A practical approach for selection of optimum array pattern and analysis of Plantation related affects

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Introduction

When earth is excited either with surface sources, or explosive sources blasted in a shot hole, surface waves are also generated in addition to the P-wave. This surface wave travels with velocity around 300 - 600 m/sec. and having frequency around 5 Hz to 20 Hz, generally. Amplitude of surface wave is normally very large compared to the amplitude of reflected P-wave, therefore, it is necessary to suppress this wave before entering into the instrument. Since surface wave has low frequency and low velocity compared with the signal, the apparent wave number of surface wave is smaller than that of reflected P-wave. Therefore suitable spatial filter is designed which discriminates the waves according to wave numbers. This can be done in the field by designing proper arrays of sources or/and receivers, instead of a single source/receiver. Design of array depends on the characteristics of surface waves and requirement of resolution in a particular area. Parr, J.O. & Mayne W.H., Geophysics - 1955, Vol.20, **(**P539—564) "A new method of Pattern Shooting" has suggested a criterion of finding optimised weighted array. This array is symmetrical about the centre of the array and all the secondary peaks in the reject region have equal magnitudes. Mark Holtzman (1963) suggested a most practical and effective optimized geophone array called Chebyshev Array for cancellation of surface noise. This deals with the arrays in which the reject band peaks are all of equal amplitudes. These arrays have the remarkable property that for a given absolute upper bound in the reject band, they have the narrowest width of pass band lobe as measured between the first nulls. He has claimed that this array is more effective than the array suggested by Parr& Mayne. A more practical way of selection of uniformly weighted array is described below along with **analysis of plantation related affects.**

Practical Approach

In Smith's approach, longest noise wavelength has been kept at 3db attenuation point, which corresponds to very small attenuation. In Parr & Mayne's and Chebyshev's approach, any amount of noise attenuation can be achieved if we don't limit the element spacing and array length. But attenuation of highest frequency component of signal by this array has not been considered at all. Therefore arrays selected by these criteria may not be practically useful. Hence I have considered a practical way of selecting array parameter on the consideration of signal and noise both.

Uniform array Vs. weighted array

As can be seen from the response curve, uniform arrays always have lesser effective length than the tapered array for equal amount of attenuation of noise. Consequently, due to large effective length tapered array produce more attenuation on signal as compared to uniform array. Therefore, as far as possible uniform arrays may be used if noise problem is not very severe.

Optimum Value of (X/Z)

First of all maximum allowable value of (X/Z) is calculated on the basis of shortest wavelength component of signal required to fulfill the geological objectives and prominent noise wavelength which is interfering with the signal at the level of main zone of interest. Attenuation of desired shortest wavelength signal must not be more than 3 dB (half power point) and that of prominent noise must be more than or equal to 20 dB. As shown in fig. 2.8, 3 dB attenuation occurs at $L / \lambda_{sx} = 0.44$ and 20 dB attenuation at $L / \lambda_N = 0.91$ for any uniform array of elements more than 3. Where, λ_{sx} is the apparent shortest wavelength of signal and λ_N is the wavelength of prominent noise and 'L' is effective array length. Thus we have

$L / \lambda_{sx} \leq 0.44$

$L / \lambda_N \geq 0.91$

And for limiting values

$\lambda_N / \lambda_{sx} = 0.44/ 0.91=0.48$

$\lambda_N /\lambda_s = 0.48$ Cosec θ, since $\lambda_{sx} = \lambda_s$ Cosec θ, where θ is incident angle is incident angle.

Substituting the value of Cosec θ for reflectorof dip Ø, we get

$\lambda_N / 0.48\lambda_s = 1+ [4Z^2.\cos^2Ø/ (X\pm 2Z \sin Ø)^2]^{1/2}$

After simplification this becomes

$X/Z = 2 \cos Ø/[(2.08 \lambda_N / \lambda_S)^2-1]^{1/2} \pm 2\sin Ø$

Here,

(+) for up dip shooting

(-) for down dip shooting.

