WORKSHOP REPORT

Workshop to Plan for Creating an Updatable Version of the CFM for use by Earthquake Simulators

PI:
Terry E. Tullis, Brown University
CoPIs:
Michael Barall, Invisible Software
Jim Dieterich, UC Riverside
Ned Field, USGS
Scott Marshall, Appalachian State

SUMMARY

The SCEC Community Fault Model (CFM) is the most detailed description of the geometry of faults in California. As such, it is the logical fault description to be used by future increasingly detailed simulations of long historic earthquake sequences. However, several problems arise in trying to use the CFM in Earthquake Simulators. The purpose of this workshop was to discuss these problems and potential solutions to them by a small and diverse group of specialists in order to define how and by whom the CFM can be made useful for Earthquake Simulators. An additional intent is to define a process by which future updates to the CFM can be easily made usable by Earthquake Simulators.

Among the problems needing solutions that were discussed are the following:

- How best to create CFM versions that involve roughly equal-sized and equant-shaped elements and whether grids should be created having triangular elements, rectangular elements, or both.
- The top edges of the faults in the CFM follow actual topography, but Earthquake Simulators require an upper planar surface on a half-space, so a version of the CFM needs to be created in which the topography is somehow flattened.
- The CFM contains fault geometry, but does not have either slip rates or slip rakes, both of which are needed by Earthquake Simulators, which currently are loaded by back slip. Some method is needed to assign slip rates and rakes for the many faults having no such data and also to reconcile the many instances where finding a simple correspondence between the faults included in the CFM and those included in UCERF3 for which slip-rate and slip-rake data do exist.

The hope was that from this workshop would emerge:

- A consensus as to the best way to solve these problems
- A team of individuals who will agree to do collaborate via one or more SCEC proposals to do the required work
- An approach is developed so that once an initial CFM-EQSIM is created it can easily be updated as improvements are made to the CFM

The agenda of the workshop is reproduced at the end of this report. Slides showing the formal presentations given at the workshop can be found at http://www.scec.org/workshops/2017/cfm.

The workshop was quite successful. Interesting ideas were presented by many of the participants which provide potential solutions for the problems presented in the bulleted list just above. This will be described in the RESULTS section below. At the SCEC Annual Meeting, in a follow-on to the workshop, several of the participants discussed a plan to test one of these potential solutions, and a proposal to do this is being prepared to submit to the SCEC Planning Committee.

RESULTS

Modifying the CFM mesh to create one that can be used by earthquake simulators.

The difficulty of using any of the existing triangulated versions of the CFM is that the triangles are not well configured for use by earthquake simulators. The problems are illustrated in the presentations shown in the workshops by both Michael Barall and by Scott Marshall. Even in the re-triangulated versions of the CFM that have been provided by the CFM developers to have more equidimensional triangles, many of the triangle configurations are too varied in size and shape, especially near the edges of the mesh, to be suitable for use by earthquake simulators. In addition, the CFM extends up to the actual topographic surface of the Earth. This means that earthquake simulators that use elastic half-space equations to determine the Greens functions that relate slip on an element to stress on other elements cannot use the CFM meshes. Thus, the CFM mesh must be modified to terminate at a planar upper surface. To date the only way that has seemed practical to make a triangulated mesh that is more suitable for use by simulators is to make modifications by hand, a tedious and time-consuming process. With this method of modifying the CFM, future updates to the CFM require repeating this laborious modification process. Consequently, these modifications do not tend to be redone with new releases of the CFM and so the manually-modified versions currently in use for various sub-regions of the CFM are based on several different versions of the CFM.

An approach for solving this problem was suggested during the workshop discussions by Ahmed Elbanna and Ossian O'Reilly. The idea is to fit a 3D spline surface to each of the fault surfaces in the CFM, a process that should be capable of automation. Then an automatic mesh generator would be applied to the spline surface that would exactly follow the edges of the fault surfaces as well as any interior curves formed by fault intersections, and would closely approximate the fault surface smoothly elsewhere. The advantage of the spline is that it provides an abstract mathematical representation of the fault shape at arbitrary resolution. The mesh generator could ideally generate a mesh composed either of triangles or of rectangles, at whatever scale of resolution is desired. A version of the splined fault surface could either include the topography that exists in the CFM or each spline could be cut at its intersection with a horizontal plane at sea-level. Chopping off the topography above sea-level was the solution that the workshop participants felt was the best way to flatten the topography in the CFM.

Experience in re-meshing the CFM, particularly the experience of Scott Marshall and his co-workers, strongly suggests that no automatic process will be able to re-mesh the entire CFM. However, it seems reasonable to hope that an automated process like the one just described might be able to re-mesh 90% of the faults in the CFM. If this can be done successfully, then the number of faults that must be re-meshed by hand would be reduced from 300 to 30, which would be a huge step toward creating a version of the CFM that is suitable for earthquake simulators. The application of the automated process, combined with manual re-meshing of the faults that cannot be handled automatically, would hopefully be simple enough that it could be reapplied to any faults that are changed or added in future versions of the CFM, thereby satisfying the desire to make earthquake-simulator-compatible versions that are consistent with future releases of the CFM. A group of workshop participants plans to submit a proposal to SCEC to investigate the feasibility of this approach.

