IMAGING OF NEAR SURFACE VELOCITY HETEROGENEITIES OF THE MEDIUM IN WAVE PATTERN OF ACOUSTIC MODELING

Nasar Elzawam

Faculty Of Science. –Sebha University

Abstract:

Shallow refraction seismics has long been used for the determination of the near surface layer structure. The most common goal of this investigation in seismic prospecting for gas and oil was the definition of the static corrections . The model of near surface layer was the result of refraction interpretation allowing to derive estimates of the thicknesses and velocities of the near-surface layers by analyzing the first breaks of head waves. Several methods have been proposed for the interpretation of refraction data . However, all these methods have certain drawbacks restricting their range of applications. Nowadays the CDP method (Common Depth Point method) is the dominating method of surface acquisition. This information may be used to estimate static corrections. Additionally we can realize special velocity surveys in deeper shot holes and use their results (traveltimes) to derive velocity model of LVL (Low Velocity Layer). Their is no such a possibility in the case of Vibroseis method. In this case we must practically obtain all the information about LVL only from reflection field records. This information is mainly inherent in first breaks of refraction arrivals.

In the presented paper the results of imaging near surface velocity heterogeneities of the medium in the wave pattern of finite difference acoustic modeling have been described. The main goal of this modeling was to define the effect of near surface layer heterogeneities on the breaks of head waves connected with shallow refractors. The effect of heterogeneities dimensions, velocity distributions in the near surface layer as well as the seismic signal parameters on the wave pattern of head waves breaks of reflection records has been estimated. The analysis has been undertaken to assess the possibility of applications these breaks for recovering near surface velocity distributions by means of head wave tomography. The seismic modeling has been performed using computer program of 2-D finite difference modeling available in the processing system ProMAX.

Introduction

Several methods have been proposed for the interpretation of refraction data, such as the intercept–time method, the wavefront-reconstruction method (Thornburgh 1930), the plus-minus method (Hagedoorn 1959), the general reciprocal method (Palmer 1980, 1981), the delay time method (Barry 1967) the intercept–time method, However, all these methods have certain drawbacks restricting their range of applications. First of all they were designed only for interpretation of refraction data and it was not simple to include other types of waves (for instance reflected waves). They cannot detect velocity inversions (a low-velocity layer beneath a high-velocity) and cannot to resolve thin beds (known as the hidden layer problem). Most of the refraction techniques were designed to compute static corrections for a constant velocity weathering layer of slowly changing thickness overlying a refractor of constant velocity. When these conditions do not exist, then unacceptable errors arise in the computed statics. Nowadays the CDP method (Common Depth Point method) is the dominating method of surface acquisition. When the dynamite seismics is applied we measure so called uphole time by using uphole geophone near each shot hole. This information may be used to estimate static corrections. Additionally we can realize special velocity surveys in deeper shot holes and use their results (traveltimes) to derive velocity model of LVL. Their is no such a possibility in the case of Vibroseis method. In this case we must practically obtain all the information about LVL only from reflection field records. This information is mainly inherent in first breaks of refraction arrivals To overcome these limitations new solutions based on tomographic inversion have been proposed for determination of the LVL structure and static corrections (Bohm 2006, Bridle 2006, De Amorim 1987, Ditmar 1999, Docherty 1992). The static corrections based on tomographic approach are named tomostatics (Zhu 1992). Tomostatics has advantages over traditional refraction statics in regions where it is not easy to identify refractors and where we can meet velocity inversion. The tomographic method enables us to consider complex geological models with dipping or variously curved layers and with strong lateral velocity variations and rough topography. Model parametrization is much more flexible. The next advantage of this method is the possibility of jointly inverting the different kinds of waves generated within a seismic experiment (turning waves, head waves, reflected waves). Including different kind of waves increases the effective aperture in the data providing much more reliable solutions. The velocity fields resulting from tomographic inversion may be used for statics estimation as well as for determination of migration velocity field in shallow part of the medium. Tomostatics is mainly based on turning wave tomography and head wave tomography. Taking into account the theoretical principles of tomographic inversion we can distinguish between ray tomography (traveltime tomography) and diffraction tomography (Lo, Inderwiesen 1994). The first one is based on ray approach to wave propagation well known from theory of seismic modeling. Such a approach is commonly applied in all production applications of seismic tomography in seismic processing systems including system ProMAX® and OMEGA®. The diffraction tomography and wave-equation tomography based on the wave approach found only limited applications in seismic prospecting (Nolet 1987, Pratt, Tura et al. 1994, Woodward 1992; Harris, Wang 1996).

