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Improvement of signal to noise ratio by Group Array Stack of single sensor data

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Summary

Shot generated noise and the cultural noise is a major problem in seismic survey because they are time and space coincident energy with reflected arrivals. High dynamic range recording systems are capable of recording weak signals of the order of few nano volts, but the presence of high amplitude ambient noise obscure the signal amplitude which sometimes becomes irretrievable. Some ground rolls and air blasts are difficult to remove with conventional array based shot records due to the events being spatially aliased. In the event of using longer array base, high frequency signal is severely affected at far offsets for shallow and dipping reflectors.

However, very close spatial sampling and post acquisition pre-processing with Group Array Formation (GAF) and Group Array Stack (GAS) can result in noise attenuation considerably with increased signal to noise ratio.

This paper shows the improvement of signal to noise ratio seismic data acquired on an experimental basis to test the efficacy of Group Array Formation.

Introduction:

A conventional array design is based on the array response of number of elements in a group to attenuate a range of noise wavelengths and the same time taking care of attenuation of probable spatially aliased signal. Sometimes it becomes desirable to use array lengths more than the group interval to attenuate dominant ground roll. But a larger array base has an adverse effect on the high frequencies at longer offsets, dipping reflectors and rough uneven terrain conditions.

A uniform distribution of geophones along the spread i.e. equally spaced, equally weighted, spatially array length equal to the group interval, yields even, regular and continuous traces having the same length as the spread on the gather and attenuates the range of noise wavelengths on stacking (Nigel A. Anstey,1986).

The in-line spread in 2D mode is not effective for noise attention in 3D seismic survey particularly in orthogonal shot geometry which is widely adopted for wide azimuth survey. The reason being, the shot generated noise approach the geophone array in different directions for shots in different orthogonal positions. In case of bunching of geophones at the desired group interval, the spatial aliasing effect is still worse for high frequencies /shorter wavelengths. Random noise effect is also predominant over the weak reflection arrivals.

So it is necessary to design 3- dimensional array to attenuate the ground roll in in-line and cross line directions and the random noise effects in 3D data acquisition.

Methodology and Analysis

With advent of digital geophones with high dynamic range and recording systems having sufficient channel recording capacity, the close spatial sampling makes useful for recording most of the signal and noise unaliased.

Depending on the noise scenario in the area, the individual geophone elements are laid in number of sub-lines in close spacing to sample the wave field (noise and signal) from inline and cross line directions. In post acquisition, preprocessing is done on the raw data by using range of

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noise attenuation algorithms (for coherent and random noise), in addition to application of static correction on each element.

In contrast to conventional array where it is decided prior to data recording, GAF is made from the aerially distributed geophone elements in a pattern to form arrays in a group to further attenuate noise in vertical stacking of elements in groups.

With-in the group of elements, intra-group statics is computed by cross correlation of traces in a narrow time window comprising the first breaks to eliminate the time difference due to the path difference of the individual elements from the shot within the group.

The group of traces is assigned to have the concentration of energy at the centre of the group. After stacking process of all the elements in the group, the elements are added in phase and the true waveform of the group is retained.

The Group Array Stack (GAS) further attenuates the effect of noise components (random and coherent) thereby improving the signal to noise ratio.

Data Acquisition

An experimental survey was conducted in Mayavaram area of Cauvery Basin, India to test the efficacy of above hypothesis. The digital geophones were used with explosive as energy source. Five receiver lines (500 channels per line) were laid with shot orthogonal to end-on spread geometry. The lay out of the spread is given in Fig-.1

Fig-:1 The spread geometry having 500 channels in each sub-line and shot spacing 30m orthogonal to spread

The field parameters are:
Table-1

Element interval (in line) –	10m
Line interval (sub line)	5m
No. of sub lines	5 (SL-1 to SL-5)
No channels per sub lines	500
Spread length of each sub line	5000m
Total shots: 30 Shot interval:	30m

Data Processing

The processing sequence adapted in post acquisition data is as follows,

- Geometry merging-Gain application
- Field Statics correction
- Noise attenuation
- Pattern identification and Group Array Formation (GAF)
- Estimation of intra group statics and application (Perturbation correction) by cross correlation method.
- Vertical stack of traces in groups and generation of shot records for further processing

