Paper No. 28

ON THE CAUSE OF THE OSCILLATORY CHARACTER OF GROUND MOVEMENT DURING EARTHQUAKES

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The ground motion during an earthquake is of a very complex character, and the disturbance is recorded as a train of waves on a seismogram. The observed oscillatory motion in seismograms may be illustrated with the help of fig. 1, representing a typical earthquake record. Of course, the seismogram as such does not give a true picture of the earth movement, as the motion is amplified and complications arise from the fact that in actual case the period

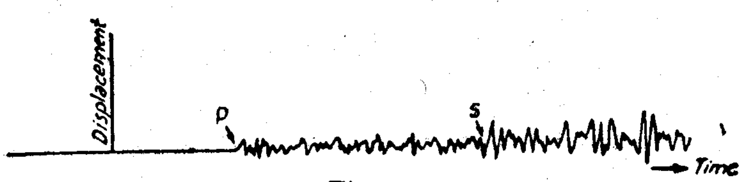

Figure 1

dependent dynamic magnification, of the seismograph and not the static, is of significance. The actual ground movement is still noted to be oscillatory in character, even though its form may not be quite similar to that of the seismogram. It has been considered by earlier workers that these oscillatory movements may be due to dispersion effects. But only the dispersion of surface waves has to some extent lent itself to mathematical formulation and no satisfactory analysis has been put forward to explain the oscillatory character of motion on seismograms attending the body waves.

Theoretical considerations show that an impulsive disturbance in a homogeneous medium should spread out as an impulsive disturbance, and not give rise to a train of oscillations. At a distant point the disturbance takes the form of three movements, namely the P, S and the Rayleigh type respectively, each consisting of a single displacement and a return. As the P and S waves, in the case of a perfectly elastic isotropic media, travel independently of each other, a consideration of a simple hypothetical earthquake sending out P and S waves through a homogeneous medium, gives the graph, displacement vs. time, of a distant particle of the form shown in fig. 2 (see also, Bullen, K.E., 1963, p. 77). The graph does not show any oscillatory movement. There is a quiescent interval between the arrivals of the P and S disturbances.

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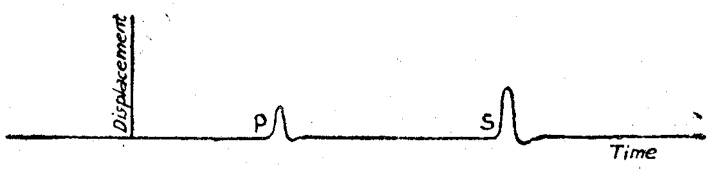

Figure 2

Evidently, the motion recorded on a seismogram following an earthquake is markedly different from that of fig. 2. Jeffreys (1931) has considered the effects of scattering, the complex initial conditions at the focus, fluctuations in the local gravity value during the passage of a disturbance, imperfections in elasticity and continuous variations in density and elastic parameters within the earth and has shown that none of these is a sufficient cause. If the original disturbance at the focus is assumed to be oscillatory, it would explain the oscillations in P and S, but in such a case the duration of the oscillation should be the same for all distances, whereas it is actually observed to increase with distance. The cause of seismic wave dispersion must therefore be sought in terms of heterogeneities inside the earth, most probably in the crust, but the precise way in which it occurs must await more detailed knowledge of the crustal structure than is yet available.

Pekeris (1955) investigated the motion of the surface of a uniform elastic half-space produced by the application at the surface of a point pressure pulse varying with time like the Heaviside unit function. He also considered the case of a burried pulse (Pekeris 1955, Pekeris and Lifson 1957). Pekeris and Longman (1958) considered the motion of the surface of a uniform elastic half-space produced by the application of a burried torque-pulse. The time variation of the torque being assumed to be represented by the Heaviside unit function. In all these analyses the computed theoretical curves do not exhibit any oscillatory movement.

Pekeris and Longman (1958) considered the problem of propagation of explosive sound in layered liquid and derived the exact solution based on ray theory. Here again the time variation of the pressure pulse was assumed to have the form of a Heaviside unit function. For a high speed bottom, the pressure pulse at large ranges, as computed by the ray theory,

