SECURITY IMPROVEMENT FOR OIL AND GAS PIPELINE INFRASTRUCTURE

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Abstract

This research has been inspired by security concerns due to the recent increase in the terrorist threat to gas and crude oil transportation around the world, especially in regions that are of significant value for the energy supplies. Computational mechanics methods will be used in this research to apply shock wave analysis for possible damage assessment of the affected pipelines. These methods may be also used for pipelines at power plants (especially nuclear), which are usually placed high on the homeland security priority list. The main goal of this research is focused on establishing effective simulation methodology to study the influence of shock waves (caused by explosion) on pipeline systems (buried, on surface, or underwater) to ensure their security. This study is primarily focused on the behaviour of a pipeline subjected to the shock wave produced by the detonation of highly explosive (HE) materials. The results of this study will primarily allow for analysis of the blast wave propagation and the resulting damage inflicted by the pipeline. Outcomes of this research are important in preventing damage progression of pipelines under the blast loading. This data will also be used to develop improved design guidelines for safer and less vulnerable pipelines. The study allows for determining a type of structure of the high energy absorbing protective system.

Keywords: *security, simulation, modelling*

1. Introduction

The earth gas is both one of the most essential heat-energy carriers and the basic raw material for the chemical industry. As a heat-energy carrier, most commonly it is used in households. Recently, it has become a major source used to generate electricity. Long-distance gas transportation is performed under high pressure, in the form of liquefied natural gas by pipelines. Only after having the gas delivered at its destination, it is decompressed to reach the distribution-pressure level. This fact is of great significance to the safety of gas transportation to end-users. The gas transportation safety is extremely sensitive to any acts of terrorism. In practice, it is impossible to safeguard and protect any gas-transmission pipelines that spread out over thousands of kilometres against terrorist attacks. What can and should be done is to minimise its susceptibility to probable attacks, i.e. to minimise effects of the most disadvantageous variants of terrorist attacks against the gas transmission pipelines.

The safety of gas delivery via gas transmission pipelines can be increased under the above-mentioned conditions by the following means: diversification of power supply sources into separate urban agglomerations, the construction of suitably dislocated gas storage facilities, provisions for supplying end-users with gas from different sources, owing to the ring-shaped structure of the gas transmission system, suitable dislocation of engineering workshops furnished properly to quickly restore serviceability of the gas pipeline after the terrorist attack and high energy absorbing systems of protective layers [2, 4, 5, 6, 8, 9].

When setting about to analysing possible terrorist actions against gas transmission pipelines, one should assume that terrorists who want to achieve their goals would not confine their actions to sabotage alone to effect economic impairment of the State. They would rather, or even above all, try to effect the mass neurosis in the society to force the State authorities to make some definite concessions. The above assumed to be a starting-point for the analysis of possible terrorist actions aimed at gas transmission pipelines implies the necessity of giving estimates on: components of the gas transmission pipelines most susceptible to terrorist attacks, points of attacks where the greatest hazards to human beings and environment, as well as economical losses would be provoked, points of attacks that could paralyse the whole country, and hence, the State's functioning, locations, times, and ways of performing terrorist attacks that, on the one hand, would threaten society to the greatest degree possible, whereas on the other hand, evoke the sense of the State's helplessness. Results of the above-suggested assessments would become a starting-point for the analyses of: possible ways of reducing the harmfulness of potential terrorist actions, the cost of preventive actions.

Full-scale experimental testing of the effects of explosion on conventional structures is prohibitively expensive. A solution to these problems is offered by modern computational tools like FEM. Recently developed features of commercial FE codes allow, at a low cost, the numerical simulation of high explosive (HE) blasts to be repeatedly run and compared. Results from blast wave simulation studies were published and discussed in several recent publications [2, 6, 7, 10]. Such simulations require complex meshes with advanced constitutive material models capable of describing the behavior of air, the high explosive material (HE) and an engineering object subjected to blast wave resulted from the blast wave detonation.

The main goal of this research was focused on checking the effectiveness of multi-layer protective panels on pipeline systems in absorbing the energy of the explosion-induced shock wave.

