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Additive manufacturing of a cylindrical arch of viscoelastic aging material under gravity action at various modes of the process

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Abstract

The engineering problem of successive construction of a heavy circular vault (a cylindrical arch) on a smooth rigid horizontal base is studied. The constructed vault manifests properties of creep and aging. The construction goes by layer-by-layer buildup of a prefabricated residual stress-free vaulted preform originally installed on the base. A buildup process in which a large number of thin layers of additional material are successively attached to the interior cylindrical surface of the arch is considered. The process is modeled as a continuous accretion process, that is, an infinitely thin material layer is added to the solid on every infinitesimal time interval. The added material is assumed not to be prestressed. The sliding mounting of the vault to the base is assumed. The case of plane strain of the vault is examined. The initial-boundary value problems describing deformation process of the structure in question before, during and after its accretion within the framework of the linear theory of viscoelasticity of accreted solids are stated and solved analytically in series and quadratures. Numerous numeral calculations for different time modes of the viscoelastic vault constructing process are performed. The influence of the temporal characteristics of the process on obtained stress state of the constructed vault is investigated. Some practically relevant phenomena are discovered. Requirement of taking into account the gravity forces in the course of the whole constructing process but not only in the terminal structure configuration is shown convincingly.

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Keywords: additive manufacturing; accretion; constructing; building; raising; vault; arch; structure; gravity; viscoelasticity; aging material; time mode; temporal characteristic; deformation process; stress state; technological stresses; structural analysis

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1. Introduction

The vast majority of large structures do not appear instantly on the place of their location. They are built there gradually, element by element that is during an accretion process. It is easily seen that the stress-strain state of such structures under gravity action can not be determined only by their final form. Indeed, the weight of every newly added material element exerts additional mechanical influence on the present part of the structure being formed and thus excites its additional strain in compliance with the current stiffness of the structure. That means that the stress-strain state of an accreted structure is formed incrementally. As a result the final state of the completely built structure essentially differs in general case from the state this structure would have if it were exposed to gravity action only on completing. As in the last case the structure would deform as a comprehensive whole.

Thus to determine the stress-strain state of a structure being built under gravity action this action is necessary to take into account during the whole building process. The analysis of accreted bodies deformation, that is of bodies gradually formed due to surface inflow of additional material, lets us make the fundamental conclusion that mentioned accounting can not be correctly implemented in the frameworks of classical solid mechanics, even if we consider the traditional equations and boundary conditions in a time-varying region. It is necessary to use special approaches and methods based on growing solids mechanics concepts.

Remark that if the structural material used possesses rheological properties (e.g. elastic aftereffect or creep) than both any actual and the final state of the built structure should considerably depend on the building time mode. During a building process of a structure of such a kind there are two tendencies that are continuously interacting. The first one is the tendency of permanent loading the structure with weight of additional elements and the second one is the stress rearrangement in elements so far added due to strain procrastination under changing structure geometry. The type and the result of this interaction are determined by various particular factors that can be analyzed only by solving the corresponding accretion problem.

One can inquire about some solved problems in accreted solids mechanics in [1–5].

Nomenclature

t	time
$\mathbf{r}$	radius-vector of a point in the body
$\mathbf{j}$	upward-directed unit normal vector to the horizontal rigid base
f	specific weight of the material used for the arch manufacturing (gravity force intensity)
L_s and N_s	Volterra integral operators over time with a real parameter s
I	identity operator
$K(t,\tau)$	creep kernel
$R(t,\tau)$	relaxation kernel
$\Delta(t,\tau)$	specific strain function ($t \geq \tau \geq 0$, see Fig. 1, 2)
$\omega(t,\tau)$	creep measure in pure shear ($t \geq \tau \geq 0$, see Fig. 1, 2)
$G(t)$	variable elastic shear modulus (see Fig. 1, 2)
ν	constant Poisson ratio both by elasticity and creep
t_0	time instant of installation of the initial piece (vaulted preform) on the base
t_1	time instant of the accretion process start
t_{2k-1} and t_{2k}	time instants of onset and termination respectively of the k^{th} stage of continuous accretion
$a(t)$	manufactured arch internal radius, variable (decreasing) due to attaching additional material (see Fig. 3)
$a_0 = a(t_0)$	initial value of the arch internal radius, i.e. the initial piece (preform) initial radius (see Fig. 3)
$a_k = a(t_{2k})$	internal radius value on completing the k^{th} stage of continuous accretion
N	total number of stages of continuous accretion in the course of arch manufacturing
b	constant external radius of the manufactured arch (see Fig. 3)
ρ	polar radius of an arbitrary point of the body counted from the arch longitudinal axis (see Fig. 3)
φ	polar angle of an arbitrary point of the body counted in arch cross-section upwards from the base (see Fig. 3)