EUROPEAN UNION

Interreg Austria – Czechia

Co-funded by the European Union

BOKU UNIVERSITY

BRNO UNIVERSITY OF TECHNOLOGY

1st IREC WORKSHOP

Project supported by the European Regional Development Fund (ERDF) under the Interreg Austria–Czechia 2021–2027 Cooperation Programme.

Project Number: **ATCZ00068**

Project Acronym: **IREC**

Project Duration: **01. 06. 2024–30. 11. 2027**

URL: **https://irec.boku.ac.at/**

Introduction
Assessment Level III: ÖNORM B 4008-2:2025

TIME SCHEDULE

Session 1	**Opening and Project Overview**	
10:00–10:15	Welcome and opening remarks	*prof. Novák*
10:15–10:40	Presentation of the IREC project, including a mention of the participating industry partners	*prof. Strauss*
Session 2	**Fundamentals and Basic Template Introduction**	
10:40–11:00	Reliability-based assessment concepts, FReET–Excel interface	*prof. Novák*
11:00–11:10	Overview of the IREC methodological framework, general template	*prof. Lehký*
11:10–11:50	Standardised Excel–FReET templates	BUT + BOKU
11:50–12:10	Discussion and questions	
12:10–14:00	**Lunch Break**	
Session 3	**Plenary Discussion**	
14:00–14:30	Students' works / FReET–Excel applications	*BUT students*
14:30–14:40	(Research results: Shear strength code models uncertainties assessment)	*prof. Novák*
14:40–15:10	Advanced reliability and performance concepts, Assessment Level III: ÖNORM B 4008-2:2025	*prof. Strauss*
15:10–15:30	Stakeholder expectations and practical constraints, Future developments, Technical discussion	
15:30–16:00	**Wrap-Up and Next Steps, Closing Remarks**	
16:00	**Coffee Break and Informal Programme**	

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INTEGRATED RESEARCH CENTER FOR STRUCTURES – IREC

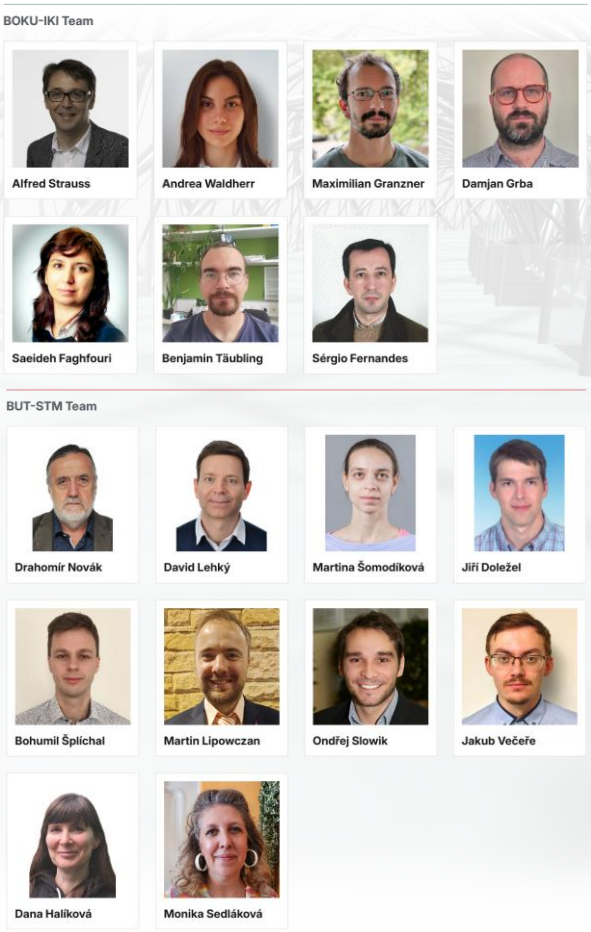
Introducing the European INTERREG Austria–Czechia project

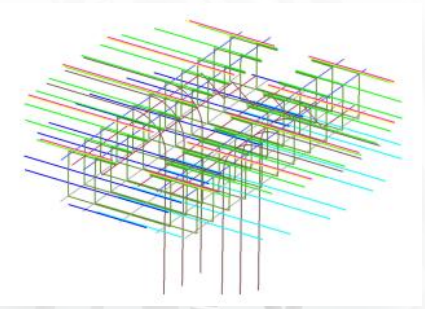
"IREC was established for the advanced numerical and analytical analyses of the reliability, performance, and service life of existing and new structures such as bridges, tunnels, and natural hazard protection structures."

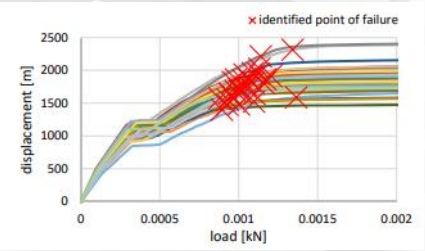
Mission: Establishing a leading centre for the assessment, monitoring, and life-cycle management of critical engineering structures.

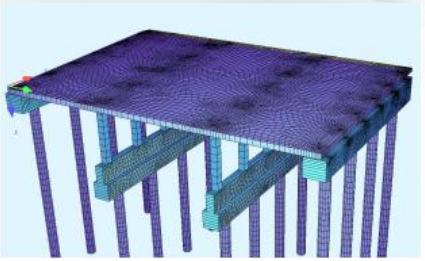
Key Objectives

- Innovation: Developing standardized methods for evaluating aging infrastructure,
- Sustainability: to optimize maintenance cycles to reduce costs and environmental impact,
- Knowledge Transfer: while bridging the gap between academic research and regional engineering practice.









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INTEGRATED RESEARCH CENTER FOR STRUCTURES – IREC

Organisational and content structure of the integrated research centre

Website is set up to offer our services in the field of durability and reliability assessment of building structures, testing of material parameters, etc.
The website has a general management tool to allow users to enter their specific requests as a project and further submit requests. The dashboard will be progressively optimised based on feedback from target groups.

Meeting needs of target groups

A report has evaluated key areas of interest for the target groups.
Representatives of target groups (regional, national public organisations, transport infrastructure managers and SMEs) were surveyed to identify common and individual/specific issues, need and interest related to performance assessment, reliability, durability and sustainability.

Software and methodological templates for IREC services

Software and methodological templates for repetitive basic and advanced tasks will be developed, including user manuals and databases of parameters, including their stochastic properties, based on the results of experimental measurements. The use of templates for advanced probabilistic assessment of structures will be demonstrated using simple studies and will be compared with standard procedures. Analysis demonstrating applying reliability concepts and safety factors to existing and new structures will also be carried out.

Keeping up with progress

Workshops will be held in regular intervals to teach the handling of different templates and discuss interesting use cases.

Partners

We thank all partners for offering valuable insights and feedback

Czech Partners

- MORAVIA CONSULT Olomouc a.s.
- EXprojekt s.r.o.
- SAGASTA s.r.o
- SUDOP BRNO, spol. s r.o.
- ROAD-TRAFFIC s.r.o.
- Klokner Institute CTU in Prague
- Krajská správa a údržba silnic Vysočina
- Správa a údržba silnic JMK
- Správa železnic

Austrian Partners

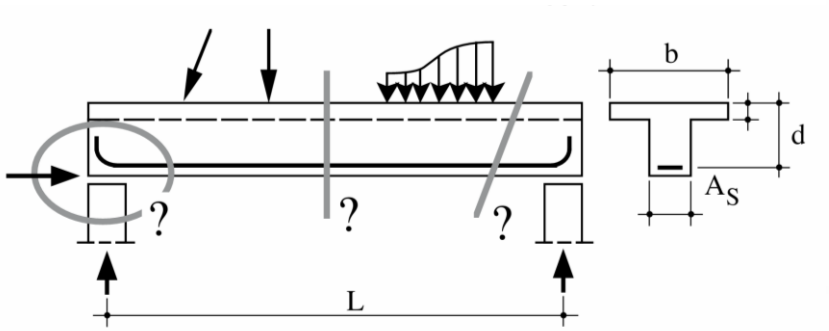
- Stadt Wien – MA 29
- Land Niederösterreich – Abteilung Brückenbau
- Nationales Komitee 014 – Brückenbau Allgemeines
- TU Wien
- Camillo Site Bautechnikum
- Hottinger Brüel & Kjaer
- ÖBB Infra
- ASFINAG
- KOB ZT Ges.m.b.H
- Vill Ziviltechniker GmbH
- Schimetta Consult ZT GmbH
- REVOTEC ZT GmbH



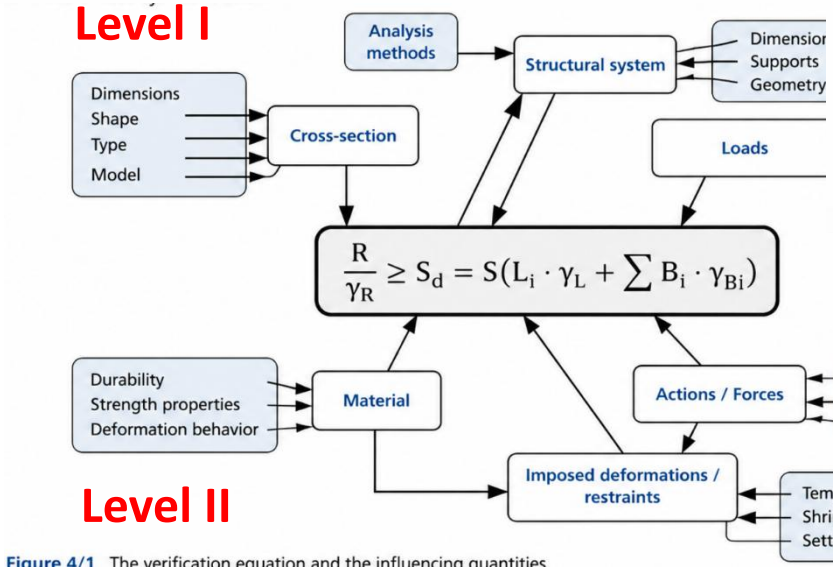
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ADVANCED RELIABILITY AND PERFORMANCE CONCEPTS, ASSESSMENT LEVEL III: ÖNORM B 4008-2:2025

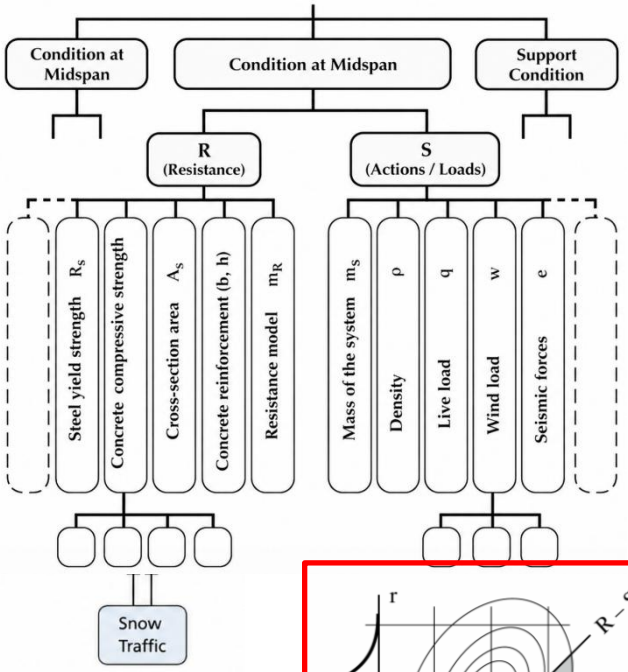


Level I

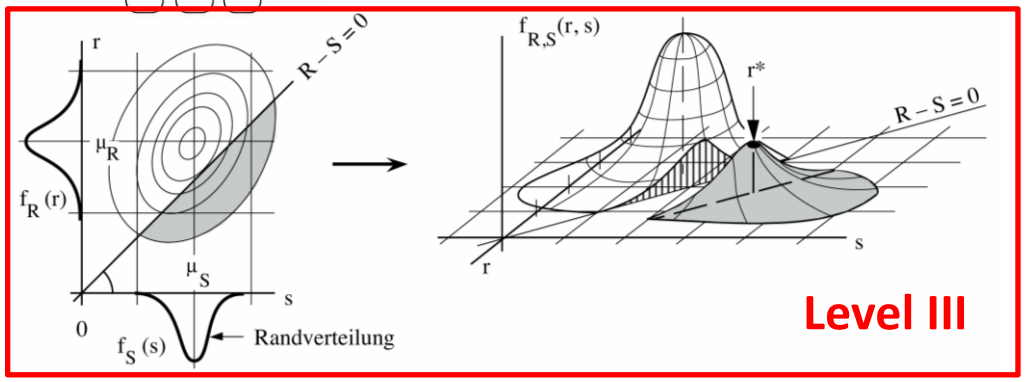


Level II

Figure 4/1 The verification equation and the influencing quantities



ÖNORM B 4008-2:2025 Level III is a modern, reliability-based framework for assessing whether existing bridges are still safe—using increasingly sophisticated methods depending on the situation.



Level III

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ADVANCED RELIABILITY AND PERFORMANCE CONCEPTS, **ASSESSMENT LEVEL III: ÖNORM B 4008-2:2025**

➢ ÖNORM B 4008-2

Current version
Date of issue: 2025-12-01
Assessment of the load-bearing capacity of existing structures – Part 2: Bridge construction

This Austrian standard regulates the most realistic possible assessment of the load-bearing capacity of existing bridge structures. A reassessment of the load-bearing capacity may be required in cases such as the detection of structural damage, prior to modifications or strengthening measures, after exceptional events, or when new findings arise that affect the load-bearing capacity.



ENTWURF

ÖNORM B 4008-2

Ausgabe: 2025-07-15

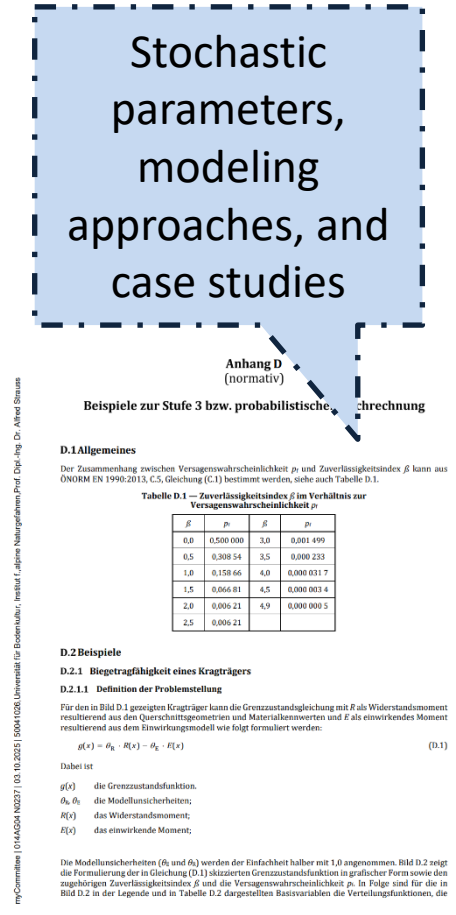
Bewertung der Tragfähigkeit bestehender Tragwerke

Teil 2: Brückenbau

Assessment of load capacity of existing structures — Part 2: Bridge construction

Evaluation de la capacité des structures existantes — Partie 2: Construction des ponts

Limit state functions are defined for standard verification procedures.



Stochastic parameters, modeling approaches, and case studies

Anhang D
(normativ)

Beispiele zur Stufe 3 bzw. probabilistische Nachrechnung

D.1 Allgemeines

Tabelle D.1 — Zuverlässigkeitsindex β im Verhältnis zur Versagenswahrscheinlichkeit p_f

β	p_f	β	p_f
0,0	0,500 000	3,0	0,001 499
0,5	0,308 54	3,5	0,000 233
1,0	0,158 66	4,0	0,000 031 7
1,5	0,066 81	4,5	0,000 003 4
2,0	0,006 21	4,9	0,000 000 5
2,5	0,006 21		

D.2 Beispiele

D.2.1 Biegetragfähigkeit eines Kragträgers

D.2.1.1 Definition der Problemstellung

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WEBPAGE

Webpage Link: https://irec.boku.ac.at/



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1st IREC WORKSHOP

Reliability-based assessment concepts
FReET–Excel Interface

OUTLINE

- Introduction/motivation
- Uncertainty simulation – LHS
- Statistical correlation – simulated annealing
- FReET software – statistical, sensitivity, reliability analyses
- FReET – MS Excel interface
- Conclusions



MOTIVATION

- Uncertainties are involved in every part of the system Structure – Load – Environment, probabilistic assessment of engineering systems
- Random response Z is a function of basic random variables (or random fields) **X**:

$$Z = g(\mathbf{X})$$

where function g(**X**) represents a computational model

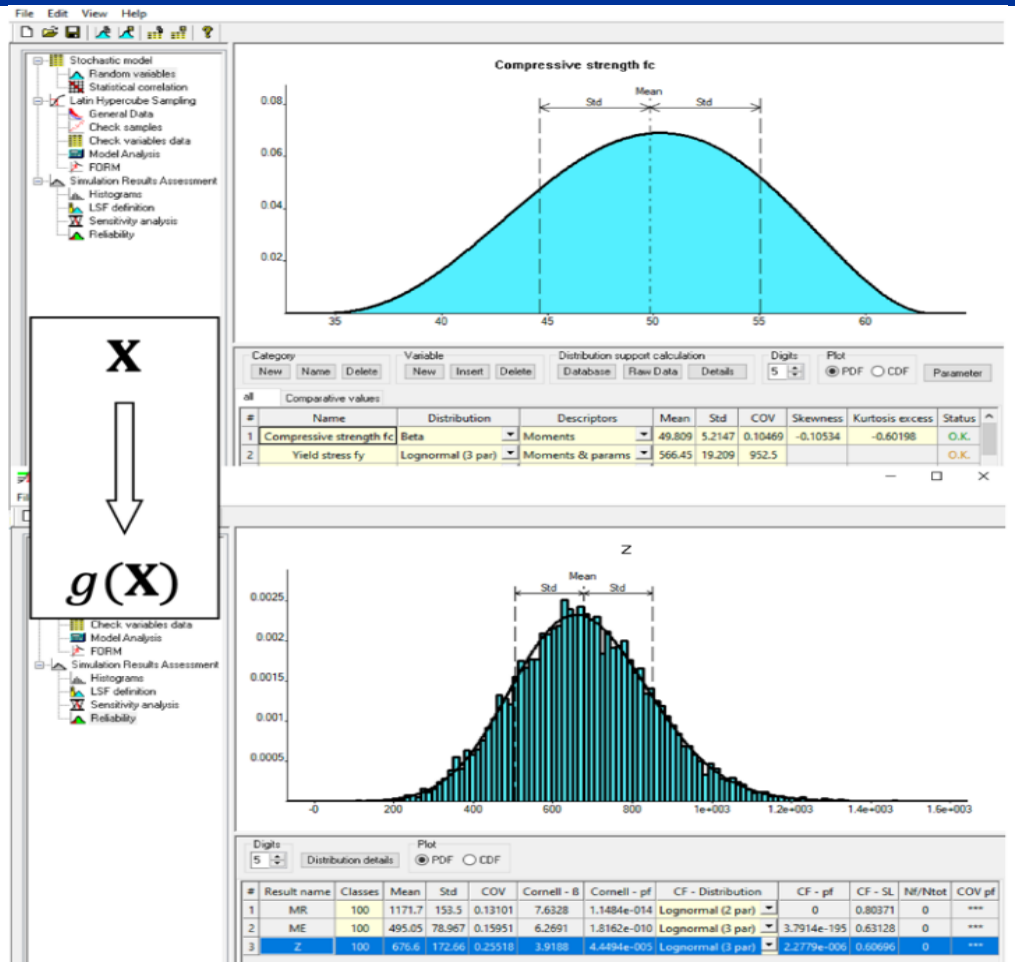
Statistical analysis
Reliability analysis
Sensitivity analysis

$$\mu_g = \int g(\mathbf{X})\, f_{\mathrm{x}}(\mathbf{X})\, \mathrm{d}\mathbf{X}$$

$$p_f = \mathrm{P}(Z \le 0)$$

- **Computationally intensive problems/nonlinear FEM**
- **Many relativelly simple problems of g(X) in MS Excel!**

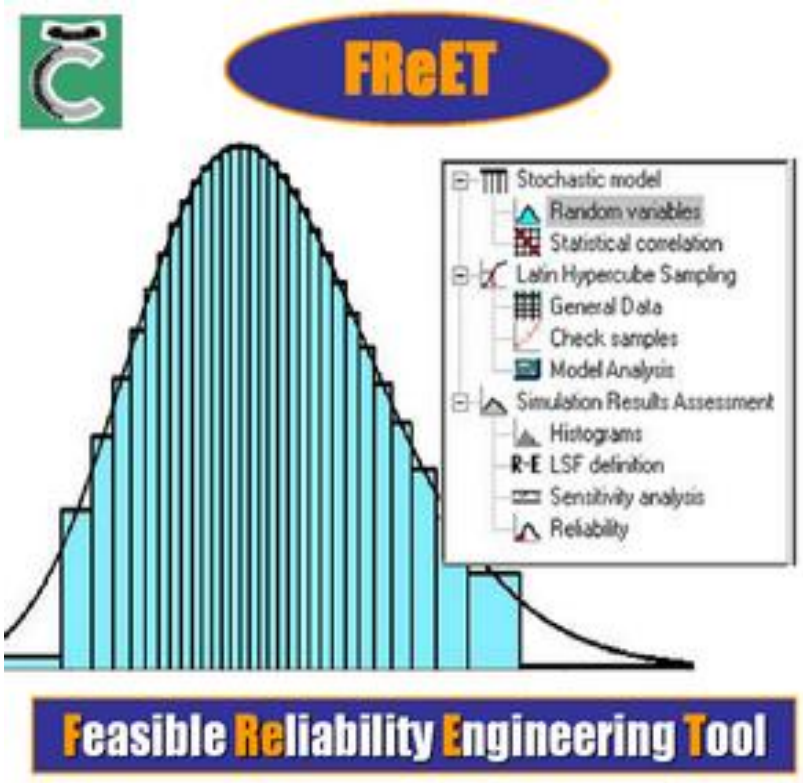
UNCERTAINTIES PROPAGATION



FReET SOFTWARE

Feasible Reliable Engineering Tool – FReET, version 1.7:

- 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.



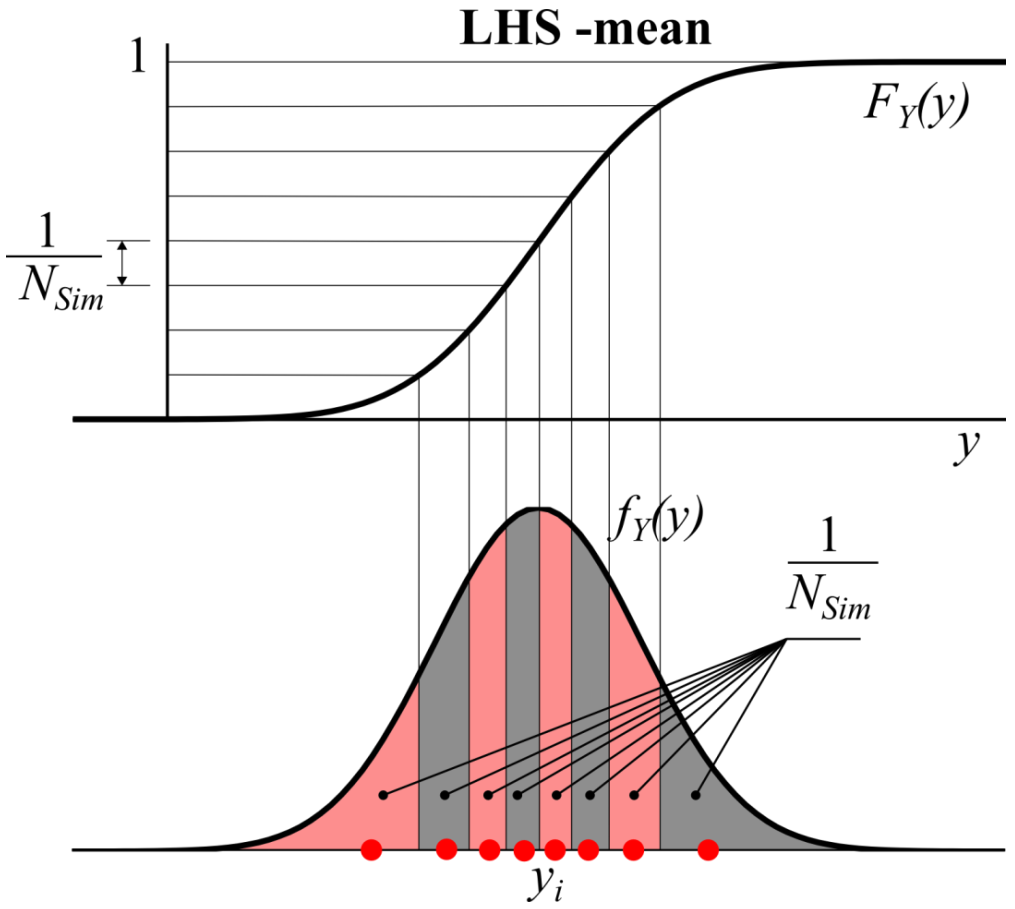
UNCERTAINTY SIMULATION
SMALL-SAMPLE SIMULATION OF MONTE CARLO TYPE

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

- 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

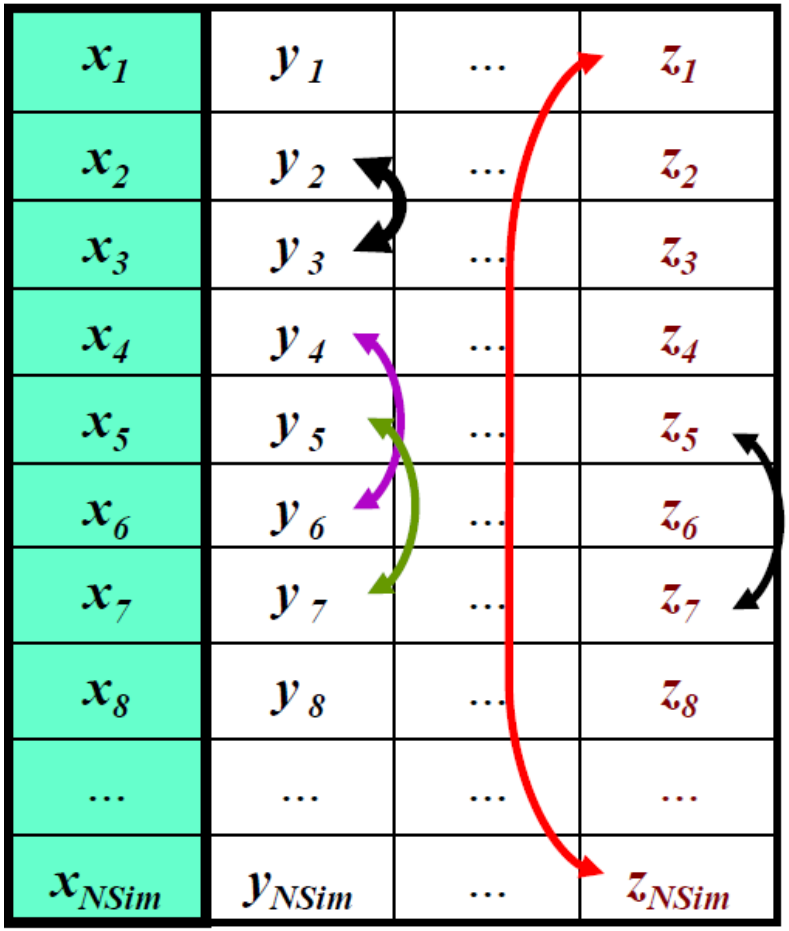
- Correlation matrices:
  - prescribed (target) – **T**
  - generated (actual) – **A**
- Difference matrix (error matrix): $\mathbf{E} = \mathbf{T} - \mathbf{A}$

