Calculation of Reinforced Concrete Floor Elements for Special Dynamic Loads under Technogenic Impacts

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Abstract. The problem of calculating reinforced concrete structures for explosive and shock loads is considered. A method for evaluating beam structures when considering work in elastic, plastic is proposed. For the dynamic calculation of reinforced concrete structures for explosive and shock loads, the methods have been used in which dependencies are given to determine the parameters of dynamic loads arising from the explosions of various substances. The design scheme of the slab is represented as joint areas without cracks.

The method of the dynamic method for calculating reinforced concrete slabs is presented, it allows to ensure the protection of the floor slab against collapse under the action of a special dynamic load. The plate deformation is considered in two stages of deformation: elastic, plastic.

The proposed method for determining the safety of reinforced concrete slabs, while meeting the requirement of preserving the carrying capacity.

A method in which the end of the elastic stage is represented through the ultimate elastic deflection has been used.

Examples of calculation of the plate for the action of special dynamic loads are given.

1. Introduction

In man-made emergencies (the explosion of various substances, impact forces), special dynamic loads arise, which often lead to unacceptable deformations of structures and even their collapse. Recently, possible explosive and shock effects on civilian buildings and structures, terrorist acts. On the night of Sunday, May 12, 2019, an explosion of domestic gas occurred in the village of Chistoozerny in the Kamensky District of the Rostov Region, as a result of which residential buildings were completely destroyed, four more were damaged.

The explosion of domestic gas occurred in a residential building in Volgograd as well. "The gas explosion occurred in a four-story residential building when gas services were working there," the inter-floor space of the third entrance collapsed, according to preliminary data, 12 apartments were destroyed from the fourth to the first floor."

Explosive and shock loads characterized by high intensity and short duration are short-term dynamic loads. For conventional civil and industrial construction that are not specifically designed for their perception, these loads are accidental influences, acting only once on the structure. Under the action of these loads, only one claim is submitted on the such construction: the structures must be capable of withstanding without causing the structure to collapse. Therefore, in these cases permanent
deformation are possible of the main structures and even local destruction of one or several of them, but not leading to the collapse of structures or parts of it, can be allowed in such structures.

In the works of N. Popova and B. Rastorguev [8, 9, 20] describes in more detail the theory of dynamic deformation of reinforced concrete structures. In these works, the dynamic calculation of reinforced concrete structures for the action of special dynamic loads is set forth: beams, slabs supported along the contour, based on elastoplastic and rigid-elastic methods.

The problems of calculating special structures on the action of intense dynamic loads were dealt with by B.S. Rastorguev, who is one of the founders of the relevant section of the dynamics of structures.

All the basic parameters of structures (loads, forces and deformations) are random variables or functions. Therefore, it is more important to apply the probability technique of calculating reinforced concrete slabs is implemented. A similar method for calculating beam structures is described in [1,2,8,9], in which an emergency limit state is used, which provides separate structures from collapse.

Considered rectangular concrete slab with sides l1 and l2, where l1 ≥ l1 ≥ 11 ≤ l2 ≤ 211, when the slab is bending in two directions. The fastening of the slab along the contour is possible articulated, rigid and pliable.

Load taken uniformly distributed over the area and consisting of static qst and dynamic: finite duration during Θ p(t)=pf(t), l2≥t≥0 or in the form of an instant intensity pulse i (f(t)=0).

When deriving the calculated dependencies, the dynamic load will be used with a constant in time intensity p (f(t)=1).

Plates with conventional reinforcement of grids with longitudinal and transverse reinforcement with a diameter of d=5…12 mm с уравнением 150…250 мм. Sites of working reinforcement on 1 m of the plate are marked: Asx in the direction of the axis OX (span l1), Asy away from OY (span a l2).

As experiments in the process of deformation in the slab show, various stages are possible depending on the places of formation of cracks: above the supports, in the middle zone. Dynamic calculation of the plates, taking into account the influence of these stages, including plastic, was considered in work [12, 14, 16, 19].

