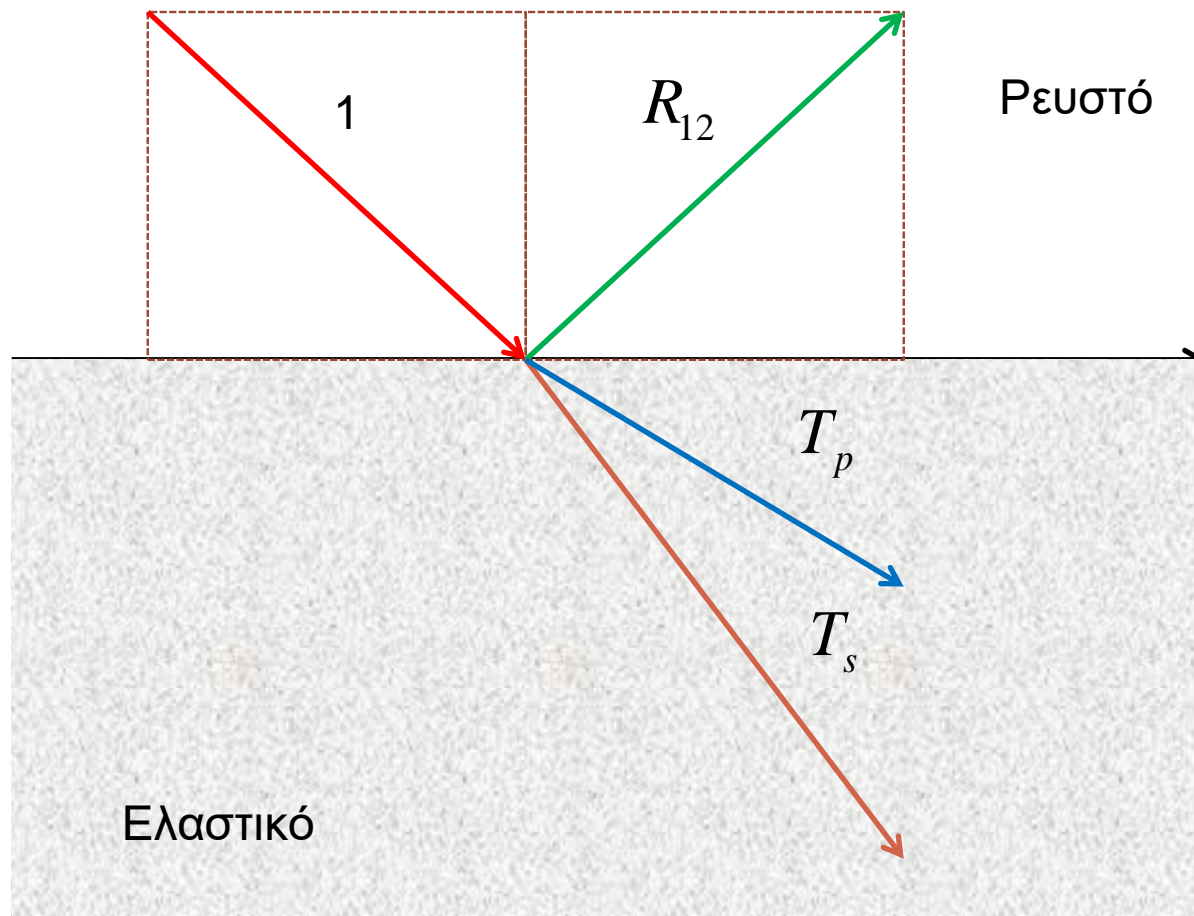
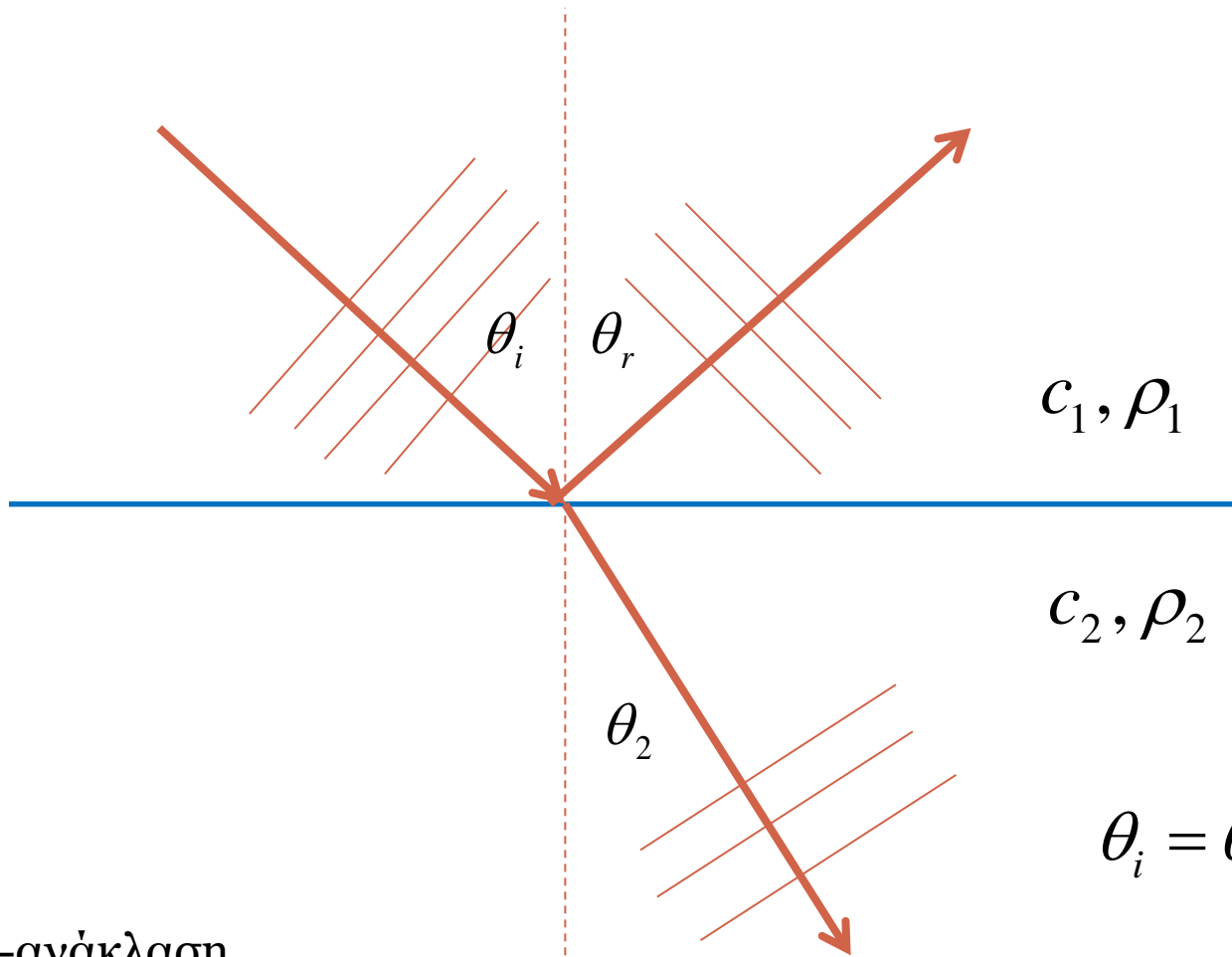


