E3S Web of Conferences **376**, 03031 (2023) https://doi.org/10.1051/e3sconf/202337603031
ERSME-2023

Evaluation of the dynamic behavior of buildings and structures by generalized oscillators

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Abstract. The paper considers aspects of the reactive behavior of structural elements of large-panel housing construction. The problem of determining the position in space of the material point (center of mass) of the objects under study is solved, thus allowing us to evaluate the kinetics of the behavior of structural elements as a whole. New original calculation schemes are proposed, relative to all spatial axes, for determining dynamic reactions in the connections of structural elements under pulsed dynamic action on buildings and structures. A system of local oscillator forces balanced by inertial internal and external influences has been compiled by the method of kinetostatics. The interpretation of the behavior of structural elements of buildings using various oscillators is proposed. This interpretation made it possible, using periodic harmonics, to quantify the change in kinetic energy of structural elements as a result of their impact on each other due to external pulsed dynamic influences. An algorithm for determining dynamic reactions in the junctions of structural elements of buildings and structures has been developed and presented.

1 Introduction

Fig.1 shows a fragment of the result from traces of pulsed dynamic action [1] on buildings and structures, presented in the form of an extensive network of cracks of different lengths and different widths [2]. According to the nature of crack development, the results of different vector dynamic destructive effects are clearly revealed, indicating the complex spatial kinetics of destructive factors. The paper substantiates the interest in the systemic question asked in such cases: -"Are these cracks the result of only external dynamic action, or are they also the result of a combination of various factors, such as, - external and internal inertial reactive behavior of structural elements when interacting with each other, and with the supporting frame of the building"?

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Fig. 1. Spatial kinematics of destruction in the form of vertical, horizontal and inclined cracks from dynamic impacts.

As a result of the analysis of the image in Fig.1, linear and torsional deformations of both individual material bodies of structural elements and individual material points belonging to these elements are obvious. In this regard, the following problem can be formulated: - "How, at least theoretically, would it be possible to prevent the development of the various vector deformations of structural elements shown earlier in Fig. 1"? In our opinion, one of such possibilities is the kinetic-static balancing [3] of elements of buildings and structures by balancing individual material points belonging to these structural elements. Thus, the described balancing of the designated task can be represented as a system-wide, as a universal balancing of buildings and structures using the described calculation scheme of the previously designated task.Research methods and models.

Due to various external influences on buildings and structures and on their individual structural elements, as well as due to the corresponding responses of elements to these external and internal influences, these elements of buildings and structures actually perform complex, alternating short-term trajectories of movement in space.

Fragments of possible spherical trajectories of structural elements, which are estimated by six degrees of freedom, as well as the local calculation scheme proposed by the authors of this article to determine the analytical dependencies of the characteristics of the movements of these material points belonging to structural elements are shown in Fig. 2.

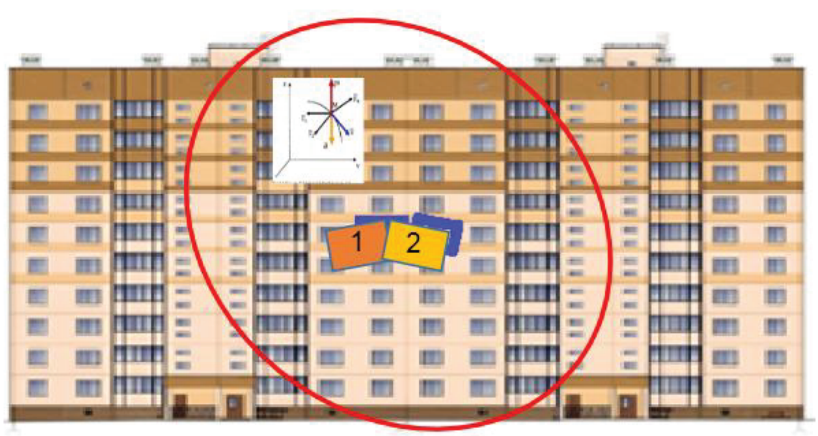

Fig. 2. Scheme of fluctuations of the efficiency panels relative to each other and relative to the skeleton of the building; 1- an ordinary panel that took a deviation "to the left" at a discrete moment of time from a pulsed dynamic impact; 1- an ordinary panel that took a deviation "to the right" at a discrete moment of time from a pulsed dynamic impact.

Let us denote the provisions used by the authors of the article to justify the achievement of equilibrium conditions of the structural elements considered in Fig. 2.

