Fitting Computation Parameters for 2.5D-3C Modeling

Method

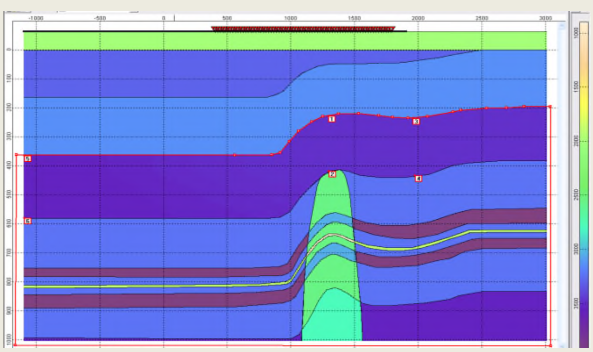
- In 2.5D-3C modelling, the displacement velocity vector $\mathbf{u} = (u_1, u_2, u_3)$ in the 3D spatial domain is obtained by applying the inverse Fourier transform for each spatial frequency k_2:

$$\mathbf{u}(x_1, x_2, x_3, t) = \sum_{k_2} \exp(ik_2 x_2)\mathbf{u}(x_1, k_2, x_3, t),$$

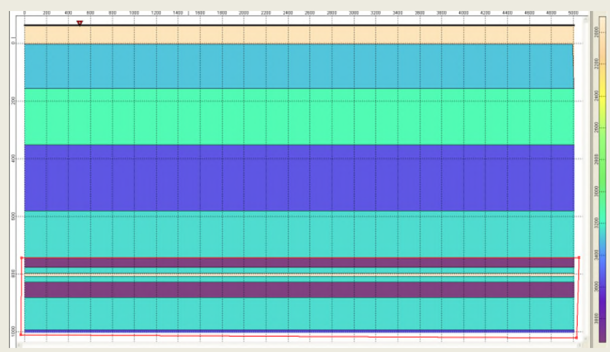
where $\mathbf{u}(x_1, k_2, x_3, t)$ is the vector of displacement velocity for each spatial frequency k_2, which is calculated by solving the 2D pseudo-wave equation.

- To run the 2.5D-3C finite-difference modelling computations, the bandwidth and interval of spatial frequencies k_2 need to be specified properly. If the ***bandwidth of*** k_2 is too narrow, some spatial frequencies along X_2 will be missed and waves with high horizontal slowness will be distorted. On the contrary, if k_2 is too large, an aliasing effect will result, i.e., the signal of mirror sources along the OX_2 direction will be observed in the resulting shot gather. Since $k_2 = \omega p_2$, where ***ω*** *is the temporal frequency*, ***p₂*** *is the horizontal slowness* in the OX_2 direction, the ***condition*** $k_{2\max} \geq \omega p_{2\max}$ must be fulfilled, in order to correctly simulate the events with maximum horizontal slowness.

- The *maximum horizontal slowness* $\boldsymbol{p_{2max}}$ depends on the modelled wave types. For example, if there is need to generate surface waves propagating along the OX_2 direction (surface waves have lower horizontal velocity V_0 and so the largest horizontal slowness $p_0 = 1/V_0$), then $p_{2\max} = p_0$. The vertical sections along the OX_2 direction of the 2.5D model represent a horizontally layered medium with constant elastic properties within each layer, as shown below:



Sections of the 2.5D model along the axis OX_1



Sections of 2.5D model along the axis OX_2 *for* $X_1 = 0$.

- Modelling for such 1D medium[1] enables the determination of the maximal horizontal slowness $p_{2\max}$ for selected wave types and the corresponding maximum temporal frequency ω. Usually, the value

[1]For the horizontally-layered medium (1D model), the Haskell-Thomson method (Roganov et al., 2009) is considered to be the most suitable approach to separately model the propagation of different types of waves (1D-3C modelling).

$\omega = \frac{2}{3}\omega_0$ is used, where ω_0 is the peak angular frequency of the signal. This kind of evaluation may be done for different X_1 = *const*. And it enables us to unambiguously determine the value of maximum horizontal slowness.

- The ***mirror sources***, which generate a wave field that looks like it is from a real source, have a discrete spatial spectrum and so are located at the distances $y_m = 2\pi m / \Delta k$ along OX_2, where m is an integer value and $m \neq 0$. The nearest mirror sources are located at the distance $y_1 = \pm 2\pi / \Delta k$ along the OX_2 axis.