Περίπτωση ρευστών
στρωμάτων

Εισαγωγή στην Ακουστική Ωκεανογραφία

Ανάκλαση από ελαστικό ημιάπειρο πυθμένα





Διάδοση-ανάκλαση
 ακουστικού κύματος ανάμεσα
 σε δύο ρευστά μέσα

$$\theta_i = \theta_r = \theta_1$$

$$\frac{c_1}{\sin \theta_1} = \frac{c_2}{\sin \theta_2}$$

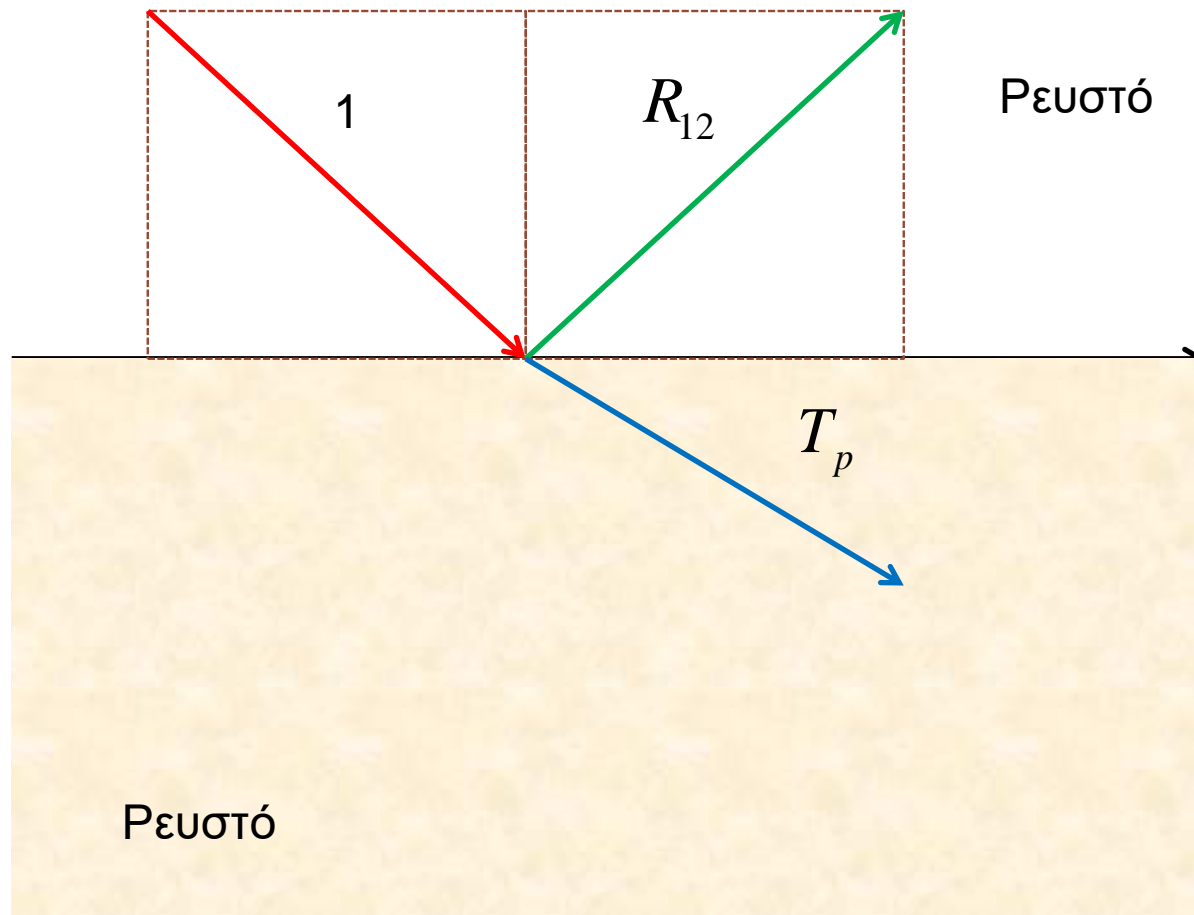
Περίπτωση Ρευστού Πυθμένα

$$\Phi_{1i} = e^{i(k_x x + k_{z1} z - \omega t)}$$

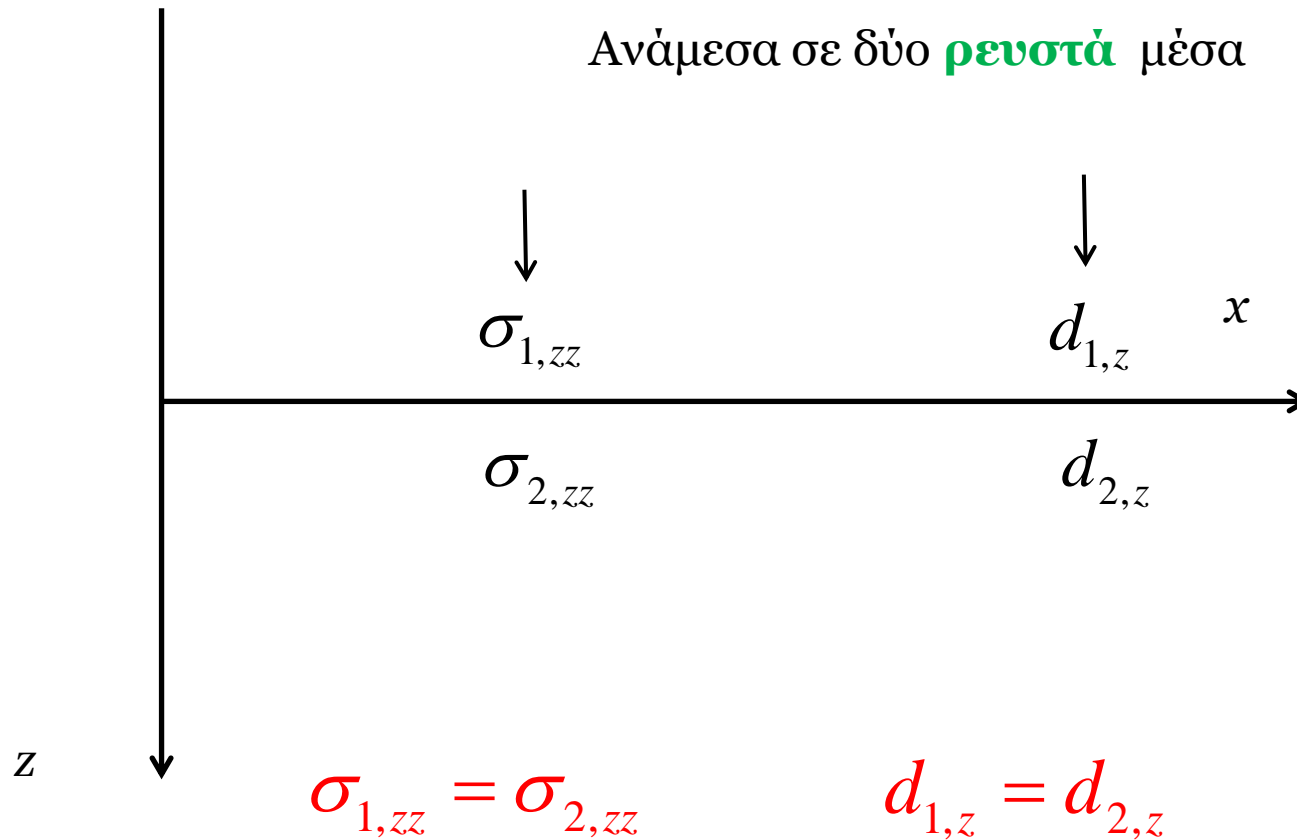
$$\Phi_{1r} = R_{12} e^{i(k_x x - k_{z1} z - \omega t)}$$

$$\Phi_2 = T_p e^{i(k_x x + k_{z2} z - \omega t)}$$

Ανάκλαση από ρευστό ημιάπειρο πυθμένα



Οριακές συνθήκες στη διεπιφάνεια $z=0$



Οριακές Συνθήκες

$$\sigma_{1,zz} = \sigma_{2,zz}$$

$$d_{1z} = d_{2z}$$

$$\sigma_{zz} = \lambda \nabla^2 \Phi, \quad \vec{d} = \nabla \Phi$$

$$\lambda = \rho c_p^2$$

$$\nabla^2 \Phi = \frac{1}{c_p^2} \frac{\partial^2 \Phi}{\partial t^2}$$

$$\rho_1 \frac{\partial^2 \Phi_1}{\partial t^2} = \rho_2 \frac{\partial^2 \Phi_2}{\partial t^2}$$

$$\frac{\partial \Phi_1}{\partial z} = \frac{\partial \Phi_2}{\partial z}$$

$$\Phi_1 = \Phi_{1i} + \Phi_{1r}$$

$$\Phi_2$$

$$\rho_1 \omega^2 \left\{ e^{i(k_x x + k_{z1} z - \omega t)} + R_{12} e^{i(k_x x - k_{z1} z - \omega t)} \right\} = \rho_2 \omega^2 T_p e^{i(k_x x + k_{z2} z - \omega t)}$$

$$ik_{z1} \left\{ e^{i(k_x x + k_{z1} z - \omega t)} - R_{12} e^{i(k_x x - k_{z1} z - \omega t)} \right\} = ik_{z2} T_p e^{i(k_x x + k_{z2} z - \omega t)}$$

