BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LX No. 3A/2008	89 - 94	Seria Tehnică

Quality Based Design for Reliability of LPG Spherical Tanks using Probabilistic Methods

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Abstract

The paper demonstrates the use of probabilistic methods to assess the behavior of LPG spherical tanks under the presence of sustaining loadings. Probabilistic Methods are used to assess uncertainties involved in the manufacturing of LPG spherical tanks. Probabilistic methods guide the design of these LPG storage tanks to achieve a robust and reliable design in a most efficient way. The methods illustrated here are implemented in the latest version of the ANSYS Finite-Element program.

Key words: *Finite-Element Analysis, Probability Density Functions, Probabilistic Analysis*

Introduction

The ANSYS Probabilistic Design System (PDS) analyzes a component or a system involving uncertain input parameters.

These input parameters (geometry, material properties, boundary conditions, etc.) are defined in the ANSYS model. The variation of these input parameters are defined as random input variables and are characterized by their distribution type (Gaussian, lognormal, etc.) and by their distribution parameters (mean values, standard deviation, etc.). Any interdependencies between random input variables are also defined as correlation coefficients. The important results are defined as random output parameters. During a probabilistic analysis, ANSYS executes multiple analysis loops to compute the random output parameters as a function of the set of random input variables. The values for the input variables are generated either randomly (using Monte Carlo simulation) or as prescribed samples (using Response Surface Methods).

This article includes the following items:

- The deterministic model (the ANSYS model that computes the results and result parameters for a given set of input parameters);
- The random input variables and their specifications;
- Correlations between random input variables;
- Solution sets containing the results of each probabilistic analysis;
- Response surface sets containing the results of fitting of response surfaces

The statistics of the random output parameters were computed using the ANSYS results and illustrate the properties of the output parameters using histogram plots, cumulative distribution curves, and/or history plots. The influence of random input variables on individual output parameters (known as the "sensitivity") are illustrated as bar and pie charts.

The analysis model

Geometry

The model is based on a spherical tank for LPG storage, with a capacity of 1000 m^3, having a discrete sub-equatorial supporting, as shown in figure 1.

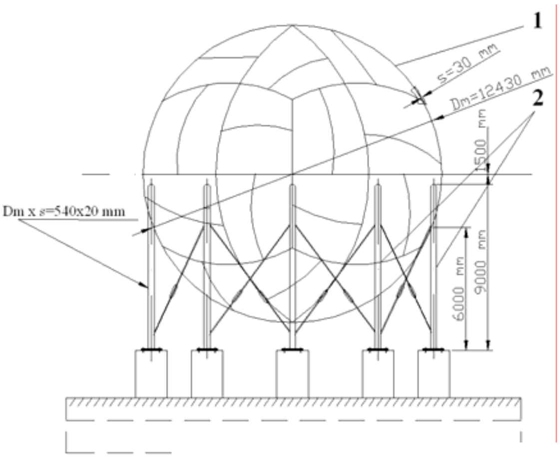


Fig. 1. Spherical LPG tank

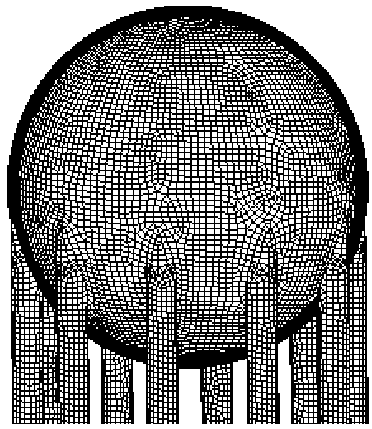


Fig. 2. FE mesh of the spherical tank

For modeling there have been used the mean diameter of the sphere with value of 12430 mm, the thickness of 30 mm for sphere shell and for supporting tubular legs the mean diameter of 540 mm with the thickness of 20 mm,[1].

Finite-Element Model

For the probabilistic analysis of the sphere model the effects of the sphere shell thickness, the supporting tubular leg thickness and the maximum working pressure have been investigated. In order to calculate these output parameters, a full finite element analysis (FEA) using the ANSYS Finite Element program is performed.

The FEA model is constructed by extruding a large volume from a sphere and cylinder models and then subtracting the ten cylinders from the volume of the sphere.

The resultant volume is the "domain" which is meshed, as shown in figure 2.

The resultant meshed model typically has about 17,232 elements and 16,961 nodes, as shown in figure 2.

