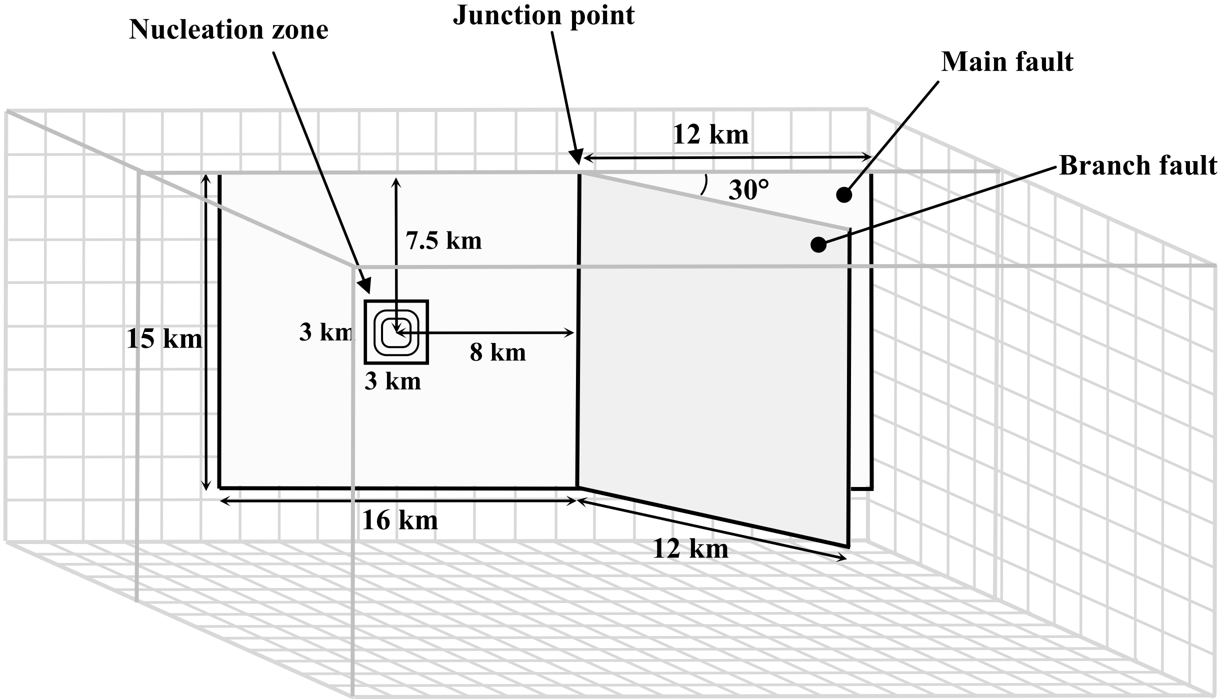
TPV14 and TPV15
Branched-Fault Benchmarks

January 5, 2011

Contents

Part 1: Description of the 3D Benchmarks



Fault Geometry

The model volume is a half-space.

There are two faults, called the **main fault** and the **branch fault**. The two faults are vertical, planar, strike-slip faults. The faults reach the earth's surface. In TPV14, they are right-lateral faults. In TPV15, they are left-lateral faults.

The main fault is a rectangle measuring 28000 m along-strike and 15000 m deep. The branch fault is a rectangle measuring 12000 m along-strike and 15000 m deep. There is a junction point. It is located 12000 m from the right edge of the main fault, and the main fault passes through it. The branch fault makes an angle of 30 degrees to the main fault, and it ends near, but does not fully reach, the junction point.

The nucleation zone is a square measuring 3000 m × 3000 m. It is centered in the left side of the main fault. That is, the center of the square is 8000 m from the junction point, and 7500 m deep.

A node which lies precisely on the border of the nucleation zone is considered to be inside the nucleation zone, and so has the elevated initial shear stress given below. Likewise, a node which lies precisely on the border of the main or branch fault is considered to be inside the fault, and so should be permitted to slip. These are the same rules we have used in previous benchmarks.

The main fault runs continuously through the junction point. The branch fault does not connect with the junction point. Instead, the branch fault starts one element away from the junction point. So, a rupture beginning at the nucleation zone can propagate freely into the right side of the main fault, but the rupture must jump a short distance to propagate into the branch fault. This is discussed in detail later.

Material Properties

The entire model volume is a linear elastic material, with the following parameters:

Density $\rho = 2670 \text{ kg/m}^3$

Shear-wave velocity $V_s = 3464 \text{ m/s}$

Compressional-wave velocity $V_p = 6000 \text{ m/s}$

Note, these are the same material properties used in benchmark TPV5.

