CHAPTER 7

THE VSP METHOD FOR REFRACTED WAVES

The waves recorded in the early portion of the seismogram at offsets great as compared with the depth of the interface consist mainly of refracted (head*) and transcritically reflected waves. The study of the origin and the relative intensities of such waves is of great interest for both theory and practice, since this factor is of decisive importance for the exploration potential of one of the principal methods – that of the correlational method of refracted waves. The difficulties associated with such studies are due mainly to the ambiguity of interpretation of the wave's origin arising from the similarity between the kinematic features of the head, the curved-path and the reflected waves recorded on the surface at great distances from the energy source, so that they cannot be used to identify the wave type reliably. Accordingly, it was presumed that the end could well be served by VSP. Down-hole observations at large offset distances from the shot-point have the following advantages over surface observations [14]:

1. The study of the wave field in the medium underlying the refracting interface provides the most authentic data about the mechanism of energy return and, hence, about the origin of the wave recorded above the refracting interface.

2. The recording of waves as first arrivals in the immediate proximity of the refracting interface and near the point of emergence enables the reliability of stratigraphic correlation to be improved.

3. The employment of such a sensitive parameter as the trajectory of particle motion of the medium for determining the wave's origin.

4. The rapid decrease in the seismic background noise with depth enables a much higher useful instrumentation sensitivity to be utilized, so that waves of very low intensity can be studied.

5. A chance to compare the intensity of various waves observed in the immediate proximity of the interface, which is important, because the intensity ratio may change with the distance from the interface.

The correlation of head and curved path waves in VSP is characterized by the fact that, because they have similar or equal apparent velocities, such waves form extensive zones of interference. However, they differ sharply in intensities, and this occasions a substantial difference in their conditions for correlation. Curved-path waves, which dominate the early portion of the record can be reliably tracked in both the first and later arrivals; head waves can be identified and tracked in the first arrivals.

Waves reflected at large angles from the boundaries of a layer or from within it, when observed at large offset distances from the source can approach the head wave quite closely and interfere with it, exercising a strong effect on its parameters. In this respect, it is of major importance that VSP be supplemented by observation systems and theoretical computations of the wave fields devised on the basis of detailed studies of

* The term head wave as distinct from a curved-path wave is used to describe a wave whose energy returns to the surface as the result of diffraction.
the velocity distribution. A specific feature of VSP, as used in the refraction method is
the need to employ the polarization method to study the total vector of oscillations of
each wave. The recording and study of just the vertical components of the record, in
the case of waves approaching from directions close to the horizontal, can substantially
distort the true picture of the relative intensities of different wave types, and lead to
erroneous conclusions as to their origin.

A large volume of VSP work in a variety of media and structures has been carried
out to study waves recorded in the early portion of the record. The first VSP studies
that we carried out in the Ukraine in 1959, and in the Kuibyshev province in 1960 [15],
demonstrated that head waves associated with thin layers are so weak that it is
practically impossible to detect them on the surface seismograms. These results were
subsequently corroborated by studies carried out in the Krasnodar province. Waves
associated with individual thick high-velocity layers were studied in the Stavropol'province. Wave fields typical of carbonate sections were studied in the Volgograd
province. In recent years, theoretical and experimental studies of waves associated with
the crystalline basement [113] and with thick layers were carried out on the basis of
VSP. The effect of individual elements of the geologic section on the wave field observed
at large offset distances from the shot-point has also been studied [21], and principles
have been formulated for the construction of models corresponding to the observed
wave patterns. The following are the principal results:

(1) The intensity of transcritically reflected waves is always higher than that of the
head waves originating at the same interface, the difference in the intensities being as
much as two orders of magnitude or more. For this reason, head waves on surface
seismograms cannot be identified in either the later or even the early arrivals [13], in
the presence of transcritically reflected waves. Thin high-velocity layers play a decisive
part in the formation of the wave field at comparatively short distances from the
shot-point. With increasing separation, the effect of thin layers diminishes, and
curved-path waves in the bed underlying the layer become dominant. The relative
intensity of the head wave increases as the layer thickness increases, but it still remains
appreciably less than that of the transcritical wave.

(2) It has been demonstrated, by means of direct observations in the underlying layer,
that in the earth there is generally an increase in velocity with depth, and that it is not
a head wave that is recorded first on the seismograms but a curved-path wave.
Refraction and transcritical reflection play a decisive part in determining the intensities
of the waves, and act as the chief mechanism of transporting energy back to the surface.

(3) In observations at ranges covered by the refraction method, as well as at ranges
covered by the reflection method, the upper portion of the section can exercise a
substantial effect on the wave field observed on surface seismograms. Observations
carried out at great depths both below the source and at appreciable distances from it,
enabled the reflected-refracted and the refracted-reflected waves to be separated. This
supports the theory that waves recorded in the early portion of the seismogram with
velocities similar or equal to those of first arrivals may be reflected-refracted waves
associated with the upper portion of the section.

It should be remembered, that unfortunately, only Z-component seismograms have
generally been recorded in the VSP refraction studies, and this greatly limits the scope
of wave analysis.