TPV22 and TPV23
Stepover Benchmarks

January 28, 2013

These 3D benchmarks use a stepover in a linear elastic half-space. We are doing two benchmarks, as shown in the following table.

Benchmarks			
Benchmark	*Dimension*	*Stepover Type*	*Material Properties*
TPV22	3D	Right-step on right-lateral faults, extensional step.	Linear elastic.
TPV23	3D	Left-step on right-lateral faults, compressional step.	Linear elastic.

We request that you run these benchmarks using two resolutions: 100 meter resolution, and 50 meter resolution.

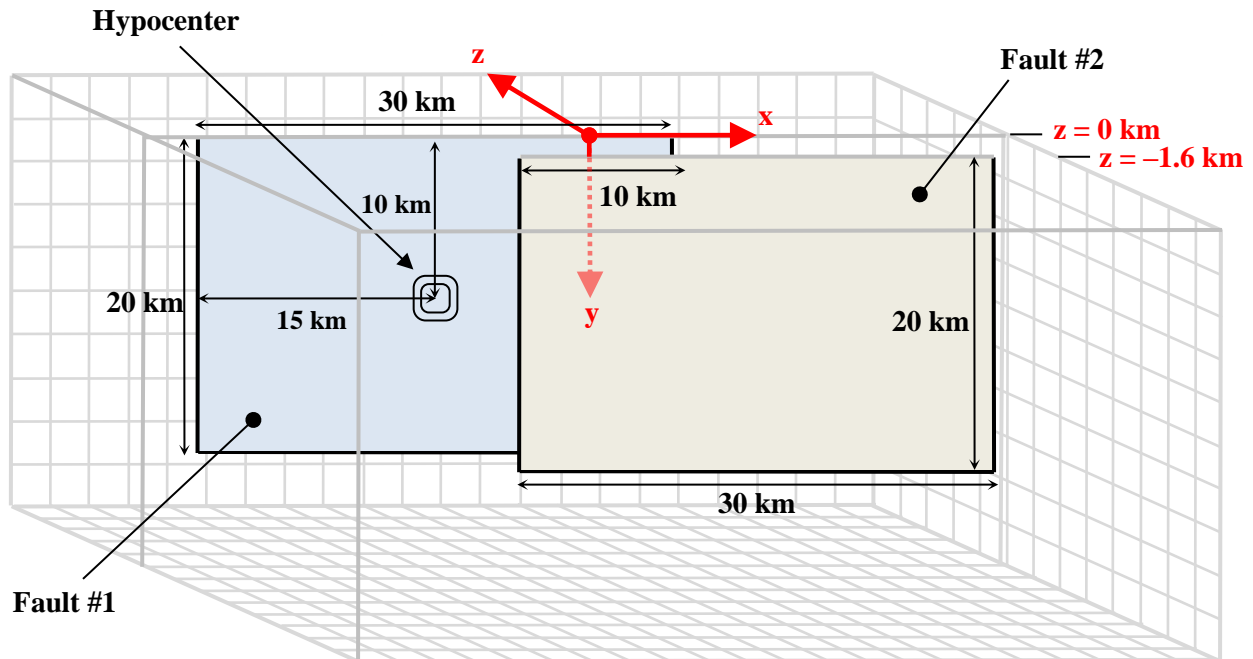The material properties are the same as in benchmark TPV5 and several other benchmarks.

We are introducing some changes from earlier benchmarks:

- The fault boundary condition is that slip goes to zero at the border of the fault. So, a node which lies precisely on the border of a fault should *not* be permitted to slip.

- Nucleation is done using a smoothed forced rupture. The forced rupture is applied over an interval of 0.5 seconds (instead of being applied instantaneously as in earlier benchmarks), and the forced rupture velocity varies with distance from the hypocenter.

- Near the bottom of the faults, the rupture is made to stop gradually by tapering the initial shear stress down to a low value.

Contents

Part 1: Fault Geometry for TPV22 (Extensional Stepover)

The model volume is a half-space. There are two faults, called **fault #1** and **fault #2**. The two faults are vertical, planar, strike-slip, right-lateral faults. The faults reach the earth's surface. The hypocenter is located in the center of fault #1.

Each fault is a rectangle measuring 30000 m along-strike and 20000 m deep. The overlap between the faults is 10000 m. The stepover distance between the faults is 1600 m.

