Measurement of Velocity Gradients of Beds At Unwana, Nigeria

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Abstract: *Seismic compressional waves have been used in Unwana to measure velocity gradients of beds. The seismic refraction method was employed. Unwana is situated within latitude $5^0 50'$ to $5^0 55'$ N and longitude $7^0 50'$ to $7^0 57'$E. It has an area of about $48km^2$. A digital type signal enhancement seismograph was the equipment used along with its accessories. Forward and reverse shootings were carried out along the same profile line and the seismic velocities and thicknesses of underlying layers were estimated. The velocity gradients of the refracting beds were hence evaluated. The primary wave velocities for both forward and reverse shots were found to be 315m/s and 300m/s respectively for the first layer and 608 and 600m/s respectively for the second layer. The thickness measured from both forward and reverse ends of the profile line were 2.1m and 2.0m respectively for the first layer and 7.3m and 4.7m respectively for the second layer. These gave values of velocity gradients as $149s^{-1}$ and $150s^{-1}$ respectively for layer 1 and $83s^{-1}$ and $127s^{-1}$ respectively for the second layer. The result indicates that the materials of the first layer in Unwana are laterally homogenous and are flat-laying while those of the second layer are dipping although with no lateral inhomogeneity.*
Keywords: *Refraction, compressional, seismic, seismograph.*

I.   Introduction

The seismic refraction method can be used for very many purposes. These include determination of groundwater potential of an area, deduction of rock lithology and estimation of thickness and velocity values of rock layers.

This work shows how the method can be used to deduce velocity gradient.

Velocity gradient is hereby defined as the ratio of seismic wave velocity of a substratum to its thickness. Because the refracting interface is in most cases not horizontal, the assumption of flat layers then leads to errors in velocity and depth computations. When an interface is presumed to be dipping, the velocities of the layers and the dip of the interface can be obtained by shooting a second complementary profile in the opposite direction. (Lowrie, 1997).

As an illustration, consider two impact points A and B along a profile line, AB. The two shot points are located at the end of a geophone array that covers AB with A as the shot point for the forward profile and B for the reverse profile.
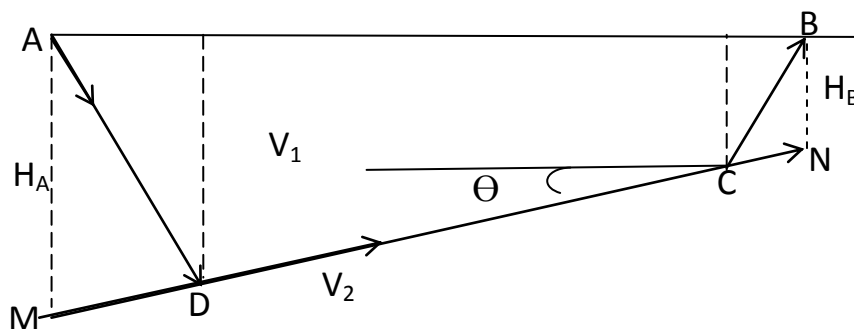

Fig.1: Schematic Diagram of a Dipping Bed

DC is the refractor, V_1 and V_2 are the velocities in the upper and lower medium respectively. H_A is the layer thickness measured from point A while H_B is the layer thickness measured from point B and θ is the dip angle of the interface (fig. I). Obviously, $H_A > H_B$. When an impact is made at A, the seismic ray ADCB from point A impinges on the refractor at point D and travels parallel to the boundary along the up-dip direction to point C as a head wave before entering a receiver at B. In the reverse profiling the ray BCDA from impact point B travels along the boundary in the down-dip sense to point A through points C and D accordingly. The travel time versus offset graphs i.e. t-x curves (Fig.. 2) would not, be the same for the forward and reverse profiling but the total travel-time must be equal (Kearey and Brooks, 1991).

