SeisSol as a Community Code for Reproducible Computational Seismology - COCORECS

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Abstract

The SeisSol software package is designed for solving the earthquake dynamic rupture problem coupled to seismic wave propagation. SeisSol utilizes an arbitrary high-order Derivatives Discontinuous Galerkin (ADER-DG) finite element method. SeisSol is available to the scientific and engineer community as an open source distribution (https://github.com/SeisSol/SeisSol). We aim at establishing and maintaining a model environment to distribute open-source HPC simulation software at Leibniz Supercomputing Centre (LRZ) with adequate tutorials, training, courses, and user support. An open-source solution for geometry and mesh generation (e.g Gmsh) has been established and updated, complementing the existing commercial software (e.g. SimModeller) workflow. SeisSol's pre- and post-processing routines have been professionalised, to simplify the definition of material, parameters, etc., and to allow the flexible definition of output quantities. To build a lively community, it is mandatory to establish a well-functioning support system for the installation process, meshing procedures, code configuration and execution, and post-processing. While SeisSol is currently primarily used by computational seismologists who aim at the development and improvement of simulation models and respective numerical algorithms, our goal is to make SeisSol also accessible and easy to use for researchers who want to use the existing models in SeisSol for production runs, parameters studies, etc.

Modeling Framework

SeisSol's features:

* **Arbitrary high-order derivative Discountinuous Galerkin** method (ADER-DG), orthogonal basis functions (modal), elastic wave equation in velocity stress formulation (linear byperbolic system)
* **Exact Riemann solver** computes upwid flux of neighbour cells
* **High-order accuracy** in space and time
* **Unstructured tetrahedral meshes** to account for complex geometries, e.g. high resolution topography and bathymetry, 3D subsurface structure, and fault networks
* **Heterogenous media** (elastic, viscoelastic, viscoplastic)
* **Non-linear friction** (e.g. rate-and-state friction)
* **A Parallel Server for Adaptive Geoinformatio**n (ASAGI)
* **Verified** for branching and dipping fault systems, heterogenous background stresses, bi-material faults and rate-and-state friction (e.g. SCEC benchmark center)

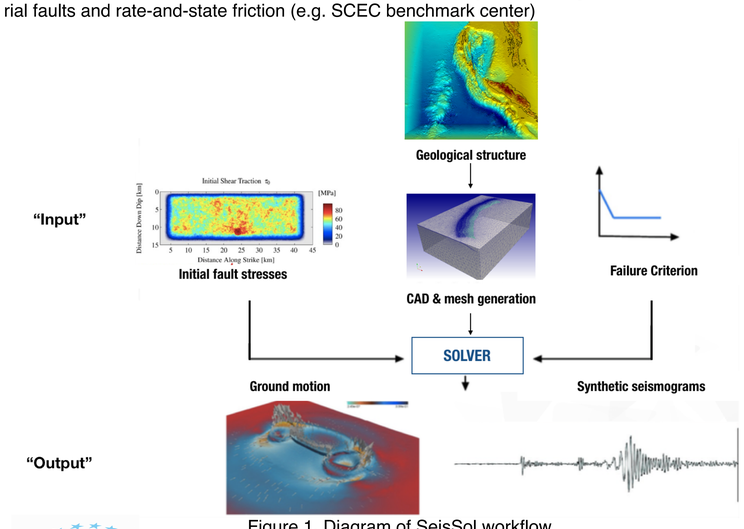


Figure 1. Diagram of SeisSol workflow

Highlighted awards:

2014 PRACE ISC Award for producing the first simulations that obtained the "magical" performance milestone of 1 Peta-flop/s

2014 ACM Gordon Bell Prize Finalist for performing multi-physics simulations of a 1992 Landers earthquake scenario on the largest existing supercomputers

SC17 Best Paper Award for largest and longest high-resolution dynamic rupture scenario performed

Scenarios of Large Earthquakes

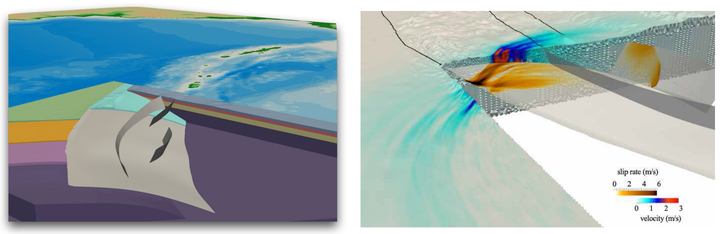


Figure 2. The 2004 Mw 9.1 Sumatra-Andaman tsunamigenic earthquake was an unexpected, very large event rupturing faults of 1300 to 1500 km, lasted 8 to 10 minutes. Dynamic rupture scenario of the 2004 Mw9.1 Sumatra-Andaman earthquake is the largest and longest simulation ever [Uphoff et al., 2017]. (Left) The subsurface includes a horizontally layered continental crust, subjecting oceanic crust and two splay faults in the continental crust. (Right) Dynamic rupture and seismic wave propagation on the megathrust and splay fault.