These numbers vary slightly with the PDS geometric tolerances applied. The meshingwas done with element SHELL 63, which is defined by four nodes, four thicknesses, an elastic foundation stiffness, and the orthotropic material properties.

The maximum equivalent stresses at the top surface at the junction between the tubular leg and the spherical shell are shown in figure 3.

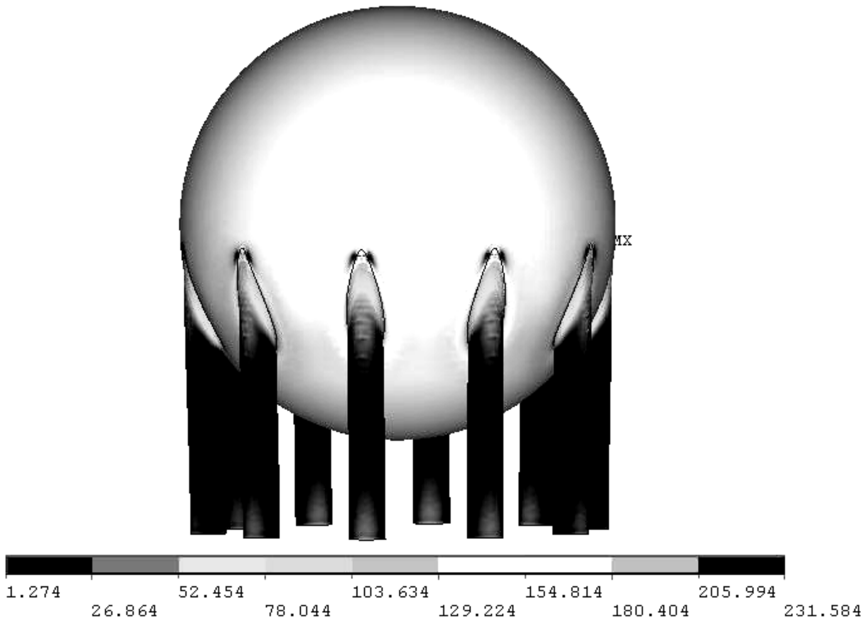


Fig. 3. Equivalent stress at the top surface of the spherical shell

The probabilistic model

The objective of the study was to show how FEA and probabilistic design can be used to simulate the effects of thicknesses tolerances and hydrostatic pressure on the behavior of the spherical tank. Uncertainties are either random variables (constant in time and space), random fields (constant in time, but random function of spatial coordinates), random processes (constant in space, but random functions of time) or combinations of these[2]. This paper focuses on random variables only.

Random variables usually are described in terms of statistical distribution functions. A linear distribution of random variables was assumed. The limits for the random variables are shown in table 1.

Table 1. Random Input Variable Specifications

No.	Name	Type	Par1	Par2
1	GROCI	UNIF	15.000	25.000
2	GROSF	UNIF	25.000	35.000
3	PRES	UNIF	1.0000	2.0000

There are various probabilistic methods available in literature. This paper is focused on the Monte Carlo Simulation method. Due to its advantageous properties the so-called Latin Hypercube Sampling techniques has been used. Details about this method are given in [3]. Among others this technique has been implemented in the ANSYS probabilistic design system (ANSYS/PDS). The ANSYS/PDS is part of the latest Release 11.0 of the ANSYS Finite-Element program as a Beta feature. It allows for the definition of uncertainties based on various statistical distribution functions such as the normal, log-normal, uniform, Beta distribution and so on. It also allows to model random effects as random fields, which is not covered here.

Probabilistic results

The intention of the probabilistic analysis is to demonstrate the use of probabilistic methods to guide the design process of spherical tanks to achieve a more reliable and robust design. For the probabilistic analysis 120 Latin Hypercube samples have been run. The resulting statistics of the output parameters, are given in table 2.

Table 2 . Result Set - Statistics of the Random Output Parameters

Statistics	Mean	Standard Deviation	Minimum	Maximum
MED_GROCI	20.00	0.000	20.00	20.00
MED_GROSF	30.00	0.000	30.00	30.00
MED_PRES	1.500	0.000	1.500	1.500
PROB_GROCI	0.1000	2.2298E-16	0.1000	0.1000
PROB_GROSF	0.1000	2.2298E-16	0.1000	0.1000
PROB_PRES	1.000	0.000	1.000	1.000
STD_GROCI	2.887	1.3379E-15	2.887	2.887
STD_GROSF	2.887	1.3379E-15	2.887	2.887
STD_PRES	0.2887	8.9190E-16	0.2887	0.2887
TENS	299.6	77.22	172.6	530.0

