Assessment of Protective Structures on the Basis of Their Acceleration Caused by Blast Wave

Jiří Štoller(✉) and Branislav Dubec

Faculty of Military Technology, Department of Engineer Technology, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic
{jiri.stoller, branislav.dubec}@unob.cz

Abstract. The purpose this study was to assess the protective structures of different shapes on the basis of their acceleration caused by blast wave. Six variants of models was assessed in the software environment Ansys Autodyn, an explicit tool for modelling the nonlinear dynamics of solids, fluids, gases and their interactions, where the compared parameter was the value of the acceleration of the structures loaded with blast wave. This study represent the second step in the search for optimal shape of protective structure with regard to limitations such as building materials on the base of concrete, low manufacturing cost, modularity and easy transportability and follows the conclusions from the study [11].

Keywords: Acceleration · Ansys Autodyn · Protective structures · Shape optimization · Blast wave · FEM

1 Introduction

The changes in the security environment and development of armed conflict receding the importance of classical field fortification. The reason to that is a change in the nature of conflicts, tactics, equipment of troops, where the usage of small, highly mobile units comes to the foreground. While the danger of massive conflicts is still present, in present day, the main focus of armed troops is directed towards local conflicts that can very quickly change its center of gravity [5].

Another aspect of the changing nature of conducting operations is the deployment of armed forces operations in diverse and unpredictable geopolitical environments. The possible threats, which arise from the asymmetrical nature of conflicts, place demands for research and development of new ways of force protection. While in combat operations, the task is to minimalize life losses of troops connected with direct combat, there is an equal effort to eliminate the losses in the context of other tasks. The army personnel can support diplomatic efforts, cooperate on mitigation of consequence of humanitarian problems in unsteady environment, support civilian reconstruction teams etc. Huge defensive positions, fortifications and places of gathering were thus replaced by smaller military bases and peacekeeping camps, where also the non-military personnel are present. Besides the attacks performed by conventional weapons, the main

A. Kravcov et al. (eds.), *Durability of Critical Infrastructure, Monitoring and Testing*,
Lecture Notes in Mechanical Engineering, DOI 10.1007/978-981-10-3247-9_2

threat to camps and bases comes from the usage of improvised explosive devices and charges carried by persons, luggage or vehicles [12].

Despite the relatively large amounts of resources of the Army of Czech republic dealing with designing protective structures in both, the theoretical and practical aspects in, there has not been yet introduced to the usage a protective structure, that would meet the all the requirements, which contemporary force protection requires. Contemporary protective structures are characterized by one or more deficiencies that reduce their protective value. The most relevant is the lack of optimization [9], and therefore its low resistance to the effects of the blast waves. So far, this deficiency was mostly ad hoc eliminated by the usage of adequate amount of construction material of outer protective layers of the structures [8]. Another drawback of protective structures is a relative time-consuming and labor-intensive construction. The structure is usually made of several different materials and different parts, which require heavy machinery for their assembly which is also connected to another major drawback and that is demanding character of their transportation [4].

This study continues in the search of a new protective structure that will remove deficiencies mentioned in previous paragraphs and open the next phase that is the creation of its structural design.

2 Acceleration

Blast waves cause two types of acceleration of objects, such as structures, vehicles and biological specimens. The first is characterized by its very high value, accompanied by small values of translation of objects. In general, its presence is associated exclusively with the phenomena of explosive nature. The second one is characterized by lower value, where higher values of translations of object are present. This acceleration is typical also for other phenomena like traffic accidents [3].

In the context of force protection, protection of materials or equipment to the effects of explosions are these two types of acceleration counted among the devastating parameters that must be eliminated or reduced to acceptable levels. Among injuries caused by the effects of acceleration are mainly first limb injuries, spinal or brain ranging from nerve damage, through soft tissue injury, fracture or shatter bone, crushed cartilage, ligament rupture etc. All these injured arise due to the passage of the shock wave and the body’s inability to absorb this energy. Effects of the second type causing injuries and damage due to different acceleration of parts or the secondary collision of these parts with other objects [7].

Acceleration of the construction caused by the blast wave of the explosion that is transmitted to human beings located in structure, is therefore appropriate indicator for assessing the level of ballistic resistance of protective structure. Since the objective of this study was to find a suitable shape of protective structures, it was not necessary to find out the real value of the acceleration of the structure and evaluate its effects on the personnel. The assessment of the quality of ballistic resistance of the designed protective structure of different shapes to the effect of the blast wave is obtained by comparing values of acceleration of individual models of these structures.