Initial Normal and Shear Stress on the Faults

In TPV14, the initial stresses on the faults are:

Initial normal stress $\sigma_{\text{ini}} = 120.0 \text{ MPa}$

Initial shear stress on main fault $\tau_{\text{ini}}^{\text{main}} = 70.0 \text{ MPa}$ (right-lateral)

Initial shear stress on branch fault $\tau_{\text{ini}}^{\text{branch}} = 70.0 \text{ MPa}$ (right-lateral)

Initial shear stress in nucleation zone $\tau_{\text{ini}}^{\text{nuke}} = 81.6 \text{ MPa}$ (right-lateral)

In TPV15, the initial stresses on the faults are:

Initial normal stress $\sigma_{\text{ini}} = 120.0 \text{ MPa}$

Initial shear stress on main fault $\tau_{\text{ini}}^{\text{main}} = -70.0 \text{ MPa}$ (left-lateral)

Initial shear stress on branch fault $\tau_{\text{ini}}^{\text{branch}} = -78.0 \text{ MPa}$ (left-lateral)

Initial shear stress in nucleation zone $\tau_{\text{ini}}^{\text{nuke}} = -81.6 \text{ MPa}$ (left-lateral)

Since these are strike-slip faults, the initial shear stress in the along-dip direction is zero.

Remember that the nucleation initial shear stress $\tau_{\text{ini}}^{\text{nuke}}$ applies to all nodes that are inside the nucleation zone, and to all nodes that lie precisely on the border of the nucleation zone.

Note, the initial stresses on the main fault and in the nucleation zone are the same as in TPV5.

The initial shear stress is the only difference between TPV14 and TPV15.

Friction Parameters

We use linear slip-weakening friction with the following parameters:

Static coefficient of friction $\mu_s = 0.677$

Dynamic coefficient of friction $\mu_d = 0.525$

Slip-weakening critical distance $d_0 = 0.40$ m

Frictional cohesion $c_0 = 0.0$ MPa

Note, these are the same friction parameters used in benchmark TPV5.

Running Time, Node Spacing, and Results

Run the model for times from **0.0 to 12.0 seconds after nucleation**.

We recommend using **100 m node spacing** on the fault planes.

The requested output files are:

- **On-fault time-series files**, which give slips, slip rates, and stresses for each on-fault station at each time step. These files are described in *Part 5*.

- **Off-fault time-series files**, which give displacements and velocities for each off-fault station at each time step. These files are described in *Part 6*.

- **Contour-plot files** which, for each node on one of the two faults, gives the time at which the slip rate first changes from 0 to greater than 0.001 m/s. There are two contour-plot files, one for the main fault and one for the branch fault. These files are described in *Part 7*.

Part 2: Description of the 2D Benchmarks

We are also doing 2D versions of TPV14 and TPV15, which are called TPV14-2D and TPV15-2D.

The 2D model consists of a horizonal planar slice through the 3D model, passing through the hypocenter. It is a horizontal plane, at a depth of 7.5 km.

All the model parameters, initial stresses, material properties, nucleation patch, friction parameters, station locations, and so forth, are exactly the same as in the 3D model.

The main fault in the 2D model is a line, 28 km long. The branch fault is a line 12 km long. The junction point is located 12 km from the right end of the main fault, and the main fault passes through it. The branch fault forms an angle of 30 degrees to the main fault, and it ends near, but does not fully reach, the junction point.

The nucleation zone is a line 3000 m long. The center of the nucleation zone is located 8000 m to the left of the junction point.

The 2D model has no motion in the vertical direction. That is, all motion is within the horizontal plane.

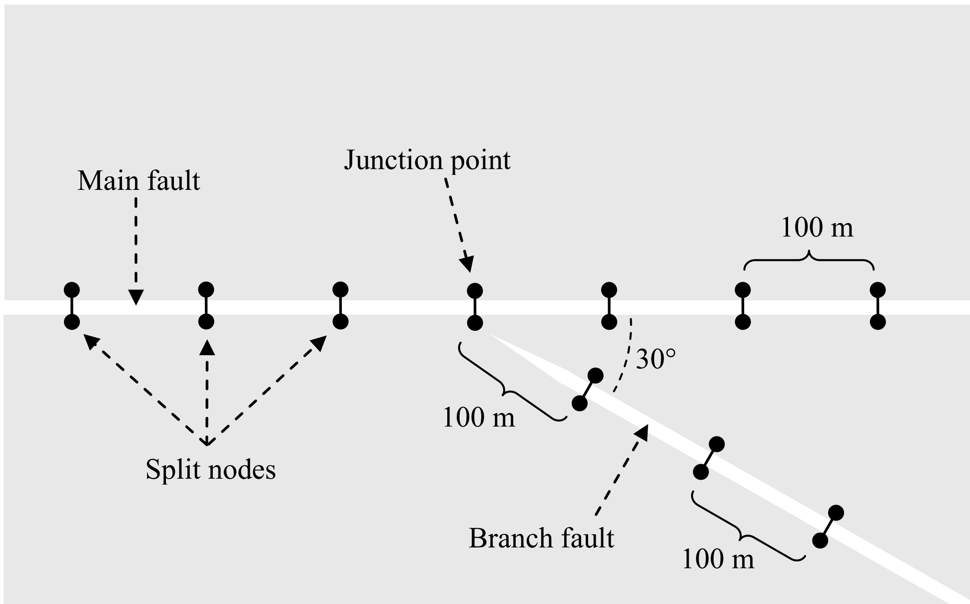
Run the 2D model for times from **0.0 to 12.0 seconds after nucleation**.

We recommend using **100 m node spacing** on the fault lines.

