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SOFTWARE PACKAGE PROBCALC FROM THE POINT OF VIEW OF A USER

PROGRAMOVÝ SYSTÉM PROBCALC Z HLEDISKA UŽIVATELE

Abstract

The development of Direct Optimized Probabilistic Calculation method (DOProC) started in 2002. DOProC applications are processed in ProbCalc – this software is being improved all the time. It is rather easy to implement an analytical transformation model of the specific probabilistic application into ProbCalc. The reliability function under analysis can be expressed in ProbCalc analytically as a sign arithmetic expression or can be expressed using data from the dynamic library.

Keywords

Direct Optimized Probabilistic Calculation, DOProC, software package ProbCalc, HistOp, HistAn, probabilistic calculation, reliability assessment, probability of failure, reliability function, random variable.

Abstrakt

Metoda Přímého Optimalizovaného Pravděpodobnostního Výpočtu (dále jen POPV) je vyvíjena od roku 2002. V současné době již lze metodou POPV s využitím optimalizačních kroků výhodně řešit značné množství pravděpodobnostních úloh. Pro aplikaci metody POPV je možno použít stále vyvíjený programový systém ProbCalc, do něhož lze relativně jednoduše implementovat analytický transformační model řešené pravděpodobnostní úlohy.

Klíčová slova

Přímý Optimalizovaný Pravděpodobnostní Výpočet, POPV, programový systém ProbCalc, HistOp, HistAn, pravděpodobnostní výpočet, posudek spolehlivosti, pravděpodobnost poruchy, funkce spolehlivosti, náhodné proměnné.

1 INTRODUCTION

When developing DOProC, it became clear that a software package would be essential that would be able to define generally any mathematical calculation of the probabilistic calculation. The result of such efforts is the ProbCalc which is still being developed. This software package consists of three separate calculation modules that were introduced first in [1]. The software was also presented at [2, 3, 4].

There is also HistAn [5] - a software tool that analyses the input histograms of random quantities in detail. Basic material operations can be carried out with the histograms in calculations.

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For instance, in case of a combined load, the histograms of the individual types of load will be summed up. HistOp [6] is another software application. In this software, it is possible to carry out basic arithmetic operations with histograms.

In standard practice, even more complicated operations should be carried out with the histograms. Such operations depend on definition of a calculation model. In fact, calculation procedures are still the same. It is only necessary to develop an efficient computation tool so that the user could describe even more complicated models, for instance, by using a text. For those reasons, [7] (Fig.1) has been under development since 2004. It includes all options from the previous applications and can be used for the probabilistic calculation of mathematical models.

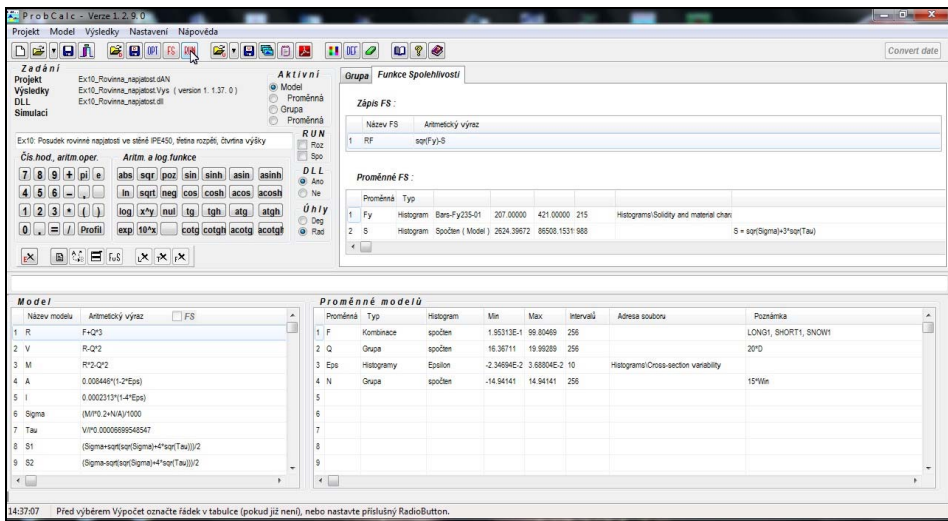
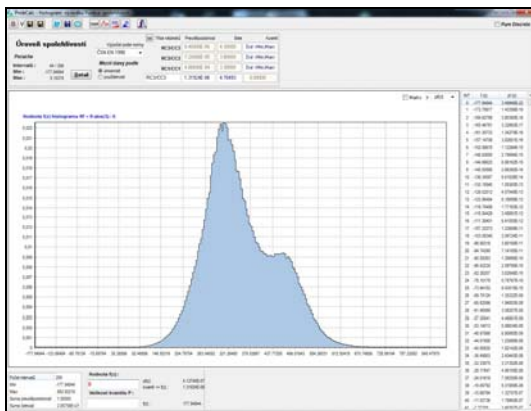
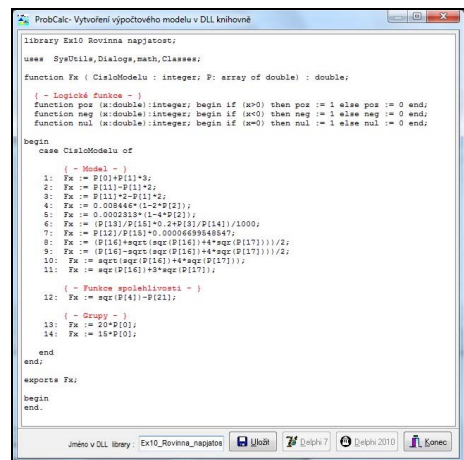


