ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2003
Seria: BUDOWNICTWO z. 101 Nr kol. 1595

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PHYSICAL PARAMETERS' IDENTIFICATION FOR TECHNICAL FABRICS – VISCOELASTIC MODEL

Summary. Practical application of technical fabrics for construction requires the knowledge of their physical properties. The constitutive models of material, particularly viscoelastic models of solid, have the essential use here. Two models have been selected (the linear standard model and its non-linear variation) and their constitutive equations have been written in one-dimensional case. Laboratory tests of uniaxial tension with constant strain rate have been conducted, and the inelastic effect have been observed during them. The least squares method has been chosen for the models' parameters identification and also the fabric model – the dense net model have been chosen for further applications.

IDENTYFIKACJA PARAMETRÓW FIZYCZNYCH TKANIN TECHNICZNYCH – MODEL LEPKOSPRĘŻYSTY

Streszczenie. Praktyczne wykorzystanie tkanin technicznych w konstruowaniu wymaga znajomości ich własności fizycznych. Konstytutywne modele materiału mają tu zasadnicze zastosowanie, a w szczególności modele lepkosprężyste ciała stałego. Spośród wielu znanych modeli wybrano dwa (liniowy model standardowy i jego wariant nieliniowy) i zapisano ich równania konstytutywne w układzie jednowymiarowym. Przeprowadzono badania laboratoryjne jednoosiowego rozciągania ze stałą prędkością odkształcenia, podczas których zaobserwowano efekt niesprężysty. Do identyfikacji parametrów modeli wybrano metodę najmniejszych kwadratów, a jako model samej tkaniny do dalszych zastosowań – model sieci gęstej.

1. Introduction

Technical fabrics have many applications. They are used for construction of civil engineering structures like hanging roofs (Fig. 1), pneumatic stores, sport halls etc, as well as transporting belts or reinforcement of road structures. One of them called "Panama" is the subject of research. For calculation of textile structures special finite element programs, most

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often employing viscoelastic or viscoplastic constitutive models, are applied. They base on the specially developed finite elements, which must include change of the thread family direction, anisotropy of the fabric, influence of coating. In spite of geometric nonlinearity often also change of material properties must be introduced here. Constitutive models incorporate not only change of material properties with respect of time, but also variation of them in the deformation process. The choice of the constitutive model depends strongly on the possibility of the model parameters' identification. Higher number of parameters better expresses the model behavior but leads to rapid increase of identification problems. Therefore sometimes the models with only a few parameters can be the most effective.

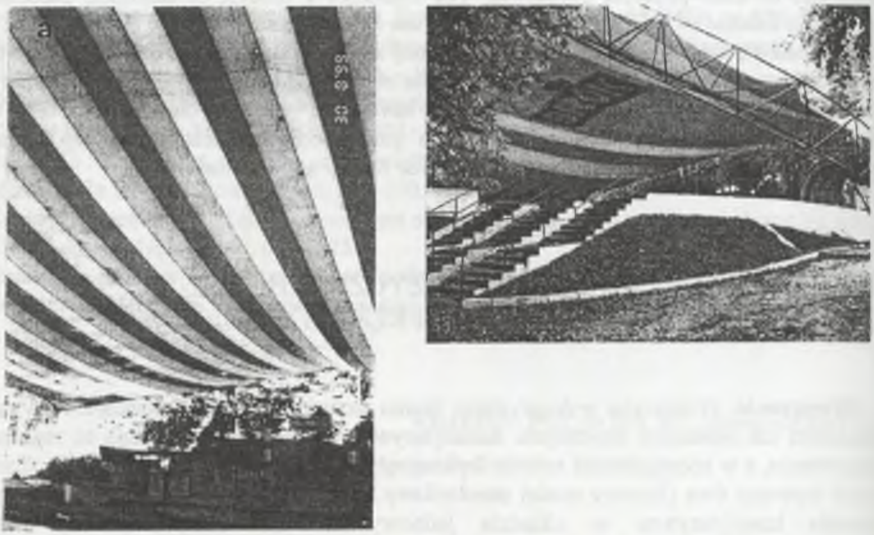

Fig. 1. Exemplary structures where technical fabrics are used: a – Forest Opera in Sopot; b – Open Air Theatre in Połczyn Zdrój made of "Panama" fabric

