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EFFECT OF PULSED LOAD FORM ON RETAINED DEFLECTIONS OF RIGIDLY-PLASTIC PLATES OF A COMPLEX SHAPE

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Plates with a complex shape are used extensively in structures subject to intense pulsed loads. In order to predict the degree of plate damage under the action of dynamic loading it is important to know the effect of the nature of change in load with time on finite displacements.

All known solutions of this problem only concern rigidly-plastic round freely-supported plates [1-4]. It is concluded in [1, 4] that there is an insignificant dependent of retained plate deflection on the form of pulsed load although this is done on the basis of partial calculations with limited changes in values of operating loads. In [2, 3] after considering the whole possible range of loads it is concluded that the form of load may have a marked effect in retained deflections for round hinged plates.

In this work simple analytical expressions are obtained on the basis of results in [5, 6] for maximum retained deflection of a rigidly-plastic plate with a complex shape. The effect of load pulse form on plate retained deflection is studied. A simple procedure is suggested which makes it possible to evaluate the damage for complex shaped plates under the action of an arbitrary dynamic load of high intensity. We consider an ideally rigidly-plastic plate under the action of a uniformly distributed arbitrary dynamic short-term load of intensity $P(t)$ distributed over the surface. In shape this may be a regular polygonal plate, a round plate, a regular polygonal plate with rounded tips or a plate obtained from the latter by changing the mutual position of the rounded and rectilinear sections of the shape, and also an irregular polygonal plate on whose shape it is possible to inscribe a circle (Fig. 1). We assume the contour of the plate is hinged or restrained. All of these plates have similar dynamic behavior which has been considered in detail in [5, 6]. With quite a high level of loads plate dynamics may be accompanied by the occurrence, development, and disappearance of zones of intense plastic deformation I_p moving progressively. The equations which describe the dynamic behavior of such a plate have the form [5, 6]

$$\delta^3(4-3\delta)\ddot{\alpha} = 2p_1(\tau)\,\delta^2(3-2\delta) - m_0; \tag{1}$$

$$(\delta\dot{\alpha})^{\cdot} = p_1(\tau), \tag{2}$$

where $p_1 = P/r$; r is the radius of a circle drawn on the polygonal contour or the radius of a round plate; a period means differentiation with respect to dimensionless time $\tau = t/t_0$; t_0 is characteristic time; $m_0 = 12\,M_0\,t_0^2(2-\eta)/(\rho r^3)$ for regular polygonal, round, and irregular plates on whose contour it is possible to draw a circle; $m_0 = 12\,M_0\,t_0^2(\mathrm{ctg}\varphi + \psi)(2-\eta)/[\mathrm{ctg}\varphi + \psi/\sin^2\varphi)\rho r^3]$ for polygonal plates with rounded tips; ρ is plate material surface density; M_0 is the limiting bending moment; $\eta = 0$ with a restrained contour; $\eta = 1$ with hinging; α is the angle of deviation for a rigid region I from the horizontal; $\delta = \delta(\tau)$ is a dimensionless parameter which characterizes the size of the central plastic region I_p (Fig. 1, where $|AO| = r$, $|AD| = \delta r$, $\angle OBA = \varphi$, $\angle BOC = \psi$, $\angle OAB = 90°$).

Deflection W at the center of a circle drawn on a polygonal contour (point O, Fig. 1) is determined from the relationship

$$\dot{w} = \delta\dot{\alpha} \qquad (w = W/r). \tag{3}$$

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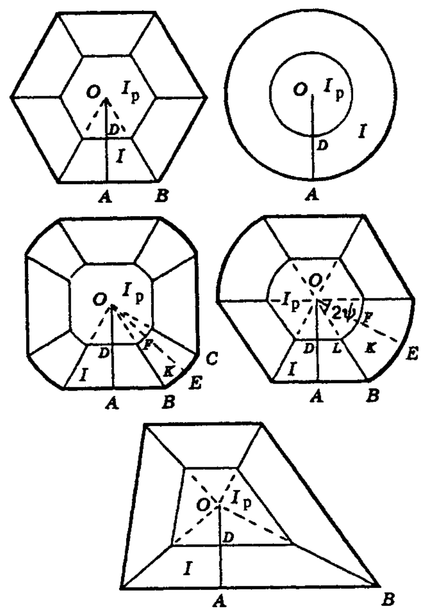

