Cyklus prednášok pod záštitou rektora STU

Lecture series under the auspices of STU rector

ViP

siting rofessors'

College STU

Material parameters and damage identification based on artificial neural networks small-sample training

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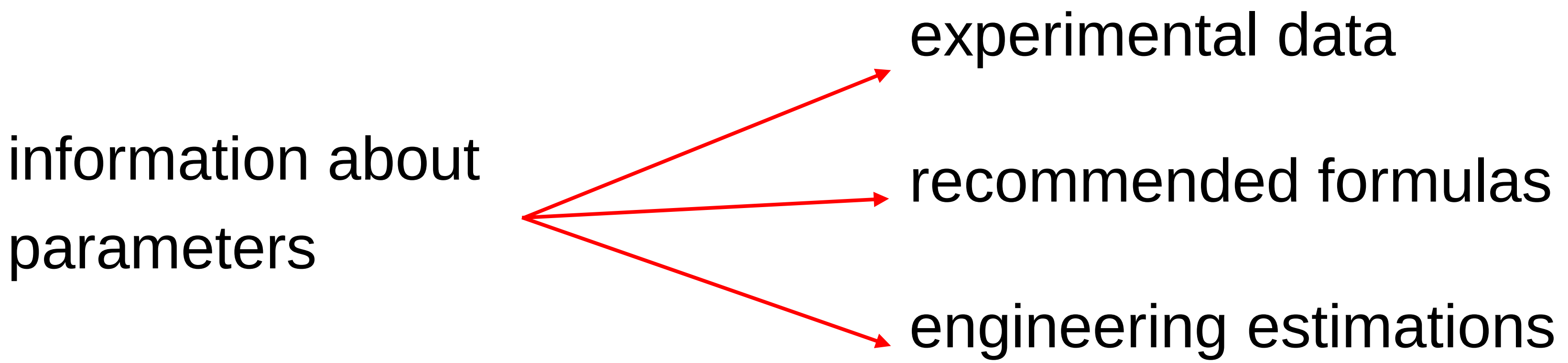
Parameters of numerical models

- Usually, we want some numerical model to match measurements performed in laboratory or in situ.
- How do we find parameters of numerical models?
- by Inverse Analysis
- typically parameters of material (elastic modulus, density, strength, ...)



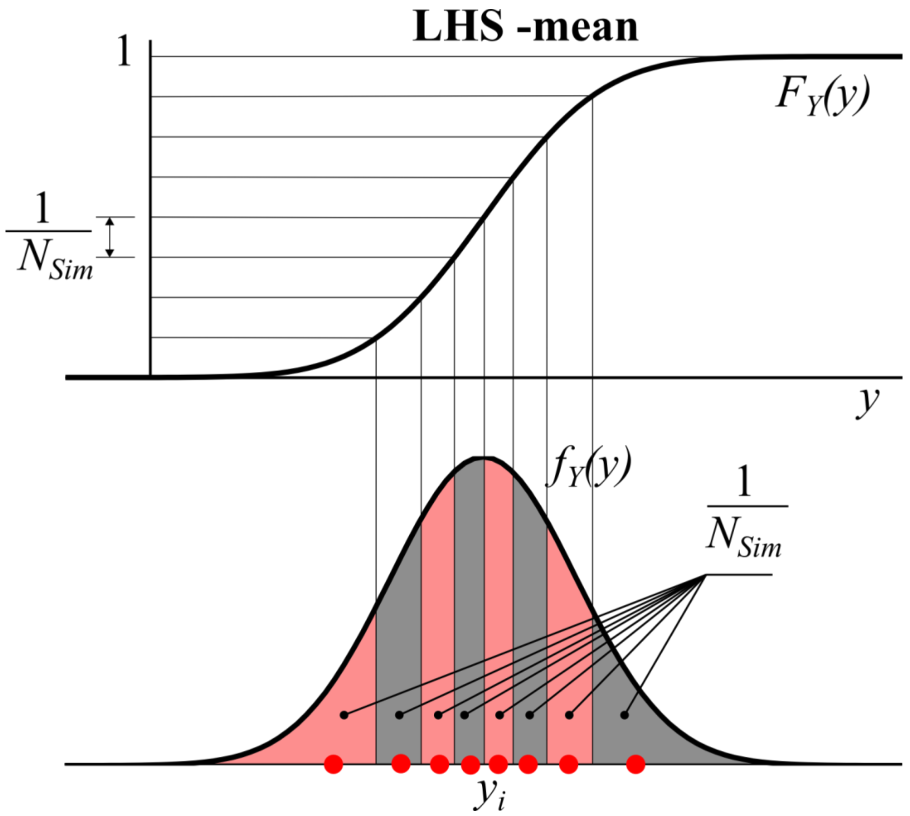
Uncertainty simulation
Small-sample simulation of Monte Carlo type

