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Practical Dynamic Stability Control of Light Structures

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Abstract

Recently in both, the light usual industrial structures and those used in the research of space, the need for slender elements has arised. The problems brought about by these peculiarities, though are not easily and straightforwardly dealt with, could nevertheless be tackled and solvcd in what regards the static and dynamic analyses. The stability analysis is, instead, complicated due to mainly the interactivity of general and local instability associated with large deformations which can not be inferred from the today static, stability and dynamic analyses. In the submitted study, the authors propose both, a theoretical approach to these phenomena and a technical procedure to control them via imposing frequency ratios. From their experience, the authors concluded that using spring end devices or actuator type devices, the above mentioned instability phenomena can be controlled at least under permanent loads, though it is inefficient for temporary loads. The mathematical model is a system of differential equations based on the deformed structural shape and using a moving system of coordinates. The numerical computation is of a step-by-step procedure.

Rezumat

În ultima vreme a apărut nevoia unor elemente structurale zvelte atât în cazul structurilor industriale uşoare obişnuite cât şi în cazul celor folosite pentru cercetarea spaţiului. Deşi problemele ridicate de specificul acestor structuri nu sunt uşor de soluţionat, totuşi ele pot fi abordate şi rezolvate prin studii statice şi dinamice. Analiza la stabilitate introduce complicaţii în primul rând datorită interacţionării instabilităţii generale cu cea locală asociată unor deformaţii mari care nu pot fi deduse prin analizele statice, dinamice şi de stabilitate. În acest articol, autorii propun atât o abordare teoretică a acestor fenomene cât şi o procedură tehnică pentru controlul lor prin intermediul coeficienţilor (rapoartelor) de frecvenţă. Din experienţa lor autorii au ajuns la concluzia că folosind dispozitive de capăt cu arc sau dispozitive de tip actuator, fenomenele de instabilitate menţionate mai sus pot fi controlate, cel puţin în cazul încărcărilor permanente, deşi sunt ineficiente în cazul încărcărilor temporare. Modelul matematic este un sistem de ecuaţii diferenţiale bazate pe forma structurală deformată şi pe utilizarea unui sistem de coordonate mobil. Calculul numeric se efectuează printr-o procedură de tip pas cu pas.

Keywords: Light structures, Stability, Control, Frequency ratios, Spring actuator.

1. Introduction

The tendency in the field of light structures, both ground based and launched in space, is to design

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and build more and more slender structures, which, in its turn, requires the breaking of the classical forms and, in the same time, new malerials with high performances. The loose of stability of these structures involves huge material losses and this fact generated the need of monitoring their behaviour rather than giving up the slenderness. It is well-known that the geometrical imperfections, the incidental vibrations due to the support displacements, to the excentrincities of forces and due to of lateral forces, generate a difference between the theoretical value of the exact critical load and the *on the spot value*. The site measurements and the structure monitoring emphasize that even under small loads there are deformations not contained into the stability hypotheses. The continuous development of these deformations lead to an interactive lost of stability via buckling. In the case of light structures made up of linear elements, the vibrations have, usually large amplitudes which, beside the extra stresses induced into the structure, lead to the instability state. The node displacements have an essential contribution to these phenomena, [1].

The specific parameters emphasized by the long time monitoring of the structural behaviour are: displacements, deformations and the kinematic parameters (speed and acceleration) of the vibrations. The dynamic properties of a structure are greatly dependent on the structural loading and continuosly changing during its life.

Usually, a quick control of the structure or of a part of it, from the dynamic point of view, is performed by [1], [2]:

- Using the cantilever defectometer, which allows the measuring of vibration displacements in a frequency spectrum from 0.0 to 60.0 *Hz*.
- Using an accelerometer to record the accelerations of the vibrations, the procedure being valid for values of accelerations of the $\pm 10^{-5} g$ order.

The long time monitoring of the light structures requieres a perfect coroboration of the methods, equipment, analysis methodology, result interpretation and economic aspects.

Following the rapid progress in the field of electronics and microelectronics, the long time monitoring may be performed using sophisticated equipment for in situ recording.