Fig. 1

Initial conditions for α and w are as follows:

$$\alpha(0) = \dot{\alpha}(0) = w(0) = \dot{w}(0) = 0. \tag{4}$$

In order to determine the limiting static load $\ddot{\alpha} = 0$ should be adopted in Eq. (1). Then the limiting load is determined from the condition

$$p_1^0 = \min p_1 = \min_{0<\delta\leqslant 1} m_0/[2\delta^2(3-2\delta)] = m_0/2. \tag{5}$$

Here the plastic zone I_p degenerates to point O.

Let us in a section of time $0 \leq \tau \leq \tau_1$ (first phase) have $p_1(\tau) \leq p_1^0$ (low loads), then in this period of time the plate retains an undeformed state and it remains at rest.

We determine the state of a plate at the instant of the start of its movement. By integrating (2) taking account of the notation $\dot{\alpha}(\tau_k) = \dot{\alpha}_k$, $\alpha(\tau_k) = \alpha_k$, $\delta(\tau_k) = \delta_k$, we find that

$$\delta\dot{\alpha} = J_k(\tau) + \delta_k\dot{\alpha}_k, \quad J_k = \int_{\tau_k}^{\tau} p_1(s)\,ds, \quad k = 0, 1, 2, \ldots,$$

where τ_k is the time at which the plastic zone I_p exists in an undegenerated form. By using this equality and excluding $\ddot{\alpha}$ from (1) and (2) we obtain

$$[\delta^2(2-\delta)(J_k + \delta_k\dot{\alpha}_k)]^{\cdot} = m_0 = 2p_1^0,$$

whence

$$\delta^2(2-\delta) = [2p_1^0(\tau - \tau_k) + \delta_k^3(2-\delta_k)\dot{\alpha}_k](J_k + \delta_k\dot{\alpha}_k)^{-1}. \tag{6}$$

From (6) it follows that with $k = 1$

$$\lim_{\tau\to\tau_1} \delta^2(2-\delta) = \delta_1^2(2-\delta_1) = 2p_1^0/p_1(\tau_1).$$

Whence it can be seen that $\delta_1 < 1$ with $p_1(\tau_1) > 2p_1^0$ and $\delta_1 \geq 1$ with $p_1(\tau_1) \leq 2p_1^0$. This means that if the load is such that $p_1(\tau_1) > 2p_1^0$ ("high" load) then plate movement commences with a developed plastic zone I_p and it will be described by system (1)-(3) with initial conditions $\delta = \delta_1$ and (4).

With load $p_1^0 < p_1(\tau_1) \leq 2p_1^0$ (since in a sense δ cannot exceed values equal to one) it may be assumed that plate movement commences with absence of a plastic zone and it will be described by Eq. (1) with $\delta = 1$.

We consider in detail plate movement under the action of a load an "impact" type increasing from zero and then falling. In this case in the second phase ($\tau_1 \leq \tau \leq \tau_2$) with consideration of initial conditions $\alpha(\tau_1) = \dot{\alpha}(\tau_1) = 0$, $\delta = 1$ we have

$$\begin{gathered}\dot{\alpha}(\tau) = 2J_1(\tau) - 2p_1^0(\tau-\tau_1), \qquad \alpha(\tau) = 2Y_1(\tau) - p_1^0(\tau-\tau_1)^2, \\ \dot{w}(\tau) = \dot{\alpha}(\tau), \qquad w(\tau) = \alpha(\tau),\end{gathered} \tag{7}$$

where $Y_k(\tau) = \int\limits_{\tau_1}^{\tau} J_k(s)ds$ $(k = 1, 2, \ldots)$.