$$z = 0 \quad \longrightarrow \quad \rho_1 (1 + R_{12}) = \rho_2 T_p$$

$$k_{z1} (1 - R_{12}) = k_{z2} T_p$$

$$R_{12} = \frac{k_{z1}\rho_2 - k_{z2}\rho_1}{k_{z1}\rho_2 + k_{z2}\rho_1}$$

$$T_p = \frac{2k_{z1}\rho_1}{k_{z1}\rho_2 + k_{z2}\rho_1}$$

$$k_{z1} = k_1 \cos\theta_1 = \frac{\omega}{c_1} \cos\theta_1$$

$$k_{z2} = k_2 \cos\theta_2 = \frac{\omega}{c_2} \cos\theta_2$$

$$R_{12} = \frac{\rho_2 c_2 \cos\theta_1 - \rho_1 c_1 \cos\theta_2}{\rho_2 c_2 \cos\theta_1 + \rho_1 c_1 \cos\theta_2}$$

$$\sin \theta_2 = \frac{c_2}{c_1} \sin \theta_1$$

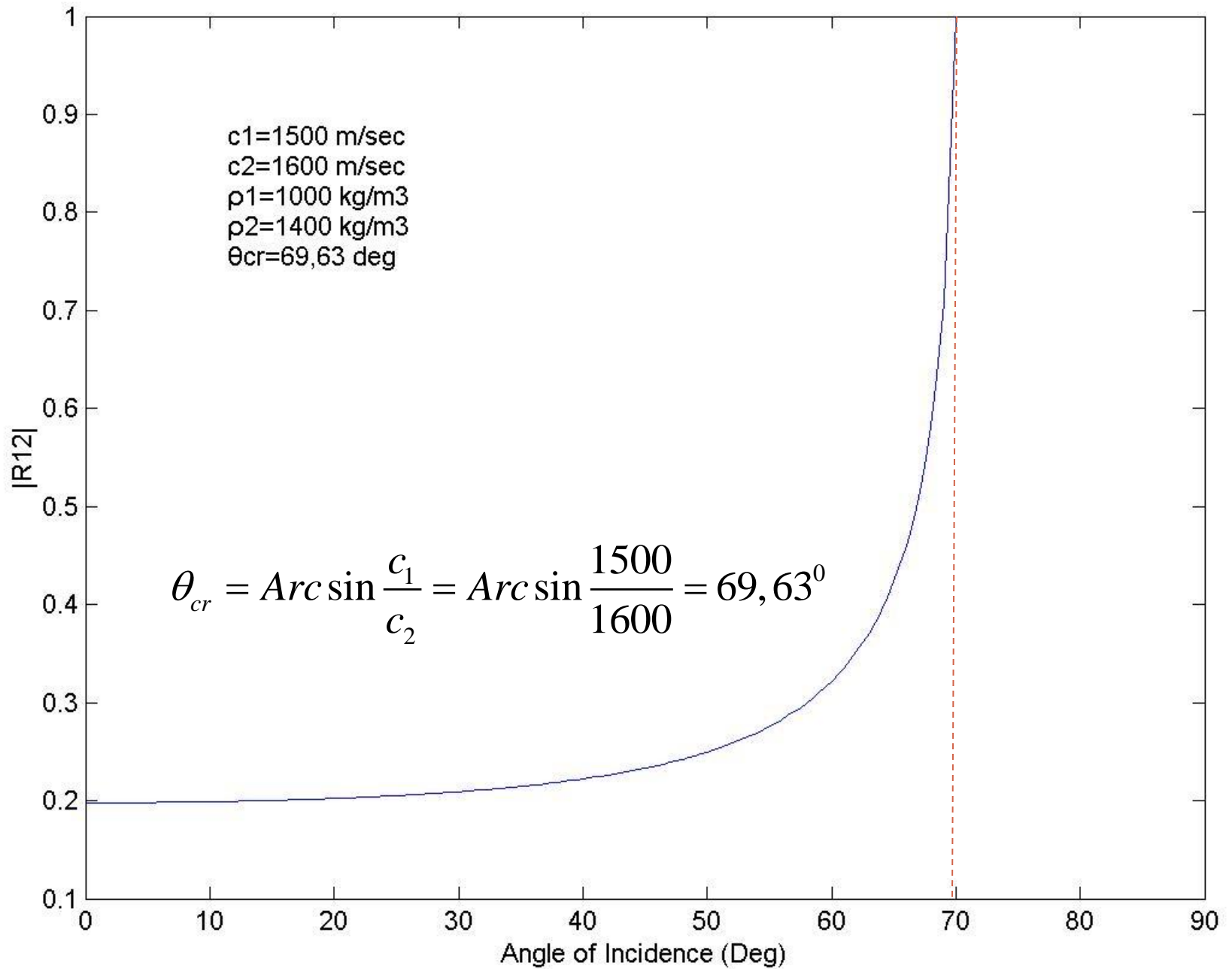
$$\cos \theta_2 = \sqrt{1 - \left(\frac{c_2}{c_1}\right)^2 \sin^2 \theta_1}$$

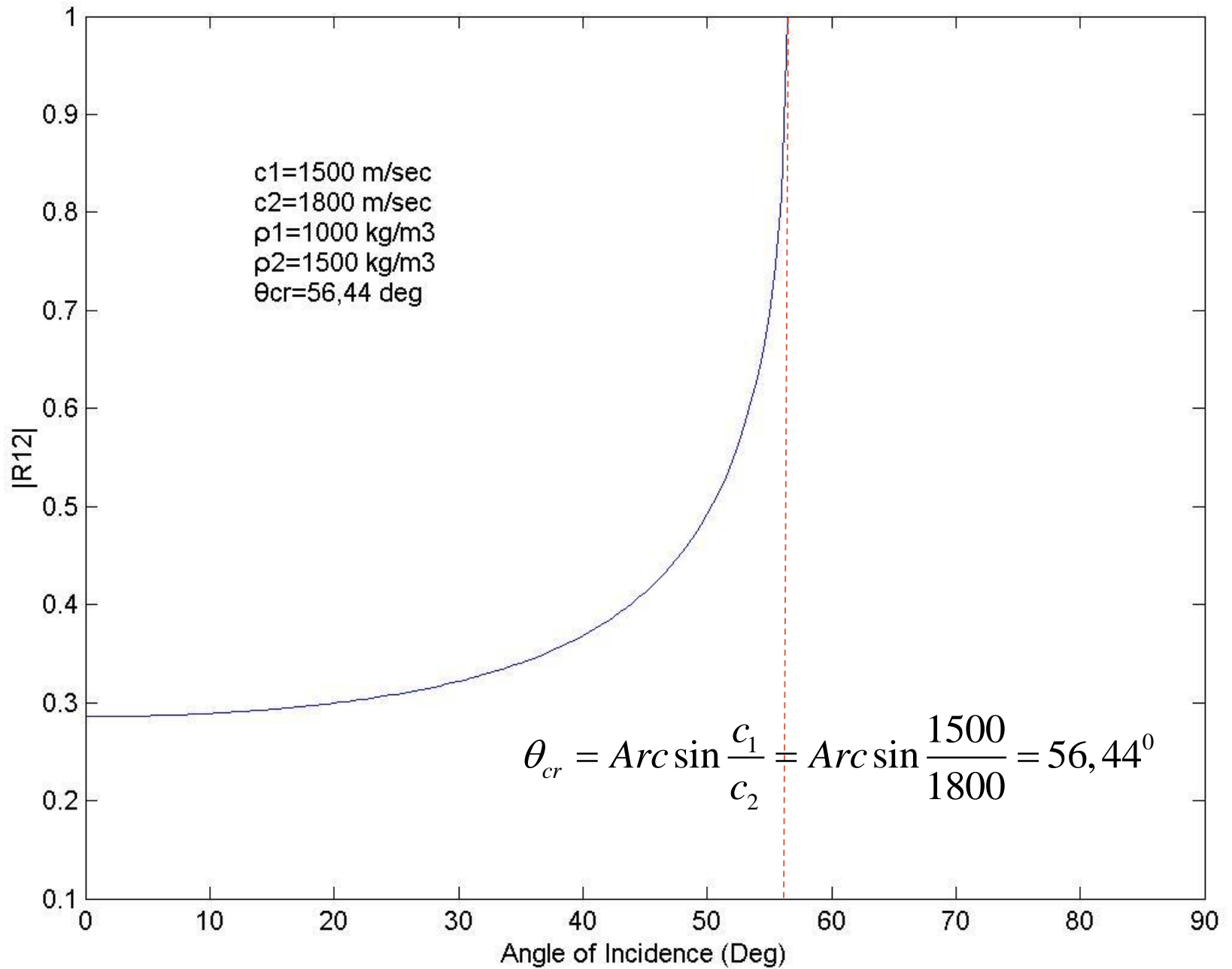
$$\theta_{cr} = \text{Arc sin} \frac{c_1}{c_2} \quad \text{Κρίσιμη γωνία}$$