Now, calculate the value of (X/Z), on the basis of the value of λ_N, λ_s and Ø (dip angle). If (X/Z) calculated, comes out to be equal to or greater than the value as decided on the basis of NMO stretch and attenuation of multiple criteria, then there is no problem, we can keep that value of X/Z. If it is less than the above value, then we must keep less far offset as calculated here, to attenuate the noise and preserve the signal at required level. Otherwise we have to satisfy with, either lesser attenuation of noise or greater attenuation of signal. So, a compromise for (X/Z) value is done at this level, if required.

Effective array length 'L':

After deciding (X/Z) value, the maximum effective array length is calculated on the basis of following relations:

$L = 0.44\,\lambda_{sX} = 0.44\,\lambda_s \,\text{Cosec}\,\theta$, from eqn. (1).

Substituting the value of Cosec θ for different cases, we get the follow result

Up-dip

$$L = 0.44\,\lambda_s\,[1+ \{4Z^2.\text{Cos}^2Ø/ (X-2Z\,\text{Sin}Ø)^2\}]^{½} \quad \textbf{(4)}$$

Down-dip

$$L = 0.44\,\lambda_s\,[1+ \{4Z^2.\text{Cos}^2Ø/ (X+2Z\,\text{Sin}Ø)^2\}]^{½} \quad \textbf{(5)}$$

Non-dip

$$L = 0.44\,\lambda_s\,[1+ \{4Z^2. / (X)^2\}]^{½} \quad \textbf{(6)}$$

Number of elements 'N' and element spacing 'd'

If value of 'L' calculated from the above relation is more than the prominent noise wavelength λ_N, then keep

$$\lambda_N = N.d \quad \text{for } \lambda_N \le L \quad \textbf{(7)}$$

to kept λ_N at the first notch.

Otherwise, $L = Nd$ for $\lambda_N > L$ **(8)**

to keep λ_N at 20 dB attenuation point.

N & d may be varied, such that N ≥ 4 and d < geophone spacing in the string and base-length closest to group-interval, if equal values of base-length and group interval are not possible.

No. of elements, $N= L /(L-L_B)$

Where, L_B = desired base length of the array, preferably equal to group interval.

If equation (9) does not provide suitable value of N, then any other suitable combination of N & d may be tried satisfying the condition in equation (7)or(8) and their effectiveness can be tested by fold-back experiment and (F-K) diagram.

PRACTICAL EXAMPLE FOR DESIGNING OF OPTIMUM ARRAY PARAMETERS FOR A GIVEN SITUATION:

Exercise

In an area, λ_N = 36 m, λ_S = 40 mZ = 2500 m, X = 3000 m
ΔX = 30 m, design the optimum array.(Assuming Φ = 0)

Solution

(i) This gives, X/Z = 1.26, according to eqn. (3), i.e. X=3150m, which comes out more than the previous value, X = 3000 m (as given). Therefore we can keep X = 3000m safely.

(ii) Now, X = 3000 m, Z = 2500 m.
Therefore, L = 34 m, according to equation (6)

(iii) Since, $\lambda_N > L$,
We put, L = Nd As in equation (8)
i.e. Nd = 34

(iv) If we put base-length = group interval = 30m (as given)
No. of elements, $N = L /(L-L_B) = 34/4 = 8.5 = 8$ (Say).

(v) Element spacing 'd'= L /N= 34/ 8/ = 4.25 m.

FOLD-BACK EXPERIMENT AND ANALYSIS OF THE RESULT:

As discussed above, two possible optimum arrays are decided, based on the signal and noise characteristics and their effectiveness is tested with respect to the bunched geophones in real field conditions. Layout of the array is shown in Fig.1 If n is the numbers of active channels, channels 1 to (n/3) are in the first row and geophones are planted with parameters of first array pattern. In the second row at a distance of a few m, are channels (n/3+1) to (2n/3) and geophones are planted with bunching of geophones, and in the third row are channels (2n/3+1) to (n) second array pattern parameters. Group interval ΔX in each row is the same and equal to the group interval to be kept in production work. First shot with optimum parameters is taken at an offset, equal to near offset to be used in production work. Second shot at an offset equal to (nΔX/3) from the first shot point, and third shot again at an offset of (n ΔX/3) from the second shot point are taken. For 96 channels recording, 30m group interval and initial near offset 150 m, first record shows the behavior of arrays from 150 m to 1080 m. Second record shows the behavior of arrays from 1110 to 2040m. Third record shows the behavior of arrays from 2070m to 3000m. 3000 m is the far offset distance to be kept in production work.