Latin Hypercube Sampling

$$y_i = \frac{\int_a^b y \cdot f(y)\ \mathrm{d}y}{\int_a^b f(y)\ \mathrm{d}y} = N_{Sim} \int_a^b y \cdot f(y)\,\mathrm{d}y$$

where $a = \frac{i-1}{N_{Sim}} \qquad b = \frac{i}{N_{Sim}}$

- takes mean value of each interval = interval centroid



Uncertainty simulation

Small-sample simulation of the Monte Carlo type

LHS-mean

- sample averages equal exactly the mean values of variables;
- variances of the sample sets are much closer to the target values compared to other selection schemes;
- for some probability density functions (including e.g. Gaussian, Exponential, Laplace, Rayleigh, Logistic, Pareto, etc.) the integral can be solved analytically;
- for others, the extra effort of doing the numerical integration is definitely worthwhile.

Uncertainty simulation
Small-sample simulation of the Monte Carlo type

Imposing statistical correlation

- Correlation matrices:
  - prescribed (target) – **T**
  - generated (actual) – **A**
- Difference matrix (error matrix):

$$\mathbf{E} = \mathbf{T} - \mathbf{A}$$

⇩

- a suitable norm of the matrix E defined as an objective function: minimum among all possible rank combinations.
- There exist $(N_{sim}!)^{N_{var}-1}$ possibilities

⇩

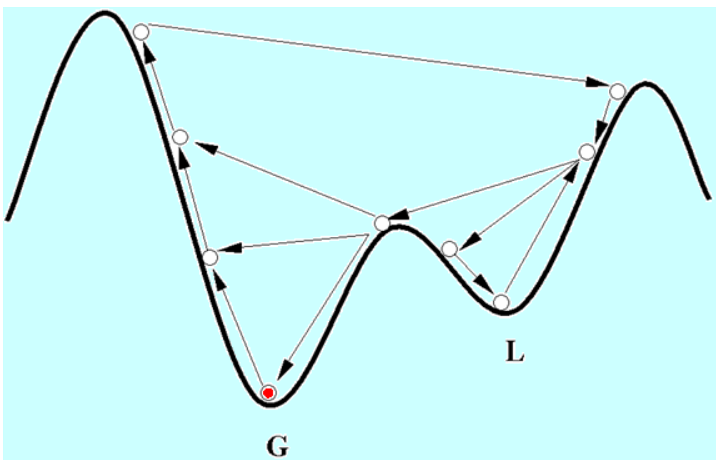
simulated annealing

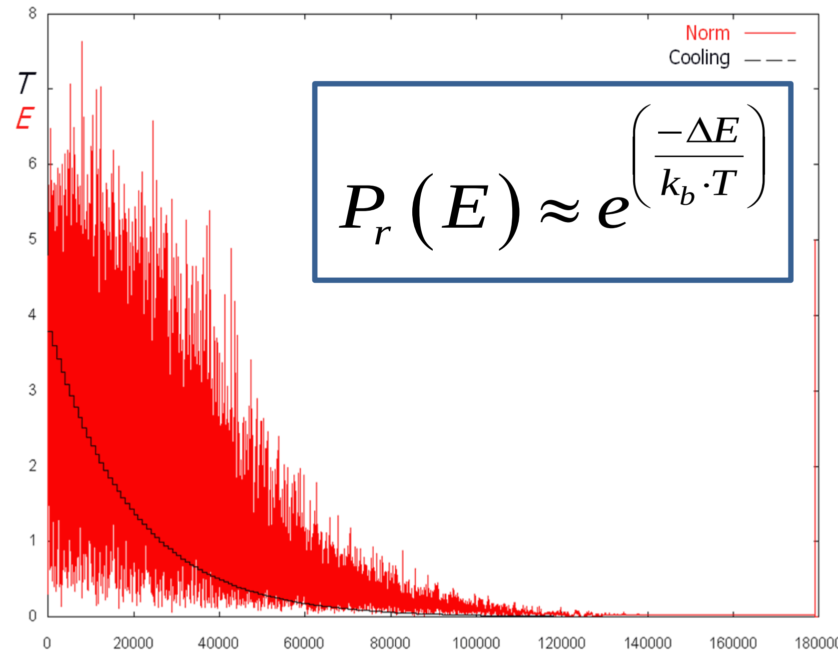
x_1	y_1	…	z_1
x_2	y_2	…	z_2
x_3	y_3	…	z_3
x_4	y_4	…	z_4
x_5	y_5	…	z_5
x_6	y_6	…	z_6
x_7	y_7	…	z_7
x_8	y_8	…	z_8
…	…	…	…
x_{NSim}	y_{NSim}	…	z_{NSim}

Uncertainty simulation
Small-sample simulation of the Monte Carlo type

Imposing statistical correlation – simulated annealing

- Probability to escape from local minima.
- Cooling – decreasing of system excitation.
- Boltzmann PDF, energetic analogy.