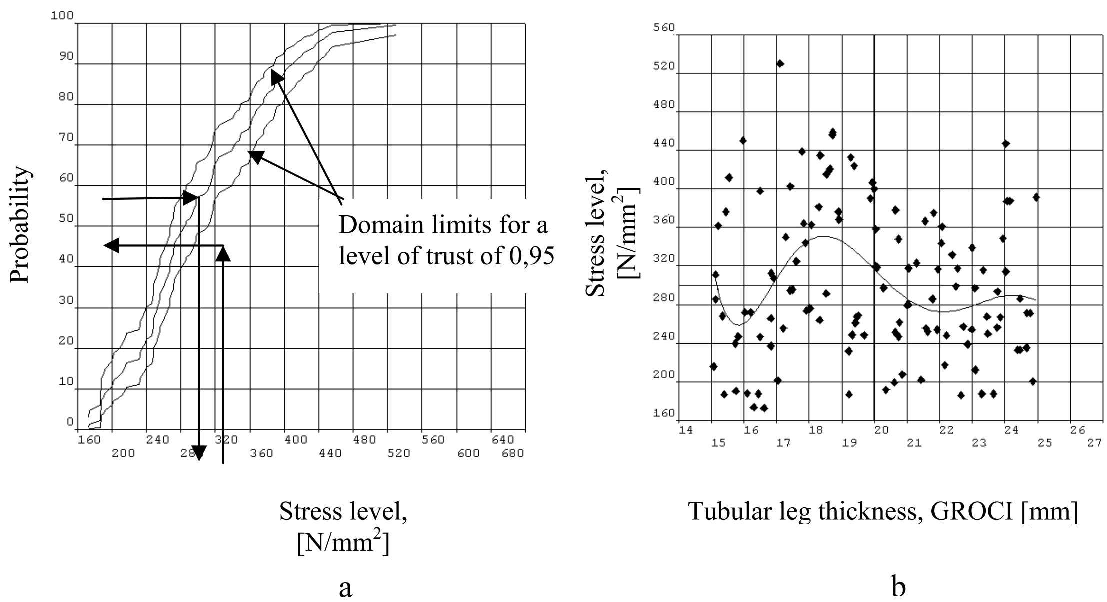
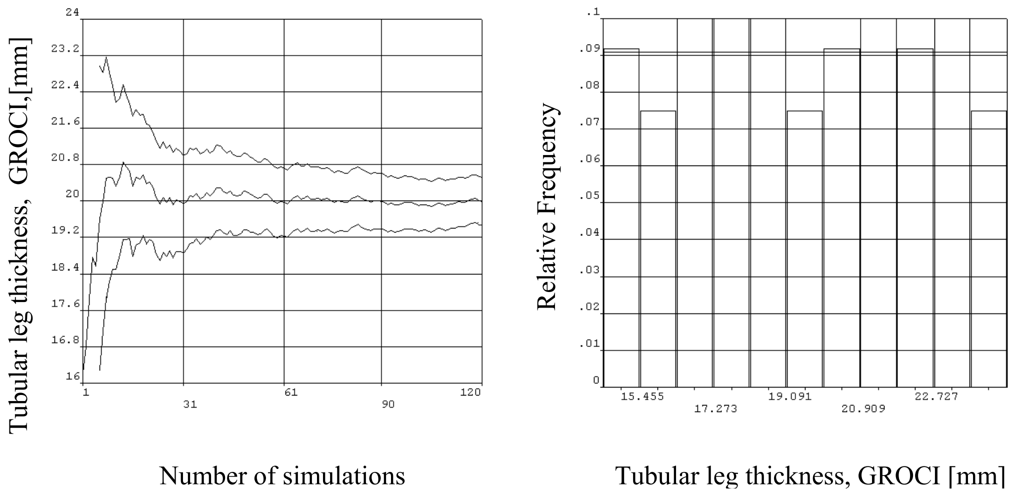


Fig. 4. Probability distribution for input and output random variables : a – probability curve for output random variable, the level of stress; b – the stress level distribution and the tubular leg thickness, GROCI;