2. Calculation of the plate in the elastic stage

The slab is deformed in both directions as joint areas with and without cracks, the bending moment and the torque are determined by the formulas

\[ M_x = -\beta x \frac{\partial^2 n}{\partial x^2}, \quad M_y = -\beta y \frac{\partial^2 n}{\partial y^2}, \quad M_{xy} = -\beta x y \frac{\partial^2 n}{\partial x \partial y} \]  \hspace{1cm} (1)

where \( \beta x \) and \( \beta y \) - flexural stiffness in width 1m , \( \beta xy \) - torsional stiffness in a rack with cracks is assumed to be \( \beta xy = 0,2(\beta x + \beta y) \). Using the equilibrium condition of the plate in the cracked stage, a relation representing the reaction of the internal forces is obtained.

\[ L(\omega) = \beta x \frac{\partial^4 \omega}{\partial x^4} + 2\beta x y \frac{\partial^4 \omega}{\partial x^2 \partial y^2} + \beta y \frac{\partial^4 \omega}{\partial y^4} \]  \hspace{1cm} (2)

For static and dynamic deflection, the following equations are valid.

\[ L(\omega_{st}) = q_{st} \]  \hspace{1cm} (3)

\[ L(\omega) + m \frac{\partial^2 \omega}{\partial t^2} = pf(t) \]  \hspace{1cm} (4)

Under the action of multiple pulses p=0, impulse value enters the initial condition. [20]. The static deflection from the unit load is equal to

\[ \omega_{st} = zF_1(x)F_2(y), \]  \hspace{1cm} (5)

where \( F_1(x) \), \( F_2(y) \) - forms of beam deflections: determined from the equations \( F_1^{IV} = 1, F_2^{IV} = 1 \) in the direction OX and OY. Border conditions (at \( x=0 \) and \( x=l_1, y=0 \) and \( y=l_2 \)) meet the conditions of fixing the sides of the plate. Parameter \( Z_0 \) is obtained from the expression (3)

\[ L(\omega) = (\beta x F_1 + 2\beta x y F_1 F_2 + \beta y F_2) Z_0 = 1 \]  \hspace{1cm} (6)

The use of the Bubnov-Galerkin method leads to the relation
\[ Z_0 = \frac{1}{\beta_1} \cdot \beta_1 = \beta x \frac{1}{S_2^2} + \beta xy \frac{1}{S_1^2} S_2 + \beta y \frac{1}{S_1^2} \]  

(7)

where \[ s_1^2 = \int F_1 \, dx / \int F_1^2 \, dx \]  
[ s_2^2 = \int F_2 \, dy / \int F_2^2 \, dy \]

coefficients \( \lambda_1^2 \) and \( \lambda_{22} \) equal to the frequency coefficients of the beams: when attaching the ends of the articulated pinched malleable.

\( x_1^2 = \pi^2; 22.42; 15.4; (\lambda_1 = \pi, 4, 72; 3, 92) \)

Values \( \lambda_{11}, \lambda_{22} \) take values close \( \lambda_1^2, \lambda_2^2 \).

For the function of the deflection with the same pliable fastenings, the following expressions are valid

\[ F_1(x) = \frac{1}{12} \left( \frac{x^4}{2} - lx^3 + l^2 x^2 / 2 \right) \gamma_1 + l^3 x / 2 \gamma_2 \]

where \( \gamma_1 = k^x / 2 + k \), \( \gamma_2 = l^2 / 2 + k^x \), \( k = k_l / \beta \)

(8)

\( \kappa \) - stiffness coefficient of supporting fixing.

With articulated bearings \( \kappa = 0, \gamma_1 = 0, \gamma_2 = 1 \); with rigid supports \( \kappa = \infty, \gamma_1 = 1, \gamma_2 = 0 \); with compliant supports of a particular type, when \( \kappa = 0, \gamma_1 = 3 / 4, \gamma_2 = 1 / 4 \)

With one hinge and other rigid supports

\[ F_1(x) = \frac{1}{12} \left( \frac{x^4}{2} - 5 / 4 lx^3 + 3 / 4 l^2 x^2 \right) \]

(9)

For function \( F_2(y) \) similar expressions with modified parameters are valid.