Fig. 1: ProbCalc desktop



a) RF reliability function and the assessment of reliability



b) Transformation of the pre-defined calculation model from a calculator into a dynamic library

Fig. 2: Working windows in ProbCalc

If the objective of the probabilistic calculation is assessment of reliability of a structure, ProbCalc can calculate the failure probability p_f based on the probabilistic function RF and can also make the necessary assessment in line with standards and regulations in force (Fig.2.a). Interesting

features of ProbCalc include a 3D view of the analyzed reliability function RF (Fig.3) where the probabilistic task can be investigated in detail.

The reliability function can be expressed in ProbCalc analytically as a sign arithmetic expression (using the so-called calculator) or can be expressed using data from the dynamic library (the file with DLL extension) where the library can be created in any programming language (for instance, in Delphi, C++ or FORTRAN). The key advantage of using the dynamic libraries in ProbCalc probabilistic calculations is a possibility to define a mathematical model which should be limited only by capabilities of the software (in the „calculator“ model, the mathematical model is limited by 30 text lines). This means, it is possible to include all software development procedures into the calculation model (logical decision-making processes or cycles). Or, numerical analysis algorithms can be used for the probabilistic calculation. In case of probabilistic calculations with a mathematical model which is defined in the calculator mode (this means, in a text mode), ProbCalc automatically generates a source text for a dynamic library in Delphi (Fig. 2.b). After the file name is entered, the text can be loaded in the application, compiled into a machine code and attached to ProbCalc. This reduces the machine time needed for calculations approximately four times (the software does not need to transform definitions of the mathematical model from the text mode into machine code instructions).

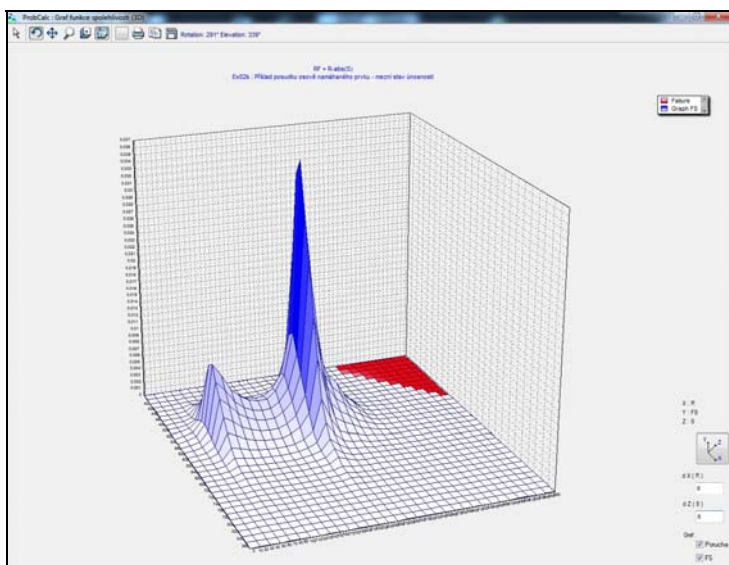


Fig. 3: 3D view of the reliability function in ProbCalc

In order to reduce the time needed for the probabilistic calculation, the software includes a number of optimizing techniques (see Chapter 3) that run often independently of the users. Following chapters describe in detail ProbCalc from the point of view of a user.

