Application of the Direct Optimised Probabilistic Calculation Method

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*Abstract:*The probabilistic methods find its application in engineering practice at solving of tasks when variables with random character enter in the computational model. The newly developed method, Direct Optimised Probabilistic Calculation - DOProC, appears as a very effective one for a line of tasks considering either computing time, either obtained solution accuracy. The computing procedure does not use any simulation technique and works in purely numerical way. The described algorithm has already been implemented in several applications which were successfully used at solution of probabilistic tasks and probabilistic reliability evaluations.

Key-Words: DOProC, Direct Optimized Probabilistic Calculation, ProbCalc, HistAn, HistAn2D, HistAn3D, HistOp, Anchor, FCProbCalc, probabilistic methods, reliability assessment, random variable, probability of failure

1 Introduction to the Issue

At present a line of computing procedures are used for evaluation of bearing structures reliability which come out of the probability theory and mathematical statistics the development of which has been passing through significant growth lately. These computing procedures contribute to qualitatively higher level of the reliability evaluation and also to security provision of users of the designed object[1, 8, 23, 24, 26]. They are suitable for design of bearing structure elements with set reliability level when at least some of the design variables have random character. At defining the input random variables they are frequently based on values coming from measurements performed with real objects even the long-term ones [2, 25].

The probabilistic evaluation process and structure design have just entered in the common design practice [29]. The stated computing procedures are used namely at designs of structural [9] or underground bearing systems [28] when also the service life of the construction can be estimated in addition to its reliability, or to analyse its resistance to degradation effects [27] and corrosion respectively [22, 30].

The article is focussed on the utilisation of original and newly developed probabilistic method Direct Optimised Probabilistic Calculation (hereinafter DOProC), which functions purely numerically without application of any of the simulation techniques which results in a more precise solution of probabilistic tasks and in certain situations also to a far more quicker calculation[5, 11].

The calculation methodology using the DOProC method was already theoretically processed in several publications [3, 4]. At present a line of probabilistic tasks can be solved using the DOProC method. For these purposes several software means applying the DOProC method were developed.

2 Application of DOProC Method for Universal Use

For the probabilistic calculations with the possibility to freely define the computing model and also the input random variables the continually developed program system ProbCalc can be used which consists of several computing modules [5, 14].

2.1 HistAn Program

The program tool HistAn(see Fig. 1) serves for more detailed analysis of input and resulting histograms. Using this tool we can obtain histogram basic characteristics and also perform simple calculations - for instance setting of functional value with correspondent quantile and even the inversion operation - setting of quantile for set variable functional value. Using it we are also able to determine combinations of several input histograms

and so called summary histogram which can be used for the so called wind rose calculations. Last but not least histograms with parametric distribution of probability can be compiled in the program after entering necessary parameters depending on the applied probability division. The program user can select from the list of twenty mostly used types of parametric distribution of probability.

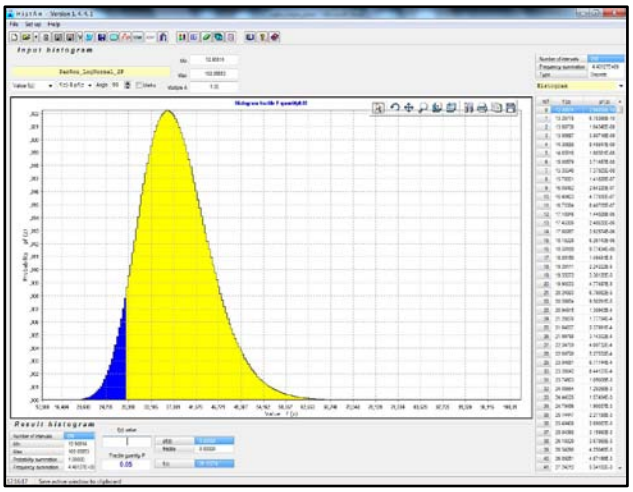

Fig.1:Desktop of HistAn program: histogram with parametric distribution of probability and calculated quantile

Histograms with parametric or non-parametric (empirical) distribution of probability can be formed even upon measured data which are statistically assessed and classified in classes. In case of parametric distribution of probability the most suitable type of parametric distribution of probability is recommended upon the determination coefficient for selected data. These calculation operations can be performed in corresponding shape even in other computing modules of the ProbCalc system.