The external system of forces shown in Fig. 2 is reduced to a "balanced system of forces" by the method developed by D'Alembert (the method of kinetic statics ([4].

To do this, at a fixed point of a complex trajectory of motion, at a discrete moment in time, in addition to the effects shown in Fig.2 on structural elements and their characteristic points, we "forcibly" add the force of inertia. As a result, - considered by us in Fig.2 system, - will be balanced,

For a characteristic (material) point of the corresponding structural element of the building, - the balancing force will be a force - equal in modulus to the product of the mass of this point by its corresponding tangential and/or normal accelerations and - directed in the direction opposite to the directions of its accelerations.

Further, the inertial forces "forcibly" applied to the characteristic points of the structural elements will be replaced, respectively, by the main force and the main moment [5].

We apply the indicated vectors to the center of application. The force vector is equal to the main vector of inertia forces, and the moment vector is equal to the main moment of inertia forces relative to the center of application, i.e. (the center of mass of the structural elements under consideration) in such a way that:

$$\vec{F} = -m\overrightarrow{\mathrm{a}_{\mathrm{c}}}; \tag{1}$$

$$\overrightarrow{M_{\mathrm{c}}^{F}} = \frac{d\overrightarrow{K_c}}{dt} \tag{2}$$

Where $\overrightarrow{K_c}$ is the kinetic moment of the elements under consideration relative to the center of mass (point C).

When an element having a plane of material symmetry rotates around an axis passing through the center of mass perpendicular to this plane, the system of forces is reduced to a pair of forces lying in the plane of material symmetry of the element. The moment vector of this pair is defined by the following equation

When an element having a plane of material symmetry rotates around an axis passing through the center of mass perpendicular to this plane, the system of forces is reduced to a pair of forces lying in the plane of material symmetry of the element. The moment vector of this pair is defined by the following equation:

$$\overrightarrow{M_{\mathrm{C}z}^{F}} = \frac{d(I_{Cz}\vec{\omega})}{t} = -I_{Cz}\vec{\varepsilon} \tag{3}$$

where I_{Cz} is the moment of inertia relative to the axis passing through the center of mass.

The algebraic moment of a pair of inertia forces is defined as follows

$$M_{\mathrm{C}z}^{F} = -I_{Cz}\varepsilon_z = -I_{Cz}\omega_z = -I_{Cz}\ddot{\varphi} \tag{4}$$

With the flat motion of the objects under consideration, having a plane of material symmetry, we will bring the system of inertia forces to a force and to a pair of forces lying in the plane of material symmetry as follows:

$$\vec{F} = -m\overrightarrow{a_C}, \tag{5}$$

$$M_{\mathrm{C}z}^{F} = -I_{Cz}\varepsilon_z \tag{6}$$

where is the moment of inertia relative to the axis passing through the center of mass perpendicular to the plane of material symmetry.

For practical determination of dynamic reactions of interactions of the studied objects with each other and with the supporting frame of the building in the form of "dynamic reactions of supports" with partial rotation of the studied structural elements and nodes around a fixed axis, we will make a virtual calculation scheme shown in Fig.3. As the axes of rotation shown in Fig.3, in this paper we will consider the vertical and horizontal seams between the structures of the building:

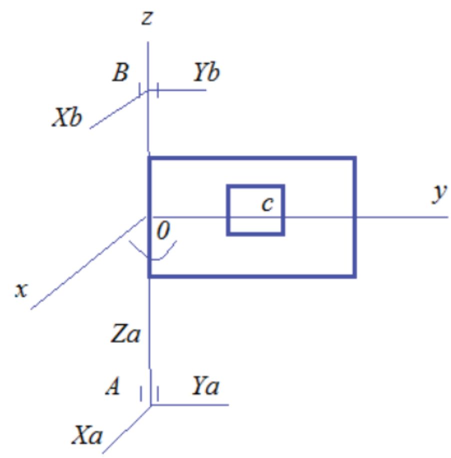

Fig. 3. Calculation scheme for determining dynamic reactions in the attachment points (with conditional rotation of the panel around the 0Z axis. The vertical seam between the structures of this building in this case is considered the vertical axis 0Z).