⇩

- 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

⇩

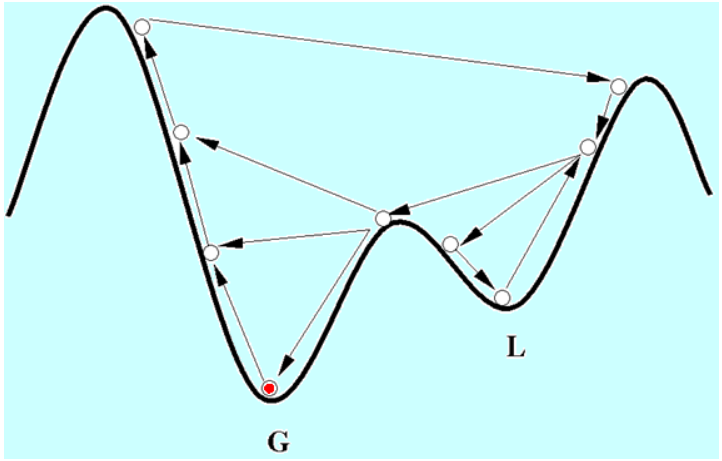
simulated annealing

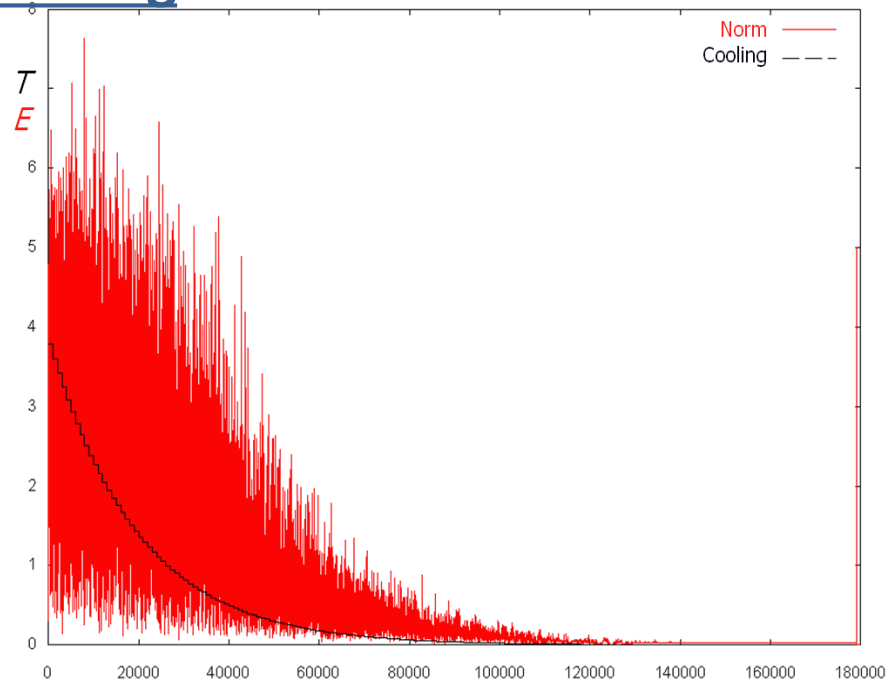


UNCERTAINTY SIMULATION
SMALL-SAMPLE SIMULATION OF THE MONTE CARLO TYPE

Imposing statistical correlation – simulated annealing

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

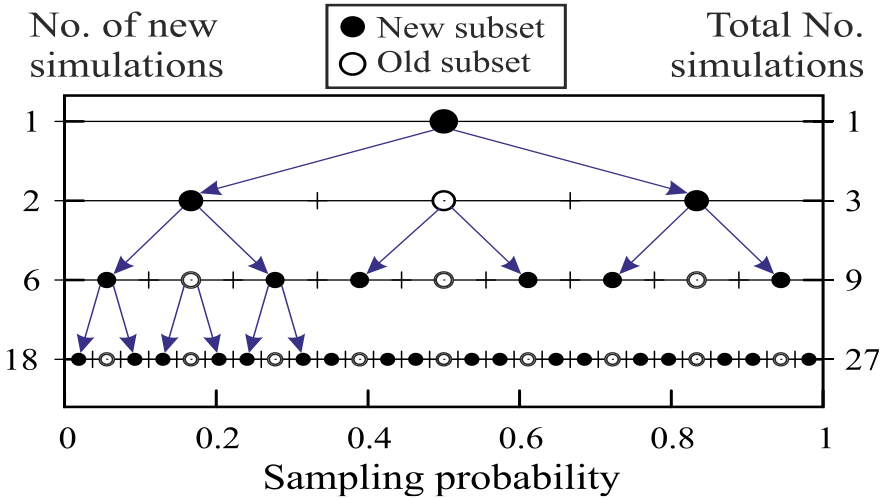




- Performs much better than other widely used algorithms for correlation control, e.g. both Iman and Conover's Cholesky decomposition and Owen's Gram-Schmidt orthogonalization.

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.

UNCERTAINTY SIMULATION
A SMALL-SAMPLE SIMULATION OF THE MONTE CARLO TYPE

Sensitivity analysis:

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

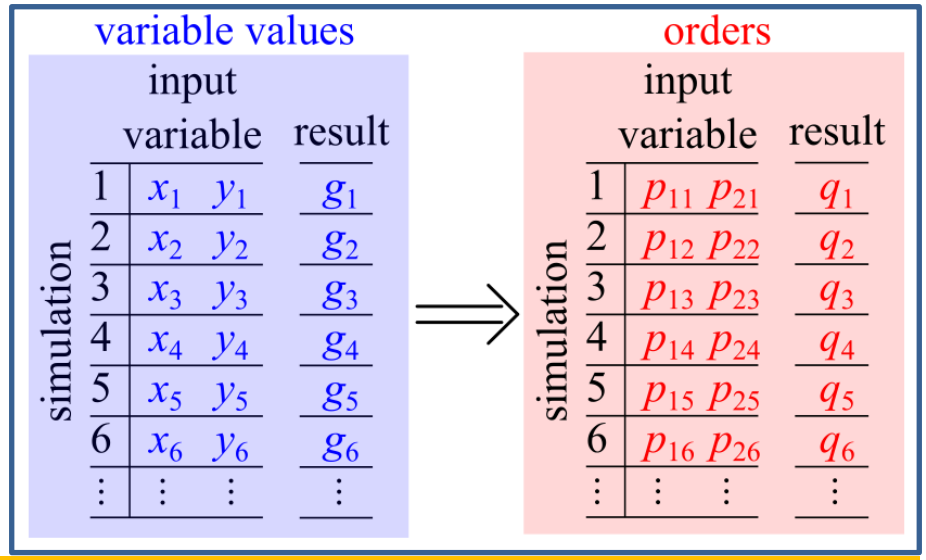
  Kendall tau:

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

  Spearman's coefficient of correlation:

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

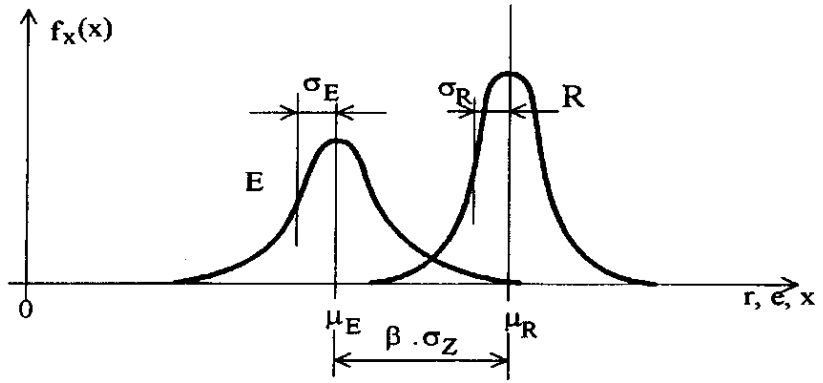
- Robust – uses only orders.
- Additional result of LHS simulation, no extra effort.
- Bigger correlation coefficient = high sensitivity.
- Relative measure of sensitivity (-1, 1).

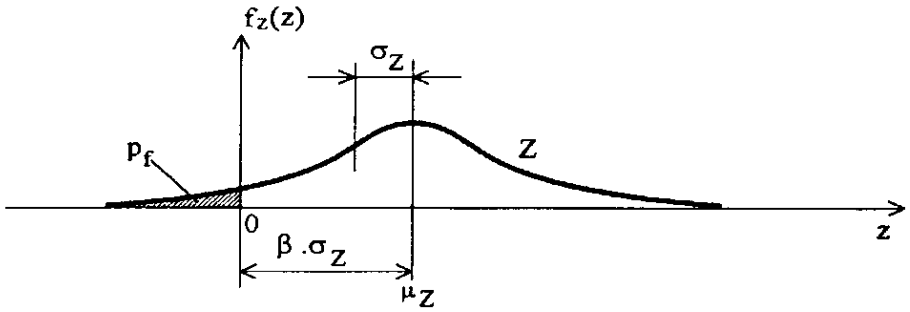


UNCERTAINTY SIMULATION
A SMALL-SAMPLE SIMULATION OF THE MONTE CARLO TYPE

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…

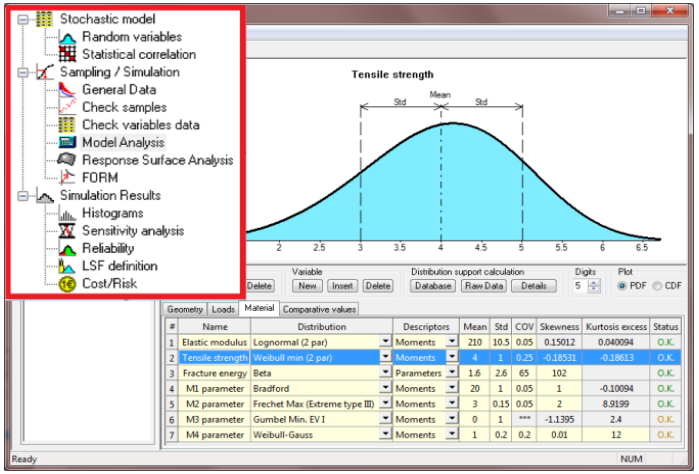


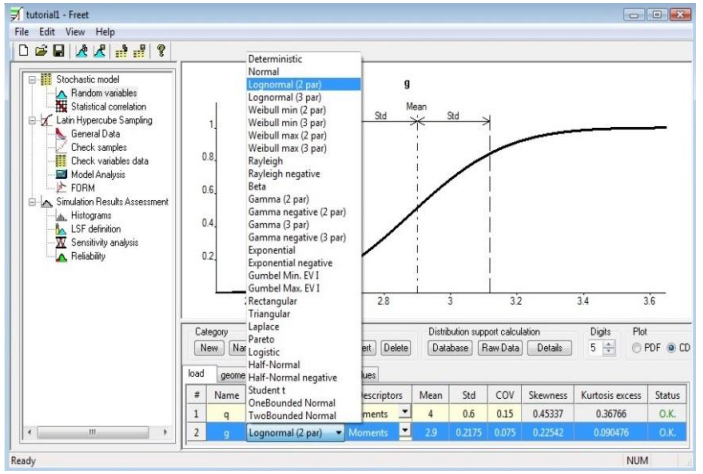


FReET SOFTWARE

„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.

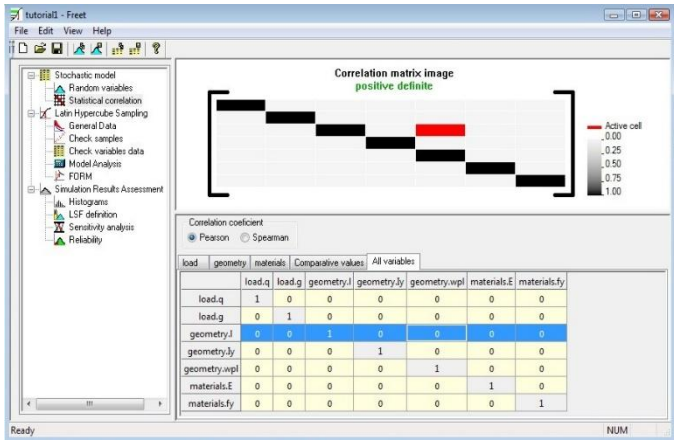




FReET SOFTWARE

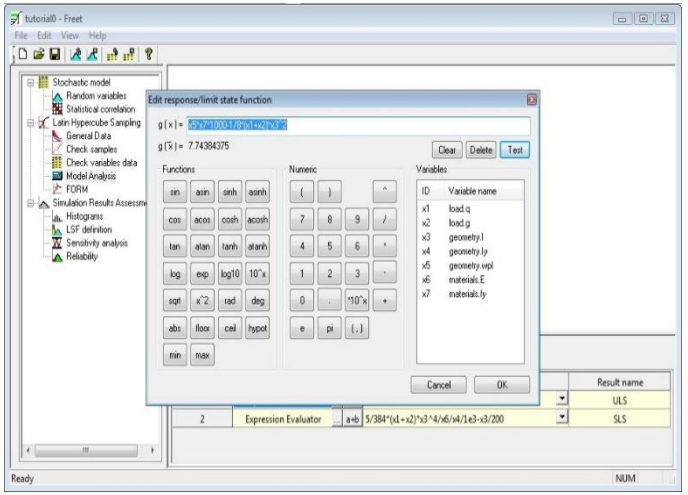
„Statistical correlation“ window:

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



„Limit state/response functions“ window:

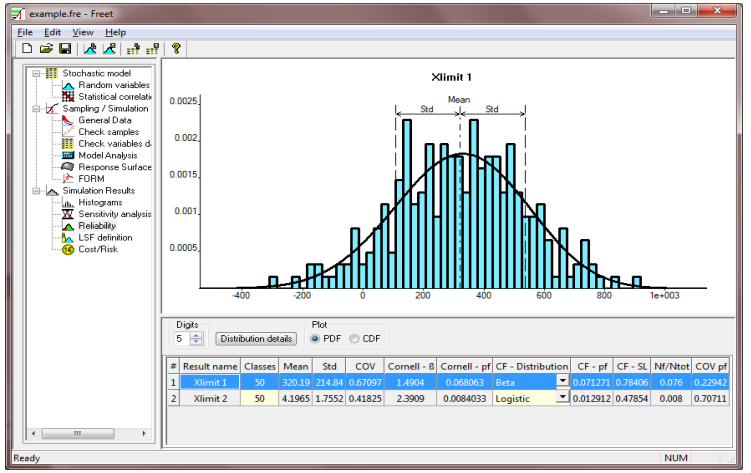
- closed form (direct), using the implemented Equation Editor (simple problems);
- numerical (indirect), using a user-defined DLL function that can be prepared in any language (C++, Fortran, Delphi, etc.);
- general interface to third-party software using user-defined *.BAT or *.EXE programs based on input and output text communication files;
- **NEW! Interface to MS - Excel**
- multiple response functions assessed in the same simulation run.



FReET SOFTWARE

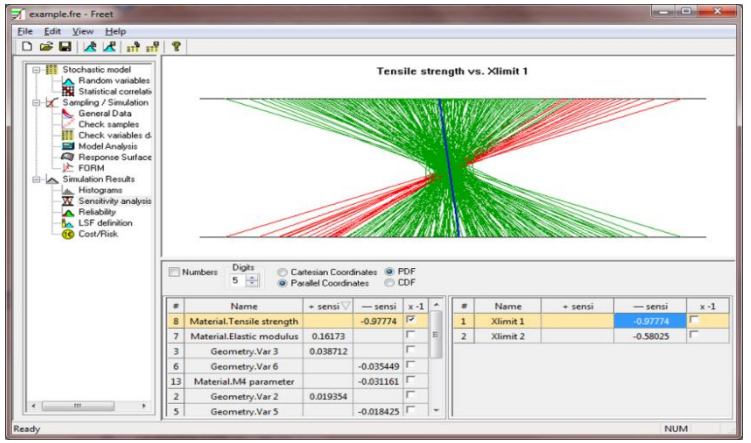
„Reliability“ window:

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



Probabilistic techniques:

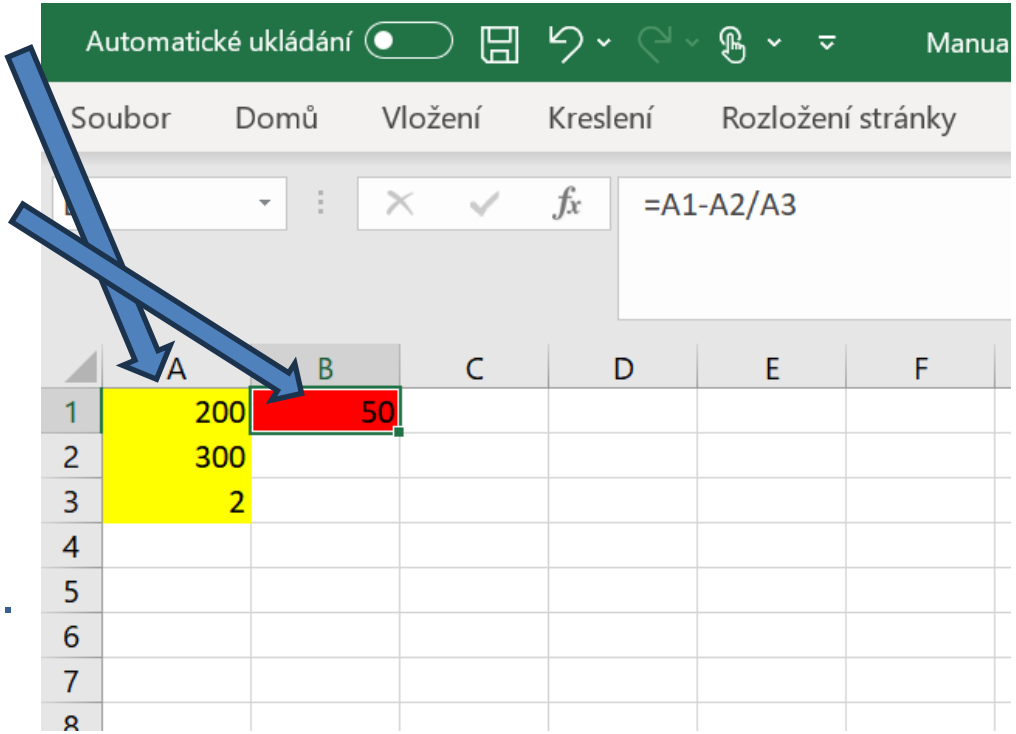
- crude Monte Carlo simulation;
- Latin Hypercube Sampling (3 alternatives);
- Hierarchical Latin Hypercube Sampling;
- First Order Reliability Method (FORM);
- Curve fitting;
- Simulated Annealing employed for correlation control over inputs;
- Bayesian updating;



1st IREC Workshop

CONCEPT OF FReET – MS Excel INTERFACE

- Random realizations of basic random variables – column A
- Result of limitstate/response function in cell B1
- 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 is allowed.



EXAMPLE OF EN SHEAR STRENGTH MODEL IN MS Excel SHEET

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 t	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

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

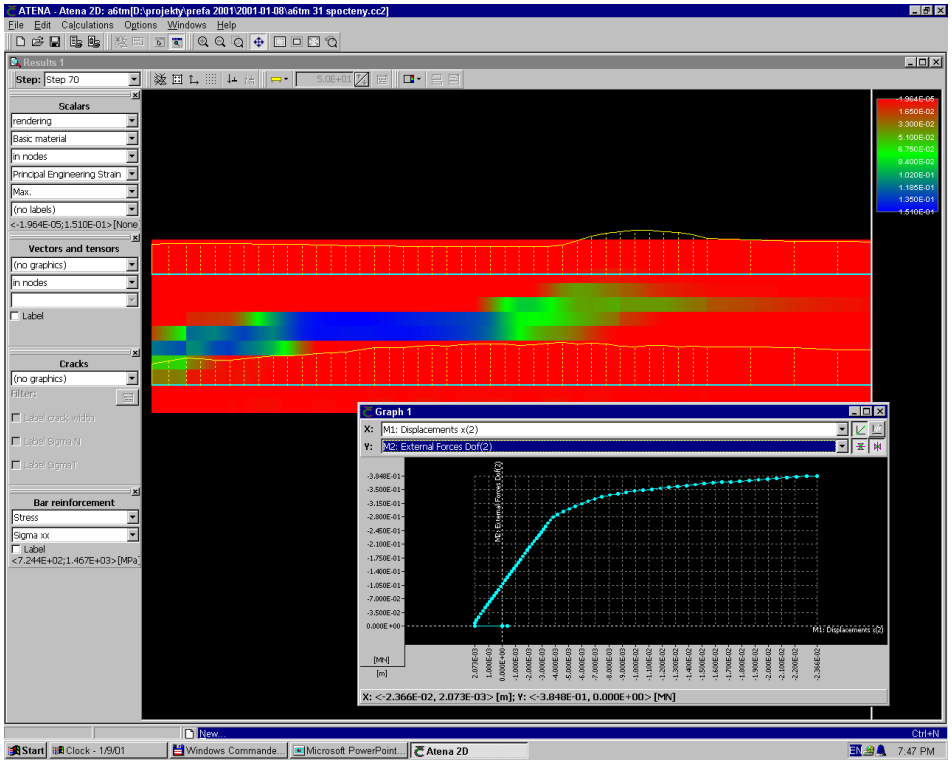
FReET-D MODULE

Feasible Reliable Engineering Tool for Degradation – FReET–D:

- module of the software FReET;
- combination of analytical models and simulation techniques for assessing the potential degradation of newly designed as well as existing concrete structures;
- models for carbonation, chloride ingress, reinforcement corrosion, sulphide, acid and frost attack;
- can serve for design or performance-based specification.



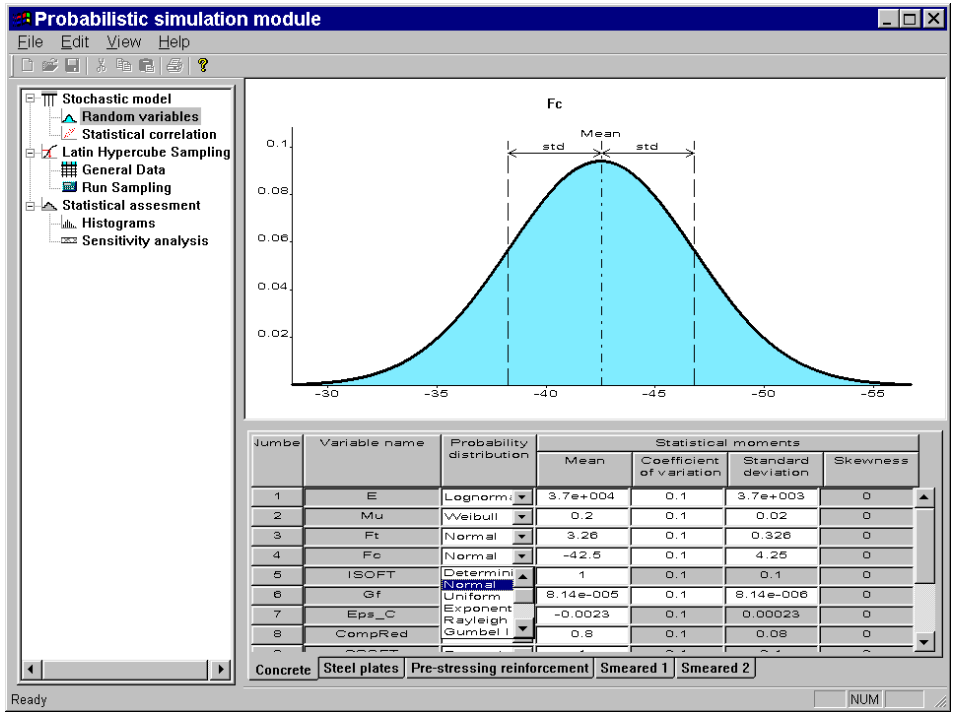
SARA SOFTWARE



nonlinear fracture mechanics software ATENA

+

probabilistic software FReET



CONCLUSIONS

- efficient techniques of employing stochastic simulation methods were combined in FReET software
- an advanced tool for the probabilistic assessment of user-defined problems;
- FReET-D = degradation models implemented, durability limit states;
- SARA = complex integration of probabilistic engine (FReET) and nonlinear FEM (ATENA).
- Already hundreds applications/users worldwide

- A new interface of FreET software to MS Excel represents a user-friendly alternative for “making reliability analysis easy”.