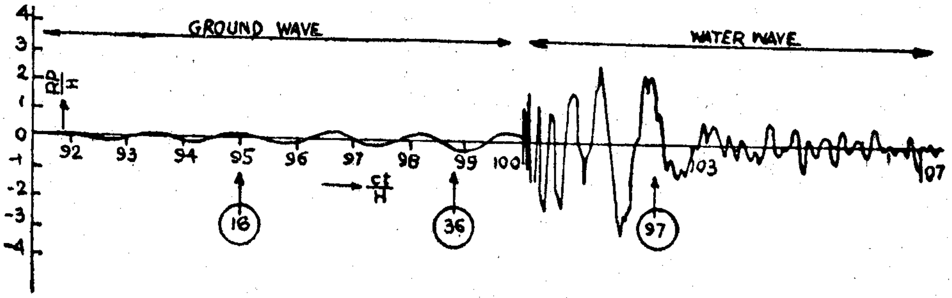

Figure 3. Theoretical Pressure Records due to an Underwater Explosion of Heaviside form in a Layered Liquid. P=pressure, H=depth of layer r=horizontal distance, c= sound velocity at depth H/2, $\rho_2=2\,\rho_1$, $c_2=1\cdot1\,c_1$. The encircled figures denote the number of rays arriving before the given epoch. The logarithmic infinities have not been drawn in (After Pekeris and Longman, 1958).

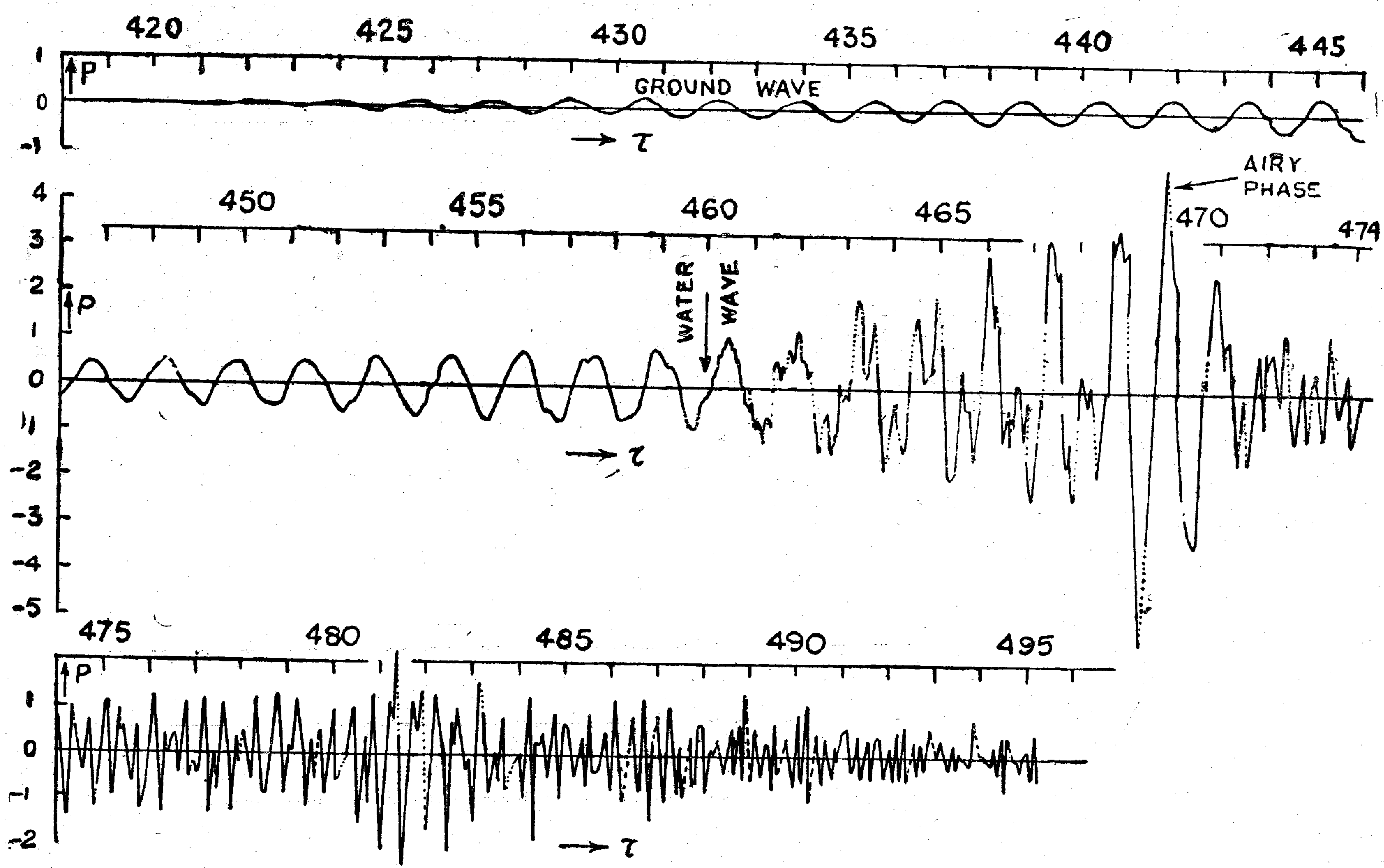

Figure 4. Exact Theoretical Pressure Record Resulting from an Underwater Explosion of Heaviside form in a Layered Liquid. Solution obtained by ray theory. Velocity of sound in bottom c_2 is 1.1 times the velocity of sound in water. Density of the bottom is twice the density of water. P=pressure, H=depth of layer, $r=460$ H, $\tau = ct/H$. The dotted portions show where logarithmic infinities have been omitted. (After Pekeris, Longman and Lifson 1959).