Let us imagine the nodal fastening of the object under study at the corresponding points "A" and "B" shown in Fig.3,

Having compiled the projection conditions of equilibrium by the method developed by D'Alembert, we obtain a statically definable system of equations of equilibrium of forces and moments (7)

$$:\begin{cases} X_{\mathrm{Adin}} + X_{\mathrm{Bdin}} + my_C\ddot{\varphi} + mx_C\dot{\varphi}^2 = 0 \\ Y_{\mathrm{Adin}} + Y_{\mathrm{Bdin}} - mx_C\ddot{\varphi} + my_C\dot{\varphi}^2 = 0 \\ Z_{\mathrm{Adin}} = 0 \\ Y_{\mathrm{Adin}}|z_A| - Y_{\mathrm{Bdin}}|z_B| + I_{xz}\ddot{\varphi} - I_{yz}\dot{\varphi}^2 = 0 \\ -X_{\mathrm{Adin}}|z_A| + X_{\mathrm{Bdin}}|z_B| + I_{yz}\ddot{\varphi} - I_{xz}\dot{\varphi}^2 = 0 \end{cases} \tag{7}$$

where $X_{\mathrm{Adin}}, X_{\mathrm{Bdin}}, Y_{\mathrm{Adin}}, Y_{\mathrm{Bdin}}$ the corresponding dynamic reactions in the supports for the points "A" and "B" indicated in FIG. 3. The reactions of the supports are determined for the alternating rotational form of motion caused by external and internal pulsed dynamic action.

From the system of equations (7), all unknown values $X_{\mathrm{Adin}}, X_{\mathrm{Bdin}}, Y_{\mathrm{Adin}}, Y_{\mathrm{Bdin}}$ are expressed in a standard way, by jointly solving the above equations.

2 Goals and objectives of the work

1. It is necessary to calculate the equation of motion of a given material point belonging to the building object under study in a given location;

2. It is necessary to determine the reactions of the supports in the attachment points of structures from impulse-dynamic effects on the building;
3. To develop an algorithm for solving the problems specified in paragraphs 1 and 2 of the goals and objectives of this work.

3 General provisions

To obtain analytical dependences on the kinematic movements of individual structural elements, as well as to determine the dynamic reactions from the interactions of research objects with each other and with the supporting skeleton of the building, we will develop the calculation scheme shown in Fig.4.

Figure 2 shows a possible diagram of the trajectories of vibrations of structural elements of the building relative to each other, as well as a possible trajectory of vibrations of elements relative to the skeleton of the building. The relative axes (0,x,y,z) are introduced and indicated. The kinetics of the dynamic behavior of elements No. 1 and No. 2 is similar to the behavior of a conditional oscillator, in the form of a conditional mathematical pendulum, relative to the point "0" indicated in Fig. 2, with an angle of deviation from the equilibrium position equal to "φ ".

The rectangular panel of the building with dimensions ( ) and mass "m" will be shown in Fig.4 in the form of a conditional load "P". In this calculation scheme, we will consider the cargo "P" to be a material point with a concentrated mass. We attach the load "P" with the help of a conditional weightless rod, a rod conditionally having no weight, a rod of conditional length "L" to the hinge node, at point 0, as shown in Fig. 4:

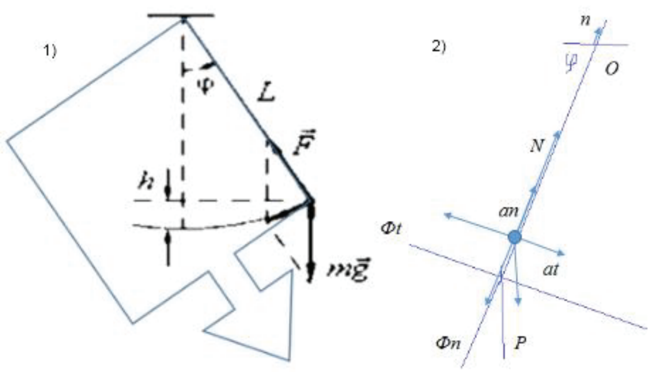

Fig. 4. 1) Calculation scheme for determining the dynamic coupling response of the specified oscillator with a deviation "to the right". 2) Balancing the system of forces of the virtual oscillator with a deviation "to the left".

4 The algorithm

Instruction 1 Schematically, we present a fragment of the oscillator model in Fig.4.2 with the initial angle of rotation equal to "φ " . The angle of rotation will be counted from the initial equilibrium position.

Instruction 2 Let's define the forces presented in the diagram, Fig.4.2, as the force of gravity equal to "$\vec{P} = m\vec{g}$ ", and the force of internal force in the rod "$\vec{N}$ ", as the reaction of the support indicated in Fig.4.2 rods.