From the T-X curves, true velocities V_1 and V_2 of the first and second layers of the subsurface can be obtained as follows.
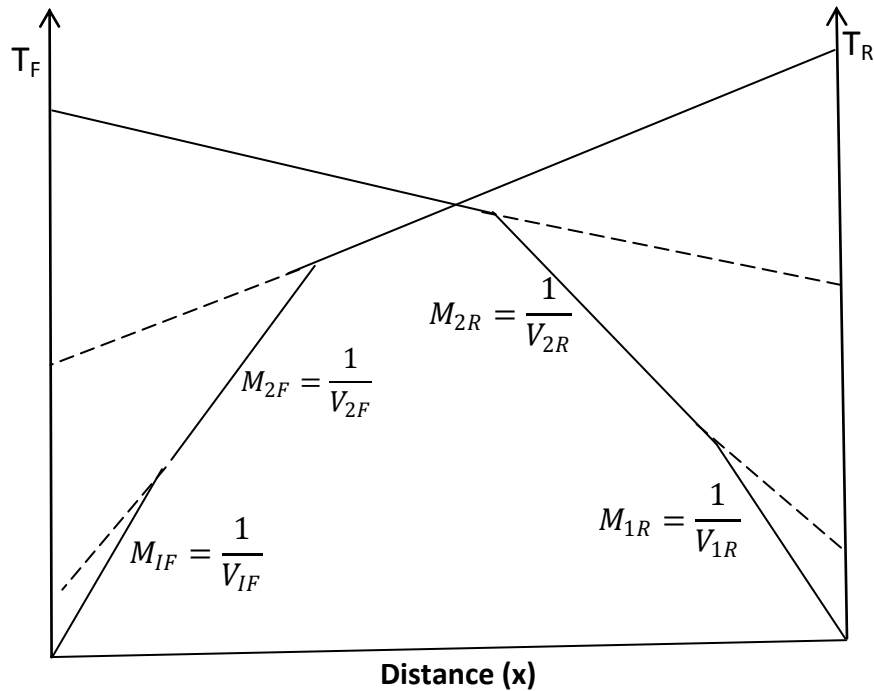

Figure 2: T-X curves for forward and reverse

$$V_1 = \left({}^{V_{IF} + V_{IR}}\!/_2 \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

$$V_2 = \frac{2\cos\theta}{\dfrac{1}{V_{2F}} + \dfrac{1}{V_{2R}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where F and R represent forward and reverse profiles respectively and θ is the dip angle. V_{IF} and V_{IR} are calculated from the reciprocal slopes, M of the curves. The dip angle θ and the critical angle, i_c are determined from V_1, V_{IF}, and V_{IR} respectively as follows:

$$\theta = \frac{1}{2} \left[Sin^{-1}\left(\frac{V_1}{V_{1F}}\right) + sin^{-1}\left(\frac{V_1}{V_{1R}}\right) \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3)$$

$$i_C = \frac{1}{2} \left[Sin^{-1}\left(\frac{V_1}{V_{1F}}\right) - sin^{-1}\left(\frac{V_1}{V_{1R}}\right) \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

With the knowledge of the dip angle, θ the true velocity, V_2 is calculated as shown in equation (2) above (Okwueze, 1988).
Apparent velocities V_{2F} and V_{2R} are obtained from the relations:

$$\frac{1}{V_{2F}} = \frac{1}{V_1} Sin\,(i_c + \theta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5)$$

$$\frac{1}{V_{2R}} = \frac{1}{V_1} Sin\,(i_c - \theta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (6)$$

The velocity gradient (V/h) at each of the short points for a given layer thickness, h are evaluated using the values of V_{1F}, V_{1R}, V_{2F} and V_{2R}, etc. This work involves the use of the seismic refraction method to estimate the velocity gradient at Unwana, Nigeria. Unwana is situated within latitude $5^0 50'$ to $5^0 55'$ N and longitude $7^0 50'$ to $7^0 55'$ E

II. Materials And Method

As in all seismic refraction surveys involving shallow investigations, the materials needed included a seismograph, sets of geophones, and source of signal. In this particular work, the seismograph was a signal enhancement type. The geophones were electromagnetic type with frequency 10Hz. The signal was compressional waves generated mechanically, as a result, only P-wave geophones were arrayed. Single line

profiling method of seismic refraction survey was adopted. About 12 geophones were interconnected in series with the shot point and the inter-geophone spacing was 5m. After the initial shooting (forward shooting), the shot point was moved to the rear of the geophone array for the reverse shot. The shot-detector spacing at both extremes of the array was also 5m.

