DYNAMIC RESPONSE OF VISCOPLASTIC THIN-WALLED GRIDERS IN TORSION

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This work deals with analysis of isotropic or orthotropic girders subjected to transient dynamic loads. Numerical calculations were performed with the finite element method using ANSYS® software. The results of computation were presented as maximum angle of rotation of the girder in a function of the dynamic load factor, DLF (the ratio of pulse loading amplitude to static critical load). In study it has been taken into account apart from the elastic-plastic range of material with isotropic hardening as well as the strain rate effect described by Perzyna model.

1. INTRODUCTION

The structural stability problem has been investigated for over a century and is now very extended. On the other hand, dynamic impulse loading of thin-walled members with flat walls has been discussed only recently – mainly for dynamic buckling of thin-walled members or plates subjected to compressive or shear pulse loads [1, 3, 4, 5, 6, 7, 10, 11, 15]. These papers describe the phenomenon of dynamic buckling and the part of them shows some criteria for the assessment of the dynamic stability of structural plate structures. Mania in his works [8, 12, 13] extended the analysis of dynamic buckling of girders taking into account strain rate effect according to Perzyna model and Stoffel [18] assumed the application of different constitutive laws in the studies of the circular plate high strain rate response. However, in the case of torsional loading, only a few publications concern dynamic loads, even though some papers discuss static loads and analysis of girders [8].

The stability of thin-walled plate structures subjected to static torsion has been studied both theoretically and empirically. Some papers exploring dynamic stability under the influence of a dynamic torsional torque are devoted to thin-walled cylindrical shells [14, 19, 20, 21], but there are no works dealing with thin-walled girders. Actually, this field of interest is still developed because the criteria of dynamic stability in torsion weren't established.

In this paper, the author studies a behavior of a structure under pulse loading in torsion whose duration equals the fundamental natural vibration period of the given structure. Numerical calculations were conducted to obtain the dynamic response of such structures under rectangular pulse loading. For computations it was assumed the plate structure with rectangular cross-section considering the materials in a elastic-plastic range and strain rate effect. The simulation has been carried out in Ansys code using finite element method.

2. GIRDERS SHAPE AND APPLIED MATERIAL

For purpose of assessment of influence of plate structure response it was focused on only one shape of column. Namely, the study concerns a rectangular girders composed of plates of the diagonal 2*R* and the thickness of wall equals to 1 [mm] or 0.5 [mm] (Fig. 1). The material properties for elastic range used in the calculations are shown in Table 1.

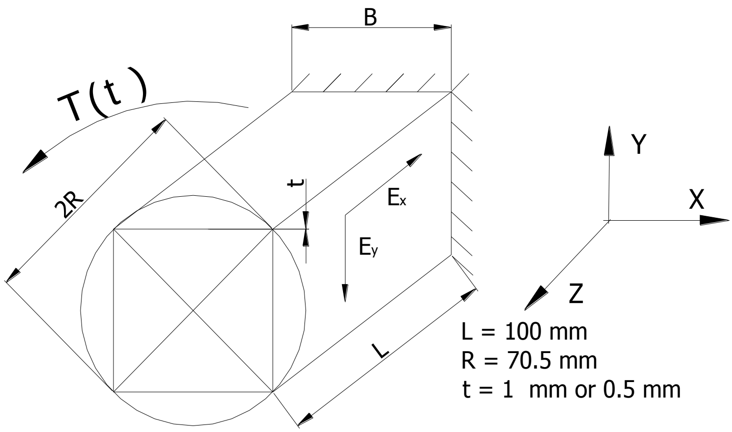

Fig. 1. The dimensions of the columns and direction of the moduli

In the further part of work it assumed isotropic material with bilinear curves for a different yield stress and for different tangential modulus in elasto-plastic range given on diagrams. For purpose of simulation with viscoplastic material it was considered the Perzyna model [16, 17] simply described through eq. 1, where $\dot{\varepsilon}^{p}$ is the strain rate, m and γ^{*} mean the constants, σ_o a static yield stress. For the ductile steel, Jones [6] suggests $m = 0.2$ and $\gamma^{*} = 40.4$ and such values have been taken into account in this work.