3. Dynamic plate calculation

For approximate solutions of equation (4), the dynamic deflection is represented as

\[ \omega_i(x,y,t) = \omega_0(x,y)pT_i(t) \]

(10)

where \( T_i(t) \) - dynamic function for the elastic stage. Considering that \( L \omega_i = 1 \), having \( L \omega_i = \omega f(t) \) and equations (4) is in the form

\[ pT_i(t) + \omega_0^2 S_1^2 S_2 \omega_i = \omega f(t) \]

(11)

After applying the Bubnov-Galerkin method and transformations, we obtain

\[ T_i + \omega^2 T_i \omega_i = \omega f(t) \]

(12)

where \( \omega^2 = \frac{1}{mZ_0 S_1^2 S_2^2} \) – the circular frequency of oscillation of the slab in the cracked stage, which is represented in the formula

\[ \omega^2 = B/m = \beta \gamma_1^2 S_2^2 / m \]

(13)

The generalized stiffness of a cracked slab is found using (7)

\[ \beta = \beta x \frac{l_1^2 \gamma_1^4}{\lambda_2^4} + \beta xy \frac{l_1^2 \gamma_1^2}{\lambda_1 \lambda_2^2} + \beta y \frac{l_1^2 \gamma_1^4}{\lambda_1^4} \]  

\[ 2 \beta xy \frac{l_1^2 \gamma_1^4}{\lambda_1 \lambda_2^4} \]

(14)
The maximum deflection of the slab is determined by the formula (5) in section $x_0 = l_1/2$, $y_0 = l_2/2$, where $F_1(x_0) = l_1^4/\alpha_1$, $F_1(y_0) = l_2^4/\alpha_2$: in the elastic stage without cracking will be $\beta x = \beta y = \beta xy = D$ and

$$\beta_1 = D \left( \frac{l_1^4}{\lambda_{11}} + \frac{2l_1^2 l_2^2}{\lambda_{11} \lambda_{22}} + \frac{l_2^4}{\lambda_{22}} \right)$$

Marking $\beta_2 = \frac{\beta_1}{l_2^4} = \frac{1}{\lambda_{22}} + \frac{2x^0}{\lambda_{11} \lambda_{22}} + \frac{x^4}{\lambda_{22}}$, received

$$\omega_m(x_0, y_0) = \frac{\alpha p l_1^4}{D},$$

(15)

where $\alpha_p = 1/\alpha_1 \alpha_2 \beta_2$

in the calculations it is assumed: for the hinge plate support $\lambda_{11} = \lambda_{22} = \pi^2$; for clamped plate $\lambda_{11} = \lambda_{22} = 35 = 1.56 \lambda_{10}$, $\lambda_{10} = 22.4$. For slabs with arbitrary (mixed) fixed sides with appropriate $\lambda_{10}$ the value $\lambda_{11}$ is taken by linear interpolation between the values $\pi^2$, $\lambda_{10}$, $35$ [4, 15, 17].

The solution of equation (12) consists of the sum of the total and particular solutions.

$$T_i(t) = T_i(0) \cos t + \frac{T_i(0)}{\omega} \sin \omega t + \frac{T_i(0)}{\omega^2} \cos \omega t + T_i^{(1)}(t)$$

For a particular solution with the derivative function $f(t)$, it is advisable to use the element's reaction on a single impulse $\psi(t) = \sin \omega t/\omega$.

