Spectrum Journal of Innovation, Reforms and Development

Volume 21, November, 2023 | ISSN (E): 2751-1731

Website: www.sjird.journalspark.org

ANALYTICAL CALCULATION OF BENDING ELEMENTS WITH BASALT FIBER REINFORCEMENT AND GLASS COMPOSITE ROD UNDER SHORT-TERM DYNAMIC LOADING

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Abstract

During the construction and operation of buildings and structures, in addition to static loads, short-term dynamic impacts caused by explosions, accidents, etc. may occur on building structures and their elements. As a result, damage or destruction of structures may occur, which leads to possible casualties and significant material losses.

Taking into account the influence of such impacts on the load-bearing capacity of building structures is relevant. A significant number of works by domestic and foreign authors are devoted to methods for calculating the bending of reinforced concrete elements under static and short-term dynamic loading. In the vast majority of cases, the object of research is flexural concrete elements with steel rod and/or fiber reinforcement. The issues of predicting and assessing the stress-strain state of bending concrete elements reinforced with glass-composite reinforcement and/or basalt fiber under short-term dynamic loading have not been sufficiently studied. Current building codes and regulations provide for the calculation of such elements only under the influence of static loads.

Keywords: composite reinforcement, fiber-reinforced concrete, crack resistance, strength, structure, bending element, beam.

Introduction

In recent years, cases of emergencies that threaten the safety of buildings and structures have become more frequent.

These situations are of natural or man-made origin and often have a dynamic impact on building structures (seismic impacts, explosions, impacts, etc.). Dynamic loads are characterized by a rapid change in time in their magnitude, direction or point of application, and significant inertia forces arise in structures, which must be taken into account in calculations. In connection with the development of technology and technology, the number of explosions has increased, in which damage and destruction of load-bearing structures of buildings and structures occur, often leading to their collapse and mass death of people. [1][3].

Such explosions can result in intense blast loads and shocks caused by the collapse of overlying structures. The parameters of air shock waves (pressure, duration of action, propagation speed, etc.) depend on the source of explosion energy, the environment, distance from the source of the explosion, etc. The processes of deflagation combustion of gases and dust-air mixtures in a closed and semi-closed volume can be considered quasi-static. The deformation rates of various materials under the influence of explosive dynamic loads are within the range ε = 1…100 c $^{-1}$.

An important property of building structures that are resistant to short-term dynamic impacts is their ability to absorb significant energy without destruction. In this case, the formation of plastic deformations in materials and structures as a whole is allowed. Thus, when designing load-bearing building structures capable of withstanding explosive dynamic loads, it is important the factor is to ensure their high strength and the possibility of plastic deformation. This can be achieved by using high-strength concrete and reinforcement, fiber-reinforced concrete, combined reinforcement, rational structural forms, accurate calculation methods, etc. [2][4].

2. Materials and Methods

Analytical and numerical methods for calculating the bending of BF S-GKF elements under the action of short-term dynamic load. A method is proposed for calculating the strength and crack resistance of normal sections of ordinary and prestressed bending elements BF S-GKF under short-term dynamic loads, based on a nonlinear deformation model using regions of relative strength and crack resistance. To study the stress-strain state of dynamically loaded bending elements of the BF S-GKF, the EFES software package was used, which allows one to assess with a high degree of reliability the deformation, cracking and strength of the studied materials and structures of complex structures. geometric shape at different times [5]. This program uses a mathematical model to describe the behavior of a compressible medium in a three-dimensional coordinate system (i = 1, 2, 3), expressed by a system of equations of energy (1), continuity of the medium (2) and motion of the continuous medium (3):

$$\frac{dE}{dt} = \frac{1}{\rho}\sigma^{ij}e_{ij} \qquad (1)$$

$$\frac{\partial\rho}{\partial t} + \rho\nabla_i v^i = 0 \quad (2)$$

$$\rho a^k = \nabla_i\sigma^{ik} + F^k \quad (3)$$

где: $a^k = \frac{\partial\vartheta^k}{\partial t} + \vartheta^i\nabla_i\vartheta^k, \nabla_i\ \sigma^{ik} = \sigma_i^{ik} + \Gamma_{im}^k\sigma^{im} + \Gamma_{ij}^k\sigma^{ik}, e_{ij} = \frac{1}{2}\left(\nabla_i\vartheta_j + \nabla_j\vartheta_i\right), \qquad (4)$

in which: F^k- components of the mass force vector; Γ_{ij}^k- Christophelian symbols; σ^{ij}- contravariant components of the symmetric stress tensor; E- specific internal energy; ρ- medium density; ϑ^i- velocity vector components; e_{ij}- components of the symmetric strain rate tensor.

