Software Application of the DOProC Method

Martin Krejsa, Petr Janas and Vlastimil Krejsa

***Abstract*—**Various calculation methods based on the theory of probability and statistics are used for designing and assessing elements and systems in load-carrying structures. Those methods have been becoming very popular recently. Using the probabilistic method, it is possible to analyze a reliability margin defined in a computational model where at least some input characters are random. New methods which are being developed now include the Direct Optimized Probabilistic Method ("DOProC"). This is a purely numerical method which uses no simulation techniques. Results of the probabilistic tasks are more accurate and, often, more fast to reach. The described algorithm has already been implemented in several applications which were successfully used at solution of probabilistic tasks and probabilistic reliability evaluations.

***Keywords*—**DOProC, Direct Optimized Probabilistic Calculation, HistAn, HistOp, ProbCalc, Anchor, FCProbCalc, probabilistic methods, probability of failure, random variable, reliability assessment.

I. Introduction

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 [1]. These computing procedures contribute to qualitatively higher level of the reliability evaluation and also to security provision of users of the designed object [2, 29, 30, 32]. They are suitable for design of bearing structure elements with set reliability level when at least some of the design variables have random character (e.g. [5, 11]). At defining the input random variables they are frequently based on values coming from measurements performed with real objects even the long-term ones [3, 27, 28, 31].

The probabilistic evaluation process and structure design have just entered in the common design practice [35]. The stated computing procedures are used namely at designs of structural [12] or underground bearing systems [34] when also the service life of the construction can be estimated in addition to its reliability, or to analyse its resistance to degradation effects [33] and corrosion respectively [26, 36].

The article is focussed on the utilisation of original and newly developed probabilistic method Direct Optimized 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 [8].

II. Principles of the Method

DOProC has been developed since 2002 and theoretical backgrounds have been described in many publications [6, 7]. The DOProC probabilistic calculation is clearly determined for the task by its algorithm, while in Monte Carlo simulation methods the calculation data for the simulation are randomly generated.

This basic feature of the method gave originally the name to this method - Direct Determined Fully Probabilistic Method – DDFPM. The word "determined" was, however, misleading and that is why the name was altered.

Reasons for the term "optimized" in the final naming of the method are as follows: The number of random quantities which are used in the calculation of the probability of failure is limited by the ability to manage the task numerically. If there are too many random quantities, the tasks require too much time even if the advanced computational facilities are used. Therefore, optimizing methods have been developed and searched for which would reduce the number of operations and maintain correctness of the calculation.

A. Basic algorithm of calculations

The calculation algorithm of DOProC results from basic terms and techniques used in the theory of probability. When DOProC is used, computational operations are performed with histograms of random input quantities which might be expressed by discrete or purely discrete distribution of probabilities.

The resulting histogram, B, is any function, f (e.g., the function of reliability for the probabilistic reliability assessment) for the input histograms A_j, where j is from 1 to n. This means:

$$B = f\left(A_1, A_2, A_3, ..., A_j, ..., A_n\right). \quad (1)$$

Each histogram A_j has got i_j classes (intervals). The number of classes, i_j, in each histogram, A_j, can be different. The number of intervals, i, in the resulting histogram, B, can differ

This project has been completed thanks to the financial support provided to VSB-Technical University of Ostrava by the Czech Ministry of Education, Youth and Sports from the budget for conceptual development of science, research and innovations for the year 2013.

M. Krejsa is with the VSB - Technical University Ostrava, Faculty of Civil Engineering, Department of Structural Mechanics, Ludvika Podeste 1875/17, 708 33 Ostrava - Poruba, Czech Republic (phone: +420 59 732 1303; e-mail: martin.krejsa@vsb.cz).

P. Janas is with the VSB - Technical University Ostrava, Faculty of Civil Engineering, Department of Structural Mechanics, Ludvika Podeste 1875/17, 708 33 Ostrava - Poruba, Czech Republic (e-mail: petr.janas@vsb.cz).

V. Krejsa is with the VSB - Technical University Ostrava, Faculty of Civil Engineering, Department of Structural Mechanics, Ludvika Podeste 1875/17, 708 33 Ostrava - Poruba, Czech Republic (e-mail: Vlast.krejsa@seznam.cz).

as well. The number of intervals is the decisive factor for the number of computational operations and time needed for the calculation. The number of interval influences also considerably accuracy of the probabilistic calculation. Fig. 1 shows the principles of numerical operations in the probabilistic calculation with two random quantities expressed in a histogram. This case combines two load components – this means, the sum of two histograms.