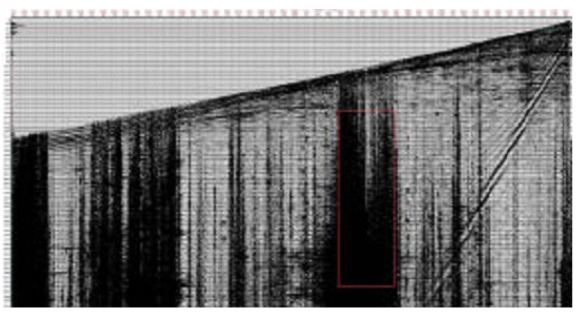

Fig-2(a) Middle line of SP.11001 having 500 traces

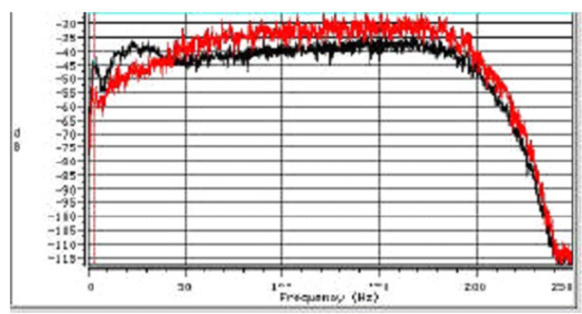

Fig-2(b) Frequency spectrum shows noise dominating the signal beyond 32 Hz.

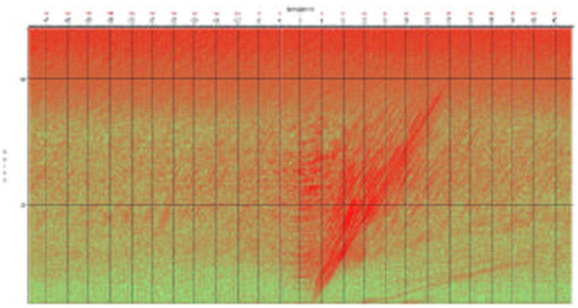

Fig-2(c) F-K spectrum of the shot record in fig: 2a

Fig:-2(a) shows part of the seismic record pertaining to the middle line of a shot gather (SP 11001) after geometry merging gain application with t^ (1.8) where t is time in seconds. The field statics correction is also applied at each receiver station. The random noise is observed to be of prominent amplitude masking the signals at some places.

Frequency spectrum of the raw data Fig-.2(a) shows the dominance of the high frequency components of random noise (above 32Hz) where as the shot generated noise (wavelength from 35-47m and frequency band of 5-8 Hz) is relatively less significant. The coherent and random noise needs to be attenuated to some extent before the formation of group array and subsequent stacking.

The f-k analysis of the shot gather (fig: 2a) shows that the spatial sampling with 10m station interval has no spatial aliasing of dipping events even at higher frequencies beyond 40 Hz (fig: 2c).If we consider a 3D acquisition geometry involving single element/bunching of geophones at a desired group interval 30m (say), the spatial aliasing effect is considerable for frequencies with higher dipping events.

Fig-3(a) shows the decimated element traces at an interval of 30m from the shot gather in Fig-2(a). The F-K analysis of the shot records is shown in fig-3(c).

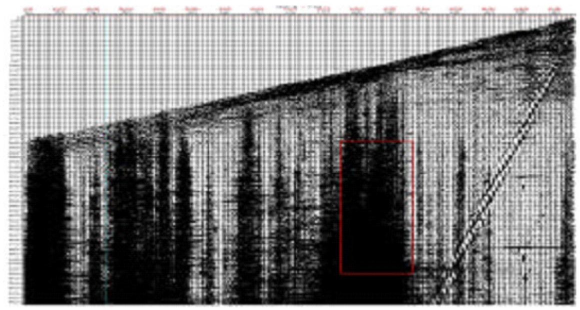

Fig-3(a) The middle line of a shot decimated at 30m interval.

