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STRESS CHANGES IN CEMENTED BOREHOLE ANNULUS

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ABSTRACT

Cemented boreholes annulus its stability achieved tightness must be maintained in the continuation phase of drilling, is that in the process of drilling, cementing, production. Preserving stability in the working life of the wells threatened and technological stage of the production process due to the natural development of conditioned stress-laden formation (swelling) and a reduction of fluid volume in the reservoir and operational procedures (from moderate to high pressures and temperatures, as well as - technical interventions (changes type of working fluid, leaking testing, perforating, injection, hydraulic fracturing, other operations). From cement mixture composition depend on the mechanical properties of hardened cement stone. Increase elasticity is associated with a reduction in the compressive strength and must always check that the compressive strength of cement stone ensure the stability of pipes due to well working life.

Key words: *borehole, cement stone, stress state, finite element method*

INTRODUCTION

Previous laboratory well cements testing and their values are part of the input, variables for technical and technological analysis and evaluation of maintenance quality and stability cement stone. In the laboratory tests showed that it is essential to analyze and value parameters Young's modulus and Poasson's coefficients. The values of the mechanical parameters indicate the size limit of cyclic stresses in the case of an increase or decrease of pressure in the well. The values of these coefficients indicate the achieved quality of the cement stone and its specific features in the deep well conditions apply.

Cement mixtures in which the values of the elastic parameters so determined to meet the demand for long term mechanical durability, must be addressed. These types of cement mixtures containing additives to increase the volume, which leads to the optimal composition of the cement mixture to prevent loss of insulation layer due to changing conditions in the well. However, even when all the conditions are met, and when the operation cementing is performed technically correct, different drilling operations in the system leading to the occurrence of stress state and the creation of forces that are sufficient to destroy the integrity of the cement lining. Permeability of annulus can result in a long-term problem of gas migration.

CEMENT STONE STRESS IN WELL ANNULUS

Cement mixture, which when cured, have the tensile strength of the lower Young's modulus of elasticity compared with the formation are the best in terms of conservation of mechanical strength.

These requirements are a function of specific drilling environment as well as the geometry, properties of pipes, mechanical properties and superior load formations in the borehole. Mechanical damage caused by the increased pressure in the borehole (leaking testing of pipes, increasing density of drilling fluids, casing perforation, stimulation, production of gas), a large increase in temperature in the well (geothermal production, steam injection wells, and the extreme HTHP conditions) or formation damage (ice, compression, faulting ...). The situation is worse in unconsolidated formations as they are not able to monitor mechanical deformation of cement stone. Mechanical damage can be caused by excessive shrinkage of cement stone and recommended the use of cement mixtures without reducing volume. In the process of drilling mud density changes leading to changes in pressure and temperature changes caused by the backflow of mud. Increasing pressure and vibrations due to perforations in the hole is made with deep Rifles (perforator) with bullets or shaped charge, the fired individual or in series.Increasing pressure during hydraulic fracturing layers is drastically since the time effects increased pressure measured hours and then a sharp drop in pressure.

Increasing pressure and temperature during operation generally causes damage to the cement stone in cemebted annulus section near the mouth of wells where the pressure is increased from atmospheric to initial production pressure and the temperature, in some cases, increased, up to the temperature at the bottom of the well. Although the pressure changes mainly expressed in the tubing, increased pressure in a cemented annulus, in the case of gas migration is the result of gas expansion due to temperature increase. Pressure reduction during operation mainly affects the bottom of the wells where the pressure at the bottom, which is controlled by decreasing the production of formation pressure to the pressure of production. Cement stone in the annulus has to fulfill a multitude of functions, of which the most important are bracing of pipes to the walls of the borehole and the tightness of annulus. From this point of view, determining the composition of the cement mixture (and a team of hardened cement stone) must be given the same attention as the kind when performing drilling procedure. Until now, the state of preservation of tightness in the annulus during exploitation of wells were not given attention, in addition to achieving the highest possible strength of cement stone to the pressure, as a condition of quality cement.

During the life of the wells identified two main phases relevant to protect achived annulus stability tightness by cement stone:

a. PHASE CONSTRUCTION WELLS: drilling, cementing, testing
b. TECHNOLOGICAL PHASES IN THE PRODUCTION PROCESS

During this phase of work affects the planned / unplanned operations would seriously endager the preservation of stability tightness cemented annulus. Examples of later technological stages that are present in the life of the wells:

- Natural progression of stresses caused by:
  - settling formation, swelling
  - reduce fluid in the reservoir
- Operational procedures:
  - from moderate to operation at high pressures and temperatures,
  - water / steam injection / gas storage / production
- Technical - technological interventions:
  - the change of the working fluid,
  - leaking testing,
  - shootings,
  - injection,
  - hydraulic fracturing,
  - other operations.