Table 1. Materials property for an elastic range

Material	E_x [GPa]	E_y [GPa]	ν_{yx} [–]	G [GPa]	ρ[kg/m^3]
mat_1	200	200	0.3	80	7800
mat_2_1	29.523	97.423	0.3	11.818	2000
mat_2_2	97.423	29.523	0.09	11.818	2000

$$\sigma = \sigma_o \left[1 + \left(\frac{\dot{\varepsilon}^{p}}{\gamma^{*}} \right)^{m} \right] \qquad (1)$$

3. NUMERICAL SIMULATION

Discrete models of the considered girders are presented in Fig. 2b, which show the element mesh and boundary conditions. Along the edges of one end of the girder, zero values of displacement along all directions were adopted (restraint), while at nodes situated at the opposite end of the girder, a load corresponding to the torsional moment was applied, which was implemented by uniform distribution of the forces applied at the nodes along the free edges within a cylindrical coordinates system adopted for these nodes. To ensure that the edges of the girder are straight, a transverse plate was mounted to the model in the plane in which the load was applied, which was several times thicker than the other girder walls. The pulse loading of torque was rectangular with its duration equaling to the fundamental natural vibration period of the given structure. The calculation was conducted for transient analysis with implicit method of the integration equations.

In numerical simulations, it has taken an eight-node element type shell281 with six degrees of freedom at each node (Fig. 2a). This element is well-suited both for linear and particularly for high-rotation or high-strain nonlinear applications.

a) b)

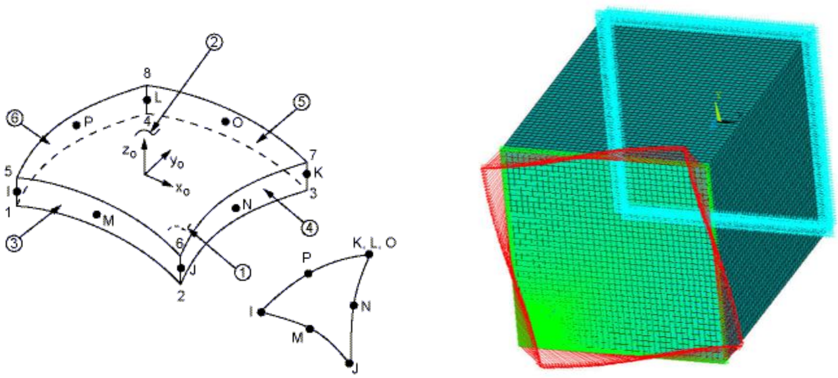

Fig. 2. Drawing of element type shell281 and numerical model with loading and boundary conditions

4. RESULTS OF NUMERICAL SIMULATION

The most of the diagrams presents the relationship between the maximum angles of rotation of the free end of columns obtained in the entire range of the loading as a function of the torque. It seems that this approach of evaluation of dynamic response can be the most reliable. With regard to the lack of criterion of dynamic stability of plate structures in torsion, author assumed that column can endure the maximal value until the angle of rotation suddenly increases.

Figure 3 presents a sample course of the angle of rotation of a girder as a function of time of action of the torsional moment at an overload of 1.5 T_{cr}. The curve of the angle changes depending on the dynamic loading, and for low moments (below 1T_{cr}) the highest angle appeared at 0.2÷0.3 T_p of the time of application, while after increasing the amplitude the maximum value was observed at 0.6÷0.8 T_p.

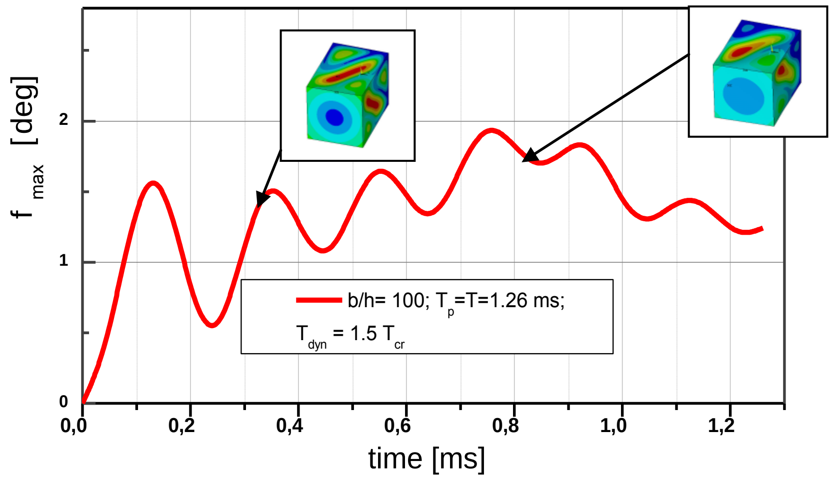

Fig. 3. The course of torsion angle dependent upon the duration of the dynamic torque equaling 1.5 T_{cr}