Channels having the same offset in the three groups of detectors are compared for each offset. S/N and peak frequency of the signal is calculated at the zone of interest, from the defloat monitor record. Amplitude spectrum and auto-correlation function can also be obtained at the zone of interest at several offsets with the help of computer. In the field lay-out as shown below, channels 1 to 32 are having array 3-4-5-5-4-3 with geophone spacing 6m; channels 33 to 64 are having bunched geophones and channels 65 to 96 are having array 4-4-4-4-4-4 with geophone spacing 6 m. Frequency analysis has been done at four offsets and plot of frequency spectrum are shown in Fig.2 (offset 1080 m) and Fig.3 (offset 150 m). Channels 1, 64 & 65 corresponding to an offset = lO80 m, channels 16,49 & 80 corresponding to an offset=600 m, channels 32, 33 & 96 corresponding to an offset = 150m and channels 13, 52 and 77 corres-ponding to an offset = 510 m. Channels 13, 16 and 52 are having peak frequency 14 Hz (Table 1), which is the frequency of prominent noise. At all the four offsets, channels 65 to 96 (array 4-4-4-4-4-4) are showing higher peak frequencies as compared to others.

TABLE -1
Amplitude spectra of fold—back Record

FREQUENCY	Offset 1080 m.			Offset 600 m.			Offset 150 m			Offset 510 m.		
	Channels			Channels			Channels			Channels		
	1	64	65	16	49	80	32	33	96	13	57	77
	NORMAL AMPLITUDE			NORMAL AMPLITUDE			NORMAL AMPLITUDE			NORMAL AMPLITUDE		
0	4	3	1	1	1	0	2	3	2	8	4	10
2	4	4	1	2	1	2	3	3	2	8	4	10
4	4	4	1	4	2	4	4	5	1	9	4	11
6	4	4	2	6	3	7	6	6	1	9	4	11
8	5	4	3	8	6	8	8	12	3	13	7	20
10	6	4	2	8	9	9	12	0.4	5	18	8	11
12	11	10	15	39	22	41	38	44	34	59	34	62
14	43	48	34	100	77	48	31	94	38	100	100	92
16	61	45	43	78	100	71	80	62	60	40	49	64
18	8	40	15	92	78	100	48	54	52	89	51	91
20	22	19	34	48	27	45	10	10	86	40	20	60
22	100	100	100	42	17	26	41	37	40	39	25	45
24	12	12	18	21	10	20	14	15	31	38	16	27
26	41	27	47	74	32	50	81	66	100	74	31	100
28	33	22	43	90	40	67	69	55	79	56	26	84
30	16	5	17	14	4	11	37	19	30	11	8	2
32	10	5	12	18	6	17	15	19	26	31	5	47
34	16	5	20	7	3	7	21	19	26	20	14	42
36	17	8	25	30	14	19	29	24	34	30	10	29
38	13	11	18	18	6	12	30	15	29	24	7	31
40	2	2	6	14	6	10	8	10	15	8	4	7
42	1	2	2	20	5	15	10	8	11	22	10	28
44	4	3	4	20	9	18	5	2	6	21	6	26
46	1	1	1	15	7	15	11	9	14	6	1	8
48	3	3	4	10	6	10	5	6	9	8	2	6
50	3	2	3	7	4	8	2	1	4	5	0	4

Fold-Back layout is given below.