For example, if the receiver has a cross-line offset y_r, it will record the direct wave from the nearest mirror source at the time $t = \left| \pm y_1 - y_r \right| / V$, where V is velocity of the direct wave. So the condition $\left(y_1 - y_r \right) / V > t_{\max}$ must be fulfilled, where $t_{\max}$ is the maximum recording time. It implies that, to avoid mirror source direct waves in the synthetic gather, the condition $\Delta k < 2\pi / \left(y_r + Vt_{\max} \right)$ must be fulfilled.

- The *direct wave* is not always the first arrival. Very often, the head waves are the first arrivals. And this case has to be taken into account while specifying the parameters for the 2.5D-3C modelling. Let's first run 2D-2C modelling for section X_1 = const and then estimate distance R between the source and the receiver with the first arrival recorded at maximum time $t_{\max}$. Then, the interval of the spatial frequency k_2 must satisfy the condition:

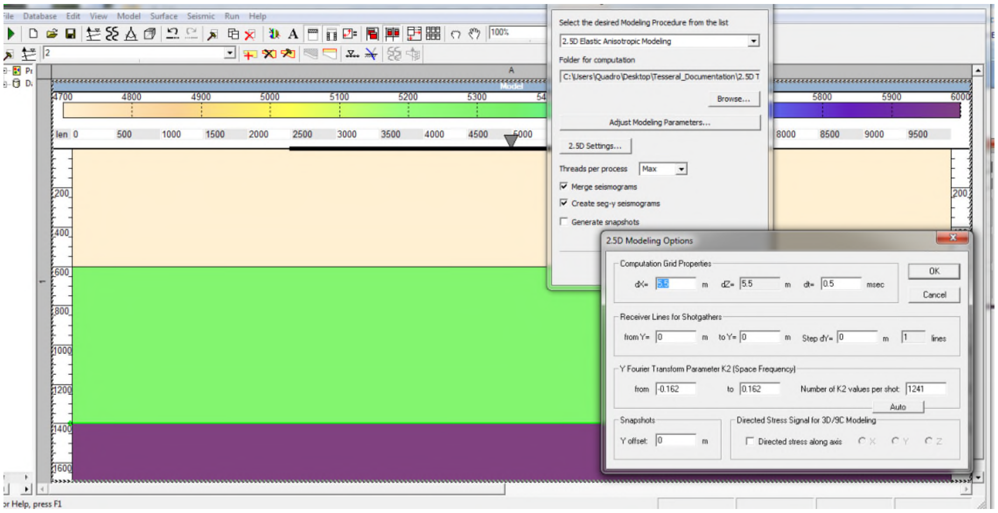
$$\Delta k < \frac{2\pi}{y_r + R} \qquad (1)$$

- Please use *Troubleshooting Guide*(*http://www.tesseral-geo.com/support.en.php tab /Troubleshooting Theory and Thesaurus*) to find description of theory behind 2.5D-3C modeling.
- Please see 2.5D *Modeling* examples (http://www.tesseral-geo.com/solutions.en.php *tab /Modeling*).
- Please, *use Help button*  in produced submenus and dialogs and see provided description.