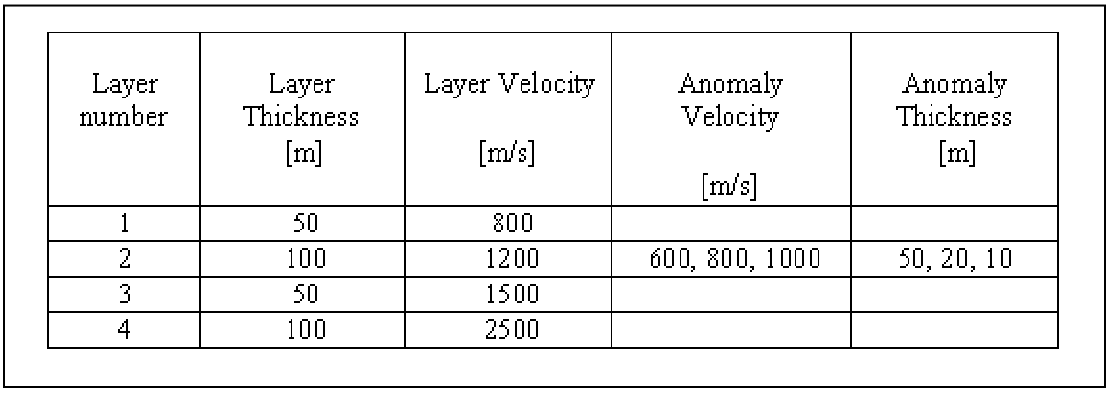
Turning-ray and head wave tomography is an accurate and efficient tool used for estimation 2D/3D near-surface velocities for static corrections, wave-equation datuming and prestack depth migration (Zhu 2002). Accurate near-surface velocities can also be integrated into a velocity-depth model for better imaging deep structures in prestack depth migration. The simplest way of defining near-surface velocities is the inversion of first breaks on reflection records. However the near-surface medium may include thin layers and the breaks of head waves may occur not only in the first brekas zone. In such situation the question arises about the possibility of identification these breaks for the purpose of picking and tomographic inversion. Additionally the imaging of small heterogeneities of the low velocity near-surface layers in these later breaks becomes very important for the inversion process.

For the purpose of the analysis of first and later breaks of the head waves on reflection records the 2-D finite difference acoustic modeling has been used. The main goal of this modeling was to define the effect of heterogeneities dimensions, velocity distributions in the near-surface layer as well as the seismic signal parameters on the wave pattern of head waves breaks and on head waves traveltimes. The analysis has been undertaken to assess the possibility of applications these breaks for recovering near-surface velocity distributions by means of head wave tomography.

1- VELOCITY MODEL AND MODELING PARAMETERS

The velocity model of near-surface medium was composed of three horizontal layers with parameters defined in the Table (1). In the second layer the low velocity body was inserted of effective width 600 m. The velocity of this body named in the paper velocity anomaly was changing during consecutive computation from 600 m/s through 800 m/s to final value of 1000 m/s. The thickness of the body was changing from 50 m through 20 m to 10 m. The velocity model (***Figure 1***) has been defined for 4001 CDP points with CDP interval equal 1 m.

Table 1. Parameters of Seismological Models



Layer number	Layer Thickness [m]	Layer Velocity [m/s]	Anomaly Velocity [m/s]	Anomaly Thickness [m]
1	50	800		
2	100	1200	600, 800, 1000	50, 20, 10
3	50	1500		
4	100	2500		

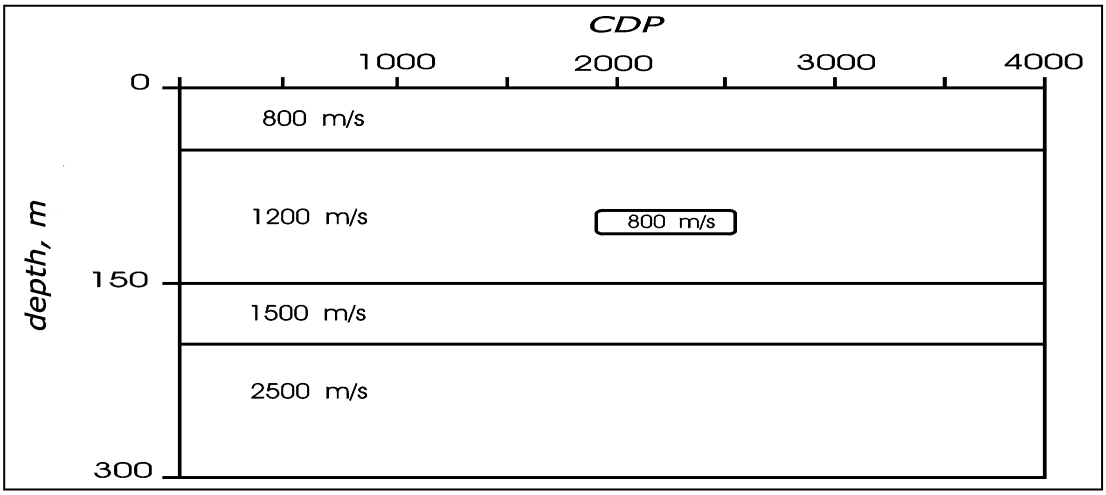


Figure. 1. The velocity model of near-surface layer used in synthetic records calculation

The off-end spread has been used with 400 receiver stations (channels) and receiver interval 10 m. The shot has been located at the left edge of the velocity model on the surface. The zero-phase Ricker signal has been used as point source wavelet with dominant frequency 50 Hz, 70 and 100 Hz. The input computation grid had dimensions (1 x 1 m), and has been automatically modified during computation to effective grid dimensions protecting against numerical errors.