2 INPUT RANDOM VARIABLES

The input quantities used in the probabilistic calculation in ProbCalc can be expressed by means of histograms with a non-parametric (empirical) distribution which is divided in Fig. 4 for discrete quantities or in Fig. 5 for purely discrete quantities.

The variability of the input random variables can be expressed in probabilistic calculations by means of a histogram with a well-chosen parametric distribution of the probability which is possible if there are few measured data only or in cases when the quantity cannot be measured, but is estimated only.

When creating the histograms in ProbCalc, the parametric probability distribution can be approximated using the technique set forth in Fig. 6. The histograms can be built once the necessary parameters are entered. They include the required number of intervals (classes) and ε which is needed to limit the definition area for the probabilistic distribution of a continuous random quantity (see Fig. 6). This quantity corresponds to the probability in the place of truncation. This place is defined for the chosen type of the parametric distribution of the probability on the basis of an iteration calculation.

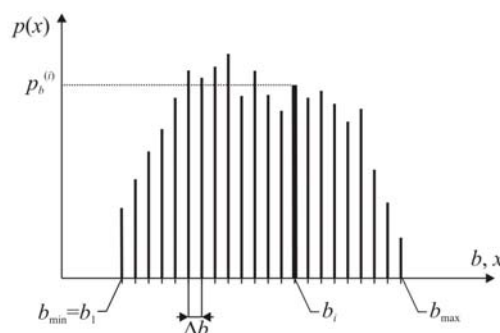
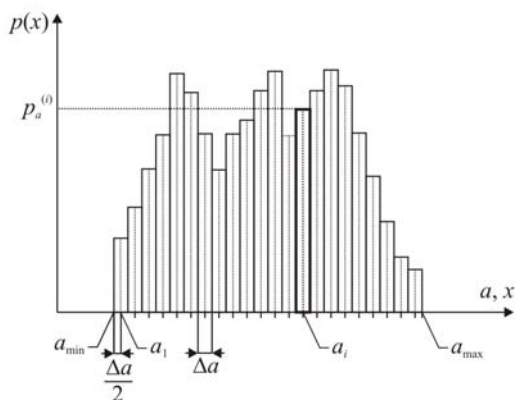


Fig. 4: Histogram – a discrete random quantity Fig. 5: Histogram – a pure discrete random quantity

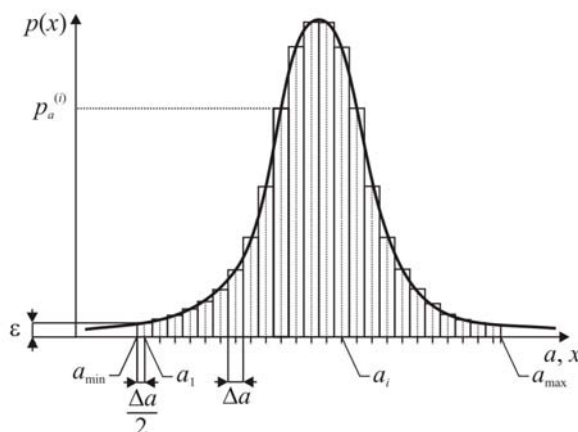


Fig. 6: Histogram – an approximated random quantity with the parametric distribution of probabilities

The histogram of an approximated random quantity with the parametric distribution of probabilities can be created automatically in the ProbCalc software package if the user chooses *Parametric Distribution* as an option when entering the input quantity.

HistAn, HistOp and ProbCalc contain a module for entering and assessment of measured data. The software can read values saved in a text file and can create histograms with non-parametric distribution of the probabilities. It is also possible to select there the number of intervals or histograms with parametric distribution of the probabilities. Twenty four different types of the parametric distribution of the probabilities are available. It is possible to choose the best one for the file of collected or measured data. A determination coefficient can be defined as a level of suitability for a probabilistic parametric distribution density curve.