We determine the end of this phase corresponding to the start of forming zone I_p. From (6) with $k = 2$, $\delta_2 = 1$ we find that

$$\delta\,\dot{\delta}\,(4-3\delta) = \frac{2p_1^0(J_2+\dot{\alpha}_2) - [2p_1^0(\tau-\tau_2)+\dot{\alpha}_2]\,p_1(\tau)}{(J_2+\dot{\alpha}_2)^2},$$

whence it follows that with $p_1(\tau_2) = 2p_1^0$ the equality $\dot{\delta}(\tau_2) = 0$ is fulfilled and with $p_1(\tau) > 2p_1^0$ and $\delta(\tau) < 1$ the inequality $\dot{\delta}(\tau) < 0$ is correct. Since $\delta \leq 1$, then δ starts to decrease which corresponds to an increase in zone I_p at instant of time τ_2 satisfying the condition τ_2 satisfying the condition $p_1(\tau_2) = 2p_1^0$. With $\tau = \tau_2$

$$\begin{gathered}\dot{\alpha}(\tau_2) = 2J_1(\tau_2) - 2p_1^0(\tau_2-\tau_1), \quad \alpha(\tau_2) = 2Y_1(\tau_2) - p_1^0(\tau_2-\tau_1)^2, \\ \dot{w}(\tau_2) = \dot{\alpha}(\tau_2), \qquad w(\tau_2) = \alpha(\tau_2).\end{gathered} \tag{8}$$

During the third phase ($\tau_2 < \tau \leq \tau_3$) movement occurs with a developed plastic zone I_p which may increase reaching its maximum size, and then it starts to contract to complete disappearance. Movement is described by set (1)-(3) with initial conditions $\delta(\tau_2) = 1$, $\dot{\alpha}(\tau_2) = \dot{\alpha}_2$, $\alpha(\tau_2) = \alpha_2$, $\dot{w}(\tau_2) = \dot{w}_2$, $w(\tau_2) = w_2$.

As a result of this we obtain

$$\begin{gathered}\dot{\alpha}(\tau) = \delta^{-1}[\dot{\alpha}_2 + J_2(\tau)], \qquad \alpha(\tau) = \int\limits_{\tau_2}^{\tau}[\dot{\alpha}_2 + J_2(s)]\delta^{-1}ds + \alpha_2, \\ \delta^2(2-\delta) = [2p_1^0(\tau-\tau_2)+\dot{\alpha}_2](J_2+\dot{\alpha}_2)^{-1}, \\ \dot{w}(\tau) = \dot{w}_2 + J_2(\tau), \qquad w(\tau) = \dot{w}_2(\tau-\tau_2) + Y_2(\tau) + w_2.\end{gathered} \tag{9}$$

It can be seen from (9) that with $\tau > \tau_2$ and $G(\tau) < 0$, where

$$G(\tau) = 2p_1^0[J_2(\tau)+\dot{\alpha}_2] - [2p_1^0(\tau-\tau_2)+\dot{\alpha}_2]p_1(\tau),$$

we have $\dot{\delta}(\tau) < 0$, and consequently plastic zone I_p increases, but with $G(\tau) > 0$ then I_p decreases and at instant $\tau_m > \tau_2$, when $G(\tau_m) = 0$, the plastic region reaches its maximum size.

At instant τ_3 there is contraction of zone I_p to point 0 when $\delta(\tau_3) = 1$. Then time τ_3 in accordance with (9) is determined from the condition

$$J_2(\tau_3) = 2p_1^0(\tau_3 - \tau_2). \tag{10}$$

At the end of the third movement phase

$$\dot{\alpha}(\tau_3) = \dot{\alpha}_2 + J_2(\tau_3), \qquad \alpha(\tau_3) = \int\limits_{\tau_2}^{\tau_3} [\dot{\alpha}_2 + J_2(\tau)]\, \delta^{-1}(\tau)\, d\tau + \alpha_2.$$

