Remeshing the CFM for use in Mechanical Models

Scott T. Marshall
Appalachian State University

BEM Model of slip on the Channel Islands Thrust, CA
Credit Where Credit is Due: Michele Cooke

Michele Cooke – UMass Amherst

- Has been training students/postdocs to work with and remesh the CFM since at least 2003
- Michele and I have developed slightly different tools/methods, but our overall approach and goals are the same

Main meshing software

- Move suite (Midland Valley Exploration)
- [www.mve.com](http://www.mve.com)
- Available to academic institutes for a small annual fee ~€200/yr
- We also use several home-grown Perl scripts for various tasks

First* publication using CFM-based mesh:
Publications Using Various Remeshed CFM’s


15. Herbert, J. W., M. L. Cooke, M. Oskin, and O. Difo (2014b), How much can off-fault deformation contribute to the slip rate discrepancy within the eastern California shear zone?, *Geology*, 42(1), 71-75.


**Apologies if I left yours out!**
The Raw CFM: The Good

The Raw CFM Mesh...

• Is highly irregular
  • mesh density/resolution
  • triangle shape/size
    • Many triangles have poor aspect ratios

The Good

• The mesh is carefully constructed based on all available data
  • TONS of work!
• Mesh density shows where there is data and where there is not
• Packaged as ascii files (tsurfs)
  • Easy to read/write

The Northridge Thrust (CFM5.0)

Relocated aftershocks from Carena & Suppe (2002)
The Raw CFM: Potential Issues

Mesh Quality

- The mesh is has too much variation in triangle size/shape to be numerically stable
  - Ideal: Equilateral triangles (not possible for nonplanar/irregular faults)

- Some faults have small gaps/holes
  - Difficult to visually detect
  - Can write scripts do check this
  - I can share mine, if anyone is interested
The Raw CFM: Potential Issues

Subsurface Fault Intersections

• The CFM mesh does not intersect faults along triangle edges
• BEM models calculate values at Elt centroids
  • Interpenetrating Elts can cause stress singularities
  • Kinematic models are OK with intersections
• Faults must be remeshed to intersect along triangle edges
  • Subsurface intersections are typically unconstrained

The Newport-Inglewood fault (blue) intersects the Compton Thrust (gray) in CFM5.0
The Raw CFM: Potential Issues

CFM Surfaces only cover Seismogenic Depths

- Modeling interseismic deformation requires extending faults to depth
  - Must extend faults beyond CFM depths
  - Marshall et al. (2009, JGR) provides a computationally-efficient method
  - Many faults many intersect when extended
  - Unconstrained; requires arbitrary geometric decisions
  - Should small faults be extended? How far?
The Raw CFM: Potential Issues

Fault Traces Follow Topography

- Z-values are elevation, not depth
- Fault traces go up to their actual surface elevation
  - Most faults don’t occur at high elevations
  - Total surface area above z=0 is typically small
  - Offshore faults don’t go to z=0 (are they blind?)

Modeling Challenges

- Most BEM models use a halfspace
  - Could make a surface topography mesh
    - Shear traction-free
    - Surface would be complex (many elts)
    - Would need to fix fault intersections with surface (very time consuming)
  - Increase computation time
Flattening Topography: Two Choices

Choice #1
- Project the surface trace down to some datum (z=0)

The Good
- Fault trace is in correct location

The Bad
- Fault is at least one of the following:
  - Mislocated in the subsurface
  - Incorrect dip and mislocated
  - Must curve/kink to merge with correct fault location at depth
  - Surface area changes
- These cause significant changes in mechanics
Flattening Topography: Two Choices

Choice #2*  *this is what I do…

• Remove portion of fault surface above the datum

The Good

• Fault orientation is unchanged
  • Correct location in subsurface

The Bad

• Fault trace is mislocated (for non-vertical faults)
• Surface area changes
• Less significant changes in compared to choice #1
Flattening Topography: The Santa Susana Fault

Software: 3DMove from Midland Valley
www.mve.com
Flattening Topography: The Santa Susana Fault
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- Unnecessary Triangles
- Poor aspect ratios
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Meshing: A Bit of an Art

- Creating good fault meshes is a combination of science and art
  - Science: must fit the data
  - Art: how good is good enough?

- **VERY** time consuming
  - Each fault: 1-3 hrs
  - Depends on number of intersections
  - Blind faults are easier

- Is this possible to automate?
  - Maybe
  - I have tried and failed many times

Transverse Ranges Mesh Based on CFM5.0
Marshall et al. (2017, GRL)
79 Faults; 21,054 Elements
Numerous subsurface fault intersections
Determination of Slip Rates/Rakes

• Such a dataset would almost certainly need to be model-derived
• Our groups have been doing this since Cooke & Marshall (2006, GRL)
• For recent examples, see

Beyer et al. SCEC Poster #219
“Getting pushy with the San Gorgonio Pass: Investigating active fault geometries with crustal deformation models”

Dorsett et al. SCEC Poster #218
“Mechanical Models of Fault Slip Rates in the Imperial Valley, CA”
Stuff to Share

Scripts Useful for Meshing and Visualization

- **ts2matlab.pl**: converts t-surf to a MATLAB-friendly format
- **plotMesh.m**: plots a fault surface used with ts2matlab.pl
- **ts2facet.pl**: converts to facet format (FEM models)
- **fixTS.pl**: makes a grouped surface into a single surface
- **remTRGL.pl**: used to find holes, and fix intersections
- **checkFaultTop.pl**: checks to make sure faults go to z=0
- **checkFaultBottom.pl**: checks the maximum depth of faults
- **mesh.pl**: a simple planar or sinusoidal mesh generator

Contact me if you think these would be of use