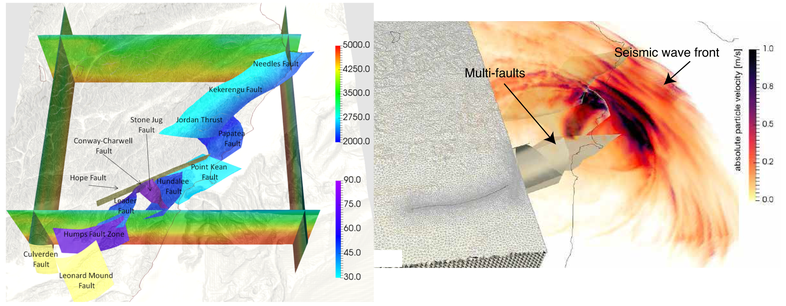


Figure 3. The 2016 Mw7.8 Kaikoura earthquake is one of the most complex and puzzling ruptures observed to date, unusual quantity and quality of intriguing observations that challenge our current understanding of earthquake dynamics. We model 90 seconds on a computational mesh consisting of 29 Million elements requires typically 2 hours on 3000 Sandy Bridge cores of the supercomputer SuperMuc. (Left) CAD model of multi-segment fault system used in SeisSol simulation [Ulrich et al., 2019a]. (Right) Snapshot of the seismic wavefield and slip rates across the fault network in the multi-fault scenario of the 2016 Mw7.8 Kaikoura earthquake.

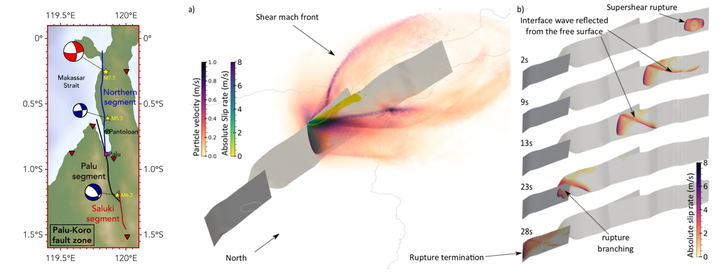
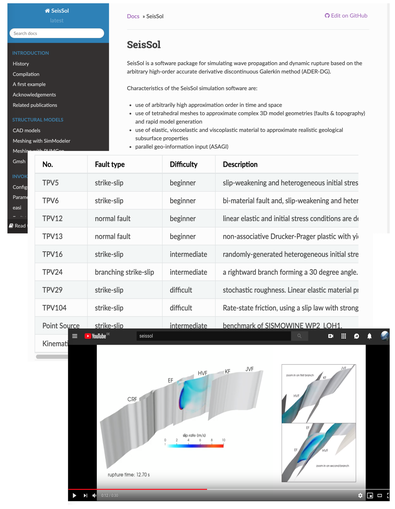


Figure 4. SeisSol has strong capacities for coupling with various physics-based simulations and achieving novel geophysical topics in practice. Recent application of SeisSol modeling to the 2018 earthquake-tsunami Palu, Sulawesi event within weeks after the event illustrates the potential of physics-based modeling complementing the rapid response toolset after devastating events [Ulrich et al., 2019b, submitted].

Goals of CoCoReCS

1. Enhancing Ability and Software Quality:
   * open-source mesh generation procedure
   * improved user-friendly workflow with improved pre- and postprocessing.
   * software quality control: unit tests and validation



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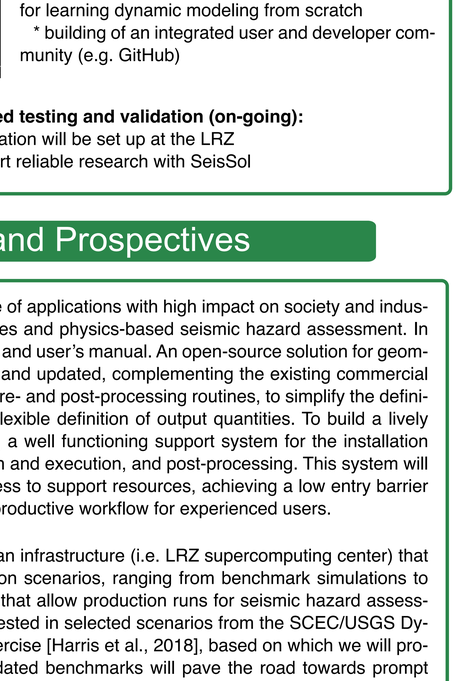

2. Tutorials, Training and User Support:
   * updated installation process and first-level support in GitHub (https://github.com/SeisSol/SeisSol)
   * tutorials and documentations are available for new users (https://seissol.readthedocs.io/en/latest/)
   * repository for cookbook provides lots of materials for learning dynamic modeling from scratch
   * building of an integrated user and developer community (e.g. GitHub)

3. Reproducibility Infrastructure for automated testing and validation (on-going):
   * infrastructure for automated testing and validation will be set up at the LRZ
   * repository for reproducible research to support reliable research with SeisSol

Conclusions and Prospectives

SeisSol has excellent potential for a wide range of applications with high impact on society and industry, such as the simulation of induced earthquakes and physics-based seismic hazard assessment. In CoCoReCS project, we have improved instllation and user's manual. An open-source solution for geometry and mesh generation has been established and updated, complementing the existing commercial software workflow. We have polished SeisSol's pre- and post-processing routines, to simplify the definition of material, parameters, etc., and to allow flexible definition of output quantities. To build a lively community, we are now working on establishing a well functioning support system for the installation process, meshing procedures, code configuration and execution, and post-processing. This system will be open to all users of SeisSol, giving easy access to support resources, achieving a low entry barrier for new users as well as ensuring a maintained productive workflow for experienced users.

We will further put efforts to design and install an infrastructure (i.e. LRZ supercomputing center) that maintains a wide range of reproducible simulation scenarios, ranging from benchmark simulations to constantly validate the software up to scenarios that allow production runs for seismic hazard assessment. Up to date, SeisSol has been intensively tested in selected scenarios from the SCEC/USGS Dynamic Earthquake Rupture Code Verification Exercise [Harris et al., 2018], based on which we will provide full-featured production setups. These validated benchmarks will pave the road towards prompt simulations of new earthquake events, up to urgent computing scenarios.

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