

The Effect of a Dipping Layer on a Reflected Seismic Signal.

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ABSTRACT

Modern seismic reflection prospecting is based on the common depth point (CDP) seismic reflection technique in which the same subsurface reflection point is covered several times. Signals from the same reflection point are then added together. Such a stacking scheme is based on the assumption that the common reflection point lies mid-way between the source and receivers. This assumption only holds when horizons are horizontal. However, when the layers dip, the reflection point is no longer mid-way between the source and the receiver. The sources and the receivers now have a distribution of reflection points. An expression for this displacement is derived in terms of the reflection slope. A computer program was written to quantify these displacements for various angles of slope.

(Keywords: seismic reflection, common depth point, CDP, displacements, dipping layer)

INTRODUCTION

Of all the physical methods used in geophysical exploration, the seismic methods are perhaps the most direct; when applied they give the least ambiguous results (Dobrin, 1976). Seismic prospecting has as its goal the determination of geologic structure in the sedimentary section, the detection of hydrocarbon accumulations and the estimation of total energy reserves in an area (Telford, 1983). The aim is to determine boundaries such as interface between various sedimentary layers on reef edges or fault positions or other irregularities by using seismic waves, their reflection properties, their refraction properties and their scattering properties (Dobrin, 1976).

More recently, it has been possible to relate signal amplitude to the physical properties of the medium traversed and in particular make inferences about the oil and gas content of the

buried rocks (Waters, 1980). Reflection seismology is the most widely used geophysical technique today for delineating the subsurface structure of the earth. At a time of increasing economic interest in natural resources, it provides a means to determine the location and estimating the quantities of oil, natural gas and coal deposits in the earth's sedimentary layers (Grant and West, 1980).

The most usual method of generating an artificial seismic pulse is by firing a shot of high explosive in a hole tampered with water which may be as much as 30m deep (Dobrin, 1980). For shallow investigations, smaller charges and shot holes only a few meters deep can be used. It is often practicable to produce pulses of adequate amplitude by striking with a hammer a steel plate lying on the earth's surface or by dropping a weight (Haeni, 1986). Continuous waves, as opposed to discrete pulses can be produced by various types of mechanical and electromechanical vibrators which impart a periodic vertical or horizontal motion to a limited area of the surface (Waters, 1980).

The elastic disturbance, created by seismic energy sources, propagate through the earth where interfaces between geological strata reflect spreading wavefronts (Figure 1). Arrival times of single bounce echoes (primary reflections at surface receivers) permit the determination of depths and inclination angles of reflectors when subsurface velocities are known (Dobrin, 1980).

FORMULATION OF THE PROBLEM

In designing shooting geometry for multi-fold cover in seismic reflection geophysical prospecting, the underlying assumption is that the reflection point lies in the subsurface mid-way between the shot and receiver (Mayne, 1962). A stacking scheme based on this common mid-point concept is maximally efficient only when

horizons are horizontal (Figure 1). However, in practice, most reflecting boundaries of interest slope significantly. One consequence of this is that the common depth point (CDP) gathers no longer have a common mid-point. Instead, the reflection points are displaced from the common mid-points (Figure 2).

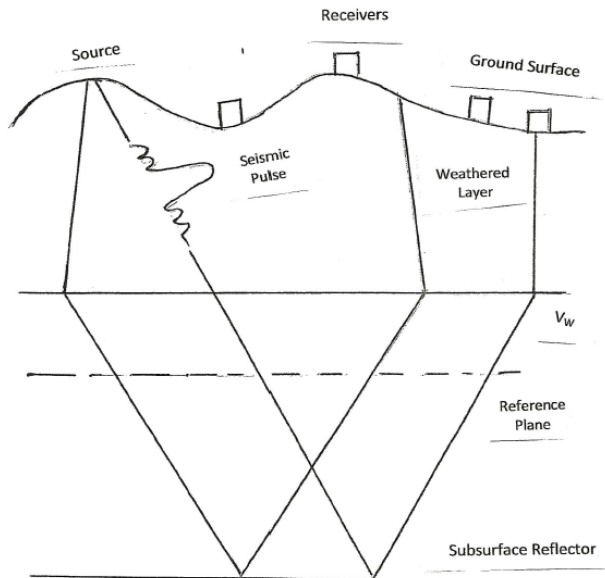


Figure 1: Basic Model of a Reflection Seismograph System (Wood and Treital, 1975).

