

VIRTUAL MODELING AND SIMULATION OF A CYLINDER BUNDLE VERTICAL AND ROTATIONAL DROP

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Abstract: A cylinder bundle is a portable assembly which consists of a frame and two or more cylinders, each of a capacity up to 150 l and with a combined capacity of not more than 3000 l, or 1000 l in the case of toxic gases, connected to a manifold by cylinder valves or fittings such that the cylinders are filled, transported and emptied without disassembly. The type approval of the cylinder bundle covers series of tests regarding its structure and its behavior during and after the tests. The research, presented in this paper, is focused on virtual testing, i.e. modeling and simulation of a cylinder bundle drop tests. First, a CAD model of a cylinder bundle which contains five cylinders is built, and then a vertical and rotational drop tests are simulated in virtual environment. The obtained results are analyzed in line with the demands defined in the international standard ISO 10961:2010(E). They could serve as a base for further improvement of the model and point out the possibility for validation of the virtual testing.

Keywords: CYLINDER BUNDLE, VIRTUAL MODEL, VIRTUAL TESTING, DROP TESTS

1. Introduction

Cylinder bundles are portable assemblies which are widely used for transport and storage of gases on sites, where the gases are further used. According to the international standard ISO 10961:2010(E), a cylinder bundle is a portable assembly which consists of a frame and two or more cylinders, each of a capacity up to 150 l and with a combined capacity of not more than 3000 l, or 1000 l in the case of toxic gases, connected to a manifold by cylinder valves or fittings such that the cylinders are filled, transported and emptied without disassembly. The exploitation of a cylinder bundle is preconditioned with its type approval. The type approval itself covers series of tests regarding the structure of the cylinder bundle and its behavior during and after the tests. The most demanding tests are the vertical drop test and the rotational drop test as defined in the international standard ISO 10961:2010(E) [7]. These tests have the following pass criteria: the primary frame structure shall not fail such that subsequent movement by fork-lift truck or slinging is not possible; the cylinders and manifolds shall remain constrained in the frame, though deformation of components is acceptable; the bundle shall not leak.

The research, presented in this paper, is focused on virtual testing [1, 2, 4, 5, 7] regarding the above mentioned tests. They are conducted on a model of a cylinder bundle which was already produced. The bundle contained five Vitkovice cylinders 690/150, intended for carriage of high pressurized gas (over 200 bar). The produced cylinder bundle is presented on fig. 1.



Fig. 1 Produced cylinder bundle

The model of the bundle is built in a CAD software package [6]. It is a relevant representative of the real bundle. The virtual model is presented on fig. 2.



Fig. 2 Virtual model of the cylinder bundle

The remainder of the paper is organized as follows: The virtual modeling and simulation of the cylinder bundle vertical drop test are presented in section 2. Section 3 presents the virtual modeling and simulation of the cylinder bundle rotational drop test. Finally the conclusions are laid down in section 4.

2. Virtual modeling and simulation of the cylinder bundle vertical drop test

The procedure of the vertical drop test prescribes that the bundle is dropped at a height of 100mm on a concrete surface. Also, the initial inclination of the bundle towards the surface should be at least 5°.

The initial setup of the virtual testing is in line with the requirements defined in point 7.2.2.3.4 of the international standard ISO 10961:2010(E) [7]. The model is set on a height of 100mm from concrete surface and the initial inclination of the bundle towards the surface is set on 10° (fig. 3.).