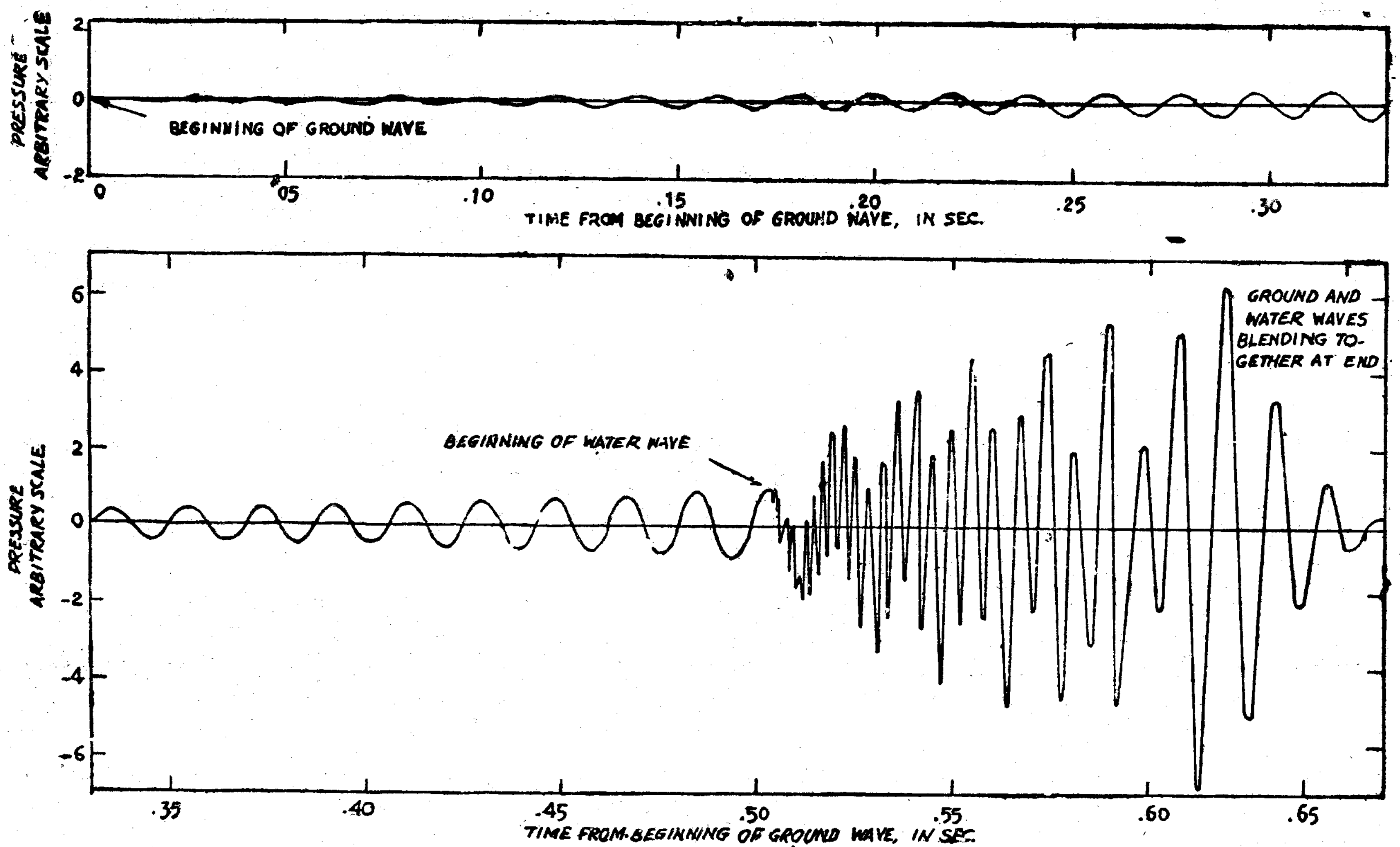

Figure 5. Theoretical Pressure Record for the same Conditions as in figure 4, computed by the Normal Mode Theory, using only the First Mode. (After Pekeris 1948).