Guidelines for choosing parameters for 2.5D-3C Modeling

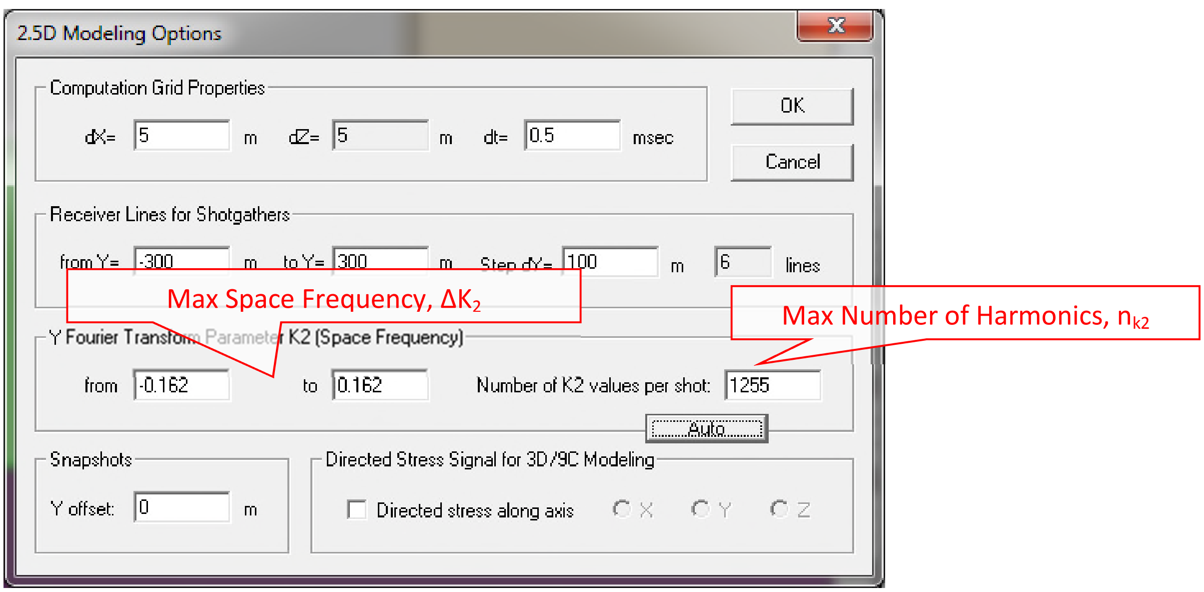
As soon as your 2D Model has been created and shooting/recording parameters set up, you need to choose parameters for 3D synthetic gathers calculation.

- Click ***Run*** on the top bar and choose ***Run Modeling*** and in drop down menu select ***2.5D Elastic Anisotropic Modeling***, click on ***2.5D Settings…***



this will bring you in ***2.5D Modeling Options*** where you can describe number of Receiver Lines and distance between them, Computation Grid Parameters, Maximum Space Frequency for generation of 3D synthetic gathers and Maximum number of harmonics which will be generated for each synthetic gather calculation.

- If you choose ***Auto*** (*Max Space Frequency, ΔK_2*) and (*Max Number of Harmonics, n_{k2}*) will be calculated automatically.



- But for the better result it is recommended to use the following steps for your parameters calculation:
  - Let's calculate ***Max Space Frequency, ΔK_2*** and ***Max Number of Harmonics, n_{k2}*** using a model which has several layers with compressional and shear velocities

    V_{p1}=4700 m/s, V_{p2}=5300 m/s, V_{p3}=6000 m/s,

    V_{s1}=2723 m/s, V_{s2}=3083 m/s, V_{s3}=3510 m/s.

  - Pick frequency for our signal is f_0= 30Hz, so let's assign f_{max} between ($2f_0$~$3 f_0$), in our case f_{max} will be 80Hz [$f_{max}=2.66 * f_0$]. To generate direct wave correctly we need to use formula

    $K_{max}=2\pi f_{max}/ V_{p1}$ =2*3.14*80/4700=0.1

The basis for these calculations is that compressional direct wave has the biggest space frequency for compressional waves and the similar statement can be related to shear waves. So the biggest space frequency will be tied with surface waves and K_{max} is chosen based on specified task.

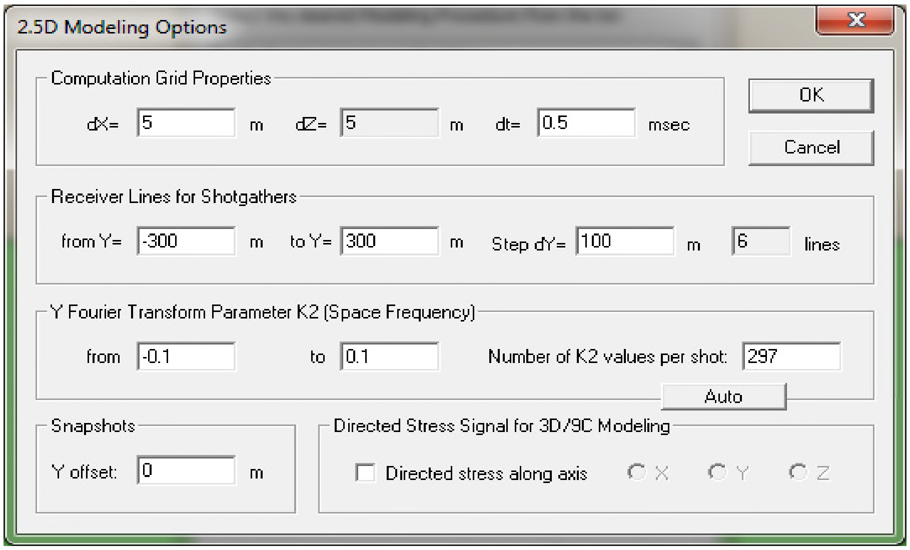
- To remove "mirror" frequencies in recording time range of 1.5 seconds, we need to use formula

