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Acceleration of probabilistic analysis of steel structures by DOProC and Monte Carlo approaches with use of distributed computing

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Abstract

This paper introduces the recent development of the Direct Optimised Probabilistic Calculation (DOProC) method and its application in analysis of steel structures. There is proposed to more streamlined approach to parallel execution of the algorithm and its implementation. The results of a selected case are presented. These results were compared by comparison on a Monte Carlo-based approach. Further development directions are also discussed.

Keywords: reliability, probability, fatigue, parallel, fracture mechanics.

1 Introduction

Civil engineering structures are subject of never-ending evolution and development. The obvious goal is to design more effective structures which will use less material, which will require lesser amount of construction works and which will have smaller environmental impact. Obviously, usability and service life of structures should not be compromised. Such goals require use of precise methods for design and assessment of such structures. It is obvious that such methods must at least to some extend respect the random nature of many processes and parameters and the risks and uncertainties involved. For example, this includes actions of loads and material and geometry parameters of structures. The presented work is oriented to area of reliability assessment of steel structures, especially steel bridges. Such structures are very common in the world, and they are, among others, subjected to repeating loads which may lead to fatigue effects.

The presented approach is based on the probabilistic analysis of behaviour of critical details regarding the prediction of fatigue damage. The analysis is based on a linear fracture mechanics. The probabilistic effects are included with use of the Direct Optimised Probabilistic Calculation (DOProC) method or with use of the Monte Carlo method. The DOProC method is used as the main method by the authors and the Monte Carlo-based approach is used mostly for reference and comparison of results.

Both methods use large number of repeated calculations which may require non-trivial amounts of computational time when used for real civil engineering applications. The DOProC method can be speeded-up in several ways using so-called "optimization" techniques but the most straight-forward approach is to introduce parallel computations. Such possibility was tried in the past and it was verified that it is feasible and very effective. These works were done by modifications of a serial program code which ran on the personal computer. In that case the scalability was limited.

The ongoing works are thus focused on creation on a new, more streamlined, DOProC algorithm which can be parallelised.

2 Methods

The Direct Optimised Probabilistic Calculation method was discussed in detail in work of Krejsa et al [1]. It does not use simulation and thus potentially allows to obtain repeatable results with higher accuracy [2]. It thus can be viewed as an alternative to simulation-based methods such are methods based on the Monte Carlo [3]. It resolves some of issues of simulation methods however it introduces its own issues. The main one is a huge number of computations which can be of magnitude higher that number of Monte Carlo simulations required for the same problem. The number of realisations (computations) can be predicted and several approaches (called "optimisations" in [5]) for minimising of number of computations have been developed [4]. These approaches are of different level of complexity and sometimes require additional knowledge of solved problem which makes their use less flexible in some real-world cases. However, most of the computations can be run in parallel. Thus, parallelisation of the DOProC algorithm is viewed and the most feasible approach to speed-up the method. It is greatly helped by the fact there are no operations with random data. Thus, no random generator is required, and the computed data can be collected at the very end of the analysis. The input data ar e been represented by histograms and the results can be represented in the same way.

The program code has been written with use of the MATLAB [6] environment. A Single Program Multiple Data (SPMD) approach was adopted. The input data are distributed to all created parallel processes (the "worker") then every process analyses only a part of these data. After the parallel computations are finished the results are collected and the final representation of computed data is constructed. This solution can be implemented in any traditional programming language (the C/C++ with use of the MPI [7], for example and this is one of the future goals) but the MATLAB

implementation makes development and testing of the approach much faster and more straightforward.

The Monte Carlo based solution is used for comparison with the DOProC-based approach. It used the Monte [3][8] program code which is implemented in the C language with use of the MPI [7] and the SPRNG parallel random numbers generator [9]. As such it is not directly comparable in terms of computational speed, but it provides results which can be studied and compared.

3 Results

A simple problem of fatigue behaviour of simple supported testing sample with pre-defined crack (see Figure 1) was studied as an example of probabilistic solution. This problem was studied previously with the older implementation of the DOProC [12]. There is available an analytical solution [10],[13] which obviously limits available geometry of the sample. The input parameters have been defined as random variables represented by histograms.

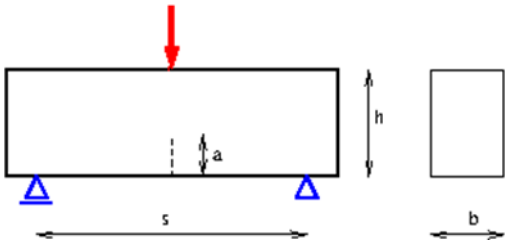

Figure 1: Scheme of studied example

The solution was conducted for times from 5 to 100 years in steps of 5 years. The initial implementation of the program was done in serial form. The solution time reached 3.7 hours on a modern workstation computer with 12 processor cores. Then the parallel code which used the above mentioned SPMD approach was used. The obtained times were 6500s (thus 1.8h) for two processes and just under 1000s for eight processes. It can be concluded that for this problem there is very little speed-up form more than 14 processes. The results obtained for serial and parallel version of the code were very close, there was no important difference (first three non-zero number of results were always identical) thus it can be stated that the parallel execution has no considerable effect on precision of the results of the studied problem.

The alternative Monte Carlo-based solution provided similar speed-up behaviour as the DOProC code and provided very close results (because of simulation-based mature of this method the results always slightly differ between computations). The absolute computational times are not compared because of different implementations of the codes.

4 Conclusions and Contributions

The article proposed the new parallel implementation of the Direct Probabilistic Computation method which is in detail described in [1]. This implementation is based on the Single Program Multiple Data paradigm and thus is potentially offers good scalability. The nature of the method made parallel implementation possible because there is very moderate need for operations on all input data. Only collection and final analysis of data is needed.

In the current stage of the works the method can be used to analyse real-world problems of limited complexity as it was demonstrated on a fatigue analysis of rectangular steel sample problem.

The obtained results show that the parallel execution of computations lead to noticeable reduction of computational times while precision of solution is not considerably degraded.

The ongoing and future works on this method must include verification of the approach on larger number of real-world problems (it is aimed to study different types of fatigue behaviour of steel structures) and it is planned to implement selected so-called "optimization" techniques [5] for the method which would further reduce computational times. These techniques may introduce new problems as they can require more intensive communication of parallel processes during different stages of computation. Thus, it is expected that the "optimization" approaches as described in [4] would require further development and changes to allow their effective use in the parallel computational algorithm.

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