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PARAMETRIC STUDY OF THE STRUCTURAL RESPONSE OF NPP CONTAINMENT TO IMPACT LOADING

Abstract

The presented article is a contribution to the discussion concerning nuclear safety which has intensified after the Fukushima Daiichi nuclear disaster. A parametric study concerning various materials, containment wall thicknesses and different aircraft speeds at the time of impact was performed. The aim of this study was to establish damage extent of various variants of a containment structure. Containment damage was evaluated by means of the value of maximum permanent deformation and plastic strain extent. The purpose of this study was also to foster experiential suggestions for improving the explicit method in the RFEM program in order to release it for RFEM users.

Keywords

Explicit method, damage extent, finite element method, plane impact, nonlinear dynamics, RFEM.

1 INTRODUCTION

A sudden increase of interest in the field of nuclear safety, exemplified in a paper by Králik [1], has arisen after Fukushima Daiichi disaster, which was caused by an earthquake and subsequent tsunami. This paper could be a contribution to this worldwide discussion. Results of a parametric study focused on NPP containment damage caused by impact of an airliner are presented in this article. Possibility of RFEM software usage for analysis of nonlinear transient dynamic events was also to be proved by this study.

2 NUMERICAL MODEL OF THE CONTAINMENT AND THE AIRLINER

The shape and size of the containment building was derived from the Bushehr nuclear power plant containment. The choice of dimensions of the structure model (see Fig.1) was based on data found in [2] and [3]. The study was focused on two different material types of containment structure - steel and reinforced concrete. Material model of steel was considered as elasto-plastic with von Mises yield criterion. Smeared crack model was included in material model of reinforced concrete.

The numerical model of the plane was inspired by Boeing 737-900, which belongs to the family of the most widely spread airliner. For the numerical model of the airliner only shell elements with six degrees of freedom were used. According to the fact, that the objective of this study was the containment structure (not the airliner), the plane structure was not modeled in detail and the inner parts of the airliner were not specifically considered. For the purpose of the study it was fundamental

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to preserve the momentum of the plane, which would correspond to take-off weight and average or maximum speed of this airliner.

Wall thicknesses were in case of reinforced concrete containment chosen from 0,60 to 1,80 m and in case of steel containment from 0,05 to 0,14 m. Commonly used wall thicknesses are included in these intervals together with smaller and bigger values to gain more complex perspective of dependency of containment damage extent on the choice of wall thickness, material and airliner speed at the time of impact.

The airliner speed at the time of impact was chosen 500 km/h to simulate accidental crash and the speed of 867 km/h (Boeing 737 maximum speed) was chosen to simulate intentional impact.

