Research of Disclosure of Relief Venting Structures with Polycarbonate Fencing in Conditions of Explosion

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Abstract. The article considers the processes of release of the openings of relief venting structures based on honeycomb polycarbonate sheets under action of an explosion. The use of honeycomb polycarbonate sheets enables saving transparent fence against destruction, decreasing risks of human traumatism with glass shards, reduce weight of relief venting structures. There were investigated the conditions of the ratio of the opening sizes of the sections of relief venting structures with honeycomb polycarbonate sheets, under which this opening is reliably released to reduce the pressure during the explosion to safe values. A mathematical model was proposed that establishes a relationship between the value of the explosion pressure and the opening size at which the opening of relief structures with honeycomb polycarbonate sheets. The article proposes a calculation method for designing the sections of relief structures with honeycomb polycarbonate sheets using nomograms. The use of developed method lets significantly simplify calculating for design of relief structures with honeycomb polycarbonate sheets.

1. Introduction

Premises of categories A and B, as to the explosion and fire hazard, in accordance with the norms in force in Ukraine DSTU B B.1.1-36: 2016 [1], should be equipped with external relief venting structures (RVS). In this case, this document states that the required area of RVS should be determined by calculation. The use of flexible fencing elements installed in standard window profiles made of polyvinyl chloride polymeric material is promising for the RVS construction, as they can be used repeatedly after their removal from the frames in case of an explosion.

The use of polycarbonate honeycomb sheets is promising as flexible fencing elements [2]. When using such a design of RVS it is necessary to study the main features of its behavior in case of an explosion, and to determine the conditions of releasing the edges of flexible elements from the locks of window frames of standard profile. At the same time, it is important to ensure that the design dimensions of
RVS openings are such that their release under the action of excess pressure from explosion with a boundary value would be reliable and guarantee a rapid decrease of the pressure to safe values.

2. Analysis of recent achievements and publications
As a result of the analysis of scientific studies it was found that ensuring safety from an explosion in industrial buildings with certain technological processes is quite important and the main technical solution for this is the installation of relief structures [2-10].

When installing relief venting structures to protect buildings and structures from explosion, there are methods of their designing with the calculation of explosion resistance in the deflagration explosion of gas-air mixtures in premises [1]. As an example of such effective methods of RVS designing can be considered the method given in the Technical Code of Established Practice, which is valid in the Republic of Belarus TKP 45-2.02-38-2006 (02250) [11], the methods given in other standards in this field, for example, the US standard NFPA 68 [12].

British standard BSEN 14491: 2012 [13], there are also a number of monographs, publications, theses [14], etc., which address the issues of explosion protection of explosion hazardous facilities with the use of safety structures.

A study [2] of the behavior of RVS fencing based on cellular polycarbonate sheets (CPS) proposed a mathematical model describing the behavior of CPS under explosion conditions, but did not propose methods for designing such RVSs based on it.

3. Purpose
The purpose of this work is to develop a method for calculating the design dimensions of the openings in relief structures for their reliable release for the boundary values of excess explosion pressure by developing special nomograms.

4. Method
When considering the CPS fixed in the frames of the window profile, it is considered as a rectangular plate, hinged with the possibility of free movement of the CPS ends in the longitudinal direction, loaded with an evenly distributed load. Figure 1 shows a calculated scheme of application of the load on the CPS under the influence of the explosion on it, in accordance with the approach developed in the study [2].

![Figure 1. Scheme of load application on the cellular polycarbonate sheet in the section of the relief structure](image_url)
deformation. Given that the deformation of the CPS occurs in the elastic zone, the equilibrium equation for the CPS appears as a following expression [2]:

\[
P_e \cdot a \cdot b = \frac{w_{max}^6 D \cdot a \cdot b}{16} \times \left[ \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{(-1)^{(2m+1)+(2n+1)}}{(2m+1)(2n+1)} \left( \frac{(2m+1)^2 + (2n+1)^2}{a^2} \right)^2 \right]^{-1} - 2q_f \left( \frac{b \pi w_{max}}{a^2 + \pi^2 w_{max}^2} + \frac{a \pi w_{max}}{b^2 + \pi^2 w_{max}^2} \right) = 0.
\] (1)

here \(a\) and \(b\) are the height and width of the opening in the RVS section, according to Figure 2; \(D\) is the effective parameter of CPS stiffness, \(m = 1, 3, 5, 7, \ldots; n = 1, 3, 5, 7, \ldots\) are odd whole numbers, \(w_{max}\) is the maximum deflection of the CPS, at which its edges release from the locks of the window profile of the RVS sections.

**Figure 2.** Scheme of the opening in the section of the relief venting structure with honeycomb polycarbonate sheets

The maximum deflection of the CPS is calculated by the following expression:

\[
w_{max} = \frac{9a^2}{\pi(a - 2x_{max})} - \frac{12a}{\pi} + \frac{3}{\pi} \left( a - 2x_{max} \right)
\] (2)

here \(x_{max}\) is the maximum displacement of the CPS edge when it is released out of the locks of the standard window profile of the RVS section.

