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INTERACTION OF A CIRCULAR CYLINDRICAL LAYER WITH A VISCOUS INCOMPRESSIBLE FLUID

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Abstract:
This is a scientific research which investigated the interaction of a circular cylindrical layer and a shell of great length with flows of liquids and gases. It can be applied to research engineering and industry, mechanical engineering, mining mechanics, oil and gas extraction, aviation and space technology and other branches of science.

Keywords: Mining mechanics, oil and gas extraction, space technology, layer-liquid, shell-liquid, deformation, rotation inertia.

INTRODUCTION:

Circular cylindrical layers and shells of long length (tunnels, pipelines, drill strings) interacting with flows (both external and internal) of liquids and gases are widely used in a number of branches of science, technology and industry, including mechanical engineering, mining mechanics, oil and gas extraction, aviation and space equipment, etc. [1,2].

One of the important problems in the "layer-liquid" and "shell-liquid" systems dynamics is the determination of frequencies and natural vibrations shapes. In many works, such problems have been solved by considering a cylindrical layer or a thick-walled tube as a beam [3] or on the basis of Kirchhoff-Lyav shell theory [4]. In [1], similar problems are solved based on the refined equations that take into account the rotation inertia and transverse shear deformations.

This work is devoted to solving applied problems about the axis symmetric vibrations of a circular cylindrical elastic layer interacting with viscous incompressible and ideal compressible fluids based on the equations of vibration obtained in chapter 2.

Restricting ourselves to the zero approximation (n=0) in the general equations of torsional vibrations of a cylindrical layer containing a viscous incompressible fluid, we obtain

$$\begin{gathered}\frac{r_2^2}{2}\lambda_2 U_{\theta,0}+r_1\left[\frac{1}{2}\left(\lambda_2-\frac{4}{r_2^2}\right)+\frac{r_2^2}{8}\left(\ln\frac{r_2}{r_1}-\frac{1}{4}\right)\lambda_2^2\right]U_{\theta,1}=\frac{1}{\mu}f_{r\theta}(z,t);\\ \frac{r_2^2}{2}\lambda_2 U_{\theta,0}+\frac{r_1^2}{4}\frac{\mu'}{v'\mu}\frac{\partial^2 U_{\theta,0}}{\partial t^2}+\left(\frac{2}{r_1}+\frac{r_1}{2}\lambda_2-\frac{r_1^3}{32}\lambda_2^2\right)U_{\theta,1}+\frac{r_1}{4}\frac{\mu'}{v\mu}\frac{\partial^2 U_{\theta,1}}{\partial t^2}=0,\end{gathered}\qquad(1)$$

where $\lambda_2^n=\left[\frac{1}{b^2}\left(\frac{\partial^2}{\partial t^2}\right)-\left(\frac{\partial^2}{\partial z^2}\right)\right]^n,\quad n=0,1,2,...;\; b=\sqrt{\frac{\mu}{\rho}}.$

METHODS AND MATERIALS.

When solving problems about free vibrations of the layer surface free from external loads, so the function $f_{r\theta}(z,t)$ in the right part of the first equation of the system (1) will be considered equal to zero. The influence of the viscous incompressible fluid contained in the layer is taken into account by the second and fourth terms of the second equation of system (1). In the system (1) we put $f_{r\theta}(z,t)=0$ and pass to dimensionless variables by

$$U_{\theta,0}=U^*_{\theta,0};\quad U_{\theta,1}=r_1U^*_{\theta,1};\quad r=r_1r^*;\quad t=\frac{r_1}{b}t^*;\quad z=r_1z^*;\quad r_2=r_1r_2{}^*;\quad r_1{}^*=1\qquad(1^*)$$

formulas and for convenience of writing we omit "asterisks" above the notations hereafter. We get

$$\frac{r_2^2}{2}\left(\frac{\partial^2}{\partial t^2}-\frac{\partial^2}{\partial z^2}\right)U_{\theta,0}+\frac{1}{2}\left[\left(\frac{\partial^2}{\partial t^2}-\frac{\partial^2}{\partial z^2}-\frac{4}{r_2^2}\right)+\frac{r_2^2}{4}\right]+\left[\frac{r_2^2}{8}\left(\ln\frac{r_2}{r_1}-\frac{1}{4}\right)\times\left(\frac{\partial^2}{\partial t^2}-\frac{\partial^2}{\partial z^2}\right)^2\right]U_{\theta,1}=0;$$

$$\frac{1}{4}\left(\frac{\partial^2}{\partial t^2}-\frac{\partial^2}{\partial z^2}\right)U_{\theta,0}+\frac{1}{4}\frac{\rho_0}{\rho}\frac{\partial^2 U_{\theta,0}}{\partial t^2}+\left[2+\frac{1}{2}\left(\frac{\partial^2}{\partial t^2}-\frac{\partial^2}{\partial z^2}\right)-\frac{1}{32}\left(\frac{\partial^2}{\partial t^2}-\frac{\partial^2}{\partial z^2}\right)^2\right]U_{\theta,1}+$$

$$+\frac{1}{4}\frac{\rho_0}{\rho}\frac{\partial^2 U_{\theta,0}}{\partial t^2}=0. \qquad (2)$$

