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Making uncertainties propagation, reliability analysis, optimization easy using FReET software employing MS Excel

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The paper describes the main features and recent achievements of multipurpose reliability software FReET development. A new interface between the reliability software FReET and MS Excel has been developed enabling easy and understandable uncertainties propagation, reliability analyses and optimization possible. The contribution should be considered as an informative technical note on a new possibility to implement the response/limit state function for both present and future users of software. The interface logic is described and illustrated by an example.

Keywords: Uncertainties propagation, reliability, sensitivity, optimization, probabilistic software.

1 Introduction

Probabilistic techniques are used in various fields of engineering, and they offer advantages over the more traditional deterministic methods. In deterministic methods therefore, part of the information available is not inherently exploited, but for instance, safety factors are considered, leading usually in this way to conservative and therefore safe answers in design or assessment. By contrast, in probabilistic methods, these uncertainties are directly utilized fully as inputs. Less conservative answers are therefore obtained as uncertain reality is simulated.
Efficient methods for statistical, sensitivity and reliability assessment were implemented in FReET software, Novák et al. (2014, 2025). Attention is given to those techniques that have been developed for the analysis of computationally intensive problems; nonlinear FEM analysis being a typical example, the most successful application of software is represented by software SARA, Strauss at al. (2019), Novák et al. (2023). The possibility of "randomizing" of any engineering computational tasks in the sense of the Monte Carlo type of simulation is enabled. The stratified simulation technique Latin hypercube sampling is used in order to achieve variance reduction of the estimated outputs at a given (small) number of simulations. A robust technique to impose statistical correlation based on the stochastic method of optimization called simulated annealing has been proposed by Vořechovský and Novák (2009).
Many reliability software have been developed worldwide during last decades. But in most cases such software has no interface to Excel. We can only mention here software Oracle Crystall Ball which was developed over MS Excel, used mainly in economy and offers very limited methods, like crude Monte Carlo simulation only
The paper describes the main features and recent achievements of software FReET development. A new interface between the software FReET and MS Excel has been developed enabling easy and understandable statistical, sensitivity and reliability analyses possible. The contribution should be considered as an informative technical note on a new easy possibility to implement response/limit state function for both present and future users of software.

2 Purpose/concept

The program FReET is designed as user-friendly tool for simulating realizations of random variables X_i according to their probability distribution functions (vector $\boldsymbol{X}$) and to process numerically user-defined response/limit state function $g(\boldsymbol{X})$. The concept of uncertainty propagation is illustrated in Figure 1 by "input and output" software windows. Generally following types of analyses can be performed:

- Statistical analysis – program estimates the mean value, standard deviation (statistical moments) of g, and shows the suitable probability density function of g.
- Sensitivity analysis – program calculates the level of influence of random variables X_i on $g(\boldsymbol{X})$.
- Reliability analysis – program calculates the failure probability (and/or reliability index) p_f, as probability that g is smaller than zero.

The concept of program FReET is characterized by the aim to provide a very practical software tool, which can be used and handled very easily – in a straightforward feasible way. Software is optimized with an emphasize on interactivity and user-friendliness.

The user has several options to define the analyzed function g. The complexity of the task is decisive for the selection of an appropriate interface:

- Closed form (direct), using the implemented Equation Editor (simple problems).

- Numerical (indirect), using a user-defined DLL function that can be prepared in practically any programming language (C++, Fortran, Delphi, etc.).
- General interface to third-party software using user-defined *.BAT or *.EXE programs based on input and output text communication files.
- Interface to MS Excel; this new feature available from 2025 will be described in details here.

