Air Blast Loaded Safety Devise Dynamical Response Analysis

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Abstract: *Equipment of many oil and gas processing plants in Russian Federation is considerably worn-out. This cause the decrease of reliability and durability of equipment, and to rise of accident rate. An air explosion is the one of the most dangerous cases for plants in oil and gas industry, usually caused by uncontrolled emission and inflammation of oil products. Air explosion can lead to significant danger for life and health of plant staff, so it needs necessity of safety device usage. New type of safety device designed. Numerical simulation is necessary to analyze design parameters and performance of safety device, subjected to air blast loading. Coupled fluid-structure interaction analysis performed to determine strength of protective devise and its performance. Coupled Euler-Lagrange method allowable in Abaqus by SIMULIA selected as the most appropriate analysis tool to study blast wave interaction with safety device. Absorption factors of blast wave evaluated for safety devise. This factors allow to assess efficiency of safety devise, and its main structural component – dampener. Usage of CEL allowed to fast and accurate model the dampener behavior, and to develop the parametric model to determine safety devise sizes.*

Keywords: *deflagration, air blast wave, finite element method, internal energy, deformation, safety devise, Coupled Euler-Lagrange method*

1. Introduction

Equipment of many chemical, petrochemical, oil and gas processing plants in Russian Federation is considerably worn-out. Besides, equipment exploitation regimes very often disrupted by hold-up in work materials delivery, low technological and manufacturing discipline etc. This factors cause decrease of reliability and durability of equipment, and rise of accident rate. In current economic situations, companies forced to use equipment until it partial of full outage.

Any accident on chemical, petrochemical, or oil & gas processing plant can cause a harm of personnel involved in production, harm the nearby plants personnel and civilians. This feature distinguish chemical and oil & gas plants from other industries plants, which usually do not cause risk to surrounding objects in case of extreme situation. Thereby, due to high potential danger of petrochemical and oil & gas plants, the problem of safeguarding for such objects is actual.

An air explosion is the one of the most dangerous cases for plants in oil and gas industry, usually caused by uncontrolled emission and inflammation of oil products. Very often constructions used in oil plants cannot sustain such disaster, because they designed without consider of air explosion loading or became depreciated. Air explosion can lead to significant danger for life and health of plant staff, so it needs necessity of safety device usage.

Usually that type of construction is operating station, which controls most of processes at oil plant, and where most of plant staff are present. Reconstruction of such a stations required great amount of time, and could bring financial losses due to the plant idle. In such case, most reasonably is using protective devices instead of reconstruction. Air explosion danger for such buildings as operation stations, may be significantly reduced by corresponding safety device.

2. Safety device features

Team of authors developed new type of protective device, which are able significantly reduce shock wave front pressure excess and thus reduce blast loading for operational station [1].

Safety device include special dampers, mounted on frame made from I-beams. Devise designed to disseminate the blast wave energy by partial reflection and scatter in the extinguishers.

Damper designed as welded box with specially oriented steel plates inside, which shape is comb-like channel inside the box. This comb-like channel cause the blast wave reflection between plates and decrease the overpressure. Damper also can decrease wave energy by its dissipation to elastic-plastic deformation due to plate collapse. This two energy dissipation mechanism allow to gradually decreasing wave overpressure. Safety devise sketch is shown on Figure 1.

