Is the optimum XY spacing of the Generalized Reciprocal Method (GRM) constant or variable?

Abstract

The Generalized Reciprocal Method (GRM) is suggested to be used for mapping subsurface structures with lateral variations. This method depends mainly on a single parameter called the optimum XY distance. At the optimum XY separation, the rays to each geophone emerge from near the same point on the refractor. This value is based on heuristic determination and it is always a doubtful matter. The uncertainties of the optimum XY spacing will be discussed on several synthetic models.

Key words

Optimum XY, dipping refractor, faulted layer, irregular refractor, undulating topography.

Introduction

The Generalized Reciprocal Method (GRM) introduced by Palmer (1980) uses separate imaginary points on the travel time curves to estimate the optimum XY spacing. The optimum XY spacing is defined by Palmer (1980) as follows: At the optimum XY separation, the rays to each geophone emerge from near the same point on the refractor.

This method has acquired a considerable support of some geophysicists who work in this field. On the other hand, the optimum XY spacing is criticized by many authors, e.g., Leung (2003 & 1995), Sjorgen (2000) and Whiteley (2006).

In this study, some simplified models will be reviewed in order to show the uncertainties of the optimum XY spacing.

First case:

A two layers case with a plane dipping refractor

This model represents a two layers case with a dipping refracting interface (Fig.1). The dip angle is about 5 degrees. Applying the definition of the optimum XY spacing as suggested by Palmer (1980 &1`986) on this simple model, the following will be found:

1- There are numerous separations at which the rays emerge from the same point on the refractor and have different XY spacing (Fig 1a). This indicates that there is no single value from which the rays emerge from the same point (or near from it) on the refractor (optimum XY spacing).
2- At three different points on the refractor, it will be found that there are three optimum XY spacing: in the middle part XY value equals to 10.8 m, while this value is equal to 6.1 m at X'Y' and 14.9 m at X"Y" (Fig.1b). This means that if the rays emerge from the same point on the refractor, then they will have different XY values varying from 6.1 m to 14.9 m.
3- If the XY spacing is selected as 10.8 m, then the X'Y' and X"Y" rays will emerge from two different points (not from near the same point) on the refractor (Fig. 1c).
4- In case of the XY spacing is selected as 10.8 m, then the depth from which the rays emerge to X'Y' will be below the refractor, while the rays emerging to X"Y" will be above this refractor (Fig. 1d).

It is clear that the differences between XY, X'Y' and X"Y" will increase with the increasing of the refractor slope. Where an optimum XY spacing can be found?