Mostly independent random quantities are involved in the assessment of reliability of structures. Some input quantities can be, however, statistically dependent – for instances, the cross-section characteristics, strength or rigidity parameters of materials. The variable statistically dependant input quantities have been so far dealt with particularly in connection with the cross-section of rolled sections. In the DOProC calculation, they can be entered by means of independent quantities which are described, for instance, by histograms. The direct entry of the statistically dependant input quantities for the DOProC calculation is being developed now.

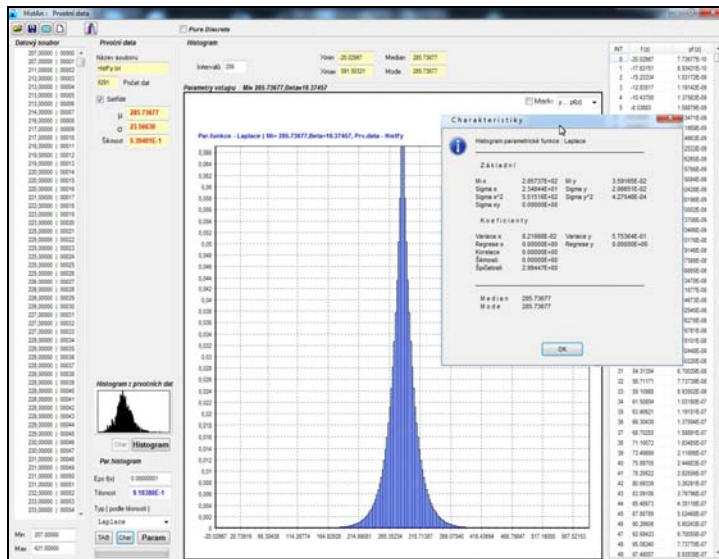


Fig. 7: Histogram based on the measured data – the best parametric distribution of probabilities

HisAn: Tabulka charakteristik

Charakteristiky prvotních dat

	Mix	Sigma x	Sigmat
	285.73677	23.56630	5.59401E-1

Charakteristiky histogramu prvotních dat

i	T y p	Těsnost	Medan	Mode	Mix	Sigma x	Sigma x^2	Miy	Sigma y	Sigma y^2	Sigma xy	Variance x	Regress x	Variance y	Regress y	Korelace
1	Prvotní data	1.00000	284.95648	281.52579	285.64725	23.47477	551.06505	1.95314E-2	6.47657E-3	4.19459E-5	-2.7055E-2	8.21235E-02	4.9031E-05	4.7863E-01	-1.77941E-01	

