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Actions of explosive loads of the protecting designs taking into account vibration combustion

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Abstract. Emergency explosions inside room (EIR) cause significant damage. The public increasingly reacts to them. The resident and industrial buildings are not counted on the action EIR in Russia despite the fact that industrial buildings can be recognized explosive. The use of safety structures (SS) is the only way to reduce the impact EIR. The action of SS is studied experimentally and theoretically exclusively for case of a quasistationary explosion and constant burning rate . In presented article the influence of the acceleration of burning and wave effects on the formation of explosive loads on the enclosing structures at EIR is studied. In particular, vibrational combustion is studied that generates standing waves and case of acceleration of combustion with the formation of blast wave. Standing nonlinear acoustic waves are generated against the back-ground of excess pressure and the outflow of gases at vibrational combustion. The pressure in standing waves is approximated by the sine. The frequency of oscillations corresponds to the basic mode of oscillation of the volume of hot explosive products. The amplitude of the oscillations depends on the geometric shape of the volume and the rate of explosive combustion at the onset of vibration combustion. Pressure perturbation from vibrational combustion are superimposed on the pressure profile of a triangular shape at the moment of maximum pressure. Profile is characterized by rise time and pressure drop time. So the formed lead acts on a system with elastic deformation with a concentrated mass. The maximum deformation and the coefficient of dynamism of the system are determined depending on the ratio of the frequency of the pressure oscillations in the acoustic oscillations of the rise and fail time of pressure, and frequency of natural oscillations of the system. The obtained results make it possible to clarify the calculation of the bearing capacity of buildings.

1. Introduction

The emergency explosions of combustible gases and vapors in rooms cause the significant damage.

The public reacts to them more and more painfully. The residential and production buildings are not calculated on action of the emergency explosions.

The depressurization through open apertures is the single measure for decrease in damage from internal explosions. This measure is effective in case explosion has quasistatic character, that is there are no wave effects.

The last condition is satisfied in case explosive combustion happens to low speed and pressure manages to be leveled on all volume and when change of burning rate happens rather smoothly.

Pressure gradient in volume is absent. In case of the quasistatic nature of explosion change of the current pressure in volume defines explosive loads of the protecting designs.

From the protecting effort designs through communications are transferred to load-bearing frames. The last pay off on a carrying capacity on the chosen limiting condition. In the modern practice calculation of building constructions on the equivalent dead loads is widespread. The basis of this method is data of action of an actual inertial reaction to static, causing equal deformation [1-5].

Actual explosive loadings replace model, for example, triangular. Further the resilient or elasto-plastic system is counted on action of this model loading. Determine the equivalent dead load by the maximal deformation of system.

2. Materials and Methods

The concept of the equivalent dead load is inseparably linked with character of an inertial reaction. As the law of change of an inertial reaction in time at the emergency gas explosions, often apply loading with the linear increase and and recession in time:

$$\Delta P(t) = \Delta P_{\max} f(t) \tag{1}$$

Where f(t) - function of change of an inertial reaction in time:
in [3,4] it is recommended

$$f(t) = \begin{cases} \dfrac{t}{\theta_1}, 0 \le t \le \theta_1 \\ 1 - \dfrac{t-\theta_1}{\theta_2}; \theta_1 < t \le \theta_1 + \theta_2 \\ 0, t > \theta_1 + \theta_2 \end{cases} \tag{2}$$

Here ΔP_{max} – the maximal value of an inertial reaction, θ_1 и θ_2 – building-up period and pressure decay, fig. 1.

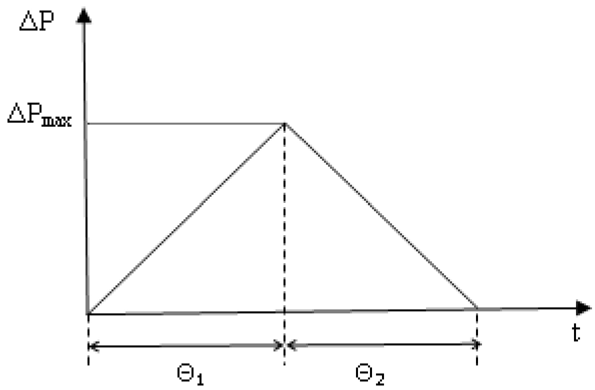

Figure 1- The law of change of explosive loading at quasistatic explosion

When calculating on a resistance the basic is calculation of a carrying capacity. At the same time designs are considered in a stage of development of plastic strains up to destruction. In this work it is considered only elastic deformations.