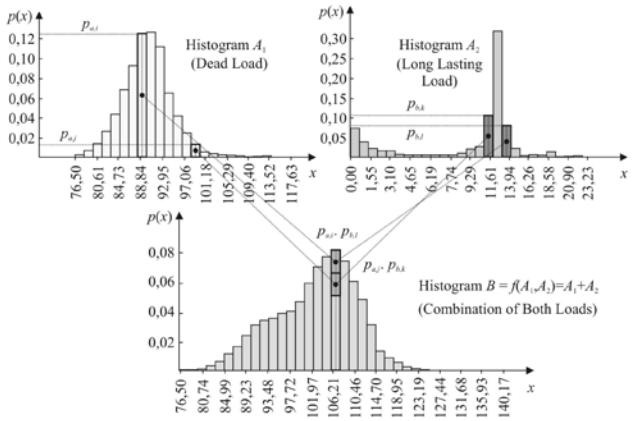

Fig. 1 Principles of numerical operations with two histograms (combination of two load components)

In case of the probabilistic reliability assessment of the construction or a structural element [4], f in the formula (1) is given by the computational model which defines the reliability function, *RF*, as follows:

$$RF = R - E, \tag{2}$$

where R is resistance of the construction and E is the load effect. The basic algorithm of the probabilistic task processed by DOProC is that shown in Fig. 2.

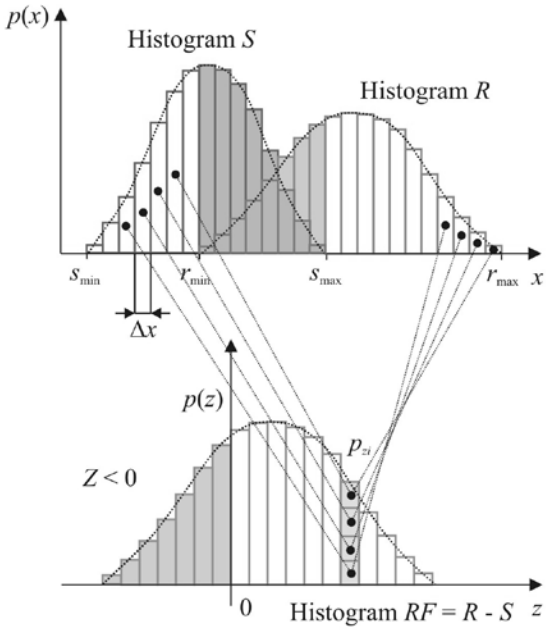

Fig. 2 Basic calculation of the reliability function histogram, *RF*, of two random variables using DOProC

B. Optimizing techniques

The goal of the optimizing techniques which were developed in DOProC is to minimize the time of calculation because the basic algorithm is limited to a certain extent, the being in particular, the case of extensive tasks where the number of computational tasks is very high. If the optimizing techniques are applied in DOProC, the result of the probabilistic task can be determined in a real time, maintaining the necessary correctness and sufficient accuracy even for relatively complex probabilistic tasks.

Below are the available optimizing actions:

(a) **Grouping of input variables:** This technique uses only input variables (such as the load components) which can enter the calculation jointly and for which a joint histogram can be prepared. This technique is well suited for situations when the combined load consists of several components of random variables with the same point of action. Then, only one joint histogram can be used. This technique is applicable to similar situations with other input quantities.

(b) **Interval optimizing:** This technique reduces the number of classes of the input variables in the histograms, which the total extent of each random input variable is maintained. This method which accelerates the calculation is used in such a way so that the result and correctness of the solution would not be affected too much. First, the influence of the number of interval of each random variable on the solution is tested. Then, the number of intervals is minimized.

(c) **Zone optimizing:** The calculation uses only those intervals which are involved in the searched value, for instance, the probability of failure of the construction, p_f.

(d) **Trend optimizing:** This technique considers the suitable direction (trend) in the calculation probability algorithm.

(e) **Grouping of partial results of the calculation:** Partial results are grouped – for instance, when preparing the resulting reliability function, *RF*.