  $\Delta K_2=2\pi/(Y_{max} + V_{max} * t_{max})$, where Y_{max} is maximum offset of Receiver Line (in our case it is 300m)

  $\Delta K_2=2*3.14/(300 + 6000*1.5)=0.000675$

- Therefore

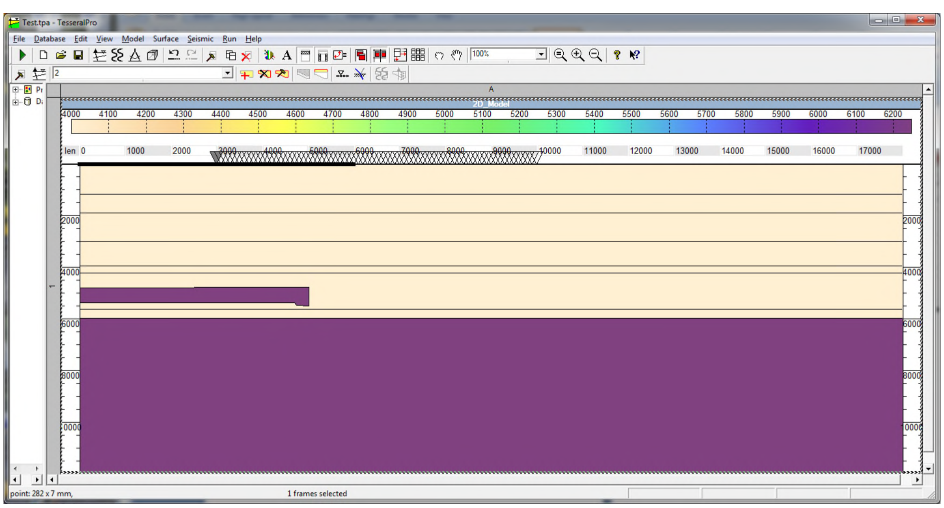
  $n_{k2}=2* K_{max}/\Delta K_2 + 1=2*0.1/0.000675 + 1=297$



➢ The main considerations which should be taken into account for 2.5D modeling are:

- bigger harmonics number ensure mapping of stip reflections;
- smaller space frequency allows to reduce or avoid *mirror* frequencies.

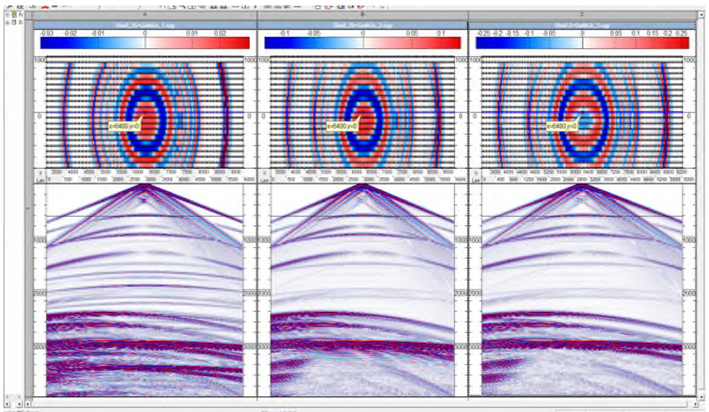
Here is some examples of 2.5D synthetic gathers for the following model:

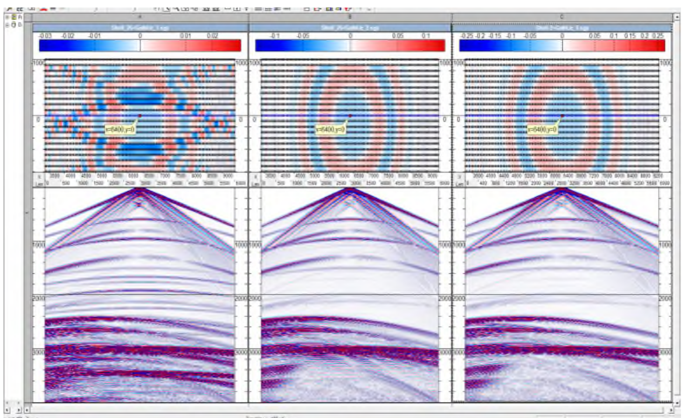


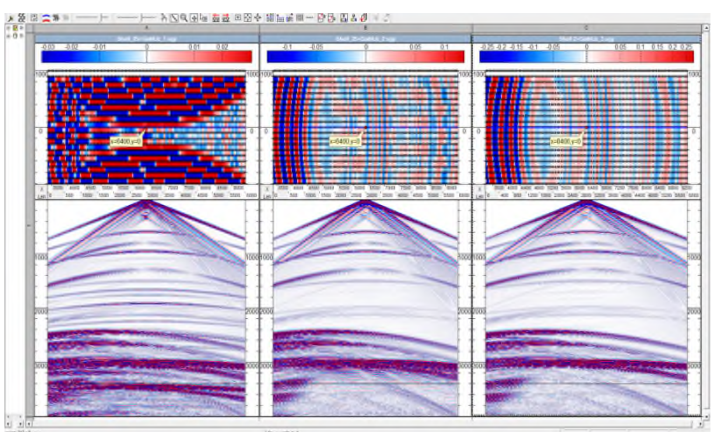
Test 1 (left):	Test 2 (center):	Test 3 (right):
Max Space Frequency, K_{max}	Max Space Frequency, K_{max}	Max Space Frequency, K_{max}

0.15	0.0175	0.0175
Max Number of Harmonics, n_{k2}	Max Number of Harmonics, n_{k2}	Max Number of Harmonics, n_{k2}
351	89	351

You can see vertical (Y=0) and horizontal time slices of 2.5D synthetic gathers for each test (time slices are taken at: 600 ms, 2000 ms and 3400 ms). As we can see that using smaller values of ***Max Space Frequency, K_{max}*** and bigger ***Max Number of Harmonics, n_{k2}*** we are generating more realistic 3D synthetic gathers which are less contaminated by *mirror* frequencies and artifacts.







- ✓ You should take into account that using small space frequencies, big harmonic numbers and big recording times will significantly increase calculation time.

- ✓ To create a similar task using Linux clusters you need to click ***Run*** on the top bar and choose ***CLUSTER Create Task…*** and in drop down menu select *2.5D Elastic Anisotropic Modeling*, click on *2.5D Settings…*, the rest steps are similar to which have been described above.
- ✓ To start this ***runtask.ini*** job you need to run ***run.sh*** file.

Example of the parameter determination for 2.5D-3C modelling

Let's consider the 2.5D model whose vertical section along the OX_1 is shown in Fig.1. Fig.2 shows the vertical section of this same 2.5D model along the axis OX_2 for $X_1 = 0$.

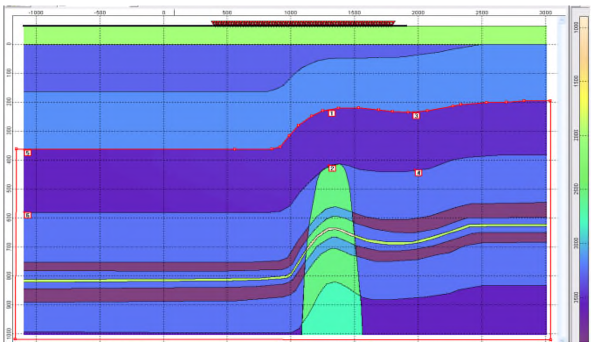


Fig.1. *Sections of the 2.5D model along the axis* $0X_1$

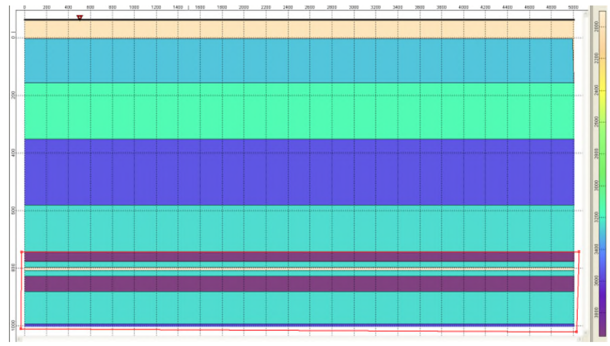


Fig.2. *Sections of 2.5D model along the axis* $0X_2$ *for* $X_1 = 0$.