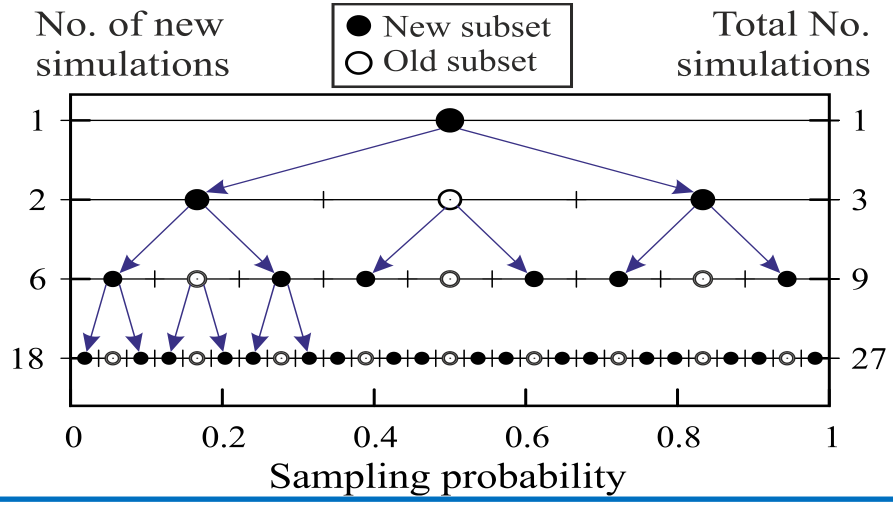


$$P_r(E) \approx e^{\left(\frac{-\Delta E}{k_b \cdot T}\right)}$$

- Performs much better than other widely used algorithms for correlation control, e.g. both Iman and Conover’s Cholesky decomposition and Owen’s Gram-Schmidt orthogonalization.

Uncertainty simulation
Small-sample simulation of the Monte Carlo type

Hierarchical sampling



- in conventional LHS it is necessary to specify the number of simulations in advance;
- overcame by the Hierarchical Latin Hypercube Sampling;
- the addition of simulations to the current sample set (hierarchical refinement of sampling probabilities) while maintaining the desired correlation structure by employing an advanced correlation control algorithm for the extended part of the sample;
- the whole procedure of a cascade of sampling runs can be fully automated and the stopping criterion might be e.g. the significance of output statistics, or the desired computational time.

Nonparametric rank-order based sensitivity analysis
A small-sample simulation of the Monte Carlo type

Sensitivity analysis:

- Nonparametric rank-order correlation between input variables and output response variable.

  Kendall tau:

$$\tau_i = \tau\left(q_{ji}, p_j\right), \quad j = 1, 2, \ldots, N$$

  Spearman's coefficient of correlation:

$$r^s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n-1)(n+1)}$$

variable values

simulation	input variable		result
1	x_1	y_1	g_1
2	x_2	y_2	g_2
3	x_3	y_3	g_3
4	x_4	y_4	g_4
5	x_5	y_5	g_5
6	x_6	y_6	g_6
⋮	⋮	⋮	⋮

$\Longrightarrow$

orders

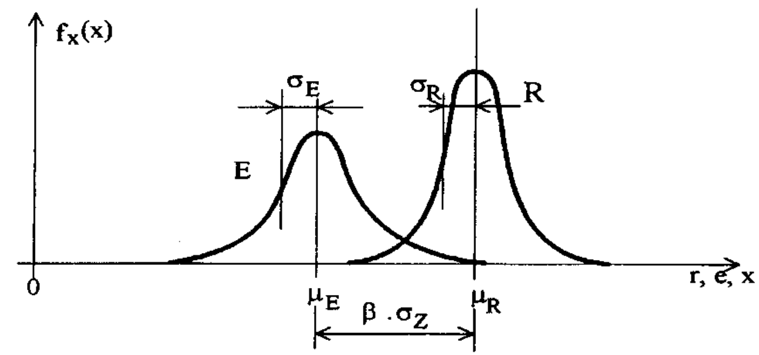
simulation	input variable		result
1	p_{11}	p_{21}	q_1
2	p_{12}	p_{22}	q_2
3	p_{13}	p_{23}	q_3
4	p_{14}	p_{24}	q_4
5	p_{15}	p_{25}	q_5
6	p_{16}	p_{26}	q_6
⋮	⋮	⋮	⋮

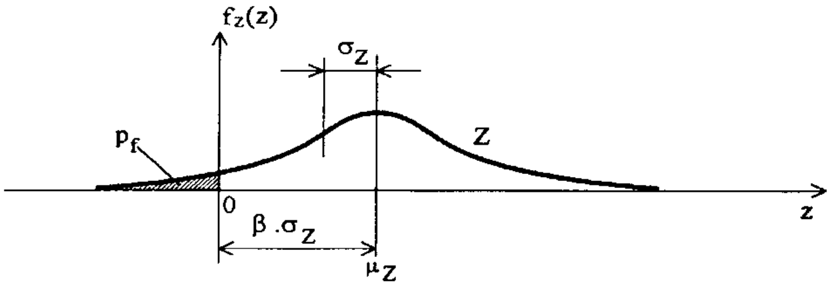
- Robust – uses only orders.
- Additional result of LHS simulation, no extra effort.
- Bigger correlation coefficient = high sensitivity.
- Relative measure of sensitivity (-1, 1).

