

Contemporary Technique of Seismic Data Acquisition for better Subsurface Imaging in AAFB

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Abstract

Steeply dipping, compressed, reverse faulted and rotated anticlines with exposed hard formation at surface and rugged topography offer biggest challenge in sub-surface imaging through current seismic data acquisition methods being used in Assam-Aarakan fold belt. In view of the structural complexities of sub-surface, a contemporary geometry with shooting pattern defined as “flip-flop asymmetric split spread with shoot-through technique” has been designed and modelled in NORSAR software. This geometry has been implemented in the field and a high resolution 2D seismic data has been acquired along a dip line over Mashimpur Anticline of eastern Cachar fold belt. Acquisition of quality seismic data was ensured by putting all possible efforts in the field and representative seismic sections are generated for the area.

Keywords

Geometry, modelling, up-dip asymmetric, shoot through.

Introduction

Mashimpur Anticline is part of Mashimpur Indernagar line of folding in Eastern Cachar fold belt (Fig.5). Previous 2D and 3D seismic investigations during which conventional symmetric split spread method was implemented, provided very limited information about the sub-surface of Mashimpur Anticline. Due to complex sub-surface geology, the seismic waves may not follow the conventional path in the sub-surface and the recorded seismic data may not have good S/N ratio. The present work is mainly focused on trace management by which maximum number of traces may be recorded by the deployed seismic spread and most of which have good S/N ratio. A contemporary seismic spread has been conceptualized on the basis of following observations from NORSAR Ray trace model (Fig.1) of symmetric split spread (600+600) geometry (G1).

- Due to scattering of seismic energy (Fig. 1) from steeply dipping subsurface horizons, most of the traces generated from shots in blue region and reflected from points like P (Fig.1) may not be recorded by the symmetric split spread resulting in reduced fold in practical as compared to planned one. Since the S/N ratio is directly proportional to acquired fold, the recorded data through symmetric split spread may have poor S/N ratio.
- Due to steep dips of subsurface horizons, the reflected traces along the down dip arm of the

symmetric split spread may be recorded at much longer offsets because of the large angles of incidence and reflection (Fig. 1: C to D). The effect of angle of incidence can be understood by Avseth's formulation (Avseth et al, 2006).

$$R(\theta) = W - X \sin^2 \theta + Y \frac{1}{\cos^2 \theta_{\text{avg}}} - Z \sin^2 \theta \quad \text{-----Eq.1}$$

Where,

$$W = \frac{1}{2} \frac{\Delta \rho}{\rho}; \frac{\Delta \rho}{\rho} = \frac{(\rho_2 - \rho_1)}{((\rho_2 + \rho_1)/2)}$$

And

$$X = 2 \frac{V_S^2 \Delta \rho}{V_P^2 \rho}, Y = \frac{1}{2} \frac{\Delta V_P^2}{V_P^2}, Z = 4 \frac{V_S^2 \Delta V_S^2}{V_{P1}^2 V_S^2}$$

Where, R = Reflection coefficient, θ = Angle of incidence, θ_{avg} = average of angle of incidence and refraction, ρ_1 = Density of upper layer, ρ_2 = Density of lower layer, V_{P1} = P-wave velocity in the upper layer, ρ = Mean of density of upper and lower layers, V_P = Mean of P-wave velocity of both layers and V_S = Mean of S-wave velocity of both layers

In Eq.1, reflection coefficient will decrease as θ increases and hence the S/N ratio of the recorded signal will decrease. Further, seismic traces recorded at much larger offsets will have larger path length resulting in higher spherical divergence and hence the lower S/N ratio.

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- Shots taken in exposed formations do not illuminate the horizon interfaces above that particular formation, as can be seen in Fig.1 for reflection point P at a subsurface horizon, there is no source-receiver combination for which shot would lie in exposed formation below that particular horizon, resulting in reduced fold from such horizons and hence the reduced S/N ratio.
- Receivers laid over the exposure region and on the other side of the anticline do not receive primary reflections from point P (XY & ZB region of Fig. 1).