For this 1D model shown in Fig. 2, the synthetic gather obtained by elastic 2D-2C modeling is shown in Fig.3. It can be seen that the surface wave indicated by the blue arrow has the maximum horizontal slowness.

Utilizing the Haskell-Thomson method, the dispersion curves of these Rayleigh waves are obtained and shown in *this Slide*. For peak frequency of the signal spectrum ω_0= *40Hz*, the maximum acceptable frequency is 100 Hz. As observed from this dispersion curves, then $k_{2max}=0.4m^{-1}$.

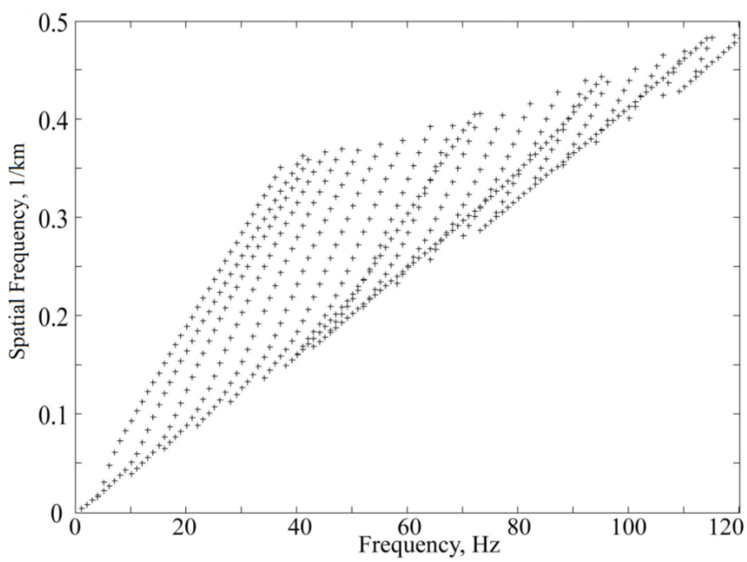


Fig.4. *Dispersion curves of Rayleigh waves by Haskell-Thomson method*

In the Fig.3 the intersection of the line $t_{\max}$ = 1.0 s with the first arrival is marked by the red arrow for the R = 3200 m.

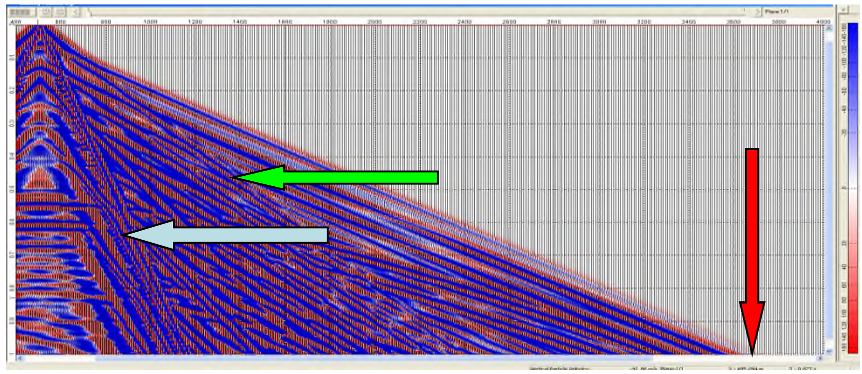
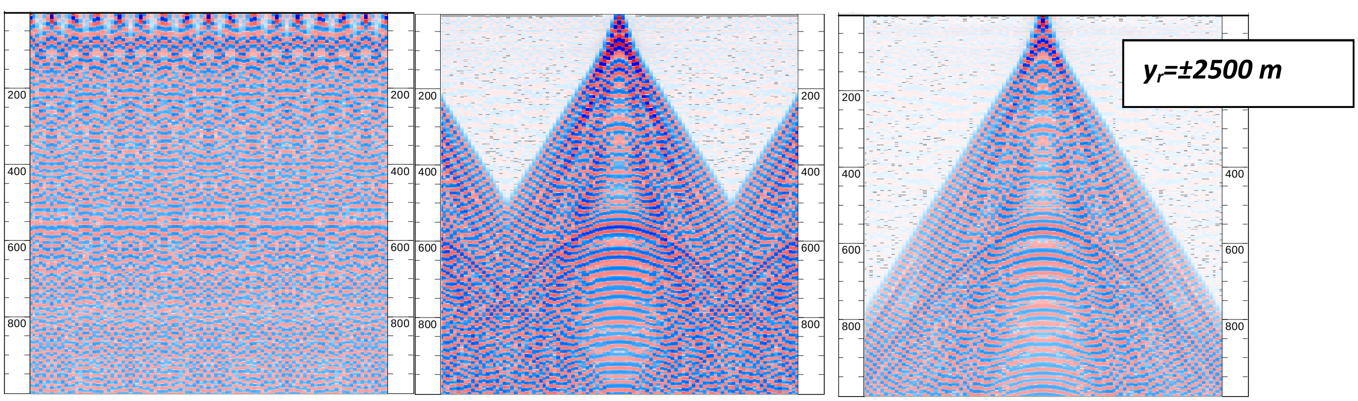


