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FITTING MODEL PARAMETERS OF PRESTRESSED CONCRETE BRIDGE: COMPUTATIONAL ASPECTS

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Abstract: *Many tasks, in our case fitting parameters of a numerical model, need enormous computing time that is not usually easily accessible. Here enormous means many days or months when a common computer is used. Nowadays there exists a possibility to utilize distributed resources like grid or volunteer computing. This contribution is focused on an application of distributed computing for fitting model parameters of a real structure. We are focused on a three-span prestressed concrete bridge in Mělník. This 23 years old bridge has a serious problem with an excessive deflection. The evaluation of monitoring results clearly shows that after 23 years since putting the bridge into operation the deflection is still growing.*

Keywords: Grid computing, Volunteer computing, Parallel processing, Prestressed concrete, SIFEL.

1. Introduction

This paper presents fitting of finite element model parameters of the bridge over the Labe river in Mělník. It is a box girder road bridge from prestressed concrete with three spans of lengths 72 m, 146 m and 72 m, see Fig. 1. Since its erection in 1994, the midspan deflection of the bridge is still increasing, see publications (Vodsloň, 2008; Urban et al., 2009; Vráblík et al., 2009). Suspected causes are relaxation of prestressing steel (Bažant & Yu, 2013) and creep of concrete (Bažant et al., 2011). Up to now, a rate of their influence and more importantly, their interaction is not known. Therefore, this contribution is a part of a pathway to the identification of the main causes of the excessive deflection of the bridge.

Fig. 1: Bridge in Mělník.

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2. Finite Element Model

The bridge was analyzed with the help of a finite element method. Three-dimensional model was based on hexahedral finite elements used for concrete and one-dimensional bar (tension/compression) elements used for tendons. Mesh contains 73 765 nodes, 48 896 hexahedral elements and 10 448 bar elements, see Fig. 2. With respect to general position of tendons in the structure, hanging nodes were used for nodes defining the bar elements. Displacements of the hanging nodes are obtained as a linear combination of the master nodes, in our case the master nodes are nodes of the hexahedral elements.