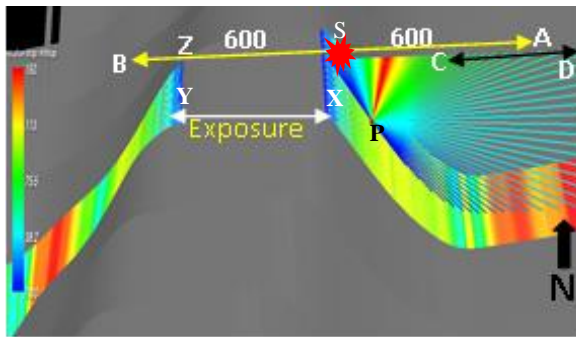


Fig.1: NORSAR ray trace model. Trace distribution of all reflected traces from a point of reflection P at eastern limb of Upper Bhuban top.

In view of the above, a seismic spread needs to be designed in such a way that maximum number of seismic traces could be recorded within the active seismic spread with most of them having smaller angles of incidence & reflection, smaller path length and hence good S/N ratio.

Geometry Design

The parameters of geometry already being used and new geometry are mentioned in Table1.

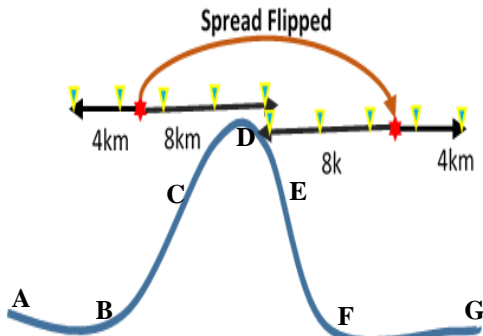


Fig. 2: Schematic Diagram of Asymmetric Split Spread.

Table: 1

Parameters	Current Geometry (G1)	Contemporary Geometry (G2)
No of Channels	1200	
Geometry type	SSS (600+600)	Asymmetric split spread (400+800) with shoot through (G2)
RI (m)	10	
SI (m)	40	20 at flank/40 at top of the anticline
Fold	150	375
Min Offset (m)	5	
Max Offset (m)	5995	7995

To record maximum number of traces with shorter path length and with small angle of incidence an up-dip asymmetric split spread (Fig.2) of 1200 channels with spread definition 400+800 or 800+400 has been designed in MESA software (Fig.2) and modelled in NORSAR.

The contemporary geometry (G2) has been described by moving across the anticline from points A to G in Fig.2.

- i) From point A far from the anticline to point B at the foot of the anticline, active seismic spread is 600+600
- ii) From point B to C the active seismic spread is 400+800 up-dip, this configuration will continue till 400 receivers crossed the axis of the anticline and it happens for shot at C
- iii) From point C to D spread is fixed, only shot moves making the geometry up-dip to SSS to down-dip
- iv) Beyond point D the geometry is flipped keeping 400 receivers towards point C and 800 towards point E and again for shots from point D to E the spread remain same as in (iii). For shot at point E the spread becomes of 800+400 up-dip.
- v) From point E to F the spread will be 800+400 up-dip which will continue till the end of the anticline i.e. point F. Again, 600+600 will continue from point F to G and onwards.

The approximate position of axis of the anticline and its width is obtained from geological map (Fig.5).

The geometry G2 designed as above could be justified from NORSAR ray trace model in Fig. 3 and Fig.4.

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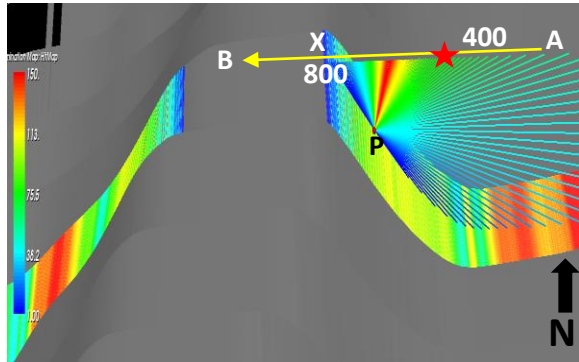


Fig. 3: Up-Dip Asymmetric Split Spread over NORSAR ray trace model at Upper Bhuvan top shows that most of the reflected traces are recorded in up-dip direction and have smaller angle of reflection.