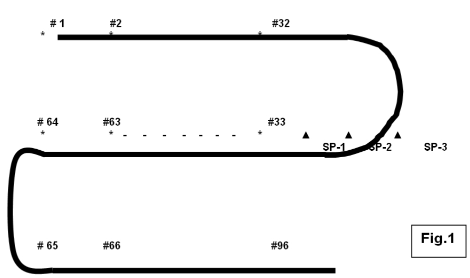

Fig.1: Fold-back experiment for comparison of Array Response

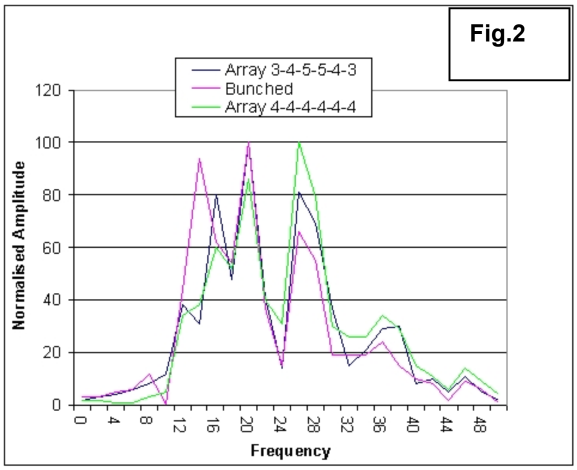

Fig.2

Channels 1 to 3: Array 3,4,5 - 5, 4,3.
Channels 33 to 64 : Bunched geophones.
Channels 65 to 96: Array 4,4,4 –4,4,4

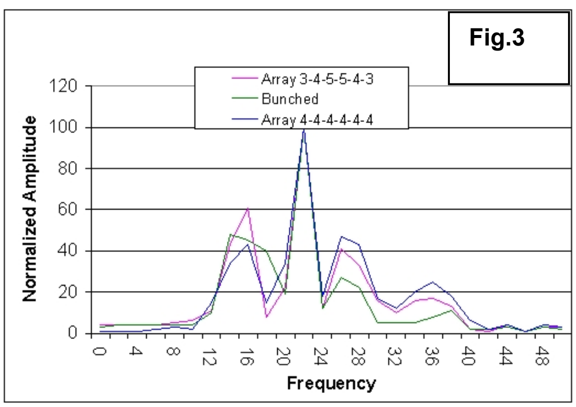

Fig.3

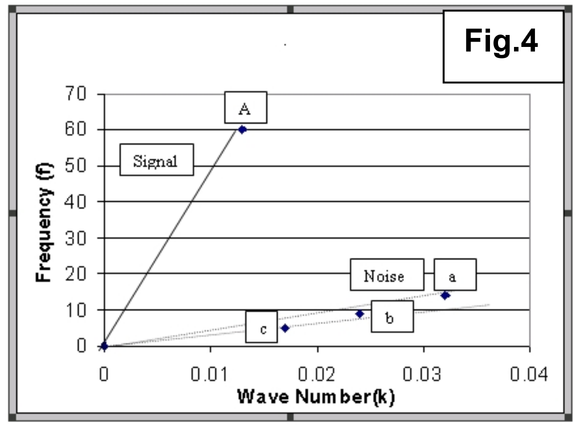

Fig.4

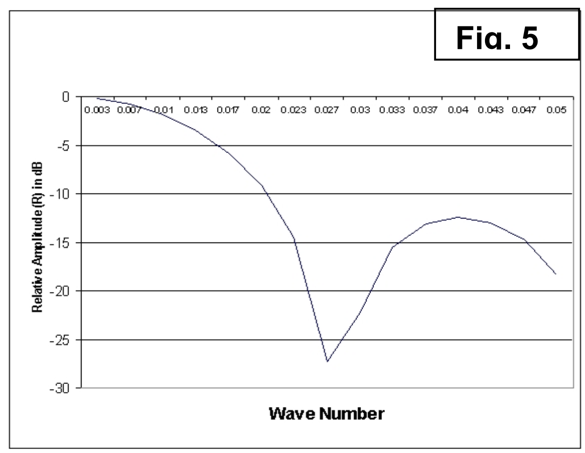

Fig. 5

(F-K) DIAGRAM

(f-k) diagram is very useful tool for design and performance evaluation of an array. This provides a direct indication of how well noises are attenuated and what affects the array has on desired reflection events. To draw (f- k) diagram, each (f, k) pair both for noise and signal is plotted on (f-k) plane as a point (k is apparent wave number, f is frequency) and these points are joined with the origin by a straight line. Slope of each straight line gives the corresponding apparent velocity. Just below this sketch, (R-K) diagram (array response curve) of the array, which we wish to use is drawn. A practical example of (f-k) diagram is shown in fig. 4 and array response curve in fig.5 Signal & noise have following characteristics.