2. The nature of detonation

Explosives produce violent exothermic reactions induced by external effects [10]. These reactions result in mechanical work through the evolution of highly compressed hot gases. The explosive material, filled with the gas generated products, are highly compressed at the surface. The surrounding medium generates a sudden pressure jump, reaching values of tens GPa. Another element of extremely high importance throughout this process is velocity of the detonation-wave propagation, usually within the range of 1000-10000 m/s. Gas products of detonation, high reaction rate, and the exothermic nature of the blast, are the most fundamental factors responsible for strong and destructive effects of explosion. Classic physical theory describes the shock wave as a surface of strong discontinuity where thermodynamic parameters (pressure, density, internal energy, mass velocity, entropy, temperature) are undergone a sudden and jumping changes. Equations involving these parameters in the initial state (before shock front) and on the shock wave front can be derived with the mass, momentum and energy conservation laws, including equation of state (EOS) [10]. Material properties in respect of shocks propagation are often characterized by Hugoniot Adiabat (HA) [10].The detailed forms of the HA can be obtained empirical or analytical based on given EOS. Every HA is located over the Poisson Adiabat (PA) because of entropy change in the shock wave front. The typical shock front thickness in the gases is in the order of several free paths of the molecules. Shockwaves propagate with the velocity exceeding the local sound speed of the material before the front. The value of this velocity depends on the shock intensity (pressure on the front), stronger shocks travel faster. Every expanding shock diminishes as it overcomes successive distance from the originating point except the converged shockwaves. The geometric factor and entropy production are responsible for the shock intensity diminishing. The shock intensity declines together with increasing of the distance from the originating point r in relations increases. The diminishing rate varies between ($1/r$) and ($1/r^3$), depending on the front geometry.

3. The numerical tests

The detonation process from numerical point of view can be implemented through the automated programmed burn model, supported by LS-Dyna [2, 3]. The Jones-Wilkins-Lee (JWL) equation can be used to characterize the products of detonation of the high explosive. The numerical study the case with the detonation of explosive placed on the pipe were analyzed [6]. The shape of the explosive material was a rectangular prism. Preliminary simulation results of this study allowed for analysis of the blast wave propagation and the resulting damage inflicted by the tube element. Time-pressure and acceleration histories were of special interest in this study as well as the damage of the structure [6, 10]. The numerical results of this study clearly showed that at the initial stage of detonation process the rectangular piece of metal sheet is cut out from the pipe wall. The rapture process of the pipe first starts on the edges and mainly is caused by shear and tension stresses. The presented results and capabilities to numerically analyse/represent the process of the pipeline component interacting with the detonation wave have proved very low resistance of it to strong short-lasting pressure pulse generated in effect of burning the explosive charge. Results of our own work on the one hand, and on the other hand, nearly every day news on terrorist attacks aimed at cutting off local communities from the sources of energy (e.g. gas or oil/petroleum) to skillfully affect decision-making processes confirm the above-formulated statement. Additionally coupled Euler-Lagrange formulation which was used in the FE analysis accurately represents the detonation phenomenon. Analysis of the several numerical cases showed that complex meshes for Euler and Lagrange formulations are required [1-4]. Thanks to applied very complicated materials models and additional, an option allowing for interaction between different materials, the very good and reasonable results were achieved [6].

4. Experimental tests of the ability of multi-layer protective panels

Research related with blast wave propagation is not only aimed on its effect on structures but also on developing new concepts of protective panels [2, 4, 5, 6, 8, 9]. These panels often manufactured as removable are made from different types of materials with high energy absorption capacity as multi-functional composites, elastomeric materials, metal foams, etc. The first group of materials is characterized by a high relative energy absorption capacity. Advanced protection ability of the panels made from the multi-functional elastomeric composites is improved continuously, therefore they can be used to protect against existing threats as well as future ones. These new advanced materials can be often easily combined resulting in reduced production, maintenance and operating costs. All these features make multi-functional composites popular and inexpensive with increased resistance to destructive action of blast wave.The experimental testing of the effectiveness of multi-layer protective panels in absorbing the energy of the explosion-induced shock wave was carried out using a steel pipe of the diameter D = 406 mm and wall thickness g = 7 mm.

The first stage of experimental work (pipe elements without any protective layer subjected to HE) have shown very low resistance of gas-pipe components to explosive-charge-effected loads.

