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Simulation of Deflagration Explosion in Industrial Building with Consideration of Influence of Safety Structures

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***Abstract*— Installation of safety enclosure structures is one of the ways of protecting industrial buildings from indoors explosions. The present article provides a computational technique which allows to take into account a variety of factors affecting overpressure level during deflagration explosion of domestic gas, namely the availability of safety structures and separations in a room, the location of the source of ignition, time of mixture ignition, the size of a premise. By the solution of the sequence of information related problems (gas dynamics and strength), it's possible to determine the size and type of safety structures, their most rational arrangement, as well as examine safety of a particular object.**

Index Terms—**Deflagration explosion, industrial buildings accidents, buildings protection, Flow Vision, ANSYS.**

I. INTRODUCTION

The ways of industrial buildings protection from indoor gas explosion is an acutely topical subject for researches today. An active federal law of the Russian Federation No.384-FZ "Technical Regulations on the Safety of Buildings and Structures" prescribes the protection of buildings from such non-designed dynamic and thermal effects like explosions and fires. However, there are no standards for registration of the mentioned factors and a number of existing recommendation manuals has difference in the calculation procedures of structures and development of safety measures. The problem of protecting buildings from indoor deflagration explosions consists of a wide range of issues and associated with a large number of related problems. One of the tasks of industrial buildings designers' is the development of safety enclosure structures that allow to reduce the excessive pressure in the explosion to an acceptable level. This level means the pressure level above which a building's bearing structures do not get accident-caused damages and can maintain bearing capacity at least for the period necessary for evacuation of the working staff. Acceptable levels of explosive loads inside of the buildings should not exceed Pcr=10-15 KPa. Main building structures of majority buildings are destroyed at pressures above Pcr. [1], [2]. Safety structures (SS) used in industrial buildings today differs in many ways. According to the method of opening one distinguishes light removable panels or roof slab; hinged gates, doors, windows with shutters: swivel structures – revolving wall panels, slabs with rotational joints; fragile structures (dumb glazed windows opened as a result of destruction of glasses). In addition, safety structures vary in size, density, strength of materials and the mass of lay bare parts. Calculation of such systems is mainly based on empirical formulas that use different opening - from the parameters of SS and pressure. All these functional connections were obtained by many scientists and researches experimentally. Most of these experimental data are described in the "Manual for design and examination of buildings and structures exposed to blast loads" [1]. Modern computers and software systems allow simulate feasible emergency situation at each hazardous site and take into account a variety of factors that affect the force of the explosion. Such a computational technology is proposed in this paper.

II. DEFLAGRATION EXPLOSION

Indoor gas explosion from the start of gas leakage before the destruction of structures caused by dynamic and thermal effect as a result of combustion of gas-air mixture is a complex emergency situation depending on many factors. Such explosions as a rule have deflagration nature, they require inflammable gas or steam and air are blended in the proportion to form the mixture which is within lower and upper concentration explosive limits. The reaction can commence either after the ignition of the mixture from a source of ignition (open flames, incandescent light) or from spontaneous combustion of the mixture (under certain conditions). Deflagration explosion is the process of noiseless combustion forming a fast-spreading zone (front) of chemical transformations. Energy transmission from the combustion zone in the direction of the front movement is due to heat transfer, while in case of detonation, the zone of transformation is spreading at supersonic speed and energy transmission is the result of shock compression. The physical aspects of deflagration gas explosion experimentally investigated and described by A.A. Komarov [3], [4]. Excessive pressure at closed-space indoor deflagration explosion can reach 700…900 KPa, but due to the availability of safety structures (SS) in buildings such as glazed windows and light removable structures, the pressure level can be significantly reduced to safe level (2 – 5 KPa). This pressure

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is not injury for a human being. The value of the maximum pressure at deflagration domestic gas explosion mainly depends on the pressure of the beginning of glazing destruction and a room size [4]. A room's geometrical characteristics, namely the ratio of length to width to height in the disproportionate ratio (10:1 and more) can have a significant effect on the turbulence of combustion at explosion and consequently on the overpressure value. The availability of adjacent premises and obstacles on the flame front also has an effect on the possibility of forming powerful air flow in passages between apartments and adjacent rooms. These steams (but not shock waves as it is often interpreted especially in press) lead to throwing construction structures fragments out from the emergency room. One should keep in mind that structures destruction occurs under the influence of excessive pressure and their subsequent throwing out occurs under the influence of velocity pressure [5].