The dynamic effect of influence of explosive load of a design significantly depends:
1) from time of its response to explosive loading, characterized by the dimensionless parameter $\omega\theta_1$;
2) relation θ_2/θ_1 recession and increase of pressure of explosion.

In [6-12] cases when the quasistationary mode of explosion suddenly gains wave character are considered. The maximal pressure of explosion (fig. 1) is reached at the moment corresponding to the maximal area of the combustion front. Then the area of a flame because of contact with volume walls sharply decreases. The permission wave which revolts the flame front is as a result generated, burning rate increases and the wave of compression is generated. The strong acoustic vibrations which are imposed on quasistatic pressure are as a result formed. In fig. 2 the typical indicator diagram of explosion with vibration combustion is presented.

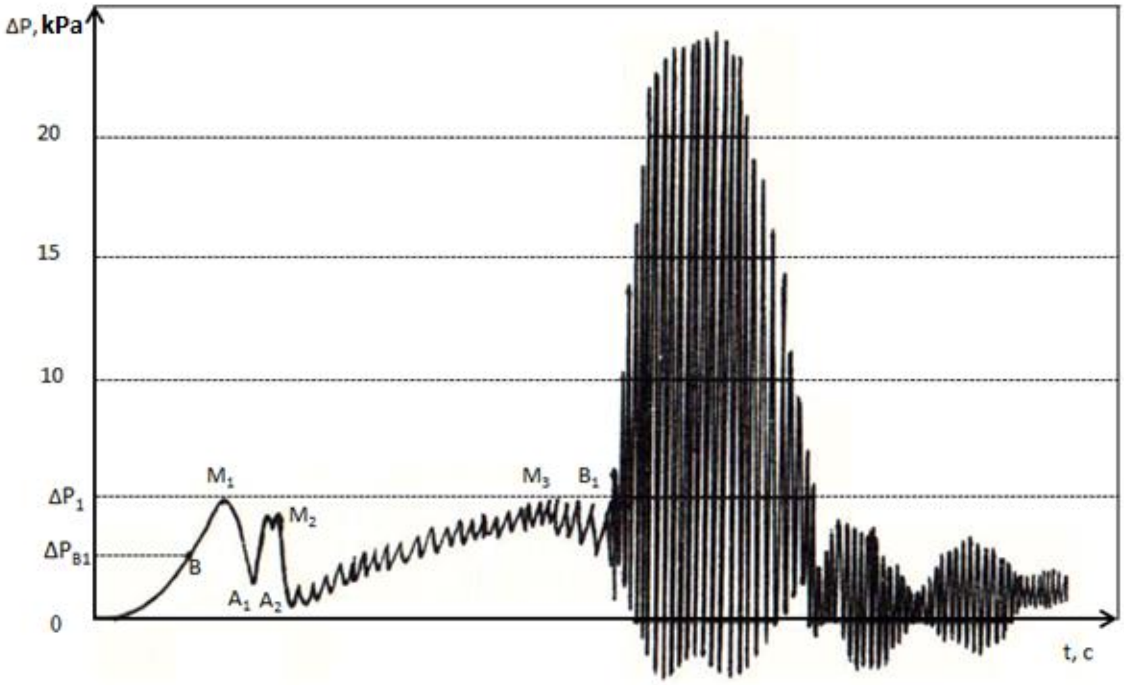

Figure 2- The oscillogram of internal explosion with vibration combustion

Such chart can be submitted function:

$$f_1 = \begin{cases} \dfrac{t}{\theta_1}, 0 \le t \le \theta_1 \\ \left(1 - \dfrac{t'}{\theta_2}\right) + \dfrac{\Delta P_1}{\Delta P_{\max}} \sin(\Omega t'); 0 < t' \le \theta_2 \\ 0, t' > \theta_2 \end{cases} \tag{3}$$

Deformation of resilient system is described by the equation

$$\ddot{X} + \omega^2 X = \Delta P_m f_1(t) \tag{4}$$

X (t) – deformation, ω - the frequency of eigentones of a design.