Instruction 3. Consider the natural forces. The force acting in the direction of the normal to the considered trajectory of motion is equal to «$\overrightarrow{F_n} = -m\overrightarrow{a_n}$». The force acting in the

 https://doi.org/10.1051/e3sconf/202337603031

direction of the tangent line to the considered trajectory of motion is equal to « $\overleftarrow{F_\tau} = -m\overleftarrow{a}_\tau$». At the same time, «$a_n = \frac{v^2}{\ell}$ and $a_\pi = \frac{dv_\tau}{dt}$» bearing in mind that «$v = \int a \cdot dt$». With that said, we will balance the one presented in Fig.4.1 and 4.2 the calculation scheme by the natural forces indicated by us.

Let's imagine the desired reaction of the support in the form of ($\overrightarrow{N_R}$) ⃗) acting in the direction of the line connecting the panel to its support, thus we present the desired reaction of the support as one of the elements of the set of balanced system of forces $\{\{\vec{P}, \overrightarrow{N_R}, \overrightarrow{F_n}, \overrightarrow{\Phi_\tau}\}$.

Consider the equilibrium equations for the case under consideration

$$\sum_{k=1}^{n} F_{k\tau} = 0, \quad m \cdot g \cdot cos(\varphi) - \Phi_\tau = 0 \tag{8}$$

$$\sum_{k=1}^{n} F_{kn} = 0, \quad N_R - \Phi_n - m \cdot g \cdot sin(\varphi) = 0 \tag{9}$$

From here:

$$m\frac{dv_\tau}{dt} = m \cdot g \cdot cos(\varphi);\ and\ N_R = m \cdot g \cdot sin(\varphi) + \frac{mv^2}{\ell} \tag{10}$$

Let's replace the variable in the differential equation (11) and determine the velocity of the point in question with a mass equal in magnitude to the value "m".

Recall that the load of the design scheme shown in Fig.4 is hanging on the "communication line-a weightless rod", which is essentially the fastening of the panel to the supporting frame of the building, in which, by definition, the so-called "normal" force «N_R» arises.

$$\frac{dv_\tau}{dt} = \frac{dv_\tau}{d\varphi} \cdot \frac{d\varphi}{dt} = \omega \cdot \frac{dv_\tau}{d\varphi},\ when\ \ \omega = \frac{v_\tau}{\ell} \tag{11}$$

As a result of replacing the variable, the differential equation for the movement of the panel node takes the following form:

$$\frac{v_\tau}{\ell} \cdot \frac{dv_\tau}{d\varphi} = m \cdot g \cdot cos(\varphi),\ \ under\ the\ initial\ condition\ v_\tau|_{\varphi=0} = 0 \tag{12}$$

Let 's solve the differential equation under a given initial condition

$$\int_0^{v_\tau} v_\tau \cdot dv_\tau = g \cdot \ell \cdot \int_0^{\varphi} cos(\varphi) \cdot d\varphi \tag{13}$$

Integrating, we obtain the desired equation of motion and the analytical expression of the kinematics equation:

$$\frac{v_\tau^2}{2} = g \cdot \ell \cdot sin(\varphi) \tag{14}$$

Using the previously found velocity of the panel point, we will find the module of the value «N_R»

$$N_R = 3 \cdot m \cdot g \cdot sin(\varphi) \tag{15}$$

It follows from (15) that all elements of buildings under given conditions, if they are represented by separate material points, perform complex spatial movements based on harmonic proper and forced oscillations with an oscillation period equal to:

$$T = 2 \cdot \pi \cdot \sqrt{\frac{L}{g}} \tag{16}$$

where "L" is the dimensions of the connection.

Let us draw your attention to the fact that the specified oscillation period is directly proportional to the square root of the ratio "L/g".