For the deflection at point O considering (8) and (10) and the relationship

$$Y_k(\tau) = \int\limits_{\tau_k}^{\tau} \left(\int\limits_{\tau_k}^{\theta} p_1(s)\, ds \right) d\theta = \tau J_k(\tau) - \int\limits_{\tau k}^{\tau} s p_1(s)\, ds,$$

we have

$$\dot{w}(\tau_3) = \dot{w}_2 + J_2(\tau_3) = J_1(\tau_2) + J_2(\tau_3) - 2\, p_1^0(\tau_2 - \tau_1),$$

$$w(\tau_3) = w_2 + \dot{w}_2(\tau_3 - \tau_2) + Y_2(\tau_3) = -\int\limits_{\tau_1}^{\tau_2} s p_1(s)\, ds - \int\limits_{\tau_1}^{\tau_3} s p_1(s)\, ds - p_1^0(\tau_2 - \tau_1)^2 +$$

$$+ 2\tau_2 J_1(\tau_2) + \tau_1 J_2(\tau_3) + J_2(\tau_3)[J_1(\tau_2) + J_1(\tau_3)]/(2p_1^0).$$

The fourth phase ($\tau_3 < \tau \le \tau_4$) occurs with degeneration of zone I_p to complete stopping of the plate. Movement is described by set (1)-(3) with $\delta = 1$. As a result of this we obtain

$$\begin{aligned}
&\dot{\alpha}(\tau) = \dot{\alpha}_3 + 2J_3(\tau) - 2p_1^0(\tau - \tau_3),\\
&\alpha(\tau) = \alpha_3 + 2Y_3(\tau) - p_1^0(\tau - \tau_3)^2 + \dot{\alpha}_3(\tau - \tau_3),\\
&\dot{w}(\tau) = \dot{w}_3 + 2J_3(\tau) - 2p_1^0(\tau - \tau_3),\\
&w(\tau) = w_3 + 2Y_3(\tau) - p_1^0(\tau - \tau_3)^2 + \dot{w}_3(\tau - \tau_3).
\end{aligned}$$

From the condition $\dot{\alpha}(\tau_4) = 0$ the time for stopping is determined $\tau_4 = \tau_1 + J_1(\tau_4)/p_1^0$ [$J_1(\tau_4)$ is the total load pulse]. It can be seen that the time for cessation of movement does not depend on the form of the loading function and it is determined by its total pulse.

Retained deflection at point O

$$w_f = w(\tau_4) = J_1^2(\tau_4)/p_1^0 - J_2^2(\tau_3)/(4p_1^0) - 2\int\limits_{\tau_1}^{\tau_4} (\tau - \tau_1) p_1(\tau)\, d\tau + \int\limits_{\tau_2}^{\tau_3} (\tau - \tau_2) p_1(\tau)\, d\tau \tag{11}$$

and in the case of a hinged round plate it conforms with the deflection obtained in [3].

For "moderate" loads $p_1^0 < p_1(\tau) \le 2p_1^0$ time τ_2 corresponds to the instant of plate stopping and movement is described by Eq. (7). Time τ_2, determined from the condition $\bar{\alpha}(\tau_2) = 0$, satisfies the relationship

$$\tau_2 = \tau_1 + J_1(\tau_2)/p_1^0$$

and as can be seen it does not depend on pulse form. Retained deflection at point O

$$w_f = w(\tau_2) = J_1^2(\tau_2)/p_1^0 - 2\int\limits_{\tau_1}^{\tau_2} (\tau - \tau_1) p_1(\tau)\, d\tau \tag{12}$$

and for a hinged round plate it conforms with the result in [3].

In the case of a rectangular pulse of "moderate" load p_1 = const, $p_1^0 < p_1 \leq 2p_1^0$ with $0 \leq \tau \leq \tau_k$ the retained deflection of point O

$$w_f = [p_1^2(1 - p_1^0/p_1)/p_1^0]\tau_k^2.$$

With a dynamic load of high intensity arising instantaneously at the initial instant and then decreasing ("explosive" type) $p_1(0) > 2p_1^0$ the plastic zone I_p forms and it has the maximum size at the initial instant. Here within the structure described above the solution for the first and second phase of movement is discarded, it is assumed that $\tau_1 = \tau_2$, $\dot\alpha(\tau_2) = \alpha(\tau_2) = \dot w(\tau_2) = w(\tau_2) = 0$ and the initial value $\delta_0 = \delta(\tau_1)$ is determined from the equality

$$\delta_0^2(2 - \delta_0) = 2p_1^0/p_1(\tau_1),$$

obtained from (6) with the limited transition $\tau \to \tau_1$ with $k = 1$. The retained deflection at point O

$$w_f = 3J^2/(4p_1^0) + \tau_1 J - \int_{\tau_1}^{\tau_4} \tau p_1(\tau)\,d\tau, \tag{13}$$

where $J = \int_{\tau_1}^{\tau_4} p_1(\tau)d\tau$ is the total load pulse.

