

### 3-D multicomponent survey design: P-P versus P-S fold

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#### ABSTRACT

The area of coverage and resultant fold of a 3-D seismic survey are fundamental parameters in the survey's design. For converted (P-S) waves, in a single homogeneous layer, the area of coverage provided by a given set of orthogonal shot and receiver lines is smaller than that of the corresponding P-P waves. But, in the covered area, the P-S fold is higher. In addition, the larger the  $V_p/V_s$  value, the smaller the area of P-S coverage.

#### INTRODUCTION

The design of a 3-D seismic survey is a key component in the cost and resulting quality of the final data volume. Thus, considerable effort has been (and is) spent on the design of the acquisition program. Especially important are shooting geometries and the final effect of various parameters (e.g., shot and receiver spacing, or areal coverage and average fold). When considering converted-wave surveys, we need to be at least as diligent in the survey design as with P-wave acquisition because multicomponent measurement will be somewhat more expensive than conventional 3-D work and the P-S images may be more sensitive to the shooting parameters.

Let's start the multicomponent design analysis by considering the simple case of crossed shot and multicomponent receiver lines of length  $2l$  (Figure 1).

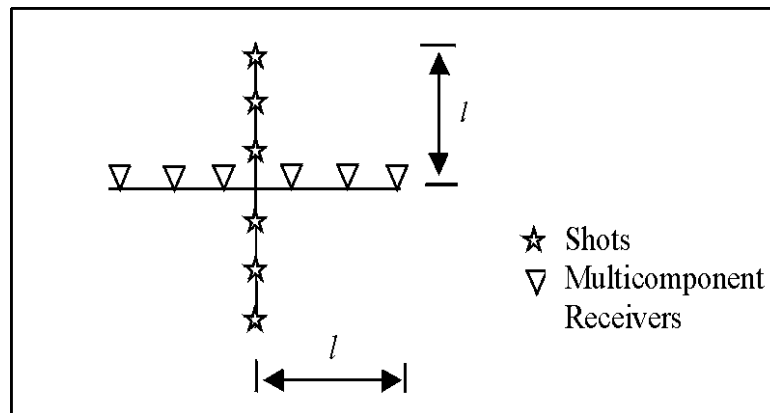


Fig. 1. Schematic diagram of a simple 3C-3D survey with crossed shot and receiver lines of length  $2l$ .

For a homogeneous layer with a single  $V_p$  value, the area of P-P reflection coverage (Figure 2) is simply:

$$A_{pp} = l^2. \quad (1)$$

What is the similar areal coverage for the converted-wave case, with a  $V_p/V_s$  value equal to  $\gamma$ ? We know that  $X_{ps} = X / (1 + \gamma)$  for a single layer, where  $X_{ps}$  is the offset of

the conversion point from the receiver, using a source-receiver offset of  $X$ . This extends  $P$ - $S$  coverage in the receiver line direction and shortens it in the shot line direction. In fact, the area of coverage is:

$$A_{ps} = \frac{2l}{1+\gamma} \cdot 2l \cdot \left(1 - \frac{1}{1+\gamma}\right) = \frac{4l^2\gamma}{(1+\gamma)^2} \quad (2)$$

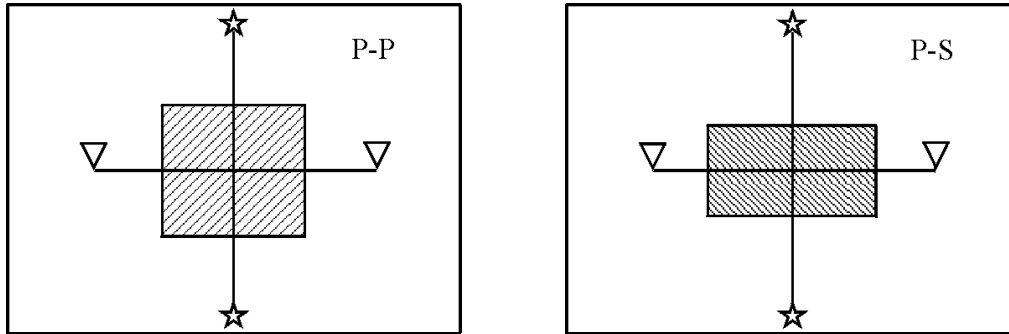


Fig. 2. Areas of coverage for the crossed shot and receiver lines of Figure 1 for  $P$ - $P$  (a) and  $P$ - $S$  waves (b).

We note that the ratio of the two areas is:

$$\frac{A_{ps}}{A_{pp}} = \frac{4\gamma}{(1+\gamma)^2} \quad (3)$$

If  $\gamma = 1$ , then  $A_{ps}/A_{pp} = 1$ ; for  $\gamma = 2$ ,  $A_{ps}/A_{pp} = 8/9$ ; if  $\gamma$  is large,  $A_{ps}/A_{pp} \sim 4/\gamma$ . Equation (3) is graphed in Figure 3(a) for  $\gamma$  value varying between 1 and 10. Of course, with a given number of shots and receivers, due to smaller coverage area, the  $P$ - $S$  fold is higher than the  $P$ - $P$  fold in the area of coverage. This reciprocal of the area ratio is shown in Figure 3(b).