The solution of the equation (4) with starting conditions also $X(0) = 0$ and $\dot{X}(0) = 0$ has an appearance:

$$X(t) = \frac{\Delta P_m}{k}\left(\frac{t}{\theta_1} - \frac{\sin \omega t}{\omega \theta_1}\right), t \le \theta_1$$

$$\dot{X}(t) = \frac{\Delta P_m}{k\theta_1}\left(1 - \cos \omega t\right), t \le \theta_1 \tag{5}$$

At $t > \theta_1$, the decision can be written down in a look:

$$X(t') = A\sin\omega t' + B\cos\omega t' + \frac{\Delta P_m}{k}\left(1 - t'/\theta_2\right) + \frac{\Delta P_1}{k}\frac{\sin\Omega t'}{1-\Omega^2/\omega^2} \tag{6}$$

$$A = \frac{\Delta P_m}{k\omega\theta_1}\left(1 - \cos\omega\theta_1 + \frac{\theta_1}{\theta_2} - \frac{\Delta P_1}{\Delta P_m}\frac{\Omega\theta_1}{1-\Omega^2/\omega^2}\right) \tag{7}$$

$$B = -\frac{\Delta P_m}{k}\frac{\sin\omega\theta_1}{\omega\theta_1}$$

In expressions (6) and (7) time of t' considered from $t=\theta_1$, that is at $t=\theta_1, t'=0$.

At $t=\theta_1, t'=0$ the decision (5) and (6-7) are combined.

In (6) and (7) Ω - the frequency of acoustic vibrations.

$\Omega = \frac{C}{2L}$, where C – acoustic speed in a gaseous fluid at vibration combustion, L – the room size.

Results of calculations of conditions of deformation of the system described by the equation (4) at various values of defining parameters are presented in table 1.

Treat the last $\omega\theta_1; \frac{\theta_1}{\theta_2}$ and Ω/ω. Influence of parameters $\omega\theta_1$.

and $\frac{\theta_1}{\theta_2}$ at a size of the equivalent dead loads it was investigated in [13-16] earlier.

Influence of parameter Ω/ω was not investigated.

Follows from decisions (6) and (7) that influence of parameter Ω/ω most strongly affects at $\Omega/\omega \to 1$ (resonance). Actual designs have frequency ω usually less than Ω. For rooms of the big size the frequency of Ω decreases and comes nearer to ω. In rooms of the different size in case of vibration combustion first of all designs with a frequency of eigentones of the acoustic waves, most close to an oscillation frequency, are exposed to destruction.

3 Results

Results of calculations for various values t', that is for various conditions of impact of vibrations (top the left-hand corner) and for conditions corresponding to influence of triangular loading without vibration are presented in table 1 in an of every line. Comparison of these data allows to draw the following conclusions:

1) the acoustic waves caused by vibration combustion increase the maximal deformation of designs $\left(\frac{\Omega^2}{\omega^2} - 1\right)$;

2) the maximal deformation occurs the earlier, than less difference, the maximal value of deformation not monotonically depends on a difference $\left(\frac{\Omega^2}{\omega^2} - 1\right)$.

Such behavior of deformation is explained by the resonance phenomena at $\left(\frac{\Omega^2}{\omega^2} - 1\right)$ and height coefficient A at $\cos\omega\theta_1 \to -1$ and $\sin\omega t' \to 1$.

Table 1. Results of calculations of the conditional deformation of designs depending on parameters of loading and design

t'	$1/60*\theta_2$	$1/50*\theta_2$	$1/40*\theta_2$	$1/30*\theta_2$	$1/25*\theta_2$
Ω=60, θ=2,355					
ω=30	1.410/1.035	1.58/1.027	1.779/1.012	1.787/0.974	1.389/0.944
ω=20	1.167/0.987	1.257/0.994	1.389/1.004	1.517/1.017	1.463/1.022
ω=3	1.035/1.031	1.053/1.047	1.078/1.068	1.120/1.108	1.152/1.137
Ω=90, θ=2,355					
ω=30	1.426/1.035	1.508/1.027	1.490/1.012	1.160/0.974	0.965/0.944
ω=20	1.170/0.987	1.229/0.994	1.263/1.004	1.216/1.017	1.207/1.022
ω=3	1.035/1.031	1.052/1.047	1.075/1.068	1.115/1.108	1.145/1.137

Example of manifestation of wave effect is also very widespread situation, especially at the beginning of explosion. At this moment the speed of explosive combustion can be of great importance thanks to starting conditions. These conditions are implemented on condition of combustion initiation by high-speed streams of combustible combustion gases and existence of high clutter of space in this place.