3 Ansys Autodyn Simulation

Ansys Autodyn is explicit analysis tool for modeling the nonlinear dynamics of solids, fluids, gases and their interactions. When calculating the propagation and effects of the pressure wave from the explosion as a physical problem, its mathematical model based on a system of partial differential equations is discretized and afterwards solved using numerical methods. Ansys Autodyn represent a standalone executable component of an integrated software environment Ansys Workbench (AW) where the entire process of the creation of the simulation can be managed within a few subsequent steps.

At the beginning of the creation of a computational model, explicit dynamics component was chosen, where the tasks connected with explosions can be solved. Afterwards, the proper materials used in the simulation had to be chosen. Material Library of AW is divided into several categories according to the nature and complexity of the simulation material models, where explicit material model for concrete named CONC140Mpa, representing the building material of the protective structure was chosen.

The next preparatory step consist of creation of the models geometry that can be used in the simulations. Since in our case our task was to simulate the effect of an explosion on a protective structure, the base geometry represented by the model of the protective structure created by CAD software Autodesk Inventor was imported into an software component of AW for creating the geometry for simulation called Design-Modeler (Fig. 1). To reduce the computational demands, model was adapted to the shell structure with a volume of 0.0046 m^3. After that step, it was proceed to a creation of a mesh.

Meshing is a process of a creation of the numerical network of the model geometry. Through this process the model is divided into a finite number of elements, where each element carries information about the detected parameters in its node (Fig. 2). Network quality greatly affects the accuracy, speed and fluency of calculation and therefore a refinement and adjustment of a default network with regards to the size of the minimum element and the overall quality of elements was made. Because of the necessity to enter at least one initial conditions, the model was defined with the direction of the

