The combination of numerical simulation of strong dynamic loading effects and big data technologies

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Abstract. Near the zones of impact, explosion and other strong dynamic loading, the stress peak is very high, action time is very short, and the medium distortion is very large. The involving scientific problems are strong nonlinearity, multi-physics coupling, and so on. Numerical simulation and experimental investigation are mainly research method for these effects. However, the difficulty of the numerical simulation is at the top of the pyramid of scientific computation, and the noise, *simulation is not true*, is the biggest trouble currently existed. The emergence of big data technologies provides a feasible way to solve the current dilemma and realize accurate numerical simulation. Combination the big data technologies, such as data acquisition, infrastructure, data mining, statistical analysis, model prediction and so on, the numerical simulation of strong dynamic load effects is possible to achieve precision by automation of solver, intelligence of material state description library, expertization of human-computer interaction interface, credibility of simulation result data, virtual reality of simulation image. The combination of big data technology and numerical simulation will be the key to research the strong dynamic load effects, which would realize the transformation from numerical simulation to digital experiment, and the noise, *simulation is not true*, would be disappear completely.

1. Overview of the development of numerical simulation

Strong dynamic loading effects, such as impacts and explosions, are very closely related to the national economy and people's livelihood [1,2]. There are many strong dynamic loading effects problem, for example, safety of daily vehicle, protection of satellites and spacecraft in space, safety of nuclear power plant on the ground, safety analysis on meteorite impact and underground mining. Their scientific problems involve strong nonlinearity, multi-physics field coupling, and multi-scale structures, components, and materials, etc. The cost of the experimental investigation is expensive and there is a widespread problem that the required data cannot be accurately measured. Therefore, in the design, construction and operation of major project and complex equipment, accurate numerical simulation on supercomputers has become a must.

For numerical simulation of strong dynamic loading effects, its essence is an experiment conducted by professional simulation software on high performance computing platform. Its core is to solve the equations of engineering problems including the interaction between projectile and target, the shock wave discontinuity formed by the explosion, and the large deformation of the material near the loading. The disciplines cover many disciplines from solid mechanics, fluid mechanics, mathematical physics, numerical methods, explosion mechanics, wave theory to computer technology [3,4].

Near the strong dynamic load, the pressure peak is as high as Gigapascals or even tens of Gigapascals, and the action time is as short as several milliseconds. Under such a severe load, the
medium will be deformed, broken, even liquefied and vaporized, resulting in multiple nonlinearities. A series of problems, such as discontinuous wave and material multi-state, make the numerical simulation of these effects the most difficult subject in scientific calculation [5-7].

After more than 50 years of development, the numerical simulation of strong dynamic loading effects has become a huge systematic project [8,9], which consists of six parts, that is computing environment, human-machine interface, material state description, software system, credibility and visualization. Among of them, intelligent material state description, high-precision computation method, expert help system, credibility guarantee, image realization, etc. The big data technologies have applied more or less unconsciously, and these technologies have play a driving role in the development, application and credible evaluation of numerical simulation of strong dynamic load effects. In particular, some models and data have been solidified in software and help systems, greatly promoting the advancement and development of numerical simulation technology.

2. Current dilemmas and solutions of numerical simulation

2.1. Current dilemma [8]

In the past 30 years, with the rapid development of computer hardware technology and the popularization of commercial numerical simulation software, numerical simulation has become an indispensable tool in the analysis of engineering problems of strong dynamic loading effects, and plays an important role. But compared with the essential effect of numerical simulation and people's expectations, there are still many gaps and development bottleneck as follows. First, the development of numerical simulation software systems lags far behind computing hardware, and existing software systems are far from the high performance of supercomputer hardware. Second, the essential effect of numerical simulation are not well reflected. Due to factors such as computation algorithm, base data, model scale, etc., the reliability of numerical simulation results is not high, giving people the illusion, 

\textit{simulation is not true}. Third, the interface of software module is not unified. The current software functions are single, each software system is separate, there is no unified standard, data transmission between them is difficult, and the degree of generalization is very low, which makes it very difficult to use. Fourth, the material constitutive model library is insufficient and the data is lacking. There are no unified and accepted theoretical models and complete databases for common engineering materials such as concrete, rocks. Fifth, professional software systems are scarce and not adequately promoted. The current applications of numerical simulation are flourishing, but the professional software research is subject to various aspects of sustainable development planning deficiencies, lack of project promotion. These obstacles and bottlenecks have severely restricted the development of numerical simulation of strong dynamic loading effects, making it difficult to gain quantitative credible results [11].