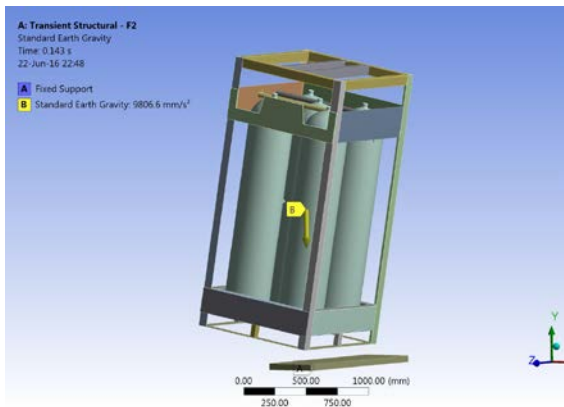


Fig. 3 Initial setup of the vertical drop test simulation

The virtual vertical drop test is conducted with two consecutive and connected simulations-analyses [3]. The first one is a transient structural analysis. It treats the free fall of the bundle till the impact with the concrete surface. The free fall lasts for 0.143s. The position of the bundle at different time moments is presented on fig. 4, fig. 5 and fig. 6. The second simulation is an explicit dynamics analysis. This simulation treats the impact of the bundle with the concrete surface and lasts for 30ms. The stress condition of the bundle is stable after this time period. The equivalent stresses which appear in the bundle at different time moments of the explicit dynamics analysis are presented on fig. 7, fig. 8 and fig. 9.