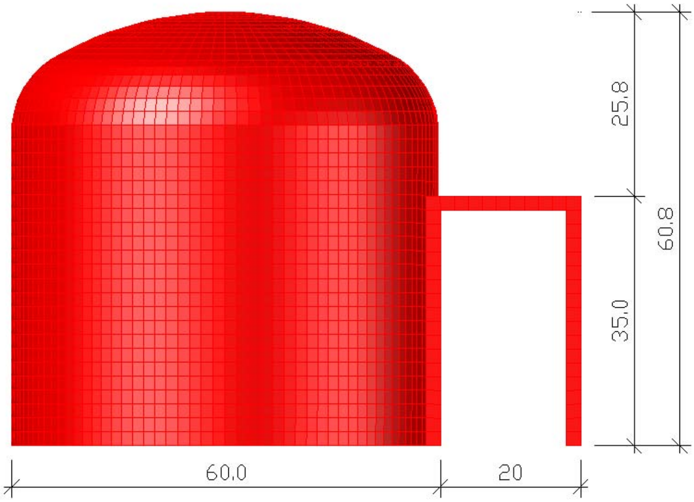

Fig.1a: The dimensions and the shape of containment structure

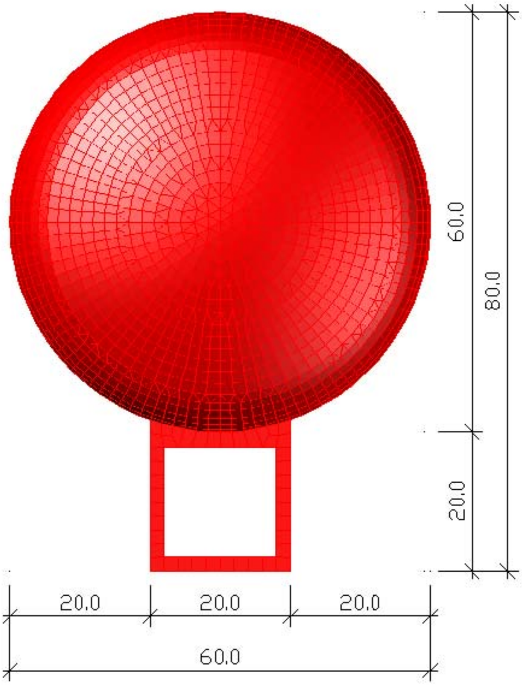

Fig.1b: The dimensions and the shape of containment structure

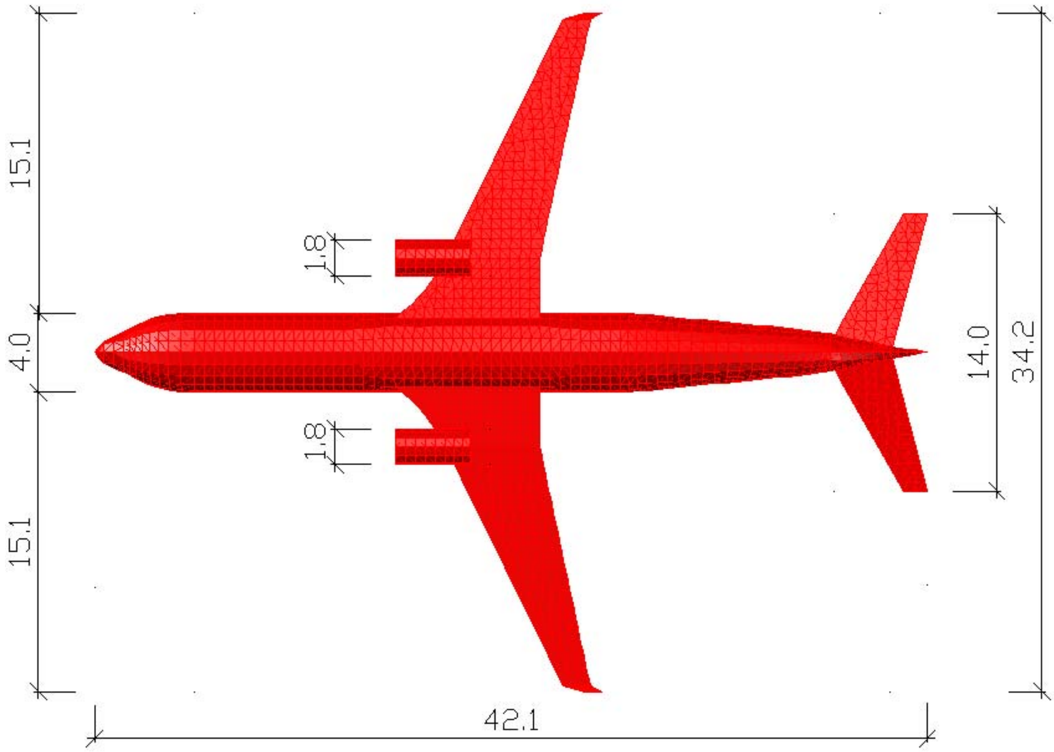

Fig. 2a: The dimensions and the shape of the airliner

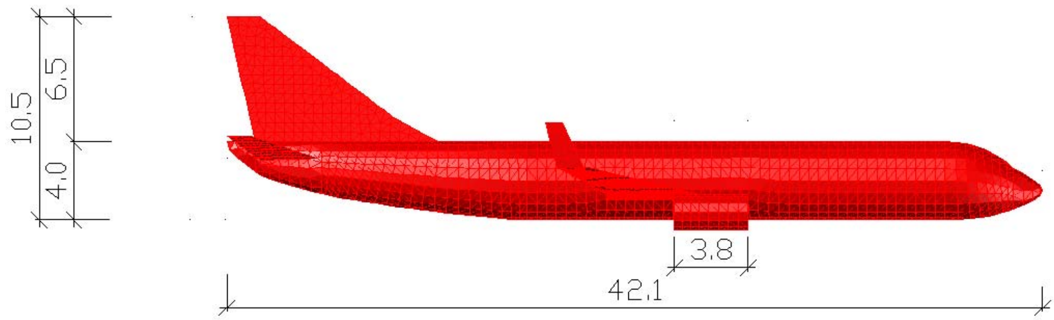

Fig.2b: The dimensions and the shape of the airliner

3 SOLUTION METHOD

The analyses were performed by means of the explicit finite element method utilizing RFEM software. The solution consisted of two steps. In every step only one structure model was used. Initially, analysis of the impact of the airliner into a rigid wall was performed. Results of this analysis were used as input data (impact loading) in the next step. Impact of the airliner into the containment structure in real time is visualized in the Fig. 3, which was created on the basis of performed numerical simulations.