The improving the structural behaviour from the dynamic stability point of view may be achieved through reducing the amount of induced energy into the structure or through using dampers aiming at a reduced dynamic phenomenon.

2. Passive dampers

The passive dampers do not require an external energy to be introduce into the structure, the optimization of the dynamic response being achieved by variation of the internal properties of the system (3).

Mechanisms of passive type with internal damping due to the material, lumped damping masses, isolators made of rubber or elastomers have been used since 1960'.

In the figure l several damping systems designed by tlie authors for reducing transversal and longitudinal vibrations are presented.

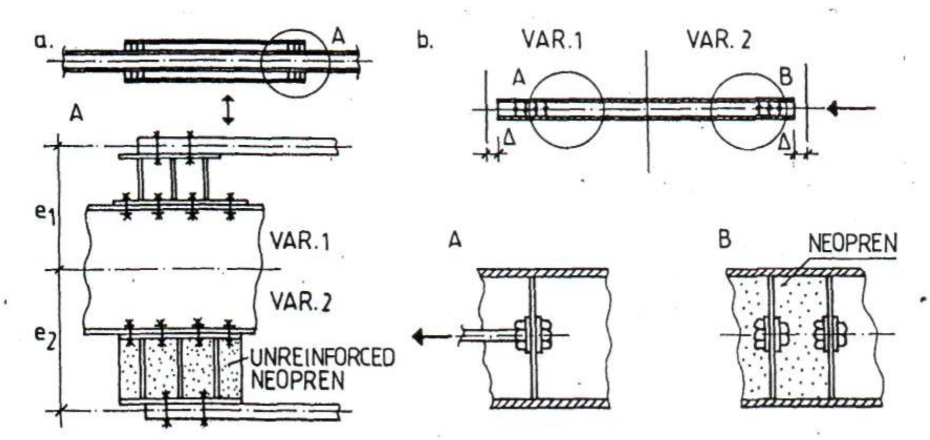

Fig.1. Passive dampers

In figure 2 a new type of passive damper, named *lamella* by the authors, is presented.

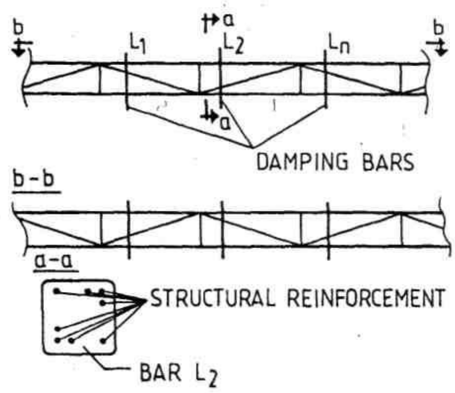

Fig.2. Passive damper in the form of lamella

The bar (lamella) is made up of a viscous material (Fig.3).

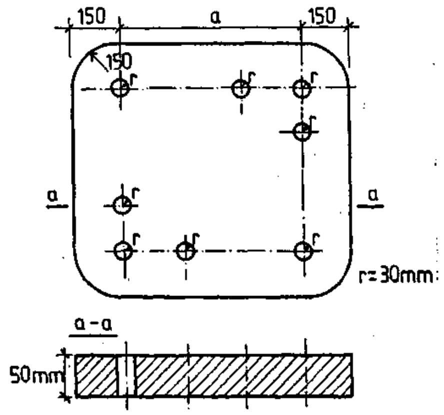

Fig.3. Bar detail

A detail of its longitudinal connection is shown in figure 4.