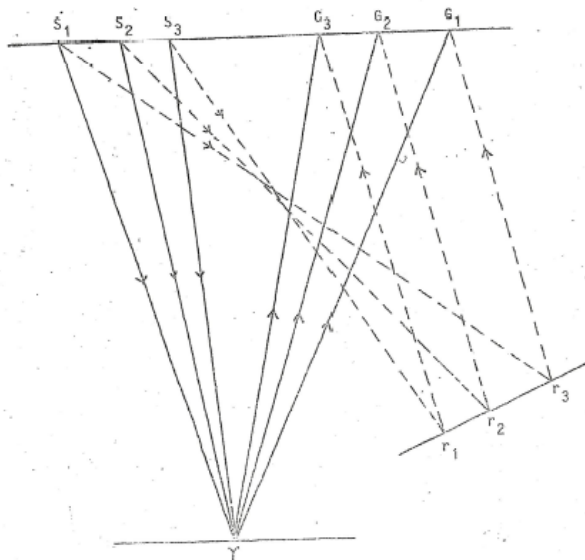


Figure 2: Traces Producing a Common Reflection Point on a Flat Bed Produce Different Reflection Points on a Dipping Bed.

This paper was stimulated by a desire to determine the effect of the localized dip of each reflector with the aim of quantifying the displacements in terms of the reflector slope. A companion paper will further address the effect of the displacements on the stack attenuation for various fold coverage. To ease computations, the model used for computations is a simple one in which the curvature of the reflecting surfaces has been neglected and the dip is assumed to be wholly in line with the seismic profile. Straight ray paths are assumed throughout and the probable effects of multiple reflections are ignored. What follows, although theoretical in nature may help to provide a direct grasp of the mechanics of seismic pulse propagation with respect to dipping reflectors.

DERIVATION OF THE EXPRESSION FOR THE DISPLACEMENT

In Figure 3, AB is the surface on which we have the shot point S and the geophone G. CD is the horizontal layer while C¹D¹ is the dipping reflector and α is the angle of dip.

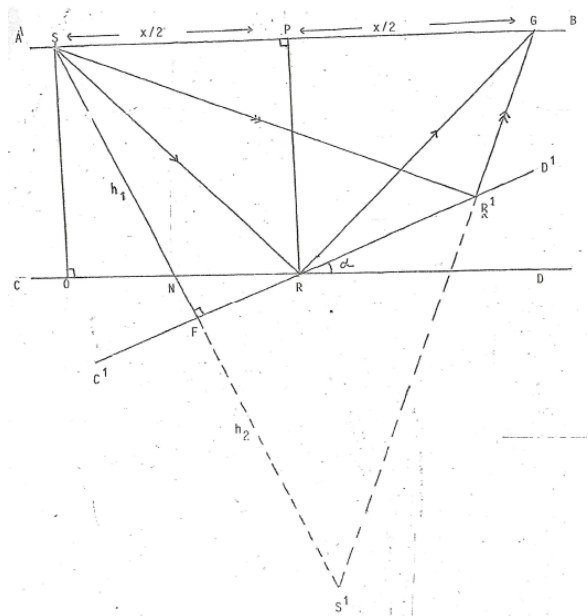


Figure 3: RR¹ is the Scatter Produced by the Dipping Reflector C¹D¹.