The parameters of the effective stiffness of the CPS \(D\) and the maximum displacement \(x_{max}\) do not have a specific physical meaning in this case, but are the effective characteristics of the CPS, which are determined experimentally using the setup shown in Figure 3.
It was found that the effective stiffness and critical displacement depend only on the thickness of the CPS and their values are given in Table 1.

### Table 1. Effective stiffness and critical displacement characteristics of cellular polycarbonate sheets

| Effective parameter       | Thickness of honeycomb polycarbonate sheet |
|---------------------------|--------------------------------------------|
| Effective parameter       | Thickness of honeycomb polycarbonate sheet |
| Stiffness, $D$, N-m       | 4 mm            | 289.064  | 6 mm            | 244.196  | 8 mm            | 206.044  |
| Maximal displacement, $x_{\text{max}}$, mm | 2.915  | 7.708  | 9.773         |

Using these characteristics and expression (2), the equation takes the form, which is given below:

$$
P_{\text{end}}ab = \frac{9a^2}{\pi(a - 2\Delta x_{\text{exp}})} - \frac{12a}{\pi} + \frac{3}{\pi}(a - 2\Delta x_{\text{exp}}) \frac{\pi^6 ab D_b}{16} \left[ \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{(-1)^{(2m+1)(2n+1)}}{2} \left( \frac{(2m+1)^2 (2n+1)}{a^2} + \frac{(2n+1)^2}{b^2} \right) \right]^{-1} -$$

$$- \frac{2\pi^2}{\pi(a - 2\Delta x_{\text{exp}})} \frac{12a}{\pi} + \frac{3}{\pi}(a - 2\Delta x_{\text{exp}}) \frac{\pi^6 ab D_b}{16} \left[ \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{(-1)^{(2m+1)(2n+1)}}{2} \left( \frac{(2m+1)^2 (2n+1)}{a^2} + \frac{(2n+1)^2}{b^2} \right) \right]^{-1}$$

$$- \frac{9a^2}{\pi(a - 2\Delta x_{\text{exp}})} + \frac{12a}{\pi} + \frac{3}{\pi}(a - 2\Delta x_{\text{exp}})$$

$$= 0 \quad (3)$$

The obtained equation can be used to determine the design dimensions $a$ and $b$ of the openings of the sections of the RVS with CPS, by solving it with respect to these parameters as unknown.

### 5. Consideration on methods and results

Using equation (3), the nomograms were built to determine the design parameters of the openings of the CPS sections in accordance with Figure 2 for certain boundary values of excess pressure from explosion. The built nomograms are shown in Figure 4.
Figure 4. Nomograms to determine the parameter $a$, depending on the parameter $b$ of relief venting structures based on cellular polycarbonate sheets with a thickness of 4 mm (a), thickness of 6 mm (b) and thickness of 8 mm (c) at a certain excess pressure for which it must be provided the release: 1 – 2,500 Pa; 2 – 5,000 Pa; 3 – 7,500 Pa; 4 – 10,000 Pa; 5 – 12,500 Pa; 6 – 15,000 Pa; 7 – 20,000 Pa; 8 – 30,000 Pa.

When determining the design parameter $a$, according to the previously accepted values of the excess pressure from explosion and the height of the opening of the RVS section, one can use the nomograms shown in figure 4. Excess pressure is determined from the preliminary calculation, and the height of the opening of the RVS section can be determined basing on the design of the premises and the convenience of the location of the RVS sections in the premises. When choosing the height of the RVS sections, there is a restriction: the height of the opening of the RVS section must be at least 500 mm. When using nomograms from Figure 4, linear interpolation can be used to determine the design parameter $a$ from the intermediate values of the excess pressure from explosion and the height of the opening of the RVS section.

Thus, the method of selecting the design parameters of the RVS sections on the basis of CPS consists of performing the following procedures.

The minimum height of the RVS section $a$ is selected on the basis of the design and architecture requirements for construction of the relevant floor. That is, the height can be set by the designer of the building.

The value of excess pressure from explosion is set by means of preliminary calculation.

Depending on the RVS location, the thickness of the CPS is selected. If the RVS is indoors, a CPS with 4 mm thickness should be used. If the RVS is installed in the fence of the building from the outside space, there should be installed CPS with 8 mm thickness. The installation of 6 mm thick CPS requires additional justification, taking into account wind loads in the area.

According to the values of excess pressure and thickness of the CPS, the appropriate curve is determined to determine the design parameter of the opening width of the RVS section. According to this curve, the value of the opening height of the RVS section and the corresponding values of the opening width are selected. When finally determining the width of the opening, the design or architectural solutions can be taken into account by increasing the width of the opening from a certain minimum value, but not more than 1.75 m.

6. Conclusions
As a result of our research we can point following.
1. To develop a method for determining the dimensions of the opening of the RVS section with CPS for their guaranteed release after reaching the critical value of the excess pressure from the explosion, an equation was proposed in which these dimensions are included as independent variables.

2. According to the obtained equation, the nomograms were built to determine the geometric dimensions of RVS openings with CPS for their guaranteed release after reaching the critical value of excess explosion pressure; tables were developed to determine the design dimensions of RVS openings.

3. A method for designing RVS out of CPS on the basis of the offered nomograms was developed.

4. It was shown that the developed method has a simple implementation, cost-effective calculation algorithms and allows designing effective RVS based on CPS.

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