Για $\theta_1 > \theta_{cr}$

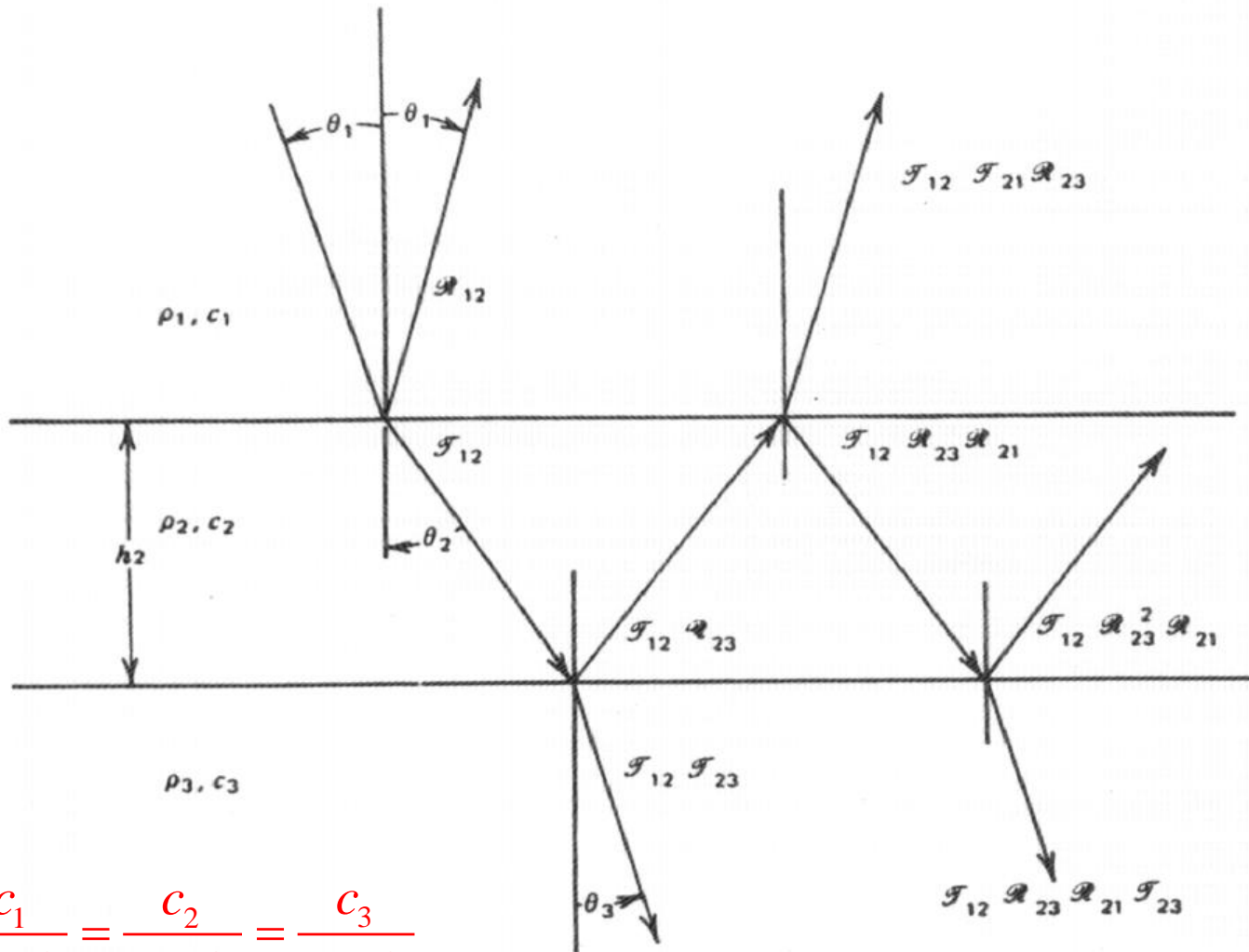
$$R_{12} = \frac{k_{z1} \rho_2 - i g_2 \rho_1}{k_{z1} \rho_2 + i g_2 \rho_1}$$

$$R_{12} = -e^{i2\chi} \quad |R_{12}| = 1 \quad \chi = \text{Arc tan} \left(\frac{\rho_2}{\rho_1} \frac{k_{z1}}{g_2} \right)$$





Πολυστρωματοποιημένα μέσα



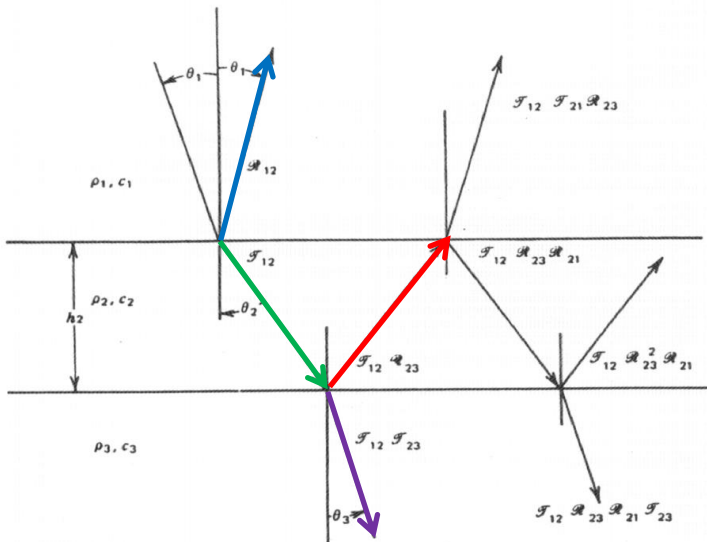
$$\frac{c_1}{\sin \theta_1} = \frac{c_2}{\sin \theta_2} = \frac{c_3}{\sin \theta_3}$$

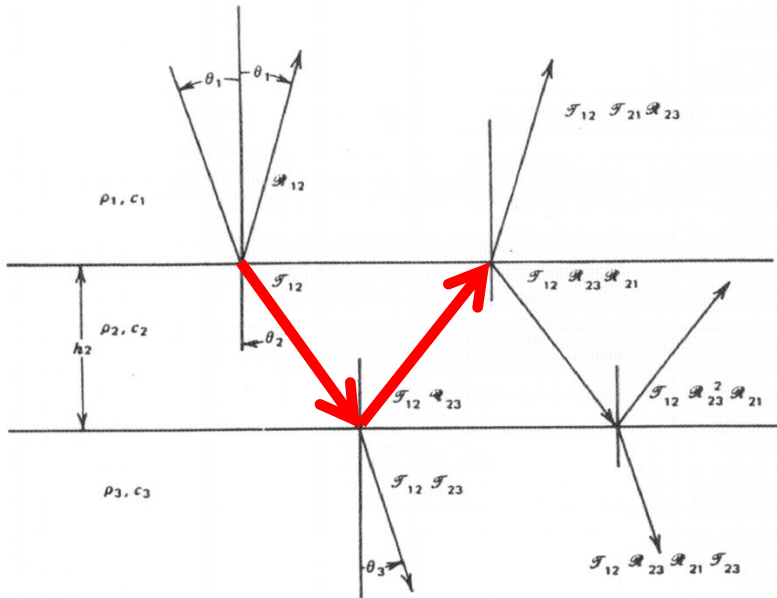
$$R_{12} = \frac{\rho_2 c_2 \cos \theta_1 - \rho_1 c_1 \cos \theta_2}{\rho_2 c_2 \cos \theta_1 + \rho_1 c_1 \cos \theta_2}$$

$$R_{23} = \frac{\rho_3 c_3 \cos \theta_2 - \rho_2 c_2 \cos \theta_3}{\rho_3 c_3 \cos \theta_2 + \rho_2 c_2 \cos \theta_3}$$

$$T_{12} = \frac{2\rho_1 c_2 \cos \theta_1}{\rho_2 c_2 \cos \theta_1 + \rho_1 c_1 \cos \theta_2}$$

$$T_{23} = \frac{2\rho_2 c_3 \cos \theta_2}{\rho_3 c_3 \cos \theta_2 + \rho_2 c_2 \cos \theta_3}$$





$$2k_2 h_2 \cos \theta_2 = 2k_{z2} h_2$$

$$R_{12} = -R_{21}$$

$$T_{12} T_{21} = 1 - R_{12}^2$$

$$R_{13} = R_{12} + T_{12} T_{21} R_{23} \exp(2i\phi_2) + T_{12} T_{21} R_{23}^2 R_{21} \exp(4i\phi_2) + \dots$$

$$\phi_2 = k_2 h_2 \cos \theta_2$$

$$S = \sum_{n=0}^{\infty} r^n = (1-r)^{-1} \quad |r| < 1$$

$$R_{13} = R_{12} + T_{12}T_{21}R_{23} \exp(2i\phi_2) \sum_{n=0}^{\infty} [R_{23}R_{21} \exp(2i\phi_2)]^n$$