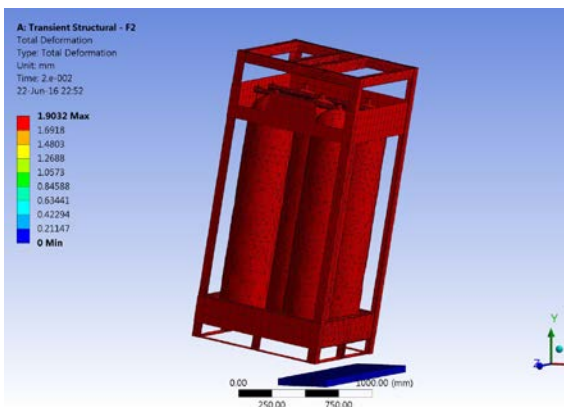


Fig. 4 Position of the bundle at time $t=0.02s$

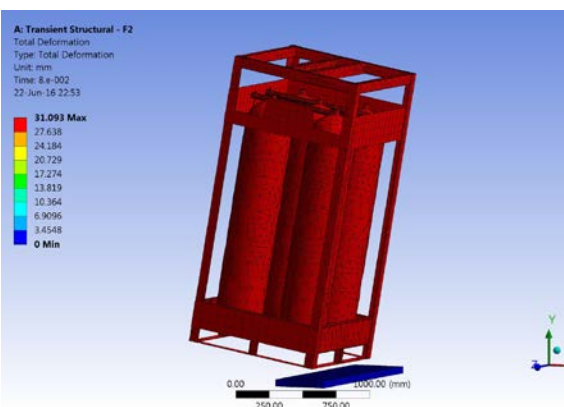


Fig. 5 Position of the bundle at time $t=0.08s$

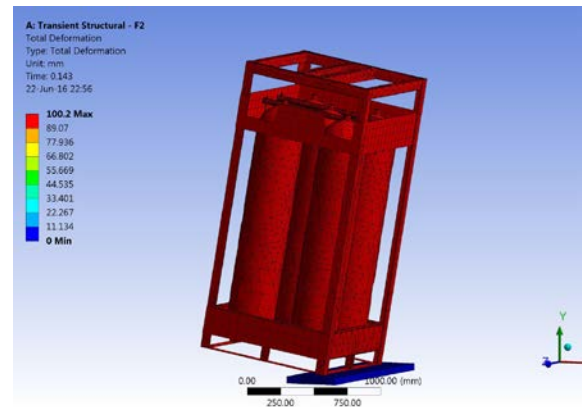


Fig. 6 Position of the bundle at time $t=0.143s$

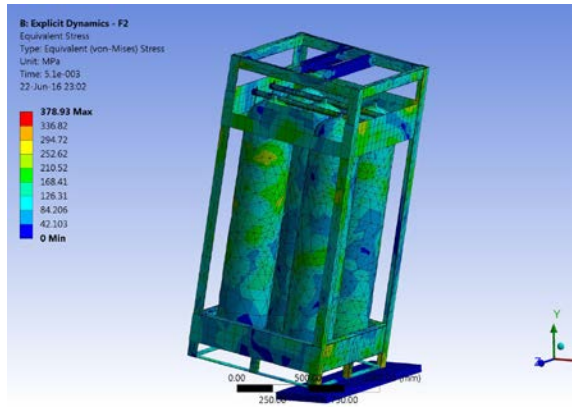


Fig. 7 Equivalent stresses in the bundle at time $t=0.0051s$

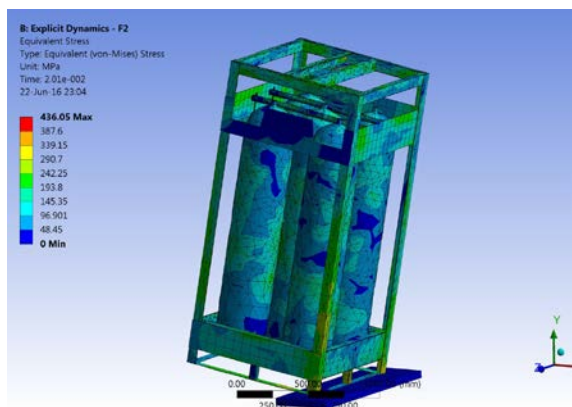


Fig. 8 Equivalent stresses in the bundle at time $t=0.0201s$

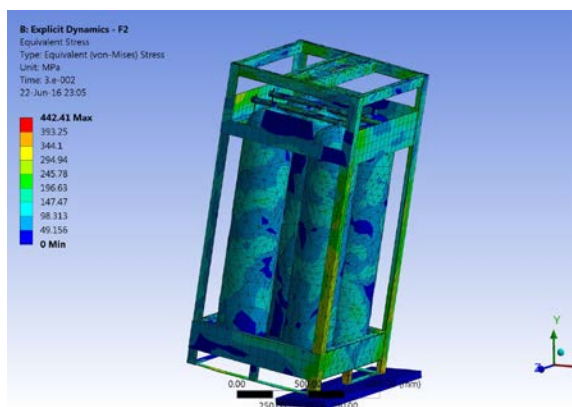


Fig. 9 Equivalent stresses in the bundle at time $t=0.0051s$

The explicit dynamics analysis shows that the stresses in the bundle, which appear during the impact, are below the ultimate stress of the material. The maximum stress appears in the vertical beams of the bundle, in the impact zone. Its range is about 440N/mm^2 . The plastic deformations of the bundle during the impact are below 8.1% of the size of the model's final elements.

Based on the results of the performed combined analyses it can be concluded that the bundle satisfies the requirements as defined in point 7.2.2.3.4 of the international standard ISO 10961:2010(E)[7], regarding the vertical drop test.

3. Virtual modeling and simulation of the cylinder bundle rotational drop test

The procedure of the rotational drop test prescribes that the bundle falls from a platform on a concrete surface. The platform has a minimal height of 1200mm. During the fall, the bundle rotates about point 2 (fig. 10).

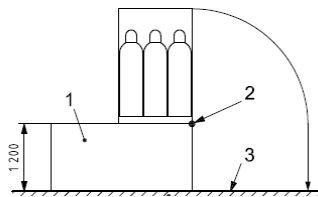


Fig. 10 Rotation drop test – procedure (1 – platform, 2 – rotational point of the bundle, 3 – concrete surface)

The initial setup of the model, regarding the rotational drop virtual testing, is in line with the requirements defined in point 7.2.2.3.4 of the international standard ISO 10961:2010(E)[7]. The model is set on a height of 1200mm from concrete surface and the initial inclination of the bundle towards the surface is set on 35° (fig. 11.). This inclination is defined according to the bundle's center of gravity and ensures rotational free fall of the bundle.

