude in the semicircular depression will have a greater decline, and when the wave is incident horizontally $\alpha = 90^\circ$, the displacement amplitude of the semicircular depression (near $x/R = 0$) reaches about 3, and the hills on the left and right have an enlarged effect on it. When the wave is incident vertically $\alpha = 0^\circ$, the maximum displacement amplitude of the isosceles trapezoid hill (near $x/R = 3$) can reach about 3.5. When the wave is incident vertically $\alpha = 90^\circ$, the displacement amplitude of the isosceles trapezoid hill (near $x/R = 3$) has a slightly decreasing trend, and the displacement amplitude of the flat section on the right side of isosceles trapezoid hill gradually decreases to 2 and then reaches stabilization, which shows that when the wave level is incident from the left to the right, the isosceles triangular hill on the left and the semicircular depression have a "barrier effect" on the isosceles trapezoidal hill on the right.

In the case $\eta = 2$, as shown in Figure 5(c), as the frequency of the incident wave increases, the surface displacement distribution of complex landforms becomes more complicated. The displacement spatial shock gradually intensifies, and the mutual interference between the waves becomes more obvious. When the incident wave changes from vertical incidence to horizontal incidence, the surface displacement amplitude of the isosceles triangle hill (near $x/R = -3$) will be greatly decreased by the "barrier" effect, and the minimum surface displacement amplitude is 0.2. Compared with the low frequency $\eta = 0.5$, it is reduced by nearly 90%. The surface displacement amplitude of the isosceles trapezoid hill (near $x/R = 3$) is also greatly decreased, and the surface displacement amplitude is close to 2. Compared with the low frequency $\eta = 0.5$, it is reduced by nearly 50%. There is no obvious increase or decrease in the amplitude of the surface displacement in the semicircular depression (near $x/R = 0$). On the whole, when waves are incident horizontally $\alpha = 90^\circ$ from the left to the right, the left side of the isosceles triangle hill ($x/R \leq -4$) is determined by the displacement response of the isosceles triangle hill itself, the displacement amplitude distribution on the right side of the isosceles trapezoid hill ($x/R \geq -4$) is determined by the complex landform coupling "barrier" effect, and the displacement amplitude is significantly reduced. When the incident frequency is higher, the "barrier" effect is more obvious. When the wave is incident vertically $\alpha = 0^\circ$, with the increase of the incident frequency, the amplification effect of the displacement amplitude of the isosceles triangle hill (near $x/R = -3$) and the isosceles trapezoid hill (near $x/R = 3$) is more obvious, and the displacement amplitude distribution oscillation is intensified. However, the semicircular depression basin has a more obvious inhibitory effect.

Figure 6 shows the effect of changes in the distance between isosceles triangular hill, semicircular depression, and isosceles trapezoidal hill on the internal seismic response of complex landforms under different incident angles. In order to explore how far the distance between the landforms is, the influence between the landforms will be ignored. We give the distribution map of the displacement amplitude of the complex landforms under four conditions: the distance between the center point of the isosceles triangle hill and the center point of the semicircular depression and the distance between the center point of the isosceles trapezoid hill and the center point of the semicircular depression are $L_1 = L_2 = 3, 4, 6, 10$. We set the incidence frequency $\eta = 1$, and the radius of the base of the isosceles triangle hill, the radius of the semicircular depression, and the radius of the base of the isosceles trapezoid hill are $L_1 = R_1 = 1$. The top radius of the isosceles trapezoid hill is $L_3 = 0.5$. The height of the isosceles triangle hill is $h_1 = 1$, and the height of the isosceles trapezoid hill is $h_2 = 0.5$. To research the surface displacement amplitude of complex landforms, first, we analyze the isosceles triangle hill. When the wave is incident vertically $\alpha = 0^\circ$ and the isosceles triangle hill is $L_4 = 3$ away from the semicircular depression, the surface displacement amplitude of the isosceles triangle hill (near $x/R = -3$) reaches the maximum at the apex, and the maximum displacement amplitude is about 3.8. When the isosceles triangle hill is $L_4 = 4$ away from the semicircular depression, the surface displacement amplitude of the isosceles triangle hill (near $x/R = -4$) reaches the maximum at the apex, and the maximum displacement amplitude is about 5. When the isosceles triangle hill is $L_4 = 6$ away from the semicircular depression, the surface displacement amplitude of the isosceles triangle hill (near $x/R = -6$) reaches the maximum at the apex, and the maximum displacement amplitude is about 5. When the isosceles triangle hill is $L_4 = 10$ away from the semicircular depression, the surface displacement amplitude of the triangular hill (near $x/R = -10$) reaches its maximum at the apex, and the maximum displacement amplitude is also about 5. In summary, when $L_4$ reaches 4, the influence of terrain coupling between complex landforms on the isosceles triangular hill will be negligible.