Introduce an (x, y, z) coordinate system, where x increases from left to right, y increases from top to bottom, and z increases from front to back. The origin is on the earth's surface, 5000 m from the right edge of fault #1. In this coordinate system, fault #1 is:

$$-25000 \text{ m} \leq x \leq 5000 \text{ m}$$
$$0 \text{ m} \leq y \leq 20000 \text{ m}$$
$$z = 0 \text{ m}$$

Fault #2 is:

$$-5000 \text{ m} \leq x \leq 25000 \text{ m}$$
$$0 \text{ m} \leq y \leq 20000 \text{ m}$$
$$z = -1600 \text{ m}$$

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Part 2: Fault Geometry for TPV23 (Compressional Stepover)

The model volume is a half-space. There are two faults, called **fault #1** and **fault #2**. The two faults are vertical, planar, strike-slip, right-lateral faults. The faults reach the earth's surface. The hypocenter is located in the center of fault #1.

Each fault is a rectangle measuring 30000 m along-strike and 20000 m deep. The overlap between the faults is 10000 m. The stepover distance between the faults is 1000 m.
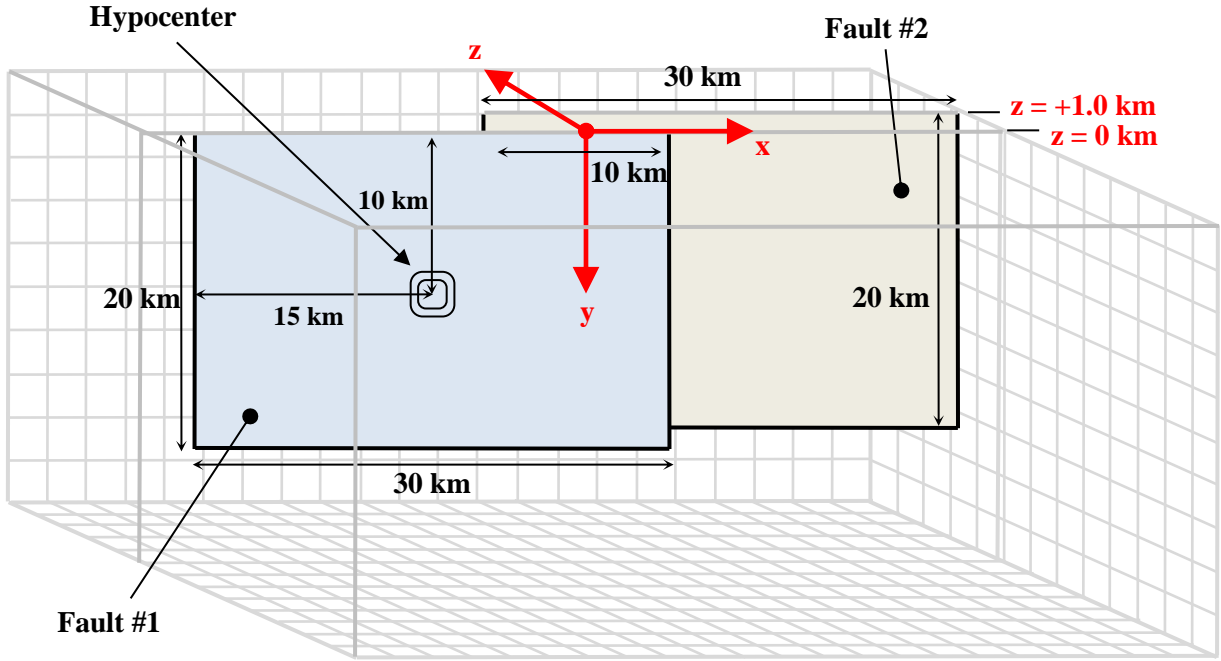
Introduce an (x, y, z) coordinate system, where x increases from left to right, y increases from top to bottom, and z increases from front to back. The origin is on the earth's surface, 5000 m from the right edge of fault #1. In this coordinate system, fault #1 is:

$$-25000 \text{ m} \leq x \leq 5000 \text{ m}$$
$$0 \text{ m} \leq y \leq 20000 \text{ m}$$
$$z = 0 \text{ m}$$

Fault #2 is:

$$-5000 \text{ m} \leq x \leq 25000 \text{ m}$$
$$0 \text{ m} \leq y \leq 20000 \text{ m}$$
$$z = 1000 \text{ m}$$

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Part 3: Description of the 3D Benchmarks

Fault Geometry

Fault geometry for TPV22 and TPV23 is shown in parts 1 and 2 respectively.

The hypocenter is centered along-strike at a depth of 10 km in fault #1. That is, the hypocenter is 15000 m from the left edge of fault #1, and 10000 m deep, at location $(x, y, z) = (-10000 \text{ m}, \ 10000 \text{ m}, \ 0 \text{ m})$.