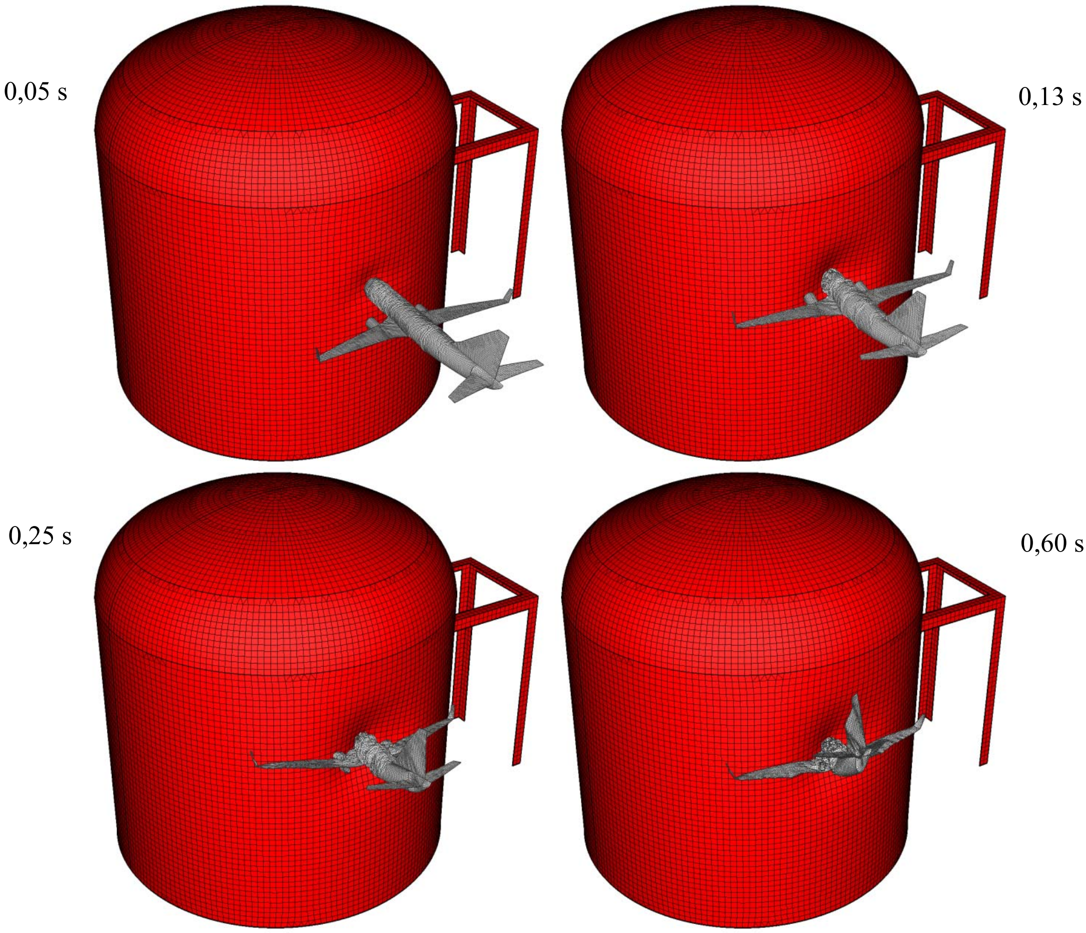

Fig. 3: Illustrative image of the course of the airliner impact into the containment structure

4 CONTAINMENT DAMAGE

For the purpose of results evaluation the value of maximum permanent deformation and plastic strain extent were monitored. The ascertained values of these quantities for different wall thicknesses of containment structures, different material models and airliner speed before impact are stated in table 1 and 2.

Tab. 1: Steel containment damage

	Wall thickness [m]	0,05	0,08	0,10	0,12	0,14
500km/h	Max deformation [m]	2,80+0	1,03E+0	8,71E-1	2,35E-1	1,73E-1
	Plastic strain	2,58E-2	1,80E-2	1,30E-2	7,20E-3	5,10E-3
876km/h	Max deformation [m]	1,03E+1	5,84E+0	4,03E+0	3,27E+0	2,66E+0
	Plastic strain	9,18E-2	5,31E-2	4,36E-2	3,55E-2	3,23E-2

Graphical representations of selected results are presented in the figures below.

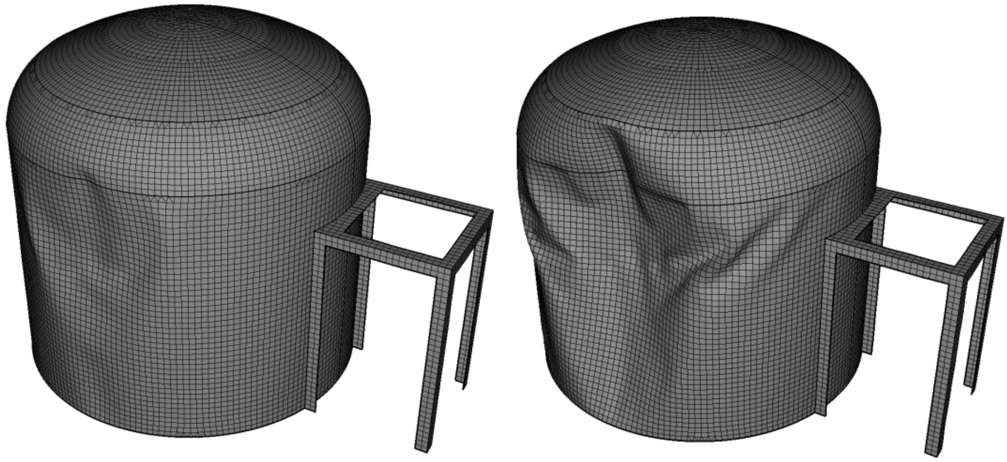

Fig. 4: Permanent deformation of the steel containment with wall thickness of 0,05 m and the airliner speed of 500 km/h (left) and 876 km/h (right)

