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MECHANICS

Matching Growth Mechanisms of Irreversible Deformation of a Hollow Sphere under Uniform Compression

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Abstract—It is proposed to divide the process of accumulation of irreversible deformations by a deformable solid into successive parts differing in the mechanisms of production of such deformations. With the growth of stresses in the solid due to mechanical action on it, initially irreversible deformations are produced due to the viscous properties of the material of the deformed solid as a creep deformation, and, when the stressed states emerge onto the loading surface, the mechanism of their production changes to plastic. Under unloading, the sequence reverses from a rapid plastic to a slow viscous mechanism. The continuity in such a growth of irreversible deformations is provided by the corresponding set of creep and plasticity potentials. The features of this approach are illustrated by the solution of the boundary-value problem of elastoplastic deformation on the compression of the spherical layer by an external uniform pressure, when the viscous properties of the material are specified using the Norton creep power law and the properties of the ideal plastic—by the plastic potential in the form of the Mises plasticity condition.

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On the basis of the relationship between the model of large elastoplastic deformations [1, 2], it is proposed in [3] to divide the irreversible deformations acquired by the solid into deformations of creep and plastic flow by the mechanism of their production. Then the equation of variation of irreversible deformations is proved to be common for the deformations of creep and plasticity. The source of irreversible deformations is set in it differently. In the first case, it is the rates of creep strains during the deformation, which precedes the plastic flow or, during unloading in the second case, the rates of plastic deformations under the conditions of matching the stress states of the loading surface. The elastoplastic boundaries prove to be surfaces where the mechanism of accumulation of irreversible deformations changes from viscous (creep) to plastic and vice versa. The laws of creep and plastic flow should be coordinated in such a way that continuous growth of irreversible deformations was implemented on such surfaces, which is achieved by an appropriate choice of the conditions of plasticity and creep laws. In [4, 5] by the example of solving the boundary-value problems in the theory of large deformations, different approaches are indicated for this consistent choice using the generalization of the Tresca–Saint-Venant plasticity conditions for the case of viscous resistance to plastic flow. Here, we show such a match in the Norton creep law [6] and the Mises condition for ideal plasticity [7] by the example of solving the deformation problem under uniform compression of a hollow sphere providing both active loading and unloading including the possibility of repeated plastic flow.

1. We consider the one-dimensional problem of the loading and unloading of a spherical viscoelastoplastic layer bounded by the surfaces $r = r_0$ and $r = R$ ($r_0 < R$) loaded by the pressure on its outer surface:

$$\sigma_{rr}(R) = -p(t), \quad \sigma_{rr}(r_0) = 0. \tag{1}$$

In relations (1), $p(t)$ is a set function and σ_{rr} is the radial component of the stress tensor in the spherical coordinate system r, θ, φ. For the components $u = u_r$ of the displacement vector, the tensors of the small complete d_{ij}, reversible e_{ij}, irreversible p_{ij} deformations, and the stresses σ_{ij}, we have

$$d_{rr} = e_{rr} + p_{rr} = \frac{\partial u}{\partial r}, \quad d_{\theta\theta} = d_{\varphi\varphi} = e_{\varphi\varphi} + p_{\varphi\varphi} = \frac{u}{r},$$
$$\sigma_{rr} = (\lambda + 2\mu)e_{rr} + 2\lambda e_{\varphi\varphi}, \tag{2}$$
$$\sigma_{\theta\theta} = \sigma_{\varphi\varphi} = \lambda e_{rr} + 2(\lambda + \mu)e_{\varphi\varphi}.$$

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