When the wave is incident vertically $\alpha = 0^\circ$, the same is applied to the influence of terrain coupling between complex landforms on the semicircular depression (near $x/R = 0$). It can be seen from Figure 6 that when $L_4 = L_5$ reach 4, the surface displacement amplitude of the semicircular depression (near $x/R = 0$) will reach about 1.8 and become stable. When the wave is incident vertically $\alpha = 0^\circ$, we analyze the impact of terrain coupling between complex landforms on isosceles trapezoid hill. It can be seen from
Figure 6 that when $L_4 = L_5$ reach 4, the surface displacement amplitude of the isosceles trapezoid mountain will reach about 3.3 and become stable. On the whole, when $L_4 = L_5$ reach 4 and the wave is incident vertically, the characteristics of the surface displacement between the landforms will depend on their own response, and the mutual influence between the terrains will be negligible.

When the wave is incident horizontally $\alpha = 90^\circ$, because of the “barrier” effect, it is equally important to analyze the mutual influence of the distance between the landforms. It can be seen from Figure 6 that at that time $L_4 = L_5 = 3$, the maximum displacement amplitude of the isosceles triangle hill (near $x/R = -3$) reached 2.5 and no longer increased with the increase of $L_4$ and $L_5$. At that time $L_4 = L_5 = 4$, the maximum displacement amplitude of the semicircular depression (near $x/R = 0$) reached 1.5 and no longer increased with the increase of $L_4$ and $L_5$. At that time $L_4 = L_5 = 4$, the maximum displacement amplitude of the isosceles trapezoid hill (near $x/R = 4$) reaches 0.8, it will no longer increase with the increase of $L_4$ and $L_5$, and the flat displacement on the right side of the isosceles trapezoid hill will reach about 1.5 and then tend to remain unchanged. On the whole, when the
wave is incident horizontally, the complex landforms show a certain shielding effect. As the distance between the landforms increases, the shielding effect will tend to stabilize.

7. Conclusions
An analytical solution of steady-state SH wave scattering problem in semispace complex landforms (including an isosceles triangular hill, a semicircular depression, and an isosceles trapezoid hill) is presented by using region matching method, multipolar coordinate technique, and complex function method. A numerical example is given to calculate the surface displacement amplitude of complex landforms. The results of numerical examples show the following.

When the incidence frequency increases from 0.5 to 2, the fluctuation of the surface displacement amplitude distribution over complex landforms becomes more and more severe, and the oscillation range of the surface displacement amplitude gradually increases. When the frequency reaches 2, the displacement amplitude of the hill surface is twice that of the depression surface, which indicates that there is a
stronger wave interference between different landforms in the case of high frequency.

When the wave is horizontally incident from left to right, the surface displacement amplitude of the left isosceles triangular hill is determined by its own displacement response. The right semicircle depression and isosceles trapezoidal hill are affected by the "barrier" effect, and the surface displacement amplitude is significantly reduced.

When the wave is vertically incident, with the increase of the incident frequency, the surface displacement amplitude of the hills will increase by a certain value, and the surface displacement amplitude of the depression will be obviously suppressed.

When the distance between different landforms reaches a certain value, the surface displacement amplitude between different landforms will reach a stable value under the influence of coupling.

Appendix

The corresponding expressions for $\xi^{(l)}_m$, $\tilde{\xi}^{(l)}_m$, $l = 1, 2, 3, 4, 5, 6, 7$ in equation (58) are shown as follows.