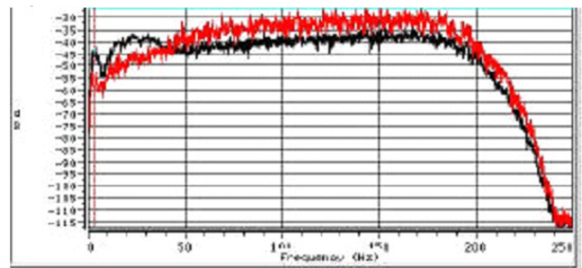

Fig-3(b) shows the random noise dominating the signal,

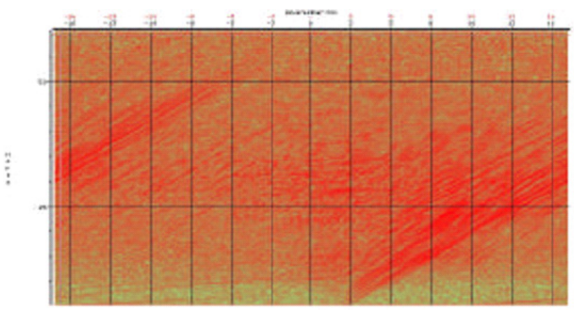

Fig-3(c) F-K spectrum shows the events in T-X domain (shot record) are aliased onto the negative quadrant beyond 30 Hz.

The spatial aliasing effect is minimized with relatively close sampling of 10m spacing compared to 30m spacing. It is not possible to retrieve faithful signal beyond 30 Hz with associated dips by f-k filter where some events are spatially aliased on shot gather 3(a).Application of band pass filter with high cut at 30 Hz will avoid aliasing but high frequency data beyond 30 Hz will be lost.

Group Array Formation (GAF)

The lay out of geophones were grouped in a pattern and the trace nos were identified corresponding to each shot. The optimum pattern design depends on the objective of survey and the noise characteristics to be attenuated. Fig-: 4 shows an array design of 15 elements with 3 elements from each line assigned to form a group & the centre of the groups marked by the circles. The total no of groups formed by GAF process were 167.

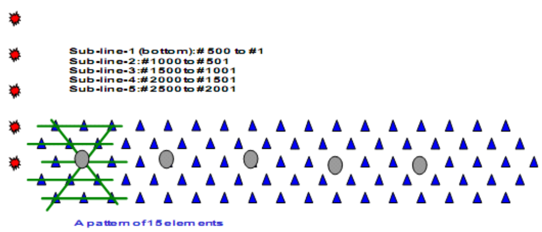

Fig-4 A pattern of geophone array with spacing of 30m between the groups having center marked by the circles.

The data from all the sub lines were grouped in the above pattern of 30x20m areal space. Fig--5 shows the group array formed from a representative shot gather. The same is done for all 30 shots.

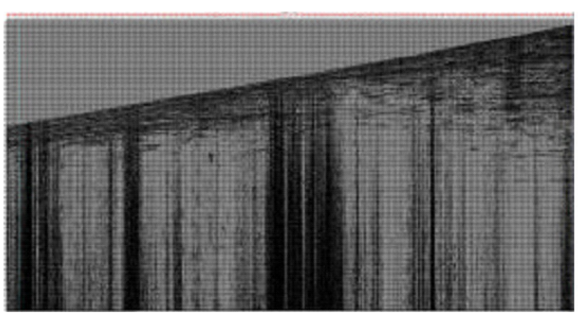

Fig-5 All the 2500 no. of traces pertaining to a shots forms 167 groups having 15 elements in each group

The individual groups corresponding to each shot were vertically stacked to get a stacked out put of 167 traces as shown in Fig-: 6 (a).This may be thought of as the shot gather of a conventional areal array of dimension 30x20m. In comparison to the shot gather of single element spacing of 30m as group interval (Fig-: 3(a)), the relative attenuation of noise 13dB less but the array stack has not fulfilled the objective in bringing out reflections in stacking process. Therefore it is necessary to attenuate the noise on the raw data before group formation and stacking.