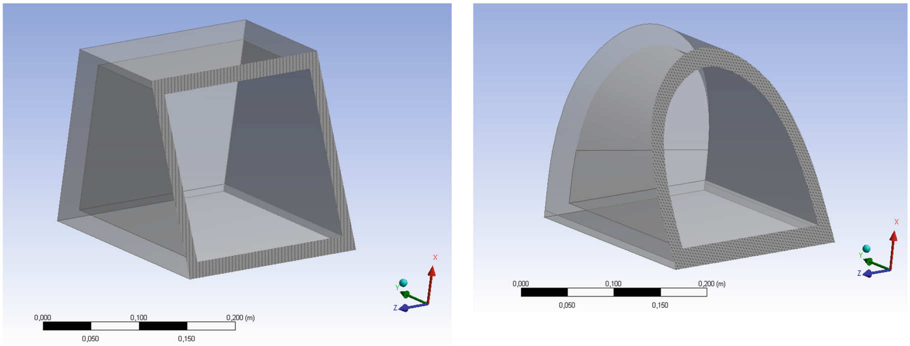

Fig. 1. Cross-sections of the models in DesignModeler

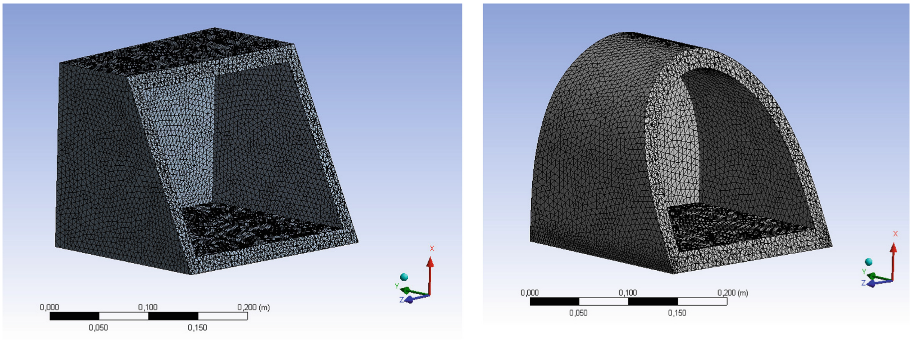

Fig. 2. Mesh of the models

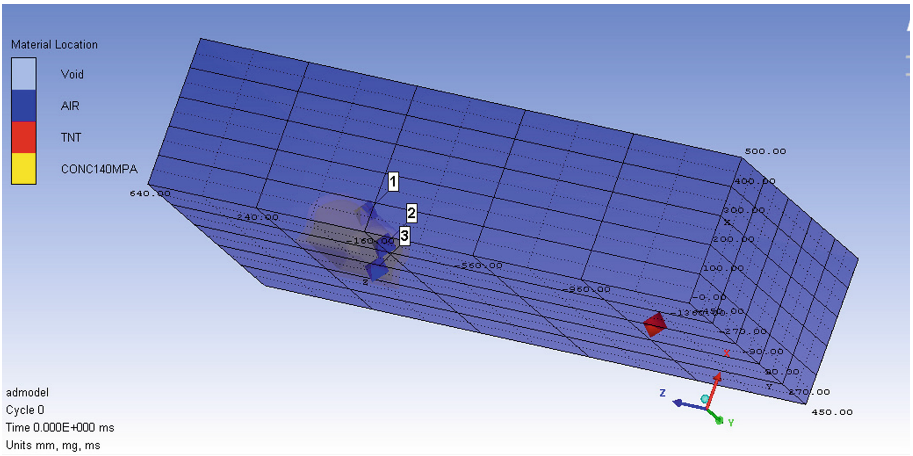

Fig. 3. Computational domain

gravitational acceleration with the direction of negative x. Pre-prepared model was subsequently linked and opened in Ansys Autodyn, where another settings was specified and where the final calculation of the propagation of blast wave and its effect on the protective structure was simulated.

Besides the already chosen material model of the construction, another two materials required for the interaction between a physical model of an explosion, such as air and TNT were loaded. Air was used as a filling of the computational domain of propagation of blast waves and TNT filled part of this domain, representing the explosive charge of total weight 106.4 g. The detonation point was situated to a distance of 1 m from the front edge of the building (Fig. 3) in the center of the placed charge. On the five planes of the domain except for bottom plane YZ of the domain representing the earth's surface was applied Flow_Out condition, which allowed free movement of material through this areas.

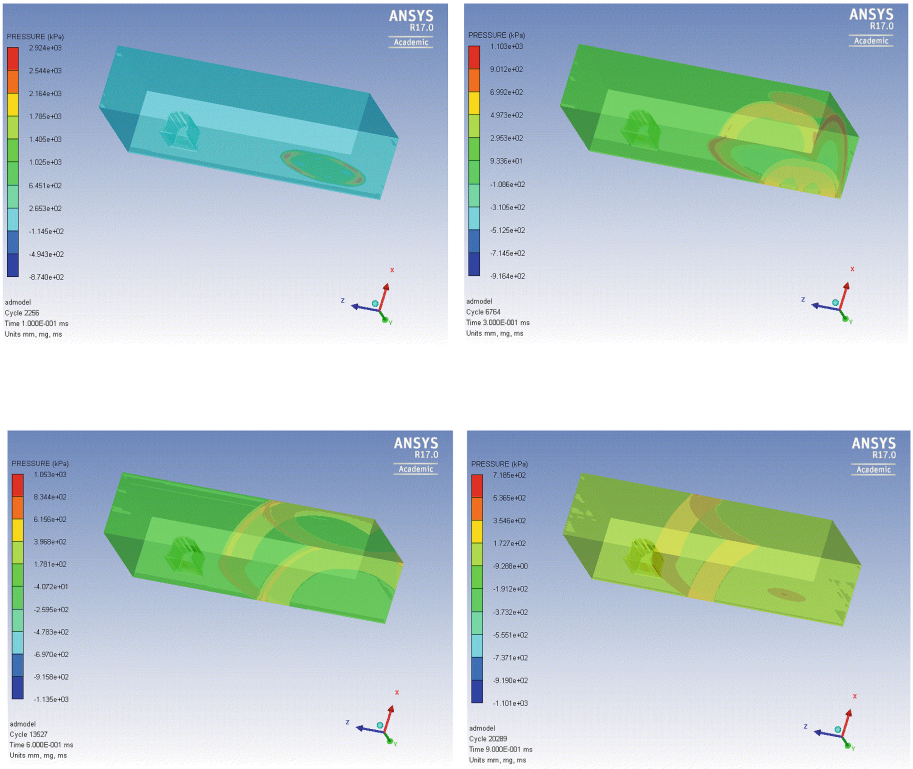

Fig. 4. Progress of the simulation

Before the start of the simulation, three gauge points for recording the value of the acceleration in direction of axis negative z were placed into the shell of the model. After this step, the duration of simulation was set and calculation was launched for the first model (Fig. 4).