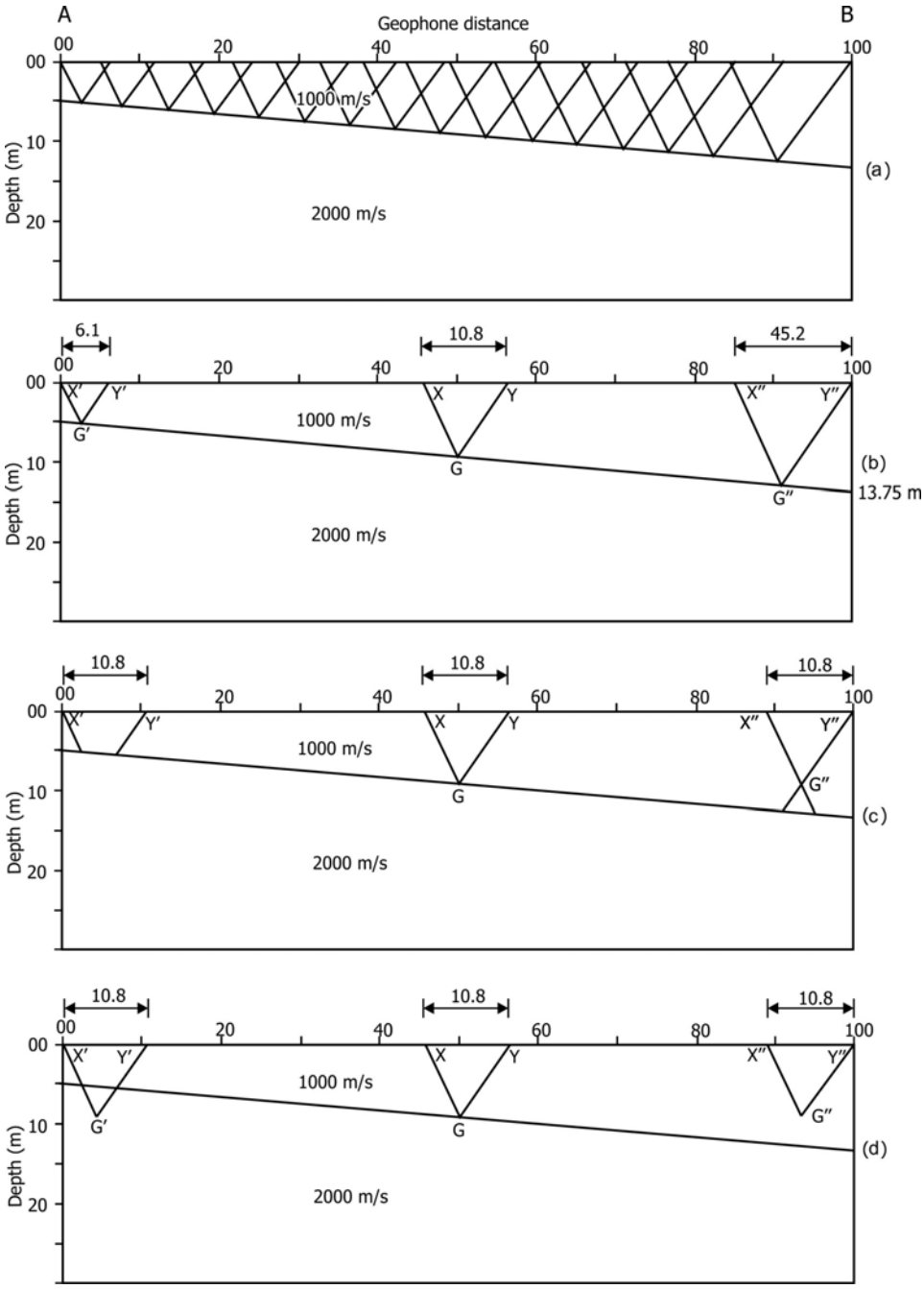


Figure 1: (a) Different optimum XY spacing from the same refractor, (b) Three different values of XY reacted at three different parts from the same refractor, (c) Three spaces on the refractor when the optimum XY is selected as a constant (10.8 m) and (d) Three different depths from which the rays will emerge when the optimum XY is selected as a constant (10.8 m)

Second case:

A step or a fault case (Palmer, 1986, p.64)

In case of a step or a fault model (Fig. 2), the first arrival traveltime curve has three different traveltime elements recoded from three different refracting interfaces from each side of shootings. Using the ray tracing technique (Fig. 2), it will be found that:

1- The optimum X'Y' spacing along the refracting interface 2 is constant and equal to 4.36 m.
2- The optimum X"Y" value spacing the refracting interface 4 is also constant and equal to 13.09 m. and
3- The refracting interface 3 has several different values of XY.

Accordingly, there is no single constant value that can be accepted to be optimum. The use of 10 m as optimum XY value (as suggested by Palmer, 1986, p. 100) will be found at a single point on the refracting interface 3. At other points on the refracting interfaces, all rays with XY = 10 m will emerge from two different points either below or above the refracting interfaces.

In his book (1980), the same model is used and the velocity analysis is suggested to be similar that shown in Figure 3. While in 1986, the velocity analysis function cannot be used to determine the true velocity of the refractor. It is so strange that for the same model, different results are obtained (Fig. 2c). The main reason for this is the absence of an optimum XY spacing that can be used for such model. As discussed above, refracting interfaces 2 and 4 have two constant XY values while the refracting interface 3 has numerous optimum XY values (Fig. 2b).