Slip goes to zero at the border of a fault. So, a node which lies precisely on the border of a fault should not be permitted to slip. This is a change from earlier benchmarks.

Material Properties

In TPV22 and TPV23, the entire model volume is a linear elastic material, with the following parameters.

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

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

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

Note that these are the same material properties used in benchmark TPV5 and several other benchmarks.

Initial Normal and Shear Stress on the Faults

The initial normal stress σ_{ini}, and the initial shear stress τ_{ini}, are:

$$\sigma_{\text{ini}} = 60.00 \text{ MPa}$$

$$\tau_{\text{ini}} = \begin{cases} 29.38 \text{ MPa}, & \text{if depth} \leq 15000 \text{ m} \\ 29.38 \text{ MPa} - (0.002938 \text{ MPa/m})(\text{depth} - 15000 \text{ m}), & \text{if depth} \geq 15000 \text{ m} \end{cases}$$

The initial shear stress, τ_{ini}, is right-lateral. The initial shear stress is a piecewise-linear function of depth, with a value of 29.38 MPa at depths of 0 to 15000 m, and 14.69 MPa at a depth of 20000 m. The reduced initial shear stress at depths of 15000 m to 20000 m makes the bottom of the fault behave like a "soft" barrier that brings the rupture to a gradual stop.

Friction Parameters and Nucleation

We use a linear slip-weakening friction law, which has the following six parameters.

Friction Parameters		
Symbol	*Parameter*	*Unit*
μ_s	Static coefficient of friction.	Dimensionless
μ_d	Dynamic coefficient of friction.	Dimensionless
d_0	Slip-weakening critical distance.	Meter
C_0	Frictional cohesion.	Pascal
T	Time of forced rupture.	Second
t_0	Forced rupture decay time	Second

The operation of the slip-weakening friction law is described in detail later, in part 4.

The friction parameter values are as follows, where r denotes distance to the hypocenter, and r_{crit} denotes the radius of the nucleation zone:

$$\mu_s = 0.548$$

$$\mu_d = 0.373$$

$$d_0 = 0.30 \text{ m}$$

$$C_0 = \begin{cases} (0.0014 \text{ MPa/m})(5000 \text{ m} - \text{depth}), & \text{if depth} \leq 5000 \text{ m} \\ 0.0 \text{ MPa}, & \text{if depth} \geq 5000 \text{ m} \end{cases}$$

$$r_{\text{crit}} = 3000 \text{ m}$$

$$T = \begin{cases} \dfrac{r}{0.7 \, V_S} + \dfrac{0.081 \, r_{\text{crit}}}{0.7 \, V_S} \left(\dfrac{1}{1 - (r/r_{\text{crit}})^2} - 1 \right), & \text{if } r < r_{\text{crit}} \\ 1.0\text{E}+9, & \text{if } r \geq r_{\text{crit}} \end{cases}$$

$$t_0 = 0.50 \text{ s}$$

The variation in the value of T near the hypocenter causes the rupture to nucleate, in a manner that is described later, in part 5.

Note that the frictional cohesion C_0 is a piecewise linear function of depth. It is 7.0 MPa at the earth's surface, and 0.0 MPa at depths of 5000 m to 20000 m.

Running Time, Node Spacing, and Results

Run the model for times from **0.0 to 15.0 seconds after nucleation**.

Please submit results for two resolutions:

- Using **100 m node spacing** on the fault planes.

- Using **50 m node spacing** on the fault planes.

Use the "Change Version" function on the website to submit your two sets of results. If you are unable to run the simulation with 50 m node spacing, then it is OK to submit just 100 m results.

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 6.

- **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 7.

- **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 fault #1 and one for fault #2. These files are described in part 8.

Part 4: Linear Slip-Weakening Friction

Benchmarks TPV22 and TPV23 use linear slip-weakening friction, with frictional cohesion and forced rupture. This friction law has the following parameters and variables:

Friction Parameters		
Symbol	*Parameter*	*Unit*
μ_s	Static coefficient of friction.	Dimensionless
μ_d	Dynamic coefficient of friction.	Dimensionless
d_0	Slip-weakening critical distance.	Meter
C_0	Frictional cohesion.	Pascal
T	Time of forced rupture.	Second
t_0	Forced rupture decay time	Second

Friction Variables		
Symbol	*Parameter*	*Unit*
σ_n	Normal stress acting on the fault, taken to be positive in compression.	Pascal
τ	Shear stress acting on the fault.	Pascal