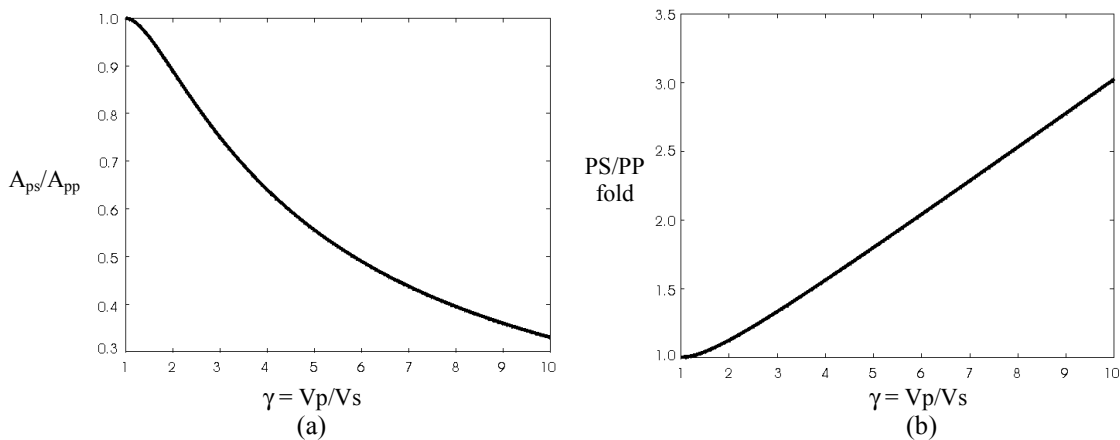


Fig. 3. (a) Graph of the ratio of  $P$ - $S$  covered area to  $P$ - $P$  coverage as a function of  $\gamma$ . (b) For a given number of shots and receivers, the relative  $P$ - $S$  versus  $P$ - $P$  fold (the reciprocal of Figure 3a).

### MULTIPLE LINE COVERAGE

More generally, we usually design 3-D surveys with multiple shot and receiver lines. Consider north-south shot lines of length  $L_S = (n-1)\Delta s$ , where  $n$  is the number of shots per line and  $\Delta s$  is the shot spacing, and east-west receiver lines of length  $L_R = (m-1)\Delta r$ , where  $m$  is the number of receivers per line with receiver spacing  $\Delta r$ . The receiver line interval is  $\Delta R$  and shot line interval is  $\Delta S$  (Figure 4). Let us assume that we have  $N$  shots in total, divided into a number of shot lines  $k$ . Furthermore, suppose that we have  $M$  live receivers in  $l$  receiver lines. What is the area of coverage and what is the average fold if the output bin size is  $\Delta x^2$ ?

Let us assume that shot and receiver lines are orthogonal and regularly spaced. In addition, suppose that the receiver spread is centred and enclosed in the area of shot coverage (Figure 5). We note that there are  $n$  shots per line and  $m$  receivers per line. Also, the cross-line shot spread  $W_S$  is given by  $(k-1)\Delta S$  and the cross-line receiver spread  $W_R$  is given by  $(l-1)\Delta R$ .

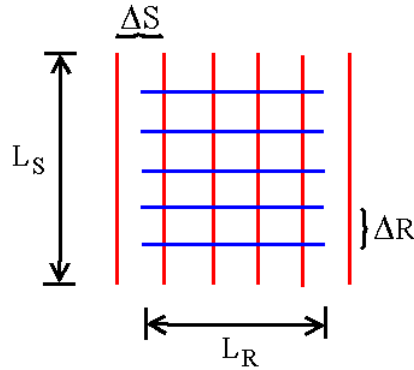


Fig. 4. Multiple shot and receiver line geometry.

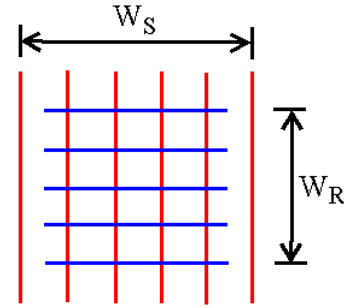


Fig. 5. Total length of the shot and receiver spreads.

Let's calculate the area of P-S coverage:

$$\begin{aligned}
 A_{ps} &= 2 \left[ \left( \frac{L_S}{2} - \frac{W_R}{2} \right) \frac{1}{1+\gamma} + \frac{W_R}{2} \right] \times 2 \left[ \left( \frac{W_S}{2} - \frac{L_R}{2} \right) \frac{1}{1+\gamma} + \frac{L_R}{2} \right] \\
 &= \left( \frac{L_S - W_R}{1+\gamma} + W_R \right) \left( \frac{W_S - L_R}{1+\gamma} + L_R \right) \\
 &= \frac{[L_S - W_R + (1+\gamma)W_R][W_S - L_R + (1+\gamma)L_R]}{(1+\gamma)^2} \\
 &= \frac{(L_S + \gamma W_R)(W_S + \gamma L_R)}{(1+\gamma)^2} \tag{4}
 \end{aligned}$$

We note that if there is one shot line and one receiver line of equal length, then  $W_R = W_S = 0$ ,  $L_S = L_R$  and equation (4) reduces to equation (2).

Given this area of coverage, the number of bins is:

$$B = \frac{A_{ps}}{\Delta x^2} \quad (5)$$

And thus the average fold  $F$  is the total number of traces divided by the number of bins:

$$F = \frac{M \cdot N}{B} \quad (6)$$

### CONCLUSIONS

For a crossed shot and receiver line, the P-S coverage is extended in the receiver-line direction and shortened in the shot line direction. The total P-S area of coverage is smaller than that of the P-P wave. The larger the  $V_p/V_s$  value, the smaller the P-S area of coverage. However, this gives higher fold on the covered area for a given number of shots and receivers. For multiple orthogonal shot and receiver lines, the area of coverage is defined by the lines' lengths and spread widths.

### ACKNOWLEDGEMENTS

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