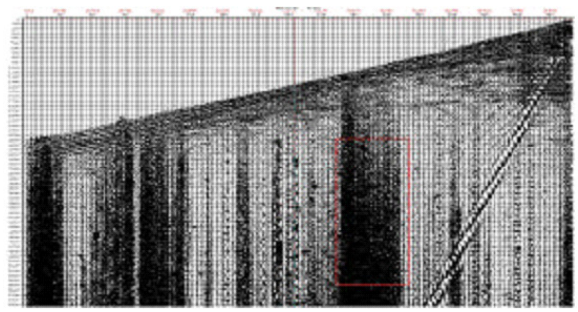

Fig-6(a): The group array stack of raw data SP 11001 as per the designed pattern

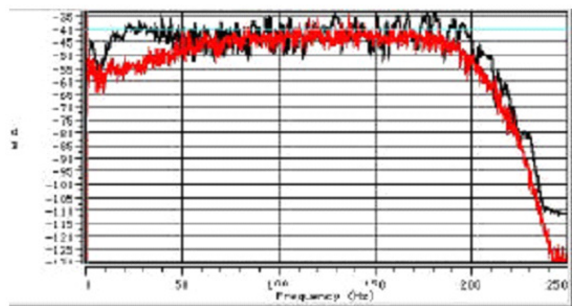

Fig-6(b) Frequency spectrum of the time window marked in 6(a) is shown in red colour in 6(b) with relative attenuation of 13 dB compared to 3(a).

Noise attenuation

Frequency dependent noise attenuation was carried out on shot gather after application of Butterworth filter (3Hz18dB/oct,90Hz-72dB/oct).Severe noise attenuation process is not desirable which modifies/attenuates the signal components. The effect of ground roll and high frequency components of the random noise got substantially attenuated in above process in the raw data. (Fig-7).

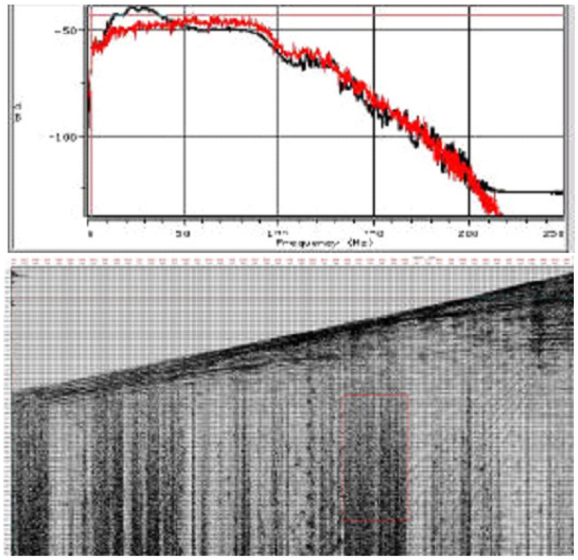

Fig-7 Noise attenuated shot gather (Fig-.2a) with Butterworth filter (3Hz-18dB/oct., 90Hz-72dB/oct.) and frequency dependant noise attenuation. The random noise effect is down by 14 dB but above 40Hz. noise is dominating over the signal amplitude in the time window shown in fig:7

Grouping of element traces was made in the above pattern fig:4. Fig-8 (a,c,e) is the zoomed portion of some parts of the group array made from the shot gather 11001 which depicts the intra-group statics shift significant on the first break of the traces even after application of the field statics. The static shift/perturbations is resulting due to the path difference from the shot to individual elements in the group, lateral variation in weathering etc. The stacking of such groups will result in alteration of signal waveform due to the phase difference associated with elements in the groups. So the time shift analysis is required to be made with respect to the center of group assigned to be the center of energy and individual groups needs to stack in phase. The perturbation correction is computed in each group by cross correlation of the traces in a time window of 120 ms along the first breaks of each group. The intra-group static shift was applied on the gather. Fig-8 (a,b, c, d, e,f) depicts the groups with and without application of perturbation correction.