III. COMPUTATIONAL TECHNOLOGY FOR CALCULATION OF THE FORCE OF DOMESTIC GAS EXPLOSION

We have developed a computational technology for calculation of domestic gas explosion pressure in a closed-space room and its impact on the building's structure [6]-[8] allows to carry out numerical experiments on the usage of various SS without physical experiments which considerably facilitates the work of a researcher. Mathematical models used in this technology are based on the classic works on fluid and gas dynamics, on the theoretical works of present-day scientists [9]–[12], the results of real experiments [3] and the inspection analysis of results of real buildings after an accident [13]. The model of gas in the air combustion is a set of equations of convection-diffusion transfer described in the weakly compressible fluid model and include Navier-Stocks equations, equation of state, law of conservation of energy (law of energy conservation), equation for scalar quantities ξ describing fuel concentration, oxidant (oxidizing agent), products of combustion, neutral gas, nitrogen oxide and markers. Also, the standard $k-\varepsilon$ turbulence model is used [9], [10]. For the numerical implementation of the problem a method of finite volumes (MFV) is used [14]. The process of explosion is simulated in Flow Vision software package (FV) that makes possible to do gas-dynamic tasks and adjoint problems of interaction between the flow and a deformable body in conjunction with finite-element programs (ANSYS in our case). This technology is verified by the example of calculating the domestic gas explosion in inhabited building [15], [16] and can be applied for calculations of indoor explosions in industrial buildings. The industrial facilities designers to determine the appropriate composition and the number of safety structures in an industrial building are required very often. According to the practice, at the present time the methods used to solve that problem are quite approximate and may not take into account all the components of the process. Ventilation of premises plays the important role, but, as a rule, calculations of explosions at a factory are based on the fact that the emergency ventilation may fail and air outflow (and, hence, the gas-air mixture) before opening a safety structure occurs through natural cracks in enclosure structures. According to SNIP 31-03-2001, the area of light removable structures should be determined by calculation. In the absence of estimated data the area of light removable structures should be not less than 0, 05 m^2 for 1 m^3 of premises space capacity of category A by explosiveness and not less than 0, 03 m^2 for the category B. The ratio of SS area and a room space capacity are very approximate figures and calculations are not confirmed as a rule. The calculations of the required area are usually performed by [1], [2], [11], but even in such computations there is always a number of "blind" issues for a designer when he is forced to accept the results of other scientists' researches (which do not have regulatory status, experimental ones) and improper settings should be calculated by interpolation between the values given in the methodology. That is to take full responsibility for any used numerical value and assumption with all the ensuing consequences. We are convinced that a more rational option of design research is a computational simulation of a possible emergency situation at each hazardous production facility in particular. This allows:

- To determine more accurately the pressure level on structures at explosion at a particular production site;
- To consider more accurately the variety of factors that affect the explosion;
- To determine more precisely the required size and type of SS for each object separately;
- To determine the most rational location for SS installation at activation of explosive device;
- To perform safety expertise of a particular object in order to determine sufficiency or insufficiency of protective system;
- To analyze the accident to produce temporal and case-and effect picture of occurrence.

IV. SIMULATION OF AN EMERGENCY AT A PRODUCTION FACILITY OF THE GAS INDUSTRY

In the course of our research we have simulated a possible emergency situation at a real hazardous production facility of the gas industry in a pump unit protective building which includes one room category A by explosiveness. As initial settings was accepted the following:

A room capacity excluding equipment and prominent parts of construction structures (unconfined space) is 4657 m^3. Protective cover building simulated in ANSYS software package is shown in Fig. 1;

SS allowed for in the design in this room are light removable panels. The pressure when opening occurs is not specified in the design;

Natural gas is used in the production. The main component

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of gas mixture is methane (content in the mixture is 92-98%);

Ventilation of premises is provided by air permeance of filling of doors and windows openings. The ventilation rate of emergency ventilation in the room – 5;

The most dangerous scenario of accident development is pipes break, seal wear and loss-of-piping integrity in flange joints. Estimated time of pipeline trip after the beginning of leakage is not more than 2 minutes. The volume of gas released in the accident is 2114 m^3.