In the case of an arbitrary dynamic short-term load with very high amplitude it is possible to ignore action of the load in time intervals $\tau_1 \leq \tau \leq \tau_2$ and $\tau_3 \leq \tau \leq \tau_4$, then it may be assumed that

$$\tau_2 \approx \tau_1, \quad J_2(\tau_3) \approx J, \quad \int_{\tau_2}^{\tau_3}(\tau - \tau_2)p_1(\tau)\,d\tau \approx \int_{\tau_1}^{\tau_4}(\tau - \tau_1)p_1(\tau)\,d\tau,$$

and the maximum retained deflection (11) is also determined approximately by Eq. (13).

For a rectangular pulse of high load p_1 = const, $p_1 > 2p_1^0$ within the whole time of pulse operation $\delta(\tau) = \delta_0$, and instant τ_m corresponds to the instant of load removal τ_k. Here the maximum retained deflection

$$w_f = [p_1^2(1{,}5 - p_1^0/p_1)/(2p_1^0)]\tau_k^2.$$

We consider expression (13) for the maximum retained deflection in detail. We shall assume that $\tau_1 = 0$ and the load is removed at instant τ = T. Then

$$w_f = 3J^2/(4p_1^0) - J^*. \tag{14}$$

Here $J = \int_0^T P_1(\tau)d\tau$ is the total pulse; $J^* = \int_0^T \tau p_1(\tau)d\tau$.

We can see that the maximum retained deflection depends not only on the total pulse J, but also on J^*. This dependence for maximum retained deflection on J and J^* for round hinged plates was noted in [3].

Thus, if the different forms of pulse are such that they have the same integral characteristics J and J^*, then the plates of complex shape in question after action on them of such pulsed loads have the same maximum deflections calculated by Eq. (14). In addition, calculations in a computer showed that the retained deflections will conform for all points of a plate. Deflections at all points of a plate $\bar w(x, y, \tau)$ are calculated by the equations

$$\bar w(x, y, \tau) = w(\tau), \qquad (x, y) \in I_p,$$

$$\overline{w}(x,y,\tau)=d(x,y)r^{-1}\int_{\tau_k}^{\tau}\dot{\alpha}(s)\,ds+\overline{w}(\tau_n),\quad (x,y)\in I,\quad n=0,1,2,\ldots,$$

where $d(x, y)$ is the distance from point (x, y) to the supported side of region I (Fig. 1). In region K for a plate with rounded tips the deflection over line EF equals the deflection over LB of region I (Fig. 1).

Given in Fig. 2 is the retained deflection of a square hinged plate with different forms of load function which have the same integral characteristics $\bar{J} = 18$, $\bar{J}^* = 9$ ($\bar{J} = (r^2/M_0)\int_0^1 P(\tau t_0)d\tau$, $\bar{J}^* = (r^2/M_0)\int_0^1 \tau P(\tau t_0)d\tau$) and corresponding to lines 1-5 in Fig. 3:

$$1)\quad \frac{r^2}{M_0}P(\tau t_0)=\begin{cases}18, & 0\leqslant\tau\leqslant 1,\\ 0, & \tau>1;\end{cases}$$

$$2)\quad \frac{r^2}{M_0}P(\tau t_0)=\begin{cases}24(1-2\tau/3), & 0\leqslant\tau\leqslant 1,\\ 0, & \tau>1;\end{cases}$$

$$3)\quad \frac{r^2}{M_0}P(\tau t_0)=\begin{cases}P_{\max 3}\,\mathrm{e}^{-\tau/T_3}, & 0\leqslant\tau\leqslant T_3,\\ 0, & \tau>T_3,\end{cases}$$