When the fault is sliding, the shear stress τ at a given point on the fault is given by:

$$\tau = C_0 + \mu \max(0, \sigma_n)$$

The time-varying coefficient of friction μ is given by the following formulas, where D is the total distance the node has slipped, and t is the time since the start of the simulation:

$$\mu = \mu_s + (\mu_d - \mu_s) \max(f_1, f_2)$$

$$f_1 = \begin{cases} D/d_0, & \text{if } D < d_0 \\ 1, & \text{if } D \geq d_0 \end{cases}$$

$$f_2 = \begin{cases} 0, & \text{if } t < T \\ (t-T)/t_0, & \text{if } T \leq t < T + t_0 \\ 1, & \text{if } t \geq T + t_0 \end{cases}$$

The distance D that the node has slipped is path-integrated. For example, if the node slips 0.4 m in one direction and then 0.1 m in the opposite direction, the value of D is 0.5 m (and not 0.3 m).

The time of forced rupture T is used to nucleate the rupture, as described in part 5. At time $t = T$, the coefficient of friction begins to decrease, reaching its final dynamic value at time $t = T + t_0$. So, the node is forced to begin sliding somewhere in the interval $T < t < T + t_0$. Notice that because of the expression $\max(f_1, f_2)$, forcing has no effect if friction has already weakened due to the accumulated slip. If a given node does not undergo forced rupture, then the value of T is 1.0E9.

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 $\max(0, \sigma_n)$.

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.

Part 5: Nucleation

Nucleation is performed by forcing the fault to rupture, within a circular zone surrounding the hypocenter. Forced rupture is achieved by artificially reducing the friction coefficient, beginning at a specified time T. The parameter t_0 specifies how long it takes for the friction coefficient to be artificially reduced from its static value to its dynamic value. So, the friction coefficient reaches its dynamic value at time $T + t_0$. We reduce the friction coefficient gradually, over an interval of time, in order to smooth the nucleation process and reduce unwanted oscillations.

Recall that we selected $t_0 = 0.5$ s, and that the time of forced rupture is defined to be

$$T = \begin{cases} \dfrac{r}{0.7\,V_S} + \dfrac{0.081\,r_{\text{crit}}}{0.7\,V_S}\left(\dfrac{1}{1-(r/r_{\text{crit}})^2} - 1\right), & \text{if } r < r_{\text{crit}} \\ \\ 1.0\text{E}+9, & \text{if } r \geq r_{\text{crit}} \end{cases}$$

where r is distance from the hypocenter, and where $r_{\text{crit}} = 3000$ m is the radius of the nucleation zone. At the hypocenter, $T = 0$. The value of T then increases with distance from the hypocenter, which creates an expanding circular region of forced rupture.

The time T is computed so that the forced rupture expands at a variable speed. Near the hypocenter, the forced rupture expands at a speed of $0.7\,V_S$. The speed decreases with increasing distance from the hypocenter, finally reaching a speed of zero at a distance of 3000 m from the hypocenter. The variable speed allows for a smooth transition between forced rupture and spontaneous rupture, because the spontaneous rupture should gradually overtake the ever-slowing forced rupture. The graph below shows the forced rupture speed $V_R \equiv dr/dT$ as a function of distance from the hypocenter.

Speed of forced rupture V_R/V_S.

Distance from hypocenter r, meters.

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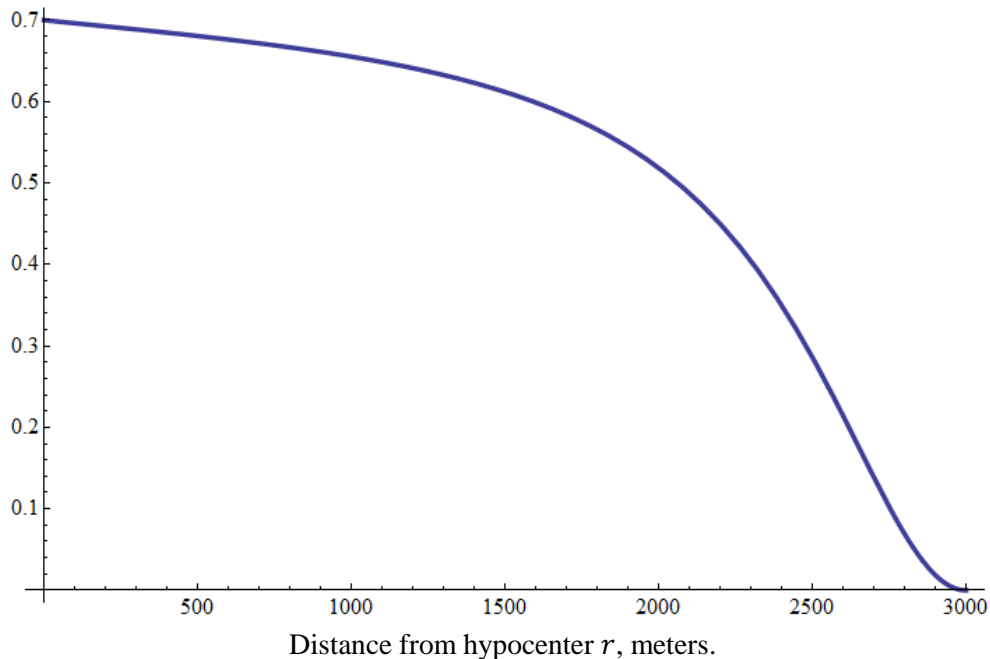
## *Part 6: On-Fault Stations, and Time-Series File Format*