Fig. 1. Pipe rapture after experimental tests

Photo presented in Fig. 1 show characteristic damages in the form of pieces of metal cut out from the pipe's structure. These pieces of metal represent geometric shapes of cubes of the detonation material. In practice, every instance given consideration (after having analysed results of measuring the deformations) confirms that putting any explosive directly on the pipe wall results in plastic strain (permanent deformation) of local range which means cutting some element out of the pipe wall. Visual inspection proves that pieces cut out of the pipe walls behaved like elements of a fragment, i.e. they were deforming the opposite internal wall of the pipe.

At the second stage the tree multi-layer protective panels were used in our experiments. The following solutions found their applications in the panels

- elastomer layer-the elastomer placed between two layers of sheet metal (Fig. 2a),
- corrugated layer-corrugated layers (placed between two layers of sheet metal) were made from the epoxy-glass composite (Fig. 2b),
- spatial structures (placed between two layers of sheet metal) made of the epoxy-glass composite material (Fig. 2c).

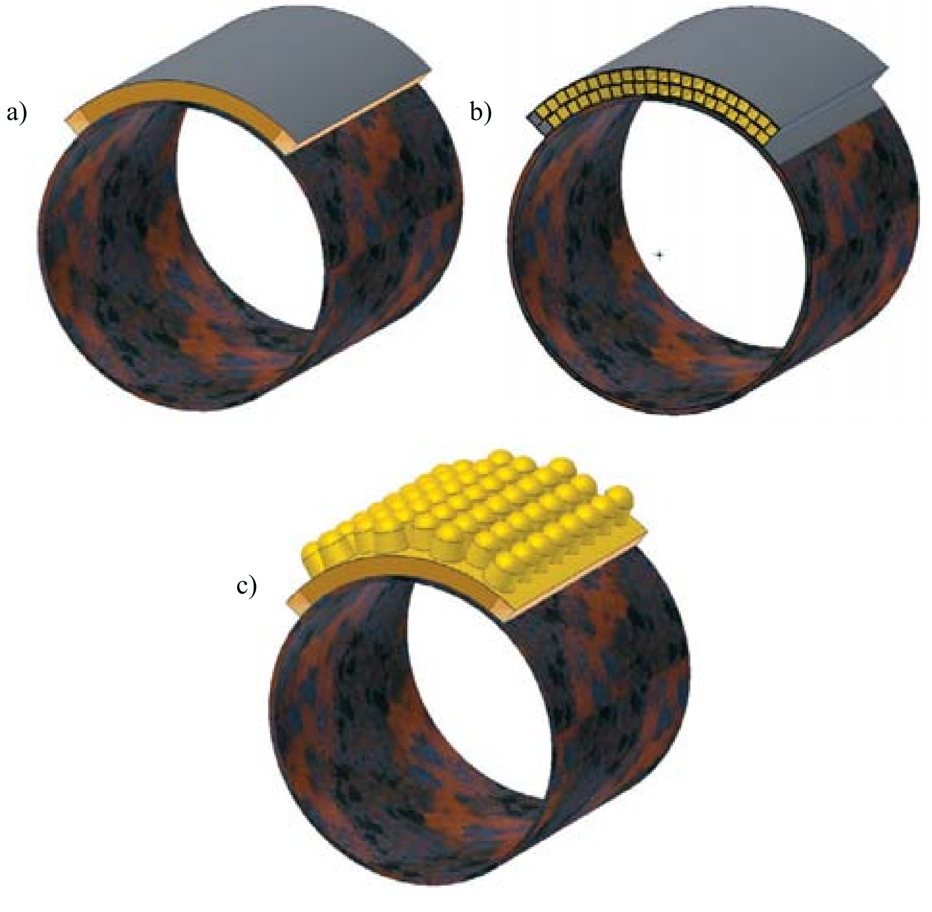

Fig. 2. Tree multi-layer protective panels were used in our experiments

Tests on how the explosion-induced shock wave affects the selected sections of a pipe protected with multi-layer panels were carried out in the firing range. The specimens were loaded with the shock wave induced by the explosion of the 100-gramme TNT block. The block explosive was placed at the level of 10 cm above the comparative specimen and particular panels. Such conditions were generated to check how the major explosion products, mainly the shock-wave pressure and temperature, affect the protected structure and the panels themselves. The strain-gauge bridge ESAM Traveller Plus, Vishay, furnished with the corresponding, strain-gauge measurements dedicated software was used during the testing work. Measurements of longitudinal and circumferential strains were taken with electric resistance wire strain gauges.