Rys. 1. Przykładowe konstrukcje, w których zastosowano tkaniny techniczne: a – Opera Leśna w Sopocie; b – Teatr Letni w Połczynie Zdroju wykonany z tkaniny „Panama"

2. Dense net model of technical fabric

The FEM calculations of a structure made from the technical fabric, require the finite element generation of special type. The dense net model developed in [1], [2], and [3], dividing the textile structure into mesh of triangle three-node finite elements is based on correlation between a typical plane stress state element and the substructure consisting of two thread families. In this model the angle between wrap and weft can change during deformation process (Fig. 2).

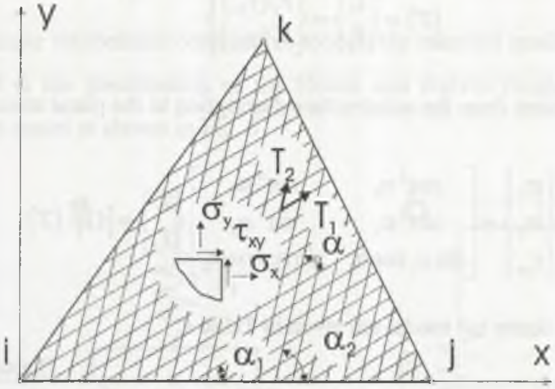

Fig. 2. Dense net finite element
Rys. 2. Element skończony sieci gęstej

The actual angle between thread families can be appointed as a difference of the angles between each thread family and the *x* axis of the local coordinate system according to equations

$$\begin{gathered}\tan(\alpha_1)=\frac{1+\varepsilon_y}{1+\varepsilon_x}\tan\left[\left(\pi-\gamma_{xy}\right)\frac{\alpha_{10}}{\pi}+\frac{\gamma_{xy}}{2}\right]\\ \tan(\alpha_2)=\frac{1+\varepsilon_y}{1+\varepsilon_x}\tan\left[\left(\pi-\gamma_{xy}\right)\frac{\alpha_{20}}{\pi}+\frac{\gamma_{xy}}{2}\right]\\ \alpha=\alpha_2-\alpha_1\end{gathered}\tag{1}$$

where:

$\alpha_{10,}\ \alpha_{20}$ - initial values of threads' angles with *x* axis.

The fibre strains of warp and weft can be calculated from the strains of the plain stress state

$$\{\gamma\}=\begin{Bmatrix}\gamma_{11}\\ \gamma_{22}\end{Bmatrix}=\begin{bmatrix}\cos^2\alpha_1 & \sin^2\alpha_1 & \sin\alpha_1\cos\alpha_1\\ \cos^2\alpha_2 & \sin^2\alpha_2 & \sin\alpha_2\cos\alpha_2\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\end{Bmatrix}=[\Omega]\{\varepsilon\}\tag{2}$$

The value of the thread forces depends on the constitutive model used in the calculation. Generally, the most often linear or nonlinear rheological models, independent for each fibre family, are applied here. Therefore, despite anisotropy of the fabric, the relation for thread forces can be isotropic as follows:

$$\{T\}=\begin{Bmatrix}T_1\\T_2\end{Bmatrix}=\begin{Bmatrix}F_1(\gamma_{11})\\F_2(\gamma_{22})\end{Bmatrix} \tag{3}$$

Using equation (3) we return from the substructure description to the plane stress state

$$\{\sigma\}=\begin{Bmatrix}\sigma_x\\\sigma_y\\\tau_{xy}\end{Bmatrix}=\begin{bmatrix}\cos^2\alpha_1 & \cos^2\alpha_2\\ \sin^2\alpha_1 & \sin^2\alpha_2\\ \sin\alpha_1\cos\alpha_1 & \sin\alpha_2\cos\alpha_2\end{bmatrix}\begin{Bmatrix}T_1\\T_2\end{Bmatrix}=[\Omega]^T\{T\} \tag{4}$$

The main features of the dense net model are given in Table 1.