When describing the behavior of materials in the calculations, a mathematical model was used that takes into account the possible plasticity and destruction of the material. Components of the stress tensor σ^{ij} in materials before failure represent the sum of the deviatoric S^{ki} and spherical parts P :

$$\sigma^{ij} = -Pg^{ij} + S^{ij}, \qquad (5)$$

Where: g^{ij}- metric tensor.

Pressure in materials is found as a function of specific internal energy E and density ρ from the solution of the equation Mi–Gruneisen, in which K_0, K_1, K_2, K_3, – Gruneisen coefficients, V_0 and V – initial and current specific volumes of the final element:

$$P = \sum_{n=1}^{3} K_n \left(\frac{V}{V_0} - 1\right) + K_0 \rho E \qquad (6)$$

The relationship between the components of the stress deviator and the strain rate tensor, taking into account the shear modulus of the material G, is presented in the form of the expression:

$$2G\left(g^{im} g^{jk} e_{mk} - \frac{1}{3} g^{mk} e_{mk} g^{ij}\right) = \frac{DS^{ij}}{Dt} + \lambda S^{ij},\ (\lambda \geq 0), \qquad (7)$$

в котором:

$$\frac{DS^{ij}}{Dt} = \frac{dS^{ij}}{dt} - g^{im}\omega_{mk}S^{kj} - g^{jm}\omega_{mk}S^{ik},\ \omega_{ij} = \frac{1}{2}(\nabla_i \vartheta_j - \nabla_j \vartheta_i), \qquad (8)$$

The nature of the work of materials is determined from the Mises condition:

$$S^{ij} S_{ij} = \frac{2}{3}\sigma_d^2, \qquad (9)$$

at which the material is elastically deformed (λ = 0). If condition (9) is violated, the material behaves plastically (λ > 0), as a result, to describe its behavior in the plastic region of deformation, the components of the stress tensor deviator are reduced to the yield circle by S^{ij} multiplying them with a normalizing coefficient. In condition (9) σ_d the dynamic yield strength of the material is found, which for concrete BF S and GKF [6].

The calculations used the generalized Tsai–Wu criterion for the destruction of materials, presented as a function with the components of the stress tensor as arguments:

$$f(\sigma_{ij}) = F_{ij}\sigma_{ij} + F_{ijkl}\sigma_{ij}\sigma_{kl} + \ldots \geq 1, \qquad i, j, k, l = 1,2,3., \qquad (10)$$

Here F_{ij} and F_{ijkl}– tensor components of the second and fourth rank, respectively, and are defined as follows:

$$F_{ab} = F_{ij} q_{ia} q_{jb}\ , \quad F_{abcd} = F_{ijkl} q_{ia} q_{jb} q_{kc} q_{ld}, \qquad (11)$$

The components of the second-rank tensor are determined using the following dependencies:

$$F_{ii} = \frac{1}{X_{ii}} - \frac{1}{X_{ii}^!},\ \ F_{iiii} = \frac{1}{X_{ii} X_{ii}^!}\ , \quad F_{ij} = \frac{1}{2}\left(\frac{1}{X_{ij}} - \frac{1}{X_{ij}^!}\right),\ \ F_{ijij} = \frac{1}{4X_{ij} X_{ij}^!} (12)$$

Where X_{ii} and $X_{ii}^!$- respectively, the limits of dynamic compressive and tensile strength of the material in the direction i ; X_{ij} and $X_{ij}^!$- respectively, the limits of dynamic compressive and tensile strength of the material in the direction $i \neq j$.

When the destruction criterion (10) is met, the material is considered damaged and a model of a fragmented medium is used for its further description. According to this model, in finite elements where failure occurs under tensile conditions (e_{kk} >0), it is assumed that the material is completely destroyed and the values of the stress tensor components are equal to zero [7][8]. When fractured under compression conditions (e_{kk} ≤0) it is assumed that the material does not resist shear and tension, but is capable of providing it under volumetric compression. Then the pressure in the material is calculated by the expression:

$$P = \left[\exp\left(4\beta\frac{V_0 - V}{V_0}\right) - 1\right]\frac{\rho_0\alpha^2}{4\beta} \qquad (13)$$

Where ρ_0– initial density of material; α and β– shock adiabatic coefficients determined from the dependence $D = \alpha + u_m\beta$; u_m– mass speed.

3. Results and Discussion

Numerical studies of flexible elements of BOS-ASK were carried out in a full three-dimensional dynamic formulation using experimentally obtained mechanical characteristics of materials. Geometric parameters of structures and loading (geometric dimensions, design solution, design diagram, loading parameters, etc.) are assumed to be similar to the experimental data presented in the dissertation.