CONCLUSIONS

Thank you for your attention!

www.freet.cz



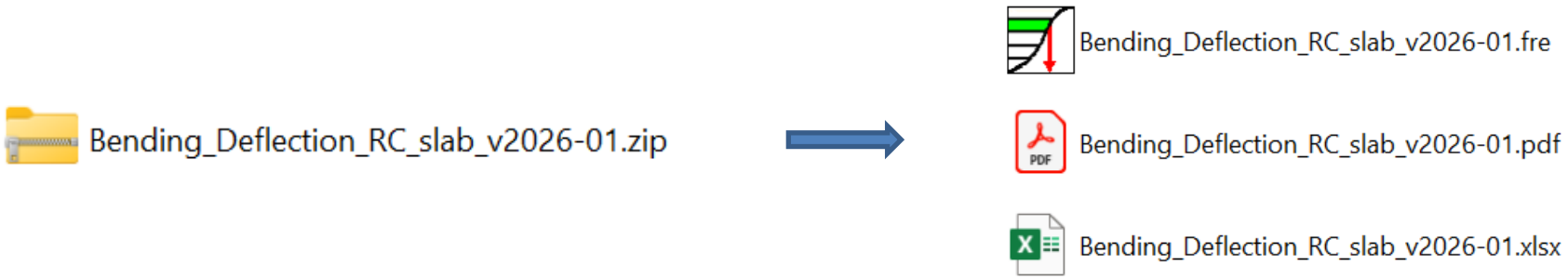
1st IREC WORKSHOP

IREC Template Manual
How to use Excel–FReET Templates

Co-funded by the European Regional Development Fund

INTRODUCTION

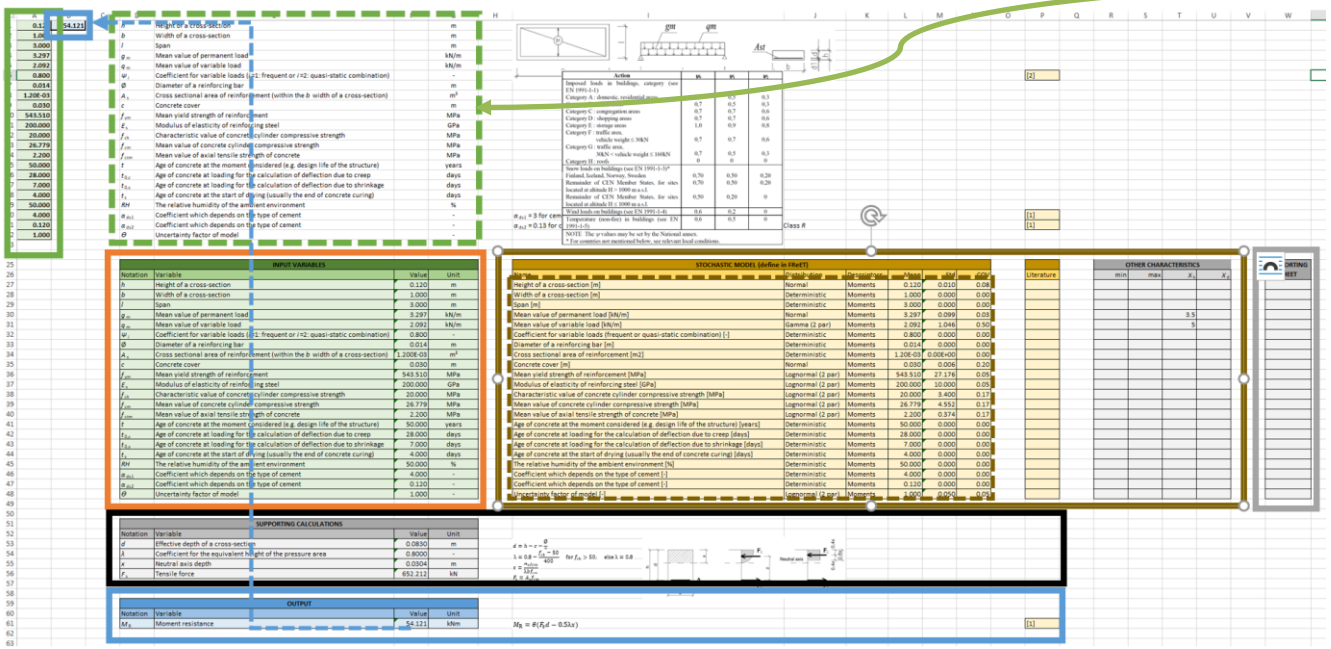
- For each problem solved, three documents are available:
  - 'File_name_vyyyy-mm**.xlsx**' – an **Excel file** with pre-programmed calculations;
  - 'File_name_vyyyy-mm**.fre**' – a **FReET file** for calculations based on the stochastic model;
  - 'File_name_Example_vyyyy-mm**.pdf**' – an **example file** with a detailed description of the solution to a specific example.



- With regard to possible further developments and updates to the templates, '**v**yyyy-mm' in the file name indicates the version of the template, i.e. the year and month of its update.

Excel TEMPLATE DESCRIPTION

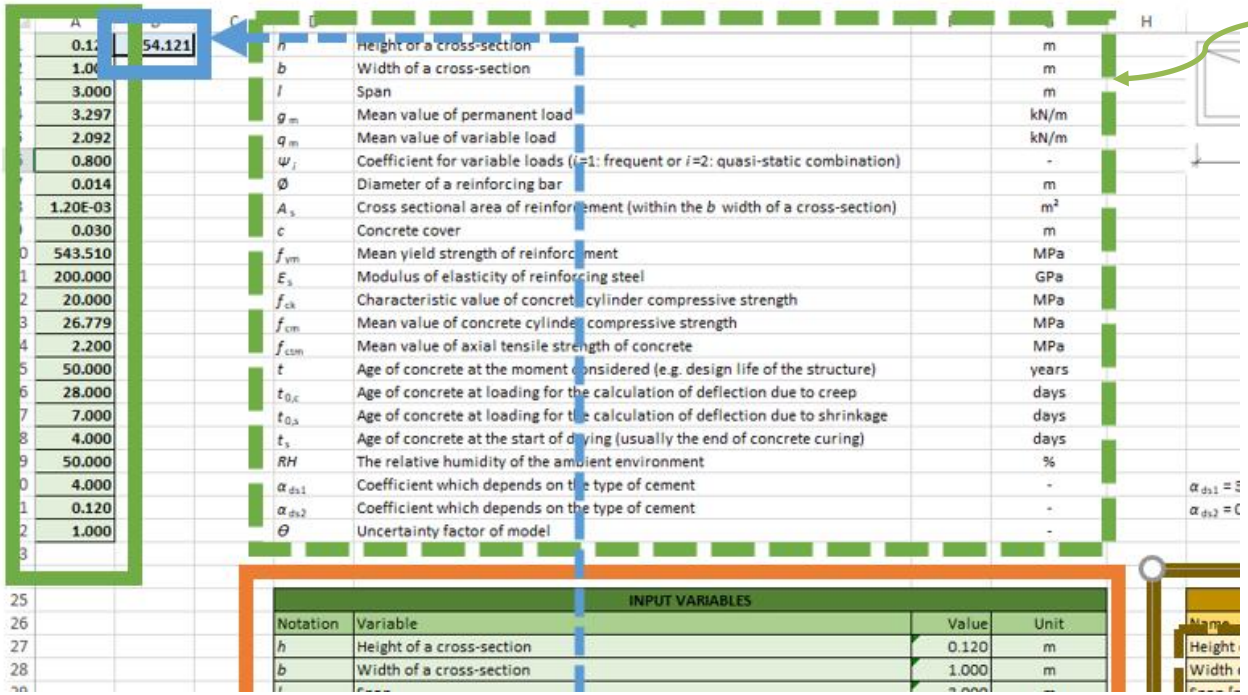
- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



➢ Input parameters for the calculation

Excel TEMPLATE DESCRIPTION

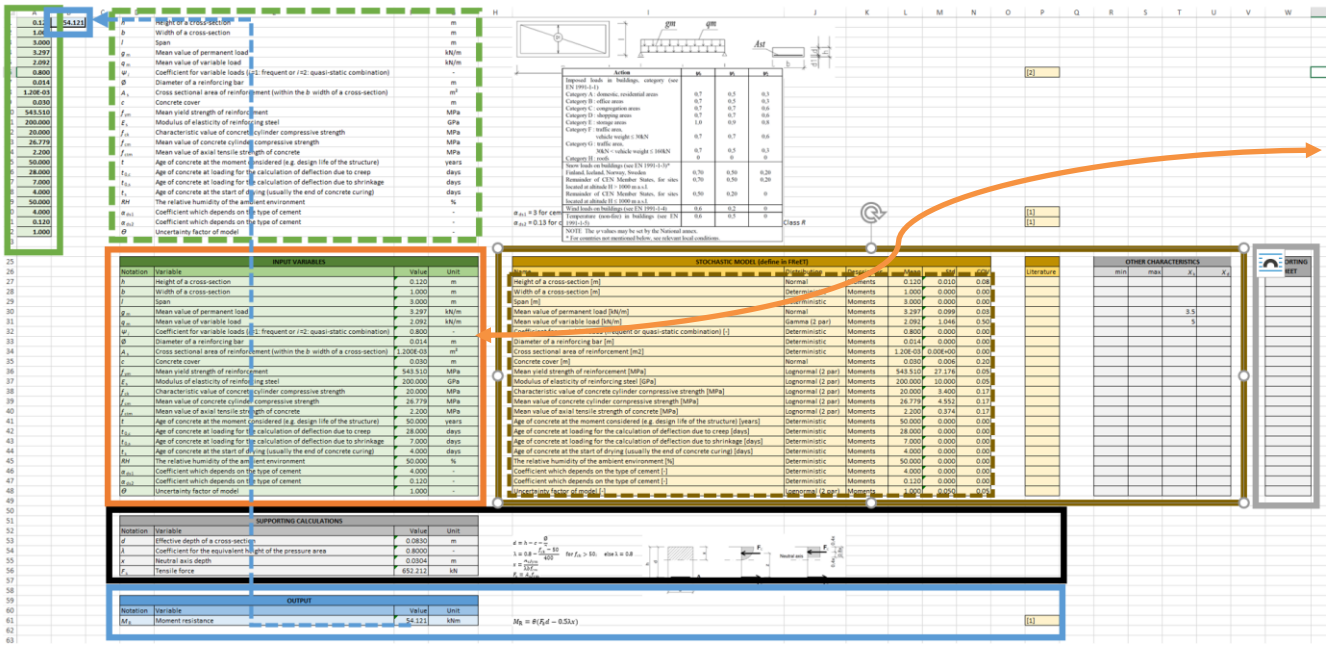
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➢ Input parameters for the calculation

Excel TEMPLATE DESCRIPTION

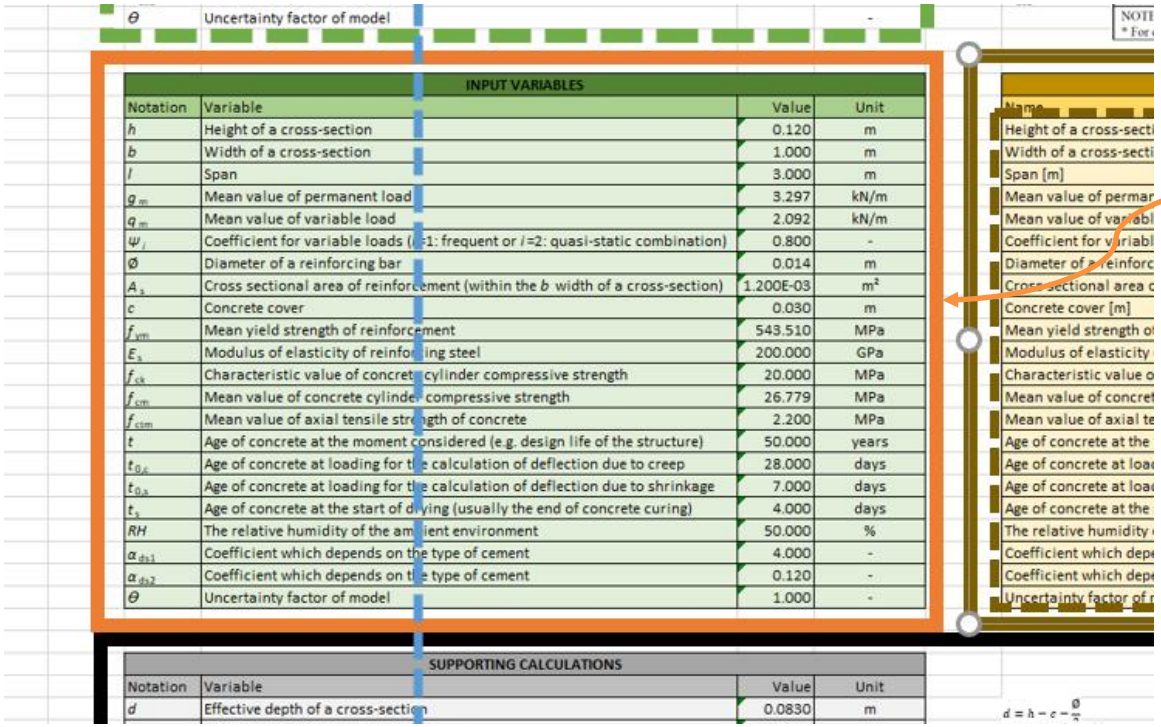
- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition

Excel TEMPLATE DESCRIPTION

- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



	Uncertainty factor of model		-

INPUT VARIABLES

Notation	Variable	Value	Unit
h	Height of a cross-section	0.120	m
b	Width of a cross-section	1.000	m
l	Span	3.000	m
g_m	Mean value of permanent load	3.297	kN/m
q_m	Mean value of variable load	2.092	kN/m
ψ_i	Coefficient for variable loads (i=1: frequent or i=2: quasi-static combination)	0.800	-
Ø	Diameter of a reinforcing bar	0.014	m
A_s	Cross sectional area of reinforcement (within the b width of a cross-section)	1.200E-03	m²
c	Concrete cover	0.030	m
f_{ym}	Mean yield strength of reinforcement	543.510	MPa
E_s	Modulus of elasticity of reinforcing steel	200.000	GPa
f_{ck}	Characteristic value of concrete cylinder compressive strength	20.000	MPa
f_{cm}	Mean value of concrete cylinder compressive strength	26.779	MPa
f_{ctm}	Mean value of axial tensile strength of concrete	2.200	MPa
t	Age of concrete at the moment considered (e.g. design life of the structure)	50.000	years
$t_{0,c}$	Age of concrete at loading for the calculation of deflection due to creep	28.000	days
$t_{0,s}$	Age of concrete at loading for the calculation of deflection due to shrinkage	7.000	days
t_s	Age of concrete at the start of drying (usually the end of concrete curing)	4.000	days
RH	The relative humidity of the ambient environment	50.000	%
α_{ds1}	Coefficient which depends on the type of cement	4.000	-
α_{ds2}	Coefficient which depends on the type of cement	0.120	-
θ	Uncertainty factor of model	1.000	-

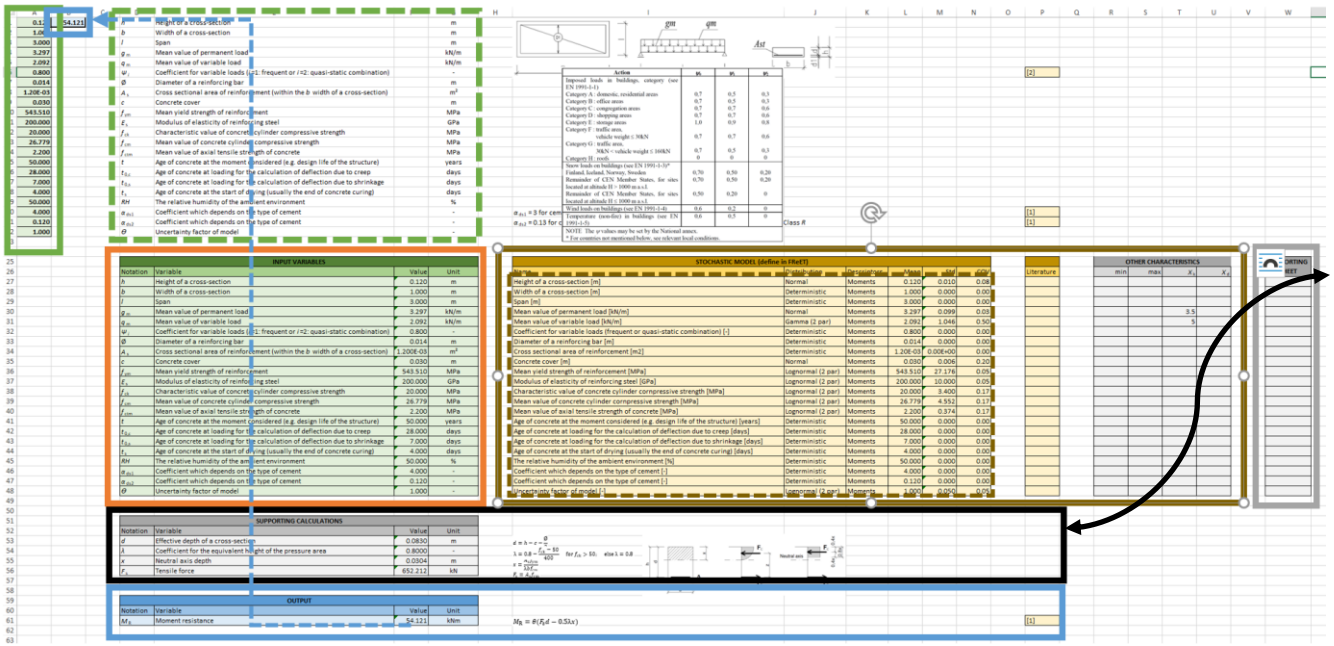
SUPPORTING CALCULATIONS

Notation	Variable	Value	Unit
d	Effective depth of a cross-section	0.0830	m

- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition

Excel TEMPLATE DESCRIPTION

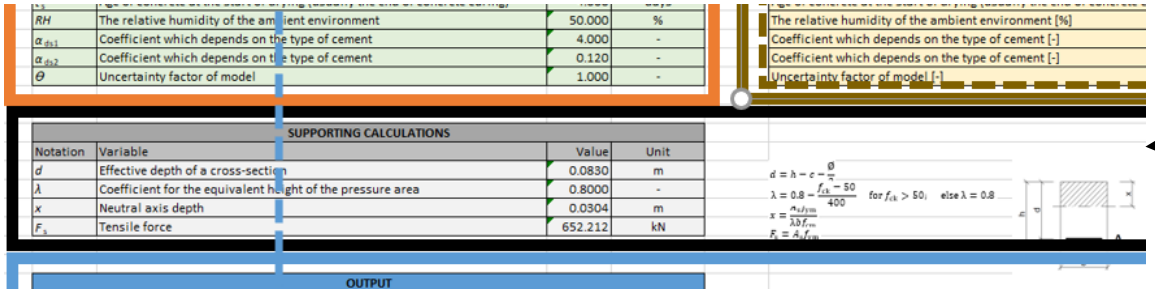
- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
- All the 'SUPPORTING CALCULATIONS'

Excel TEMPLATE DESCRIPTION

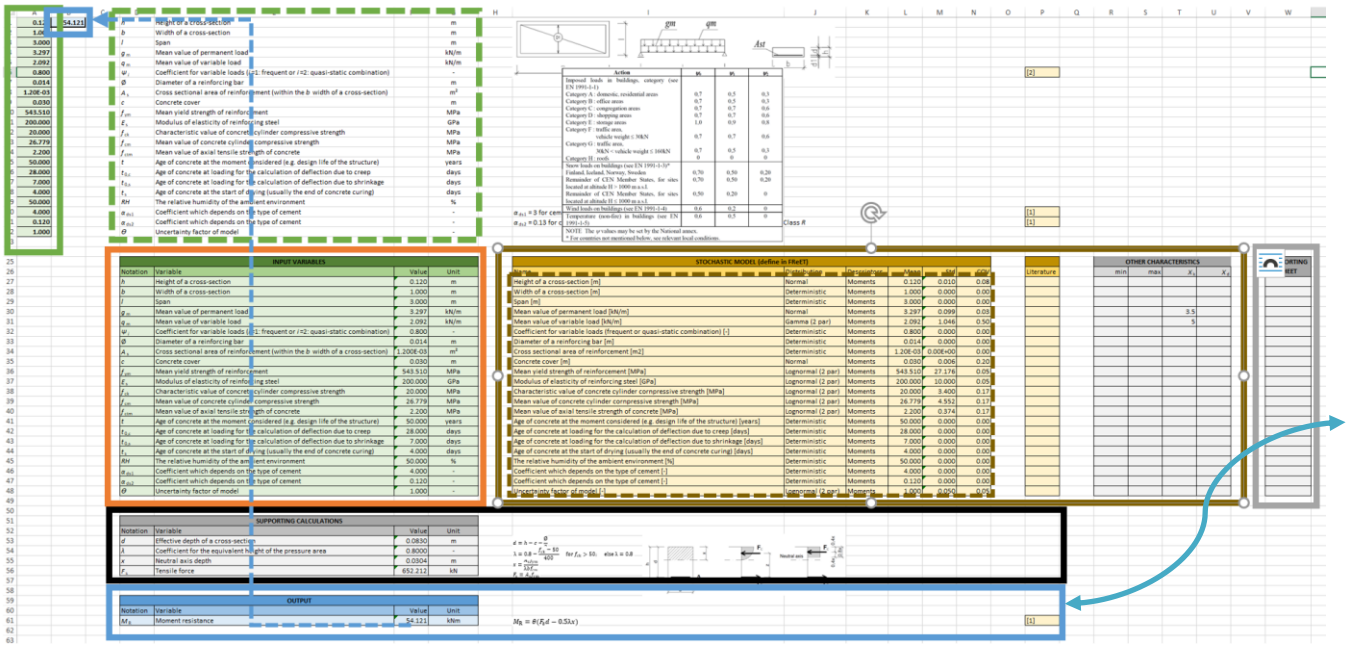
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- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
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Excel TEMPLATE DESCRIPTION

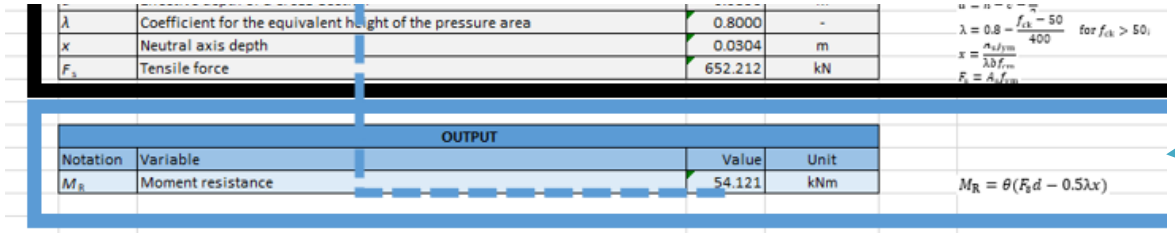
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- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
- All the 'SUPPORTING CALCULATIONS'
- Table of 'OUTPUT'

Excel TEMPLATE DESCRIPTION

- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



λ	Coefficient for the equivalent height of the pressure area	0.8000	-
x	Neutral axis depth	0.0304	m
F_s	Tensile force	652.212	kN

$\lambda = 0.8 - \frac{f_{ck} - 50}{400}$ for $f_{ck} > 50$,

$x = \frac{\sigma_{sd,ys} A_s}{\lambda b f_{cm}}$

$F_s = \sigma_{sd,ys} A_s$

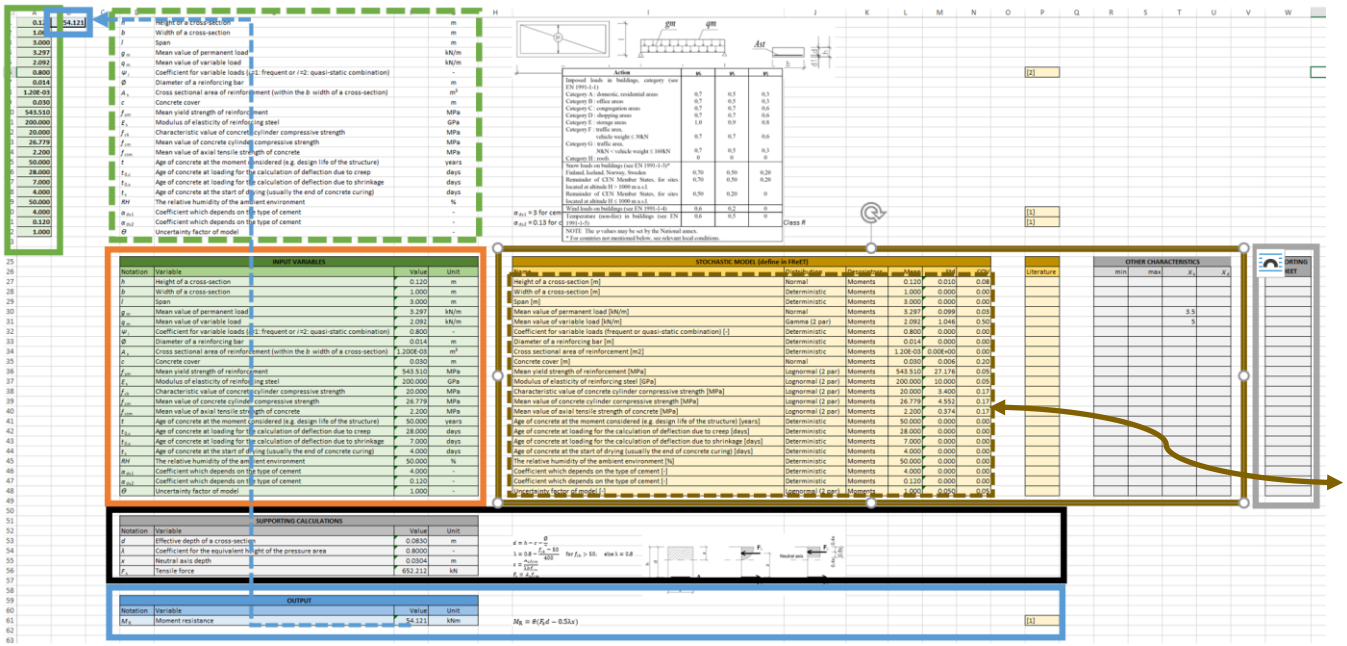
OUTPUT			
Notation	Variable	Value	Unit
M_R	Moment resistance	54.121	kNm

$M_R = \theta(F_s d - 0.5\lambda x)$

- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
- All the 'SUPPORTING CALCULATIONS'
- Table of 'OUTPUT'

Excel TEMPLATE DESCRIPTION

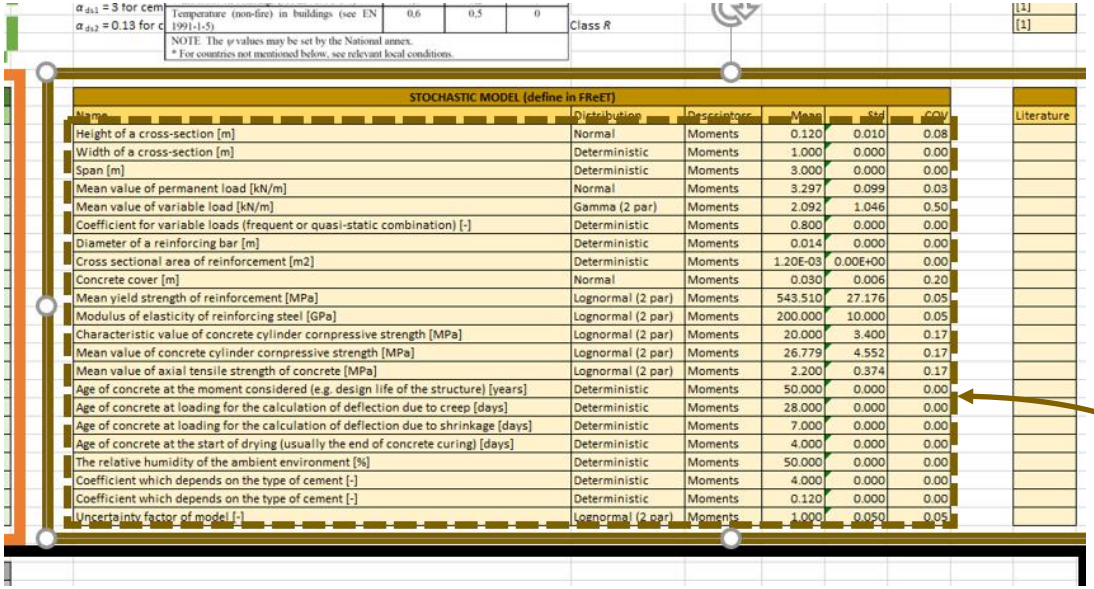
- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
- All the 'SUPPORTING CALCULATIONS'
- Table of 'OUTPUT'
- Basic 'STOCHASTIC MODEL' (can be copied directly into the .fre file)

Excel TEMPLATE DESCRIPTION

- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0	Class R	[1]

NOTE The ψ values may be set by the National annex.
* For countries not mentioned below, see relevant local conditions.