Then

$$T_i(t) = T_i(0) \cos t + \frac{T_i(0)}{\omega} \times \sin \omega t + \omega \int_0^t f(\tau) \sin \omega t \cos \omega (t-\tau) d\tau$$

(16)

when

$$\dot{T}(t) = -\omega \sin \omega t T_i(0) + \frac{T_i(0)}{\omega} \cos \omega t + \omega^2 \int_0^t f(\tau) \cos \omega (t-\tau) d\tau$$

(17)

At zero initial conditions will be

$$T_i(t) = \omega \int_0^t f(\tau) \sin \omega (t-\tau) d\tau, \dot{T}(t) = \omega \int_0^t f(\tau) \cos \omega (t-\tau) d\tau$$

(18)

For the case of action of a constant load in time $(f(t)=1)$

$$T_i(t) = \cos \omega t, \dot{T}(t) = \sin \omega t$$

(19)

Under the action of an intensity pulse $i$ instead (10) takes

$$\omega_i(x, y, t) = \omega_i(x, y) T_i(t)$$

(20)

From the equality of the amount of movement of the plate instantaneous impulse we get

$$m \ddot{\omega} = m z_0 F_1(x) F_2(y) T_i(0) = i$$

(21)

or $m z_0 \int F_1^2 \, dx \int F_2^2 \, dy \, T_i(0) = i \int F_1 \, \int F_2$

from here $\dot{T}(0) = i \omega_i^2$

then $T_i(t) = i \omega_i \sin \omega t, \dot{T}(0) = i \omega_i^2 \cos \omega t$

(22)

As the plate deflection increases, the stress of the reinforcement and bending moments hangs, in some sections of the plate there arises a yield point in the reinforcement and, accordingly, limiting moments during hard clamping of some sides of the plate, it is possible that limiting moments occur on the supports and implementation in the plate of the elastic stage. In the general case, quite complex processes of transition from the elastic to the plastic stage are possible [10, 11, 13].

More appropriate is the method based on the representation of the end of the elastic stage through the limiting elastic deflection, which is taken equal to

$$w_0 = q \omega_i(x_0, y_0)$$
where \(x_0, y_0\) - the coordinates of the point of the plate with the maximum deflection, \(q_n\) - ultimate load determined by the method of limiting equilibrium from the ratio
\[
q_n l_1^2 / 12 (3l_2 - l_1) = (2M_1 + M_1') l_2 + (2M_2 + M_2') l_1
\] (23)

where \(M_1, M_2\) - ultimate flight moments, \(M_1, M_1', M_2, M_2'\) - extreme support points The end time of the elastic stage is found from the equations:
- for a load of finite duration
\[
pT_1(t_1) \omega_0(x_0,y_0) + q_0 \omega_0(x_0,y_0) = q_0 \omega_0(x_0,y_0)
\]
from here \(T_1(t_1) = q_n - q_{st}/p = \gamma_p\) (24)

for a constant load in time, according to (19) will be
\[
\cos \omega_1 = \gamma_p
\] (25)

- for instantaneous impulse according to (20) and (22) receive
\[
\sin \omega_1 = q_n - q_{st}/l_{st} = \gamma_i
\] (26)

Coefficients \(\gamma_p, \gamma_i\) as dynamic load factors. With their known values is the load \(q_n\), on which the construction of the element happen.

4. Calculation of the plate in the plastic stage
In the plastic stage, the plate is broken by linear plastic hinges into four hard disks. Diagonal plastic hinges taken at an angle of 45° to the sides of the plate. Then the angles of rotation of all disks are the same and denoted by \(\psi(t)\). The equation of plate motion in the plastic stage is
\[
m \ddot{\psi} = (p(t) + q_n + q_a) S
\]
where \(I = \sum l_i, S = \sum S_i, S_i J_i\) is the moment of inertia and static moment relative to the rotation of the \(i\) disk. For a rectangular disk
\[
S = bh^2 / 2 J = bh^3 / 3, \text{ for a triangular disk } S = bh^2 / 6, J = bh^3 / 12.
\]

5. Calculation on the effect of constant load
For a constant in time load will be
\[
\dot{\psi} = -A_1, A_1 = Sp / ml(\gamma_0 - 1); \varphi_{max} = \varphi_0^2 / 2A_1
\] (28)