Table 1

Feature of the fabric	Dense Net Model
Plane stress state in the fabric	Introduces
Uniaxial stress in threads	Introduces
Shear stresses	Introduces
Anisotropy of the fabric	Introduces
Isotropy of threads	Introduces
Different properties of warp and weft	Introduces
Tension stresses only	Introduces
Change of angle between threads families	Introduces
Influence of coating	Not introduces
Correlation of threads families' forces (friction effect)	Not introduces
Change of fabric thickness	Not introduces

3. Viscoelastic constitutive relations

The viscoelastic constitutive equations are most often used for descriptions of the rheological properties of the textile materials. The second promising possibility is application of viscoplastic equations [4], [5]. The main aim of the research is the parameters identification for selected viscoelastic models and the comparison of their properties. Due to lack of available publications on similar investigation, among the number of linear and nonlinear models of solid materials, initially only the simplest viscoelastic models have been selected.

3.1. Linear constitutive equations (Zerner model)

From the linear viscoelastic constitutive models the standard model (Zerner model) is used most often. It is the combination of the Hooke and Kelvin-Voight models of solids. The scheme of this model is shown in Fig. 3.

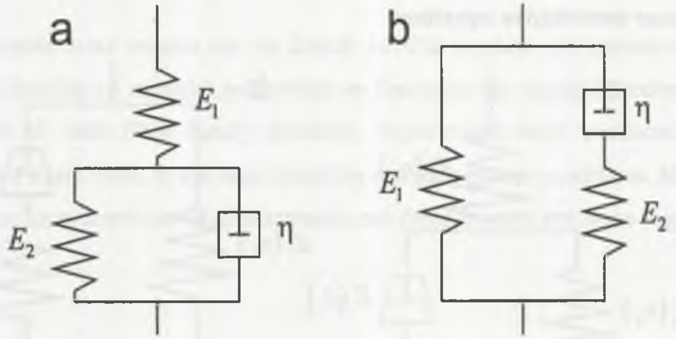

Fig. 3. Two variants of linear standard model
Rys. 3. Dwa warianty standardowego modelu liniowego

It is based on the assumption of additivity of elastic and inelastic strain rates

$$\dot{\varepsilon} = \dot{\varepsilon}_E + \dot{\varepsilon}_I \tag{5}$$

where:

$\dot{\varepsilon}$ - the total strain rate
$\dot{\varepsilon}_E, \dot{\varepsilon}_I$ - elastic and inelastic strain rates

In the uniaxial stress state, which is suitable for the parameters' identification, the linear constitutive relation for the stress components can be written (variant I – Fig. 3a)

$$\sigma + \frac{\eta}{E_1 + E_2}\dot{\sigma} = \frac{E_1 E_2}{E_1 + E_2}\varepsilon + \frac{\eta E_1}{E_1 + E_2}\dot{\varepsilon} \tag{6}$$

where:

E_1, E_2, η - two elastic and viscosity parameters adequately

For the variant II (Fig. 3b) the corresponding equation is

$$\dot{\sigma} + \frac{E_2}{\eta}\sigma = (E_1 + E_2)\dot{\varepsilon} + \frac{E_1 E_2}{\eta}\varepsilon \tag{7}$$

This simple model demands only three parameters to be identified, but its main disadvantage is lack of nonlinear effects. Thus some more complex strain-stress relation can be described improperly by this model. Therefore the standard model can be developed into more complex the four parameters', Bürgers or generalized models [6].