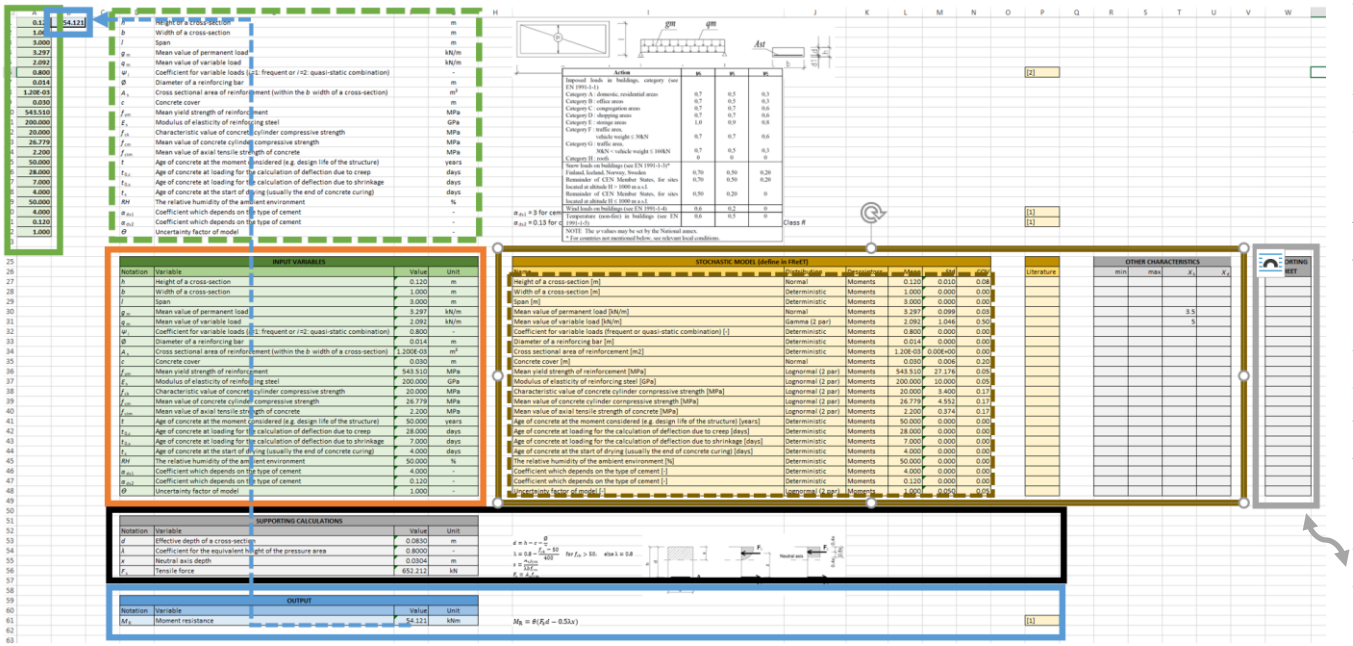
STOCHASTIC MODEL (define in FReET)

Name	Distribution	Descriptors	Mean	Std	COV	Literature
Height of a cross-section [m]	Normal	Moments	0.120	0.010	0.08	
Width of a cross-section [m]	Deterministic	Moments	1.000	0.000	0.00	
Span [m]	Deterministic	Moments	3.000	0.000	0.00	
Mean value of permanent load [kN/m]	Normal	Moments	3.297	0.099	0.03	
Mean value of variable load [kN/m]	Gamma (2 par)	Moments	2.092	1.046	0.50	
Coefficient for variable loads (frequent or quasi-static combination) [-]	Deterministic	Moments	0.800	0.000	0.00	
Diameter of a reinforcing bar [m]	Deterministic	Moments	0.014	0.000	0.00	
Cross sectional area of reinforcement [m2]	Deterministic	Moments	1.20E-03	0.00E+00	0.00	
Concrete cover [m]	Normal	Moments	0.030	0.006	0.20	
Mean yield strength of reinforcement [MPa]	Lognormal (2 par)	Moments	543.510	27.176	0.05	
Modulus of elasticity of reinforcing steel [GPa]	Lognormal (2 par)	Moments	200.000	10.000	0.05	
Characteristic value of concrete cylinder cornpressive strength [MPa]	Lognormal (2 par)	Moments	20.000	3.400	0.17	
Mean value of concrete cylinder cornpressive strength [MPa]	Lognormal (2 par)	Moments	26.779	4.552	0.17	
Mean value of axial tensile strength of concrete [MPa]	Lognormal (2 par)	Moments	2.200	0.374	0.17	
Age of concrete at the moment considered (e.g. design life of the structure) [years]	Deterministic	Moments	50.000	0.000	0.00	
Age of concrete at loading for the calculation of deflection due to creep [days]	Deterministic	Moments	28.000	0.000	0.00	
Age of concrete at loading for the calculation of deflection due to shrinkage [days]	Deterministic	Moments	7.000	0.000	0.00	
Age of concrete at the start of drying (usually the end of concrete curing) [days]	Deterministic	Moments	4.000	0.000	0.00	
The relative humidity of the ambient environment [%]	Deterministic	Moments	50.000	0.000	0.00	
Coefficient which depends on the type of cement [-]	Deterministic	Moments	4.000	0.000	0.00	
Coefficient which depends on the type of cement [-]	Deterministic	Moments	0.120	0.000	0.00	
Uncertainty factor of model [-]	Lognormal (2 par)	Moments	1.000	0.050	0.05	

- Input parameters for the calculation
- Table of ‘INPUT VARIABLES’ definition
- All the ‘SUPPORTING CALCULATIONS’
- Table of ‘OUTPUT’
- Basic ‘STOCHASTIC MODEL’ (can be copied directly into the .fre file)

Excel TEMPLATE DESCRIPTION

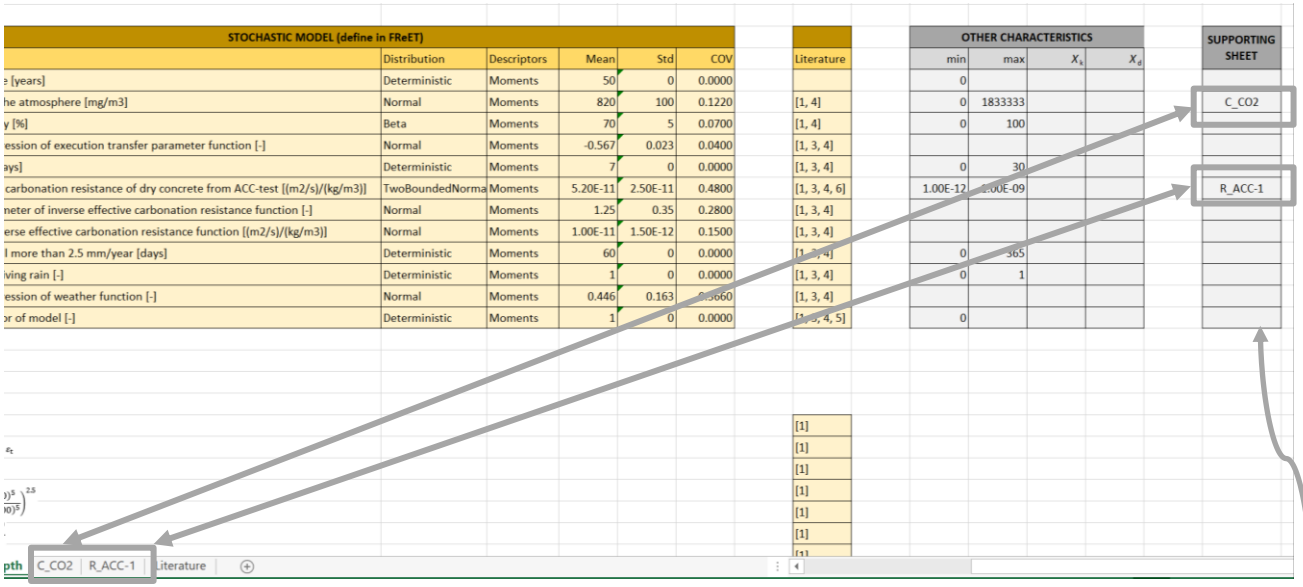
- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
- All the 'SUPPORTING CALCULATIONS'
- Table of 'OUTPUT'
- Basic 'STOCHASTIC MODEL' (can be copied directly into the .fre file)
- 'SUPPORTING SHEET' for an individual input

Excel TEMPLATE DESCRIPTION

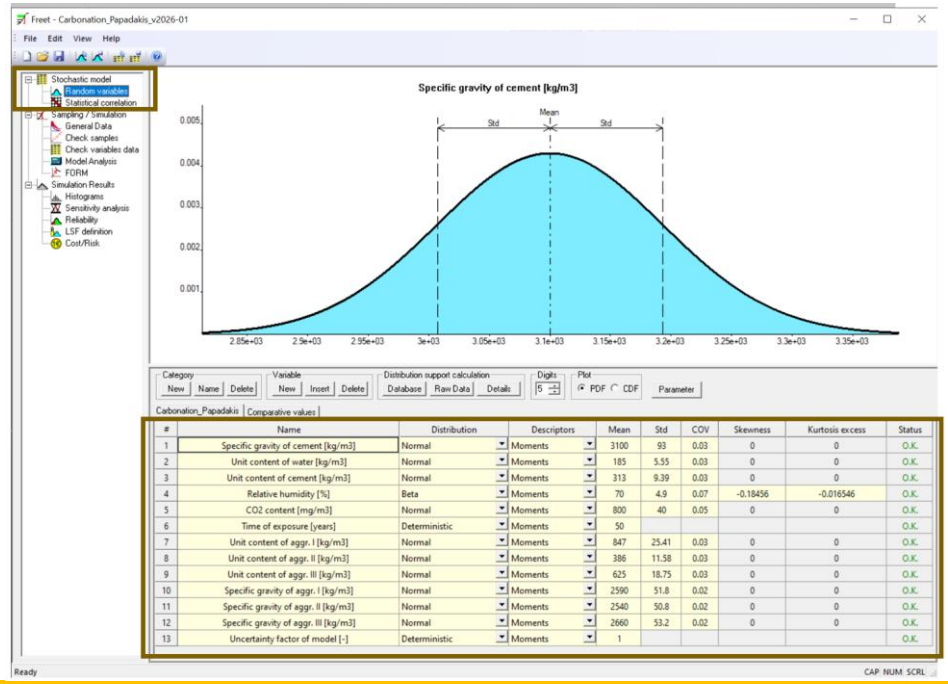
- Two or more sheets depending on the problem being solved
- All sheets with pre-prepared calculations have the following structure:



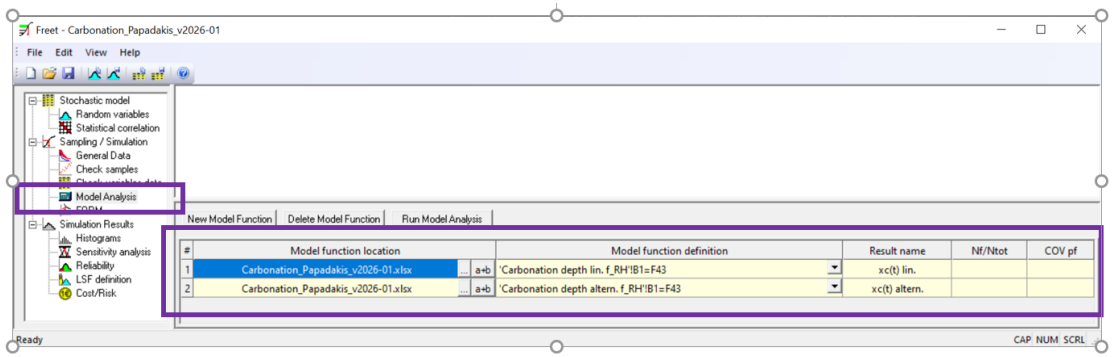
- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
- All the 'SUPPORTING CALCULATIONS'
- Table of 'OUTPUT'
- Basic 'STOCHASTIC MODEL' (can be copied directly into the .fre file)
- 'SUPPORTING SHEET' for an individual input

FReET TEMPLATE DESCRIPTION

- A basic stochastic model, corresponding to the one provided in the Excel template.
- The stochastic model can be modified according to user needs.

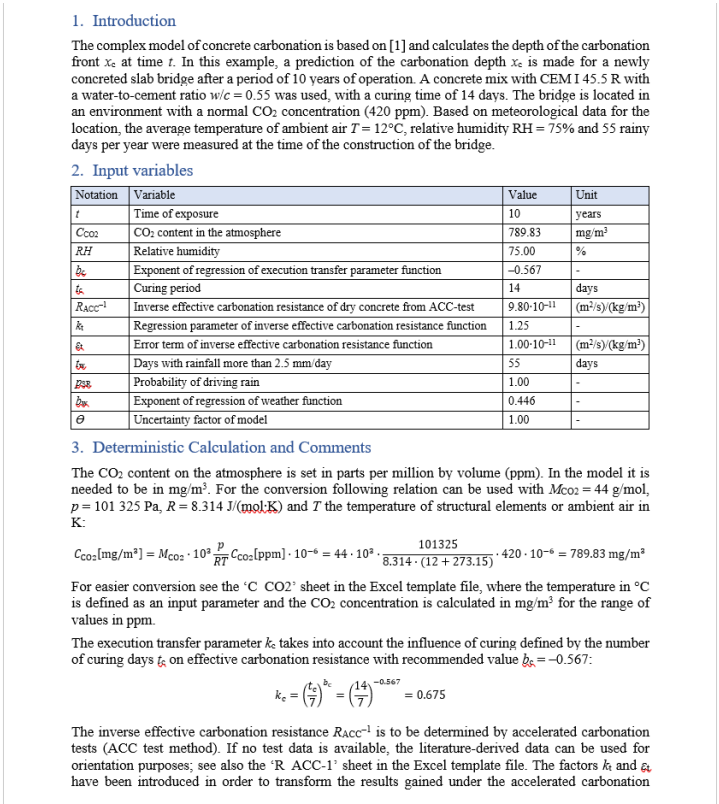


- The .xlsx file required for the calculation is loaded in the Model Analysis section.
- If the .xlsx file contains multiple calculation sheets, the corresponding number of analyses is prepared.



EXAMPLE DESCRIPTION

- A .pdf file containing a (so far deterministic) solution to a specific problem is prepared for each template.
- The documentation consists of a description of the specific problem, a table of input variables, a calculation section, and references.
- It is planned to extend the documentation with stochastic calculations and all necessary information and sources.



1. Introduction

The complex model of concrete carbonation is based on [1] and calculates the depth of the carbonation front x_c at time t. In this example, a prediction of the carbonation depth x_c is made for a newly concreted slab bridge after a period of 10 years of operation. A concrete mix with CEM I 45.5 R with a water-to-cement ratio $w/c = 0.55$ was used, with a curing time of 14 days. The bridge is located in an environment with a normal CO_2 concentration (420 ppm). Based on meteorological data for the location, the average temperature of ambient air $T = 12°C$, relative humidity RH = 75% and 55 rainy days per year were measured at the time of the construction of the bridge.

2. Input variables

Notation	Variable	Value	Unit
t	Time of exposure	10	years
C_{CO2}	CO_2 content in the atmosphere	789.83	mg/m³
RH	Relative humidity	75.00	%
b_c	Exponent of regression of execution transfer parameter function	–0.567	-
t_c	Curing period	14	days
R_{ACC}^{-1}	Inverse effective carbonation resistance of dry concrete from ACC-test	$9.80 \cdot 10^{-11}$	(m²/s)/(kg/m³)
k_t	Regression parameter of inverse effective carbonation resistance function	1.25	-
ε_t	Error term of inverse effective carbonation resistance function	$1.00 \cdot 10^{-11}$	(m²/s)/(kg/m³)
t_w	Days with rainfall more than 2.5 mm/day	55	days
p_{SR}	Probability of driving rain	1.00	-
b_w	Exponent of regression of weather function	0.446	-
Θ	Uncertainty factor of model	1.00	-

3. Deterministic Calculation and Comments

The CO_2 content on the atmosphere is set in parts per million by volume (ppm). In the model it is needed to be in mg/m³. For the conversion following relation can be used with $M_{CO2} = 44$ g/mol, $p = 101\,325$ Pa, $R = 8.314$ J/(mol·K) and T the temperature of structural elements or ambient air in K:

$$C_{CO2}[\text{mg/m}^3] = M_{CO2} \cdot 10^3 \frac{p}{RT} C_{CO2}[\text{ppm}] \cdot 10^{-6} = 44 \cdot 10^3 \cdot \frac{101325}{8.314 \cdot (12 + 273.15)} \cdot 420 \cdot 10^{-6} = 789.83 \text{ mg/m}^3$$

For easier conversion see the 'C CO2' sheet in the Excel template file, where the temperature in °C is defined as an input parameter and the CO_2 concentration is calculated in mg/m³ for the range of values in ppm.

The execution transfer parameter k_c takes into account the influence of curing defined by the number of curing days t_c on effective carbonation resistance with recommended value $b_c = -0.567$:

$$k_c = \left(\frac{t_c}{7}\right)^{b_c} = \left(\frac{14}{7}\right)^{-0.567} = 0.675$$

The inverse effective carbonation resistance R_{ACC}^{-1} is to be determined by accelerated carbonation tests (ACC test method). If no test data is available, the literature-derived data can be used for orientation purposes; see also the 'R ACC-1' sheet in the Excel template file. The factors k_t and ε_t have been introduced in order to transform the results gained under the accelerated carbonation

$$R_{NAC,0}^{-1} = k_t \cdot R_{ACC}^{-1} + \varepsilon_t = 1.25 \cdot 9.80 \cdot 10^{-11} + 1.00 \cdot 10^{-11} = 13.25 \cdot 10^{-11} \frac{\text{m}^2/\text{s}}{\text{kg/m}^3}$$

Time of wetness is the number of rainy days t_w per year (days with rainfall more than 2.5 mm/day):

$$ToW = \frac{t_w}{365} = \frac{55}{365} = 0.151 \text{ years}$$

The environmental function k_e considers the influence of relative humidity RH on the carbonation resistance of the concrete and is calculated as (with $RH_{ref} = 65\%$):

$$k_e = \left(\frac{1 - (RH/100)^5}{1 - (RH_{ref}/100)^5}\right)^{2.5} = \left(\frac{1 - (75/100)^5}{1 - (65/100)^5}\right)^{2.5} = 0.691$$

The exponent of weather function w is calculated as follows with the recommended value of the exponent $b_w = 0.446$:

$$w = \frac{(p_{SR} \cdot ToW)^{(b_w)}}{2} = \frac{(1.00 \cdot 0.151)^{0.446}}{2} = 0.215$$

Parameters p_{SR} and ToW take into account the rain events. A probability of driving rain p_{SR} is a constant parameter of the average distribution of the wind direction during rain events which be carried out by determining the wind direction during rain events, based on data from the nearest weather station. For interior structural elements $p_{SR} = 0$ and for horizontal elements subjected to rain events $p_{SR} = 1$.

The weather function $W(t)$ for a reference time t_0 is calculated as:

$$t_0 = \frac{28}{365} = 0.0767 \text{ years}$$

$$W(t) = \left(\frac{t_0}{t}\right)^w = \left(\frac{0.0767}{10}\right)^{0.215} = 0.351$$

The carbonation rate is calculated according to following formula with $R_{NAC,0}^{-1}$ being converted into (mm²/year)/(kg/m³):

$$A = \sqrt{2 \cdot 315.5 \cdot 10^{11} \cdot k_e \cdot k_c \cdot R_{NAC,0}^{-1} \cdot C_{CO2} \cdot 10^{-6}}$$
$$= \sqrt{2 \cdot 315.5 \cdot 10^{11} \cdot 0.691 \cdot 0.675 \cdot 13.25 \cdot 10^{-11} \cdot 789.83 \cdot 10^{-6}} = 1.76 \text{ mm/year}^{0.5}$$

Finally, including the model uncertainty factor ψ (recommended value $\Theta = 1$), the carbonation depth x_c in time t is calculated based on the formula:

$$x_c(t) = \theta \cdot A \cdot \sqrt{t} \cdot W(t) = 1.00 \cdot 1.76 \cdot \sqrt{10} \cdot 0.351 = 1.95 \text{ mm}$$

4. Literature

[1] fib – International Federation for Structural Concrete (2006) fib Bulletin 34: Model Code for Service Life Design. Lausanne, Switzerland.

THE LIST OF TEMPLATES BEING PROCESSED

- Bending and Deflection of RC slabs/beams
- Shear capacity of RC beams with and without stirrups (Eurocode)
- Shear force verification of RC slabs
- Crack width verification of RC beams
- Concrete Carbonation (Bob & Afana, fib Bulletin 34, Papadakis, Eurocode, Zambon model)
- Chloride transport model in cementitious materials
- Corrosion of Reinforcement (uniform, pitting corrosion)
- Reliability Analysis for Flexural Capacity of RC Bridge Slabs (JCSS Model Code Example)
- Reliability Analysis of RC Column in Multi Storey Frame (JCSS Model Code Example)
- Comparison of Bending Capacity of RC Beam According to Eurocode 2 and Model Code 2020 Considering Varying Reinforcement Ratios and Depths
- Verification of Load-Bearing Capacity of RC Columns (Eurocode, Model Code 2020)
- Comparative Design of Punching Shear Resistance in RC Slabs (Eurocode, Model Code 2020)

THE LIST OF TEMPLATES IN PREPARATION

- Design and Assessment of Concentrated Load Transfer in RC Structures with New-to-Old Concrete Interfaces (Jountal-Brücke)
- Assessment of Concrete Durability Using Gas Permeability Tests and Lifetime Prediction Models
- Fiber Optic Inclinometer System for Strain and 3D Displacement Monitoring in Engineering Structures
- Torsion
- Combination of tension/compression and bending

STANDARDISED Excel–FReET TEMPLATES

- In following section these standardised Excel–FReET templates will be introduced:

– Bending and deflection of RC slab according to Eurocode 2	BUT (Martina)
– Shear of RC beam according to EN 1992-1-1	BUT (Jakub)
– Concrete Carbonation	BOKU (Florian)
– Chloride ingress	BOKU (Benjamin)

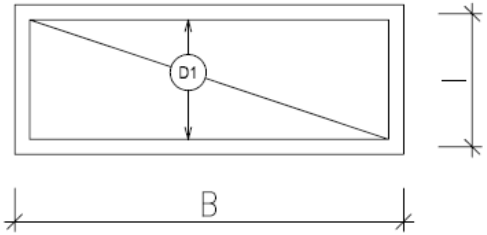
1st IREC WORKSHOP

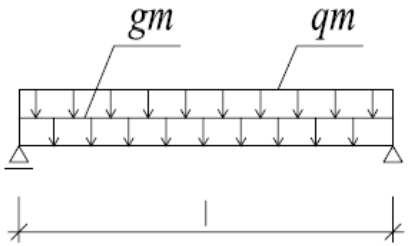
Bending and Deflection of RC slab – EN 1992-1-1

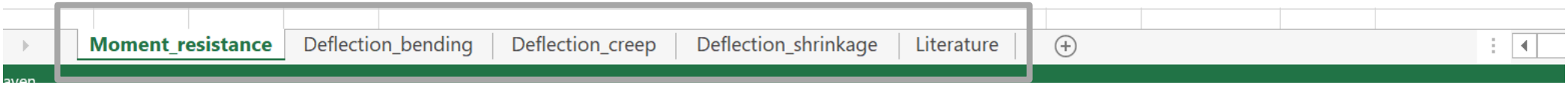
BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
INTRODUCTION

- The template covers the calculation of:
  - (1) Moment of resistance
  - (2) Deflection due to uniform continuous load
  - (3) Deflection with creep effect
  - (4) Deflection with shrinkage effect