Here ρ_0 and ρ are unperturbed liquid densities and the cylindrical layer material; $U_{\theta,0}$, $U_{\theta,1}$ are the main parts of torsional displacement - the layer points. In the zero approximation case, there is the following relation between them

$$U_\theta=U_{\theta,1}+r_1U_{\theta,0},$$

Which after passing to dimensionless variables will be

$$U_\theta=U_{\theta,1}+U_{\theta,0}. \qquad (3)$$

The system (1) solution will be sought in the form

$$U_\theta=\overline{U}_{\theta,0}e^{i(\alpha z+\omega t)}$$

$$U_{\theta,1}=\overline{U}_{\theta,1}e^{i(\alpha z+\omega t)}. \qquad (4)$$

The dimensionless frequency ω and the wave number α are entered by the formulas $\omega^*=\frac{b}{r_1}\omega;$; $\alpha^*=r_1\alpha$, b is the propagation velocity of transverse waves in the layer.

Let us introduce the following notations

$$u=\frac{1}{4}\frac{\rho_0^{'}}{\rho};\quad b_1=\frac{1}{16}\alpha^2-\frac{1}{2}-u;\quad b_2=2+\frac{1}{2}\alpha^2-\frac{1}{32}\alpha^4;\quad b_3=-\frac{1}{4}-u;$$

$$b_4=\frac{r_2^2}{2}\left(\ln r_2-\frac{1}{4}\right);\quad b_5=-1-\frac{r_2^2}{2}\left(\ln r_2-\frac{1}{4}\right)\alpha^2;\quad b_6=\alpha^2-\frac{4}{r_2^2}+\frac{r_2^2}{4}\left(\ln r_2-\frac{1}{4}\right)\alpha^4. \qquad (5)$$

In notation (5), the value U is a coefficient in the terms of the equation that take into account the effect of viscous fluid on the torsion vibrations of the cylindrical elastic layer. Substituting (5) into equation (1) we will have

$$\left[\frac{r_2^2}{64}-b_3b_4\right]\omega^6+\left[-\frac{1}{64}\alpha^2r_2^2-b_1\frac{r_2^2}{2}-\frac{1}{4}\alpha^2b_4-b_3b_5\right]\omega^4+$$

$$+\left[b_1\frac{r_2^2}{2}\alpha^2-b_3\frac{r_2^2}{2}-\frac{1}{4}\alpha^2b_5-b_3b_6\right]\omega^2+\left[\frac{b_2}{2}\alpha^2r_2^2+\frac{1}{4}\alpha^2b_6\right]=0. \qquad (6)$$

Let us introduce further notations according to formulas

$$a_6 = \frac{r_2^2}{64} - b_3 b_4; \quad a_4 = -\frac{1}{64}\alpha^2 r_2^2 - b_1\frac{r_2^2}{2} - \frac{1}{4}\alpha^2 b_4 - b_3 b_5;$$
$$a_2 = b_1\frac{r_2^2}{2}\alpha^2 - b_3\frac{r_2^2}{2} - \frac{1}{4}\alpha^2 b_5 - b_3 b_6; \quad a_0 = \frac{b_2}{2}\alpha^2 r_2^2 + \frac{1}{4}\alpha^2 b,$$

Taking into account which the frequency equation (6) can be rewritten in the form convenient for numerical realization of

$$a_6\omega^6 + a_4\omega^4 + a_2\omega^2 + a_0 = 0. \qquad (7)$$

RESULTS:

To solve this equation, the Gorner scheme was applied, a program in Pascal was compiled and implemented on a personal computer (appendix).

For the numerical research of the problem, rocks were used as the layer material for the effect of viscous fluid on the torsion vibrations of a cylindrical elastic layer.

Figs. 1 and 2 show the same dependences for sandstones 1, 2. From the graphs it is clear that the vibrations frequency of P.1 is always greater than the vibrations frequency of P.2, which in turn is much greater than the vibrations frequency of P.3, both in the absence (u=0, Figure 2), and in the presence (u =1, Figure 1) of liquid inside the cavity layer. It is possible to make infinitely high order differential equations concerning the principal parts of the torsion displacement of the intermediate surface points of a cylindrical elastic layer with a viscous incompressible fluid.

