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NONLINEAR STRUCTURAL DYNAMICS IN XXI CENTURY: SPECIFIED MODELS, VIBRO-COMFORT BUILDINGS, NONLINEAR DAMPENING DEVICES

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ABSTRACT

In this paper methods of nonlinear structural dynamics, which were reported by the author on the ND-KhPI-2004, 2007, are applied to dynamics of modern buildings and structures. Schemes and models of new dampers are created. Three types of nonlinearities can be detected in operating period of these devices: geometric, physical and structural ones. The complexity of calculation of structure dynamics with such nonlinearities is explained by the fact that the systems have variable structure. It is presented five variants of ways to reduce the level of bending vibrations of structures (declarative patents of Ukraine are obtained).

On previous conference ND-KhPI 2007 (Kharkov, Ukraine) several works were devoted to the vortex-inducted vibration of constructions in the flow (see, for example, the work [1]) and to the different variants of the analysis and reduction of linear and nonlinear vibrations (see, for example, works by Avramov and Mikhlin). The author of this article developed [2-8] certain approaches in analysis not less than three of types of different non-linearity, in correct design of devices to reduce amplitudes of vibrations in buildings and structures.

Therefore, the aim of this work is to show some ways of "useful" application of nonlinear devices and characteristics. This is an example of design of the new damping devices to reduce the level of bending vibrations of structures and their elements.

One of the main places here is the development of non-linear calculated models to make the correct choice of damping, parameters and shapes of steel and composite structures. Such subject was also presented by the author on the conference "Steel & composite structures" in Manchester-2007.

In this work we consider an theoretical and some practical issues, based on theories of nonlinear dynamics of building objects. Modern building industry has reached literally enormous heights (the height of the building Burj Dubai, had been raised in eve 2010, is 818 m) and stairwells (bridge in Messina strait with stairwell more than 3 km). So, the achievements for this field of nonlinear dynamics are exceedingly important.

It's very interesting to watch the stages, taking into account the dynamics, the “race” of competitive process of the scientific and engineering elaboration of unique industrial and civil engineering structures:

- a schematic design of a new object. Approximate calculations of the main carrying constructions on simplified linear dynamic model can be produced on this stage;
- a creation of Special Technical Conditions (STC) for design, construction and operational monitoring of structures technical state. In this and subsequent stages of the building's exploitation, scientific organizations are usually involved to prepare corresponding documents and guarantee the “scientific support" on the object. For example, in Moscow the STC has been made for buildings having height of 60-75m or more (the requirements for the calculations: the model, modal analysis, the interaction of the object with a base, etc., are given);

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• on the stage of final detailed design the "shuttle" method of designing and nonlinear dynamic calculations is made. The very important aspect is the purpose of the form of the nonlinear dynamic model and all its parameters. In complicated cases we determine the dissipative properties and other parameters of the model, the dynamic testing of separate subsystems and elements of buildings are entered into the shuttle scheme.

In such a "race" we can see, that some technical problems of building non-linear dynamics are similar to the problems of mechanical engineering and machine building. For example, builders can learn from machine builders to design and to test the dumping devices, which use the dry friction force (in dynamics of suspension of vehicles, etc.). But modern unique building objects have enormous sizes. So, it is very difficult not only to determine dynamical loadings for them, but to compose the space model, which could take into account peculiarities of all subsystems and elements of these objects. Unfortunately, modern domestic computer construction systems are too carried away with the quantitative aspect of calculations, using for many problems the finite element method (FEM), but loosing, as a result, many qualitative effects of real non-linear structural dynamics.

Modern software (PC) is correct if, in particular, it can take into account in dynamical estimate of the new model multi-story building, a damping of vibrations by means of small relative shifts and displacements of elements in nodes of the construction. So-called "semi-rigid" nodes are becoming the innovation in the large-scale building structures, created at the end of XX and the beginning of XXI centuries. Their work and efficiency depend on the level of amplitudes of forced oscillations. At the low level nodes with dry friction are blocked and “do not breathe", the relative displacements do not occur, and at higher levels, nodes work as a friction dampers; their elements are mutually displaced. In other words, the construction works like a “system with variable structures”.

In such “complex nonlinear” systems the term “modal analysis” is not clear yet, because it is not only non-linear, but also “instantly changing”, that is depending on the method of excitation and research of free oscillations.