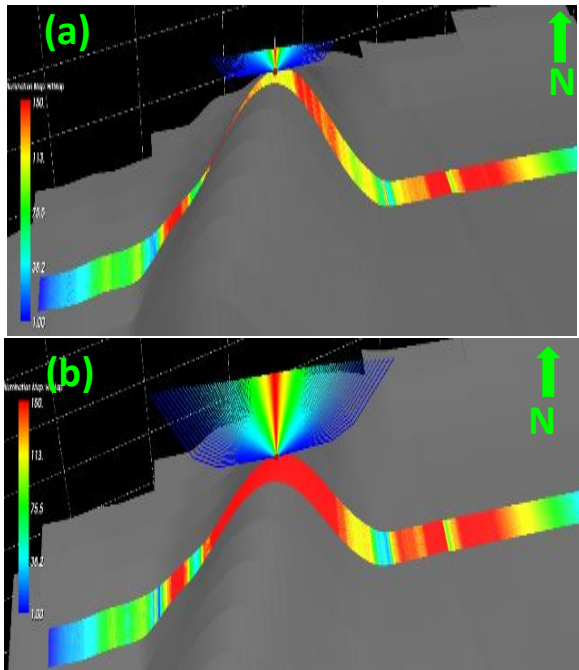


Fig. 4: Ray trace Model of (a) Middle Bhuvan top and (b) Lower Bhuvan top

Since the Upper Bhuvan formation is exposed in the area of investigation, a major segment XB of active seismic spread in figure 3 does not receive signal from the point of reflection P (Fig. 3). Thus, this segment of the active seismic spread remains unutilized. Hence, the seismic spread in this direction needs to be fixed in such a way that most of the part of active seismic spread should receive signal. But ray trace model of middle Bhuvan and upper Bhuvan formation (Fig.4) shows that the traces from point

of reflection at the top of Middle Bhuvan and further deeper formations will be recorded in both sides of the anticline. So, fixing one arm of the spread is very tricky, since few reflected traces at longer offsets from these horizons could be missed in the direction of fixed arm of the seismic spread.

Therefore, assuming minimum depth of top of the target horizon in the anticlinal part to be 4000 m, it had been decided that if a maximum of 400 receivers (offset = 4000m) cross the axis of the anticline the spread would be fixed. Keeping the spread fixed and shots moving it has become shoot through spread (Fig. 5).

The active seismic spread of G2 has been overlapped with geological map of Cachar in MESA software (Fig.5) to get the flipping point as close as possible to the axis of the Mashimpur anticline.

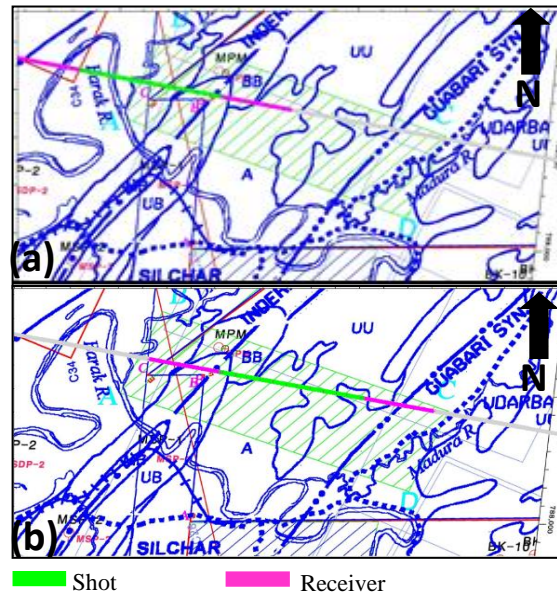


Fig. 5: Overlap of active Shoot Through spread over Mashimpur Anticline at Structure Contour Map of Eastern Cachar fold belt. a) West to East Approach, and b) East to west Approach.

NORSAR Modelling

Ray trace model (Fig. 1, 3 & 4) has been generated to understand the path of the rays reflected from a dipping and exposed formation. Using geometries G1 and G2 illumination maps at Upper Bhuvan top have been generated and compared (Fig. 6).

For modelling purpose, the eastern flank of the Mashimpur anticline, which has more steep dip as compared to western

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flank, is considered. With geometry G1, significant drop in illumination intensity can be seen at the eastern flank of the anticline as compared to synclinal part of the same (Fig.6a). One of the reason for drop in illumination intensity is because of the shots taken in exposed part of the Upper Bhuban formation do not contribute in illuminating the Upper Bhuban top. Whereas, geometry G2 (Fig. 6b) illuminates the flank of the anticline better than geometry G1.