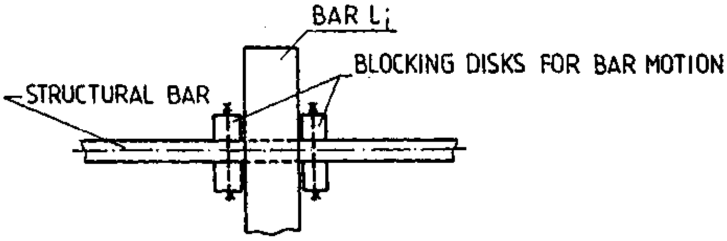

Fig.4. Connecting the bars

3. Active damping

Introducing a reaction mechanism is an efficient solution to make up for the influence of any type of perturbations on a mechanical system functionality. Viewing this specific characteristic of the closed systems, an adjusting or automatic driving system may be defined aiming at assuring the desired dynamic behaviour of a structure. The basic idea of controling the dynamic response and the dynamic stability consists of modifying the values of the parameters that govern the inerţia, damping and elastic properties of the system by introducing a set of correcting (modifying) forces. The active devices introduce external energy into the system depending on the system behaviour. In figure 5 the principle of several active dampers based on piezoeleclric crystals are presented.

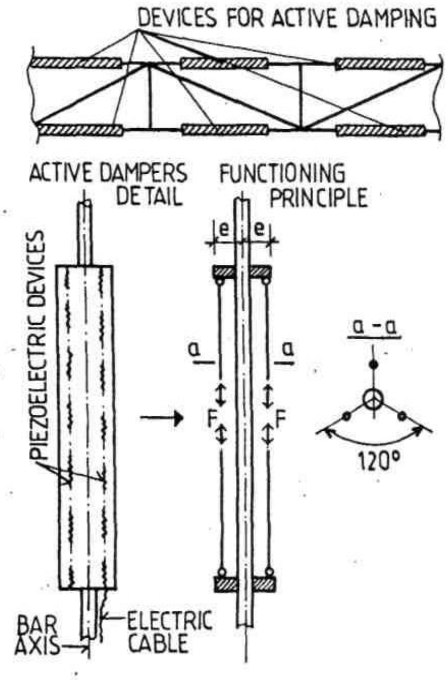

Fig.5. Active damper with piezoelectric crystals

4. Structural analysis

The matrix $\Delta \boldsymbol{F}_{(I)}$ of the unbalanced forces at the time t_I, is associated to the N degrees of freedom of the structure. These forces may be partioned as it follows:

$$\Delta \boldsymbol{F}_{(I)} = -\boldsymbol{F}_{(I)}^{I} - \boldsymbol{F}_{(I)}^{C} - \boldsymbol{F}_{(I)}^{R} - \boldsymbol{F}_{(I)}^{P}$$

where:

- $\boldsymbol{F}_{(I)}^{I}$ is the instantaneous force due to inerţia and added masses,

- $\boldsymbol{F}^{C}_{(I)}$ is the instantaneous force due to internal and external damping,
- $\boldsymbol{F}^{R}_{(I)}$ is the internal reaction force,
- $\boldsymbol{F}^{P}_{(I)}$ is the instantaneous perturbation force at time t_I.

The matriceal differential equation of dynamic equilibrium is made up of nonlinear equations of the form, [3], [4],

$$\Delta \boldsymbol{F}(x, \dot{x}, \ddot{x}) = \boldsymbol{0}$$

The dynamic tangent stiffness is defined as the Jacobian of $\Delta \boldsymbol{F}$,

$$\boldsymbol{J} = \Delta \boldsymbol{F}_{,x} + \Delta \boldsymbol{F}_{,\dot{x}} \dot{x}_{,x} + \Delta \boldsymbol{F}_{,\ddot{x}} \ddot{x}_{,x}$$

where the right hand side terms are partial derivatives.
The present study is mainly concerned with the damping matrix $-\Delta \boldsymbol{F}_{,\dot{x}}$ which reads

$$-\Delta \boldsymbol{F}_{(I),\dot{x}} = \boldsymbol{F}^{I}_{(I),\dot{x}} + \boldsymbol{F}^{C}_{(I),\dot{x}} + \boldsymbol{F}^{R}_{(I),\dot{x}} + \boldsymbol{F}^{P}_{(I),\dot{x}}$$

Or, in a more familiar form

$$\boldsymbol{C}_{(I)} = \boldsymbol{C}^{I}_{(I)} + \boldsymbol{C}^{C}_{(I)} + \boldsymbol{C}^{R}_{(I)} + \boldsymbol{C}^{P}_{(I)} \tag{1}$$

In the following, a linearization of (1) is oblained by keeping only the term $\boldsymbol{C}^{C}_{(I)}$. Delailed explanations of computing the stiffness matrix may be found in [4].