The benchmarks use 7 stations on fault #1 and 11 stations on fault #2, which are listed below. Diagrams of station locations are given following the table. You need to supply one time-series file for each station.

On-Fault Stations, for TPV22 and TPV23	
Station Name	**Location**
fault1st-100dp000	On fault #1, −10.0 km along strike, 0.0 km down-dip.
fault1st000dp000	On fault #1, 0.0 km along strike, 0.0 km down-dip.
fault1st-100dp050	On fault #1, −10.0 km along strike, 5.0 km down-dip.
fault1st-100dp100	On fault #1, −10.0 km along strike, 10.0 km down-dip (hypocenter).
fault1st-050dp100	On fault #1, −5.0 km along strike, 10.0 km down-dip.
fault1st000dp100	On fault #1, 0.0 km along strike, 10.0 km down-dip.
fault1st-100dp150	On fault #1, −10.0 km along strike, 15.0 km down-dip.
fault2st000dp000	On fault #2, 0.0 km along strike, 0.0 km down-dip.
fault2st050dp000	On fault #2, 5.0 km along strike, 0.0 km down-dip.
fault2st200dp000	On fault #2, 20.0 km along strike, 0.0 km down-dip.
fault2st040dp050	On fault #2, 4.0 km along strike, 5.0 km down-dip.
fault2st050dp050	On fault #2, 5.0 km along strike, 5.0 km down-dip.
fault2st000dp100	On fault #2, 0.0 km along strike, 10.0 km down-dip.
fault2st050dp100	On fault #2, 5.0 km along strike, 10.0 km down-dip.
fault2st065dp100	On fault #2, 6.5 km along strike, 10.0 km down-dip.
fault2st100dp100	On fault #2, 10.0 km along strike, 10.0 km down-dip.
fault2st200dp100	On fault #2, 20.0 km along strike, 10.0 km down-dip.
fault2st050dp150	On fault #2, 5.0 km along strike, 15.0 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 origin of the (x, y, z) coordinate system Positive locations are to the right of the origin.