Fig.3. It can be seen that the surface wave indicated by the blue arrow has the maximum horizontal slowness. The intersection of the line t_{max} *= 1.0 s* with the first arrival is marked by the red arrow for the R = 3200 m.

For the receiver line shifted along the *0X₂* by the distance y_r = 500m (cross-line offset) Δk =0.0017 m^{-1} by the formula (1). When $k_{2\max}$ =±0.4 m^{-1}, the minimum number of harmonics is n=471, in order to obtain the undistorted result for the given spatial frequency range and cross-line offsets. Considering the symmetry of the modelled wave field relating to $0X_2$, only half of harmonics are actually needed.

Fig.5 shows the vertical sections of the 3D shot gather along the $0X_2$ axis, generated by 2.5D-3C modelling where the range of cross-line offsets is ***y_r****=±2500 m for different number of harmonics:* 41, 401 and 801.



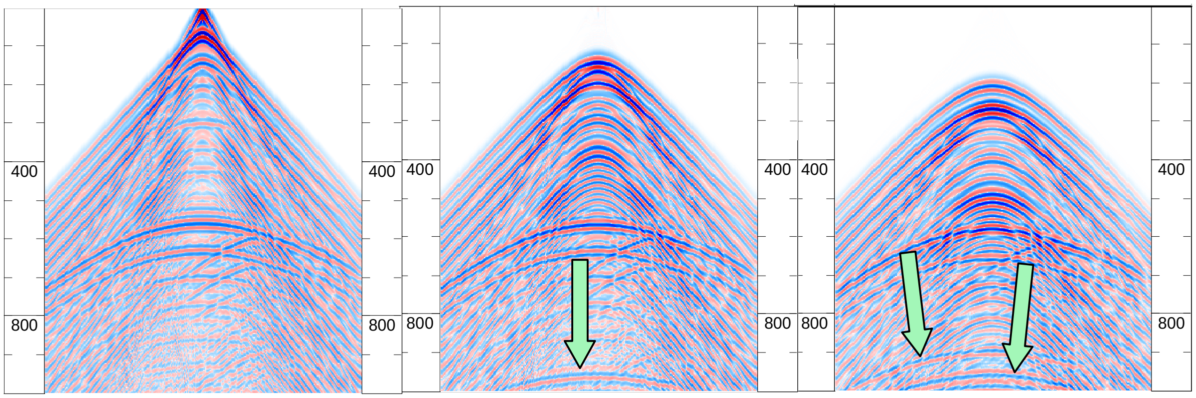
(a) n=41 ***(b) n=401*** ***(c) n=801***

Fig.5. *Vertical section of the 3D shot gathers along the $0X_2$ axis, which are computed for the transverse-offset y_r =±2500m for different number of harmonics*

From Fig. 5c, it can be seen that, when n=801, there is no signal from mirror sources within the range y_r =±2500 m of cross-line offsets. In Fig.6, the sections of the 3D shot gather obtained for the same number of harmonics n = 401 (this is less than the estimated number of harmonics for the y_r = 500) for different y_r =0 m (Fig.6a), y_r = 300 m (Fig. 6b), and y_r = 500 m (Fig. 6c).