2-THE WAVE PATTERN OF SYNTHETIC RECORDS

2-1 The case of the near-surface medium without velocity anomaly

The synthetic record calculated for the layered model from ***Figure (1***) but without velocity anomaly using zero-phase Ricker source signal with dominant frequency 50 Hz is presented in ***Figure (2)*** for the case of end-off spread and in ***Figure (3***) for the case of split spread. Additionally the results of approximate interactive apparent velocity analysis have been presented in ***Figure (3***) for the purpose of wave identification. Analysis of the wave pattern of these figures lets us to draw the following conclusions:

- the waves which can be identified without any difficulties in first breaks comprise the direct wave and the head wave connected with the deepest refractor with velocity 2500 m/s,
- the breaks of head waves are well distinguished in first and later breaks,
- the head wave connected with the

deepest refractor with velocity 2500 m/s is dominated in first breaks and can be identified in broad range of offsets,

- it is possible to realize the picking of head waves not only in first breaks but in later breaks too,
- the differences in apparent velocity are as usual very useful in head waves identification.

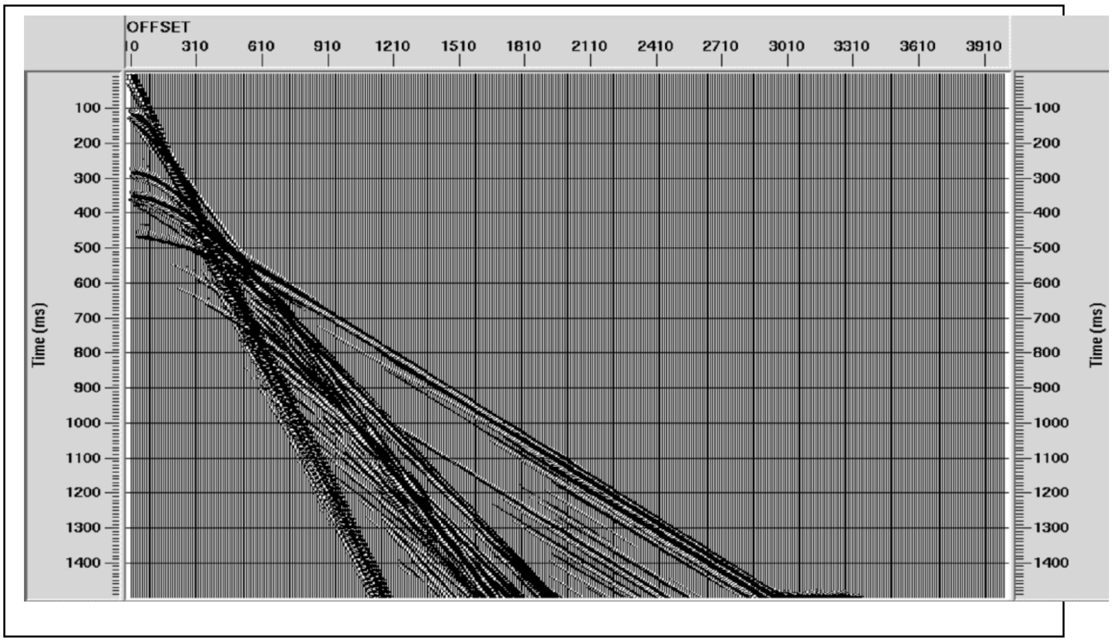


Figure. 2. The synthetic record calculated for the layered model without velocity anomaly using zero-phase Ricker source signal with dominant frequency 50 Hz.