Formation of microchannels is another important cause of loss of tightness of spaces. Microchannels can be formed between the casing and the cement stone (internal) or between the cement and stone formation (external microchannels). Internal microchannels can be determined by electric logging (loss of cement bond log response - CBL). It was created, for example, the radial moving as a result of changes in temperature or pressure, especially when the pressure or temperature in the well decreased (change in specific gravity of the mud, working fluids during the overhaul of wells, injection of cold water) when the cement stone has cured.

STRESS CHANGES IN WELL ANNULUS

Material system, as an object of observation Geomechanics, is part of the rock mass to be influenced by effects of the forces is in equilibrium. By external forces in the system between the particles act internal forces. Primary stress state of rock massif is a stress state corresponding to a time when rock massif is not disturbed mining activity.

Primary three-dimensional stress state is the size of which is defined with 9 components: σ_x, σ_y, σ_z, τ_{xy}, τ_{xz}, τ_{yx}, τ_{yz}, τ_{zx}, τ_{zy}. From the moment equation implies that the tangential stresses on two mutually parallel sides with respect to the coordinate system x, y, z are equal to one. In this way, the stress state is ultimately reduced to 6 components: σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, τ_{zx}. In order to determine the stress state in three dimensions very complex and time-consuming process in practice, the stress condition is usually analyzed in two dimensions, ie. in the plane. In this case it is assumed that all the external forces acting in one plane (xy) and the thickness of the body (z-axis) is negligible compared to the other two dimensions. To evaluate the stress level is necessary to determine the four components: σ_x, σ_y, τ_{xy}, τ_{yx}. It is often convenient to express stress components in the polar coordinate system. Position of the point in the coordinate system is determined by the coordinates r and θ. Elements of power [1] in this coordinate system are shown in Figure 1.

Development of mining properties, in this case the wells, there is a disturbance of the primary stress state, the stress concentration and its redistribution in the rockmass. This new situation is called a secondary stress state. Creating drill hole, which, at a certain depth in the plane perpendicular to the axis of the borehole, located in two dimensional stress state. Well dimension in the direction of the vertical axis is much larger than the cross-sectional dimension, and then the stress state is reduced to the axial symmetric condition.

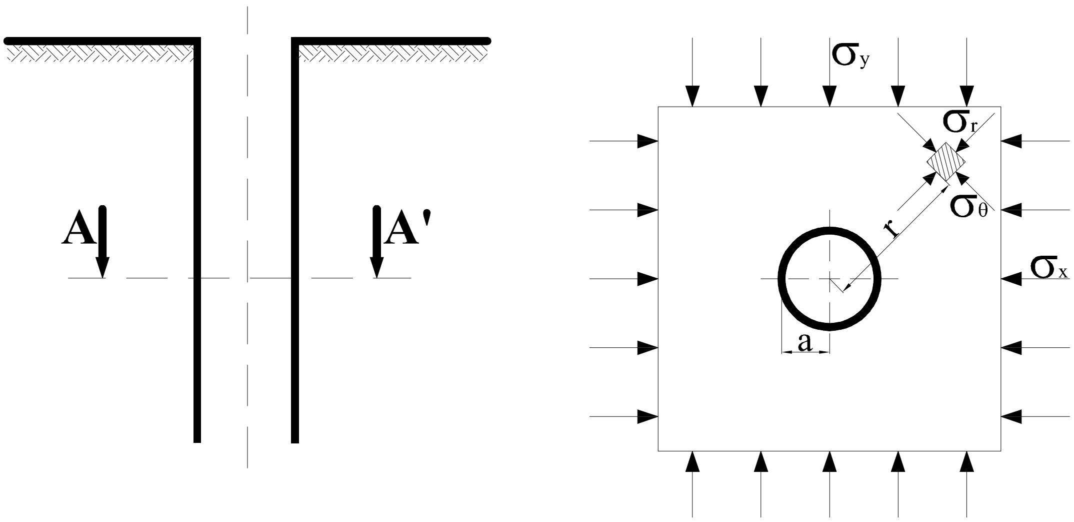

Figure 1. Well with stress components in the plane perpendicular to the axis of the borehole

Stress state of rockmass around of the well is determined equations [2]:

$$\sigma_r = \sigma_x \cdot \left(1 - \frac{a^2}{r^2}\right) \qquad \sigma_\theta = \sigma_x \cdot \left(1 + \frac{a^2}{r^2}\right)$$

where: σ_r – radial stress,
σ_θ – tangential stress,
a – borehole half radius (m),
r – distance from borehole axis (m).