Uncertainty simulation
A small-sample simulation of the Monte Carlo type

Reliability analysis:

- Simplified – rough estimates, as constrained by extremally small number of simulations (10–100)!
- Cornell safety index.
- Curve fitting.
- FORM, importance sampling, response surface...

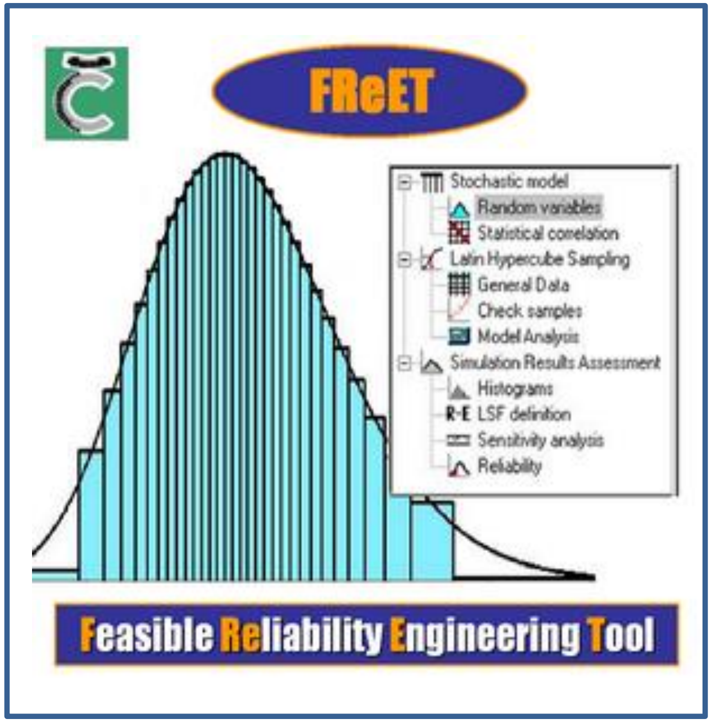




FReET software

<u>F</u><u>easible</u> **<u>Re</u>**<u>liable</u> **<u>E</u>**<u>ngineering</u> **<u>T</u>**<u>ool –</u> **<u>FReET, version 1.5</u>**<u>:</u>

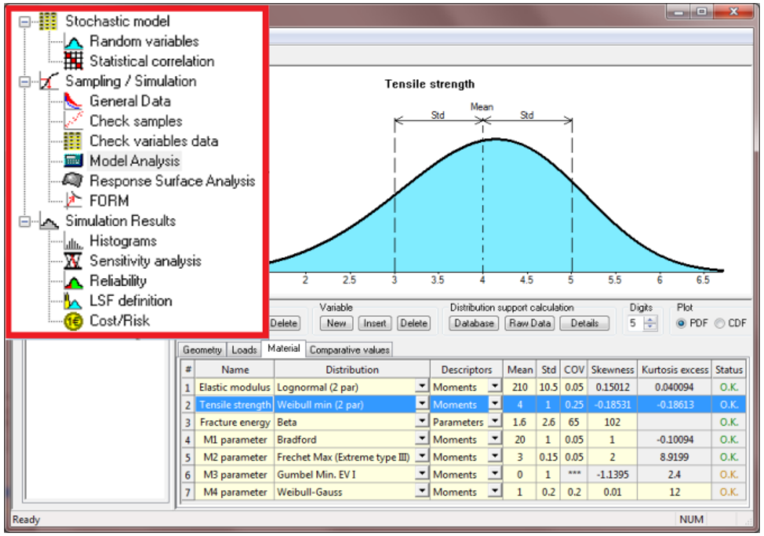
- multipurpose probabilistic software for statistical, sensitivity and reliability analysis of engineering problems;
- allows to simulate uncertainties of the problem at random variables level (typically in civil/mechanical engineering – material properties and loading, geometrical imperfections);
- developed at Brno University of Technology, Institute of Structural Mechanics.