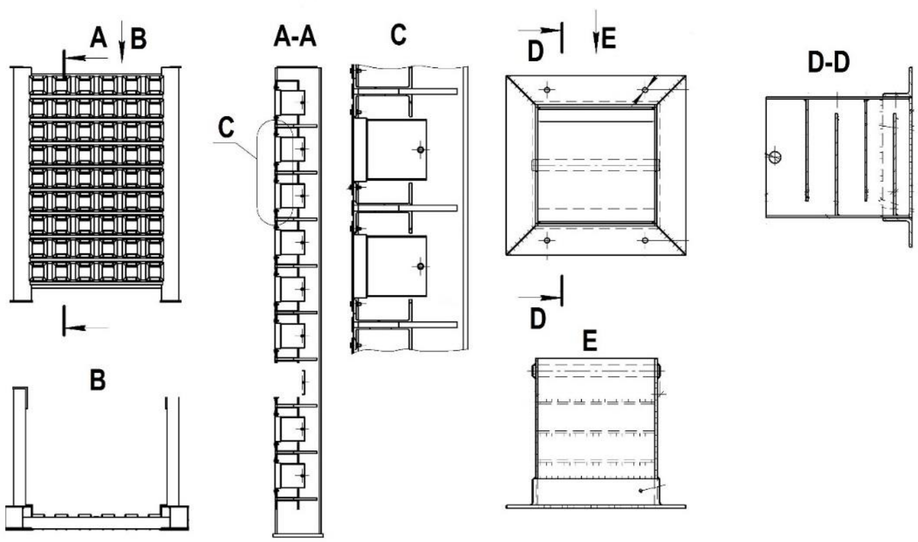

Figure 1. Safety device and damper sketch.

3. Research method

To analyze safety devise behavior under blast load we must solve coupled flow dynamic and dynamic stress problems. Analysis of such problem with analytical methods is complicated due to necessity of solution of large amount of coupled nonlinear problems, and an empirical method is complicated due to cost of experiments involving blast waves.

To find such coupled solution, numerical simulation model need to be made. Many commercial solvers can solve coupled solution of fluid structure interaction. In this study, we have used the CEL technology in Abaqus/Explicit.

One of most convenient techniques to analyze fluid-structure interaction problems is to use Coupled Euler Lagrange analysis method, which implemented in Abaqus/Explicit. This method allows simultaneously model coupled dynamic flow and stressing problem in single solution space.

It is necessary to determine efficiency of protective device due to blast waves loading with different parameters. In addition, it is necessary to determine deformation or collapse behavior of damper – its deformation behavior directly affects the efficiency of shock wave energy reduction.

Simulation for such analysis made with Abaqus/Explicit solver, and divided to the following steps:

1. Flow simulation of blast wave propagation through the media.
2. Dynamic stress simulation of the damper.
3. Coupled fluid-structure interaction simulation of blast wave propagation through the deformable extinguisher.

Step 1 and 2 necessary to verify fluid and dynamic stress simulation. Coupled model completely assembled after such verification. Combination for Coupled Euler-Lagrange analysis shown on Figure 2.

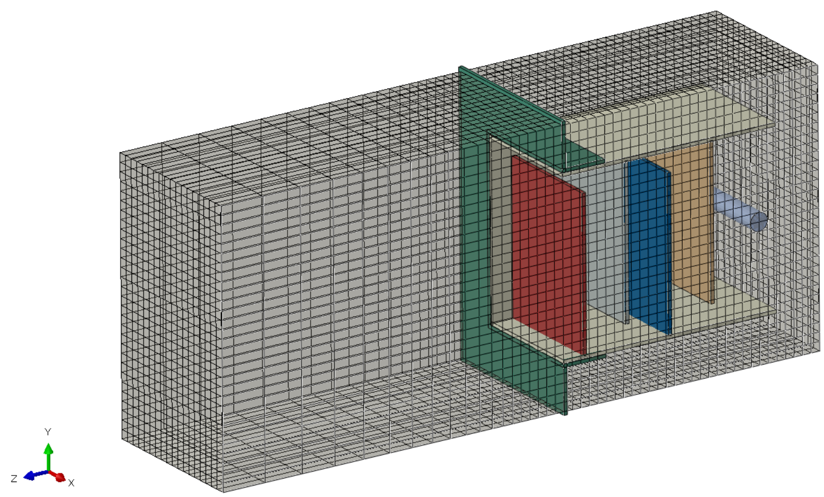

Figure 2. Coupled Euler-Lagrange simulation model.

General contact technology used to transfer pressures and mesh motions between flow and dynamic strength analysis. This technology allow to automatically tracking interaction surfaces in simulation media.

Is result of simulation achieved the pressure distribution in gas media and plastic deformations in extinguisher.