These equations is satisfied that at infinite distance from the borehole secondary stress state [1] is equated with the primary.

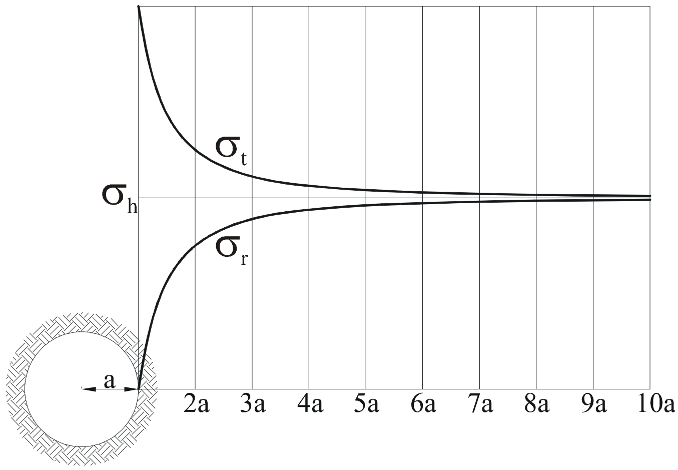

Figure 2. Stress distribution in the plane perpendicular to the axis of the borehole

STRESS AND STABILITY ANALYSIS IN ANNULUS

The modern design and stress analysis of stability in the space between the borehole is usually done stress-deformation methods and the highest use of finite element method analysis. This method is analyzed changes in the stress state in the system for casing-cement stone-formations and on the basis of defined areas where the change of stress and eventually destroy stability. With this approach it is possible to determine the zone in which there is an increase or even stress fracture and thus consider the impact of the proposed system design solutions for casing-cement stone-the formation of stress concentration mainly in the cement stone. That way you can look at all the pros and cons of proposed solutions, and to predict their impact on the further continue drilling or performing certain operations in exploitation.

Model for casing-cement stone-formation system has done according to applied construction of wells in the southeastern part of the Pannonian Basin and all necessary information. Of course, it is not possible to cover all the depths and production layers with well construction that folow them. The model is designed to fully corresponds to the situation and the existing conditions in the well. Its formation Phase^2 software package is divided into [3] two parts:

- graphical representation model and
- determine the properties of the model.

The model was shown in Figure 3, presented one of the structures of production casing applied in wells in the southeast part of the Pannonian Basin.

The model analyzed wells with built-exploitation of the casing string that represent areas with higher temperatures and pressures and has the following characteristics [2]:

- Bit dia: 215.9 mm.
- Total depth: 2800 m.

- Casing: Outside dia 177.8 mm,
  Inside dia 152.9mm,
  GRAD P-110.
- Formation: medium hard and hard.

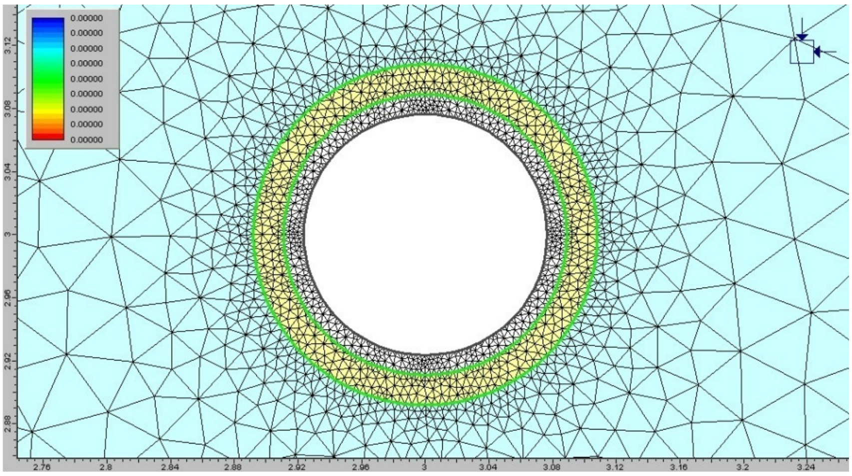

Figure 3. Well model with production casing 177.8 mm P-110 (51.8 kg/m′) up to 2800m

For production casing number of finite elements is 21872 and the number of nodes 11136.

Details can be analyzed: stress state (maximum principal stress $\sigma_1 = \sigma_\theta$, minimum principal stress $\sigma_3 = \sigma_r$), and the direction of deformation.