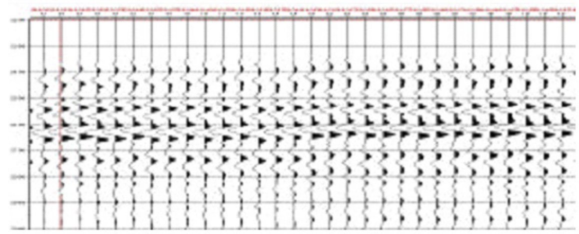

Fig-8(a) group no. 14-15 (far offsets), before perturbation correction

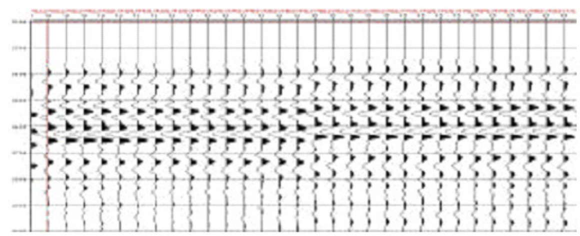

Fig-8(b) group no. 14-15(far offsets), after perturbation correction

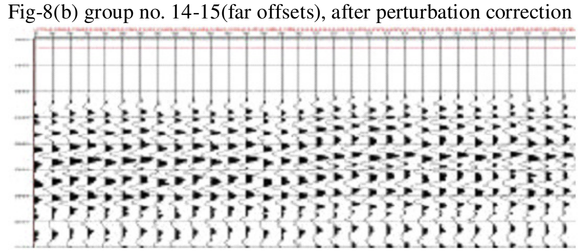

Fig-8(c) group no. 36-37(mid offsets), before perturbation correction

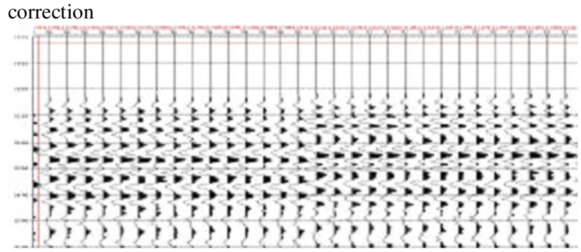

Fig-8(d) group no. 36-37 (mid offsets), after perturbation correction

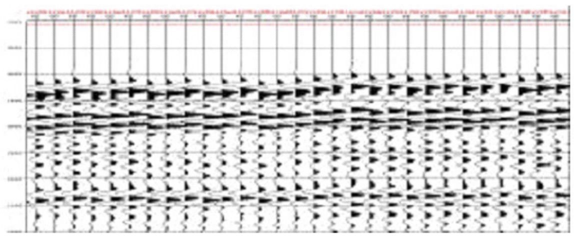

Fig-8(e) group no. 65-65(near offsets), before perturbation correction

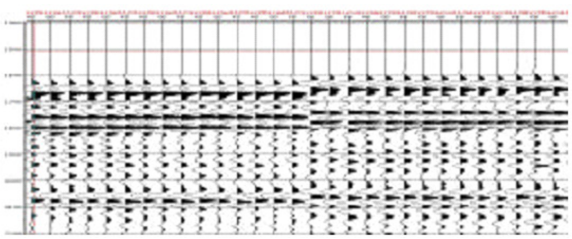

Fig-8(f) group no. 65-66 (near offsets), after perturbation correction

GAS is obtained by vertical stack of individual group before and after perturbation correction for each shot for comparison and the resulting output is a shot gather of in 30m trace spacing and 167 traces with considerable attenuation of random noise components.

A comparison GAS obtained with and without perturbation correction is shown in Fig-9 with corresponding frequency spectrum. The far offset traces in the time window suffers a frequency reduction in stacking process as shown in the spectrum corresponding to stacks of with out perturbation correction. This effect is more observed for the shots moving far from line i.e. with increase in offsets of groups from the shots as observed in the time window marked in the gathers (1) and (2) of SP 11001 and SP11006 with their corresponding frequency spectra.

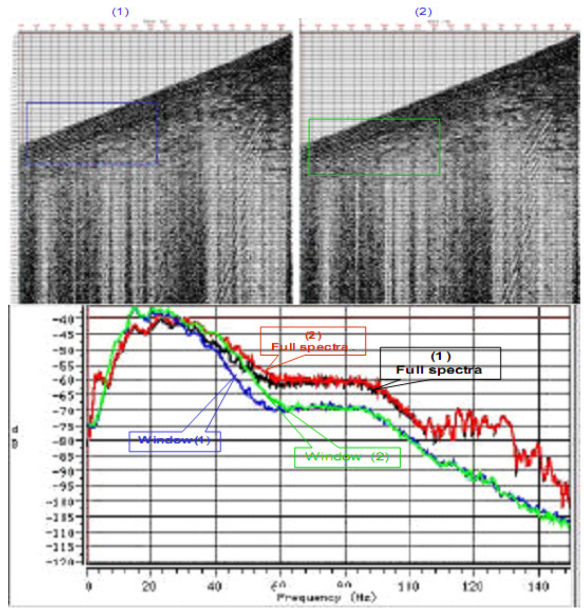

Fig-9(a) GAS without perturbation correction (1) and with perturbation correction (2) for SP 11001