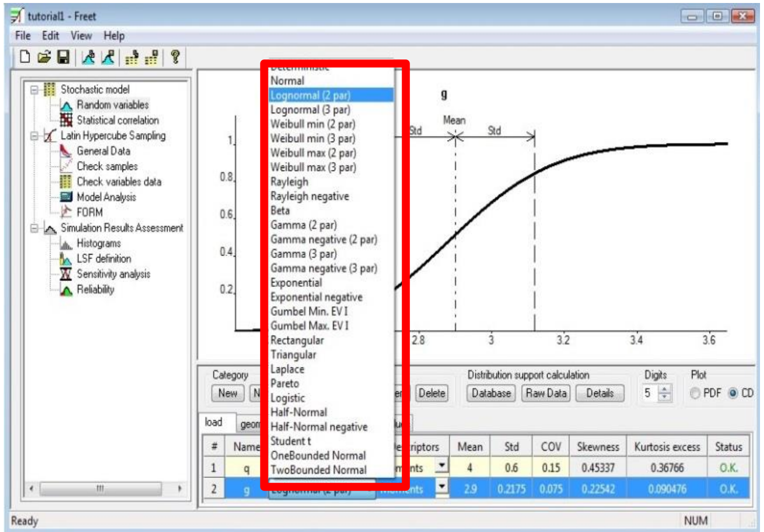


FReET software

„Random variables“ window:

- friendly Graphical User Environment;
- 30 probability distribution functions (PDF), mostly 2-parametric, some 3-parametric, two 4-parametric (Beta PDF 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.





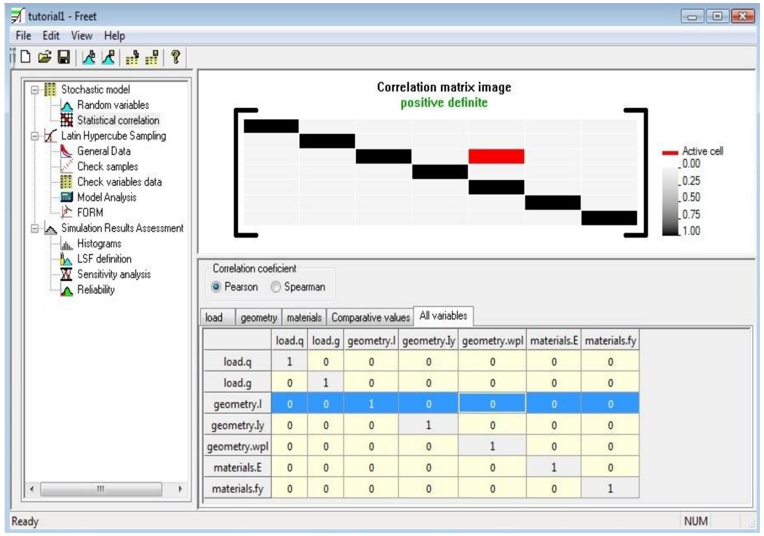
FReET software

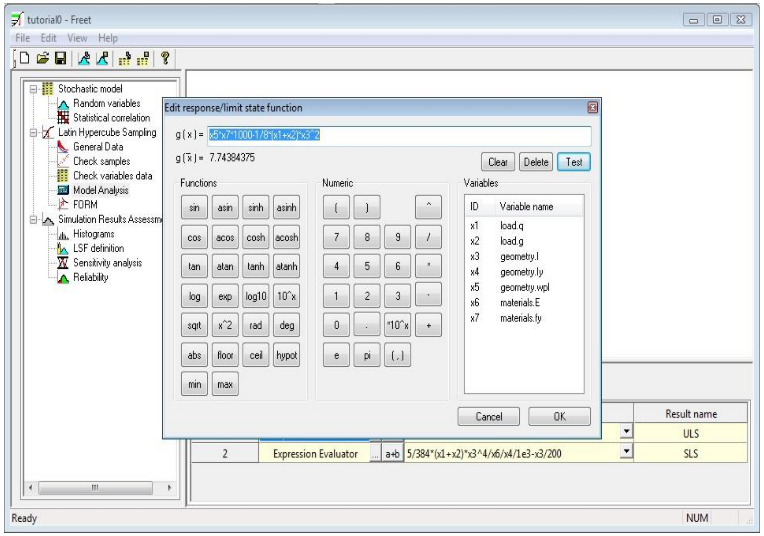
„Statistical correlation“ window:

- visualization in both Cartesian and parallel coordinates;
- also a weighting option.

„Limit state/response functions“ window:

- 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;
- multiple response functions assessed in the same simulation run.