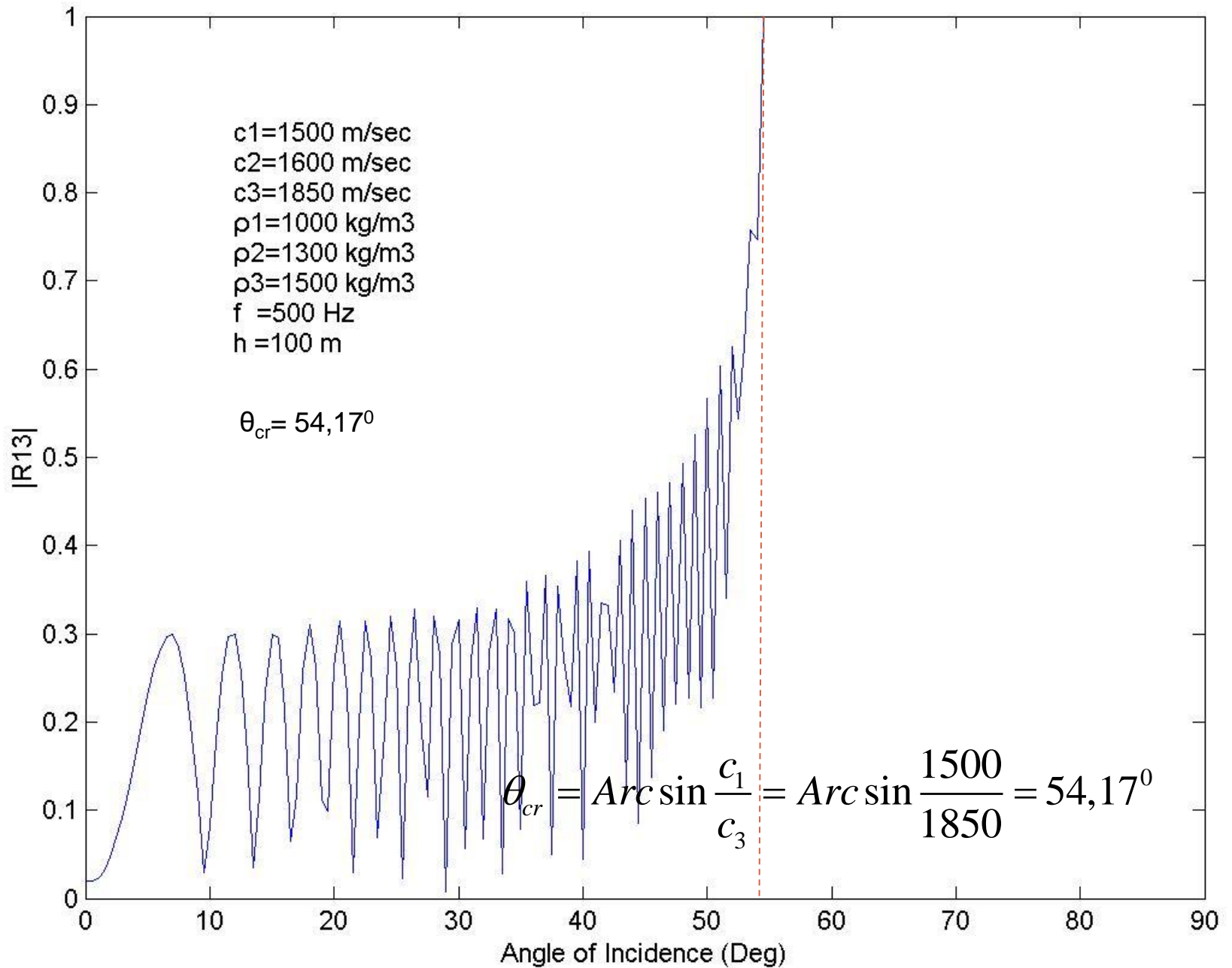
$$R_{13} = \frac{R_{12} + R_{23} \exp(2i\phi_2)}{1 + R_{12}R_{23} \exp(2i\phi_2)}$$

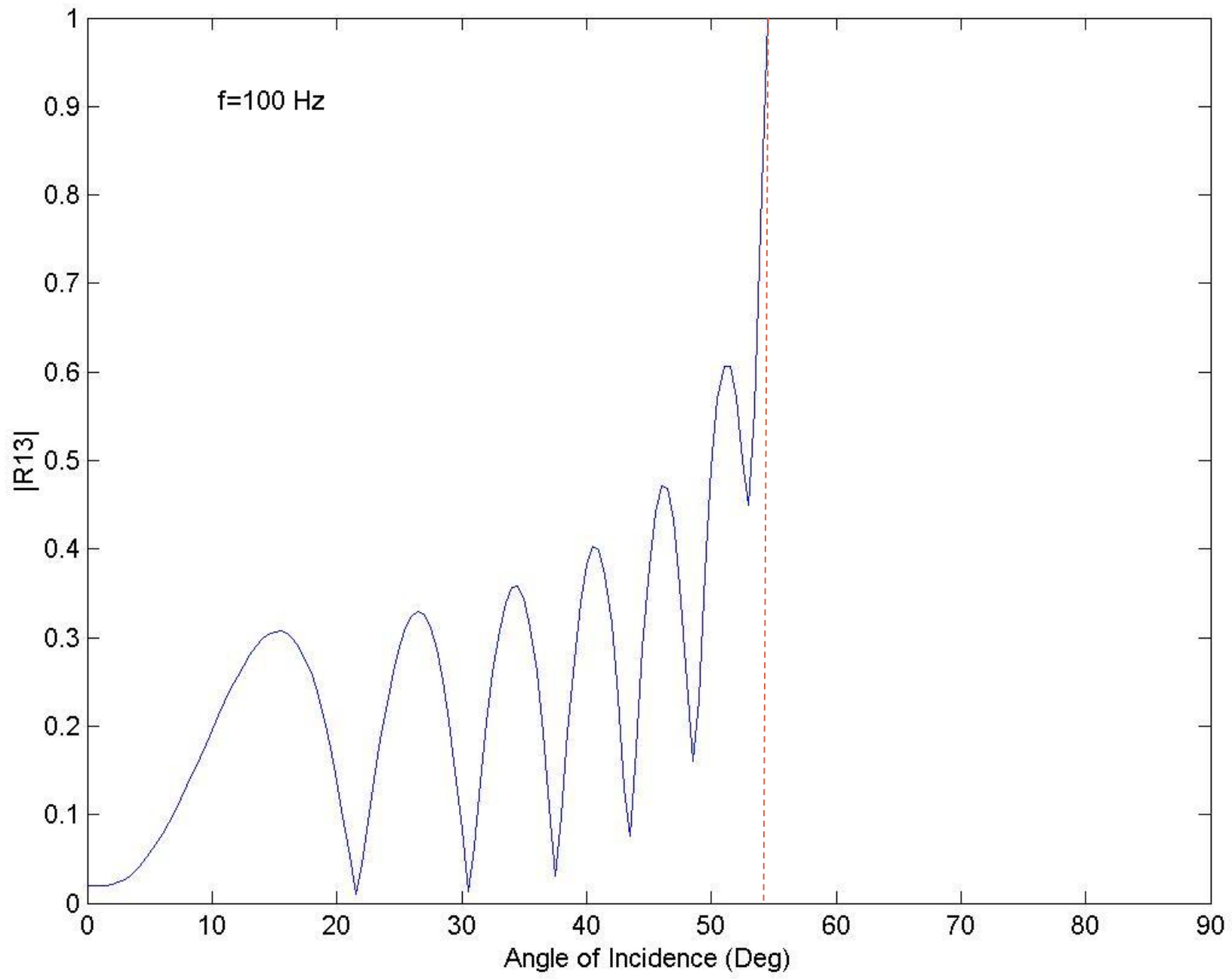
$$T_{13} = \frac{T_{12}T_{23} \exp(i\phi_2)}{1 + R_{12}R_{23} \exp(2i\phi_2)}$$

$$R_{(n-2)n} = \frac{R_{(n-2)(n-1)} + R_{(n-1)n} \exp(2i\phi_{n-1})}{1 + R_{(n-2)(n-1)} R_{(n-1)n} \exp(2i\phi_{n-1})}$$