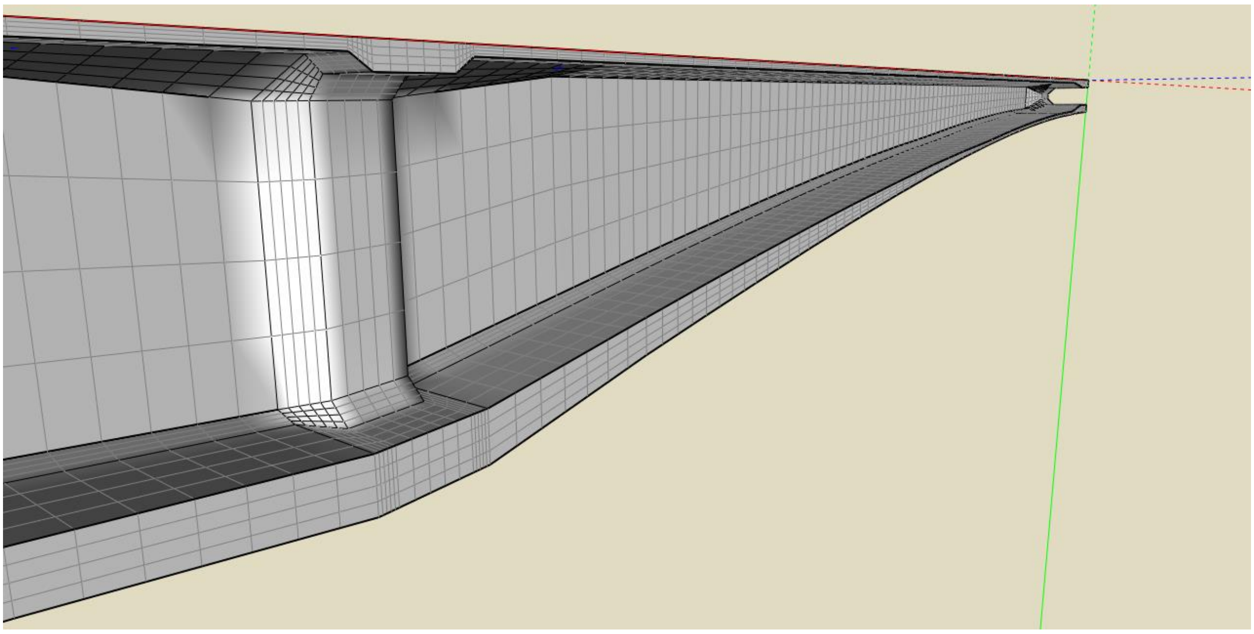

Fig. 2: Mesh on bridge.

The aim of the analysis was to describe long term behavior of the bridge. B3 creep material model (Bažant & Baweja, 2000) was used for concrete and relaxation of stresses in tendons was described by a model of relaxation based on Eurocode standard. The numerical model took into account construction phases of the bridge. All nodes and finite elements were equipped with a time function. The nodes or elements were taken into account only when the time function had the value 1.

3. Solver

Calculation of the model was performed in an open finite element software SIFEL (Krejčí et al., 2011; Kruis et al., 2001-2014). SIFEL offers analysis of various mechanical problems, e.g. simple elasticity, plasticity, dynamics, visco-elasticity, geomechanics and many others. Results can be exported to commercial graphical postprocessor GiD which provides robust environment for their visualization. SIFEL is written in C++ with respect to portability and extensibility, therefore it can be run on both Linux and Windows platforms.

4. Searching for Parameters

To assess the influence of individual parameters and to fit the long term deflection, it is necessary to perform global sensitivity analysis. Particularly, individual parameters are varied inside estimated bounds. The individual combinations then form so called Design of Experiments (DoE); see e.g. (Myšáková & Lepš, 2012) for more details on DoE as well as on applied methodology of DoE creation.

Then the computational demands are following: we have prepared a DoE comprising of 3000 combinations. In average, one evaluation takes around 4 hours of CPU time. Therefore, 12 000 CPU/hours are needed, i.e. we need 500 CPU/day. Two possibilities of distributing computational burden over many computers are described in the following text.

5. Volunteer Computing Project

“Volunteer computing” is a type of distributed computing in which computer owners can donate their spare computing resources (processing power, storage and Internet connection) to one or more research projects. Volunteer desktops and laptops can be connected to form the equivalent of a single huge super computer. Volunteers are motivated by various factors: support for the goals of the research, participation in online communities, and competition based on computational power. Our project CONVECTOR (Nosek, 2013-2014) is based on BOINC middleware (BOINC, 2010). At the time of writing, the project contains more than 3000 computers worldwide.

Tab. 1: Percentage of operation systems.

Operating system	Number of hosts	%
Windows based	2905	85.11
Linux based	414	12.13
Other	94	2.76

One disadvantage of a volunteer project is a requirement of availability of compiled applications for more than one software platform. A current representation of individual platforms shown is in Tab. 1. For these reasons, it was necessary to port SIFEL software to windows systems. Despite the great support of SIFEL authors, the 32 bit windows version was not able to correctly allocate all data into memory. Hence, we have decided to try to solve the task via grid computing in MetaCentrum under a Linux platform.

6. Grid Computing

MetaCentrum is a Czech national grid. It is widely open grid computing network for an academic research where all computers are running under Linux. However, each task must be entered by PBS (Portable Batch System). PBS is a batch job and computer system resource management package. It accepts batch jobs (shell scripts with control attributes), preserves and protects a job until its end, runs a job, and finally, delivers an output back to the submitter. Each task is assigned to a specific queue. Each queue has priority, an allowed maximum time length and a number of tasks in each queue. Most free is a queue called “Backfill” where we can have up to 1000 tasks at one time. Moreover, maximum running time is limited to 24 hour for each task. But this freedom queue has one disadvantage. If another queue with higher priority needs more CPU, it can kill your task immediately. If this happens one must identify this case and again to create a new task with same parameters at the end of the queue. Despite this complication we were able to finish all computations in a few days.