Station Locations on Fault #1

Earth's Surface / Top of Fault #1
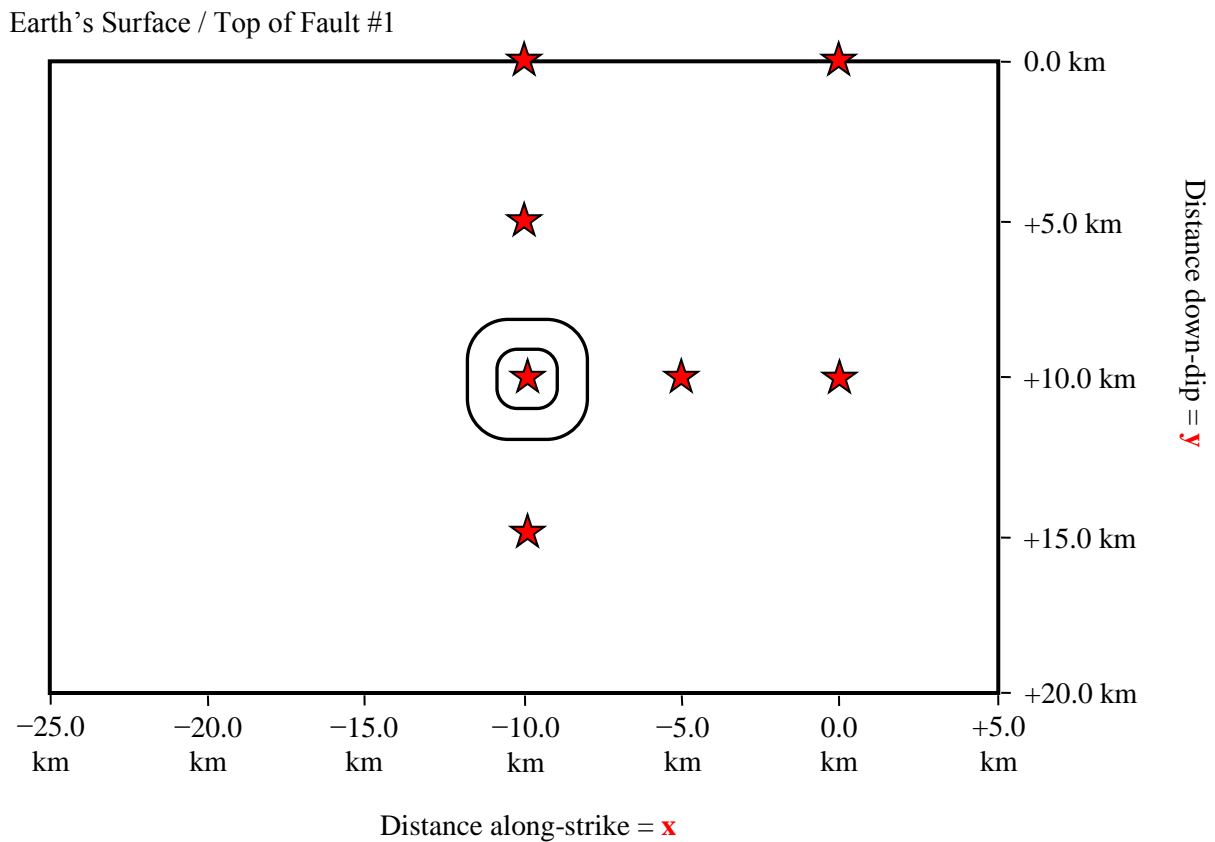
There are 7 stations:

- −10.0 km and 0.0 km along-strike, and 0.0 km down-dip distance.

- −10.0 km along-strike, and 5.0 km down-dip distance.

- −10.0 km , −5.0 km, and 0.0 km along-strike, and 10.0 km down-dip distance.

- −10.0 km along-strike, and 15.0 km down-dip distance.

Note that location along-strike is measured relative to the origin of the (x, y, z) coordinate system Positive locations are to the right of the origin.
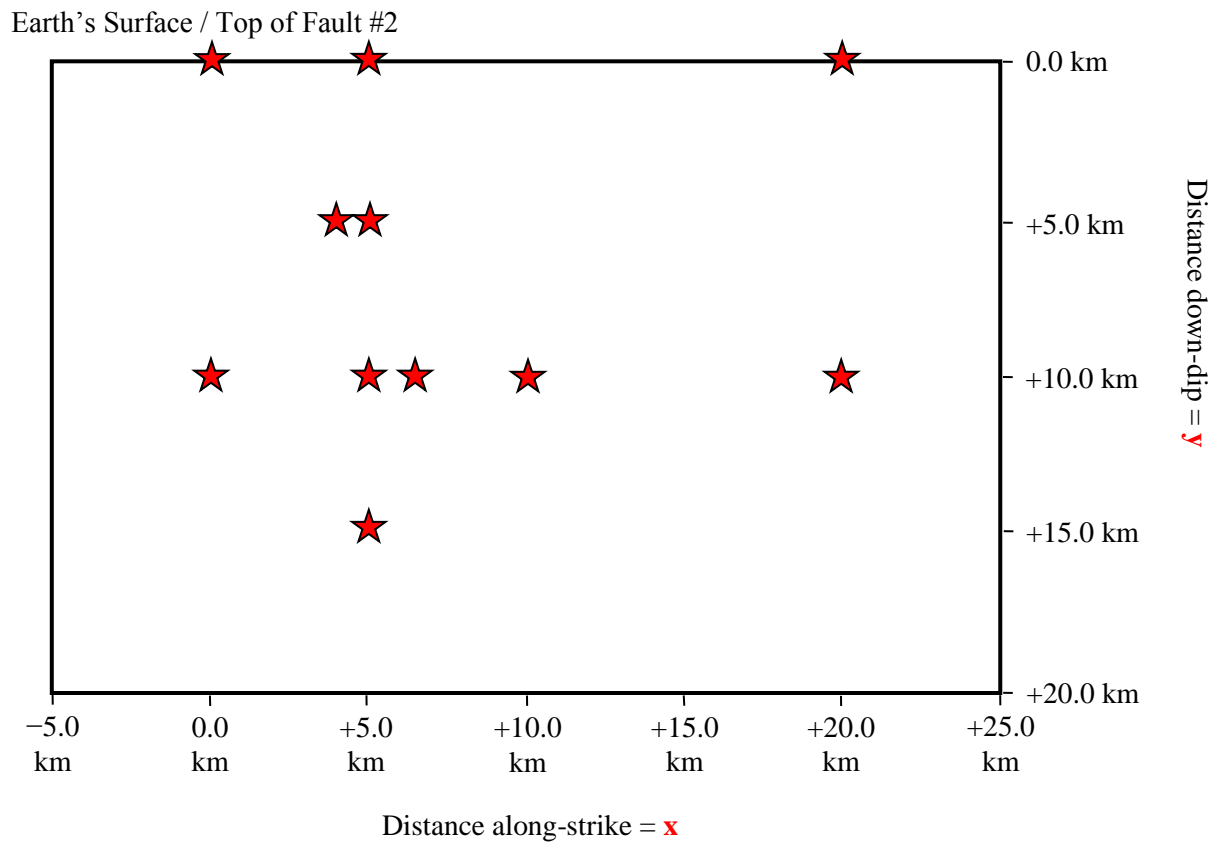
Station Locations on Fault #2