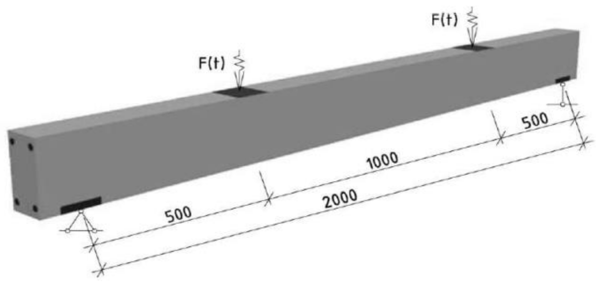

Figure 1 – General view of the finite element model of the beam

During the simulation, the beam was divided into tetrahedral finite elements (see Figure 2a). The time step size in the calculations was determined from the Courant stability criterion. The total number of finite elements in the calculations was 15,3x10 ^{6}, number of nodes 3,6x10 ^{6}. A gradually increasing and decreasing dynamic load was applied according to the law of its change over time (see Figure 2b).

a) b)

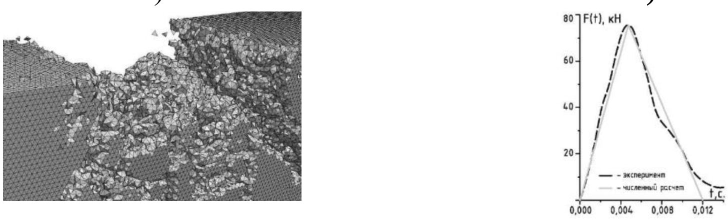

Figure 2 – Numerical modeling of a beam: a) general view of the finite element mesh; b) a characteristic graph of changes in dynamic load, gradually increasing and decreasing over time;

As a result of numerical studies, quantitative and qualitative characteristics of deformation, cracking and destruction of beams were obtained (see Figure 3), which showed satisfactory convergence with the results of experimental data.

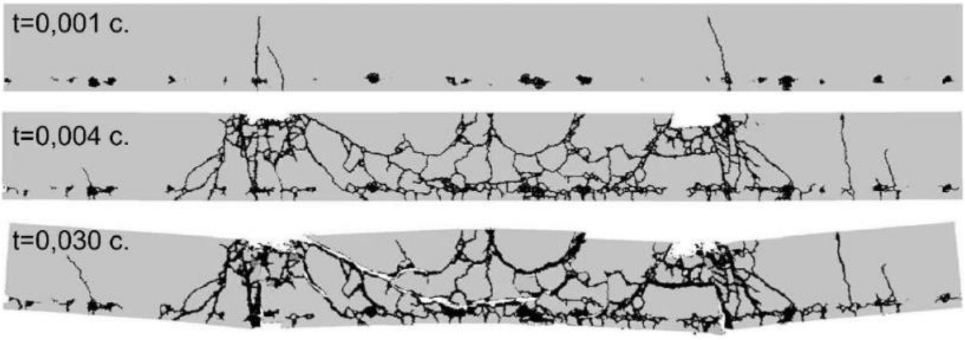

Figure 3 – Typical patterns of cracking and destruction of a beam during numerical calculations at times of 1 ms, 4 ms, 30 ms;

A comparison of the experimental and calculation results showed a qualitative similarity in the patterns of cracking and destruction of beams; quantitative coincidence of calculated and experimental stress values in the DP S and GKF of the normal section of beams with a difference of within 15%. The discrepancy between the maximum deflection values in numerical models and experimental samples did not exceed 7%.

The considered software systems and the mathematical models implemented in them make it possible to evaluate the stress-strain state of the bending elements of the S-GKF DP under short-term dynamic impact. At the same time, a complete three-dimensional dynamic formulation of the problem makes it possible to reliably and in detail analyze the deformation of both individual elements and the structure as a whole. This makes it possible to search for optimal design solutions by varying the numerical calculation parameters [9][10].

4. Conclusion

Qualitative and quantitative agreement has been established between the results of numerical calculations of bending elements of the BF S-GCF, performed in the EFES program under short-term dynamic loading, with experimental data. A method has been developed for calculating the strength and crack resistance of conventional and prestressed bending elements BF S-GKF under short-term dynamic loading, based on the theory of the areas of relative resistance of such elements in terms of strength and crack resistance. and implements a nonlinear deformation model taking into account real material deformation diagrams. This method makes it possible to estimate the VAT of such elements in numerical and graphical form with a high degree of reliability, as well as solve problems of a research and applied nature.

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