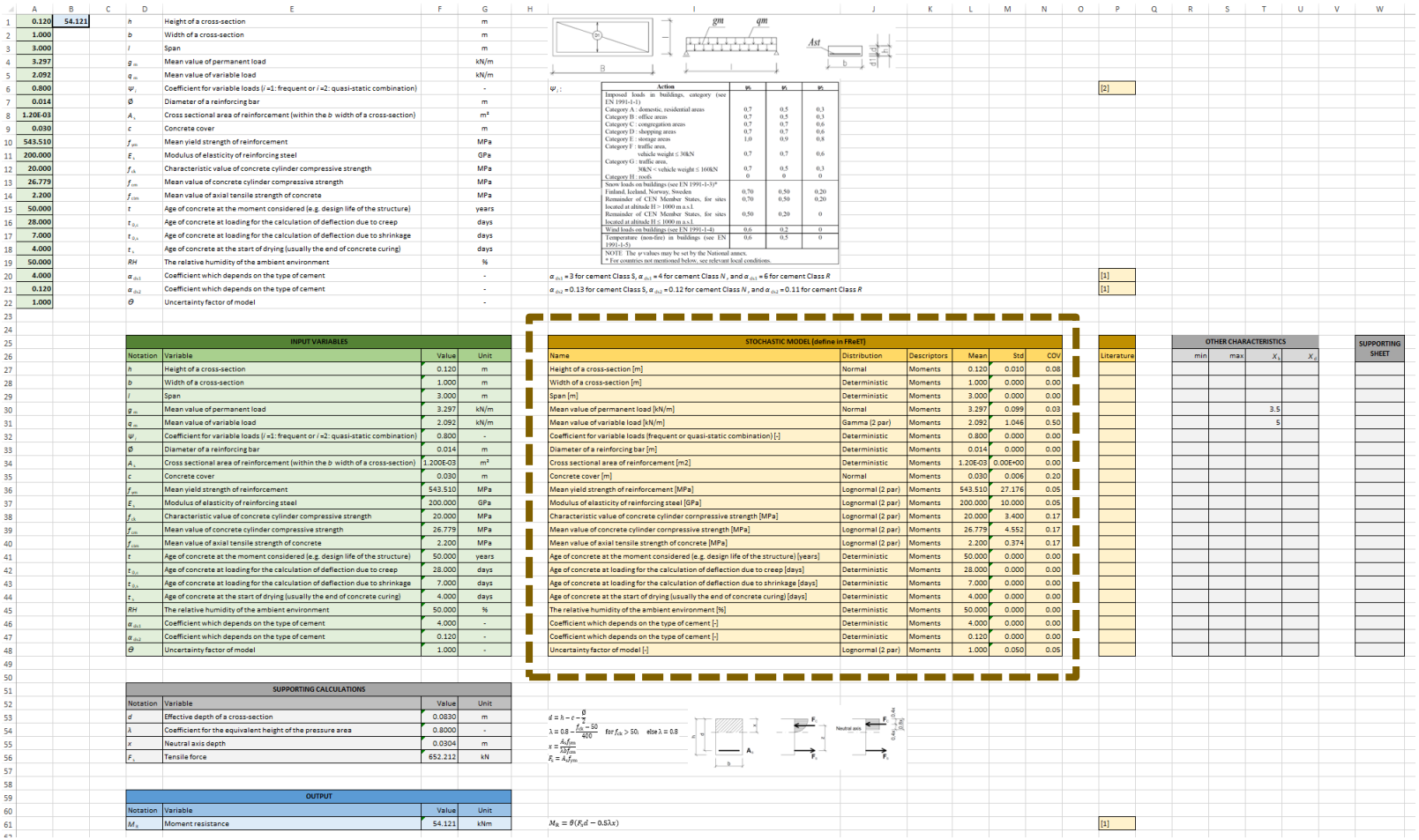
of RC slab of *B* and *l* dimensions







BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
Excel FILE

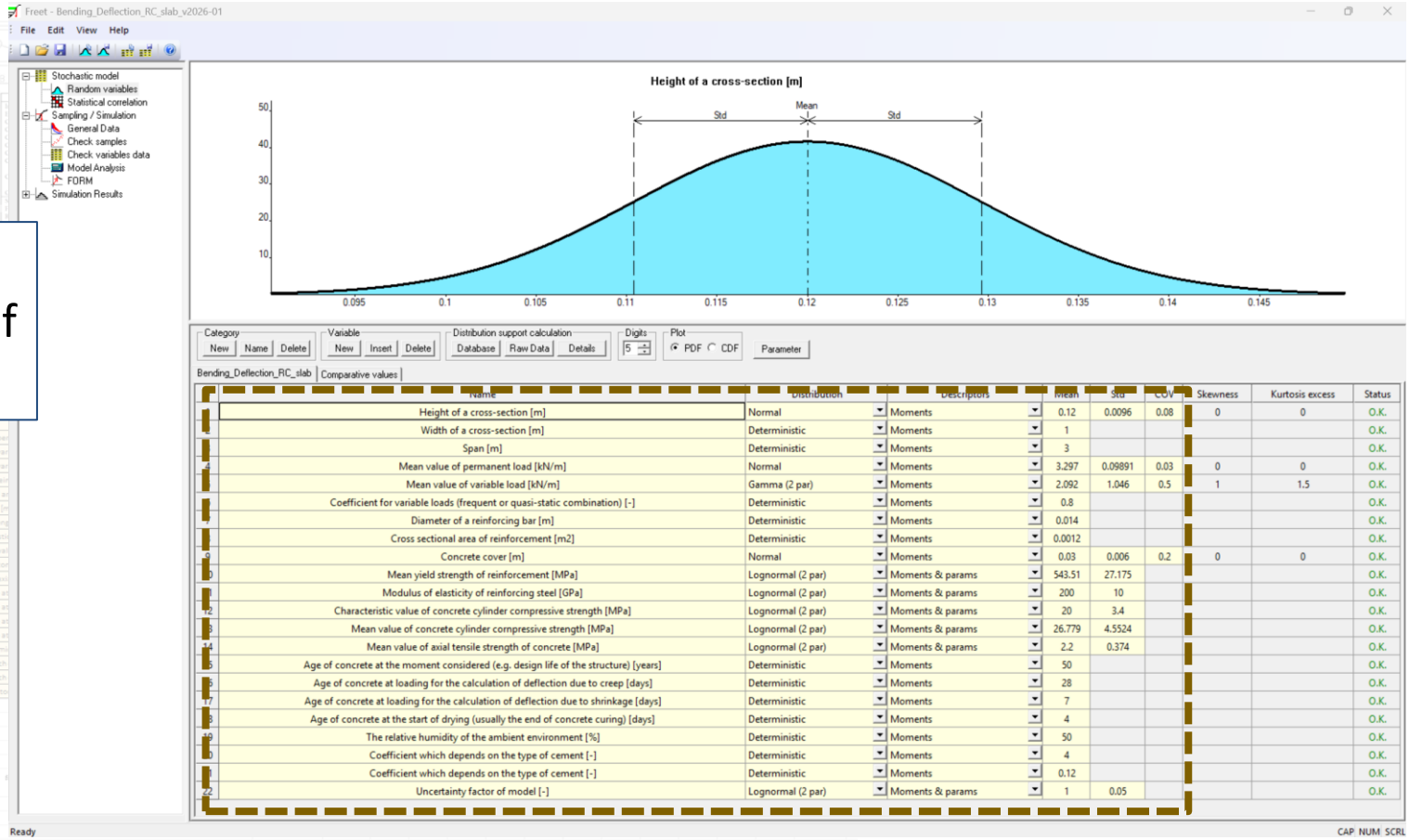


- Input parameters for the calculation
- Table of 'INPUT VARIABLES' definition
- All the 'SUPPORTING CALCULATIONS'
- Table of 'OUTPUT'
- Basic 'STOCHASTIC MODEL'
- 'SUPPORTING SHEET' for an individual input

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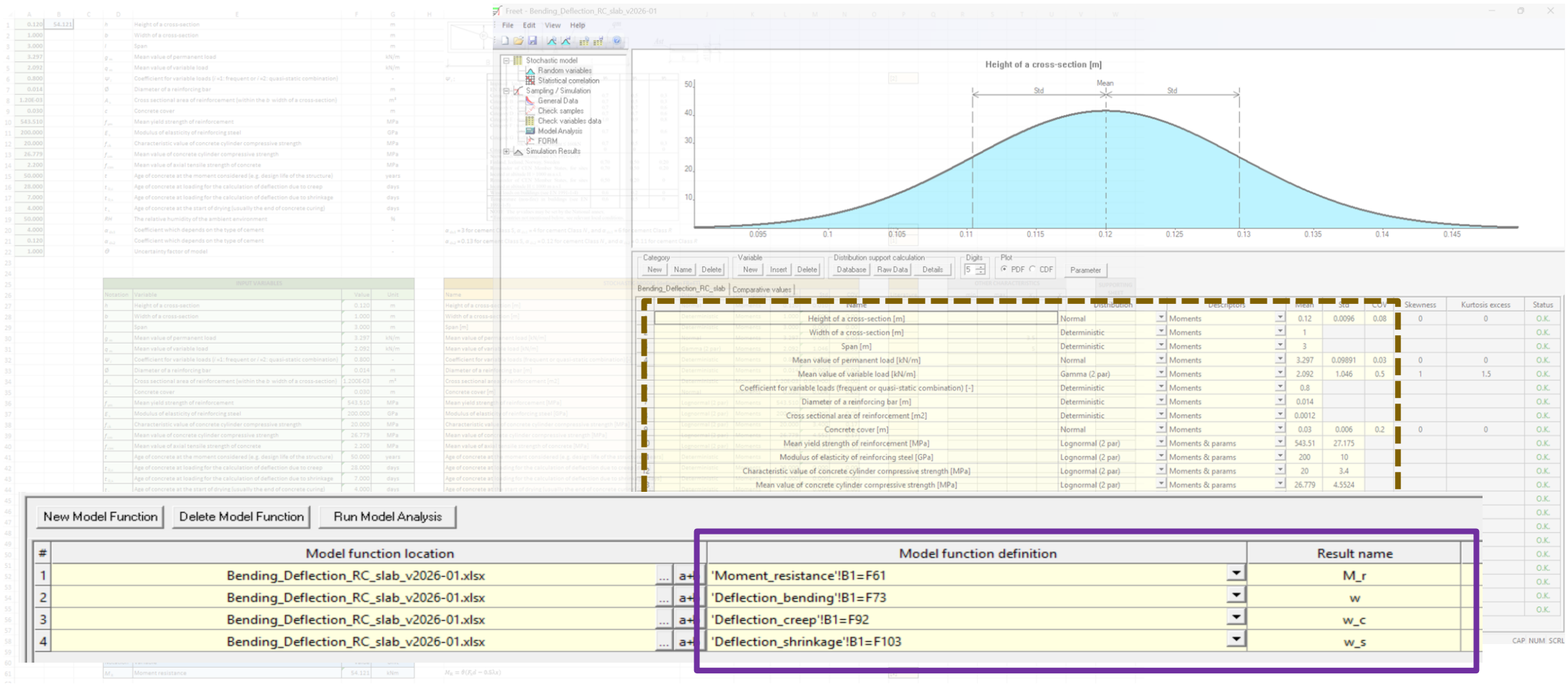
BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
FReET FILE – STOCHASTIC MODEL

Note:
Use a decimal point instead of a decimal comma.



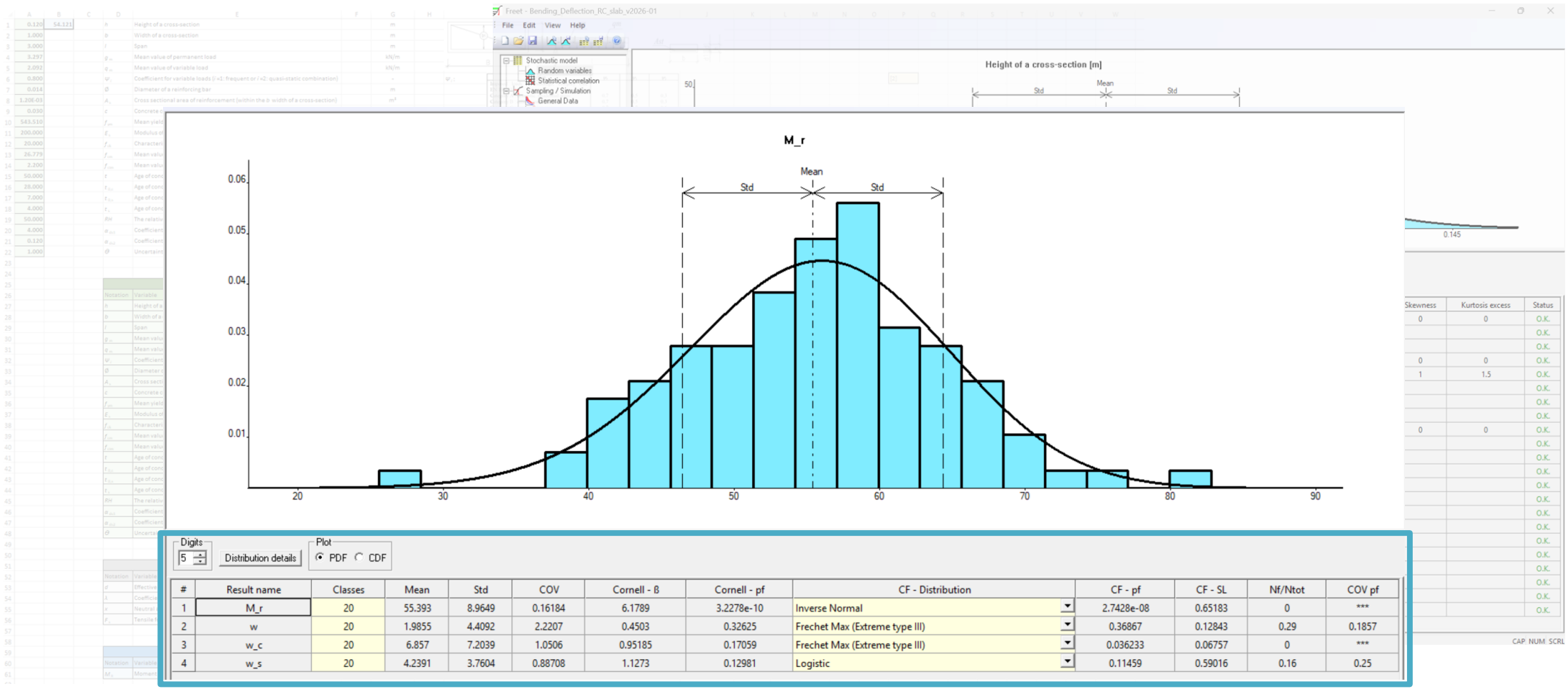
Name	Distribution	Descriptors	Mean	Std	CoV	Skewness	Kurtosis excess	Status
Height of a cross-section [m]	Normal	Moments	0.12	0.0096	0.08	0	0	O.K.
Width of a cross-section [m]	Deterministic	Moments	1					O.K.
Span [m]	Deterministic	Moments	3					O.K.
Mean value of permanent load [kN/m]	Normal	Moments	3.297	0.09891	0.03	0	0	O.K.
Mean value of variable load [kN/m]	Gamma (2 par)	Moments	2.092	1.046	0.5	1	1.5	O.K.
Coefficient for variable loads (frequent or quasi-static combination) [-]	Deterministic	Moments	0.8					O.K.
Diameter of a reinforcing bar [m]	Deterministic	Moments	0.014					O.K.
Cross sectional area of reinforcement [m2]	Deterministic	Moments	0.0012					O.K.
Concrete cover [m]	Normal	Moments	0.03	0.006	0.2	0	0	O.K.
Mean yield strength of reinforcement [MPa]	Lognormal (2 par)	Moments & params	543.51	27.175				O.K.
Modulus of elasticity of reinforcing steel [GPa]	Lognormal (2 par)	Moments & params	200	10				O.K.
Characteristic value of concrete cylinder compressive strength [MPa]	Lognormal (2 par)	Moments & params	20	3.4				O.K.
Mean value of concrete cylinder compressive strength [MPa]	Lognormal (2 par)	Moments & params	26.779	4.5524				O.K.
Mean value of axial tensile strength of concrete [MPa]	Lognormal (2 par)	Moments & params	2.2	0.374				O.K.
Age of concrete at the moment considered (e.g. design life of the structure) [years]	Deterministic	Moments	50					O.K.
Age of concrete at loading for the calculation of deflection due to creep [days]	Deterministic	Moments	28					O.K.
Age of concrete at loading for the calculation of deflection due to shrinkage [days]	Deterministic	Moments	7					O.K.
Age of concrete at the start of drying (usually the end of concrete curing) [days]	Deterministic	Moments	4					O.K.
The relative humidity of the ambient environment [%]	Deterministic	Moments	50					O.K.
Coefficient which depends on the type of cement [-]	Deterministic	Moments	4					O.K.
Coefficient which depends on the type of cement [-]	Deterministic	Moments	0.12					O.K.
Uncertainty factor of model [-]	Lognormal (2 par)	Moments & params	1	0.05				O.K.

BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
FReET FILE – STOCHASTIC MODEL



#	Model function location	Model function definition	Result name
1	Bending_Deflection_RC_slab_v2026-01.xlsx	'Moment_resistance'!B1=F61	M_r
2	Bending_Deflection_RC_slab_v2026-01.xlsx	'Deflection_bending'!B1=F73	w
3	Bending_Deflection_RC_slab_v2026-01.xlsx	'Deflection_creep'!B1=F92	w_c
4	Bending_Deflection_RC_slab_v2026-01.xlsx	'Deflection_shrinkage'!B1=F103	w_s

BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
FReET FILE – SIMULATION RESULTS



Digits: 5 | Distribution details | Plot: PDF / CDF

#	Result name	Classes	Mean	Std	COV	Cornell - β	Cornell - pf	CF - Distribution	CF - pf	CF - SL	Nf/Ntot	COV pf
1	M_r	20	55.393	8.9649	0.16184	6.1789	3.2278e-10	Inverse Normal	2.7428e-08	0.65183	0	***
2	w	20	1.9855	4.4092	2.2207	0.4503	0.32625	Frechet Max (Extreme type III)	0.36867	0.12843	0.29	0.1857
3	w_c	20	6.857	7.2039	1.0506	0.95185	0.17059	Frechet Max (Extreme type III)	0.036233	0.06757	0	***
4	w_s	20	4.2391	3.7604	0.88708	1.1273	0.12981	Logistic	0.11459	0.59016	0.16	0.25

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BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1 EXAMPLE

Interreg Austria – Czechia
Co-funded by the European Union

Integrated Research Centre (IREC)

Example Manual

Bending and Deflection of RC slabs

BOKU University & Brno University of Technology
Version 2026-01

Table of Contents

Bending and deflection of RC slab according to Eurocode 2 2
1. Problem Description 2
2. Input variables 2
3. Deterministic Calculation of Moment of Resistance 3
4. Deterministic Calculation of Deflection Caused by Bending 4
5. Deterministic Calculation of Deflections due to Creep and Shrinkage 6
6. Literature 11

BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
PROBLEM DESCRIPTION, TABLE OF INPUT VARIABLES

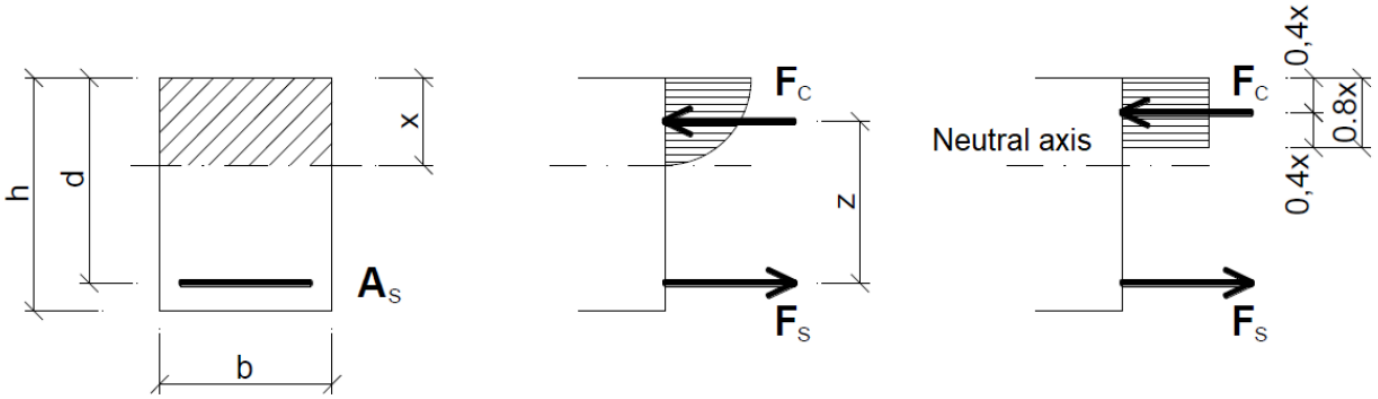
- All the Excel sheets contain of complete list of input variables
- In the Example file, the last column of a table of inputs contains the Excel Sheet numbers in which the given variable is used for the calculation and for which it is necessary to be correctly defined

Notation	Variable	Value	Unit	**Model**
h	Height of a cross-section	0.140	m	**1,2,3,4**
b	Width of a cross-section	1.000	m	**1,2,3,4**
l	Span	3.840	m	**2,3,4**
g_m	Permanent load	5.400	kN/m	**2,3,4**
q_m	Variable load	1.250	kN/m	**2,3,4**
Ψ_i	Coefficient for variable loads (i=1: frequent or i=2: quasi-static combination)	0.800	-	**3,4**
$Ø$	Diameter of a reinforcing bar	0.012	m	**1,2,3,4**
A_s	Cross sectional area of reinforcement (within the b width of a cross-section)	$6.463 \cdot 10^{-4}$	m²	**1,2,3,4**
c	Concrete cover	0.025	m	**1,2,3,4**
f_{ym}	Mean yield strength of reinforcement	525.000	MPa	**1**
E_s	Modulus of elasticity of reinforcing steel	200.000	GPa	**2,3,4**
f_{ck}	Characteristic value of concrete cylinder compressive strength	25.000	MPa	**1,4**
f_{cm}	Mean value of concrete cylinder compressive strength	33.000	MPa	**1,2,3,4**
f_{ctm}	Mean value of axial tensile strength of concrete	2.600	MPa	**2,3,4**
t	Age of concrete at the moment considered (e.g. design life of the structure)	50.000	years	**3,4**
$t_{0,c}$	Age of concrete at loading for the calculation of deflection due to creep	28.000	days	**3**
$t_{0,s}$	Age of concrete at loading for the calculation of deflection due to shrinkage	7.000	days	**4**
t_s	Age of concrete at the start of drying (usually the end of concrete curing)	4.000	days	**4**
RH	The relative humidity of the ambient environment	40.000	%	**3,4**
α_{ds1}	Coefficient which depends on the type of cement	4.000	-	**4**
α_{ds2}	Coefficient which depends on the type of cement	0.120	-	**4**
Θ	Uncertainty factor of model	1.000	-	**1,2,3,4**

BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
DETERMINISTIC CALCULATION – MOMENT OF RESISTANCE

- Calculations are based on classical beam theory

- Moment of Resistance Calculation



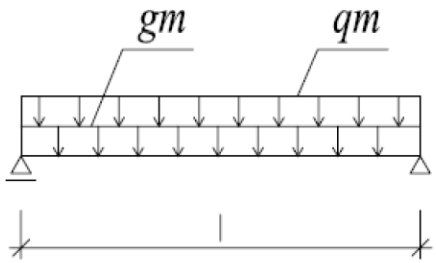
➢ Neutral axis depth:

$$x = \frac{A_s f_{ym}}{\lambda b f_{cm}}$$

$$M_R = \theta F_s (d - 0.5\lambda x)$$

BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
DETERMINISTIC CALCULATION – DEFLECTION

- Deflection of a simply supported beam (slab) loaded by a uniform continuous load due to:
  - Bending (short-term load)
  - Creep and shrinkage (long-term load)
- For short-term load:



$$w = \theta \left[\frac{5}{48} M_{Sk} (f_{m,1} + f_{m,2}) l^2 \right]$$

$$M_{sk} = \frac{1}{8} \cdot (g_m + q_m) \cdot l^2$$

$$f_{m,1} = (1 - \xi) \cdot \frac{1}{E_{cm} \cdot I_I}$$

$$f_{m,2} = \xi \cdot \frac{1}{E_{cm} \cdot I_{II}}$$

➢ EC2 recommends using an effective stiffness that acounts for tension stifenning, interpolating between uncracked and fully cracked states

BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
DETERMINISTIC CALCULATION – DEFLECTION DUE TO CREEP AND SHRINKAGE

- Calculations are based on modification of the material stiffness over time
- Long-term deflection is typically evaluated using an effective modulus of elasticity method
- Cracking is also considered

- For creep, reducing the short-term modulus of elasticity:

$$E_{c,eff} = \frac{E_{cm}}{1 + \varphi(t, t_0)}$$

$\varphi(t, t_0)$ … creep coefficient (dependent on time, humidity, member size, age at loading)

$$\boldsymbol{w_{creep} = \theta \left[\frac{5}{48} M_{Sq} (f_{m,1} + f_{m,2}) l^2\right]}$$

- For shrinkage, additional curvature in the member is introduced:

$$\frac{1}{r_{cs}} = \varepsilon_{cs} \cdot n_{eff} \cdot \left[(1 - \xi) \cdot \frac{S_I}{I_I} + \xi \cdot \frac{S_{II}}{I_{II}}\right]$$

$\varepsilon_{cs} = \varepsilon_{cd}(t) + \varepsilon_{ca}(t)$ … total shrinkage strain (drying and autogenous shrinkage)

$$\boldsymbol{w_{shrinkage} = \theta \left[\frac{1}{8} r_{cs}^{-1} l^2\right]}$$

BENDING AND DEFLECTION OF RC SLAB – EN 1992-1-1
NUMERICAL CALCULATION

- All relationships used are presented, including numerical substitutions and values obtained on the basis of defined inputs
- User can solve and check such an example by simply entering numerical values into the Excel template

- References:

[1] EN 1992-1-1:2004+A1:2014. Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. Brussels: European Committee for Standardization (CEN), 2014.

[2] EN 1990:2002+A1:2005. Eurocode 0: Basis of structural design. Brussels: European Committee for Standardization (CEN), 2005.

1st IREC WORKSHOP

Shear of RC beam – EN 1992-1-1

Co-funded by the European Regional Development Fund

SHEAR OF RC BEAM – EN 1992-1-1
SHEAR WITHOUT SHEAR REINFORCEMENT

- $V_{\mathrm{R,c}} = \max\left(V_{\mathrm{R,c1}}; V_{\mathrm{R,c,min}}\right)$
- $V_{\mathrm{R,c1}} = \theta \cdot \left(C_{\mathrm{R,c}} \cdot k \cdot (100 \cdot \rho_{\mathrm{l}} \cdot f_{cm})^{\frac{1}{3}} + k_1 \cdot \sigma_{\mathrm{cp}}\right) \cdot d \cdot b$
- $V_{\mathrm{R,c,min}} = \theta \cdot \left(v_{\mathrm{min}} + k_1 \cdot \sigma_{\mathrm{cp}}\right) \cdot b \cdot d$

  - $C_{\mathrm{R,c}}$ - Coefficient for concrete shear resistance.
  - k – Effective depth coefficient.
  - ρ_{l} – Degree of reinforcement of longitudinal drawn reinforcement.
  - f_{m} – Mean value of concrete cylinder compressive strength.
  - d – Effective depth.
  - b_{w} – Cross-sectional width (minimal width in tensile area).
  - σ_{cp} - Mean value of axial stress in the cross-sectional area due to loading.
  - v_{min} - Minimum shear stress.
  - θ - Uncertainty factor of model.

