What Can Open Source Structural Software Do For You?

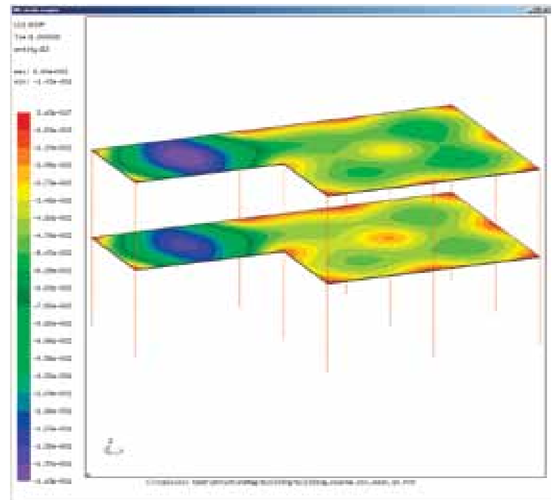
By Arturo Montalva, P.E., Jeff Baylor, and Klaus Wittig

Structural engineers rely on analysis software in their everyday work. This software helps to solve problems as simple as the design of a beam or as complex as the optimization of a high-rise building design. Different structural engineering software programs solve different types of problems. For example, some programs specialize in steel construction while others specialize in concrete design. While most solve linear static problems, some can solve non-linear and/or dynamic problems.

Deciding on the appropriate analytical tool for each project is sometimes challenging, particularly because most projects require more than one program. For this reason, structural engineers need access to a wide range of programs. Purchasing a large number of commercially available software packages can pose a significant financial hurdle for many companies. Open source analysis software provides a viable alternative for many structural engineers.

This article introduces the reader to open source with one example of an open source engineering program, CalculiX. Subsequent articles will also introduce other useful open source programs available to the structural engineering community like OpenSees and OOFem, as well as further discussion of important concepts related to open source software such as licensing, available support, and testing/benchmarking of the code.

Open source software is an approach to the design, development, and distribution of computer programs, offering practical accessibility to the computer code. Users can compile, change, update and improve the computer code to fit their specific requirements. Open source software is typically licensed under the general public license (GPL) which allows free access, modification, and redistribution of the code as long as any changes on the software are redistributed under the same license. However, the user must be aware of the specific requirements of the license as some open source software have restrictions on the redistribution of the code. Because everybody has access to the source code, it becomes a living entity where users and developers collaborate though internet groups and forums to provide development suggestions and bug reports. Therefore, collaboration is an important parameter to consider if you want to use open source software. While the use of open source software is free, some businesses provide support or add-on applications for a fee.



Deflected contour plot under self-weight using CalculiX.

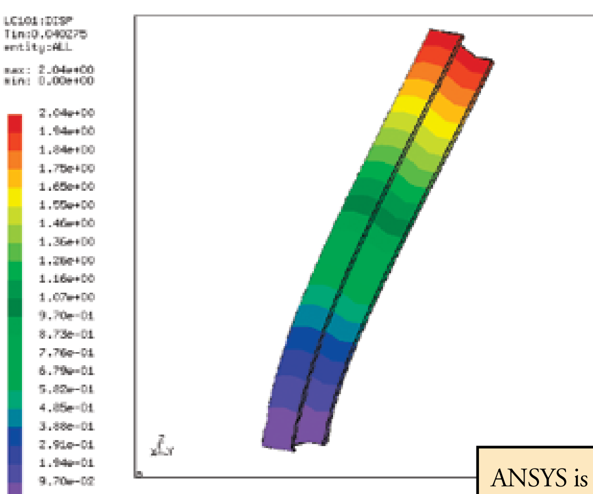
Open source software is becoming more and more prevalent in many everyday applications. Netbooks, cellphones, internet routers, etc. are loaded with open source codes. Governments and public institutions are adopting open source format for their documents. The "One Laptop per Child" initiative seeks to bring one low cost computer to every child, with a free open source operating system and software applications which play a large role in reducing the overall cost of the system. The growing availability of open source software in the engineering community mirrors these broader trends.

There are multiple structural open source programs that can be very useful for the structural engineering community. Many of them are developed by universities as part of their research programs and used extensively by their students. Others are developed by practicing engineers and maintained by the engineering community. Often these codes were developed to solve very specific problems, but with the contributions and support of the engineering community they have evolved into very complex programs. In this and subsequent articles, we will introduce a few of these open source programs starting with CalculiX.

CalculiX is a widely used finite element analysis (FEA) suite in the mechanical and aerospace engineering community developed for more than a decade by the original authors (Guido Dhondt and Klaus Wittig) and a growing community of practicing engineers and scientists. This code is being used by large multinational corporations as well as many small businesses seeking an open source finite element solution. CalculiX is distributed under the GPL which allows free use, reproduction, modification, and distribution of the code.