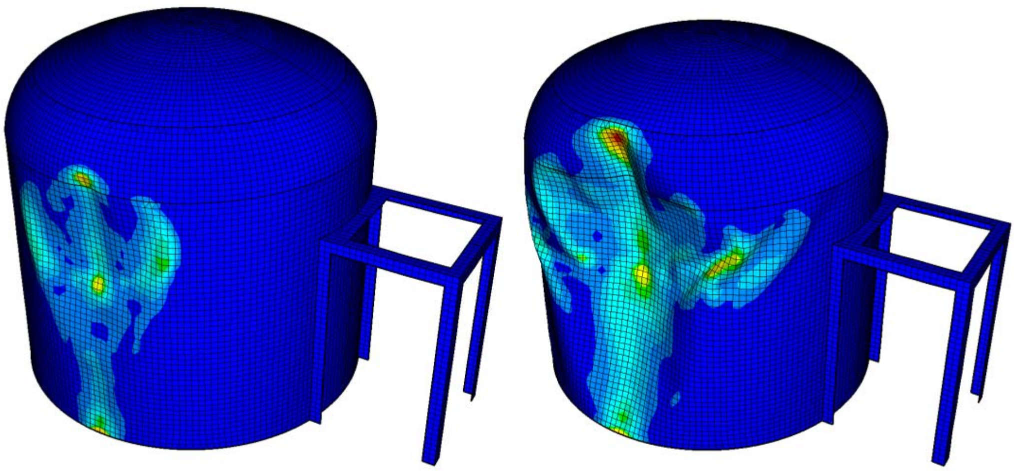

Fig. 5: Plastic strain extent of the steel containment with wall thickness of 0,05 m and the airliner speed of 500 km/h (left) and 876 km/h (right)

Tab. 2: Reinforced concrete containments damage

	Wall thickness [m]	0,60	0,80	1,00	1,20	1,40	1,60	1,80
500km/h	Max deformation [m]	2,43E+0	9,90E-1	1,37E-1	1,61E-2	4,01E-3	1,01E-3	2,16E-4
	Plastic strain	1,25E-1	8,00E-2	1,70E-2	2,70E-3	9,40E-4	4,26E-4	1,90E-4
876km/h	Max deformation [m]	8,26E+0	6,06E+0	4,52E+0	3,25E+0	2,07E+0	1,06E+0	4,19E-1
	Plastic strain	2,85E-1	2,65E-1	2,54E-1	2,40E-1	1,88E-1	1,27E-1	6,40E-2

Graphical representations of selected results are presented in the figures below.

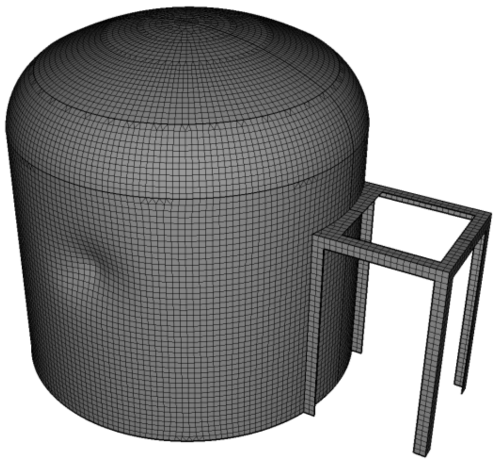

Fig .6: Permanent deformation of the reinforced concrete containment with wall thickness of 0,6 m and the airliner speed of 500 km/h (left) and 876 km/h (right)