SHEAR OF RC BEAM – EN 1992-1-1
SHEAR WITH SHEAR REINFORCEMENT

- $V_{\mathrm{R,c}} = \min\left(V_{\mathrm{R,max}}; V_{\mathrm{R,s}}\right)$
- $V_{\mathrm{R,max}} = \theta \cdot \alpha_{\mathrm{cw}} \cdot b \cdot z \cdot v_1 \cdot f_{\mathrm{cm}} \cdot \frac{\cot\theta + \cot\alpha}{1 + \cot^2\theta}$
- $V_{\mathrm{R},s} = \theta \cdot \frac{A_{\mathrm{sw}}}{s} \cdot z \cdot f_{\mathrm{ywm}} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha$

  - z – Lever arm of internal forces.
  - f_{ywm} – Mean value of yield strength of shear reinforcement.
  - A_{sw} – Cross-sectional area of shear reinforcement.
  - s – Spacing of the stirrups.
  - α – Angle between stirrups and longitudinal centroidal axis.
  - $\cot\theta$ – Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force.

SHEAR OF RC BEAM – EN 1992-1-1
INPUT VARIABLES

- Table with input variables

Notation	Variable	Unit	Model
b	Cross-sectional width (minimal width in tensile area)	m	1, 2
d	Effective depth	m	1, 2
A_c	Cross-sectional area of concrete	m^2	1
A_{sl}	Cross-sectional area of longitudinal reinforcement	m^2	1
f_{cm}	Mean value of concrete cylinder compressive strength	MPa	1, 2
N	Applied axial force (compression positive)	kN	1
f_{ywm}	Mean value of yield strength of shear reinforcement	MPa	2
A_{sw}	Cross-sectional area of shear reinforcement	m^2	2
s	Spacing of the stirrups	m	2
α	Angle between stirrups and longitudinal centroidal axis	°	2
$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	-	2
Θ	Uncertainty factor of model	-	1, 2

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

0.15	55.38	b	Cross-sectional width (minimal width in tensile area)	m
0.38		d	Effective depth	m
0.06		A_c	Cross-sectional area of concrete	m^2
0.00		A_{sl}	Cross-sectional area of longitudinal reinforcement	m^2
31.00		f_{cm}	Mean value of concrete cylinder compressive strength	MPa
0.00		N	Applied axial force (compression positive)	kN
510.00		f_{ywm}	Mean value of yield strength of shear reinforcement	MPa
0.00		A_{sw}	Cross-sectional area of shear reinforcement	m^2
0.20		s	Spacing of the stirrups	m
90.00		α	Angle between stirrups and longitudinal centroidal axis	°
1.50		$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	-
1.00		Θ	Uncertainty factor of model	-

INPUT VARIABLES			
Notation	Variable	Value	Unit
b	Cross-sectional width (minimal width in tensile area)	0.15	m
d	Effective depth	0.38	m
A_c	Cross-sectional area of concrete	0.06	m^2
A_{sl}	Cross-sectional area of longitudinal reinforcement	0.00	m^2
f_{cm}	Mean value of concrete cylinder compressive strength	31.00	MPa
N	Applied axial force (compression positive)	0.00	kN
f_{ywm}	Mean value of yield strength of shear reinforcement	510.00	MPa
A_{sw}	Cross-sectional area of shear reinforcement	0.00	m^2
s	Spacing of the stirrups	0.20	m
α	Angle between stirrups and longitudinal centroidal axis	90.00	°
$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	1.50	-
Θ	Uncertainty factor of model	1.00	-

STOCHASTIC MODEL (define in FReET)						
Name	Distribution	Descriptors	Mean	Std	COV	Literature
Cross-sectional width (minimal width in tensile area) [m]	Normal	Moments	0.15	0.01	0.04	[1]
Effective depth [m]	Log-normal	Moments	0.38	0.01	0.03	[1]
Cross-sectional area of concrete [m^2]	Normal	Moments	0.06	0.00	0.06	[1]
Cross-sectional area of longitudinal reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Mean value of concrete cylinder compressive strength [MPa]	Log-normal	Moments	31.00	4.65	0.15	[2,3]
Applied axial force (compression positive) [kN]	Deterministic	Moments	0.00	0.00	0.00	
Mean value of yield strength of shear reinforcement [MPa]	Normal	Moments	510.00	30.60	0.06	[1]
Cross-sectional area of shear reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Spacing of the stirrups [m]	Deterministic	Moments	0.20	0.00	0.00	
Angle between stirrups and longitudinal centroidal axis [°]	Deterministic	Moments	90.00	0.00	0.00	
Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force [-]	Deterministic	Moments	1.50	0.00	0.00	
Uncertainty factor of model [-]	Deterministic	Moments	1.00	0.00	0.00	

SUPPORTING CALCULATIONS			
Notation	Variable	Value	Unit
ρ_l	Longitudinal reinforcement ratio	0.01	-
k	Size effect factor	1.73	-
σ_{cp}	Mean value of axial stress in the cross-sectional area due to loading	0.00	MPa
v_{min}	Minimum shear stress	0.44	MPa
$V_{R,c,min}$	Minimum shear strength	25.13	kN
$V_{R,c1}$	Shear force	55.38	kN

OUTPUT			
Notation	Variable	Value	Unit
$V_{R,c}$	Shear strength without stirrups	55.38	kN

$$\rho_l = \frac{A_{sl}}{b \cdot d} \leq 2.0$$

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0 \qquad \sigma_{cp} = \frac{N}{A_c} \leq 0.2 \cdot f_{cm}$$

$$v_{min} = 0.035 \cdot k^{\frac{3}{2}} \cdot f_{cm}^{\frac{1}{2}}$$

$$V_{min} = \theta \cdot (v_{min} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

$$V_{R,c1} = \theta \cdot (0.18 \cdot k \cdot (100 \cdot \rho_l \cdot f_{cm})^{\frac{1}{3}} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

$$V_{R,c} = \max(V_{R,c1}; V_{min})$$

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

0.15	55.38	b	Cross-sectional width (minimal width in tensile area)	m
0.38		d	Effective depth	m
0.06		A_c	Cross-sectional area of concrete	m^2
0.00		A_{sl}	Cross-sectional area of longitudinal reinforcement	m^2
31.00		f_{cm}	Mean value of concrete cylinder compressive strength	MPa
0.00		N	Applied axial force (compression positive)	kN
510.00		f_{ywm}	Mean value of yield strength of shear reinforcement	MPa
0.00		A_{sw}	Cross-sectional area of shear reinforcement	m^2
0.20		s	Spacing of the stirrups	m
90.00		α	Angle between stirrups and longitudinal centroidal axis	°
1.50		$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	-
1.00		Θ	Uncertainty factor of model	-

INPUT VARIABLES

Notation	Variable	Value	Unit
b	Cross-sectional width (minimal width in tensile area)	0.15	m
d	Effective depth	0.38	m
A_c	Cross-sectional area of concrete	0.06	m^2
A_{sl}	Cross-sectional area of longitudinal reinforcement	0.00	m^2
f_{cm}	Mean value of concrete cylinder compressive strength	31.00	MPa
N	Applied axial force (compression positive)	0.00	kN
f_{ywm}	Mean value of yield strength of shear reinforcement	510.00	MPa
A_{sw}	Cross-sectional area of shear reinforcement	0.00	m^2
s	Spacing of the stirrups	0.20	m
α	Angle between stirrups and longitudinal centroidal axis	90.00	°
$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	1.50	-
Θ	Uncertainty factor of model	1.00	-

STOCHASTIC MODEL (define in FReET)

Name	Distribution	Descriptors	Mean	Std	COV	Literature
Cross-sectional width (minimal width in tensile area) [m]	Normal	Moments	0.15	0.01	0.04	[1]
Effective depth [m]	Log-normal	Moments	0.38	0.01	0.03	[1]
Cross-sectional area of concrete [m^2]	Normal	Moments	0.06	0.00	0.06	[1]
Cross-sectional area of longitudinal reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Mean value of concrete cylinder compressive strength [MPa]	Log-normal	Moments	31.00	4.65	0.15	[2,3]
Applied axial force (compression positive) [kN]	Deterministic	Moments	0.00	0.00	0.00	
Mean value of yield strength of shear reinforcement [MPa]	Normal	Moments	510.00	30.60	0.06	[1]
Cross-sectional area of shear reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Spacing of the stirrups [m]	Deterministic	Moments	0.20	0.00	0.00	
Angle between stirrups and longitudinal centroidal axis [°]	Deterministic	Moments	90.00	0.00	0.00	
Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force [-]	Deterministic	Moments	1.50	0.00	0.00	
Uncertainty factor of model [-]	Deterministic	Moments	1.00	0.00	0.00	

SUPPORTING CALCULATIONS

Notation	Variable	Value	Unit
ρ_l	Longitudinal reinforcement ratio	0.01	-
k	Size effect factor	1.73	-
σ_{cp}	Mean value of axial stress in the cross-sectional area due to loading	0.00	MPa
v_{min}	Minimum shear stress	0.44	MPa
$V_{R,c,min}$	Minimum shear strength	25.13	kN
$V_{R,c1}$	Shear force	55.38	kN

$$\rho_l = \frac{A_{sl}}{b \cdot d} \leq 2.0$$

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0 \qquad \sigma_{cp} = \frac{N}{A_c} \leq 0.2 \cdot f_{cm}$$

$$v_{min} = 0.035 \cdot k^{\frac{3}{2}} \cdot f_{cm}^{\frac{1}{2}}$$

$$V_{min} = \theta \cdot (v_{min} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

$$V_{R,c1} = \theta \cdot (0.18 \cdot k \cdot (100 \cdot \rho_l \cdot f_{cm})^{\frac{1}{3}} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

OUTPUT

Notation	Variable	Value	Unit
$V_{R,c}$	Shear strength without stirrups	55.38	kN

$$V_{R,c} = \max(V_{R,c1}; V_{min})$$

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

0.15	**55.38**	b	Cross-sectional width (minimal width in tensile area)	m
0.38		d	Effective depth	m
0.06		A_c	Cross-sectional area of concrete	m^2
0.00		A_{sl}	Cross-sectional area of longitudinal reinforcement	m^2
31.00		f_{cm}	Mean value of concrete cylinder compressive strength	MPa
0.00		N	Applied axial force (compression positive)	kN
510.00		f_{ywm}	Mean value of yield strength of shear reinforcement	MPa
0.00		A_{sw}	Cross-sectional area of shear reinforcement	m^2
0.20		s	Spacing of the stirrups	m
90.00		α	Angle between stirrups and longitudinal centroidal axis	°
1.50		$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	-
1.00		Θ	Uncertainty factor of model	-

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

INPUT VARIABLES			
Notation	Variable	Value	Unit
b	Cross-sectional width (minimal width in tensile area)	0.15	m
d	Effective depth	0.38	m
A_c	Cross-sectional area of concrete	0.06	m^2
A_{sl}	Cross-sectional area of longitudinal reinforcement	0.00	m^2
f_{cm}	Mean value of concrete cylinder compressive strength	31.00	MPa
N	Applied axial force (compression positive)	0.00	kN
f_{ywm}	Mean value of yield strength of shear reinforcement	510.00	MPa
A_{sw}	Cross-sectional area of shear reinforcement	0.00	m^2
s	Spacing of the stirrups	0.20	m
α	Angle between stirrups and longitudinal centroidal axis	90.00	°
$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	1.50	-
Θ	Uncertainty factor of model	1.00	-

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

0.15	55.38	b	Cross-sectional width (minimal width in tensile area)	m
0.38		d	Effective depth	m
0.06		A_c	Cross-sectional area of concrete	m^2
0.00		A_{sl}	Cross-sectional area of longitudinal reinforcement	m^2
31.00		f_{cm}	Mean value of concrete cylinder compressive strength	MPa
0.00		N	Applied axial force (compression positive)	kN
510.00		f_{ywm}	Mean value of yield strength of shear reinforcement	MPa
0.00		A_{sw}	Cross-sectional area of shear reinforcement	m^2
0.20		s	Spacing of the stirrups	m
90.00		α	Angle between stirrups and longitudinal centroidal axis	°
1.50		$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	-
1.00		Θ	Uncertainty factor of model	-

INPUT VARIABLES			
Notation	Variable	Value	Unit
b	Cross-sectional width (minimal width in tensile area)	0.15	m
d	Effective depth	0.38	m
A_c	Cross-sectional area of concrete	0.06	m^2
A_{sl}	Cross-sectional area of longitudinal reinforcement	0.00	m^2
f_{cm}	Mean value of concrete cylinder compressive strength	31.00	MPa
N	Applied axial force (compression positive)	0.00	kN
f_{ywm}	Mean value of yield strength of shear reinforcement	510.00	MPa
A_{sw}	Cross-sectional area of shear reinforcement	0.00	m^2
s	Spacing of the stirrups	0.20	m
α	Angle between stirrups and longitudinal centroidal axis	90.00	°
$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	1.50	-
Θ	Uncertainty factor of model	1.00	-

STOCHASTIC MODEL (define in FReET)						
Name	Distribution	Descriptors	Mean	Std	COV	Literature
Cross-sectional width (minimal width in tensile area) [m]	Normal	Moments	0.15	0.01	0.04	[1]
Effective depth [m]	Log-normal	Moments	0.38	0.01	0.03	[1]
Cross-sectional area of concrete [m^2]	Normal	Moments	0.06	0.00	0.06	[1]
Cross-sectional area of longitudinal reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Mean value of concrete cylinder compressive strength [MPa]	Log-normal	Moments	31.00	4.65	0.15	[2,3]
Applied axial force (compression positive) [kN]	Deterministic	Moments	0.00	0.00	0.00	
Mean value of yield strength of shear reinforcement [MPa]	Normal	Moments	510.00	30.60	0.06	[1]
Cross-sectional area of shear reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Spacing of the stirrups [m]	Deterministic	Moments	0.20	0.00	0.00	
Angle between stirrups and longitudinal centroidal axis [°]	Deterministic	Moments	90.00	0.00	0.00	
Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force [-]	Deterministic	Moments	1.50	0.00	0.00	
Uncertainty factor of model [-]	Deterministic	Moments	1.00	0.00	0.00	

SUPPORTING CALCULATIONS			
Notation	Variable	Value	Unit
ρ_l	Longitudinal reinforcement ratio	0.01	-
k	Size effect factor	1.73	-
σ_{cp}	Mean value of axial stress in the cross-sectional area due to loading	0.00	MPa
v_{min}	Minimum shear stress	0.44	MPa
$V_{R,c,min}$	Minimum shear strength	25.13	kN
$V_{R,c1}$	Shear force	55.38	kN

OUTPUT			
Notation	Variable	Value	Unit
$V_{R,c}$	Shear strength without stirrups	55.38	kN

$$\rho_l = \frac{A_{sl}}{b \cdot d} \le 2.0$$

$$k = 1 + \sqrt{\frac{200}{d}} \le 2.0 \qquad \sigma_{cp} = \frac{N}{A_c} \le 0.2 \cdot f_{cm}$$

$$v_{min} = 0.035 \cdot k^{\frac{3}{2}} \cdot f_{cm}^{\frac{1}{2}}$$

$$V_{min} = \theta \cdot (v_{min} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

$$V_{R,c1} = \theta \cdot (0.18 \cdot k \cdot (100 \cdot \rho_l \cdot f_{cm})^{\frac{1}{3}} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

$$V_{R,c} = \max(V_{R,c1}; V_{min})$$

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

SUPPORTING CALCULATIONS			
Notation	Variable	Value	Unit
ρ_l	Longitudinal reinforcement ratio	0.01	-
k	Size effect factor	1.73	-
σ_{cp}	Mean value of axial stress in the cross-sectional area due to loading	0.00	MPa
v_{min}	Minimum shear stress	0.44	MPa
$V_{R,c,min}$	Minimum shear strength	25.13	kN
$V_{R,c1}$	Shear force	55.38	kN

OUTPUT			
Notation	Variable	Value	Unit
$V_{R,c}$	Shear strength without stirrups	55.38	kN

$$\rho_l = \frac{A_{sl}}{b \cdot d} \leq 2.0 \qquad k = 1 + \sqrt{\frac{200}{d}} \leq 2.0 \qquad \sigma_{cp} = \frac{N}{A_c} \leq 0.2 \cdot f_{cm}$$

$$v_{min} = 0.035 \cdot k^{\frac{3}{2}} \cdot f_{cm}^{\frac{1}{2}} \qquad V_{R,c,min} = \theta \cdot (v_{min} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

$$V_{R,c1} = \theta \cdot (0.18 \cdot k \cdot (100 \cdot \rho_l \cdot f_{cm})^{\frac{1}{3}} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

0.15	55.38	b	Cross-sectional width (minimal width in tensile area)	m
0.38		d	Effective depth	m
0.06		A_c	Cross-sectional area of concrete	m^2
0.00		A_{sl}	Cross-sectional area of longitudinal reinforcement	m^2
31.00		f_{cm}	Mean value of concrete cylinder compressive strength	MPa
0.00		N	Applied axial force (compression positive)	kN
510.00		f_{ywm}	Mean value of yield strength of shear reinforcement	MPa
0.00		A_{sw}	Cross-sectional area of shear reinforcement	m^2
0.20		s	Spacing of the stirrups	m
90.00		α	Angle between stirrups and longitudinal centroidal axis	°
1.50		$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	-
1.00		Θ	Uncertainty factor of model	-

INPUT VARIABLES

Notation	Variable	Value	Unit
b	Cross-sectional width (minimal width in tensile area)	0.15	m
d	Effective depth	0.38	m
A_c	Cross-sectional area of concrete	0.06	m^2
A_{sl}	Cross-sectional area of longitudinal reinforcement	0.00	m^2
f_{cm}	Mean value of concrete cylinder compressive strength	31.00	MPa
N	Applied axial force (compression positive)	0.00	kN
f_{ywm}	Mean value of yield strength of shear reinforcement	510.00	MPa
A_{sw}	Cross-sectional area of shear reinforcement	0.00	m^2
s	Spacing of the stirrups	0.20	m
α	Angle between stirrups and longitudinal centroidal axis	90.00	°
$\cot\theta$	Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force	1.50	-
Θ	Uncertainty factor of model	1.00	-

STOCHASTIC MODEL (define in FReET)

Name	Distribution	Descriptors	Mean	Std	COV	Literature
Cross-sectional width (minimal width in tensile area) [m]	Normal	Moments	0.15	0.01	0.04	[1]
Effective depth [m]	Log-normal	Moments	0.38	0.01	0.03	[1]
Cross-sectional area of concrete [m^2]	Normal	Moments	0.06	0.00	0.06	[1]
Cross-sectional area of longitudinal reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Mean value of concrete cylinder compressive strength [MPa]	Log-normal	Moments	31.00	4.65	0.15	[2,3]
Applied axial force (compression positive) [kN]	Deterministic	Moments	0.00	0.00	0.00	
Mean value of yield strength of shear reinforcement [MPa]	Normal	Moments	510.00	30.60	0.06	[1]
Cross-sectional area of shear reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01	[1,4]
Spacing of the stirrups [m]	Deterministic	Moments	0.20	0.00	0.00	
Angle between stirrups and longitudinal centroidal axis [°]	Deterministic	Moments	90.00	0.00	0.00	
Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force [-]	Deterministic	Moments	1.50	0.00	0.00	
Uncertainty factor of model [-]	Deterministic	Moments	1.00	0.00	0.00	

SUPPORTING CALCULATIONS

Notation	Variable	Value	Unit
ρ_l	Longitudinal reinforcement ratio	0.01	-
k	Size effect factor	1.73	-
σ_{cp}	Mean value of axial stress in the cross-sectional area due to loading	0.00	MPa
v_{min}	Minimum shear stress	0.44	MPa
$V_{R,c,min}$	Minimum shear strength	25.13	kN
$V_{R,c1}$	Shear force	55.38	kN

$$\rho_l = \frac{A_{sl}}{b \cdot d} \le 2.0$$

$$k = 1 + \sqrt{\frac{200}{d}} \le 2.0 \qquad \sigma_{cp} = \frac{N}{A_c} \le 0.2 \cdot f_{cm}$$

$$v_{min} = 0.035 \cdot k^{\frac{3}{2}} \cdot f_{cm}^{\frac{1}{2}}$$

$$V_{min} = \theta \cdot (v_{min} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

$$V_{R,c1} = \theta \cdot (0.18 \cdot k \cdot (100 \cdot \rho_l \cdot f_{cm})^{\frac{1}{3}} + k_1 \cdot \sigma_{cp}) \cdot d \cdot b$$

OUTPUT

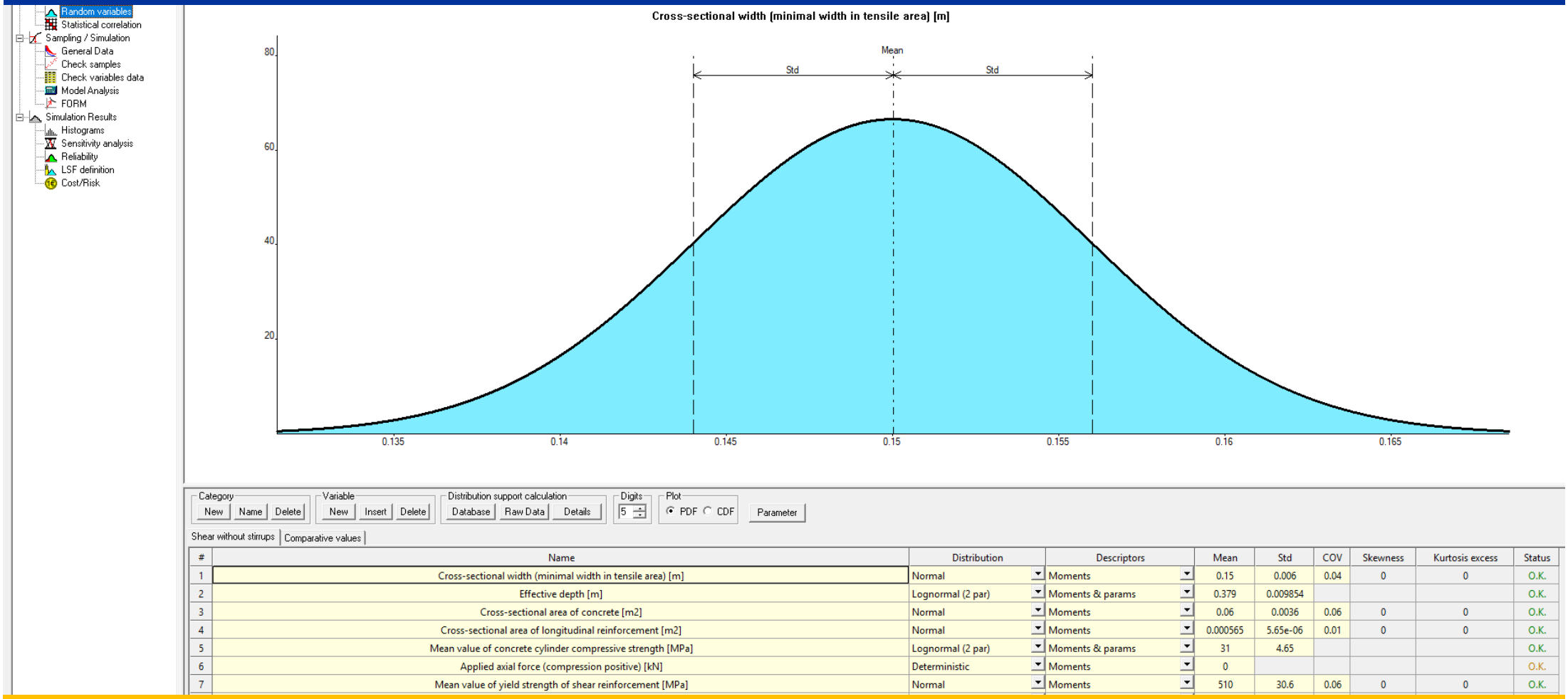
Notation	Variable	Value	Unit
$V_{R,c}$	Shear strength without stirrups	55.38	kN

$$V_{R,c} = \max(V_{R,c1}; V_{min})$$

SHEAR OF RC BEAM – EN 1992-1-1
EXCEL SHEET

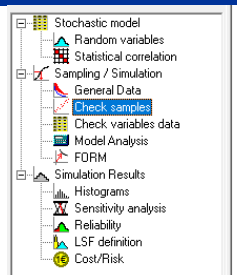
STOCHASTIC MODEL (define in FReET)					
Name	Distribution	Descriptors	Mean	Std	COV
Cross-sectional width (minimal width in tensile area) [m]	Normal	Moments	0.15	0.01	0.04
Effective depth [m]	Log-normal	Moments	0.38	0.01	0.03
Cross-sectional area of concrete [m^2]	Normal	Moments	0.06	0.00	0.06
Cross-sectional area of longitudinal reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01
Mean value of concrete cylinder compressive strength [MPa]	Log-normal	Moments	31.00	4.65	0.15
Applied axial force (compression positive) [kN]	Deterministic	Moments	0.00	0.00	0.00
Mean value of yield strength of shear reinforcement [MPa]	Normal	Moments	510.00	30.60	0.06
Cross-sectional area of shear reinforcement [m^2]	Normal	Moments	0.00	0.00	0.01
Spacing of the stirrups [m]	Deterministic	Moments	0.20	0.00	0.00
Angle between stirrups and longitudinal centroidal axis [°]	Deterministic	Moments	90.00	0.00	0.00
Cotangent of angle between the concrete compression strut and the beam axis perpendicular to the shear force [-]	Deterministic	Moments	1.50	0.00	0.00
Uncertainty factor of model [-]	Deterministic	Moments	1.00	0.00	0.00

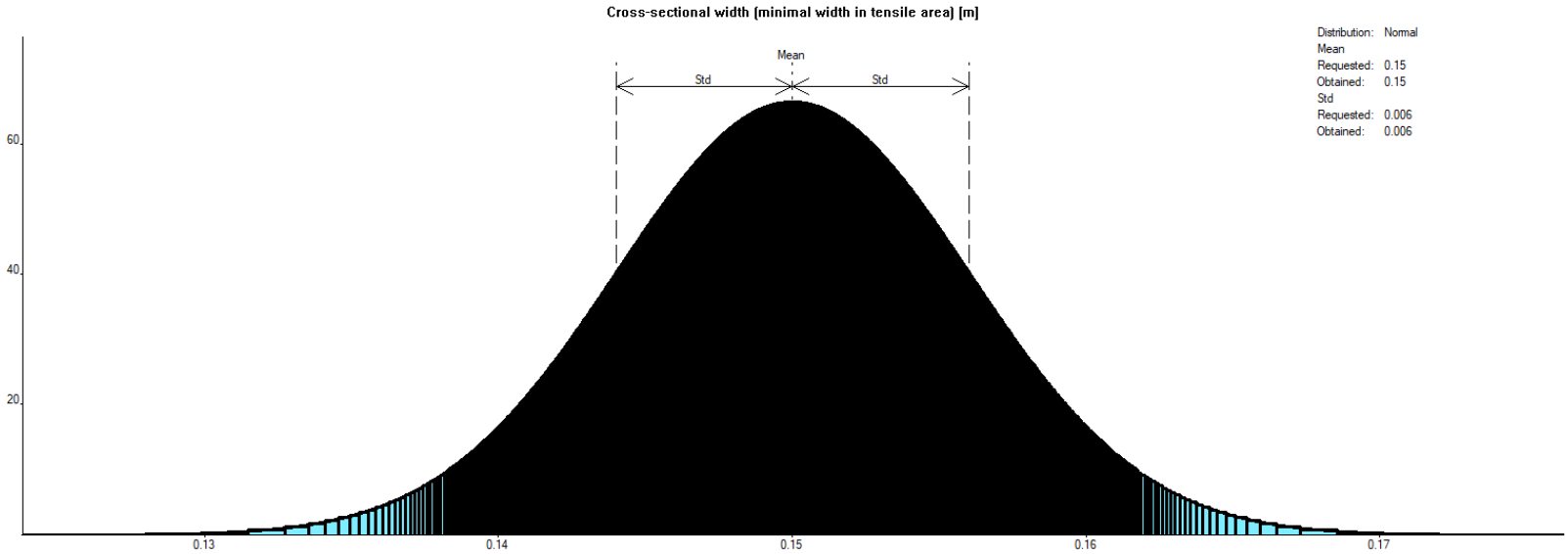
SHEAR OF RC BEAM – EN 1992-1-1
FREET SHEET



#	Name	Distribution	Descriptors	Mean	Std	COV	Skewness	Kurtosis excess	Status
1	Cross-sectional width (minimal width in tensile area) [m]	Normal	Moments	0.15	0.006	0.04	0	0	O.K.
2	Effective depth [m]	Lognormal (2 par)	Moments & params	0.379	0.009854				O.K.
3	Cross-sectional area of concrete [m2]	Normal	Moments	0.06	0.0036	0.06	0	0	O.K.
4	Cross-sectional area of longitudinal reinforcement [m2]	Normal	Moments	0.000565	5.65e-06	0.01	0	0	O.K.
5	Mean value of concrete cylinder compressive strength [MPa]	Lognormal (2 par)	Moments & params	31	4.65				O.K.
6	Applied axial force (compression positive) [kN]	Deterministic	Moments	0					O.K.
7	Mean value of yield strength of shear reinforcement [MPa]	Normal	Moments	510	30.6	0.06	0	0	O.K.