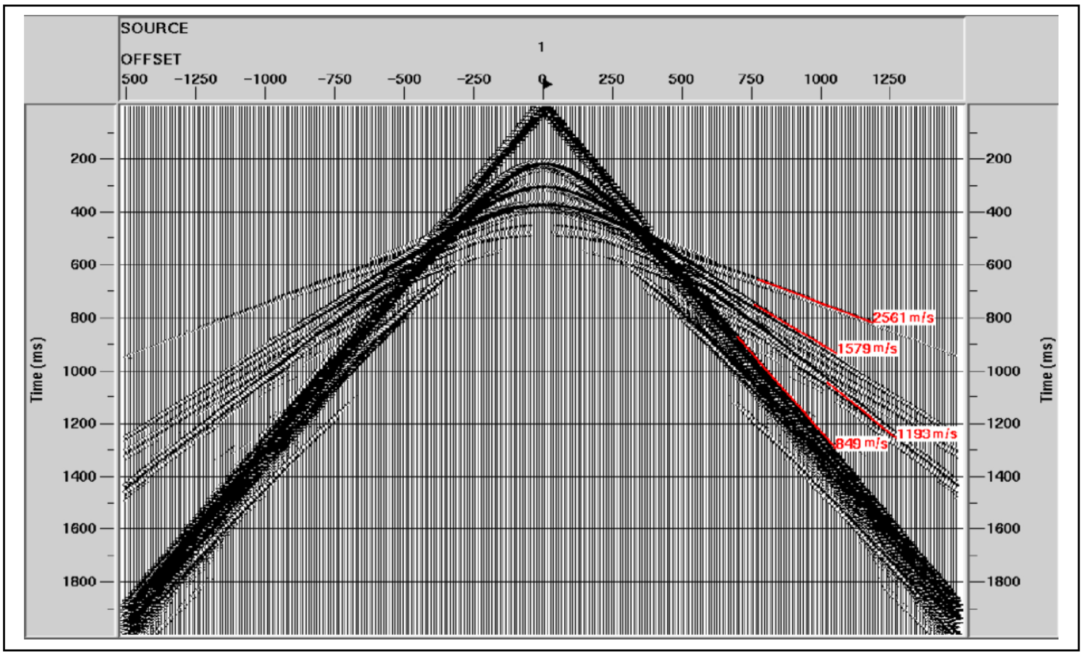


Figure. 3. The synthetic record calculated for the case of the split spread and the velocity model without anomaly with results of approximate interactive apparent velocity analysis

2-2 The case of the near-surface medium with velocity anomaly

In the next step the calculation of the records have been accomplished for the case of near-surface medium with velocity anomaly in the second layer. The results of the calculations for the selected thickness of anomaly (50 m) and for the selected velocity of anomaly (800 m/s) are presented in ***Figures (4, 5, 6)*** It can be seen that the traveltime delay related to low velocity anomaly is clearly marked in the first breaks of the head wave propagating from the deepest refractor and in the breaks of head wave from the second boundary.

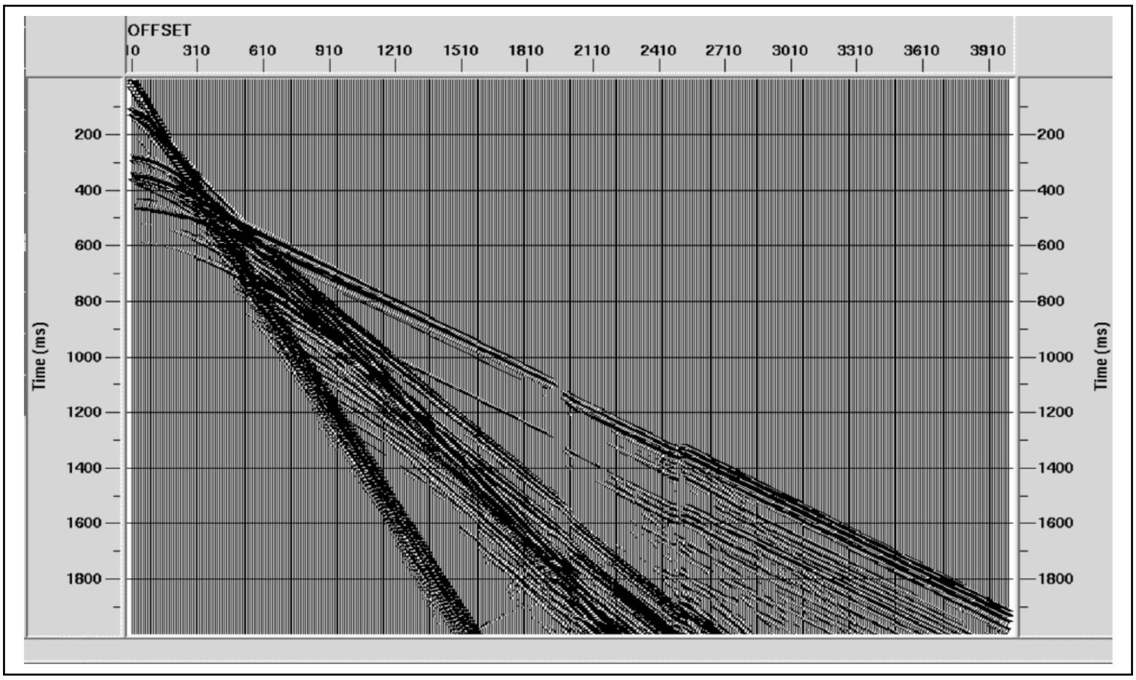


Figure. 4. The synthetic record calculated for the layered model with velocity anomaly (thickness 20 m, velocity 800 m/s) using zero-phase Ricker source signal with dominant frequency 50 Hz; the zone of breaks in the area of imaging traveltime delays related to velocity anomaly is located in the range of offsets 1800 – 2510 m

