IDENTIFICATION AND SIMULATION OF SHELLS GEOMETRIC INITIAL IMPERFECTIONS

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1. Introduction

It is well known that the effect of structural geometric imperfections can dramatically decrease the nominal load carrying capacity of shell structures. As it is difficult and expensive to measure the initial structure imperfections in situ or in laboratory a methodology of identification and description of the available data should be provided. An important part of the structural imperfection modelling in a reliability context is the representation of random fields describing the statistical variation of properties or structure parameters. The presented procedure provides an opportunity for the reproduction of the measured maps of steel cylindrical tank geometric imperfections. Generations of the nonhomogeneous random fields based on the original conditional-rejection method of simulation are applied [1, 3]. Using the measured data an envelope of the imperfections is also estimated. It allows for simulation of extreme but still realistic fields of imperfections. When nonlinear geometric and material effects are taken into consideration the shell reliability can be evaluated only numerically. Nonlinear numerical analyses of petrol tanks, silos and underground tanks with and without initial geometric imperfections are performed. Soil parameter randomness is also included in the calculations. The results indicate that the initial imperfections influence the solutions.

2. Identification of the measured geometric imperfections

The identification and simulation procedure is presented on the basis of measured in situ imperfections of nine steel cylindrical vertical tanks of $V = 5000 \div 50000$ m^3 capacity [2]. The tank side surface imperfections can be considered in terms of a two-dimensional scalar random field described by a probability density function. The following hypotheses were formulated and proved [3]: the stochastic process is stationary and ergodic along the horizontal lines, and the random variables can be described by a Gaussian probability density function. Using the above assumption the following nonhomogeneous correlation function is introduced

(1) $$K(y_1, y_2, z_1, z_2) = \alpha \frac{z_1 z_2}{h^2} \cos(\omega(y_2 - y_1)) \exp(-\beta|y_2 - y_1| - \gamma|z_2 - z_1|),$$

where: y_1, y_2, z_1, and z_2 are the point coordinates, and h denotes the tank height. The correlation function parameters α, ω, β, and γ are estimated on the basis of the measured data. The assumption that the random field of imperfections is ergodic along the horizontal lines, makes it possible to analyse not single (the measured) but hundreds of realizations. The global experimental covariance matrix $\mathbf{K}_e$ of the measured imperfection field was obtained according to the following statistical formulas:

(2) $$\mathbf{K}_e = \frac{1}{NR-1} \sum_{i=1}^{NR} (\mathbf{x}_i - \bar{\mathbf{x}})(\mathbf{x}_i - \bar{\mathbf{x}})^T, \qquad \bar{\mathbf{x}} = \frac{1}{NR} \sum_{i=1}^{NR} \mathbf{x}_i,$$

where $\mathbf{x}_i$ ($i = 1, \ldots NR$) is the measured imperfection vector, NR is the number of realizations, and $\bar{\mathbf{x}}$ represents the mean value vector. Making use of the calculated matrix $\mathbf{K}_e$ the parameters of the correlation function (1) are determined by a standard regression analysis. The error analysis proved that the scattered pattern of imperfections was modelled accurately.

It is possible to describe the correlation function as an envelope of the extreme imperfections. Examining the calculated normalized standard deviations for all tank data it is easy to notice that the simplest solution is the approximation of the standard deviation to a parabolic function.

3. Simulation of the geometric imperfections

The field of geometric imperfections is numerically simulated taking advantage of the correlation function (1) and the estimated constants. In the process the conditional-rejection simulation method is used [1, 3]. An important role in the calculations is played by the propagation base scheme covering sequentially the mesh points and the random field envelope which allows to fulfill the geometric and boundary conditions of the structure model. Any homogeneous or non-homogeneous field of practically unlimited sizes can be generated.

The simulation process is presented using the data of tank of 5000 m^3 capacity. Two cases are analysed, i.e. the simulation of the measured imperfections as precisely as possible, and the simulation of the maximal imperfection values. As the field of the initial imperfections is an example of circular data the simulation method has been appropriately modified. As many as 2000 realizations have been simulated. The calculated global and variance errors of the simulations indicate excellent convergence of the field estimators.

4. Numerical calculations and conclusions

The numerical calculations include three cases of tank of 5000 m^3 capacity. The first case refers to an ideal cylindrical shell. The tank data for the second case include the measured initial geometric imperfections. The third calculation is performed for the simulated extreme imperfections.

The results of the nonlinear calculations indicate that the tank initial imperfections can cause significant variations in stress fields in comparison with the solution related to an ideal surface. The steel of the tank with imperfections has yielded at a point connecting the bottom with the side plates, and in the areas where extreme imperfections appear. It should be noted that the yielding process has occurred despite the fact that the initial field of imperfections is rather a typical one.

Additionally, the random numerical model of tanks is extended by introducing random variability of soil foundations which can have a degrading effect on the tank loading capacity. To this end the randomness of the soil parameters should be described by a correlation function which was chosen arbitrarily. The results indicate that the influence of the soil parameters variability is not significant in this case.

The numerical calculations for silos and underground tanks revealed that the initial geometric imperfections influenced their mechanical behaviour. However, because of the lack of experimental data the results are preliminary ones.

It should be stressed that formulation of a methodology of identification, classification and description of the tank imperfections can lower the laborious and high cost of experiments, and ensure a better and much safer design.

5. References

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