SHEAR OF RC BEAM – EN 1992-1-1
FREET SHEET





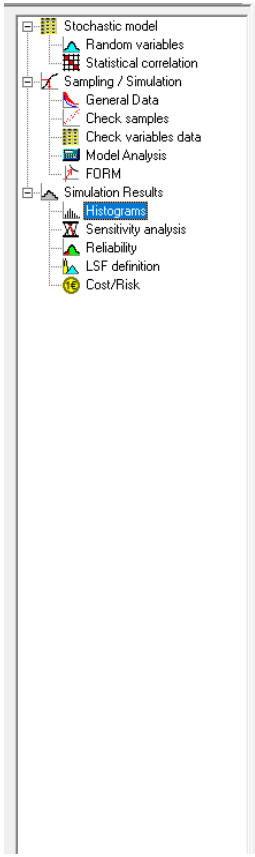
Numbers | Digits 5 | Cartesian Coordinates | Parallel Coordinates | PDF | CDF | g(X) <= 0 Not drawn

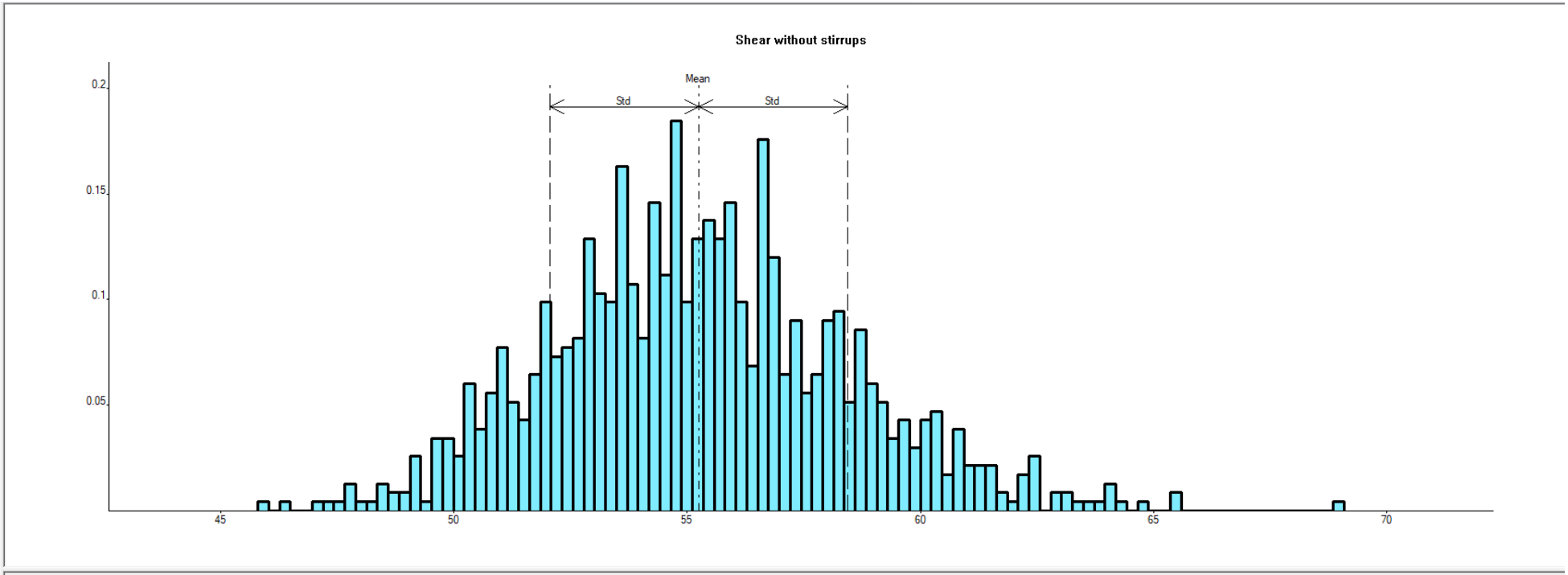
Shear without stirrups | Comparative values | All variables

	Cross-sectional width (minimal width in tensile area) [m]	Effective depth [m]	Cross-sectional area of concrete [m2]	Cross-sectional area of longitudinal reinforcement [m2]	Mean value of concrete cyl
Cross-sectional width (minimal width in tensile area) [m]	1	0	0	0	
Effective depth [m]	-0.00017863	1	0	0	
Cross-sectional area of concrete [m2]	-8.6359e-06	0.00032342	1	0	
Cross-sectional area of longitudinal reinforcement [m2]	-0.0005416	-0.00014135	0.0001938	1	
Mean value of concrete cylinder compressive strength [MPa]	0.0003619	9.5347e-05	0.0011065	-0.00043	
Applied axial force (compression positive) [kN]	0	0	0	0	
Mean value of yield strength of shear reinforcement [MPa]	-2.6689e-05	0.00048858	-0.0012039	0.00017039	0.(
Cross-sectional area of shear reinforcement [m2]	-2.9891e-05	3.8083e-06	-0.00034272	-6.6561e-05	0.(
Spacing of the stirrups [m]	0	0	0	0	

1st IREC Workshop

SHEAR OF RC BEAM – EN 1992-1-1
FREET SHEET

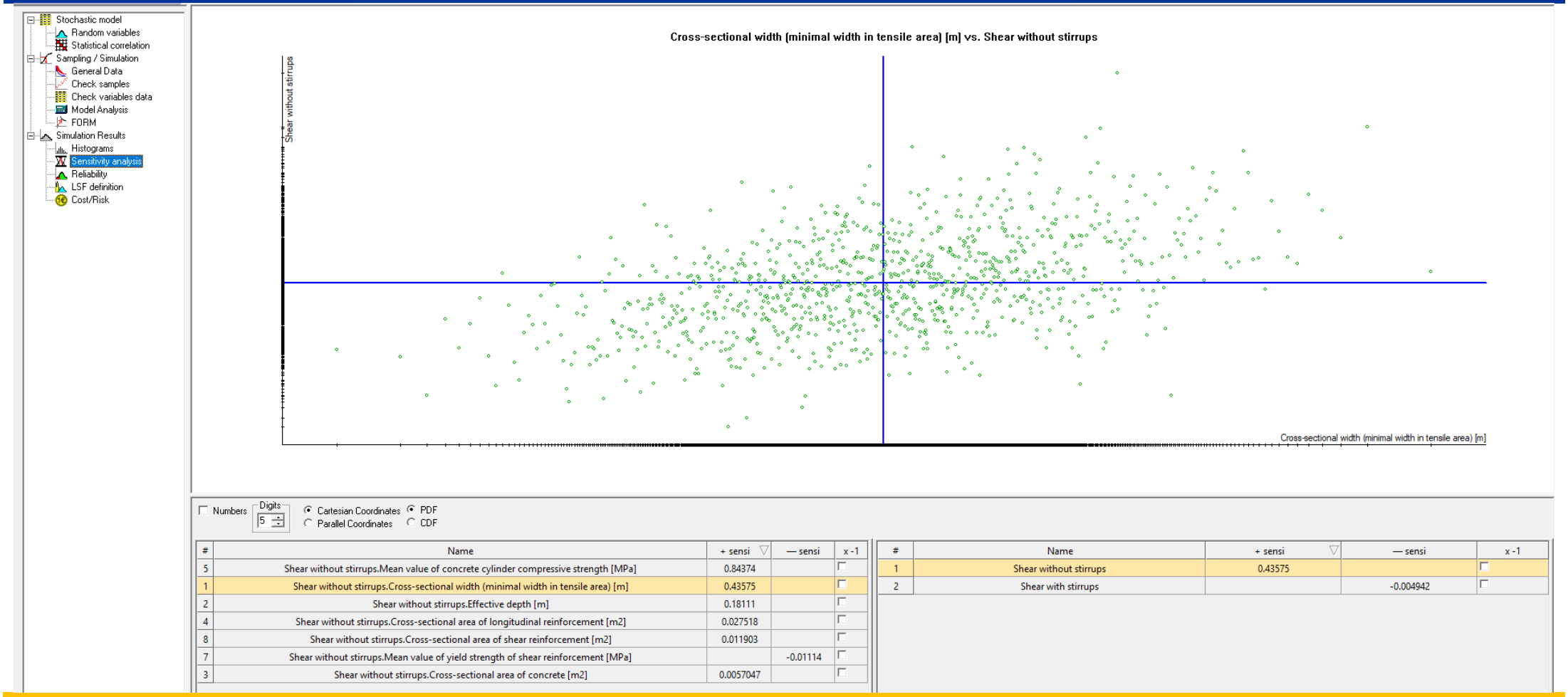




Digits 5 Plot PDF CDF

#	Result name	Classes	Mean	Variance	Std	COV	Skewness	Kurtosis	Min	Max	Range
1	Shear without stirrups	100	55.232	10.199	3.1935	0.05782	0.29216	0.2965	45.781	69.078	23.297
2	Shear with stirrups	100	131.78	75.97	8.7161	0.066143	0.026266	-0.092126	103.97	161.51	57.538

SHEAR OF RC BEAM – EN 1992-1-1
FREET SHEET

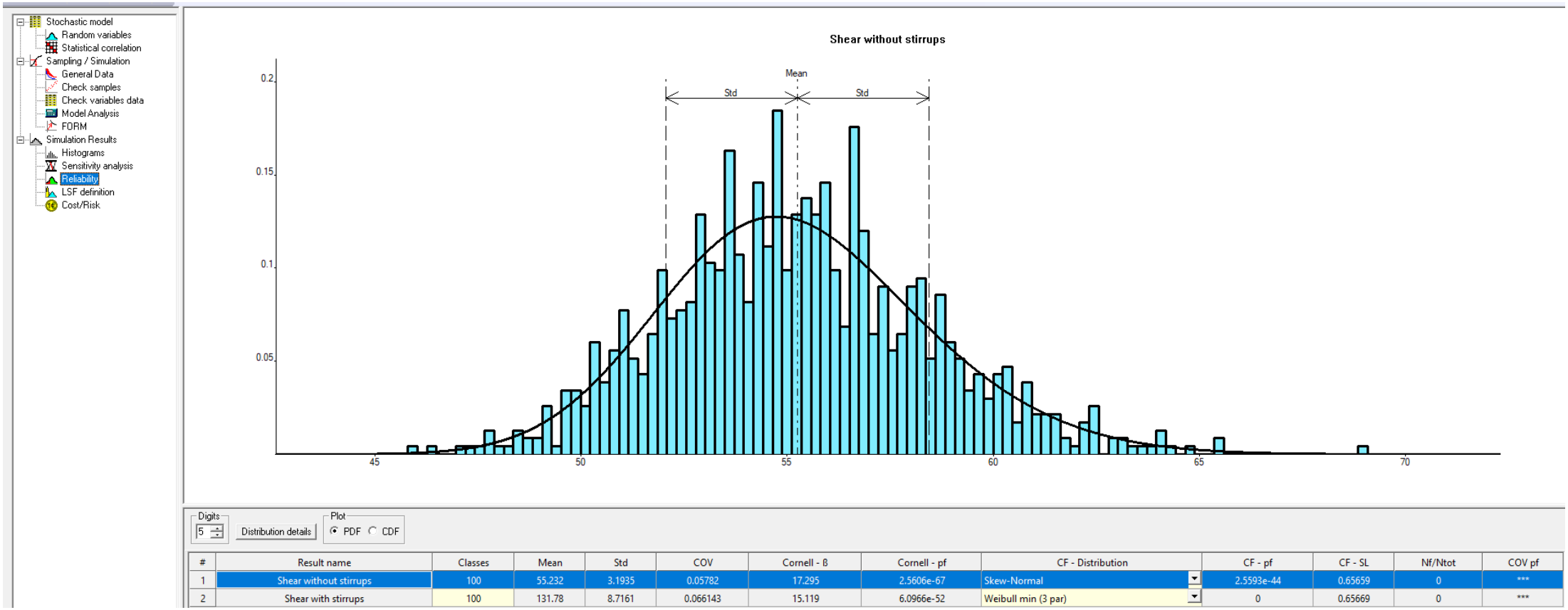


#	Name	+ sensi	— sensi	x -1
5	Shear without stirrups.Mean value of concrete cylinder compressive strength [MPa]	0.84374		
1	Shear without stirrups.Cross-sectional width (minimal width in tensile area) [m]	0.43575		
2	Shear without stirrups.Effective depth [m]	0.18111		
4	Shear without stirrups.Cross-sectional area of longitudinal reinforcement [m2]	0.027518		
8	Shear without stirrups.Cross-sectional area of shear reinforcement [m2]	0.011903		
7	Shear without stirrups.Mean value of yield strength of shear reinforcement [MPa]		-0.01114	
3	Shear without stirrups.Cross-sectional area of concrete [m2]	0.0057047		

#	Name	+ sensi	— sensi	x -1
1	Shear without stirrups	0.43575		
2	Shear with stirrups		-0.004942	

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SHEAR OF RC BEAM – EN 1992-1-1
FREET SHEET



#	Result name	Classes	Mean	Std	COV	Cornell - ß	Cornell - pf	CF - Distribution	CF - pf	CF - SL	Nf/Ntot	COV pf
1	Shear without stirrups	100	55.232	3.1935	0.05782	17.295	2.5606e-67	Skew-Normal	2.5593e-44	0.65659	0	***
2	Shear with stirrups	100	131.78	8.7161	0.066143	15.119	6.0966e-52	Weibull min (3 par)	0	0.65669	0	***

1st IREC WORKSHOP

Carbonation model based on the fib Model Code 2010 and 2020

CARBONATION

Purpose:

estimate carbonation front depth $x_c(t)$ and compare it with concrete cover c

depassivation becomes possible when the front reaches the reinforcement

Origin:

DuraCrete model → slightly enhanced in DARTS → fib Bulletin 34 service-life framework; later reformulated by von Greve-Dierfeld & Gehlen.

carbonation-front model with empirical-physical correction factors

$$x_c(t) = k_{NAC} * \sqrt{k_e * k_c * k_a} * \sqrt{t} * W(t)$$

CARBONATION

- The carbonation depth x_c at time t is calculated
- The formular uses the carbonation rate under standard natural carbonation test conditions *(k_{NAC})*, which is then adapted to the actual exposition.
- *(k_{NAC})* from carbonation testing on cores/specimens or approximated from cement type and w/c ratio.

$$x_c(t) = k_{NAC} * \sqrt{k_e * k_c * k_a} * \sqrt{t} * W(t)$$

CARBONATION

- Factor describing the impact of relative humidity (environment)

$$k_e = \left(\frac{1 - \left(\frac{RH_a}{100}\right)^5}{1 - \left(\frac{RH_l}{100}\right)^5} \right)^{2,5}$$

- Input value:
  - RH_a … relative humidity of ambient air [%]
  - RH_l … relative humidity in laboratory [%]

- Factor describing the impact of the curing time

$$k_c = \left(\frac{t_c}{7}\right)^{b_c}$$

- Input value:
  - t_c … curing time [days]
  - b_c … exponent of regression [-]

CARBONATION

- Factor describing the impact of the CO_2-concentration (atmosphere)

$$k_a = \frac{C_a}{C_l}$$

- Input value:
  - C_a … CO_2-concentration of ambient air [%]
  - C_l … CO_2-conventration in laboratory [%]

- Factor describing the impact of wetting events (weather)

$$W(t) = \left(\frac{t_0}{t}\right)^{\frac{(p_{dr} * ToW)}{2}^{b_w}}$$

- Input value:
  - t_0 … reference time = 0,0767
  - p_{dr} … probability of driving rain [-]
  - ToW … time of wetness [days]
  - b_w … exponent of weather function [-]

CARBONATION

- Input values and distributions:

Notation	Variable	Unit	Distribution
t	time of exposure	*years*	Deterministic
k_{NAC}	carbonation rate	$mm/year^{0,5}$	Beta
RH_a	relative humidity of ambient air	*%*	Weibull(max)
RH_l	relative humidity in laboratory	*%*	Deterministic
t_c	curing time	*days*	Deterministic
b_c	exponent of regression	-	Normal
C_a	CO_2-concentration of ambient air	*ppm*	Normal
C_l	CO_2-conventration in laboratory	*ppm*	Deterministic
p_{dr}	probability of driving rain	-	Deterministic
ToW	time of wetness	*days*	Deterministic
b_w	exponent of weather function	-	Normal

Stochastic models for cement types were systematically analyzed for the various environmental classes.

Example for analysed cement classes

CEM I (k_{NAC} = 1,75mm/$y^{0,5}$)
CEM II/B-S (k_{NAC} = 2,50mm/$y^{0,5}$)
CEM II/B-LL (k_{NAC} = 4,44mm/$y^{0,5}$)

Zementart	Wasserzementwert [-]	k_{NAC} $[mm/jahr^{0,5}]$	R_{AAC}^{-1} $[\frac{mm^2/jahr}{kg/m^3}]$
CEM I 42,5R	0,50	1,75	2.208,50
CEM II/B-S 42,5N	0,45	2,50	3.155,00
CEM II/B-LL 32,5R	0,65	4,44	10.727,00

CARBONATION

Structure of the Excel-based framework for Model Code 2010 and 2020, aligned with the Eurocode background.

It supports deterministic and probabilistic (stochastic) assessments and includes models for different cement types.

CEM I, CEM II/B-S, and CEM II/B-LL

-0,567	b_c	Exponent of parameter for curing time
0,0426	Ca	CO_2 concentration of ambient air
0,14	p_{dr}	Probability of driving rain
60	ToW	Time of wetness, i.e., days with daily rainfall ≥ 2.5 mm
0,446	b_w	Regression exponent of weather function

INPUT VARIABLES			
Notation	Variable	Value	Unit
t	Time of exposure	50	years
k_{NAC}	Carbonation rate for standard test conditions	3	mm/year$^{0.5}$
RH_a	Relative humidity of ambient air	76	%
t_c	Curing time	7	days
b_c	Exponent of parameter for curing time	-0,567	-
C_a	CO2 concentration of ambient air	0,043	kg/m^3
p_{dr}	Probability of driving rain	0,140	-
ToW	Time of wetness, i.e., days with daily rainfall ≥ 2.5 mm	60	-
b_w	Regression exponent of weather function	0,446	-

STOCHASTIC MODEL (define in FReET)	
Name	Distri
Time of exposure [years]	Deterr
Carbonation rate for standard test conditions [mm/year$^{0.5}$]	Norma
Relative humidity of ambient air [%]	Beta
Curing time [days]	Deterr
Exponent of parameter for curing time [-]	Norma
CO2 concentration of ambient air [kg/m^3]	Norma
Probability of driving rain [-]	Deterr
Time of wetness (days with daily rainfall ≥ 2.5 mm	Deterr
Regression exponent of weather function [-]	Norma

SUPPORTING CALCULATIONS			
Notation	Variable	Value	Unit
RH_l	Reference (laboratory) humidity	65	%
f_e	Constant in factor describing humidity	5	-
g_e	Constant in factor describing humidity	3	-
k_e	factor describing the impact of humidity	0,655	-
k_c	facor describing the impact of curing time	1,000	-
C_l	CO_2 concentration during concrete testing in laborator	0,0400	kg/m^3
k_a	factor describing the impact of CO2	1,065	-
t_0	reference time	0,0767	years
ToW	Time of wetness, i.e., days with daily rainfall ≥ 2.5 mm	0,164	years
W(t)	Weather function	0,547	?

OUTPUT			
Notation	Variable	Value	Unit
x_c	Carbonation depth at time t	9,377	mm

$$k_e = \left(\frac{1-\left(\frac{RH_a}{100}\right)^{f_e}}{1-\left(\frac{RH_l}{100}\right)^{f_e}}\right)^{g_e}$$

$$k_c = \left(\frac{t_c}{7}\right)^{b_c}$$

$$k_a = \frac{c_a}{c_l}$$

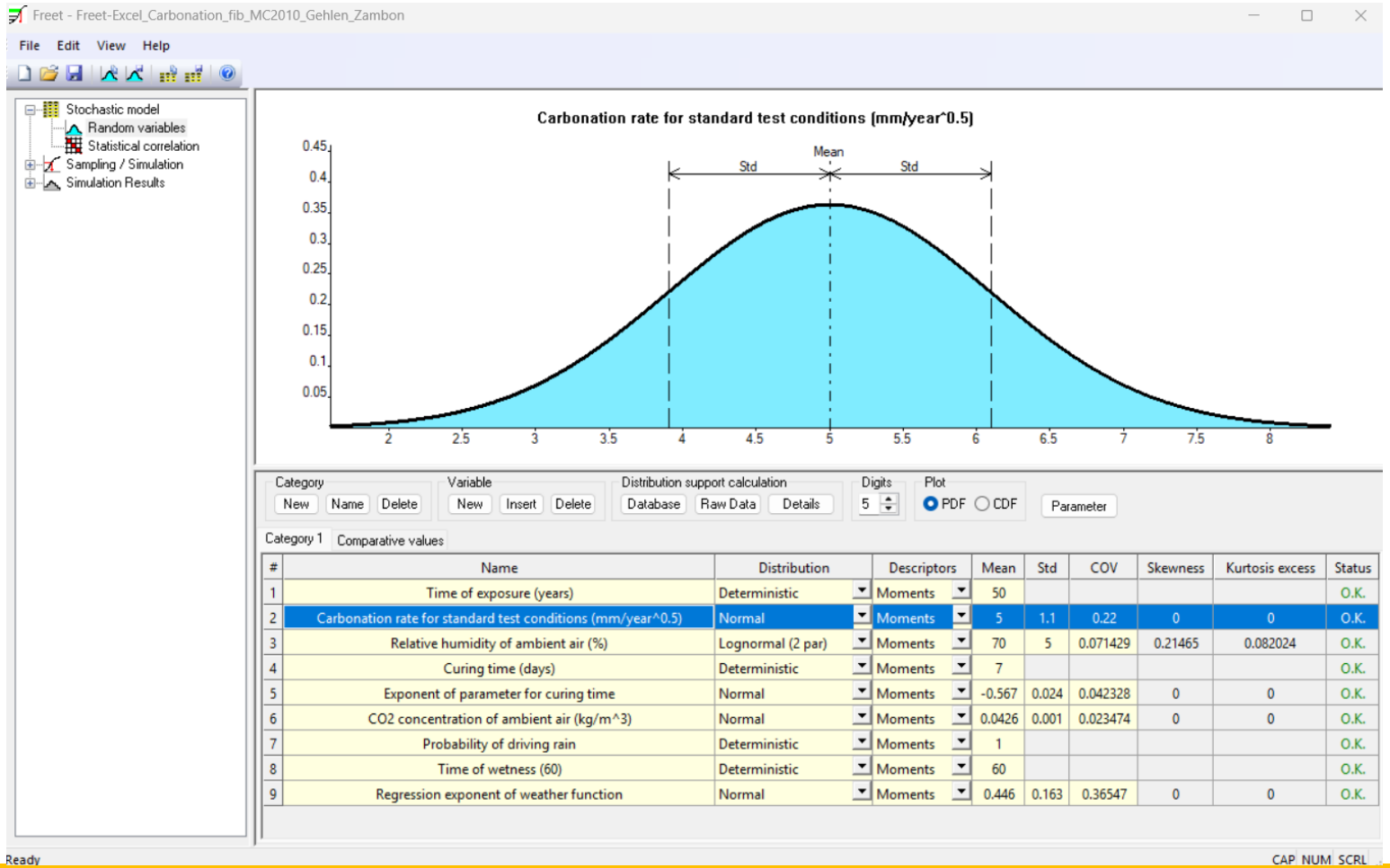
$$W(t) = \left(\frac{t_0}{t}\right)^{\frac{(p_{dr}\cdot ToW)^{bw}}{2}}$$

$$x_c(t) = k_{NAC}\cdot\sqrt{k_e\cdot k_c\cdot k_a}\cdot\sqrt{t}\cdot W(t)$$

CARBONATION

FReET interface directly linked to the Excel framework,

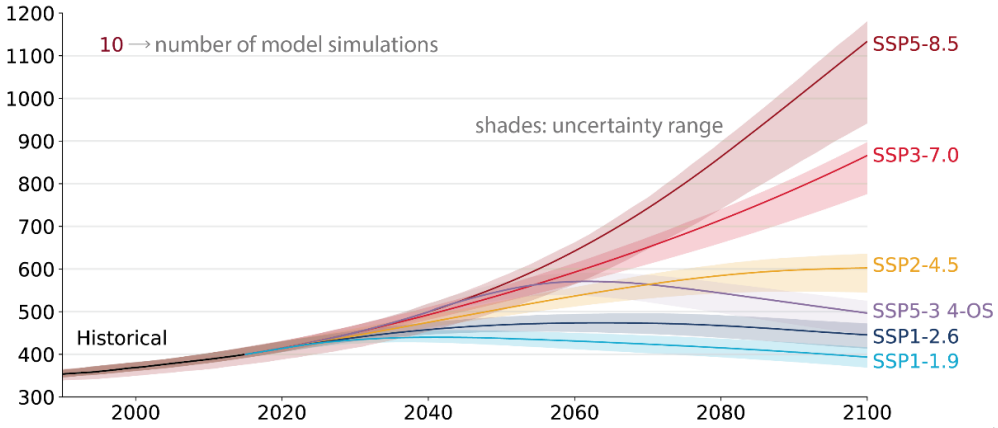
allowing users to modify input parameters beyond default values to match real conditions.