(f) **Parallelizing the calculation:** several processors or cores are calculating the processors or cores at the same time.

(g) Combination of the mentioned optimizing techniques.

The calculation methodology using the DOProC method including theoretical background of the optimizing techniques was already theoretically processed in several publications [6, 7]. 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.

III. 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 [8, 17, 25].

A. HistAn Program

The program tool HistAn (see Fig. 3) 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.

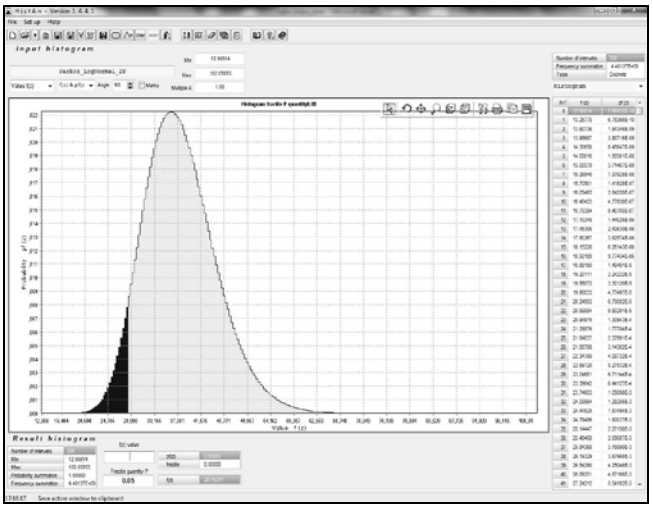

Fig. 3 Desktop of HistAn program: Histogram with parametric distribution of probability and calculated quantile

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.

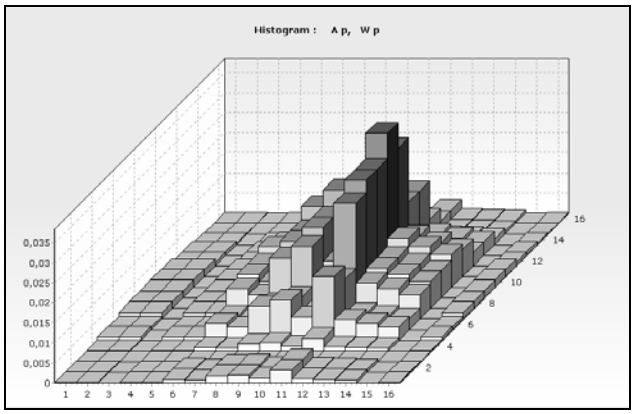

Fig. 4 Desktop of HistAn2D program: Behavior of two statistically independent random quantities - cross-section area *A* and cross-section modulus W_y

B. HistAn2D and HistAn3D Programs

The HistAn2D and HistAn3D applications were created to form the so called dual and triple histograms [10] 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. 4 and 5, [24]). 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 [23].

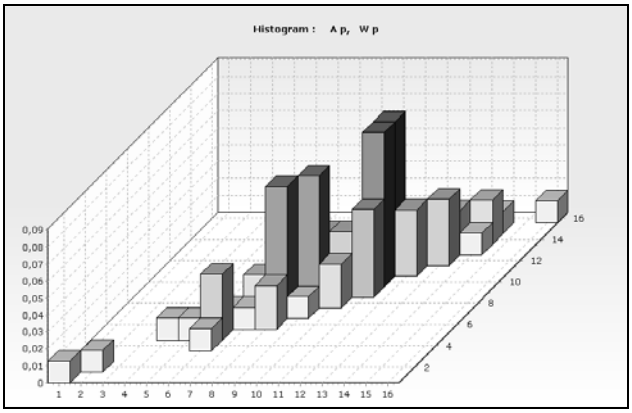

Fig. 5 Output from HistAn2D program: Dual histogram for two statistically dependent random quantities - cross-section area *A* and cross-section modulus W_y