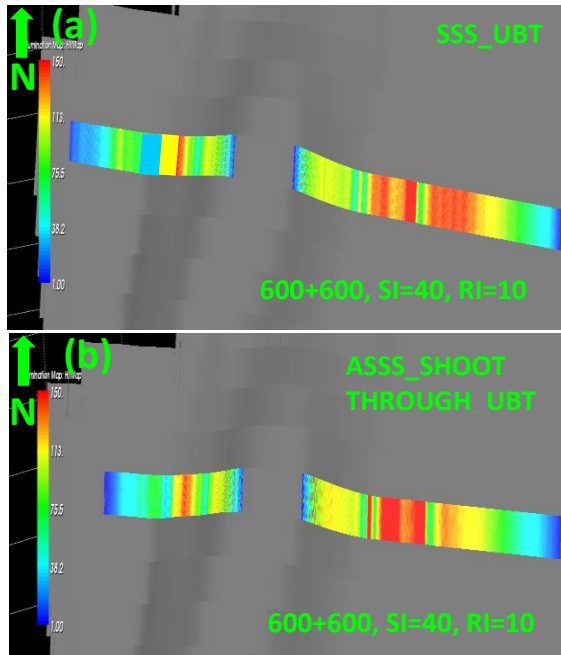


Fig. 6: Illumination Map of Upper Bhuban Top. a) Symmetric split spread. b) Asymmetric split spread with shoot through.

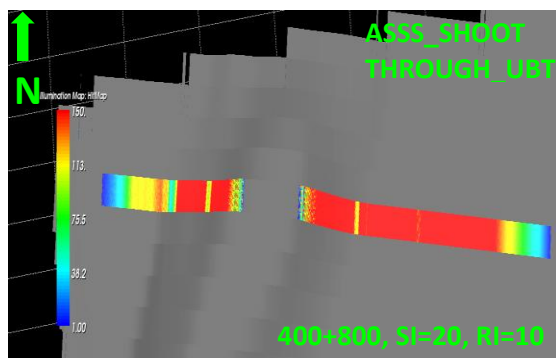


Fig. 7: Illumination map of Upper Bhuban top after halving the shot interval from 40m to 20m i.e. doubling the shot density at the flank of the anticline.

Since the traces generated from the shots taken in exposed formations do not contribute in illuminating the formation tops or interfaces above those horizons, therefore in geometry G2 shot density has been increased over the flank of the anticline to compensate the drop in fold (Fig. 7).

After detailed analysis of NORSAR models, final geometry G2 has been adopted for implementation.

Implementation of the Geometry in Field

After testing the geometry G2 named “flip-flop Asymmetric split spread using shoot through technique” through NORSAR modelling and comparing the illumination models with that of symmetric split spread geometry, the former was implemented in the field during field season 2018-19 over Mashimpur Anticline. 200 shots were added on either side of the anticline over its flank by halving the shot interval (Table 1). Minimum data gap was ensured and optimum depth decided with help of uphole was maintained. Daily QC of data was ensured using field processing unit and scope of improvement was implemented to ensure good quality of data.

Results and Discussion

The acquired seismic data was processed and PSTM stacks were generated for both 40m (Fig.8) and 20m (Fig. 9) shot intervals. The up-dip asymmetric shooting resulted in seismic raw data having good signal to noise ratio (Fig.8), while due to long offsets, the velocity analysis had been more accurate (Daniele Colombo, 2005).

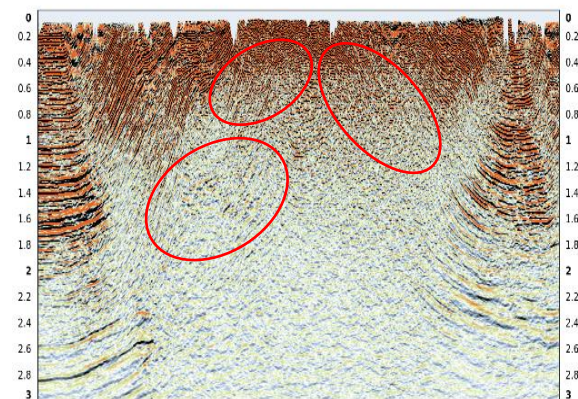


Fig. 8: PSTM stack for Asymmetric split spread for shot interval 40m

To compensate the loss in traces from interfaces above the exposed formation the shot density was doubled at the flank of the anticline.