Charakteristiky parametrických histogramů

i	T y p	Těsnost	Medan	Mode	Mix	Sigma x	Sigma x^2	Miy	Sigma y	Sigma y^2	Sigma xy	Variance x	Regress x	Variance y	Regress y	Korelace
1	Laplace	9.1830E-1	288.12557	288.12557	285.73677	23.48437	551.51560	3.59165E-2	2.06651E-2	4.27046E-4	0.00000	8.21888E-02	0.0000E+00	5.75364E-01	0.0000E+00	0.0000E+00
2	Fisher-Tippett	8.0039E-1	294.62354	287.85055	296.84544	23.47423	551.03968	2.31283E-2	9.95282E-3	2.35726E-4	-1.29894E-1	7.90790E-02	-2.35726E-04	4.30331E-01	-1.31129E+03	5.59572E-01
3	Gumbelovo_1	7.9980E-1	283.45150	276.96491	286.28923	23.47424	551.03972	2.21503E-2	9.53197E-3	9.08594E-5	-1.24402E-1	8.19948E-02	-2.25788E-04	4.30331E-01	-1.36918E+03	5.59572E-01
4	Logistic	7.4318E-1	285.73677	285.73677	285.73677	23.47424	551.03978	2.57904E-2	1.15338E-2	1.33029E-4	0.00000	8.21534E-02	0.0000E+00	4.47214E-01	0.0000E+00	0.0000E+00
5	LogNormal_3P	6.7129E-1	284.74694	280.93989	286.02544	23.47424	551.04002	1.57369E-2	6.30878E-3	3.90006E-5	-4.79680E-2	8.20705E-02	-8.70500E-05	4.00892E-01	-1.20521E+03	-3.2390E-01
6	LogNormal_2P	6.78174E-1	285.67191	283.97778	285.86646	23.47424	551.04011	1.38763E-2	5.48159E-3	3.00478E-5	-2.00326E-2	8.21611E-02	-3.63542E-05	3.94976E-01	-6.66691E+02	-1.55682E-01
7	Normalní	6.72509E-1	285.73677	285.73677	285.73677	23.47424	551.04015	1.33824E-2	5.26356E-3	2.77050E-5	0.00000	8.21534E-02	0.0000E+00	3.93320E-01	0.0000E+00	0.0000E+00
8	Raised-cosine	2.85538E-1	285.73677	285.73677	285.73677	23.47424	551.04009	5.85938E-3	1.95313E-3	3.81470E-06	0.00000	8.21534E-02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	Studentovo	2.48468E-1	0.00000	0.00000	0.00000	5.21201	27.16507	4.34574E-1	1.13416E-1	1.28633E-2	0.00000	undefined	0.0000E+00	2.60893E-01	0.0000E+00	0.0000E+00
10	Snedecorovo	1.64418E-1	57.83928	19.33010	98.55594	339.13326	115011.36557	5.62408E-1	2.57817E-1	8.86948E-2	-32.88440	3.44104E+00	-2.59523E-04	5.29537E-01	-3.70759E+02	-3.25589E-01
11	Exponenciální	1.20498E-1	500.57650	160.00544	580.74952	284.95886	80973.74640	3.58220E-2	2.07218E-2	4.25391E-4	-5.10768	4.89896E-01	-6.30782E-05	5.76854E-01	-1.18952E+04	6.66213E-01
12	Weibull	1.16118E-1	255.53633	160.25793	288.05107	193.29388	37362.52362	1.45934E-2	5.69196E-3	3.23895E-5	-0.06446E-1	6.69182E-01	-2.42608E-05	3.90037E-01	-2.79780E+04	-8.23875E-01

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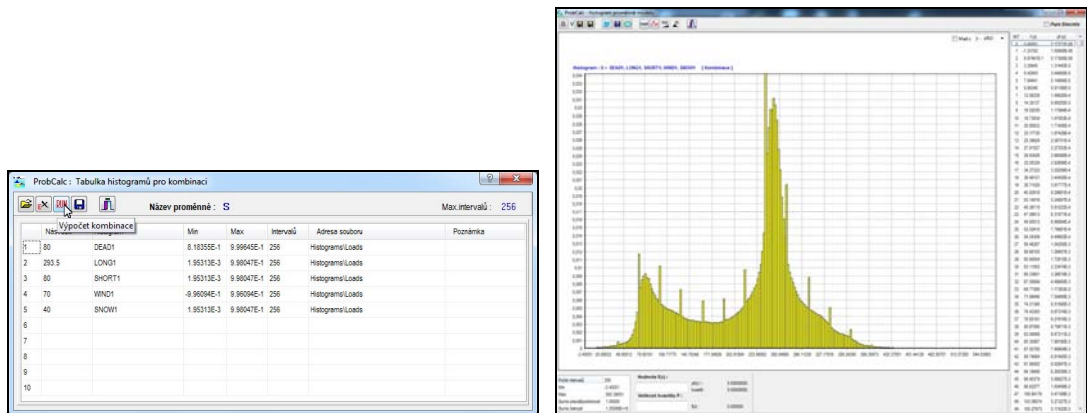
Fig. 8: List of the best parametric distributions and their parameters

3 OPTIMISING THE CALCULATION IN PROBCALC

The purpose of the DOProC optimizing techniques is to minimize the computing time since the algorithm is limited to a certain extent, in particular, for extensive applications where too many simulations exist. If the optimizing techniques are used in DOProC, the failure probability, p_f , can be determined in a real time. On top of this, results are reliable and accurate enough even in relatively demanding probabilistic tasks.

The optimizing techniques include:

- a) **Grouping of variable input quantities** which eliminate the number of input variable histograms – if possible, the resulting histogram is determined on the basis of the required mathematical operation. Then, the histogram is used for the probabilistic calculation of the model. If the grouping (this means, the creation of joint histograms of the input quantities) is possible and reliable, it is a very efficient and reasonable optimizing technique which reduces dramatically the number of computational operations in the probabilistic calculation. This optimizing technique is used most frequently in calculations of the combined load (Fig. 9) or in a summary histogram which expresses impacts of wind loading by means of a „wind rosette“. This feature can be turned on in individual ProbCalc modules in the table of input quantities. Before entering the group of the input quantities where the mathematical definition is other than a sum, the user can open the *Groups* folder in the ProbCalc desktop (this is, for instance, the case of a variable cross-section characteristics).