2.2. Breakthrough way

Big data technologies include data collection and cleaning, data access, infrastructure, data processing, data mining, statistical analysis, model prediction, and data visualization [12,13]. Big data technology appears far later than numerical simulation. In the development and use of numerical simulation of strong dynamic loading effects, simulation workers have unconsciously applied big data technologies, but these applications are very fragmented, does not form a systematic theory, and lacks the corresponding tools. The emergence, growth and maturity of big data technologies have gradually formed a series of theoretical methods and software tools, and many engineering cases for reference. These provides a new breakthrough way to solve the dilemma of numerical simulation of strong dynamic loading effects.

3. Combination numerical simulation and big data technology

The numerical simulation system of strong dynamic loading effects includes the computing environment, human-machine interface, material state description, software system, credibility and other parts. These parts are combined with different big data technologies respectively, which will crack the spell of the numerical simulation, and the final simulation results will be accurate.
3.1. High efficiency of computation environment architecture
The computation environment is the hardware system that carries the simulation platform and the corresponding supporting environment, including operating system, programming environment, parallel mechanism, management control, etc. The numerical simulation algorithm, data flow and communication mechanism of strong dynamic loading effects require various professional solvers due to different objects and analysis zones. These solvers are generally different from the simple matrix operations of conventional tests, if no special adjustments are made to computing environment, the computational efficiency will be extremely low. With big data technologies, it is possible to systematically analyze the specific numerical simulation process, eliminate the calculation of the isolated points, balance the load of each process, and set a consistent computation environment according to the computing requirements, data flow, and computing scale. Therefore, the high performance of the hardware can be fully utilized, and finally the computing environment is highly efficient.

3.2. Automation of software system run
The software solution system is the core part of numerical simulation, and it is also the difficulty of numerical simulation of strong dynamic loading effects. It determines that the solver is very complex and needs to integrate the existing solvers, such as dynamic finite element, finite difference and finite volume basic solvers, SPH and other meshless, ARM adaptive, block model and other new solvers, Lagrangian and Euler coupling, grid and gridless coupling, and newly developed mapping solver, in addition to multi-physics, static-dynamic conversion and other solvers. By learning from others, we can achieve various functions of various solvers in order to accurately obtain the effects of various dynamic loading. However, the existing solver function is single, the conversion between the solvers requires human control, and it is difficult to smoothly reflect the complex physical-chemical processes in the strong dynamic loading effect. Applying big data technologies, on the one hand, it can be automatically switched to a suitable solver at different stages of a solution process according to an intrinsic mechanism, and the results of the previous solver can be automatically transferred to the subsequent solver, on the other hand, in different regions of the simulation model, according to the regional medium and deformation characteristics, the appropriate solver is automatically selected, and all the regions are automatically coupled. The final numerical simulation results can accurately reflect the evolution process of the whole model.

3.3. Intelligent of material state library
Strong dynamic loading mechanism, includes the compaction effect of volume deformation and the yielding and cracking of shear deformation. Its loading rate is from static one ten thousandth microstrain per second to a dynamic tens of thousands of microstrain per second. Its deformation phase is from elastic, strengthen, soften to the residue. The mechanism can describe the whole process of material from complete to smash, and so on. These characteristics require extensive and numerous experimental support, including at least: tests such as flyers (equations of state), tensile and triaxial tests (shear equations), dynamic tests such as SHPB (dynamic effects), survey of holes and joints (rocks), and so on. It should be pointed out that although the material state model is derived from the experiment, it is the summarization of various experimental data and the sublimation of the theoretical level. The good material state model has experienced the test of thousands of trials. These require the systematic constitutive theory and the huge data support. Without the support of the big data technologies, it will be difficult to convert all kinds of material test data and principles into pseudo-reality and turn into near-real theory and available data. The material state model library established for the numerical simulation of strong dynamic loading effects will be different from the general constitutive model, and should have intelligent functions and error correction capabilities, as the number of uses increases, the accuracy will also increase. In this way, the numerical simulation accuracy will be higher and higher, and the closer to the true distance.

3.4. Expertization of human-computer interface
In the current numerical simulation, most of the artificial time is spent on modeling, because most of the modeling is independent, and the engineering and construction are two standards. In other words, the drawings need to be manually processed. Numerical simulation models are cumbersome and error-prone. The numerical simulation uses a solid model, each point is consistent with the concrete object, and the current CAD drawings have not yet reached full digitization, only used for manual use, cannot be used by digital machine tools, numerical simulation is similar to fully digital drawings of digital machine. To achieve the sharing of numerical simulation and design drawings, it is necessary to develop corresponding standards to achieve full digitalization. In addition, even fully digital drawings, to be converted into a solid model, need to be further simplified to facilitate dispersion, highlighting the key points that need to be understood, while ignoring some secondary factors. These drawings conversion and engineering modeling, if without an expert guidance system, a large model will lead to the collapse of the entire numerical simulation. Now big data technologies have gradually been applied to this field, which greatly reduces the user's labor intensity, also improves simulation accuracy. In addition, numerical simulation is only a part of the whole research and development, and needs to be coordinated with planning, design, specification and construction. It needs to be integrated and work together under one big platform. If these huge data are not processed, it will be difficult to coordinate.