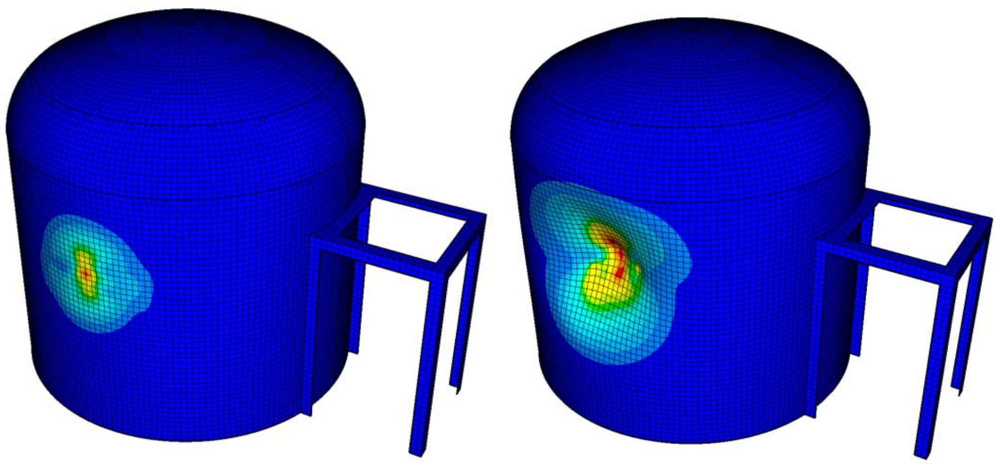

Fig .7: Plastic strain extent of the reinforced concrete containment with wall thickness of 0,6 m and the airliner speed of 500 km/h (left) and 876 km/h (right)

5 CONCLUSIONS

Parametric study of a typical containment structure damage extent, which was caused by impact of the common airliner, was presented in the paper.

Concerning the airliner speed of 500 km/h at the time of impact and reinforced concrete containment structures, for thicknesses greater than 1,40 m only negligible values of permanent strain were established. On the contrary, for wall thicknesses smaller than 1 m, considerable plastic strains occurred. Different signs of strain were obtained on opposite surfaces of the containment shell (negative sign prevailing). Thus it could be assumed that even if severe damage and cracking might appear on the inner surface of the containment body, containment wall near midsurface could remain without substantial damage. However, more detailed analyses, which would include crack localization and detailed model of reinforcing steel, should be performed.

Concerning the steel containments for airliner speed of 500 km/h at the time of impact some plastic yielding and permanent deformations were established for all variants of wall thicknesses of containment structure. However, a maximal obtained plastic yielding for this speed before impact should not lead to a steel rupture, under given assumptions. According to the fact that the analysis was performed without consideration of rate dependency of material characteristics, results of the study are only to be considered as approximate values.

As expected, for airliner speed of 876 km/h at the time of impact the damage of both steel and reinforced concrete containment structures was more significant. The rupture of the containment shell would probably not occur even for this speed of the airliner before impact under given assumptions.

Capability of the RFEM software to perform nonlinear transient dynamic analysis was proved by the presented study. The results of the study could be used for assessment of damage of similar existing containment structures or for the design of new structures mainly in the phase of structure draft design.

REFERENCES

[1] KRÁLIK, J., Stress Test of the NPP Safety in Slovakia after Accident in Fukushima, In *Proceedings of international conference Modeling in Mechanics 2012*, Ostrava, pp. 11-13, ISBN 978-80-248-2694-3.

[2] R. OECD/NEA Group of Experts, *SOAR on Containment Thermalhydraulics and Hydrogen Distribution, report of OECD/NEA*, June 1999, http://www.oecd-nea.org/nsd/docs/1999/csni-r99-16.pdf, page 17-48.

[3] FHESSHEIMER, M. F., DAMERON, R. A., *Containment Integrity Research at Sandia National Laboratories: An Overview*, July 2006, page 32-49.

[4] NĚMEC I., et al., *Finite Element Analysis of Structures - Principles and Praxis*, 1st ed., Shaker Verlag, Aachen, 2010, ISBN 978-3-8322-9314-7, page 469-578.

[5] BITTNAR, Z. ŘEŘICHA, P., *Metoda konečných prvků v dynamice konstrukcí*, 1st ed., Státní nakladatelství technické literatury, Praha, 1981, pp. 257. (in Czech)

[6] BELYTSCHKO, T., LIU, W. K., MORAN, B., *Nonlinear Finite Elements for Continua and Structures*, John Wiley & Sons Ltd., 2000, page 309-317.

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