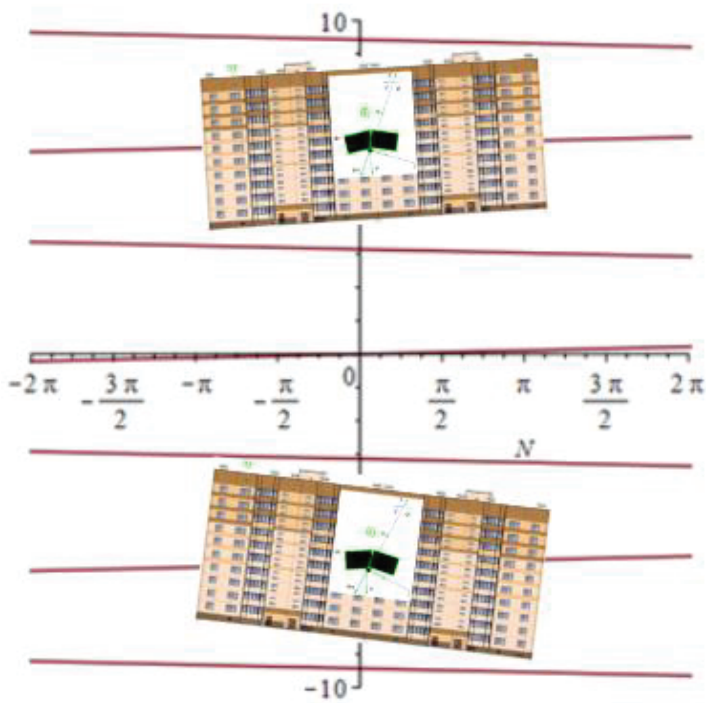

Fig. 5. Angular diagrams of virtual oscillators as separate elements of a building under dynamic influences.

Let us draw your attention to the fact that Figure 5 shows slight deviations from the equilibrium position, from the horizontal. It is the harmonic diagrams that are shown, which in their essence do not represent a type of damped or resonant oscillations, but theoretically have a permanent character.

The given amplitude-frequency analysis of Fig.5 clearly indicates, for given initial conditions, a constant periodic change in the kinetic energy [6] of the building elements under consideration.

According to the results of discrete analysis (15), the pulse-dynamic behavior of the objects under study, due to normal impulse forces ($\frac{N_R}{\tau}$), where "τ" is the duration of the force), appears to us to be periodic changes in the amount of motion (m *v) of the objects under study.

Note that the indicated quantitative change in the amount of movement, so to speak, falls on half the length (half the size "(m*v) / (l/2)" of the element in question.

Thus, the reaction of structural elements of buildings to pulsed dynamic effects can be generically characterized by a cumulative oscillator, the phases of which are shown in Figure 6.

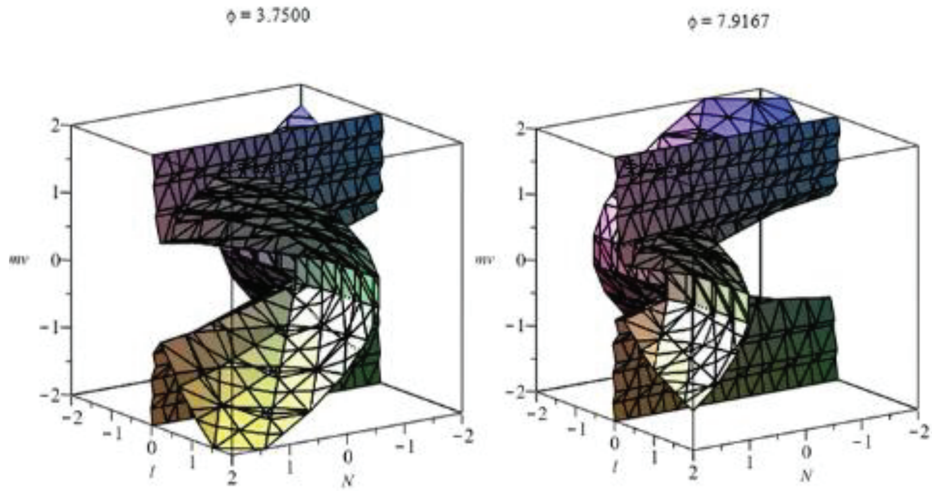

Fig. 6. Form of the change in the amount of motion $[m \cdot v]$ falling on $[(½)l]$ half the size of the element dimension from the pulse of normal force $[\frac{N_R}{\tau}]$ in the reference connection.

Figure 6 shows two stages of figures [8,9] of changing the dynamics of the behavior of a point virtual oscillator at rotation angles equal to "φ = 3.75 degrees and φ = 9.17 degrees", respectively.

The harmonic essence of the behavior of the oscillator under study in the range of values "φ" from 0 to 10 degrees is obvious. The initial and final stages, in form, are identical to each other.

5 Conclusions

1. A method has been developed to identify the kinetic dependencies of the motion of the material point of the objects under study;
2. The problem of determining the position of a material point (center of mass) of a structural element of efficiency at a discrete time is solved;
3. A method is presented for determining dynamic coupling reactions under the impulse dynamic effect of structural elements of efficiency on each other and on the supporting frame of the building;
4. All of the above methods for solving the tasks are combined into one, common algorithm;
5. The dynamics of the reactive behavior of efficiency buildings by point and generalized oscillators is presented, proving the harmonic change in the states of the studied objects from pulsed dynamic influences.

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