The initial angular velocity \(\dot{\psi}_0\) is the equality of the quantities of motion at the end of the elastic and the beginning of the plastic stage.
\[
pT_1(t_1) \int \omega_0(x,y) dx dy = pT_1(t_1) p z_0 \int F_1(x) dx \int F_2(y) dy = S \dot{\psi}_0
\] (29)
\[\text{t.e } \dot{\psi}_0 = p z_0 / S \int F_1 dx \int F_2 dy T_1(t_1)
\] (30)

Denote \(\int_0^{l_1} F_1(x) dx = l_1^2 / c_1, \int_0^{l_2} F_2(y) dy = l_2^2 / c_2\) taking into account relations (3) (13); or constant in time load, taking into account dependencies (19), (25) and
\[
\dot{T}_1(t_1) = \omega \sqrt{p(2 - \gamma_p)}. \text{ Will get } \varphi_{max} = e (2 - p)(q_{nd} - q_{st}) / \gamma_p - 1,
\]
where \(e = \lambda_1^2 / c_1^2, \lambda_2^2 / c_2^2, J / 2s^3, l_1^2 l_2^2 / B_1\)
(31)

The value of the coefficients \(C1, C2\) is equal to: for elements with hinged ends, \(C1=120\) with clamped ends \(C1=720\); with flexible supports \(C1=320\); with one pinched and another articulated \(C1=320\). Similarly, it was denoted for \(C2\) [8,9].

The limiting state of the plate occurs after the maximum opening angle in plastic hinges reaches the limiting value \(\varphi_u\). In the rectangular plate under consideration, the opening angles \(\varphi_{max}\) will be equal:
\( \varphi_{\text{max}} \) -- in pinched sectional supports, \( \sqrt{2} \varphi_{\text{max}} \) -- in diagonal plastic hinges, \( 2 \varphi_{\text{max}} \) -- in flying-plastic hinge occurring at \( l_2 > l_1 \).

Denoting \( \psi_{\text{max}} = \chi \varphi_{\text{max}} \), where the parameter \( \chi \) depends on the considered section of plastic hinges.

The strength conditions of the slab are represented as

\[
\psi_{\text{max}} = \chi \varphi_{\text{max}} \leq \psi_{\text{max}}
\]

where \( \psi_{\text{u}} \) - is the limiting opening angle in the considered plastic hinge

\[
\psi_{\text{max}} = e_1 \frac{(2 - \gamma_P)(q_n - q_{st})}{\gamma_P - 1}, e_1 = \chi e
\]

For the limiting angle of disclosure \( \psi_{\text{u}} \) dependency is used

\[
\psi_{\text{u}} = \frac{K_0}{\xi}, K_0 = 0.004
\]

The relative height of the compressed zone \( \xi \) depends on the direction of the reinforcement bars in the plastic hinge [5,6,20].

Inclined plastic hinges, for example, diagonal intersecting in mutually perpendicular rods directed along the axes OX and OY, with cross-sectional areas \( A_x \) and \( A_y \) respectively. The longitudinal force in inclined section is equal to

\[
N = N_x \sin^2 \alpha + N_y \cos^2 \alpha, \quad \text{where } N_x = R_x A_x, N_y = R_y A_y
\]

where \( \alpha \) - angle between the directions \( N_x \) (OX) and inclined sections

Equilibrium condition in oblique section

\[
R_b b x = R_s \left(A_x \sin^2 \alpha + A_y \cos^2 \alpha\right), \xi = \frac{R_s}{R_c} \left(\frac{A_x}{bh_0} \sin^2 \alpha + \frac{A_y}{bh_0} \cos^2 \alpha\right)
\]

\[
= \frac{R_c}{R_c} (\mu_x \sin^2 \alpha + \mu_y \cos^2 \alpha)
\]

then

\[
\xi = \xi_1 \sin^2 \alpha + \xi_2 \cos^2 \alpha, \xi_1 = \frac{R_s}{R_b} \mu_x, \xi_2 = \frac{R_s}{R_b} \mu_y
\]

with \( \alpha = 45^\circ \), \( \xi = \frac{1}{2} (\xi_1 + \xi_2) \)