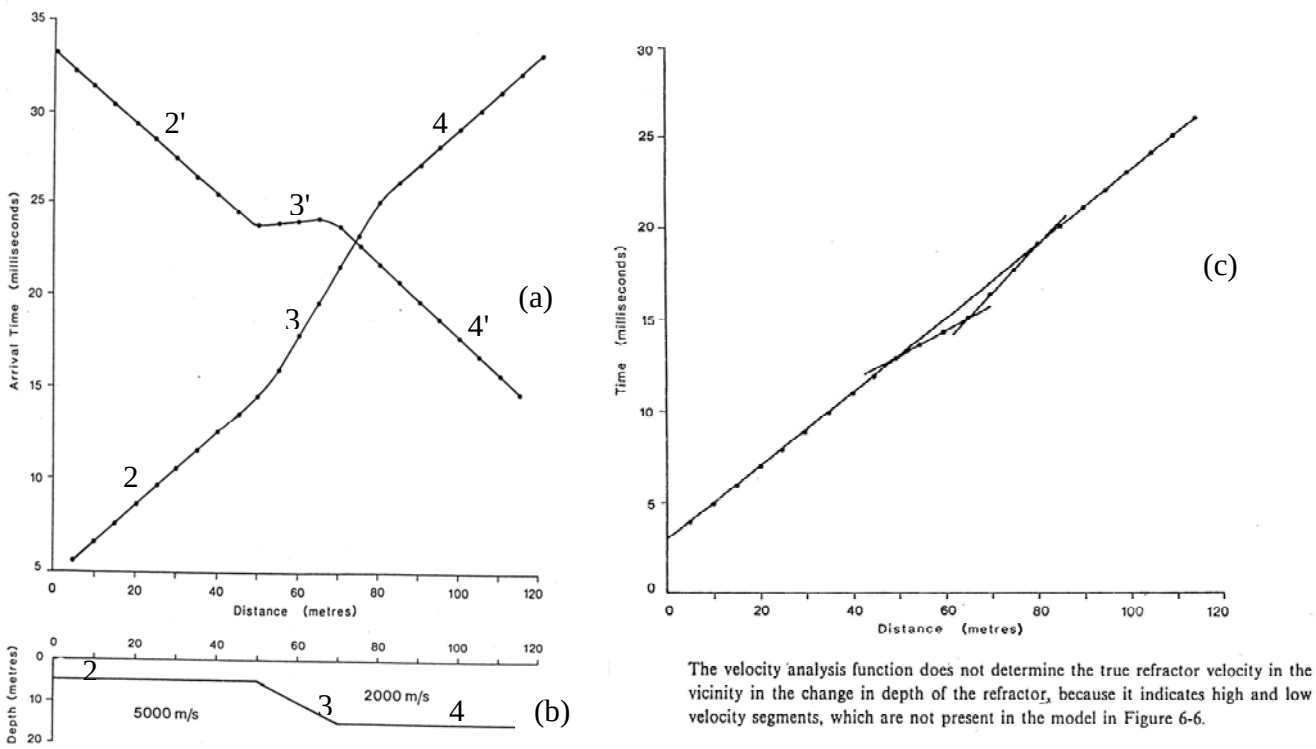


Figure 2: The traveltime curve (a) of the step model. In Figure C, the velocity analysis cannot be used for correct determination of the XY spacing.

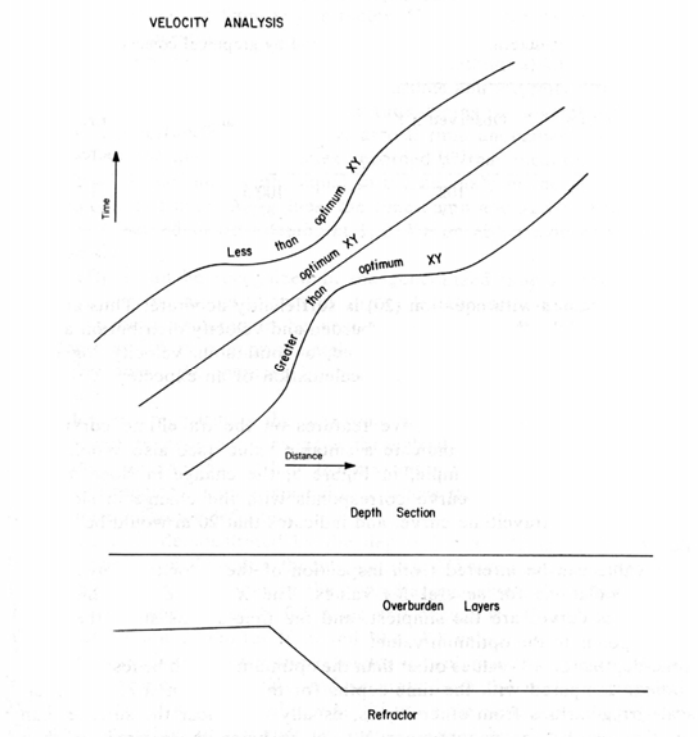


Figure 3: The same model as in Figure 2 and the value of optimum XY spacing (Palmer, 1981)

Third case:

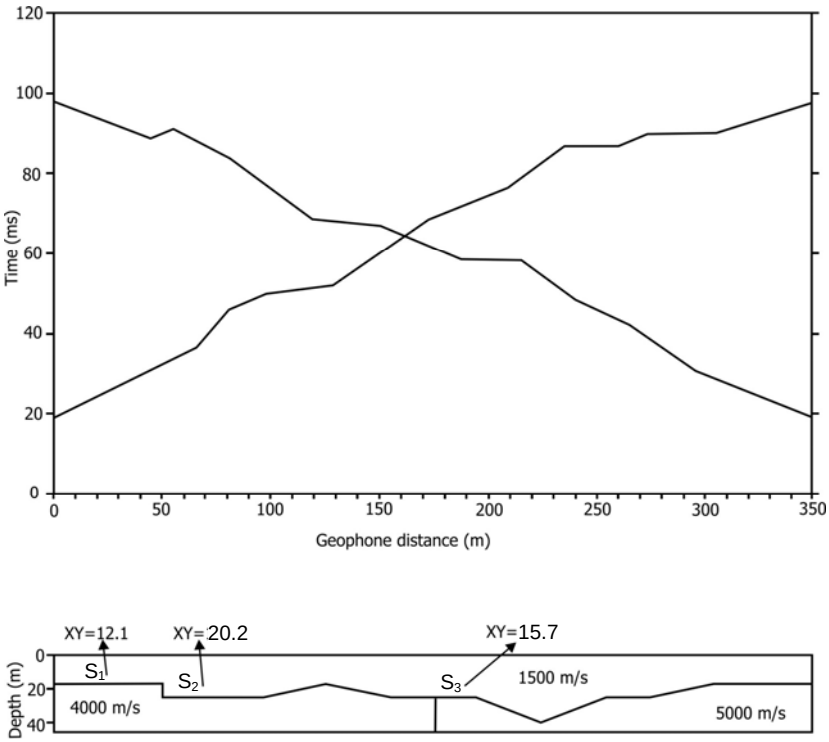
Irregular refractor surface (Pamer, 1981, p. 17)

In this case, the refractor consists of several refracting interfaces. The emerged rays from each refracting interface have different optimum XY spacing (Fig.4). Consequently, the optimum XY values are different. They are ranging from about 12.1 m to20.2 m.

In case of the refracting interfaces have the same velocities and vary in thickness (or depths), the optimum XY values will be also variable (12.1 m if the depth of the refractor is equal to 15 m at S_1 and 20.2 if the depth equals to 25 m at S_2, respectively)

If the refracting interfaces have the same thickness but varied in velocities, then the rays emerged from points at the same depth will have different optimum XY values. The points S_2 and S_3 have the same depth (25 m), but the emerged rays from these points have two different optimum XY values (equal to 16.2 and 15.7, respectively) as a result of the variations in velocity along these refracting interfaces (Fig. 4b).

Figure 4: Irregular refracting interfaces. The XY values are not constant along interfaces with either different depths and/or velocities.



Fourth case:

Irregular ground surface (Palmer,1986, p.60)

In case of an undulating topography, the rays at the ground surface and emerged from the same points on the refractor (even a horizontal one) have two different optimum XY values (Fig. 5). The studied model shows that the XY spacing has different values (Fig. 5b).