Characteristics of Signal

Let depth of target horizon be z =2500m, average velocity to the target horizon = 2400m/sec and far offset X=3000m. If as per objective, resolution of 10 m thick bed is required, then shortest wavelength component of signal required to be recorded is 40 m and corresponding frequency would be f=V/λ = 60Hz. The required apparent wavelength of the signal would be

$\lambda_a = \lambda / \sin\theta = 78$ m : where, $\theta = \tan^{1}(X/2Z) = 31^{0}$
Therefore, K= 0.013 cycle/m.
This (f,k) pair corresponds to point (A) in the (f-k) diagram.

Characteristics of Noise

According to figures 4& 5, the three groups of noises have the following characteristics

(a) f = 14Hz, V_2 = 440 m/Sec., λ_2 = 31 m, K_2 = 0.032
(b) f = 9 Hz, V_3 = 370 m/Sec., λ_3 = 41 m., K_3 = 0.024
(c) f = 5 Hz, V_4 = 295 m/sec., λ_4 = 59 m., K_4 = 0.017

These are shown as points (a), (b) and (c) in the (f-k) diagram.

Below this diagram, response curve of one suitable array 4-4-4-4-4-4 with 6 m. spacing is drawn. Attenuation of noise (a) is around 19 dB and that of noise (b) is about 17.5 dB by this array. Noise (C) may be suppressed with the help of low cut filter of the recording device. The required signal, which corresponds to point (A) in the (f-k) diagram, is well within the Pass-band of the array response curve. Therefore the array 4-4-4-4-4-4, for the above mentioned noise and signal is a suitable one.

Conclusions

Above finding is based on practical approach and can be used successfully in the field. Due importance was given to signal, while deciding for optimum array parameters. Besides the best design of array parameters, we must also pay attention to the following points. Deviations from the optimum parameters may seriously affect the attenuation characteristics of the array. (a) If geophone plantations are not uniform i.e. either the coupling with the ground is different or geophones are inclined at different angles with the vertical, then even if the numbers of geophones are equal at each element positions, their sensitivity will not be equal. And, therefore, uniform array will change into tapered, and position of notches & cut off point will be shifted. (b) If geophones are not planted exactly at the same distance as planned, even if plantations are uniform, there will tapering in spacing. In this case also characteristics of the array will be changed considerably. (c) If there is elevation changes within the group, there will be phase shift of the reflected wave coming nearly vertical to the ground within the array between element to element, and resulting wavelet will have less amplitude and frequency. Thus proper geophone plantation is very essential to get desired result from geophone array.

REFERENCES:

1.Anstey, N.A., 1970, Signal characteristics and instrument specifications, Gebruder Borntraeger-Berlin-Stuttgart.

2.Denhan, L.R., 1979, Field technique design for seismic Reflection, Interrnal. Mtg. and Expose:, Soc. Explor.Geophysics, New orleans.

3.Graebner, R.J., 1960, Seismic data enhancement, Geophysics,25, 283 - 311.

4.Holtzman, Mark., 1963, Chebyshev optimised geophone array, Geophysics, 28, No.2, 145.

5.Knapp. R.W., Steeples, D.W., 1986, High resolution common-depth point reflection profiling: Field acquisition parameter design, Geophysics, 51, No.2, 283 - 294.

6.Knapp, R.W., Steeples, D.W., 1986, High resolution common-depth-point reflection profiling: Instrumentation, Geophysics,51, No.2, 276 - 282.

7.Khatri, K.N., 1979, Tapered linear seismic array, ONGC, Bulletin, 16, No.1.

8.Lombardi, L.V., 1955, Notes on the use of multiple geophones, Geophysics, 20, 215- 226.

9.Parr, J.O., and Mayne, H.W., 1955, A new method of pattern shooting, Geophysics, 20, 539 - 564.

10.Smith, M.K., 1956, Noise analysis and multiple seismometer theory, Geophysics,21,No.2,337- 360.

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