4.1. Structures with average passive damping of viscous type

The damping force that is born due to the vibration of the thin bar (lamella) in a viscous medium is

$$F^{C}_{(I)} = \frac{1}{2} \rho d c v \tilde{v}$$

where:
- ρ is the density of the viscous medium,
- d is the thin bar diameler,
- c is the influence coefficient of the damping medium,
- v is the speed of vibrations,
- $\tilde{v}$ is the instant speed of the bar (proporţional to *v*).

From the parţial derivative $\boldsymbol{F}^{C}_{(I),\dot{x}}$, the damping matrix $\boldsymbol{C}^{C}_{(I)}$, of the viscous medium is obtained.
It is supposed that al least two bars are not involved in vibration and, therefore, they may be considered supports for the viscous bar (lamella).

4.2. Structures with hysteretic damping of passive type

The structural analysis takes into account the necessity that the dissipated energy should be greater tlian the kinetic energy of the perturbations, [5], [6], [7],

$$E_{DIS} \geq E_k \tag{2}$$

For a practical analysis, the hysteretically dissipated energy may be approximalely taken (5) as

$$E_{DIS} = F_{pl} D \tag{3}$$

where:

- D is the maximum allowable displacement imposed by the dynamic stability condition,
- F_{pl} is the total yielding force of the bars.

The yielding force for n bars is computed from

$$F_{pl} = nW_{pl}R_{pl} \tag{4}$$

where:

- W_{pl} is the plastic strength modulus,
- R_{pl} is the plastic strength.

From the relations (2), (3) and (4) the number *n* of the viscous bars yields

$$n = \frac{E_k}{W_{pl}R_{pl}D} \tag{5}$$

For the structure presented in figure l,a the computation of the number of hysteretic bars (lamellas) necessary to guide the critical energy induced by a meteorit with a mass of $0.01 daNs^2 / m$ and the speed $v = 1000 m/s$, is required. A displacement of $D = 15cm$ of the slender bar is admitted. The dimensions of the bar (lamella) are $0.5 \cdot 3 \cdot 6cm^3$. It is considered an $R_{pl} = 3000 daN/cm^2$.

One gets:

$$E_{pl} = \frac{0.01 \cdot 1000^2}{2} = 500 daNm, \; W_{pl} = \frac{3 \cdot 0.5^2}{4} = 0.1875cm^3$$

From the relation (5) it follows

$$n = \frac{50000}{0.1875 \cdot 3000 \cdot 15} \cong 6$$

4.3. Structures with active dampers

An important first step of the analysis is to build-up functional input-output mathematical models or structurally functional models (input-state-output).
The izoparametric finite elements may be used to achieve this goal. The order of the model obtained by structural discretization is, usually, very high and difficult to manipulate. The order may be reduced by dynamic condensation, [4].

5. Concluding remarks

The procedures proposed in the study may be used for any structure aiming at reducing the risk of stability lost due to excessive vibrations.

The presented passive dampers may control the vibrations displacements, mainly of the fundamental mode component. Nevertheless, the dampers may not reduce the danger of loosing the dynamic stability in the case of non-stationary stochastic excitations presenting a strong tranzitory nature. It has to be said that the solution to this problem is not an expensive one.

The use of active dampers allows for reducing the participation of the fundamental mode component of the vibrations or even of a limited number of higher modes.

The design process requires a close cooperation between the architect and engineer.

Lightweight design is necessary for wide-span or high-rise structures and is advantageous for mobile and deployable structures.

The key principle of lightweight systems is their structural optimization. The shape developed by optimization process and form finding methods are the key for the high efficiency. This is achieved when all aesthetic, technical, functional and economical aspects are addressed to, [8], [9], [10], [11], [12], [13].

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