Supply time-series files for on-fault and off-fault stations. The on-fault station locations are the same as for the 3D model, except that only stations located at 7.5 km depth are used. The off-fault station locations are the same as for the 3D model, except moved from the earth's surface to a depth of 7.5 km. File formats are the same as for the 3D model. In the time-series files, data values that refer to vertical motion should be set to zero. This is explained further in *Part 5* and *Part 6*.

Supply contour-plot files for the main and branch faults. In order for the web site to draw 2D contours correctly, each node must be listed twice in the contour-plot file, once with a depth of 0.0 km and once with a depth of 15.0 km. This is explained further in *Part 7*.

Part 3: Junction Point Behavior



The figure illustrates the main and branch faults near the junction point. The faults are implemented using split nodes, which in the figure are spaced at intervals of 100 m along the faults. Each split node consists of a pair of nodes on opposite sides of the fault. Fault slip is achieved by allowing the two halves of a split node to move relative to each other.

The main fault runs continuously through the junction point. At the junction point, the main fault has an ordinary split node. So, **a rupture that begins on the left side of the main fault can propagate freely onto the right side of the main fault**.

The branch fault does not meet the junction point. The first split node on the branch fault is located 100 m from the junction point, measured parallel to the strike of the branch fault as shown in the figure. (So, the first split node on the branch fault is located at 50 m perpendicular distance from the main fault.) If the branch fault were extended toward the main fault, it would intersect the main fault at the junction point. The branch fault does not have a split node at the junction point, and so it does not connect to the main fault. As a result, **in order for a rupture on the main fault to propagate onto the branch fault, the rupture must jump a short distance from the main fault to the branch fault**.

Part 4: Linear Slip-Weakening Friction

Benchmarks TPV14 and TPV15 use linear slip-weakening friction. This friction law has four parameters:

μ_s = static coefficient of friction.

μ_d = dynamic coefficient of friction.

d_0 = slip-weakening critical distance.

c_0 = frictional cohesion.

(In TPV14 and TPV15, the frictional cohesion c_0 equals zero.) The behavior of a node on the fault is influenced by the following variables, which vary as a function of time:

σ_n = normal stress, taken to be positive in compression.

τ = shear stress.

Initially, the node is locked. Failure occurs, and the node begins to slip, when

$$\tau > \mu_s \times \max(\sigma_n, 0) + c_0$$

When the node has slipped a total distance d, the time-varying coefficient of friction μ is

$$\mu = \mu_s + (\mu_d - \mu_s) \times d/d_0 \qquad \text{if } d \leq d_0$$

$$\mu = \mu_d \qquad \text{if } d > d_0$$

While the node is slipping, the shear stress on the fault is

$$\tau = \mu \times \max(\sigma_n, 0) + c_0$$

Tension on the fault: If you encounter tension on the fault, you should **treat tension on the fault the same as if the normal stress equals zero**. This is shown in the above formulas by the expression $\max(\sigma_n,\ 0)$. (In TPV14 and TPV15 you are not likely to encounter tension on the fault.)

You should **constrain the motion of the node so that the fault cannot open (that is, only permit sliding parallel to the fault), even when the fault is in tension**. During the time the fault is in tension, continue to accumulate the slip distance d as usual.

Backwards motion: If you encounter backwards motion, the slip distance d appearing in the formulas above is the total slip distance, not the net slip distance. For example, if the fault slips 0.3 m in one direction and then slips 0.1 m in the opposite direction, the slip distance d is 0.4 m (and not 0.2 m).

Part 5: On-Fault Stations, and Time-Series File Format

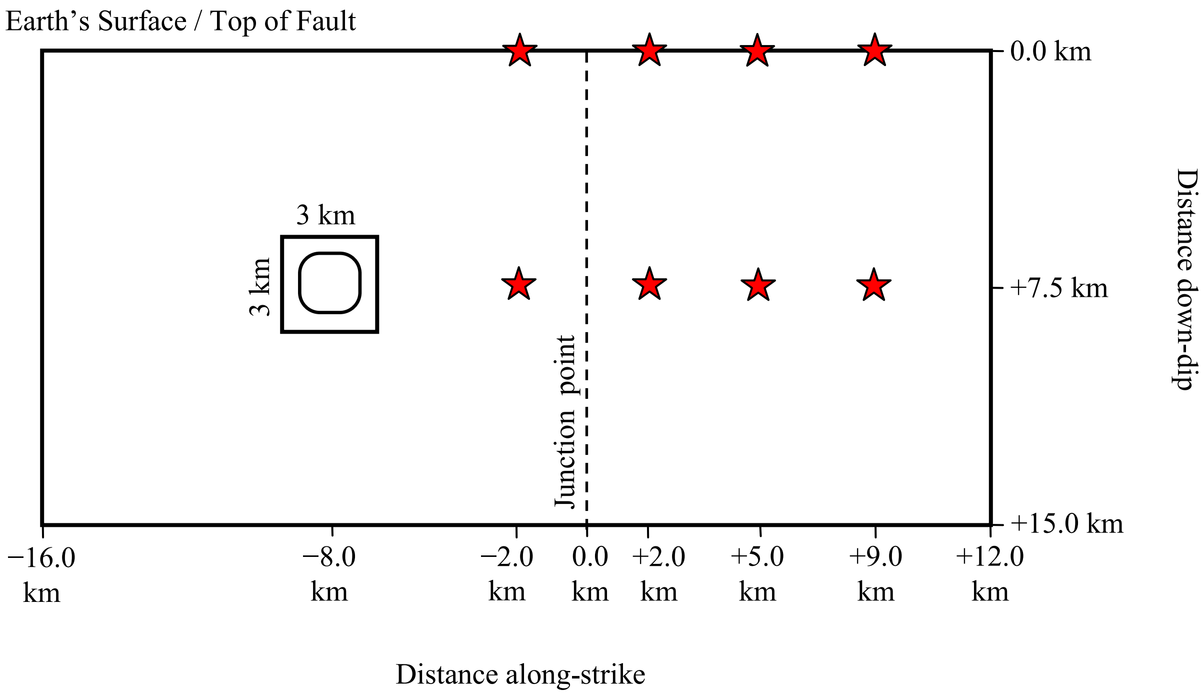
The 3D benchmarks use 8 stations on the main fault and 6 stations on the branch fault, which are listed below. The 2D benchmarks use the 7 stations located at 7.5 km depth. Diagrams of station locations are given following the table. You need to supply one time-series file for each station.