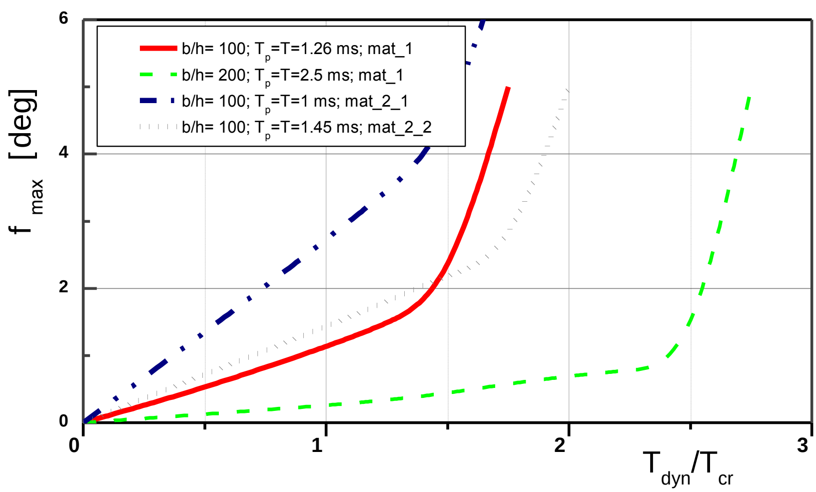

Fig. 4. The courses of maximal torsion angle dependent upon the dynamic torque for isotropic and orthotropic material

In Fig. 4, it was observed that the thinner structures carry the greater dynamic torsional loading with respect to its critical loading (even over two times for the thickness t = 0.5 [mm] and about 1.4 T_{cr} for grider with thickness t = 1 [mm]). For moduli along the x axis that were higher than those along the transverse direction, the structure may bear the greater dynamic loads (a sharp increase in the angle of rotation appears at 1.7 T_{cr}).

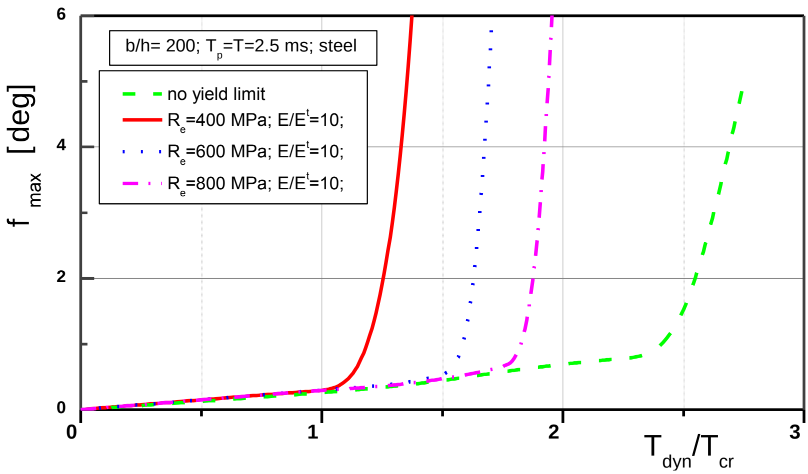

Fig. 5. Course of maximal torsion angle dependent upon the dynamic torque for isotropic material with bilinear characteristic for different yield stress

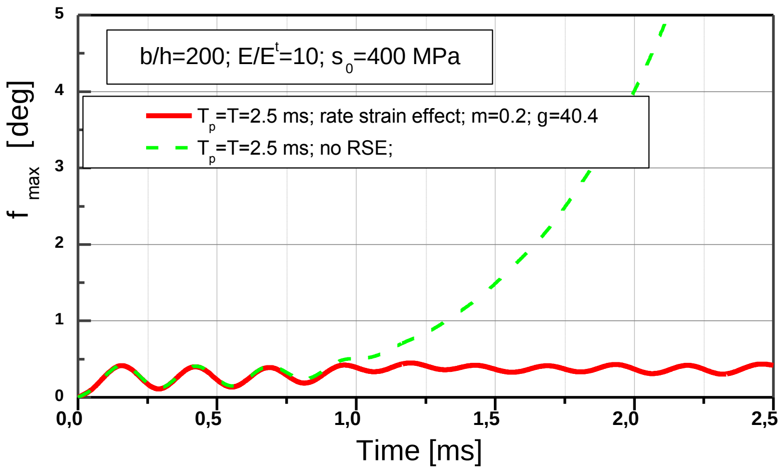

Fig. 6. Comparison of curves of maximal torsion angle dependent upon duration of pulse loading with or without consideration of strain rate effect for T_{dyn}=1.5 T_{cr}