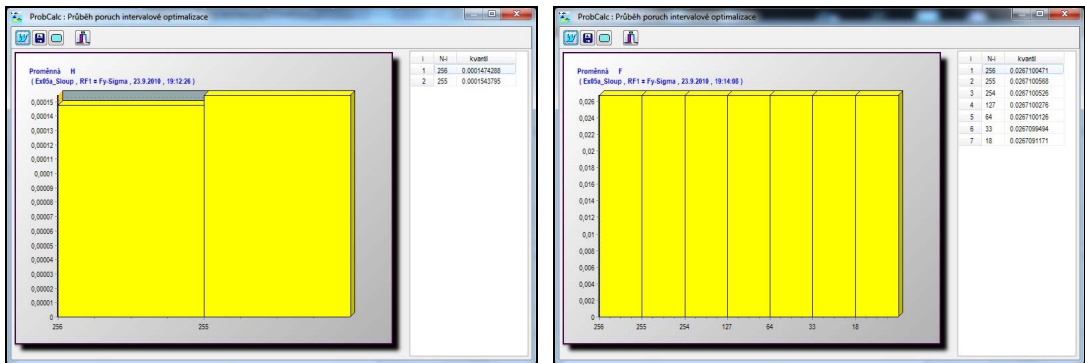


a) a table for entering individual load components

b) a combined load histogram

Fig. 9: Calculating the combined load in ProbCalc

- b) **Interval optimizing** - the objective is to minimize the number of classes used in the input quantity histograms. This reduces the number of computation operations and minimizes the machine time needed for the probabilistic calculation. A mandatory condition for this optimizing technique is the maintaining of sufficient accuracy of the required results. For this optimizing technique it is essential to check the influence of such reduction onto the result. In each interval optimizing, impacts of individual input quantities on the result should be analyzed in terms of sensitivity. If the sensitivity of some quantities is lower (such as Fig. 10.b.), it is generally possible to decrease the number of interval considerably more than for the quantities with a high sensitivity (Such as Fig. 10.a). The permitted deviation from the accurate solution can be entered using ϵ . For instance, 0.01 represents 1% deviation from the standard solution. The machine time needed for the interval optimizing (Fig. 11) is in an order of seconds.
- c) **Zone optimizing** – only intervals affecting a certain value, for instance the failure probability of a structure, p_f , are involved in the calculation. In the zone analysis, each input quantity interval is divided into zones (see Fig. 12) which affects the failure probability, p_f , for all possible values in other histograms:
- zone #1 – the intervals (the classes) in the input quantity histograms always affect the failure probability, p_f . This means, they affect the failure probability irrespective of combinations of the intervals of the remaining input quantities (in ProbCalc, this histogram zone is marked in red).



a) a sensitivity analysis of a random quantity with a high influence on the failure probability p_f

b) a sensitivity analysis of a random quantity with a low influence on the failure probability p_f