4 Variants Assessment

Overall six variants of protective structures was assessed (Fig. 4). These variants of protective structures represent the entire range of values of the drag coefficient obtained by CFD conducted in paper [11] and the both factors, requirements for the dimensions and volume of internal space [4] of protective structure or the possibility to construct them were taken into account by their selection. The model number 1 (Fig. 5) represent the specimen with the lowest value of drag coefficient, the model number 6 represents the model with the highest value (Fig. 5).

Table 1 shows the values of the parameters of models in ascending order according to their drag coefficients [11], as well as absolute values of the maximum values of their

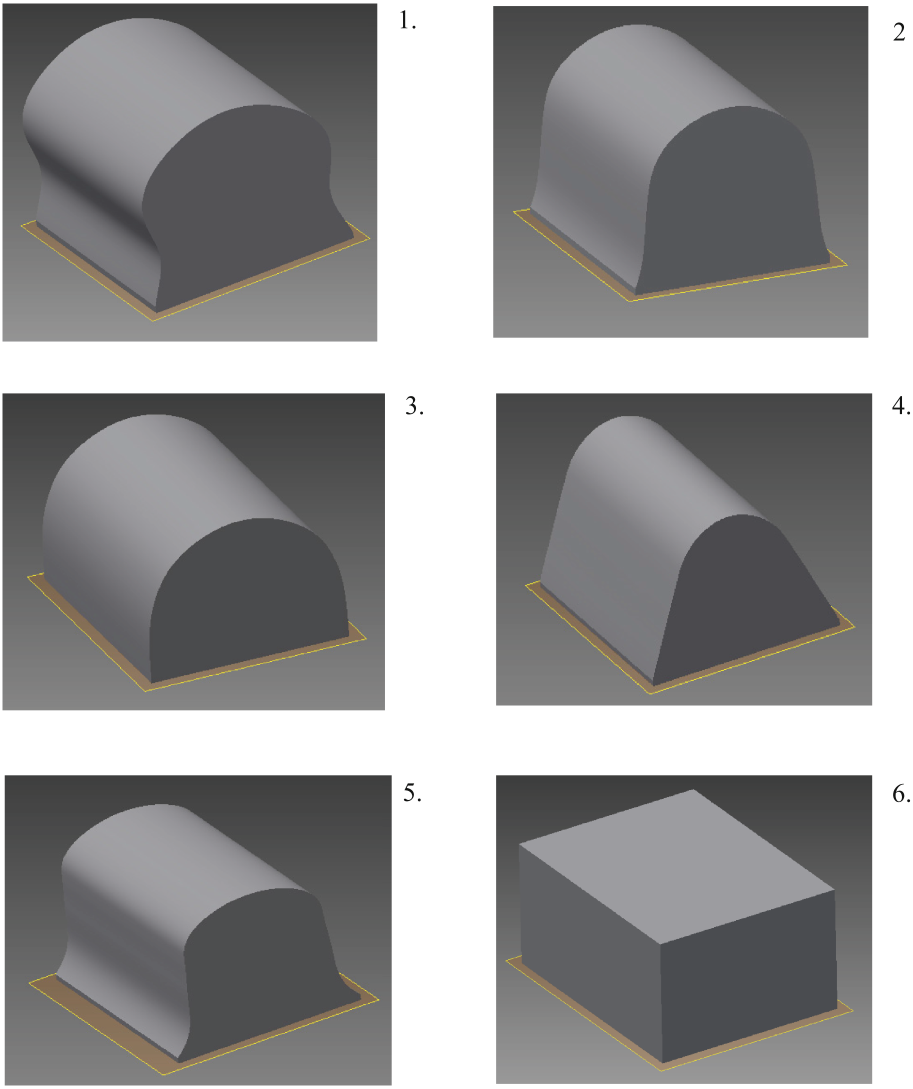

Fig. 5. Shapes of assessed models

acceleration obtained from three gauge points placed on the models caused by blast load obtained from the simulation by the usage of Ansys Autodyn.

The bar graph (Fig. 6) is a visualization of the data from Table 1. It is evident, that the correlation among the value of drag coefficients and the value of acceleration is not present. However from the assessments by the usage of both, CFD software environment Anys Afluent and Ansys Autodyn, it is clear, that the traditional shape of the protective structure (model number 6) is not optimal from the ability to resist the effects of loads from blast waves point of view.