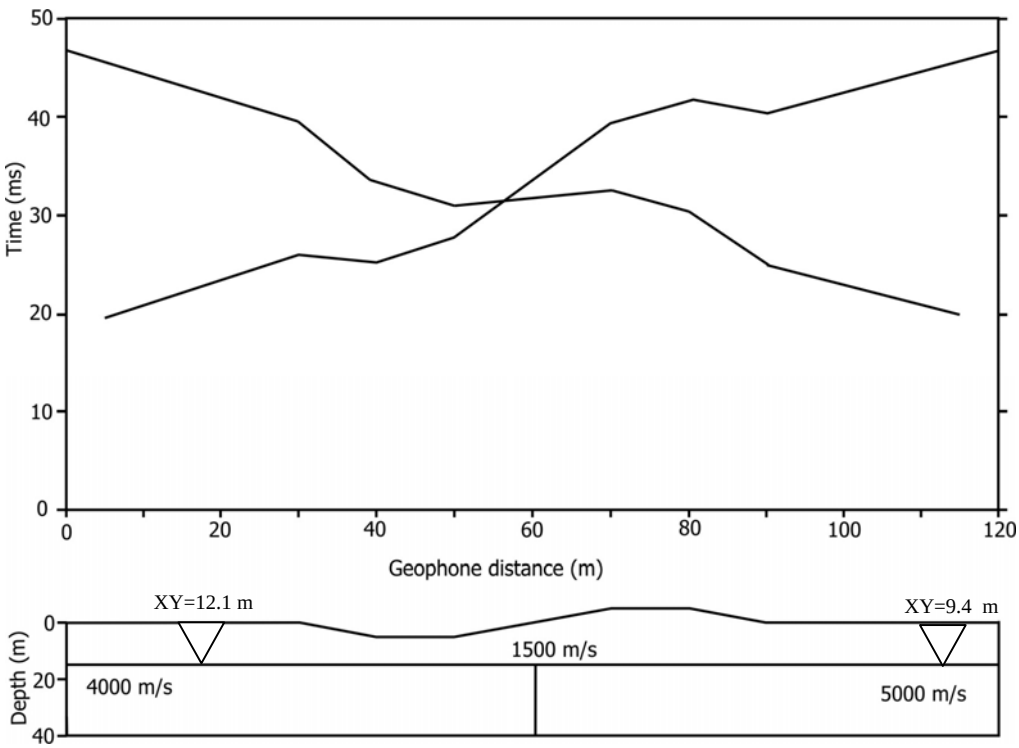


Figure 5: Irregular topography. The optimum XY changes as the topography changes.

Zero Optimum XY Value

The optimum XY distance is attained when the rays at the ground surface have emerged from the same point on the refractor. At a zero XY distance, the rays will be emerged from to two points on the refractor and the rays have a surface common point (zero spacing) on the ground surface. This indicates that there is

no clear differentiation between the GRM and the conventional reciprocal time (Hawkins, 1961). So Whiteley 2006 considered that GRM is a restriction of the reciprocal method

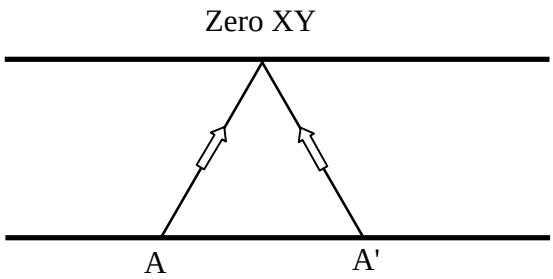


Figure 6: Zero offset distance. In this case the rays must be refracted from two different point on the refractor.

Main parts of the GRM

The GRM has two functions, the velocity analysis and the time-depth functions. The velocity analysis function is given by:

$$t_v = (T_{AY} - T_{BX} + T_{AB})/2$$

The optimum XY showing maximum smoothness (less structure) will confirm to the geophysical assumptions that valid for most geology

While, the time-depth function is:

$$T_G = T_{AY} + T_{BX} - T_{AB} - XY/V_2$$

Palmer suggested that the values of these functions can be used also to calculate the optimum XY spacing.

It is clear that these two functions depend mainly on the estimation of the optimum XY spacing,

Discussions and conclusions

In this study, all models; except the first one, are discussed in Plamer (1980 & 1986). The XY spacing is backbone of the GRM. The velocity analysis and the time-depth functions depend mainly on this spacing. In all previous examples, the existence of the optimum XY is a doubtful matter. The optimum constant XY spacing with rays emerging from near the same point on the refractor is found in a two horizontal layer case with constant velocities. In all other cases, the optimum XY spacing has neither constant value nor emerging from near the same point on the refractor. On the contrary, most of XY values have different spacing.

The GRM is suggested also to be applied for undetected layer problems (hidden layers and velocity inversion) and seismic anisotropy. In case of the undetected layer problems, there is no recoded data as first arrivals on the traveltime curve. It is so strange that the GRM can be applied on the traveltime curves without first arrivals from these layers. If the application of the GRM on simple models is a doubtful matter, then the use of it in relative complex structure or seismic anisotropy will be also in doubt.

The shallow seismic refraction technique has inherent problems, such as the undetected layers, ambiguities, first and later arrivals….etc. Other main problems are related to the interpretation techniques themselves. Most of them are restricted to simple models, but the generalization is responsible to false interpretation.

Since the GRM has heuristic assumptions and has no mathematical derivation, more uncertainties are raised in its application, even in case of a simple models as discussed before. The lack of constant XY spacing in all cases (except the horizontal ones) will lead to more uncertainties in its application.

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