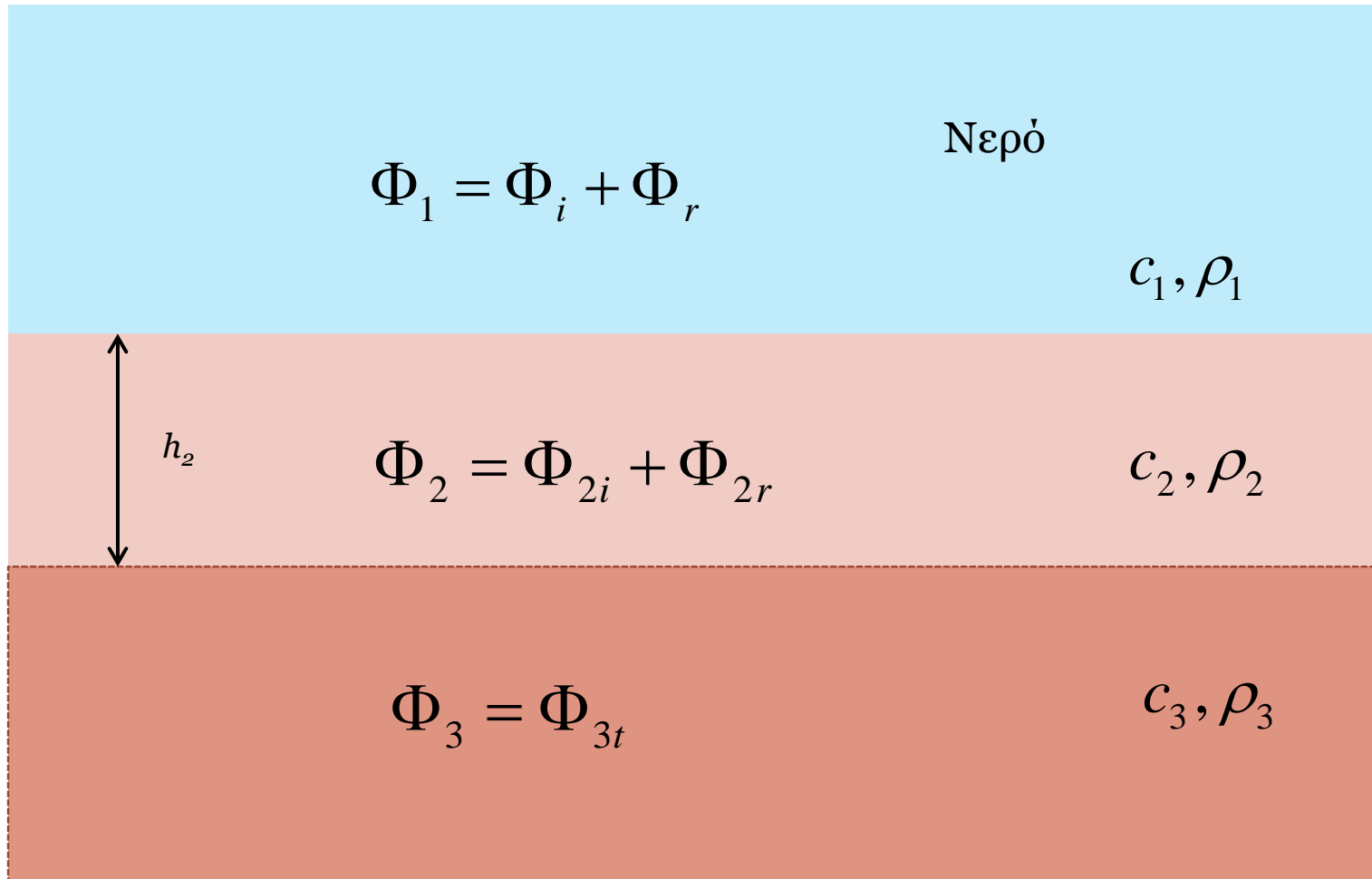
$$R_{(n-3)n} = \frac{R_{(n-3)(n-2)} + R_{(n-2)n} \exp(2i\phi_{n-2})}{1 + R_{(n-3)(n-2)} R_{(n-2)n} \exp(2i\phi_{n-2})}$$

$$R_{1n} = \frac{R_{12} + R_{2n} \exp(2i\phi_2)}{1 + R_{12} R_{2n} \exp(2i\phi_2)}$$





Νερό + 2 ρευστά στρώματα πυθμένα



Περίπτωση Ρευστού Πυθμένα

$$\Phi_1 = e^{i(k_x x + k_{z1} z - \omega t)} + R_{13} e^{i(k_x x - k_{z1} z - \omega t)}$$

$$\Phi_2 = A_2 e^{i(k_x x + k_{z2} z - \omega t)} + B_2 e^{i(k_x x - k_{z2} z - \omega t)}$$

$$\Phi_3 = A_3 e^{i(k_x x + k_3 z - \omega t)}$$

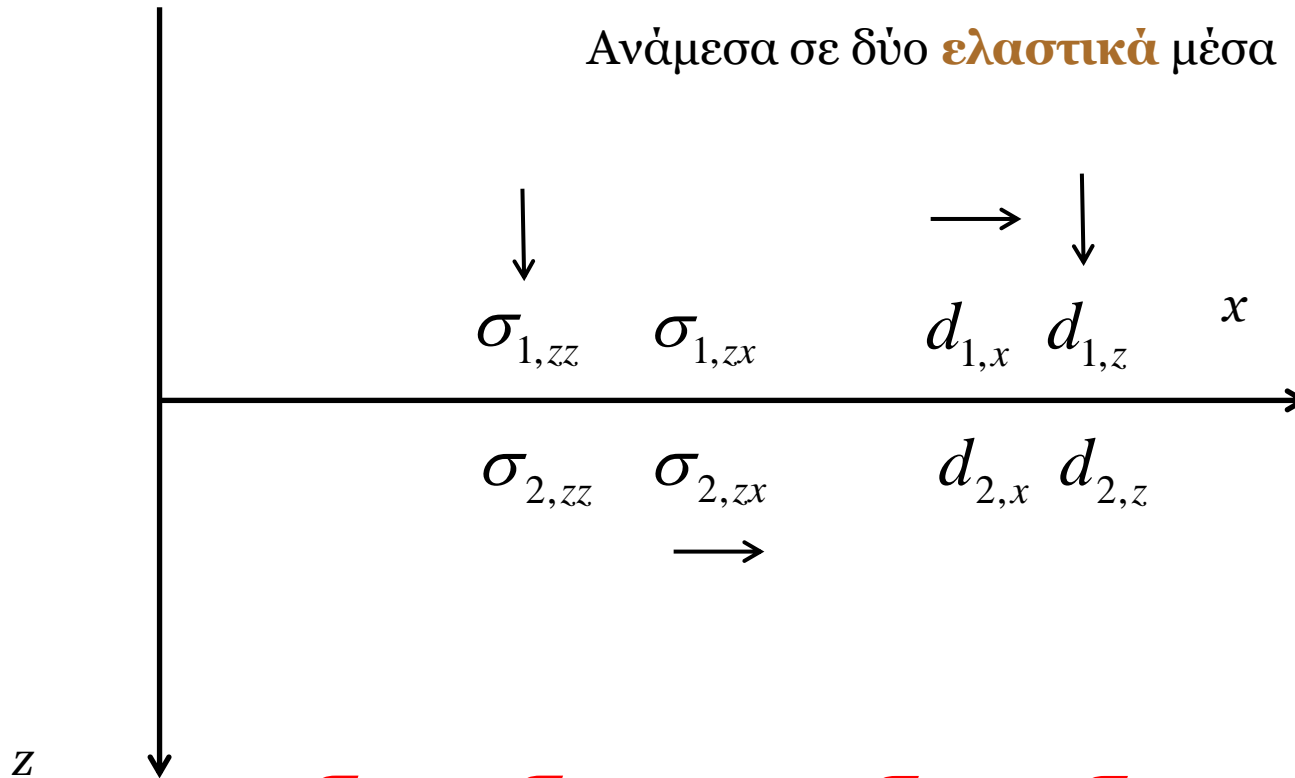
Εφαρμογή Οριακών Συνθηκών για $z=0$ και $z=h_2$