On-Fault Stations, for TPV14 and TPV15	
Station Name	**Location**
`faultst-020dp000`	On main fault, -2.0 km along strike, 0 km down-dip (3D only).
`faultst020dp000`	On main fault, 2.0 km along strike, 0 km down-dip (3D only).
`faultst050dp000`	On main fault, 5.0 km along strike, 0 km down-dip (3D only).
`faultst090dp000`	On main fault, 9.0 km along strike, 0 km down-dip (3D only).
`faultst-020dp075`	On main fault, -2.0 km along strike, 7.5 km down-dip.
`faultst020dp075`	On main fault, 2.0 km along strike, 7.5 km down-dip.
`faultst050dp075`	On main fault, 5.0 km along strike, 7.5 km down-dip.
`faultst090dp075`	On main fault, 9.0 km along strike, 7.5 km down-dip.
`branchst020dp000`	On branch fault, 2.0 km along strike, 0 km down-dip (3D only).
`branchst050dp000`	On branch fault, 5.0 km along strike, 0 km down-dip (3D only).
`branchst090dp000`	On branch fault, 9.0 km along strike, 0 km down-dip (3D only).
`branchst020dp075`	On branch fault, 2.0 km along strike, 7.5 km down-dip.
`branchst050dp075`	On branch fault, 5.0 km along strike, 7.5 km down-dip.
`branchst090dp075`	On branch fault, 9.0 km along strike, 7.5 km down-dip.

If you do not have a node at the location of a station, there are two options: (1) you can move the station to the nearest node, or (2) you can interpolate the data values from nodes near the station location.

Note: Location along-strike is measured relative to the junction point. Positive locations are to the right of the junction point. This is different than previous benchmarks, where location along-strike was measured relative to the center of the fault. On the branch fault, distance is measured from the junction point parallel to the strike of the branch fault (so the first split node on the branch fault has an along-strike location of 100 m, assuming 100 m node spacing).

Station Locations on the Main Fault



There are 4 stations at the earth's surface:

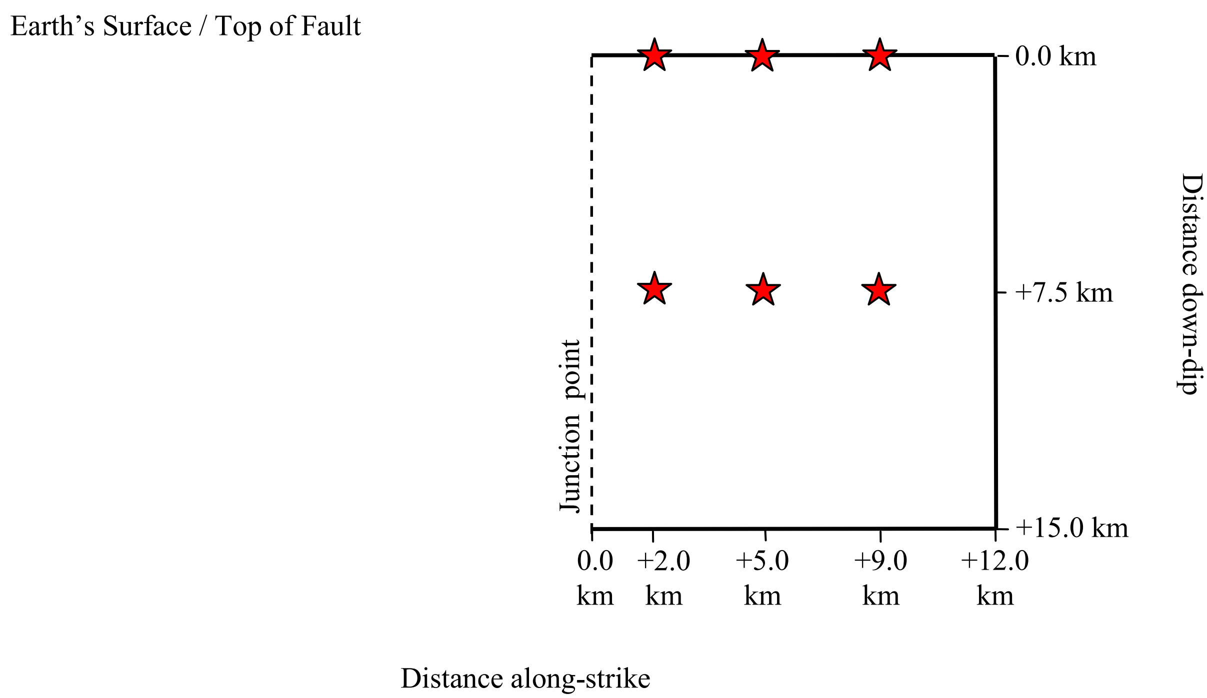
- −2.0 km, +2.0 km, +5.0 km, +9.0 km along-strike, and 0 km down-dip distance.