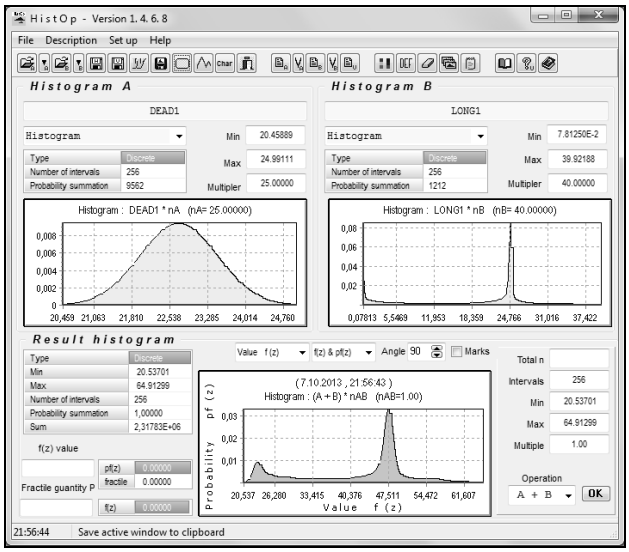

Fig. 6 Desktop of HistOp program: Calculation of dead and long-lasting load combination

C. HistOp 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 tool HistOp (Fig. 6) has been developed which enables to carry out the following arithmetical operations with a pair of histograms:

sum, difference, product and ratio of histograms, square and absolute value of the histogram.

D.ProbCalc Program

The main computing utility of the ProbCalc system (Fig. 7 and 8) 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.

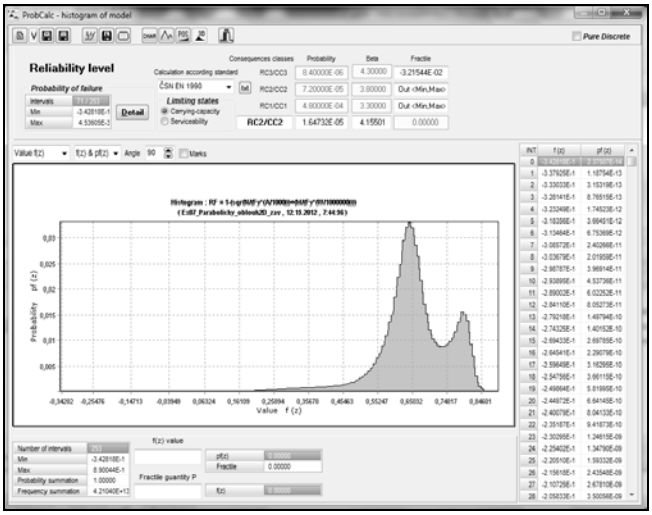

Fig. 7 Desktop of ProbCalc program: Histogram of calculated reliability function *RF* under probabilistic reliability assessment

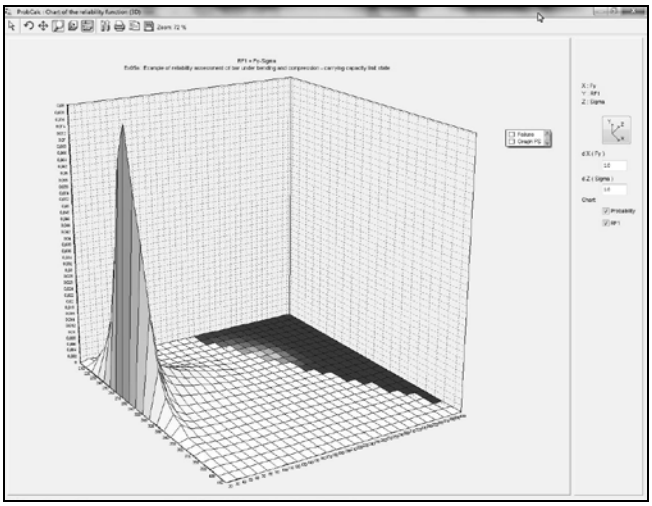

Fig. 8 Desktop of ProbCalc program: 3D chart of calculated reliability function *RF* under probabilistic reliability assessment

Among other things the optimization processes (interval, zone and trend optimization) 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 optimization 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:

$$RF = R - E \geq 0 \ , \tag{3}$$

where RF is reliability function (2), R resistance of the construction and E load effect, the calculation of failure probability p_f:

$$p_f = P\left(RF = R - E < 0\right) \ , \tag{4}$$

and also the very evaluation acc. to Eurocodes:

$$p_f \leq p_d \ , \tag{5}$$

where p_d is design probability of failure defined in Eurocodes then the RF analysed reliability functions can be simply carried out with the final histogram [16]. 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.