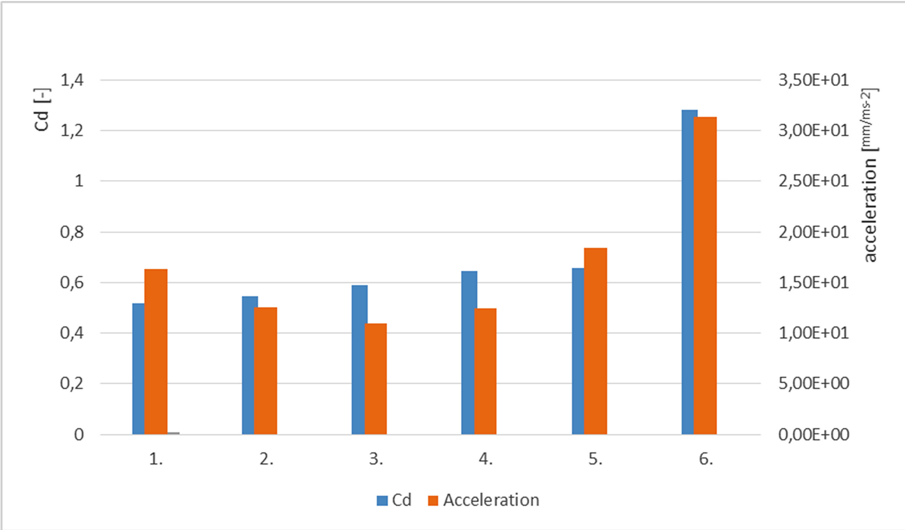

Fig. 6. Drag coefficient and acceleration of models

Table 1. Input parameter values and their range

Model num	Parameter DS_1 [mm]	Parameter DS_2 [mm]	Parameter DS_3 [mm]	Parameter DS_4 [mm]	Parameter DS_5 [mm]	Force – z [N]	Drag coeff C_d	Accel [mm/s.10^{-6}]
1.	88,3	119,4	112,6	95,1	112,5	44,67	0,5186	16,3
2	83,5	101	105	107	110,7	47,12	0,5471	12,5
3.	80	105	117	120	120	45,53	0,59	10,9
4.	60	73	91	100	112	55,61	0,645	12,4
5.	98	87,9	97,1	94,3	100,7	56,59	0,657	18,4
6.	Cuboid, A × B, A = 240 mm, B = 190,7 mm					110,1	1,282	31,3

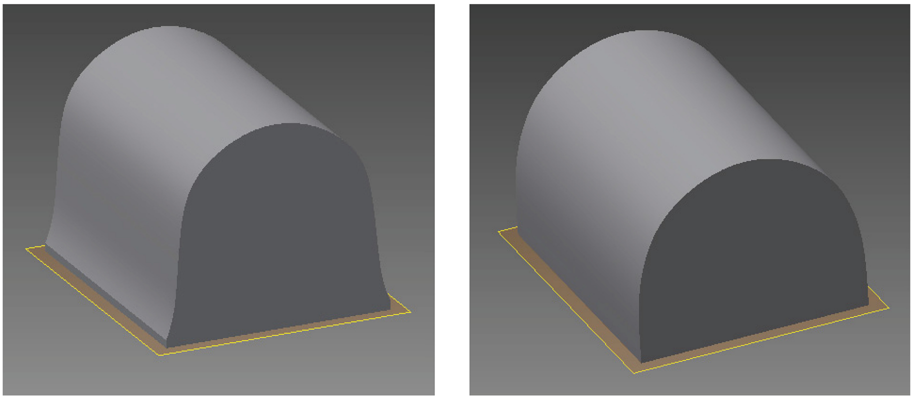

Fig. 7. Expedient shapes of protective structure

This assessment also led to conclusion to exclude model number1 and model number 5. Three models felt into consideration, model number 1, model 2 and model 3. After excluding model 4 because of its unfavorable internal topology, model number 2 and model number 3 became models (Fig. 7), which structural design will be worked up.

5 Summary

This work presents the second step in design of new protective structure to the effects of the blast wave and follows the results obtained in previous study, where the numerical simulation in the software environment Ansys Fluent based on computing model of the external flow around the models [1] of protective structure was conducted as a method for finding the optimal shape. The criterion for comparison was represented by the value of drag coefficient [11].

In this study, six models of different shape were assessed in the software environment Ansys Autodyn to the effect of the blast created by surface explosion, where the value of acceleration of the construction caused by the blast wave from the explosion was compared. Based on the results of both simulations the most expedient shapes of protective structures optimized to the effect of explosive blast wave were selected.

