Seismic Elastic Modeling

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Abstract— In this paper, I am providing the information which I studied and analyzed about the seismic elastic modeling. The seismic data processing provides the information of seismic waves which are captured from earth subsurface in human readable form. The seismic data processing determines the actual graphical representation of the earth's substructure. The seismic data processing has some applications in that major applications are seismic modeling, seismic migration, and inversion. The seismic modeling provides the seismic data of wave propagation in the earth subsurface, further it will use in seismic migration and inversion application which predict that what is inside in the earth subsurface. The seismic modeling is the computational geological model which has input velocity model to define the physical properties of the earth's subsurface. It simulates the wave response by using mathematical wave equation. By using this technology we can find the seismic response in form of data. The seismic data processing technique is mainly used to find the oil and gas inside the earth.

Key words: Seismic Elastic Modeling, Seismic Migration

I. Introduction

The main aim of the seismic data processing is to generate an actual image of earth's substructure. So we can understand the actual location of oil and gas. In the actual field of seismic data processing, the seismic wave will propagate through the vibroseis or dynamite. The vibroseis is the vibrator truck which radiates the elastic energy inside the earth. Such as dynamite radiate the acoustic energy inside the earth.

In computational seismic model we use elastic or acoustic wave equation to determine the wave response in seismic data form. This computational geological model is the high compute intensive application which requires the high computational power. The seismic modeling process requires the number of routine for wave propagation. To achieve the high computational power we require to use the high-performance computing system (HPC) [10].

The HPC system used to generate seismic applications such as seismic migration, seismic modeling, and inversion of seismic wave. The HPC system has the large size of memory and processing power with high speed communication. The HPC system combines the number of processor and threads to achieve high processing power on large size of the program. The HPC system divides the task among the threads and processors so as a result we get the high performance during execution of the program [11].

The seismic modeling requires velocity model as an input model, source wave propagation as single or multiple shots, time step to wave propagation, sampling interval and total grid size (array size). Those required factors decide the size of seismic modeling application i.e. in that major factors are the size of input model and propagation of seismic wave source in single as well as multiple shots.

The normal computer system can't be able to run these kinds of application, because processing power of normal computer is very low it took more time for execution sometime it might be crash down the system. The HPC system can able to run these kinds of application. The HPC system detects the time-consuming part of the program and divides this time consuming part among the number of processing elements. By using HPC system the seismic application can execute quickly and efficiently [11].

II. Background

We cannot visualize that what is inside the earth. To analyze it, firstly we have to know about the velocity of the subsurface of earth with respect to its sub-layers. We can simulate the seismic response by using the numerical solution on velocity model. For that, we have to create the computational geological model. This computation model is based on the earth's velocity model. The numerical wave will radiate inside this computational velocity model. It will show the actual displacement and distortion of the wave while propagating into the sub-layers of earth subsurface. This computational geological model is known as seismic modeling.

To understand the seismic responses associated with a variety of subsurface conditions of earth the seismic modeling is used. Seismic modeling is essentially construction of geologic computer models and simulating their seismic wave propagation response. The term forward modeling is used to refer this process [3].

The earth's subsurface structure has major two types of the model they are Isotropic and Anisotropic earth model. The Isotropic model has single velocity or single layer only. The anisotropic model has different sub-layers inside the earth which have different velocity per layer. The major types of earth's substructure are as follows,

A. Isotropic Acoustic Model

The purely isotropic or acoustic models are based on physical parameters which will define the wave propagation. These physical parameters are density ρ(x, y, z), and interlude or synchronous velocity υ(x, y, z). These two properties are related with fluids properties. The wave propagation in such environments can be simulated efficiently [6].

B. Isotropic Elastic Model

Isotropic elastic models have three physical parameters i.e. density ρ (x, y, z), compressional velocity vp (x, y, z), and shear velocity vs (x, y, z). An isotropic elastic model has two wavefields, first is a compressional wave and the second is a shear wave. In comparisons with an acoustic model the compressional waves are identical. These wavefields are identified by particle motions i.e. particle vibrations in the direction of propagation which is called as compression and rarefaction. In recorded wave the compressional wave will measure in purely vertical particle motion and the shear wave will characterize by purely horizontal particle motion. The velocity of the compressional wave is higher than the velocity of the shear wave. The shear and compressional waves continually interact and convert from one form to another form as the propagation progresses. To handle isotropic elastic data successfully, we must acquire data which can directly relate to the vertical and horizontal particle motions i.e. we have to acquire vector data [6].