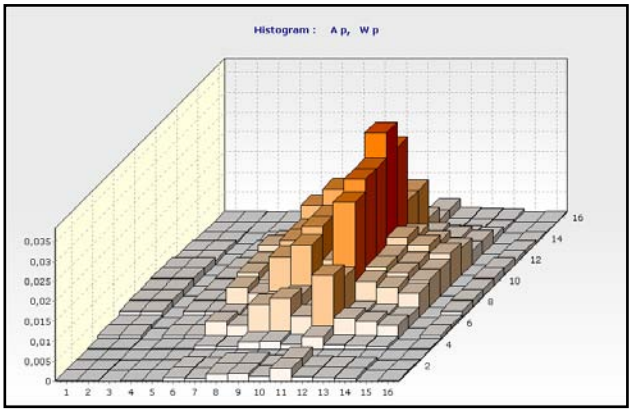

Fig.2:Desktop of HistAn2D program: Behavior of two statistically independentrandom quantities - cross-section area A and cross-section modulus W_y

2.2HistAn2D and HistAn3D Programs

The HistAn2D and HistAn3D applications were created to form the so called dual and triple histograms [7] which enable to express the statistical dependency between two res. among three random variable quantities (for instance with strength characteristics of building materials or sectional characteristics, Fig. 2 and 3, [21]). The obtained multidimensional histograms then may enter in the probability calculations solved by the DOProC method using other computing modules, for instance in the ProbCalc program [20].

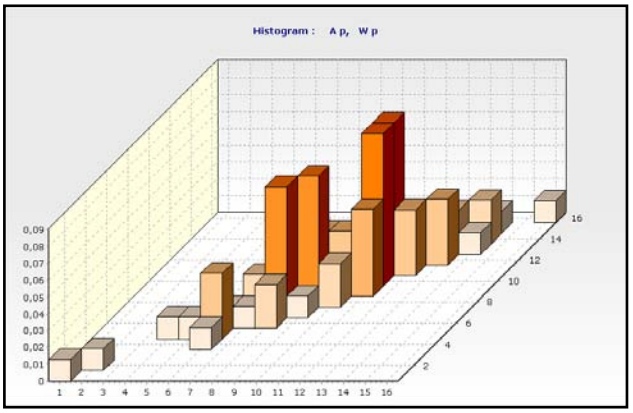

Fig.3:Outputfrom HistAn2D program: Dual histogram for two statistically dependentrandom quantities - cross-section area A and cross-section modulus W_y

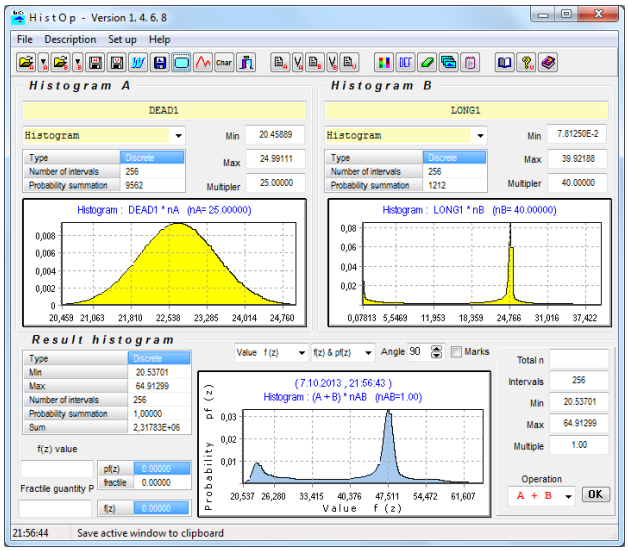

Fig.4:Desktop of HistOp program: Calculation of dead and long-lasting load combination

2.3HistOp Program

With histograms the basic mathematical operations can be carried out. For instance, in case of load combinations these mathematical operations are mostly used for summation of histograms of particular equipment types. For performing basic arithmetic operations with histograms the program

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tool HistOp(Fig. 4) has been developed which enables to carry out the following arithmetical operations with a pair of histograms: sum, difference, product and ratio of both histograms, square and absolute value of the histogram.

2.4ProbCalc Program

The main computing utility of the ProbCalc system (Fig. 5 and 6) is formed by the same name program into which the analytical transformation model of the solved probability task can be implemented using a text oriented editor.