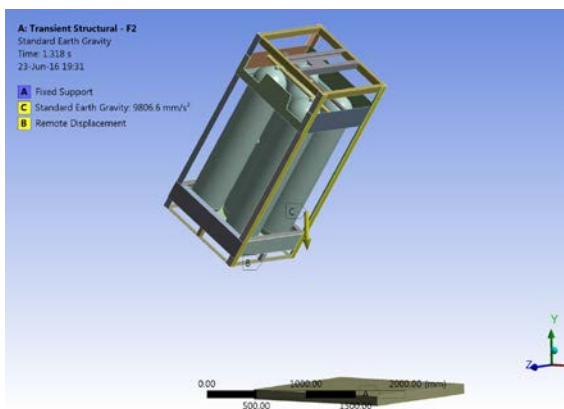


Fig. 11 Initial setup of the rotational drop test simulation

The rotational drop test alike the vertical drop test is conducted with two consecutive and connected simulations-analyses [3]. The first one is a transient structural analysis. It treats the rotational free fall of the bundle till the impact with the concrete surface. This free fall lasts for 1.318s. The position of the bundle at different time moments is presented on fig. 12, fig. 13 and fig. 14. The second simulation is an explicit dynamics analysis. This simulation treats the impact of the bundle with the concrete surface and lasts for 175ms. Within this time interval, the bundle has complete translational and rotational freedom. The time span of explicit dynamics analysis is sufficient to cover the dominant dynamics of the impact. The equivalent stresses which appear in the bundle at different time moments of the explicit dynamics analysis are presented on fig. 15, fig. 16 and fig. 17.