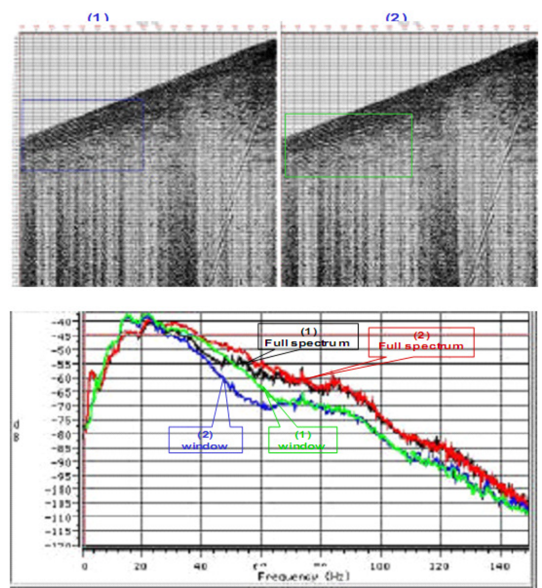

Fig-9(b) GAS without perturbation correction (1) and with perturbation correction (2) for SPs 11006

The spectra of the time window (1500-3500 ms) at farther offsets (1) and (2) are shown in same colour as in time window which shows frequency reduction in the high frequency components in the stacks without perturbation correction. (The high frequency reduction is quite significant with increasing shot offsets.) The bandwidth at -12db is given in Table-2.

Table-2

			1	2
Fig-9(a)	SP-11001	Full Spectrum	9-50 Hz	9-58 Hz
		Window	10-41 Hz	9-52 Hz
Fig-9(b)	SP-11006	Full Spectrum	10-39 Hz	10-43 Hz
		Window	12-41 Hz	12-52 Hz

A comparison is made with shot records of conventional shooting (G.I-30m) and GAS obtained from the above process under similar noise attenuation algorithms applied on the data shown in Fig-10(a) and10 (b) respectively. The corresponding spectrum (Fig-:10c) shows the random noise effect significantly reduced in the time window marked in the GAS compared the gather in 30m spacing.

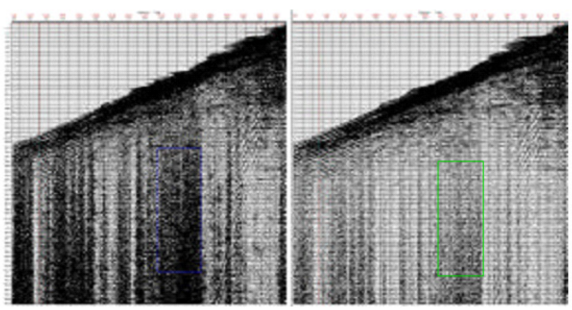

Fig-:10(a) Noise attenuated gather (30m trace spacing) (b) GAS for SP 11001

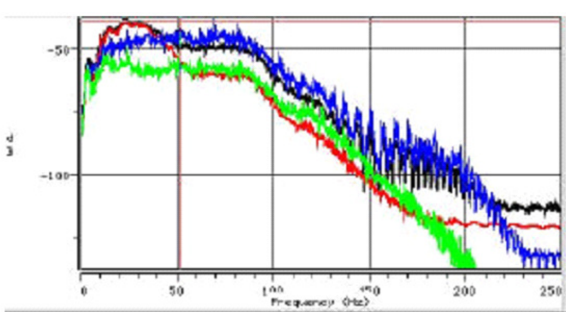

Fig-10(c) Spectrum comparison of full gathers and time window marked in the gather

Colour legend of above frequency spectrum
Black : Full spectrum of Noise attenuated gather (30m)
Red : Full spectrum of Group Array Stack (GAS)
Blue : Spectrum in the time window 2600-5200ms of (1)
Green: Spectrum in the time window 2600 – 5200ms of (2)

The comparison of the noise attenuated gather and GAS of SP 11001 in the time window 2400-4500ms shows reflection events better delineated in GAS with increase in signal to noise ratio as seen in Fig -11(a) and 11 (b).