$$P_{\max 3}=36\,\mathrm{e}\,(\mathrm{e}-2)/(\mathrm{e}-1)^2\approx 23{,}8,\quad T_3=(\mathrm{e}-1)/[2(\mathrm{e}-2)]\approx 1{,}2;$$

$$4)\quad \frac{r^2}{M_0}P(\tau t_0)=\begin{cases}(P_{\max 4}-12)\tau/T_4+12, & 0\leqslant\tau\leqslant T_4,\\ 0, & \tau>T_4,\end{cases}$$

$$P_{\max 4}=12(1+\sqrt{2})\approx 28{,}97,\quad T_4=3/(2+\sqrt{2})\approx 0{,}879;$$

$$5)\quad \frac{r^2}{M_0}P(\tau t_0)=\begin{cases}12(-3\tau^2+3\tau+1), & 0\leqslant\tau\leqslant 1,\\ 0, & \tau>1.\end{cases}$$

In the case of a moderate load expression (12) for the maximum retained deflection (if it is assumed that $\tau_1 = 0$ and T is the time of load removal) takes the form

$$w_f=J^2/p_1^0-2J^*. \tag{15}$$

For a load of any form it is always possible to select a load equivalent to it with a rectangular pulse so that retained deflections at all points of a plate after the action of these loads coincide. Here the amplitude of a rectangular pulse $p_1 = J^2/(2J^*)$, and the time of load operation $T = 2J^*/J$. The maximum retained deflections will be calculated by Eq. (14) for a high load and by Eq. (15) for a moderate load.

It follows from Eq. (14) that with a condition of a constant overall pulse J we obtain the greatest retained deflection for a load of an ideal pulse when the load is described by the Dirichlet function:

$$\lim_{\tau\to+0}p_1(\tau)=\begin{cases}+\infty, & \tau=0,\\ 0, & \tau\neq 0\end{cases}\qquad\text{with}\qquad \lim_{T\to+0}\int_0^T p_1(\tau)\,d\tau=J.$$

In fact, in this case for J^* we have

$$0\leqslant J^*=\int_0^T\tau p_1(\tau)\,d\tau\leqslant T\int_0^T p_1(\tau)\,d\tau=TJ\underset{T\to 0}{\to}0,\quad J^*=0.$$

Then from (14) we obtain

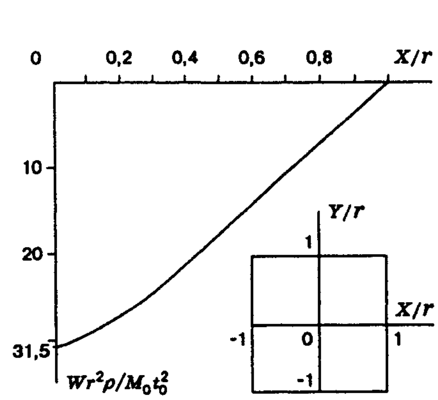

Fig. 2

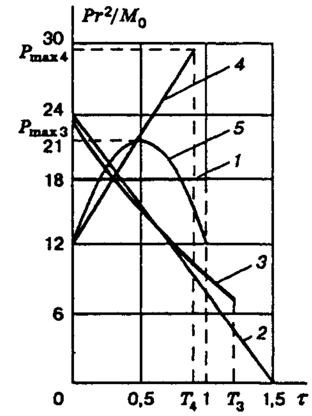

Fig. 3

$$w_f = 3J^2/(4p_1^0). \tag{16}$$

With a pulsed load for hinged round and square plates Eq. (16) conforms with the results obtained in [9, 10].