Fig. 3. Exemplary pipe specimen with attached protective panels used in field tests

The tests resulted in finding how strains were changing with time. On the grounds of the analyses of findings on how the strains were changing one can determine the effectiveness of particular panels in absorbing the shock-wave energy. The lowest values of elastic strains were gained for the spatial structure panel (number 3). At the same time, no plastic strains were in practice recorded in the course of tests with the same structure panel employed. For the panel 1 and 2 the overall strains gained were contained within the range of 0.008-0.009, whereas the plastic strains-within the range of 0.004-0.009. What confirmed the reliability of the measurements taken with the strain-gauge method were permanent pipe deformations (Fig. 4).

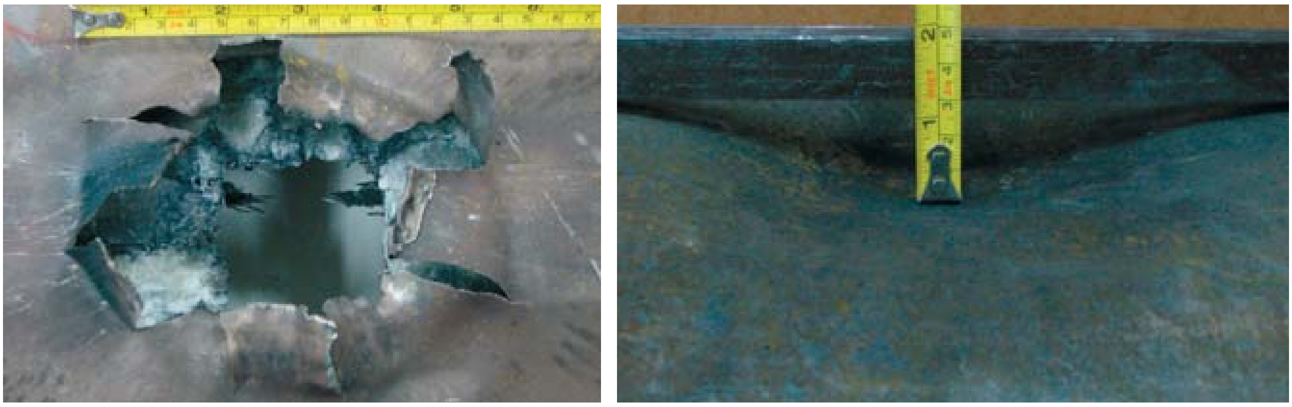

Fig. 4. Destroyed protective panel and permanently deformed pipe wall after field tests

5. Conclusions

The protective panels often manufactured as removable are made from different types of materials with high energy absorption capacity as multi-functional composites, elastomeric materials, metal foams, etc. The first group of materials is characterized by a high relative energy absorption capacity. Advanced protection ability of the panels made from the multi-functional elastomeric composites is improved continuously, therefore they can be used to protect against existing threats as well as future ones. These new advanced materials can be often easily combined resulting in reduced production, maintenance and operating costs. All these features make multi-functional composites popular and inexpensive with increased resistance to destructive action of blast wave.

The experimental testing work on the effects of a shock wave affecting the specimen in the form of the pipe section with protective panels attached have proved the capability of energy-consuming structures to absorb the energy of the explosion-induced shock wave.

Depending on the complexity of the panel (i.e. the number and types of layers employed), and thus, the degree to which different destructive mechanisms affected the object under investigation, different energy-consuming capabilities of different panels were found.

Tests conducted on the pipes without the protective layers produced a perforation of the pipe wall, while application of the protective panels caused only a local, permanent deformation of the pipe wall. The first outcomes encouraged our team to conduct further work which can be aimed at finding optimum (dimensions, combination of layers with different possible fillings, etc.) solution of the protective panel from the standpoint of both the resistance to detonation-wave effects and energy-absorbing capability. The second criterion, also of great importance and taken into account throughout the testing program, is the cost of manufacturing such a panel, which is closely related to developing a suitable manufacturing and mounting processes.

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