4. Research results

For the analysis of safety device and its extinguishers blast wave parameters defined under the regulation methodic [2] and [3]. Risk class 3 objects containing 5000 kg of gasoline selected for analysis. Calculated deflagration wave parameters shown on Figure 3.

Figure 3. Blast wave parameters

	R	E (J)	ΔP+	ΔP-	T+ (s)	T- (s)
5000 kg	50	2,2E+11	198 KPa	30 Kpa	0,0616	0,204

Where R – distance from explosion center, E – effective explosion energy, ΔP+ - positive wave peak overpressure, ΔP- – negative wave pressure, T+ - positive wave duration, T- negative wave duration.

Pressure and velocity distribution in gas media shown on Figure 4 and 5. Pressure distribution diagram for different points in extinguisher shown on Figure 6.

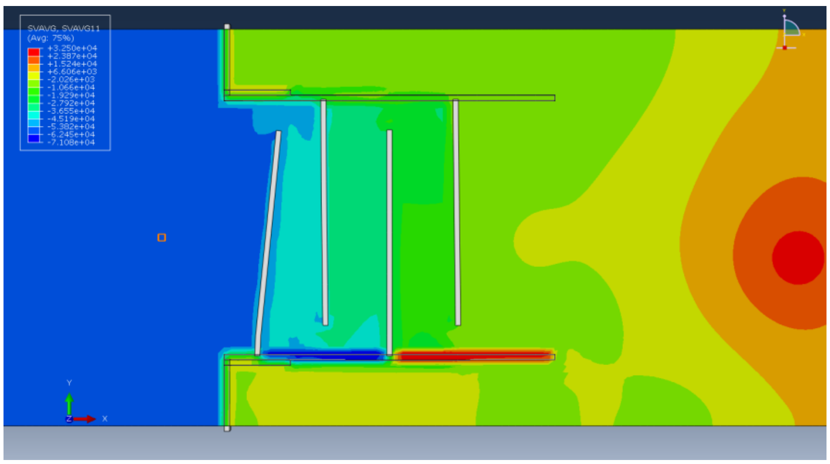

Figure 4. Pressure distribution over deformed damper.

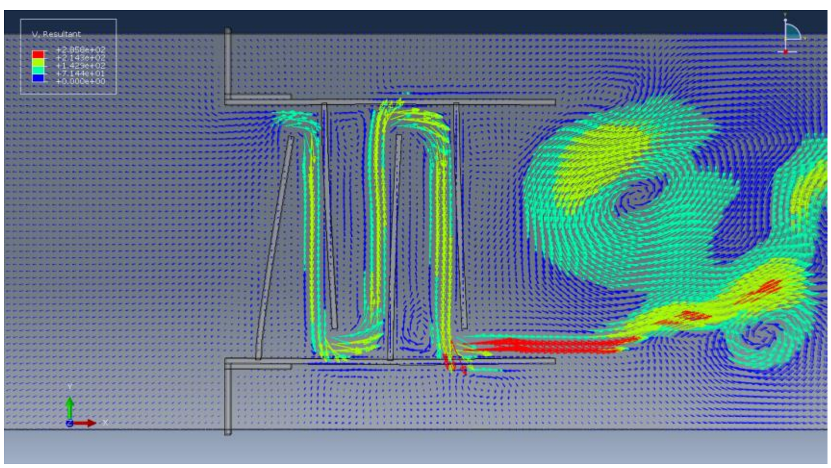

Figure 5. Flow velocity distribution over deformed damper.