Comparing the isotropic material with the composite in which the modulus E_x is smaller than the modulus E_y, it was noticed that the dynamic torque remain at the same level, even though in the latter case the angle of rotation is twice as high for the same overload. The next diagram (Fig. 5) shows the influence of a initial yield stress on the maximal angle of rotation for column with *b/h*=200 and $E^t / E = 10$, where E^t means tangential modulus in elastic-plastic range for steel. Obviously, for the greater yield stress of material the structures can endure the greater torque. For steel with $R_e = 400 \; MPa$, the rapid growth of angle rotation in the column appeared in 1.2 T_{cr}.

In Fig. 6 and Fig. 7, diagrams show a response difference of column with consideration of the strain rate effect or without. In the first plot it seems that curves are alike till the velocities of strain are small (in the initial stage) but for the further courses diverge [Fig. 6]. Taking into account the viscoplastic material constitutive law (Fig. 8) indicates that structures can bear significantly the greater loading in torsion as well as presented in works [8, 12, 13] under other loads (about 80 [%]).

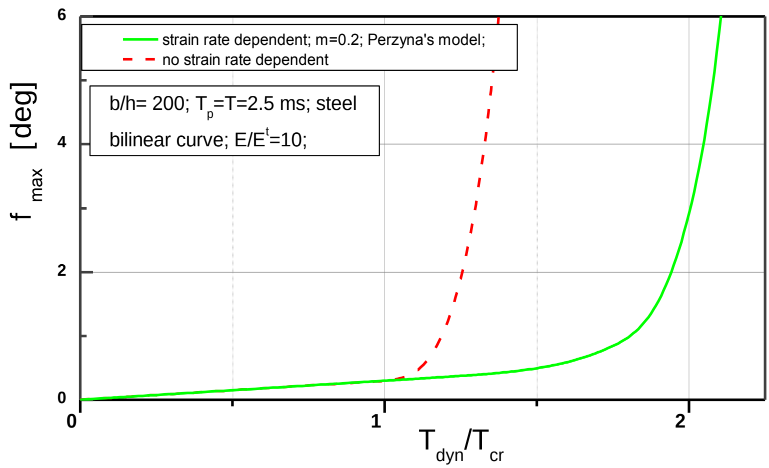

Fig. 7. Comparison of curves of maximal torsion angle with regard to torque with consideration or without consideration of strain rate effect

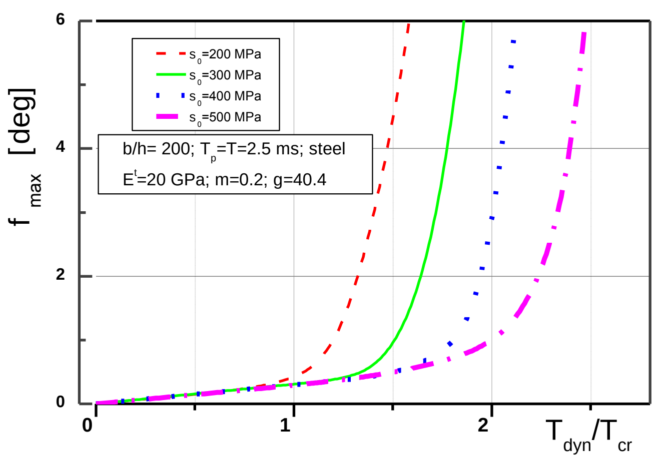

Fig. 8. Curves of maximal torsion angle in the function of torsional pulse loading with consideration of the strain rate effect

Looking at the all diagrams it observes similarity between curves for the girders with consideration of SRE at $R_e = 500$ MPa and curves obtained assuming the only elastic range of material.

5. FINAL REMARKS AND CONCLUSIONS

The paper presents the results of numerical calculations for girders subjected to dynamic torsion. Analysis was conducted through the transient application of loading to a given structure and the determination of its behavior throughout the pulse duration. In the case of torsion, the criteria for dynamic stability evaluation have not been established in the literature, so here it was assumed the ultimate dynamic loading ends till the angle of rotation grows rapidly.

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