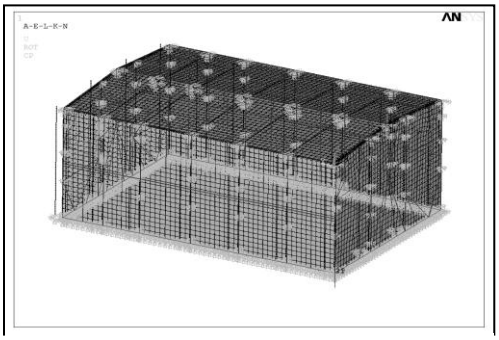

Fig. 1. Model of a building in ANSYS

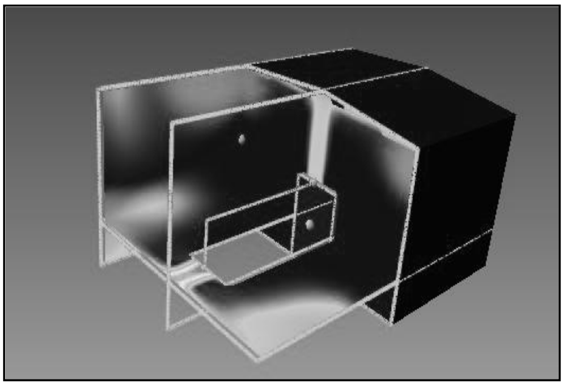

Fig.2. Premises Model in Flow Vision

The most likely cause of ignition is an open-flame source (i.e. welding while repair works performance).

The computational domain is a three-dimensional geometric model of the room (premises) where deflagration occurs. This domain of computation is transferred to FV programmer. It should be noted that only enclosing structures are exported to Flow Vision as FV identifies only shell elements of SHELL type (Fig.2). To obtain enclosed volume in ANSYS the floor surface is simulated additionally. Then the floor surface is removed from the model at finite-element calculation of the building. For numerical realization of the task (i.e. to determine the pressure caused by explosion on the building structure) the finite-volume method has been used. The alteration of independent physical parameters in time in the dedicated area of space is determined by physical flows (convection or diffusion), penetrating inside the area through its surface, as well as the sources (volumetric and surface) inside the area itself. As SS the walls and available building's glazing are considered. They are set in FV by changing the boundary conditions in some areas of the model in the certain moments of time. The boundary condition "wall" for the surfaces of FV model simulating solid obstacles:

- Impermeability condition: $V_n = 0$, $V_t = 0$;
- Null bias for scalar quantities (f - scalar): $\left.\frac{\partial f}{\partial n}\right|_w = 0$,

Replaced, when in the model pressure on walls and windows becomes critical (Fig.3), on the condition "Free Exit" (for the surfaces that simulate gas discharge):

Null bias/vent:

$P=0$; $(V,n) > 0$, $V|_w = V_{tw}$;

$(V,n) \le 0$, $\nabla(V_i, n)|_w = 0$.

Thus, for our case it is accepted (on the basis of fitting analysis and design model) that wall slabs can be removed at a pressure 2 KPa. Existing windows in a building can be destroyed only at the pressure not less than 4 KPa.

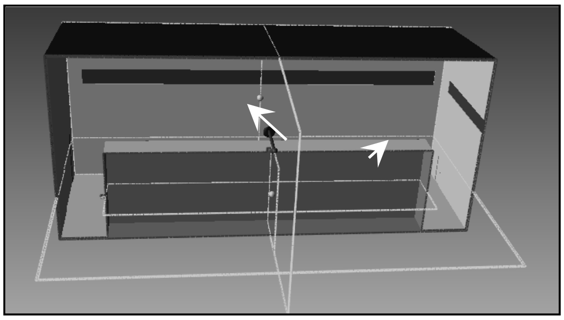

Fig. 3. Surfaces of the Model FV with a boundary condition for destructible windows

In consequence of non-reactivity of a mixture which runs out through opening, only a part of initially available mixture is able to react at indoors deflagration explosion. Remaining part of a mixture is discharged to the atmosphere through an opening. Therefore, at the partial gaseousness of a room (more than 15-20%) explosive loads close to the loads which are implemented in completely gas contaminated premises. In the centre of protective room of the actual building there is the pumping equipment which occupies the significant room area. In FV model this object is represented as a rectangular volume overlapped by walls (Fig.4), with the same boundary conditions as the rest envelopes of the model (boundary condition is the "wall"). The availability of such indoor obstacle significantly affects the results of gas mixing and the pressure distribution at explosion.

In Fig.5, Fig.6 a process of emergency situation is illustrated. The calculation consists of two parts:

1- Calculating the cold gas flow (without burning). Gas flows into the target area with the air inside and both gases mix

2 – When gas concentration in the room sufficient, burning initiation occurs – the mixture ignition.