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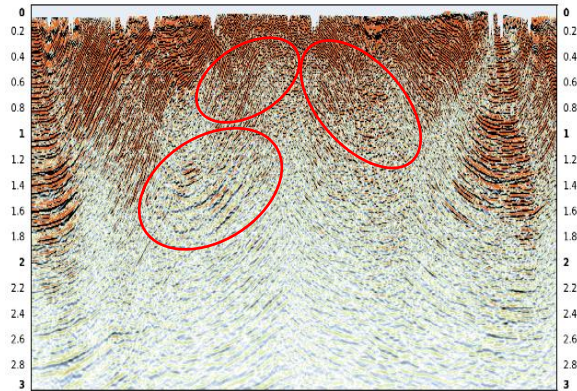


Fig. 9: PSTM stack for Asymmetric split spread for shot interval 20m

It can be clearly observed that PSTM stack of data with 20m shot interval (Fig.9) have better resolution and continuity in seismic events than that in PSTM stack of data with 40m shot interval (Fig.8).

Further, the authors would compare the results of present study with that of previous work.

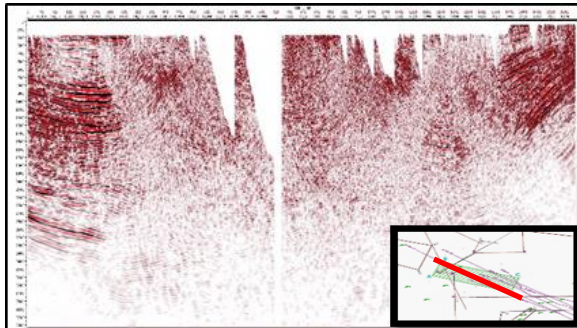


Fig. 10: PSTM Stack of Previous 2D line.

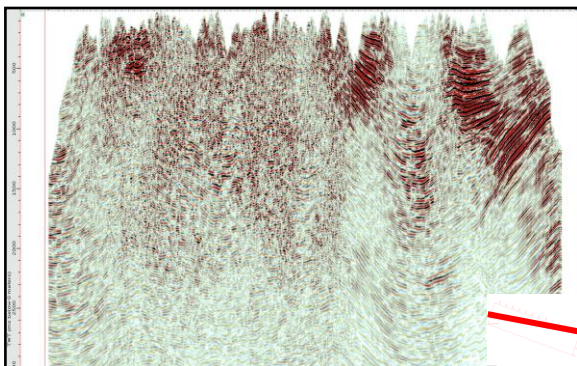


Fig. 11. RC line of PSTM Stack of Previous 3D along current 2D line

Table 3

Parameters	2D	3D
No of Channels	96	2176
Geometry Type	End-on	SSS (136+136)
RI (m)	25	35
SI (m)	25	35
RLI (m)		350
SLI (m)		280
Fold	48	68
Min-Min Offset (m)	250	24.75
Max-Max Offset (m)	2625	5400

The event continuity, and resolution in PSTM stack of current 2D seismic data (Fig. 8 & 9) is better than that in PSTM stack of previous re-processed 2D seismic data (Fig. 10) and PSTM stack of previous 3D seismic data (Fig. 11).

The resolution and continuity of seismic data at the flank of the anticline is very poor even for the shallower horizons in the PSTM stack of previous investigations (Fig. 10 & 11), while the PSTM stack of current survey (Fig.9) shows that not only shallower horizon at the flank of the anticline are clearly mapped but deeper horizons are also mapped. The shallower horizons are exposed at the top of the anticline up to Upper Bhuban, so the deeper horizons like Middle Bhuban to Renji formation are at shallower depths in the anticlinal part.

Conclusion

From modeling and PSTM stack it is clearly evident that up-dip asymmetric shooting with shoot through in the anticlinal part gives better imaging of subsurface of the anticline.

Further, increasing the shot density at the flank of the anticline drastically improves the subsurface image, as the added shots are compensating for the fold loss at the dipping reflectors.

Moreover, based on the comparison of Fig. 8 & 9, authors conclude that any technique adopted to compensate for the fold loss due to geological complexities or to get higher fold would further improve the subsurface imaging.

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