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PhD Thesis: *Laboratory measurements and viscoelastic constitutive modeling of rock creep with application to stress prediction in intraplate sedimentary basins*

Summary

The past and current stress states in the subsurface determine the natural phenomena like the occurrence of earthquakes or development of fractures and joints, and influence strongly human underground activity. Stress measurements are expensive and technologically challenging, and thus only limited amount of direct stress magnitude data is available during stress analysis in sedimentary basins. Therefore, several theoretical stress prediction methods have been proposed. In this thesis, a new method of stress prediction in intraplate sedimentary basins is introduced, which takes into account elastic and creep deformations of rocks, as well as stress transfer between layers of different mechanical properties. The method is developed basing on samples and experimental data from the Baltic basin, northern Poland.

Prior to development of the method, the important aspects of stress modeling are described. First, it is crucial to choose a proper constitutive law to describe the mechanical behavior of rocks. Thus, the important deformation mechanisms in rocks are presented, including elasticity, viscous flow, plasticity, poroelasticity and viscoelasticity. From the above constitutive laws, viscoelasticity is selected to represent rock properties, because it can model both immediate elasticity and creep.

Next, three-dimensional viscoelastic constitutive law for rocks is derived. Such law must incorporate separation of volumetric deformations, which are finite and usually are set elastic, and the distortional deformations. In isotropic materials, such division is performed by use of the bulk-deviatoric split. However, shale rocks are known to exhibit both anisotropy and creep, and therefore a more complex volumetric-distortional decomposition is presented, which is a base of anisotropic viscoelastic constitutive law.

In order to feed the constitutive law with parameters, a series of creep laboratory tests was performed on samples from the Baltic basin. The tests were carried out in the Rock Mechanics Laboratory at the University of Wisconsin-Madison, USA. Data analysis allowed to choose the fractional Maxwell power law approach to describe the viscoelastic deformations, and provide the necessary parameters. Also, the time-dependent Poisson's ratio behavior was analyzed. However, the available data did not allow to constrain with confidence all the anisotropic functions, and in the following stress modeling the isotropic formulation is used.

After describing sedimentary rocks as elastically compressible viscoelastic material, various aspects of stress modeling are presented. First, the sources of stress in the lithosphere are introduced. Then, the stress state in sedimentary basins is characterized based on available stress data. Also, the commonly used stress prediction methods are presented. Even though the amount of stress measurements in layered systems is small, the data show that stress magnitudes change among layers of different properties, and that creep and subsequent relaxation in weak layers induce equilibration of horizontal stresses, which tend towards the overburden stress magnitude. Such observation is contrary to the results of commonly used linear elastic stress models which neglect stress relaxation.

In the final chapters of the thesis, the influence of rock viscoelasticity on the stress state is described, and the novel method is presented. The new approach assumes that the sedimentary basin consists of welded together, viscoelastic layers subjected to far field tectonic forces. Such boundary conditions allow to model stress changes during relaxation, and quantify the stress transfer between layers. If the driving tectonic force is constant, and the layers are welded together, then when a weak layer undergoes relaxation, the stress is transferred to the stronger layers. This phenomena may be a cause of fracture and joint development in strong layers, e.g. limestones, surrounded by thick intervals of weak rocks, e.g. shales. As an example of application of the method, Baltic basin glacial stress modeling is performed and analyzed.

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