Fig. 10: The interval optimizing in ProbCalc

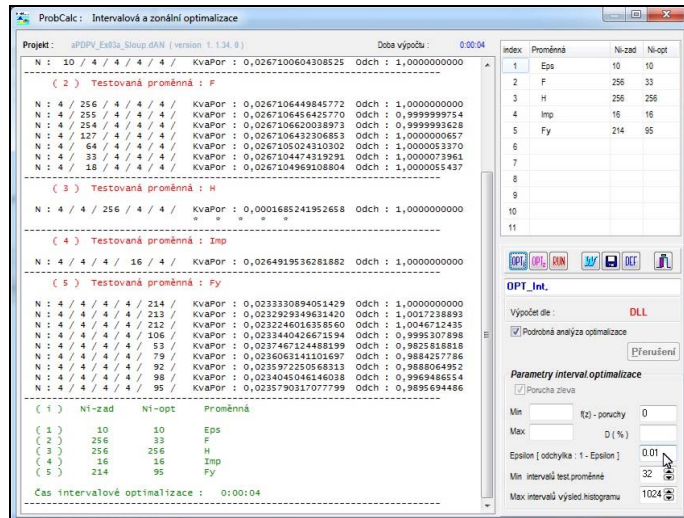


Fig. 11: ProbCalc desktop - the interval optimizing

- zone #2 - the intervals (the classes) in the input quantity histograms may affect the failure probability, p_f . This means, they affect the failure probability only for some combinations of the intervals of the remaining input quantities (in ProbCalc, this histogram zone is marked in yellow).
- zone #3 - the intervals (the classes) in the input quantity histograms never affect the failure probability, p_f . This means, this part of the histogram can be completely neglected when determining the failure probability, p_f , (in ProbCalc, this histogram zone is marked in blue).

From the point of view of the machine code, the knowledge of zones makes calculation of the failure probability, p_f , more efficient. The failure probability consists now of two components:

$$p_f = p_{f,1} + p_{f,2}, \quad (1)$$

where $p_{f,1}$ is the sum of all probabilities in the zone #1 interval of the analyzed histogram. (If this zone exists, the probabilities for the zone #1 interval affect the failure probability, p_f , in

each case. $p_{f,2}$ is a section (where the failure may occur, but does not need to) for the affect the failure probability, p_f in the interval within the zone #2 (the zone #3 do not affect the failure probability, p_f).

- d) **Trend optimizing** – the algorithm considers the suitable trend of the probabilistic calculation. This optimizing technique starts automatically when the zone optimizing technique is chosen, if the *Trend optimizing* checkbox is checked in the *Settings* window in ProbCalc. In the context of the zone optimizing technique, the calculation is carried out only for the zone #2 intervals (yellow). If the trend is that the resulting positive value of the reliability function increases with changes in the random variable, it does not make any sense to introduce other computational combinations. For such a quantity, the reliability function cannot reach negative values and cannot influence the failure probability p_f . This means, it is possible to eliminate computational combinations and to keep only those which are really needed.

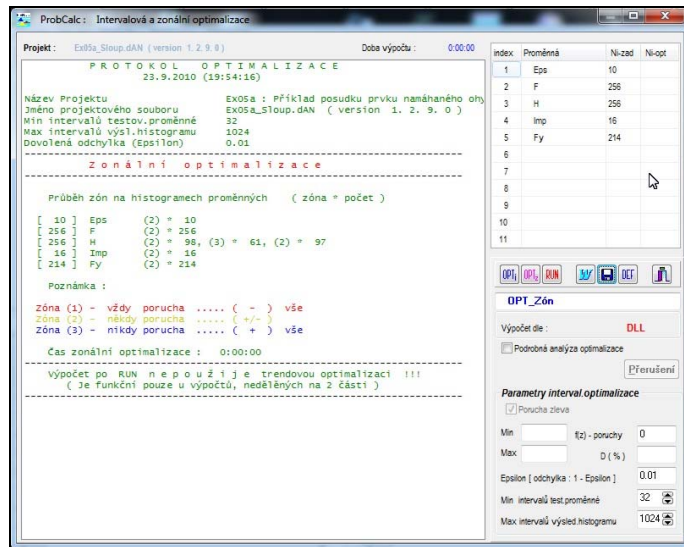
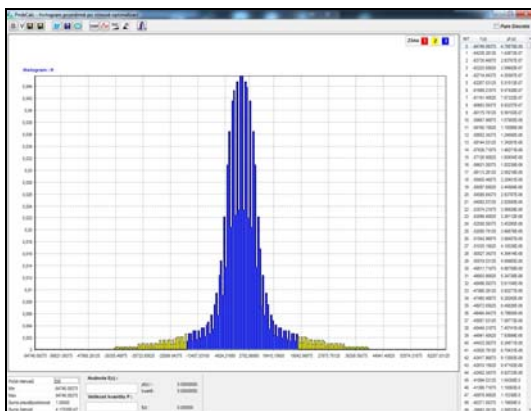
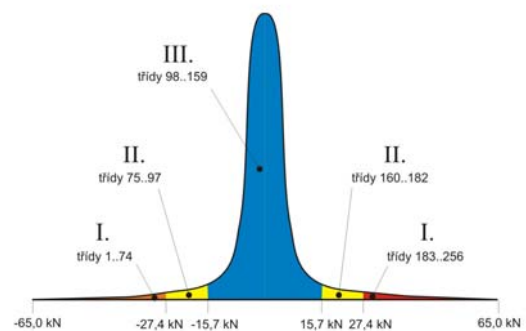