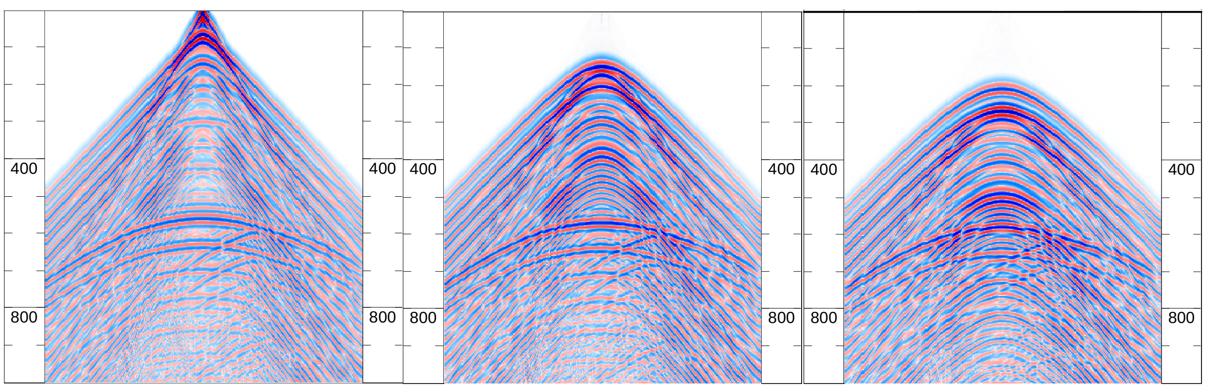
For the purpose of comparison, Fig. 7 show the sections of the 3D synthetic gather obtained for n = 801 (this is more than the estimated number of harmonics for y_r =500), for different cross-line offsets: y_r = 0 m (Fig.

7a), y_r = 300 m (Fig 7b), and y_r = 500 m (Fig 7c). The gathers obtained for y_r = 0 are the same for the both cases. But the gathers obtained for y_r = 300 m and y_r = 500 m differ. The reflections marked by the green arrow in the lower part of the Fig. 6b and 6c is absent in Fig. 7b and 7c, which implies that these reflections are caused by the mirror sources.



(a) ***y_r =0 m;*** **(b)** ***y_r =300 m;*** **(c)** ***y_r =500 m;***

Fig.6. *Sections of the* ***3D shotgather obtained for different cross-line offsets*** *in the case of* ***n = 401.***



(a) ***y_r =0 m;*** **(b)** ***y_r =300 m;*** **(c)** ***y_r =500 m;***

Fig.7. *Sections of the* ***3D shotgather obtained for different cross-line offsets*** *in the case of* ***n = 801.***

Summary

The 2.5D-3C modeling is an efficient method to generate 3D-3C synthetic gathers for heterogeneous thin-layered elastic models with arbitrary anisotropic properties. The explicit finite-difference calculations can be well parallelized using cluster computing. However, the optimal setting of the spatial frequency bandwidth and sampling rate along X_2 direction for 2.5D-3C modeling computations in practice often causes difficulties. Incorrect assignment of those parameters, as it was shown in provided example, leads to the emergence of artificial reflections from mirror sources on resulting synthetic gathers. In this study, we have shown the technological sequence for proper determining of those parameters. It allows to obtain high quality 3D-3C synthetic gathers for realistically complex medium models. The proposed method can be easily automated, which will simplify industry-scale application of 2.5D-3C modeling.

References

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- Kostyukevych A., Marmalevskyi N., Roganov Y., Tulchinsky V. [2008]. Anisotropic 2.5D-3C finite-difference modelling. 70th EAGE Conference, P043.
- Neto, F., and Costa, J. [2006]. 2.5D anisotropic elastic finite-difference modeling. *76th SEG Annual Meeting*, Expanded Abstracts, 2275-2279.
- Roganov V., Roganov Y., Kostyukevych A. [2009]. 3D-3C seismic wave modeling in multilayered anisotropic viscoelastic media using the Haskell-Thomson method, 71st EAGE Conference, P134.
- Optimizing the spatial frequency bandwidth and sampling in 2.5D-3C modeling. 74th EAGE Conference, June 2012

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