Conclusions

In 3D data acquisition, spatial aliasing effects are minimized by close element spacing in the inline and crossline directions. Field statics applied on each element removes the effect of elevation variation. Application of perturbation correction helps in retaining the true waveform after group stacking. The weak reflection events are brought out in the presence of high amplitude noise without much alteration to signal. The shot gather obtained from the GAS show considerable improvement of signal to noise ratio.

The use of Group Array Formation (GAF) and Group Array Stack (GAS) will lead to improvement in signal to noise ratio to delineate of subtle geologic features for exploration of hydrocarbons.

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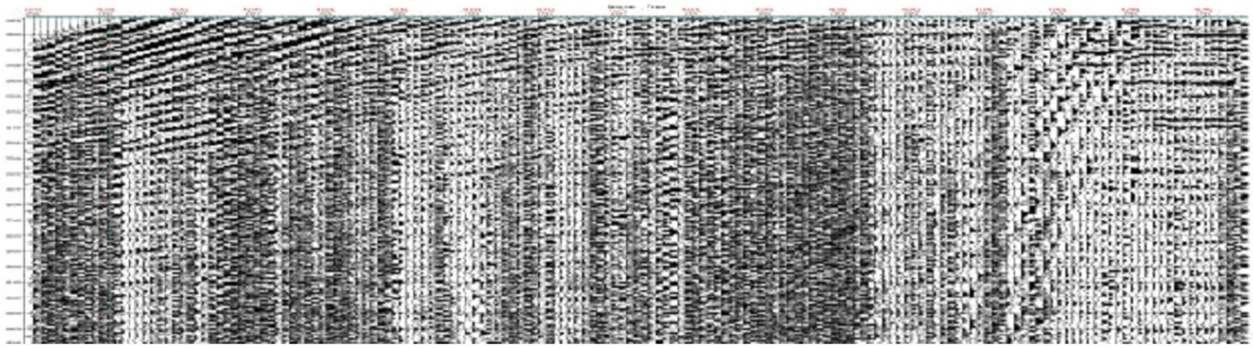

Fig-11(a) Noise attenuated gather

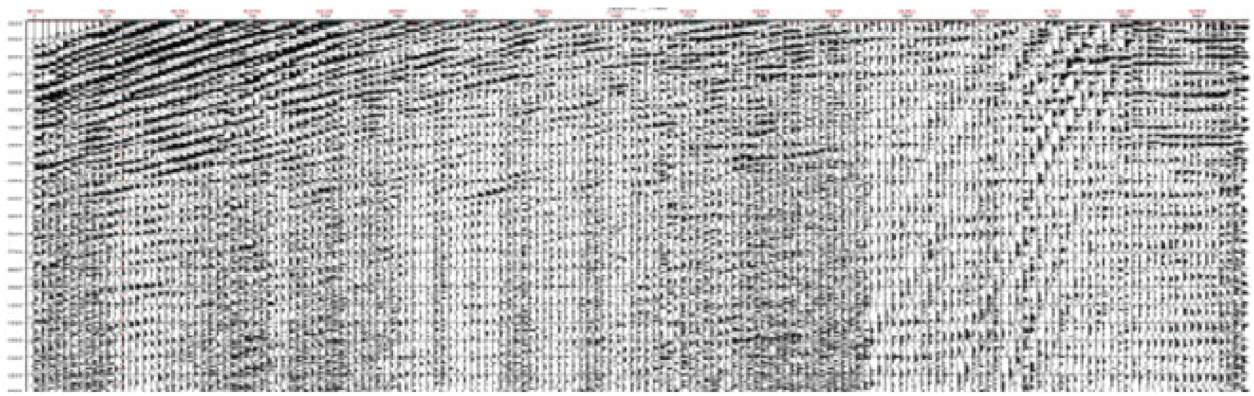

Fig11(b) Group Array Stack

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