QDYN

Quasi-DYNamic earthquake simulator

User's Manual

V 0.1.0

Summary

QDYN is a boundary element software to simulate earthquake cycles (seismic and aseismic slip on tectonic faults) under the quasi-dynamic approximation (quasi-static elasticity combined with radiation damping).

Features

- Rate-and-state friction, with velocity cut-offs, aging and slip laws
- Arbitrarily heterogeneous frictional properties
- Slow and fast, aseismic and seismic slip transients (adaptive timestep)
- Non-planar faults (currently limited to variable dip, rectangular elements)
- 3D, 2D and 1D (spring-block)
- Tectonic and oscillatory loads
- Matlab wrapper and graphic output display utilities
- Parallelized for shared memory systems (OpenMP)

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1. Installation

1.1 Download and update QDYN

QDYN is managed under Subversion. You may checkout the most current version by executing the following command on Linux (first time only):

```
svn checkout http://qdyn.googlecode.com/svn/trunk/ qdyn-read-only
```

This creates a directory 'qdyn-read-only' which contains the whole QDYN package.

1.2 Install QDYN

Type 'make' in your 'working directory'/src to install QDYN. You can modify the 'Makefile' script to change the path to the executable and the compiler settings. By default, QDYN is installed at `$(HOME)/bin/qdyn`

1.3 Modify Matlab wrapper

If you change the path to the executable, you should modify the path also in the Matlab wrapper qdyn.m in line 289.

1.4 Update QDYN

After the first-time checkout, you can update the package by executing the following command in your working directory:

```
svn update
```

2. Running a simulation

2.1 The Matlab wrapper

You can use the wrapper qdyn.m to set parameters and perform simulations from within the Matlab environment:

```
SYNTAX        [pars,ot,ox] = qdyn(mode,[parsin],['Property',Value,...])

INPUTS mode   'set'     gives the default parameter structure (pars),
                              overrides by fields present in structure parsin
                              or by Property/Value pairs
                        'run'     sets parameters and runs a simulation
                        'read'    reads parameters and outputs from a previous simulation
              parsin    parameter structure to override the default parameters
              'Prop'    property to be set, a fieldname of the parameter structure
              Value   of the above property, overrides default and parsin

              These are the parameters that can be set through 'parsin' or 'Prop/Value' pairs:

  MESHDIM = mesh dimension,
      0 = spring-blocke system
      1 = 1D fault, 2D medium
      2 = 2D fault, 3D medium
              L = fault length (L scales the stiffness for the spring-block case)
              FINITE = boundary conditions: (in 2D case)
                        0 = periodic along-strike, steady loading at distance W from the fault line
                        1 = rate-and-state fault segment of finite length (L) surrounded by steady slip
              W  = Length along-dip (in 2D case,ignored if FINITE=1 )
              MU = shear modulus
              LAM = elastic modulus LAMBDA (for 3D simualtion)
              VS = shear wave velocity. If VS=0 radiation damping is turned off
  V1 = cutting off velocity of direct effect (m/s)
  V2 = cutting off velocity of evolutional effect (m/s), controls velocity
     weaking to strengtherning transition while a<b, V2 should <= V1
  **set V1, V2 a large value (e.g 100) for no transition**
              NX  = number of fault nodes (elements) along-strike (3D)
              NW  = number of fault nodes (elements) along-dip (3D)
              N  = number of fault nodes (elements)
              TMAX = total simulation time (in seconds)
              NSTOP = stop at (0) t=TMAX, (1) end of localization or (2) first slip rate peak
              DTTRY = first trial timestep (in seconds)
              DTMAX = maximum timestep (0=unrestricted)
              ACC = solver accuracy
              NXOUT = spatial interval (number of nodes) for snapshot outputs
              NTOUT = temporal interval (number of iterations) for snapshot outputs
              A  = amplitude of direct effect in rate-and-state friction
              B  = amplitude of evolution effect in rate-and-state friction
              DC = characteristic slip in rate-and-state friction
              MU_SS = reference steady-state friction coefficient
              V_SS = reference steady-state slip velocity
              TH_SS = reference steady-state state (normally TH_SS=DC/V_SS)
              THETA_LAW = evolution law for the state variable:
                        0 = ageing in the "no-healing" approximation
                        1 = ageing law
                        2 = slip law
              SIGMA = effective normal stress
  DW = along-dip lengh (km) of every node nalong-dip, from deeper to shallower
  DIP_W = dipping angel (degree) of every node nalong-dip, from deeper to shallower
  Z_CORNER = - depth (km) of bottom left node (3D)
  IC = ot output sampling node
              V_0 = initial slip velocity
              TH_0 = initial state
```