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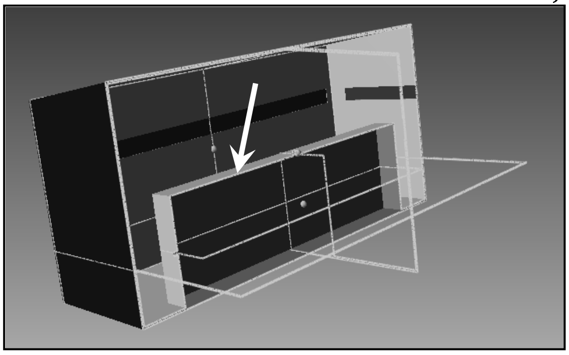

Fig. 4. Internal Close-Spaced Volume in FV Model, Simulating Equipment

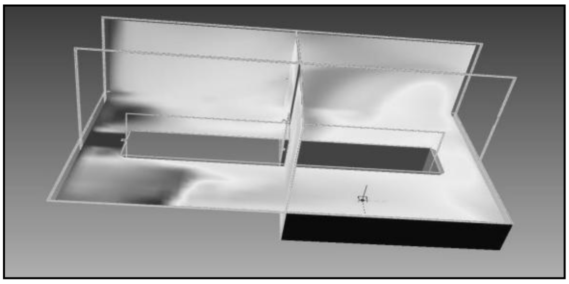

Fig. 5. A Mixture Ignition

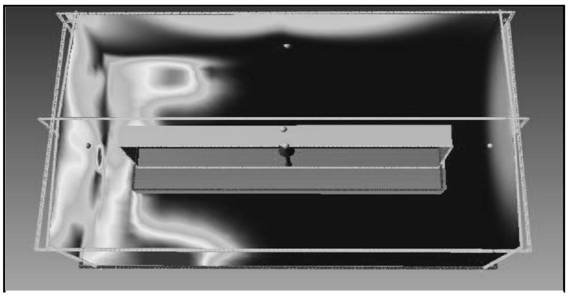

Fig. 6. Mix of Gas and Air in a Shop with Defective Pipelines

V. THE RESULTS OF PRESSURE CALCULATION OF DOMESTIC GAS EXPLOSION

In Flow Vision software package the numerical experiments were made to determine the pressure intensity of domestic gas explosion for several versions of identifying the source of ignition location and time of mixture ignition (on the 60th second after leakage commencement; on the 120th second after the total volume of gas dispatching). The minimum and maximum pressure values for each iterationare illustrated in Fig.7 (time step is 0,05 sec).

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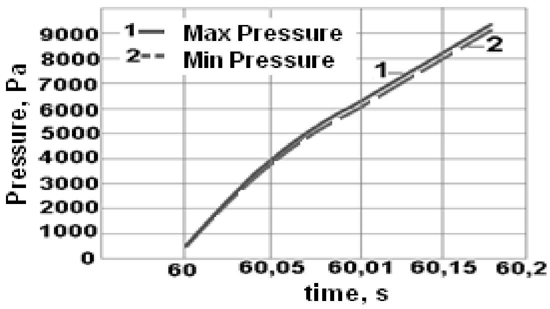

Fig. 7. Pressure Curve at Ignition on the 60th Second and Nonoperation of Any Type of SS

According to the results of calculations the pressure curves at a time were made for the incident when none of the safety structures activates (Fig.7), and for the various types of SS opening depending on the moment their opening (Fig.8, Fig.9).

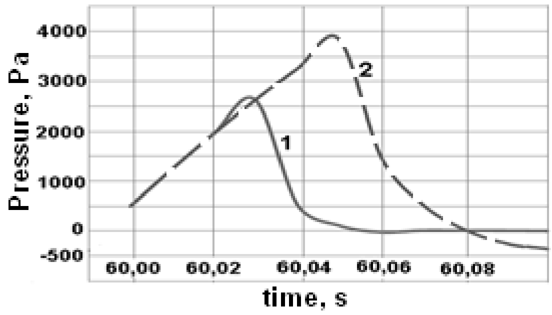

Fig. 8. Pressure Curve at Ignition on the 60th Second at Operation of Various SS: 1-Wall; 2-Window

The calculation determined that the area of available SS in the form of wall slabs (approx. 200 m^2) is sufficient for decompression below the acceptable level of 5 KPa. Windows' size in order to identify them as safety structures is enough if they are 100% opening (which is unlikely and is not confirmed by the manufacturers of these structures).