6. Calculation of base plates along the contour

6.1. Calculation of plates supported by the office

The reinforced concrete slab supported along the contour with wall dimensions \( l_1 = 4 \text{m}, \ l_2 = 6 \text{m} \), thickness \( h = 0.2 \text{m} \) (\( h_0 = 0.17 \text{m} \)). Fixing the sides: hinged at \( x = 0 \) and \( x = l_1 \), rigid at \( y = 0 \) and \( y = l_2 \). Armature class A400 of span and above-window grids with a diameter of 16mm with a step of 150 mm in a transverse direction (\( A_x = 14.07 \text{ cm}^2 \)) and with a step of 200 mm in the longitudinal direction (\( A_y = 12.06 \text{ cm}^2 \)). The calculated dynamic resistances of concrete class B30 and reinforcement are assumed to be equal.

- \( R_{bd} = 1.2 \cdot 22 = 26.4 \text{ Mpa} \), \( (E_u = 32.5 \text{ Mpa}) \), \( R_{bd} = 1.2 \cdot 400 = 480 \text{ Mpa} \)

- Static load \( q_{st} = 10 \text{ kPa} \)

- Flexural rigidity of the slab is determined by the formula

\[
B_x = 0.8 E_u A_{xx} (h_0 - x_1), B_y = 0.509 \cdot 10^4 \text{ kN} \cdot \text{m}
\]

\[
\mu_x = 8.3 \cdot 10^{-3}, \varphi_x = 0.15, \quad B_x = 0.509 \cdot 10^4 \text{ kN} \cdot \text{m};
\]

\[
\mu_y = 7.1 \cdot 10^{-3}, \varphi_y = 0.13, B_y = 0.458 \cdot 10^4 \text{ kN} \cdot \text{m};
\]

\[
B_{xy} = 0.2(B_x + B_y) = 0.19 \cdot 10^4 \text{ kN} \cdot \text{m}
\]

Frequency ratios should be equal to:

\[
\lambda_1^2 = \pi^2, \lambda_{11} = \pi^2, \lambda_2 = 22.4; \quad \lambda_{22} = 35
\]

Relevant parameters:

\[
S_1^2 = \pi^4 / 4^4 = 0.381, \quad S_2^2 = 22.4^2 / 6^4 = 0.387
\]
By the formulas $B_1 = B_x \frac{t_1}{\lambda_2} + 2B_{xy} \frac{t_1}{\lambda_{11} \lambda_{22}} + B_y \frac{t_1}{\lambda_1^4}$, we find:

$$B_1 = 3.13 \cdot 10^4 \text{kN} \cdot \text{m}, \quad m = 10 \cdot \frac{1}{g} = 1.02 \text{t/m}^2$$

$$\omega_0^2 = 0.387 \cdot 0.391 \cdot \frac{1}{1.02} \cdot 3.13 \cdot 10^4 = 0.452 \cdot 10^4, \quad \omega_n = 67.3 \text{s}^{-1}$$

Limit moments in slab sections: $M_1=M_3=0$;

$M_2 = R_x A_1 h_0 (1 - 0.6 \varphi) = 480 \cdot 10^3 \cdot 14.07 \cdot 10^4 \cdot 0.17 (1 - 0.5 \cdot 0.15) = 106.2 \text{kNm/m}$

$M_4 = M_5 = M_e = 480 \cdot 10^3 \cdot 12.06 \cdot 10^4 \cdot 0.17 (1 - 0.5 \cdot 0.13) = 92 \text{kNm/m}$

$B_1^* = 12 \cdot 6 / 4^2 \cdot 14 = 0.32; \quad B_2^* = 12 / 4 \cdot 14 = 0.214$

The maximum load is found by the formula

$$q_{ud} = \frac{8}{l^2} (M_{ud}^{(snp)} + M_{ud}^{(sn)})$$

$$q_{act} = 0.32 \cdot 2 \cdot 106.2 + 0.214 \cdot 4 \cdot 92 = 146.7 \text{kN/m}^2$$