There are 4 deeper stations:

- −2.0 km, +2.0 km, +5.0 km, +9.0 km along-strike, and 7.5 km down-dip distance.

Note that location along-strike is measured relative to the junction point. Positive locations are to the right of the junction point.

Station Locations on the Branch Fault



There are 3 stations at the earth's surface:

- +2.0 km, +5.0 km, +9.0 km along-strike, and 0 km down-dip distance.

There are 3 deeper stations:

- +2.0 km, +5.0 km, +9.0 km along-strike, and 7.5 km down-dip distance.

Note that location along-strike is measured relative to the junction point. Positive locations are to the right of the junction point.

Each time series file is an ASCII file that contains 8 data fields, as follows.

On-Fault Time Series Data Fields for TPV14 and TPV15	
Field Name	**Description, Units, and Sign Convention**
`t`	Time (s).
`h-slip`	Horizontal slip along-strike (m). Sign convention: Positive means **right lateral** slip.
`h-slip-rate`	Horizontal slip rate along-strike (m/s). Sign convention: Positive means **right lateral** motion.
`h-shear-stress`	Horizontal shear stress along-strike (MPa). Sign convention: Positive means shear stress that tends to cause **right-lateral** slip.
`v-slip`	Vertical along-dip slip (m). Sign convention: Positive means **downward slip** (that is, the far side of the fault moving downward relative to the near side of the fault). Note: For the 2D benchmarks, this field should be zero (or very small).
`v-slip-rate`	Vertical along-dip slip rate (m/s). Sign convention: Positive means **downward motion** (that is, the far side of the fault moving downward relative to the near side of the fault). Note: For the 2D benchmarks, this field should be zero (or very small).
`v-shear-stress`	Vertical along-dip shear stress (MPa). Sign convention: Positive means shear stress that tends to cause **downward slip** (that is, the far side of the fault moving downward relative to the near side of the fault). Note: For the 2D benchmarks, this field should be zero (or very small).
`n-stress`	Normal stress (MPa). Sign convention: Positive means **extension**.

The **near side** of a fault is in the front of the diagram.
The **far side** of a fault is in the back of the diagram.

The on-fault time series file consists of three sections, as follows.

On-Fault Time Series File Format for TPV14 and TPV15	
File Section	**Description**
File Header	A series of lines, each beginning with a # symbol, that gives the following information: • Benchmark problem (TPV14 or TPV15) • Author • Date • Code • Code version (if desired) • Node spacing or element size • Time step • Number of time steps in file • Station location • Descriptions of data columns (7 lines) • Anything else you think is relevant
Field List	A **single line**, which lists the names of the 8 data fields, in column order, separated by spaces. It should be: `t h-slip h-slip-rate h-shear-stress v-slip v-slip-rate v-shear-stress n-stress` (all on one line). The server examines this line to check that your file contains the correct data fields.
Time History	A series of lines. Each line contains 8 numbers, which give the data values for a single time step. The lines must appear in order of increasing time. **C/C++ users:** For all data fields except the time, we recommend using 14.6E or 14.6e floating-point format. For the time field, we recommend using 20.12E or 20.12e format (but see the note on the next page). **Fortran users:** For all data fields except the time, we recommend using E15.7 floating-point format. For the time field, we recommend using E21.13 format (but see the note on the next page). The server accepts most common numeric formats. If the server cannot understand your file, you will see an error message when you attempt to upload the file.

Note: We recommend higher precision for the time field so the server can tell that your time steps are all equal. (If the server thinks your time steps are not all equal, it will refuse to apply digital filters to your data.) If you use a "simple" time step value like 0.01 seconds or 0.005 seconds, then there is no need for higher precision, and you can write the time using the same precision as all the other data fields. When you upload a file, the server will warn you if it thinks your time steps are not all equal.