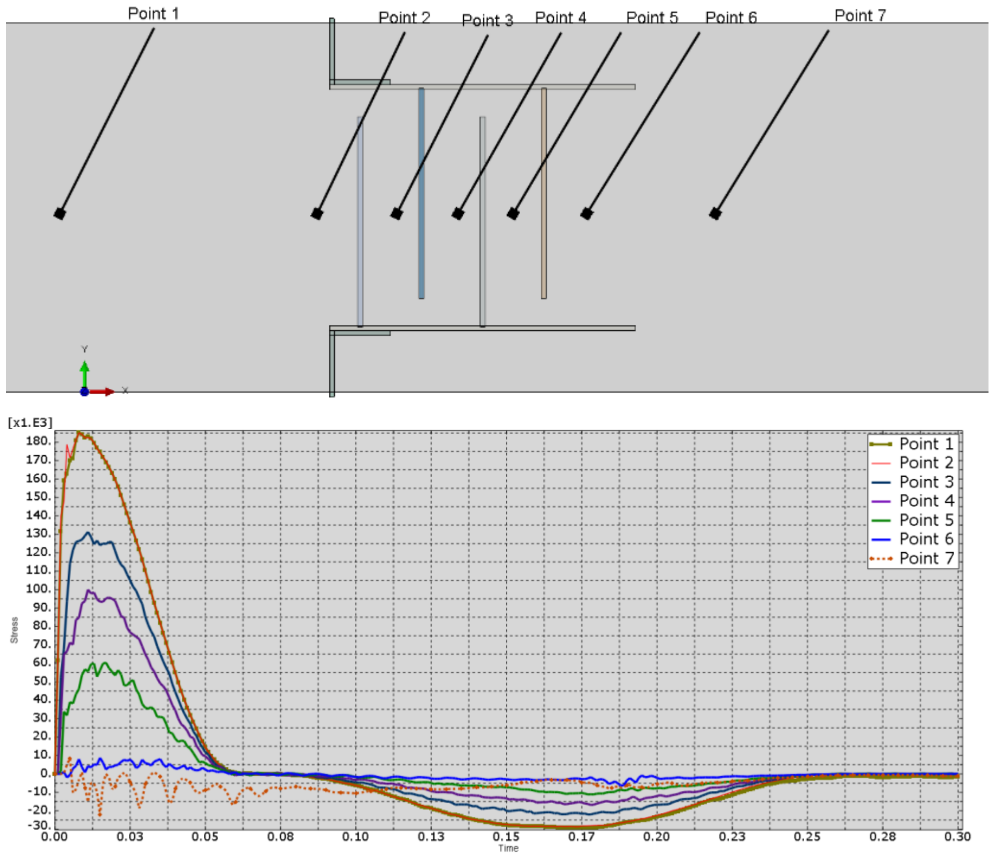

Figure 6. Overpressure distribution in various points in damper.

Figure 7 show the values of minimum and maximum pressure measured in damper points. Achieved values show that over pressure gradually decreased.

Figure 7. Overpressure in selected points.

	1 (KPa)	2 (KPa)	3 (KPa)	4 (KPa)	5 (KPa)	6 (KPa)	7 (KPa)
ΔP+	185	185	132	101	60	8	5
ΔP-	-29	-29	-22	-17	-11	-6	-19

Stress analysis of damper performed. Plastic deformation point shown on Figure 9. Maximum stress achieved in model is 250 MPa, which lead to yielding of St 3 material. Yielding point located in channel plate attachment point.

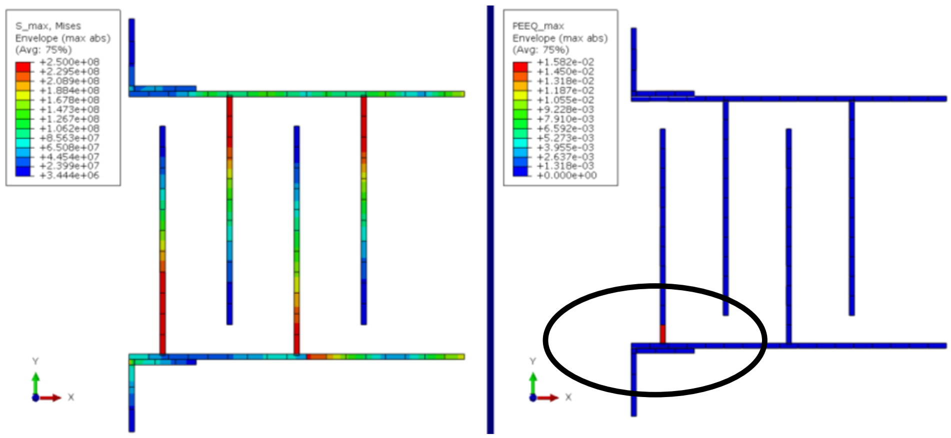

Figure 9. Stress an equivalent plastic strains distribution in damper.