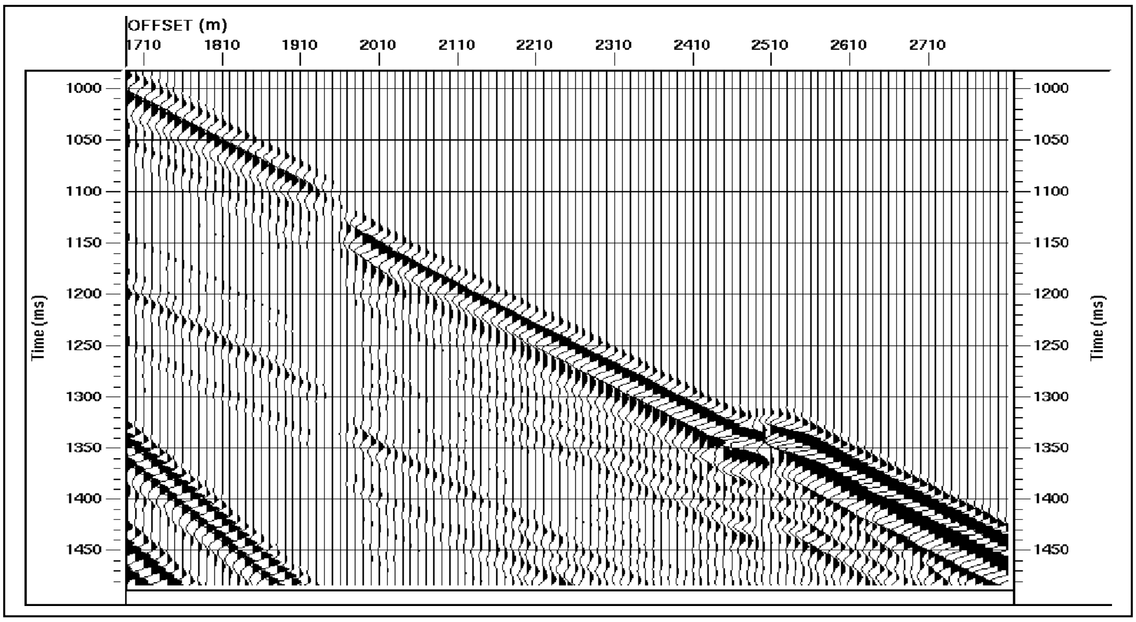


Figure. 5. Enlargement of first breaks zone of the synthetic record from Figure 4 in the area of imaging traveltime delays related to velocity anomaly (thickness 20 m)

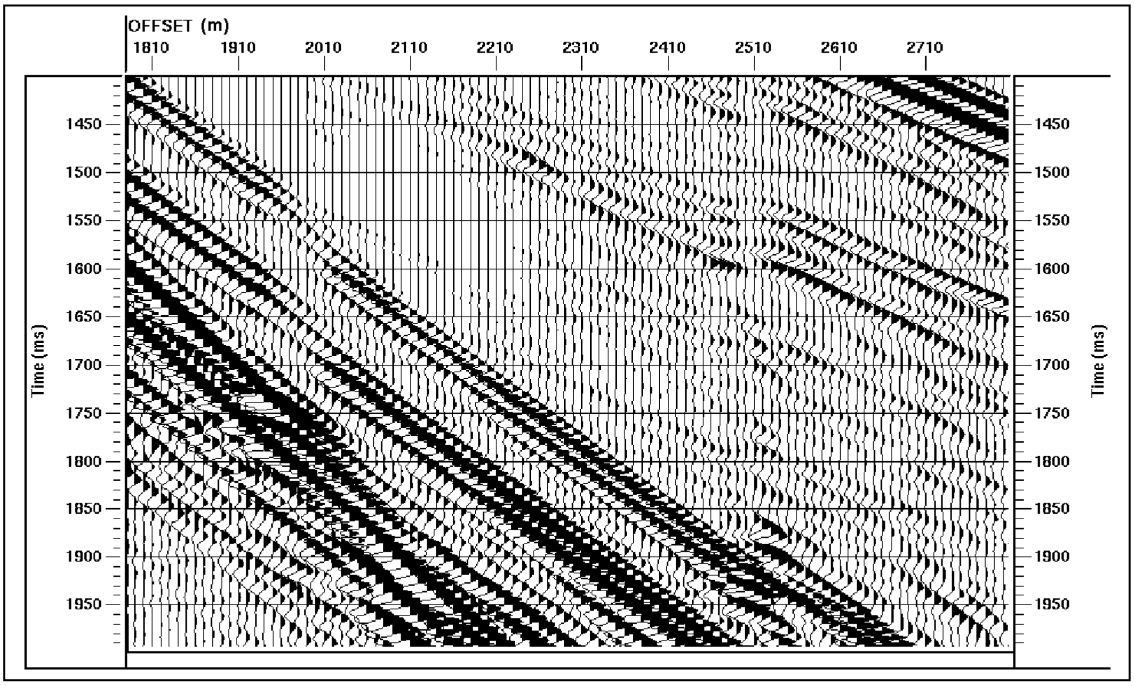


Figure. 6. Enlargement of later breaks zone of the synthetic record from Figure 4 in the area of imaging traveltime delays related to velocity anomaly (thickness 20 m)