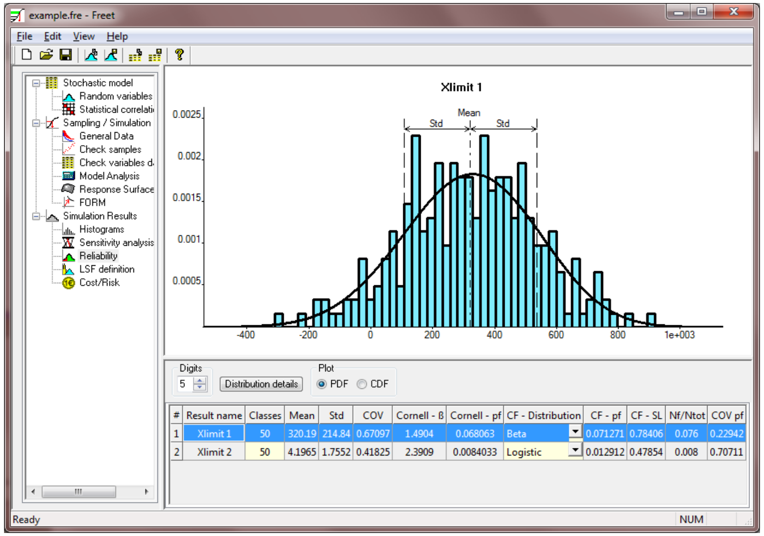
FReET software

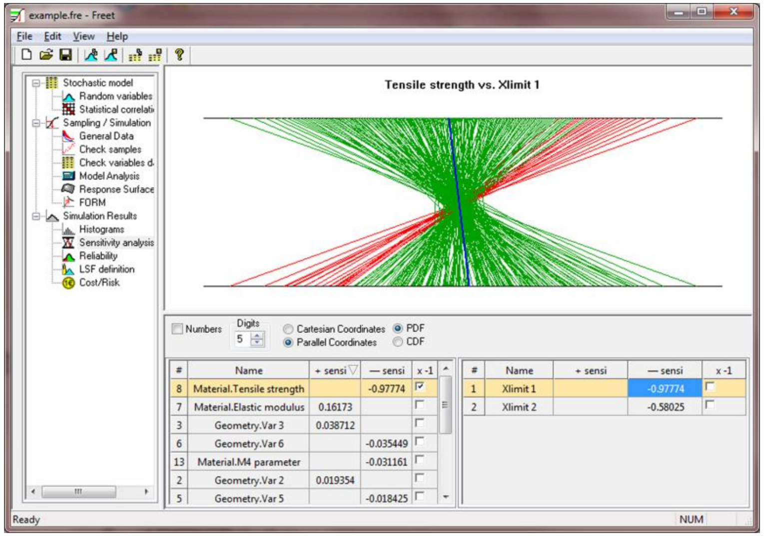
„Reliability“ window:

- histograms of output variables;
- sensitivity analyses;
- reliability estimates by various simulation and approximation methods;
- limit state functions;
- parametric studies;
- cost/risk assessment.

Probabilistic techniques:

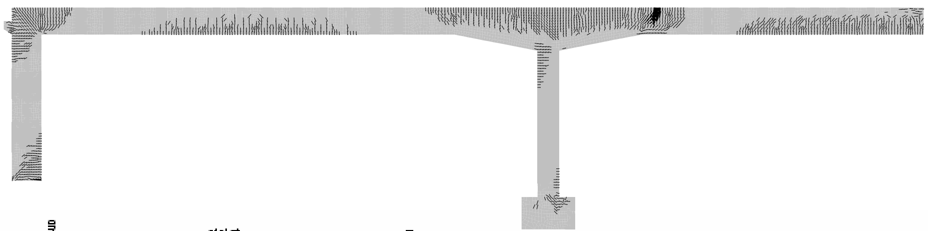
- crude Monte Carlo simulation;
- Latin Hypercube Sampling (3 alternatives);
- Hierarchical Latin Hypercube Sampling;
- First Order Reliability Method (FORM);
- Curve fitting;
- Simulated Annealing employed for correlation control over inputs;
- Bayesian updating;

