

# Programs for calculating the explosion resistance of buildings and structures

**Nikita Shevchenko<sup>1</sup>, Rachik Manucharyan<sup>1</sup>, Marina Gravit<sup>1</sup> and Yuriy Geraskin<sup>2</sup>**

<sup>1</sup> Peter the Great St.Petersburg Polytechnic University, 195251, St. Petersburg, Russian Federation

<sup>2</sup> Moscow State University of Civil Engineering, 26, Yaroslavskoye shosse, Moscow, 129337, Russia

E-mail: [serious.nick19@gmail.com](mailto:serious.nick19@gmail.com)

**Abstract.** Trends in the development of the oil and gas processing industry and facilities using liquefied hydrocarbon gases in the technological processes lead to an increase in the number of emergency situations and as a result to the increase of the damage and environmental degradation. A gasified housing stock is a special group of explosive objects. The accident in such disasters lead to hundreds of human victims. The main danger of explosive effects on objects can lead to a large-scale destruction connected with an "internal explosion". It results in the release of combustible substances (gas, oil, etc.) into enclosed or semi-enclosed rooms (modules) with the ignition (in explosion mode of deflagration or detonation) of air gas mixtures (AGM).

## 1. Introduction

Numerous researches in Russia and abroad are devoted to the problem of explosive loadings for buildings and constructions [1-12]. The analysis of the existing methodical normative and departmental documents defining the area of waste apertures, the easily dumped designs (EDD) for the decrease of the explosive pressure to the safety level the need of their modification. Besides, the mentioned techniques don't consider the probability of explosive loading emergence defining algorithm of which is similar to methodology of the quantitative risk analysis. [13].

The general recommendations about justification the explosion resistance of buildings and constructions which are based at the following methods:

a) modeling and calculating the emergency outflow and spread of dangerous substances (DS) in all possible scenarios of accidental depressurization of equipment and the ignition of fuel-air mixtures (FAM);

b) calculation of the destruction zones under the impact of a shock wave in emergency explosions of fuel-air mixtures;

c) calculation of the risk including an estimate of the frequency of exceeding of the pressure amplitude at the front of the incident shock wave for each (if necessary) building, structures on the territory of the dangerous production facility;

d) the application of justified criteria for the acceptable risk of destruction of buildings, taking into account their design.



At evaluating the consequences of explosions, are recommended to take into account the main mechanisms for the development of explosive phenomena, such as the drift cloud of fuel - air mixtures (FAM), the explosive transformation mode (deflagration / detonation), the explosion impact for buildings and structures in accordance with the Safety Manual "Methodology assessment of the consequences of accidental explosions of fuel-air mixtures".

## 2. Recommendations about justification of explosive resistance

Explosion resistance of buildings, structures, technical devices or other material objects is characterized by the limiting pressure in the front of the incident shock wave  $P_{pr}$ , which can perceive the structure of the building without losing its bearing capacity or its suitability for further operation. Are recommended that  $P_{pr}$  for buildings should be defined by the design organization according to calculations made in the course of design, and for structures and technical devices in accordance with the regulatory document or document of organizations approved by the government of the Russian Federation such as: PJSC Gazprom, PJSC LUKOIL, PJSC NK Rosneft, the safety manual "Methodological framework for conducting hazard analysis and the risk assessment of accidents at hazardous production facilities" or other regulatory or methodological documents.

Are recommended to assume that the explosion resistance of a building by the criterion of the maximum possible explosive load in an external explosion is ensured if the condition is satisfied in which the building is outside the maximum possible impact zone of the shock wave with a pressure amplitude at the shock wave front exceeding the design pressure:

$$P_{pr\ k} > \max(\Delta P_{fn}), \quad (1)$$

where  $P_{pr\ k}$  — the limiting (projected) pressure in the front of the shock wave, to which the k-th building is calculated ( $k = 1, 2, \dots, n$ );

$\Delta P_{fn}$  — pressure in the front of a shock wave incident on the building;

$n$  — script number ( $n = 1, 2, \dots, n$ );

$N$  — number of scenarios with explosion.