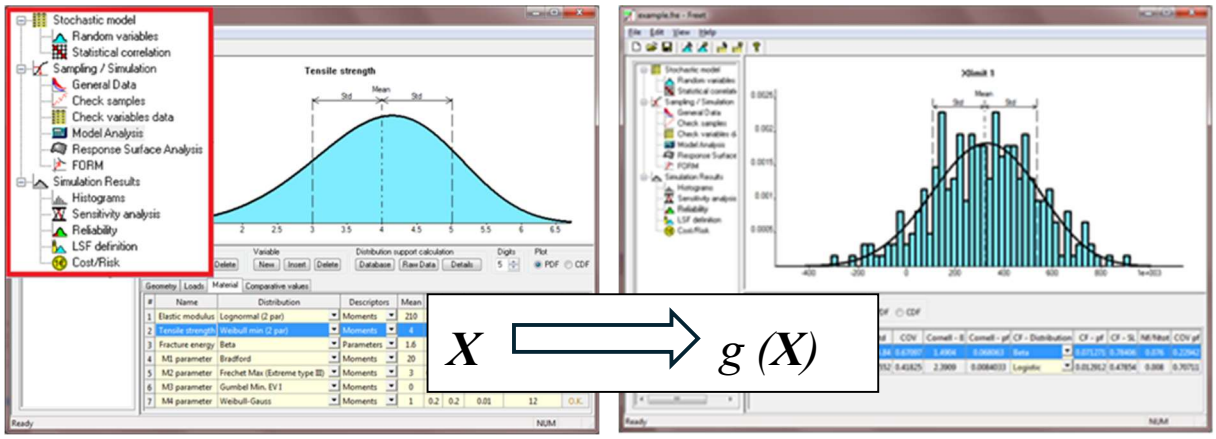


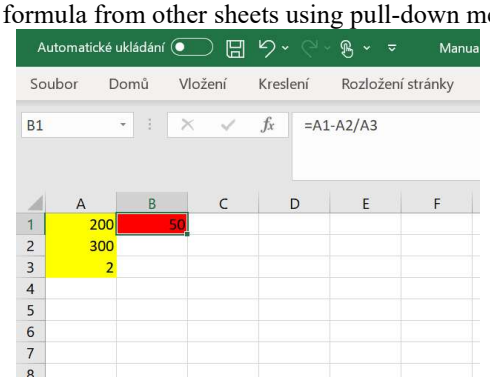
Figure 1. Uncertainties propagation concept in FReET: "Random variables" window - INPUT (left); "Reliability" window with empirical histogram - OUTPUT, (right).

3 FreET Interface to MS Excel

A new feature has recently been implemented in FReET: The user can debug response/limit state function in MS Excel spreadsheet deterministically and then switch to its randomization prepared by FReET. In this way, the MS Excel spreadsheet can be used directly for the uncertainty propagation of function prepared in Excel.

The analyzed response/limit state function is defined in MS Excel (*.xlsx) file: the user creates and debugs a limit state function in the following way. All individual random variables defined in FReET must appear in in column "A" in the same ordering as in FReET (see the vector with yellow background in the Figure 2). The output value (formula) must be in cell "B1" (see the red background). Intermediate calculations needed for evaluation of the final output formula located in cell "B1" can occupy any other cells of the Excel sheet, located in same sheet as is cell "B1" or in any other sheets. So cross-evaluations over more sheets are allowed.

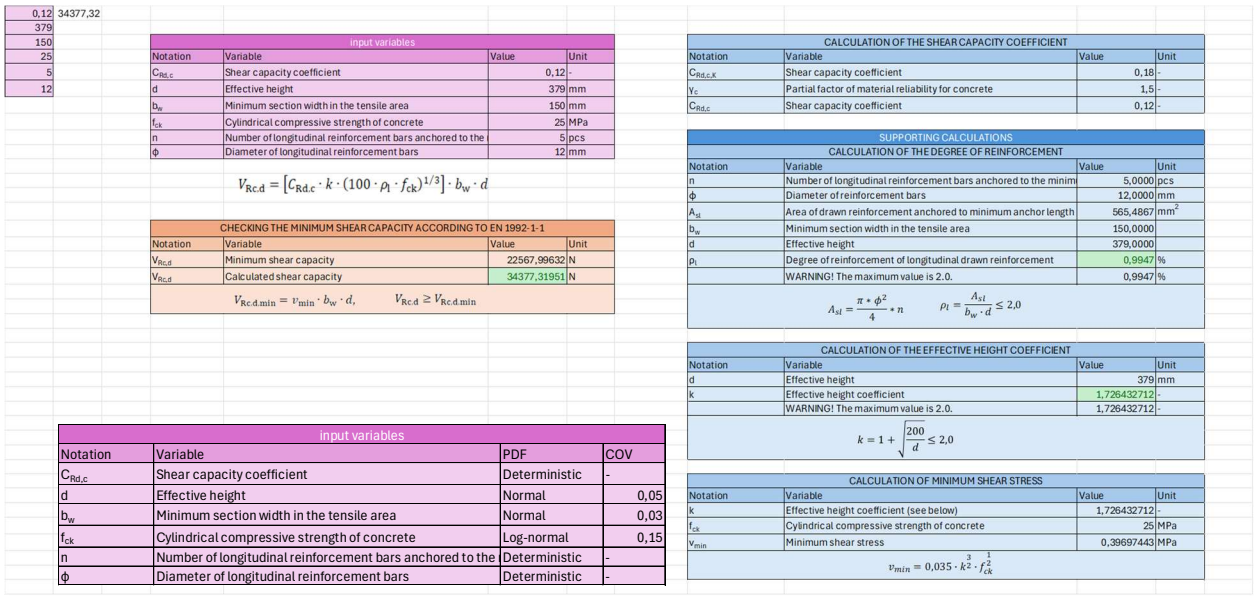
The function (response or limit state) is activated in FReET in "Model analysis" using "…" button by selecting the name of *.xlsx file. Several *.xlsx files can be used simultaneously. Parallel calculation of several functions based on *.xlsx file and functions defined in other way (e.g. using Equation Editor or DLL function) is also possible.
Several functions can be defined in several sheets of Excel. When *.xlsx file is defined in "Model Analysis", "New Mode Function", formula of first sheet is selected and shown in "Model Function Definition". User can select other formula from other sheets using pull-down menu in "Model Function Definition".