### 6.2. Calculation of the plate on the effect of constant dynamic load

Accepted load

$$p = 120 \text{kN/m}^2, \quad y_r = \frac{136.7}{120} = 1.14$$

The end of the elastic stage $\cos \omega t_1 = -0.14; \quad \sin \omega t_1 = 0.99 \quad \omega t_1 = 1.71$

Geometric characteristics of disks

$$S = 18.66 \text{m}^2, \quad I = 21.2 \text{m}^4$$

The initial angular velocity will be

$$\varphi_0 = \frac{P L_5^5}{S B_1 C_1 C_2 \sqrt{y_0 (1 - y_0)}}$$

$$\varphi_0 = 120 \cdot 4^5 \cdot 6^5 \cdot 66 / 18.66 \cdot 120 \cdot 720 \cdot 3.13 \cdot 10^4 = 1.25 \text{sec}^{-1}$$

$$A_1^* = 120 \cdot 18.66 \cdot 0.14 / 1.02 \cdot 21.2 = 14.56; \quad \varphi_0 / A_1^* = 1.25 / 14.5 = 0.086; \quad 2\psi / uA_1^* = 2 \cdot 10^{-3}$$

According to the formula

$$\bar{t}_2 = \frac{\varphi_0}{A_1^*} - \sqrt{\left(\frac{\varphi_0}{A_1^*}\right)^2 - \frac{2\psi_0}{xA_1^*}}$$

$$\bar{t}_2 = 0.086 - \sqrt{0.086^2 \cdot 2 \cdot 10^{-3} = 0.086 - 0.074} = 0.012; \quad \omega \bar{t}_2 = 0.8$$

Cable system

$$H_1 = 480 \cdot 10^3 \cdot 14.06 \cdot 10^{-4} = 675.6; \quad \frac{H_1}{l_1^2} = 42.2$$

$$H_2 = 480 \cdot 10^3 \cdot 12.06 \cdot 10^{-4} = 579; \quad \frac{H_2}{l_2^2} = 16.08$$

$$\frac{H_1}{l_1^2} + \frac{H_2}{l_2^2} = 58.3; \quad \omega_5^2 = \frac{58.3 \cdot \pi^2}{1.02} = 567; \quad \omega_5 = 23.8 \text{sec}^{-1}$$

Angular velocity at the end of the plastic stage

$$\varphi(t_2) = -A_1^* t_2 + \varphi_0 = -14.56 \cdot 0.012 + 1.25 = 1.075$$
\[ Z_0 = \pi^2 \times 18.66 \times 1.075 / 4 \times 4 \times 6 = 2.06; \quad A = 2.06 / 23.8 = 0.0865 \quad B = 16 \cdot 130 / \pi^4 \cdot 58.3 = 0.366 \]

\[ Z_{\text{max}} = 0.366 + \sqrt{0.134 + 0.748} = 0.386 + 0.376 = 0.762 \]

\[ \varepsilon_{\text{max}} = \pi^2 \cdot 0.762^2 / 4 \cdot 4^2 = 0.0895 > \varepsilon_u = 0.084 \]

Exceeding the limit deformation is insignificant and the maximum load is close K C1=120

6.3. Calculation of the plate on the action of the instantaneous pulse

The value of the conditional impulse \( I_{\text{on}} = 850; \quad \gamma_1 = 136.7 / 850 = 0.161 \)

The end of the elastic stage \( \sin \omega t_1 = 0.161; \quad \cos \omega t_1 = 0.987; \quad \omega t_1 = 0.102 \)

The values of the geometric characteristics of plate disks: \( S = 18.66 m^3, J = 21.3 m^4 \)