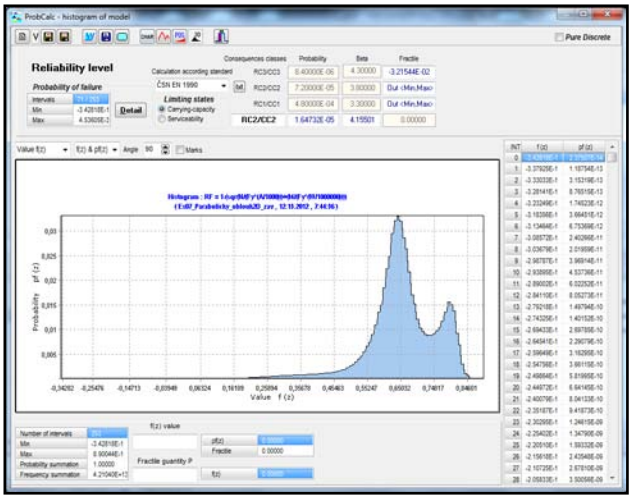

Fig.5:Desktop of ProbCalc program: Histogram of calculated reliability function *RF* under probabilistic reliability assessment

Among other things the optimisation processes (interval, zone and trend optimisation) were implemented into the developed software, which enable a significant reduction of the so called calculation steps and thus also the computing time of the calculation. These optimisation techniques can be mutually combined.

Another way of time intensity reduction of solved probability tasks is also its paralleling. The computing operations occurring during solution of more difficult tasks using the DOProC methods can easily be modified in a way they occur parallel which has been implemented also in the ProbCalc program. If the used computer has two or eventually more processors or cores, the calculation time can be substantially reduced in this way.

With more complex numerical computing models there is the option of utilisation of user programmed procedure in form of dynamic library (file with DLL extension). Setting of probability task in the ProbCalc program system therefore requires a quite advanced capability of the calculator. At least the base of method algorithm must be known which has its influence on the definition way of computing model and selection of suitable optimisation technique.

If the reliability evaluation of the solved construction is the subject of the probability calculation based on the inequality:

$$RF = R - E \geq 0 \ , \tag{1}$$

whereRF is reliability function, R resistance of the construction and E load effect, the calculation of failure probability p_f :

$$p_f = P(RF = R - E < 0) \ , \tag{2}$$

and also the very evaluation acc. to Eurocodes:

$$p_f \leq p_d \ , \tag{3}$$

wherep_d is design probability of failure defined in Eurocodes then the *RF* analysed reliability functionscan be simply carried out with the final histogram [13]. To the interesting features of the program also the 3D image of the *RF* reliability analysed function belongs which results in more detailed analysis of the solved probability task.

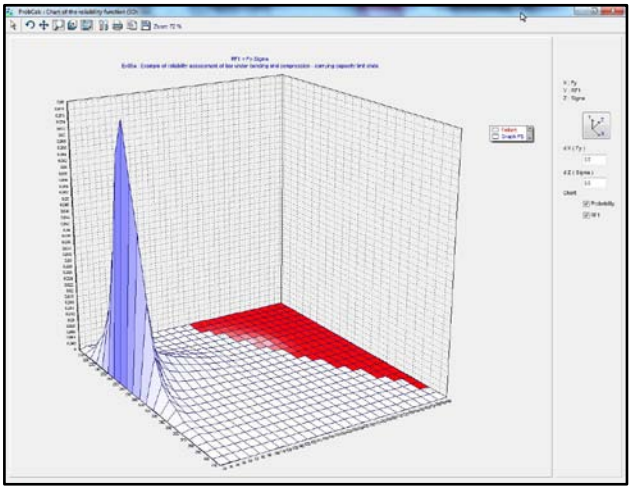

Fig.6:Desktop of ProbCalc program: 3D chart of calculated reliability function *RF* under probabilistic reliability assessment

3 Sophisticated Software Applying the DOProC Method

The shortage of a quite more challenging interface of the ProbCalc program (which is given by the requirements for its universal application) is removed in case of sophisticated application software, tailored for particular probability task. Therefore the user is no more required to complexly define the task computational model or to select the type of required optimisation technique. It only has the possibility to enter input variables, start calculation and analyse results of the probabilistic task.

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3.1Anchor Program

The Anchor program (Fig. 7 and 8) enables to probabilistically design and evaluate the anchoredsupportin mine workings which at present represents an important part of the reinforcement method in mining, tunnelling and underground civil engineering [6, 17]. The computing procedure applied in this sophisticated software enables to probabilistically design and evaluate anchor reinforcement length, number and bearing capacity.

Also a database of input random variables forms part of the computing module which was compiled upon measurements at producers of anchor reinforcement elements and in mine workings in Ostrava-Karvina coal district where the bolted reinforcement was realised.