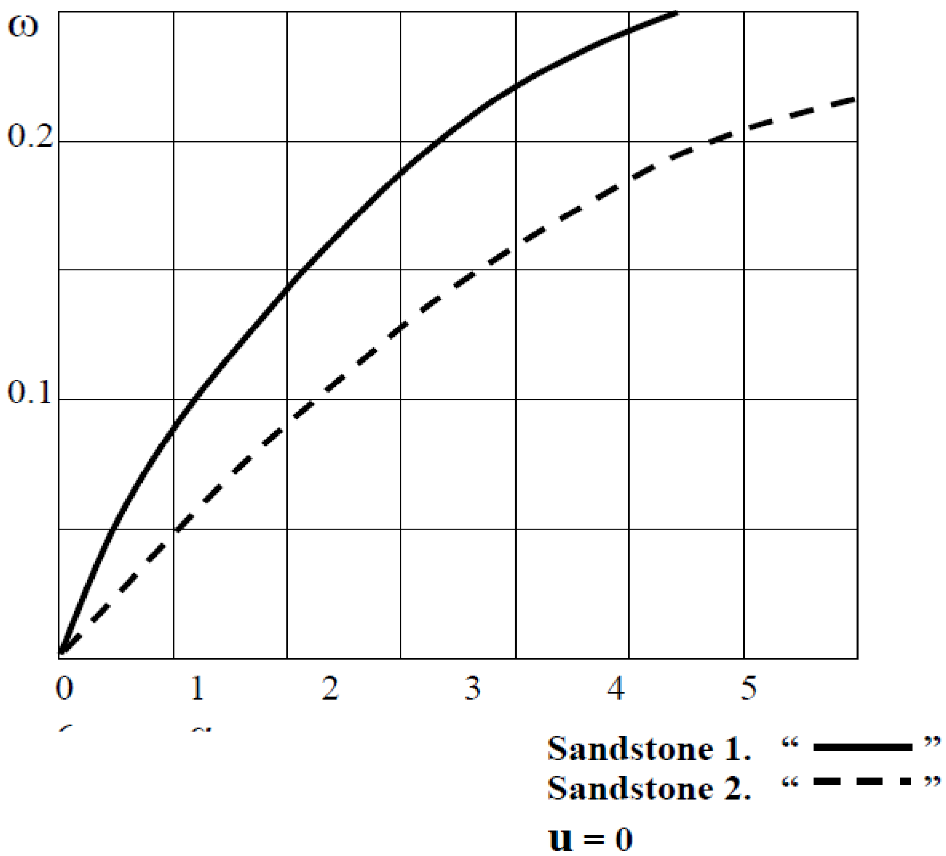

Fig. 1. Dependences of the first frequencies on the wave number in the absence of liquid (u = 0)

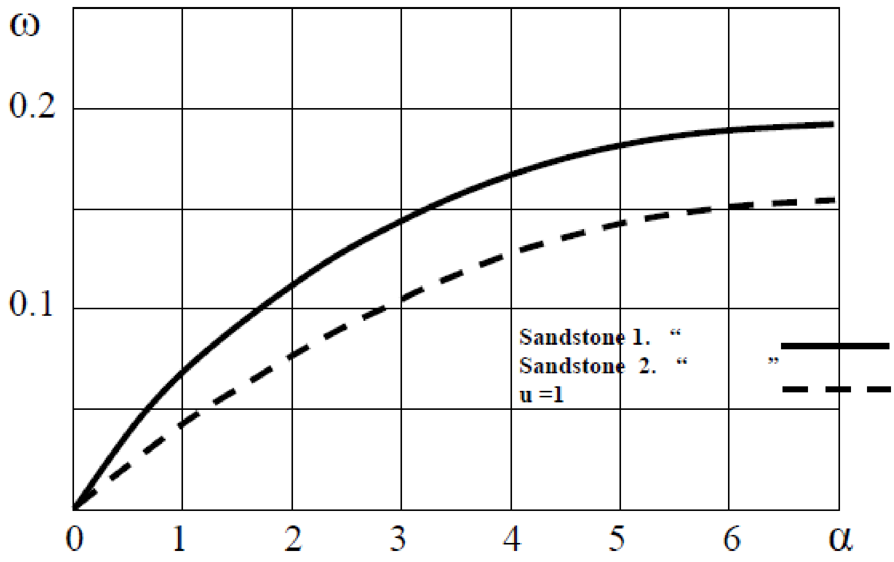

Fig. 2. Dependencies of the first frequencies on the wave number with liquid (u=1)

Figures 1 and 2 show the same dependencies for silstone 1, 2. The graphs show that the oscillation frequency of p.1 is always greater than the oscillation frequency frequency of p. 2, which in turn is much greater than the oscillations of p. 3, both in the absence (u=0, Fig. 2) , and in the presence (u=1, Fig. 1) of fluid inside the layer cavity.We can conclude that as the Poisson's ratio value and rock density increase, its oscillation frequency decreases.

CONCLUSION:

In this research obtained in earlier papers imposed on the oscillations frequency and the wave number of propagating waves being limited to zero (u=0), the first (u=1) and other approximations, one can obtain the oscillations equations suitable for solving engineering problems.

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