Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 96 (2016) 920 – 929

Procedia Computer Science

20th International Conference on Knowledge Based and Intelligent Information and Engineering Systems, KES2016, 5-7 September 2016, York, United Kingdom

Numerical modeling of wave processes during shelf seismic exploration

Alena Favorskaya[a*], Igor Petrov[a], Nikolay Khokhlov[a]

[a]*Moscow Institute of Physics and Technology, 9 Institytsky Pereylok st., Dolgoprudny, Moscow Region, 141700 Russian Federation*

Abstract

The attention to Arctic shelf is explained by the real need of exploration and development of oil-fields and gas-fields. The computer modeling is a single appropriate approach because the physical experiments in Arctic are expensive and sometimes difficult or impossible to make. In this research, the wave processes during seismic exploration of Arctic shelf are studied. The up-to-date numerical simulation by gird-characteristic method was applied. This method allows to obtain all types of elastic and acoustic waves (longitudinal P-waves, transverse S-waves, Stoneley, Rayleigh, Love, scattered PP-, SS-, and converted PS- and SP-waves) in the heterogeneous media, using mathematically correct conditions on boundaries and interfaces. Also a comparison of acoustic and elastic wave processes during shelf seismic exploration was implemented. The experiments show that it is more precise and informative to solve the elastic wave equation in geological media and the acoustic wave equation in the sea water layer only despite of sources and receivers, which are located in the water layer near the surface. The experiments demonstrate the opportunity to measure the reflections in the water from the converted PS-waves and the reflected SS-waves, using receivers in the water layer. The software based on grid-characteristic method was developed. It is possible to use different interface and boundary conditions and obtain full wave pattern.

Peer-review under responsibility of KES International

Keywords: seismic exploration; Arctic shelf; ice formations; wave processes; numerical modeling; grid-characteristic method

* Corresponding author. *E-mail address:* aleanera@yandex.ru

1. Introduction

More than 25 % of hydrocarbon resources are located in the Arctic region[1]. There are eight fields discovered on the Arctic shelf of Russian Federation in 1983-1992 with estimates of reserves of hydrocarbons about 2.7 trillions m^3. Five of these eight fields are the objects related to the objects of federal significance: Ledovoe, Ludlovskoe, Murmanskoe in the Barents Sea, Pomorskoe, Gulyaevskoe in the Pechora Sea, Leningradskoe, Rusanovskoe in the

Peer-review under responsibility of KES International
doi:10.1016/j.procs.2016.08.271

Kara Sea. The ice-resistant platform called Prirazlomnaja was constructed for oil production in the Pechora Sea. The project of the Shtokman field in the Barents Sea is designed for gas production. The improvement of estimates of hydrocarbon reserves volumes is required for these fields[2]. A significant complicating factor in the production of hydrocarbons in the North Seas is the existence of ice and different kinds of ice formations. The drifting ice is observed almost during all year in the Kara Sea, as well as the icebergs and the ice hummocks are in the Barents and the Pechora Sea. The depths of these North Seas in the industrial zones reach up to 300 m. For example, the Pechora Sea and the Kara Sea are covered with drifting ices most time of the year. The speed of ices may exceed 5 m/s, the thickness of plane ice[3] is up to 2 m, the thickness of draft ice hummocks is 20 m. Thus, the structure and parameters of the ice, covering the Northern seas, are significant parameters, determining the extreme loads at fixed and floating offshore oil and gas industrial structures[4,5,6].

The hydrocarbon exploration in the Arctic area has its own specificity. In particular, one of the layers, through which the seismic signals are propagated, is the sea, another layer is the ice[7,8,9,10]. The icebergs, ice hummocks, drifting ice, and ice cover have also contributed to the measured or calculated responses obtained during the seismic exploration. In addition to seismic technology, the electrical exploration of hydrocarbons is an effective approach. The review of studies on this topic is given in[11,12].

In this paper, the wave processes occurred during seismic exploration at the Arctic shelf using numerical modeling by grid-characteristic method[13,14,15,16,17,18,19] are discussed in detail. The remainder of this paper is organized as follows. Section 2 describes the systems of equations of proposed numerical methods. Section 3 gives a brief survey of grid-characteristic method used. Section 4 describes the problem definition and section 5 represents the results of numerical experiments. Section 6 includes conclusions.

2. Numerical modeling of elastic and acoustic waves

For numerical modeling of seismic prospecting the systems of equations describing acoustic waves is usually used[20,21,22]. There are three most common types of numerical methods for modeling in geophysics, such as direct methods, integral-equation methods, and asymptotic methods[23]. In direct methods[24], it is possible to use a topography, to solve large-scale problems[25], to obtain high-order accuracy[26,27], to model heterogeneous acoustic media[28], to involve some of elastic effects[29], and to apply curvilinear grids[30] using finite-difference methods.

The system of equations, describing the acoustic wave propagation, can be written as follows[31]:

$$\rho \vec{v}_t = -\nabla p \tag{1}$$

$$p_t = -c^2 \rho (\nabla \cdot \vec{v}) \tag{2}$$

In equations (1), (2) p is an acoustic pressure field, $\vec{v}$ is a velocity, and c is a speed of the sound in the acoustic medium.

However, it is more correct to solve the system of equations, describing the elastic wave propagation[32]. There are a lot of methods for finding these solutions, for example, finite-difference[33,34], including fluid-solid case[35]. Also one can use discontinuous Galerkin method[7,8,9,10], high-order spectral element method[36], a multidomain PSTD method[37], fully unstructured hexahedral meshes[38], and the collocated grids considering a surface topography[39]. A comprehensive review of the mentioned above methods for modeling of elastic wave propagation one can found in[40].

The system of equations, describing the elastic wave propagation, can be written as follows[32]:

$$\rho \partial_t \vec{v} = \left(\nabla \cdot \boldsymbol{\sigma}\right)^{\mathrm{T}} \tag{3}$$

$$\partial_t \boldsymbol{\sigma} = \rho\left(c_p^2 - 2c_s^2\right)\left(\nabla \cdot \vec{v}\right)\mathbf{I} + \rho c_s^2 \left(\nabla \otimes \vec{v} + \left(\nabla \otimes \vec{v}\right)^{\mathrm{T}}\right) \tag{4}$$

In equations (3), (4) ρ is a density, $\vec{v}$ is a velocity, $\boldsymbol{\sigma}$ is the stress tensor, c_p is a speed of P-waves, and c_s is a