The geometry of the diagram shows that a seismic wave travelling from S is reflected at point R on the horizontal layer to the geophone G, while the same pulse is reflected at the point R¹ in

$$FR = PP^1 - PR^1$$

$$= \left\{ \frac{x \cos \alpha}{2} - h_1 \sin \alpha \right\} \quad (13)$$

The displacement RR^1 is:

$$RR^1 = FR^1 - FR \quad (14)$$

Knowing FR^1 from Equation (12) and FR from Equation (13), RR^1 becomes:

$$RR^1 = \left\{ \frac{x \cos \alpha}{2} + \frac{x^2 \sin \alpha}{4h_1} \right\} - \left\{ \frac{x \cos \alpha}{2} - h_1 \sin \alpha \right\}$$

$$= \frac{x^2 \sin \alpha}{4h_1} + h_1 \sin \alpha$$

$$= \left\{ \frac{x^2}{4h_1} + h_1 \right\} \sin \alpha \quad (15)$$

Tables 1, 2 and 3 present the results obtained from a computer program written to evaluate the displacement RR^1 for various angles of dip in the case of a 12-fold coverage.

Table 1: 12-Fold Coverage.

The Displacements for Various Angles of Dip (Depth – 2,000m). Average Vertical Velocity – 2,250 m/s.

S.P No.	Station No.	Off-Set (m)	Displacements (m)			
			10 ⁰	20 ⁰	30 ⁰	40 ⁰
1	1	0	347.3	684.1	1000.0	1285.1
2	3	133	347.4	684.4	1000.0	1286.0
3	5	233	348.8	687.0	1004.4	1291.3
4	7	399	350.8	690.8	1010.0	1298.6
5	9	532	353.4	696.2	1017.8	1308.6
6	11	665	356.9	703.0	1027.8	1321.3
7	13	798	361.2	711.4	1040.0	1337.0
8	15	931	366.2	721.3	1054.4	1355.6
9	17	1064	372.0	732.6	1071.1	1377.0
10	19	1197	378.6	745.6	1090.0	1401.2
11	21	1330	385.9	760.0	1111.1	1428.4
12	23	1463	394.0	776.0	1134.4	1458.4

Table 2: 12-Fold Coverage.

The Displacements for Various Angles of Dip (Depth – 3,000m). Average Vertical Velocity – 3,333.3 m/s.

S.P No.	Station No.	Off-Set (m)	Displacements (m)			
			10 ⁰	20 ⁰	30 ⁰	40 ⁰
1	1	0	520.9	1026.0	1500.0	1928.3
2	3	133	521.2	1026.6	1501.7	1929.3
3	5	233	521.9	1028.1	1503.0	1932.2
4	7	399	523.2	1030.6	1506.6	1936.9
5	9	532	525.0	1034.2	1511.8	1943.6
6	11	665	527.3	1038.7	1518.5	1952.2
7	13	798	530.2	1044.3	1526.6	1962.6
8	15	931	533.6	1050.9	1536.3	1975.0
9	17	1064	537.4	1058.5	1547.4	1989.3
10	19	1197	541.8	1067.1	1560.0	2005.5
11	21	1330	546.6	1076.7	1574.0	2033.6
12	23	1463	552.1	1087.3	1589.6	2043.6

Table 3: 12-Fold Coverage.*The Displacements for Various Angles of Dip (Depth – 4,800m). Average Vertical Velocity – 3,550 m/s.*

S.P No.	Station No.	Off-Set (m)	Displacements (m)			
			10 ⁰	20 ⁰	30 ⁰	40 ⁰
1	1	0	833.5	1641.7	2400.0	3085.3
2	3	133	833.6	1642.0	2400.4	3085.9
3	5	233	834.2	1642.9	2401.8	3087.9
4	7	399	834.9	1644.5	2404.2	3090.7
5	9	532	836.1	1646.7	2407.4	3094.9
6	11	665	837.5	1649.6	2411.5	3100.2
7	13	798	839.3	1653.1	2416.6	3106.8
8	15	931	841.4	1657.2	2422.7	3114.5
9	17	1064	843.8	1661.9	2429.6	3123.4
10	19	1197	846.5	1664.0	2437.5	3133.6
11	21	1330	849.6	1673.3	2446.3	3144.9
12	23	1463	852.9	1680.0	2456.1	3157.4

CONCLUSION

The values obtained for the displacements from the assumed common reflection point from this study show that for constant dips, the displacements increase as both the off-sets and the dips are increased. The displacement is rather large, so that, the determination of the dips for both shallow and deep formations is very important in seismic exploration work.

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