IV. 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 optimization technique. It only has the possibility to enter input variables, start calculation and analyze results of the probabilistic task.

A. Anchor Program

The Anchor program (Fig. 9 and 10) enables to probabilistically design and evaluate the anchored support in mine workings which at present represents an important part of the reinforcement method in mining, tunnelling and underground civil engineering [9, 20]. 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.

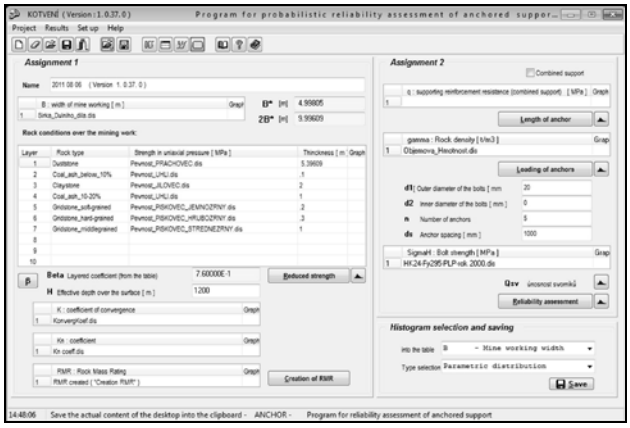

Fig. 9 Desktop of Anchor program: Description of all input quantities which were entered into the system

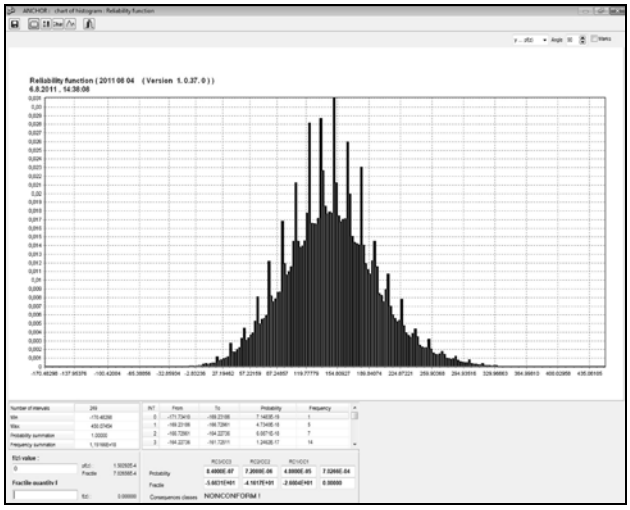

Fig. 10 Desktop of Anchor program: Resulting histogram of reliability function and reliability assessment of anchor reinforcement

B. FCProbCalc Program

In the FCProbCalc program (Fig. 11, [14, 18]) 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 [15, 21, 22]. 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 [13, 19]. At setting of the reliability required rate also time of the first inspection of the construction can be set which will be focused 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.

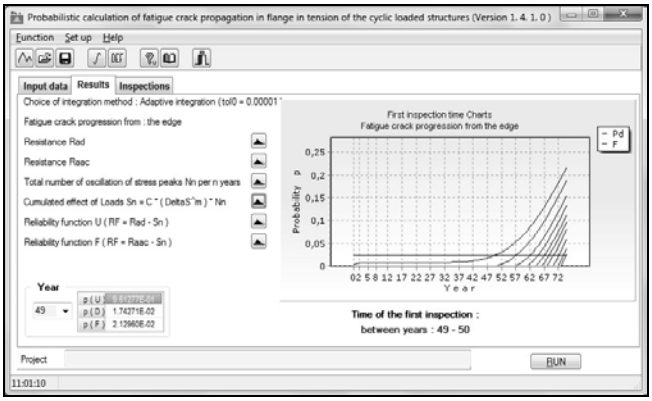

Fig. 11 Desktop of FCProbCalc program: Results of the probabilistic modeling of propagation of a fatigue crack from the edge

V. 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.

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.

References

[1] R. Cajka, P. Mateckova, M. Stara, L. Mynarzova, "Probability Assessment of Compressive Strength as a Basis for Post Tensioned Masonry Testing". *Recent Researchers in Environmental & Geological Sciences*, Kos Island, Greece, WSEAS Press, pp. 447-450 (4 p), ISSN 2227-4359, ISBN 978-1-61804-110-4, 2012.