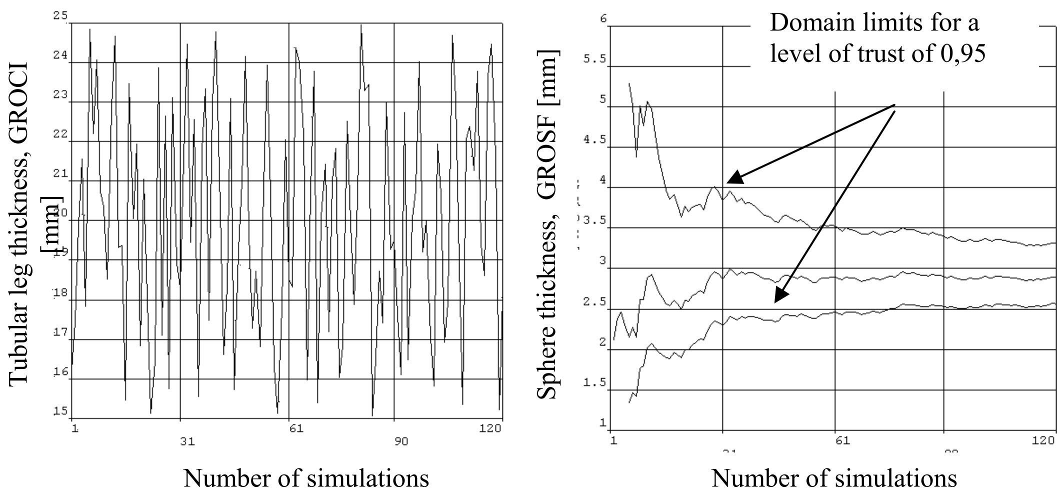
The probability distribution of the input(tubular leg thickness) and output(level of stress) random variables are shown in figure 4.

The histogram of the tubular leg thickness shown in figure 5 and 6 illustrate the scatter induced in the output parameters due to the scatter of the input variables. The relative frequency shown in the histograms is equal to the number samples within a certain interval divided by the total number of samples (120 in this case). Figure 7 shows the sensitivities of only the significant input variables for the electrostatic force. The sensitivities are given as absolute values (bar chart) and relative to each other (pie chart).



a b

Fig. 5. Mean values and relative frequency: a –mean values for tubular leg thickness, GROCI with the number of simulations(120); b – histogram for tubular leg thickness, GROCI;



a b

Fig. 6. Simulated values for input random variables: a –values simulated for tubular leg thickness, GROCI, with the number of simulations(120); b – mean values sphere thickness, GROSF with the number of simulations;

Conclusions

There are two important conclusions that can be derived from sensitivity diagrams:

First, if the design is not sufficient, e.g. not reliable enough, it is the most important input variables that must be modified or controlled by quality assurance measures during manufacturing. It doesn't make sense to focus on input variables having only a minor importance or no significance at all. Here, the level of stress is sensitive only to 2 input variables, pressure and sphere thickness. This is a reduction of the complexity of the problem from 3 input variables down to only 2. This reduction of the problem complexity ensures that necessary design changes are identified in the most efficient way.

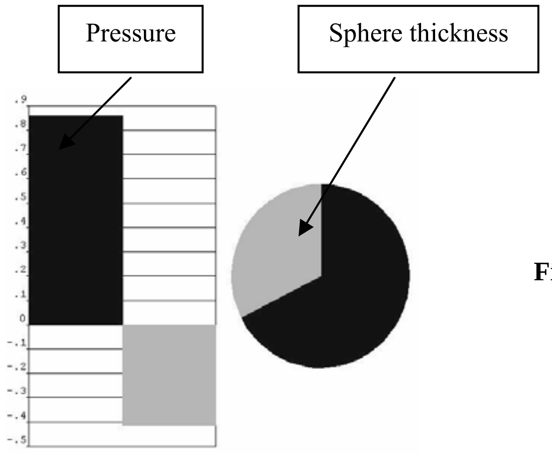


Fig. 7. Sensitivities of the input variables

Secondly, if the design is satisfactory there is usually the need to reduce the manufacturing costs without sacrificing reliability [5]. In this case the manufacturing tolerances of the insignificant or the less important input parameters can be relaxed, since they have no impact. As illustrated in the present paper, probabilistic methods can be used to quantify the reliability of the spherical tanks and to achieve a more robust design and improved quality.

Probabilistic sensitivities can be used to reduce the complexity of the problem and derive measures for improving the product quality. This provides guidance for necessary design changes in a most efficient way. In addition, probabilistic methods are capable of identify where reductions of the manufacturing costs are possible.

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Design optim pentru fiabilitatea rezervoarelor sferice de LPG utilizând metode probabilistice

Rezumat

Utilizarea metodelor probabilistice pentru optimizarea designului pentru o fiabilitate ridicată a rezervoarelor sferice de depozitare gaze petroliere lichefiate.