The CalculiX suite contains a solver, a pre/post processor, and data translation tools to facilitate interaction with other codes. The solver, CCX, uses a text input file format similar to Abaqus, and therefore some proprietary pre-processors may be used to generate input files for CalculiX.

As a general purpose solver, CCX can solve static and dynamic problems using implicit and explicit formulations. Material nonlinearities, as well as geometrical nonlinearities, can be introduced to solve more complex structural and mechanical problems. The code is not limited to structural or mechanical problems but



Deflected shape of a wide flanged cantilever column subjected to air-blast load.

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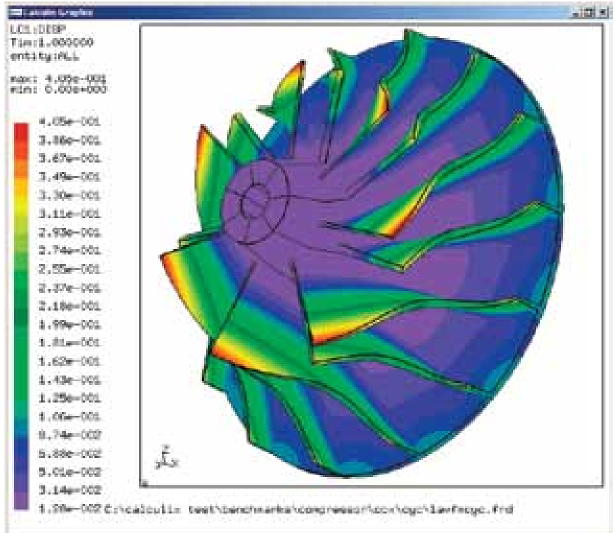
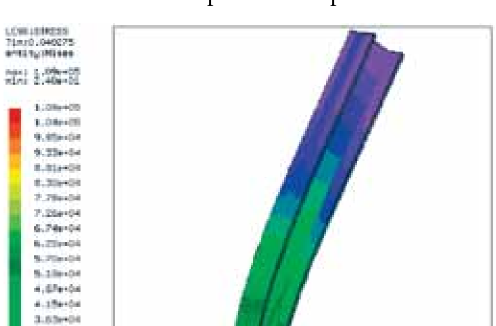
also includes algorithms to solve heat transfer, modal and buckling analyses, and fluid dynamics (CFD), the latter improved in version 2.2 released in August, 2010. This code can be used by the structural engineering community to solve complicated problems, including multi-physics such as the effects of fire in structural members, fluid-structure interactions, connection details, and nonlinear static and dynamic response of structures.



Deflection of a compressor.

CalculiX includes a complete element library for volumetric elements, as well as quadratic formulations for plane stress, plane strain, axi-symmetric, shells, and beam elements. All beam and plane elements are internally changed to 3D 20-node brick elements with appropriate boundary conditions, because the CCX solver neglects nodal rotational degrees of freedom. This limits the modeling capabilities of beams to simple cross sections, but increases the analytical performance of complex models. Complex beam sections can be modeled using multiple rectangular beam elements offseted from the neutral axes of the section, but this is not as convenient as a beam element formulation with arbitrary cross section. Hopefully, a traditional beam formulation will be developed in future releases.

Other modeling capabilities of CalculiX include cyclic-symmetry, contact surfaces, gaps, and single-point and multi-point constraints, which together with the concentrated and distributed loads and body forces allows an engineer to describe a wide variety of relevant structural cases. In general, the performance and accuracy of Calculix is equivalent to proprietary software (except CFD, which is in prototype form), with the advantage that the basic matrix library can be changed to platform-specific optimized solvers like SPOOLES, Arpack, or Pardiso (for Intel® CPU's) which can also allow multiprocessor capabilities. The pre/post processor, CGX, can generate structured meshing and create input data for CCX, Nastran, Ansys, and Abaqus, as well as process the output results from the CalculiX solver. Basic preprocessor functionality is very easy to understand; however, generation of complex models can be challenging and may require some training.



Von Mises Stresses of a wide flange cantilever column subjected to air-blast load.

New users to CalculiX will benefit from a complete user manual, as well as a broad set of examples and their solutions. These example problems provide valuable references as well as test-cases. In addition, benchmark tests defined by the National Agency on Finite Elements Methods and Standards (NAFEMS) and solved with CalculiX can be viewed on the Convergent Mechanical Solutions website (**http://bConverged.com/benchmarks**). These benchmark tests provide industry-standard solutions to FEA problems and can be used to test the accuracy of CalculiX.

Further information about CalculiX is available on its website (**www.calculix.de**) which includes manuals, source code, and compiled versions for Linux. The Windows version is available from Convergent Mechanical Solutions (**http://bConverged.com/calculix**). An active user and developer community provides support through the CalculiX Yahoo group (**http://groups.yahoo.com/group/calculix**).▪

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Klaus Wittig, is the creator of cgx, a pre- and post-processor for CalculiX, a free FEM code. Mr. Wittig specializes in gas-turbine structural-design.