Note that the number of random variables in function defined in column A of the .xlsx file should correspond with the number of random variables defined in "Stochastic Model" section of FReET. Note, that just exactly number of random variables defined in "Stochastic Model" are used for randomization of cells in column "A". User can use in column "A" also additional cells, but they will not be randomized by FReET. This is fully the responsibility of the user as FReET cannot check this fundamental requirement. FReET generates realizations of the random variables defined in "Stochastic model", transfer them into Excel file, every simulation of function is calculated in Excel and results are then transferred back into FReET.

Figure 2. Definition of response/limit state function in MS Excel sheet.

Example of application: Intensive research focused on performance of analytical and code shear strength computational models has been done recently, Novák et al., 2025. The aim was to assess many analytical models, some of them are code models to predict shear strength from probabilistic point of view. Models with both steel and GFRP reinforcement were tested. All models were prepared in MS Excel according to concept described in section 3 and randomized. Example of one model (EN 1992-1-1) arranged in one folder is shown in Figure. 3 without any deep explanation and results obtained, the purpose here is just to show computational arrangement in MS Excel following concept described above.



0,12	34377,32
379	
150	
25	
5	
12	

input variables

Notation	Variable	Value	Unit
$C_{Rd,c}$	Shear capacity coefficient	0,12	-
d	Effective height	379	mm
b_w	Minimum section width in the tensile area	150	mm
f_{ck}	Cylindrical compressive strength of concrete	25	MPa
n	Number of longitudinal reinforcement bars anchored to the	5	pcs
ϕ	Diameter of longitudinal reinforcement bars	12	mm

$$V_{Rc,d} = \left[C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3}\right] \cdot b_w \cdot d$$

CHECKING THE MINIMUM SHEAR CAPACITY ACCORDING TO EN 1992-1-1

Notation	Variable	Value	Unit
$V_{Rc,d}$	Minimum shear capacity	22567,99632	N
$V_{Rc,d}$	Calculated shear capacity	34377,31951	N

$$V_{Rc,d,min} = v_{min} \cdot b_w \cdot d, \qquad V_{Rc,d} \geq V_{Rc,d,min}$$

CALCULATION OF THE SHEAR CAPACITY COEFFICIENT

Notation	Variable	Value	Unit
$C_{Rd,c,K}$	Shear capacity coefficient	0,18	-
γ_c	Partial factor of material reliability for concrete	1,5	-
$C_{Rd,c}$	Shear capacity coefficient	0,12	-

SUPPORTING CALCULATIONS

CALCULATION OF THE DEGREE OF REINFORCEMENT

Notation	Variable	Value	Unit
n	Number of longitudinal reinforcement bars anchored to the minim	5,0000	pcs
ϕ	Diameter of reinforcement bars	12,0000	mm
A_{sl}	Area of drawn reinforcement anchored to minimum anchor length	565,4867	mm^2
b_w	Minimum section width in the tensile area	150,0000	
d	Effective height	379,0000	
ρ_l	Degree of reinforcement of longitudinal drawn reinforcement	0,9947	%
	WARNING! The maximum value is 2.0.	0,9947	%

$$A_{sl} = \frac{\pi * \phi^2}{4} * n \qquad \rho_l = \frac{A_{sl}}{b_w \cdot d} \leq 2{,}0$$

CALCULATION OF THE EFFECTIVE HEIGHT COEFFICIENT

Notation	Variable	Value	Unit
d	Effective height	379	mm
k	Effective height coefficient	1,726432712	-
	WARNING! The maximum value is 2.0.	1,726432712	-