2-3 The effect of anomaly velocity on first breaks traveltimes

The relation of the traveltimes after changing velocity of anomaly from 600 m/s to 800 m/s and 1000 m/s can be defined from the differences of first breaks traveltimes presented in ***Figure*** (*7*) . These differences achieve the values from 6 ms to 16 ms in the range of anomaly offsets and their graph is nearly the same for pick frequency 50 Hz and 70 Hz

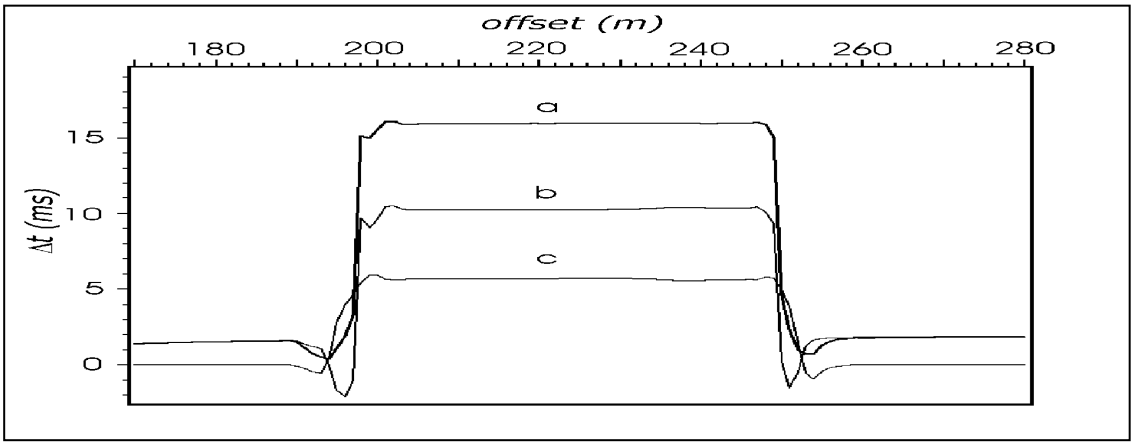


Figure. 7. Traveltimes differences between first breaks of head wave for the model without and with anomaly for different values of anomaly velocity: (a) V = 600 m/s, (b) V = 800 m/s, (c) = 1000 m/s; dominant frequency 50 Hz, anomaly thickness 20 m

2-4 The effect of anomaly thickness on first breaks traveltimes

The next model parameter taken into consideration was the thickness of velocity anomaly. It was changed from 50 m through 20 m to 10 m for the velocity 800 m/s. The resulting difference curves of first breaks traveltimes have been presented in ***Figure (8).*** These differences achieve the values from 5 ms to about 18 ms in the range of anomaly offsets

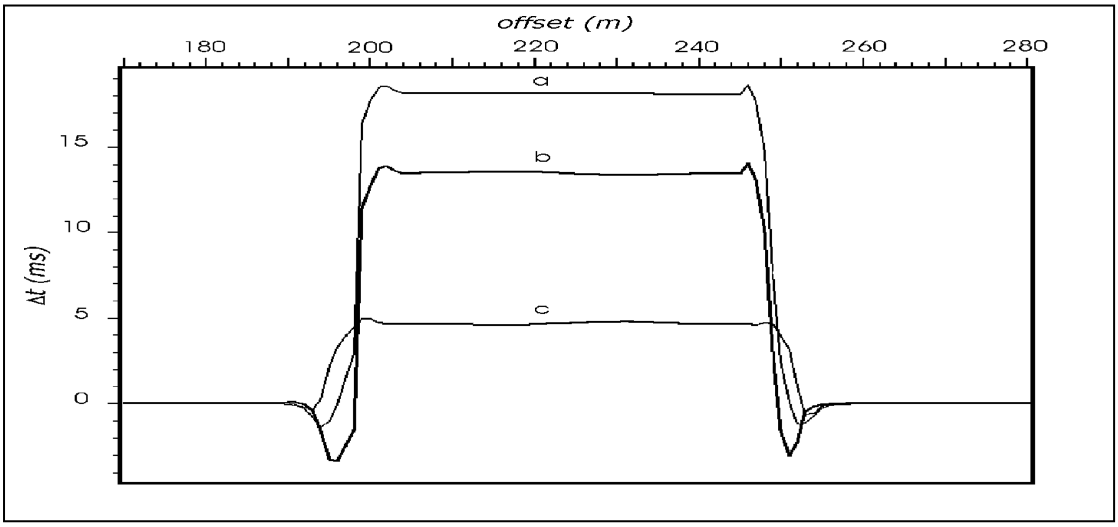


Figure. 8. Traveltimes differences between first breaks of head wave for the model without and with anomaly for different values of anomaly thickness: (a) Δh = 50 m, (b) Δh = 20 m, (c) Δh = 10 m; pick frequency 50 Hz, anomaly velocity 800 m/s.