Here is an example of an on-fault time-series file. This is an invented file, not real modeling data.

```
# Example on-fault time-series file.
#
# This is the file header:
# problem=TPV14
# author=A.Modeler
# date=2011/01/23
# code=MyCode
# code_version=3.7
# element_size=100 m
# time_step=0.005
# num_time_steps=1600
# location= on main fault, 9 km along strike, 7.5km down-dip
# Column #1 = Time (s)
# Column #2 = horizontal slip (m)
# Column #3 = horizontal slip rate (m/s)
# Column #4 = horizontal shear stress (MPa)
# Column #5 = vertical slip (m)
# Column #6 = vertical slip rate (m/s)
# Column #7 = vertical shear stress (MPa)
# Column #8 = normal stress (MPa)
#
# The line below lists the names of the data fields:
t h-slip h-slip-rate h-shear-stress v-slip v-slip-rate v-shear-stress n-stress
#
# Here is the time-series data.
# There should be 8 numbers on each line, but this page is not wide enough
#  to show 8 numbers on a line, so we only show the first five.
0.000000E+00   0.000000E+00   0.000000E+00   7.000000E+01   0.000000E+00  ...
5.000000E-03   0.000000E+00   0.000000E+00   7.104040E+01   0.000000E+00  ...
1.000000E-02   0.000000E+00   0.000000E+00   7.239080E+01   0.000000E+00  ...
1.500000E-02   0.000000E+00   0.000000E+00   7.349000E+01   0.000000E+00  ...
2.000000E-02   0.000000E+00   0.000000E+00   7.440870E+01   0.000000E+00  ...
2.500000E-02   0.000000E+00   0.000000E+00   7.598240E+01   0.000000E+00  ...
# ... and so on.
```

Part 6: Off-Fault Stations, and Time-Series File Format

The 3D benchmarks use the 11 off-fault stations listed below. All stations are at the earth's surface.

The 2D benchmarks use the same 11 stations, except they are moved to a depth of 7.5 km. (In the station names, change "`dp000`" to "`dp075`" for the 2D benchmarks.)

Refer to the next page for a diagram of station locations.

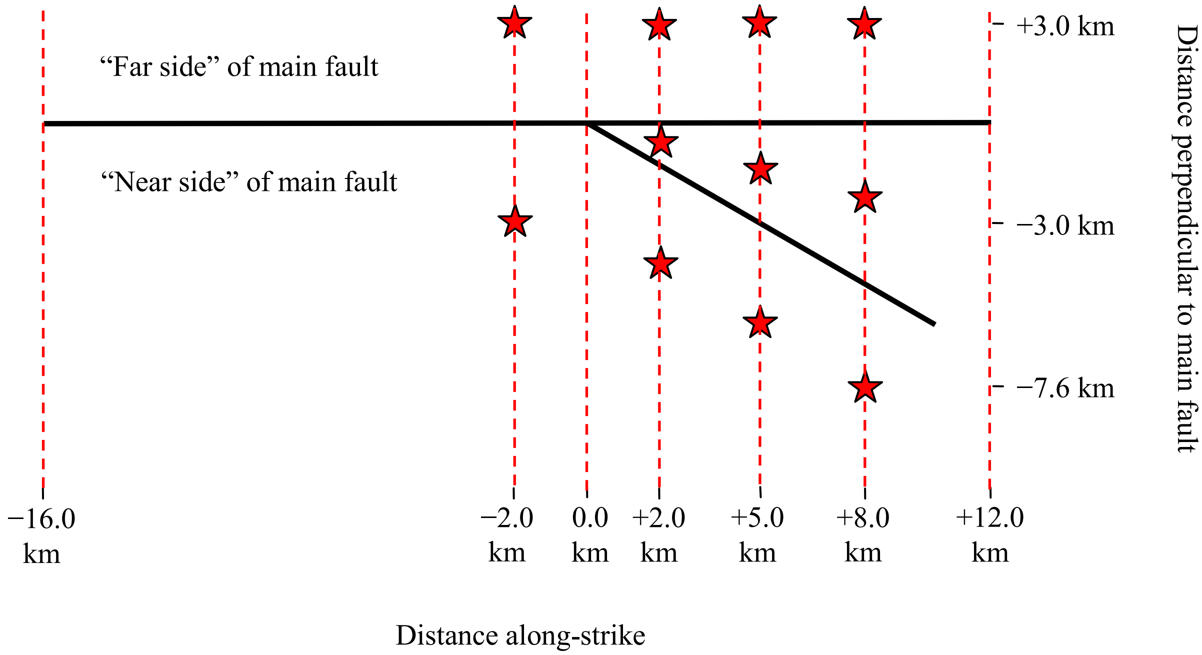
You need to supply one time-series file for each station.

Off-Fault Stations for TPV14 and TPV15	
Station Name	**Location**
`body030st-020dp000`	3.0 km off main fault (far side), -2.0 km along strike, 0 km depth.
`body-030st-020dp000`	-3.0 km off main fault (near side), -2.0 km along strike, 0 km depth.
`body030st020dp000`	3.0 km off main fault (far side), 2.0 km along strike, 0 km depth.
`body-006st020dp000`	-0.6 km off main fault (near side), 2.0 km along strike, 0 km depth.
`body-042st020dp000`	-4.2 km off main fault (near side), 2.0 km along strike, 0 km depth.
`body030st050dp000`	3.0 km off main fault (far side), 5.0 km along strike, 0 km depth.
`body-014st050dp000`	-1.4 km off main fault (near side), 5.0 km along strike, 0 km depth.
`body-059st050dp000`	-5.9 km off main fault (near side), 5.0 km along strike, 0 km depth.
`body030st080dp000`	3.0 km off main fault (far side), 8.0 km along strike, 0 km depth.
`body-023st080dp000`	-2.3 km off main fault (near side), 8.0 km along strike, 0 km depth.
`body-076st080dp000`	-7.6 km off main fault (near side), 8.0 km along strike, 0 km depth.