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2{,}0$$

CALCULATION OF MINIMUM SHEAR STRESS

Notation	Variable	Value	Unit
k	Effective height coefficient (see below)	1,726432712	-
f_{ck}	Cylindrical compressive strength of concrete	25	MPa
v_{min}	Minimum shear stress	0,39697443	MPa

$$v_{min} = 0{,}035 \cdot k^{\frac{3}{2}} \cdot f_{ck}^{\frac{1}{2}}$$

input variables

Notation	Variable	PDF	COV
$C_{Rd,c}$	Shear capacity coefficient	Deterministic	-
d	Effective height	Normal	0,05
b_w	Minimum section width in the tensile area	Normal	0,03
f_{ck}	Cylindrical compressive strength of concrete	Log-normal	0,15
n	Number of longitudinal reinforcement bars anchored to the	Deterministic	-
ϕ	Diameter of longitudinal reinforcement bars	Deterministic	-

Figure 3. Example of EN shear strength model in MS Excel sheet.

4 Software features/methods summary

State-of-the-art probabilistic algorithms are implemented in FReET to compute the stochastic response and reliability. FReET is a modular computer system for performing probabilistic analysis developed mainly for computationally intensive deterministic modeling and the running of user-defined tasks/subroutines. The main features of the software are:

4.1 *Stochastic model (inputs)*

The fundamental part of the software is the user-friendly handling of inputs – basic random variables and statistical correlation. The main features are:

- A friendly Graphical User Interface (GUI).
- 30 probability distribution functions (PDF), mostly 2-parametric, some 3-parametric, two 4-parametric (Beta and normal PDF with a Weibullian left tail).
- Unified description of random variables with the optional use of statistical moments or parameters or a combination of moments and parameters.
- PDF calculator.
- Extreme value distributions and order statistics for any available parametric distribution.
- Statistical correlation (including a weighting option).
- Categories and comparative values for PDFs.
- Visualization of random variables, including statistical correlation in both Cartesian and parallel coordinates.

4.2 *Results (output)*

The assessment of outputs (the results of Monte Carlo-type simulation) consists of:

- Statistical moments and histograms of output variables.
- Sensitivity analyses.
- Reliability estimates (failure probability and/or reliability index) by various simulation and approximation methods.
- Limit state functions visualization.
- Parametric studies.
- Cost/Risk assessment.

4.3 *Probabilistic techniques*

Both standard and advanced statistical, simulation and reliability techniques are implemented:

- Crude Monte Carlo simulation.
- Latin Hypercube Sampling (3 alternatives).
- Hierarchical Latin Hypercube Sampling (extension of sample size).
- First Order Reliability Method (FORM).
- Curve fitting for PDF.
- Simulated Annealing employed for correlation control over inputs.
- Bayesian updating.

5 Optimization

A very easy heuristic optimization can be performed based on uncertainties propagation concept. Design variables (now parameters) X_i are simulated according to their probability distribution functions (vector $\boldsymbol{X}$), reflecting design space (rectangular distribution is a reasonable choice) and to process numerically user-defined objective function $g(\boldsymbol{X})$. Then the extreme (minimum or maximum) of objective function $g(\boldsymbol{X})_{ext}$ is selected from all stochastic simulations and corresponding vector $\boldsymbol{X}_{opt}$ represents optimized variables. Such optimization is very simple and transparent, but due to the ability of Latin Hypercube Sampling to cover space of design parameters well using small number of simulation and it can be used for computational demanding tasks providing satisfactory results. An improvement of such simple procedure is so called the Aimed Multilevel Sampling (AMS) method, enabling efficient optimization of design parameters under limited computational budgets. The AMS method, described in (Lehký et al., 2018). divides the simulation process into several sequential levels. At each level, sampling is performed within a defined design space and the sample providing the best performance with respect to the optimization objective is selected. The technique has been implemented within the framework of node architecture approach, which is a base for other improvements and application for the real-world model updating problems (Slowik and Novák, 2019; Cervenka et al. 2025).

6 Conclusions

The presented software tool may be applied in the advanced design/assessment of engineering tasks, when making decisions about alternatives, when searching for optimum life-cycle cost solutions, and in cost-effective decision-making processes. A new interface of FReET software to MS Excel represents a user-friendly alternative for "making reliability analysis easy". It is used for both research and teaching purposes, especially for teaching a reliability subject is very successful for its user-friendly simplicity.

Acknowledgments

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