The creation of the structural design is the task of the third step in designing the new protective structure. To reduce production costs, reduce transport costs and demands and to facilitate assembly of the structure, which were the original requirements and conditions of the new design, it seems expedient to divide the overall construction of the protective structures into several structural prefabricated elements. This design can fulfil the requirements placed on protective structure, as well as demands for its resistance against the means of destruction of the enemy [10]. The basis of the structure can be created by several concrete frames as this type of structural design was used in the past for construction of protective structures. These were mainly soil covered shelters, outposts, hideouts, observation posts etc. [6]. Since the advantages of frame-type structures is their considerable resistance, durability and relative ease of production as well as vast means for their transport, the frame is a structural element suitable for construction of protective structures in present day.

The possibilities for further advancements in development of protective structures can be divided into several categories. Ansys Autodyn as a component of an integrated platform, Ansys Workbench, along with other components of the platform offers extensive options for dealing with the design and evaluation of protective structures. One of the main conditions to achieve accurate results is the necessity to input correct parameters [2]. The material models used in this simulation did not correspond to the planned building material model of the new protective structure. Although the nature of the simulation did not require its existence, its creation and incorporation into the material library of the software would help improve the accuracy of the computational model and the results obtained in subsequent simulations.

Another improvement of the quality of protective structure is the development of manufacturing capabilities allowing the production of shaped elements, which removes some of the constraints imposed on the geometry of the protective structure.

The creation of a rotationally symmetrical body with the infinite planes of symmetry could help to further minimize the interaction of blast waves with a protective structure [9]. Possibility of production of shape and dimensionally more diverse components of the structures would allow to emergence a wider range of shape and dimension solutions of protective structures.

The design of the new protective structure presented in this study will enable units operating in foreign missions increase their level of protection. The elimination of threats which are the units in this type of operations exposed to requires new solutions and continuous improvements in force protection.

Acknowledgment. The work presented in this article has been supported by the Czech Republic Ministry of Defence - K 201 Department development program "Development of technologies in weapons construction, ammunition, weapons instrumentation, materials engineering and military infrastructure".

References

1. ANSYS, Inc. ANSYS Fluent Theory Guide, Release 15, USA, SAS IP, Inc., November 2013
2. ANSYS, Inc. Design Exploration, Release 12.1, USA, SAS IP, Inc., November 2009
3. Boyd, S.D.: Acceleration of a plate subject to explosive blast loading - trial results, Australia, Department of Defence, Maritime Platforms Division Aeronautical and Maritime Research Laboratory, March 2000
4. Cerny, F., Porocak, L.: Fortification II. S-3151/2. Military academy of ground forces, Vyskov (1999)
5. Coufal, D.: Modelling of effects of blast wave on the protective structures. Dissertation Thesis. University of defence in Brno, Faculty of military technology, Brno, 102 p. (2013)
6. Coufal, J., Kaplan, V.: Protective structure. S-297/III. Military academy in Brno (1993)
7. Courtney, M.W., Courtney A.C.: Working towards exposure thresholds for blast-induced traumatic brain injury: thoracic and acceleration mechanisms, USA, U.S. Air Force Academy, Force Protection Industries
8. Field fortification: Surface and Soil-covered Shelters. Zen-2-1/1 Prague: MNO (1972)
9. Gebbeken, N., Doge, T.: Explosion protection-architectural design, urban planning and landscape planning. Int. J. Protective Struct. **1**, 1–22 (2010)
10. STANAG 2280 - MC ENGR (Edition 1) (Ratification draft 1) – Design Threat Levels and Handover Procedures for Temporary Protective Structures. NATO Standardization Agency, June 2007
11. Stoller, J., Dubec, B.: Design and assessment of shape of protective structure by usage of CFD software environment Ansys Fluent. Manuscript submitted for publication (2016)
12. Zalesky, J.: Military engineering support of force protection in foreign missions. Dissertation thesis. University of defence in Brno, Faculty of economy, Brno, 162 p. (2012)

Springer

http://www.springer.com/978-981-10-3246-2

Durability of Critical Infrastructure, Monitoring and Testing
Proceedings of the ICDCF 2016
Kravcov, A.; Cherepetskaya, E.B.; Pospichal, V. (Eds.)
2017, IX, 261 p., Hardcover
ISBN: 978-981-10-3246-2