2-5 The effect of pick frequency on first breaks traveltimes

In the last step the effect of pick frequency of source signal on the first breaks traveltimes has been analysed. Three pick frequency have been used during modeling: 50, 70 and 100 Hz. The difference curves of first breaks traveltimes are presented in ***Figure (9).*** we can observe some dependence of difference curve values on the offset. The average value of difference curve achieves the greatest value about 7 ms for the case of pick frequencies 50 and 100 Hz. For the frequency pairs (50 Hz, 70 Hz) and (70 Hz, 100 Hz) the average value is about 3,5 ms. The dependence of difference values of first breaks traveltimes on the offset is confirmed by the slope of these curves

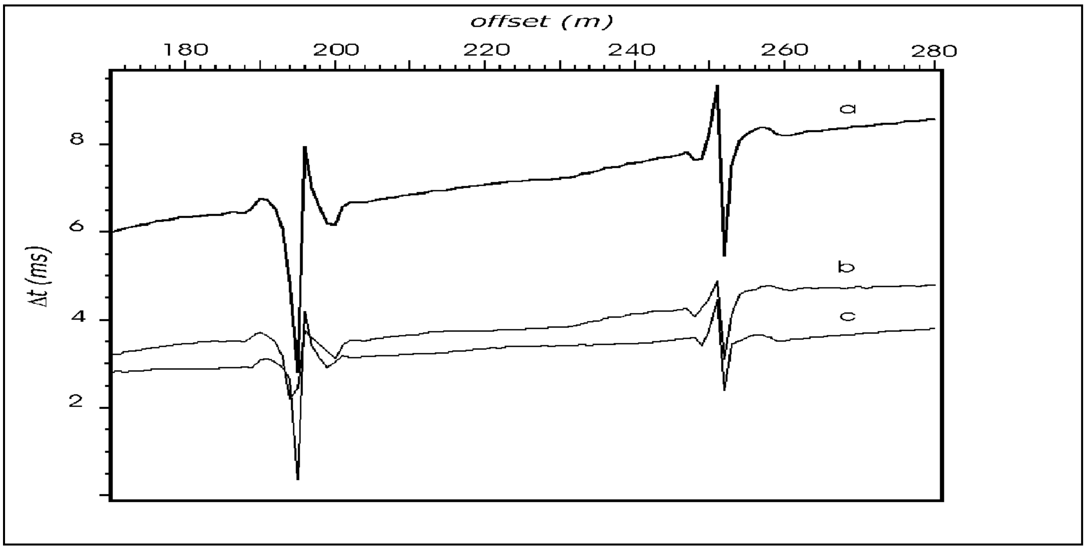


Fig. 9. Traveltimes differences between first breaks of head wave for the model with anomaly for different values of pick frequency of source signal: (a) Δt = t(50 Hz) – t(100 Hz), (b) Δt = t(50 Hz) – t(70 Hz), (c) Δt = t(70 Hz) – t(100 Hz), anomaly velocity 800 m/s, anomaly thickness 20 m.

CONCLUSIONS

The results of undertaken model calculation let us to draw the conclusions important form the point of view of applications seismic tomography for imaging near-surface velocity heterogeneities:

the breaks of head waves are well distinguished for the discussed near-surface layered medium in first and later breaks,

it is possible to realize the picking of head waves not only in first breaks but also in later breaks,

the main factors affecting the first breaks traveltimes in the model with velocity anomaly are the anomaly thickness and anomaly velocity; the change of traveltimes

achieves values from about (6 to 18 ms) for the discussed models, analysis of first breaks traveltimes obtained for different pick frequencies of source signal confirms the effect of some velocity dispersion on observed first breaks

traveltimes even for the assumed frequency variation from 50 to 100 Hz.