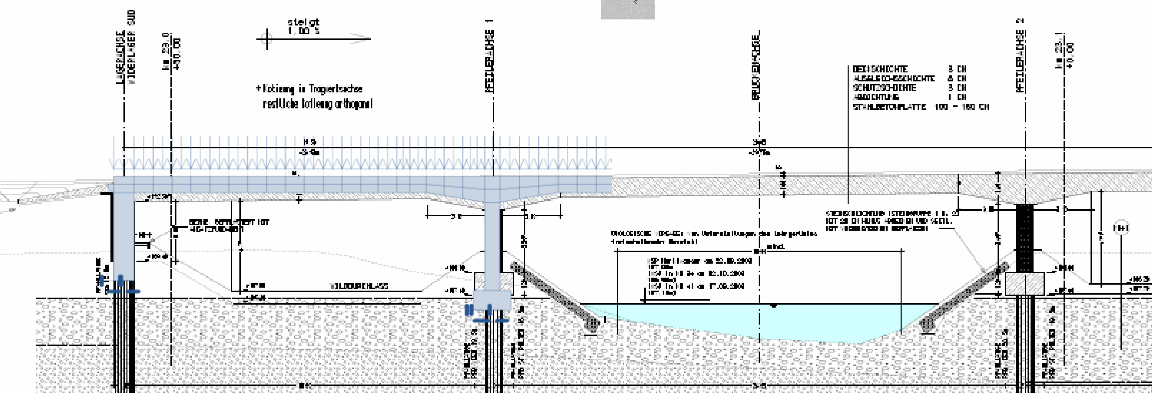


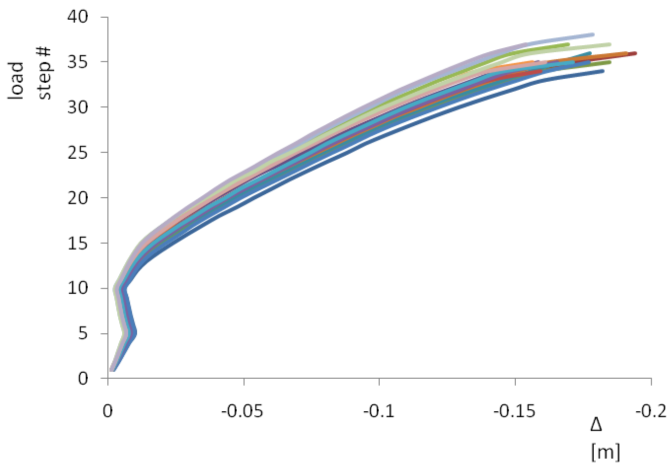


Applications: S33.24 bridge in Austria

- Jointless bridge
- Casting in the end of March 2009
- Testing after 28 days
- Material parameters identification





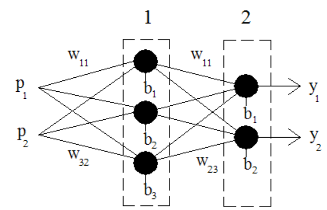


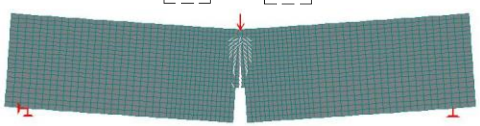
Applications: S33.24 bridge in Austria

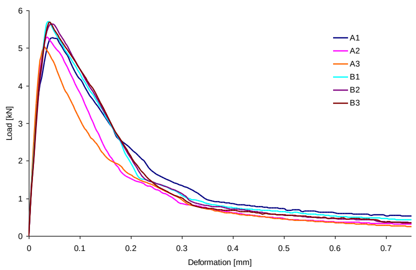
Selected parameters of steel:

	Symbol	Unit	Mean	Coeff. Of Variation	PDF	Source
Elastic Modulus	E	Gpa	210	0.03	LN	Literature
Yield stress	f_y	Mpa	475	0.07	LN	Literature

Variable	E	f_y
E	1.0	**0.60**
f_y	0.59	1.0







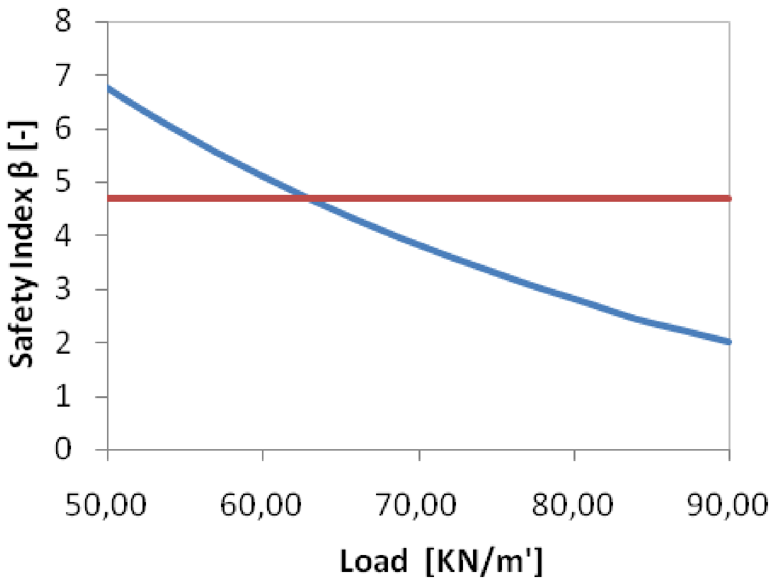
Selected parameters of concrete:

	Symbol	Unit	Mean	Coeff. of Variation	PDF	Source
Elastic Modulus	E	Mpa	39500	0.1	N	Identification
Poisson's ratio	ν	-	0.20	0.05	LN	Literature
Tensile strength	f_t	Mpa	2.90	0.09	Weibull	Identification
Compressive strength	f_c	Mpa	-28.90	0.1	LN	Literature
Specific fracture energy	G_f	N/m	178.00	0.13	Weibull	Identification
Uniaxial compressive strain	ε_c	-	0.0018	0.15	LN	Literature
Reduction of strength	c_{Red}	-	0.80	0.06	Rect.	Literature
Critical comp. displacement	w_d	m	-0.0005	0.1	LN	Literature
Specific material weight	ρ	MN/m^3	0.023	0.1	LN	Literature

Variable	E	f_t	f_c	G_f	ε_c
E	1.0	**0.69**	**-0.9**	**0.5**	**0.9**
f_t	0.70	1.0	**-0.78**	**0.89**	**0.61**
f_c	-0.86	-0.76	1.0	**-0.61**	**-0.89**
G_f	0.52	0.87	-0.60	1.0	**0.49**
ε_c	0.85	0.61	-0.88	0.47	1.0