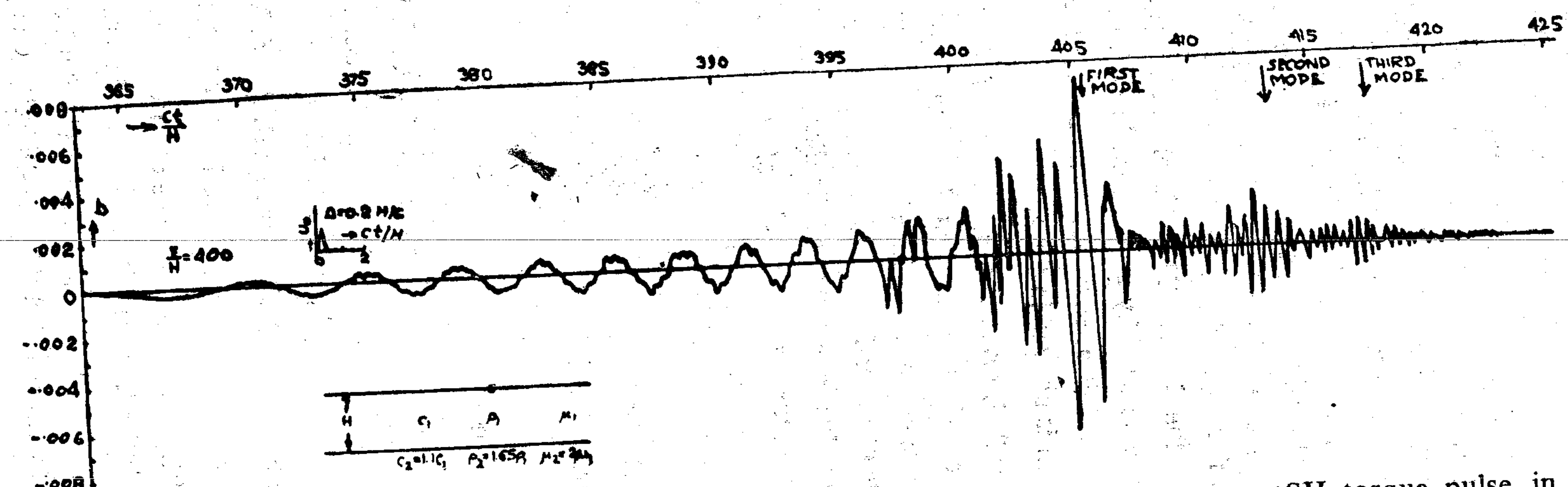

Figure 6. Horizontal displacement at the surface q caused by the application of an SH-torque pulse in a layered elastic half-space. Depth of source is H/2. H denotes thickness of layer, and r horizontal distance. The source produces a displacement u_0 which at large distances approaches the form of a sawtooth:

$f(t)=(t-R/c)H(t-R/c)-2(t-\Delta-R/c)H(t-\Delta-R/c)+(t-2\Delta-R/c)H(t-2\Delta-R/c)$.

(After Pekeris, Alterman and Abramovici. 1963) exhibits the well known features, first observed by Ewing and Worzel (1948) and later deduced from the normal mode theory of a long period ground-wave followed by a high frequency dispersive water-wave (fig. 3). The curves obtained by them show some oscillatory character, though not quite similar to actual seismograms (Pekeris and Longman, 1958, figs. 2-5). Pekeris, Longman and Lifson (1959) applied the ray theory solution to the problem of long-range propagation of explosive sound in a layered liquid. The exact ray theory solution exhibits the characteristic features of a ground wave followed by a dispersive water wave (fig. 4). The curve computed by the normal mode theory, using only the first mode, for the same conditions is given in fig. 5, for reference. Pekeris, Alterman and Abramovici (1963) investigated the motion of the surface of a layered elastic half-space produced by a torque-pulse from a point source situated inside the layer. The axis of the torque was assumed vertical (SH) and its time variation being represented by a step-function with rounded shoulders. The displacement due to the source approaches a saw-tooth shape at large distances. The curve for one particular case given by them is shown in fig. 6.

An examination of the figures 3–6, reveals the presence of oscillatory movements. It follows, therefore, from the above considerations that layering may be considered to be the major cause for the observed oscillatory movement in seismograms. Further apart from layering, if we could include the effects of other factors influencing elastic wave propagation, such as, fluctuations in the local gravity value, curvature of the discontinuities encountered, internal friction, scattering etc., a more satisfactory result would be obtained. However, the general case of a layered solid media with arbitrary source excitation does not seem to have been investigated so far, owing of course to the very difficult nature of the problem.

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