Let’s consider the following variants:

I. Theoretical and experimental researches of natural vibrations of the nonlinear system can be carried out in the time domain if the chosen initial displacements correspond to ones of the considered nonlinear natural mode. In this case the initial velocities must be chosen equal to zero.

II. Researches can be "active" using the force-machine (in particular, using the resonant method).

III. Research can be organized "passively", that is from some effects of varying the oscillating object, making records of arbitrary moments, processing these records, spectral analysis, etc.

Naturally, it is impossible to obtain single-valued results for a system with variable structure. Frequencies and modes of free (not their own ones, typical for conservative systems) oscillations in the nonlinear systems are unstable, in some cases are chaotic (see, for example, Hayashi’s research) and depend on the level of disturbances of the structure, the input spectrum, the initial conditions, etc.

For small oscillations of the whole structure the free oscillations modes in some cases can be converted into linear ones. Increased disturbance will add relative vibration displacements alternately in one or more nodes.

Such analysis show the complicity both for a description and functioning of the separate subsystems, and for the whole buildings, bridges, towers if they contain non-linear damping devices. Probably, only such efficient devices (absorbing external energy of the dynamic loads) allow design and use reliable and safe objects as vibro-defensive, winds-stability, seismo-steadfast and terror-protected ones.

The following main particularities of the design and usages (and analysis of the nonlinear vibrations) of the buildings and structures in XXI age are discussed in this report:

1. The new dynamic loads and influences which appeared recently, connected with new large sizes of buildings and power of machine technology, climate changes and unexpected social events (in the form, for example, of terrorist acts) etc.
2. The unbeneficial combinations of the loads become more complicated. In nonlinear characteristics of systems and models the use of the superposition principle is impossible.
3. Requirements for the “vibro-ecology” quality of life and work in building and structures are increased. In particular, the admissible range of vibration frequencies of the pedestrian and other town bridges is limited. The monitoring of velocity and acceleration is introduced. A limitation of the “doze of vibration”, obtained by people, that is the integral level of obtained vibration energy for the limit interval of time, is very important at present.

4. New materials and nodes (with poorly known properties), often very different in the same building, which does not allow to conduct the study of their vibrations on former linear models with similar (in type and value) dissipation, springy and inertia parameter "general on object" have been used.
5. Possibilities of mathematical and computer modeling are changed, alternative methods and approaches to solve the nonlinear dynamics problems, are appeared. But there is a small number of works on comparison of such methods and approaches. Works on more precise definition of these approaches limitation in nonlinear dynamics are desirable, in particular, of the analytical and numerical methods (including FEM), researches in the time domain etc.

In given report it is expected a consideration of the ways of creation and testing nonlinear models by using multiple examples of dynamics of the buildings and structures. We will demonstrate examples of accurate models in dynamic calculation of the buildings, structures and their element with different non-linearity:

a) "geometric" one (cable, threads);
b) "constructional" one (the systems with clearance, slippage and others);
c) " physical" one:

- nonlinear-springy (see the theory of Duffing`s equations and Prandtl`s diagrams for bodies which are springy-plastic, plastic and springy; see the under-changing rubber in shock absorber, air-cushion and others);
- nonlinear-dissipative (with dry friction).

As a result of the works [2-7] we have successfully patented five inventions in 2009. Methods of the nonlinear dynamics calculation and tests, together with PGASA and DonNASA, was created and tested in natural conditions.

These inventions (see their schemes and corresponding patents in *Table 1*) are directed only on one of the type of vibrations of the large structures, namely, they reduce the vibration bending of the buildings and their elements. These principles allow to provide protection of the object from different forces and vibrations, to reduce the level not only bending, but also longitudinal and other types of the vibrations in building constructions (high-altitude buildings, overlapping, tower, masts, bridges).

Detailed description of the work for each device is given, drawing up of the dynamic models, nonlinear differential equations of the vibrations of the objects with devices and vibrograms, proving efficient device.

In conclusion it needs to indicate a necessity of the further development of the alternative methods of the nonlinear devices calculation. Otherwise the correct design of the modern buildings and structures, working at dynamic loads, is impossible.

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Table 1. Patents of Ukraine on useful models device, which reduce the bending vibrations of the constructions

1 № 40431		4 № 40434	
2 № 40099		5 № 40434	
3 № 40094		6 № 40435