On Some Features of the Development of Infrastructures in the Polar Regions

V I Shabunevich

1JSC “VNIKTI”, 410 Oktyabrskoy Revolutsii str., Kolomna, 140402, Russia

E-mail: vnikti_odpi@list.ru

Abstract. The paper describes the possible fact of increased oscillations of the Earth crust in the polar region as compared with the equatorial zone, obtained in the course of numerical experiments, and it has been suggested to conduct a full-scale test experiment. Some basic results of the linear harmonic analysis of simplified finite-element models of the Earth of different scales, which may effect on the design standards of various infrastructures developed in the Arctic region, are given.

1. Introduction
The problem of the earthquake proofing of structures and constructions is a complex problem. It is based on special knowledge in the field of earthquake engineering, the theory of oscillations and dynamics of structures, the building mechanics, the strength of materials and the safety of structures, design methods and other disciplines related to the construction industry [1].

Every year up to a million earthquakes occur on our planet. Fortunately, only a small part of them leads to catastrophes and people death. No matter how developed the earthquake seismology is today, people are still learning to control the seismic activity of the Earth [2–5]. However, to protect ourselves from the seismic danger and to make our existence safe to the maximum, the humanity is quite capable. Modern technologies, worked out specifically for the earthquake engineering, are designed to reduce the impact of earthquake activity by two, three, and in some cases, more times. They impose developers to include the increased structure reliability for objects of a high degree of responsibility even at the design stage.

2. Methods and main results of the study
The aim of this work was to detect by the numerical experiments the fact of increased oscillations of the Earth crust in the polar region as compared with the equatorial zone and to plan test experiments on full-scale models and on the Earth itself. Simplified finite-element models of the planet Earth of different scales, which are spherical shells of different radii with cores and without them, are considered [6–12]. There is pressure inside each model.

When conducting a harmonic analysis in the equatorial plane of the first two models with cores under consideration, normal frequency-varied transverse forces were applied to their surfaces. In the third (experimental) case, a frequency-varied vertical overload was applied to the shell model without a core.

In the first case, the model is a spherical shell with a mantle and a core in it, with a radius of 9 m and a thickness of 0.1 m. The pressure of 650,000 Pa (6.5 atm) is inside the shell. The radius of the
inner core is 3 m. The elasticity modulus of the shell in the model is $6.1 \cdot 10^{10}$ Pa, its density is 2,330 kg/m³. The space between the shell and the core is filled with the mantle. The elasticity modulus of the mantle adopted in the calculations is $1.0 \cdot 10^{8}$ Pa, its density is 800 kg/m³. Similarly, the elasticity modulus of the core is $2.1 \cdot 10^{11}$ Pa; its density is 7,800 kg/m³. The mass of the model is respectively $3.354 \cdot 10^{26}$ kg.

The view of the finite-element model is presented in Figure 1. Figure 2 shows the change in frequency of the calculated magnitudes of nodes displacements at the pole and at the equator under the transverse force harmonic loading of 1,000 N, the internal pressure of 650,000 Pa and the rotation with the angular velocity $\omega_z = 100,000$ rad/s.

![Figure 1](image1.png)

**Figure 1.** The view of the Earth finite-element model.

![Figure 2](image2.png)

**Figure 2.** The change in frequency of the calculated magnitudes of nodes displacements 7,622 (at the pole) and 8,225 (at the equator) of the first model (R=9 m) under the transverse force harmonic loading of 1,000 N, the internal pressure of 650,000 Pa and the rotation with the angular velocity $\omega_z = 100,000$ rad/s.

In the second case, the considered Earth model was a spherical shell with a mantle and a core in it, with a radius of 6,333 km and a thickness of 210 km, respectively. The pressure of 650,000 Pa is also inside the model. The radius of the model core is 3,475 km. The elasticity modulus of the shell in the models is $7.0 \cdot 10^{10}$ Pa, its density is 2,700 kg/m³. The space between the shell and the core is filled with the mantle. The elasticity modulus of the mantle adopted in the calculations is $7.0 \cdot 10^{7}$ Pa, its density is 3,700 kg/m³. Similarly, the elasticity modulus of the core is $7.0 \cdot 10^{10}$ Pa; its density is 13,000 kg/m³. The mass of the model is $5.45 \cdot 10^{24}$ kg.
Figure 3 shows the change in frequency of the calculated magnitudes of nodes displacements at the pole and at the equator of the Earth model under the transverse force harmonic loading of 10,000 N, the internal pressure of 650,000 Pa and the rotation with the angular velocity $\omega_z = 7.2685201E-005$ rad/s.

Figure 3. The change in frequency of the calculated magnitudes of nodes displacements 100,154 (at the pole) and 97,805 (at the equator) of the Earth model (R=6,333 km) under the transverse force harmonic loading of 10,000 N, the internal pressure of 650,000 Pa and the rotation with the angular velocity $\omega_z = 7.2685201E-005$ rad/s.

The model without a core suggested for the field experiment is a steel spherical shell with a radius of 0.45 m and a thickness of 5 mm, filled with water. The pressure of 650,000 Pa (6.5 atm) is also inside the model. The elasticity modulus of the shell in the model is $2.1 \cdot 10^{11}$ Pa, its density is 7,800 kg/m³. The elasticity modulus of the water inside the shell adopted in the calculations is $1.0 \cdot 10^8$ Pa, its density is 1,000 kg/m³. The mass of the model is respectively $4.568 \cdot 10^2$ kg. The rotation with the angular velocity $\omega_z = 10$ rad/s and the frequency-varied vertical acceleration, equal to 9.81 m/s², are applied to the model.

Figures 4 and 5 show the change in frequency of the calculated magnitudes of displacements and Mises stresses for nodes at the pole and at the equator of the model. The maximum values of displacements and stresses at the resonance peaks are 0.4 mm and 75 MPa, respectively, which are significantly lower than the limit values for steel, i.e. there is no threat of destruction.

Figure 4. The change in frequency of the calculated magnitudes of nodes displacements 4,211 (at the pole) and 4,347 (at the equator) of the shell model (R=0.45 m) under the vertical acceleration harmonic loading of 9.81 m/s², the internal pressure of 650,000 Pa (6.5 atm) and the rotation with the angular velocity $\omega_z = 10$ rad/s.
**Figure 5.** The change in frequency of Mises stresses at nodes 294 (at the pole) and 4,323 (at the equator) of the shell model ($R=0.45$ m) under the vertical acceleration harmonic loading of $9.81$ m/s$^2$, the internal pressure of $650,000$ Pa (6.5 atm) and the rotation with the angular velocity $\omega_z = 10$ rad/s.

Figure 6 shows the possible stress-strain state of main pipelines in the polar and equatorial regions with the same their support. It is obvious that in the polar region the axial and bending stresses in pipelines are much larger in magnitude than in the equatorial region.

**Figure 6.** The change in frequency of axial (a) and bending (b) stresses in main pipelines near the pole (the node of the finite-element mesh 111,659) and at the equator (the node of the finite-element mesh 110,979).
3. Conclusions
The conducted harmonic analysis of various (with the core and without it) models of the Earth shows that the displacements of the surface of the Earth crust in the polar regions are at least twice as large as in the equatorial region. All these estimates were made without taking into account differences in the thickness of the Earth crust; taking into account these differences, the variance will multiply increase. Therefore, design standards for various infrastructures in the Arctic region should take this phenomenon into account. Currently, in connection with the planned large-scale development of the Arctic regions (the construction of the northern sections of the Russian railway, the development of mining and transportation of mineral resources in the Arctic Circle, the creation of various other infrastructures), the issues discussed in the paper become very urgent.

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