Earth's Surface / Top of Fault #2

There are 11 stations:

- 0.0 km, +5.0 km, and +20.0 km along-strike, and 0.0 km down-dip distance.

- +4.0 km and +5.0 km along-strike, and 5.0 km down-dip distance.

- 0.0 km, +5.0 km, +6.5 km, +10.0 km, and +20.0 km along-strike, and 10.0 km down-dip distance.

- +5.0 km along-strike, and 15.0 km down-dip distance.

Note that location along-strike is measured relative to the origin of the (x, y, z) coordinate system
Positive locations are to the right of the origin.

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

On-Fault Time Series Data Fields for TPV22 and TPV23	
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).
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).
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).
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 TPV22 and TPV23	
File Section	**Description**
File Header	A series of lines, each beginning with a # symbol, that gives the following information: • Benchmark problem (TPV22 or TPV23) • Author • Date • Code • Code version • 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 or 1PE15.6 floating-point format. For the time field, we recommend using E21.13 or 1PE21.12 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=TPV22
# author=A.Modeler
# date=2013/01/23
# code=MyCode
# code_version=3.7
# element_size=100 m
# time_step=0.005
# num_time_steps=2400
# location= on fault #2, 5.0 km along strike, 10.0 km 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 7: Off-Fault Stations, and Time-Series File Format

The benchmarks use the 6 off-fault stations listed below. All stations are at the earth's surface.

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 TPV22 and TPV23	
Station Name	**Location**
body030st-050dp000	3.0 km off fault #1 (far side), −5.0 km along strike, 0 km depth.
body-030st-050dp000	−3.0 km off fault #1 (near side), −5.0 km along strike, 0 km depth.
body030st050dp000	3.0 km off fault #1 (far side), 5.0 km along strike, 0 km depth.
body-030st050dp000	−3.0 km off fault #1 (near side), 5.0 km along strike, 0 km depth.
body030st150dp000	3.0 km off fault #1 (far side), 15.0 km along strike, 0 km depth.
body-030st150dp000	−3.0 km off fault #1 (near side), 15.0 km along strike, 0 km depth.

In the station names, the first number is the horizontal perpendicular distance from the station to fault #1. A positive number means that the station is located on the **far side** of fault #1.