[2] R. Cajka, "Accuracy of stress analysis using numerical integration of elastic half-space". *Applied Mechanics and Materials*, Vol. 300-301, pp. 1127-1135 (9 p). ISSN: 16609336, ISBN: 978-303785651-2, DOI: 10.4028/www.scientific.net/AMM.300-301.1127, 2013.

[3] R. Cajka, M. Krejsa, "Measured Data Processing in Civil Structure Using the DOProC Method". *Advanced Materials Research*. Zurich, Switzerland: Trans Tech Publications, Vol. 859, pp. 114-121 (8 p), ISSN 1662-8985, DOI: 10.4028/www.scientific.net/AMR.859.114, 2014.

[4] J. Gocal, J. Vican, R. Hlinka, J. Jost, "Laboratory tests of a typical fatigue prone riveted steel railway bridge structural detail". *Procedia Engineering*, Vol. 2, Issue 1, pp. 1761-1766 (6 p). ISSN: 18777058, DOI: 10.1016/j.proeng.2010.03.189, 2010.

[5] P. Hradil, J. Kala, V. Salajka, P. Vymlatil, "The application of concrete nonlinear model exposed to impact load". In: *Proceedings of the 13th WSEAS International Conference on Automatic Control, Modelling and*

Simulation (ACMOS'11), Lanzarote, Canary Islands, pp. 283-286 (4 p), WSEAS Press, ISBN 978-161804004-6, 2011.

[6] P. Janas, M. Krejsa, V. Krejsa, "Structural Reliability Assessment Using Direct Determined Probabilistic Calculation". In: *Proceedings of the Twelfth International Conference on Civil, Structural and Environmental Engineering Computing: CC 2009*, Civil-Comp Press, 2009, 20 p, ISBN 978-1-905088-31-7. Elsevier B.V., ISBN 978-190508830-0, DOI: 10.4203/ccp.91.72, 2012.

[7] P. Janas, M. Krejsa, V. Krejsa, "Using the Direct Determined Fully Probabilistic Method (DDFPM) for determination of failure". In *Proceedings of European Safety and Reliability Conference (ESREL 2009): Reliability, Risk and Safety: Theory and Applications*, Vols 1-3, London: Taylor & Francis Group, pp. 1467-1474 (8 p), ISBN 978-0-415-55509-8, WOS 000281188500203, 2010.

[8] P. Janas, M. Krejsa, V. Krejsa, "Software Package ProbCalc from the Poin of View of a User". *Transactions of the VŠB - Technical University of Ostrava, Civil Engineering Series*. Versita, Vol. 10, Issue 1, pp. 1-11. ISSN 1804-4824, DOI: 10.2478/v10160-010-0010-7, 2010.

[9] P. Janas, R. Snupárek, M. Krejsa, V. Krejsa, "Designing of Anchoring Reinforcement in Underground Workings Using DOProC Method". In: *Transactions of the VŠB - Technical University of Ostrava, Civil Engineering Series*. Versita, vol. 10, Issue 2, pp. 1-13. ISSN 1804-4824, DOI: 10.2478/v10160-010-0020-5, 2010.

[10] P. Janas, M. Krejsa, V. Krejsa, "Statistical Dependence of Input Variables in DOProC Method". In: *Transactions of the VŠB - Technical University of Ostrava, Civil Engineering Series*. Versita, Vol. 12, Issue 2, pp. 48-58 (11 p). ISSN 1804-4824. DOI: 10.2478/v10160-012-0017-3, 2012.

[11] Z. Kala, J. Kala, "Variance-Based Sensitivity Analysis of Stability Problems of Steel Structures using Shell Finite Elements and Nonlinear Computation Methods". In: *Proceedings of the 2nd WSEAS International Conference on Engineering Mechanics, Structures and Engineering Geology (EMESEG '09)*, Rhodes, Greece, Mathematics and Computers in Science and Engineering, pp. 89-94 (6 p), WSEAS Press, ISBN 978-960-474-101-4, WOS: 000276584000011, 2009.

[12] J. Kralik, J. Kralik Jr, "Probability assessment of analysis of high-rise buildings seismic resistance". *Advanced Materials Research*, Vol. 712-715, pp. 929-936 (8 p), ISSN 1022-6680, DOI: 10.4028/www.scientific.net/AMR.712-715.929, 2013.