تقدير للتغير في سرعه الطبقه القريبه من سطح الارض ، في نموذج
Waves Acoustic

نصر الزوام
كلية العلوم – جامعة سبها

الملخص

يستخدم الانكسار السيزمي الضحل لتحديد تركيب الطبقة القريبة من سطح الارض . حيث ان الهدف الاساسي من هذا البحث في الاستكشاف السيزمي من اجل النفط والغاز هو لايجاد مايعرف بالتصحيح الثابت *Static Correction* . ونموذج الطبقة القريبة من السطح هو حصيله لتفسير الانكسار والذي يحدد كلا من السمك والسرعة للطبقة القريبة من السطح ، ويتم ذلك بواسطة تفسير ما يعرف بالانكسار الاول لموجات الرأس *Head Waves* . هناك طرق عدة لتفسير معطيات الانكسار ، وهذه الطرق لها محدودية التطبيق ، وحاليا تستعمل طريقة نقطة العمق المشتركه والتي تعرف اختصار (*CDP*) وهي طريقة سائدة في التراتيب السطحية *Surface Acquisition* ومن هذا المعلومات يمكن تحديد التصحيحات الثابته ، ويمكن تعيين المسح السطحي من خلال حفر التفجير العميقة وذلك باستعمال ازمنة الانتقال لايجاد سرعة الطبقة المنخفضة السرعة (*LVL*) . اما في حالة استعمال طريقة الرج *Vibroseis Method* فانه عمليا يمكن ايجاد كل المعلومات عن السرعة في الطبقة المنخفضة السرعة من خلال تسجيلات الانعكاس الحقلية. تصف هذه الدراسه ، نتائج تقديرالتصور للتغير في السرعه للطبقه القريبه من سطح الارض ، في نموذج *Acoustic Waves Model* ، حيث كان الهدف الرئيسي لهذا النموذج هو تعيين أثر ، التغير في سرعة الطبقه القريبه من سطح الارض ، وذلك على الموجه المنكسره والمرتبطه بالانكسار الضحل. ويشمل كلا من التغير في الابعاد ، وتوزيع السرعات في الطبقه القريبه من سطح الارض ، وكذلك متغيرات الاشاره للموجه المنكسره على قطاع التسجيل الانعكاس. التحاليل للبيانات أنجزت بأستخدام برامج الكمبيوتر *2D* والمعروفه في نظام تحليل العمليات السيزميه *ProMAX* .

REFERENCES

Barry K. M., 1967- Delay time and its application to refraction profile interpretation. *Seismic Refracting Prospecting,* Musgrave (ed.), 348-361. SEG, Tulsa.

Bohm G., Accaino F., Rossi G. and Tinivella U., 2006 - Tomographic joint inversion of first arrivals in a real case from Saudi Arabia, Section I – Madrid Workshop on Near-

Surface 2005. *Geophysical Prospecting*, 2006, vol. 54, 721–730

Bridle R., Barsoukov N, Al-Homaili M., Ley R. and Al-Mustafa A., 2006 - Comparing state-of the art near-surface models of a seismic test line from Saudi Arabia, Section I –Madrid Workshop on Near-Surface 2005, *Geophysical Prospecting*, 2006, vol. 54, 667–680

De Amorim M, Hubral W.N., P. and Tygel, M., 1987 - Computing Field Statics with the Help of Seismic Tomography. *Geophysical Prospecting*, vol. 35, 907-919

Ditmar P., Penopp J., Kasig R. and Makris J., 1999 - Interpretation of shallow refraction seismic data by reflection/refraction tomography. *Geophysical Prospecting*, 1999, vol. 47, 871–901

Docherty P., 1992 - Solving for the thickness and velocity of the weathering layer using 2-D refraction tomography. *Geophysics*, vol. 57, no. 10, 1307-1318

Hagedoorn J.G., 1959 - The plus-minus method of interpreting seismic refraction sections. *Geophysical Prospecting*, vol. **7**, 158–182

Harris J. H., Wang G. Y., 1996 - Diffraction tomography for inhomogeneities in layered background medium. *Geophysics*, vol. 61, 570-583

Lo T., Inderwiesen P. L., 1994 - Fundamentals of seismic tomography. Geophysical Monograph Series, no. 6, SEG, Tulsa, USA

Nolet G., 1987 - Waveform tomography. *In* Seismic tomography *ed.*G.Nolet. D. Reidel Publishing Company, Dordrecht, Holland, 301-322

Palmer, D. 1980 - *The Generalized Reciprocal Method of Seismic Refraction Interpretation*, K. B. *S* . Burke (ed.). SEG, Tulsa

Palmer. D., 1981 - An introduction to the generalized reciprocal method of seismic refraction interpretation. *Geophysics*, 46, 1508-1518

Pratt R. G., Worthington M. H., 1988 - The application of diffraction tomography to cross-hole seismic data. *Geophysics*, vol. 53, 1284-1294

Thornburgh H.R. 1930 - Wavefront diagrams in seismic interpretation. *AAPG Bulletin* 14, 185-200.

Tura M., Greaves R., Beydoun W., 1994 - Crosswell seismic reflection/diffraction tomography: A reservoir characterization application. *Geophysics*, vol. 59, 351-361

Woodward M. J., 1992 - Wave-equation tomography. *Geophysics*, vol. 57, 15-26

Zhu X., Sixta, D. P., Angstman, B. G., 1992 - Tomostatics: Turning-ray tomography + static corrections. *The Leading Edge*, 11, no. 12, 1

Zhu X. 2002 - Velocity imaging through complex near-surface structures by tomography. E37, EAGE 64th Conference & Exhibition — Florence, Italy, 27 - 30 May 2002