3.2. Non-linear constitutive equations

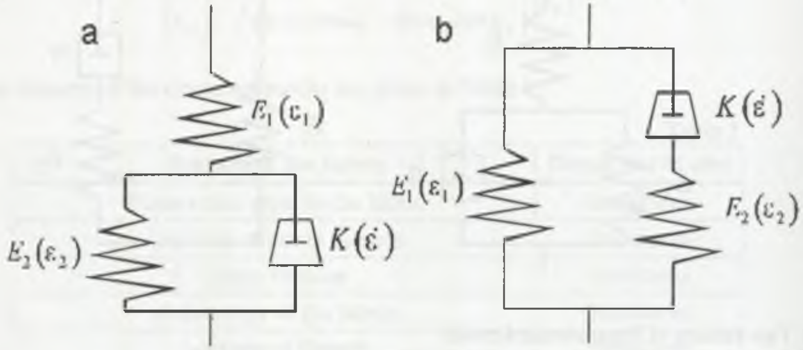

Fig. 4. Nonlinear viscoelastic model based on the standard model
Rys. 4. Nieliniowy model lepkosprężysty oparty na modelu liniowym

Figure 4 shows the simplest non-linear viscoelastic model, which arises when non-linear relation between the elastic strain $\dot{\varepsilon}_E$ and stress σ in the standard model is considered [7].

$$\varepsilon_E = f(\sigma) \tag{8}$$

The non-linear function for inelastic strain rate can be also assumed as follows:

$$\dot{\varepsilon}_I = K\left(\sigma - E(\varepsilon_E)\right) \tag{9}$$

where:

$E(\varepsilon_E)$ - the inverse function of $f(\sigma)$

Finally uniaxial constitutive equations for both types of model presented in Fig. 4 are

$$\dot{\sigma} = \dot{\varepsilon}\,\Phi_1(\sigma) + \Phi_2(\sigma,\varepsilon) \tag{10}$$

where:

Φ_1 and Φ_2 - nonlinear model functions which must be identified

Nonlinear viscoelastic constitutive relations were given also by Rabotnov, Leaderman, Schapery or Volterra-Frechet and others, but they all are described with complex equations, which demand simplifying, since they become not convenient for practical application.

4. Experiments

The experiments were carried out on Zwick 147670 machine for tension-compression tests. For identification of models' parameters or functions the uniaxial tension tests have been performed in each fibre family direction. Experiments were conducted with five different constant strain rates, in the same humidity and temperature conditions. Necessary for the identification time functions of displacement and force in each test were registered by a computer.

5. Identification

The procedure of identification based on the Marquardt-Levenberg variant of the least squares method is applied for identification. This method is very often used for numerical calculations. Succession of parameter identification is as follows. First is to identify elastic and inelastic parameters of the material, then viscoelastic parameters for the chosen constitutive model are to be found. After the identification the validation and results verification by numerical simulation of the laboratory tests will be carried out. Further research for the identification methods can be carried out if the results from the least square method are not successful enough.

6. Conclusion

In the current stay of the research the experiments and selection of the constitutive models are already made. Now, the identification procedure is developed in details. The results will be presented during the Conference.

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Recenzent: Prof. dr hab. inż. Adam Bolt

Omówienie

Praktyczne wykorzystanie tkanin technicznych w konstruowaniu wymaga znajomości ich własności fizycznych. Konstytutywne modele materiału mają tu zasadnicze zastosowanie, a w szczególności modele lepkosprężyste ciała stałego. Spośród wielu znanych modeli wybrano dwa (liniowy model standardowy i jego wariant nieliniowy) i zapisano ich równania konstytutywne w układzie jednowymiarowym. Przeprowadzono badania laboratoryjne jednoosiowego rozciągania ze stałą prędkością odkształcenia, podczas których zaobserwowano efekt niesprężysty. Do identyfikacji parametrów modeli wybrano metodę najmniejszych kwadratów, a jako model samej tkaniny do dalszych zastosowań – model sieci gęstej.