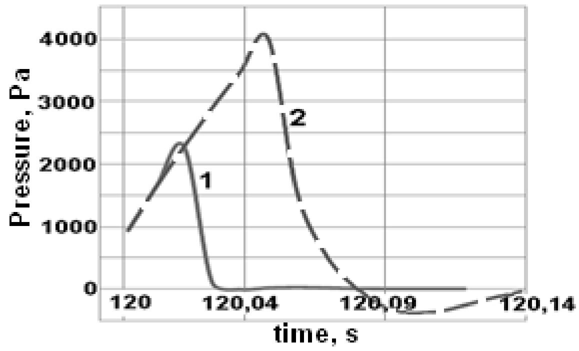

Fig. 9. Pressure Curve at Ignition on the 120th Second at Operation of Various SS: 1-Wall; 2-Window

As a result of solving gas-dynamic problem the value of excessive pressure is found, which is, being used to carry out strength ANSYS analysis in software complex [4]. For solving a complex of problems related to gas-dynamics and strength analysis in various software systems (Flow Vision and ANSYS) an algorithm and research programme module ANSYS-Flow Vision was developed [17] which automates information-related tasks.

VI. STRENGTH STRUCTURE ANALYSIS

After gas-dynamic calculations the explosion load is exported from FV model to ANSYS, so that information-related tasks are solved. As a result of gas-air mixture explosion a shock wave directed to all sides appears in a room. That is so-called "volumetric explosion" which is

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characterized by the same pressure at each point of volume at each moment of time [1], [3], so the explosive load is applied as uniformly distributed (spread) load to all surfaces of the room. The calculated finite elements model of the frame protective building was created with the use of the following:

- Beam finite element BEAM188, supporting the stress-stain properties, bending and constrained torsion – for the steel frame (Fig.10);
- Multi-layer shell element SHELL181, tetra joint with 6 degrees of freeness in each joint – for wall sandwich-panels and roof.

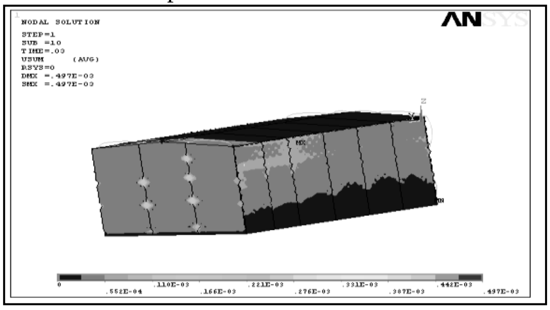

Fig. 12. Horizontal Mobility in Panels at Explosion Taking into Account Dropping of SS

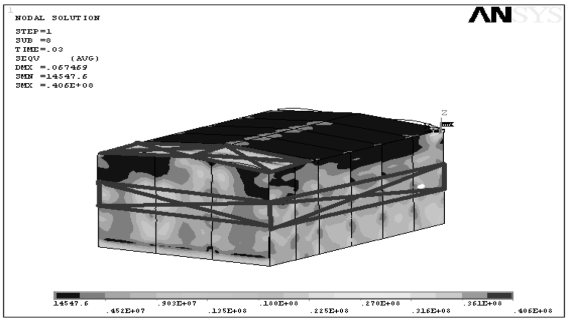

Fig. 13. Possible Locations for SS

As a result of computational experiments the analysis of stress-strain state of bearing and enclosing structures is carried out (Fig.11, Fig.12). The weaknesses were revealed in the enclosing structures. These locations are the most suitable for the safety structures installation (Fig.13).

VII. CONCLUSION

1. Safety enclosing structures is one f the method of protecting an industrial building from indoors explosions. Such structures allow to reduce excessive load at explosion to an acceptable level for construction structures (10-5 kPa) and for a person (2-5 kPa).
2. The developed computational technology in the form of a sequence of information related problems (gas-dynamic and strength) allows the following:

- To determine more accurately the pressure level on structures at explosion at a particular production site;

- To consider more accurately the variety of factors that affect the explosion, namely: the location of ignition source in the room, time of the mixture ignition, the room size and availability of obstacles;

- To determine more precisely the required size and type of SS for each object separately;

- To determine the most rational location for SS installation at activation of explosive device;

- To perform safety expertise of a particular object in order to determine sufficiency or insufficiency of protective systems;

- To analyze the accident to produce temporal and case-and effect picture of occurrence.

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