The initial angular velocity determined by the formula [3,8]

\[ \phi_0 = \frac{I_{t_1} S}{S B_1 C_1 C_2 \hat{T}_1 (t_1)} \]

\[ \hat{T}_1 (t_1) = 850 \cdot 67.3 \cdot 0.987 = 5.65 \cdot 10^4 \]

\[ \phi_0 = 4.5 \cdot 65 \cdot 5.65 \cdot 10^4 / 18.66 \cdot 120 \cdot 720 \cdot 3.13 \cdot 10^4 = 8.91 \text{sec}^{-1}; \quad A_2 \]

\[ = 18.66 \cdot 136.7 / 1.02 \cdot 21.3 = 117.3; \]

The end time of the plastic stage \( \bar{t}_2 = \phi_0 / A_2 - \sqrt{\phi_0^2 / A_2^2 - 2W_0 / xy A_2} \]

\[ \bar{t}_2 = 0.076 - \sqrt{5.776 \cdot 10^{-3} - 0.247 \cdot 10^{-3}} = 0.076 - 0.0744 = 0.0016 \text{sec}; \quad \omega t_2 = 0.108 \]

Speed in the end of the plastic stage \( \dot{\phi} (t_2) = -117.3 \cdot 0.0016 + 8.31 = 8.72 \)

Speed at the beginning of the stayed stage \( Z_{\text{max}} = 0.028 + \sqrt{0.494 + 7.6 \cdot 10^{-4}} = 0.028 + 0.703 = 0.73 \text{m} \)

Checking condition \( Z(0) = Z_0 = \pi^2 / 4L_1 L_2 S \psi (t_2) / (A_1 t_2 + \phi_0); \quad \psi (t_2) = A_1 \bar{t}_2 + \phi_0 \)

\[ Z(0) = Z_0 = \frac{\pi^2}{4L_1 L_2 S} \frac{\psi (t_2)}{(A_1 t_2 + \phi_0)} \psi (t_2) = A_1 \bar{t}_2 + \phi_0 \]

if \( \gamma_p < 1 \) and \( \psi (t_2) = A_1 \bar{t}_2 + \phi_0 \), if \( \gamma_p > 1 \)

(if \( I = 0 \)) for rods long \( l_1 = 4 \text{m} \)

\[ \varepsilon_{\text{max}} = \pi^2 \cdot 0.73^2 / 4 \cdot 4^2 = 0.083 < \varepsilon_n = 0.084 \]

We define the limiting dynamic load corresponding to an instantaneous pulse. Take \( i = 0.5P_0, \theta, \omega_0 = P_0 \omega \theta \)

Dynamically, the load is represented by an instantaneous pulse at \( \omega \theta \leq \pi / 2 \). Take \( \theta = 1.5 \), then

\[ P_n = 2i \omega / \omega_0 \theta = 2 \cdot 850 / 1.5 = 1133 \text{ kN/m}^2, \]

which is substantially more than the one defined in the example 6.2 \( P=100 \text{ kN/m}^2 \)
7. Findings

1. Special dynamic loads arising in emergency situations have a high intensity and a short time of action and can lead to the destruction of structures and structures. Special requirements for structures are characterized by an emergency limit state based on the assumption in the design of short-term plastic deformations (deflections), which are determined by the calculation of structures in the elastic and plastic stages. At the same time, among special loads, two particular cases are distinguished: a constant load in time and represented as an instantaneous impulse.

2. For calculations in the elastic stage, a method is adopted that is valid for a wide class of structures (beam, slab). Obtaining the calculated dependences is reduced to the definition of the dynamism function, which depends on the circular frequency of oscillations. The calculation method was applied for arbitrary special loads, simple analytical dependencies were obtained for two particular cases of load. The end of the elastic stage is determined from the condition of the design reaching the ultimate elastic deflection.

3. In the plastic stage, the structure is broken up by plastic hinges into hard disks so that it turns into a mechanism. The calculated dependence is obtained for a flat element of arbitrary configuration in the plan and divided into hard disks of trapezoidal shape. Linear plastic hinges are on the intersection of the discs between themselves and with the contours of the element. Displacements of all disks are expressed through the deflection of the upper contour for which the equation of motion is obtained. The solution of this equation is given for an arbitrary special load and for two special cases.

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