Pressure reduction coefficient k_{loc} calculated for damper. Coefficient determined as $k_{loc} = P_{in}/P_{out}$, where P_{in} – pressure before extinguisher; P_{out} – pressure after extinguisher. Pressure reduction coefficient for analyzed extinguisher design is 18.

Achieved results let us made a hypothesis that safety devise is impenetrable for blast wave with selected parameters, and consider protective devise as continuous wall. This assumption allow us considerably decrease size of safety devise blast wave interaction simulation. For further steps safety device considered as rigid – stress analysis of full devise for acting pressure will made after the full analysis.

To determine the overpressure level acting on operation station structure, simulation model of blast wave interaction with building made. Sizes of the building is following: height – 4 meters, length - 15 meters. Explosion occurs in 65 meters away from building front wall. Blast wave interaction with building shown on Figure 10.

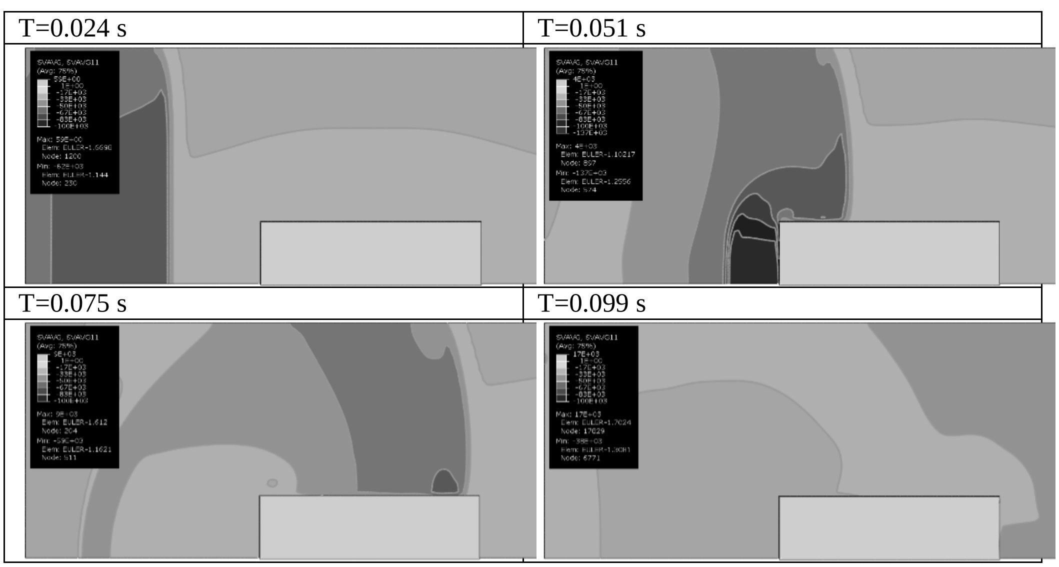

Figure 10. Blast wave interaction with unprotected building.

Pressure distribution over the building divided to specific areas: Flow separation area – areas near the edges of building walls; wall central area – area in the center of wall where pressure distribution is regular. Overpressure values for considered areas was achieved in simulation, and provided on Figure 11

Figure 11. Overpressure on specified building areas

	Pressure
Maximum of building	178 kPa
Front wall	125 kPa
Roof	62 kPa
Back wall	36 kPa

Due to regulation [2] overpressure higher that 100 kPa lead to complete destruction of buildings. Hence, it is necessary to decrease overpressure on operational station wall.