We show that for an arbitrary dynamic load and a constant total pulse J there is no direct dependence of retained deflection on maximum load. We consider two functions with the same J and maximum loads $p_{1\,\max}$ (lines a and b in Fig. 4):

$$1)\quad p_{1a}(\tau) = \begin{cases} p_{1\max} - \tau(p_{1\max} - p_{1T})/T, & 0 \leqslant \tau \leqslant T, \\ 0, & \tau > T, \end{cases}$$

$$p_{1T} = p_{1a}(T) > 2p_1^0, \quad p_{1\max} = p_{1a}(0) > 2p_1^0;$$

$$2)\quad p_{1b}(\tau) = \begin{cases} p_{1T} + \tau(p_{1\max} - p_{1T})/T, & 0 \leqslant \tau \leqslant T, \\ 0, & \tau > T. \end{cases}$$

Then

$$J_a^* = \int_0^T \tau p_{1a}(\tau)\,d\tau = (p_{1\max} + 2p_{1T})T^2/6,$$

$$J_b^* = \int_0^T \tau p_{1b}(\tau)\,d\tau = (2p_{1\max} + p_{1T})T^2/6,$$

and since $p_{1T} < p_{1\,\max}$, then $J_a^* < J_b^*$, and consequently in view of (14) the retained deflection in case 1 will be greater than in case 2.

In [11] for a hinged beam, a hinged round plate, and a round cylindrical shell secured by rigid ends loaded by uniformly distributed external pressure varying with time, a procedure is suggested for estimating the level of structural damage for different forms of load pulse based on a single characteristic curve for parameters $(p_e/p_1^0,\ J/J_0)$ (Fig. 5):

$$\begin{aligned} &6(J/J_0)^2(1 - p_1^0/p_e)/5 = 1, \quad 1 \leqslant p_e/p_1^0 \leqslant 2, \\ &(J/J_0)^2[1 - 4p_1^0/(5p_e)] = 1, \quad p_e/p_1^0 > 2. \end{aligned} \tag{17}$$

Here p_1^0 is the limiting load for the structure in question; p_e is the effective force calculated by the equation

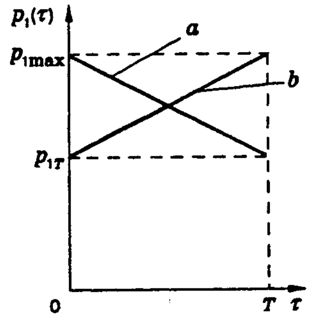

Fig. 4

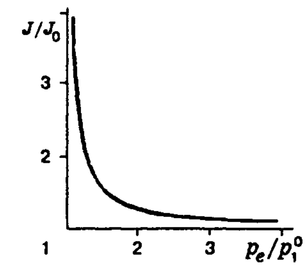

Fig. 5

$$p_e = J^2\left[2\int_{\tau_0}^{\tau_f}(\tau-\tau_0)p_1(\tau)\,d\tau\right]^{-1}; \tag{18}$$

J is total load pulse:

$$J = \int_{\tau_0}^{\tau_f} p_1(\tau)\,d\tau; \tag{19}$$

τ_0 and τ_f are the time for the start and finish of structural deformation; J_0 is an ideal pulse after whose action on the structure it acquires the critical maximum deflection w_c of interest to us.

In order to determine whether the structure reaches the critical maximum deflection w_c after action on it of an arbitrary load it is necessary to calculate the values p_e, p_1^0, J, and J_0. If a point $(p_e/p_1^0, J/J_0)$ lies below the characteristic curve, then the maximum retained deflection will be less than the critical w_c.

Since expression for maximum retained deflection of the plate in question with a complex shape (11) and (12) under the action of an arbitrary dynamic load conform with expressions for retained deflection of the center of a round plate, then it is possible to expand the class of structures for which single characteristic curve (17) is constructed.

Thus, in order to estimate whether the maximum retained deflection w_f is reached for the plate in question with a complex shape the critical prescribed value w_c as a result of the action of dynamic load $p_1(\tau)$ it is necessary with respect to w_c to determine the ideal pulse J_0 by Eq. (16) causing this deflection. Then we calculate the total pulse of the operating load by (19) and the effective force p_e by Eq. (18). If a point $(p_e/p_1^0, J/J_0)$ lies below the characteristic curve (Fig. 5), then retained deflection w_f will be less than the critical w_c.

This method for preliminary estimation of the level of damage for structures may be used successfully for a broad class of engineering calculations.

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