$$\sigma_{1,zz} = \sigma_{2,zz} \quad d_{1,z} = d_{2,z}$$

$$\sigma_{2,zz} = \sigma_{3,zz} \quad d_{2,z} = d_{3,z}$$

Οριακές συνθήκες στη διεπιφάνεια $z=0$

Ανάμεσα σε δύο **ελαστικά** μέσα



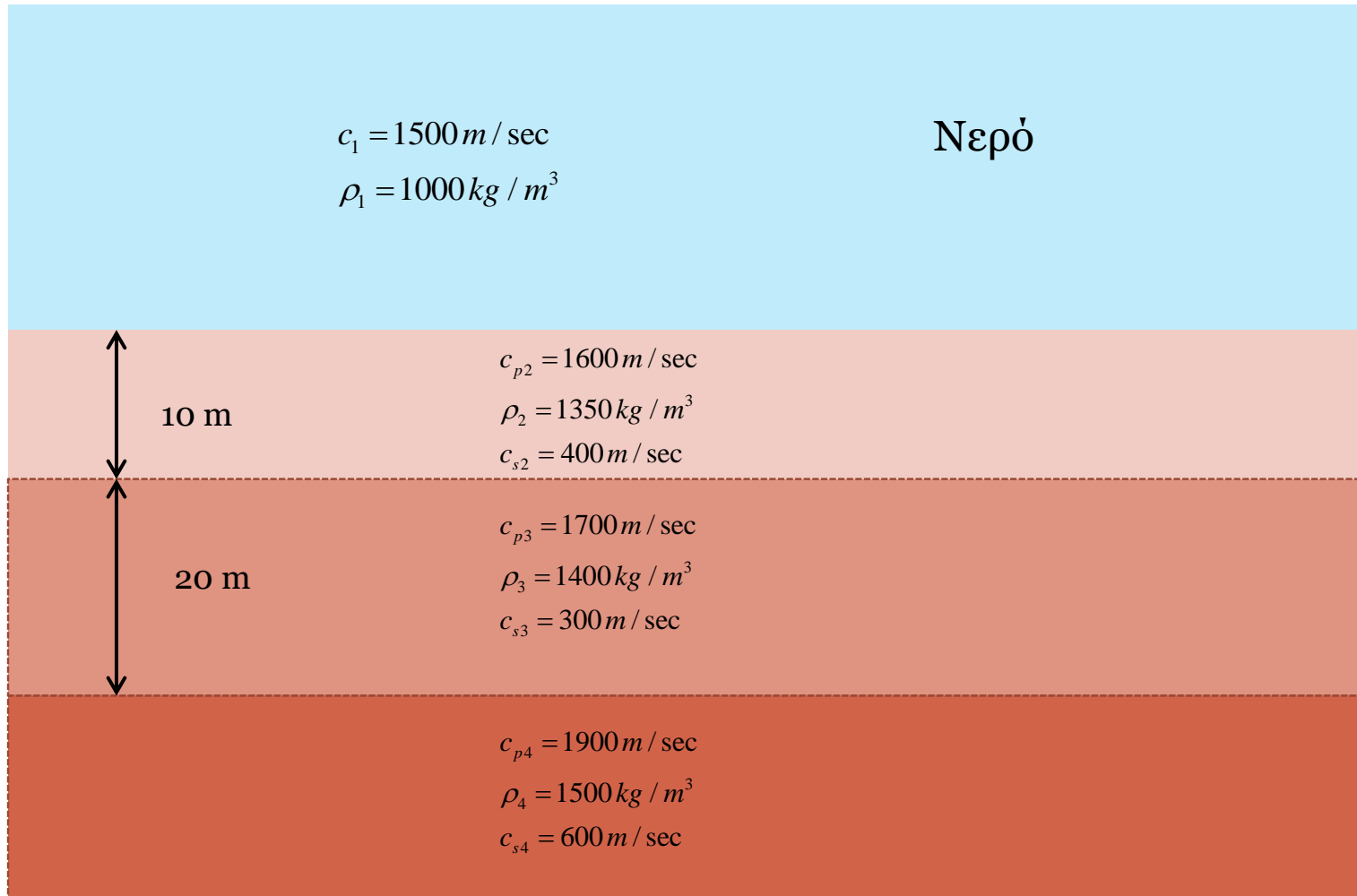
$$\sigma_{1,zz} = \sigma_{2,zz}$$

$$\sigma_{1,zx} = \sigma_{2,zx}$$

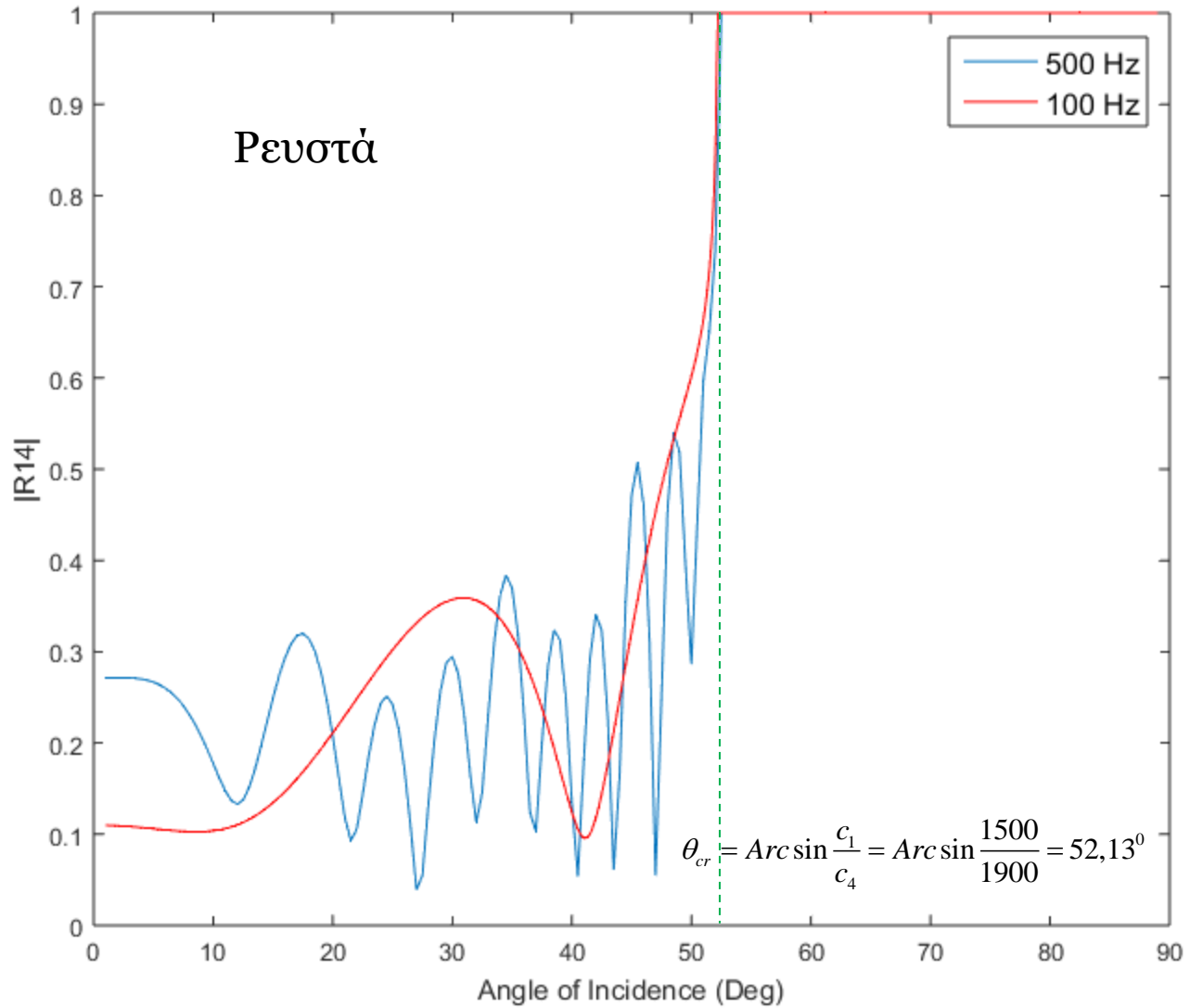