Simulation model with building covered by safety devise made. Safety devise with following parameters is analyzed:

- Safety device height – 4 m., 5.5 m., 7 m., 8.5 m.
- Device location distance from building front wall - 2 m., 4 m., 6 m., 8 m., 10 m., 12 m.

Results of simulation organized in diagrams, which show pressure-height-distance dependence. Achieved diagrams allow to preliminary design the safety devise parameters to protect the building with similar sizes from blast load with similar parameters. Global pressure reduction coefficient (GPRC) diagram shown on Figure 12. Pressure diagrams for different areas shown of Figures 13 and 14.

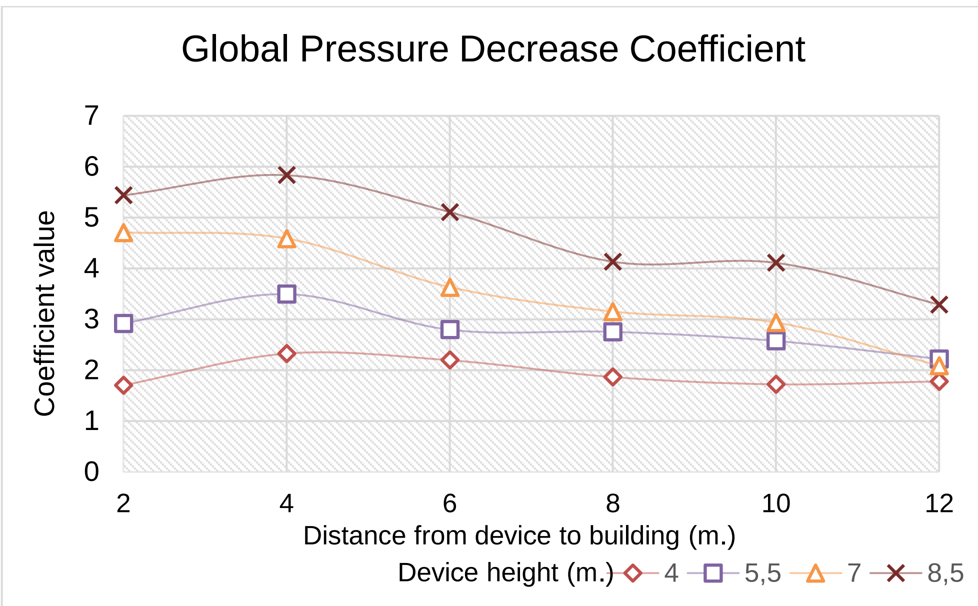

Figure 12. GPRC dependence from device height and distance from protected structure.

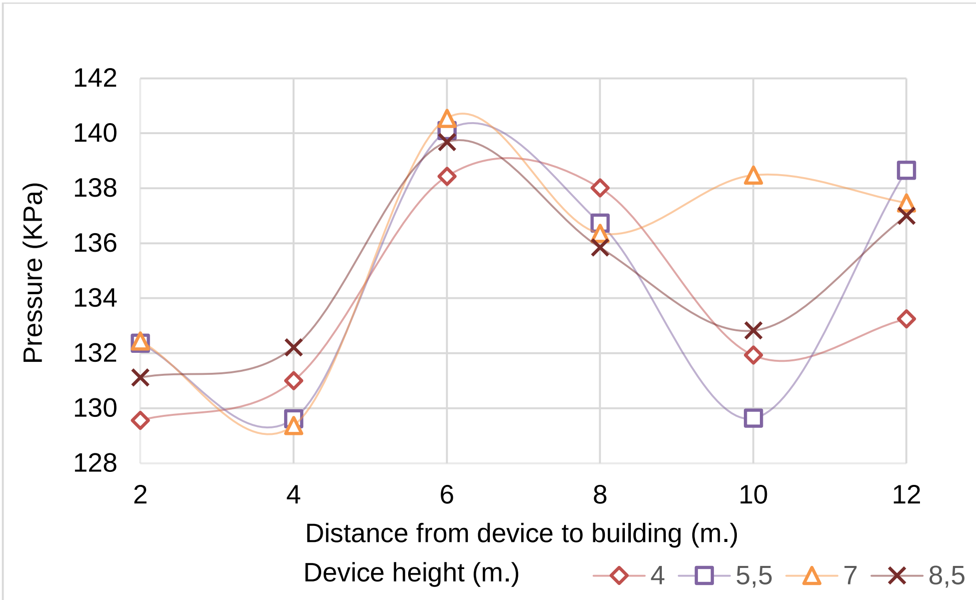

Figure 13. Pressure on device front wall depended from device height and distance from protected structure.