Model properties and their determination has been divided into two groups:

1. The first group is the determination of the stress field in which the model is analyzed (constant and gravitational), the size of which is determined by the stress, and the determination of the boundary conditions of the model. In this case, adopted a constant stress field with the values of the horizontal component σ_H = 28 MPa and 11 MPa. These values stress fields are adopted, because during the process of cementing production casing cement suppression was carried out with water.

2. In the second group will be determined physical mechanical properties of materials. This program gives the possibility of determining the characteristics of up to 10 different materials. It is necessary to set one of three materials fracture criterion (Mohr-Coulomb, Hoek-Brown, Drucker-Prager) and define the material, depending on available sizes, elastic or plastic. Table 1 gives an overview of material [4] properties, the Mohr-Coulomb's criterion, which were used for these models. All materials are considered as elastic.

Table 1. Mechanical properties of materials used in the model

Materijal	Modul elasticity E (MPa)	Poasson's coefficients μ	Tensile strenght σ_t (MPa)	Angle of internal friction φ (°)	Cohesion c (MPa)
Iron	200000	0.27	880	53.5	138.77
Cement stone: API Class G	9200	0.2	3	42.95	6.05
Cement stone: Spec. cement system (1)	4100	0.2	3	42.95	6.05

Cement stone: Spec. cement system (2)	2600	0.2	3	42.95	6.05
Formation: soft	1580	0.13	2.07	30	10.5
Formation: Medium hard	4550	0.22	2.07	30	10.5
Formation: hard	8960	0.29	2.07	30	10.5

This software allows to simultaneously analyze multiple models, so that we can considerchanging drilling conditions for different geometries of wells and determine the optimalsolution that provides satisfactory stability of connections for casing-cement-stone formations [5]. Table 2 shows the model used for the analysis of stress and deformation of cement stone [6]. For each model in this study for the class G [7] cement stone and Spec. cem. systems [8].

Table 2. Models used for the analysis of stress and strain cement stone

Model		Casing	Cement stone	Formation
I	A	177.8 mm, Grad: P-110 (51.8 kg/m′)	API Class G	Medium hard
	B	177.8 mm, Grad: P-110 (51.8 kg/m′)	Spec. cement sistem (1)	Medium hard
I	A	177.8 mm, Grad: P-110 (51.8 kg/m′)	API Class G	hard
	B	177.8 mm, Grad: P-110 (51.8 kg/m′)	Spec. cement sistem (1)	hard

Changes in drilling conditions [2] are simulated by changing the pressure inside the borehole, from the equilibrium (zero) state after hardening cement stone to the maximum expected pressure for a given system design for casing-cement stone-formation. Analysis of pressure was performed in 5 steps, or 5 per value. The table 3 shows the pressure values for each step as well as the maximum value of pressure within the system.

Table 3. The simulated values of pressure in the test

System: casing-cement stone-formation	I step (MPa)	II step (MPa)	III step (MPa)	IVstep (MPa)	V step (MPa)
177.8 mm, Grad P-110 (51.8 kg/m′) API Class G Medium hard formation	0	5	10	15	20
177.8 mm, Grad: P-110 (51.8 kg/m′) Spec. cement sistem (1) Medium hard formation	0	5	10	15	20
177.8 mm, Grad: P-110 (51.8 kg/m′) API Class G Hard formation	0	5	10	15	20
177.8 mm, Grad: P-110 (51.8 kg/m′) Spec. cement sistem (1) Hard formation	0	5	10	15	20

CONCLUSION

To provide a long life well cement stone must be mechanically and chemically resistant. Cement stone made of API well cement is resistant to aggressive fluids but must be resistant to the stresses during manufacturing or operation of the well, ie. tightness testing of pipes, stimulation operations, temperature changes during the production cycle during well life. It is necessary to analyze the mechanical behavior of hardened cement of different types of cement mixtures under well conditions in order to obtain the optimum composition of the cement mixture. Instead of the strength analysis of cement stone as the main features should be considered a complete mechanical system that consists of protective pipe, cemented and gap formation. Increasing pressure or temperature in the borehole will cause stress transmitted to the cement stone, which must be resistant to cyclic loads.

The wells that will not be subjected to cyclic stresses or changes in drilling conditions must be a model to analyze whether the compressive strength of hardened cement sufficient to withstand radial, tangential stress and strain. If so, the standard types of cement mixtures with adequate compressive strength of cement stone, provide security for preservation stability cemented annulus in the working life of the well.

Model is widely used in cementing the production casing of exploration, gas production and gas storage wells, where during the life of wells, drilling conditions change, analyze the radial, tangential stress and deformations hardened cement in annulus. Their analysis, we are able to perform the appropriately selected cement mixture to protect stability cemented annulus during life of the well.

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