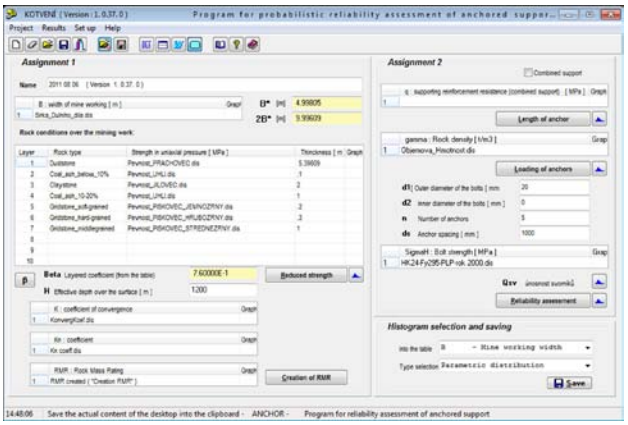

Fig.7:Desktop of Anchor programwith description of all input quantities which were entered into the system

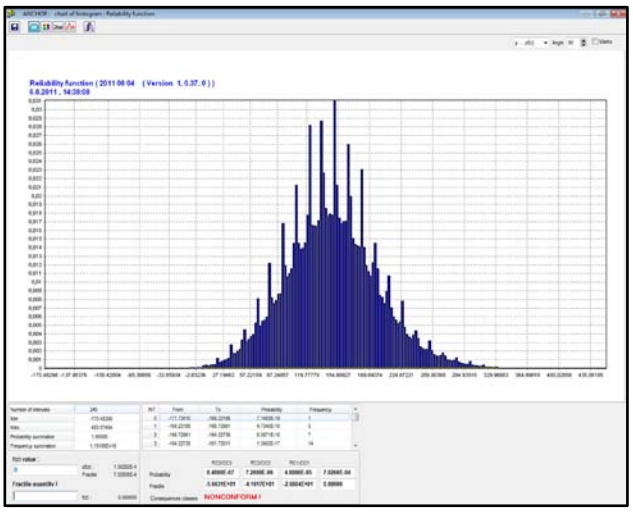

Fig.8:Desktop of Anchor program with resulting histogram of reliability function and reliability assessment of anchor reinforcement

3.2FCProbCalc Program

In the FCProbCalc program (Fig. 9, [11, 15]) the computing procedures for probability calculation of fatigue cracks spreading from edge and surface of steel cyclically loaded construction were applied which are based on computing model upon linear fracture mechanics [12, 18, 19]. Using the program the probability evaluation of construction reliability can be carried out upon exact definition of fatigue crack admissible size and definition of occurrence probability of three basic facts related with spreading of fatigue cracks which lead to calculation of failure probability for each operational year of the solved construction [10, 16]. At setting of the reliability required rate also time of the first inspection of the construction can be set which will be focussed on fatigue damage and using the conditioned probability also times of the following inspection checks.

The processed methodology together with the stated application thus may substantially improve the estimation of costs spent in maintenance of cyclically loaded constructions and bridges.

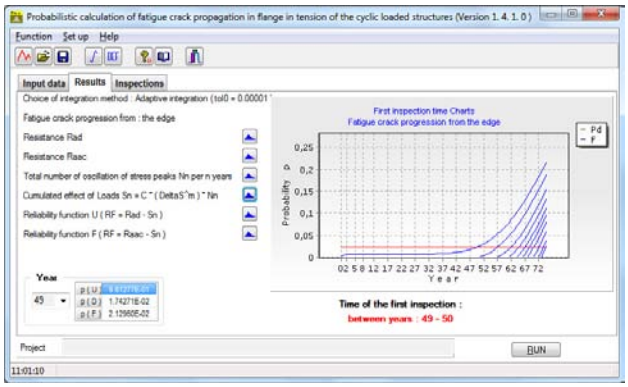

Fig.9:Desktop of FCProbCalc programwith results of the probabilistic modeling of propagation of a fatigue crack from the edge

4 Conclusion

The development of probabilistic methods and its application in construction reliability evaluation were pointed out in this article with focus on newly developed probabilistic method DOProC. The DOProC method appears as a very effective tool for obtaining solution of probabilistic tasks, loaded only with a numerical error and error given by discretisation of input and output variables.

Also the developed program tools implementing the DOProC method were stated and which are at present able to solve a line of probabilistic calculations. The DOProC method has shown to be suitable not only for the tasks leading to reliability evaluation but also to other probabilistic calculations for which also the mentioned ProbCalc software system or other of the described sophisticated programs can be used.

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Appendix

A lite version of the computational modules in ProbCalc and other software applications which are based on DOProC can be downloaded at http://www.fast.vsb.cz/popv.

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