[13] M. Krejsa, V. Tomica, "Determination of Inspections of Structures Subject to Fatigue". In: *Transactions of the VŠB - Technical University of Ostrava, Civil Engineering Series*. Versita, Vol. 11, Issue 1, pp. 1-11. ISSN 1804-4824. DOI: 10.2478/v10160-011-0007-x, 2011.

[14] M. Krejsa, "Probabilistic Calculation of Fatigue Crack Progression Using FCProbCalc Code". In: *Transactions of the VŠB - Technical University of Ostrava, Civil Engineering Series*. Versita, Vol. 12, Issue 1, pp. 1-11. ISSN 1804-4824. DOI: 10.2478/v10160-012-0003-9, 2012.

[15] M. Krejsa, "Stochastic Modelling of Fatigue Crack Progression using the DOProC Method". In: *Proceedings of the Eleventh International Conference on Computational Structures Technology*, Civil-Comp Press, pp. 1-18, ISBN 978-1-905088-54-6, ISSN 1759-3433, DOI: 10.4203/ccp.99.113, 2012.

[16] M. Krejsa, P. Janas, R. Cajka, "Using DOProC method in structural reliability assessment". *Applied Mechanics and Materials: Mechatronics and Applied Mechanics II*. Trans Tech Publications, Vol. 300-301, pp. 860-869 (10 p), ISSN 1660-9336, ISBN 978-303785651-2, DOI: 10.4028/www.scientific.net/AMM.300-301.860, 2013.

[17] M. Krejsa, P. Janas, V. Krejsa, "Direct Optimized Probabilistic Calculation". In: *Recent Advances in Systems Science & Mathematical Modelling: Proceedings of the 3rd International Conference on Mathematical Models for Engineering Science (MMES '12)*. WSEAS Press, pp. 216-221 (6 p). ISBN 978-1-61804-141-8, 2012.

[18] M. Krejsa, "The Probabilistic Calculating of Fatigue Crack Propagation Using FCProbCalc Program". In: *Proceedings of 18th International Conference Engineering Mechanics 2012*. ITAM AS CR, Prague, Czech Republic, pp. 745–754 (10 p). ISBN 978-80-86246-39-0, 2012.

[19] M. Krejsa, "Inspection Based Probabilistic Modeling of Fatigue Crack Progression". In: *Recent Advances in Mechanical Engineering & Automatic Control: Proceedings of the 3rd European Conference of Mechanical Engineering (ECME' 12)*. WSEAS Press, pp. 104-109 (6 p). ISBN 978-1-61804-142-5, 2012.

[20] M. Krejsa, P. Janas, I. Yilmaz, M. Marschalko, T. Bouchal, "The Use of the Direct Optimized Probabilistic Calculation Method in Design of Bolt Reinforcement for Underground and Mining Workings". *The Scientific World Journal*, vol. 2013, Article ID 267593, 13 p. doi:10.1155/2013/267593, 2013.

[21] M. Krejsa, "Probabilistic Failure Analysis of Steel Structures Exposed to Fatigue". *Key Engineering Materials.* Vol. 577-578, pp. 101-104 (4 p), ISSN 1662-9795, DOI: 10.4028/www.scientific.net/KEM.577-578.101, 2013.

[22] M. Krejsa, "Probabilistic reliability assessment of steel structures exposed to fatigue". In *Proceedings of Conference ESREL 2013: Safety, Reliability and Risk Analysis: Beyond the Horizon*, Amsterdam, Nederland, 2013, London: Taylor & Francis Group, pp. 2671-2679 (9 p), ISBN 978-1-138-00123-7, 2014.

[23] M. Krejsa, P. Janas, V. Krejsa, "Probabilistic calculation using DOProC method with statistically dependent input variables". In: *Proceedings of the 11th International Probabilistic Workshop*, Brno, Czech Republic, pp. 203-218 (16 p), ISBN 978-80-214-4800-1, 2013.

[24] M. Krejsa, R. Cajka, "The foundation slab monitoring of the National Supercomputing Center - IT4 Innovations during construction". In: *Proceedings of the 11th International Probabilistic Workshop*, Brno, Czech Republic, pp. 219-234 (16 p), ISBN 978-80-214-4800-1, 2013.