Fig. 12: ProbCalc desktop - the zone optimizing technique



a) zones in the analyzed histogram



b) explanation of the zone analysis

Fig. 13: Results of the zone analysis

- e) **Grouping of partial computational results** - the purpose is to decrease the number of computational operations during the final assessment of the histograms of the quantities being the result of the computational model. In case of the probabilistic reliability assessment, this

group is defined by the reliability function RF where the entered values are the calculated reliability of the structure, R , and loading impacts, S . In some cases, it is possible to enter directly the input quantity histogram into this group. (Such quantity can be the strength characteristic of the used material if the reliability assessment is done for the tension and the quantity is not involved in the computational model, or a limit deflection of the reliability assessment is based on the ultimate state of usability).

- f) **Computation parallelization** – the computation is carried out in several processors or core at the same time. In the basis algorithm of DOProC, the scope of the computational operations can be divided into several parts. The number of those parts is the same as the number of available computational units. After partial computations are carried out, the partial results are compiled to create the final histogram of the quantity, for instance the reliability function, RF , for the probabilistic assessment. A separate software application - ProbCalcDV – calculates the individual parts, while ProbCalc compiles them to create a whole. It is only necessary to check in the checkbox *RUN - Roz* in the main window if the calculation could be divided or *RUN - Spo* if the calculation should be compiled together. In both cases, it is necessary to carry out same working operations until the moment when the *Run* button is pressed and the calculation starts. This means, by that time, it is necessary to calculate the combinations, summary histograms or groups of the input quantities. In case of the interval optimizing or zone optimizing techniques, the calculations should be completed before the calculation is divided, while before the compiling the sections together, this is not necessary anymore (but does not matter, if still done). The computation parallelism process in ProbCalc has been tested so far in two-processor computers.

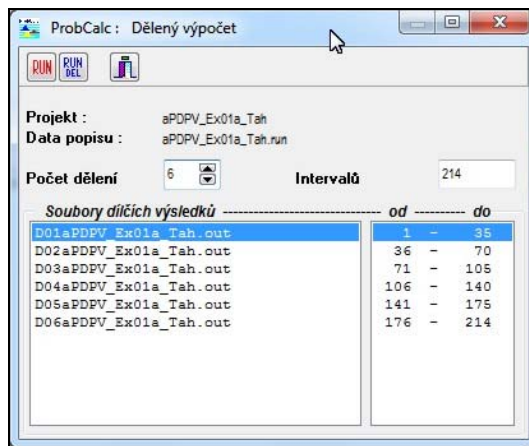


Fig. 14: ProbCalc module where the probabilistic task can be processed in separate sections

- g) **Combination of the optimizing techniques above.** The optimizing techniques have been implemented into ProbCalc and can be combined in the probabilistic calculation. The number of computational operations and the resulting machine time in ProbCalc can be influenced, to a certain extent, by the user who specifies the computational model. Below is the recommended sequence of the optimizing techniques in ProbCalc:

1. **Grouping of the input and output quantities** which should be used always, if possible.
2. **Interval optimizing.** It is recommended to minimize the number of histogram groups, particularly, when debugging the computational algorithm. Then, the number of the histogram classes should be optimized for specific results.
3. **Other optimizing techniques** which should be used, if possible and feasible in terms of complexity.

4 CONCLUSION

DOProC appears to be a very efficient tool that results in the solution affected by a numerical error and by an error resulting from the approximation of the input and output quantities only. In case of the probabilistic assessment of the reliability of structures, DOProC expresses directly the failure probability, p_f , which can be compared with the designed probability, p_d , defined in standards and regulations in force.

ProbCalc is DOProC-based software that can be widely used in probabilistic tasks occurring in the technical practice. If the optimizing techniques are used in DOProC, the failure probability, p_f , can be determined in a real time. On top of this, results are reliable and accurate enough even in relatively demanding probabilistic tasks.

Where the failure probability, p_f , is zero (the structure is excessively reliable) or equal to one (the input quantities in any combination result in a failure), DOProC estimates the result immediately and no probabilistic calculations are needed anymore.

A light version of ProbCalc can be downloaded at [8].

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