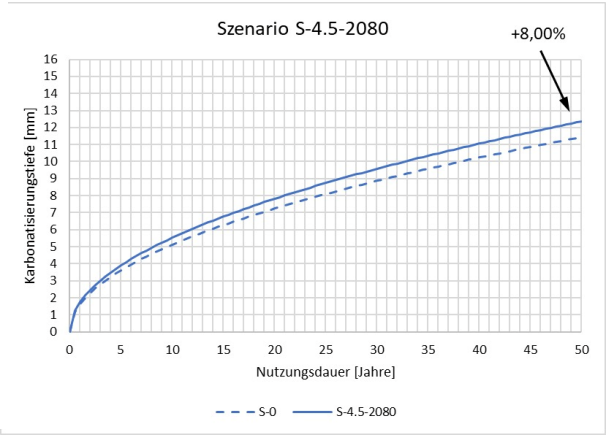


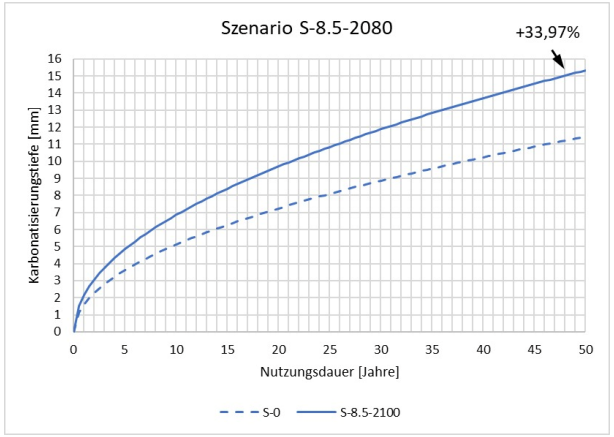
#	Name	Distribution	Descriptors	Mean	Std	COV	Skewness	Kurtosis excess	Status
1	Time of exposure (years)	Deterministic	Moments	50					O.K.
2	Carbonation rate for standard test conditions (mm/year^0.5)	Normal	Moments	5	1.1	0.22	0	0	O.K.
3	Relative humidity of ambient air (%)	Lognormal (2 par)	Moments	70	5	0.071429	0.21465	0.082024	O.K.
4	Curing time (days)	Deterministic	Moments	7					O.K.
5	Exponent of parameter for curing time	Normal	Moments	-0.567	0.024	0.042328	0	0	O.K.
6	CO2 concentration of ambient air (kg/m^3)	Normal	Moments	0.0426	0.001	0.023474	0	0	O.K.
7	Probability of driving rain	Deterministic	Moments	1					O.K.
8	Time of wetness (60)	Deterministic	Moments	60					O.K.
9	Regression exponent of weather function	Normal	Moments	0.446	0.163	0.36547	0	0	O.K.

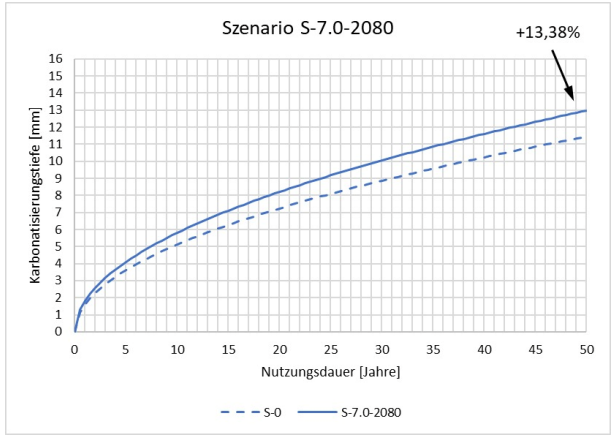
CARBONATION

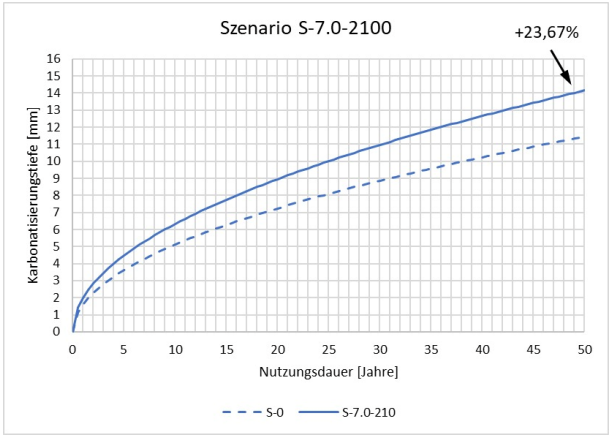
Prediction of carbonation depths under climate mitigation pathways for CEM I, CEM II/B-S, and CEM II/B-LL cement types





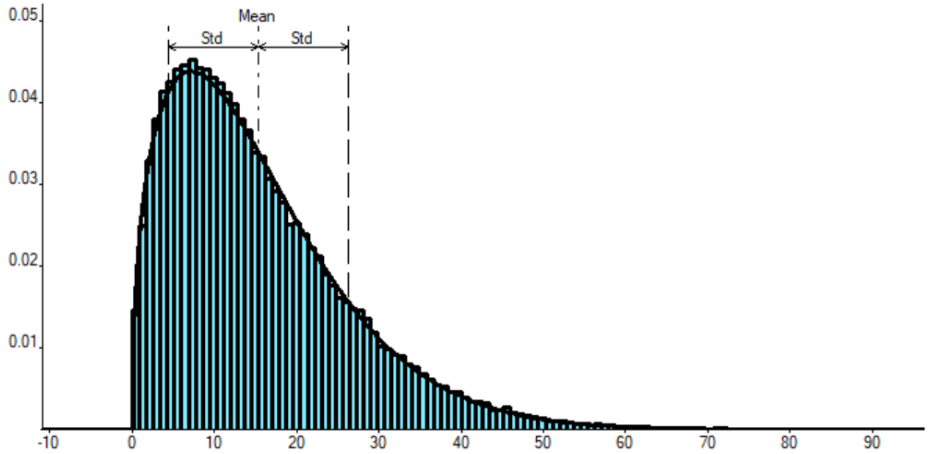






CARBONATION RESULT (EXAMPLE)

Findings from these simulations indicate that a Beta distribution or a Weibull (minimum) distribution provides an appropriate fit for the carbonation depth data.



The sensitivity analysis identifies the most influential input parameters as follows:

- **Carbonation rate** k_{NAC} **:**sensitivity factor ≈ 0.55
- **Relative humidity of ambient air** RH_a **:** sensitivity factor ≈ −0.50
- **Exponent of weather function** b_w **:**sensitivity factor ≈ 0.50
- **CO_2 concentration of ambient air** C_a **:**sensitivity factor ≈ 0.02–0.05
- **Exponent of regression** b_c **:**sensitivity factor ≈ 0.00”

1st IREC WORKSHOP

Chloride Ingress Model based on the fib Model Code 2010 and 2020

CHLORIDE INGRESS MODEL

Purpose:

estimate chloride content *C(x,t)* at a given depth and time.

Possible limit state: depassivation risk is checked at reinforcement depth against a defined critical chloride content *(Ccrit).*

Origin:

fib Bulletin 34 / Task Group 5.6 based on DuraCrete and DARTS; formulation carried into fib Model Code 2010 durability clauses.

concentration-profile model with practical corrections
for temperature/environment, ageing, and near-surface convection zone Δx

CHLORIDE INGRESS MODEL

$$C(x,t) = C_0 + (C_{s,\Delta x} - C_0)\left[1 - \operatorname{erf}\left(\frac{x - \Delta x}{2\sqrt{D_{\mathrm{app},C}(t)\,t}}\right)\right]$$

with $D_{\mathrm{app},C}(t) = k_e\, D_{RCM,0}\, k_t\, A(t)$ and $A(t) = \left(\frac{t_0}{t}\right)^{\alpha}$

- The main transport parameter of the formula *($D_{RCM,0}$)*, is the chloride migration coefficient from the RCM test, measured at 28 days. It expresses how fast chloride ions move through the concrete.

- Values can be approximated from cement type and w/c ratio.

  the error function (erf) is the mathematical function that gives the smooth diffusion profile of chloride with depth (the analytical solution of Fick's second law)

CHLORIDE INGRESS MODEL

Stochastic Models – Key Descriptive & Input Parameters

- **Distributions:** mean (μ), variance (σ^2), distribution type

Notation	Variable	Unit	Obtain by
Δx	Convection zone thickness Delta x	mm	
C_0	Initial chloride content	wt-%/cem	measure
$Cs\Delta x$	Substitute surface chloride at Delta x	wt-%/cem	measure
D_{RCM0_raw}	RCM coefficient in 1e-12 m^2/s	1e-12 m^2/s	Literature / measurement
k_t	Transfer parameter	-	Literature
be	Temperature regression constant	K	Literature
T_{ref}	Reference temperature	K	
T_{real}	Real concrete temperature	K	Monitoring / timeseries
α	Ageing exponent	-	Literature
C_{crit}	Critical chloride threshold	wt-%/cem	
x_cover	Concrete cover depth (steel depth)	mm	Plan documents / measure
t	Exposure time since chloride attack starts	years	
x	Depth from exposed surface	mm	

wt-%/cem = mass percent by weight of cement

CHLORIDE INGRESS MODEL

Structure of the Excel-based framework for Model Code 2010 and 2020, aligned with the Eurocode background.

It supports deterministic and probabilistic (stochastic) assessments

12	0.2715917	Dx	Convection zone thickness Delta x	mm	**fib Chloride Model according to Bulletin 34 and MC2010 [1, 2]**
0.02		C0	Initial chloride content	wt-%/cem	wt-%/cem = mass percent by weight of cement
0.7		CsDx	Substitute surface chloride at Delta x	wt-%/cem	RCM = Rapid Chloride Migration. It is the accelerated laboratory test used to obtain the chloride migration coefficient
6.5		DRCM0_raw	RCM coefficient in 1e-12 m^2/s	1e-12 m^2/s	
1		kt	Transfer parameter	-	
4800		be	Temperature regression constant	K	
293		Tref	Reference temperature	K	
285		Treal	Real concrete temperature	K	
0.3		alpha	Ageing exponent	-	
0.4		Ccrit	Critical chloride threshold	wt-%/cem	
45		x_cover	Concrete cover depth (steel depth)	mm	
20		t	Exposure time since chloride attack start	years	
40		x	Depth from exposed surface	mm	

INPUT VARIABLES			
Notation	Variable	Value	Unit
Dx	Convection zone thickness Delta x	12	mm
C0	Initial chloride content	0.02	wt-%/cem
CsDx	Substitute surface chloride at Delta x	0.7	wt-%/cem
DRCM0_raw	RCM coefficient in 1e-12 m^2/s	6.5	1e-12 m^2/s
kt	Transfer parameter	1	-
be	Temperature regression constant	4800	K
Tref	Reference temperature	293	K
Treal	Real concrete temperature	285	K
alpha	Ageing exponent	0.3	-
Ccrit	Critical chloride threshold	0.4	wt-%/cem
x_cover	Concrete cover depth (steel depth)	45	mm
t	Exposure time since chloride attack start	20	years
x	Depth from exposed surface	40	mm

STOCHASTIC MODEL (define in FReET)					
Name	Distribution	Descriptors	Mean	Std	COV
Convection zone thickness Delta x (Dx) [mm]	Beta (0<Dx<50) / Lognormal	Moments	8.9	5.6	
Initial chloride content (C0) [wt-%/cem]	Deterministic	Moments	0		
Substitute surface chloride at Delta x (CsDx) [wt-%/cem]	Lognormal	Moments	1.6	1.1	
RCM coefficient in 1e-12 m^2/s (DRCM0_raw) [1e-12 m^2/	Normal	Moments	16	3	
Transfer parameter (kt) [-]	Deterministic	Moments	1		
Temperature regression constant (be) [K]	Normal	Moments	4800	700	
Reference temperature (Tref) [K]	Deterministic	Moments	293		
Real concrete temperature (Treal) [K]	Normal	Moments	283	3	
Ageing exponent (alpha) [-]	Beta (0<a<1) / Lognormal	Moments	0.3	0.12	
Critical chloride threshold (Ccrit) [wt-%/cem]	Beta (0<Ccrit<2) / Lognormal	Moments	0.6	0.15	
Concrete cover depth (steel depth) (x_cover) [mm]	Normal	Moments	32	8	
Exposure time since chloride attack starts (t) [years]	Deterministic		20		
Depth from exposed surface (x) [mm]	Deterministic		40		

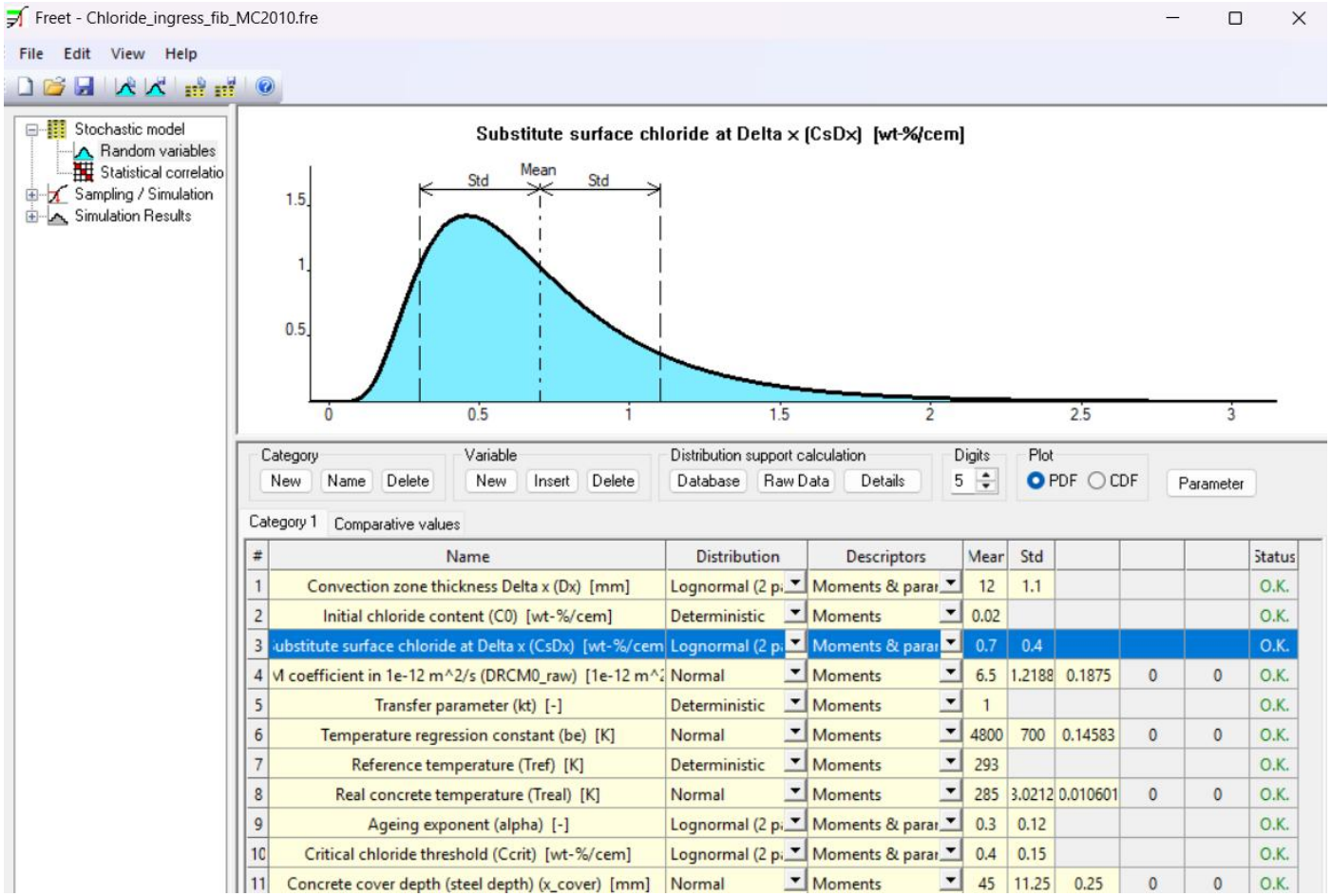
SUPPORTING CALCULATIONS			
Notation	Variable	Value	Unit
t0	Reference time (28 days in years)	0.07671233	years
DRCM0_mm2y	Converted RCM coefficient	204.984	mm^2/year
kT	Temperature factor	0.63137664	-
Dapp	Apparent diffusion coefficient at age t	24.3870362	mm^2/year

OUTPUT					
Variable		Value	Unit		
C_xt	**Chloride at depth x and time t**	**0.27159166**	**wt-%/cem**	**Result for FReET**	**(goes to Excel Cell B1)**
x_Ccrit	Depth where C(x,t) equals Ccrit	30.2583187	mm		
C_at_cover	Chloride at steel depth x_cover	0.21767671	wt-%/cem		

CHLORIDE INGRESS MODEL

FReET interface directly linked to the Excel framework,

allowing users to modify input parameters beyond default values to match real conditions.

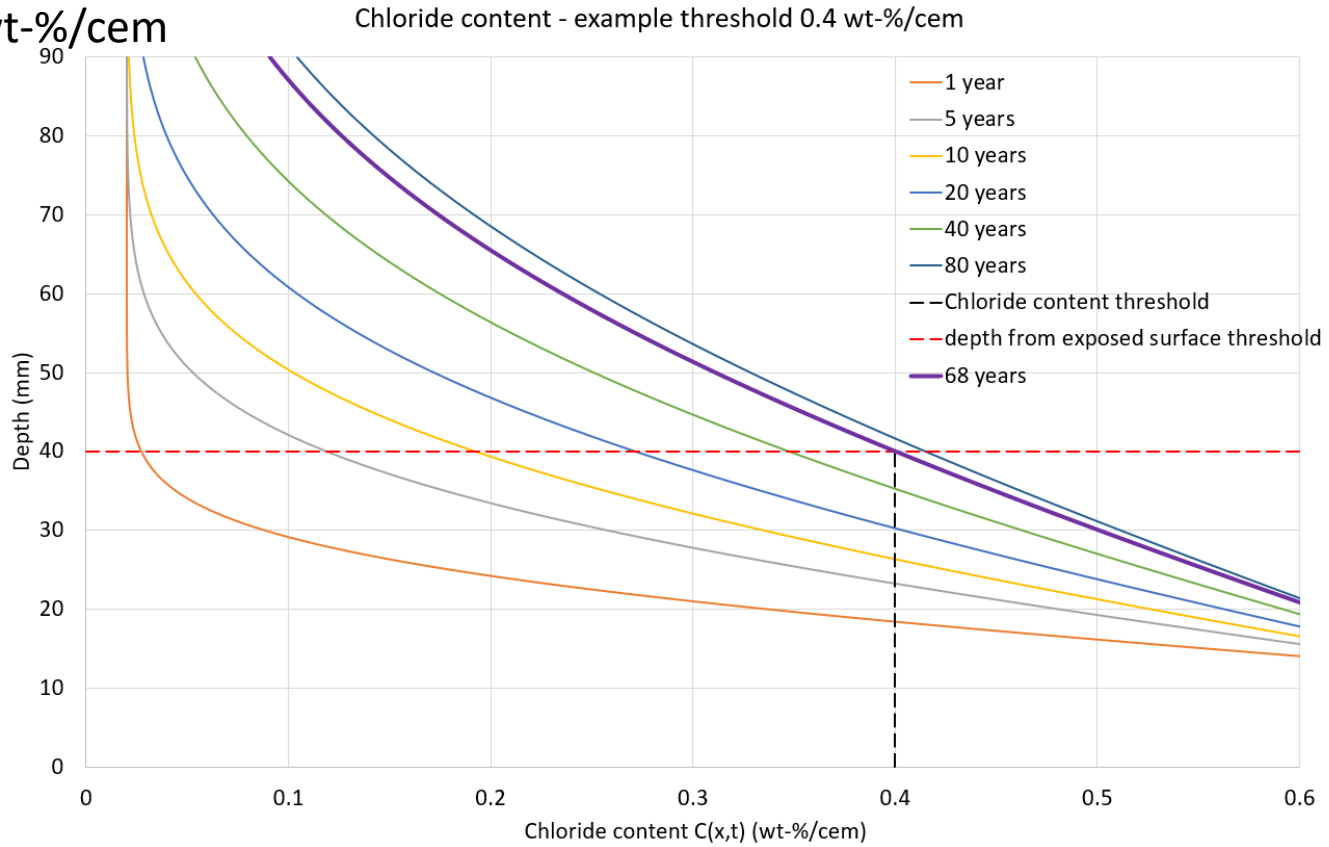


#	Name	Distribution	Descriptors	Mean	Std				Status
1	Convection zone thickness Delta x (Dx) [mm]	Lognormal (2 p	Moments & para	12	1.1				O.K.
2	Initial chloride content (C0) [wt-%/cem]	Deterministic	Moments	0.02					O.K.
3	ubstitute surface chloride at Delta x (CsDx) [wt-%/cem	Lognormal (2 p	Moments & para	0.7	0.4				O.K.
4	M coefficient in 1e-12 m^2/s (DRCM0_raw) [1e-12 m^2	Normal	Moments	6.5	1.2188	0.1875	0	0	O.K.
5	Transfer parameter (kt) [-]	Deterministic	Moments	1					O.K.
6	Temperature regression constant (be) [K]	Normal	Moments	4800	700	0.14583	0	0	O.K.
7	Reference temperature (Tref) [K]	Deterministic	Moments	293					O.K.
8	Real concrete temperature (Treal) [K]	Normal	Moments	285	3.0212	0.010601	0	0	O.K.
9	Ageing exponent (alpha) [-]	Lognormal (2 p	Moments & para	0.3	0.12				O.K.
10	Critical chloride threshold (Ccrit) [wt-%/cem]	Lognormal (2 p	Moments & para	0.4	0.15				O.K.
11	Concrete cover depth (steel depth) (x_cover) [mm]	Normal	Moments	45	11.25	0.25	0	0	O.K.

CHLORIDE INGRESS MODEL

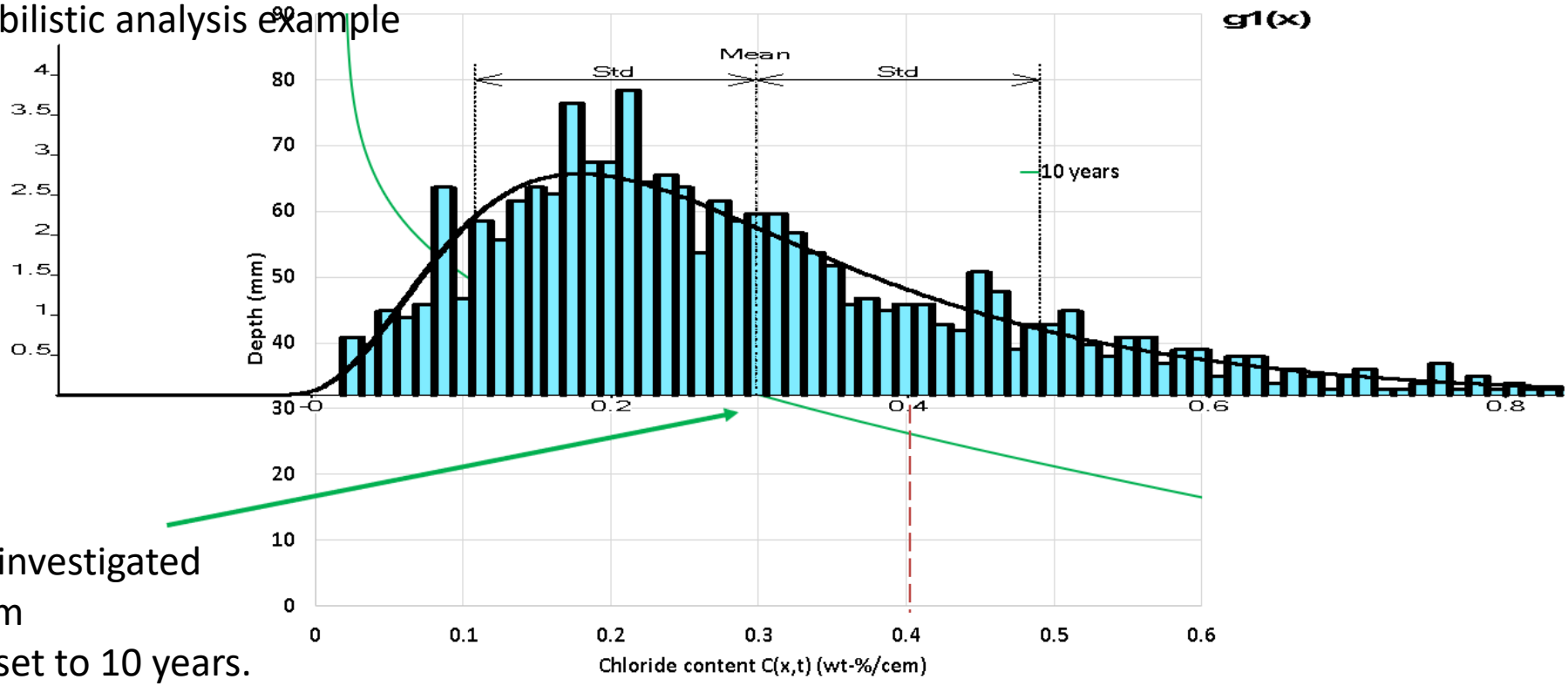
- Curves are created by variation of exposure time *(t)* and depth from the exposed surface *(x)*
- In the example C_{crit} is defined as 0.4 wt-%/cem
- And concrete cover depth 40 mm

- The defined critical chloride content is reached after 68 years of exposure



CHLORIDE INGRESS MODEL

- Outlook: Probabilistic analysis example



Chloride content is investigated
at a depth of 32 mm
and exposure time set to 10 years.

Early result interpretation: probability of exceedance at this point is around 30%

1st IREC WORKSHOP

Thank you for your attention.

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