If condition (1) can't be fulfilled to justify explosion resistance are recommended to use the results of a quantitative explosion risk analysis and a probabilistic criterion according to which the frequency of building destruction  $R_{pk}$  within a year should not exceed the permissible value  $R_{add}$ :

$$R_{pk} < R_{add}, \quad (2)$$

Depending on the duration of the load, are necessary to distinguish between constant and temporary (long, short, special) loads. Explosive impacts refer to special stresses, which should be taken into account in the design of buildings and structures. Requirements for accounting for the risk of explosion are also presented in the legislative acts of the Russian Federation.

The main criterion for the validity of methods and software products for the calculation of explosion resistance is the coincidence of the calculation results for them with accident investigation data, as well as with the results of calculations performed with the help of other software products. Using the example of Ref. for calculating of the fracture zones in an accident that occurred on November 22, 2006 at CAI and Arnel Manufacturing Facility, located on the same production basis, it was concluded that the calculation procedure given at a known flame propagation speed allows predicting the consequences explosions of the fuel-air mixture in the deflagration mode with acceptable accuracy, in contrast to the "Baker-Strehlow-Tang" (BST) technique, which are part of the PHAST software package of the international firm DNV. One of the reasons for the discrepancy in the results may be related to the use of simplified models of the explosive process used in the parametric type methodology, which are laid down in the most common TOXI + Risk (NTC "Prombezopasnost") and PHAST (Det Norske Veritas).

## 3. Comparison of the functionality of software packages

Russia began to apply new technologies for the calculations not so long ago. Parametric and integral models solve many problems with adequate accuracy, but a number of task in the modeling of

emergency situations require more detail, in particular, obtaining more complete data on the change of a parameter in any point of area. Such more complex tasks include: the emissions of hazardous substances in the real conditions of development territory, terrain, weather conditions; the explosions of emissions in a cluttered and confined space. To solve such problems apply special mathematical methods based on numerical solution of systems of partial differential equations, - the methods of computational hydrodynamics, or CFD-methods (computational fluid dynamic methods). The most famous and effective tool for the computational fluid dynamics of explosive emergency processes are currently considered the PC FLACS developed by the Norwegian company GEXCON ([www.gexcon.com](http://www.gexcon.com)). A comparison of the main features of the TOXI, PHAST and FLACS software complexes are given in Table 1.

**Table 1.** Comparing the PC to the functionality

Operation	TOXI+Risk	PHAST+ RISK	FLACS
Calculation of the consequences of individual accident scenarios			
The assessment of the consequences of accidental emissions taking into account the drift of the cloud:			
- toxic	+	+	+
- flammable	+	+	+
Calculation for hazardous substances in the liquid and gas phase	+	+	+
Calculation for partial and complete destruction of equipment	+	+	+
Calculation for gases is both lighter and heavier than air	+	+	+
Calculation for a fire-flash	+	+	+
Calculation for flare combustion	+	+	+
Calculation of shock wave shock from physical explosions	—	+	+
Evaluation of the thermal impact in the fires of the Strait	+	+	+
Estimation of the effectiveness of a fuel-air mixture explosion	+	+	+
Calculation of the intensity of thermal radiation and the lifetime of a fireball	+	+	—
Calculation of the factors affecting the shock wave from a fireball	—	+	—
Estimation of the maximum amount of hazardous substance in the cloud, limited by the concentration limits	+	+	+
Drawing of zones of defeat on plans of district	+	+	+
Situational plan:			
- support for raster and vector graphics formats (bmp, jpg, wmf, AutoCAD)	+	+	—
- deposition of a large number of vector layers of recipients	+	+	—
Calculation of the number of victims	+	+	—
The software selection of the most dangerous wind direction (with a large number of casualties)	+	—	—

The construction of graphs of changes in the values of physical quantities during the process	+	+	+
The task of virtual concentration sensors in area	+	+	+
Animation of the process of gas cloud spreading	+	+	+
Calculation of risk indicators			
Construction of a potential risk field (risk contours)	+	+	+
Assessment of the individual risk of death in industrial buildings during a fire (calculation of the probability of evacuation)	+	—	—
Assessment of risk indicators for outdoor facilities	+	+	—
Accounting for real meteorological data	+	+	+
Export results in MS Word format according to user templates (in the form as close as possible to Russian requirements)	+	—	—

From Table 1 it follows that the software complexes for the capabilities of calculating the main phenomena and risk indicators almost coincide. The exception is the absence in the PHAST RISK program of methods for calculating the probability of evacuation, in the TOXI + RISK lacks a method for calculating the shock from a shock wave in a fireball and physical explosion.