Andreas Plesch pointed out that the CFM is one of the community models under the USR umbrella. Key features of such models include: consistency across models; the availability of multiple representations of an underlying abstract base model; allowance for alternative representations of a given feature (to allow for differences of opinion); easy access; and versioned releases. Due to these requirements, we cannot change the process by which the CFM is developed, so whatever we do will need to be applied after the main CFM development effort is complete.

Determining slip rates and rakes for faults in the CFM

Earthquake simulators presently are loaded by backslip, which means that a long-term slip rate and a slip rake need to be prescribed for every element on a fault surface. UCERF3 assigns a slip rate and slip rake to each fault, but the CFM does not. Some of the faults in the CFM can be identified with faults in the UCERF3 deformation model, and in those cases the UCERF3 slip rate and slip rake can be used. Some other faults in the CFM may be in some way associated with faults in UCERF3, but expert opinion is needed to determine what the proper association is, due to differences in naming conventions, fault segmentation, and the level of detail. In addition, many faults in the CFM are not in the UCERF3 model and may or may not have a slip rate and slip rake that is known by some geologist. (Ned Field pointed out that faults without known slip rates and slip rakes were intentionally excluded from UCERF3.) Consequently, a good way to assign slip rates and rakes to the CFM faults differs from fault to fault and in many cases no good solution may exist.

In the case of the faults for which some knowledge exists, collecting a group of geologists with knowledge of the faults in question is clearly the best approach if the association between the CFM and UCERF3 faults is unclear. This will leave many faults to be determined in some other way.

For the faults in which insufficient geologic knowledge exists several solutions were discussed. One possibility might be to simply assign some standard low slip rate and a slip rake that is consistent with what is known about the geologic setting and the rake of similar faults nearby. Another might be to use boundary element models to invert for the slip rate and rake that are consistent with the known slip rate on other nearby faults and with remote boundary conditions derived from geodetic data [Cooke and Marshall, 2006; Herbert et al., 2014; Marshall et al. 2009; 2013]. A third method might be to treat small faults as if they are not tectonically driven, but instead slip only in response to slip on the major faults.

Resolving the best way to determine slip rates and rakes remains to be considered further. It may be that the best approach to this is to turn to it more carefully if we determine that the idea described above for using splines to fit CFM faults gets us over the hurdle of how best to mesh the CFM.

NEXT STEPS

The workshop resulted in some very useful ideas and communication among those working on this and related problems. A sub-set of the participants at the workshop plan to submit a proposal to the SCEC Planning Committee for funding a test of the idea of meshing the CFM via an intermediate step of fitting a spline surface to each fault, as described above. If this approach proves to be feasible, then subsequent work using this approach could be done on the entire CFM. At that stage, the problem of exactly how to assign slip rates and rakes on all the faults would also have to be addressed more deeply.

AGENDA

Sunday, September 10, 2017

13:00-13:10	Introduction and goals of workshop	Terry Tullis
13:10-13:30	Brief Description of 2015	Michael Barall
13:30-13:35	Discussion of what shape elements to use and how to create them	Terry Tullis
13:45-14:00	Remeshing the Community Fault Model for use in Boundary Element Method Models	Scott Marshall
14:00-14:15	Discussion of best way to flatten topography	All
14:15-14:30	Overview of efforts to determine slip rates and rakes in UCERF3	Ned Field
14:30-14:45	Discussion of what can be done to determine slip rates and rakes for faults in the CFM	All
14:45-15:00	*Break*	
15:00-15:15	Current plans for ongoing improvements to the CFM	Andreas Plesch
15:15-15:30	Discussion of how the CFM process could be augmented to include a version without topography and with slip-rate and slip-rake data	All
15:30-16:00	Discussion of who is interested in being part of a collaborative proposal to create an initial CFM-EQSIM and what role they would play	All
16:00-16:15	Discussion of how could future updates to the CFM lead to the same version of an updated CFM-EQSIM	All
16:15-17:00	General discussion of issues that were short-changed	All
17:00	*Adjourn*	

REFERENCES CITED

Cooke, M.L., and Marshall, S.T. 2006. Fault slip rates from three-dimensional models of the Los Angeles metropolitan area, California, *Geophysical Research Letters,* 33, L21212, doi:10.1029/2006GL027850.

Marshall, S.T., Funning, G. J., Owen, S.E. 2013. Fault slip rates and interseismic deformation in the western Transverse Ranges, California. Journal of Geophysical Research, Vol. 118, p. 4511-4534, doi: 10.1002/jgrb.50312.

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