$$d_{1,z} = d_{2,z}$$

$$d_{1,x} = d_{2,x}$$

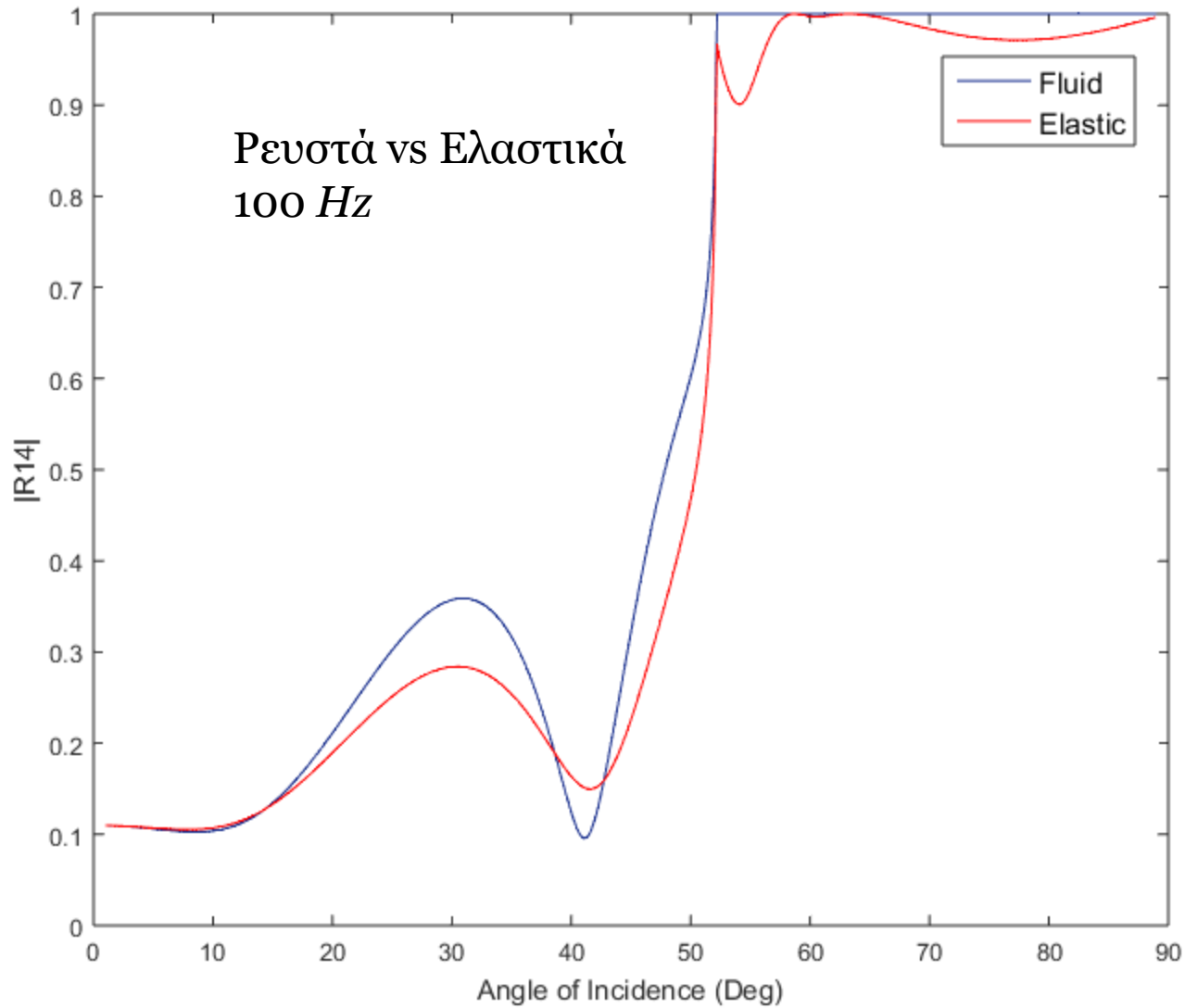
Νερό + 3 στρώματα πυθμένα



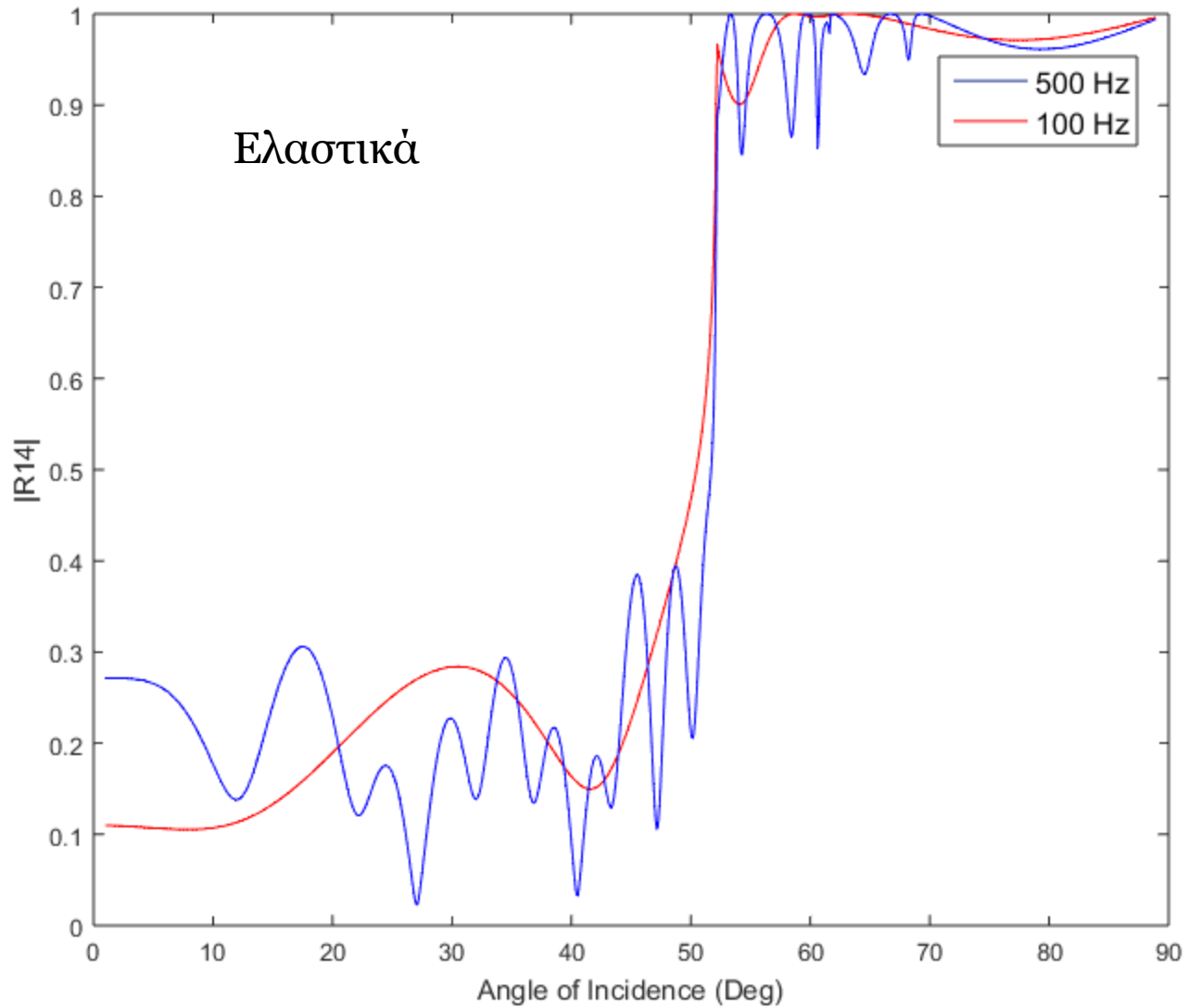
Νερό + 3 στρώματα πυθμένα



Νερό + 3 στρώματα πυθμένα



Νερό + 3 στρώματα πυθμένα



Απώλεια Πυθμένα – Bottom Loss (BL)

$$BL = -20 \log |R_{1n}|$$

Για ολική ανάκλαση ($|R_{1n}| = 1$), $BL=0$