If the initial increased flame velocity W* also remains it apart $a\sigma^{1/3}$ from the place of ignition, that maximal pressure of reflection apart L/2 is equal [17-18]

$$\frac{\Delta P}{P_0} = \frac{3\gamma}{1+W^*/C_0}\left(\frac{W^*}{C_0}\right)^2 \frac{\sigma-1}{\sigma}\frac{a\sigma^{1/3}}{L/2} \tag{8}$$

Where σ – expansion at combustion.
The effect of reflection is considered by a factor 2.

Let's compare pressure from wave loading to quasistatic pressure in the selfcontained room until opening. At the same time the amount of the burned-down gas is identical in both cases. Let's demand that wave loading exceeded quasistatic. Then it is necessary that:

$$\left(\frac{W^*}{C_0}\right) > 1.5\frac{a}{V_0^{1/3}} \tag{9}$$

If as admissible pressure to accept pressure in 5 kPa indoors, then restriction for burning rate and the size of the center of explosion will turn out.

Comparisons of pressure from action of a wave with pressure and the second dive of pressure [13] where burning rate can be other $W^* \neq W_0$.

Wave loading will exceed quasistatic under a condition:

$$\sigma\gamma\left(\frac{W^*}{C_0}\right)^2 \frac{a\sigma^{1/3}}{V^{1/3}} > 0.5\left(\frac{W_0 C_0}{K^2}\right)^2 \Phi^2 \rightarrow \frac{W^*}{W_0} > \frac{0.6}{K}\left(\frac{V^{1/3}}{a}\right)^{1/2} \tag{10}$$

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Here, $\Phi = \frac{S_f^*}{V^{2/3}}$, S_f^* - the area of a flame corresponding to the moment of the maximal pressure. Often maximal value of the area of a flame in explosion time,

$K = \frac{F}{V^{2/3}}$, F – the area of the expiration of gases from explosion volume,

$W_0 = U_2\sigma$ - flame speed at the second peak of pressure.

The experimental results of explosions with the accelerating combustion at the beginning of explosion are presented in table 2. Combustion accelerated on barriers №1 and № 2. A barrier №1 – a hemisphere with a radius of a_1 =53 mm, a transmittivity ψ_1 = 0.16, diameter of an opening of d_1 = 15 mm. A barrier №2 – a hemisphere with a radius of a_2 =110 mm, a transmittivity ψ_2 = 0.37, diameter of an opening of d_2 = 5 mm.

Table 2. – Results of the pilot studies of quasistationary and wave explosion

№p/p	Amount of propane, l	Size of an opening, m		$\Delta P^* / P_0$	$\Delta P_2 / P_0$	W^* / W_0	$\frac{0.6}{K}\sqrt{\left(\frac{L}{a}\right)}$
1	20	0.6*0.6	0	0	$0.5*10^{-3}$	1.0	-
2	20	0.6*0.6	No.1	$1.8*10^{-3}$	$0.6*10^{-3}$	6.0	3.5
3	20	0.6*0.6	No.2	$9.0*10^{-3}$	$0.6*10^{-3}$	5.0	2.5
4	20	0.2*0.2	0	-	$5.0*10^{-2}$	1.0	-
5	20	0.2*0.2	No.1	$2.5*10^{-3}$	$6.0*10^{-2}$	6.0	32.0
5	20	0.2*0.2	No.2	$6.10*10^{-3}$	$4.6*10^{-2}$	5.0	45.0

4.Conclusions

Two cases of emergence of wave processes at the emergency gas explosion indoors are considered. The first is bound to emergence of the strong vibrations of a gaseous fluid at sharp reduction of burning area. It occurs at the time of contact of a flame of walls of the room.

The second case is possible at intensive combustion at the initial moment of explosion that it can be caused by the strong source of inflaming.

In case of the former the maximal deformation can increase by 60% in comparison by quasistatic explosion if the oscillation frequency of a gaseous fluid exceeds the frequency of eigentones of a design no more than by 5 times.

If the oscillation frequency of gas exceeds a design oscillation frequency by 20 times and more, action of fluctuations can be neglected. In the second case wave loading can exceed maximal quasistatic on condition of realization (9). In case of realization (10) and (11) wave pressure do not exceed 5 kPa provided that quasistatic pressure decreases as a result of opening of apertures. Results are confirmed experimentally. The technique and the pilot unit are described in [12].

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