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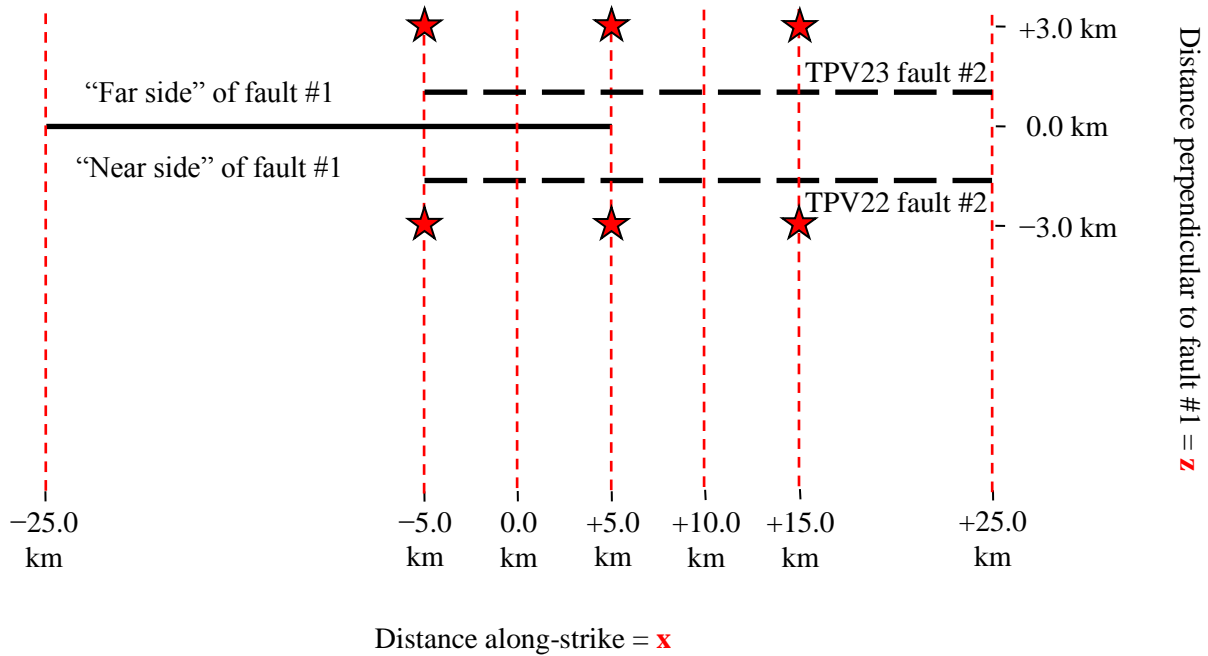
The diagram shows the earth's surface, looking downwards.

There are 6 stations at the earth's surface:

- −5.0 km, +5.0 km, and +15.0 km along-strike, and +3.0 km perpendicular distance from the fault #1 trace.

- −5.0 km, +5.0 km, and +15.0 km along-strike, and −3.0 km perpendicular distance from the fault #1 trace.

The **near side** of fault #1 is in the front of the diagram.
The **far side** of fault #1 is in the back of the diagram.
Positive perpendicular distance from fault #1 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 TPV22 and TPV23	
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.
v-vel	Vertical velocity (m/s). Sign convention: Positive means motion **downward**.
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 fault #1 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 fault #1 and toward the far side of the fault).

The **near side** of fault #1 is in the front of the diagram.
The **far side** of fault #1 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 TPV22 and TPV23	
File Section	**Description**
File Header	A series of lines, each beginning with a # symbol, that gives the following information: • Benchmark problem (TPV22 or TPV23) • Author • Date • Code • Code version • 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 or 1PE15.6 floating-point format. For the time field, we recommend using E21.13 or 1PE21.12 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=TPV22
# author=A.Modeler
# date=2013/01/23
# code=MyCode
# code_version=3.7
# element_size=100 m
# time_step=0.005
# num_time_steps=2400
# location= 3.0 km off fault, 5.0 km along strike, 0.0 km 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 8: Contour-Plot File Format

There are two contour-plot files, one for fault #1 and one for fault #2, as shown here:

Contour-plot files for TPV22 and TPV23	
File Name	**Description**
cplot_1	Rupture times for fault #1.
cplot_2	Rupture times for fault #2.

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 TPV22 and TPV23	
Field Name	**Description, Units, and Sign Convention**
j	Distance along strike (m). Sign convention: Positive means a location **to the right** of the (x, y, z) origin. For TPV22 and TPV23, the value of j can range from −25000 to 5000 on fault #1, and from −5000 to 25000 on fault #2. (Note that j is equal to the x coordinate value.)
k	Distance down-dip (m). Sign convention: Zero is the earth's surface, and positive means **underground**. For TPV22 and TPV23, the value of k can range from 0 to 20000. (Note that k is equal to the y coordinate value.)
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. It is equal to the (x, y) coordinates.

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

Contour Plot File Format for TPV22 and TPV23	
File Section	**Description**
File Header	A series of lines, each beginning with a # symbol, that gives the following information: • Benchmark problem (TPV22 or TPV23) • Author • Date • Code • Code version • 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 or 1PE15.6 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=TPV22
# author=A.Modeler
# date=2013/01/23
# 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.
```