\[
\begin{align*}
\xi^{(1)}_m &= J_{mp}(k|z_1 + h_1|) - (-1)^m \left( \frac{z_1 + h_1}{|z_1 + h_1|} \right)^{mp} \\
\xi^{(2)}_m &= -H^{(1)}_m(k|z_1|) - (-1)^m \left( \frac{z_1}{|z_1|} \right)^{m} \\
\xi^{(3)}_m &= -H^{(1)}_m(k|z_1 - iL_4|) - (-1)^m \left( \frac{z_1 - iL_4}{|z_1 - iL_4|} \right)^{m} \\
\xi^{(4)}_m &= -H^{(1)}_m(k|z_1 - i(L_4 + L_5)|) - (-1)^m \left( \frac{z_1 - i(L_4 + L_5)}{|z_1 - i(L_4 + L_5)|} \right)^{m} \\
\xi^{(5)}_m &= J_{mp-1}(k|z_1 + h_1|) - (-1)^m J_{mp+1}(k|z_1 + h_1|) - (-1)^m J_{mp-1}(k|z_1 + h_1|) - (-1)^m J_{mp+1}(k|z_1 + h_1|) \\
\xi^{(6)}_m &= -H^{(1)}_{m-1}(k|z_1|) - (-1)^m H^{(1)}_{m+1}(k|z_1|) - (-1)^m H^{(1)}_{m-1}(k|z_1|) - (-1)^m H^{(1)}_{m+1}(k|z_1|) \\
\xi^{(7)}_m &= -H^{(1)}_{m-1}(k|z_1 - iL_4|) - (-1)^m H^{(1)}_{m+1}(k|z_1 - iL_4|) - (-1)^m H^{(1)}_{m-1}(k|z_1 - iL_4|) - (-1)^m H^{(1)}_{m+1}(k|z_1 - iL_4|) \\
\xi^{(8)}_m &= -H^{(1)}_{m-1}(k|z_1 - i(L_4 + L_5)|) - (-1)^m H^{(1)}_{m+1}(k|z_1 - i(L_4 + L_5)|) - (-1)^m H^{(1)}_{m-1}(k|z_1 - i(L_4 + L_5)|) - (-1)^m H^{(1)}_{m+1}(k|z_1 - i(L_4 + L_5)|) \\
\end{align*}
\]
\[\xi_m^{(24)} = -H_m^{(1)}(k|z_1 - i(L_4 + L_5))(z_1 - i(L_4 + L_5))^{-m-1} e^{\theta_i} + (-1)^m H_m^{(1)}(k|z_1 - i(L_4 + L_5))(z_1 - i(L_4 + L_5))^{-m-1} e^{\theta_i},\]

\[+ (-1)^m H_m^{(1)}(k|z_1 - i(L_4 + L_5))(z_1 - i(L_4 + L_5))^{-m-1} e^{\theta_i} + H_m^{(1)}(k|z_1 - i(L_4 + L_5))(z_1 - i(L_4 + L_5))^{-m-1} e^{\theta_i},\]

\[\xi_m^{(32)} = H_m^{(1)}(k|z_2 + i(L_4 + L_5))\left(\frac{z_2 + i(L_4 + L_5)}{|z_2 + i(L_4 + L_5)|}\right)^m + (-1)^m \left(\frac{z_2 + i(L_4 + L_5)}{|z_2 + i(L_4 + L_5)|}\right)^m,\]

\[\xi_m^{(33)} = H_m^{(1)}(k|z_2 + iL_5)\left(\frac{z_2 + iL_5}{|z_2 + iL_5|}\right)^m + (-1)^m \left(\frac{z_2 + iL_5}{|z_2 + iL_5|}\right)^m,\]

\[\xi_m^{(34)} = H_m^{(1)}(k|z_2)\left(\frac{z_2}{|z_2|}\right)^m + (-1)^m \left(\frac{z_2}{|z_2|}\right)^m,\]

\[\xi_m^{(35)} = -H_m^{(1)}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m - (-1)^m H_m^{(1)}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m,\]

\[\xi_m^{(36)} = -J_{mp_1}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m - (-1)^m J_{mp_1}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m,\]

\[\xi_m^{(42)} = H_m^{(1)}(k|z_2 + i(L_4 + L_5))\left(\frac{z_2 + i(L_4 + L_5)}{|z_2 + i(L_4 + L_5)|}\right)^m e^{\theta_i} - (-1)^m H_m^{(1)}(k|z_2 + i(L_4 + L_5))\left(\frac{z_2 + i(L_4 + L_5)}{|z_2 + i(L_4 + L_5)|}\right)^m e^{\theta_i},\]

\[+ (-1)^m H_m^{(1)}(k|z_2 + i(L_4 + L_5))\left(\frac{z_2 + i(L_4 + L_5)}{|z_2 + i(L_4 + L_5)|}\right)^m e^{-\theta_i} - H_m^{(1)}(k|z_2 + i(L_4 + L_5))\left(\frac{z_2 + i(L_4 + L_5)}{|z_2 + i(L_4 + L_5)|}\right)^m e^{-\theta_i},\]

\[\xi_m^{(43)} = H_m^{(1)}(k|z_2)\left(\frac{z_2}{|z_2|}\right)^m e^{\theta_i} - (-1)^m H_m^{(1)}(k|z_2)\left(\frac{z_2}{|z_2|}\right)^m e^{\theta_i},\]

\[\xi_m^{(44)} = -H_m^{(1)}(k|z_2)\left(\frac{z_2}{|z_2|}\right)^m e^{\theta_i} - (-1)^m H_m^{(1)}(k|z_2)\left(\frac{z_2}{|z_2|}\right)^m e^{\theta_i},\]

\[\xi_m^{(45)} = -H_{mp_{p_1}}^{(1)}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m e^{\theta_i} - (-1)^m H_{mp_{p_1}}^{(1)}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m e^{\theta_i},\]