C. Anisotropic Model

The anisotropic model is the most complex model of the earth. In this model, the velocity of sound will vary with propagation angle, and it also has three propagation modes at any given instant. These three propagation modes include compressional wave and other are two types of shear wave, each of these waves have its own local angle-dependent velocity profile for propagation. The physical parameters of purely anisotropic model are density ρ(x, y, z), vertical velocity vp(x, y, z), shear horizontal velocity vs(x, y, z) and additional "Thomsen" parameters are δ(x, y, z), ε(x, y, z) and γ(x, y, z). Due to the Thomsen parameters, this model is also known as vertically transverse isotropic (VTI) model. The anisotropic VTI model has the suitable form of symmetry which makes it easier and less computationally complex version of the anisotropic model. In the anisotropic processing vector data is used where each vector has three components [6].

The analysis of wave response among these three earth's models will simulate through computation numerical model. Numerical seismic modeling will simulate the seismic wave propagation in a geological medium in order to generate synthetic seismograms by solving wave equation.

The 2D seismic modeling has 2-dimensional array for x and z-axis. The x-axis is used for to indicate the surface position of the earth and z-axis used to determine the depth of the earth subsurface. The coordinate system of 2D seismic model is given below,

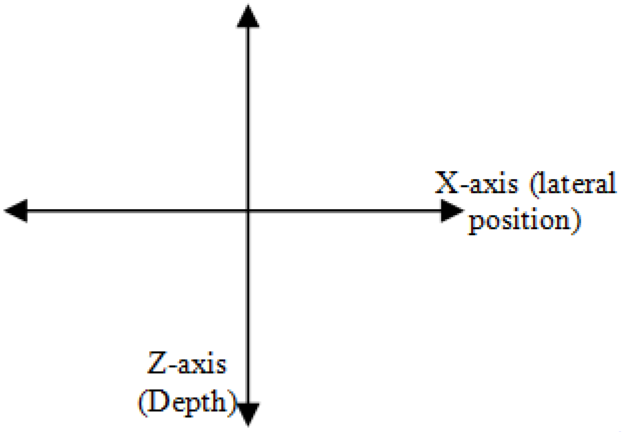

Fig. 1: The Coordinate system of the 2D seismic model

The earth model has the different physical properties with respect to the sub-layers of earth. According to this physical properties wave will propagate inside the simulation model. The behavior of elastic material has nature that it will regain its original position after stretched and squeezed. The main purpose of seismic modeling is to produce the seismic data of wave response inside the earth subsurface. This data will be used in some seismic application to analysis for determination of hydrocarbons inside the earth. It plays an important role in oil and gas exploration.

The propagation of wave within the earth's subsurface according to the Snell's law states that the velocity increases across the interface or boundary some energy of wave will reflect and refract. The refraction causes the change in the phase of the wave direction. The refraction depends on the physical properties of the earth. Some rays will reflect towards the earth surface. This reflected wave gives the important information about a structure of the earth.

The reflected wave will store in the receiver array while simulating the computational model. The response of wave propagation will be interpreted in the form of seismic data which given the internal structure of earth.

The simulated model produces seismic data of wave propagation according to the sub-layers of the earth subsurface. It shows wave propagation through earth subsurface at a particular time. The simulated model also produces the traces which are the data collected from receivers point. At the receiver point has geophone actually but in the computational model we use array to store wave response. This geophones record the reflected data from the interface. The interface is the medium between the two different layers of earth.

III. APPLICATION OF SEISMIC MODELLING

It validates a hypothesized earth model by comparing the seismic response obtained from the model with the recorded data. It computes synthetic sections used in conjunction with inversion algorithms. It conducts geophysical research using techniques in computational physics, complementing both analytical and experimental studies. Thus, computer modeling can greatly enhance the processes which determining the seismic response of the earth [7].