In the station names, the first number is the horizontal perpendicular distance from the station to the main fault. A positive number means that the station is located on the **far side** of the main fault.

If you do not have a node at the location of a station, there are two options: (1) you can move the station to the nearest node, or (2) you can interpolate the data values from nodes near the station location.

Off-Fault Station Locations



The diagram shows the earth’s surface, looking downwards.

There are 11 stations at the earth’s surface:

- −2.0 km along strike, 0 km depth, and ±3.0 km perpendicular distance from the main fault trace.
- +2.0 km along strike, 0 km depth, and +3.0 km, −0.6 km, −4.2 km perpendicular distance from the main fault trace.
- +5.0 km along strike, 0 km depth, and +3.0 km, −1.4 km, −5.9 km perpendicular distance from the main fault trace.
- +8.0 km along strike, 0 km depth, and +3.0 km, −2.3 km, −7.6 km perpendicular distance from the main fault trace.

The **near side** of the main fault is in the front of the diagram.
The **far side** of the main fault is in the back of the diagram.
Positive perpendicular distance from the main fault means that the station is on the **far side**.

Each time series file is an ASCII file that contains 7 data fields, as follows.

Off-Fault Time Series Data Fields for TPV14 and TPV15	
Field Name	**Description, Units, and Sign Convention**
`t`	Time (s).
`h-disp`	Horizontal displacement, parallel to the fault strike (m). Sign convention: Positive means displacement **to the right** relative to the station's initial position.
`h-vel`	Horizontal velocity, parallel to the fault strike (m/s). Sign convention: Positive means motion **to the right**.
`v-disp`	Vertical displacement (m). Sign convention: Positive means displacement **downward** relative to the station's initial position. Note: For the 2D benchmarks, this field should be zero (or very small).
`v-vel`	Vertical velocity (m/s). Sign convention: Positive means motion **downward**. Note: For the 2D benchmarks, this field should be zero (or very small).
`n-disp`	Horizontal displacement, perpendicular to the fault strike (m). Sign convention: Positive means displacement **away from the viewer, into the paper** (that is, away from near side of the main fault and toward the far side of the fault) relative to the station's initial position.
`n-vel`	Horizontal velocity, perpendicular to the fault strike (m/s). Sign convention: Positive means motion **away from the viewer, into the paper** (that is, away from near side of the main fault and toward the far side of the fault).

The **near side** of the main fault is in the front of the diagram.
The **far side** of the main fault is in the back of the diagram.

The off-fault time series file consists of three sections, as follows.

Off-Fault Time Series File Format for TPV14 and TPV15	
File Section	**Description**
File Header	A series of lines, each beginning with a # symbol, that gives the following information: • Benchmark problem (TPV14 or TPV15) • Author • Date • Code • Code version (if desired) • Node spacing or element size • Time step • Number of time steps in file • Station location • Descriptions of data columns (7 lines) • Anything else you think is relevant
Field List	A **single line**, which lists the names of the 7 data fields, in column order, separated by spaces. It should be: `t h-disp h-vel v-disp v-vel n-disp n-vel` (all on one line). The server examines this line to check that your file contains the correct data fields.
Time History	A series of lines. Each line contains 7 numbers, which give the data values for a single time step. The lines must appear in order of increasing time. **C/C++ users:** For all data fields except the time, we recommend using 14.6E or 14.6e floating-point format. For the time field, we recommend using 20.12E or 20.12e format (but see the note on the next page). **Fortran users:** For all data fields except the time, we recommend using E15.7 floating-point format. For the time field, we recommend using E21.13 format (but see the note on the next page). The server accepts most common numeric formats. If the server cannot understand your file, you will see an error message when you attempt to upload the file.

Note: We recommend higher precision for the time field so the server can tell that your time steps are all equal. (If the server thinks your time steps are not all equal, it will refuse to apply digital filters to your data.) If you use a “simple” time step value like 0.01 seconds or 0.005 seconds, then there is no need for higher precision, and you can write the time using the same precision as all the other data fields. When you upload a file, the server will warn you if it thinks your time steps are not all equal.

Here is an example of an off-fault time-series file. This is an invented file, not real modeling data.

```
# Example off-fault time-series file.
#
# This is the file header:
# problem=TPV14
# author=A.Modeler
# date=2011/01/23
# code=MyCode
# code_version=3.7
# element_size=100 m
# time_step=0.005
# num_time_steps=1600
# location= 3.0 km off fault, 5 km along strike, 0.0km depth
# Column #1 = Time (s)
# Column #2 = horizontal displacement (m)
# Column #3 = horizontal velocity (m/s)
# Column #4 = vertical displacement (m)
# Column #5 = vertical velocity (m/s)
# Column #6 = normal displacement (m)
# Column #7 = normal velocity (m/s)
#
# The line below lists the names of the data fields:
t  h-disp  h-vel  v-disp  v-vel  n-disp  n-vel
#
# Here is the time-series data.
# There should be 7 numbers on each line, but this page is not wide enough
#  to show 7 numbers on a line, so we only show the first five.
0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00   0.000000E+00  ...
5.000000E-03  -2.077270E-85  -2.575055E-83  -2.922774E-86  -3.623018E-84  ...
1.000000E-02  -1.622118E-82  -2.005817E-80  -1.387778E-83  -1.713249E-81  ...
1.500000E-02  -9.020043E-80  -1.114231E-77  -4.402893E-81  -5.424313E-79  ...
2.000000E-02  -1.201684E-77  -1.467704E-75  -4.549845E-79  -5.533119E-77  ...
2.500000E-02  -1.528953E-75  -1.866265E-73  -4.126064E-77  -5.004886E-75  ...
# ... and so on.
```