Certain disadvantages are also the software package FLACS. It does not provide the input of initial process data (pressure, temperature, defective hole size, etc.) for the equipment under analysis. Initial data are applied to the initial data (for example, the consumption of matter, probabilistic parameters, etc.), which must be previously calculated using other models (programs). Also, the feature of this software package is the complexity of preparing the initial data of the geometry surrounding area (parameters of the room, buildings, structures, terrain). Also, it should be noted that for the work in the FLACS program a high qualification of the user is required. For more exact result will be required a lot of time.

## Conclusion

Taking into account the criteria for permissible fire risk for production facilities and the data of the conditional probability people's death in destroyed buildings according to the Federal norms and regulation for industrial safety the recommended value of the permissible frequency of the impact of the explosion on the building  $R_{add}$  should not exceed the recommended value of the permissible frequency of the impact of the explosion on the building should not exceed the value  $10^{-4} \text{ year}^{-1}$ .

To solve the applied problems of estimating the consequences of emergency emissions to outdoor installations, the parametric or integral models and corresponding software complexes (TOXI + and PHAST) are used. Programs based on numerical modeling, are advisable to apply for complex geometry objects (workshop rooms, cluttered areas, semi-enclosed spaces, etc.), especially in cases when high accuracy is required and multivariate serial calculations are not needed.

Calculations of the destruction zones are recommended to be carried out by one of the two methods:

1) the method of assessing the affected areas, based on the "TNT equivalent" of the fuel-air mixture explosion (gives the approximate values of the affected areas and does not take into account the drift of the cloud).

2) by method that takes into account the type of explosive transformation (detonation, deflagration) at the fuel-air mixture ignition (the most accurate method).

## References

- [1] Pilyugin L 1988 *Konstrukcii sooruzhenij vzrivoopasnyih proizvodstv* (M Stroyizdat) pp 316

- [2] Saknite T Vatin N Goremikins V Pakrastins L and Serdjuks D 2016 *Magazine of Civil Engineering* **4** pp 26-39
- [3] Adushkin V and Kogarko S and Lyamin A 1975 *Raschet bezopasnyh rasstoyanij pri gazovom vzryve v atmosphere* (V sbornike Vzryvnoe delo №75/32 M Nedra)
- [4] Andreev K and Belyaev A 1960 *Teoriya vzryvchatyh veshchestv* (Oborongiz) pp 595
- [5] Babkin B and Buharov V 1989 *Normal'naya skorost' plameni propanovozdushnyh smesej pri vysokih davleniyah i temperaturah* pp 57-63
- [6] Malcolm S and Xiangyang Q 2006 Analysis of the Response of Body Armor to Blast, Fragment and Projectile Loading using ANSYS® AUTODYN®. 2nd International Conference on Design and Analysis of Protective Structures, Singapore, 13-15 pp 1-13
- [7] Gravit M Vaititckii A and Shpakova A 2016 *Procedia Engineering* **165** pp 1667-1672
- [8] Zienkiewicz O C 1975 *Methodes der finiten Elemente* pp 23
- [9] Gravit M Gumenyuk V and Nedryshkin O 2015 *Procedia Engineering* **117** pp 114-118
- [10] Gravit M Antonov S and Nedryshkin O 2016 *Procedia Engineering* **165** pp 1651-1657
- [11] Hamdan F 2006 *Structural strengthening of offshore topsides structures as part of explosion risk reduction methods* pp 11
- [12] C J H van den Bosch and R A P M Weterings 2005 *Methods for the calculation of physical effects* CPR 14E P 2 pp 481-524
- [13] Russian Law 384-FZ 2009 *Tekhnicheskij reglament o bezopasnosti zdanij i sooruzhenij*