[25] M. Krejsa, P. Janas, V. Krejsa, "Application of the Direct Optimised Probabilistic Calculation Method". In: *Recent Advances in Applied and Theoretical Mathematics: Proceedings of the 18th WSEAS International Conference on Applied Mathematics (AMATH '13)*, Ed.: Dana Anderson. Budapest, Hungary: WSEAS Press, North Atlantic University Union, pp. 200-205 (6 p). ISSN 2227-4588, ISBN 978-960-474-351-3, 2013.

[26] V. Krivy, L. Fabian, "Calculation of corrosion losses on weathering steel structures". *Applied Mechanics and Materials*, Vol. 188, pp. 177-182 (6 p). ISSN: 16609336, ISBN: 978-303785452-5, DOI: 10.4028/www.scientific.net/AMM.188.177, 2012.

[27] V. Krivy, K. Vavrusova, "New Digital Ground Snow Load Map for the Area of the Czech Republic". In: *Proceedings of the 5th WSEAS International Conference on Natural Hazards (NAHA ´12)*: Sliema, Malta, WSEAS Press, ISBN 978-1-61804-120-3, ISSN 2227-4359, 2012.

[28] V. Krivy, R. Cajka, K. Vavrusova, "Practical Application of the New Digital Snow Load Map". In: *Proceedings of the 5th WSEAS International Conference on Natural Hazards (NAHA ´12)*, Sliema, Malta, WSEAS Press, ISBN 978-1-61804-120-3, ISSN 2227-4359, 2012.

[29] G. Lajcakova, J. Melcer, "Dynamic effect of moving vehicles on the road concrete slabs". *Komunikacie*, Vol. 13, Issue 3, pp. 14-18 (5 p). ISSN: 13354205, 2011.

[30] I. S. Leoveanu, D. Taus, K. Kotrasova, E. Kormanikova, "Computer fluid dynamics application for establish the wind loading on the surfaces of tall buildings". In: *Proceedings of 13th WSEAS International Conference on Automatic Control, Modelling and Simulation, ACMOS'11*, pp. 433-438 (6 p). WSEAS Press, ISBN: 978-161804004-6, 2011.

[31] A. Lokaj, K. Vavrusova, E. Rykalova, "Application of laboratory tests results of dowel joints in cement-splinter boards VELOX into the fully probabilistic methods (SBRA method)". *Applied Mechanics and Materials*, Vol. 137, pp. 95-99 (5 p). ISSN: 16609336, ISBN: 978-303785291-0, DOI: 10.4028/www.scientific.net/AMM.137.95, 2012.

[32] D. Mikolasek, O. Sucharda, J. Brozovsky, "Analysis of composite timber-concrete ceiling structure by finite element method". *Applied Mechanics and Materials*, Vol. 351-352, pp. 254-259 (6 p). ISSN: 16609336, DOI: 10.4028/www.scientific.net/AMM.351-352.254, 2013.

[33] D. Novak, M. Vorechovsky, B. Teply, "FReET: Software for the statistical and reliability analysis of engineering problems and FReET-D: Degradation module". *Advances in Engineering Software*. ISSN: 09659978, DOI: 10.1016/j.advengsoft.2013.06.011, 2013.

[34] O. Spacková, J. Sejnoha, D. Straub, "Probabilistic assessment of tunnel construction performance based on data". *Tunnelling and Underground Space Technology*, Vol. 37, pp. 62-78 (17 p). ISSN: 08867798, DOI: 10.1016/j.tust.2013.02.006, 2013.

[35] M. Sykora, M. Holicky, J. Markova, "Verification of existing reinforced concrete bridges using the semi-probabilistic approach". *Engineering Structures*, Vol. 56, pp. 1419-1426 (8 p). ISSN: 01410296, DOI: 10.1016/j.engstruct.2013.07.015, 2013.

[36] D. Vorechovska, B. Teply, M. Chroma, "Probabilistic assessment of concrete structure durability under reinforcement corrosion attack". *Journal of Performance of Constructed Facilities*, Vol. 24, Issue 6, pp. 571-579 (9 p). ISSN: 08873828, DOI: 10.1061/(ASCE)CF.1943-5509.0000130, 2010.