\[\xi_m^{(46)} = -J_{mp_{p_1}}^{(1)}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m e^{\theta_i} - (-1)^m J_{mp_{p_1}}^{(1)}(k|z_2 + h_2)\left(\frac{z_2 + h_2}{|z_2 + h_2|}\right)^m e^{\theta_i},\]

\[\xi_m^{(55)} = H_m^{(1)}(k|z_3 + h_3)\left(\frac{z_3 + h_3}{|z_3 + h_3|}\right)^m e^{-\theta_i} + (-1)^m \left(\frac{z_3 + h_3}{|z_3 + h_3|}\right)^m e^{-\theta_i},\]
\[ \zeta_m^{(56)} = f_{mp_2}(k|z_3 + h_3|) \left( \left( \frac{z_3 + h_3}{z_3 + h_3} \right)^{m_{p_2}} + (-1)^m \left( \frac{z_3 + h_3}{z_3 + h_3} \right)^{-m_{p_2}} \right), \]
\[ \zeta_m^{(57)} = -f_m(k|z_3|) \left( \left( \frac{z_3}{z_3} \right)^m + (-1)^m \left( \frac{z_3}{z_3} \right)^{-m} \right), \]
\[ \zeta_m^{(63)} = H_{mp_2}^{(1)}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{z_3 + h_3} \right)^{m_{p_2}-1} e^{j\theta} - (-1)^m H_{mp_2+1}^{(1)}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{z_3 + h_3} \right)^{m_{p_2}-1} e^{j\theta}, \]
\[ \zeta_m^{(66)} = f_{mp_2-1}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{z_3 + h_3} \right)^{m_{p_2}-1} e^{j\theta} - (-1)^m f_{mp_2+1}(k|z_3 + h_3|) \left( \frac{z_3 + h_3}{z_3 + h_3} \right)^{m_{p_2}-1} e^{j\theta}, \]
\[ \zeta_m^{(67)} = -f_{m-1}(k|z_3|) \left( \frac{z_3}{z_3} \right)^{m-1} e^{j\theta} + (-1)^m f_{m+1}(k|z_4|) \left( \frac{z_4}{z_4} \right)^{m-1} e^{j\theta} - (-1)^m f_{m-1}(k|z_3|) \left( \frac{z_3}{z_3} \right)^{m-1} e^{j\theta}, \]
\[ \zeta_m^{(72)} = H_{m+1}^{(1)}(k|z + iL_4|) \left( \frac{z + iL_4}{z + iL_4} \right)^{m-1} e^{j\theta} - (-1)^m H_{m+1}^{(1)}(k|z + iL_4|) \left( \frac{z + iL_4}{z + iL_4} \right)^{m-1} e^{j\theta}, \]
\[ \zeta_m^{(73)} = H_{m+1}^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^{m-1} e^{j\theta} + (-1)^m H_{m-1}^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^{m-1} e^{j\theta} - H_{m+1}^{(1)}(k|z|) \left( \frac{z}{|z|} \right)^{m-1} e^{j\theta}, \]
\[ \zeta_m^{(74)} = H_{m+1}^{(1)}(k|z - iL_5|) \left( \frac{z - iL_5}{z - iL_5} \right)^{m-1} e^{j\theta} - (-1)^m H_{m+1}^{(1)}(k|z - iL_5|) \left( \frac{z - iL_5}{z - iL_5} \right)^{m-1} e^{j\theta}, \]
\[ \zeta_m^{(1)} = (i)^m f_m(k|z_1 - iL_4|) \left( (-1)^m e^{ima} + e^{-ima} \right) \left( \frac{z_1 - iL_4}{z_1 - iL_4} \right)^m, \]
\[ \zeta_m^{(2)} = (i)^m f_m(k|z_1 - iL_4|) - f_{m+1}(k|z_1 - iL_4|) \left( (-1)^m e^{ima} + e^{-ima} \right) \left( \frac{z_1 - iL_4}{z_1 - iL_4} \right)^m, \]
\[ \zeta_m^{(3)} = -(i)^m f_m(k|z_2 + iL_5|) \left( (-1)^m e^{ima} + e^{-ima} \right) \left( \frac{z_2 + iL_5}{z_2 + iL_5} \right)^m, \]
\[ \zeta_m^{(4)} = -(i)^m f_m(k|z_2 + iL_5|) - f_{m+1}(k|z_2 + iL_5|) \left( (-1)^m e^{ima} + e^{-ima} \right) \left( \frac{z_2 + iL_5}{z_2 + iL_5} \right)^m, \]
\[ \zeta_m^{(5)} = 0, \]
\[ \zeta_m^{(6)} = 0, \]
\[ \zeta_m^{(7)} = -(i)^m f_m(k|z|) \left( (-1)^m e^{ima} + e^{-ima} \right) \left( \frac{z}{|z|} \right)^m. \]
Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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