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Generalized force method on the example of plane geometrically nonlinear problem

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Abstract

Based on the analytical expression for stiffness of the cross section, together with the developed force method, developed the numerical algorithm and computation program in MathCad to determine the elasto-plastic deformation. The calculation of the plane rod systems subject to large displacements is implemented. A comparison of the received results with the finite element method using Ansys software is performed.

Keywords: generalized flexibility method; integral function of state law of section; tangent stiffness; elastoplastic deformation, large displacement, Mor’s formula, geometric nonlinearity.

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1. Introduction

In modern engineering practice quite often it is necessary to solve the problems connected with movements, big in comparison with the design sizes. Now it is possible to carry out the nonlinear analysis only using powerful computer programs which are based on application of FEM.

In this work elasto-plastic calculation of rod systems taking into account geometrical nonlinearity is considered by the generalized force method (GFM). The efficiency of use (compulsory health insurance) for the solution of such tasks (in comparison with FEM) consists in sharp increase in high-speed performance and reduction of the used computer resources. In the developed method use of the computing scheme, explicit on time, and definitions on each step tangent rigidity system is supposed.

Unlike the generalized method of forces, at the solution of elasto-plastic tasks on the basis of FEM on each temporary step it is necessary to solve the system of the algebraic equations which number is proportional to number of finite elements. At application of the generalized method of forces the number of preparatory operations increases, however the number of the algebraic equations on each step is equal only to number of indetermination of

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rod system.

For statically definable systems it is possible to consider geometrical nonlinearity when calculating by the generalized method of forces by definition on each step of projections of true length of an element of a rod and the corresponding internal efforts. But for statically indefinable systems, it is previously necessary to solve the system of the equations which number is equal to degree of static indefinability and then to define projections of a curvilinear rod. Further the algorithm of nonlinear calculation will be considered by the generalized method of forces.

Nomenclature

E	modulus of elasticity
E_{pl}	tangent module
M1	bending moment from a single force
ΔM^e	increment of moment for rod
b, h	dimensions of section
σ_s	yield strength
ε_s	yield strain
$\Delta\varepsilon$	increment of strain
$\Delta\sigma$	increment of stress
$\Delta\chi$	increment of curvature
u	displacement
θ	rotation angle
x	X component
Δt	time step
$\{\Delta\bar{P}\}$	vector of outside forces
$\{\bar{\Delta}\}$	vector of displacements
$[\bar{K}]$	stiffness matrix of system
$[L]$	matrix of transformation of coordinates
$\{\Delta P^e\}$	vector of force in nodes
$\{\Delta^e\}$	vector of displacement in nodes
$[K^e]$	stiffness matrix of rod

2. Mathematical model for definition of elasto-plastic deformations taking into account geometrical nonlinearity

For the solution of geometrically nonlinear task the generalized Mor’s formula with a matrix of tangent rigidity of Meleshko V. A., Rutman U. L. (2015) and Meleshko V. A., Rutman U. L. (2017) is considered . This matrix is received as the integral characteristic of an intense and deformable condition of all points of section of a rod.

For flat rod systems in which only the bend is considered determination of tangent rigidity can be significantly simplified. The analytical dependence of bending moment on integral function of a state for rectangular section is received in Kovaleva, N.V., Skvortzov V.R., Rutman Y.L. (2007), for round in Ostrovskaya, N.V. (2015).

If not to consider influence of lateral force, then bending moments are proportional to integral function of a state. Using results of Kovaleva, N.V., Skvortzov V.R., Rutman Y.L. (2007), for rectangular section the formula was received

$$T(\tau)=\begin{cases}\dfrac{\sigma_s bh^3}{4\varepsilon_s}\cdot\dfrac{1}{3},\tau\le 1\\ \dfrac{\sigma_s bh^3}{4\varepsilon_s}\cdot\dfrac{1}{3\tau(x)^3}\cdot\left[1+a\left(\tau(x)^3-1\right)\right],\tau>1\end{cases},a=\frac{E_{pl}}{E}. \tag{1}$$