III.   Result And Discussion

Fig. 4 shows the T-X graph of P-wave data obtained at the study area.
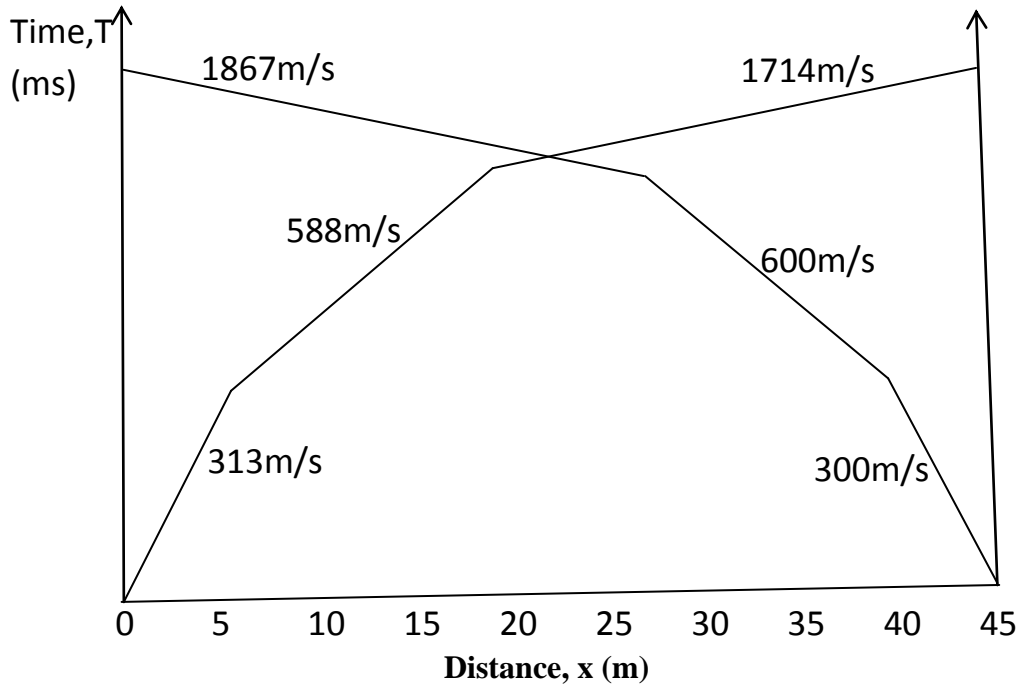

Table 1 shows the velocity gradient (V/h) measured from each end of the shot points for the various layers delineated by the wave in the study area

Table 1: Velocity (V), thickness (h), and velocity gradient (V/h) obtained in the study area

LAYER	FORWARD SHOT			REVERSE SHOT		
	V(m/s)	h(m)	V/h(s^{-1})	V(m/s)	h(m)	V/h(s^{-1})
1	314	2.1	140.05	300	2.0	150
2	608	7.3	83.02	600	4.7	127
3	1714	-		1867		

IV.   Discussion

　　The T-X graph reveal three geoseismic layers with velocities 314m/s, 608m/s and 1714m/s for layers 1,2 and 3 respectively for the forward shot and velocities 300m/s, 600m/s and 1867m/s for layers 1,2,3 respectively for the reverse shot. These velocities as well as the layer thicknesses, measured from each end of the profile and the evaluated velocity gradient, are shown in Table I.

Looking at the result, it is seen from Table I that the velocity values for forward and reverse shots which are 314m/s and 300m/s for layer 1 are nearly the same. Their thicknesses also are approximately equal - 2.1m from the forward shot point and 2.0m from the reverse shot point. The velocity gradients measured are therefore equal.

　　However for the second layer, although the seismic velocities measured from both ends of the shot point are nearly the same (608m/s and 600m/s for forward and reverse shots respectively), the thicknesses at both ends differ markedly – 7.3m and 4.7m respectively. For this reason, the velocity gradients at both ends of the shot vary widely – 83.02s^{-1} and 127s^{-1} for the forward and reverse ends respectively.

V.   Conclusion

　　The fact that the thickness values of both forward and reverse shots for the first layer are approximately the same indicates that the interface has negligible dip. The refractor is therefore flat-laying. Again because the seismic velocities measured from both ends of the profile line are nearly equal implies that lateral differences in composition of materials are negligible. Thus the materials of the first layer are homogenous and are interpreted

to be probably sandy clay. To confirm the absence of dip in the first layer and the homogeneity of materials there, the velocity gradient has the same value at both ends of the profile line.

However the result for the second layer indicates the presence of dip given the wide variation in thickness at both ends of the profile line. The material composition nevertheless seems to be uniform throughout the layer as the seismic velocities are nearly the same at both ends of the profile line. Thus, because of the variation in thickness, the velocity gradient estimated at both ends of the profile varies widely. The second refractor therefore is dipping.

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