In detail, the work needed to process a task is as follows. A short bash script for reservation via PBS was built, and the task (also called work unit) was copied to a destination machine. Work unit contains an input data file, a main program and a set of instructions how to handle an output file. The task also contains minimal requirements for hardware. At least, one core of CPU, 3 GB RAM memory and 8 GB of free space on HDD was required for each task. A multiple core CPU can run more than one task if the computer has enough memory. A time limit for each work unit was set to 20 hours. If any task exceeded this time, such work unit has been aborted. Note that abortion of some tasks also happened few times for unknown reasons.

7. Conclusion

One of the main goals was to find out suitability of volunteer computing for this type of engineering problems. The main disadvantage of volunteer computing is heterogeneity of available computers. For instance, 1563 computers with Windows 7 are currently connected to our project CONVECTOR. But in fact there are 27 different versions of Windows 7 system. Although the task of fitting parameters of the prestressed concrete bridge seems big enough for distributed computing, in fact it is too small for a volunteer computing project and concurrently, too big for a standalone cluster. Apart from these two possibilities, grid computing looks very promising. Main advantages of grid computing are (i) good knowledge about each computer and (ii) huge flexibility. On the other hand the capacity of a grid computing cluster is rather more limited in comparison to a volunteer computing project. However, both these computing methods can find utilizations in demanding engineering tasks.

Second important task was to calculate model of the bridge with varying input parameters for optimal fitting these parameters to available measurements. A typical output of such procedure is shown in Fig. 3.

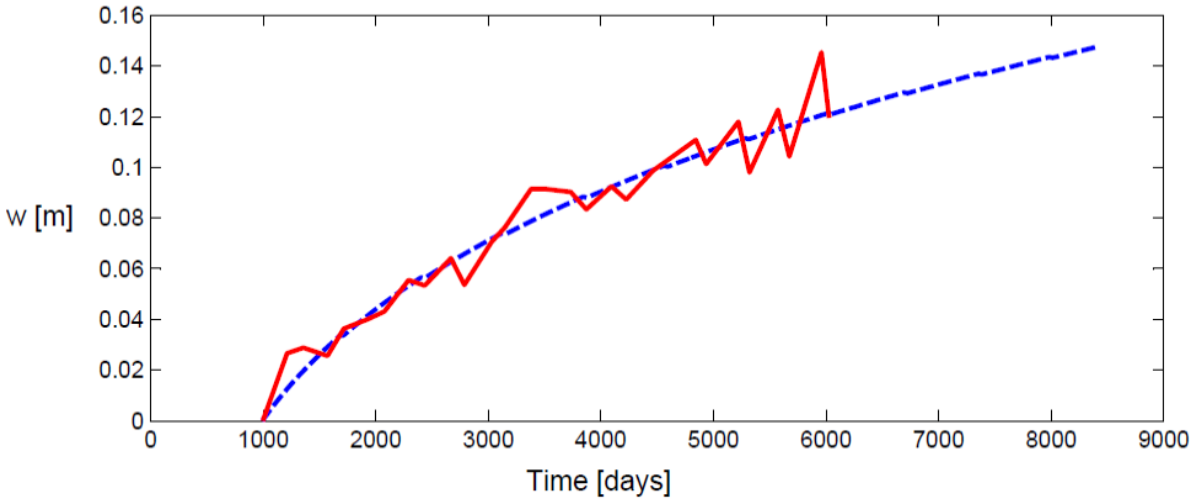

Fig. 3: Fitted deflection at midspan.

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