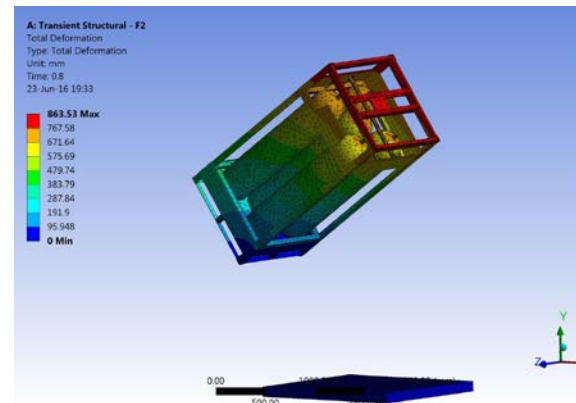


Fig. 12 Position of the bundle at time $t=0.8\text{s}$

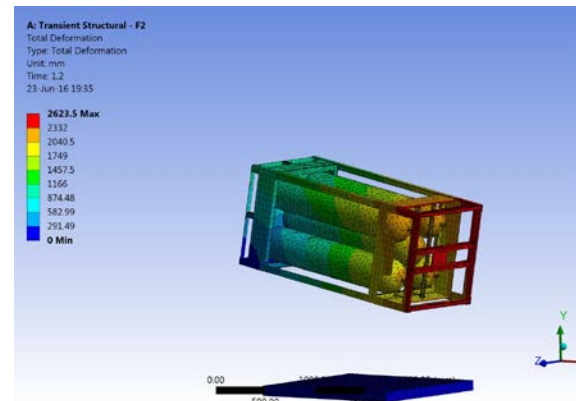


Fig. 13 Position of the bundle at time $t=1.2\text{s}$

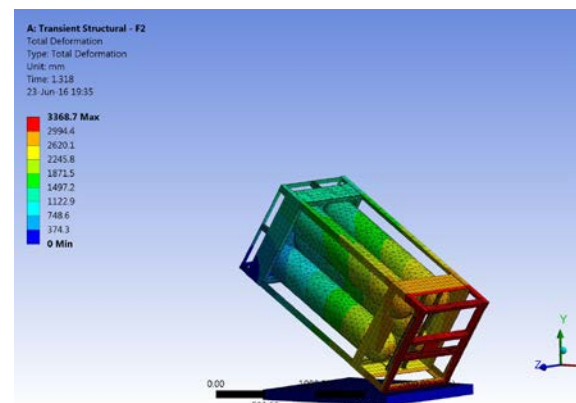


Fig.14 Position of the bundle at time $t=1.318\text{s}$

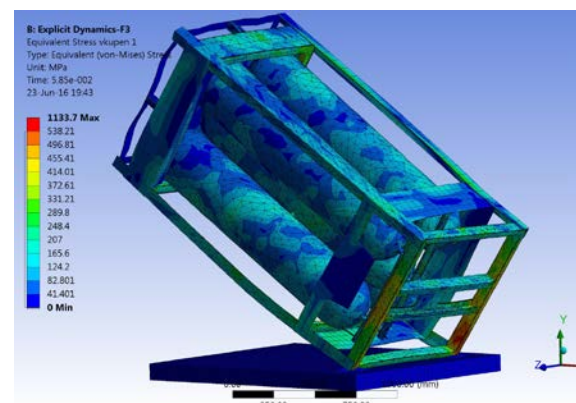


Fig. 15 Equivalent stresses in the bundle at time $t=0.0585\text{s}$

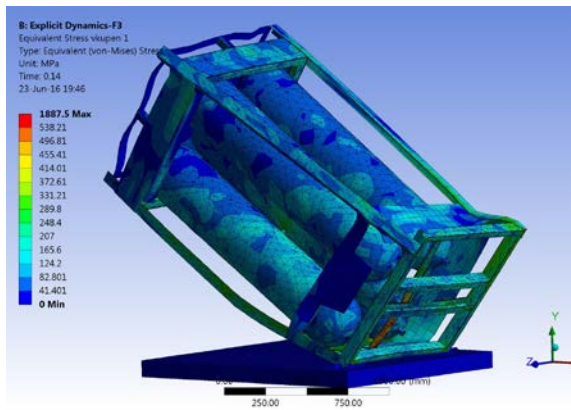


Fig. 16 Equivalent stresses in the bundle at time $t=0.14s$

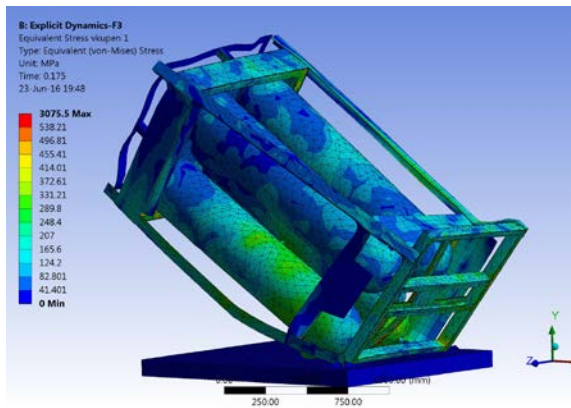


Fig. 17 Equivalent stresses in the bundle at time $t=0.175s$

The explicit dynamics analysis points out that the total deformations during the impact jeopardize the space where the cylinder valves and the manifold are mounted (fig. 18). As a result, the valves and the manifold could be damaged and a gas leakage could appear.

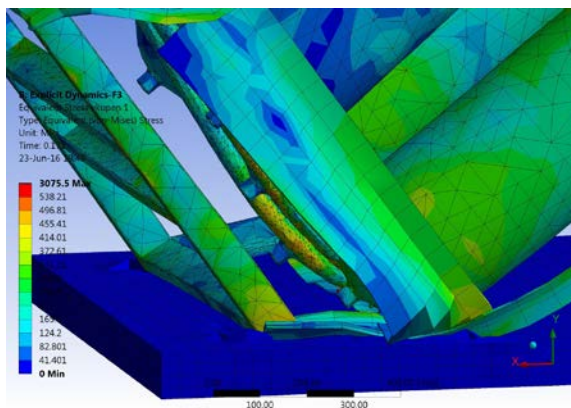


Fig. 18 Space where the cylinder valves and the manifold are mounted at time $t=0.175s$ of the explicit dynamics analysis

The equivalent stresses which appear in some segments of the bundle are over the ultimate stress of the material. The range of the maximal stresses at the end of the analysis is about 3000 N/mm^2 .

The maximal stresses, which appear in the vertical beams of the bundle, range between 417.34 N/mm^2 and 614.46 N/mm^2 . Despite these high values, the maximal plastic deformations range between 10.27% and 20.989% of the size of the part's final elements. These results show that during the impact there is no failure in the vertical beams structure, but on the other hand there is a failure in the connections between the front left beam, the upper rectangular frame and the middle side plate (fig. 19). This could lead to

significant cylinder movement, gas leakage and exclusion of the possibility for subsequent movement of the bundle by fork-lift truck or slinging.