Part 7: Contour-Plot File Format

There are two contour-plot files, one for the main fault and one for the branch fault, as shown here:

Contour-plot files for TPV14 and TPV15	
File Name	**Description**
`cplot_main`	Rupture times for the main fault.
`cplot_branch`	Rupture times for the branch fault

The contour plot file lists the locations of all the nodes on the fault surface, and the time at which each node ruptures.

The contour plot file is an ASCII file that contains three data fields, as follows.

Contour Plot Data Fields for TPV14 and TPV15	
Field Name	**Description, Units, and Sign Convention**
`j`	Distance along strike (m). Sign convention: Positive means a location **to the right** of the junction point. For TPV14 and TPV15, the value of `j` can range from -16000 to 12000 on the main fault, and from 0 to 12000 on the branch fault. (On the branch fault, `j` is the distance from the junction point, measured parallel to the strike of the branch fault. Since the branch fault starts one element away from the main fault, in actuality the values on the branch fault can range from 100 to 12000, assuming 100 m node spacing.)
`k`	Distance down-dip (m). Sign convention: Zero is the earth's surface, and positive means **underground**. For TPV14 and TPV15, the value of `k` can range from 0 to 15000.
`t`	Rupture time (s). This is the time at which fault slip-rate first changes from 0 to greater than 0.001 m/s. If this node never ruptures, use the value 1.0E+09.

A pair of numbers `(j,k)` denotes a point on the fault surface.

The contour plot file consists of three sections, as follows.

Contour Plot File Format for TPV14 and TPV15	
File Section	**Description**
File Header	A series of lines, each beginning with a # symbol, that gives the following information: • Benchmark problem (TPV14 or TPV15) • Author • Date • Code • Code version (if desired) • Node spacing or element size • Descriptions of data columns (7 lines) • Anything else you think is relevant
Field List	A **single line**, which lists the names of the 3 data fields, in column order, separated by spaces. It should be: `j k t` (all on one line). The server examines this line to check that your file contains the correct data fields.
Rupture History	A series of lines. Each line contains three numbers, which give the `(j,k)` coordinates of a node on the fault surface, and the time `t` at which that node ruptures. **C/C++ users:** We recommend using 14.6E or 14.6e floating-point format. **Fortran users:** We recommend using E15.7 floating-point format. If a node never ruptures, the time should be given as 1.0E+09. Nodes may be listed in any order.

Note: The nodes may appear in any order. The nodes do not have to form a rectangular grid, or any other regular pattern.

Note: When you upload a file, the server constructs the Delaunay triangulation of your nodes. Then, it uses the Delaunay triangulation to interpolate the rupture times over the entire fault surface. Finally, it uses the interpolated rupture times to draw a series of contour curves at intervals of 0.5 seconds.

Here is an example of a contour-plot file. This is an invented file, not real modeling data.

```
# Example contour-plot file.
#
# This is the file header:
# problem=TPV14
# author=A.Modeler
# date=2011/01/23
# code=MyCode
# code_version=3.7
# element_size=100 m
# Column #1 = horizontal coordinate, distance along strike (m)
# Column #2 = vertical coordinate, distance down-dip (m)
# Column #3 = rupture time (s)
#
# The line below lists the names of the data fields.
# It indicates that the first column contains the horizontal
#  coordinate (j), the second column contains the vertical
#  coordinate (k), and the third column contains the time (t).
j  k  t
#
# Here is the rupture history
-6.000000E+02   7.000000E+03   3.100000E-02
-6.000000E+02   7.100000E+03   4.900000E-02
-6.000000E+02   7.200000E+03   6.700000E-02
-7.000000E+02   7.000000E+03   1.230000E-01
-7.000000E+02   7.100000E+03   1.350000E-01
-7.000000E+02   7.200000E+03   1.470000E-01
# ... and so on.
```

Making a Contour-Plot File for a 2D Benchmark

In the 2D benchmarks, the faults are lines. But the web server expects the faults to be rectangles. So, for the 2D benchmarks you must “trick” the web server into believing that the faults are rectangles 15 km tall. To do this, each node on the fault line must appear twice in the contour-plot file: once with a vertical coordinate (k) of 0, and once with a vertical coordinate of 15000. For example, if the node at location 4000 along-strike ruptures at a time of 4.26 seconds, you could place the following two lines in the contour-plot file:

```
4.000000E+03   0.000000E+00   4.260000E+00
4.000000E+03   1.500000E+04   4.260000E+00
```