APER = amplitude of additional periodic loading (in Pa)
TPER = period of additional periodic loading (in s)
X,Y,Z = relative fault coordinates

```
OUTPUTS     pars    structure containing parameters, see documentation of qdyn.f
            ot      structure containing time series outputs
                    at the point of maximum slip rate
                    ot.t      output times
                    ot.locl   localization length (distance between stressing rate maxima)
                    ot.cl     crack length (distance between slip rate maxima)
                    ot.p      seismic potency
                    ot.pdot   seismic potency rate
                    ot.xm     location of maximum slip rate
                    ot.v      maximum slip rate
                    ot.th     state variable theta at xm
                    ot.om     slip_rate*theta/dc at xm
                    ot.tau    stress at xm
                    ot.d      slip at xm
                    ot.vc     slip rate at center
                    ot.thc    state variable theta at center
                    ot.omc    slip_rate*theta/dc at center
                    ot.tauc   stress at center
                    ot.dc     slip at center
            ox      structure containing snapshot outputs (x,t)
                    ox.x      fault coordinates
                    ox.t      output times
                    ox.v      slip rate
                    ox.th     state variable theta
                    ox.vd     slip acceleration
                    ox.dtau stress (-initial)
                    ox.dtaud stress rate
                    ox.d      slip
```

2.2 A simple 2D example

A 2D run with initial velocity slightly above the default steady state.
In Matlab:

```
p = qdyn('set');
[p,ot,ox] = qdyn('run','V_0',1.01*p.V_SS);
semilogy(ot.t,ot.v)
```

2.3 Complicated Simulation

An upper-layer Matlab wrapper for the base-layer Matlab wrapper qdyn.m is recommended for complicated simulations:
We have included some examples in our software package for reference:
a) A simple 3D simulation:
‘working directory’/src/test3dfft.m
b) A simplified model for the Tohoku earthquake

Please refer to examples of 2D along-dip and 3D simulations at
‘working directory’/ Examples/Tohoku

3.Optimizing Performance

3.1 Running simulations outside the Matlab environment

Under certain circumstances, you may want to perform simulations outside the Matlab environment (e.g. while computing on a HPC). In this case, use Matlab wrapper separately first to generate an input file (qdyn.in), then run the executable directly.

3.2 Managing parallel computing

3.2.1 OpenMP

QDYN is efficiently parallelized with OpenMP (shared memory parallelization). You should set the following environment variable before performing parallel simulations:

```
setenv OMP_NUM_THREADS 8
```

This command allows QDYN to run on 8 threads, which will roughly speed up calculations by a factor of 8. The number of threads should be set according to demand. In general, set this value to the maximum number of threads available on your shared memory system.

3.2.2 MPI

Features will be available in the next major update.

4.Visualizing simulation results:

The QDYN software package includes several Matlab scripts for visualizing simulation results at ‘working directory’/src/
These scripts are all self-documented:

- plot_default.m : plots slip rate of a 2D problem (along-strike);
- plot2d_slip.m : plots slip of a 2D problem (along-dip);
- plot3d_m.m: plots a sequence of snapshots of slip rate for 3D simulation;
- plot3d_faultview3.m: plotting several snapshots of slip rate for 3D simulation in one figure;