IV. HPC CHALLENGES IN SEISMIC MODELLING

The basic problem in seismic modeling is to determine the wave propagation response of a given model with solving the wave equation. Because the elastic wave equation is the coupled wave equation. In computational numeric modeling obtain the data of seismic wave propagation in a geological medium in order to generate the synthetic seismograms. Among the numerous approaches to seismic modeling, direct methods based upon approximating the geological model by a numerical mesh can give very accurate results. This approach requires large computational resources [8]. During parallelization, the problem must be broken down into set of tasks that can be solved concurrently. The major challenge is in assigned task to different processing elements to solving wave equation concurrently.

V. ELASTIC MODELING

The earth has an elastic medium of the structure. In elastic modeling the elastic wave equation is used. The elastic wave equation is the best description of propagation of seismic waves in the earth. The elastic wave equation is framed in terms of tensor operators acting on vector quantities [4]. The elastic modeling method using 2D elastic wave equation can only generate the synthetic seismogram of the Z and X component of the isotropic or anisotropic medium, in which the P and S wavefields are coupled [7]. The basic equations of 2D continuous wave in an elastic medium are governed by law of motion and the stress-strain relation. The sample elastic wave equation is given below which referred from [9],

$$\frac{\partial V_x}{\partial t} = -\frac{1}{\rho}\{\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xz}}{\partial z}\}$$

$$\frac{\partial V_z}{\partial t} = -\frac{1}{\rho}\{\frac{\partial \sigma_{xz}}{\partial x} + \frac{\partial \sigma_{zz}}{\partial z}\}$$

$$\frac{\partial \sigma_{xx}}{\partial t} = -\{\frac{1}{\kappa}\frac{\partial V_x}{\partial x} + \lambda\frac{\partial V_z}{\partial z}\}$$

$$\frac{\partial \sigma_{zz}}{\partial t} = -\{\frac{1}{\kappa}\frac{\partial V_z}{\partial z} + \lambda\frac{\partial V_x}{\partial x}\}$$

$$\frac{\partial \sigma_{xz}}{\partial t} = -\mu\{\frac{\partial V_x}{\partial z} + \frac{\partial V_z}{\partial x}\}$$

Where,
V_x is the wave motion in x-axis,
V_z is the wave motion in z-axis,
σ_{xz}, σ_{xx} and σ_{zz} are the stress tensors,
ρ is the density, κ = bulk modulus,
λ and μ are the lamé parameter.

The elastic wave equation determines the wave propagation in the seismic elastic modeling by updating its parameter during simulation.

VI. Conclusion

The seismic elastic modeling is the best description of earth motion because the structure of earth is in elastic form only. The Seismic elastic modeling is the high compute intensive application. To develop this requires the high performance computing system. The HPC system can run the seismic modeling application efficiently.

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References

[1] Kruger, J., Green Wave: A Semi-Custom Hardware Architecture for Reverse Time Migration, 2012.
[2] Schuster, G. T., Basics of Seismic Wave Theory, 2007.
[3] Chopra, S., 2005, Seismic Elastic Modeling, Arcis Corporation.
[4] Bale, R. A., Elastic wave-equation depth migration of seismic data for isotropic and azimuthally anisotropic media: PhD thesis, University of Calgary (Canada) , 2006.
[5] Zhang, J., Zhenping, T., Chengxiang, W., P- and S-wave separated elastic wave equation numerical modeling using 2D staggered-grid, 2007.
[6] Bednar, J. B., Modeling, migration and velocity analysis in simple and complex structure, 2009.
[7] Kindelan, M., Seriani, G. and Sguazzero, P., 1989, Elastic modeling and its application to amplitude versus angle interpretation. Geophysical Prospecting 37, 3-30.
[8] Dhubia, S., Phadke, S., Seismic modeling and reverse time migration on a high performance computing System, 9th Biennial International Conference & Exposition on Petroleum Geophysics, Society of Petroleum Geophysics (SPG), Hyderabad, 2012.
[9] Jan Thorbecke, 2D Finite-Difference Wavefield Modeling, 3-14, 2014.
[10] Seismic Processing, Version 1.0 released 29/1/99, retrive from http://www.xsgeo.com/course/proc.htm.
[11] Rubin H. Landau, A Beginner's Guide to High–Performance Computing, Oregon State University, Corvallis, OR 97331, United States.