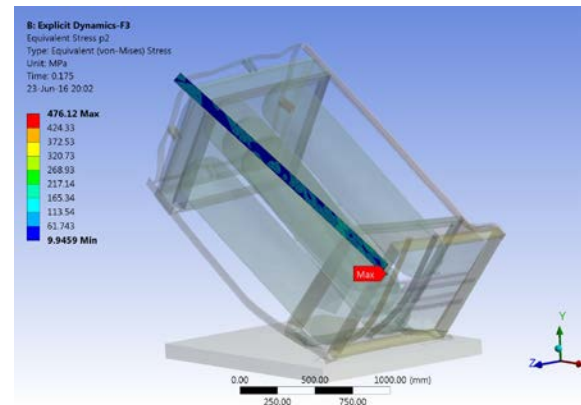


Fig. 19 Failure of the front left beam connections

The impact of the bundle brings up to tearing of the pre-tensioning bolts or failure of the connection between the bolts and the pipes that secure the cylinders (fig. 20). The equivalent stresses in the bolts range up to 700 N/mm^2 and the plastic deformations range up to 57% of the size of the part's final elements.

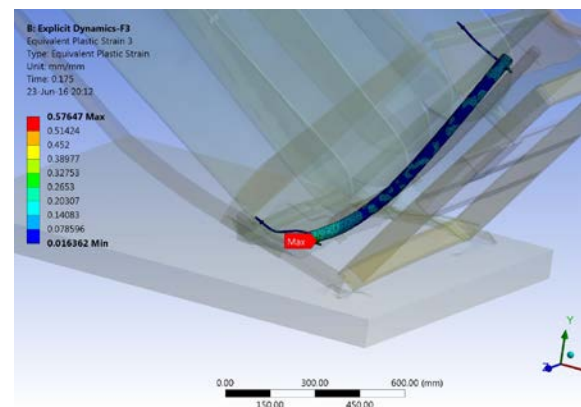


Fig. 20 Plastic deformations of the front bolts and pipe

The highest equivalent stresses appear in the middle frame of the bundle in the areas where the cylinders lean on the frame. Their range in these areas is between 700 N/mm^2 and 1100 N/mm^2 . The maximal equivalent stress is 3075.5 N/mm^2 . The range of the plastic deformations is between 50% and 82% of the size of the appropriate final elements. The maximal plastic deformation is 195.27% of the size of the appropriate final element. These results imply on crush of the middle frame in the areas where the cylinders lean on (fig. 21).

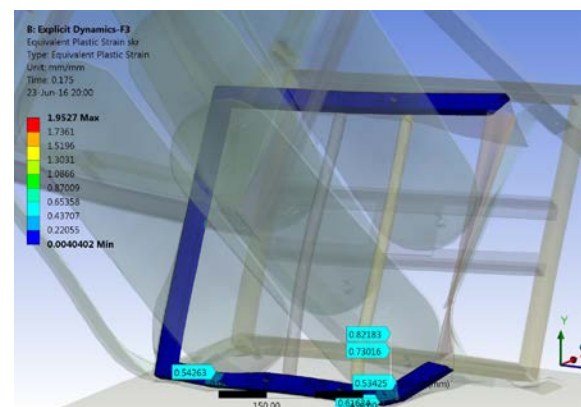


Fig. 21 Plastic deformations of the middle frame of the bundle

The results of the performed analyses point out that the bundle does not satisfy the requirements as defined in point 7.2.2.3.4 of the international standard ISO 10961:2010(E), regarding the rotational drop test.

4. Conclusion

The research presented in this paper produced numerous results which serve as a base for the following conclusions. At this stage, without validation, the developed virtual model of the cylinder bundle can be used only in preliminary structural and dynamics simulations. The real cylinder bundle would satisfy the requirements as defined in point 7.2.2.3.4 of the international standard ISO 10961:2010(E), regarding the vertical drop test. Despite this, the real cylinder bundle would not satisfy the requirements as defined in point 7.2.2.3.4 of the international standard ISO 10961:2010(E), regarding the rotational drop test. Also, the results of the virtual testing pointed out the possible weaknesses of the structure of the bundle. They can serve as a base for further improvement of the model and ultimately of the real bundle too. The experimental tests of the real bundle should be conducted only after the model passes the virtual testing. This methodology saves time and resources. The results of the experimental tests could be further used in the validation process of the model and most important in the validation process of the virtual testing.

5. References

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