3.5. **credibility of Numerical simulation results**

The numerical simulation of strong dynamic loading effects is a physical and mechanical description of the motion, deformation and even damage of the surrounding air, geotechnical, concrete and other media under impact and explosion. It is a approximation process for these laws. The difference between numerical results and real laws are inevitable, there is a certain gap, but how to judge this gap, how to determine whether the numerical simulation is effective, is the key to the success of numerical simulation application, and all of those have form the verification and valid (V&V) theory. Existing methods learn from error analysis techniques, but these techniques can only give analysis results of single section such as system error, software error and model error, but most of these analyses are qualitative, and it is very likely that these errors are coupled and interdependent, while credibility is evaluation of the whole results of numerical simulation, so error analysis cannot completely solve the numerical simulation credibility problem, it needs to adopt more systematic analysis methods, and big data technologies are just such method, which provide model prediction, data mining, statistical analysis and other methods and tools.

3.6. **virtual reality of numerical simulation image**

The purpose of scientific computing is to insight, not the data itself. High performance numerical simulation of strong dynamic loading effects involves large and complex data types and data scale. This leads to a large and complex modeling data and post-processing data, which requires the powerful data access and graphics processing capabilities of modern computers to vividly represent the data generated by the numerical simulation in a virtual reality manner, thus deepening the researchers' understanding of the objects being studied. Big data visualization technology is the result of such demand.

4. **Numerical simulation promotes big data technology**

The combination of big data technology and numerical simulation of strong dynamic loading effects also has an important supplement and promotion effect on big data technology. Although big data technology is mainly used in the information field, from the perspective of big data technology, there are many overlaps with numerical simulation, and it is similar in numerical modeling, data refinement, credibility analysis, data visualization, etc. Numerical simulation has been developed for more than 50 years. It has accumulated a large amount of basic data in related fields, developed various effective analysis tools, and formed a set of unique research methods, which can enrich the big data technology and promote its development.

Numerical simulation has been applied to all aspects from military engineering to people's livelihood engineering. It has also encountered development bottlenecks in specific research and
engineering applications. The combination of big data technology, on the one hand, will help numerical simulation to break through the development bottleneck, on the other hand, it is also an extension of the application of big data technology. Numerical simulation and big data technology are complementary each other.

5. Conclusion
The research and application history of numerical simulation of strong dynamic loading effects is far more than that of big data technology. The computer is also born due to the demand of numerical computation of these effect. From developer to application, they have unconsciously applied to all kinds of big data technologies. The current numerical simulation encounters the development bottleneck, and the combination of numerical simulation and big data technology will be a practical way to break through the bottleneck.

A variety of big data technologies, current numerical simulation has encountered development bottlenecks, the integration of numerical simulation and big data technology will be a practical way to break through the bottleneck. After the combination of the two, accurate numerical simulation of strong dynamic loading effects will be realized.

References
[1] Yan Shouyi, Tu Houjie and Liang Deshou et al. 1995 Computation method of explosive mechanics (Beijing: Beijing Institute of Technology Press)
[2] Ren Huiqi, Mu Chaomin and Liu Ruichao et al. 2016 Penetration effect and engineering protection of precision guided weapons (Beijing: Science Press)
[3] Deng Guoqiang, Zhou Zaosheng and Yang Xiumin. 2005 Journal of System Simulation 17(5) 1059-62
[4] Deng Guoqiang and Yang Xiumin. 2009 Protective Engineering. 31(4) 24-8
[5] Yang Xiumin. Numerical simulation of explosion shock phenomenon 2010 (Hefei: University of Science and Technology of China Press)
[6] Ning Jianguo, Huang Fenglei and Qin Chengsen, 2002 Theory, Method and Engineering Application of Computational Explosion Mechanics (Beijing: Beijing Institute of Technology Press)
[7] Zukas J. 2004 Introduction to hydrocodes (Netherlands. ELSEVIER.)
[8] Deng Guoqiang and Wang Limei. 2014 Protective Engineering. 3 6-11
[9] Deng Guoqiang and Zheng Quanping. 2015 Protection Engineering. 37(2) 1-6
[10] Deng Guoqiang. 2014 The 6th Annual Conference on Explosive Computational Mechanics. Zhang Jia.
[11] Deng Guoqiang and Yang Xiumin. 2018 Protection Engineering. 40(6) 75-8
[12] Cheng Xueqi, Yan Xiaolong and Yang Wei et al. 2016 Science & Technology Review 34(14) 49-59
[13] Zhou Su, Feng Wei and Wang Shuoping. 2016 Big Data Technology and Application (Mechanical Industry Press)