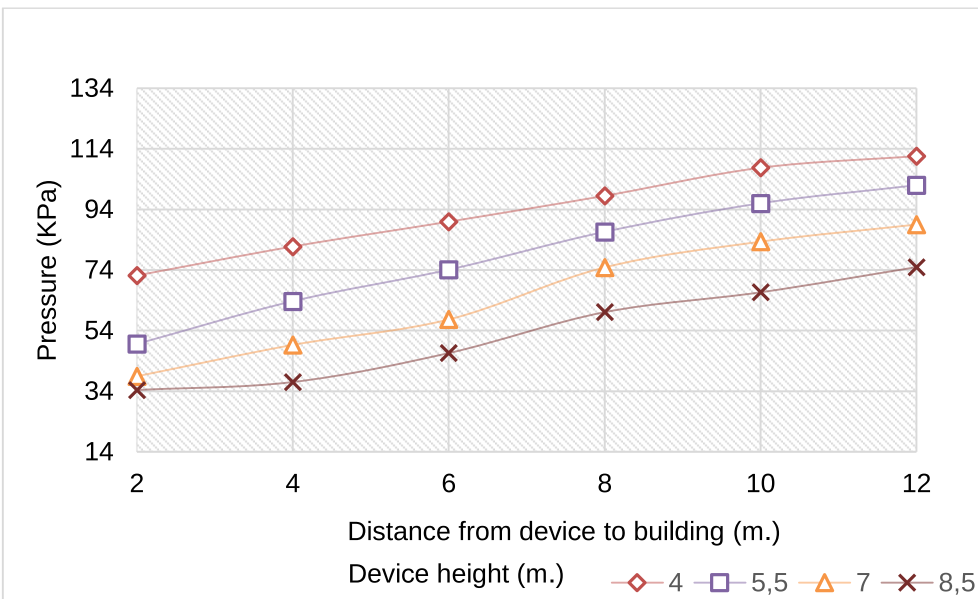

Figure 14. Pressure on building front wall dependence from device height and distance from protected structure.

5. Model and analysis time

HP EliteBook 8570w with Core i7-3840QM (4x2.80 GHz cores), 32 GB RAM used to run analysis.

Three types of model was used do made provided analysis.

1. 3-dimentional CEL model of dampener
2. Quasi 2-dimensional CEL model of dampener
3. Quasi 2-dimensional CEL model of protective devise and dampener

Run of model 1 take a ~12 Hours on mentioned PC. Model 2 created to decrease analysis run time. Run of model 2 take a ~1 hour on mentioned PC. Results from model 1 & 2 compared, and model 1 is more conservatives, than model 2.

6. Analysis verification

To verify CEL method adequacy for blast wave – structure interaction analysis we created special model to verify simulation results and real life test data.

Comparison of simulation and experimental data of blast wave interaction with brick wall made and published in paper [4]. Achieved results shows difference between simulation and experiment is no more than 3-7%.

7. Conclusion

Achieved results confirm that safety device can decrease overpressure due to blast wave load on protected structures. This allows putting the device on existing oil & gas plants, instead of rebuilding of existing infrastructure.
Provided method allows designing and analyzing safety device for different blast wave parameters. Coupled Euler-Lagrange method allow to model simulation of blast wave interaction with damper. It is possible to use method for approximate analysis of blast loads acting on protective device.
Future research will consider solution of full 3-dimentional analysis of blast wave interaction with protective devise frame with installed dampeners.

6. References

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