Applications: S33.24 bridge in Austria

ULS: g(X) = R(X) - E(X)

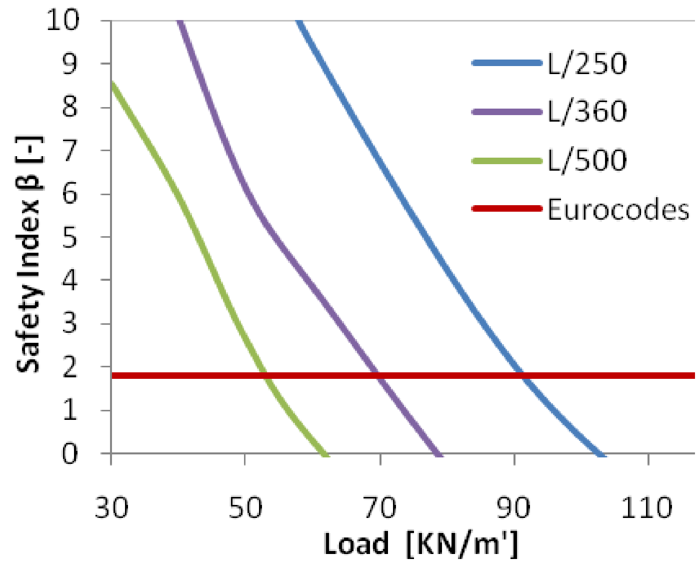


Eurocode:

β = 4.7 for one year period

Pf = 1.5E-6.

SLS: g(X) = Wlim(X) - W(X)



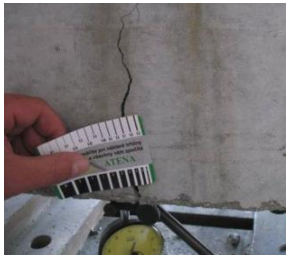
Eurocode: β = 1.8

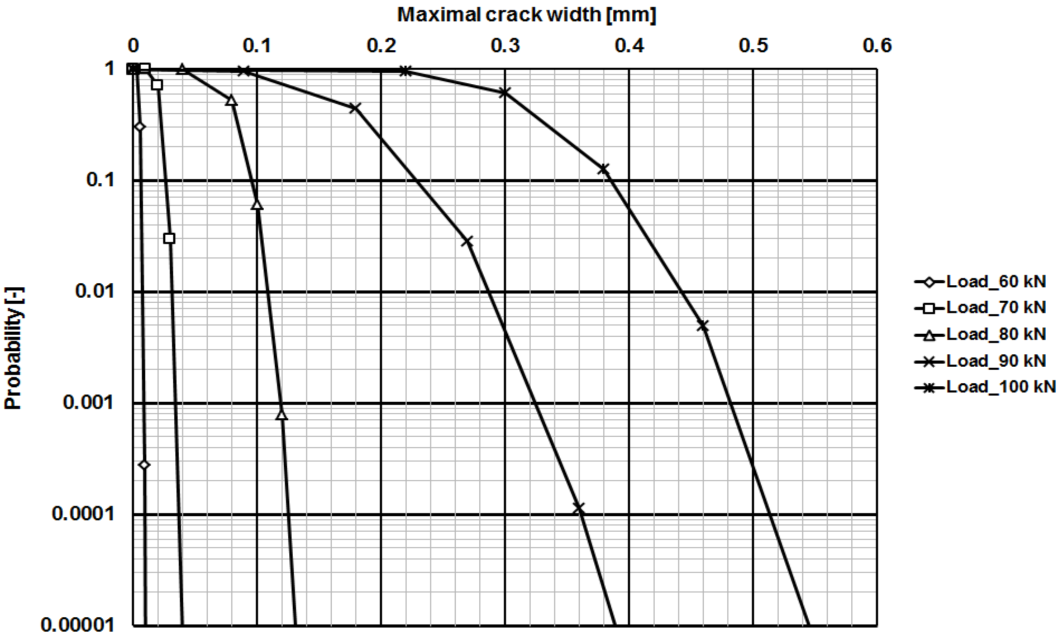
deflection limit of span: L/250 or L/500

US Standard Specifications: L/360 or L/500

Applications: railway sleeper

- pre-stressed railway sleeper (ŽPSV a.s.)
- model in ATENA 3D
- random dominant concrete parameters
- LHS simulations with imposed statistical correlation – 30 realizations
- probability of maximal crack width





Conclusions

- **efficient techniques of employing stochastic simulation methods were combined in FReET software - an advanced tool for the probabilistic assessment of user-defined problems at ultimate capacity and serviceability limit states**
- **degradation models implemented in FReET-D software can help users to choose appropriate models and assess the service life issue as applied to concrete structures - durability limit states**
- **SARA = complex integration of probabilistic engine (FReET) and nonlinear FEM (ATENA). Already hundreds applications/users worldwide, concrete structures, intensive development.**
- **ANN based material parameters and damage identification!**